REGIONAL DISTRICT OF NANAIMO

December 5, 2023

Re: Introductory Cover Letter - French Creek Water Region Phase 3 Water Budget– Regional District of Nanaimo

The geographic area of French Creek Water Region includes most of Regional District of Nanaimo (RDN) Electoral Area G, portions of RDN Electoral Area F, the Town of Qualicum Beach, and the City of Parksville. Due to the natural variability in water supply, sources, and quality; climate change impacts including drought; and growth pressures; there is a need to better understand and estimate the water availability and dynamics in the French Creek Water Region. This is important context to inform where enhanced water supply planning, natural asset preservation, and demand management may be required.

The RDN Drinking Water and Watershed Protection (DWWP) program completed a regional water budget analysis in 2013 (Waterline, 2013). This "Phase 1" work pulled all available data into a conceptual model of water supply and demand for the aquifers and surface watercourses in the region. A relative stress ranking highlighted priority areas to advance the next phases of the water budget study. "Phase 2" rolled out between 2014 -2016 in the three priority areas that were identified in the first phase: Nanoose, French Creek, and Cedar-Yellowpoint. The focus of Phase 2 was on expanded data collection and monitoring, to fill gaps identified in the initial datasets used for the analysis. It included the instrumentation of additional volunteer observation wells and hydrometric monitoring. This was a key step in preparation for "Phase 3": building a refined numerical groundwater model and then running scenarios to observe the impacts of climate change, land cover change, and water demand on water levels and relative aquifer stress. Phase 3 work for the French Creek Water Region commenced in 2021 when RDN engaged Golder (now 'WSP') as the consulting hydrogeologist to develop the model and perform the stress assessments.

As described in the following technical report, WSP developed and calibrated a 3D regional-scale numerical groundwater flow model using FEFLOW software to calculate water budgets and conduct stress assessments for current average, dry, and wet season conditions for the ten aquifers in the Study Area, including assessment of potential effects on groundwater baseflow in major creeks within the area. This included a preliminary Environmental Flow Needs (EFN) assessment for French Creek, using the provincial EFN Policy's interim risk management framework.

Using the model, WSP identified aquifers that are predicted to have relatively higher water stress under future scenarios that included potential climate change, build-out, and changes to land cover. For the stress assessments, groundwater extraction from municipal and private users plus groundwater discharge to surface water bodies (i.e. baseflow contributions) was divided by the total inputs into the aquifer (i.e. groundwater recharge) to evaluate relative aquifer stress as Low, Moderate, High or Very High. These classifications are adapted from Provincial methodology and provide the basis for prioritization of water management initiatives. It should be noted that "stress" is not an absolute; it is a relative comparison between systems identifying where estimated water use is high relative to estimated water availability. Earlier conceptual modelling did not quantify aquifer contribution to river flows, which is inferred by the report authors to partly explain differences in stress classification outcomes between Phases 1 and 3.

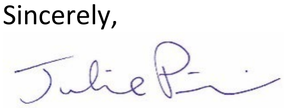
It is important to emphasize that the model is regional in scale and predicts the overall water balance for individual aquifers in the study area; analysis at the local well-field level often illuminates different localized results. The value in this regional-scale study is in considering the broader watershed context, ‘zooming out’ from looking at individual well fields in isolation, while not discrediting more specific findings at a finer-scale. It provides a technical foundation to support discussions on growth, climate change and geographic disparity in water supply and demand, in consideration of community and ecosystem needs.

The model should be considered a ‘working tool’ and additional monitoring, mapping and analysis should be conducted to further refine the model parameters and confirm water balances and stress ratings. It is intended to be updated regularly throughout time by RDN DWWP (approx. every five years) and/or as additional data inputs become available. It is also intended to be a collaborative technical tool, that can be used by all water managers in this part of the region, to explore different scenarios and dynamics in the complex groundwater system.

The work reported here was funded by the RDN Drinking Water and Watershed Protection Program, Community Works Funds for Electoral Area G, and EPCOR Water (West).

Please read on to WSP’s technical report and explore the findings of the study. For any questions or to learn more you may reach out to waterprotection@rdn.bc.ca.

Sincerely,



Julie Pisani, Drinking Water and Watershed Protection Program Coordinator
Regional District of Nanaimo

250-390-6560

REPORT

Refined Water Budget (Phase 3) for French Creek

Regional District of Nanaimo, BC

Submitted to:

Drinking Water and Watershed Protection Program

6300 Hammond Bay Road
Nanaimo, BC
V9T 6N2

Submitted by:

WSP Canada Inc.

3600 Uptown Blvd, Building 5, Suite 301, Victoria, BC V8Z 0B9, Canada

+1 250 881 7372

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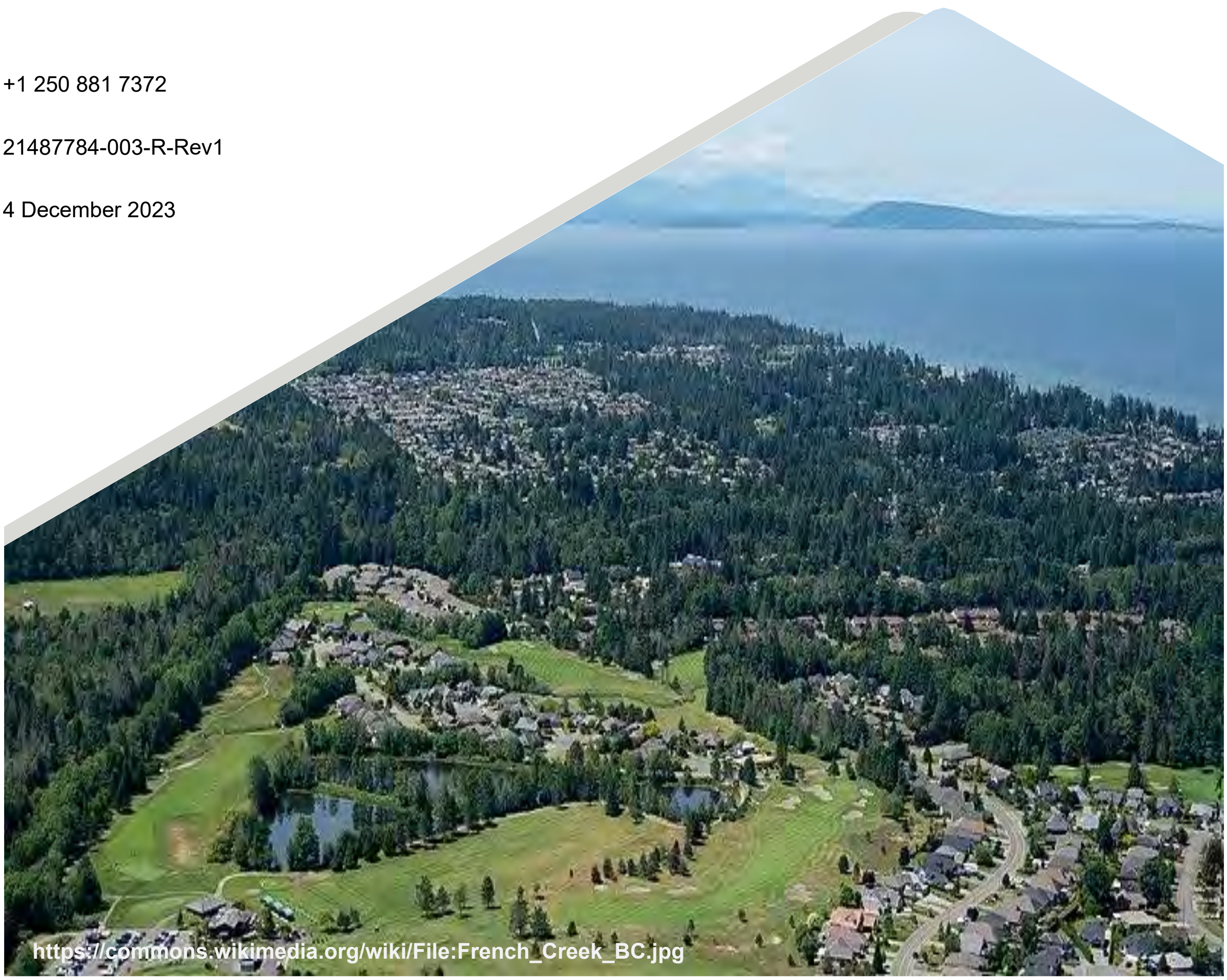
4 December 2023



Distribution List

1 e-copy: Regional District of Nanaimo

1 e-copy: WSP Canada Inc.

Executive Summary

WSP Canada Inc. (WSP, formerly Golder Associates Ltd. Member of WSP) was retained by the Regional District of Nanaimo (RDN) to conduct a Refined Water Budget for the French Creek area (Project Area). Building upon the work that had been done to date for the RDN Water Budget Project that included the compilation of a Geodatabase and development of a Conceptual Model of water resources in the RDN (Phase 1) by Waterline Resources Inc. (Waterline; 2013) and a Hydraulic Connectivity and Aquifer Mapping Study by Groundwater Solutions Inc. (GWS; 2020), the objective of the current Phase 3 French Creek Water Budget project was to develop and calibrate a three-dimensional (3D) regional-scale numerical groundwater flow model to develop refined water budgets for the French Creek Water Region (the Project Area). Based on the scale of the model, the refined water budgets are intended for assessment at the aquifer level and are not intended for site-specific analysis of localized areas or individual well fields. Detailed assessments have been conducted by others for some locations within the Project Area and are referenced in this report to provide the reader with additional information.

WSP compiled and analysed data that had become available since Phase 1 to refine the Conceptual Model, including the GWS (2020) aquifer mapping and connectivity study. Based on this refined Conceptual Model, WSP 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. WSP assessed the groundwater model uncertainty associated with the hydrogeological boundaries and parameters using a limited sensitivity analysis. The calibrated groundwater model was then used to develop refined water budgets and conduct stress assessments for average, as well as dry and wet season conditions for the ten aquifers in the Project Area, including assessment of potential effects to groundwater baseflow in major creeks within the area. WSP identified areas that are predicted to have relatively higher water stress in the future under scenarios that included potential climate change, increased development and changes to land cover. WSP also used the groundwater model to delineate capture zones for municipal water supply wells in the Project Area.

Aquifer Water Budgets and Stress Assessments

For the stress assessments, groundwater extraction from municipal and private users plus groundwater baseflow (i.e., groundwater discharge to surface water bodies) was divided by the total inputs into the aquifer (i.e., groundwater recharge) to evaluate relative Aquifer Stress that was classified as Low, Moderate, High and Very High (see table below). The classification categories were developed in discussion with the RDN and provide a framework that identifies areas of relatively higher stress and provides the basis for prioritization of water management initiatives. As indicated above, the stress assessments are at the aquifer scale and do not assess variability in water stress in different areas within aquifers.

Phase 3 French Creek Water Budget Aquifer Stress Classification Categories

Stress%	Aquifer Stress Classification
0 – 10	Low
10 – 20	Moderate
20 – 30	High
> 30	Very High

Current Conditions

The results of the water budget and stress analysis for current conditions indicated that during the dry season, unconfined Aquifer 664 and confined unconsolidated Aquifers 209, 216 and 1250 are under Very High Stress, and unconfined Aquifer 1248 is under High Stress. The water budgets for Aquifers 209, 216 and 1250 indicate that current groundwater withdrawals for water supply by municipal providers and private users represent a significant component of the overall flow within the aquifers during the dry season (approximately 50% of the total outflow from Aquifers 216 and 1250), highlighting the influence of groundwater pumping to these areas. The stress ranking for Aquifer 664 is consistent with the provincial classification; however, as mentioned above, the aquifer stress analysis is conducted at the aquifer scale and does not assess variability in water stress in different areas within aquifers. Site-specific hydrogeological assessments, like the one conducted by others for the Riverside well field, provide a more detailed understanding of groundwater conditions at the local scale.

The remaining unconsolidated aquifers were classified as Moderate (unconfined Aquifer 663, confined Aquifer 217) or Low (unconfined Aquifer 1252) Stress during the dry season. It is recognized that the hydrogeological setting in the area of Aquifer 217 is complex and there is some uncertainty regarding the extents of, and connections between, subsurface units at the local scale. Site-specific assessments that have been conducted by others in the area of the Berwick well field are referenced in this report to provide additional information for the reader.

Bedrock aquifers 212 and 220 were evaluated to be Low and Moderate Stress, respectively, at the end of the dry season under current conditions; however, it is noted that the Province has characterized Aquifer 220 as having a low productivity and the water level in provincial observation well (OBS Well) 287, located in the central portion of the aquifer, has showed a declining water level since 2004, suggesting that limitations to groundwater availability in the bedrock aquifers may be more significant than what is reflected in the Aquifer Stress classifications alone. Therefore, other aspects should also be considered for bedrock aquifers that are inherently more variable and can have localized areas of higher stress. The potential impacts of baseflow to surface water bodies are discussed in the Source Water Assessment section below.

Based on the above results, it is recommended that aquifers that are classified with Very High or High Aquifer Stress, as well as bedrock Aquifer 220, be prioritized for monitoring and water management initiatives.

Future Scenarios

The calibrated groundwater model was first run under the Future Base Case hydrogeological conditions (i.e., model run with future pumping schedule for the RDN production wells) and then under each of the following future scenarios to assess potential impacts to water budgets in the future:

- Scenario 1 – Potential Climate Change: potential effects of longer, drier summers in the future (year 2050)
- Scenario 2 – Future Build-Out: increased water demand from all properties that will be developed as part of the RDN's future build-out plan
- Scenario 3 – Changes in Landcover: changes to land cover (i.e., increase in impervious surfaces that reduce groundwater recharge) under future development
- Scenario 4 – Combined Future Conditions: combined effects of Scenarios 1 to 3

Scenario 1 – Potential Climate Change

The results of groundwater model simulations predict that the combined effects of reduced recharge (i.e., from less precipitation and a longer dry season) and increased water demand from large agricultural properties could have a significant effect on groundwater conditions within the Project Area. The biggest influence is predicted to be for confined unconsolidated Aquifers 209, 216, 217 and 1250, as the majority of private users in the Project Area extract the water from these aquifers for residential and agricultural activities. Aquifers 209, 216 and 1250 are predicted to have higher Aquifer Stress values and remain categorized as Very High Stress in the dry season, whereas Aquifer 217 is predicted to change from Moderate Stress in the Future Base Case conditions to High Stress due to the effects of climate change. Groundwater levels in confined Quadra Sand Aquifer 216 could decline by more than 10 m in the central portions of this aquifer at the end of the dry season. Water levels in Aquifers 209 and 217 are also predicted to decline by up to 8 m in the vicinity of agricultural properties by the end of the dry season.

Water levels in unconfined Aquifers 663, 1248 and 1252 are predicted to decline less (between 2 and 4 m) than the confined aquifers due to the smaller number of large private users (especially agricultural users) using groundwater from these aquifers and the hydraulic connection of some of the aquifers to permanent watercourses that control groundwater levels; although changes from the future scenarios may not result in significant changes to the Aquifer Stress classifications for the aquifers, a decrease in groundwater levels in aquifers may result in less groundwater contribution to baseflow in surface water bodies, resulting in a corresponding increase in stress for the affected surface water bodies.

Under Scenario 1, bedrock Aquifer 220 is anticipated to remain in the Moderate Stress category in the dry season; however, water levels in Aquifer 220 and the upgradient bedrock are predicted to decline by up to 5 m and 10 m, respectively, by the end of the dry season, reflecting less recharge to the bedrock and increased stress to the tributaries in the headwaters of the French Creek watershed. Stress for Aquifer 220 (and Aquifer 212) will not be uniform and is inferred to be variable and higher in localized areas where the productivity of the bedrock is lower.

Scenario 2 – Future Build-Out

At full build-out, the reduction of water demand from large-scale irrigation and livestock agricultural activities to residential development is predicted to have a positive influence on water levels and aquifer stresses in a large part of the Project Area. Water levels in the confined Quadra Sand Aquifers 216 and 217 and Aquifer 209 are anticipated to increase by up to 10 m, in areas where large agricultural properties will be converted into residential use. Aquifer Stress for Aquifers 209, 216 and 217 is predicted to decrease between 7% and 22% from Future Base Case conditions at the end of the dry season; however, Aquifers 209, 216 and 1250 are predicted to remain in the Very High Stress category and Aquifer 217 will remain in the Moderate Stress category.

The Aquifer Stress for bedrock Aquifer 220 is predicted to decline from Moderate to Low under Scenario 2. Although water levels in the bedrock underlying Aquifers 216, 217 and 209 are predicted to also increase under Scenario 2, in the upgradient portion of bedrock Aquifer 220 and upper portion of the watersheds, where land that is currently vacant will be developed as new residential properties, water levels are predicted to decline by up to 2 m.

Scenario 3 – Changes in Landcover

Changes in landcover as a result of future development and the resulting increased coverage with impervious surfaces is predicted to affect groundwater conditions at higher elevations where the reduction in recharge from precipitation is predicted to significantly decrease groundwater levels. Although Aquifer Stress values are predicted to decrease or increase modestly by up to 2% from Future Base Case conditions, a water level decline of over 10 m is predicted in the southern portion of the Project Area as a result of the reduction in recharge on the forestry lands that are identified for potential future development. Recharge from precipitation in these areas, which are in the headwaters of the French Creek watershed and upgradient of bedrock Aquifer 220, represents a main source of recharge for the downgradient confined aquifers (Aquifers 209, 216, 217 and 1250) and the bedrock aquifers. As a result, under Scenario 3, water levels in the confined aquifers are predicted to decrease between 1 m and 4 m by the end of the dry season, with more significant water level decreases generally coinciding with areas identified for development. Although the Aquifer Stress predicted for Aquifer 220 is Moderate, other considerations suggest that the stress for the aquifer may be relatively higher, particularly in areas where the productivity of the bedrock is lower.

Scenario 4 – Combined Future Conditions

It is anticipated that the combined scenario will result in a limited influence on the Aquifer Stress for the unconfined and bedrock aquifers, whereas the Aquifer Stress values for confined unconsolidated aquifers are predicted to decrease relative to Future Base Case conditions by approximately 7% (Aquifer 209), 9% (Aquifer 216) and 4% (Aquifer 217) but increase by 2% for Aquifer 1250; the resulting Aquifer Stress classifications do not change. The reduction in water use in the dry season from the conversion of agricultural activities into residential development is predicted to have a positive influence on large sections of Aquifer 209 and in the northern portions of Aquifers 216, 217 and 1250. In contrast, water level declines of up to 5 m by the end of the dry season are predicted for Aquifers 663, the eastern portion of Aquifer 216, and large portions of Aquifers 217 and 1250 where the influence of climate change and the associated reduction in recharge are anticipated to be more significant. A reduction in water levels of over 20 m is predicted in the upland areas south of bedrock Aquifer 220 due to the combined effects of changes in land cover and climate change. For Aquifer 220, the reduction in water use from future build-out is anticipated to have a positive influence and somewhat balance the reduction in recharge from landcover change and climate change and, therefore, the Aquifer Stress classification is predicted to decrease from Moderate under the Future Base Case conditions to Low for Scenario 4. Nevertheless, it is recognized that Aquifer 220 is characterized as having a low productivity and the stress to Aquifer 220 will be variable and potentially higher due to the nature of the bedrock.

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.

Surface Water Assessment

Limited hydrometric data were available for French Creek and no data were available for other watercourses in the Project Area; however, based on a review of available information, WSP estimated that flow sensitivity for French Creek, which is a small, fish-bearing stream, is low during the winter months, moderate in June and high for the July to September period. Current licensed withdrawals are also highest (>10% of mean annual discharge; MAD) during the June to September period. Using the interim risk management framework that is outlined in the BC Ministry of Forests (FOR) and BC Ministry of Environment and Climate Change Strategy (ENV) (2022) interim Environmental Flow Needs Policy, WSP considered a Risk Management Level 2 to be applicable for June, a Risk Management Level 3 for July through September, and a Risk Management Level of 1 during the remainder of the year.

WSP also used the groundwater model to assess potential changes in groundwater baseflow along French Creek for the future scenarios described above. Climate change (Scenario 1) is predicted to have the largest effect on groundwater baseflow in French Creek, with baseflow predicted to decrease up to 11% in the wet season and up to 19% in the dry season. Changes in landcover (Scenario 3) are predicted to decrease baseflow in French Creek up to 9% and 10% in the wet and dry season, respectively, whereas baseflow in French Creek is predicted to increase by 4% (wet season) and 9% (dry season) as a result of reduced agricultural water use following new development (Scenario 2). When considering the combined effects of all future scenarios (Scenario 4), although reduced infiltration resulting from climate change and changes in landcover is somewhat mitigated by the decrease in water use in some of the land that will be converted from agricultural to residential use, baseflow in French Creek is predicted to decrease by 13% in the wet season and 15% in the dry season.

Capture Zone Analyses

WSP conducted capture zone (portion of an aquifer from which groundwater is derived by a pumping well) analysis for municipal well fields in the Project Area under current average conditions to identify areas where municipal well quality is potentially vulnerable to the impacts of contamination and to provide the basis for delineation of exclusion zones. The following time-of-travel (TOT) zones (sub regions of the capture zone from which groundwater is derived in a fixed portion of time) were considered for the analysis:

- 200-day time-of-travel zone: representative of the time required for microbial contaminants moving in the groundwater to degrade
- Two-year time-of-travel zone: an intermediate travel time to provide an appropriate trigger for groundwater management initiatives
- Five-year time-of-travel zone: average time required to implement groundwater remedial measures in response to a contamination event (typically hazardous substances such as hydrocarbons or metals)
- 25-years: the convention by which the total capture zone for a well is typically defined.

For most wells, the 200-day TOT zones generally extend around the individual wells with radii in the range of approximately 30 to 95 m, with variability reflecting the aquifer properties and pumping rates. The 200-day TOT zones for some wells in the Surfside and Riverside well fields overlap into zones that represent the combined pumping from wells in relatively close proximity to each other. The two-year TOT zones also generally extend around the individual wells or clusters of wells at greater distances of up to over 500 m.

The 5-year and 25-year TOT zones generally comprise broader zones around well fields or clusters of wells and extend across broader areas and upgradient from the wells at distances of up to 3,500 m for the longer TOT considered (25-year TOT zone for French Creek and EPCOR North wells). The capture zones for the Surfside and Riverside well fields also reflect a hydraulic connection with the Little Qualicum River. A site-specific hydrogeological assessment of the Riverside well field that was conducted by others predicted the TOT zones for the Riverside wells to be smaller than those presented in this report. Therefore, the capture zone analysis that was conducted for the Riverside well field with the regional-scale numerical model is considered to be conservative. Further details, including the reference for the site-specific assessment are provided in this report.

More detailed analysis of the hydrogeological setting for Aquifer 217 and connected units at the local scale that is presented by others and referenced in this report, should also be referred to when considering the results of the capture zone analysis for the Berwick well field.

The results of the capture zone analyses provide the basis to develop and implement wellhead protection plans for the municipal water supply wells in the Project Area. The nature of the potential contaminants potentially present in the TOT zones (e.g., microbial contaminants compared to hazardous substances such as hydrocarbons or metals) should be assessed and monitoring, protection and emergency response plans could be designed to mitigate and manage the contaminants within the TOT zones.

Use of the Numerical Model and Implementation of Results

The numerical hydrogeologic model that was developed for the Phase 3 French Creek Water Budget project represents a technical basis to identify areas of potential water stress at the aquifer scale and should be considered with other factors in the broader context of conditions in the French Creek area. As discussed above, local-scale hydrogeological analyses have been conducted in certain portions of the Project Area and these studies should be referred to when assessing site-specific conditions. It is also recommended that a precautionary approach be undertaken when operationalizing the Aquifer Stress classifications for unconfined aquifers that are expected to have a strong influence on surface water bodies, and bedrock aquifers that are characterised with greater variability and uncertainty.

The results of the Phase 3 French Creek Water Budget project provide a technical basis for the RDN to implement and advocate for measures to support management, conservation and protection of water resources in the French Creek area. It is recommended that the RDN target those aquifers and areas that are identified with higher stress and predicted to be most affected in the future scenarios; bedrock Aquifer 220 and upgradient areas to the south should also be included as targeted areas. Aquifer Protection Development Permit Areas (DPAs) could be established to manage development, and initiatives and regulatory tools could be implemented to reduce groundwater use and/or enhance infiltration, particularly for new development in areas where higher stress is anticipated in the future. Examples for consideration include the following:

- Water metering, either through voluntary programs with the RDN or as required for groundwater licensing under the *Water Sustainability Act* (WSA), not only provide data required to reduce uncertainty and refine the assumptions in the water balance analysis, but also provide the basis for participants to understand their actual use and potential cost savings from conservation.
- Limitations could be established for the size/capacity of a pump that is installed in a well to restrict water usage to a specified rate, thereby encouraging conservation.
- For new development in areas of high water stress or aquifers with lower productivity, groundwater use could be supplemented with rainwater harvesting and/or secondary storage implemented to collect water during the wet season for use during drought periods.
- Groundwater protection measures could be implemented to limit ground disturbance and preserve natural soils and vegetation in order to promote infiltration of precipitation.
- Green stormwater management techniques such as permeable pavement and bioswales could also be implemented to capture precipitation and enhance infiltration into the subsurface.

The results from the Phase 3 French Creek Water Budget project also provide a framework to develop a common understanding between organizations and support collaboration and joint decision-making. Examples are provided below:

- The Phase 3 French Creek Water Budget and other initiatives that the RDN is undertaking support engagement activities with local First Nations governments to discuss shared interests in managing water resources.
- The model and supporting analyses provides a platform for the RDN to engage with the Province to support the protection and regulation of surface water and groundwater through licensing and other initiatives under the WSA such as area-based tools.
- The results from the Phase 3 project provide the basis for municipal and private water suppliers to understand the impacts of groundwater pumping and to consider a coordinated, regional approach to managing water resources. The results from the capture zone analysis also provide the basis to understand potential risks to groundwater quality and develop wellhead protection plans.

Additional Data Requirements and Model Refinement

The numerical groundwater model that WSP developed for the Phase 3 French Creek Water Budget project provides a technical basis to identify areas of potential water stress at the regional scale and inform water management. The present model is not suitable for local-scale applications such as well field design and optimization; the model could be refined in certain areas and with more site-specific data for local scale applications. It is noted that site-specific hydrogeological assessments that have been undertaken at some locations within the Project Area provide more a more detailed understanding of conditions in these areas.

The model should be considered a “working tool”, which should be periodically refined as additional information becomes available. Supplemental monitoring could be implemented to support planning and decision-making, as well as refinement of the groundwater model calibration. There are limited data regarding actual water usage outside the water service areas; implementation of water metering on both residential and non-residential properties would reduce uncertainty regarding groundwater usage in the Project Area. In addition to establishing new climate stations in different locations across the Project Area, including higher elevations, to assess geospatial influence on climate variables, refined mapping of recharge variables could also be conducted to further refine the calculated water budgets, if that is considered to be of value for the RDN. The groundwater monitoring well network could also be expanded to strategic locations to assess conditions within aquifers located in the upper portions (i.e., higher elevation) of the watersheds and aquifers that were estimated to have relatively high stress classifications. Additional hydraulic testing (long-term pumping tests) would also enable refinement of hydraulic conductivity estimates, particularly for bedrock aquifers.

It is also recommended that regular hydrometric monitoring be conducted at additional locations along French Creek and on other surface water bodies in the Project Area to support assessment of streamflow changes with location and over time. More detailed site-specific assessment of the potential impacts of additional withdrawals on flows in French Creek and other watercourses could also be conducted to support environmental flow needs (EFN) assessments that will also require consideration of biological and ecological aspects and water quality. Although the focus of Phase 3 was primarily on water quantity, in addition to programs that are currently being implemented such as the Community Watershed Monitoring Network, additional water quality monitoring could also be implemented at key surface water and groundwater monitoring locations to assess variation in water quality over time and to monitor potential effects from land use activities, including non-point and specific sources of contamination. Water quality monitoring should consider the results of the capture zone analysis to identify the objectives for the program, monitoring locations and water quality parameters.

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 French Creek, BC, WSP Canada Inc. (WSP) 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 WSP. The final version of this report and its content supersedes any other text, opinion or preliminary version by WSP.

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, WSP 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 WSP and quoted and/or used herein are considered as having been obtained according to recognized and accepted professional rules and practices, and therefore deemed valid. WSP 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. WSP 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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APPENDICES

1.0 INTRODUCTION

1.1 Background and Objective

The Regional District of Nanaimo (RDN) 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 initiatives under the DWWP is the RDN Water Budget Project. During Phase 1 of the Water Budget Project, Waterline Resources Inc. (Waterline; 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 each of the seven RDN 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 considered a high priority for monitoring programs that were required to support sustainable management of water resources and inform land use decisions. The focus of Phase 2 was to expand data collection and monitoring to address data gaps in areas that were identified as a priority during Phase 1, including the French Creek Water Region.

The objective of the current project (Phase 3 French Creek Water Budget) 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 and, using the model, to develop refined water budgets for the aquifers in the French Creek area, including assessment of potential effects to groundwater baseflow in major creeks within the area. The model was also used to 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

WSP Canada Inc. (WSP, formerly Golder Associates Ltd. Member of WSP) respectfully recognizes that the French Creek area is within Coastal Salish traditional territory of the K’omoks, Qualicum, Snaw-naw-as and Snuneymuxw First Nations.

WSP would like to thank Erica Forssman, Julie Pisani and Murray Walters of the RDN for their direction and support in developing and implementing the Phase 3 French Creek Water Budget project and providing requested data and information. We would also like to thank Jessica Beaubier, RDN Climate Change and Resilience Coordinator, for input to our assessment of future conditions and Kevin Robillard, RDN GIS Coordinator for providing GIS data. We would also like the participants who attended a Technical Advisory Committee (TAC) meeting on 20 September 2022 and who provided valuable feedback regarding the preliminary results of Phase 3 of the French Creek Water Budget.

In conducting this project, we referred to data and information provided by a number of other sources, as referenced in our report. We recognize and thank these organizations for their contributions, including Waterline (2013) for the Geodatabase and Conceptual Model that they developed on behalf of the RDN and Groundwater Solutions Inc. (GWS, 2020; draft, awaiting publication) for the Geodatabase and Leapfrog Model that they developed as part of a French Creek Area Hydraulic Connectivity and Aquifer Mapping Study for the RDN. WSP would also like to thank David Van Everdingen and Jessica Doyle of the Ministry of Forests (FOR) for providing updated aquifer delineation work for the Project Area that was used for the final version of this report. Allan Dakin of Elanco Enterprises Ltd. also provided input regarding hydrogeological assessments that had been conducted on behalf of the Town of Qualicum Beach.

2.0 SCOPE OF WORK

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

- Data Compilation and Review, Model Selection: review of existing data, data gap analysis, refinement of the Conceptual Model for the Project Area with supplementary information and selection of the numerical model code.
- Groundwater Numerical Model Development and Calibration: construction and calibration of a regional-scale groundwater numerical model based on the refined Conceptual Model of the Project Area.
- Water Budget Analyses and Stress Assessments: using the calibrated model, evaluate the groundwater flow regime and potential effects on surface water flow (groundwater baseflow), develop a water budget by aquifer, assess aquifer stress, and assess current and future groundwater conditions under different scenarios related to climate change, land use changes and increased development (i.e., groundwater withdrawals). The framework outlined in the BC Ministry of Forests (FOR) and BC Ministry of Environment and Climate Change Strategy (ENV) (2022) interim Environmental Flow Needs Policy (Interim Framework) was applied to preliminarily characterize the environmental risk management level for French Creek , and the model was also used to conduct capture zone analyses for municipal water supply wells in the area.
- Reporting, Recommendations and Presentation: The results of the study are presented in a comprehensive report (this document), including recommendations to provide decision support. WSP presented the preliminary results of the Phase 3 French Creek Water Budget to the RDN Technical Advisory Committee (TAC) on 20 September 2022.

The RDN initiated discussions with the K’omoks, Qualicum, Snaw-naw-as and Snuneymuxw First Nations to share the plan for the Phase 3 French Creek Water Budget and provide the opportunity for dialogue and collaboration. It is hoped that the results of this project, together with other initiatives, can support development of a common understanding of the area and shared interests in managing water resources.

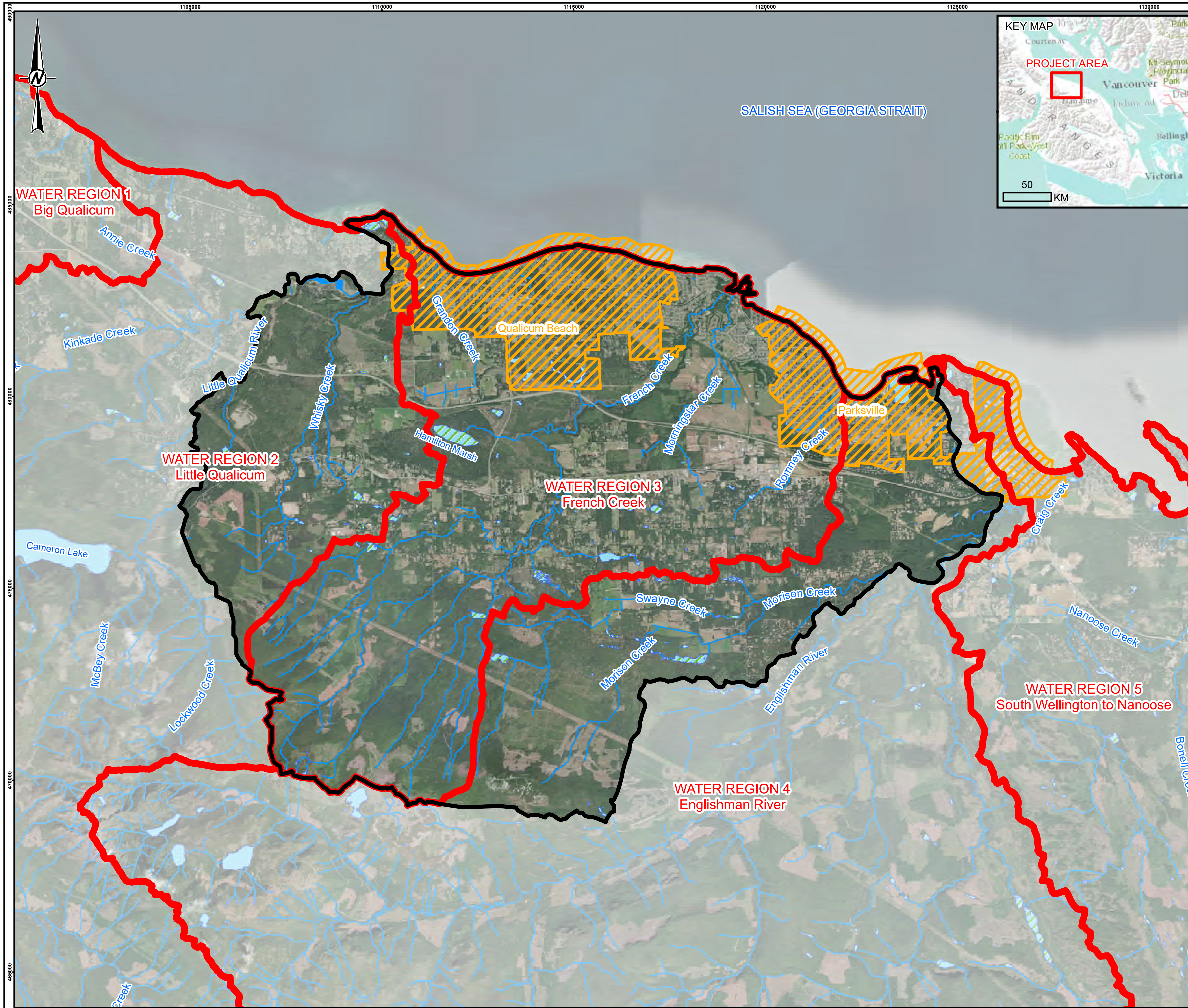
3.0 DATA COMPILATION AND REVIEW

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

3.1 Methods

WSP conducted a comprehensive data gathering exercise to obtain geologic, hydrologic and hydrogeologic information that was publicly available and provided by stakeholders in the Project Area. The objective was to build upon the technical work that had been done to date to refine the comprehensive Conceptual Model that Waterline (2013) in developed in Phase 1 with updated information regarding elements including subsurface conditions (i.e., geology, hydrostratigraphy, groundwater conditions), topography, surface water flow, and land and water use. The scope of the Phase 3 French Creek Water Budget project did not include refinement of model elements that are considered suitable for this regional-scale assessment (e.g., groundwater recharge mapping).

For the purposes of the Phase 3 French Creek Water Budget (i.e., the current project), WSP defined a Project Area that comprised the French Creek watershed and adjacent aquifers and watersheds. The French Creek watershed is included in Water Region #3 (WR#3 – French Creek) of the RDN. The extent of the Project Area is illustrated on Figure 1.



LEGEND

- PROJECT AREA
- RDN WATER REGIONS
- MUNICIPAL BOUNDARY
- WETLANDS
- WATERBODIES
- WATERCOURSES

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
SITE PLAN

CONSULTANT

YYYY-MM-DD	2023-07-19
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	1

WSP conducted a comprehensive data gathering exercise to obtain geologic, hydrologic and hydrogeologic information for the French Creek Project Area. 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 its relevant departments, other municipalities, provincial government agencies such as BC FOR and other consultants that provided information relevant to the French Creek 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. It should be noted that the GWS (2020) French Creek Area Hydraulic Connectivity and Aquifer Mapping Study, which includes the development of the hydrostratigraphic Leapfrog Model for the French Creek Area, is a draft document under review by BC FOR and awaiting publication. Once approved, this study will be part of the BC Water Science Series publications.

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

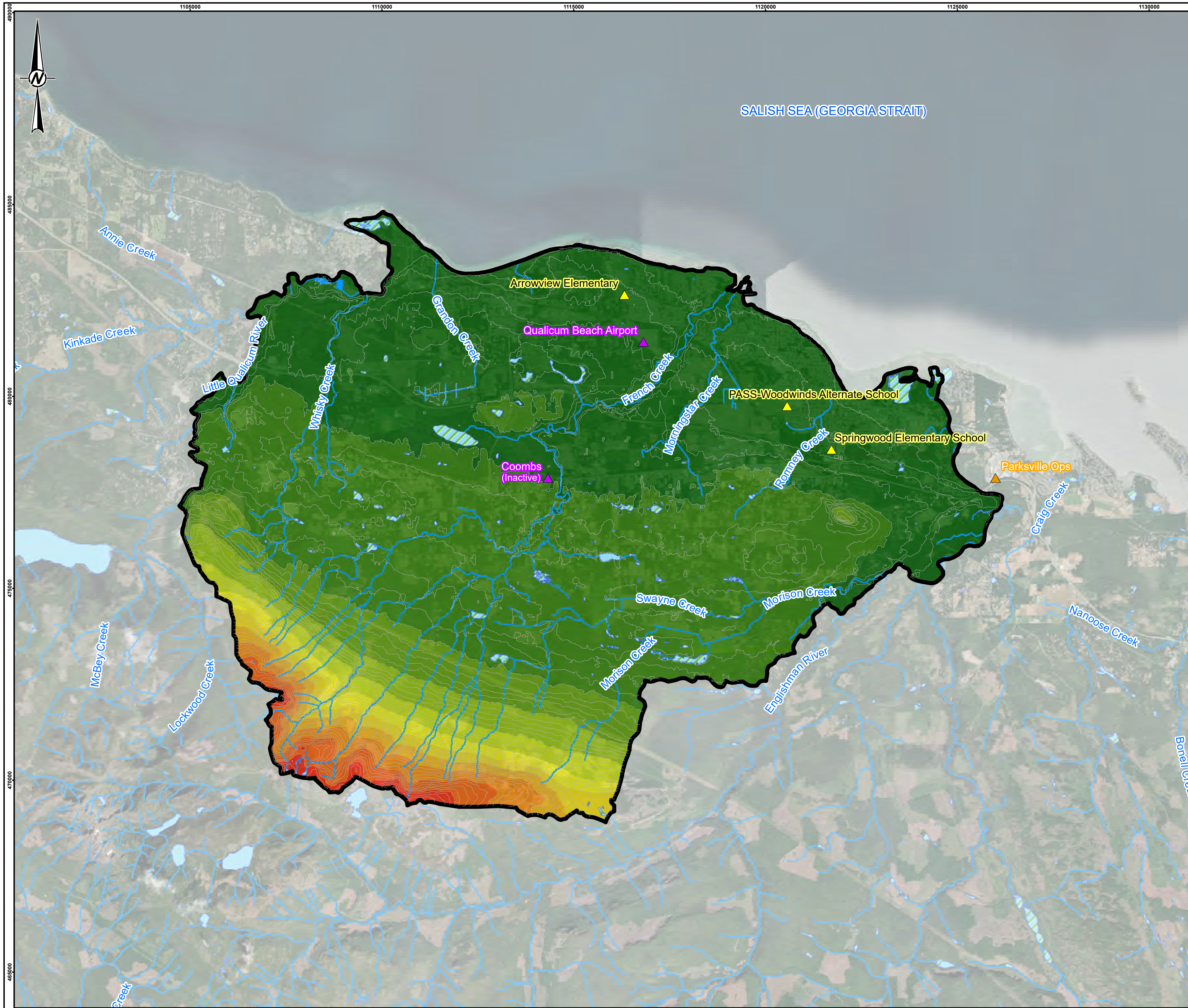
Information	Source(s)
Regional Topography	Topographic surface use in the Groundwater Solutions Inc. (GWS) Leapfrog Model (GWS, 2020). It is understood that this surface was derived from LiDAR topographic data with 2 m resolution provided by RDN (FOR, GWS, 2020)). Bathymetry Contours from Coastal BC Bathymetry in the B.C. Data Catalogue (2022)
Orthophoto imagery (georeferenced)	Base map obtained in high resolution from Google Earth. Imagery from March 2021.
Geology and Hydrostratigraphy	Waterline Phase 1 Water Budget (2013) BC ENV Water Well Database (Government of BC, 2021a) BC ENV Aquifer Delineation (Government of BC, 2023) Draft French Creek Area Hydraulic Connectivity and Aquifer Mapping Study (GWS, 2020) Benoit et al., (2016): Deep Bay Area Groundwater Study Atlas Mt. Arrowsmith Final Aquifers Modelling Project, EBA, 2005
Hydrogeological Properties of Stratigraphic Units	Waterline Phase 1 Water Budget (2013) Carmichael (2013) Compendium of Re-evaluated Pumping Test in the RDN Benoit et al., (2016): Deep Bay Area Groundwater Study Atlas Draft French Creek Area Hydraulic Connectivity and Aquifer Mapping Study (GWS, 2020) Surfside Well Field – Well Protection Plan, Thurber Engineering, 2016
Groundwater Levels	BC ENV Water Well Database (Government of BC, 2021b) Draft French Creek Area Hydraulic Connectivity and Aquifer Mapping Study (GWS, 2020) BC Provincial Groundwater Observation Network (PGOWN, Government of BC, 2021a) RDN Volunteer Monitoring Wells (RDN, 2021)
Production Well Data from Water Providers and Municipalities	RDN 2018-2021 Production Well data and well reports (RDN, 2022a) City of Parksville 2021 Production Well data (RDN, 2021) EPCOR 2021 Production Well Data (RDN, 2022a) Water Licensing Application Data (BC FOR, 2022) Qualicum Beach Production Well Data (RDN, 2022a)

Information	Source(s)
Surface Water Discharge	Three hydrometric stations along French Creek the Project Area: French Creek at Coombs, French Creek above Pumphouse and French Creek DS of Barclay Cres (from Aquarius Web Portal, 2022 and RDN, 2022) Watershed Performance Targets for Rainwater Management – French Creek Water Region (Phase 1 – Hydrologic Modelling and Performance Targets) (NHC, 2021) Flume data from FOR/DFO (included in NHC study) French Creek Flow Monitoring Summary Report 2006-2010 (Shawn Stenhouse, 2011)
Climate	ENV Canada Weather stations in the area (Government of Canada, 2022) Watershed Performance Targets for Rainwater Management – French Creek Water Region (Phase 1 – Hydrologic Modelling and Performance Targets) (NHC, 2021) Forecast Climate Change for Nanaimo from Pacific Climate Impact Consortium (PCIC, 2022)
Groundwater Recharge	Recharge rates were estimated by Waterline (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) Orthophoto comparison of change in landcover from 2011 to 2020 (RDN, 2022a) Morningstar Golf Club Irrigation Data (RDN, 2022a)
Land Use and Zoning Information	Land use and zoning map provided by RDN (December 2021) Land Use Inventory Database provided by RDN (2021) Agricultural Land Use Inventory Database provided by RDN (BC Ministry of Agriculture, 2012) Build-out map provided by RDN (2022a)
Water Use in non-serviced area	Agricultural Water Demand Study (BC Ministry of Agriculture, 2013) RDN 2019-2021 Metered Water Use (RDN, 2021) EPCOR 2019-2021 Utility Quarterly Consumption Report (RDN, 2022a) Town of Qualicum Beach 2021 Metered Water Use (RDN, 2022a) Morningstar Golf Club Irrigation Data (RDN, 2022a)

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 1,000 metres above sea level (m asl) in the southern portion of the French Creek watershed (Figure 2). Coastal bathymetry information (depth of the sea floor) available from the BC Data Catalogue (2022) for the area north of French Creek was incorporated with the available topography data. The sea floor in the area is relatively shallow (between 0 to 50 m below sea level; bsl) and then it deepens up to 200 m bsl approximately 3 km from the coast. The combined topography and bathymetry information was used to build the top layer of the numerical hydrogeological model to allow for an appropriate representation of aquifer discharge to the ocean along the coast.



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

CLIMATE MONITORING STATION

- MONITORING STATION - CITY OF PARKSVILLE
- MONITORING STATION - ENVIRONMENT CANADA
- MONITORING STATION - SCHOOL-BASED

ELEVATION (masl)

- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 900
- 900 - 1,000
- 1,000 - 1,100
- TOPOGRAPHIC CONTOURS (20 m)

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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6. m asl = METRES ABOVE SEA LEVEL

COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
TOPOGRAPHY AND CLIMATE MONITORING STATIONS

CONSULTANT		
	YYYY-MM-DD	2023-07-19
	DESIGNED	RKS
	PREPARED	RKS
	REVIEWED	AP
	APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	2

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

The climate of the French Creek area is characterized by cool, wet winters and mild, dry summers. Based on publicly available sources (Environment Canada, School-Based Network) and information provided by the RDN for the City of Parkville, six climate stations were identified in the Project Area. Table 2, below, provides a summary of data that were available for the climate stations. One of the identified climate stations is not currently active (Coombs). 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[a]	Monitoring Period	Monitoring Frequency	Data Collected	
				Temp (Y/N)[b]	Precip (Y/N)[b]
Arrowview Elementary (650 Bennett Road, Qualicum Beach, BC)	School-Based Network[c]	2007-present	Hourly	Y	Y
PASS-Woodwinds Alternate School	School-Based Network[c]	2015-present	Minute	Y	Y
Springwood Elementary School (450 Despard Avenue, Parksville, BC)	School-Based Network[c]	2006-present	Minute	Y	Y
Parksville Ops	City of Parksville	2005-present	5-minute	N	Y
Coombs (1021850)	Environment Canada	1983-2010	Daily	Y	Y
Qualicum Beach Airport (1026562)	Environment Canada	2006-present	Hourly	Y	Y

Notes:

a. Monitoring program under which the climate station is/was operated

b. Temp=temperature; Precip=precipitation; Y/N=Yes/No

c. School-Based Weather Network (http://www.victoriaweather.ca/)

Four climate stations are currently being operated in the Project Area. Three of the active climate stations within the Project Area are part of the School-Based Weather Station Network and are located in the northern portion of the Project Area, at ground surface elevations of up to 57 m asl. Climate data including temperature, precipitation, and wind speed and direction, have been collected on an hourly basis at the Arrowview Elementary station since 2007 and have been collected at the PASS-Woodwinds and Springwood Elementary stations at a frequency of every minute since 2015 and 2006, respectively. Kerr Wood Leidal Consulting Engineers (KWL, 2014) noted that, based on the monitoring equipment used, the data from some of the school-based stations were not considered to be highly accurate. Therefore, the data collected at these locations were reviewed for completeness and consistency with general patterns observed.

In addition to the three School-Based Weather Station Network stations, the Environment Canada (EC) Qualicum Beach Airport climate station, located at an elevation of 50 m asl, is also located in the Project Area and has been collecting climate data on an hourly frequency since December 2006; however, only six years were reported with a full set of precipitation data over the period from 2006 to 2020. EC also operated a climate station at Coombs, located at an elevation of 98 m asl, and collected climate data on a daily basis from 1983 to 2010; climate normals for the Coombs climate stations are presented in APPENDIX A for reference. Climate stations managed by other organizations (e.g., BC ENV air quality network, Agricultural and Rural Development Act Network) were also identified on the Pacific Climate Impacts Consortium (PCIC) Data Portal as being present in the Project Area; however, information collected at these stations was either quite dated or of limited temporal extent.

The Parksville Ops (Operations Facility) climate station is located outside of the Project Area, close to the eastern boundary on the east side of the Englishman River (Figure 2). This station, located at an elevation of approximately 30 m asl, has reported precipitation data at five-minute intervals since 2005. This data set, which was more complete than the data reported for the Qualicum Beach Airport station and is considered accurate based on monitoring equipment used, was therefore considered to be more representative of climate conditions at lower elevations for the Project Area.

A summary of precipitation reported for the Parksville Ops station for the period 2005 to 2021 is presented in Table 3 below.

Table 3: Parksville Ops Station Precipitation Data (2005-2021)

Year	Parksville Ops Monthly Precipitation (mm)												
	January	February	March	April	May	June	July	August	September	October	November	December	Total
2005	160	41	115	78	64	69	21	31	33	126	88	122	948
2006	262	101	108	63	25	14	12	10	31	32	259	199	1117
2007	121	48	78	79	12	79	29	51	55	89	113	134	887
2008	114	32	45	77	28	53	18	24	13	69	98	122	692
2009	41	27	50	17	45	15	17	8	46	104	265	64	700
2010	194	74	81	68	79	12	2	25	58	47	133	196	970
2011	120	87	159	29	84	40	58	4	55	40	116	56	847
2012	139	76	100	69	28	54	21	4	3	142	112	155	902
2013	59	50	64	38	76	65	0	33	102	16	79	23	604
2014	70	137	103	30	30	12	38	18	33	163	91	153	879
2015	77	132	38	20	7	13	11	24	41	57	83	218	720
2016	119	101	195	29	32	43	17	17	49	228	190	112	1132
2017	47	129	88	102	24	19	1	3	44	80	207	109	854
2018	237	68	28	85	6	45	7	1	91	63	107	186	923
2019	127	61	3	55	10	13	27	9	87	69	62	59	581
2020	235	60	33	34	57	40	20	41	45	82	152	159	958
2021	163	42	45	29	20	36	0	8	105	131	254	85	919
Average	134	74	79	53	37	37	18	18	52	90	142	127	861
Max	262	137	195	102	84	79	58	51	105	228	265	218	1132
Min	41	27	3	17	6	12	0	1	3	16	62	23	581

Average annual precipitation at the Parksville Ops station for the period 2005 to 2021 is approximately 861 mm. The majority of the precipitation (approximately 75%) occurs from October through March. The driest year within the last 10 years was 2019, when 581 mm of total annual precipitation was reported. Based on the review of precipitation data across the Project Area, precipitation was observed to vary with elevation. The precipitation data observed at the Parksville Ops station are on average approximately 30% less than precipitation observed at the Coombs station (Coombs Climate Data 1971 to 2000) described by Waterline (2013) in Phase 1 for the French Creek Water Region. The Parksville Ops station, like the School-Based Weather Station Network stations, is located at a relatively low elevation (30 m asl) and precipitation data collected at this station are not representative of greater precipitation that occurs at higher elevations.

Waterline (2013) in Phase 1 estimated groundwater recharge using gridded climate temperature and precipitation that vary with elevation, land cover and soil characteristics data, and using a water balance model developed by USGS (McCabe and Markstrom, 2007). Based on WSP's review of available climate data, this approach is considered appropriate considering that precipitation within the Project Area was observed to vary with elevation. Therefore, Waterline's estimate of groundwater recharge in the Project Area was adopted for the Phase 3 French Creek Water Budget project (see Section 3.2.5.2).

3.2.2 Land Use and Land Cover

The majority of the land use in the upper elevation (i.e., southern) portion of the Project Area is privately managed forest lands. Some commercial and light industrial development is located in Coombs. The central sections of the Project Area are a mixture of rural development with agriculture and low density residential. The coastal (northern) portion of the Project Area is more developed as it includes both the Town of Qualicum Beach and the north-western portion of the City of Parksville. These areas consist of high-density residential development and commercial properties.

The RDN GIS department conducted a general comparison of orthophotos from 2011 (approximately the time of the Waterline (2013) Phase 1 Conceptual Model) and 2020 to identify areas of landcover change and to confirm the assumptions used in the groundwater recharge estimates for Phase 1. Eight areas were identified to have changes in land cover between the two time periods. The locations of these areas as well as the 2011 and 2020 photos for each for these areas are shown on Figure 3. Based on this review, the amount of change to the landcover between 2011 to 2020 in the identified areas was observed to be localized at the parcel level. Based on orthophoto comparison, changes in land cover occurred mostly as a reduction in tree cover associated with expansion of existing developments and are relatively small in area compared to the dimension of the grid (i.e., 1 km x 1 km) that was used to estimate groundwater recharge by Waterline. Generally, changes in land cover from 2011 to 2020 are less than 2% of the extent of the aquifers underlying these areas. Although some impacts to recharge may have occurred as a result of the landcover change at the local scale, these changes are expected to have limited effects on groundwater recharge at the regional scale of the model and the results of the refined water budgets. As a result, the estimated groundwater recharge from precipitation from the Waterline (2013) Phase 1 was not modified to reflect the small changes in landcover in the eight areas shown on Figure 3. Refined mapping for recharge could be conducted at a later time to further refine the water balances if that is considered to be of value for more detailed assessments in particular areas of French Creek.

LEGEND

PROJECT AREA

AREAS OF CHANGE IN LAND USE 2011 TO 2020

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. POLYGONS AND ORTHOPHOTOS FOR AREAS OF LAND USE CHANGE BETWEEN 2011 AND 2020 PROVIDED BY RDN.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
LAND COVER CHANGES 2011 COMPARED TO 2020

CONSULTANT

YYYY-MM-DD	2023-07-19
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	3

3.2.3 Surface Water

3.2.3.1 Watersheds and Creek Flow Monitoring

Excluding the Englishman River, which is predominantly in adjacent Water Region 4, 11 major watersheds were identified within the Project Area (Figure 4). The largest watershed is associated with French Creek (87 km^2) (Government of BC, 2021a).

Four hydrometric stations were identified within the Project Area, all located along French Creek. Only one of the four hydrometric stations in the Project Area, French Creek DS of Barclay Cres Station (08HB0021) is currently active. Two stations were part of the Water Survey of Canada (WSC) network (French Creek at Coombs and French Creek above pumphouse) and are not currently active. The available hydrometric station information is summarised in Table 4 and the locations of the stations are presented on Figure 4.

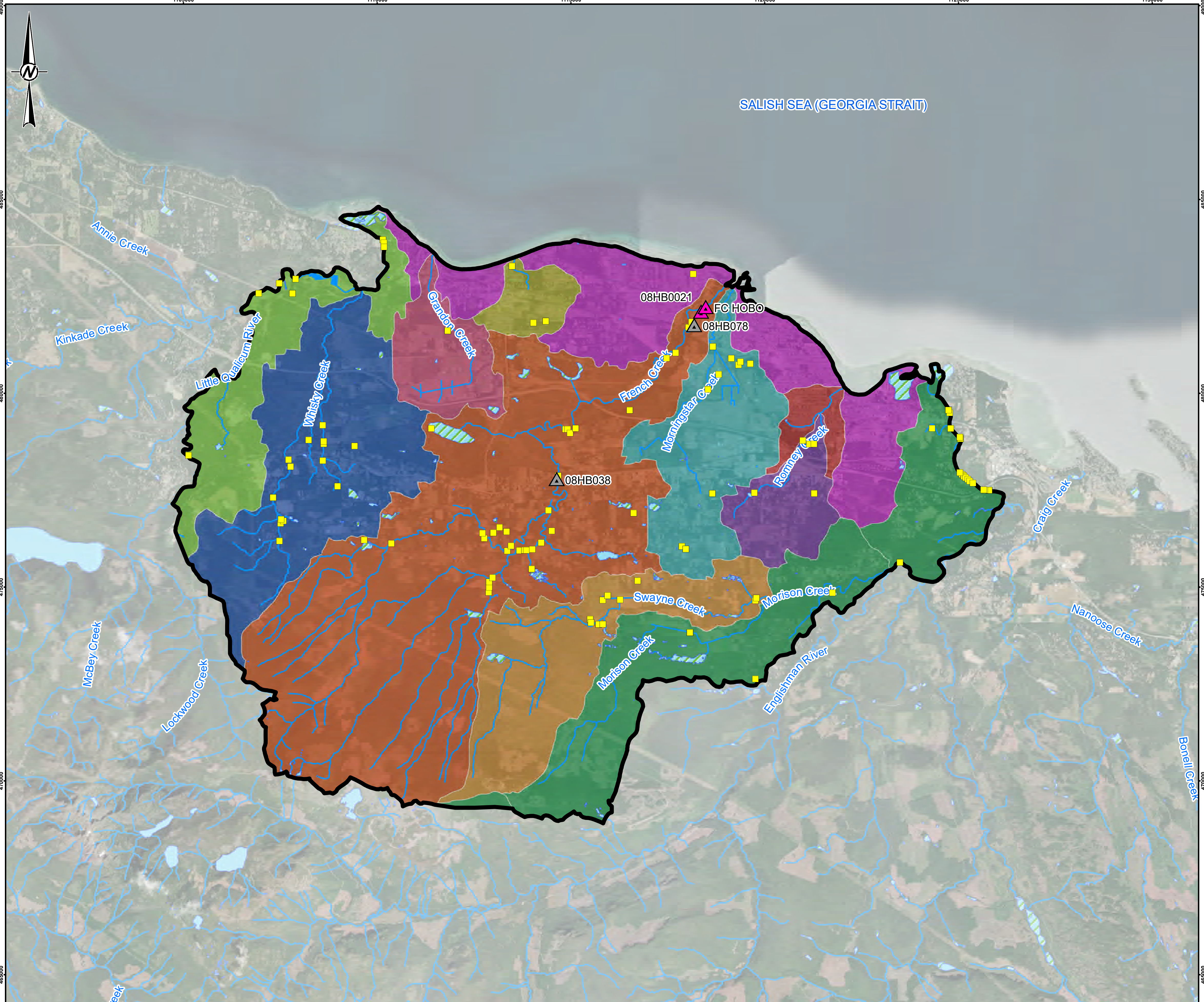
Table 4: Hydrometric Stations in Project Area

Hydrometric Station Name	Station No.	Monitoring Period	Monitoring Frequency	Drainage Area (km^2)[a]	Responsibility
French Creek at Coombs	08HB038	1969 to 1989	Daily	58.2	WSC
French Creek above Pumphouse	08HB078	1990 to 1996	Daily	86.6	WSC
French Creek DS of Barclay Cres	08HB0021	2018 to present	Hourly	87.1[b]	FOR

Notes:

a. Drainage area to the station gauge

b. Area estimate based on Freshwater Atlas Assessment Watersheds (BC Government 2021a)



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES
- ACTIVE SURFACE WATER LICENSES

HYDROMETRIC MONITORING STATION

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

WATERSHED

- BEACH CREEK
- CAREY CREEK
- ENGLISHMAN RIVER
- FRENCH CREEK
- GRANDON CREEK
- LITTLE QUALICUM RIVER
- LOCKWOOD CREEK
- MORISON CREEK
- MORNINGSTAR CREEK
- ROMNEY CREEK
- SWANE CREEK
- WHISKY CREEK
- UNNAMED

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERENMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
WATERSHEDS AND SURFACE WATER FEATURES

CONSULTANT

YYYY-MM-DD	2023-07-19
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	4

The three hydrometric stations listed in Table 4 for which flow data are reported have differing monitoring periods which do not overlap. Variations in annual flows and changes in water uses over time resulted in variations in flow conditions within the three datasets, particularly the dataset for the French Creek at Coombs station (08HB038).

Flow data from the French Creek at Coombs (08HB038) and French Creek above Pumphouse (08HB078) stations were measured manually on a seasonal basis (April to September) and are only available at daily resolution. The measurements from the active station French Creek DS of Barclay Cres (08BH0021) are collected continuous (hourly); however, several months within the monitoring period (2018 to 2021) report incomplete data.

Average monthly flow for months with less than three days of missing data were estimated and are outlined in Table 5 and on Figure 5.

Table 5: Monthly Flow Data (m^3/s) along French Creek

Station Information			Average Monthly Flow (Months of Data)											
Name	No.	Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
French Creek at Coombs	08HB038	1969 to 1989	-	-	-	1.61 (10)	0.97 (10)	0.27 (10)	0.08 (10)	0.01 (10)	0.05 (10)	-	-	-
French Creek above Pumphouse	08HB078	1990 to 1996	4.81 (2)	5.85 (2)	3.49 (2)	1.31 (6)	0.52 (6)	0.33 (6)	0.06 (6)	0.07 (6)	0.07 (6)	0.64 (2)	4.07 (2)	7.02 (2)
French Creek DS of Barclay Cres	08HB0021	2018 to 2021	6.99 (1)	2.15 (2)	-	1.34 (1)	0.44 (1)	0.05 (3)	0.03 (3)	0.01 (2)	0.21 (3)	1.21 (4)	2.15 (2)	2.88 (2)

Notes:

Dashes (-) indicate months with insufficient available data

Bracketed numbers indicate number of months of data used to calculate each average

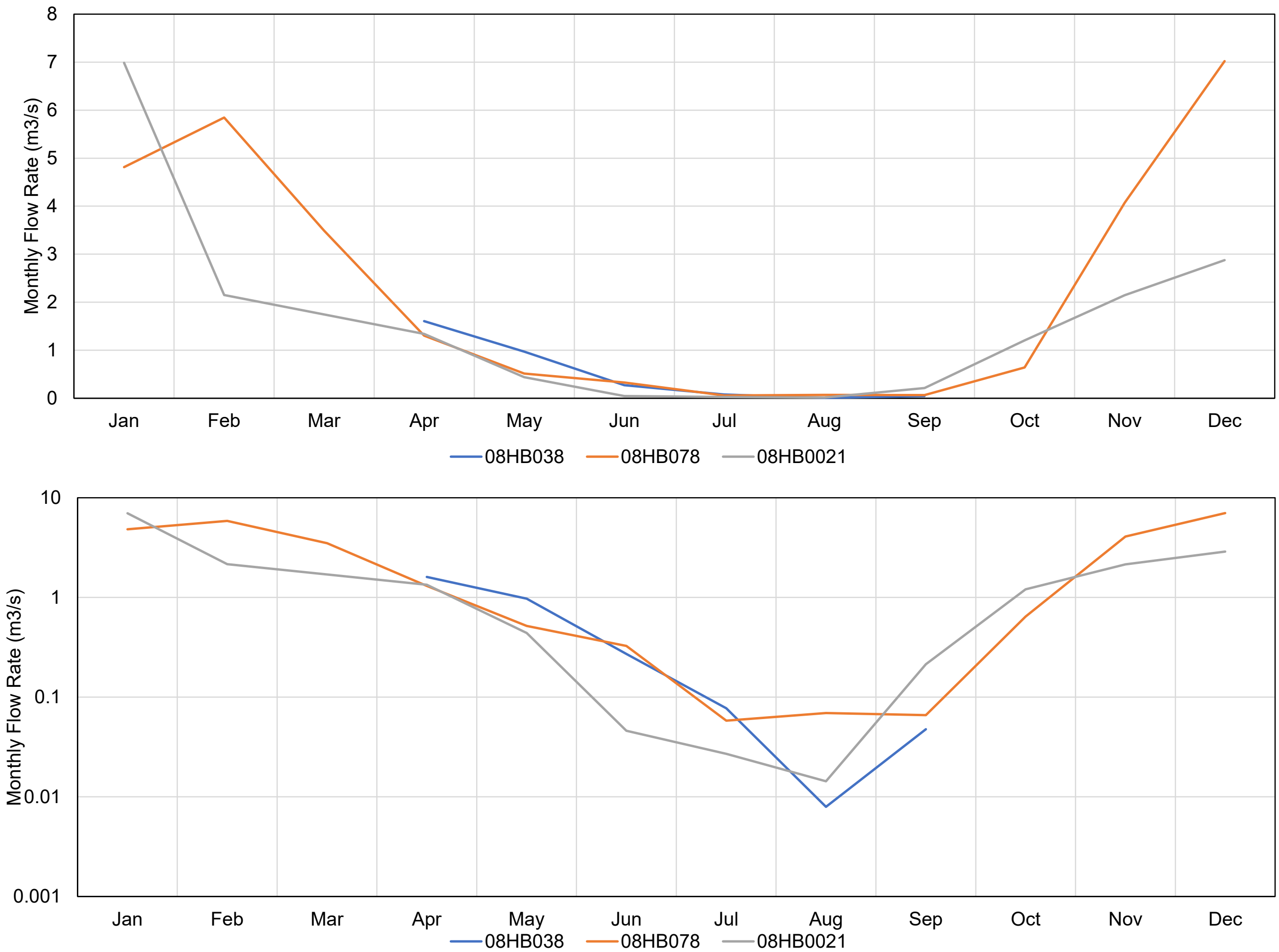

Figure 5: Average Monthly Discharge at the French Creek Hydrometric Stations[1]

As illustrated on Figure 5, the hydrometric response in French Creek is strongly correlated to seasonal precipitation patterns. Streamflow in French Creek peaks during the winter months is significantly reduced (often less than 0.1 m^3/s) during the dry, summer months (June to August). Recent discharge data from the French Creek DS of Barclay Cres station (08HB0021; 2018 to 2021) shows that creek flow between May and August is significantly lower (50% to 85%) than creek flow measured in the previous monitoring period (1990 to 1996) at the nearby French Creek above Pumphouse station (08HB078). These differences in discharge could be associated with increased surface water withdrawals from the creek during the dry season for irrigation purposes or due to changes in climate conditions between the two monitoring periods (including the effects of a very dry year like 2019); however, there are not enough data to validate this. Based on review of the data recorded at French Creek above Pumphouse station (08HB078), the average annual flow at this location is

[1] Average monthly discharge presented with normal scale (top chart) and log scale (bottom chart)

calculated to be 2.33 m^3/s. This was calculated using the two available full years of data. The remaining two stations did not include full years of data and, as a result, had insufficient data to estimate average annual flow directly.

No other information was identified regarding flow conditions for other water courses within the Project Area.

3.2.3.2 Surface Water Licenses

Water rights licences within the Project Area were downloaded from the Provincial database on 27 April 2022. Surface water licences for the Project Area reflect those uploaded in the database as of 27 of April 2022; however, additional surface water users may be present in the Project Area.

It is noted that under the *Water Sustainability Act* (WSA), 1 March 2022 was the deadline for submitting applications for an Existing Use Groundwater Licence for landowners who utilize groundwater for non-domestic purposes. Prior to this deadline, the province received numerous applications that have not yet been included in the provincial database. Although groundwater licence data were not available as input to the Phase 3 French Creek Water Budget, as discussed in Section 3.2.6, groundwater use was estimated based on available information including municipal pumping records and land use information.

A total of 218 surface water licenses were identified in the Project Area from the BC provincial database. Of the 218 surface water licenses identified, 54 were listed with a status of “Inactive”, “Abandoned” or “Canceled” and the status of 164 licenses was “Current” or “Active”. Table 6 provides a breakdown of current surface water licenses by watershed and Table 7 provides a summary of licensed surface water use.

Table 6: Watersheds and Surface Water Licenses in the Project Area

Watershed		Drainage Area (km^2)[a]	Relative Stress Level[b]	No. Current and Active Water Licenses	Annual Surface Water Demand[c] (thousand m^3)
Little Qualicum River	Whisky Creek	26.8	-	17	126
	Little Qualicum River (excluding Whisky Creek sub-watershed)	13.3	-	11	40,682
Englishman	Englishman River (excluding Morison and Swayne Creek sub-watershed)	9.2	Moderate	33	35,686
	Morison Creek (excluding Swayne Creek sub-watershed)	19.2	Moderate	6	67
	Swayne Creek	18.9	Moderate	17	65
French Creek		87	High	46	830
Morningstar Creek		15.1	-	18	211
Romney Creek		6.4	-	6	507
Carey Creek		2.5	-	-	-
Grandon Creek		7.2	-	4	28
Beach Creek		3.5	-	5	34
Unnamed No.1 (along Salish Sea coast east of Grandon Creek)		2.0	-	-	-

Watershed	Drainage Area (km^2)[a]	Relative Stress Level[b]	No. Current and Active Water Licenses	Annual Surface Water Demand[c] (thousand m^3)
Unnamed No.2 (along Salish Sea coast west of French Creek)	9.5	-	1	9
Unnamed No. 3 (along Salish Sea coast east of Morningstar Creek)	3.9	-	-	-
Unnamed No. 4 (between Englishman River and Romney Creek)	6.3	-	-	-
Unnamed No.5 (along Salish Sea coast west of Grandon Creek)	0.9	-	-	-
TOTAL			164	78,246

Notes:

a. Portion of watershed that is located within Project Area

b. 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

c. Total consumptive demand (surface water only)

Table 7: Summary of Licensed Surface Water Use in Project Area

Purpose of Surface Water Use	No. of Surface Water Licences[a]	Annual Surface Water Demand[b] (thousand m^3)
Waterworks and Water Delivery	16	8,833
Domestic	58	60
Commercial Enterprise	3	23
Pond and Aquaculture	1	9
Lawn, Fairway and Gardens	4	114
Livestock and Animal	7	10
Private Irrigation	33	341
Land Improvement	11	90
Non-Power Stream Storage	23	9,161
Conservation (Storage and Water Use)	8	59,385
TOTAL	164	78,246

Notes:

a. Surface water licenses identified as "current" or "pending"

b. Total consumptive demand

Over 98% of the annual licensed surface water use in the Project Area is reported to be for water supply, non-power stream storage or conservation (storage and water use). Approximately half of the active surface water licenses in the Project Area are located within in the Englishman River and French Creek watersheds. Excluding water supply and conservation, approximately half of the licensed use is reported to be for domestic, irrigation and livestock purposes. 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 the municipal water service areas (Section 3.2.6.2) and were also taken into consideration to assess risk management levels for French Creek based on the Interim Framework (FOR and BC ENV, 2020), as described in Section 7.0.

3.2.4 3D Hydrostratigraphic Interpretation

GWS (2020) developed an updated three-dimensional (3D) hydrostratigraphic model of the French Creek area using Leapfrog® software (the GWS Leapfrog Model). The updated model, which was based on previous work, including the RDN Phase 1 Water Budget (Waterline, 2013) and the 2014 NRCAN Nanaimo Lowlands project Leapfrog Model (Benoit et al., 2015), represents an improved understanding of the extent and distribution of aquifers in the region. The GWS Leapfrog Model presents refined geometries for aquifers in the region and updated bedrock topography and groundwater elevations for both bedrock and overburden aquifers. The GWS Leapfrog Model and associated database was made available to WSP by GWS and, following review and discussion with GWS, was used as a base to build the numerical groundwater model for the Phase 3 French Creek Water Budget.

The surficial geology in the Project Area is comprised of sediments deposited during glaciation, deglaciation, marine incursion and isostatic rebound events in the area. The maximum extent to post-glacial marine inundation is thought to be approximately 150 m above present-day sea level (Benoit et al., 2015). This elevation corresponds to an approximate upper limit on the thickest sediment deposits. Six main geological unconsolidated units have been mapped throughout the Project Area, based on work by the Geological Survey of Canada (GSC: Fyles, 1960; Benoit et al., 2015; Benoit et al., 2016). These units, from youngest to oldest in terms of deposition, are:

- Salish Sediments
- Capilano Sediments
- Vashon Drift
- Quadra Sand
- Cowichan Head Formation
- Dashwood Drift (including Mapleguard sediments)

Upland areas are mostly underlain by crystalline bedrock (Meso to Paleozoic metamorphic and intrusive basement rocks), while lowland areas are underlain by sedimentary rocks of the Nanaimo Group (mostly sandstone, conglomerate and mudstone/shale). Nanaimo Group rocks are mainly fractured at shallow depth which allows seasonal recharge and can yield appreciable amounts of water (GWS, 2020).

Detailed descriptions of the units, including their relative ages, textures and depositional environments can be found in the Nanoose – Deep Bay area, Nanaimo Lowland groundwater study atlas (Benoit et al., 2016). Figure 6 presents a view of the GWS Leapfrog Model of the French Creek area and Figure 7 presents a cross-section showing the interpreted stratigraphy.

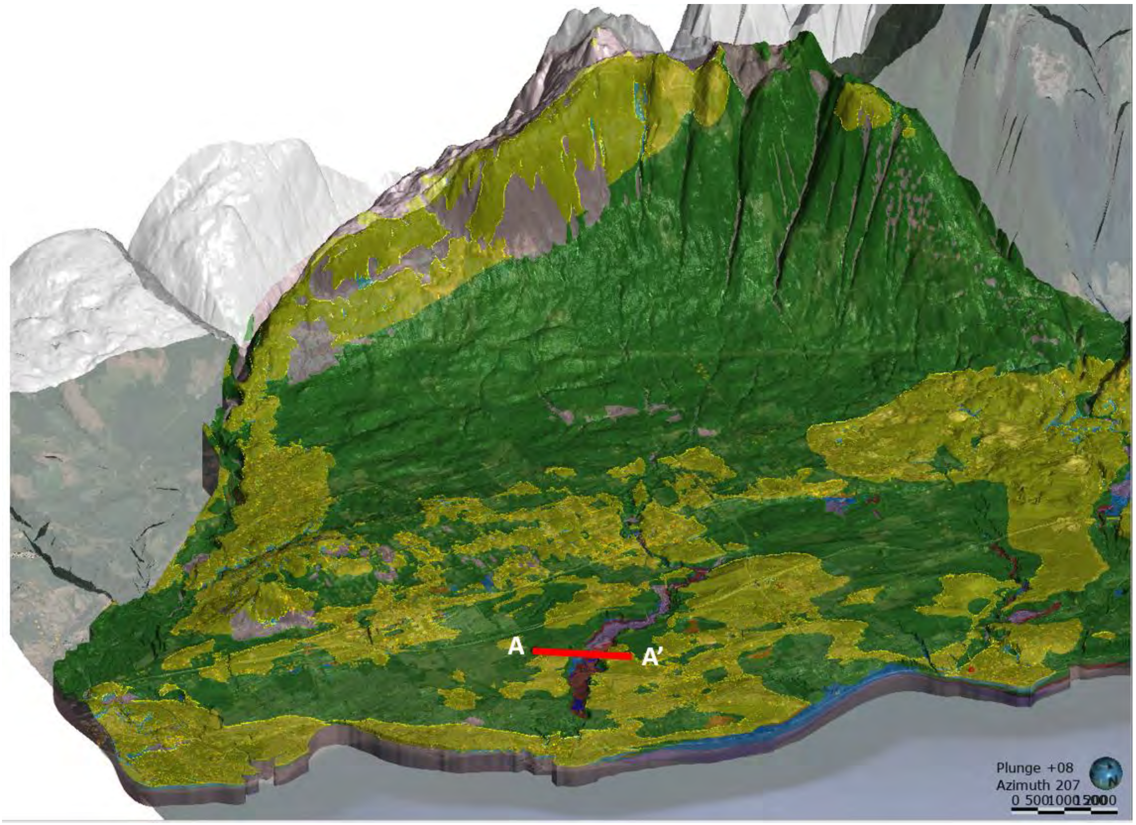

Figure 6: Angled View of GWS Leapfrog Model (Vertical Exaggeration 3:1)

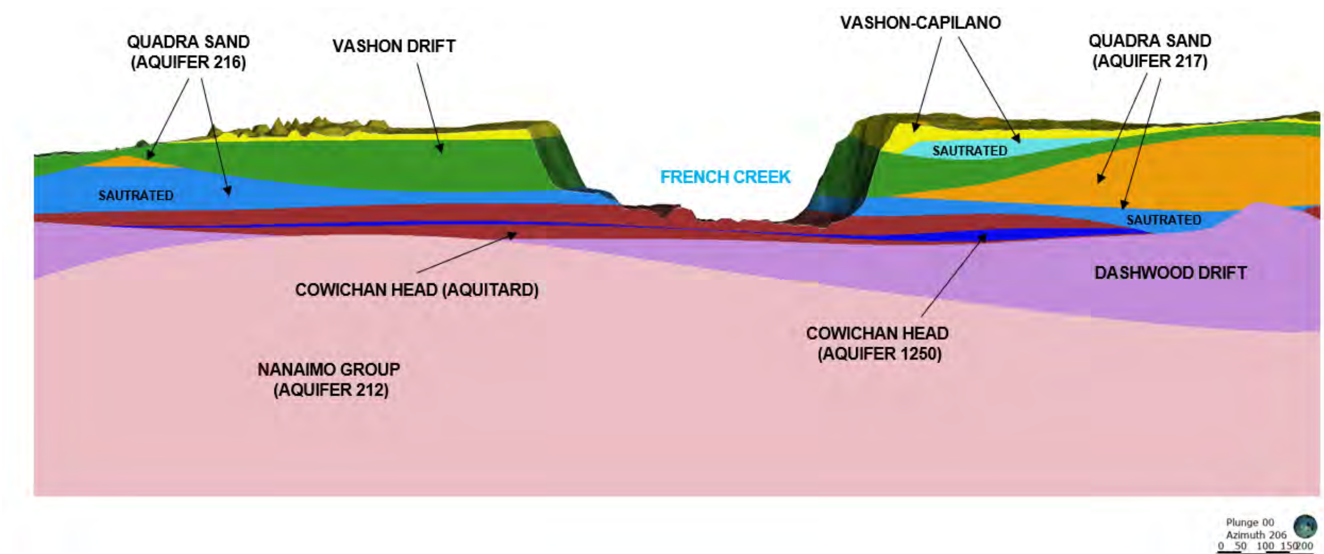

Figure 7: 2D View of GWS Leapfrog Model–Section A-A' (vertical exaggeration 5:1)

3.2.4.1 Aquifer Delineation

As part of the 2020 aquifer mapping study, GWS identified and mapped three new unconsolidated aquifers within the Project Area. GWS also refined the boundaries of the previously mapped aquifers within the Project Area and updated information regarding water levels, yield, number of wells, etc., with the exception of Aquifer 664. Figure 8 below presents a summary of aquifers mapped in the Project Area, based on the GWS aquifer mapping study. Figure 9 presents the locations of the reported water wells used in the GWS aquifer mapping study and their assignment to the different aquifers. The aquifer delineation conducted by GWS was then reviewed by FOR and provided to WSP for use in the Phase 3 French Creek Water Budget project. Hydrogeological assessments that were conducted by Piteau Associates Engineering Ltd. (Piteau) and made available to WSP after the groundwater numerical model had been developed and the water budget analysis and stress assessments were conducted, are referred to in Sections 6.0 and 8.0.

One major finding of the GWS aquifer mapping study was the delineation of a Cowichan-Dashwood deep confined aquifer system (Aquifer 1250) underlying the Quadra sand aquifer system (Aquifers 216 and 217). GWS delineated Aquifer 1250 based on analysis of the differing lithologies, screened depths, static water levels and geometry of the units observed in the GWS Leapfrog model, as well as patterns of annual groundwater levels that are markedly different between the Quadra and the deeper system. As part of the delineation work, GWS reassigned numerous water wells to Aquifer 1250, including four PGOWN and ten community water supply wells, originally assumed to be completed in the Quadra formation (Aquifers 216 and 217). WSP reviewed the reassignment of PGOWN and production wells to Aquifer 1250 to confirm that the wells were correctly assigned in the GWS Leapfrog Model. Based on the review of the GWS hydrostratigraphic interpretation, WSP considered the following regarding Aquifer 1250:

- Cowichan-Dashwood Aquifer 1250 is typically isolated from the Quadra formation by thick till and/or clay units and has a notably coarser texture with a higher gravel component than the overlying Quadra Aquifers 216 and 217, based on driller’s descriptions of lithology on borehole logs. Cowichan Head sand and gravel units may locally contact the Quadra.
- French Creek has down cut through the Quadra formation, leaving Aquifers 216 and 217 perched above the river valley bottom. Cowichan-Dashwood Aquifer 1250 underlies the river system and is inferred by GWS to likely have some degree of connection in the southern portion of the aquifer. However, based on the geological volumes provided, the thin permeable layer (Aquifer 1250) within Cowichan Head formation, is not directly connected to French Creek.

GWS modified the boundaries of Bedrock Aquifers 220 and 212 to fit with bedrock geological mapping. Aquifer 220 was extended from the boundary of the sedimentary bedrock unit towards the border of overburden Aquifers 217 and 216. Bedrock Aquifer 212 was extended from the ocean to the boundary with Aquifer 220.

Table 8: Summary of Mapped Aquifers in the Project Area (GWS, 2020)

Aquifer Sub-Type No.	Aquifer Sub-Type description	Aquifer Number[a]	Location	Hydro stratigraphic unit	PGOWN Wells[b]
Previously Mapped Aquifers					
1b	Unconfined fluvial/glaciofluvial sand and gravel aquifers along medium stream	664	Little Qualicum River valley and delta	Capilano-Salish	OW389
4a	Unconfined glaciofluvial sand and gravel aquifers	**663**	Whisky Creek headwaters	Vashon-Capilano coarse (kame)	-
4b	Confined sand and gravel aquifers	**209**	Between Swayne Creek. and the Englishman River	Vashon-Capilano coarse	-
		217	Between French Creek and Whisky Creek.	Quadra sand	OW434
		216	Between the Englishman River and French Creek.	Quadra sand	OW304, OW314, OW398, OW424
5a	Fractured sedimentary bedrock aquifers	**212**	Qualicum and Parksville	Bedrock - sedimentary	-
		220	Errington	Bedrock - sedimentary	OW287
Newly Mapped Aquifers					
4a	Unconfined glaciofluvial sand and gravel aquifers	1252	near Morison Creek, above 209	Capilano-Salish	
2	Unconfined deltaic sand and gravel aquifers	1248	French Creek valley & delta	Salish	-
4c	Confined sand and gravel aquifer (marine environment)	1250	Below aquifer 217-216 between Morningstar Creek and Grandon Creek	Cowichan-Dashwood	OW295, OW303, OW321, OW433[c]

Notes:

a. In bold are the aquifers where GWS refined the boundaries as part of their study.

b. PGOWN = Provincial Groundwater Observation Well Network; OW = Observation Well

c. PGOWN wells were reassigned to Aquifer 1250 from Aquifer 217.

LEGEND

PROJECT AREA

WETLANDS

WATERBODIES

WATERCOURSES

OVERBURDEN AQUIFER

AQUIFER NUMBER

AQ 1248

AQ 1250

AQ 1252

AQ 209

AQ 216

AQ 217

AQ 663

AQ 664

BEDROCK AQUIFER

AQUIFER NUMBER

AQ 212

AQ 220

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT

REGIONAL DISTRICT OF NANAIMO

PROJECT

REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

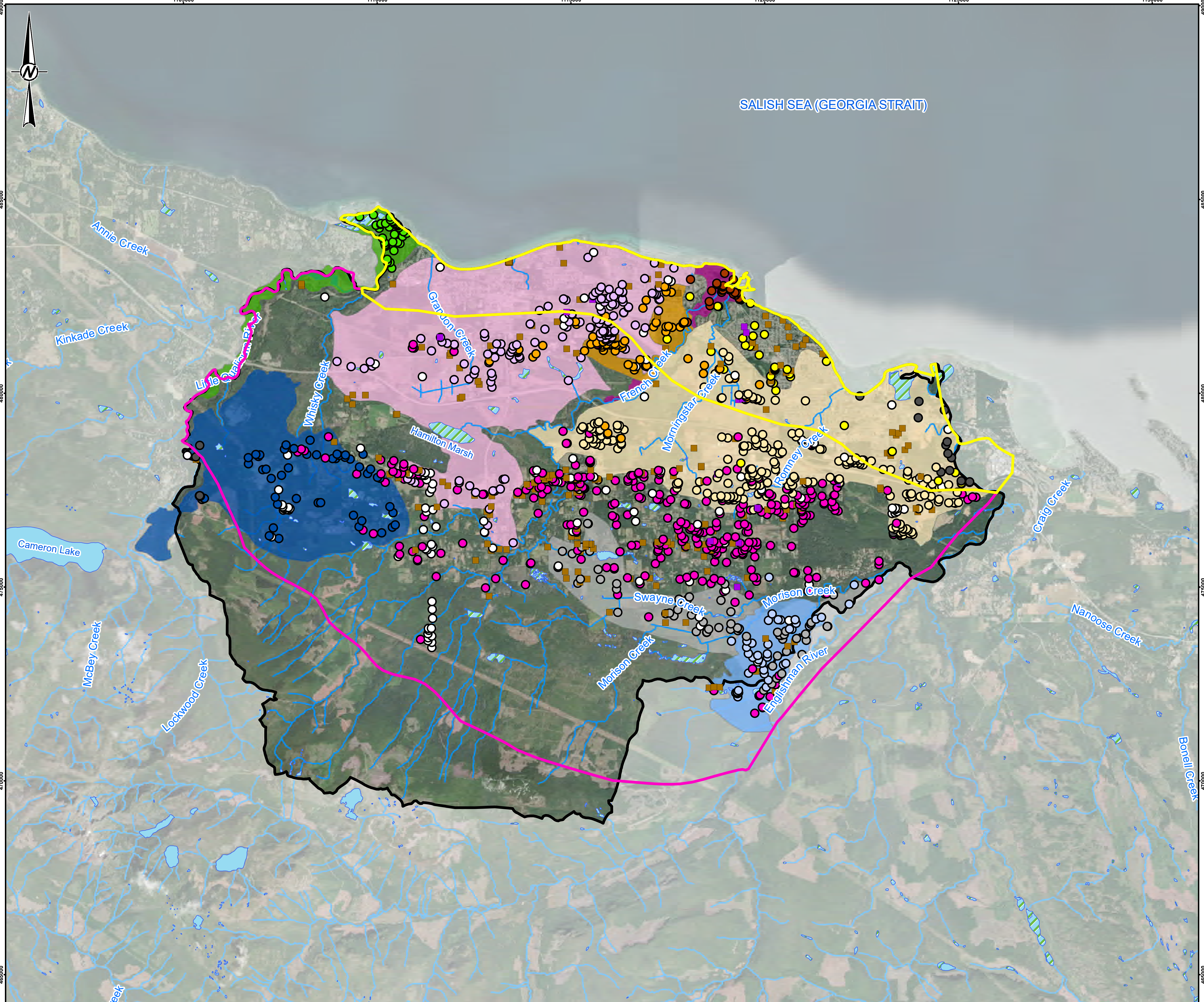
TITLE

MAPPED AQUIFERS IN PROJECT AREA

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	8



LEGEND

AQUIFER NUMBER AND FORMATION

- Aquifer 209
- Aquifer 216
- Aquifer 217
- Aquifer 663
- Aquifer 664
- Aquifer 1248
- Aquifer 1250
- Aquifer 1252
- Capilano-Salish
- Unconsolidated
- Aquifer 212 (HASLAM FORMATION)
- Aquifer 220 (HASLAM FORMATION)
- Groundwater Well Not in Project Area Aquifer
- Unassigned

BEDROCK AQUIFER

AQUIFER NUMBER

- AQ 212
- AQ 220

OVERBURDEN AQUIFER

AQUIFER NUMBER

- AQ 1248
- AQ 1250
- AQ 1252
- AQ 209
- AQ 216
- AQ 217
- AQ 663
- AQ 664
- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

0 2,000 4,000

1:100,000 METRES

NOTE(S)

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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
WELLS BY AQUIFER IN THE PROJECT AREA

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	9

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

25mm

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3.2.5 Hydrogeology

As discussed in Section 3.2.4.1, eight unconsolidated aquifers and two bedrock aquifers are mapped in the Project Area (Table 8). Data related to the hydrogeological parameters and water levels for these aquifers are described below.

3.2.5.1 Hydrogeological Parameters

WSP assembled information regarding hydrogeological parameters, including transmissivity, hydraulic conductivity and storage coefficients, 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 9.

Table 9: Summary of Hydrogeological Parameters Reported for Aquifers in the Project Area

Hydrogeological Unit	Aquifer Number	Aquifer Type and Classification	Hydraulic Conductivity K (m/s)		Storativity (-)		Source
			Min	Max	Min	Max	
Vashon-Capilano coarse	209	Confined Sand and Gravel (IIC)	9×10^{-6}	8×10^{-4}	-	-	Benoit et al., 2016
Sand and Gravel: Quadra Sand	216	Confined Sand and Gravel (IIB)	2×10^{-6}	5×10^{-4}	3×10^{-4}	4×10^{-4}	Benoit et al., 2016; Carmichael, 2013; EBA, 2005; GWS, 2020; Kohut, 2003
Sand and Gravel: Quadra Sand	217	Confined Sand and Gravel (IIC)	2×10^{-6}	4×10^{-3}	3×10^{-7}	2×10^{-2}	Benoit et al., 2016; Carmichael, 2013; EBA, 2005; Kohut, 2003; GWS, 2020
Glaciofluvial Sand and Gravel: Vashon-Capilano coarse (kame)	663	Unconfined Sand and Gravel (IIA)	9×10^{-6}	9×10^{-4}	-	-	Benoit et al., 2016; Carmichael, 2013; GWS, 2020
Fluvial/glaciofluvial Sand and Gravel - Salish	664	Unconfined Sand and Gravel (IA)	3×10^{-4}	5×10^{-1}	-	-	Benoit et al., 2016; EBA, 2005; GWS, 2020
Deltaic Sand and Gravel - Salish	1248	Unconfined Sand and Gravel (IA)	3×10^{-4}	1×10^{-2}	-	-	Benoit et al., 2016; EBA, 2005; GWS, 2020
Sand and Gravel - Cowichan	1250	Confined Sand and Gravel (IIC)	2×10^{-6}	5×10^{-3}	-	-	Benoit et al., 2016; GWS, 2020
Sand and Gravel (Glaciofluvial)- Salish	1252	Unconfined Sand and Gravel (IIB)	3×10^{-4}	5×10^{-1}	-	-	Benoit et al., 2016; EBA, 2005; GWS, 2020
Bedrock - Haslam Formation (Fractured sedimentary bedrock)	212	Confined Bedrock (IIIC)	1×10^{-10}	1×10^{-4}	-	-	Benoit et al., 2016
Bedrock - Haslam Formation (Fractured sedimentary bedrock)	220	Partially Confined Bedrock (IIIB)	1×10^{-10}	1×10^{-4}	-	-	Benoit et al., 2016

Hydrogeological Unit	Aquifer Number	Aquifer Type and Classification	Hydraulic Conductivity K (m/s)		Storativity (-)		Source
			Min	Max	Min	Max	
Surficial Till - Till/Clay (Aquitard) – Vachon Drift and Cowichan Head	-	-	5×10^{-9}	5×10^{-6}	-	-	Benoit et al., 2016; EBA, 2005

Hydrogeological parameters presented by Carmichael (2013) were estimated from data from pumping tests that were 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 Benoit et al. (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.

The circles displayed on Figure 10 show the locations where yields were reported in the BC ENV WELLS database and the colour of the yield circle illustrates the inferred aquifer assignment for the well based on mapping and connectivity study (GWS, 2020). The well yields that were recorded on the well records in the BC ENV WELLS database 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. 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 11 below, due to the increase in compressive stress and associated closing of fractures. These considerations were considered when assigning hydraulic conductivity in the numerical groundwater model and during model calibration.

LEGEND

- WATERCOURSES
- PROJECT AREA
- WETLANDS
- WATERBODIES

OVERBURDEN AQUIFER

AQUIFER NUMBER

- AQ 1248
- AQ 1250
- AQ 1252
- AQ 209
- AQ 216
- AQ 217
- AQ 663
- AQ 664

BEDROCK AQUIFER

AQUIFER NUMBER

- AQ 212
- AQ 220

WELL YIELDS (L/S)

Aquifer 1248	0 - 5	5 - 10	10 - 15	15 - 20	> 20
Aquifer 1250	0 - 5	5 - 10	10 - 15	15 - 20	> 20
Aquifer 1252	0 - 5	5 - 10	10 - 15	15 - 20	> 20
Aquifer 209	0 - 5	5 - 10	10 - 15	15 - 20	> 20
Aquifer 212	0 - 5	5 - 10	10 - 15	15 - 20	> 20
Aquifer 216	0 - 5	5 - 10	10 - 15	15 - 20	> 20
Aquifer 217	0 - 5	5 - 10	10 - 15	15 - 20	> 20
Aquifer 663	0 - 5	5 - 10	10 - 15	15 - 20	> 20
Aquifer 664	0 - 5	5 - 10	10 - 15	15 - 20	> 20
Capilano-Salish	0 - 5	5 - 10	10 - 15	15 - 20	> 20

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERENEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
WELL YIELDS (L/S) BY AQUIFER

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	10

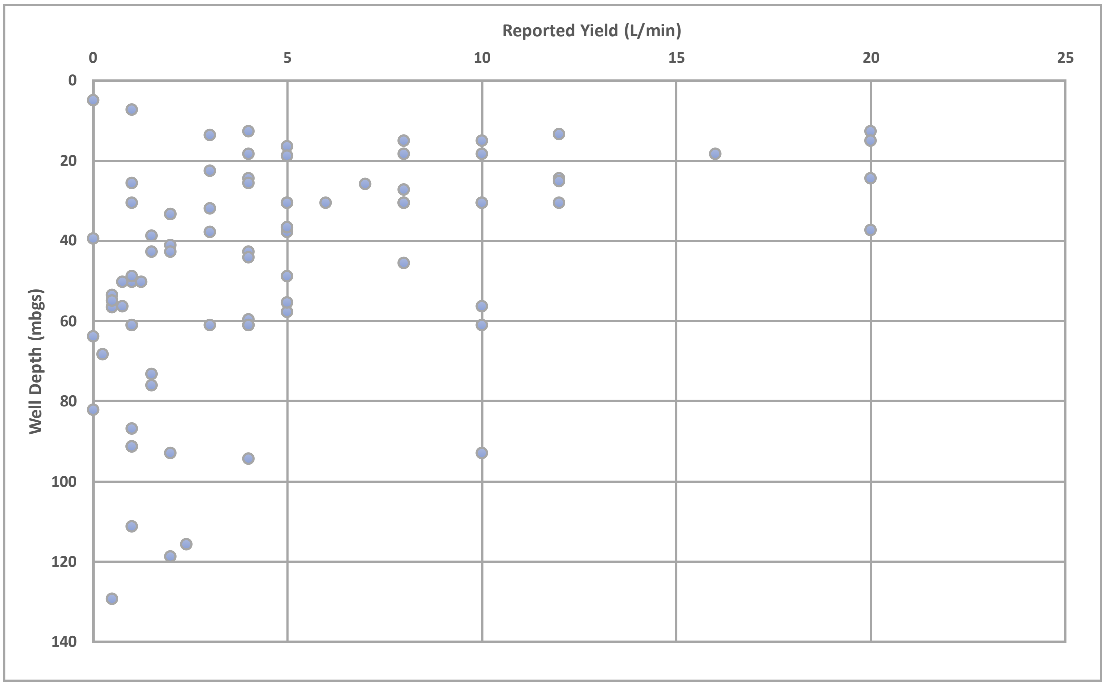


Figure 11: Well Yield vs Total Well Depth in Bedrock Groundwater Wells

3.2.5.2 Groundwater Recharge

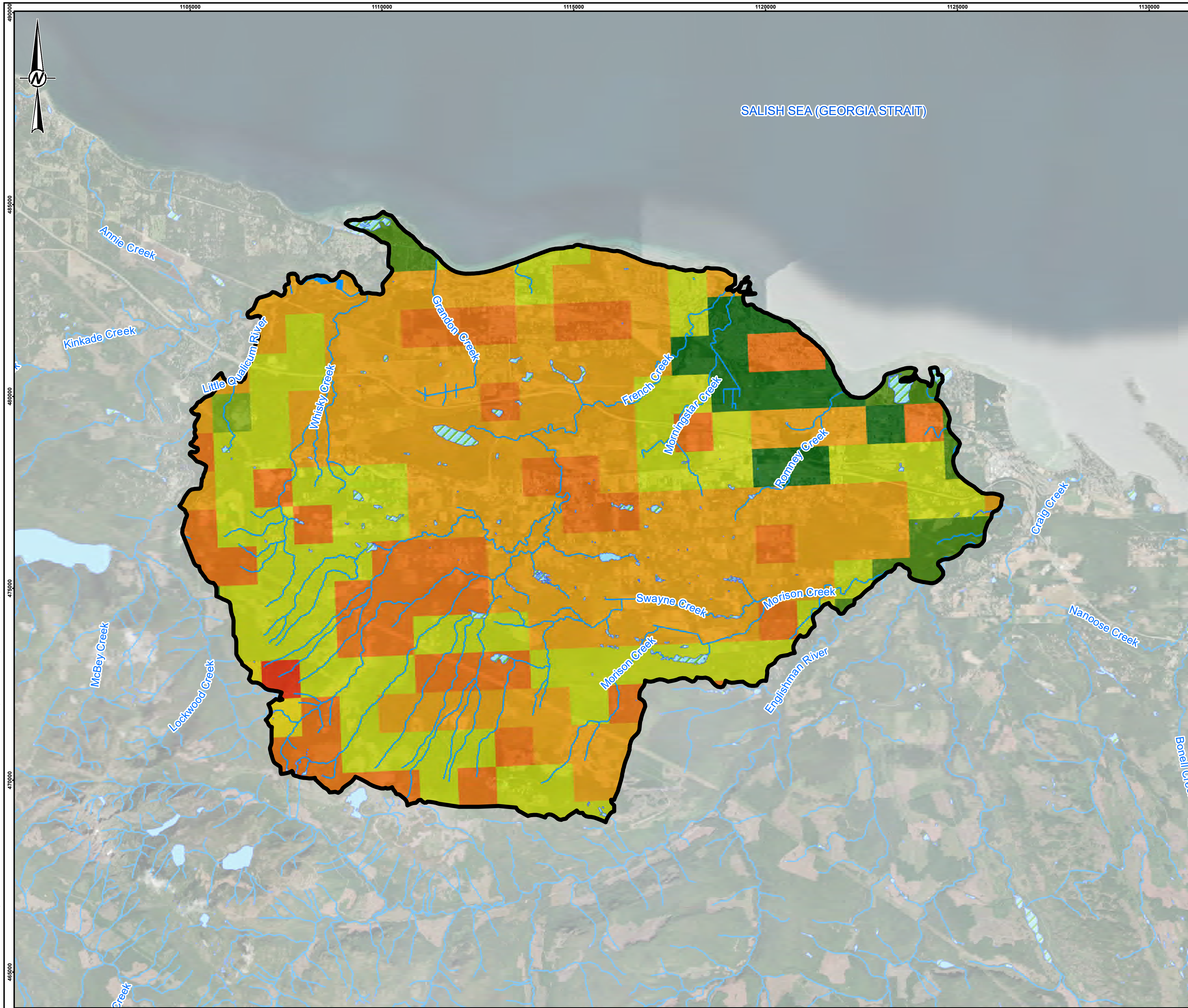
Precipitation during the wet season is the primary source of groundwater recharge to the aquifer system (overburden and bedrock) in the Project Area. Groundwater recharge is a function of the amount of precipitation, evapotranspiration and surface water runoff. Runoff is affected by a number of factors including topography, slope, vegetative cover, and the properties of the subsurface, including surficial material and the underlying aquifer material. In general, during the dry summer months, when a precipitation deficit occurs, limited recharge from precipitation is expected. In contrast, during the wet winter months a precipitation surplus occurs and both groundwater recharge and storm water runoff occur.

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. Waterline analysed a number of datasets to develop geospatially distributed recharge estimates. WSP analysed recent climate data, as described in Section 3.2.1, and assessed these data to be consistent with those reported in the Phase 1 Water Budget. In addition, WSP also analysed changes in land cover within the Project Area, as described in Section 3.2.2, and expects these changes to have limited effects on groundwater recharge at the regional scale of the model. Therefore, the groundwater recharge estimates presented in Phase 1 were considered applicable for the current Phase 3 French Creek Water Budget. Figure 12 presents the distribution of total annual groundwater recharge from precipitation values for the Project Area, as estimated by Waterline (2013). Figure 13 and Figure 14 present groundwater recharge from precipitation 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 that are connected to the municipal sewer system within the RDN water-serviced area were identified, as illustrated on Figure 15. These properties are assumed to contribute minimal amounts of groundwater recharge from wastewater. In agreement with RDN, 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).

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, following discussion with RDN, it was assumed that 70% groundwater withdrawals in areas that are not serviced by the municipal sewerage system would recharge the aquifer system via septic water return.

Groundwater recharge from irrigation activities was estimated based on zoning and land use. Outside of the water service areas, the crop types for each land parcel within the agricultural land reserve (ARL) were identified as part of the landcover layer from the Agricultural Water Demand (AWD) study from Van Der Gulik et al. (2013) provided by the BC Ministry of Agriculture. As part of the AWD study, the BC Ministry of Agriculture determined the irrigation requirements for each crop in the dry and wet seasons. The AWD study also included an estimate of the average deep percolation rate for the different irrigation methods (sprinkler, water gun, etc.) as a percentage for the total irrigation demand for the RDN. Based on this information WSP assumed that 13% of water used for irrigation purposes returns to the water table. Within the water service areas, it is assumed based on the zoning data that there is limited irrigation with the exception of domestic lawn watering and the watering of golf course fairways and greens. The irrigation of golf course grass uses a significant amount of water and therefore was included within the recharge sources for the water service area. Based on the average deep percolation rate for the golf sprinklers as a percentage for the total irrigation demand for golf courses within the Project Area estimated in the AWD study, WSP assumed that 16% of water used for irrigation purposes returns to the water table. The irrigation of domestic lawns was assumed to be a minimal source of recharge and was not included in the regional model, considering the size of lawns and the quantity of water used for their irrigation (i.e., residential water use) compared to the golf courses. The areas of anthropogenic recharge are identified in Figure 15.



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

TOTAL ANNUAL GROUNDWATER RECHARGE (mm)

- < 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120
- 120 - 140
- 140 - 160

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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4. GROUNDWATER RECHARGE DERIVED FROM WATERLINE (2013)

COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
TOTAL ANNUAL ESTIMATED GROUNDWATER RECHARGE FROM PRECIPITATION

CONSULTANT

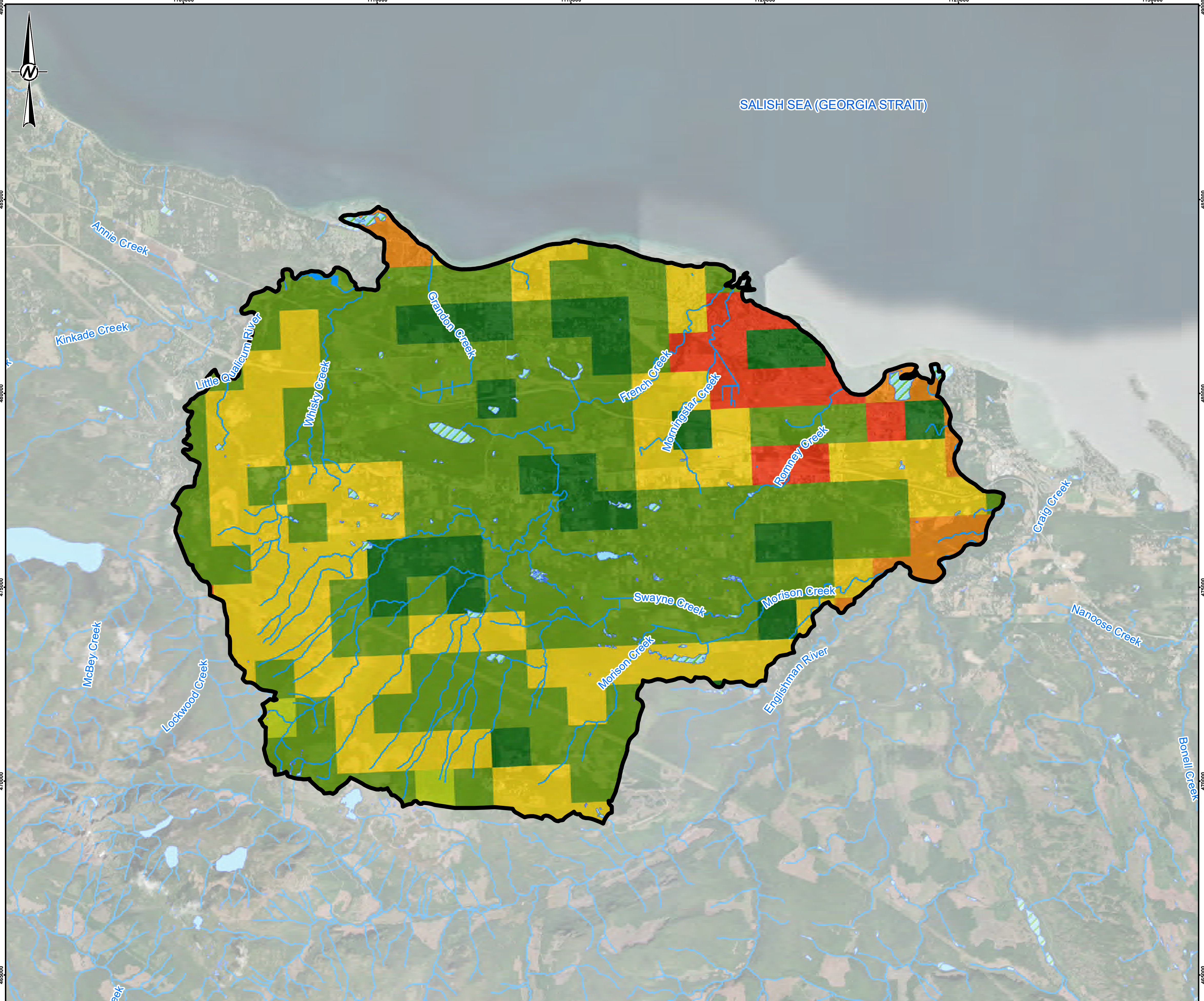
YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	12

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

25mm

0



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

GROUNDWATER RECHARGE DURING WET SEASON (mm)

- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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4. GROUNDWATER RECHARGE DERIVED FROM WATERLINE (2013)

COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
WET SEASON ESTIMATED GROUNDWATER RECHARGE FROM PRECIPITATION

CONSULTANT

YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
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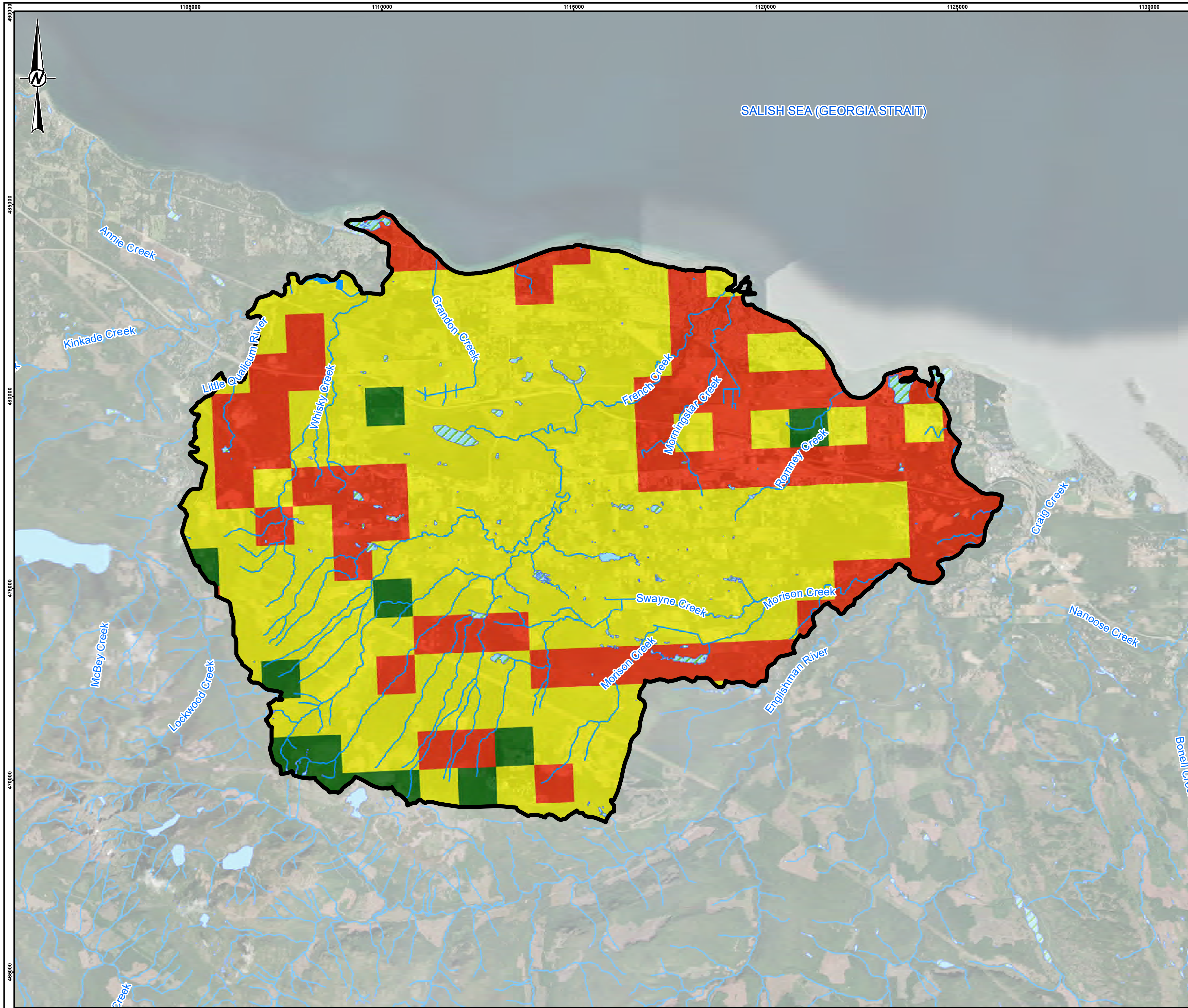

LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

GROUNDWATER RECHARGE DURING DRY SEASON (mm)

- 0 - 10
- 10 - 20
- 20 - 30

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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4. GROUNDWATER RECHARGE DERIVED FROM WATERLINE (2013)

COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

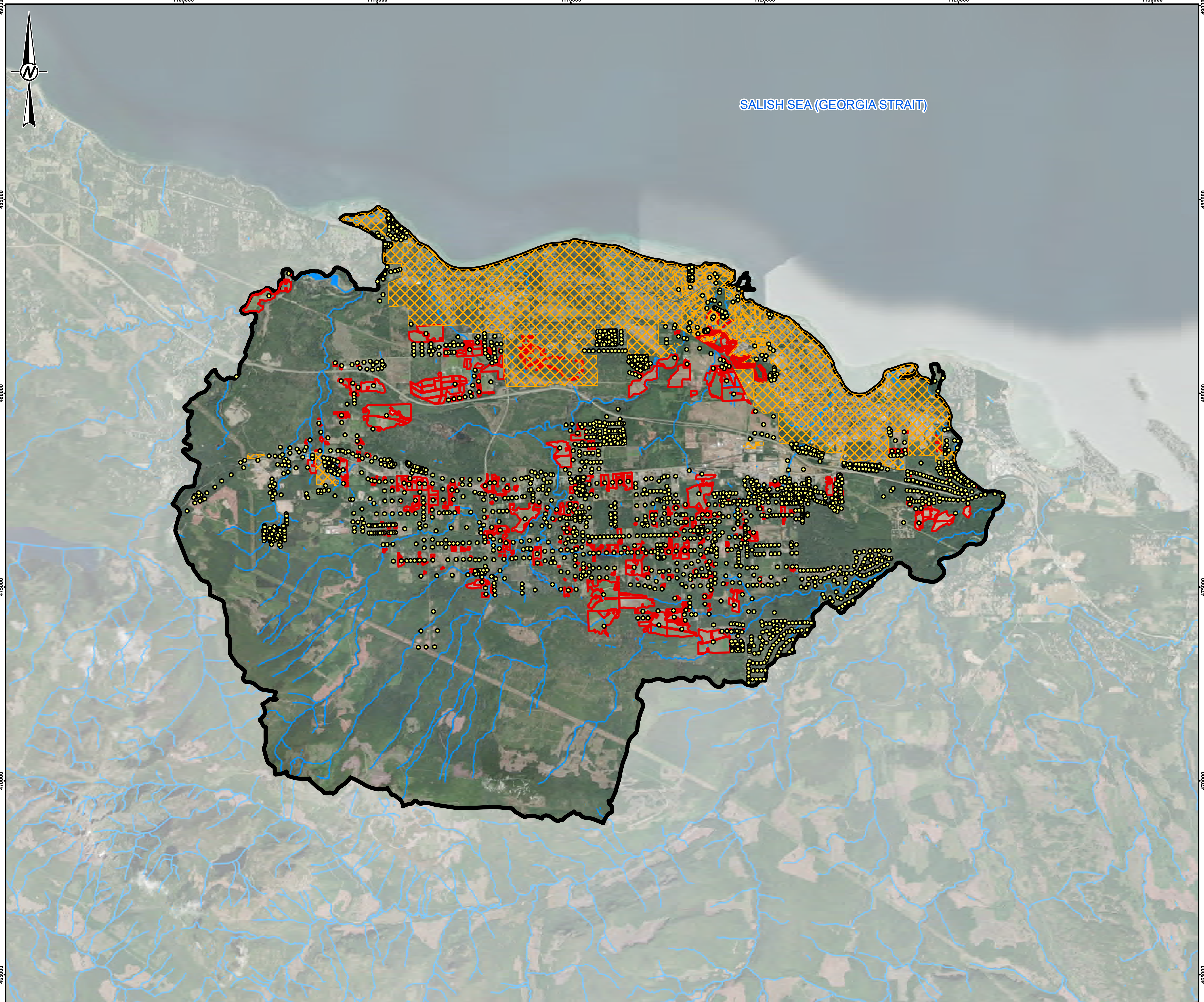
TITLE
DRY SEASON ESTIMATED GROUNDWATER RECHARGE FROM PRECIPITATION

CONSULTANT

YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	14

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



LEGEND

- Project Area
- Watercourses
- RECHARGE FROM WATER DISTRIBUTION SYSTEM LEAKAGE
- RECHARGE FROM IRRIGATION RETURN
- RECHARGE FROM SEPTIC RETURNS (CENTROID OF LOT)

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES,OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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4. GROUNDWATER RECHARGE AREAS DERIVED FROM AGRICULTURAL LAND USE INVENTORY (ALUI; 2012) AND THE RDN AGRICULTURAL WATER DEMAND MODEL (2013) AND WATER SERVICE AREAS.

COORDNATE SYSTEM: BC ALBERS

CLIENT

REGIONAL DISTRICT OF NANAIMO

PROJECT

REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE

ESTIMATED GROUNDWATER RECHARGE FROM ANTHROPOGENIC SOURCES

CONSULTANT

YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

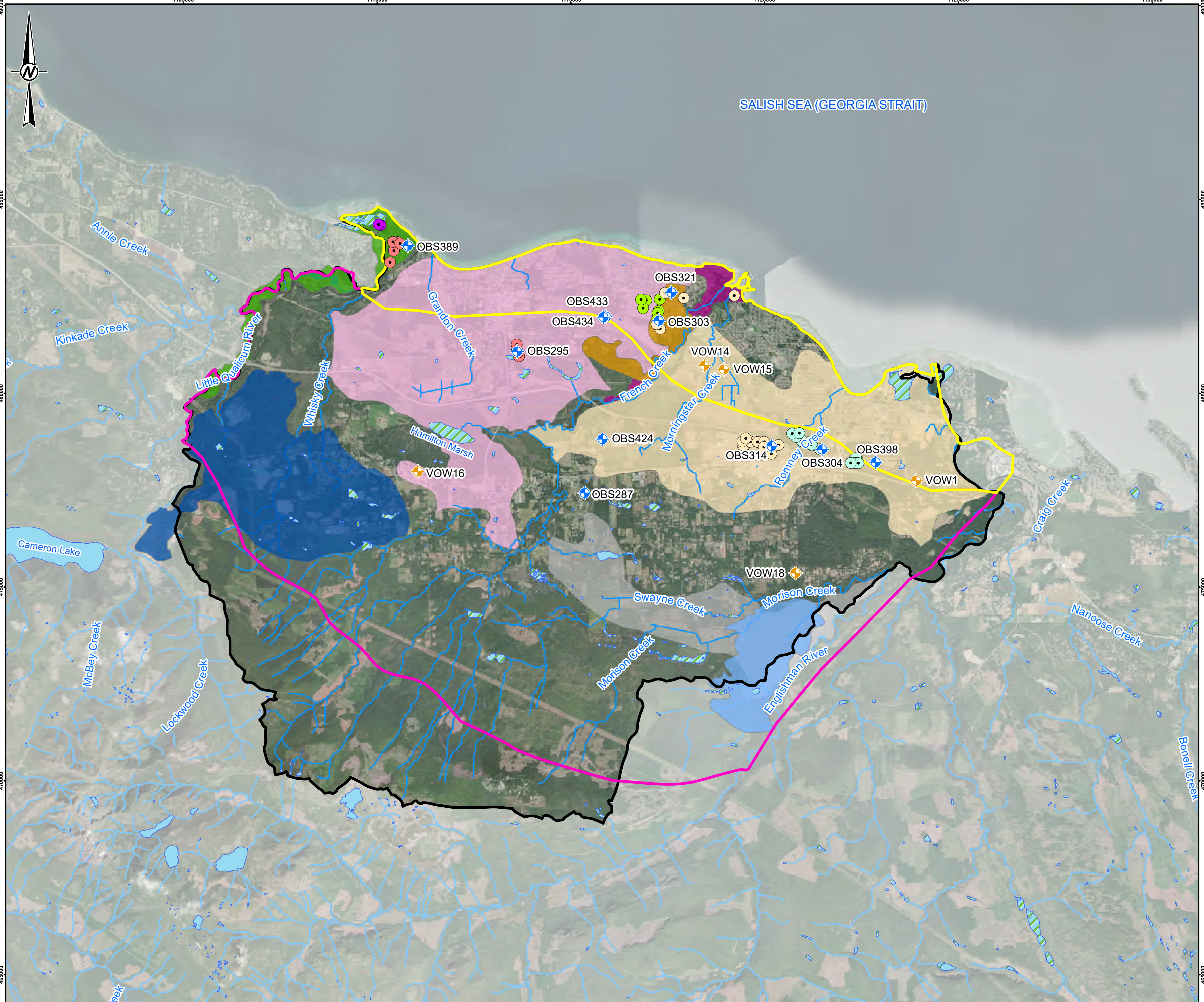
PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	15

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

3.2.5.3 Groundwater Levels and Hydraulic Heads

WSP assembled and reviewed long-term water level monitoring data for five RDN volunteer observation wells and eleven PGOWN wells that are maintained by BC ENV. Hydrographs for the volunteer observation wells and PGOWN observation wells are included in APPENDIX B and the locations of the observation wells are shown on Figure 16. 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, WSP used the water level elevations obtained from the GWS geodatabase and included in the GWS Leapfrog Model (GWS, 2020). Groundwater elevations from this database are primarily associated with static groundwater levels measured at the time of drilling and recorded in the BC ENV WELLS database and topographic information to estimate hydraulic head elevations. A summary of the water level trends is presented in Table 10.



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

OVERBURDEN AQUIFER

AQUIFER NUMBER

- AQ 1248
- AQ 1250
- AQ 1252
- AQ 209
- AQ 216
- AQ 217
- AQ 663
- AQ 664

BEDROCK AQUIFER

AQUIFER NUMBER

- AQ 212
- AQ 220

MONITORING WELL

- BC MINISTRY OF ENVIRONMENT OBSERVATION WELLS
- RDN VOLUNTARY (PRIVATE) MONITORING WELL

MUNICIPAL WATER SUPPLY WELL

- EPCOR PRODUCTION WELL
- RDN FRENCH CREEK PRODUCTION WELL
- CITY OF PARKSVILLE PRODUCTION WELL
- TOWN OF QUALICUM BEACH PRODUCTION WELL
- SURFSIDE PRODUCTION WELL

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
2. UPDATED AQUIFER BOUNDARIES OBTAINED FROM THE FRENCH CREEK AREA HYDRAULIC CONNECTIVITY AND AQUIFER MAPPING STUDY (GW SOLUTIONS INC., 2020)
3. MUNICIPAL PUMPING WELLS AND VOLUNTARY OBSERVATION WELLS PROVIDED BY RDN.
4. PROVINCIAL OBSERVATION WELLS OBTAINED FROM THE PROVINCIAL OBSERVATION WELL NETWORK.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
LOCATIONS OF MONITORING WELLS AND MUNICIPAL PRODUCTION WELLS

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	16

Table 10: Summary of Water Level Trends in Monitoring Wells in the Project Area

Lithology	Aquifer	Well ID[a]	Well Type	Seasonal Water Level Range[b] (m)	Monitoring Period	General Interpreted Trend
Overburden	216	OBS Well 304	PGOWN Monitoring Well	0.5	1988 to 2021	Declining until 2015 (~7 m) Increasing from 2017 (~4 m)
		OBS Well 314	PGOWN Monitoring Well	1 - 2	1992 to 2021	Declining until 2004 (~2.7 m) Increasing from 2017 (~1.2 m)
		OBS Well 398	PGOWN Monitoring Well	0 - 0.5	2013 to 2021	Declining until 2015 (~1 m) Increasing from 2015 (~1.5 m)
		OBS Well 424	PGOWN Monitoring Well	0.5 - 1	2013 to 2021	Increasing until 2018 (~1.5m) Declining from 2018 (~1.5 m)
		VOW1	RDN Voluntary Private Monitoring Well	0.25 - 0.5	2013 to 2021	Steady
	217	OBS Well 434	PGOWN Monitoring Well	0	2013 to 2021	Increasing 2016 to 2020 (~1 m)
		OBS Well 295	PGOWN Monitoring Well	2 - 5	1986 to 2021	Increasing 1990 to 2001 (~3 m) Decreasing 2001 to 2005 (~3 m) Increasing 2005 to 2018 (~5 m)
		VOW16	RDN Voluntary Private Monitoring Well	1 - 1.5	2017 to 2021	Declining (<0.5 m)
	664	OBS Well 389	PGOWN Monitoring Well	2 - 2.5	2010 to 2021	Steady
	1250	OBS Well 303	PGOWN Monitoring Well	3 - 6	1988 to 2021	Declining until 2003 (~6 m) Steady from 2003
		OBS Well 321	PGOWN Monitoring Well	4 - 6	1992 to 2021	Declining (~6 m) until 2013 Steady from 2013
		OBS Well 433	PGOWN Monitoring Well	5 - 6.5	2013 to 2021	Increasing (~1 m)
		VOW14	RDN Voluntary Private Monitoring Well	1 - 2.25	2017 to 2021	Steady

Lithology	Aquifer	Well ID[a]	Well Type	Seasonal Water Level Range[b] (m)	Monitoring Period	General Interpreted Trend
Bedrock	212	VOW15	RDN Voluntary Private Monitoring Well	10 - 15	2017 to 2021	Steady
	220	OBS Well 287	PGOWN Monitoring Well	1.5 - 3	1984 to 2021	Declining 1984 to 2004 (~1 m) Declining 2004 to 2021 (~3.5 m)
		VOW18	RDN Voluntary Private Monitoring Well	2 - 2.5	2017 to 2021	Steady

Notes:

a. OBS Well = Provincial Groundwater Observation Well Network (PGOWN) well; VOW = RDN Volunteer Observation Well

b. For the Provincial Groundwater Observation Well Network (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 voluntary monitoring wells, the seasonal range was estimated based on raw data provided by RDN.

In general, water levels in each observation well varied seasonally with precipitation, with reported ranges between 0.5 m and 6 m in the overburden units and ranges between 1.5 m and 15 m in the bedrock. WSP assessed the general long-term trends for the wells with sufficient monitoring data (i.e., PGOWN wells), using a linear statistically fit to each hydrograph. The linear fit method is a linear regression model that minimizes the sum of the squares in the vertical distances between each data point and the regression line. The results of water level monitoring for wells with a monitoring period of seven years or more indicates some variability in water level trends across the Project Area. In general, the following was noted:

- The water levels in PGOWN wells in Aquifer 216, generally declined prior to 2015, followed by an increasing trend in approximately the last five years, with the exception of OBS Well 424, located in the southwest corner of the aquifer, which has demonstrated a declining trend since 2018; the water level in RDN volunteer observation well (VOW1) has been relatively steady over the period monitored.
- The water levels in the two PGOWN wells in Aquifer 217 have generally increased, whereas the water level in VOW16 has exhibited a slight decline since 2017.
- The water level in OBS Well 389, located in Aquifer 664 has generally been stable since monitoring began in 2010.
- Water level trends for wells completed in Aquifer 1250 have been variable over the period of record, which may be associated with relatively low thickness (1 m) of the aquifer in a number of locations and the proximity to pumping wells. However, monitoring wells with more extensive period of records (OBS Wells 303 and 321) showed a declining trend in the first portion of the data and then water levels seemed to stabilize.
- The water levels in VOW15 and VOW18, which are completed in bedrock Aquifers 212 and 220, respectively, were relatively stable over the monitoring periods (i.e., since 2017). PGOWN OBS Well 287, which was established in 1984 to monitor water levels in Aquifer 220, has exhibited a declining trend.

It should be noted that the RDN volunteer observation 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. Therefore, fluctuations in water levels at the VOW wells may be larger than in the PGOWN wells due to pumping activities. As a result, water levels from PGOWNs were generally assumed to be more representative of regional groundwater conditions for model calibration purposes.

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

3.2.5.4 Groundwater/Surface Water Interaction

As part of the 2020 aquifer mapping study, GWS conducted a GIS analysis using elevations of riverbed, groundwater levels and elevations of estimated tops of aquifer units to assess the hydraulic connections of surface water bodies in the French Creek Water Region to the underlying aquifers and to identify reaches that are inferred to be gaining (i.e., groundwater is discharging to surface) and losing (i.e., the surface water body is recharging the aquifer). Table 11 presents a summary of the hydraulic connections between the streams and aquifers in the Project Area that GWS (2020) estimated.

Table 11: Summary of Estimated Hydraulic Connections Between Streams and Aquifers in Study Area, as presented by GWS (2020)

Watercourse Name	Hydraulically Connected?[a]	Mapped Aquifer ID	Description of Connection[b]	Level of Confidence[c]
Beach Creek	Likely connected	217	Overall Gaining; Losing at headwaters from Aquifer 217	Low
Carey Creek	Likely not connected		Lies on till	High
Englishman River	Likely connected	212	Gaining reaches in the area of Parksville	Moderate-High
		220	Losing at headwaters	
French Creek	Likely connected	220	Losing reaches in the upper watershed. Gaining reaches in the area of Coombs	High
		216	Seepage, direct connection after QB airport (gaining)	
		1248	Gaining near mouth of river	
		1250	Riverbed incised between about 3 to 4 km from the mouth (losing)	
Grandon Creek	Likely not connected		Creek is on till	High
Little Qualicum R (main near mouth)	Likely connected	664	None provided	High
Confluence of Little Qualicum R and Whisky Ck	Likely connected	217	Mostly gaining	Low
Morison Creek	Likely connected	220	Gaining between Swayne Ck and the Englishman R. Losing at the headwaters.	Moderate-High
Morningstar Creek	Likely not connected		Lies on till	Moderate
Romney Creek	Likely not connected		Lies on till	Moderate
Swayne Creek	Likely connected	220	Losing to headwaters of Swayne Ck. 1252 near the confluence with Morison Ck	Low
		1252		
Whisky Creek and tributaries	Likely connected	663	Mostly gaining	High

Notes:

a. Hydraulic connection refers to a direct connection between the watercourse and the underlying aquifers

b. Location of hydraulic connection between to watercourse and the underlying aquifers and whether the watercourse is losing water to the aquifer or gaining water from the aquifer

c. Confidence rating is based on the density of the available lithology data and water level data in the area of the watercourse and aquifers.

It is understood that the GWS (2020) Hydraulic Connectivity and Aquifer Mapping Study is still under review and changes may still be undertaken as part of this review process. Following a meeting with GWS and RDN staff, WSP received updated data in GIS format presenting the results of GWS's interpretation of the hydraulic connections between surface water bodies and the underlying Vashon-Capilano (Aquifer 209), Quadra Sand (Aquifers 216, 217), Cowichan Head (Aquifer 1250), and bedrock (Aquifers 212 and 220) aquifers and till deposits. Based on the updated information, GWS inferred the following:

- The portion of French Creek that extends between the Coombs (08HB038) and French Creek above Pumphouse (08HB078) stations (Figure 4) is a gaining reach from the Quadra Sand (Aquifers 216 and 217).
- The mouth of Grandon Creek near the Salish Sea is a gaining reach; however, based on the Leapfrog model provided by GWS the summary table of hydraulic connections, the creek was identified to overlie the Vashon Till and the hydraulic connection to the Quadra Sand may be limited.
- Gaining streams from the Quadra deposits were also identified in limited areas of Little Qualicum River and Beach Creek.

No direct hydraulic connection (gaining, losing or perched) was identified between the Cowichan Head and bedrock units in the updated file that was provided with the Hydraulic Connectivity and Aquifer Mapping Study. Streams in the upper reaches of the Project Area directly overlie till and were not inferred to be hydraulically connected to any aquifer units.

WSP considered the findings of the GWS Hydraulic Connectivity and Aquifer Mapping Study outlined above during construction and calibration of the groundwater model to qualitatively reproduce hydraulic connections between aquifers and surface water bodies in the Project Area.

3.2.6 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 providers. Potential groundwater use outside of the municipal water service areas was estimated based on land use information. Further details are provided in the following sections.

3.2.6.1 Municipal Water Supply System Service Areas

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

- RDN production well pumping records for the Surfside and French Creek wells (2018 to 2021) and well reports provided by the RDN
- Parksville production well pumping records for 2021 provided by the City of Parksville
- Qualicum Beach production well pumping records for 2021 provided by the Town of Qualicum Beach
- EPCOR production well pumping records for 2020 provided by EPCOR

Summaries of pumping flow rates for the active municipal wells for 2020 to 2021 are presented in Table 12 to Table 15 and the locations of the municipal production wells are shown on Figure 16. Based on the pumping data provided, the total volume of groundwater that was pumped from the RDN production wells was approximately 60,000 cubic metres (m^3) in 2020 (average of 164 m^3/day) and the total volume pumped from all production wells operated by municipalities and EPCOR within the Project Area was approximately 3.2 cubic megameter (Mm^3) in 2020 (average of 8,900 m^3/day). Table 12 to Table 15 also include production rates during wet (October through April) and dry season (May through September). In general, groundwater use was relatively higher in the dry summer season. On average, in the Project Area dry season pumping rates are up to 2.5 times higher than the wet season pumping rates.

Table 16 summarizes the total production rates by well field for 2020 to 2021. Well field pumping rates vary from approximately 30 m^3/day at the small Surfside well field to 5,400 m^3/day at the Town of Qualicum Beach Riverside well field in the dry season, and 8 m^3/day at Surfside to 2,565 m^3/day at Riverside during the wet season. Pumping rates at the other well fields in the Project Area generally range between approximately 900 m^3/day to 1900 m^3/day. Pumping rates by aquifer are summarized in Table 17. Pumping rates from the unconfined aquifers range from 0 m^3/day from Aquifer 1248 to approximately 5,400 m^3/day from Aquifer 664 in the dry season. For the confined aquifers, pumping rates in the dry season for 2021 were approximately 1,100 m^3/day from Aquifer 217, 1,900 m^3/day from Aquifer 1250 and 4,000 m^3/day from Aquifer 216.

Table 12: Production Rates for Regional District of Nanaimo Municipal Water Supply Wells in the Project Area

Well	Well Tag No.	Aquifer	2021 Production Rates (m^3/day)		
			Average Annual	Wet Season	Dry Season
French Creek Wells					
FC Well 1	26661	1250	N/A	N/A	N/A
FC Well 2	43090	1250	46	39	59
FC Well 4	41896	1250	55	39	71
FC Well 5	75344	1250	N/A	N/A	N/A
FC Well 6	75345	1250	N/A	N/A	N/A
FC Well 7	75346	1250	46	26	65
FC Well 8	75347	Unassigned	N/A	N/A	N/A
Surfside Wells					
Surfside 1	28459	664	9	4	14
Surfside 2	75325	664	9	4	14
TOTAL			**164**	**106**	**222**

Notes:

N/A: Not applicable as well is not currently operating

Table 13: Production Rates for City of Qualicum Beach Municipal Water Supply Wells in the Project Area

Well	Well Tag No.	Aquifer	2021 Production Rates (m^3/day)		
			Average Annual	Wet Season	Dry Season
Berwick Wells					
Berwick Well #1	805	217	337	69	576
Berwick Well #2	803	1250	369	56	825
Berwick Well #3	32242	217	256	53	436
Berwick Well #4	108897	217	101	254	62
Riverside Wells					
Riverside Well #1A	108903	664	568	290	649
Riverside Well #2	Unknown	664	N/A	N/A	N/A
Riverside Well #3	108901	664	595	381	879
Riverside Well #4	Unknown	664	N/A	N/A	N/A
Riverside Well #5	108900	664	1,027	620	1,588
Riverside Well #6	108899	664	676	438	978
Riverside Well #7	108898	664	1,035	836	1,295
TOTAL			**4,964**	**2,997**	**7,288**

Notes:

N/A: Not applicable as well is not currently operating

Table 14: Production Rates for City of Parksville Municipal Water Supply Wells in the Project Area

Well	Well Tag No.	Aquifer	2021 Production Rates (m^3/day)		
			Average Annual	Wet Season	Dry Season
Railway Wells					
Railway #1	107055	216	111	79	143
Railway #2	107040	216	203	142	264
Railway #3	107046	216	90	64	117
Railway #4	107092	216	80	57	103
Railway #5	107094	216	128	93	164
Railway #6	107096	216	151	92	209
Railway #7	107099	216	119	50	69
Railway #8	96288	216	N/A	N/A	N/A
Springwood Wells					
Springwood #1	39215	216	N/A	N/A	N/A
Springwood #2	107112	216	N/A	N/A	N/A
Springwood #3	107121	Unassigned	95	72	118
Springwood #4	107122	216	N/A	N/A	N/A
Springwood #5	37482	216	125	61	188

Well	Well Tag No.	Aquifer	2021 Production Rates (m^3/day)		
			Average Annual	Wet Season	Dry Season
Springwood #6	107119	216	63	58	5
Springwood #7	107111	216	355	208	500
Springwood #8	107112	216	263	160	367
Springwood #9	107110	216	N/A	N/A	N/A
Springwood #10	95022	216	147	105	188
Springwood #11	95023	216	177	127	227
TOTAL			**2,218**	**1,447**	**2,805**

Notes:

N/A: Not applicable as well is not currently operating

Table 15: Production Rates for EPCOR Municipal Water Supply Wells in the Project Area

Well	Well Tag No.	Aquifer	2021 Production Rates (m^3/day)		
			Average Annual	Wet Season	Dry Season
North					
TWN1 Well	Unknown	1250	25	18	31
RWN2 Well	Unknown	1250	388	225	550
Drew Rd Well #2	80104	1250	44	17	71
Ravensbourne Well	63134	1250	163	101	224
R8 Well	97150	1248	4	9	0
South					
Church Road Well #1	44079	216	57	37	76
Church Road Well #2	54994	216	3	0.6	5
Church Road Well #3	Unknown	216	23	7	40
Church Road Well #4	Unknown	216	60	42	77
Springhill Replacement Well (RWS1)	Unknown	216	224	173	275
Springhill #2A Well	83544	216	8	0.3	15
Hills of Columbia Well #6A	97107	216	70	48	91
Hills of Columbia Well #7	97122	216	70	54	86
Hills of Columbia Well #9	100351	216	46	49	43
Bosa Well	97094	216	76	81	70
Hills of Columbia Well #11	97104	216	119	98	141
ACS1	Unknown	216	233	205	260
TWS1	Unknown	216	25	32	19
TOTAL			**4,964**	**2,997**	**7,288**

Table 16: Summary of 2021 Pumping Rates for Well Fields in Project Area

Well Field	2021 Production Rates (m^3/day)		
	Average Annual	Wet Season	Dry Season
French Creek (RDN)	147	104	195
Surfside (RDN)	18	8	28
Berwick (Town of Qualicum Beach)	1,063	432	1,899
Riverside (Town of Qualicum Beach)	3,901	2,565	5,389
Railway (City of Parksville)	993	656	1,212
Springwood (City of Parksville)	1,225	791	1,593
EPCOR South	1,014	827	1,198
EPCOR North	624	370	876
TOTAL	**8,985**	**5,753**	**12,390**

Table 17: Summary of 2021 Pumping Rates by Aquifer

Aquifer	2021 Production Rates (m^3/day)		
	Average Annual	Wet Season	Dry Season
Aquifer 664	3,919	2,573	5,417
Aquifer 216	3,232	2,274	4,003
Aquifer 217	694	376	1,074
Aquifer 1248	4	9	0
Aquifer 1250	1,136	521	1,896
TOTAL	**8,985**	**5,753**	**12,390**

3.2.6.2 Properties Outside Municipal Service Areas

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

Land use within the Agricultural Land Reserve (ALR) was identified using survey data contained within the RDN Agricultural Land Use Inventory (ALUI; BC Ministry of Agriculture, 2015) and the RDN AWD model (Van Der Gulick et al., 2013) provided by the BC Ministry of Agriculture. The ALUI database includes attributes on crop production, livestock facilities, agricultural infrastructure, water management activities, non-farm activities and watercourse features. The ALUI assigned to each property a primary land use activity based on what was visually observed during a survey. The survey also recorded secondary and tertiary land use activities, if observed to be present. For properties where agriculture land use was assigned, the ALUI recorded up to four different agricultural activities, depending upon what was observed in the field.

For areas outside of the ALR, WSP reviewed land use by zoning information provided by the RDN in GIS format and updated to January 2022. Land use areas identified by zoning, along with areas identified by the ALUI survey, are shown on Figure 17.

For the purpose of estimating groundwater use for each of the properties that are not serviced by municipal water supply systems, WSP conducted a spatial correlation between the lots, the groundwater wells included in the BC ENV WELLS database and the surface water licenses to identify lots that are anticipated to use groundwater as the main source of water. For lots where one or more groundwater wells were identified, WSP then estimated groundwater use as described in this section. At properties with residential use but no wells were identified, WSP conservatively assigned a residential water use.

Land use categories contained within each information source are summarized in APPENDIX C. Table C1 presents the data on metered water use for residential and commercial properties from three different water providers (RDN, EPCOR and Town of Qualicum Beach). Table C2 presents the properties and type of activities contained in the LUI and ALUI. Table C3 presents the estimates of water requirements for irrigation and livestock as included in the RDN AWD model. 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, EPCOR and the Town of Qualicum Beach for residential and commercial properties in 2020 and 2021. Typical water requirements were estimated based on the average daily water usage for all RDN, EPCOR and Qualicum Beach metered residential and commercial properties to provide updated values that are more representative of recent water use than the estimates that were developed by Waterline (2013) in Phase 1. Water use data provided by the RDN, EPCOR and the Town of Qualicum Beach are summarized in APPENDIX C, Table C1. Based on the water consumption data provided and discussion with the RDN, WSP used the following values to represent water use for properties outside the water service area:
    - For residential properties, the water use per residential unit from RDN French Creek metered data for average annual conditions (567 L/day), dry season (639 L/day) and wet season (516 L/day) were used, as the RDN considered these values to be more representative of water use in these rural areas compared to Qualicum Beach water use.
    - For commercial properties, the water use per commercial unit from Qualicum Beach for average annual conditions (2,470 L/day), dry season (3,006 L/day) and wet season (2,165 L/day) were used, as these were the only data available for commercial properties in the Project Area.
- Irrigation requirements for different types of crops in the region were conservatively estimated from the dry year crop irrigation demand from the AWD model (mm/yr) and multiplied by the irrigated area for each lot indicated in the ALUI. WSP assumed that for each crop type, the property owner would apply enough groundwater to meet the crop growing requirements over the dry season period (May through September). Based on spatial correlation between lots, water wells and surface water license, as described previously in the section, WSP assumed that water used for irrigation within the non-serviced areas is mainly derived from groundwater. Tables summarizing the values that were used for the Phase 3 water budgets for irrigation requirements are presented in APPENDIX C, Table C3. The distribution of the crop types from the ALUI are presented on Figure 18.

- 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). The distribution and types of livestock are displayed on Figure 19.
- In addition, it is understood that irrigation occurs for the purpose of watering golf course fairways and greens at the Morningstar Golf Course (within the water service area) to the east of the Qualicum Beach Airport and at Pheasant Glen Golf Resort (outside water service area) to the west of the Qualicum Beach Airport. At these properties, irrigation requirements were applied in addition to the other water uses and groundwater was assumed to be pumped mainly from aquifers 216 and 1250.

For properties outside of the water service area, the estimated water demand for the current average annual conditions, wet season conditions and dry season conditions are presented on Figure 20, Figure 21 and Figure 22, respectively.

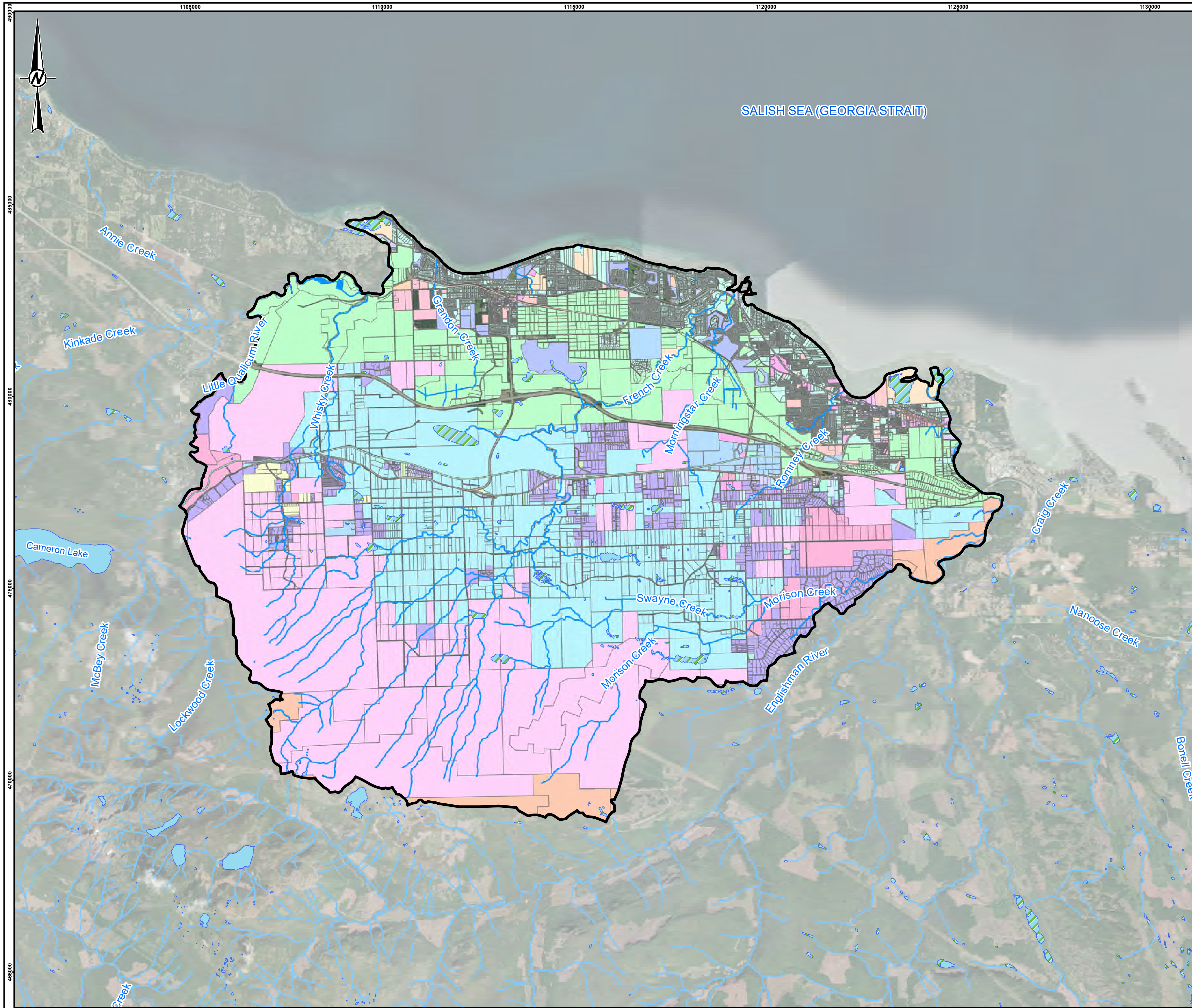
3.3 Data Uncertainty

During the data review process and update of the Conceptual Model for the Project Area, the relative levels of accuracy of the hydrogeological and hydrologic inputs were considered in order to assess the corresponding potential effects on model predictions. A general discussion on uncertainty, as related to the hydrogeological and hydrologic data reviewed for the Project Area, is discussed below. The effects of the uncertainty in the hydrogeological parameters and the model predictions were evaluated as part of the limited sensitivity analysis that is described in Section 5.6.

- Streamflow data: The uncertainty associated with stream flow records from hydrometric stations is a function of length of record and the change in flow regime (natural to regulated). As discussed in Section 3.2.3.1, the available streamflow data in the Project Area present a high degree of uncertainty related to the method of measurement (manual and seasonal for inactive stations 08HB038 and 08HB078) and the available temporal dataset (limited length of record for the active station 08HB0021). Estimates of baseflow (groundwater contribution to streamflow) that were derived from these datasets and used as calibration targets for the groundwater model are also associated with relatively high uncertainty.
- Geology, hydrostratigraphy: The geological and hydrostratigraphic interpretation was derived from the GWS (2020) study; uncertainty related to the data used for this interpretation is generally related to approximate borehole locations, elevations and lithological descriptions for the BC ENV groundwater wells and is described further in the GWS (2020). It is also recognized that the Conceptual Model is regional in scale and the hydrostratigraphic interpretation does not take into account local variability.
- Water Levels: The water level data that were used by GWS (2020) to infer groundwater flow directions throughout the Project Area and used for model calibration were primarily recorded by drillers at the times of well installation. As such, these measurements are quite uncertain as they have been collected over many decades and during different seasons, and may be influenced by the effects of drilling. Additional error likely resulted by using approximate ground surface elevation to convert the water level depth (as reported on the well logs) to groundwater elevation. Overall, the uncertainty of the water level data, when considered as a representation of the average hydrogeologic conditions in the Project Area, is anticipated to be on the order of +/- 5 m (based on resolution of the topographic data, expected seasonal variations in water levels and inaccuracies associated with the borehole logs).

- Recharge from precipitation: 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. The applicability of these estimates to this study and to the regional scale of the groundwater model has been evaluated as described in Section 3.2.5.2.
- Hydraulic parameters of the hydrogeological units: Generally, the uncertainty in hydraulic parameters assigned to hydrogeological units depends on the method used for estimates (field testing, grain size analysis, lithology and available literature information). Based on the data review presented in Section 3.2.5.1, field testing data were only available for unconsolidated Aquifers 216, 217, 663 and 664. No field-testing data were available to WSP for the other unconsolidated aquifers, for the bedrock aquifers and for the confining units. Hydraulic parameters for these aquifers were determined from descriptive logs and values reported in the literature for similar materials. Values determined using these methods are considered to have relatively high uncertainty (i.e., up to +/- 20 times); however, it is recognized that there is variability in reported values within aquifer units. It is further recognized that flow within bedrock is variable and through discrete fractures. For the confining units (i.e., aquitards), in the absence of hydraulic testing and grain size analysis, a single value was assigned to these units. In reality, properties of the confining units likely vary throughout the Project Area and the uncertainty in hydraulic properties assigned to these units is also inferred to be relatively high.

The hydrogeological and hydrometric data described in this Section 3.0, although associated with the uncertainty outlined above, was considered appropriate for the construction and calibration of a numerical groundwater model that is regional in scale and can provide a reasonable representation of regional groundwater conditions in the French Creek Project Area.



LEGEND

- PROJECT
- WETLANDS
- WATERBODIES
- WATERCOURSES

RDN LAND USE DESIGNATION

- Industrial
- Public
- Rural/Rural Residential
- Agriculture
- Civic and Technology Centre
- Commercial
- Comprehensive Development
- Comprehesive Development
- Conservation
- Forestry Resource
- Highway Commercial
- Industrial
- Industrial Community
- Manufactured Homes
- Mixed Use
- Mixed Waterfront Commercial-Residential
- Parks and Open Space
- Recreation
- Residential
- Resort Commerical
- Resource Management
- Rural
- Rural/Rural Residential
- Salvage and Wrecking
- Service Commercial
- Service Station Commercial
- Tourist Commercial
- Transportation and Recreation
- Unknown
- Utility
- Water

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERENMENT LICENSE - BRITISH COLUMBIA.
2. LANDUSE DESIGNATION FILE OBTAINED FROM AGRICULTURAL LAND USE INVENTORY (ALUI; 2012) AND THE RDN AGRICULTURAL WATER DEMAND MODEL (2013)
3.PROJECT AREA CREATED BY WSP GOLDER.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

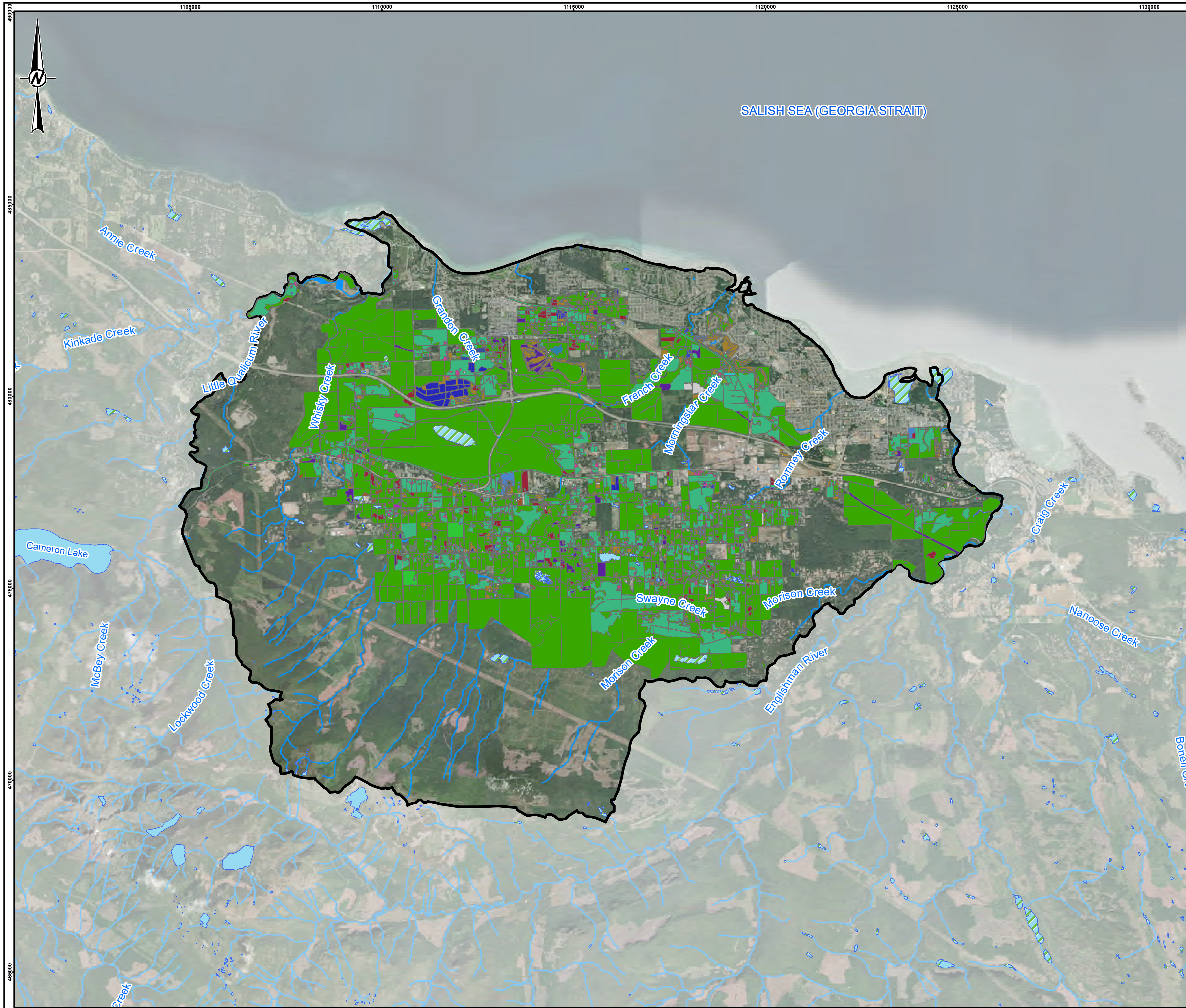
TITLE
LAND USE DESIGNATION IN THE FRENCH CREEK AREA

CONSULTANT

YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	17

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



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

LAND COVER DESIGNATION

- Bare area
- Berries
- Dump deposit
- Extraction, mine
- Farm
- Floriculture
- Forage, pasture
- Grains, cereals, oilseeds
- Grassland
- Herbaceous
- Lawn/grass
- Nursery
- Nut trees
- Other
- Poly greenhouse
- Residential
- Shrubland
- Specialty
- Transportation / Parking
- Tree fruits
- Treed
- Vegetables
- Vines

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
2. LANDUSE DESIGNATION FILE OBTAINED FROM AGRICULTURAL LAND USE INVENTORY (ALUI; 2012) AND THE RDN AGRICULTURAL WATER DEMAND MODEL (2013) AND WATER SERVICE AREAS.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
LAND COVER IN THE FRENCH CREEK AREA

CONSULTANT

YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	18

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LEGEND

- PROJECT
- WETLANDS
- WATERBODIES
- WATERCOURSES

HERD TYPE

- Alpaca
- Beef
- Beef (Goat)
- Chicken
- Chicken (Duck)
- Dairy
- Duck
- Game bird
- Goat
- Llama
- Ratite
- Sheep / lamb
- Sheep / lamb (Goat)
- Swine

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
2. LIVESTOCK TYPE OBTAINED FROM THE LANDUSE LAYER PROVIDE BY REGIONAL DISTRICT OF NANAIMO FROM THE ALUI STUDY (2013)
3. PROJECT AREA CREATED BY WSP GOLDER.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
LIVESTOCK IN THE FRENCH CREEK AREA

CONSULTANT

YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	19

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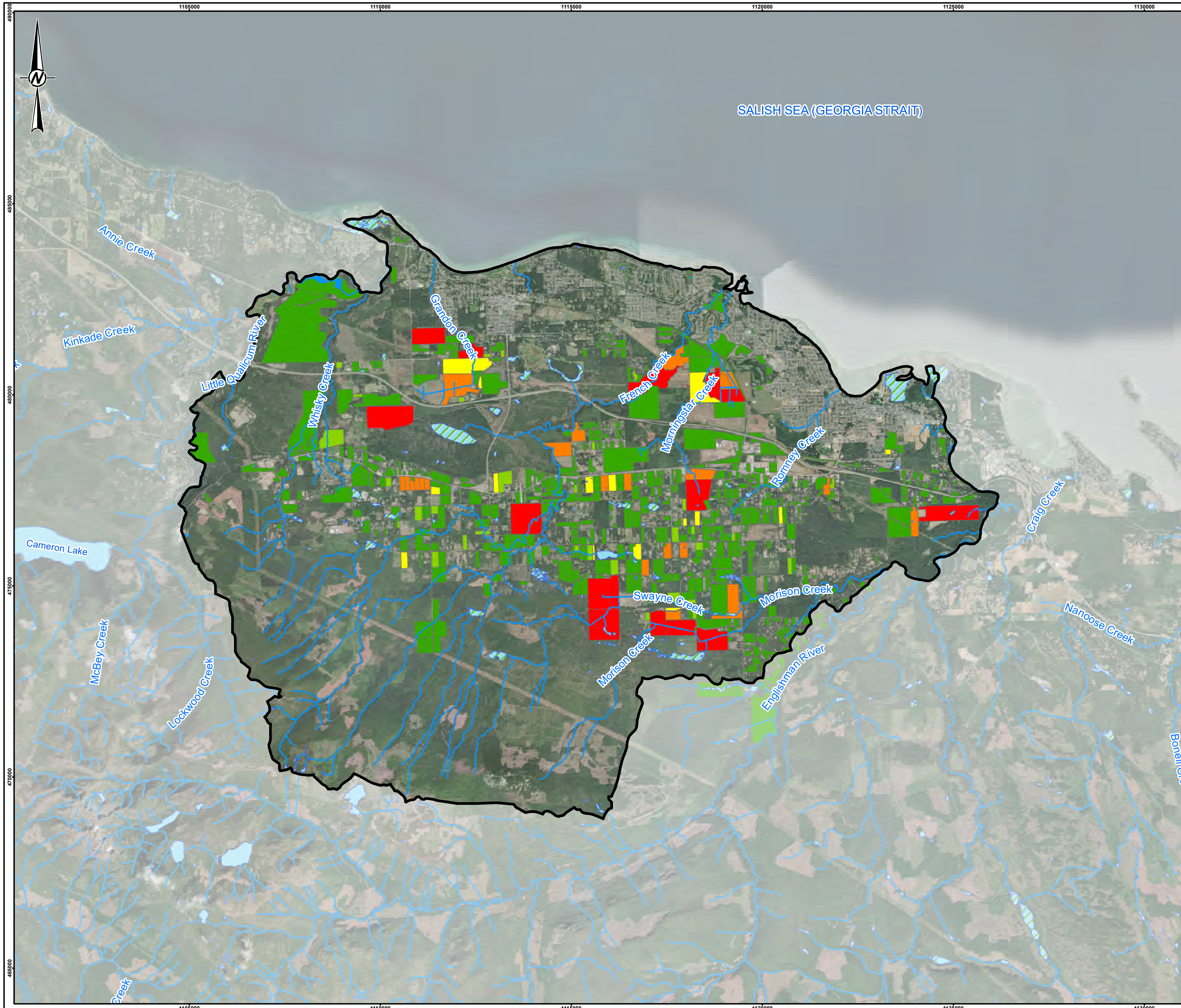

LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

WATER DEMAND (m3/d)

WATER DEMAND (m3/d)

- 0 - 5
- 5 - 25
- 25 - 50
- 50 - 200
- >200

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
2. WATER DEMAND ESTIMATED BASED ON LANDUSE DESIGNATION FILE OBTAINED FROM AGRICULTURAL LAND USE INVENTORY (ALUI; 2012) AND THE RDN AGRICULTURAL WATER DEMAND MODEL (2013) AND WATER SERVICE AREAS.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
ESTIMATED WATER DEMAND FOR PROPERTIES OUTSIDE THE WATER SERVICE AREA (CURRENT AVERAGE ANNUAL CONDITIONS)

CONSULTANT

YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	20

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

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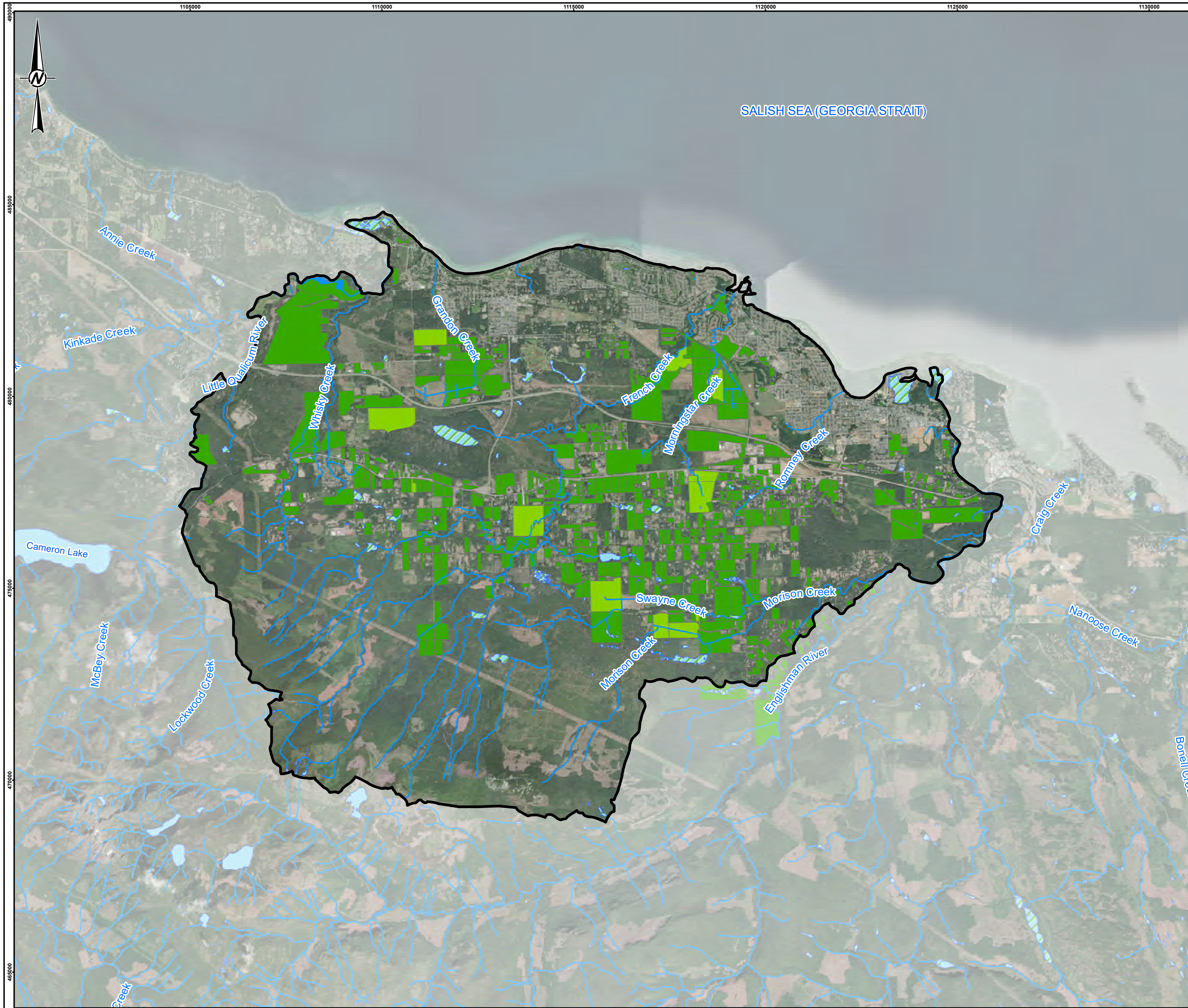

LEGEND

- PROJECT
- WETLANDS
- WATERBODIES
- WATERCOURSES

WATER DEMAND (m3/d)

WATER DEMAND (m3/d)

- 0 - 5
- 5 - 25
- 25 - 50
- 50 - 200
- >200

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
2. WATER DEMAND ESTIMATED BASED ON LANDUSE DESIGNATION FILE OBTAINED FROM AGRICULTURAL LAND USE INVENTORY (ALUI; 2012) AND THE RDN AGRICULTURAL WATER DEMAND MODEL (2013) AND WATER SERVICE AREAS.
3. PROJECT AREA CREATED BY WSP GOLDER.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

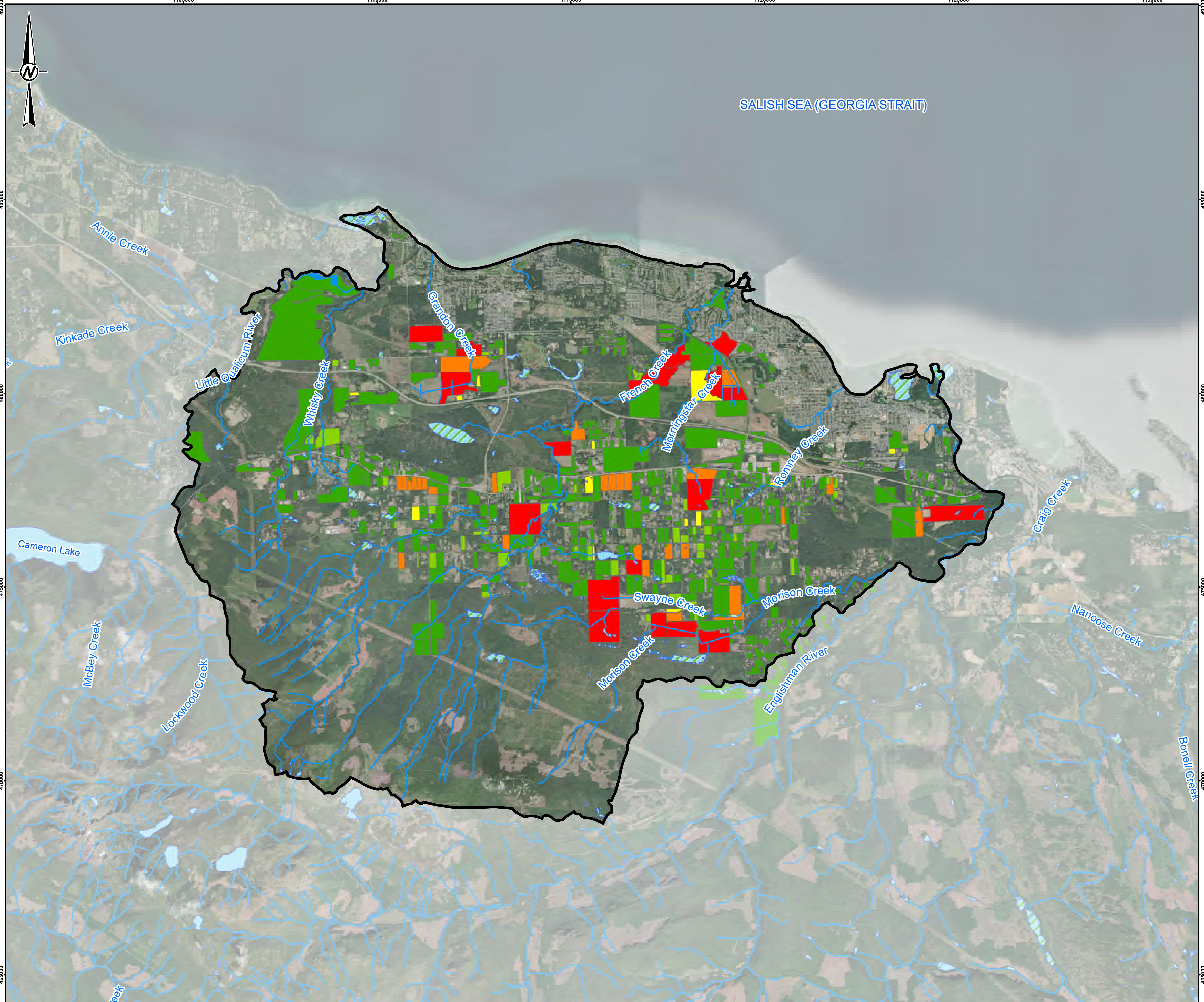
TITLE
ESTIMATED WATER DEMAND FOR PROPERTIES OUTSIDE THE WATER SERVICE AREA (CURRENT WET SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	21

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



LEGEND

- PROJECT
- WETLANDS
- WATERBODIES
- WATERCOURSES

WATER DEMAND (m3/d)

WATER DEMAND (m3/d)

- 0 - 5
- 5 - 25
- 25 - 50
- 50 - 200
- >200

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
2. WATER DEMAND ESTIMATED BASED ON LANDUSE DESIGNATION FILE OBTAINED FROM AGRICULTURAL LAND USE INVENTORY (ALUI; 2012) AND THE RDN AGRICULTURAL WATER DEMAND MODEL (2013) AND WATER SERVICE AREAS.
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COORDNATE SYSTEM: BC ALBERS

CLIENT

REGIONAL DISTRICT OF NANAIMO

PROJECT

REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE

ESTIMATED WATER DEMAND FOR PROPERTIES OUTSIDE THE WATER SERVICE AREA (CURRENT DRY SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	22

4.0 CONCEPTUAL HYDROGEOLOGICAL MODEL

A conceptual hydrogeological model is a pictorial and descriptive representation of the groundwater regime that organizes and simplifies conditions so they can be readily understood and modelled. The conceptual model must retain sufficient complexity so that the analytical or numerical models developed from it adequately reproduce or simulate the actual components of the groundwater flow system to the degree necessary to satisfy the objectives of the modelling study.

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 the Project Area. For Phase 3, WSP updated the Conceptual Model based on review of more recent information (i.e., refined hydrostratigraphy, groundwater levels, groundwater use, etc.) described in Section 3.0 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.

4.1 Hydrogeology Units

The French Creek 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, and overlie bedrock. Aquitards, which are composed of less permeable silt and clay deposits of lacustrine origin, are inferred to lie between aquifers.

The hydrostratigraphic interpretation in the Project Area was mainly derived from the review of GWS Leapfrog Model and aquifer mapping study (GWS, 2020), as discussed in Section 3.2.4. Within the Project Area, eight aquifers have been assigned to the unconsolidated deposits and two aquifers have also been assigned within the bedrock formations. The extents of the aquifers within the Project Area are presented on Figure 8. A summary of the hydrostratigraphic units is presented in Table 18 below.

Table 18: Summary of Hydrostratigraphic Units in the French Creek Area

Unit	Aquifer Tag Number[a]	Aquifer Classification[b]	Estimated Hydraulic Conductivity (m/s)[c]
Surficial Till (Aquitard) Vashon Drift	-	-	1×10^{-7}
Aquitards Dashwood Drift/Cowichan Head	-	-	1×10^{-7}
Unconfined Sand and Gravel Salish Sediments	664	IA	1×10^{-4}
Unconfined Sand and Gravel Salish Sediments	1248	IA	1×10^{-4}
Unconfined Sand and Gravel Salish Sediments	1252	IIB	1×10^{-4}
Unconfined Sand and Gravel Vashon-Capilano Sediments	663	IIA	1×10^{-4}

Unit	Aquifer Tag Number[a]	Aquifer Classification[b]	Estimated Hydraulic Conductivity (m/s)[c]
Confined Sand and Gravel Vashon-Capilano Sediments	209	IIC	2×10^{-5}
Confined Sand and Gravel Quadra Sand	216	IIB	5×10^{-5}
Confined Sand and Gravel Quadra Sand	217	IIB	5×10^{-5}
Confined Sand and Gravel Cowichan Head	1250	IIC	2×10^{-5}
Fractured Sedimentary Bedrock Haslam Formation	212	IIIC	5×10^{-7} to 1×10^{-8}
Fractured Sedimentary Bedrock Haslam Formation	220	IIIB	5×10^{-7} to 1×10^{-8}

Notes:

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

b. 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)

c. Sources for selected hydraulic conductivity values are presented in Table 9

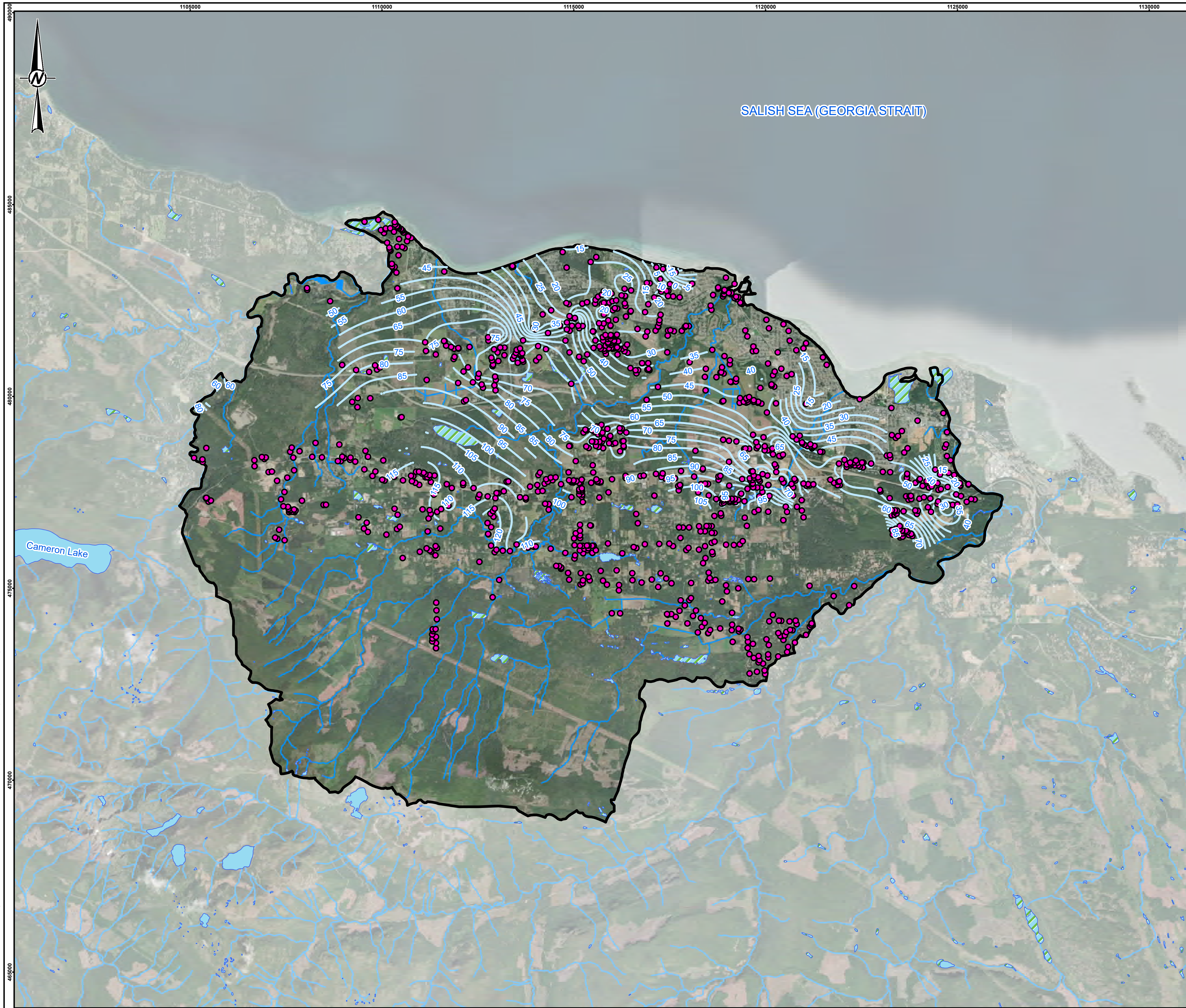
Based on the 3D hydrostratigraphic interpretation, the aquitard separating the Quadra Sand Aquifer 216 and Aquifer 217 (i.e., Cowichan Head) from the underlying Aquifer (Aquifer 1250) may be discontinuous in some areas, potentially resulting in a hydraulic connection between the aquifers.

The overburden aquifers that host Quadra and Cowichan Head deposits are underlain by mapped bedrock aquifers. As presented on Figure 8, the northern portion of the Project Area is primarily underlain by Haslam formation sedimentary rocks of Aquifer 212, generally described as sandstone, conglomerate and mudstone. The southern portion of the Project Area is underlain by bedrock Aquifer 220, which is also part of the Haslam formation of the Nanaimo Group but is generally described as shale by well drillers. 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

WSP interpreted groundwater flow directions across the Project Area and within the aquifers based on hydraulic heads included in the GWS database (Section 3.2.5.3). Contours for groundwater levels within the overburden aquifers and shallow bedrock are shown on Figure 23 and Figure 24, respectively. These results reflect general conditions at the regional scale.

Overall, the water table within the overburden and shallow bedrock is inferred to reflect a subdued impression of the local topography. Groundwater flows from higher elevations into the low-lying areas including valleys and surface water courses across the Project Area and ultimately to the ocean. Available water level data indicates that water levels in both overburden and bedrock units vary seasonally with the precipitation; seasonal fluctuations are estimated to vary from less than 0.5 to approximately 6.5 m in the overburden and from 1 m to 15 m in the bedrock.



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES
- HYDRAULIC HEAD CONTOURS IN QUADRA SAND (m asl)
- OVERBURDEN WELLS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERENEMENT LICENSE - BRITISH COLUMBIA.
2. UPDATED AQUIFER BOUNDARIES AND HYDRAULIC HEAD CONTOURS OBTAINED FROM THE FRENCH CREEK AREA HYDRAULIC CONNECTIVITY AND AQUIFER MAPPING STUDY (GW SOLUTIONS INC., 2020)
3. MUNICIPAL PUMPING WELLS AND VOLUNTARY OBSERVATION WELLS PROVIDED BY RDN.
4. PROVINCIAL OBSERVATION WELLS OBTAINED FROM THE PROVINCIAL OBSERVATION WELL NETWORK.
5. PROJECT AREA CREATED BY WSP GOLDER
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
GROUNDWATER CONTOURS IN OVERBUDERN (QUADRA SANDS)

CONSULTANT

YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	23

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

25mm

LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES
- HYDRAULIC HEAD CONTOURS IN TOP OF BEDROCK (m asl)
- BEDROCK WELLS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERENEMENT LICENSE - BRITISH COLUMBIA.
2. UPDATED AQUIFER BOUNDARIES, HYDRAULIC HEAD CONTOURS AND WELLS OBTAINED FROM THE FRENCH CREEK AREA HYDRAULIC CONNECTIVITY AND AQUIFER MAPPING STUDY (GW SOLUTIONS INC., 2020)
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
GROUNDWATER CONTOURS IN BEDROCK

CONSULTANT

YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	24

4.3 Groundwater Recharge and Discharge Areas

As presented on Figure 8, major aquifers that were identified within the overburden deposits are mainly located in the central and northern portion of the Project Area. Groundwater within these aquifers is interpreted to receive recharge from upslope areas to the south and southwest and via infiltration of precipitation, and generally flow towards the northeast and the Salish Sea. In addition to recharge from precipitation, groundwater is also recharged by anthropogenic sources (i.e., irrigation, septic fields, losses from distribution systems).

The confined Quadra Sand Aquifers 216 and 217 and confined Cowichan Head Aquifer 1250 are mainly recharged by infiltration through overlaying deposits. The hydraulic head data indicate that the vertical gradient from the Quadra Sand deposits (Aquifers 216 and 217) to the underlying deposits is downwards; however, the silt and clay deposits that confine Cowichan Head Aquifer 1250 are anticipated to control the interaction between this aquifer and the overlying Quadra Sand deposits.

Groundwater in bedrock Aquifers 212 and 220 is primarily recharged from upslope areas to the south and southwest and flows north 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 is mapped as comprising relatively thinner overburden deposits of Vashon moraine (till) and bedrock outcrop (Fyles, 1963). At higher elevations, groundwater from Aquifer 220 is interpreted to discharge to the upper reaches of the French Creek watershed and Morison Creek. In the lower elevations, the thick overburden deposits are inferred to provide some recharge to underlying Aquifer 212 via infiltration.

In the Project Area, most of the groundwater-surface water interaction is interpreted to occur between the near-surface, unconfined aquifers and the local streams and creeks. Groundwater provides baseflow to streams and creeks in areas where the water table near the streams is at a higher elevation than the adjacent surface water (groundwater baseflow). Discharge to creeks from unconfined aquifers occurs primarily from Aquifer 663 (to Whisky Creek), Aquifer 664 (to Little Qualicum River), Aquifer 1248 (to French Creek at the mouth) and Aquifer 1252 (to Morison Creek) (GWS, 2020) (see Figure 8). Limited interaction with the aquifers is expected in the areas where the streams are underlain by aquitards, because of the lower permeability of the aquitards when compared with the aquifers. For example, surface water in Morningstar Creek, Romney Creek and Grandon Creek are underlain by till (Vashon Drift) and are therefore interpreted to not have a direct hydraulic connection to Quadra Sand Aquifers 216 and 217.

Groundwater-surface water interaction is also inferred to occur at locations where watercourses cut down through the base of an aquitard and is in hydraulic connection with the underlying shallow confined aquifers. French Creek is incised in the central and north portion of its course, and it cuts through the base of Quadra Sand Aquifers 216 and 217 into the Cowichan Head Formation and Aquifer 1250. In this area, groundwater from Aquifer 216 and 217 likely seeps into French Creek along valley walls and French Creek is inferred to recharge Aquifer 1250 (GWS, 2020).

In areas adjacent to the Salish Sea, unconfined Salish Sediment Aquifers 664 and 1248 and shallow confined Quadra Sand Aquifers 216 and 217 may be potentially vulnerable to saline intrusion, particularly in areas of heavy groundwater extraction (e.g., French Creek and EPCOR North well field and Surfside and Riverside well field).

5.0 NUMERICAL GROUNDWATER MODEL

5.1 Model Selection

In discussion with the RDN, WSP selected FEFLOW for development of the numerical groundwater model. FEFLOW, which is a 3D finite element code developed by DHI-WASY Institute in Germany, was selected as the preferred model based on its capability for simulating 3D groundwater flow in complex geological settings under a variety of boundary conditions and hydrogeological stresses, conditions similar to the Project Area. FEFLOW is widely used for hydrogeological modelling and is well recognized by regulators, the research community and professional hydrogeologists.

Flow in the model was simulated using Richards' equation (for unsaturated or variably saturated media). As the objective of the modelling is not to simulate the unsaturated zone, but rather saturated groundwater flow, the unsaturated zone parameters were selected to balance numerical stability while reasonably simulating a reduction of the effective hydraulic conductivity of the unsaturated hydrostratigraphic units above the predicted water table.

5.2 Model Extent and Mesh Configuration

The extent of the numerical model was based on inferred groundwater flow conditions in the Project Area, with model boundaries set based on watershed boundaries and sufficiently distant from the main focus area (i.e., the French Creek watershed) to allow adequate representation of groundwater flow conditions in the Project Area for current conditions and future scenarios. The extent of the model domain is presented on Figure 25.

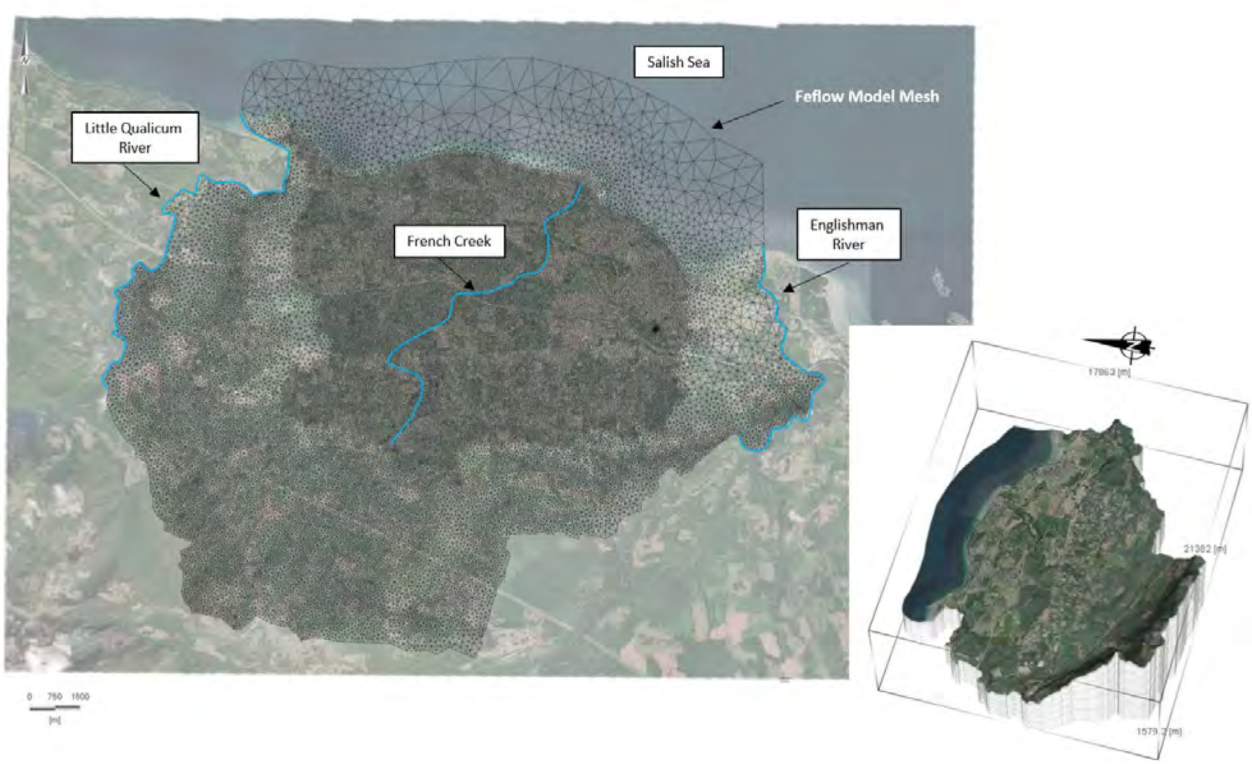


Figure 25: French Creek Groundwater Model Extent and Mesh

The numerical model grid encompasses the entirety of Water Region 3, and the main and sub-watersheds surrounding French Creek. The model extent is bounded by the Little Qualicum River to the west, the Englishman River to the northeast, major watershed boundaries to the southeast and south, and the ocean to the north. The model extends a maximum of approximately 18 km in length (north-south) and 21 km in width (northwest-southeast), with a total planar area of approximately 378 km^2.

Vertically, the model was divided into 13 separate layers. The elevation of layer one was set to ground elevation, whereas the elevation of the bottom of layer 13 was set at -500 m asl. The remaining layers were 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 an element size of approximately 250 m at the limits of the model domain to 50 m within the WR3 boundaries, in the vicinity of the production wells and near creeks and waterbodies. The horizontal and vertical grid spacing provided sufficient resolution and representation of the major aquifers in 3D to reproduce groundwater conditions on a regional scale in the Project Area.

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 developing the numerical model for the Project Area. The boundary conditions, which are illustrated on Figure 26, 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.
- For 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 an 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 level (i.e., 0 m asl). In addition to this, specified heads were also used to represent the creeks in the low subbasins (elevations below 150 m asl) where watercourses are considered to be a permanent water body and the hydraulic connection with groundwater is considered to be strong. Hydraulic connection was inferred to occur along French Creek, Morison Creek, Swayne Creek, Whisky Creek, the Little Qualicum River and the portion of the Englishman River along the north-west portion of the model, consistent with GWS (2020). 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 rivers and creeks in the upper watershed (elevations greater than 150 m asl) and to watercourses that are inferred to have no hydraulic connection with groundwater; hydraulic connection was inferred not to occur along Morningstar Creek, Carey Creek, Romney Creek and Grandon Creek, also consistent with GWS (2020). 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; seepage face). 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).
- 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) for average annual conditions and refined by WSP for the wet and dry season. A specified flux boundary (sink) was also assigned to the top of the aquifer for the properties outside the municipal water service areas (residential and agricultural water consumption, see Section 3.2.6.2) to simulate groundwater use from private groundwater wells. Water use assignment was verified using the well assignment to aquifers included in the updated aquifer mapping (GWS, 2020) as shown on Figure 9. 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 3.2.6.1.

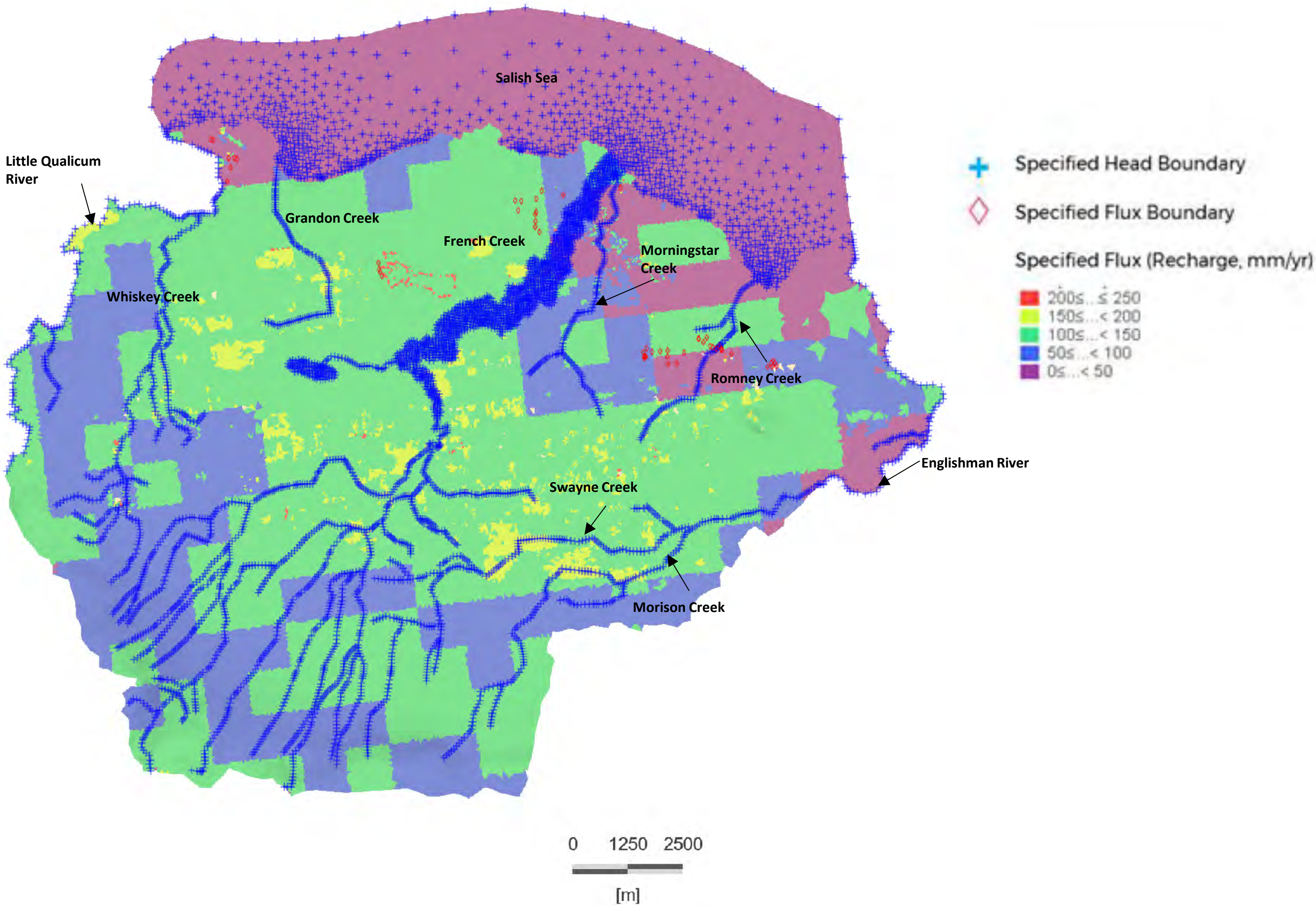


Figure 26: French Creek Groundwater Model Boundary Conditions

5.4 Hydrostratigraphy and Initial Model Parameters

The initial estimates of the model parameters that WSP assigned to the numerical model are presented in Table 19. 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 3.2.5.1. 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 27.

Table 19: Initial Hydrogeological Parameters used in the Groundwater Numerical Model

Unit	Estimated Hydraulic Conductivity (m/s)	Specific Storage (1/m)	Specific Yield[a]
Surficial Till (Aquitard) Vashon Drift	1×10^{-7}	1×10^{-4}	0.1
Aquitard Dashwood Drift	1×10^{-7}	1×10^{-4}	0.1
Unconfined Sand and Gravel Salish (Aquifer 664, 1248, 1252)	1×10^{-4}	5×10^{-5}	0.2
Unconfined Sand and Gravel Vashon-Capilano (Aquifer 663)	1×10^{-4}	5×10^{-5}	0.2
Confined Sand and Gravel Vashon-Capilano (Aquifer 209)	2×10^{-5}	5×10^{-5}	0.2
Confined Sand and Gravel Quadra Sand (Aquifer 216, 217)	5×10^{-5}	5×10^{-5}	0.2
Confined Sand and Gravel Cowichan Head (Aquifer 1250)	2×10^{-5}	5×10^{-5}	0.2
Fractured Sedimentary Bedrock Haslam Formation (Aquifer 212, 220)	5×10^{-7}(<40 m below top of bedrock) 1×10^{-7} (40 to 200 m below top of bedrock) 1×10^{-8} (>200 m below top of bedrock)	1×10^{-5}	0.1

Notes:

a. unitless parameter

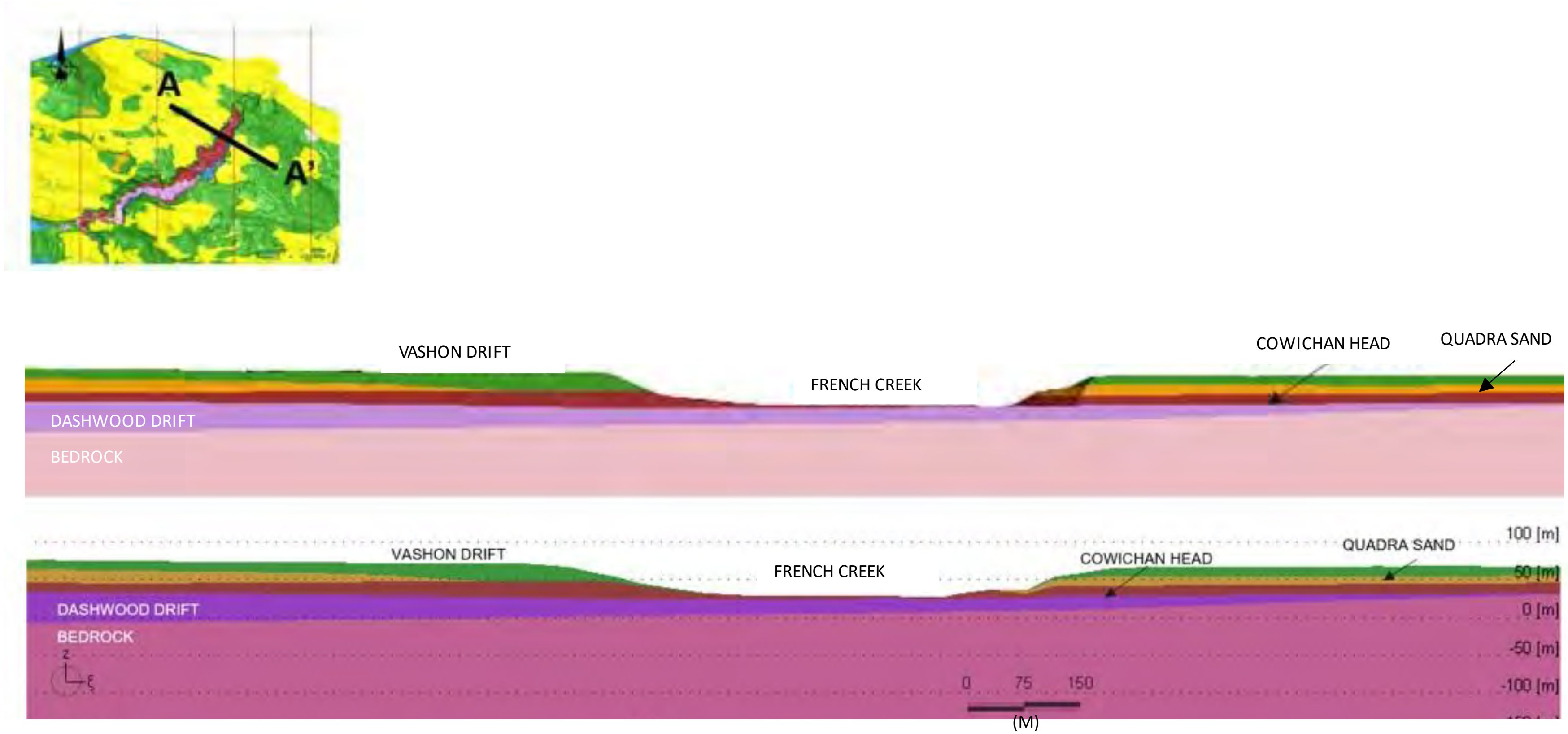


Figure 27: Cross Section of French Creek Hydrostratigraphy from Leapfrog Model (top) and FEFLOW Model (bottom)

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 Approach and 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 959 wells. As discussed in Section 3.2.5.3, 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 along French Creek where discharge data from active or historical hydrometric stations were available (Section 3.2.3.1). The average flow at each hydrometric station during the dry season (June to September) was considered representative of groundwater contribution to streamflow (groundwater baseflow) during the summer months and was used as a target for calibration.

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 service area was set to average annual values for the lots identified with groundwater user.
- Pumping rates assigned to the RDN wells and other municipal wells were set to average annual rates calculated based on annual withdrawals recorded from 2020 to 2021 (Table 12 to Table 15).

5.5.1.2 Average Seasonal Conditions

Following calibration to average annual conditions, a supplemental calibration step was taken to evaluate the ability of the model to reproduce seasonal fluctuations 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, and the RDN volunteer observation wells. As described in Section 3.2.5.3, the RDN volunteer observation wells are private domestic wells that may be subject to pumping for portions of the year and have a limited data set (four to seven years). For these reasons, fluctuations observed in those wells might not be representative of broader average seasonal fluctuations and therefore were not considered as reliable targets during model calibration. The number of wells considered in the transient simulation is relatively small when compared to the dimensions of the Project Area. Moreover, monitoring wells considered in the transient simulation are all located at low elevations within the northern portion of the Project Area. Therefore, there is higher uncertainty in model calibration to seasonal conditions compared to average annual conditions, particularly in areas where there are no monitoring wells.

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 two seasons. The model simulation starts in the wet season (October to April). 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. Figure 13 and Figure 14 present respective values of wet and dry recharge assigned to the model.
- Similar to recharge, groundwater use by private users outside municipal water service area was varied between the wet and dry seasons, based on the commercial and residential water use rates and irrigation in the dry season. Groundwater use was applied over the parcel's area (Figure 21 and Figure 22) and it is expressed in m^3/d.
- Pumping rates assigned to the production wells were varied between the dry and wet season, as shown in Table 12 to Table 15.

The hydraulic heads calculated by the steady-state model were used as initial conditions for the transient simulations. 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 the 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 the observed conditions. The model parameters that resulted in best calibration are presented in Table 20.

Changes implemented during calibration of the model are summarized in the bullets below; these changes are each included in the final calibrated model that was used to support the predictions of future conditions. Hydraulic parameter changes were made in consideration of the measured test data to improve the ability of the model to match estimated flows and/or hydraulic heads across the model domain.

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

- For the overburden aquifers, the hydraulic conductivities of unconfined Aquifers 663, 664, 1248 and 1252 were increased within 4 times from the initial estimates while the hydraulic conductivities of confined Aquifers 209, 216 and 217 were decreased within 2 times from the initial estimates to improve calibration to observed water levels and flow measured in French Creek; the calibrated hydraulic conductivity values assigned in the model are within the range of values expected based on aquifer composition and available testing results (Table 11).

- For the confining units (aquitards), the specific storage was reduced from the initial estimates along with reducing the hydraulic conductivity of the Dashwood Drift confining unit to improve the match between the simulated on observed water levels. Similar to above, the calibrated hydraulic conductivity assigned to the confining units is within the range of values expected based on aquifer composition and available testing results (Table 11).
- For the bedrock formations, the hydraulic conductivity values were increased at shallow depths to reflect additional weathered conditions and decreased at greater depths 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.
- As part of model verification to seasonal fluctuations, the specific storage values for the overburden confining units and weathered bedrock units were decreased to improve the match between predicted values and the seasonal fluctuations observed in PGOWN monitoring wells. These changes helped improve the match between predicted and observed seasonal fluctuations in the overburden aquifers.

The adjustments in hydraulic conductivity values made during model calibration were relatively small and are considered to be in good agreement with measured ranges of hydraulic conductivity values reported and the groundwater and hydrological conditions in the Project Area. Localized changes in recharge and hydraulic properties could be made to improve the match between measured and predicted values; however, such localized modifications are not considered warranted for the scale of the model (regional) to assess groundwater conditions in the Project Area. Properties were varied as entire units, to achieve a balance between all calibration targets including stream flow, hydraulic heads and seasonal fluctuations. The applied hydraulic conductivity values and recharge rates represent the best balance of objectives from the completed simulations and approximation of the flow regime for the Project Area.

Overall, based on results of model calibration described in the followings sections 5.5.2.1 and 5.5.2.2, the model is considered to be reasonably well calibrated to observed conditions considering the degree of uncertainty in the hydraulic head and groundwater 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.

Table 20: Calibrated Hydraulic Parameters Assigned to the French Creek Model

Unit	Depth (m bgs)	Hydraulic Conductivity (m/s)	Specific Storage (1/m)	Specific Yield [a]
Surficial Till (Aquitard) Vashon Drift	-	1×10^{-7}	<u>5×10^{-5}</u>	0.1
Unconfined Sand and Gravel Salish (Aquifer 664, 1248, 1252)	-	<u>4×10^{-4}</u>	5×10^{-5}	0.2
Unconfined Sand and Gravel Vashon-Capilano (Aquifer 663)	-	<u>4×10^{-4}</u>	5×10^{-5}	0.2
Dashwood Drift Confining Unit	-	<u>8×10^{-8}</u>	<u>5×10^{-5}</u>	0.1
Confined Sand and Gravel Vashon-Capilano (Aquifer 209)	-	2×10^{-5}	5×10^{-5}	0.2

Unit	Depth (m bgs)	Hydraulic Conductivity (m/s)	Specific Storage (1/m)	Specific Yield [a]
Confined Sand and Gravel Quadra Sand (Aquifer 216, 217)	-	$\underline{1 \times 10^{-5}}$	5×10^{-5}	0.2
Confined Sand and Gravel Cowichan Head (Aquifer 1250)	-	$\underline{1 \times 10^{-5}}$	5×10^{-5}	0.2
Fractured Sedimentary Bedrock Haslam Formation (Aquifer 212)	0 - 40	$\underline{1 \times 10^{-6}}$	1×10^{-5}	0.01
	40 -200	$\underline{1 \times 10^{-8}}$	1×10^{-5}	0.001
	Below 200	$\underline{1 \times 10^{-8}}$	1×10^{-5}	0.001
Fractured Sedimentary Bedrock Haslam Formation (Aquifer 220)	0 - 40	$\underline{1 \times 10^{-6}}$	1×10^{-5}	0.01
	40 -200	$\underline{1 \times 10^{-7}}$	1×10^{-6}	0.001
	Below 200	$\underline{2 \times 10^{-8}}$	1×10^{-6}	0.001

Notes:

a. unitless parameter

Underlined: Parameters changed during the calibration process

mbgs: metres below ground surface

5.5.2.1 Measured Versus Predicted Hydraulic Head

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 equals the measured hydraulic head) is presented on Figure 28.

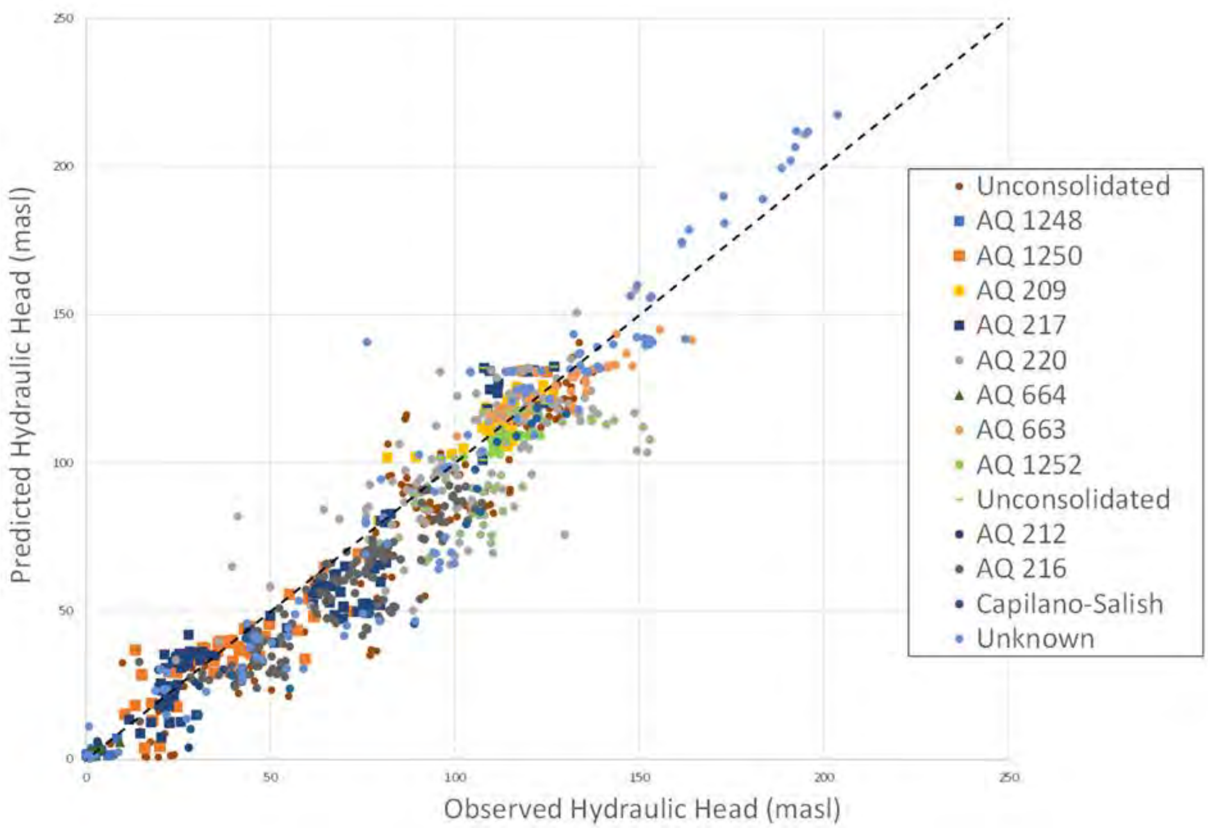
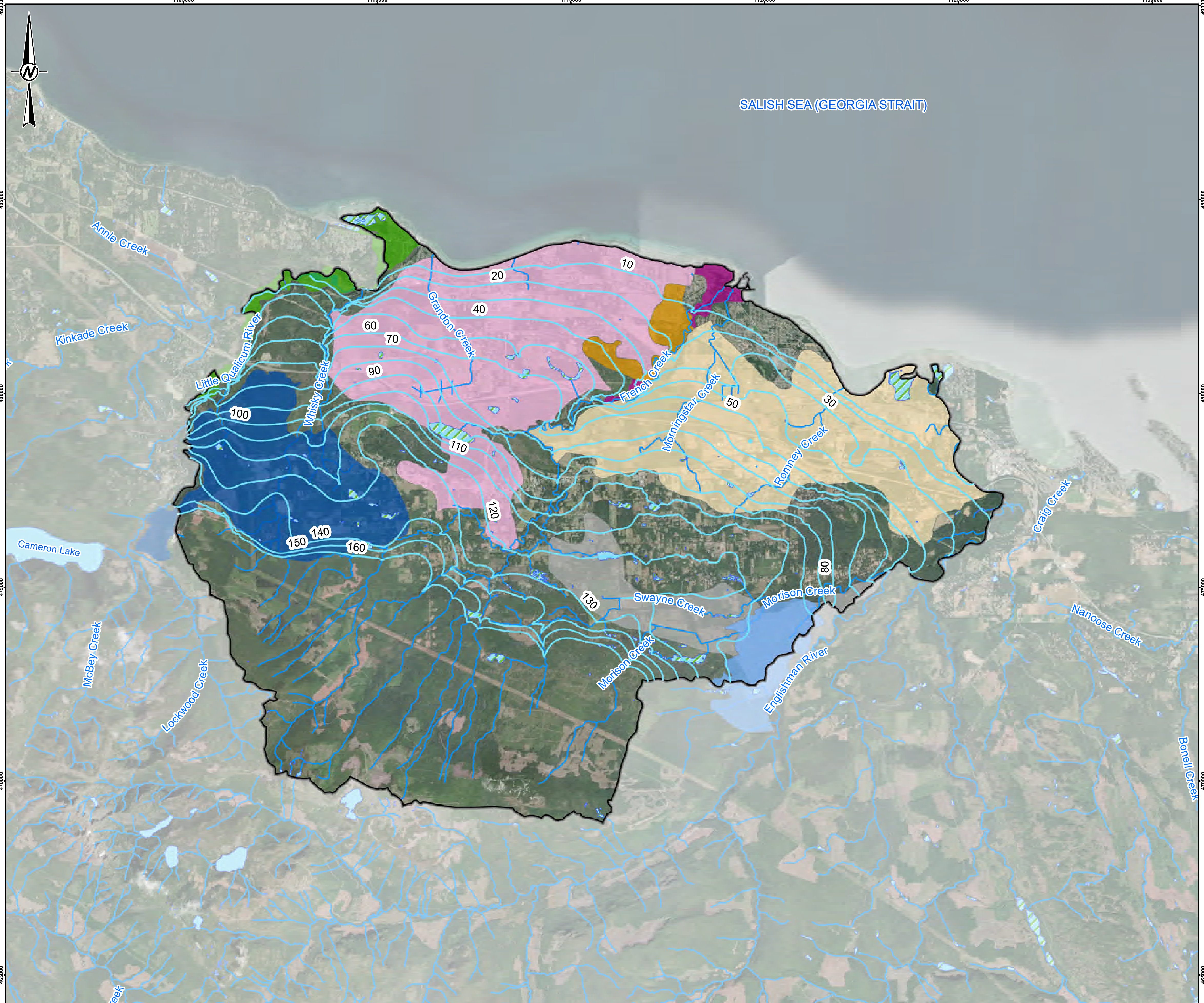


Figure 28: Observed vs Predicted Hydraulic Heads for all Wells in Project Area

Overall, the graph on Figure 28 shows that, for average annual conditions, the model can reproduce the observed regional hydraulic gradient in the Project Area. Predicted hydraulic heads are generally lower than those observed in the central portion of the Project Area (in bedrock wells and in the upper portion of Aquifers 216 and 217); in these areas the groundwater model might underpredict the flow through the aquifers and aquifer volume. However, this is considered conservative for the purposes of the groundwater model (i.e., water budget and stress analysis). The mean error between measured and predicted hydraulic head was approximately 10.1 m. This indicates that model predicted hydraulic heads were on average higher than measured data (by approximately 10.1 m); however, this is a mean value over the model domain. Relatively greater uncertainty was observed in the bedrock units where there is less information and, in the areas where the aquifer well assignment is listed as unknown or an unconsolidated unit. The normalized root-mean-square error (nRMSE), which considers the scale of head variation across the model domain, was 6% which is typically considered representative of a reasonable calibration (10%; BC ENV, 2012).

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 (Figure 29 and Figure 30). The majority of the regional groundwater discharge is predicted to be ultimately directed to the Salish Sea. The difference between the model calculated head and the observed head (the residual) for all wells in the Project Area are also presented in APPENDIX D. It should be noted that water levels for these wells were taken from the BC ENV WELLs database and typically represent the water level from time of drilling which may represent water level conditions across many decades and different seasons.



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES
- PREDICTED GROUNDWATER CONTOURS (masl)

OVERBURDEN AQUIFER

AQUIFER NUMBER

- AQ 1248
- AQ 1250
- AQ 1252
- AQ 209
- AQ 216
- AQ 217
- AQ 663
- AQ 664

0 2,000 4,000

1:100,000 METRES

NOTE(S)

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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
PREDICTED GROUNDWATER HEADS IN OVERBURDEN (CURRENT CONDITIONS)

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	29

LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES
- PREDICTED GROUNDWATER CONTOURS (masl)

BEDROCK AQUIFER

AQUIFER NUMBER

- AQ 212
- AQ 220

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERENMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
PREDICTED GROUNDWATER HEADS IN BEDROCK (CURRENT CONDITIONS)

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	30

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25mm

0

Figure 31 presents a comparison of measured versus predicted hydraulic heads for the average annual conditions for the PGOWN and VOW wells that provided more detailed water level information over an extended period of time and are considered a more reliable calibration target for water levels. The residuals of the PGOWN and VOW wells are also presented in APPENDIX D.

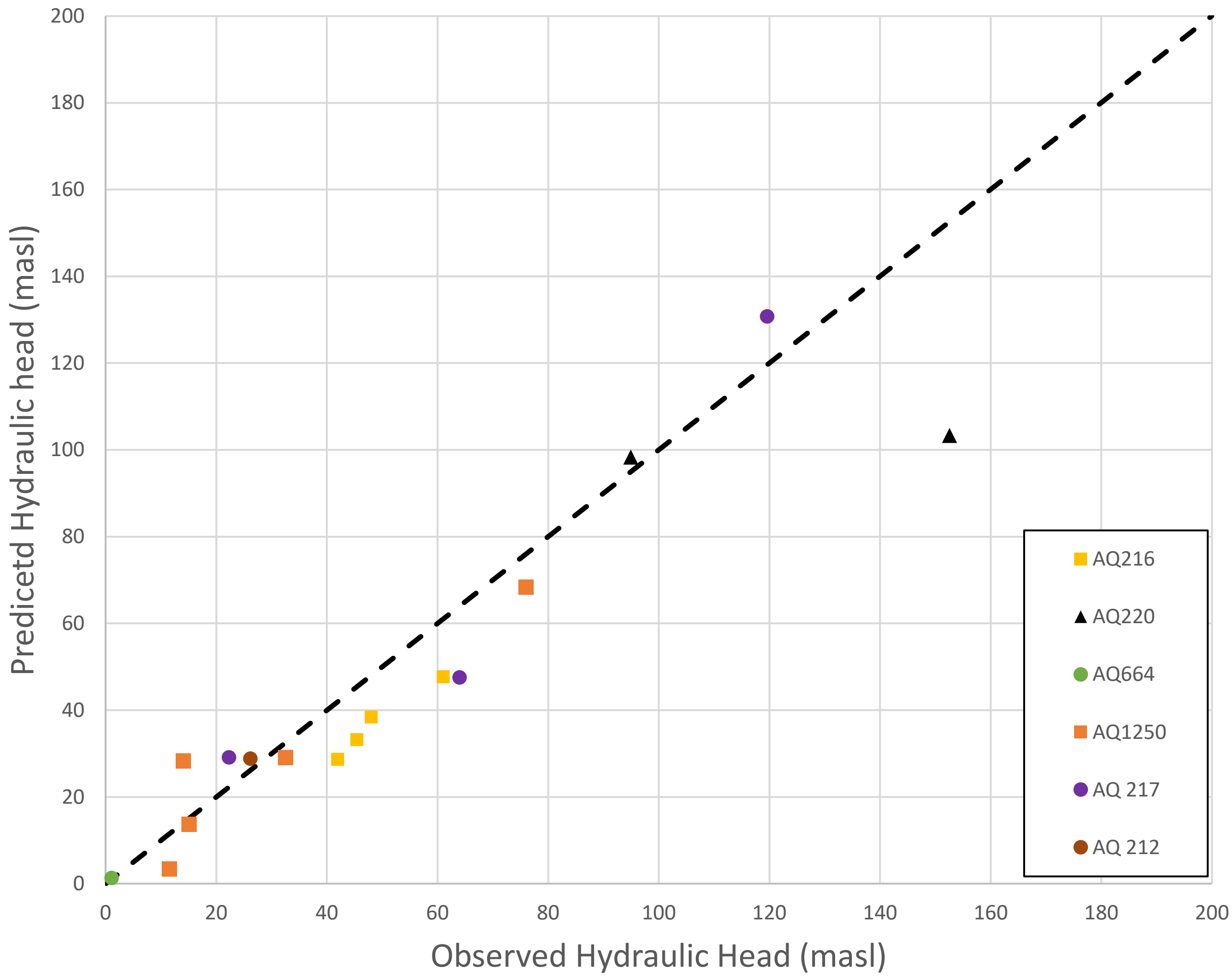


Figure 31: Observed vs Predicted Hydraulic Heads for PGOWN Wells

Predicted hydraulic heads in the PGOWN and VOW wells are reasonably close to observed values; when considering only these observation wells the mean error between measured and predicted hydraulic head was approximately 2.8 m. However, predicted hydraulic head in well VOW18, screened in bedrock and assigned to Aquifer 220, is significantly lower than the observed value, as shown on Figure 31. This well is part of the RDN voluntary observation wells network and is a domestic well subject to pumping; in addition to that, for all VOW monitoring wells there was some uncertainty in estimating well head elevation to calculate the hydraulic head. The predicted hydraulic head in PGOWN well 287 that is screened in the same Aquifer 220 is within 4 m from the observed value.

Table 21 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 PGOWN monitoring wells, the model predictions generally slightly underestimate the range of seasonal fluctuations observed in these wells. For Aquifer 216, the seasonal fluctuations predicted at the three wells are slightly lower in magnitude than the observed fluctuations; however, in general, the spatial distribution of seasonal fluctuation observed in wells screened in Aquifer 216 appears to be well reproduced by the model (i.e., fluctuations at OBS Well 314 are larger than those at OBS Well 304). For Aquifer 217, the seasonal fluctuation at OBS Well 295 is over predicted. This well is located in close proximity to a number of municipal pumping wells that are simulated as continually pumping in the model at wet and dry season rates; however, in reality these wells are not continually pumping and therefore the observed seasonal fluctuations are difficult to reproduce in the model as water levels recover to static conditions. Predicted seasonal fluctuations in Observation Wells 424 and 433 in Aquifer 1250 are smaller compared to the observed range; these wells are located at the edges of Aquifer 1250 where the aquifer is inferred to be relatively thin and may be locally influenced by this aquifer boundary. The fluctuations in head are better represented in the model by Observation Wells 303 and 321 which are located closer to the middle of the aquifer where deposits are inferred to be thicker.

Overall, the results of the calibration showed that the model slightly underestimates seasonal fluctuations in monitoring wells within the model domain; however, on average the predicted seasonal water level fluctuations are within 0.7 m of the observed values and are considered reasonable for a regional-scale model.

Table 21: Seasonal Fluctuations Predicted by Model and Average Values Measured in Available Observation Wells

Well ID	Well Type	Lithology	Aquifer	Average Observed Seasonal Fluctuation (m)[a]	Predicted Seasonal Head Range (m)[b]	Comments
OBS Well 303	PGOWN Monitoring Well	Overburden	1250	3 to 6	3.4	
OBS Well 321	PGOWN Monitoring Well	Overburden	1250	4 to 6	3.5	
OBS Well 424	PGOWN Monitoring Well	Overburden	1250	1 to 2	0.2	Located at the edge of Aquifer 1250
OBS Well 433	PGOWN Monitoring Well	Overburden	1250	3.5 to 6.5	0	Located at the edge of Aquifer 1250
OBS Well 304	PGOWN Monitoring Well	Overburden	216	0.5 to 1	0.4	
OBS Well 314	PGOWN Monitoring Well	Overburden	216	1 to 2	0.8	
OBS Well 398	PGOWN Monitoring Well	Overburden	216	0.5	0.1	
OBS Well 295	PGOWN Monitoring Well	Overburden	217	2 to 5	7.5	Located close to production well
OBS Well 434	PGOWN Monitoring Well	Overburden	217	0	0	
OBS Well 389	PGOWN Monitoring Well	Overburden	664	2 to 2.5	1.4	

Well ID	Well Type	Lithology	Aquifer	Average Observed Seasonal Fluctuation (m)[a]	Predicted Seasonal Head Range (m)[b]	Comments
OBS Well 287	PGOWN Monitoring Well	Bedrock	220	1 to 3	1.2	

Notes:

a. Observed at the well location

b. Predicted over the area of the aquifer where the observation well is located

In addition to the PGOWN wells, seasonal fluctuations at five voluntary observation wells were also evaluated during the transient model calibration. Seasonal fluctuations at these locations were generally underestimated and are difficult to reproduce in the model, as the water levels in these wells may be influenced by domestic pumping activities.

5.5.2.2 Measured Versus Predicted Groundwater Baseflows

Creek flow data from the three monitoring stations along French Creek (see Section 3.2.3.1) were assessed during calibration. As discussed previously, flow data for the three stations were limited and the periods of measurement did not overlap between stations. Therefore, the data represent creek flow conditions at different periods and cannot be correlated to estimate flow in reaches between the stations. Average creek flows calculated from automated or manual measurements during the summer months (June to September) over the available datasets were used as targets for calibration. A comparison between measured and predicted creek flows is presented in Table 22, below.

Table 22: Comparison Between Measured and Predicted Groundwater Baseflow

Hydrometric Station	Station ID	Measured Creek Flows (June to September) (m^3/d)			Predicted Creek Flows (Calibrated Model Average)
		Minimum	Average	Maximum	
French Creek at Coombs	08HB038	690	8,730	23,440	9,030
French Creek above Pumphouse	08HB078	5,010	11,230	28,210	15,500
French Creek at Barclay	08HB0021	1,240	6,500	18,455	15,600

For the Coombs (08HB038) and Pumphouse (08HB078) stations, which have larger datasets, although up until 1996, the model-predicted groundwater baseflow is within the range or very close to the estimated average flow at each hydrometric station. As described in Section 3.2.3.1, monitoring data at the Barclay (08HB0021) station between 2019 and 2021 showed a significant decrease in flow during the summer months compared to the previous monitoring period at the nearby Pumphouse station (08HB038) and the upstream Coombs station (08HB078). The decrease in summer flow could be associated with increased water withdrawal for irrigation in the summer months and/or different climate conditions (i.e., reflecting a particularly dry year). These conditions cannot be reproduced by the model. However, considering the uncertainty in the current creek flow dataset, the model is considered to reproduce reasonably well average annual groundwater contribution to streamflow.

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 (as outlined in Section 3.3), the actual current groundwater conditions (groundwater levels and flow) might differ from what was predicted with the model. Following model calibration, model sensitivity to the input hydrogeological parameters was assessed with a limited sensitivity analysis. Sensitivity analysis was completed on the calibrated model to understand which model properties may have the most effect on predicted results. The sensitivity analysis was primarily conducted by running 8 steady-state sensitivity simulations, and for each simulation varying one model parameter. 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 average annual 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
- upper bound confining unit: hydraulic conductivity of all confining units increased by a factor of 3
- lower bound confining unit: hydraulic conductivity of all confining units decreased by a factor of 3
- upper bound permeable units: hydraulic conductivity of all permeable units was increased by a factor of 3
- lower bound permeable units: hydraulic conductivity off all permeable units was decreased by a factor of 3
- upper bound recharge: increased recharge across the model by 30%
- lower bound recharge: decreased recharge across the model by 30%

The upper and lower bound range for hydraulic conductivities of the bedrock units, confining units and aquifer units is considered reasonable based on the available data (Table 9). For each sensitivity simulation, a check was completed to see how the change in a model parameter could affect the model calibration. This calibration check helps evaluate if the scenario is reasonable for assessing future conditions.

Table 23 below summarizes the results of the sensitivity analysis and presents the predicted stream flow at the three hydrometric stations along French Creek used in model calibration. These results indicate that the predicted groundwater baseflow to French Creek are most sensitive to hydraulic conductivity assigned to the overburden aquifers and bedrock units and to recharge represented in the model. For the simulations where the most significant changes to predicted groundwater baseflows are observed (upper bound of hydraulic conductivity of the overburden aquifers, bedrock and recharge), the model calibration to measured hydraulic heads is still reasonable, but the nRMSE is slightly higher than for the calibrated model (the nRMSE is still within 10%). In the upper bound scenario for recharge, the results show slightly better statistics for hydraulic heads (nRMSE); however, in this case, the predicted groundwater baseflow is significantly higher that the observed average. Based on the results of the sensitivity analysis for the most sensitive parameters (hydraulic conductivity of the overburden and bedrock units and recharge), uncertainty in predicted groundwater baseflow to French Creek ranges from 1% to 50%, with a mean uncertainty of 21%; thus, the actual flows in the creek are on average within 21% of the predicted groundwater baseflows.

The results of this limited sensitivity analysis identify the hydrogeological parameters with higher uncertainty: hydraulic conductivity of overburden aquifer and bedrock and recharge (natural and anthropogenic). Collection of additional monitoring data in subsequent phases of work would help reduce uncertainty and support model improvements, if desired (see Section 9.3).

Table 23: Results of Limited Sensitivity Analysis

Scenario	Predicted Groundwater Baseflow (m^3/day)			
	French Creek at Coombs	French Creek above Pumphouse	French Creek at Barclay	Root Mean Square (RSM) (%)
Calibrated	9,030	15,362	15,464	5.9
Upper Bound				
Bedrock K[a]	5,849	13,447	13,510	6.6
Confining Units K[a]	8,721	15,195	15,294	6.2
Aquifer Units K[a]	5,204	12,933	12,863	5.9
Recharge	13,567	22,511	22,649	5.3
Lower Bound				
Bedrock K[a]	10,761	15,698	16,842	5.9
Confining Units K[a]	9,226	15,635	15,709	5.5
Aquifer Units K[a]	10,617	16,939	17,036	5.5
Recharge	4,578	8,623	8,656	8.7

Notes:

K = hydraulic conductivity (m/s)

6.0 AQUIFER WATER BUDGET AND STRESS ASSESSMENTS

6.1 Scope and Methods for Water Budget Analysis

The preliminary water budgets that were prepared in Phase 1 of the Water Budget Project by Waterline (2013), 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 Waterline (2013) noted, these were conceptual assessments to provide a relative comparison between systems. Figure 32, below, provides a schematic that illustrates the water budget approach that was used by Waterline for Phase 1.

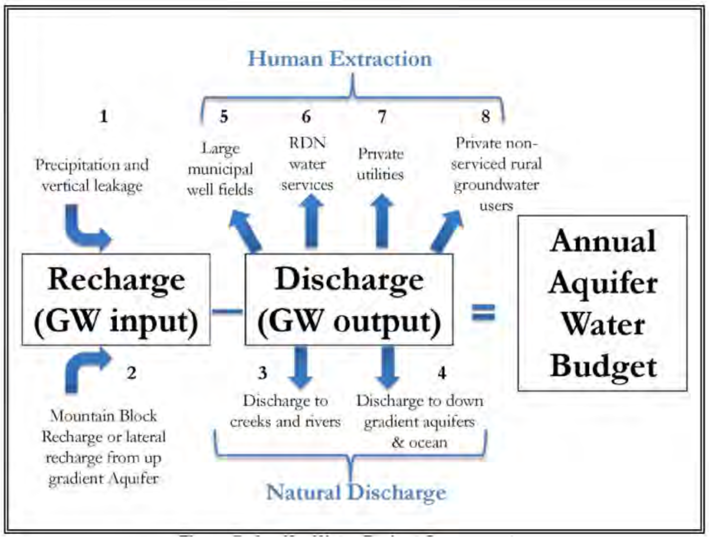


Figure 32: Aquifer Water Budget Components considered in Waterline 2013 Phase 1 Water Budget Project (Figure 7 from Waterline, 2013)

As part of the Phase 1 Water Budget, aquifer stress was determined based on a static water balance equation that used recharge as the main input; flow from other units was estimated as a constant value based on inferred hydrogeological properties of adjacent units. This approach works well for a simplified static model and provided a preliminary screening of aquifer stress to identify critical areas that needed to be prioritized. The groundwater model that WSP developed for the Phase 3 French Creek Water Budget and described in Section 5.0 represents a dynamic system that is responsive to stress where, under steady-state conditions, inflows to the system equal outflows from the system. For this reason, the groundwater model developed for Phase 3 French Creek Water Budget is more representative of the natural system and can better estimate water budget for the aquifers in the Project Area.

For Phase 3, WSP used the calibrated numerical model to run the water budget and stress analysis. For this assessment, groundwater extraction and discharge (i.e., baseflow or groundwater contribution to streamflow in creeks and rivers) was divided by the total inputs into the aquifer to evaluate relative stress (i.e., Aquifer Stress), as per the formula below:

$$Aquifer\ Stress(\%) = \frac{GW\ Extraction + baseflow}{GW\ Inputs}$$

GW Extraction	private and municipal well extractions
baseflow	baseflow in creeks/rivers
GW Inputs	flow from surface water sources, recharge from precipitation and anthropogenic sources and flow from other hydrogeological units

The approach used by WSP is a modified version of the current provincial method that is used to evaluate Aquifer Stress for unconfined aquifers and considers recharge relative to environmental flow needs (EFNs) and groundwater extraction (Forstner et al., 2018, Water Series 2018-04). The method for aquifer stress classification system by the Province consists of three categories: Less Stressed, More Stressed (less certainty) and More Stressed (high certainty). WSP developed the Aquifer Stress scale for the Phase 3 French Creek Water Budget (which differs from the Phase 1 stress analysis) with consideration of the provincial approach for EFNs and through application of professional judgement on the implications on the aquifer system. The Aquifer Stress categories that WSP used for the Phase 3 French Creek Water Budget analysis (Table 24) were developed in discussion with the RDN and provide a framework that identifies areas of relatively higher stress and a basis for prioritization of water management initiatives.

It should be noted that the stress classification method outlined in this section was developed for aquifers only. A separate assessment was conducted to evaluate risk management levels for French Creek and is described in Section 7.0.

Table 24: Phase 3 French Creek Water Budget Aquifer Stress Classification

Stress%	Aquifer Stress Classification
0 – 10	Low
10 – 20	Moderate
20 – 30	High
> 30	Very High

As noted above, the method utilized by WSP to calculate Aquifer Stress for the Phase 3 French Creek Water Budgets compares the relative proportion of groundwater extraction and baseflow to groundwater inputs. For future scenarios, if the inflows to the system (and outflows from the system) decrease but the proportion of the groundwater inflows to the outputs (i.e., groundwater extraction plus baseflow) does not change, then the relative Aquifer Stress and the corresponding classification would not change. Therefore, the total aquifer fluid volume for each future scenario was also compared to the Future Base Case conditions (see description of Future Base Case in Section 6.1.2) as another measure to assess potential changes to the water balances in the future.

6.1.1 Current Conditions

The calibrated steady-state and transient models were used to conduct a water budget analysis to assess current Aquifer Stress for the identified aquifers in the Project Area for average annual conditions and at the end of the wet and dry seasons. The pumping schedules and water consumption rates simulated in this scenario were based on the current conditions described in Section 3.2.6.

6.1.2 Future Scenarios

The calibrated model was also 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 RDN advised that pumping rates for municipal wells are anticipated to be maintained at current levels with the exception of the French Creek Water Service (FCWS) wells which will be increased to meet increased future demand. Pumping conditions for the future scenarios were based on estimated well capacities, as discussed with the RDN. Following discussion with the RDN, it was assumed that three pumping wells that are currently not in use (FC Wells #1, #5 and #6) will be utilized in the future with pumping rates derived from 2001 pumping records (when those wells were previously operated). For the remaining three wells for the French Creek well field (FC Wells #2, #4 and #7), pumping rates were approximately doubled in the wet season and increased between 2 to 2.5 times in the dry season in comparison to current rates. The production wells that are operated by other providers were assumed to be operated in the future at the current rates (see Table 13 to Table 15). Table 25 presents a list of the RDN production wells and their future pumping schedules.

Table 25: Future Production Rates for Regional District of Nanaimo Municipal Water Supply Wells in the Project Area

Well	Well Tag No.	Aquifer	Future Production Rates (m^3/day)		
			Average Annual	Dry Season	Wet Season
French Creek Wells					
FC Well 1	26661	1250	53	32	74
FC Well 2	43090	1250	98	57	137
FC Well 4	41896	1250	101	56	145
FC Well 5	75344	1250	178	102	254
FC Well 6	75345	1250	71	78	63
FC Well 7	75346	1250	99	53	145
FC Well 8	75347	Unassigned	N/A	N/A	N/A
Surfside Wells					
Surfside 1	28459	664	9	4	14
Surfside 2	75325	664	9	4	14
TOTAL			**617**	**386**	**845**

Notes:
N/A: not available as the well will not be operational

The transient model was first run under the Future Base Case hydrogeological conditions (calibrated model with future pumping schedule in Table 25) 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 Future Base Case.

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 average annual 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, WSP obtained data online from Pacific Climate Impacts Consortium (PCIC, 2022). 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 26, below, provides a summary of changes in mean temperature, precipitation and snowfall relative to a baseline historical period (1961 to 1990) projected to the 2020s, 2050s, and 2080s for the Nanaimo region (PCIC, 2022).

Table 26: Summary of Projected Climate Change for Nanaimo Region (PCIC, 2022)

Climate Variable	Season	Median	Range (10th to 90th percentile)
Projected changes to the 2050s (2040-2069)[a]			
Temperature (°C)	Annual	+2.7°C	+1.9°C to +3.9°C
Precipitation (%)	Annual	1.70%	-1.5% to +5.4%
	Summer	-13%	-41% to +3.0%
	Winter	3.40%	-0.22% to +9.3%
Precipitation as Snow* (%)[b]	Annual	-82%	-91% to -75%
	Winter	-85%	-91% to -76%
	Spring	-80%	-93% to -56%
Projected changes to the 2080s (2070-2099)[a]			
Temperature (°C)	Annual	+4.3°C	+3.2°C to +6.0°C
Precipitation (%)	Annual	7.60%	-0.52% to +13%
	Summer	-24%	-56% to -5.3%
	Winter	13%	+0.50% to +19%
Precipitation as Snow* (%)[b]	Annual	-92%	-97% to -84%
	Winter	-94%	-98% to -86%
	Spring	-91%	-100% to -71%

Notes:

a. CAUTION: Percent changes from a low baseline value can result in deceptively large percent change values. A small baseline can occur when the season and/or region together naturally make for zero or near-zero values. For example, snowfall in summer in low-lying southern areas.

b. Climate variables marked with * are derived from temperature and/or precipitation values and are not direct outputs of the climate models.

The data presented in Table 26 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 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. As discussed with the RDN (2022b), for the purposes of the Phase 3 French Creek Water Budget analysis, WSP considered median values for projected precipitation. Based on a review of historical precipitation data over the last 10 years in the Project Area (2011 to 2021) 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., 13%, as presented in Table 26) 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. 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.

It is anticipated that hotter and drier summers, combined with a longer growing season, would 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 to 2010) were estimated by Gilchrist (2017) for two climate change scenarios (stabilization scenario and high-emission scenario[2]). The results of the study predicted that, relative to current water use, for the French Creek area, approximately 40% to 60% 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 50% increase in water consumption was applied to the numerical model for properties that are identified for agricultural or rural land use.

The assumptions described above to simulate the effects of climate change to groundwater flow conditions in the Project Area are conservative and simplified. Multiple factors could influence the effects of climate change on recharge from precipitation and water requirements for crops (changes to soil moisture and ground cover, vegetation and evapotranspiration, etc.) and would require a more detailed assessment. The WSP approach outlined above was discussed with the RDN and is considered conservative and appropriate to estimate potential effects of climate change on groundwater conditions on a regional scale (RDN, 2022b).

6.1.2.2 Scenario 2 – Future Build-Out

For properties located outside of the municipal service area, future increased water demand was predicted based on application of the estimated residential groundwater use of 567 L/day/residential unit, as presented in Section 3.2.6.2, to all of the properties that will be developed as part of the future build-out plan, as provided by RDN (2022a) in GIS format. Areas of future build-out are presented on Figure 33 and the number of new or subdivided lots is summarized in Table 27. Water use for the non-serviced areas was increased proportionally, assuming each new lot or subdivided lot is anticipated to have one dwelling. Based on discussion with RDN, existing activities (i.e., currently agricultural irrigation or livestock herd) that are currently conducted on lots that will be redeveloped under the build-out plan as residential, will be discontinued following development. If an existing well was present on a lot that is planned for future build-out, groundwater use was applied to the same aquifer as the existing water use. If no existing groundwater use was identified (i.e., no water well currently present), groundwater use was applied to the shallowest aquifer identified in the area of future development.

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

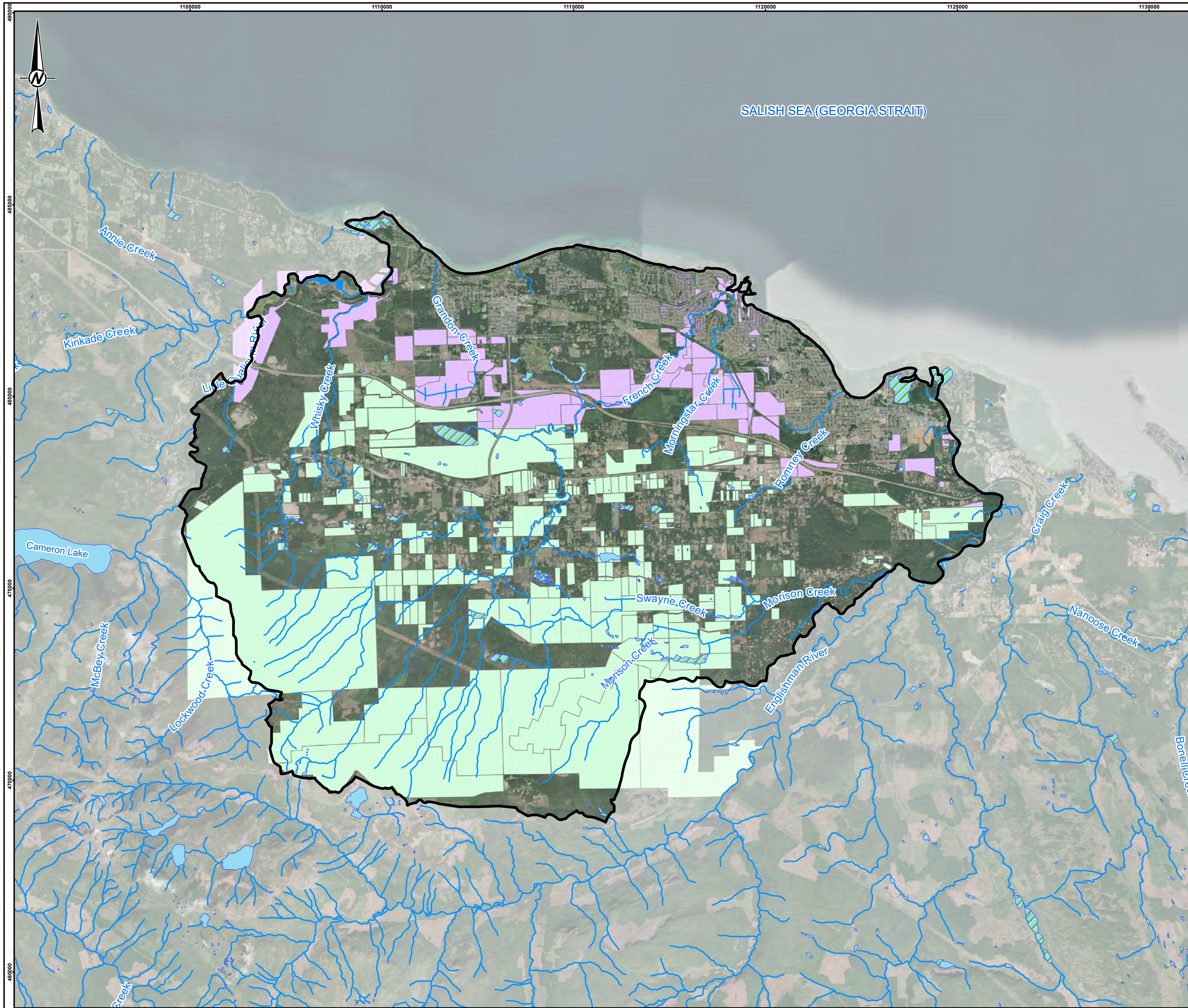
Recharge from septic returns was increased to account for the new domestic development outside the water service area and recharge from irrigation was removed for lots that are planned for future development. Increased water use within the RDN service area was accounted for with the increased future production rates.

Table 27: Summary of Build-out Information in the Project Area[a]

	Area F (in Project Area)	Area G (in Project Area)	Total
Current Lots	897	2,059	2,956
New Lots, Future Build-out	854	1,368	2,222
Total Lots, Future Build-out	1,751	3,427	5,178

Notes:
a. Based Area F and G Build-out geodatabase provided by RDN September 2022

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.



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES
- AREAS OF NEW DEVELOPMENT - RDN ELECTORAL AREA G
- AREAS OF NEW DEVELOPMENT - RDN ELECTORAL AREA F

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
2. FUTURE BUILDOUT PLAN PROVIDED FOR AREA F ANF G BY RDN
3. PROJECT AREA CREATED BY WSP GOLDER.
4. IMAGERY COPYRIGHT ESRI AND ITS LICENSORS. SOURCE: DITIGAL GLOBE. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE:20160912

COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AREAS IDENTIFIED FOR FUTURE NEW DEVELOPMENT

CONSULTANT

YYYY-MM-DD	2023-07-20
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	33

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

PATH: V:\RDN Nanaimo\French Creek\GIS Figures\99_PROJECTS\02_PRODUCTION\5000\MXD\Report\updated_20230629\Proj_21487784_5000_Figure33_Buildout.mxd PRINTED ON: 2023-07-20 AT: 11:13:58 AM

6.1.2.3 Scenario 3 – Changes in Landcover

The effect of potential changes to land cover under future development scenarios (i.e., potential increases in impervious surfaces) was evaluated in Scenario 3. The RDN provided a GIS layer of the lots that are anticipated to undergo future residential development or sub-division of existing residential lots (Figure 33). For parcels that are zoned for future development and where a change in land use 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. WSP reviewed local bylaw information (i.e., Bylaw 500; RDN, 2014) regarding the maximum allowed parcel coverage with impervious surfaces based on land use. For residential properties, the maximum allowable coverage can vary between 35% and 60%, depending on the type of development (single or multiple dwellings, etc.). Based on information available in other areas of the RDN (e.g., Nanoose), the maximum allowed coverage with impervious surfaces for the majority of residential properties is 35% (including new roads developed to connect new properties). This percentage is consistent with maximum allowed coverage for the R3/R5 residential zone outlined in RDN Bylaw 500. A visual review of air photo imagery of current lot conditions in the area of French Creek confirmed that this assumption is reasonable for lots smaller than three hectares. Therefore, 35% was selected as the percentage of new lots that will be covered by impervious surfaces for lots less than three hectares in size.

For newly developed lots that are larger than three hectares and mainly located in the southern portion (i.e., upper elevations) of the watersheds within the Project Area where forest is currently present, a rural/residential land use was assumed. In these areas, properties are planned to be much larger than those in the northern areas of the Project Area. Larger rural residential properties are expected to have a small percentage of the overall lot covered by impervious surface. In areas, where the new lot size is anticipated to be larger than three hectares, the maximum coverage of a lot with impervious surface was estimated to be 10%, which is consistent with the parcel coverage for rural properties (Rural 10), as per Bylaw 500.

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

6.1.2.4 Scenario 4 – Combined Future Conditions

One additional scenario was considered to evaluate the combined effects of potential future conditions. Scenario 4 simulated the combined effects of potential climate change, future build-out and changes in land cover, each of which is described in the preceding sections.

6.2 Results and Discussion

6.2.1 Current Conditions

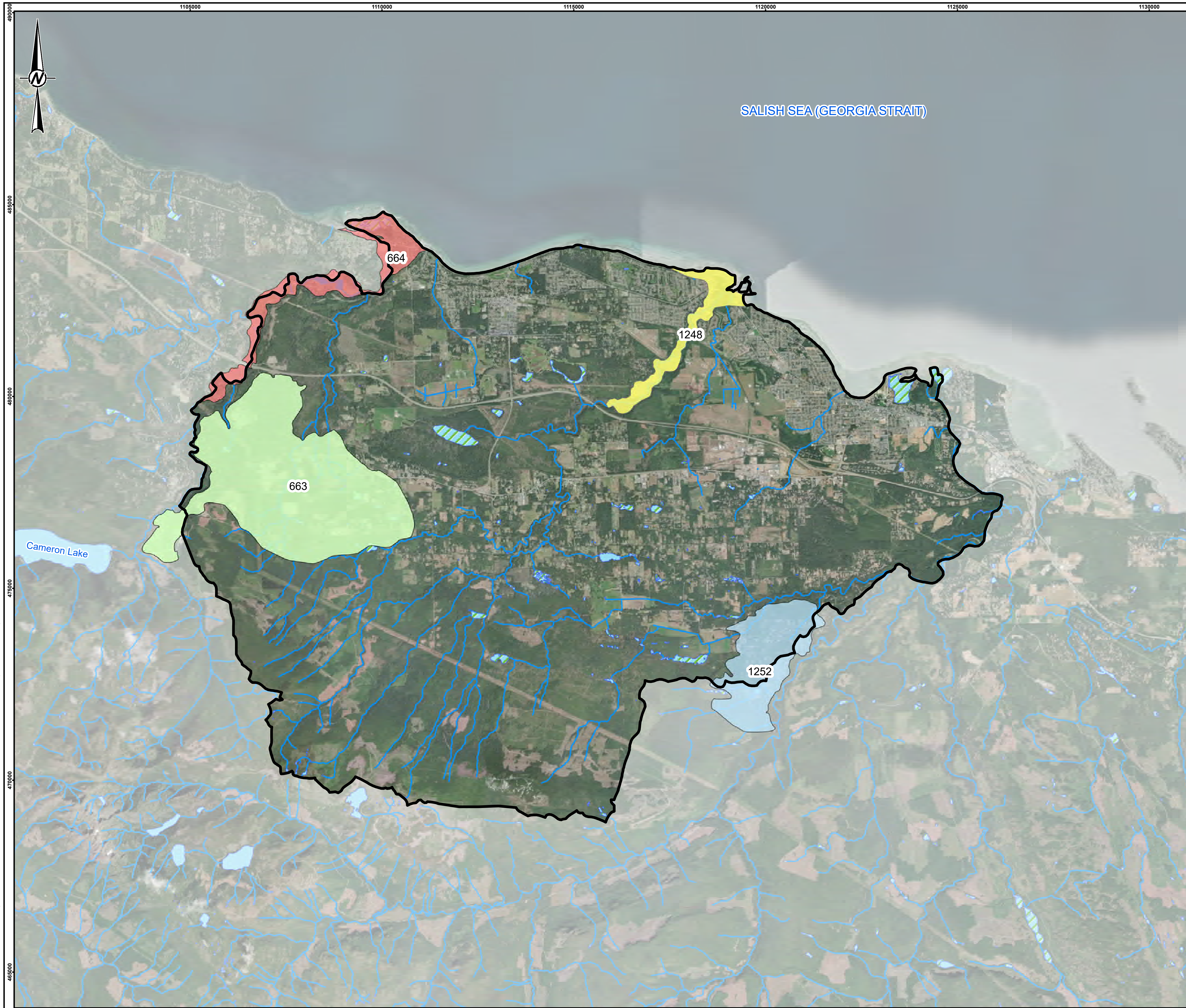
Water budgets and Aquifer Stress classifications for each of the aquifers within the Project Area under current conditions are presented in Sections 6.2.1.1 to 6.2.1.3. A full summary of the water budgets with respect to major sources of groundwater inflow and outflow to illustrate the relative contribution of groundwater recharge, surface water and anthropogenic water use to groundwater flow within the aquifers is presented in APPENDIX F. Throughout this section, Aquifer Stress classifications under current conditions for the end of dry season only are presented on accompanying figures, as this is the time of year when water stress is greatest due to less groundwater recharge and greater water demand.

6.2.1.1 Unconfined Aquifers

Within the Project Area, the four unconfined aquifers experience different levels of Aquifer Stress that reflect geospatial differences in recharge (i.e., groundwater inputs) and discharge, including groundwater demand and baseflow to surface water bodies. A summary of the Aquifer Stress classifications for the unconfined aquifers under current conditions is presented in Table 28 and presented in Figure 34.

Table 28: Unconfined Aquifer Stress Classification under Current Conditions

Aquifer Number	Aquifer Stress Classification		
	Average Conditions	End of Wet Season	End of Dry Season
Aquifer 663	Moderate (14%)	Moderate (14%)	Moderate (14%)
Aquifer 664	Very High (45%)	Very High (43%)	Very High (47%)
Aquifer 1248	High (22%)	High (21%)	High (22%)
Aquifer 1252	Low (2%)	Low (2%)	Low (2%)



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT

REGIONAL DISTRICT OF NANAIMO

PROJECT

REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE

AQUIFER STRESS CLASSIFICATION (UNCONFINED AQUIFERS) – CURRENT CONDITIONS (END OF DRY SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-13
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	34

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25mm

0

Aquifer 663 is a shallow unconfined aquifer located in the vicinity of Whiskey Creek in the southwestern portion of the Project Area. The Aquifer is inferred to be hydraulically connected to Whiskey Creek, but flow in this creek is currently not monitored. Flow from other units (i.e., geological units) and surface water are the dominant sources of recharge to the aquifer. Outflow from Aquifer 663 is predominantly to Whiskey Creek at lower elevations and outflow to other units. At the time that the numerical groundwater model was developed and calibrated, information provided indicated that no municipal supply wells extracted water from Aquifer 663 and, under current conditions, water consumption by private users constitutes less than 0.1% of the aquifer outflows. However, the Whiskey Creek Water Service Area, which services 130 residential lots and had historically been supplied by surface water from Crocker Creek, switched to a groundwater supply in late 2021 (RDN, 2022c). Pumping of the Whiskey Creek water supply well (Well Tag No. 42538) was not simulated in the current conditions, nor in the future scenarios. The monthly water consumption for the Whiskey Creek Water Service Area, which was reported by the RDN (2022c) to typically range from less than 3,000 m^3 in the winter months to approximately 5,000 to 6,000 m^3 per month in the summer, is not anticipated to represent a significant volume relative to the total groundwater inputs of over 110,000 m^3/day (i.e., 3.3 Mm^3/month) in the dry season under current conditions. If more localized or service area specific assessment were to be required in the future, the model could be rerun to include the simulation of groundwater pumping for the Whiskey Creek Service Area.

Based on the current Phase 3 Aquifer Stress classification, Aquifer 663 is inferred to be classified as Moderate Stress, as 14% of the inflow to the aquifer is inferred to supply groundwater baseflow to Whiskey Creek. The results of the Aquifer Stress assessment for Aquifer 663 demonstrate the importance of considering groundwater-surface water interaction in addition to anthropogenic groundwater use (i.e., pumping) when considering Aquifer Stress. As discussed above, flow in Whiskey Creek is currently not monitored, potentially representing a source of uncertainty. The Moderate Stress classification for Aquifer 663 is in general agreement with the current BC Provincial aquifer stress classification system, where Aquifer 663 is considered to be “Less Stressed” (Forstner et al., 2018); as discussed in Section 6.1, the classification system by the Province only consists of three categories: Less Stressed, More Stressed (less certainty) and More Stressed (high certainty).

Aquifer 664 is a shallow unconfined aquifer located along edge of the Little Qualicum River near the confluence with the Salish Sea. The aquifer is inferred to be hydraulically connected to Little Qualicum River, which represents the model boundary in this area. Therefore, Aquifer 664 is only partially represented in the model. The primary source of water for the aquifer is interpreted to be flow from other units in addition to relatively smaller contributions from the river and recharge from ground surface (precipitation and anthropogenic sources). Outflow from Aquifer 664 is predominantly to Little Qualicum River and the ocean, and municipal use from the City of Qualicum Beach. Under current conditions, water consumption by private and municipal users constitutes approximately 9% of the aquifer outflows on annual basis; however, based on the current Phase 3 Aquifer Stress classification, Aquifer 664 is inferred to be Very High Stress, as 36% of the inflow to the aquifer is inferred to supply groundwater baseflow to Little Qualicum River. Aquifer 664 is inferred to remain Very High Stress during both the dry season and the wet season. According to the current BC Provincial aquifer stress classification system, Aquifer 664 is considered to be “More Stressed (less certainty)”. Therefore, the Phase 3 Aquifer Stress classification of Very High Stress is deemed to be relatively consistent with the current Provincial classification. These classifications for Aquifer 664 reflect the overall aquifer conditions, and it is noted that stress is inferred to be variable within the aquifer units. Based on the results of site-specific assessments, Piteau (2004) assessed the Town of Qualicum Beach Riverside wells and reported the hydraulic conductivity of the aquifer deposits in this area at values that were higher than what was assigned overall to Aquifer 664 in the Phase 3 numerical model. Piteau (2004) also reported that the Little Qualicum River is the principal water source for the Riverside well field.

As discussed in Section 9.3, the numerical model that was developed for the Phase 3 water budgets is regional in scale and not suitable for local-scale applications such as well field design and optimization. It is recommended that the reader refer to the Piteau (2004) and other relevant site-specific information when considering water stress in the area of the Riverside well field.

Aquifer 1248 is a shallow unconfined aquifer that has a hydraulic connection to French Creek, at the mouth of French Creek near the confluence with the Salish Sea. Model results show that, in the area of Aquifer 1248, French Creek is gaining along some reaches (i.e., receiving baseflow from groundwater) and losing along others (i.e., recharging groundwater), depending on the elevation of the creek bottom. French Creek is mostly losing to the aquifer in the summer when groundwater levels are relatively lower. The primary source of water for the aquifer is flow from French Creek and from other units, in addition to smaller contributions attributed to recharge from ground surface (precipitation and anthropogenic sources). Outflow from Aquifer 1248 is predominantly to French Creek and the Salish Sea. Under current conditions, water consumption by private and municipal users constitutes less than 1% of the aquifer outflows on an annual basis; however, based on the current Phase 3 Aquifer Stress classification, Aquifer 1248 is inferred to be High Stress because 22% of the inflow to the aquifer is inferred to supply groundwater baseflow to French Creek. No Provincial aquifer stress classification is available for Aquifer 1248, as it is a recently delineated aquifer.

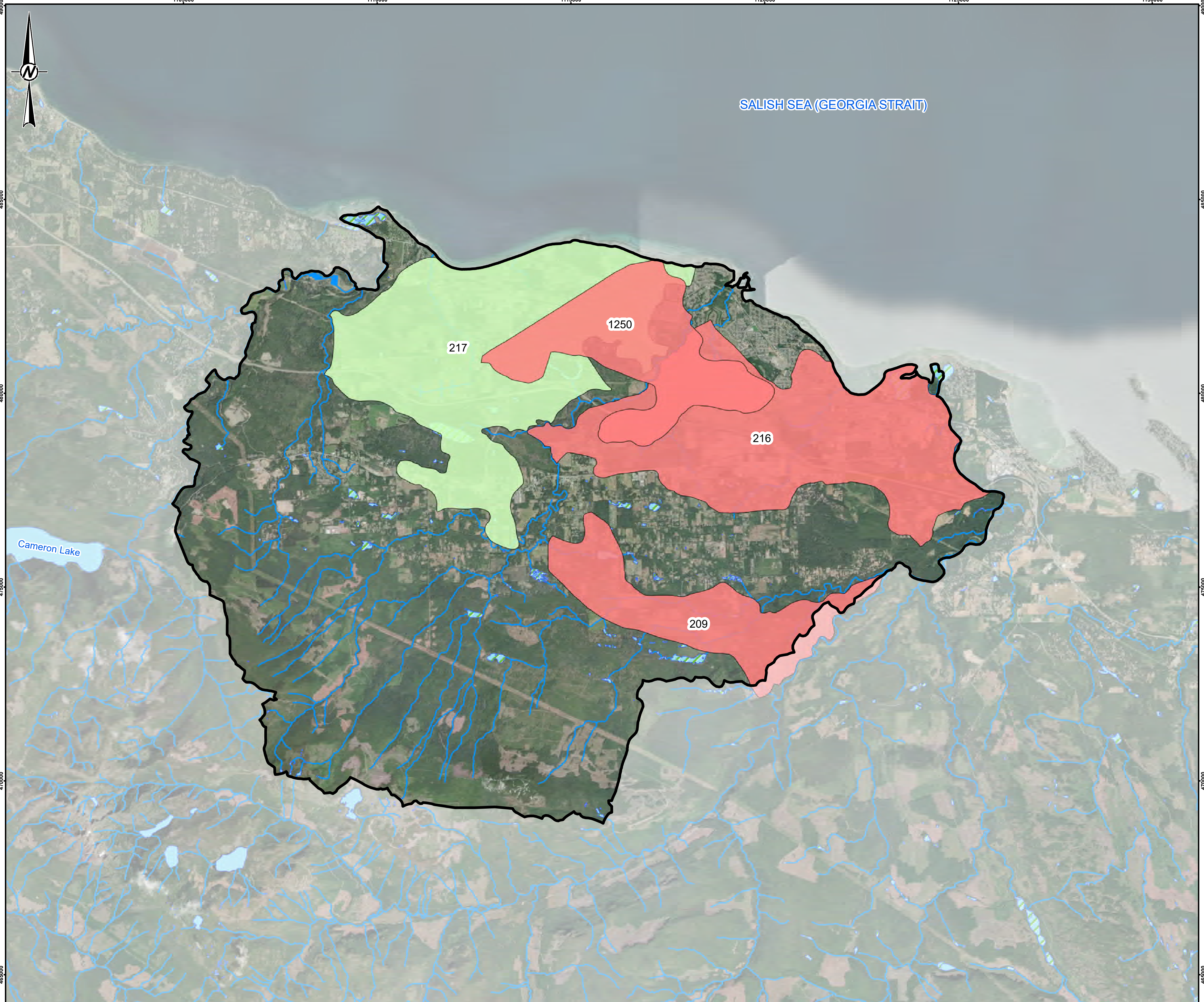
Aquifer 1252 is a shallow unconfined aquifer located in the southeastern portion of the Project Area in between Morrison Creek and Englishman River. Aquifer 1252 is inferred to be not hydraulically connected to the primary creeks evaluated in the Hydraulic Connectivity and Aquifer Mapping Study (GWS, 2020). In this area, Morrison Creek and Englishman River are the model boundary in the uplands and lowlands, respectively. As a result, only part of Aquifer 1252 is located within the model domain. Recharge to the aquifer is mostly represented by flow from surface water, flow from other units and recharge from ground surface (precipitation and anthropogenic sources). Outflow from Aquifer 1252 is predominantly to other units. Under current conditions, water consumption by private and municipal users constitutes less than 0.3% of the aquifer outflows on annual basis. Based on the limited outflow from the aquifer to surface water and the limited number of small private users of groundwater, Aquifer 1252 is classified as Low Stress. No Provincial aquifer stress classification is available for Aquifer 1252, as it is a recently delineated aquifer.

6.2.1.2 Confined Unconsolidated Aquifers

A summary of the Aquifer Stress classifications for the four confined aquifers in the Project Area (i.e., Aquifers 209, 216, 217 and 1250) under current conditions is presented in Table 29 and on Figure 35. It should be noted that no current Provincial aquifer stress classification is available for the confined aquifers, as the methodology is only applicable to unconfined aquifers (Forstner et al., 2018).

Table 29: Confined Aquifer Stress Classification under Current Conditions

Aquifer Number	Aquifer Stress Classification		
	Average Conditions	End of Wet Season	End of Dry Season
Aquifer 209	Very High (46%)	Low (2%)	Very High (55%)
Aquifer 216	Very High (41%)	High (21%)	Very High (50%)
Aquifer 217	Moderate (13%)	Low (3%)	Moderate (19%)
Aquifer 1250	Very High (36%)	Moderate (18%)	Very High (47%)



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (CONFINED AQUIFERS) – CURRENT CONDITIONS (END OF DRY SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	35

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Discussion of the elements of the groundwater inputs (e.g., recharge from surface water, flow from other hydrogeological units) and outputs (e.g., discharge to other hydrogeological units, private users, municipal wells,) is provided below and the numbers are presented in Table 1F, APPENDIX F.

Confined Aquifer 209, located in the south-eastern portion of the Project Area, underlies Aquifer 1252. Aquifer 209 is inferred not to be hydraulically connected to surface water sources, and recharge to the aquifer is associated with flow from other units. Under average annual conditions, outflow from Aquifer 209 to other units accounts for approximately 54% of the total outflow, while extraction from private users represents approximately 46% of the outflow. It is estimated that many of the private users in this area utilize groundwater as the source of irrigation of agricultural crops. As a result, during the wet season, when it is inferred that irrigation is no longer occurring, the stress on the aquifer is reduced significantly, with only 2% of the aquifer inflows being utilized to supply water for residential purposes. Therefore, Aquifer 209 is inferred to be Very High Stress under average annual conditions and to range from Low Stress in the wet season to Very High Stress during the dry season.

Aquifers 216, 217 and 1250 are primary sources of groundwater supply as they underlie the relatively more developed and densely populated areas of the Project Area. The outflows from the aquifers comprise municipal and private water use and flow to other units. Municipal and private users account for approximately 32% of the outflow under average annual conditions from Aquifer 216 and approximately 13% from Aquifer 217. Municipal demands on Aquifer 217 are lower than Aquifer 216, as a number of the municipal wells previously inferred to be located in Aquifer 217 were reassigned to the newly defined Aquifer 1250. As a result, under average annual conditions, the Aquifer Stress classification for Aquifer 216 is Very High whereas for Aquifer 217 it is Moderate. Agricultural activities account for a large portion of the water demand for both aquifers. A significant reduction in Aquifer Stress is inferred to occur in both aquifers in the wet season as a result of the reduced water demand and increased recharge during the wet season (no irrigation and reduced municipal demand during the wet season). Greater than 35% of the inflow to Aquifer 216 is inferred to be utilized by private users and municipal users during the dry season while approximately 19% is utilized in the wet season, resulting in Very High Stress and High Stress classifications for the aquifer during these respective seasons. Stress for Aquifer 217 is inferred to be Moderate during the dry season and Low during the wet season, when private and municipal users utilize 17% and 3% of the inflow, respectively. As discussed in Section 5.5.2, the groundwater model likely underpredicts hydraulic heads and flow through the upper portions of Aquifers 216 and 217. Therefore, the stress assessment for these two aquifers is considered conservative. However, the hydrogeological setting in the area of Aquifer 217 is complex and there is some uncertainty regarding the extents of, and connections between, subsurface units at the local scale. It is recommended that the reader refer to the report by Elanco Enterprises Inc. (Elanco; 2022) that summarizes and interprets site-specific assessments that have been conducted for the Berwick well field and neighbouring Pheasant Glen golf course.

Confined Aquifer 1250, which is located within a permeable layer of the Cowichan Head formation, is separated from the overlying Aquifer 216 and Aquifer 217 by low permeability layers within the upper portion of the Cowichan Head formation. Aquifer 1250, which was recently delineated, is inferred to be a primary source of water supply for a number of municipal water wells that were assigned to Aquifer 217 under previous aquifer mapping by BC ENV. French Creek is inferred to have incised into to the Cowichan Head sediments; however, there is a relatively high uncertainty regarding the hydraulic connection between Aquifer 1250 and French Creek because of the relatively thin nature of the aquifer in the area. Thus, the contributions from surface water recharge to Aquifer 1250 may be underestimated. During the wet season the aquifer is inferred to be classified as Moderate Stress, when 18% of inflows are utilized by municipal and private users, and Very High Stress in the dry season, when municipal and private users utilize approximately 48% of the inflows.

6.2.1.3 Bedrock Aquifers

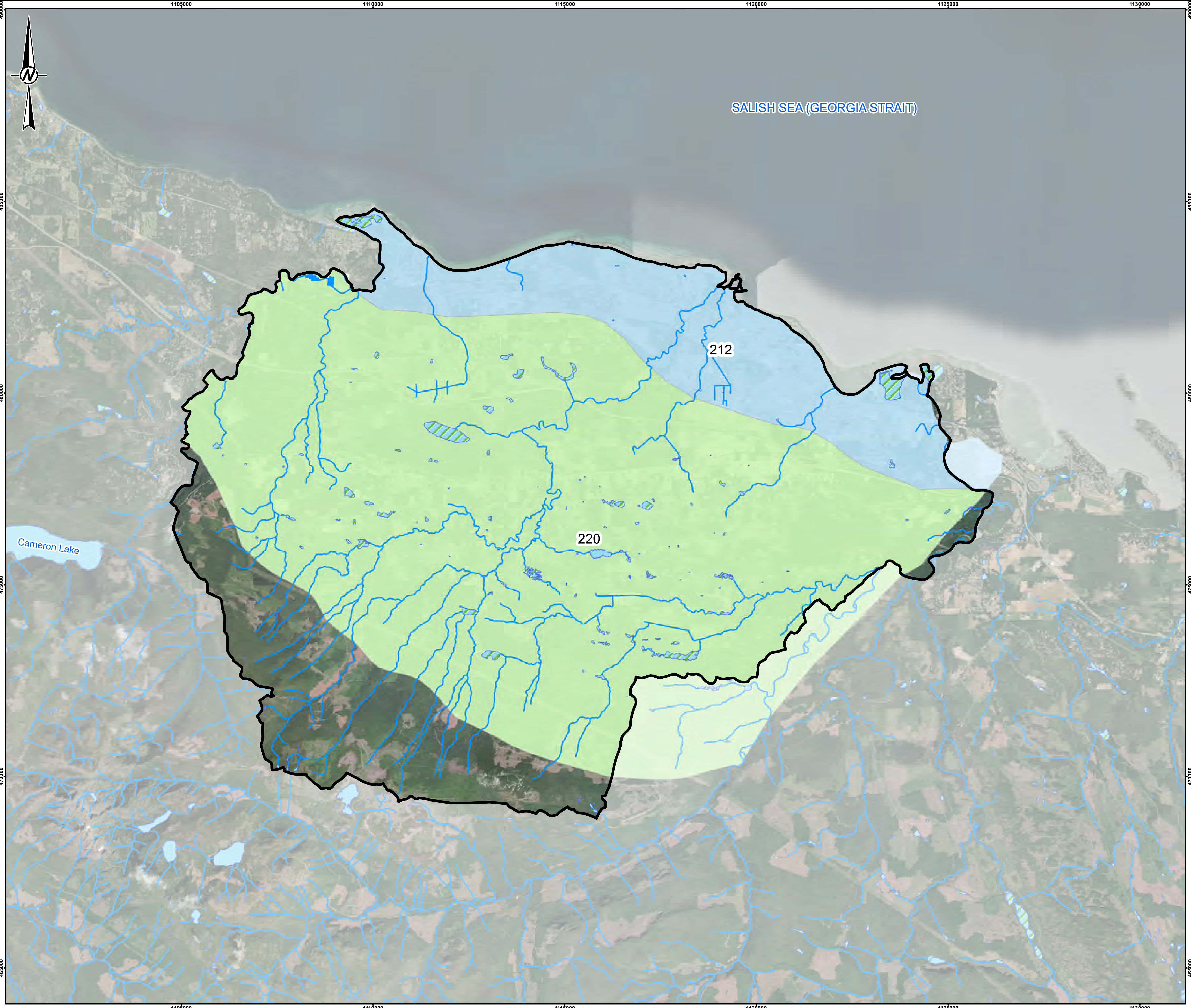
A summary of the Aquifer Stress classifications for the bedrock aquifers under current conditions is presented in Table 30 and on Figure 36.

Table 30: Bedrock Aquifer Stress Classification under Current Conditions

Aquifer Number	Aquifer Stress Classification		
	Average Conditions	End of Wet Season	End of Dry Season
Aquifer 212	Low (1%)	Low (<1%)	Low (2%)
Aquifer 220	Low (7%)	Low (1%)	Moderate (10%)[a]

Notes:

a. Aquifer Stress for Aquifer 220 at end of dry season calculated to be 10% and conservatively included in the Moderate Aquifer Stress classification (i.e., 10% to 20%)



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (BEDROCK AQUIFERS) – CURRENT CONDITIONS (END OF DRY SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-13
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	36

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Groundwater in bedrock Aquifers 212 and 220 is primarily recharged from upslope areas at higher elevations and at lower elevations from overlying overburden aquifer units through aquitards. Under current conditions, there are no municipal production wells that extract water from the bedrock aquifers. Coastal areas of Aquifer 212, where hydraulic gradient is relatively low, could potentially be subject to saltwater intrusion. Groundwater flow within bedrock aquifers is highly variable and occurs along discrete fractures and features. As a result, saltwater intrusion could potentially 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.

Although Aquifer 212 is located within the more developed region of the Project Area, groundwater from this bedrock aquifer is used less than bedrock Aquifer 220 that underlies the more rural regions in the southern portion of the Project Area. Aquifers 212 and 220 are both classified as Low Stress overall based on average conditions and in both the wet and dry season; however, the Aquifer Stress for Aquifer 220 is classified as Moderate at the end of the dry season.

The method that was utilized to calculate Aquifer Stress for the Phase 3 French Creek Water Budget project is based on total flow into and out of the aquifer over its entire extent. For the two bedrock aquifers in the Project Area, the outputs (i.e., private users) represent a relatively small portion of the groundwater inputs into the aquifers and surface water bodies, resulting in a relatively lower Aquifer Stress value and classification. Therefore, other aspects should also be considered for these bedrock aquifers that are inherently more variable and can have areas of localized flow in more productive fracture networks and other areas that have less fractures (and lower hydraulic conductivities and yields). Although the water level in VOW18, located in the eastern portion of the Aquifer 220 has been relatively stable since monitoring began in 2017, the water level in OBS Well 287, located in the central portion of Aquifer 220, showed a declining trend since 2004, demonstrating variability in different locations of the aquifer (see Section 3.2.5.3). This declining trend suggests that Aquifer 220 may exhibit relatively more stress, particularly in certain areas where there is more groundwater use. As indicated in Table 18, Aquifer 220 is also characterized by the Province as having a low productivity, which would suggest that the stress for the aquifer may be higher than the classification of Moderate at the end of the dry season. As discussed in Section 6.2.2, it is recognized that the upland areas to the south of the mapped extent of Aquifer 220 would be susceptible to changes in precipitation (groundwater recharge) and groundwater use, also resulting in a relatively higher stress for the bedrock in this area and downgradient Aquifer 220.

6.2.2 Future Scenarios

The results of the water budget analyses for the future scenarios are presented in Tables 1F, 2F, 3F and 4F located APPENDIX F. For unconsolidated aquifers, it is important to recognize the hydraulic connections to surface water bodies. Although changes from the future scenarios may not result in significant changes to the Aquifer Stress classifications for the aquifers, a decrease in groundwater levels in aquifers may result in less groundwater contribution to baseflow in surface water bodies, resulting in a corresponding increase in stress for the affected surface water bodies. Potential impacts to surface water bodies are discussed in Section 7.2.3.

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 Future Base Case

In the Future Base Case scenario, the calibrated model was updated with the future pumping schedule described in Section 6.1.2 to simulate long-term groundwater conditions and to provide a basis to assess changes to groundwater levels and flow separately for each of the four future scenarios.

In the long-term water plan, pumping will continue at the current rates with the exception of the French Creek Water System. To reflect future conditions, three of the wells that are not currently active (FC Well 1, FC Well 5, FC Well 6), were reactivated for the future scenarios and the future pumping rates that are anticipated by the RDN were applied. The RDN French Creek wells are all inferred to be completed in Aquifer 1250. The increased pumping and operation of the additional three pumping wells increased the extraction of water from Aquifer 1250 from 36% to 44% of the aquifer inflow. Increased pumping is inferred to have a localized impact on overlying Aquifer 217 in the vicinity of the well field and lower the groundwater levels by up to 4 m but does not change the Aquifer Stress values for Aquifer 217.

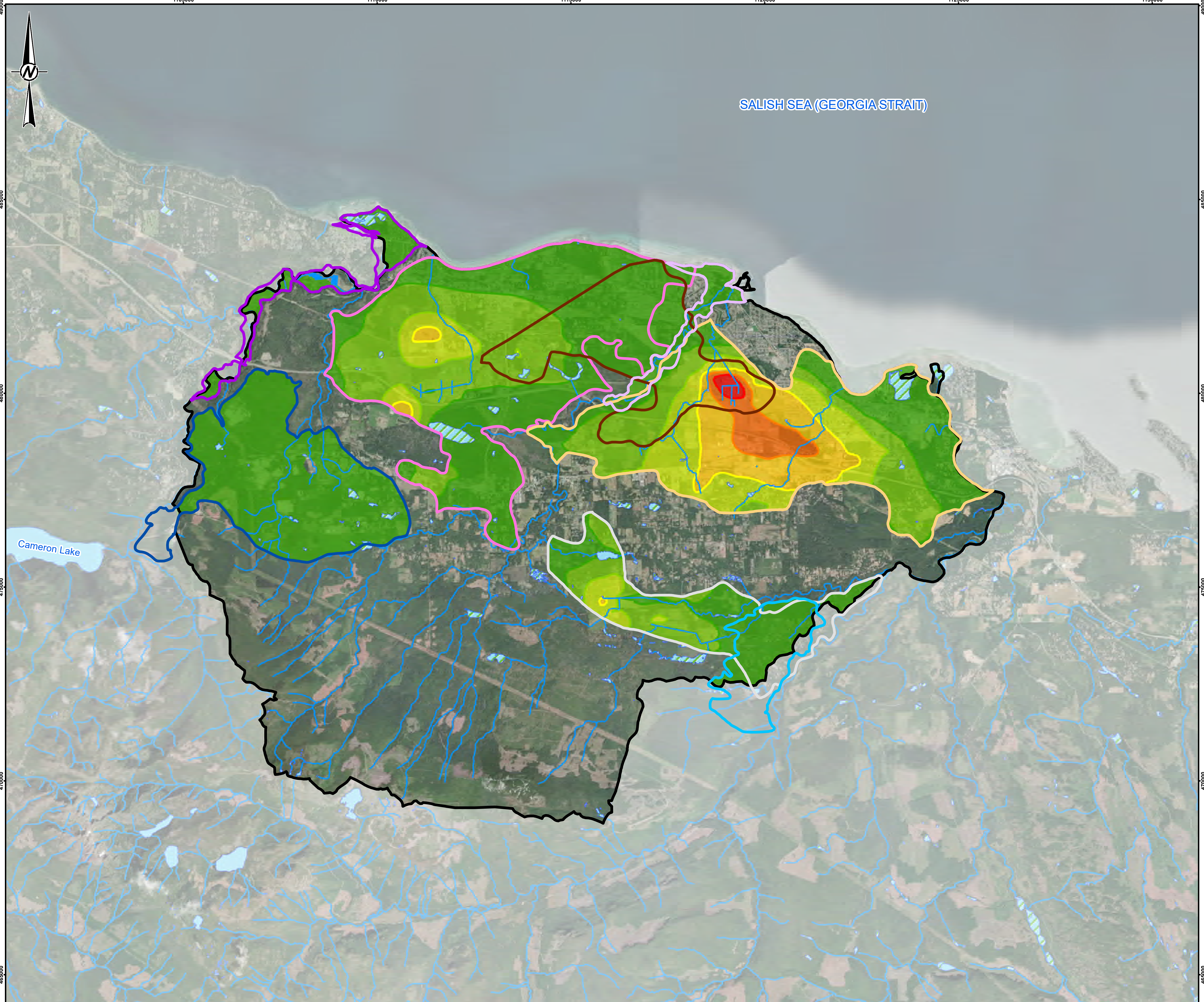
The results of the Aquifer Stress classifications for Aquifer 1250 for the Future Base Case are presented in Table 31 and show that the Aquifer Stress changes from Moderate to High during the wet season based on the anticipated future pumping rates for the French Creek Water System.

Table 31: Aquifer Stress Analysis for Future Base Case – Aquifer 1250

Aquifer Number	Aquifer Stress Classification			
	Current Conditions		Future Base Case	
	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season
Aquifer 1250	Moderate (18%)	Very High (47%)	High (26%)	Very High (54%)

6.2.2.2 Scenario 1 – Potential Climate Change

The water balance results for the potential climate change scenario are presented in Tables 3F and 4F in APPENDIX F. The predicted decline in groundwater levels in the dry season as result of climate change for overburden and bedrock aquifers are presented on Figure 37 and Figure 38, respectively.



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

OVERBURDEN AQUIFER

AQUIFER NUMBER

- AQ 1248
- AQ 1250
- AQ 1252
- AQ 209
- AQ 216
- AQ 217
- AQ 663
- AQ 664

CHANGE N WATER LEVEL

- 0 to -2 m
- -2 to -4 m
- -4 to -6 m
- -6 to -8 m
- -8 to -10 m
- >-10 m

CHANGE IN WATER LEVEL (CONTOURS)

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

0 2,000 4,000

1:100,000 METRES

NOTE(S)

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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

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

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	37

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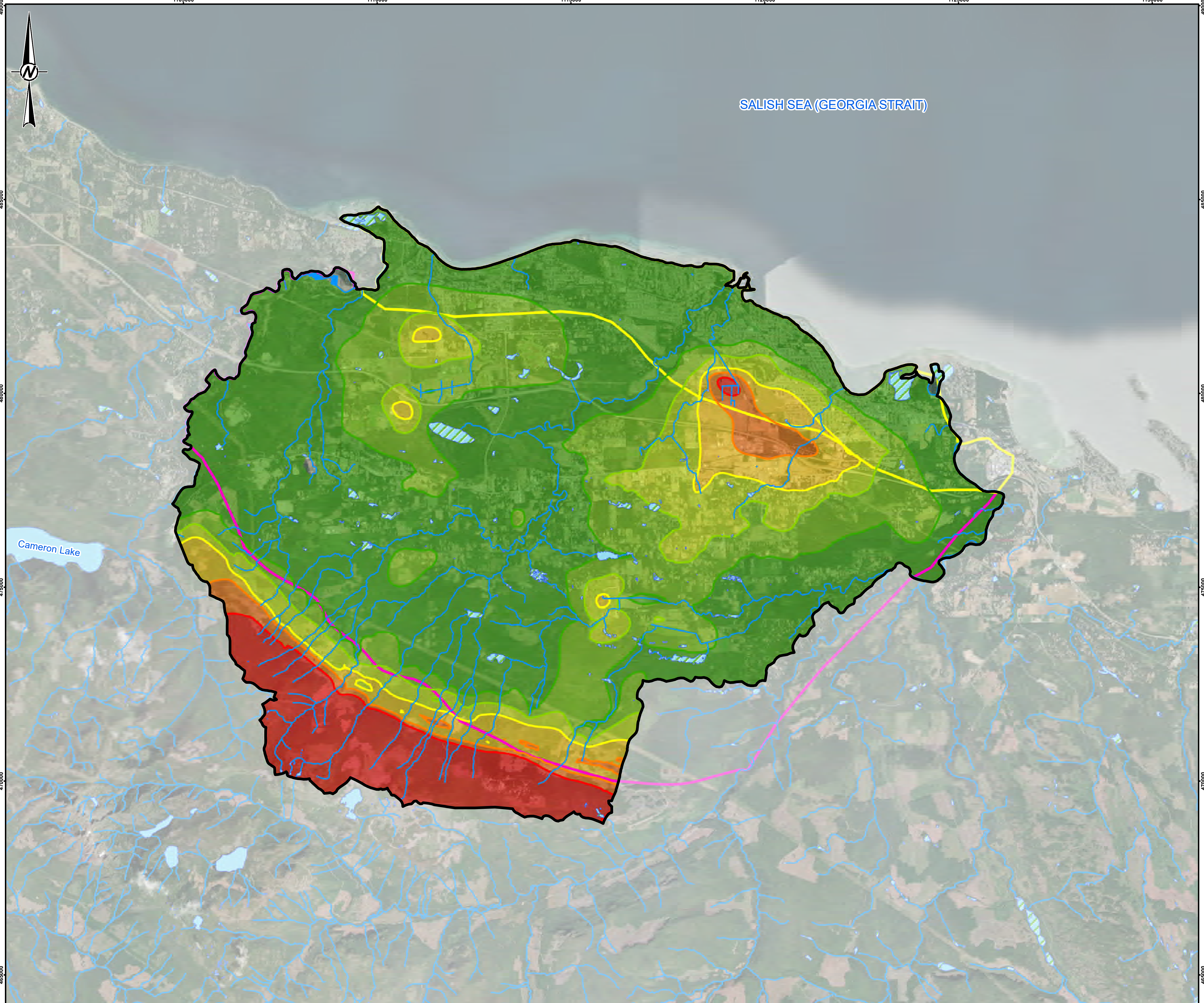

LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

BEDROCK AQUIFER

AQUIFER NUMBER

- AQ 212
- AQ 220

CHANGE IN WATER LEVEL (CONTOURS)

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

CHANGE IN WATER LEVEL

- 0 to -2 m
- -2 to -4 m
- -4 to -6 m
- -6 to -8 m
- -8 to -10 m
- > -10 m

0 2,000 4,000

1:100,000 METRES

NOTE(S)

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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

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

CONSULTANT

YYYY-MM-DD	2023-07-11
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PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	38

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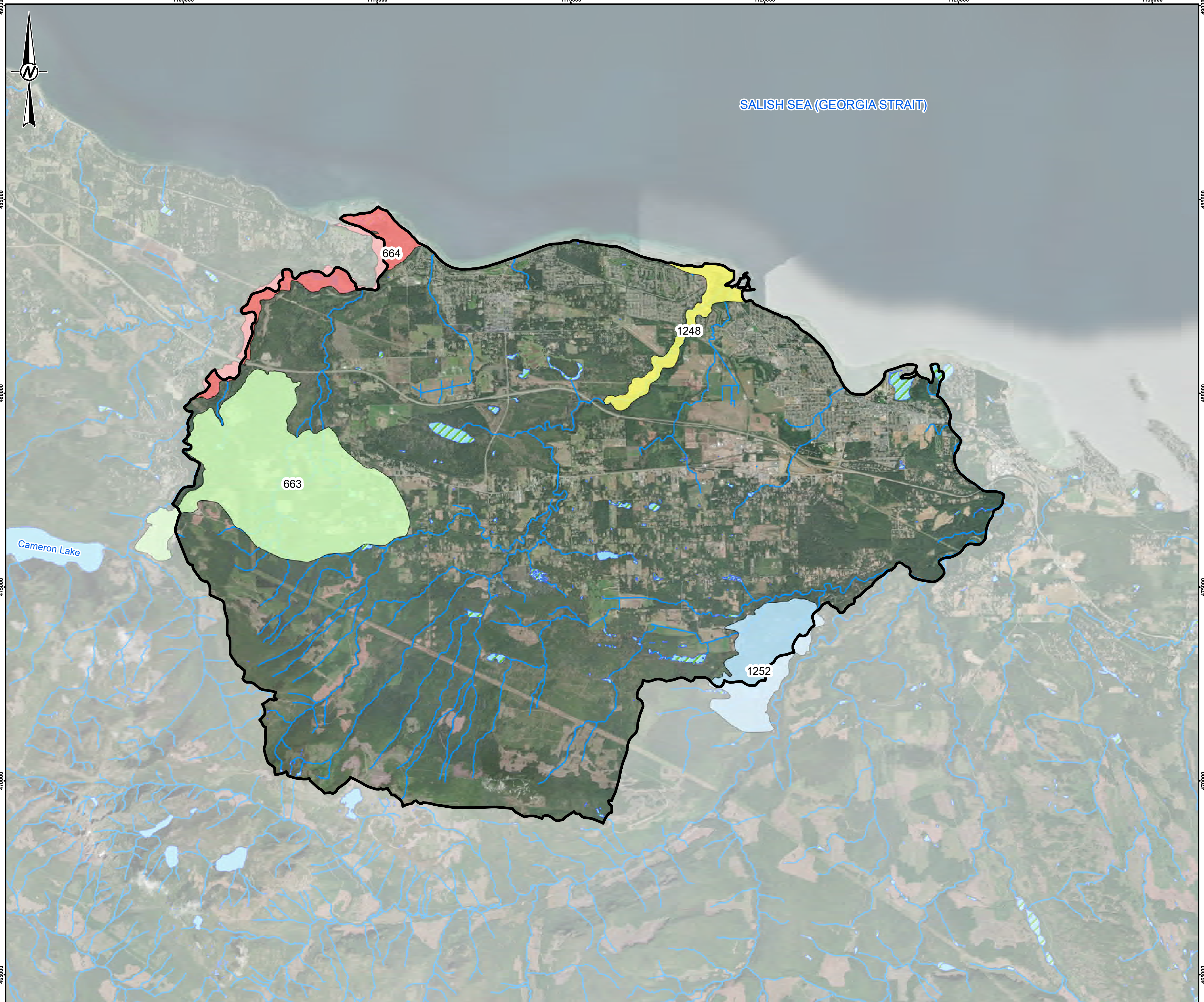
A comparison of the Aquifer Stress classifications between the Future Base Case and potential climate change conditions is presented in Table 32 below and on Figure 39 to Figure 41.

Table 32: Aquifer Stress Analysis for Scenario 1 – Potential Climate Change

Aquifer Number	Aquifer Stress Classification			
	Future Base Case		Scenario 1 – Potential Climate Change	
	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season
Unconfined Aquifers				
Aquifer 663	Moderate (14%)	Moderate (14%)	Moderate (13%)	Moderate (13%)
Aquifer 664	Very High (43%)	Very High (47%)	Very High (43%)	Very High (47%)
Aquifer 1248	High (21%)	High (22%)	High (22%)	High (22%)
Aquifer 1252	Low (2%)	Low (2%)	Low (2%)	Low (2%)
Confined Aquifers				
Aquifer 209	Low (2%)	Very High (55%)	Low (3%)	Very High (66%)
Aquifer 216	High (21%)	Very High (50%)	High (22%)	Very High (58%)
Aquifer 217	Low (3%)	Moderate (18%)	Low (3%)	High (24%)
Aquifer 1250	High (26%)	Very High (54%)	High (27%)	Very High (61%)
Bedrock Aquifers				
Aquifer 212	Low (<1%)	Low (2%)	Low (<1%)	Low (2%)
Aquifer 220	Low (1%)	Moderate (10%)[a]	Low (1%)	Moderate (14%)

Notes:

a. Aquifer Stress for Aquifer 220 at end of dry season calculated to be 10% and conservatively included in the Moderate Aquifer Stress classification (i.e., 10% to 20%)



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (UNCONFINED AQUIFERS) SCENARIO 1 POTENTIAL CLIMATE CHANGE (END OF DRY SEASON)

CONSULTANT

wsp

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	39

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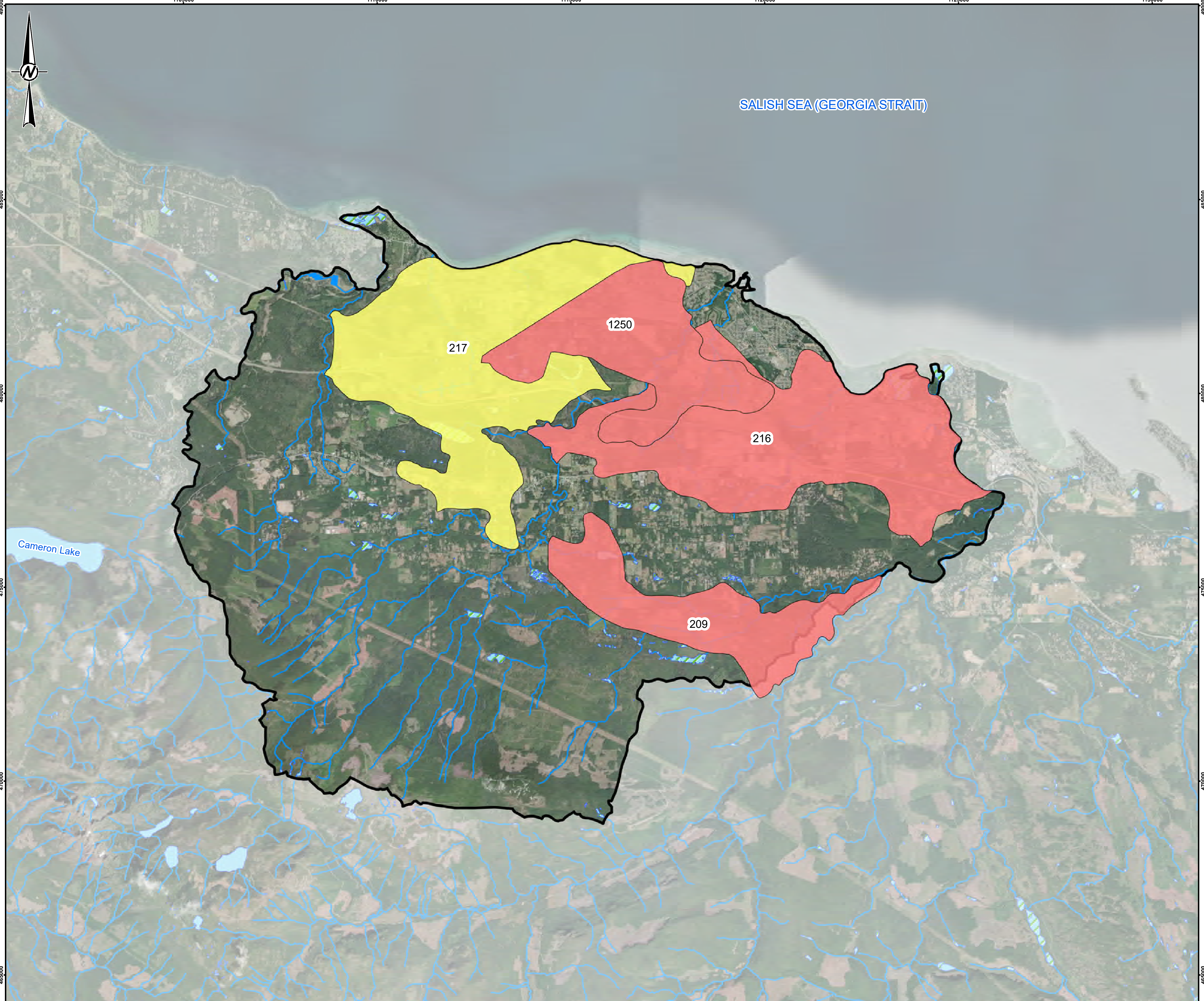

LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (CONFINED AQUIFERS) SCENARIO 1 POTENTIAL CLIMATE CHANGE (END OF DRY SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-10
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	40

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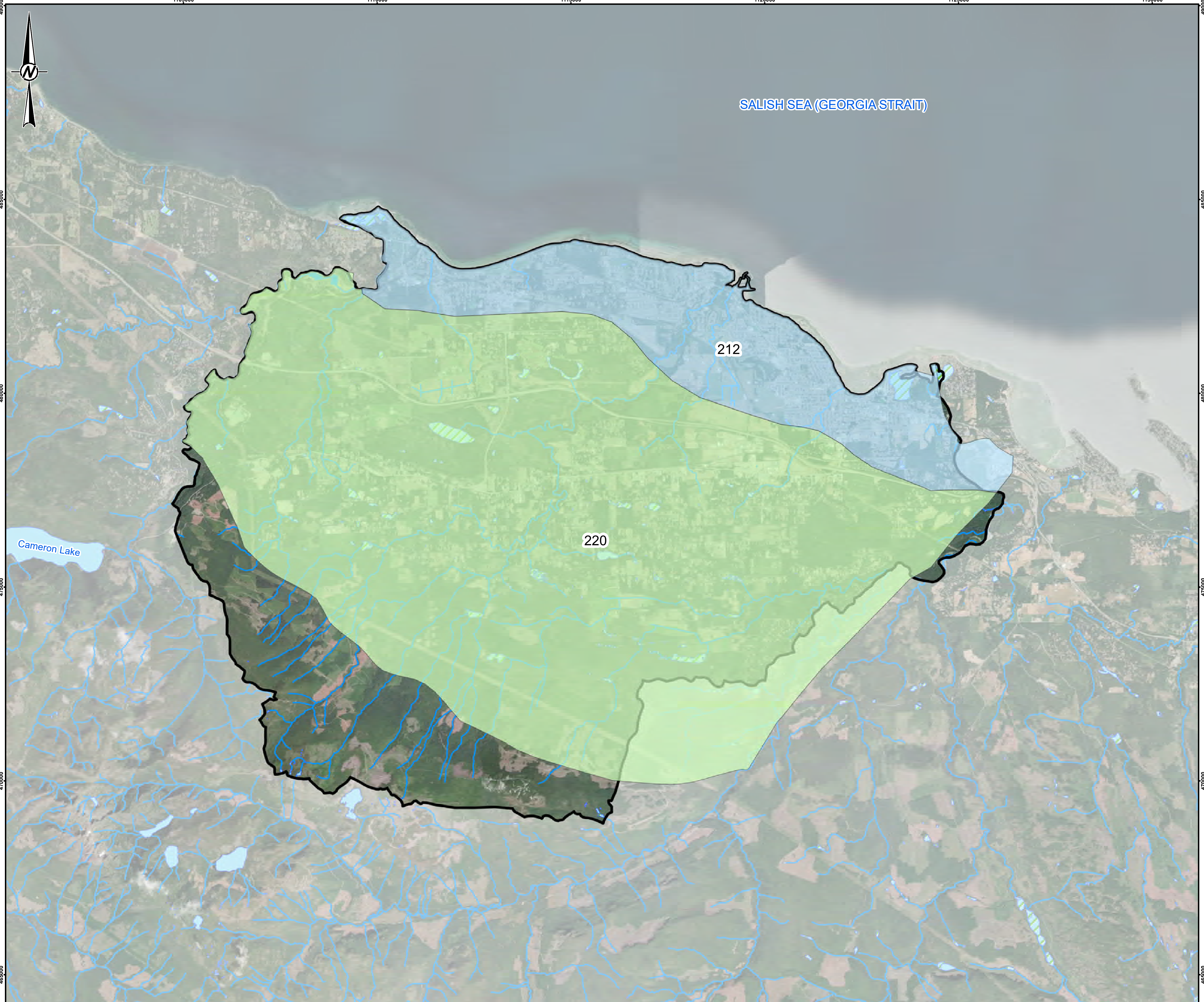
25mm



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (BEDROCK AQUIFERS) SCENARIO 1 POTENTIAL CLIMATE CHANGE (END OF DRY SEASON)

CONSULTANT

wsp

YYYY-MM-DD	2023-07-10
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	41

25mm

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The water balances and Aquifer Stress classifications for the unconfined aquifers are predicted to be minimally affected by the potential impacts of climate change. In terms of water balance, the reduction in recharge from precipitation for these aquifers is balanced by an increase in groundwater coming from other units or surface water bodies. It is important to note that, as discussed in Section 7.2.3, the baseflow to surface water bodies is predicted to decline under the potential climate change scenario, and the results of the Aquifer Stress analysis should not be considered in isolation. A limited number of large agricultural users utilize the unconfined aquifers for water supply and, therefore, the 50% increase in water demand for agricultural and rural properties to maintain adequate soil moisture during the dry season for crops in a warming climate has limited influence on the overall water demands of the unconfined aquifers, compared to Future Base Case conditions. Some of the unconfined aquifers (664, 1248 and 1252) are also limited in extent and not fully represented in the groundwater model.

As presented in Table 3F (APPENDIX F), the fluid volume in unconfined Aquifers 663, 664, 1248 and 1252 are predicted to remain the same or decrease slightly by up to 0.2%. Water levels in Aquifers 663 and 1252 are expected to decline slightly (less than 2 m) in some areas as a result of the decreased recharge and longer dry season, as presented on Figure 37. The decline in water levels in Aquifers 664 and 1252 is also expected to reduce the groundwater baseflow in some of the creeks connected with those aquifers, such as Morison Creek and Whisky Creek (see Section 7.2.3). The decreased recharge resulting from climate change does not significantly affect the volumes and water levels in Aquifers 664 and 1248, as these two aquifers are in connection with permanent watercourses (French Creek and Little Qualicum River) that provide some recharge to the aquifers and control water levels; however, it is noted that this process results in greater stress to these permanent surface water courses.

The potential climate change scenario has the greatest impact on the confined unconsolidated aquifers, as the majority of private users in the Project Area extract groundwater for residential and agricultural activities from Aquifers 209, 216, 217 and 1250. Under the conditions of the potential climate change scenario, Aquifer 209 is predicted to continue to be classified as Very High Stress in the dry season, with the stress increasing by 11% from Future Base Case conditions. The Aquifer Stress for Aquifers 216 and 1250 also remains in the Very High classification at the end of the dry season, with values increasing by 8% and 7%, respectively. During the dry season, the Aquifer Stress for Aquifer 217 is predicted to increase by 6% from the Future Base Case, resulting in the classification changing from Moderate to High in the climate change scenario. Compared to Future Base Case conditions, the aquifer fluid volumes at the end of the dry season are predicted to decrease by 3.8% and 2.1% in Aquifers 216 and 217, respectively, compared to a decrease of 0.1% for Aquifer 1250 and no change for Aquifer 209.

Water levels in confined Aquifer 216 are expected to be affected the most amongst the overburden aquifers in the Project Area. The combined effects of reduced recharge and increased water demand from large agricultural properties that withdraw water from Aquifer 216 are predicted to result in water level declines of more than 10 m in the central portion of the aquifer at the end of the dry season. By the end of the dry season, water levels in confined Aquifers 217 and 209 are also predicted to decline by up to 8 m in localized areas in the vicinity of agricultural properties. Water levels in Aquifer 1250 are predicted to decline by up to 4 m under the future climate conditions.

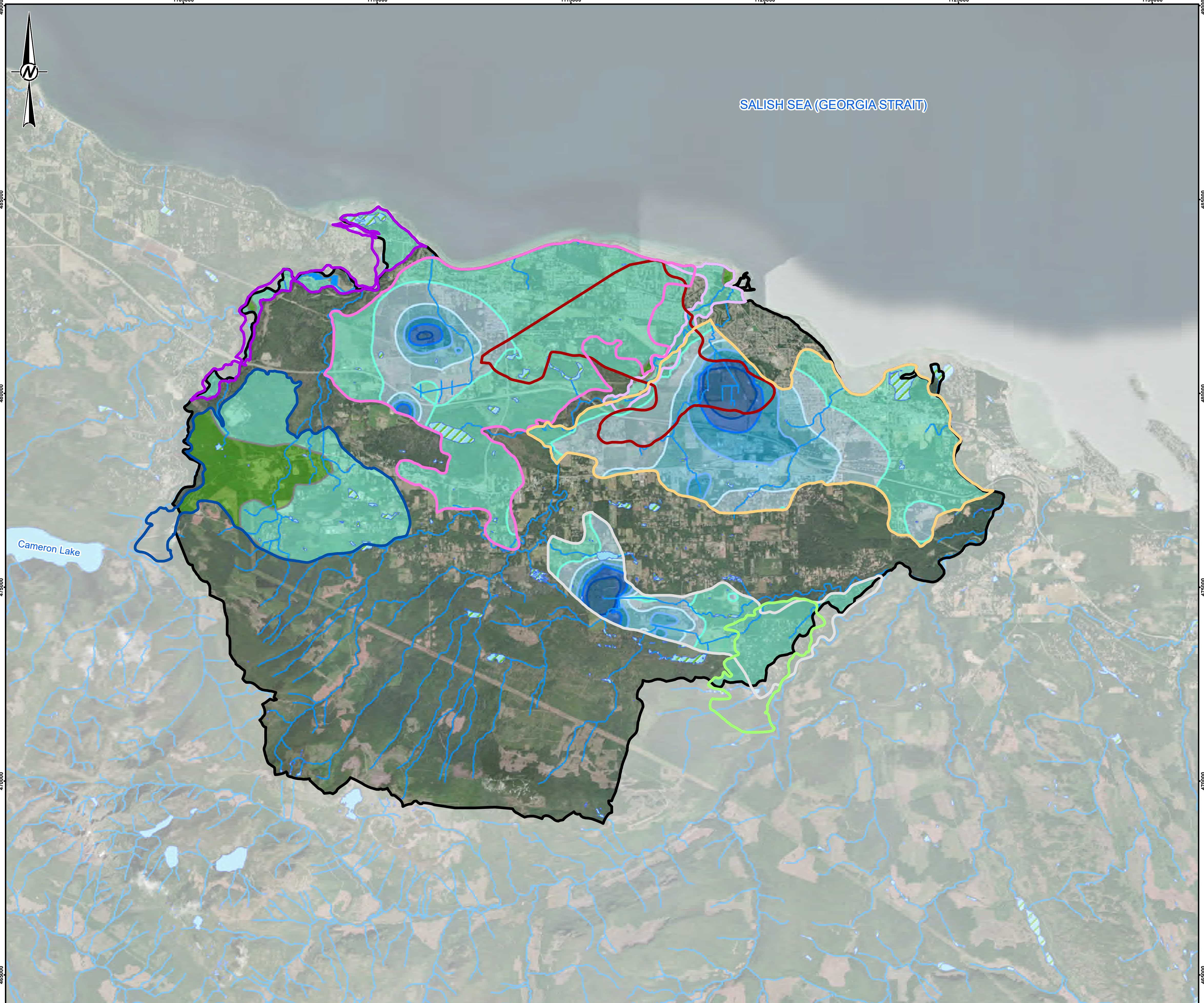
For the bedrock aquifers, the Aquifer Stress is anticipated to remain the same for bedrock Aquifer 212 under Scenario 1 and increase by 4% in the dry season for bedrock Aquifer 220, mostly because of reduced infiltration, especially at higher elevations. Relative to Future Base Case conditions, the aquifer fluid volumes for Aquifers 220 and 212 decrease by 0.4% and 0.1%, respectively, by the end of the dry season.

Aquifer 212 receives recharge from upland areas including adjacent bedrock Aquifer 220 and overlying unconsolidated Aquifers 216, 217 and 1250. Water levels in the aquifer are predicted to decline on average approximately 2 m during both the dry and wet seasons, and up to 10 m in areas where increased water demand in the dry season is predicted from large agricultural properties that withdraw water from overlying overburden aquifers.

Aquifer 220, located in the upper portion of the watersheds, receives recharge primarily from infiltration through overlaying till which is recharged by precipitation. 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 generally, with groundwater levels declining by up to 10 m in the upper portion of Aquifer 220. The greatest groundwater level declines extend south from the mapped extents of Aquifer 220 into the upgradient areas, reflecting not only less recharge to the bedrock aquifer but also likely increased stress to the tributaries in the headwaters of the French Creek watershed. It is also noted that the stress for Aquifer 220 (and Aquifer 212) will not be uniform. As discussed in Section 6.2.1.3, the hydraulic conductivity of the bedrock is variable. Therefore, the stress in the bedrock aquifers is inferred to be higher in localized areas where the productivity of the bedrock is lower; detailed assessment would be required to identify these localized areas of higher Aquifer Stress.

6.2.2.3 Scenario 2 – Future Build-Out

The water balance results for the future build-out scenario are presented in Table 3F and 4F in APPENDIX F. Changes in groundwater levels in the dry season for overburden and bedrock aquifers as a result of the changes due to future development are presented on Figure 42 and Figure 43, respectively.



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

OVERBURDEN AQUIFER

AQUIFER NUMBER

- AQ 1248
- AQ 1250
- AQ 1252
- AQ 209
- AQ 216
- AQ 217
- AQ 663
- AQ 664

CHANGE IN WATER LEVEL (CONTOURS)

- +10 m
- +8 m
- +6 m
- +4 m
- +2 m
- 0 m

CHANGE IN WATER LEVEL

- > +10 m
- +8 to +10 m
- +6 to +8 m
- +4 to +6 m
- +2 to +4 m
- 0 to +2 m
- - 2 to 0 m

0 2,000 4,000

1:100,000 METRES

NOTE(S)

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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

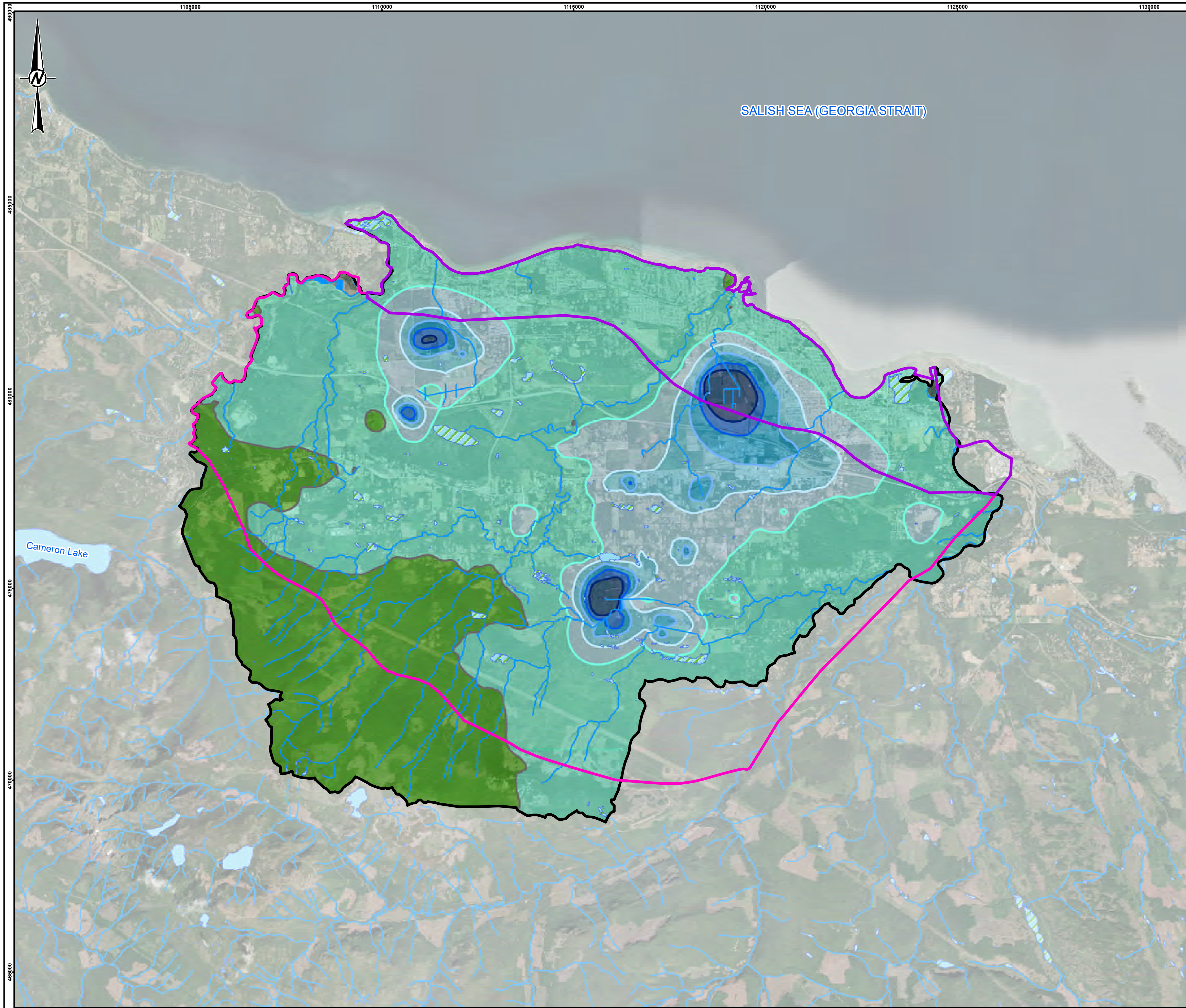
PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
SCENARIO 2 FUTURE BUILD-OUT: PREDICTED CHANGE IN WATER LEVEL (END OF DRY SEASON) IN OVERBURDEN

CONSULTANT

YYYY-MM-DD	2023-07-10
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	42



LEGEND

PROJECT AREA
WETLANDS
WATERBODIES
WATERCOURSES

BEDROCK AQUIFER

AQUIFER NUMBER

AQ 212
AQ 220

CHANGE IN WATER LEVEL (CONTOURS)

+10 m
+8 m
+6 m
+4 m
+2 m
0

CHANGE IN WATER LEVEL

> +10 m
+8 to +10 m
+6 to +8 m
+4 to +6 m
+2 to +4 m
0 to +2 m
-2 to 0 m

0 2,000 4,000
1:100,000 METRES

NOTE(S)

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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
SCENARIO 2 FUTURE BUILD-OUT: PREDICTED CHANGE IN WATER LEVEL (END OF DRY SEASON) IN BEDROCK AQUIFERS

CONSULTANT
wsp

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	43

A comparison of the Aquifer Stress classifications between Future Base Case conditions and future build-out conditions is presented in Table 33 and the Aquifer Stress classifications for the overburden and bedrock aquifers under future build-out conditions are shown on Figure 44 to Figure 46.

Table 33: Aquifer Stress Analysis for Scenario 2 – Future Build-out

Aquifer Number	Aquifer Stress Classification			
	Future Base Case		Scenario 2 – Future Build-out	
	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season
Unconfined Aquifers				
Aquifer 663	Moderate (14%)	Moderate (14%)	Moderate (14%)	Moderate (14%)
Aquifer 664	Very High (43%)	Very High (47%)	Very High (43%)	Very High (47%)
Aquifer 1248	High (21%)	High (22%)	High (21%)	High (22%)
Aquifer 1252	Low (2%)	Low (2%)	Low (3%)	Low (2%)
Confined Aquifers				
Aquifer 209	Low (2%)	Very High (55%)	Low (3%)	Very High (33%)
Aquifer 216	High (21%)	Very High (50%)	High (21%)	Very High (38%)
Aquifer 217	Low (3%)	Moderate (18%)	Low (4%)	Moderate (11%)
Aquifer 1250	High (26%)	Very High (54%)	High (25%)	Very High (53%)
Bedrock Aquifers				
Aquifer 212	Low (<1%)	Low (2%)	Low (1%)	Low (3%)
Aquifer 220	Low (1%)	Moderate (10%)[a]	Low (1%)	Low (4%)

Notes:

a. Aquifer Stress for Aquifer 220 at end of dry season calculated to be 10% and conservatively included in the Moderate Aquifer Stress classification (i.e., 10% to 20%)

LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (UNCONFINED AQUIFERS)
SCENARIO 2 FUTURE BUILD-OUT (END OF DRY SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	44

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25mm
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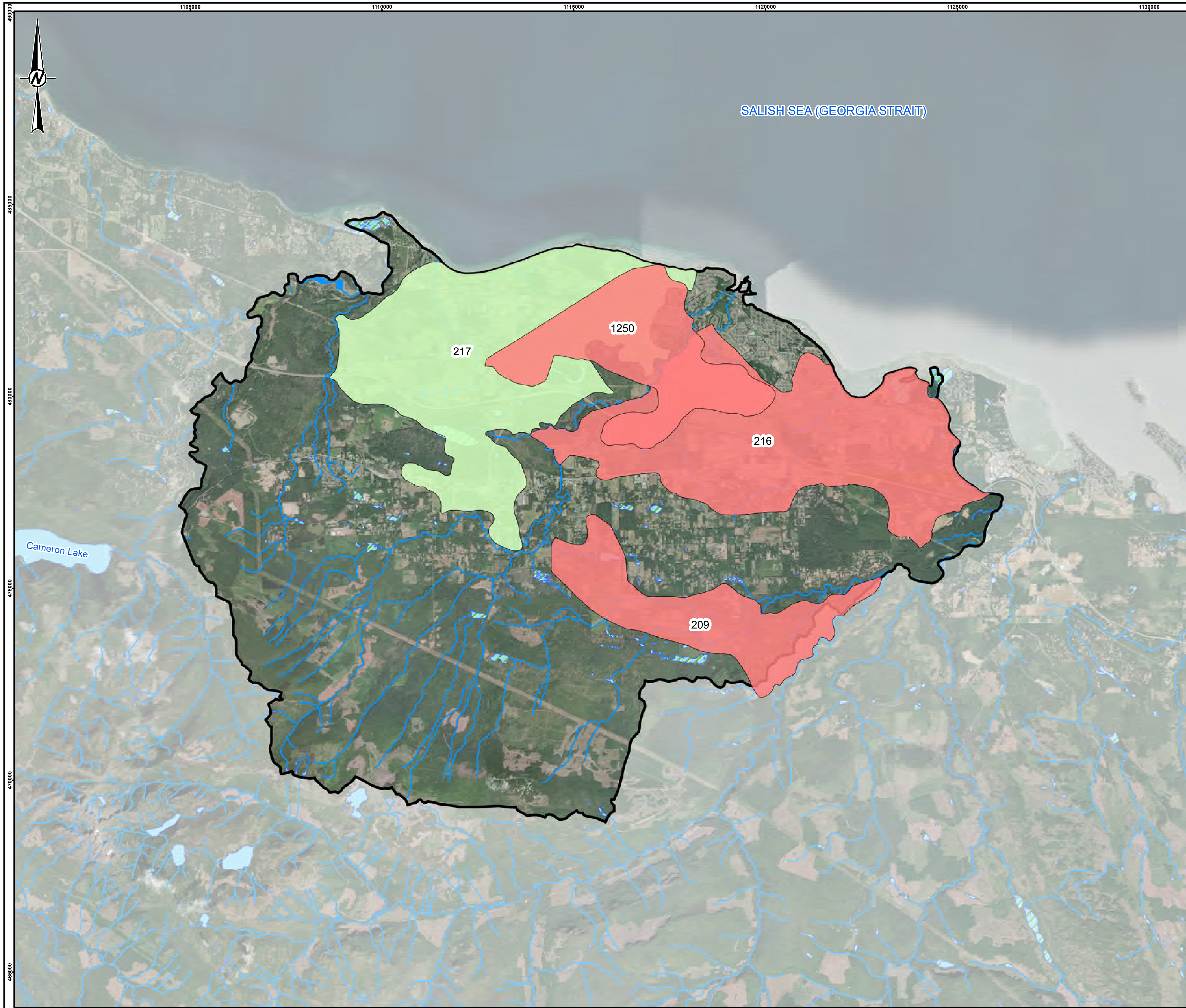

LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

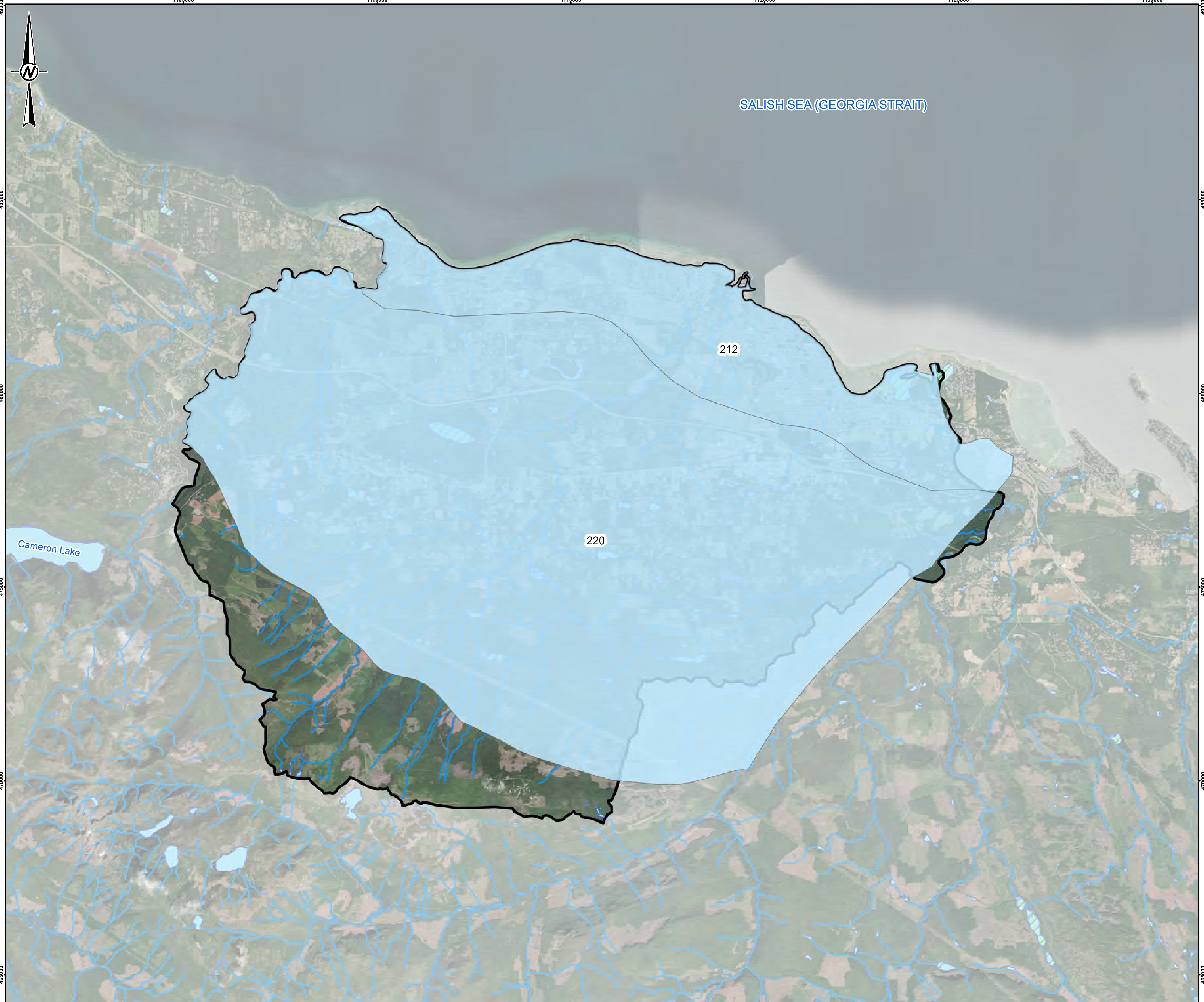
PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (CONFINED AQUIFERS)
SCENARIO 2 FUTURE BUILD-OUT (END OF DRY SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	45



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (BEDROCK AQUIFERS)
SCENARIO 2 FUTURE BUILD-OUT (END OF DRY SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	46

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25mm

For Scenario 2, the development of new residential properties and the conversion of agricultural lots into residential use have the greatest influence on the confined unconsolidated aquifers, as the majority of the lots to be redeveloped or converted are located in the areas overlying Aquifers 209, 216, 217 and 1250.

Although the Aquifer Stress classifications for confined unconsolidated aquifers don't change, the values for Aquifers 209, 216 and 217 are predicted to decrease between 7% and 22% from Future Base Case conditions at the end of the dry season, mainly because of reduction in water demand in these areas. Stress for Aquifer 1250 is predicted to slightly decrease by 1%.

Aquifer Stress for bedrock Aquifer 212 is anticipated to increase by 1% in the dry season because of new lots being developed in the areas overlying this aquifer that are expected to withdraw water from Aquifer 212. Aquifer Stress for Aquifer 220 is predicted to decrease by 6% in the dry season under Scenario 2 mainly due to a reduction in water use for agricultural purposes following redevelopment of some of the lots in this area. As a result, the Aquifer Stress classification for Aquifer 220 decreases from Moderate to Low; however, as discussed in the preceding sections, other factors such as the variability and low productivity of this bedrock aquifer suggest that the stress for Aquifer 220 may be higher, particularly in lower yielding areas of the aquifer.

The reduction in water demand from large-scale irrigation and livestock agricultural activities to residential use is predicted to have a positive influence on groundwater levels in certain portions of the Project Area. Water levels in the confined Quadra Sand aquifers 216 and 217 and in Aquifer 209 are anticipated to increase up to 10 m compared to the Future Base Case scenario in areas where large agricultural properties that are currently estimated to utilize up to 300 m^3/d of groundwater are converted to residential properties that will utilize 0.567 m^3/d/residential unit (Figure 42). The aquifer fluid volumes in Aquifers 216 and 217 are predicted to increase by 1.4% and 1.0% at the end of the dry season, respectively, relative to the Future Base Case conditions, whereas there is no change for Aquifers 209 or 1250 (Table 3F, APPENDIX F). A decline in water levels between 0 to 2 m is predicted to occur within unconfined Aquifer 663 because future development of additional residential properties will withdraw water from this aquifer; however, the aquifer fluid volume in this aquifer will not change.

Following the development of new residential properties under Scenario 2, more infiltration from overburden unconsolidated aquifers to the underlying bedrock is expected following increased water levels. As a result, water levels in the bedrock aquifers underlying Aquifers 216, 217 and 209 are also predicted to generally increase; however, in the upper portions of the watersheds where land that is currently vacant is proposed to be developed as new residential properties, decreases in water levels between 0 and 2 m are predicted. These localized water level decreases do not result in changes to the overall aquifer fluid volumes for bedrock Aquifers 212 and 220.

6.2.2.4 Scenario 3 – Changes in Land Cover

The water balance results for the potential changes in landcover are presented in Tables 3F and 4F in APPENDIX F. Changes in water levels in the dry season for overburden and bedrock aquifers as a result of the changes in landcover are presented on Figure 47 and Figure 48, respectively.

LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

OVERBURDEN AQUIFER

AQUIFER NUMBER

- AQ 1248
- AQ 1250
- AQ 1252
- AQ 209
- AQ 216
- AQ 217
- AQ 663
- AQ 664

CHANGE IN WATER LEVEL (CONTOURS)

- -2 m
- -4 m
- -6 m
- -8 m

CHANGE IN WATER LEVEL

- 0 to -2 m
- -2 to -4 m
- -4 to -6 m
- -6 to -8 m
- -8 to -10 m

0 2,000 4,000

1:100,000 METRES

NOTE(S)

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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

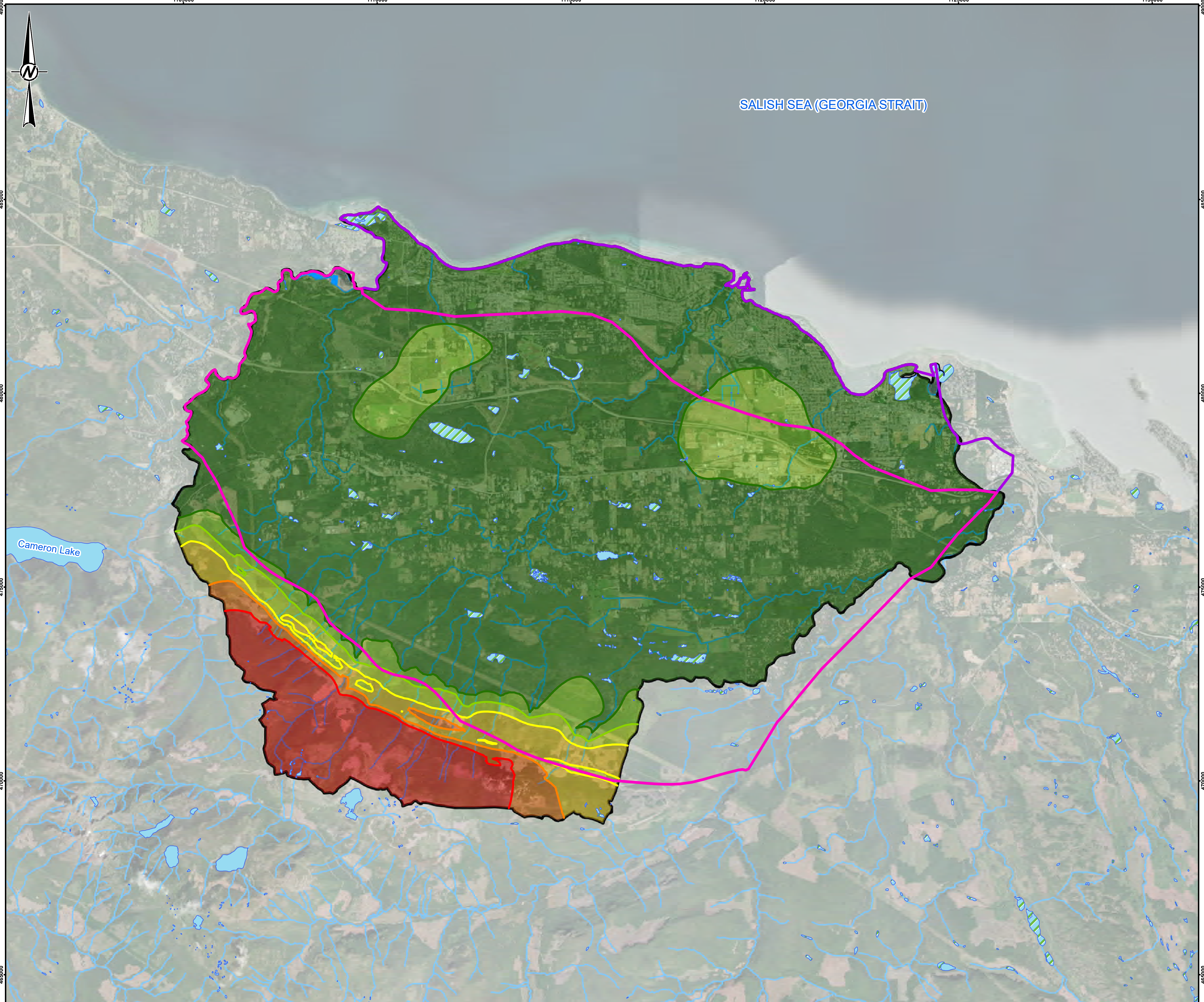
PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
SCENARIO 3 CHANGE IN LANDCOVER: PREDICTED CHANGE IN WATER LEVEL (END OF DRY SEASON) IN OVERBURDEN

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	47



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

BEDROCK AQUIFER

AQUIFER NUMBER

- AQ 212
- AQ 220

CHANGE IN WATER LEVEL (CONTOURS)

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

CHANGE IN WATER LEVEL

- 0 to -2 m
- -2 to -4 m
- -4 to -6 m
- -6 to -8 m
- -8 to -10 m
- > 10 m

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
SCENARIO 3 CHANGE IN LANDCOVER: PREDICTED CHANGE IN WATER LEVEL (END OF DRY SEASON) IN BEDROCK AQUIFERS

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	48

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

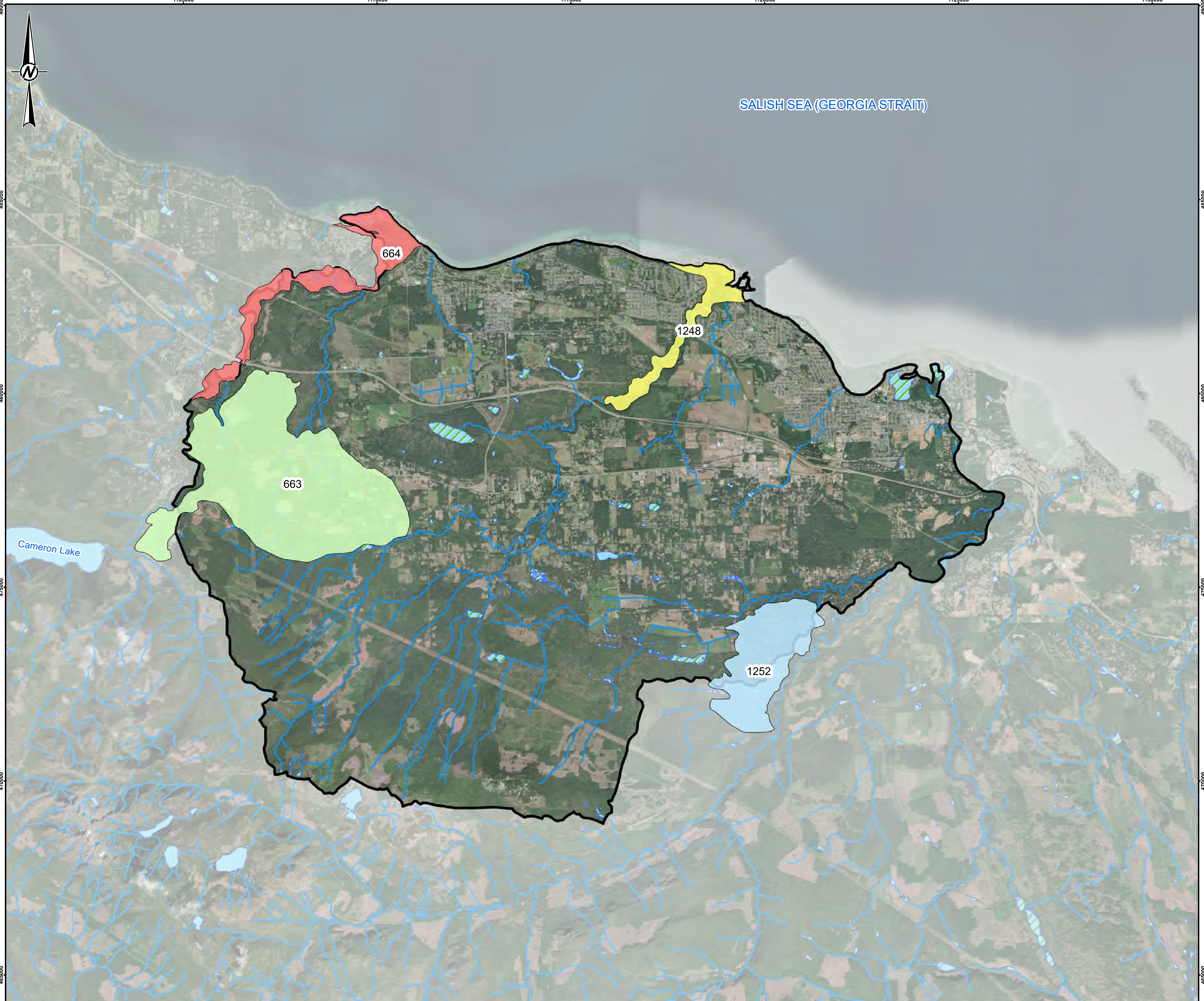
A comparison of the Aquifer Stress classifications between Future Base Case conditions and changes in landcover as a result of future development is presented in Table 34 and the Aquifer Stress classifications for the overburden and bedrock aquifers under Scenario 3 are shown on Figure 49 to Figure 51.

Table 34: Aquifer Stress Analysis for Scenario 3 – Changes in Land Cover

Aquifer Number	Aquifer Stress Classification			
	Future Base Case		Scenario 3 – Changes in Land Cover	
	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season
Unconfined Aquifers				
Aquifer 663	Moderate (14%)	Moderate (14%)	Moderate (14%)	Moderate (13%)
Aquifer 664	Very High (43%)	Very High (47%)	Very High (43%)	Very High (47%)
Aquifer 1248	High (21%)	High (22%)	High (22%)	High (22%)
Aquifer 1252	Low (2%)	Low (2%)	Low (2%)	Low (2%)
Confined Aquifers				
Aquifer 209	Low (2%)	Very High (55%)	Low (3%)	Very High (56%)
Aquifer 216	High (21%)	Very High (50%)	High (22%)	Very High (52%)
Aquifer 217	Low (3%)	Moderate (18%)	Low (3%)	Moderate (19%)
Aquifer 1250	High (26%)	Very High (54%)	High (27%)	Very High (55%)
Bedrock Aquifers				
Aquifer 212	Low (<1%)	Low (2%)	Low (<1%)	Low (2%)
Aquifer 220	Low (1%)	Moderate (10%)[a]	Low (1%)	Moderate (10%)[a]

Notes:

a. Aquifer Stress for Aquifer 220 at end of dry season calculated to be 10% and conservatively included in the Moderate Aquifer Stress classification (i.e., 10% to 20%)



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

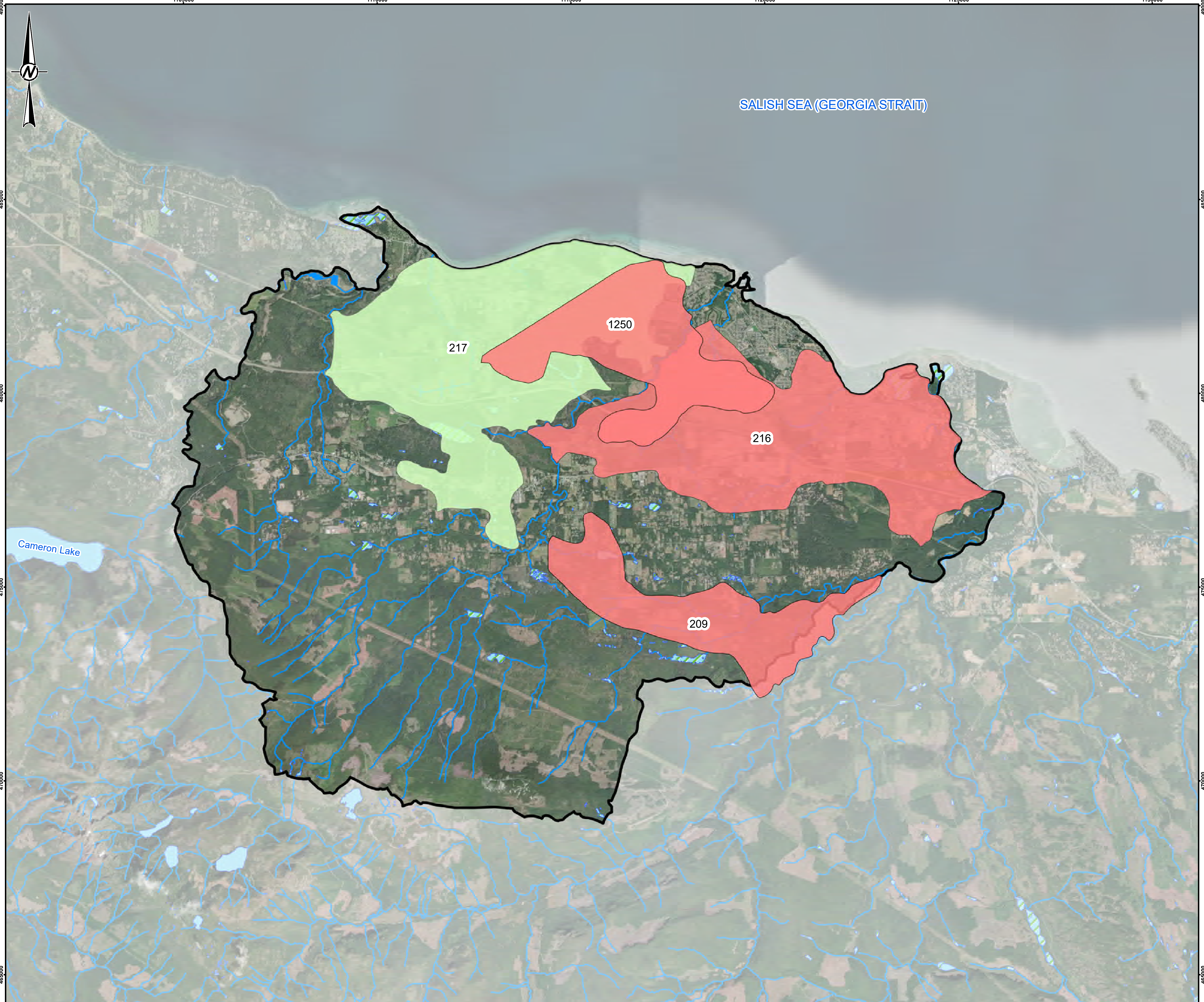
CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (UNCONFINED AQUIFERS) SCENARIO 3 LANDCOVER CHANGE (END OF DRY SEASON)

CONSULTANT		
WSP	YYYY-MM-DD	2023-07-11
	DESIGNED	RKS
	PREPARED	RKS
	REVIEWED	AP
	APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	49



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (CONFINED AQUIFERS)
SCENARIO 3 LANDCOVER CHANGE (END OF DRY SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	50

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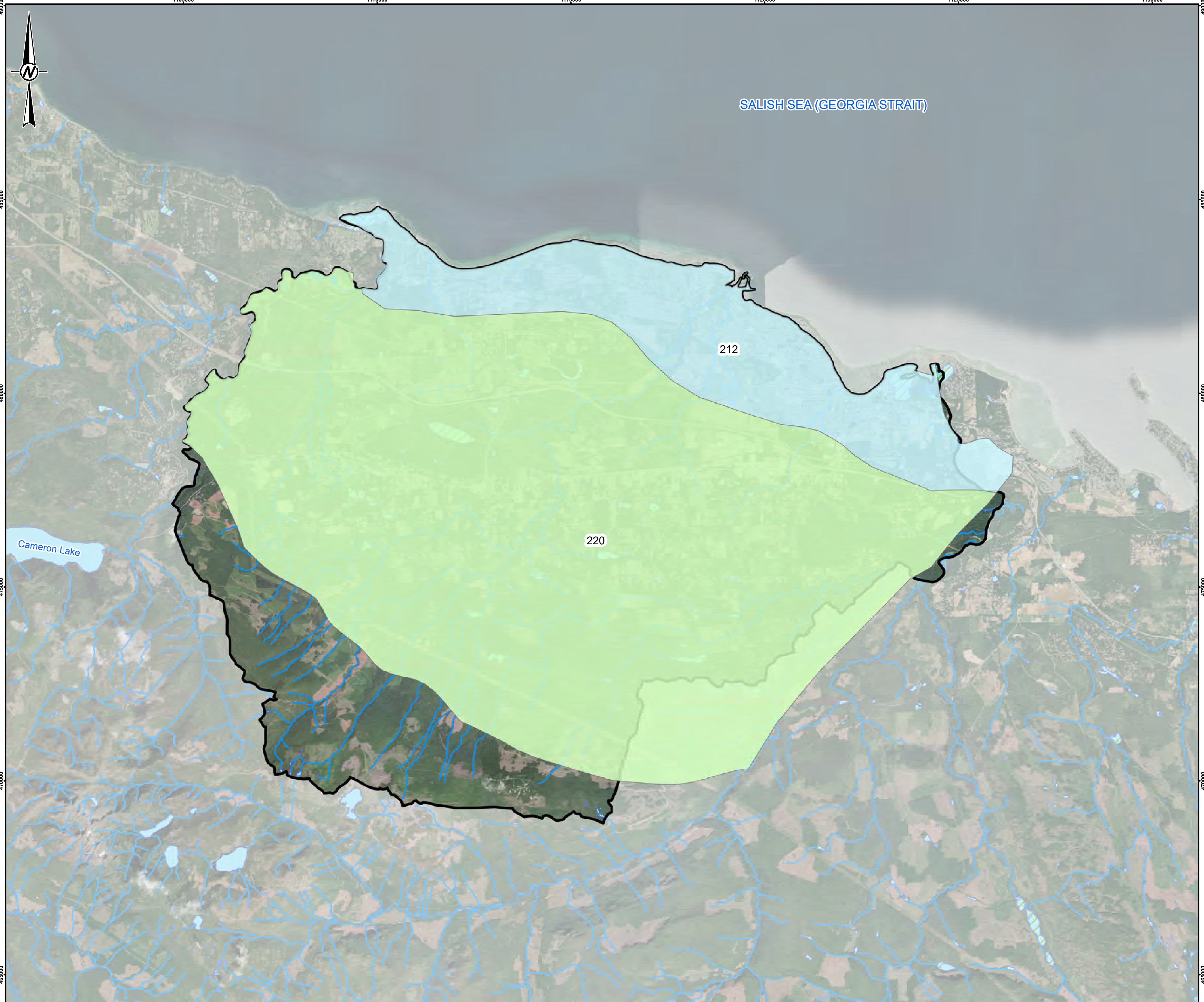

LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERENMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (BEDROCK AQUIFERS) SCENARIO 3 LANDCOVER CHANGE (END OF DRY SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	51

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

For the unconfined aquifers, the changes in land cover are predicted to have no significant influence on the Aquifer Stress classifications compared to Future Base Case conditions, as limited future development and, therefore, landcover change, is planned for these areas based on the current RDN planning; the predicted declines to surface water bodies are discussed in Section 7.2.3.

For the confined aquifers, the Aquifer Stress classifications are predicted to be the same as Future Base Case conditions (i.e., Very High for Aquifers 209, 216 and 1250 and Moderate for Aquifer 217), with the stress predicted to increase slightly at the end of dry season by 1% to 2% as a result of reduced infiltration from redeveloped lots located in the areas of these aquifers. Compared to Future Base Case conditions, the aquifer fluid volumes for the confined aquifers are predicted to remain similar for Aquifers 209 and 1250, and decrease by 1.4% for Aquifer 216 and 1.0% for Aquifer 217 (Table 3F, APPENDIX F).

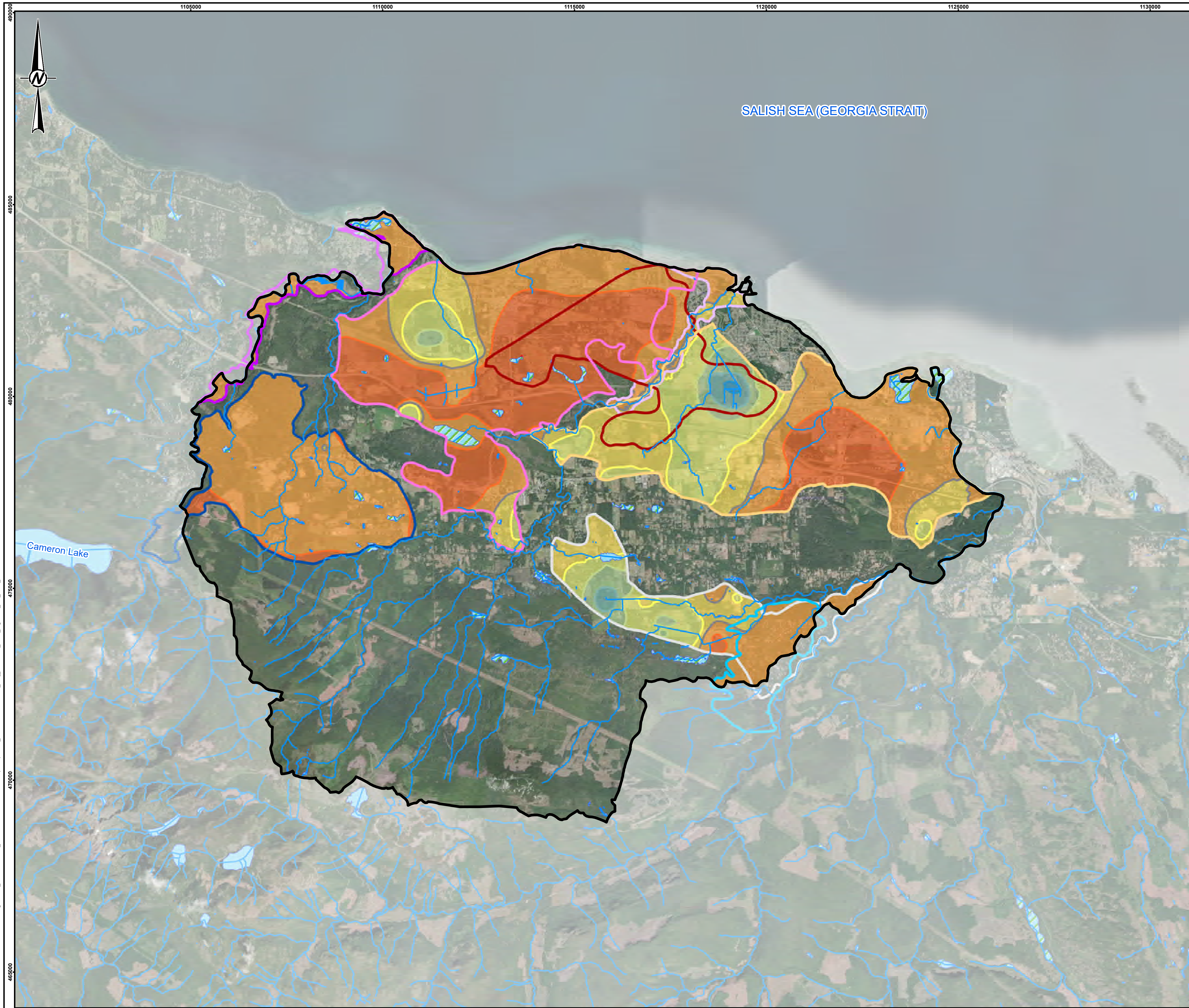
Water levels in the overburden confined aquifers located at lower elevations are predicted to decrease between 1 and 4 m, with areas of more significant decreases in water level generally coinciding with areas identified for potential future development and the associated reduction in recharge as a result of an increase in impervious surfaces.

For bedrock Aquifers 212 and 220, changes in land cover are not predicted to have a significant influence on the Aquifer Stress values and do not change the Aquifer Stress classifications. The aquifer fluid volume for Aquifer 212 remains the same and for Aquifer 220 decreases slightly by 0.2% relative to the Future Base Case conditions (Table 4F, APPENDIX F).

Based on the results of Scenario 3, the reduced infiltration at higher elevations, where land is currently zoned for forestry but is planned for future rural/residential development, is predicted to significantly decrease the water levels compared to Future Base Case conditions. Recharge from precipitation in these areas upgradient of bedrock Aquifer 220 is a main source of recharge for the downgradient confined aquifers in the study area and reduced infiltration is anticipated to have the biggest impact on the four confined aquifers (Aquifers 209, 216, 217, 1250) and bedrock Aquifer 212. A water level decline greater than 10 m is predicted at higher elevations, south and upgradient of the mapped extent of Aquifer 220 as a result of the reduction in infiltration on the forested lands that are developed under Scenario 3. As discussed in Section 6.2.1.3, although the Aquifer Stress predicted for Aquifer 220 is Moderate, other considerations such as the bedrock variability and low productivity suggest that the stress may be relatively higher, particularly in areas upgradient and also where the hydraulic conductivity of the bedrock is lower.

6.2.2.5 Scenario 4 – Combined Impacts of Climate Change, Future Build-out and Changes to Land Cover

The combined effects of Scenarios 1, 2 and 3 (i.e., climate change, future build-out and changes in landcover) on groundwater conditions in Project Area are presented in Tables 3F and 4F in APPENDIX F. Changes in water levels in the dry season for overburden and bedrock aquifers as a result of the changes due to future development are presented on Figure 52 and Figure 53.



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

OVERBURDEN AQUIFER

AQUIFER NUMBER

- AQ 1248
- AQ 1250
- AQ 1252
- AQ 209
- AQ 216
- AQ 217
- AQ 663
- AQ 664

CHANGE IN WATER LEVEL (CONTOURS)

- +20 m
- +10 m
- +5 m
- +1 m
- 0 m
- -1 m
- -5 m

CHANGE IN WATER LEVEL

- > +20 m
- +10 to +20 m
- +5 to +10 m
- +1 to +5 m
- 0 to +1 m
- 0 to -1 m
- -1 to -5 m

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
SCENARIO 4 COMBINED SCENARIO: PREDICTED CHANGE IN WATER LEVEL (END OF DRY SEASON) IN OVERBURDEN

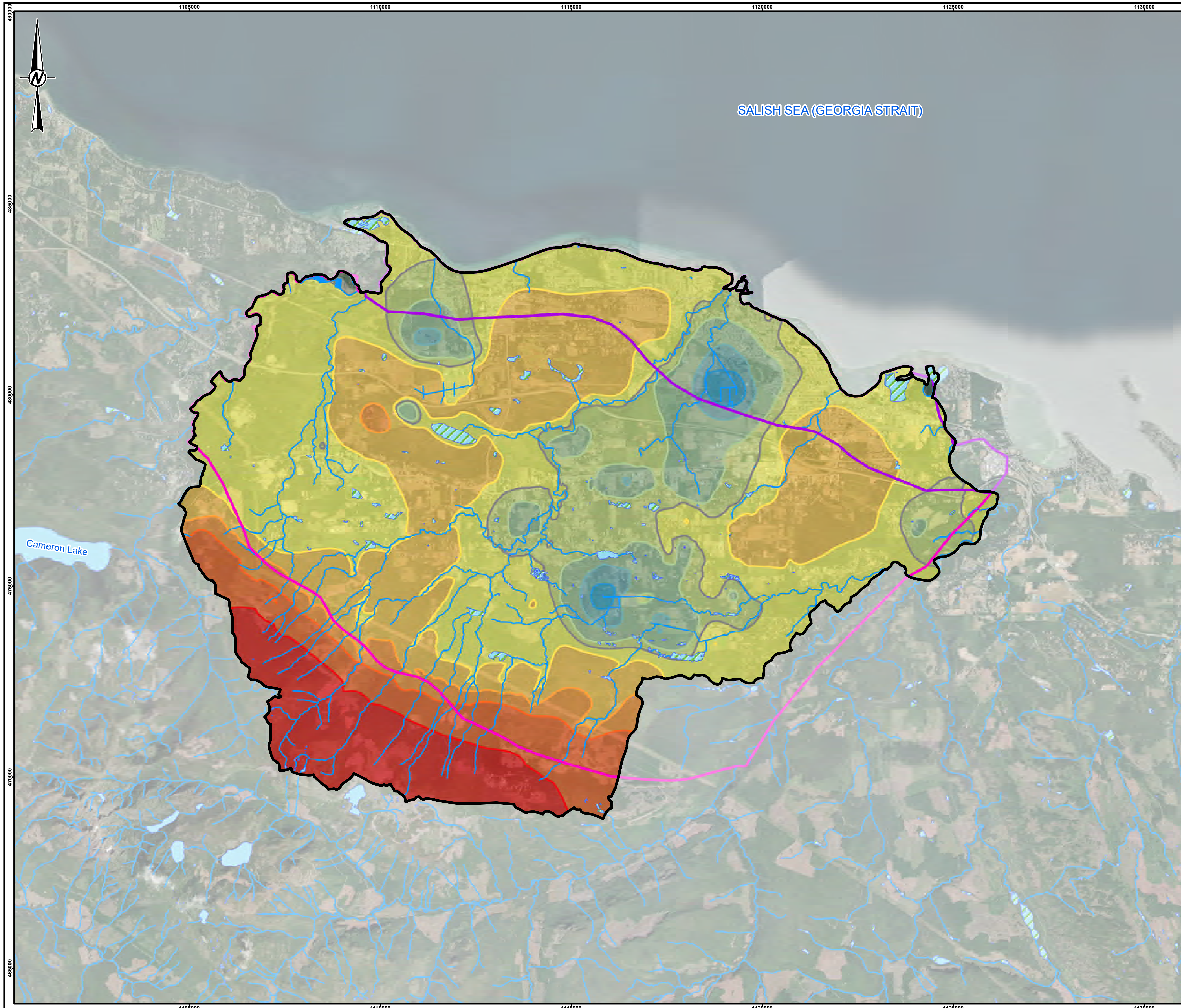
CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	52

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

25mm



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

BEDROCK AQUIFER

AQUIFER NUMBER

- AQ 212
- AQ 220

CHANGE IN WATER LEVEL (CONTOURS)

- +10 m
- +5 m
- +1 m
- 0 m
- -1 m
- -5 m
- -10 m
- -20 m

CHANGE IN WATER LEVEL

- > +10 m
- +5 to 10 m
- +1 to +5 m
- 0 to +1 m INCREASE IN WATER LEVEL
- 0 to -1 m
- -1 to -5 m
- -5 to -10 m
- -10 to -20 m
- > -20 m

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
SCENARIO 4 COMBINED SCENARIO: PREDICTED CHANGE IN WATER LEVEL (END OF DRY SEASON) IN BEDROCK AQUIFERS

CONSULTANT		
wsp	YYYY-MM-DD	2023-07-11
	DESIGNED	RKS
	PREPARED	RKS
	REVIEWED	AP
	APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	53

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

25mm

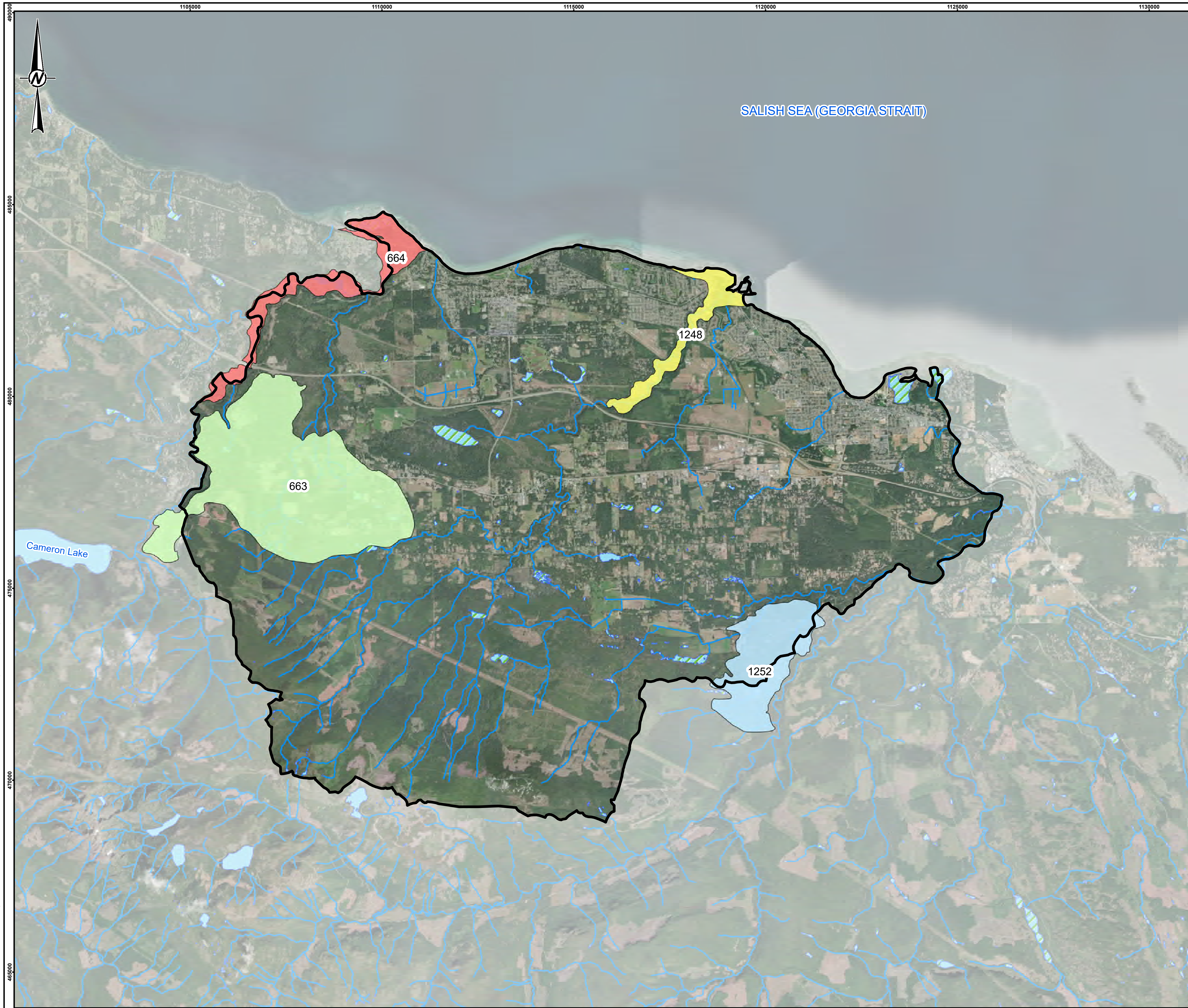
A comparison of the Aquifer Stress classifications between Future Base Case conditions and Scenario 4 is presented in Table 35 and the Aquifer Stress classifications for the overburden and bedrock aquifers under these conditions are shown on Figure 54 to Figure 56.

Table 35: Aquifer Stress Analysis for Scenario 4 – Combined Scenario

Aquifer Number	Aquifer Stress Classification			
	Future Base Case		Scenario 4 - Combined Scenario	
	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season
Unconfined Aquifers				
Aquifer 663	Moderate (14%)	Moderate (14%)	Moderate (13%)	Moderate (13%)
Aquifer 664	Very High (43%)	Very High (47%)	Very High (43%)	Very High (47%)
Aquifer 1248	High (21%)	High (22%)	High (22%)	High (22%)
Aquifer 1252	Low (2%)	Low (2%)	Low (2%)	Low (2%)
Confined Aquifers				
Aquifer 209	Low (2%)	Very High (55%)	Low (3%)	Very High (48%)
Aquifer 216	High (21%)	Very High (50%)	High (21%)	Very High (41%)
Aquifer 217	Low (3%)	Moderate (18%)	Low (4%)	Moderate (14%)
Aquifer 1250	High (26%)	Very High (54%)	High (26%)	Very High (56%)
Bedrock Aquifers				
Aquifer 212	Low (<1%)	Low (2%)	Low (1%)	Low (3%)
Aquifer 220	Low (1%)	Moderate (10%)[a]	Low (1%)	Low (6%)

Notes:

a. Aquifer Stress for Aquifer 220 at end of dry season calculated to be 10% and conservatively included in the Moderate Aquifer Stress classification (i.e., 10% to 20%)



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (UNCONFINED AQUIFERS) COMBINED SCENARIO (END OF DRY SEASON)

CONSULTANT

wsp

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	54

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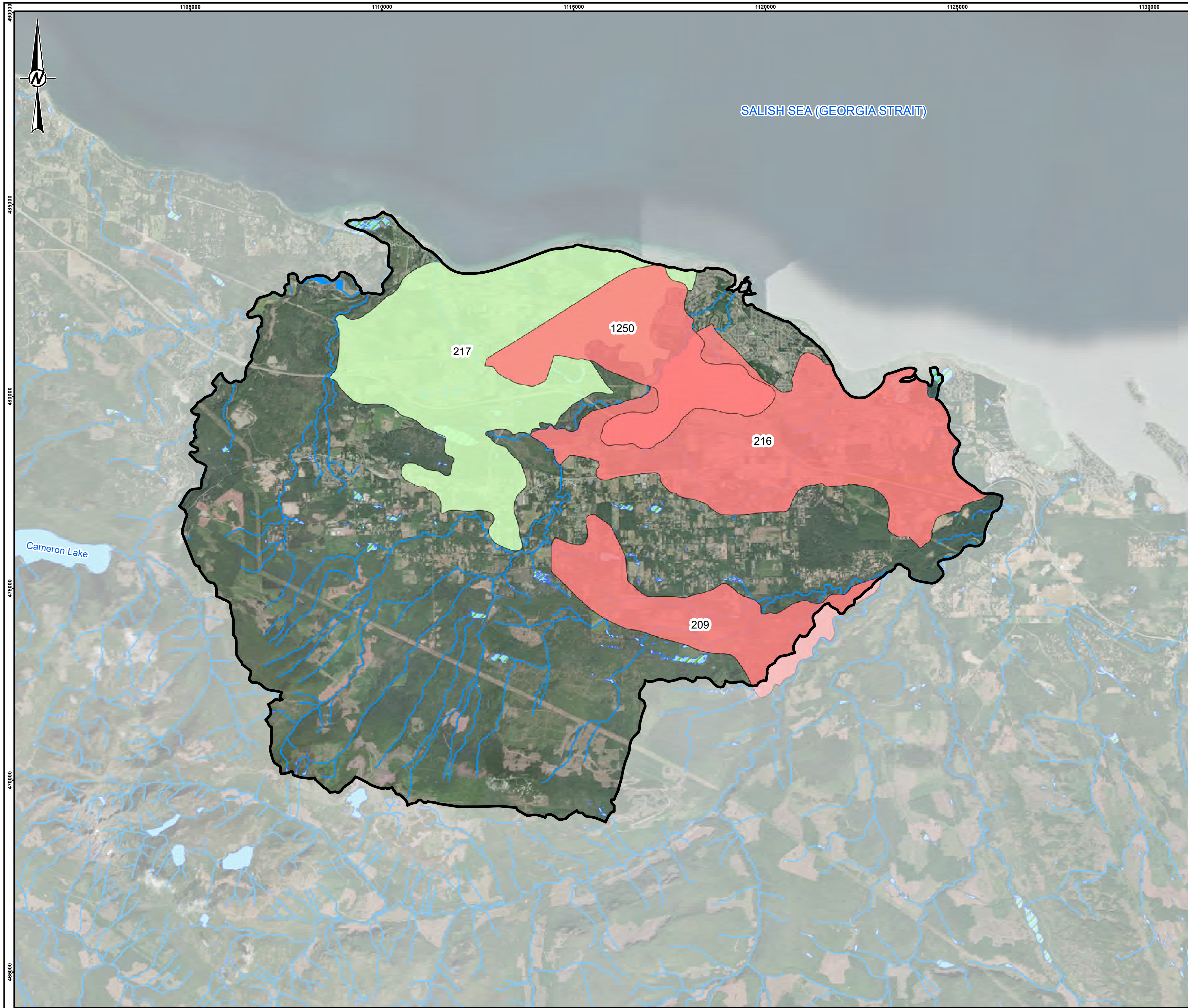

LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (CONFINED AQUIFERS) COMBINED SCENARIO (END OF DRY SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	55

LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

AQUIFER STRESS CLASSIFICATION

- VERY HIGH STRESS
- HIGH STRESS
- MODERATE STRESS
- LOW STRESS

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
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COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
AQUIFER STRESS CLASSIFICATION (BEDROCK AQUIFERS) COMBINED SCENARIO (END OF DRY SEASON)

CONSULTANT

YYYY-MM-DD	2023-07-11
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	56

For the unconfined aquifers, the combined scenario is predicted to have limited influence on the Aquifer Stress classification compared to Future Base Case conditions. As discussed previously (Section 6.2.2.2), the reduction in recharge from precipitation for these aquifers is balanced by withdrawal of water from other units or surface water bodies. Limited future development (and associated landcover change) is planned for these areas and the climate change scenario is predicted to have limited impact on these aquifers. As a result, the Aquifer Stress classifications for the unconfined aquifers do not change and the Aquifer Stress values remain constant, with the exception of Aquifer 663 which declines slightly by 1%. Compared to the Future Base Case conditions, by the end of the dry season the aquifer fluid volumes for the unconfined aquifers are predicted to remain constant or decrease slightly by up to 0.3% in Aquifer 663 (Table 3F, APPENDIX F). The corresponding predicted changes to surface water bodies are discussed in Section 7.2.3.

For confined Aquifer 209, the Aquifer Stress classification is predicted to be the same as Future Base Case conditions (Very High); however, the Aquifer Stress is predicted to be reduced from 55% to 48% at the end of dry season, as the increase in Aquifer Stress due to climate change impacts is predicted to be offset by the reduction in water demand at properties where agricultural and farm use will convert to residential land use at future build-out.

For Aquifers 216 and 217, the Aquifer Stress is also anticipated to decrease under Scenario 4 relative to Future Base Case conditions. The positive influence from the reduction in large-scale agricultural private users as a result of future development, is predicted to more than offset the negative impacts of the climate change and landcover changes. At the end of the dry season, the Aquifer Stress classification for Aquifer 216 is predicted to remain Very High, but the Aquifer Stress will decrease from 50% to 41%. The Aquifer Stress classification for Aquifer 217 under the combined scenario is also predicted to remain the same (Moderate), but with a decrease in the Aquifer Stress from 18% to 14% at the end of the dry season.

Under Scenario 4, the classification for Aquifer 1250 will remain High at the end of the wet season compared to Future Base Case conditions and Very High at the end of the dry season, when the Aquifer Stress is predicted to increase slightly from 54% to 56%. Although limited future development is identified for areas that utilize Aquifer 1250 for water supply based on the RDN build-out information (RDN, 2022a), it is anticipated that the increase in stress to this aquifer reflects increased water demand during the dry season under the climate change scenario and a reduction in recharge from upgradient areas during the longer dry season.

For bedrock Aquifers 212 and 220, the combined scenario is predicted to have some influence on the Aquifer Stress values. The smaller Aquifer 212, which is located in the lowlands, is predicted to have a minimal increase in Aquifer Stress from 2% to 3% at the end of the dry season. This is primarily due to the impacts of climate and landcover changes. For Aquifer 220, the reduction in water use from future build-out is anticipated to have a larger influence than the reduction in recharge from landcover change and climate change. As a result, the Aquifer Stress for Aquifer 220 is predicted to change from 10% to 6%, with the Aquifer Stress classification decreasing from Moderate to Low at the end of the dry season; however, as discussed in previous sections, Aquifer 220 is characterized with a low productivity and the stress for Aquifer 220 may be greater than what is predicted by the model and will be variable due to the nature of the bedrock. As discussed below, stress may be higher in the areas upgradient from Aquifer 220.

Based on the combined scenario, some localized portions of the Project Area are anticipated to have a water level increase compared to the Future Base Case, primarily due to the conversion of large agricultural properties to residential properties at future build-out. The reduction in water use in the dry season resulting from the conversion of agricultural activities into residential development is predicted to have a positive influence (up to 5 m) on water levels in sections of Aquifer 209 and the northern portions of Aquifers 216, 217 and 1250, as shown on Figure 55. A water level decline of up to 5 m compared to the Future Base Case in the combined scenario is predicted for Aquifers 663, the eastern portion of Aquifer 216 and portions of Aquifers 217 and 1250, where the influence of climate change and the reduction in recharge area are anticipated to have a greater influence.

Compared to the Future Base Case, water levels are predicted to decline by over 20 m in the uplands area south of bedrock Aquifer 220 (i.e., localized in the upper elevations) reflecting the combined effects of climate change and the reduction in recharge on the properties that are currently zoned for forestry lands but are identified for potential residential development in the future based on the RDN build-out plan (RDN, 2022a). As discussed in previous sections, these groundwater level declines are also anticipated to reflect increased stress to the bedrock and surface water tributaries in these areas.

7.0 FRENCH CREEK SURFACE WATER ASSESSMENT

This section presents the results of a preliminary surface water assessment for the French Creek watershed. WSP applied the framework outlined in the BC FLNRORD and BC ENV (2022) interim Environmental Flow Needs (EFN) Policy (Interim Framework) to preliminarily characterize the environmental risk management level for French Creek. WSP also used the groundwater model to assess potential changes in groundwater baseflow along French Creek for the future scenarios described in Section 6.1.2.

The surface water assessment and preliminary characterization of the environmental risk management level was conducted only for French Creek, as there were no monitoring data available for other watercourses in the Project Area (or not sufficient data for the analysis).

7.1 Environmental Flow Needs Policy

The EFN of a stream are defined as the volume and timing of water flow required for proper functioning of the aquatic ecosystem (BC *Water Sustainability Act*, Section 1) and must be considered when deciding a water licence or use approval application on a stream or on an aquifer that is hydraulically connected to a stream. As outlined by FLNRO and BC ENV (2022), the BC Environmental Flow Needs Policy (EFN Policy):

- provides a framework for assessing risk and identifying where cautionary measures could be taken or additional analysis may be needed, including developing site-specific environmental flow needs thresholds; and,
- applies to amendments to licences and approvals if there will be additional impacts on fish and fish habitat (e.g., if a change of works puts a point of diversion in a different part of stream or the amendment will result in changes to the volume or timing of flow).

The EFN Policy includes an interim risk management framework (Interim Framework) to characterize the environmental risk management level (Figure 57 below). The EFN Policy also identifies risk management measures to assess or mitigate potential effects of withdrawals from a stream. The measures are associated with risk management levels 1, 2, 3 or special considerations and are intended to guide where more caution may be needed. The three levels of risk management and special considerations are defined by FLRNO and BC ENV (2022) as:

- **Risk Management Level 1 –** Where the EFN risk assessment process results in Risk Level 1, for that specific flow period (e.g., month) there is sufficient water available to provide for EFN as well as for proposed water diversion and use. While Level 1 does not mean 'no risk' (i.e., lower risk of negatively influencing EFN), it indicates that supplementary information may not be required, unless the presence of sensitive species or habitats suggests the need for Special Considerations.
- **Risk Management Level 2 –** Risk Level 2 means that the aquatic environment is flow-limited for the proposed withdrawal period or that cumulative water withdrawals are greater than a specified threshold of concern. A result of Risk Level 2 suggests that more information may be required prior to a decision to grant or decline an application, or that the authorization (if granted) may include terms and conditions to minimize potential impacts to EFN.

- **Risk Management Level 3 –** Risk Level 3 means that the aquatic environment may be severely flow-limited for the proposed period of withdrawal, or cumulative water withdrawals would be greater than a specified threshold of concern, that varies depending on flow sensitivity. A result of Risk Level 3 suggests that more extensive analysis of the potential impacts of the proposed application on EFN may be appropriate prior to the decision to grant or decline the application; and/or the inclusion of comprehensive terms and conditions in the authorization (if granted).
- **Special Consideration –** If 'sensitive species or habitats' (as defined in this policy) are present within the watershed of interest it is recommended that the review of the application, consider information about these sensitive values in addition to information relevant to the identified risk level. This may involve development or review of an existing regional fish periodicity table.

A change in flow that has the potential to cause serious harm to fish[3] may also require a paragraph 35(2)(b) *Fisheries Act* authorization from DFO.

Natural flow regimes are essential for sustaining fisheries and the ecosystem structure and function which supports them (DFO, 2013) and "the probability of effects to riverine ecosystems, and subsequently the fisheries that depend on these ecosystems, increases with increasing alteration to the natural flow regime".

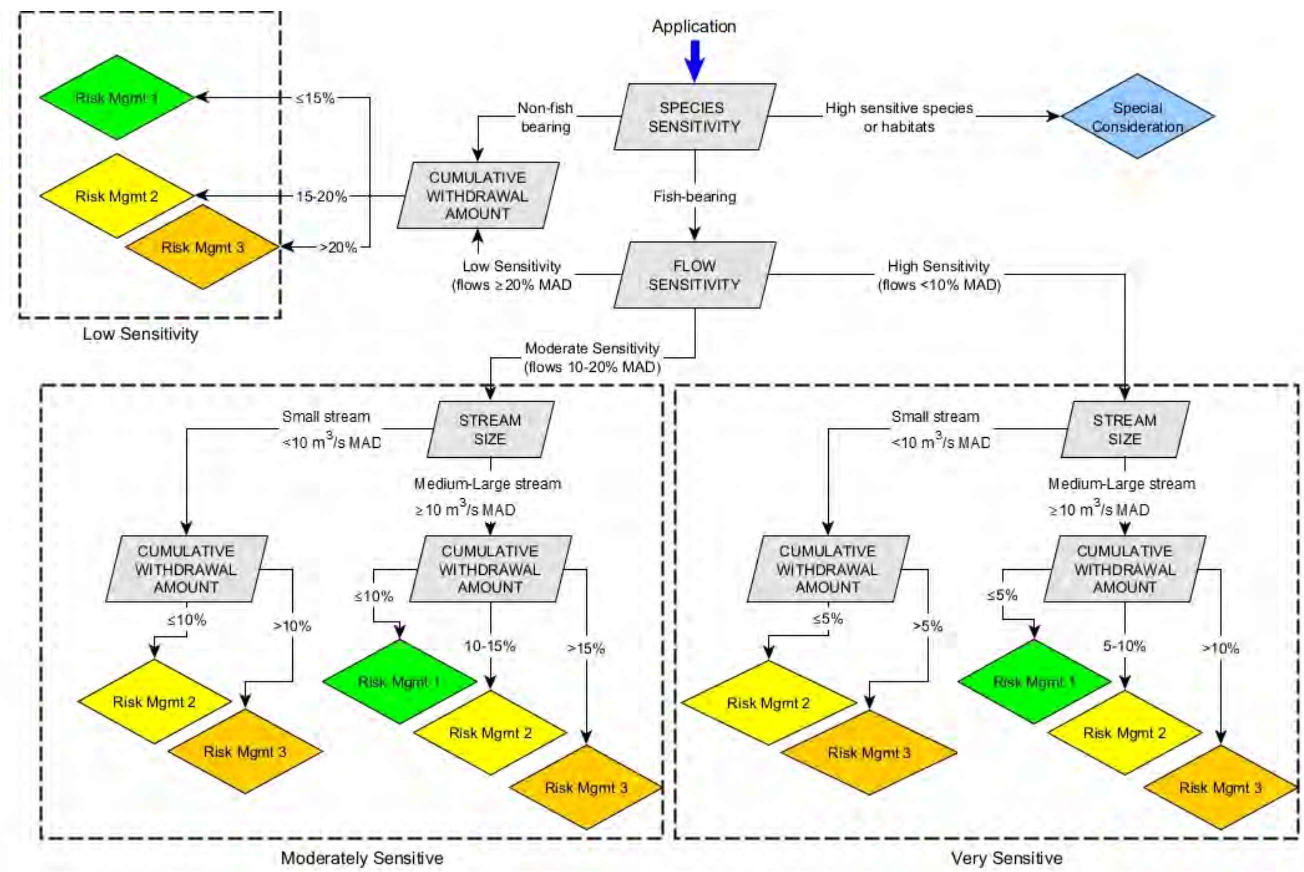

Figure 57: Schematic of Interim Environmental Risk Management Framework (FLNRO BC ENV 2016)

[3] Section 35 of the Fisheries Act prohibits serious harm to fish which is defined in the Act as "the death of fish or any permanent alteration to, or destruction of, fish habitat".

7.2 Results and Discussion

7.2.1 Naturalized Flow Assessment

The flow data presented in Section 3.2.3.1 represent stream flow measured under ambient conditions. The existing stream flow measurements represent the recharge to the streams minus the withdrawals from the streams that are related to surface water licenses. In contrast, "naturalized flows" represent conditions *prior* to the creeks having been altered by local development, including watershed changes, channel modifications, and water extractions through surface and groundwater licenses. While land use changes, groundwater extraction, and changes to river morphology all impact river flows, surface water extractions were considered likely to represent the most significant impact on natural flow volumes. Naturalized flows were characterized in this report as flows in the French Creek that would have occurred before surface water was extracted from the creek (by means of surface water licenses). Lacking specific usage information, the following analysis assumes that all licenses are used to their maximum potential at a single rate for the full license period.

Water licences in the French Creek watershed upstream of each of the hydrometric stations were reviewed using the Provincial database information (Section 3.2.3.2). Different surface water licenses were in effect during the active periods of the three hydrometric stations along French Creek, and some licenses (for irrigation or industrial use) are only applicable at certain times of year. Water license activity and total withdrawals per month during the active periods of each station are summarized in Table 36, assuming full utility of each license; however, it should be noted that water used for the French Creek Fish Hatchery (licence C063988) is returned to the creek after use, as confirmed by the hatchery, and has therefore is not considered to be withdrawn from French Creek for the analysis.

Table 36: Water Licence Activity Upstream of and During the Period of Record for each Hydrometric Station

Data Type	Station	Active Period		Month											
		Start	End	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Active Licenses	08HB038	1969	1989	16	16	16	22	22	22	22	22	22	16	16	16
	08HB078	1990	1996	23	23	23	33	33	32	32	32	32	22	23	23
	08HB0021	2018	2021	25	25	25	34	34	33	33	33	33	24	25	25
		Current		25	25	25	34	34	33	33	33	33	24	25	25
Withdrawal[a] (1000 m^3)	08HB038	1969	1989	6.9	6.2	6.9	8.5	8.8	8.5	8.8	8.8	8.5	6.9	6.6	6.9
	08HB078	1990	1996	19.9	18.2	19.9	39.6	40.9	39.5	40.8	40.8	39.5	19.9	19.3	19.9
	08HB0021	2018	2021	12.0	10.9	12.0	31.3	32.4	31.3	32.3	32.3	31.3	11.9	11.6	12.0
		Current		49.9	12.0	10.9	12.0	31.3	32.4	31.3	32.3	32.3	31.3	11.9	11.6

Notes:

a. Withdrawals reported in table and used for analysis are the licensed amounts; the actual use is not measured and, therefore, varies from what is presented in the table.

Naturalized monthly flow volumes, adjusted for watershed area compared to the currently active station location (08HB0021) and adding upstream extractions shown in Table 36, are shown on Figure 58. Station-average naturalized monthly flow volumes are weighted according to the number of data points available for each station.

Flow for Station 08HB038 is too divergent from the other stations to provide meaningful results. This divergence could be from changes in land use or from variation in water license use during the period of record. As such, Station 08HB038 was excluded from WSP's assessment.

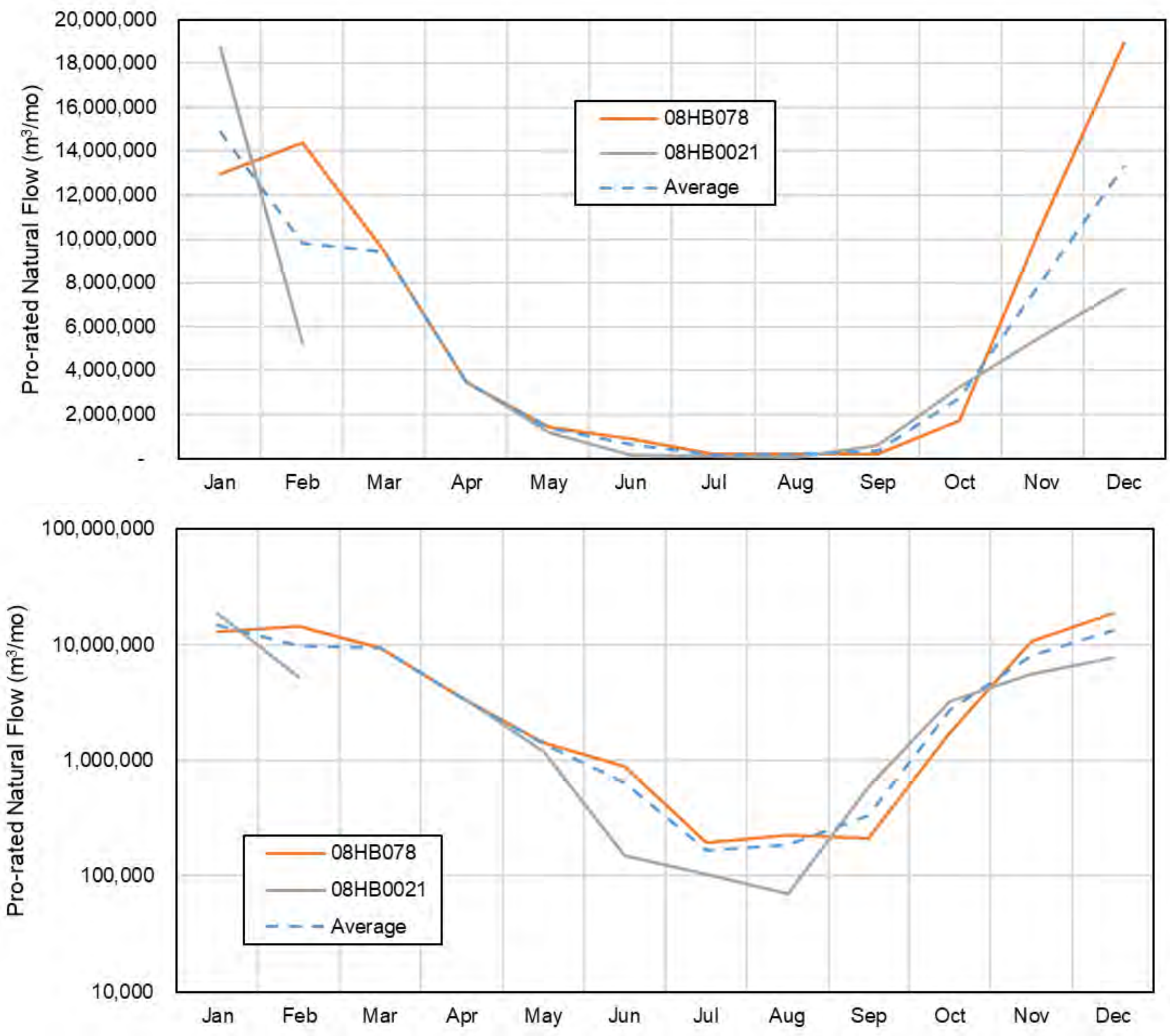

Figure 58: Naturalized monthly flow volumes pro-rated to station 08HB0021[4]

The two-station average naturalized flow rate for each month at 08HB0021, together with withdrawal rate of active licences, is shown in Table 37. The calculated long-term naturalized mean annual discharge (MAD) is 2.04 m^3/s.

[4] Average monthly discharge presented with normal scale (top chart) and log scale (bottom chart)

Table 37: Estimated Naturalized Flow and Current Licensed Withdrawal at Station 08HB0021

Flow Type	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Naturalized Flow (m^3/s)	5.56	4.02	3.52	1.33	0.52	0.25	0.06	0.07	0.13	1.03	3.13	4.97
Licensed Withdrawal (m^3/s)	0.004	0.004	0.004	0.012	0.012	0.012	0.012	0.012	0.012	0.004	0.004	0.004

7.2.2 French Creek Risk Management Levels – Current Conditions

French Creek was classified by month into different categories of flow sensitivity based on monthly natural flows as a percentage of naturalized MAD. Where naturalized monthly flows were greater than 20% MAD, flow sensitivity was considered low. For flows between 10% to 20% MAD, flow sensitivity was considered moderate and, for flows less than 10%, flow sensitivity was considered high.

The Interim Framework also distinguishes small streams (<10 m^3/s MAD) from medium to large streams (≥10 m^3/s MAD). According to this framework, French Creek is considered to be a small stream. To assess risk based on the combined effect of multiple withdrawals, WSP projected cumulative withdrawals for current licensed withdrawal. It is noted that FLNRO (2022) indicates that instantaneous demand or peak daily demand, where available, should be taken into consideration in flow sensitive scenarios. However, in the context of WSP's analysis, these data were not available for review.

Table 38: French Creek EFN Risk Management Level Categorization

Flow Type	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow sensitivity	Low	Low	Low	Low	Low	Mode rate	High	High	High	Low	Low	Low
Current Licensed Withdrawals (% of naturalized monthly flow)	0.08	0.11	0.13	0.91	2.31	4.86	19.43	17.15	9.31	0.43	0.14	0.09
Risk Management Level (fish bearing)	1	1	1	1	1	2	3	3	3	1	1	1

Flow sensitivity for French Creek is low during the winter months, moderate in June, and high for the July-September period. Current licensed withdrawals are also highest (>10% MAD) during the June-September period. As French Creek is a fish-bearing stream (Government of BC, 2005), a Risk Management Level 2 should be considered for June, and a Risk Management Level 3 for July through September. A Risk Management Level of 1 was considered applicable for the remainder of the year.

In the EFN Policy, FLNRO and BC ENV (2022) recognize that there are large uncertainties regarding EFNs. The Interim Framework is intended to be used as a screening level assessment of identifying risk and where measures should be taken, or additional analysis is recommended. Detailed assessment and development of site-specific EFN thresholds are recommended to inform decision making.

7.2.3 Predicted Changes in Groundwater Baseflow for French Creek for the Future Scenarios

Changes in the contribution of groundwater to stream flows (i.e., groundwater baseflows) for the future scenarios at the selected active hydrometric station 08HB0021 were also evaluated using the numerical groundwater model. Predicted groundwater baseflow at this station represents all groundwater exchanges with streamflow in French Creek upstream of the station.

The predicted groundwater baseflow in French Creek for the future scenarios considered is presented in Table 39 and the predicted percent changes in groundwater baseflow from the Future Base Case scenario are presented in Table 40. This assessment considers the groundwater contribution to surface water in French Creek (i.e., groundwater baseflow) only and does not include consideration of changes in the hydrological cycle which would also occur as a response to the future scenarios; detailed hydrological analysis would be required to assess changes to overland flow (i.e., surface runoff). Furthermore, it is noted that baseflow is considered an output of an aquifer's water budget (see Section 6.1) and a decrease in baseflow does not necessarily result in an increase to Aquifer Stress. Rather, the decrease in baseflow is predicted to be reflected in a greater stress to the surface water body.

Table 39: Future Scenarios – Predicted Groundwater Baseflows in French Creek

Hydrometric Stations	Predicted Baseflow (m^3/d)									
	Future Base Case		Scenario 1 Climate Change		Scenario 2 Future Build-Out		Scenario 3 Changes in Land Cover		Scenario 4 Combined Scenario	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
08HB0021	17,940	14,460	15,930	11,690	18,66059	15,740	16,300	13,080	15,690	12,340

Table 40: Future Scenarios – Changes in Predicted Groundwater Baseflow from Future Base Case

Hydrometric Stations	Changes in Predicted Baseflow from Future Base Case							
	Scenario 1 Climate Change		Scenario 2 Future Build-Out		Scenario 3 Changes in Land Cover		Scenario 4 Combined Scenario	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
08HB0021	-11%	-19%	+4%	+9%	-9%	-10%	-13%	-15%

Climate change (Scenario 1) is predicted to have the largest effect on groundwater baseflow in French Creek, with groundwater baseflow predicted to decrease up to 11% in the wet season and up to 19% from the Future Base Case scenario in the dry season. Changes in landcover (Scenario 3) are predicted to decrease groundwater baseflow up to 9% in the wet season and up to 10% in the dry season, relative to the Future Base Case scenario. Based on these results, the increased water demand and decrease in recharge from precipitation during the dry season due to climate change is predicted to have more of a significant effect on groundwater baseflow compared to the reduction in recharge due to changes in landcover. Following new development (Scenario 2), groundwater baseflow in French Creek is predicted to increase by 4% in the wet season and by 9% in the dry season from the Future Base Case scenario, reflecting a reduction in agricultural water use. When considering the combined effects of all future scenarios (Scenario 4), the reduced groundwater recharge due of climate change and changes in landcover is somewhat mitigated by the decrease in water use in some of the new developments that will be converted from agricultural to residential use. As a result, under Scenario 4, groundwater baseflow in French Creek is predicted to decrease by up to 15% from the Future Base Case scenario at the end of the dry season; a value that is less than the sum of the changes predicted for Scenarios 1, 2 and 3.

Under current summer conditions (July to September), French Creek was classified as Risk Management Level 3. Based on the predicted effects on groundwater baseflow under future conditions (i.e., the future scenarios), French Creek is anticipated to remain as a Risk Management Level 3 during the summer under these future conditions. Considering the predicted changes in baseflow also during the wet season (up to 13% compared to Future Base Case scenario), the risk management levels assigned to French Creek during this season (October to May) could also change as higher Risk Management Levels could extend over a broader period (i.e., earlier in the spring and later in the fall). A more detailed surface water assessment that includes changes in the hydrological cycle that might occur as a response to the future scenarios would be required to assess potential changes in the future.

Changes in groundwater baseflow for other creeks in the Project Area that were inferred to be hydraulically connected to aquifers (Swayne Creek, Whisky Creek and Morison Creek) were also evaluated for the future scenarios. Reduction in groundwater baseflow is predicted to occur in all three creeks, mainly related to climate change effects (reduction of recharge from precipitation and increased water use during the dry season). Groundwater baseflow in Swayne Creek and Morison Creek could decrease between 10% and 30% during the dry season from Future Base Case conditions, mainly because of increase water use for irrigation in the dry season from property located in the area. Whisky Creek groundwater baseflow is predicted to decrease between 5% and 10% as a combination of reduction in infiltration due to climate change and change in land cover. There is no available discharge monitoring data for these creeks a no hydrometric stations are currently active along these watercourses. Hydrometric monitoring data will be required to refine the assessment for these three creeks.

8.0 CAPTURE ZONE ANALYSIS

WSP conducted capture zone analysis for the municipal well fields to identify areas where municipal well quality is potentially vulnerable to the impacts of contamination and to provide the basis for delineation of exclusion zones. A capture zone is defined as the portion of an aquifer from which groundwater is derived by a pumping well. Time-of-travel zones are sub regions of the capture zone from which groundwater is derived in a fixed portion of time.

8.1 Methods

WSP used the calibrated steady-state numerical model representing current average annual groundwater conditions to conduct capture zone analysis for the municipal production wells in the Project Area, with the model settings and parameters described in Section 5.5.2. As agreed with the RDN, the analysis was conducted using the 2020 and 2021 pumping rates (current pumping conditions, as described in Section 3.2.6.1) and assumed that all wells were pumping continuously and simultaneously. As agreed with the RDN, WSP used the annual average pumping rates for the capture zone analysis. Higher pumping rates in dry season and lower pumping rates in the wet season are anticipated to have an impact on the extent of the 200-day capture zone in comparison to the annual average pumping rate capture zones. The capture zone analysis was conducted for the following well fields:

- French Creek Well Field and EPCOR North Well Field
- Springwood Well Field and EPCOR South Well Field
- Railway Well Field
- Berwick Well Field
- Surfside Well Field
- Riverside Well Field

Given the proximity of the EPCOR well fields to the French Creek and Springwood well fields, for the purposes of the capture zone analysis these well fields were combined to estimate the effects of pumping on a specific aquifer, as groundwater conditions will be affected by all pumping wells in these areas.

Time-of-travel zones (TOT) were delineated for 200-days, two-years, five-years and 25-years, with the 25-year time-of-travel zone considered representative of the total capture zone. The rationale for selection of these TOT zones is summarized below.

- 200-day time-of-travel zone: Representative of the time required for microbial contaminants moving in the groundwater to degrade. Two hundred days is consistent with a conservative travel time to achieve 4-log inactivation of viruses in groundwater, per the BC Ministry of Health (2017) Guidance Document for Determining Groundwater at Risk of Containing Pathogens (GARP)[5].
- Two-year time-of-travel zone: Representative of an intermediate travel time to provide an appropriate trigger for groundwater management initiatives, as recommended in the Well Design and Wellhead Protection guidance provided by Agriculture and Agri-Food Canada (2022).

[5] It is noted that this travel time is considered a conservative estimate as it assumes a groundwater temperature of 5°C (a temperature lower than groundwater in the area of the RDN) and does not account for subsurface filtration, adsorption or predation of viruses; note that bedrock aquifers, which are not applicable for this assessment, require further consideration.

- Five-year time-of-travel zone: Average time required to implement groundwater remedial measures in response to a contamination event (typically hazardous substances such as hydrocarbons or metals) according to the US Environmental Protection Agency (US EPA; 1987).
- 25-years: The convention by which the total capture zone for a well is typically defined (US EPA, 1987).

8.2 Results and Discussion

The results of the capture zone analysis for the well fields in the Project Area under the current annual average pumping rates are presented in the following sections. It should be noted that the predicted capture zone extents cannot be used to infer the impact of municipal withdrawals on surface water features. Although some capture zones may not directly extend to surface water features, the associated wells may be extracting groundwater that would otherwise discharge as groundwater baseflow to streams or rivers. WSP refined the numerical model mesh grid in the areas of the well fields to better define the capture zones; however, it is noted that for some well fields, the shape of the capture zones are influenced by the model grid.

8.2.1 French Creek and EPCOR North

The RDN French Creek (FC) well field and EPCOR North well field consist of the 13 wells shown in Table 41 below. The FC and EPCOR North well fields are in close proximity and the TOT zones begin to overlap beyond the 2-yr TOT zone. The wells are all screened in the confined Aquifer 1250, with the exception of R8 Well that is inferred to be screened in the unconfined Aquifer 1248. WSP used the annual average pumping rates derived from the 2021 pumping rate data provided by RDN for the capture zone analysis.

Table 41: French Creek and EPCOR North Well Field Current Annual Average Pumping Rates for Capture Zone Analysis

Well	Well Tag No.	Aquifer	2021 Annual Average Production Rates (m^3/day)
RDN French Creek Wells			
FC Well 1	26661	1250	N/A
FC Well 2	43090	1250	46
FC Well 4	41896	1250	55
FC Well 5	75344	1250	N/A
FC Well 6	75345	1250	N/A
FC Well 7	75346	1250	46
FC Well 8	75347	Unassigned	N/A
EPCOR North			
TWN1 Well	Unknown	1250	25
RWN2 Well	Unknown	1250	388
Drew Rd Well #2	80104	1250	44
Ravensbourne Well	63134	1250	163
R8 Well	97150	1248	4

Notes:
N/A: not applicable – well is not operational

The combined TOT zones for the two well fields are presented on Figure 59. Based on the current pumping rates, FC Wells 1, 5, 6 and 8 are not currently active and were therefore not included in the capture zone analysis. Additionally, R8 Well is pumping at a low pumping rate of less than 5 m^3/d and was, therefore, also not included in the capture zone analysis.

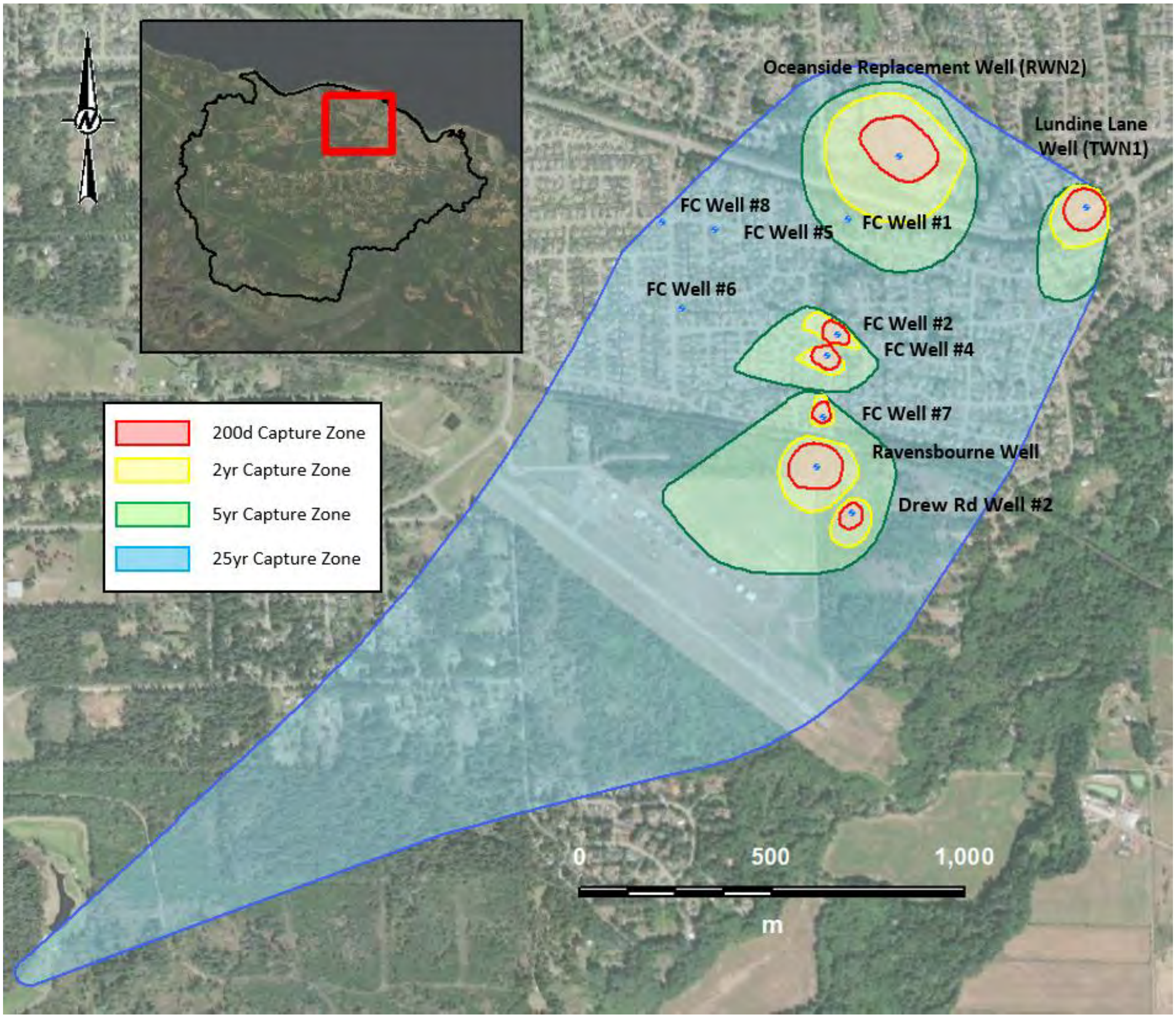

Figure 59: Time-of-Travel Zones for French Creek and EPCOR North Well Fields

The results of the groundwater model simulation are summarized as follows:

- **FC Well #2 and FC Well #4:** The 200-day TOT zones extend as a radius of up to approximately 50 m around each wellhead and the two-year TOT zones extend as radii of approximately 100 m. As presented on Figure 59, the five-year TOT zones for FC Well 2 and FC Well 4 overlap into a broader zone that extends approximately 280 m upgradient from FC Well 2 and approximately 250 m upgradient from FC Well 4. The land within this area is primarily residential development.
- **FC Well 7, Ravensbourne Well and Drew Rd Well 2:** The 200-day TOT zones extend as radii of approximately 50 m around the wellheads of FC Well 7 and Drew Rd Well 2, and approximately 70 m for the Ravensbourne Well, reflecting the higher pumping rate. The two-year TOT zones extend upgradient from FC Well 7, the Ravensbourne Well and Drew Rd Well 2 at distances of approximately 60 m, 70 m and 100 m, respectively. The five-year TOT zone for the three wells extends upgradient and southwest from the wells at distances of approximately 475 m from FC Well 7 to 210 m from Drew Road Well 2; the five-year TOT zone is approximately 430 m in width. The Qualicum Beach Airport is located directly upgradient of these wells and the edge of the airport property is located within the five-year TOT zone.
- **Oceanside Replacement Well (RWN2):** The 200-day, two-year and five-year TOT zones extend at radii of approximately 110 m, 200 m and 300 m around the wellhead, respectively; the relatively larger TOT zones reflect the higher pumping rate for this well. The land within this area is primarily residential development.
- **Lundine Lane Well (TWN1):** The 200-day, two-year and five-year TOT zones extend distances of approximately 65 m, 125 m and 165 m around upgradient of the wellhead, respectively. The land within this area is primarily residential development.
- **25-year TOT zone:** The 25-year TOT zone for the FC and EPCOR North well fields is predicted to extend approximately 200 m downgradient (NE) and 3,100 m upgradient (SW) of Oceanside Replacement Well and 65 m downgradient and 3,500 m upgradient of Lundine Lane Well. The properties within the 25-year TOT are generally a mix of residential development, the Qualicum Beach Airport, vegetated land and rural residential.

8.2.2 Springwood Well Field and EPCOR South Well Field

The current annual average pumping rates for the 24 wells that make up the Springwood and EPCOR South well fields, all of which are screened in Aquifer 216, are shown in Table 42 below. The results of the combined capture zone analyses for the two well fields are presented on Figure 60. Based on the current annual average pumping rates, Springwood #1, #3 and #9 are not currently active and were therefore not included in the capture zone analysis. Church Road #1, #3, #4 are in closer proximity than the regional-scale model can simulate as individual wells. Therefore, these wells were combined as one well with the combined pumping rate.

Table 42: Springwood and EPCOR South Well Field Current Annual Average Pumping Rates for Capture Zone Analysis

Well	Well Tag No.	Aquifer	2021 Annual Average Production Rates (m^3/day)
City of Parksville Springwood Wells			
Springwood #1	39215	216	N/A
Springwood #2	107112	216	N/A
Springwood #3	107121	Unassigned	95
Springwood #4	107122	216	N/A
Springwood #5	37482	216	125
Springwood #6	107119	216	63
Springwood #7	107111	216	355
Springwood #8	107112	216	263
Springwood #9	107110	216	N/A
Springwood #10	95022	216	147
Springwood #11	95023	216	177
EPCOR South			
Church Road Well #1	44079	216	57
Church Road Well #2	54994	216	3
Church Road Well #3	Unknown	216	23
Church Road Well #4	Unknown	216	60
Springhill Replacement Well (RWS1)	Unknown	216	224
Springhill #2A Well	83544	216	8
Hills of Columbia Well #6A	97107	216	70
Hills of Columbia Well #7	97122	216	70
Hills of Columbia Well #9	100351	216	46
Bosa Well	97094	216	76
Hills of Columbia Well #11	97104	216	119
ACS1	Unknown	216	233
TWS1	Unknown	216	25

Notes:

N/A: not applicable – well is not operational

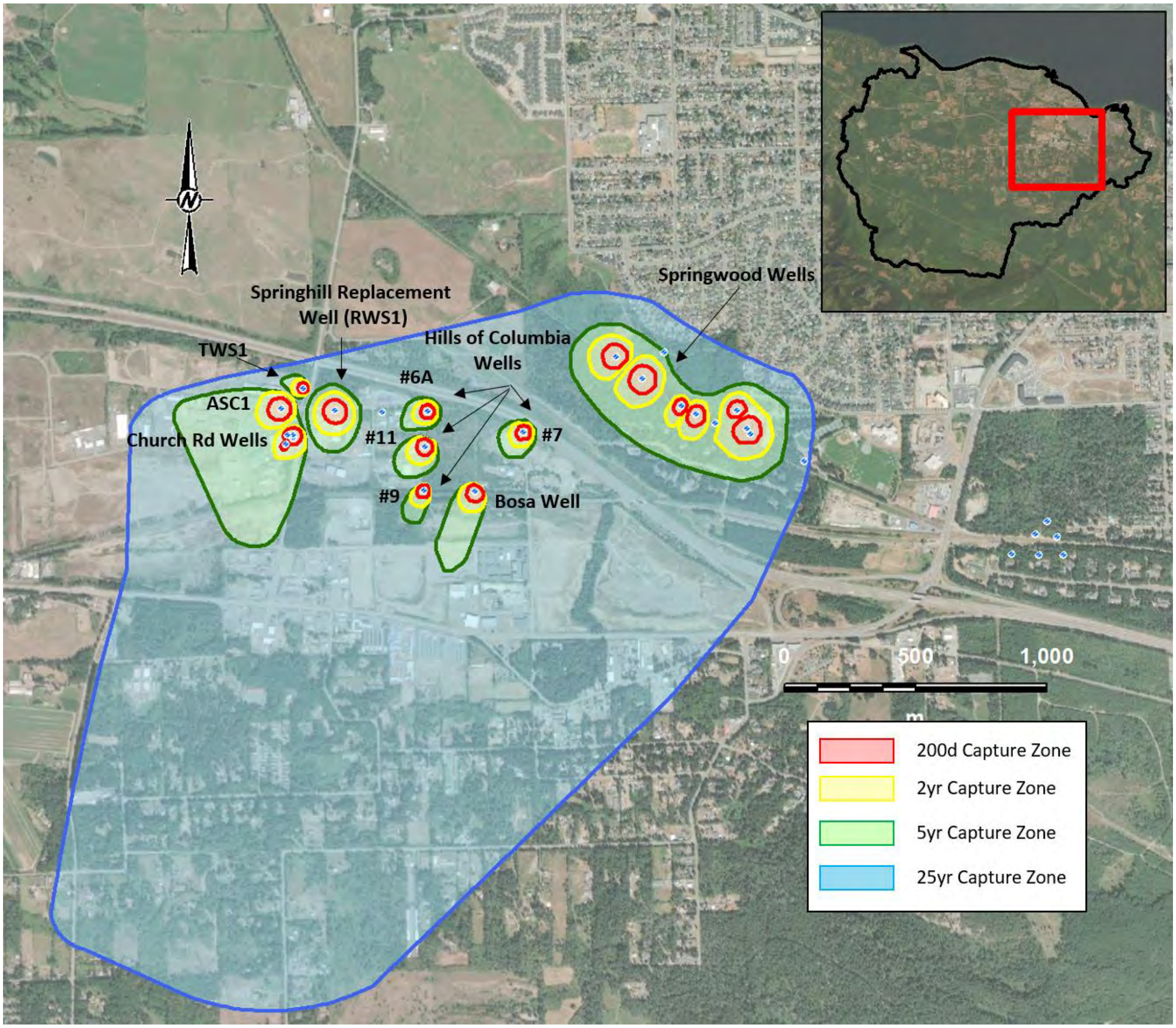

Figure 60: Time-of-Travel Zones for Springwood and EPCOR South Well Field

The results of the groundwater model simulation for the capture zone analysis indicate the following:

- **Springwood Well Field:** The 200-day TOT zones extend distances of up to 60 m in radius around the wellheads of the individual wells, and the two-year TOT zones extend up to approximately 125 m upgradient (SW) of the wellheads. The five-year TOT zone extends approximately 900 m across the well field in a NW to SE direction, and 175 m to 250 m upgradient (SW) of the wells. Land cover in the area of this well field is primarily vegetated, with some private residences.

- **EPCOR South Well Field:**
  - The 200-day and two-year TOT zones generally extend around and upgradient of the wellheads at distances of up to approximately 30 m and 60 m, respectively. The 200-day and two-year TOT zones extend distances of approximately 40 m and 85 m, respectively, from Springhill Replacement Well (RWS1) and ASC1 wells, reflecting the higher pumping rates at these wells.
  - The five-year TOT zones generally extend approximately 105 to 130 m upgradient from the wells, with the exception of the Bosa Well (300 m upgradient) and the combined 5-year TOT zone for ACS1 and Church Rd wells (460 m). The increased extent of the combined five-year TOT for the ACS1 and Church wells is inferred to be due to the increased pumping rate.
  - Within the five-year TOT zone, the properties upgradient of the EPCOR South well fields are primarily zoned for industrial activities.
- **25-year TOT zone:** The 25-year TOT zones for the Springwood and EPCOR South wells extend into one broader zone that extends up to 290 m downgradient (NE) of the Springwood Well Field and up to 2,200 m upgradient (SW) of the EPCOR South well field. Within the 25-year TOT zone, properties include rural residential and agricultural properties with a mix of residential buildings, large areas of treed vegetation and agricultural vegetation.

8.2.3 Railway Well Field

The Railway well field consists of Railway #1, Railway #2, Railway #3, Railway #4, Railway #5, Railway #6 and Railway #7. The wells are all screened in confined Aquifer 216. The results of the capture zone analysis for the well field are presented on Figure 61.

Table 43: Railway Well Field Current Annual Average Pumping Rates for Capture Zone Analysis

Well	Well Tag No.	Aquifer	2021 Production Rates (m^3/day) Average Annual
City of Parksville Railway Wells			
Railway #1	107055	216	111
Railway #2	107040	216	203
Railway #3	107046	216	90
Railway #4	107092	216	80
Railway #5	107094	216	128
Railway #6	107096	216	151
Railway #7	107099	216	119
Railway #8	96288	216	N/A

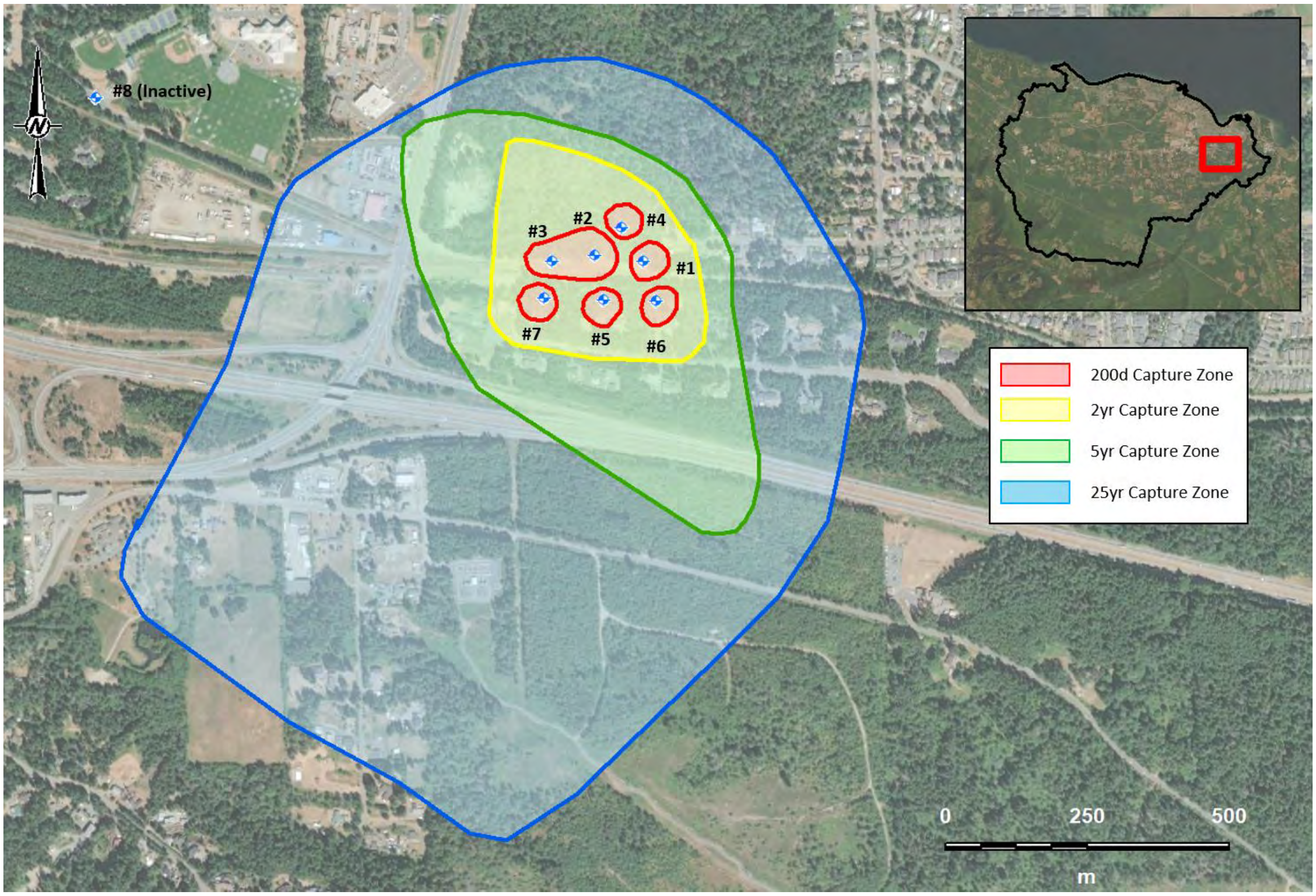

Figure 61: Time-of-Travel Zones for Railway Well Field

The results of the groundwater model simulation indicate that the 200-day TOT zones extend up to 90 m around the individual wellheads, with larger zones reflecting wells with higher pumping rates (e.g., Railway #2). The two-year TOT zones extend into a broader zone around all of the Railway wells. The two-year TOT zone extends approximately 230 m around the wellheads. The five-year TOT zone extends up to 430 m upgradient (S) of Railway Wells #5, #6 and #7 and 120 m downgradient (N) of Railway Well #4. The broader 25-year TOT zone extends up to 650 m upgradient (SW) of the well field and 250 m downgradient (N) of the well field.

The area within the 200-day and two-year TOT zones generally comprises vegetated areas, the railway alignment and residential properties. The five-year TOT zone extends south across Highway 19 and the 25-year TOT zone extends beneath commercial properties located to the south of Highway 19 and west of Highway 4A.

8.2.4 Berwick Well Field

The Berwick well field consists of Berwick #1, Berwick #2, Berwick #3 and Berwick #4 (Table 44). With the exception of Berwick Well #2, which is screened in confined Aquifer 1250, the wells in the well field are screened in confined Aquifer 217. The capture zone for the well field is presented on Figure 62.

Table 44: Berwick Well Field Current Annual Average Pumping Rates for Capture Zone Analysis

Well	Well Tag No.	Aquifer	2021 Production Rates (m^3/day) Average Annual
City of Qualicum Beach Berwick Wells			
Berwick Well #1	805	217	337
Berwick Well #2	803	1250	369
Berwick Well #3	32242	217	256
Berwick Well #4	108897	217	101

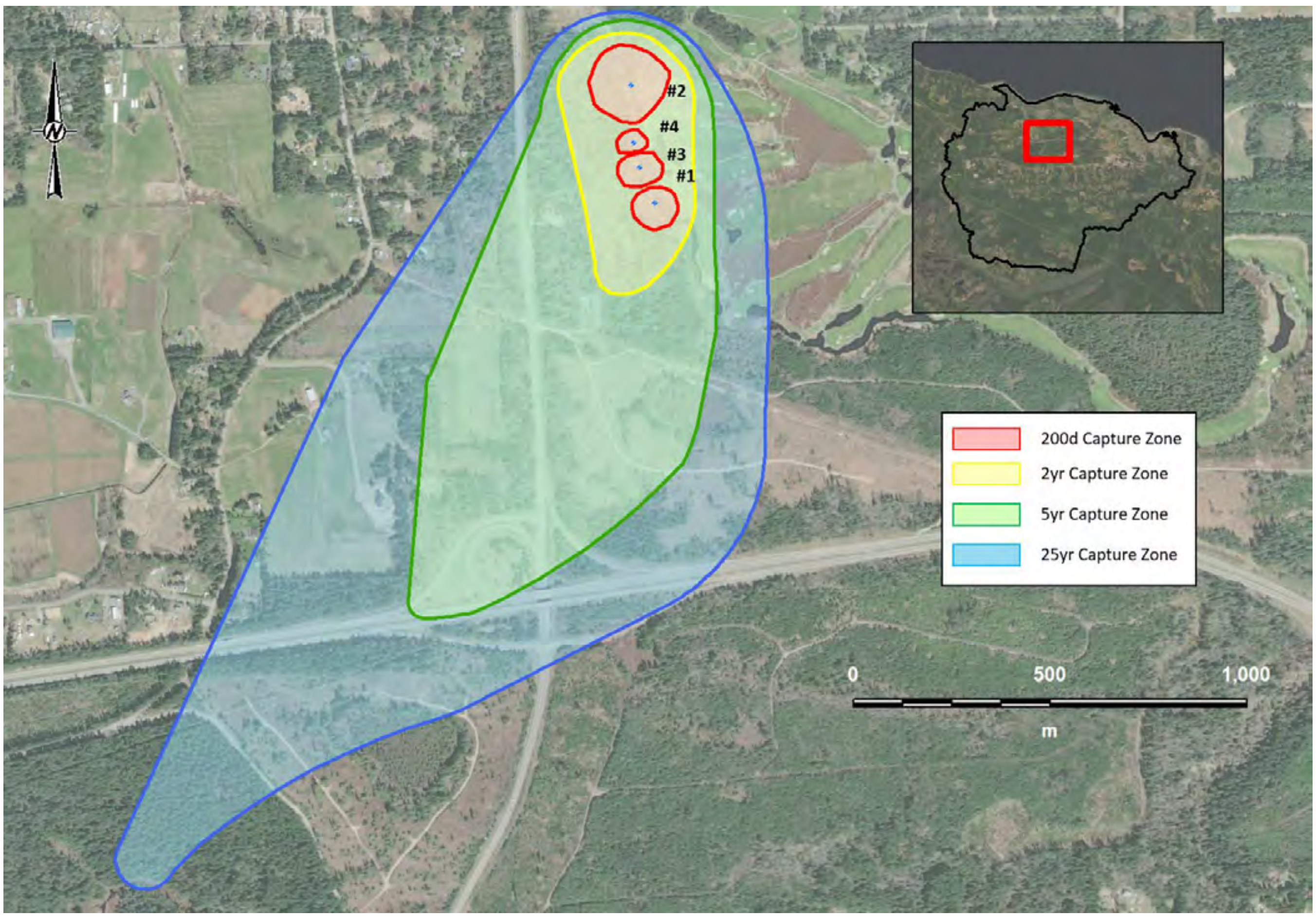

Figure 62: Time-of-Travel Zones for Berwick Well Field

The 200-day TOT zones that were simulated with the groundwater model extend as radii of approximately 50 m (Berwick Well #4) to 95 m (Berwick Well #2) around the wellheads. The two-year TOT zone extends approximately 270 m upgradient (S) of Berwick Well #1 and the five-year TOT zone is approximately 700 m wide and extends approximately 1,200 m upgradient (SW) of Berwick Well #1. At 25 years, the TOT zone is approximately 2,200 m upgradient (SW) of Berwick Well #1 and is approximately 1,200 m across at the widest point

Within the 25-year TOT zone, properties upgradient of the Berwick well field are generally zoned as rural properties with land uses including agricultural activities, a golf course, forestry and rural residential. In addition, the Inland Island Highway is located at the edge of the five-year TOT and 25-year TOT zones.

As discussed in Section 6.2.1.2, the hydrogeological setting in the area of Aquifer 217 is complex, particularly in the area of the Berwick well field. It is recommended that planning for the Berwick well field should consider the results of site-specific assessments that have been conducted in the area, as summarized by Elanco (2022). Refinements of the regional model within the area of this well field to reflect the complex hydrogeological setting at the local scale would provide the basis for more refined capture zone analysis.

8.2.5 Surfside Well Field

The Surfside well field consists of the Surfside #1 and #2 wells, which are both screened in unconfined Aquifer 664 (Table 45). The capture zone for the well field is presented on Figure 63.

Table 45: Surfside Well Field Current Annual Average Pumping Rates for Capture Zone Analysis

Well	Well Tag No.	Aquifer	2021 Production Rates (m^3/day) Average Annual
RDN Surfside Wells			
Surfside 1	28459	664	9
Surfside 2	75325	664	9

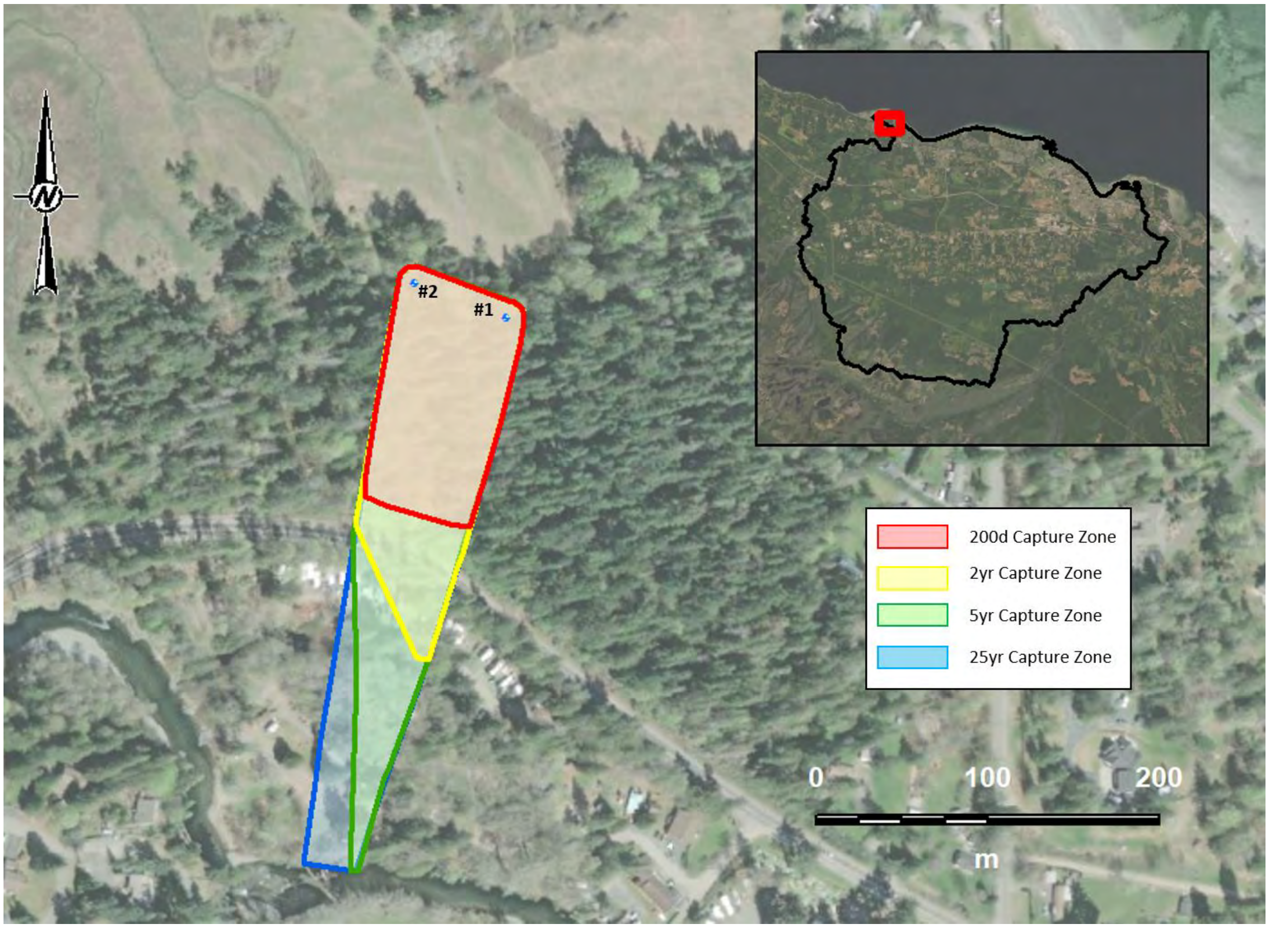

Figure 63: Time-of-Travel Zones for Surfside Well Field

The 200-day TOT zone for the Surfside wells extends up to approximately 130 m upgradient (S) of the wellheads and the two-year TOT zone extends approximately 210 upgradient of the wellhead. Both the five-year and 25-year TOT zones extend up to 300 m upgradient of the well field. The Surfside wells are inferred to have a hydraulic connection to the Little Qualicum River and the shape of the capture zones is influenced by the proximity with the watercourse. The capture zone boundary does not directly line up with the orthoimage of the Little Qualicum River due to the resolution of numerical model and meandering nature of the river; however, it is anticipated that the capture zone will extend to the river boundary.

Land use in the capture zone for the Surfside wells includes a campground for recreational vehicles.

8.2.6 Riverside Well Field

The Riverside well field consists of Riverside #1A, Riverside #2, Riverside #3, Riverside #4, Riverside #5, Riverside #6 and Riverside #7. All the wells in the well field are screened in unconfined Aquifer 664 (Table 46). The capture zone for the well field is presented in Figure 64. Based on the current pumping rates, Riverside # 2 and #4 are currently inactive and therefore not included in the capture zone analysis.

Table 46: Riverside Well Field Current Annual Average Pumping Rates for Capture Zone Analysis

Well	Well Tag No.	Aquifer	2021 Production Rates (m^3/day) Average Annual
City of Qualicum Beach Riverside Wells			
Riverside Well #1A	108903	664	568
Riverside Well #2	Unknown	664	N/A
Riverside Well #3	108901	664	595
Riverside Well #4	Unknown	664	N/A
Riverside Well #5	108900	664	1027
Riverside Well #6	108899	664	676
Riverside Well #7	108898	664	1035

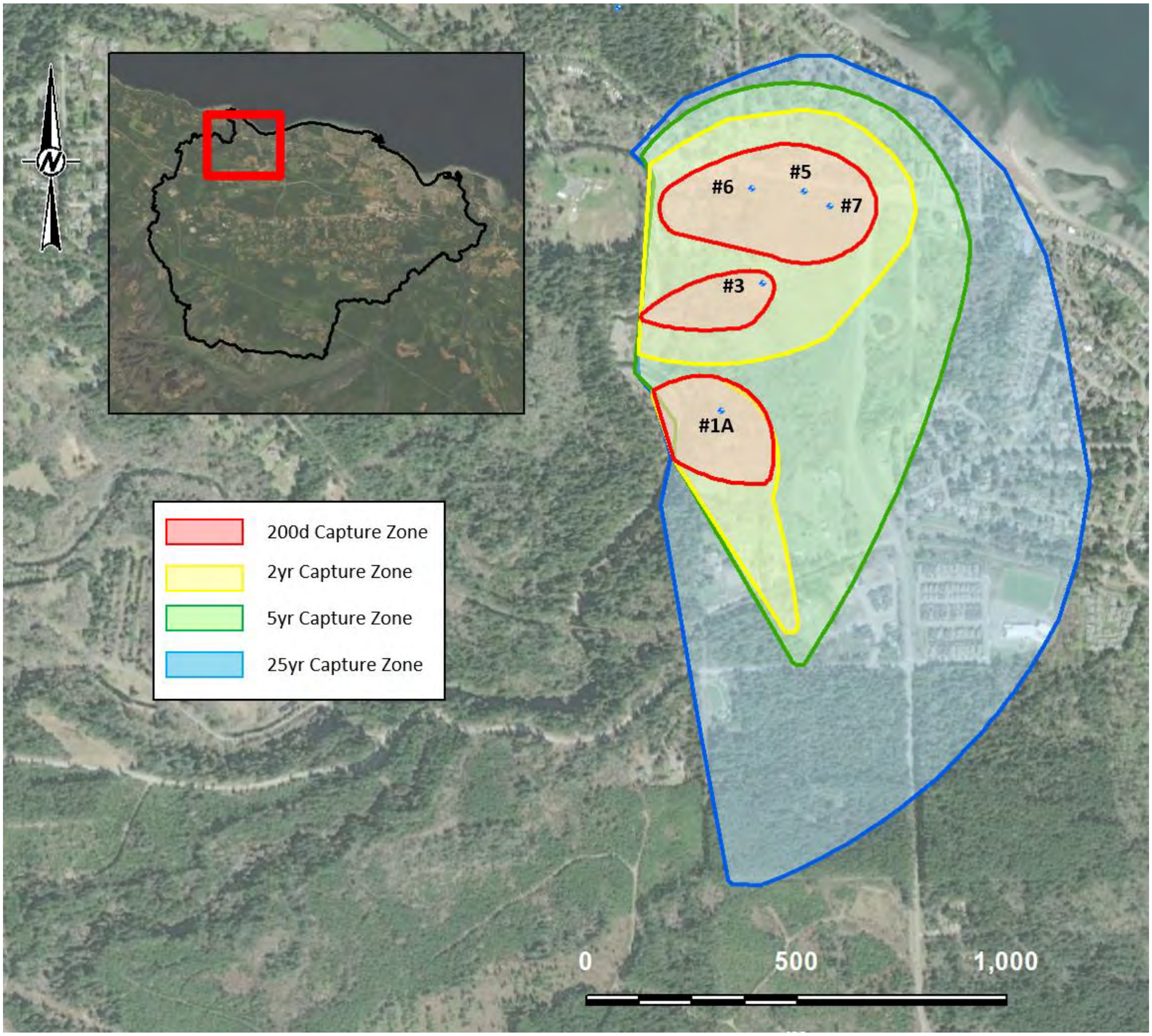

Figure 64: Time-of-Travel Zones for Riverside Well Field

The results of the groundwater model simulation that was conducted for the capture zone analysis indicated the following:

- The capture zones for the Riverside wells reflect a hydraulic connection to the Little Qualicum River.
- **Riverside Well #3, #5, #6, #7:** The 200-day TOT zone for Riverside Wells #5, #6 and #7 extends 225 m west towards Little Qualicum River. The 200-day TOT zone for Riverside Well #3 also extends west, to a distance of up to approximately 300 m. The two-year TOT zone extends approximately 500 m around the four wells and extends west to Little Qualicum River.

- **Riverside Well #1A:** The 200-day TOT zone extends up to approximately 210 m upgradient (S) of the well and 150 m to the west, where it reaches the Little Qualicum River. The two-year TOT zone extends further upgradient to a distance of 560 m south of the well.
- The five-year TOT zone includes the five wells and extends approximately 480 m to the east of Riverside #3, 630 m upgradient (s) of Riverside #1A and west to the Little Qualicum River.
- The 25-year TOT zone for the well field extends approximately 900 m to the east and 1,200 m south (upgradient) of Riverside #1A; the western boundary extends along Little Qualicum River for a distance of approximately 900 m.
- Land use within the 25-year TOT zone for the Riverside well field include a mix of rural residential properties with agricultural activities, treed vegetated areas and residential subdivision properties.

As discussed in Section 6.2.1.1, detailed assessments have been conducted for the Riverside well field. Based on site-specific data, including a higher estimated hydraulic conductivity for the aquifer in the area of the well field, Piteau (2004) developed a flow model at the local scale and predicted that the TOT zones for the Riverside wells would be narrower and extend directly to the Little Qualicum River, when compared to those that were predicted with the regional scale model and presented above. The TOT zones presented above are therefore considered to be conservative, as they predict that the TOT zones extend over a larger area. It is recommended that the reader refers to the report by Piteau (2004) for the more refined capture zone analysis in this particular area of Aquifer 664.

8.3 Sensitivity Analysis and Limitations for Capture Zone Analysis

8.3.1 Sensitivity Analysis for the Extent of Capture Zones

An assessment was made of the uncertainty in the predicted extent of the capture zones resulting from the uncertainty in groundwater model input parameters. As discussed in Section 5.6, the sensitivity in predictions was evaluated using the model with values of hydraulic conductivity of all permeable units increased by a factor of 3 and decreased by a factor of 3 from the calibrated values. Based on the review of hydraulic heads and path lines under these two scenarios, the capture zone extents appear to be most sensitive to the reduction in hydraulic conductivity of the permeable units. In general, lower hydraulic conductivity results in a lower hydraulic head in the vicinity of the pumping wells and the capture zone extending over a broader distance. The changes in the predicted capture zones for each well field based on the changes to hydraulic conductivity are summarized below:

- **French Creek and EPCOR North:** The capture zone (i.e., 25-year time-of-travel zone) is predicted to be of similar extent but may shift up to 500 m to the north-west or north-east of the base case capture zone based on the changes in hydraulic conductivity of the aquifer.
- **Springwood and EPCOR South:** The capture zone is predicted to maintain a similar shape to the base case. Under the lower hydraulic conductivity scenario, the capture zone is predicted to extend up to 500 m further west and south, 1 km further south-east and 250 m further to the north of the capture zone from the base case.
- **Railway:** The capture zone is predicted to extend further by 250 m to the north, 150 m to the east and west and 1 km to the south from the base case.

- **Berwick:** The capture zone is predicted to extend up to 100 m further to the north and 250 m further to the east on the south-east edge of the capture zone.
- **Surfside:** The capture zone is predicted to be similar in extent but may shift up to 50 m to the north-west or south-east based on the hydraulic conductivity sensitivity.
- **Riverside:** Under lower hydraulic conductivity conditions, the capture zone is predicted to extend further to the north and east by up to 270 and 120 m, respectively, and will extend along Little Qualicum River an additional length of approximately 170 m.

8.3.2 Limitations of Capture Zone Analysis

The capture zone analyses, and TOT zones were estimated using the calibrated regional groundwater flow model that incorporated available hydrogeological data. The capture zones and TOT zones that were predicted from the numerical model are deemed to be superior to those derived with less sophisticated analytical solutions or fixed radius calculations; however, capture zones that are predicted with models that are developed at the local scale using the results of detailed site-specific assessments, such as those that are presented by Piteau (2004), are inferred to provide more refined TOT zones.

Delineation of the capture zones that were predicted for the Phase 3 French Creek Water Budget project and the uncertainty of these extents are subject to the following limitations:

- The model used for the capture zone analysis does not account for the dispersion of contaminants in groundwater. Dispersion as a transport process causes a plume of contaminants to arrive at the receptor earlier than the water particle moving by advection only and causes the plume to spread at right angles to the direction of the groundwater flow. Thus, it is probable that some contaminants originating from a potential source located within the capture zone could arrive at the production well earlier than that predicted by the model. It is also probable that some contaminants from sources located outside (and nearby) the capture zone boundaries could cross into the capture zone by dispersion and then migrate towards the pumping well. Contaminants can also be transported into the capture zone by mechanisms other than the groundwater flow such as non-aqueous phase liquid (NAPL) movement down sloping boundaries.
- The model developed for the capture zone analyses does not take into consideration the retardation and degradation of contaminants in groundwater. Retardation is a process that slows down the movement of contaminants in groundwater, whereas degradation causes a reduction of the mass that originally entered the subsurface. Many, but not all contaminants, move at a velocity slower than that of the groundwater itself. Thus, it is possible that some contaminants originating from the capture zones presented above will reach the pumping well later than the times predicted by the model or, in some cases, will not arrive at the well at all.
- Flow through the unsaturated zone in the groundwater model was simplified as the objective of the modelling for water budget purposes was not to simulate the unsaturated zone, but rather saturated groundwater flow. Therefore, the estimates of time-of-travel through the unsaturated zone are underestimated. Hence, in many instances it will take longer for potential contaminants to travel from the ground surface to the wells than predicted by the model, particularly in areas where the aquifer is overlain by low-permeability materials or where the water table is relatively deep.
- The model used for the analysis of the capture zones assumes constant pumping rates at the production wells and at other major private water users. In reality, pumping rates vary on a daily and seasonal basis depending on water supply demand and downtime due to maintenance. This may result in capture zones that are of smaller extent than the ones presented in this report.

- This analysis assumed that all wells considered in the analysis are operated simultaneously at their average annual pumping rates. If some of the wells are not operated, not pumped simultaneously, or their predicted rates are adjusted, the extent of the capture zones for all the wells will change from those presented in this report.
- The model incorporated private groundwater use by applying it aerially to the top each aquifer in the model. If some existing wells included in the private groundwater use are located in the immediate vicinity of the municipal wells, they could affect the predicted extent of their capture zones. Furthermore, the model does not include large capacity users that in the future could install new wells in the aquifers utilized in the Project Area. Pumping from these new large-capacity wells could have significant impact on the capture zones of municipal wells.
- Some variation in the capture zones presented in this report may occur should additional large-capacity wells be installed in the vicinity of municipal wells or should there be significant changes to the current pumping regime of wells operated by the different municipalities.

9.0 SUMMARY AND RECOMMENDATIONS

9.1 Refined Water Budget and Stress Analysis

The numerical groundwater model that WSP developed for the Phase 3 French Creek Water Budget project represents a compilation and interpretation of geological, hydrological, climate and groundwater use data from across the area of the French Creek watershed and adjacent aquifers and watersheds. The model simulates groundwater conditions in a dynamic natural system and provides a strong technical framework to assess conditions in the Project Area. The model is regional in scale and suitable for assessing average groundwater conditions over large areas, estimating water budgets for individual aquifers as well as assessing regional effects on water levels and groundwater baseflow due to future changes related to climate, projected population growth and proposed land-use changes. Based on the scale of the model, the refined water budgets are intended for assessment at the aquifer level and are not intended for site-specific analysis of localized areas or individual well fields. Detailed assessments that have been conducted by others for some locations within the Project Area should also be referred to.

The refined water budgets and aquifer stress assessments that WSP conducted with the groundwater model identified aquifers with relatively higher stress under both current conditions and potential future scenarios; however, it is recognized that other factors should also be considered when assessing water stress. For example, the inherent properties of bedrock aquifers (i.e., flow within discrete fracture networks), particularly those characterized with low productivity, are more variable and the corresponding stress may be higher in some areas than the overall Aquifer Stress classification that was assigned with the method that was used with this regional-scale numerical model. Furthermore, changes to unconfined aquifers are expected to result in impacts to surface water bodies that have a strong hydraulic connection to these aquifers. Therefore, the numerical groundwater model is one tool that should be considered in the broader context of the French Creek area.

The preliminary risk management levels that WSP assigned to French Creek using the BC Interim Framework, coupled with the assessments of groundwater baseflow to surface water bodies that were conducted with the groundwater model, provide the basis to focus monitoring and management efforts.

The refined time-of-travel zones that WSP delineated for municipal water supply wells with the numerical model also identify target areas for implementation of refined groundwater protection measures.

Results and recommendations regarding these key aspects are provided in the following sections.

9.1.1 Aquifer Water Budget and Stress Analysis

The calibrated regional hydrogeological model was used to conduct water budget and stress analysis for current and future average, dry and wet conditions for the aquifers in the Project Area; the analysis was conducted at an aquifer scale and does not assess variability in water stress in different areas within aquifers. The results of these analyses provide a basis for the RDN to identify and implement planning measures to manage water resources in the French Creek 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 Project Area.

Current Conditions

Based on current groundwater use from municipal and private users, and groundwater discharge to surface water bodies, the results of water budget and stress analysis for current conditions showed that confined unconsolidated Aquifers 209, 216 and 1250 and unconfined Aquifer 664 are under Very High Stress conditions during the dry season, and unconfined Aquifer 1248 is under High Stress. Under current conditions, Aquifers 663 and 217 are classified as being under Moderate Stress and unconfined Aquifer 1252 is under Low Stress. A site-specific hydrogeological assessment that was conducted by Piteau (2004) for the Riverside well field provides a more detailed understanding of groundwater conditions at the local scale.

The water budgets for aquifers 209, 216 and 663 indicate that current groundwater withdrawals for water supply by municipal providers and private users represent a significant component of the overall flow within the aquifers (approximately 40% of the total outflow), highlighting the influence of groundwater pumping in these areas. Although the water levels in some monitoring wells in Aquifer 216 have showed an increasing trend since the mid-2010s (Section 3.2.5.3), the aquifer is classified to be under Very High Stress during the dry season based on current water use, as the water withdrawal by municipal wells and private users represents approximately 50% of the groundwater flow into the aquifer.

Bedrock aquifers 212 and 220 were evaluated to be Low and Moderate Stress, respectively, at the end of the dry season under current conditions; however, other aspects should also be considered for bedrock aquifers that are inherently more variable and can have localized areas of higher stress. The Province has characterized Aquifer 220 as having a low productivity and the water level in OBS Well 287, located in the central portion of the aquifer, has showed a declining trend since 2004, suggesting that limitations to groundwater availability in the bedrock aquifers may be more significant than what is reflected in the Aquifer Stress classifications alone. As discussed in Section 9.2, it is therefore recommended that the Aquifer Stress classifications be considered with other factors in the broader context of conditions in the French Creek area.

Based on the above results, it is recommended that aquifers that are classified with Very High or High Aquifer Stress, as well as bedrock Aquifer 220, be prioritized for monitoring and water management initiatives.

Future Scenarios

Scenario 1 – Potential Climate Change

The results of groundwater model simulations predict that future climate change (Scenario 1) could have a significant effect on dry and wet season groundwater conditions within the Project Area compared to the Future Base Case conditions. Climate change is predicted to have the biggest influence on the confined unconsolidated aquifers because of a reduction in groundwater recharge and increased water usage during the dry season (i.e., the majority of private users in the Project Area extract the water for residential and agricultural activities from Aquifers 209, 216, 217 and 1250). Comparison of predicted water levels for Scenario 1 to water levels predicted for the Future Base Case indicates that the combined effects of reduced recharge (i.e., from less precipitation and a longer dry season) and increased water demand from large agricultural properties that withdraw water from confined Quadra Sand Aquifers 216 and 217, could result in water level declines of more than 10 m in the central portions of Aquifer 216 at the end of the dry season. Water levels in Aquifers 209 and 217 are also predicted to decline by up to 8 m in the vicinity of agricultural properties by the end of the dry season. Water levels in unconfined aquifers (663, 1248, 1252) are predicted to decline less (between 2 and 4 m) than the confined aquifers due to the smaller number of large private users (especially agricultural users) using groundwater from these aquifers and the hydraulic connection of some of the aquifers to permanent watercourses that control groundwater levels; however, it is noted that this process results in greater stress to these surface water bodies. Aquifers 209, 216 and 1250 are predicted to remain categorized as Very High Stress in the dry season whereas Aquifer 217 is predicted to change from Moderate Stress in the Future Base Case condition to High Stress due to the effects of climate change.

The Aquifer Stress for bedrock Aquifers 212 and 220 are predicted to be Low and Moderate, respectively. Water levels are predicted to decline by up to 5 m in Aquifer 220 and 10 m in the upgradient bedrock by the end of the dry season, reflecting less recharge to the bedrock aquifer and increased stress to the tributaries in the headwaters of the French Creek watershed. As discussed above, stress for Aquifer 220 (and Aquifer 212) will not be uniform and is inferred to be higher in localized areas where the productivity of the bedrock is lower.

Scenario 2 – Future Build-Out

The results of the analysis also indicated that the simulated water demand at full build-out (Scenario 2) will potentially have significant effects on groundwater conditions in the areas of future development. The reduction of water demand from large-scale irrigation and livestock agricultural activities to residential use is predicted to have a positive influence on water levels and aquifer stresses in a large part of the Project Area. Water levels in the confined Quadra Sand Aquifers 216 and 217 and in Aquifer 209 are anticipated to increase by up to 10 m compared to the Future Base Case scenario, in areas where large agricultural properties will be converted into residential use. Aquifer Stress for Aquifers 209, 216 and 217 is predicted to decrease between 7% and 22% from Future Base Case conditions at the end of the dry season; however, Aquifers 209, 216 and 1250 are predicted to remain in the Very High Stress category and Aquifer 217 will remain in the Moderate Stress category.

Water levels in the bedrock underlying Aquifers 216, 217 and 209 are predicted to also increase under Scenario 2; however, in the upgradient portion of bedrock Aquifer 220 and upper portion of the watersheds, where land that is currently vacant will be developed as new residential properties, water levels are predicted to decline by up to 2 m.

Scenario 3 – Changes in Land Cover

Changes in landcover as a result of future development and the resulting increased coverage with impervious surfaces (Scenario 3) is predicted to affect groundwater conditions at higher elevations where the reduction in recharge from precipitation is predicted to significantly decrease groundwater levels compared to the Future Base Case scenario. Although Aquifer Stress values are predicted to increase modestly by 1% to 2%, a water level decline of over 10 m is predicted in the southern portion of the Project Area as a result of the reduction in recharge on the forestry lands that are identified for potential future development. Recharge from precipitation in these areas, which are in the headwaters of the French Creek watershed and upgradient of bedrock Aquifer 220, represents a main source of recharge for the downgradient confined aquifers (Aquifers 209, 216, 217 and 1250) and the bedrock aquifers. As a result, water levels in the confined aquifers are predicted to decrease between 1 m and 4 m, with more significant water level decreases generally coinciding with areas identified for development. Although the Aquifer Stress predicted for Aquifer 220 is Moderate, other considerations suggest that the stress for the aquifer may be relatively higher, particularly in areas where the productivity of the bedrock is lower. 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.

Scenario 4 – Combined Impacts of Climate Change, Future Build-out and Changes to Land Cover

Based on the results of Scenario 4, where the combined effects of Scenarios 1 to 3 were considered, it is anticipated that there will be a limited influence on the Aquifer Stress for the unconfined and bedrock aquifers, whereas the Aquifer Stress values for confined unconsolidated aquifers are predicted to decrease by approximately 7% (Aquifer 209), 9% (Aquifer 216) and 4% (Aquifer 217) but increase by 2% for Aquifer 1250 from Future Base Case conditions; however, under Scenario 4, the Aquifer Stress classifications do not change. Some regions of the Project Area are anticipated to have a water level increase primarily due to the conversion of large agricultural properties to residential properties based on the future build-out. The reduction in water use in the dry season from the conversion of agricultural activities into residential development is predicted to have a positive influence on large sections of Aquifer 209 and in the northern portions of Aquifers 216, 217 and 1250. In contrast, water level declines of up to 5 m are predicted for Aquifers 663, the eastern portion of Aquifer 216, and large portions of Aquifers 217 and 1250 where the influence of climate change and the associated reduction in recharge are anticipated to be more significant.

Overall, for Aquifer 220, the reduction in water use from future build-out is anticipated to generally have a positive influence and balance the reduction in recharge from changes to climate and landcover and, therefore, the Aquifer Stress classification is predicted to decrease from Moderate under the Future Base Case conditions to Low for Scenario 4. Nevertheless, a reduction in water levels of over 20 m is predicted in the upland areas south of bedrock Aquifer 220 due to the combined effects of changes in land cover and climate. Furthermore, it is recognized that Aquifer 220 is characterized as having a low productivity and the stress to Aquifer 220 will be variable and potentially higher due to the nature of the bedrock.

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. For example, stormwater management programs can be developed and implemented to support groundwater recharge in the areas where new development is planned.

9.1.2 French Creek Surface Water Assessment

Based on water licence information in the French Creek watershed upstream of each of the hydrometric stations, naturalized monthly flow and a long-term naturalized mean annual discharge (MAD) of 2.04 m^3/s was estimated. French Creek was classified by month into different categories of flow sensitivity based on monthly natural flows as a percentage of naturalized MAD. Based on the results of this assessment, flow sensitivity for French Creek is estimated to be low during the winter months, moderate in June, and high for the July to September period. Current licensed withdrawals are also highest (>10% MAD) during the June to September period. As French Creek is a fish-bearing stream (Government of BC, 2005), a Risk Management Level 2 should be considered for June, a Risk Management Level 3 for July through September, and a Risk Management Level of 1 during the remainder of the year.

Changes in the contribution of groundwater to stream flows (i.e., groundwater baseflows) for the future scenarios at the active Barclay hydrometric station along French Creek were also evaluated using the groundwater flow model. Climate change (Scenario 1) is predicted to have the largest effects on groundwater baseflow in French Creek, with groundwater baseflow predicted to decrease up to 11% in the wet season and up to 19% from the Future Base Case scenario in the dry season. Changes in landcover (Scenario 3) are predicted to decrease groundwater baseflow up to 9% in the wet season and up to 10% from the Future Base Case scenario in the dry season. Following new development (Scenario 2), groundwater baseflow in French Creek is predicted to increase by 4% in the wet season and by 9% in the dry season from the Future Base Case scenario as a result of reduced groundwater use for agricultural purposes. When considering the combined effects of all future scenarios (Scenario 4), the influence on groundwater baseflow from reduced infiltration because of climate change and changes in landcover is mitigated by the decrease in water use in some of the new developments that will be converted from agricultural to residential use. Under Scenario 4, groundwater baseflow in French Creek is predicted to decrease by up to 15% from the Future Base Case scenario at the end of the dry season. Changes in groundwater baseflow are also predicted for Swayne Creek, Whisky Creek and Morison Creek for future scenarios, mainly related to reduced infiltration and increase water use during the dry season because of climate change; however, it should be noted that no monitoring data were available for these three creeks to refine this assessment.

The provincial EFN Policy notes that assessment of EFN is an emerging science with large uncertainties. Monitoring and detailed site-specific studies are required to build lines of evidence and support adaptive management. Therefore, implementation of more detailed monitoring programs is recommended, as described further in Section 9.2.

9.1.3 Capture Zone Analysis

For most wells, the 200-day TOT zones generally extend around the individual wells with radii in the range of approximately 30 to 95 m, with variability reflecting the aquifer properties and pumping rates. The two-year TOT zones also generally extend around the individual wells or clusters of wells at greater distances of up to over 500 m. The 5-year and 25-year TOT zones generally comprise broader zones around well fields or clusters of wells and extend across broader areas and upgradient from the wells at distances of up to 3,500 m for the longer TOT considered (e.g., 25-year TOT zone for French Creek and EPCOR North wells). The capture zones for the Surfside and Riverside well fields reflect a hydraulic connection with the Little Qualicum River. The site-specific hydrogeological assessment of the Riverside well field that was conducted by Piteau (2004) should be referred to for a more refined capture zone analysis of this localized area of Aquifer 664. The reader should also refer to the detailed site-specific assessment presented by Elanco (2022) when considering the results of the capture zone analysis for the Berwick well field.

Land uses within the delineated capture zones primarily comprise forested, undeveloped and vegetated areas, agricultural properties and residential development; however, the capture zone for French Creek and the EPCOR North wells extends beneath the Qualicum Beach Airport, the capture zone for the EPCOR South wells extends beneath properties that are zoned for industrial activities and the capture zone for the City of Parksville Railway wells extends beneath commercial properties.

The results of the capture zone analyses provide the basis to develop and implement wellhead protection plans for the municipal water supply wells in the Project Area. The nature of the potential contaminants potentially present in the TOT zones (e.g., microbial contaminants compared to hazardous substances such as hydrocarbons or metals) should be assessed and monitoring, protection and emergency response plans could be designed to mitigate and manage the contaminants within the TOT zones.

9.2 Use of the Numerical Model and Implementation of Results

As discussed above, the numerical hydrogeologic model that was developed for the Phase 3 French Creek Water Budget project represents a technical basis to identify areas of potential water stress and can be used as an effective planning tool in assessing long-term groundwater management strategies. As indicated in previous sections, based on the scale of the model, the refined water budgets are intended for assessment at the aquifer level and are not intended for site-specific analysis of localized areas or individual well fields. The results from the numerical model should be considered not in isolation, but rather with other factors in the broader context of conditions in the French Creek area. In particular, it is recommended that a precautionary approach be undertaken when operationalizing the Aquifer Stress classifications for unconfined aquifers that are expected to have a strong influence on surface water bodies, and bedrock aquifers that are characterised with greater variability and uncertainty. As discussed in the following section, monitoring and collection of additional information will help to reduce uncertainty.

The results of the above analyses provide a technical basis for the RDN to implement and advocate for measures to support management, conservation and protection of water resources in the French Creek area. It is recommended that the RDN target those aquifers and areas that are identified with higher stress and predicted to be affected in the future by climate change, development and changes to land cover; bedrock Aquifer 220 and upgradient areas to the south should also be included as targeted areas. Aquifer Protection Development Permit Areas (DPAs) could be established to manage development in these areas. In addition to public awareness programs to educate land owners, initiatives and regulatory tools could be implemented to reduce groundwater use and/or enhance infiltration, particularly for new development in areas where higher stress is anticipated in the future. Examples for consideration include the following:

- It is recognized that there are limited data regarding actual water use outside of water service areas. Water metering, either through voluntary programs with the RDN or as required for groundwater licensing under the WSA (see below), not only provide data required to reduce uncertainty and refine the assumptions in the water balance analysis, but also provide the basis for participants to understand their actual water use and what cost savings there could be from conservation (e.g., electricity costs), thereby encouraging conservation. Metering is also discussed in Section 9.3.
- Limitations could be established for the size/capacity of a pump that is installed in a well to restrict water usage to a specified rate. Constant pressure systems can be equipped with variable speed pumps that are selected with a maximum flow rate that would be appropriate for typical domestic use, above which the pressure would drop, thereby encouraging conservation.
- For new development in areas of high water stress or aquifers with lower productivity, groundwater use could be supplemented with rainwater harvesting and/or secondary storage implemented to collect water during the wet season for use during drought periods.
- Groundwater protection measures could be implemented to limit ground disturbance and preserve natural soils and vegetation in order to promote infiltration of precipitation.
- Green stormwater management techniques such as permeable pavement and bioswales could also be implemented to capture precipitation and enhance infiltration into the subsurface. Green infrastructure not only increases groundwater recharge but can also improve water quality.

The results from the Phase 3 French Creek Water Budget project also provide a framework to develop a common understanding between organizations and support collaboration and joint decision-making. Examples are provided below:

- The Phase 3 French Creek Water Budget and other initiatives that the RDN is undertaking support engagement activities with local First Nations governments to discuss shared interests in managing water resources.
- The model and supporting analyses also provides a platform for the RDN to support the Province in the protection and regulation of surface water and groundwater. In addition to licensing, which may require non-domestic water users to meter water use, the Province also has a number of initiatives under the WSA that could be implemented, including area-based tools such as the development of WSA Objectives and Water Sustainability Plans (WSPs). It is anticipated that the Phase 3 French Creek Water Budget project provides the RDN with the basis to engage with the Province to share information and identify opportunities for collaboration.
- The results from the current project also provide the basis for municipal and private water suppliers to understand the impacts of groundwater pumping and to consider a coordinated, regional approach to managing water resources; however, the results of site-specific assessments should be considered when assessing conditions in specific areas and well field operations. The results from the capture zone analysis provide operators with the basis to understand potential risks to groundwater quality and develop wellhead protection plans.

9.3 Additional Data Requirements and Model Refinement

The numerical groundwater model that WSP developed for the Phase 3 French Creek Water Budget project provides a technical basis to identify areas of potential water stress at the regional scale and inform water management. Without additional refinements to site-specific conditions, the present model is not suitable for local-scale applications such as well field design and optimization. The model could be refined in certain areas and with more site-specific data for local scale applications.

The model should be considered a “working tool”, which should be periodically refined as additional information becomes available. During development of the model and refined water budget analysis, WSP identified supplemental data that, if obtained, could support planning and decision-making, as well as refinement of the model calibration and reducing uncertainty in the model predictions, if desired. Recommendations for additional data gathering are summarized below.

- <u>Water metering:</u> It is recognized that there are limited data regarding actual water usage outside the water service areas. Implementation of water metering on both residential and non-residential properties would reduce uncertainty and enable an improved understanding of groundwater usage in the Project Area. and provide the basis to refine model predictions.
- <u>Climate monitoring data:</u> Expansion of the climate monitoring station network in the Project Area could provide information required to refine local baseline conditions and 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 model. In particular, consideration could be given to restoring the former climate station at Coombs to obtain more recent climate information in areas at higher elevations in the French Creek watershed where significant changes in groundwater conditions are predicted for future

scenarios, in particular for climate change. Establishment of new climate stations in different locations across the Project Area, including higher elevations, would also support a refined understanding of the geospatial influence on climate variables.

- Refined estimates of recharge from precipitation: As discussed previously (Section 3.2.2 and Section 3.2.5.2), the recharge from precipitation that was estimated for the Phase 1 Water Budget Project by Waterline (2013) was considered appropriate for the regional scale of the numerical groundwater model that was developed for current Phase 3 assessments. Refined mapping of recharge variables could be conducted at a later time to further refine this model parameter and the calculated water balances if that is considered to be of value for planning purposes or for more detailed assessments in particular areas of the French Creek Water Region.
- Groundwater level monitoring: The existing eleven PGOWN monitoring wells and the five RDN volunteer monitoring wells are mainly located at lower elevations and provide good coverage where the most significant stress for current and future conditions is predicted (Aquifers 216, 217, 664 and 1250). However, it is recommended that monitoring wells be installed at strategic locations to assess hydraulic heads within aquifers located in the upper portions (i.e., higher elevation) of the watersheds and aquifers that were estimated to have a Moderate to High stress classification. The monitoring data from these new wells would enable assessment of 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 Aquifer 209, which is classified as Very High Stress, and in bedrock Aquifer 220 and upgradient areas where the most significant declines in hydraulic heads are predicted (i.e., above 150 m asl). If possible, it is recommended that inactive wells (i.e., not actively pumped) are selected for new monitoring wells to enable assessment of static water levels.
- Additional hydraulic testing in bedrock aquifers: During model calibration and sensitivity analysis, hydraulic conductivity of bedrock units has been identified as a parameter with a high degree of uncertainty. Additional assessment, including lineament analysis and hydraulic testing (long-term pumping tests, including monitoring of adjacent observation wells) would enable refinement of estimates of hydraulic conductivity for these units/aquifers and to reduce uncertainty in model predictions.
- Creek and river hydrometric monitoring: Hydrometric data for local water courses are limited, particularly over time. It is recommended that regular hydrometric monitoring be continued on French Creek at the Barclay station and that an additional hydrometric station be added upstream (e.g., re-establish the historical Coombs station) to obtain a more reliable estimate of flow and to confirm streamflow changes with location and over time. In addition to this, installation of new hydrometric stations in other creeks within the Project Area is suggested (i.e., Whiskey Creek, Morningstar Creek, Beach Creek), as no flow information is currently available for water courses other than French Creek. Information regarding the upper reaches of local waterbodies and inferred connections with groundwater in the Project Area would support refined assessment and confirm model assumptions. These monitoring data would also provide a means of assessing changes in groundwater baseflow over time and comparison to those predicted by the numerical model.
- Refined surface water assessment: Based on the results of the preliminary surface water assessment for French Creek, which was classified under the provincial EFN Policy as Risk Management Level 3 during the summer months (July to September), more detailed site-specific assessment of the potential impacts of additional withdrawals on flows in French Creek and other watercourses should be conducted to support EFN assessments and prior to making decisions to grant or decline future applications; site-specific detailed studies including consideration of biological and ecological aspects and water quality of French Creek and other water bodies would be beneficial to further characterize EFN and support decision-making.

- Water quality monitoring: While the focus of this project was primarily on water quantity (i.e., water budgets and stress assessments), additional water quality monitoring could also be implemented at key surface water and groundwater monitoring locations. In addition to programs that are currently being implemented such as the Community Watershed Monitoring Network (RDN, 2023), water quality monitoring could be conducted to assess variation in water quality over time and to 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.

10.0 CLOSURE

We trust this information is sufficient for your needs at this time. Should you have any questions or concerns, please do not hesitate to contact the undersigned

WSP Canada Inc.

Arianna Piazza, MASc, PEng
Principal Hydrogeologist

Richard Cunningham, MASc, PEng
Junior Water Resources Engineer

Reviewed by:

Mark Bolton, MSc, PGeo
Senior Principal Hydrogeologist

Chris Coles, MASc, PEng
Senior Principal Water Resource Engineer

AP/RC/CC/MB/syd

https://golderassociates.sharepoint.com/sites/150914/project files/6 deliverables/3.0_issued/21487784-003-r-rev1/21487784-003-r-rev1-water balance report-04dec_23.docx

Engineers and Geoscientists BC
Permit to Practice #1000200

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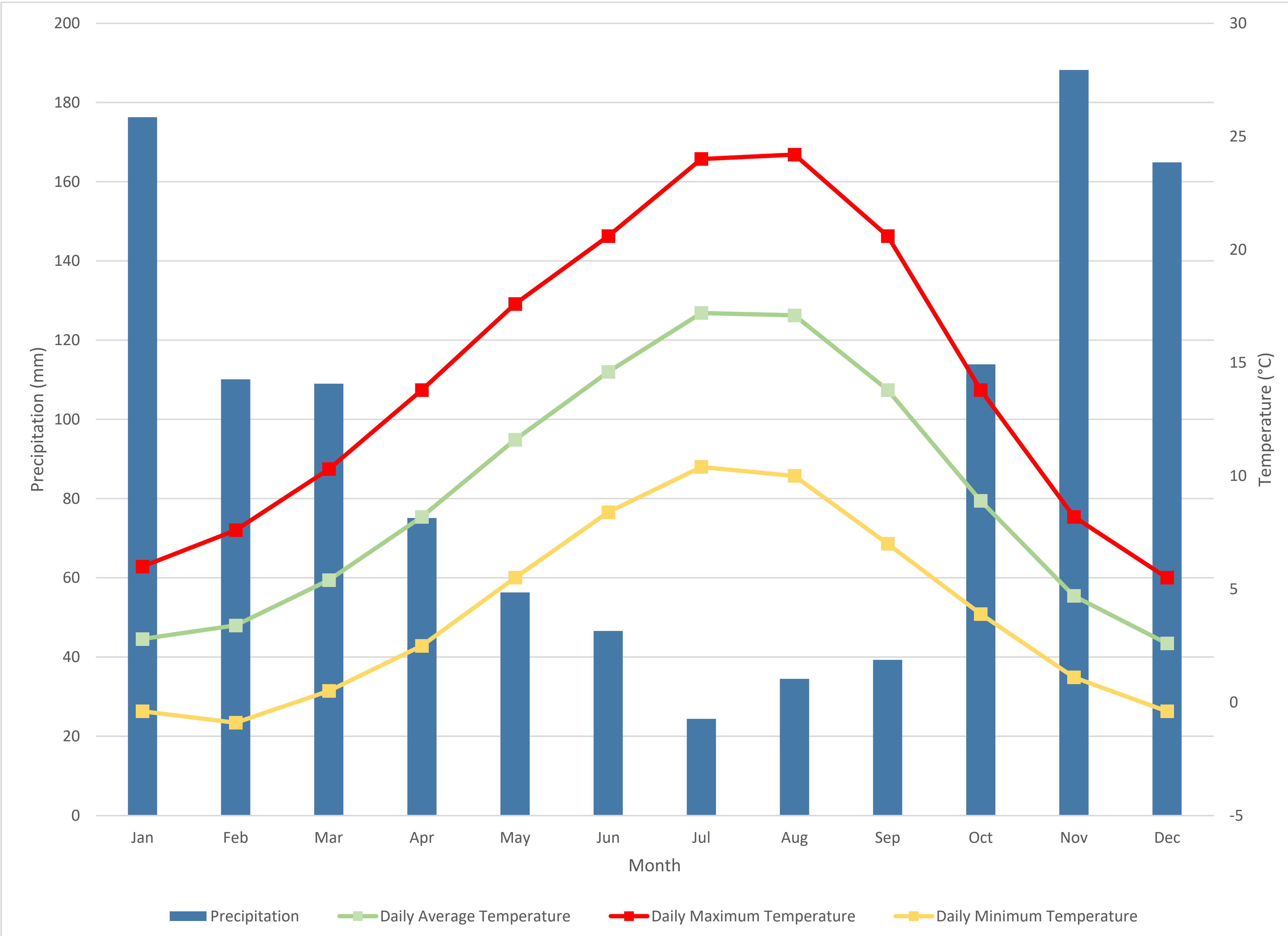
APPENDIX A

Climate Normals for Coombs Station



Precipitation (mm)
200
180
160
140
120
100
80
60
40
20
0
Temperature (°C)
30
25
20
15
10
5
0
-5
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Precipitation
Daily Average Temperature
Daily Maximum Temperature
Daily Minimum Temperature

Climate Normals 1981-2010 Station Data

Metadata including Station Name, Province, Latitude, Longitude, Elevation, Climate ID, WMO ID, TC ID

STATION_NAME	PROVINCE	LATITUDE	LONGITUDE	ELEVATION	CLIMATE_ID	WMO_ID	TC_ID
COOMBS	BC	49°18'21.000" N	124°25'45.000" W	98.1 m	1021850		

1981 to 2010 Canadian Climate Normals station data														
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Temperature														
Daily Average (°C)	2.8	3.4	5.4	8.2	11.6	14.6	17.2	17.1	13.8	8.9	4.7	2.6	9.2	C
Standard Deviation	1.4	1.6	1.1	0.9	1.3	1.1	1.1	1	1.1	0.9	1.7	1.5	1.4	C
Daily Maximum (°C)	6	7.6	10.3	13.8	17.6	20.6	24	24.2	20.6	13.8	8.2	5.5	14.4	C
Daily Minimum (°C)	-0.4	-0.9	0.5	2.5	5.5	8.4	10.4	10	7	3.9	1.1	-0.4	4	C
Extreme Maximum (°C)	15	18	22.5	26	30	33.5	35	33	33	24	17	17		
Date (yyyy/dd)	1984/28	1986/27	2004/29	1987/27	2005/28	1987/29	1998/27	Oct-90	Jan-87	Jan-87	Jun-06	2005/24		
Extreme Minimum (°C)	-14.5	-17.5	-9	-5	-3	2	3	2	-2	-8	-18	-18		
Date (yyyy/dd)	Jun-93	Apr-89	Mar-89	Sep-99	Oct-99	Apr-88	Jan-85	1992/23	1992/16	1984/31	1985/29	Jan-85		
Precipitation														
Rainfall (mm)	162.8	100.1	103.1	75.1	56.3	46.6	24.4	34.5	39.3	113.2	180.7	157.3	1093.2	C
Snowfall (cm)	13.5	10.1	5.9	0	0	0	0	0	0	0.7	7.5	7.6	45.2	C
Precipitation (mm)	176.3	110.1	109	75.1	56.3	46.6	24.4	34.5	39.3	113.9	188.2	164.9	1138.5	C
Average Snow Depth (cm)	2	2	0	0	0	0	0	0	0	0	1	1	1	C
Median Snow Depth (cm)	1	1	0	0	0	0	0	0	0	0	0	0	0	C
Snow Depth at Month-end (cm)	1	0	0	0	0	0	0	0	0	0	3	5	1	C
Extreme Daily Rainfall (mm)	80	60.8	83.2	121.2	27.4	31.8	32.6	65	29.6	52.6	57.2	85.9		
Date (yyyy/dd)	1961/14	Jan-91	1997/17	Jul-03	1984/25	Jan-62	Mar-98	1991/29	Oct-04	2003/17	2006/14	Dec-60		
Extreme Daily Snowfall (cm)	31	35	20	0	0.4	0	0	0	0	8.4	15.6	42		
Date (yyyy/dd)	Jun-05	Jan-89	Jan-91	Jan-61	Oct-85	Jan-61	Jan-61	Jan-61	Jan-61	1984/31	1985/26	1996/28		
Extreme Daily Precipitation (mm)	80	60.8	83.2	121.2	27.4	31.8	32.6	65	29.6	52.6	57.2	85.9		
Date (yyyy/dd)	1961/14	Jan-91	1997/17	Jul-03	1984/25	Jan-62	Mar-98	1991/29	Oct-04	2003/17	2006/14	Dec-60		
Extreme Snow Depth (cm)	41	40	29	0	0	0	0	0	0	6	33	81		
Date (yyyy/dd)	Aug-05	Feb-89	Feb-91	Jan-84	Jan-84	Jan-84	Jan-84	Jan-84	Jan-84	1991/29	1985/27	1996/30		
Days with Maximum Temperature														
<= 0 °C	1	0.22	0.05	0	0	0	0	0	0	0	0.83	1.4	3.5	C
> 0 °C	30	28	31	30	31	30	31	31	30	31	29.2	29.7	361.8	C
> 10 °C	2.1	4.8	15.8	26.3	30.7	30	31	31	30	26.5	7	1	236.2	C
> 20 °C	0	0	0.05	1.7	7.4	14.2	25.3	26.3	14.8	1.3	0	0	91	C
> 30 °C	0	0	0	0	0	1	2.3	1.4	0.09	0	0	0	4.8	C
> 35 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	C
Days with Minimum Temperature														
> 0 °C	12.6	10.3	14.9	21.5	29	30	31	31	29.5	24.8	16.7	12.4	263.6	C
<= 2 °C	23.4	21.1	21.5	15.6	5.6	0.13	0	0.04	1.8	11.4	18.2	23.4	142.2	C
<= 0 °C	18.4	17.3	16.1	8.5	2	0	0	0	0.52	6.2	13.3	18.6	100.8	C
< -2 °C	8.2	9	6.6	2.1	0.05	0	0	0	0	1.3	5.4	8.5	41.1	C
< -10 °C	0.71	0.96	0	0	0	0	0	0	0	0	0.48	0.3	2.5	C
< -20 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	C
< - 30 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	C
Days with Rainfall														
>= 0.2 mm	18	14.5	17.8	15.7	13.6	11.7	6.5	7	8	17.1	19.7	18	167.6	C
>= 5 mm	9.5	5.7	6.4	5.1	3.8	3.3	1.6	2	2.6	7	10.6	8.6	66.2	C
>= 10 mm	4.7	3.2	2.8	1.7	1.1	1	0.57	0.87	1.2	3.7	6.1	5.3	32.2	C
>= 25 mm	1.5	0.7	0.57	0.09	0.05	0	0.04	0.17	0.17	0.61	1.9	1.1	6.9	C
Days With Snowfall														
>= 0.2 cm	2.8	2	1.5	0	0.05	0	0	0	0	0.17	1.4	2.4	10.3	C
>= 5 cm	0.79	0.58	0.26	0	0	0	0	0	0	0.09	0.7	0.64	3.1	C
>= 10 cm	0.38	0.29	0.17	0	0	0	0	0	0	0	0.22	0.18	1.2	C
>= 25 cm	0.08	0.08	0	0	0	0	0	0	0	0	0	0	0.16	C
Days with Precipitation														
>= 0.2 mm	19.8	15.8	18.3	15.7	13.6	11.7	6.5	7	8	17.2	20.5	19.3	173.4	C
>= 5 mm	10.3	6.3	6.8	5.1	3.8	3.3	1.6	2	2.6	7	11.2	9.2	69.2	C
>= 10 mm	5.3	3.4	3.1	1.7	1.1	1	0.57	0.87	1.2	3.7	6.3	5.7	33.9	C
>= 25 mm	1.6	0.78	0.61	0.09	0.05	0	0.04	0.17	0.17	0.61	1.9	1.1	7.2	C
Days with Snow Depth														
>= 1 cm	5.4	3.6	1.2	0	0	0	0	0	0	0.04	1.7	3.9	15.8	D
>= 5 cm	3.9	2.7	0.85	0	0	0	0	0	0	0.04	1.1	2.2	10.8	D
>= 10 cm	2.7	2.3	0.45	0	0	0	0	0	0	0	0.77	0.9	7.1	D
>= 20 cm	0.45	1.2	0.05	0	0	0	0	0	0	0	0.32	0.3	2.3	D
Degree Days														
Above 24 °C	0	0	0	0	0	0	0.2	0	0	0	0	0	0.2	C
Above 18 °C	0	0	0	0	0.3	5.8	21.6	17.3	1.6	0	0	0	46.5	C
Above 15 °C	0	0	0	0.1	5.3	26.3	76.9	72.8	16.4	0.4	0	0	198.2	C
Above 10 °C	0	0.1	1	12.1	66.4	139.4	224.8	221	116.7	20.7	1.2	0.1	803.3	C
Above 5 °C	12.3	12.9	37.3	97.4	203.8	288.8	379.8	376	264.4	123.8	33.2	9.2	1838.8	C
Above 0 °C	98.4	103.6	168.1	244.9	358.7	438.8	534.8	531	414.4	274.5	146.4	90.5	3403.9	C
Below 0 °C	11.9	7.9	0.7	0	0	0	0	0	0	0.2	6.3	11.1	38	C
Below 5 °C	80.7	58.4	24.9	2.5	0.1	0	0	0	0	4.5	43.1	84.8	299.2	C
Below 10 °C	223.5	187	143.6	67.2	17.7	0.6	0	0	2.3	56.4	161	230.7	1090	C
Below 15 °C	378.5	328.2	297.6	205.2	111.7	37.5	7.2	6.8	52	191.1	309.9	385.6	2311.1	C
Below 18 °C	471.5	412.9	390.6	295.1	199.6	107	44.8	44.3	127.2	283.7	399.9	478.6	3255.2	C

1981 to 2010 Canadian Climate Normals station data (Frost-Free)							
	Frost-Free:	Code					
Average Date of Last Spring Frost	08-May	C					
Average Date of First Fall Frost	09-Oct	C					
Average Length of Frost-Free Period	153 Days	C					
Probability of last temperature in spring of 0 °C or lower on or after indicated dates	10%	25%	33%	50%	66%	75%	90%
Date	22-May	15-May	13-May	07-May	02-May	30-Apr	18-Apr
Probability of first temperature in fall of 0 °C or lower on or before indicated dates	10%	25%	33%	50%	66%	75%	90%
Date	24-Sep	27-Sep	30-Sep	05-Oct	15-Oct	20-Oct	30-Oct
Probability of frost-free period equal to or less than indicated period (Days)	10%	25%	33%	50%	66%	75%	90%
Days	128	139	143	157	161	167	179

Legend

A = WMO "3 and 5 rule" (i.e. no more than 3 consecutive and no more than 5 total missing for either temperature or precipitation)

B = At least 25 years

C = At least 20 years

D = At least 15 years

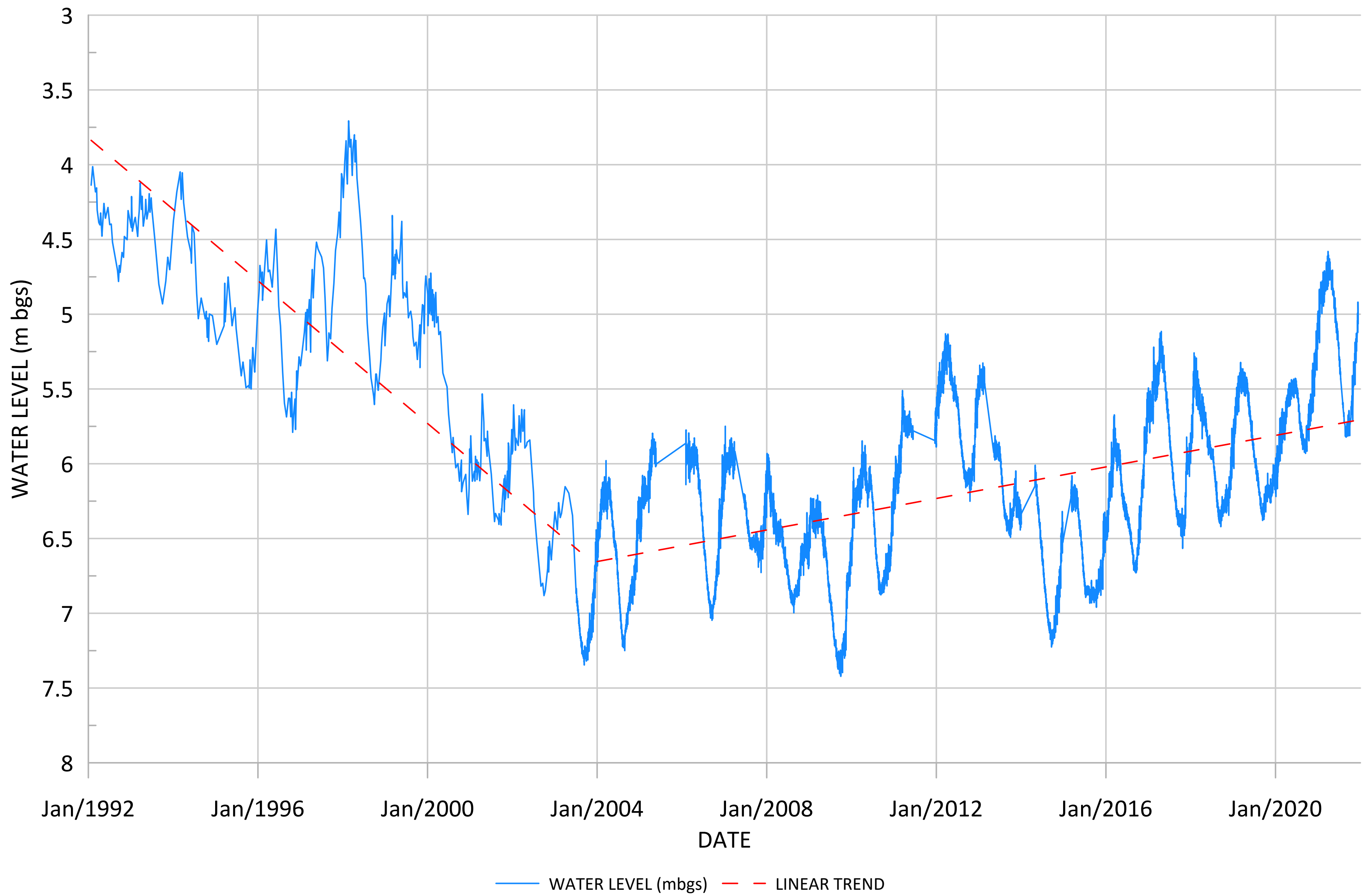
APPENDIX B

Hydrographs for PGOWN and RDN Voluntary Monitoring Wells

(1)Moving average based on data from 2004-2020.

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 FRENCH CREEK
CONSULTANT	WSP
YYYY-MM-DD	2023-01-24
PREPARED	RKS
DESIGN	RKS
REVIEW	AP
APPROVED	MAB
TITLE	BC ENV OBS WELL 304 - WATER LEVELS (AQUIFER 216)
PROJECT No.	21487784
PHASE	5000
REV	0
FIGURE	B1



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

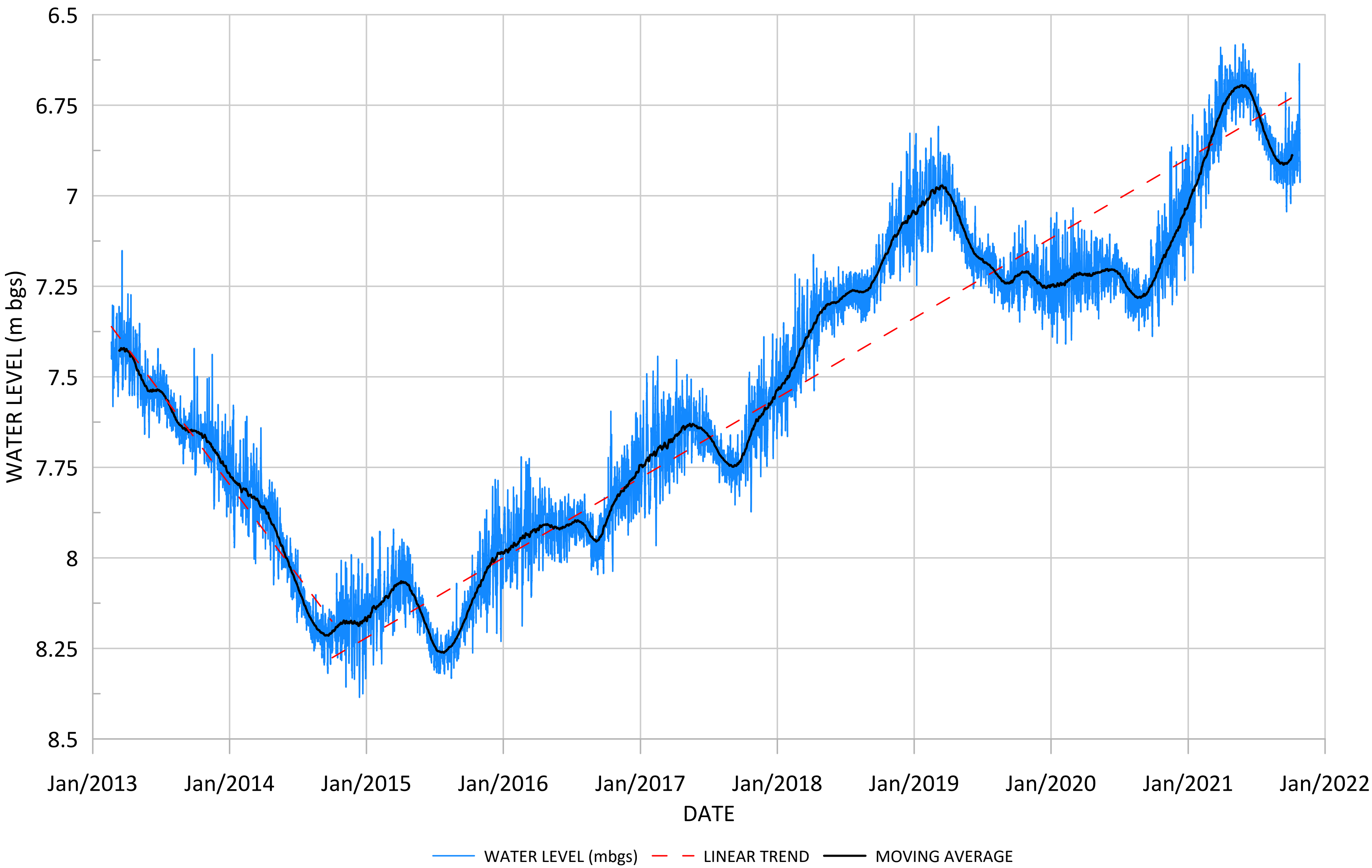
PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

CONSULTANT

YYYY-MM-DD	2023-01-24
PREPARED	RKS
DESIGN	RKS
REVIEW	AP
APPROVED	MAB

TITLE
BC ENV OBS WELL 314 - WATER LEVELS (AQUIFER 216)

PROJECT No.	PHASE	REV	FIGURE
21487784	5000	0	B2



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

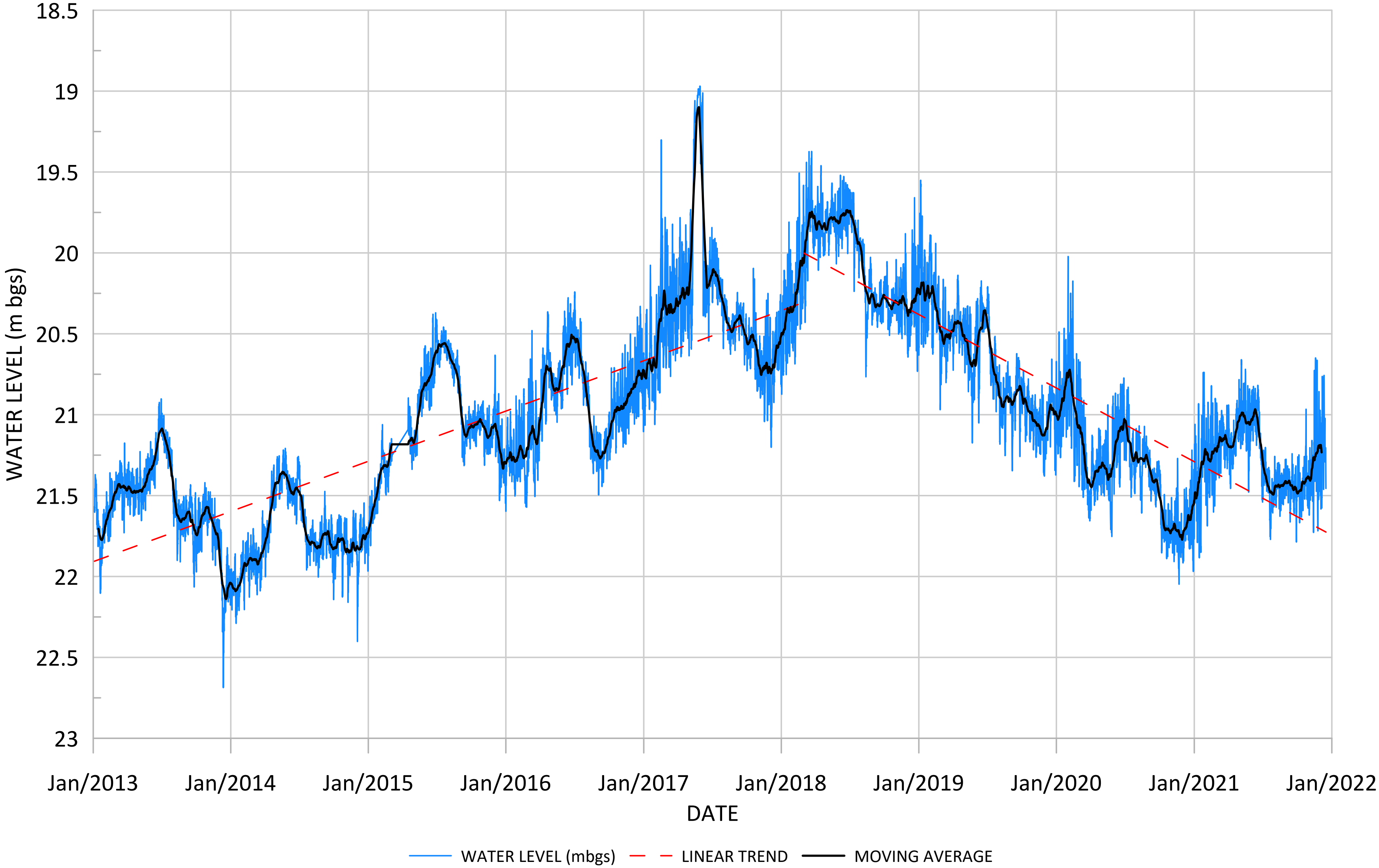
PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

CONSULTANT

YYYY-MM-DD	2023-01-24
PREPARED	RKS
DESIGN	RKS
REVIEW	AP
APPROVED	MAB

TITLE
BC ENV OBS WELL 398 - WATER LEVELS (AQUIFER 216)

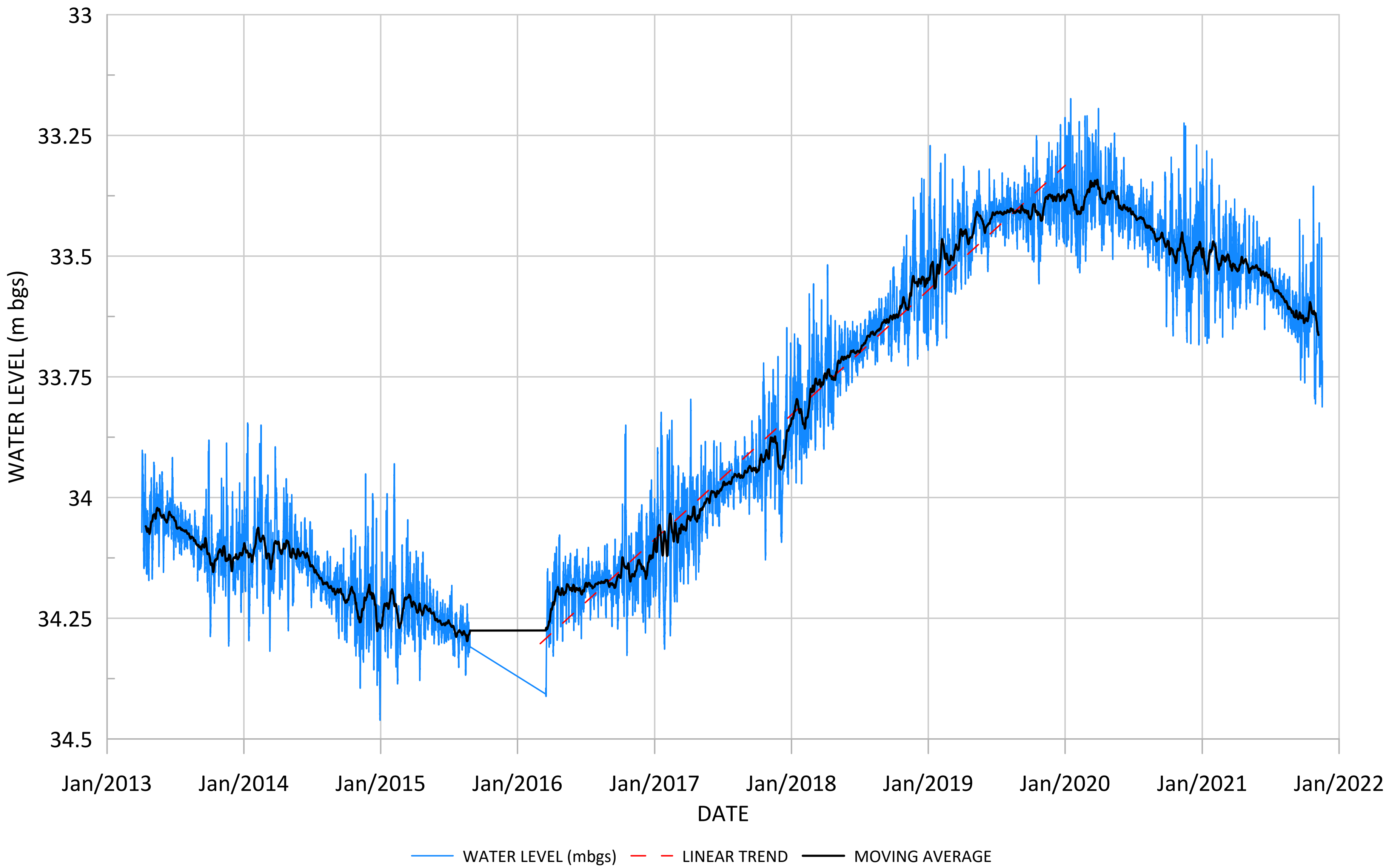
PROJECT No.	PHASE	REV	FIGURE
21487784	5000	0	B3



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

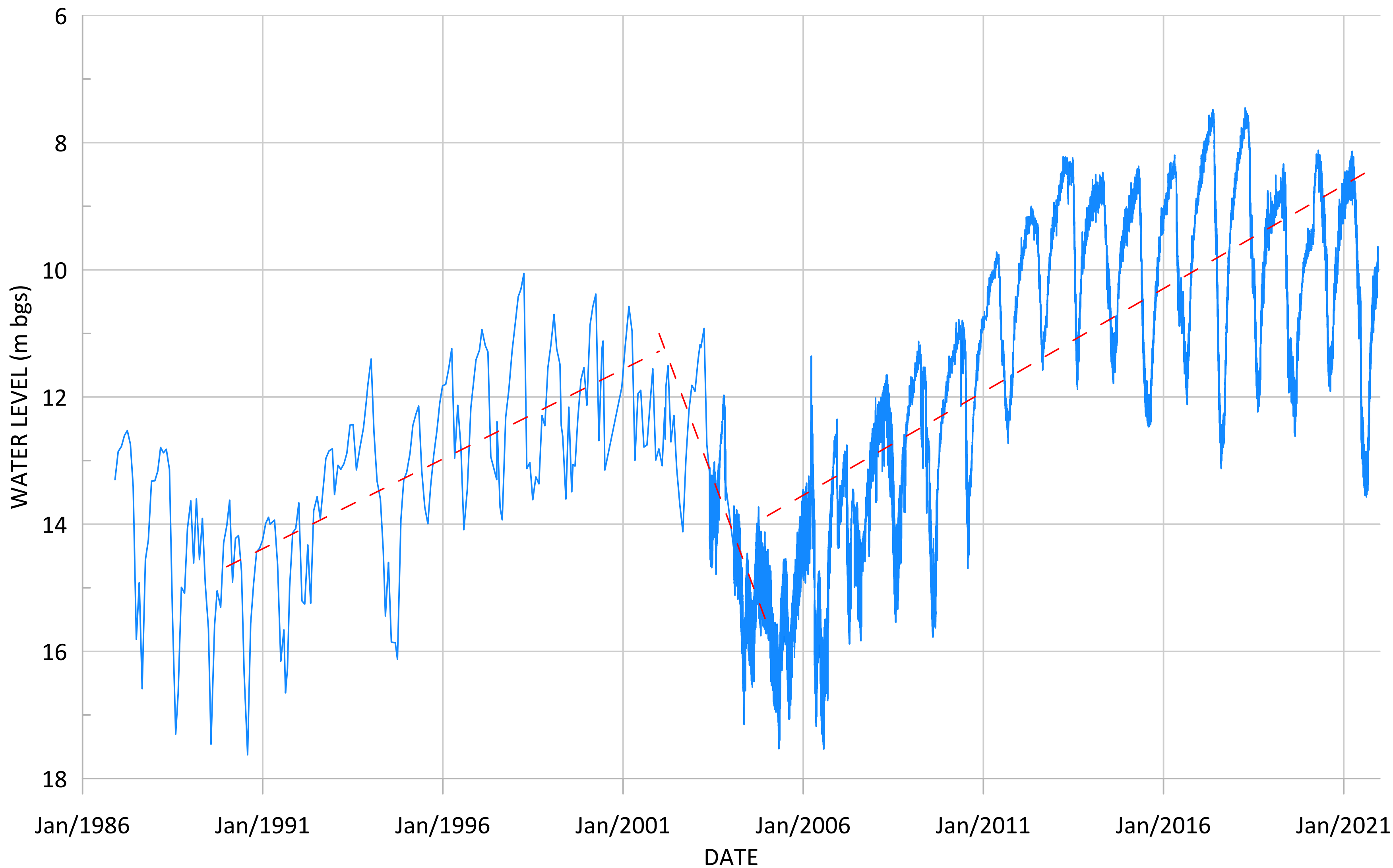
CLIENT	REGIONAL DISTRICT OF NANAIMO
PROJECT	REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK
CONSULTANT	WSP
YYYY-MM-DD	2023-01-24
PREPARED	RKS
DESIGN	RKS
REVIEW	AP
APPROVED	MAB
TITLE	BC ENV OBS WELL 424 - WATER LEVELS (AQUIFER 216)

PROJECT No.	PHASE	REV	FIGURE
21487784	5000	0	B4



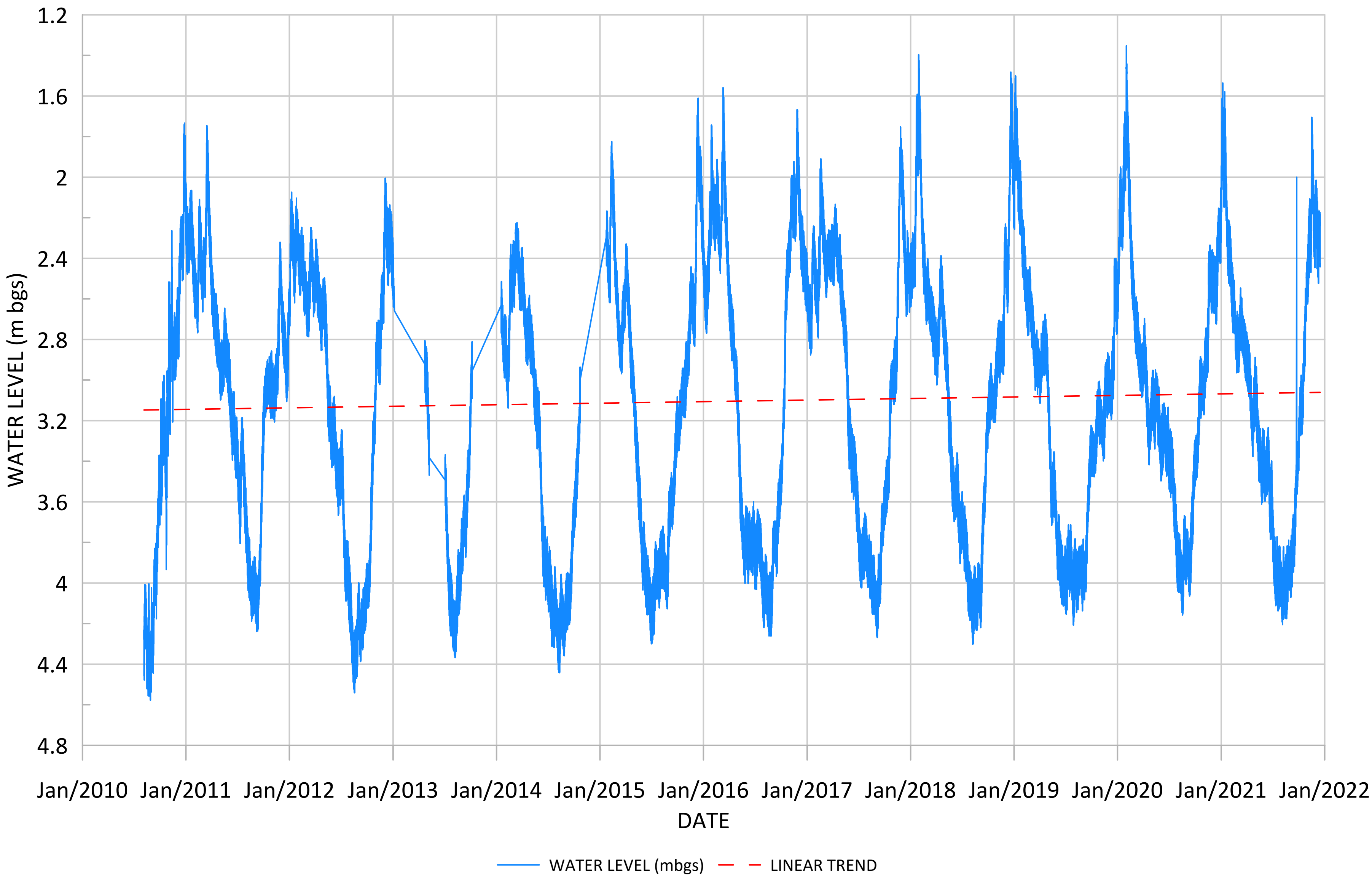
Groundwater Level Data from Aquarius Web Portal (http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CLIENT	REGIONAL DISTRICT OF NANAIMO
PROJECT	REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK
CONSULTANT	WSP
YYYY-MM-DD	2023-01-24
PREPARED	RKS
DESIGN	RKS
REVIEW	AP
APPROVED	MAB
TITLE	BC ENV OBS WELL 434 - WATER LEVELS (AQUIFER 217)
PROJECT No.	21487784
PHASE	5000
REV	0
FIGURE	B5



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 FRENCH CREEK
CONSULTANT wsp YYYY-MM-DD 2023-01-24 PREPARED RKS DESIGN RKS REVIEW AP APPROVED MAB	TITLE BC ENV OBS WELL 295 - WATER LEVELS (AQUIFER 217) PROJECT No. 21487784 PHASE 5000 REV 0 FIGURE B6



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

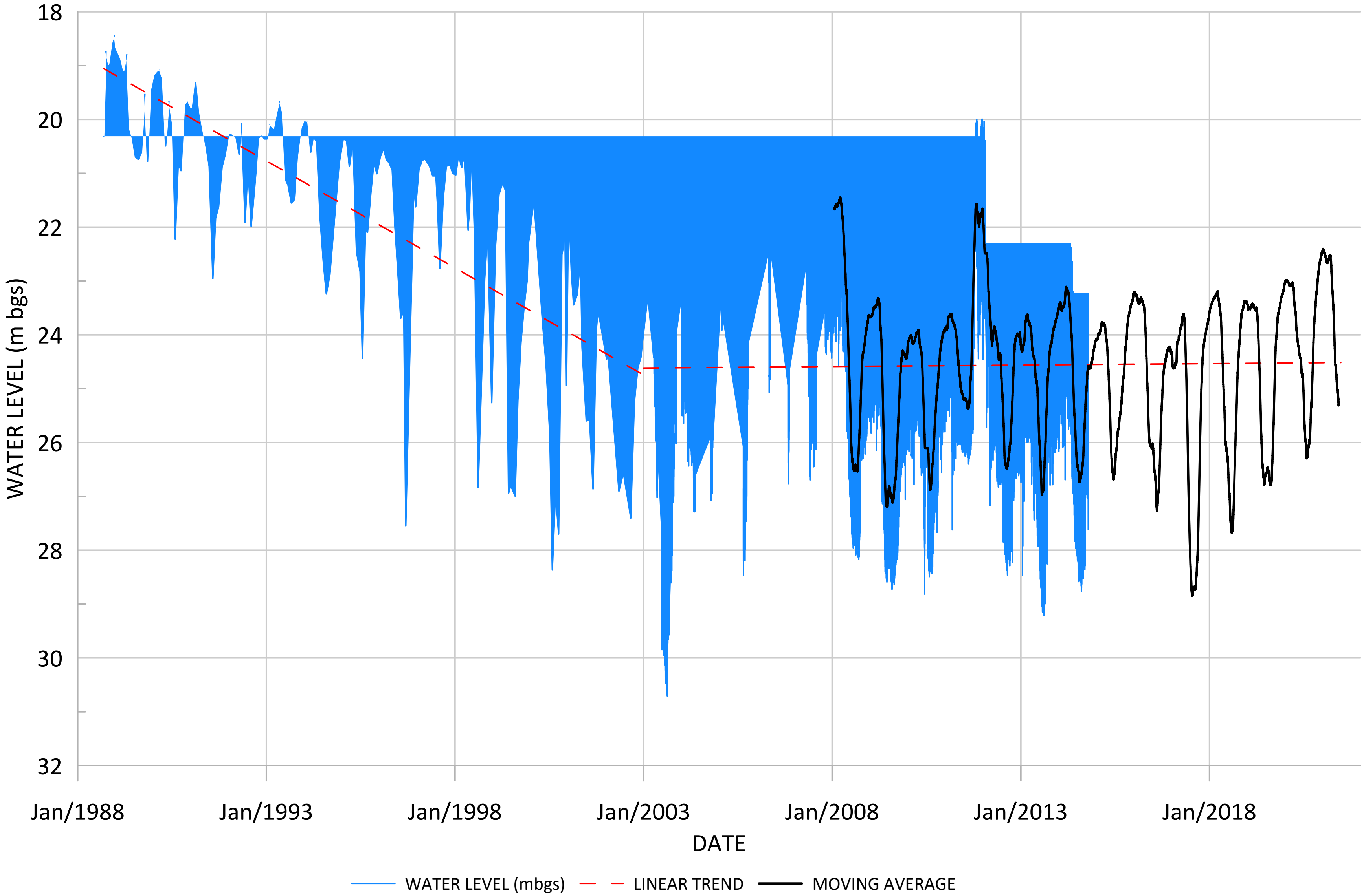
PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

CONSULTANT

YYYY-MM-DD	2023-01-24
PREPARED	RKS
DESIGN	RKS
REVIEW	AP
APPROVED	MAB

TITLE
BC ENV OBS WELL 389 - WATER LEVELS (AQUIFER 664)

PROJECT No.	PHASE	REV	FIGURE
21487784	5000	0	B7



CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

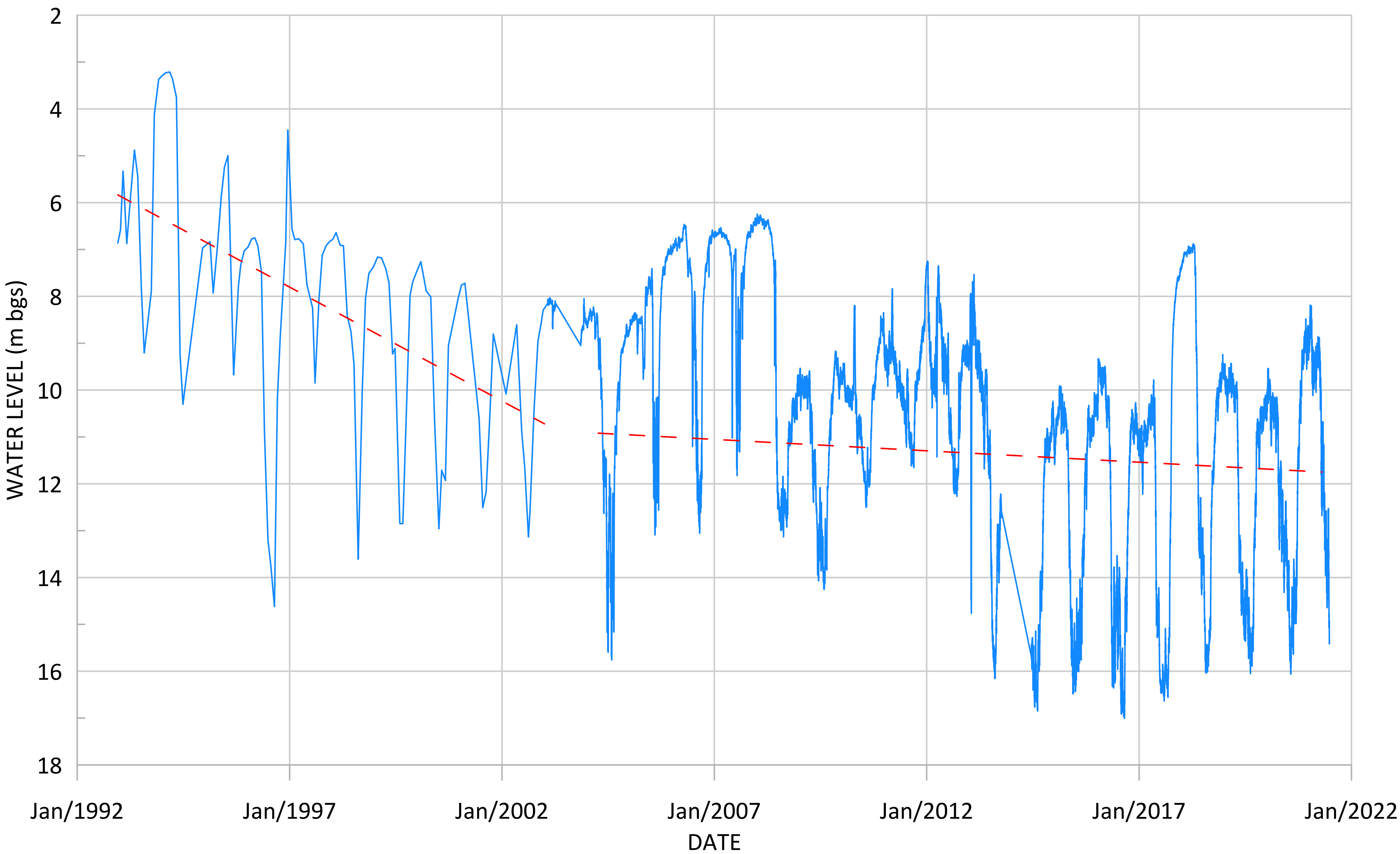
Groundwater Level Data from Aquarius Web Portal (http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CONSULTANT
wsp

YYYY-MM-DD	2023-01-24
PREPARED	RKS
DESIGN	RKS
REVIEW	AP
APPROVED	MAB

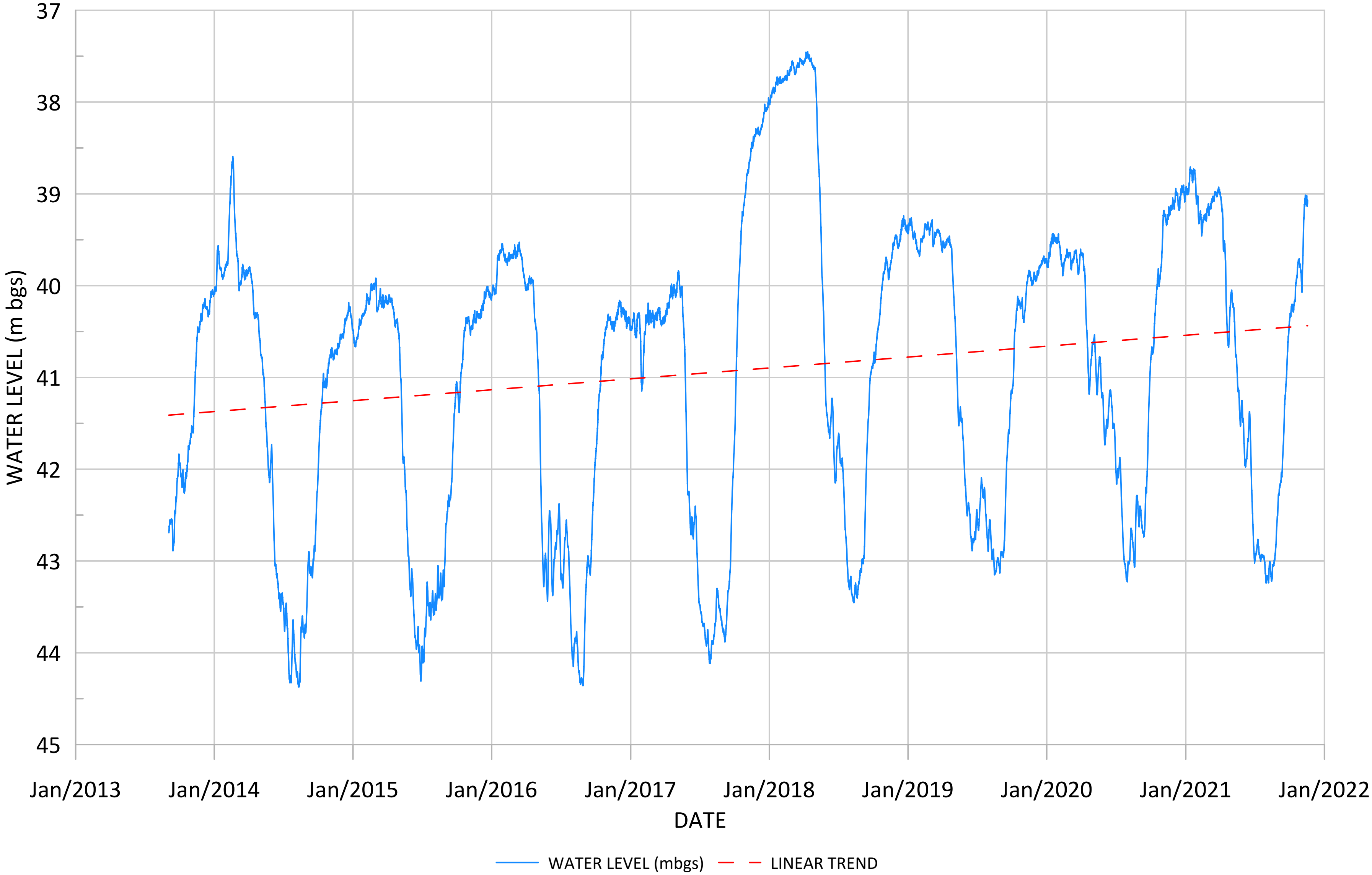
TITLE
BC ENV OBS WELL 303 - WATER LEVELS (AQUIFER 1250)

PROJECT No.	PHASE	REV	FIGURE
21487784	5000	0	B8



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 FRENCH CREEK
CONSULTANT	YYYY-MM-DD: 2023-01-24	TITLE	BC ENV OBS WELL 321 - WATER LEVELS (AQUIFER 1250)
	PREPARED: RKS		
	DESIGN: RKS		
	REVIEW: AP	PROJECT No. 21487784	PHASE 5000
	APPROVED: MAB	REV 0	FIGURE B9



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

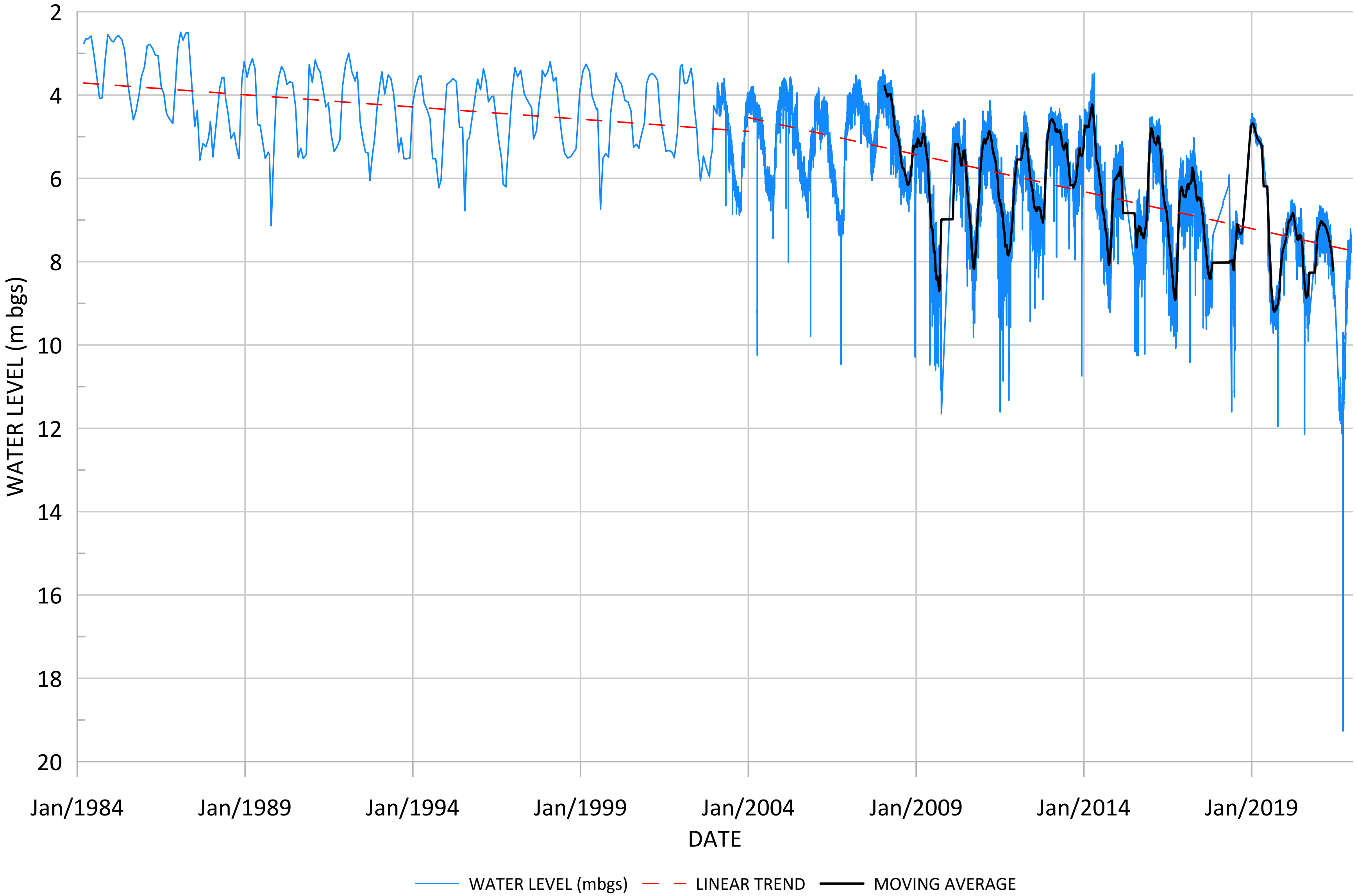
PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

CONSULTANT

YYYY-MM-DD	2023-01-24
PREPARED	RKS
DESIGN	RKS
REVIEW	AP
APPROVED	MAB

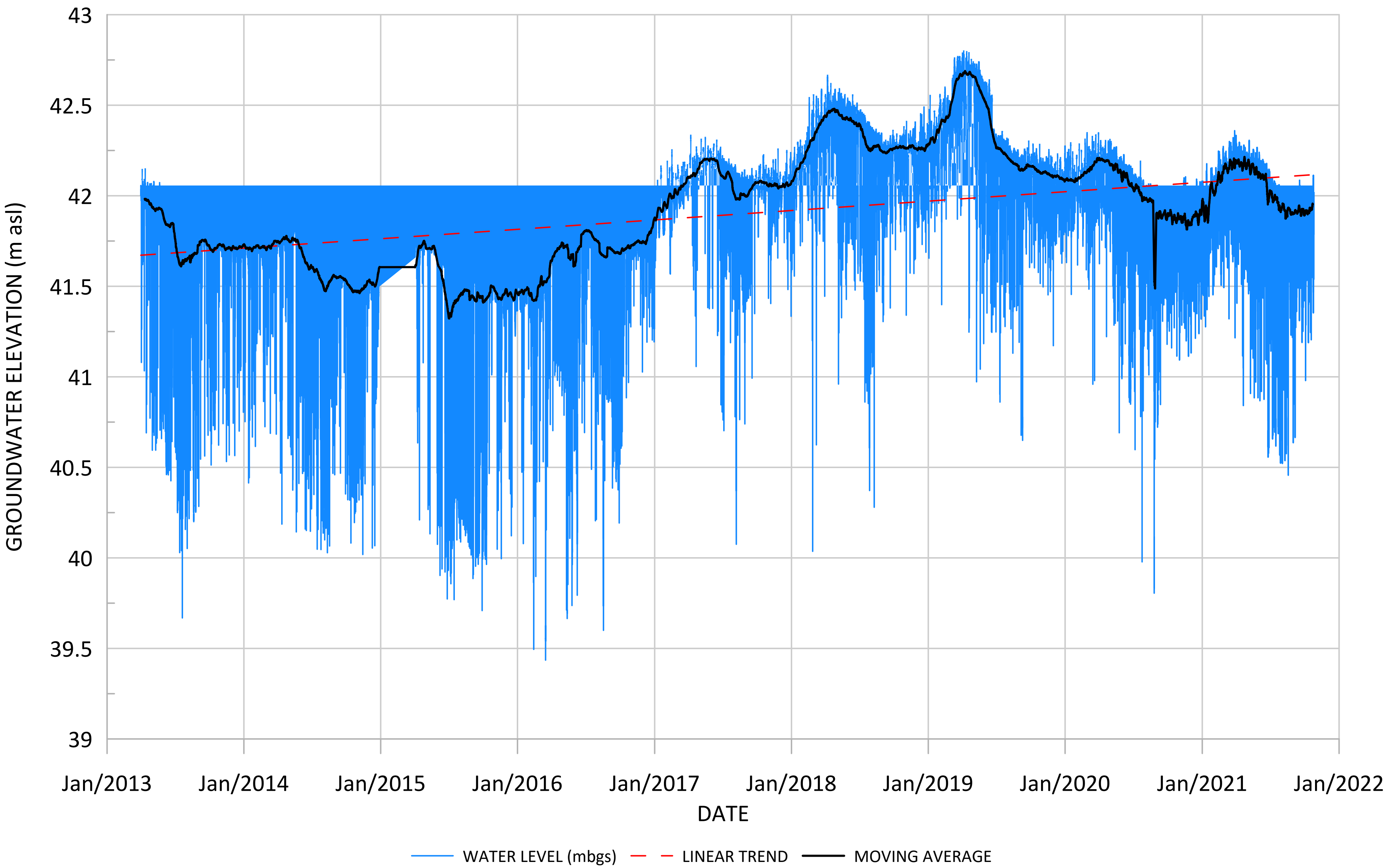
TITLE
BC ENV OBS WELL 433 - WATER LEVELS (AQUIFER 1250)

PROJECT No.	PHASE	REV	FIGURE
21487784	5000	0	B10



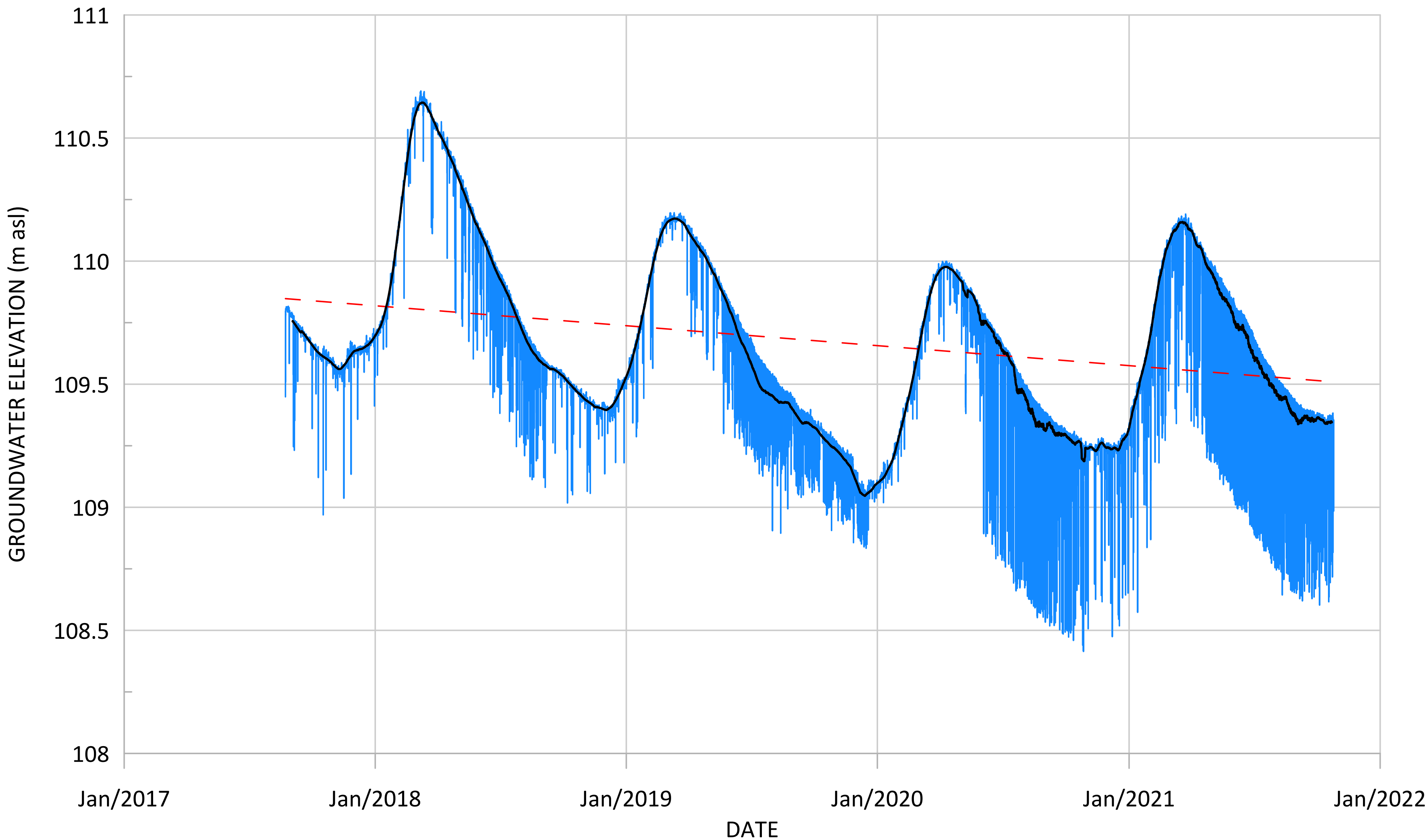
Groundwater Level Data from Aquarius Web Portal (http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CLIENT REGIONAL DISTRICT OF NANAIMO		PROJECT REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK	
CONSULTANT wsp	YYYY-MM-DD: 2023-01-24 PREPARED: RKS DESIGN: RKS REVIEW: AP APPROVED: MAB	TITLE BC ENV OBS WELL 287 - WATER LEVELS (AQUIFER 220)	
		PROJECT No. 21487784	PHASE 5000 / REV 0 / FIGURE B11



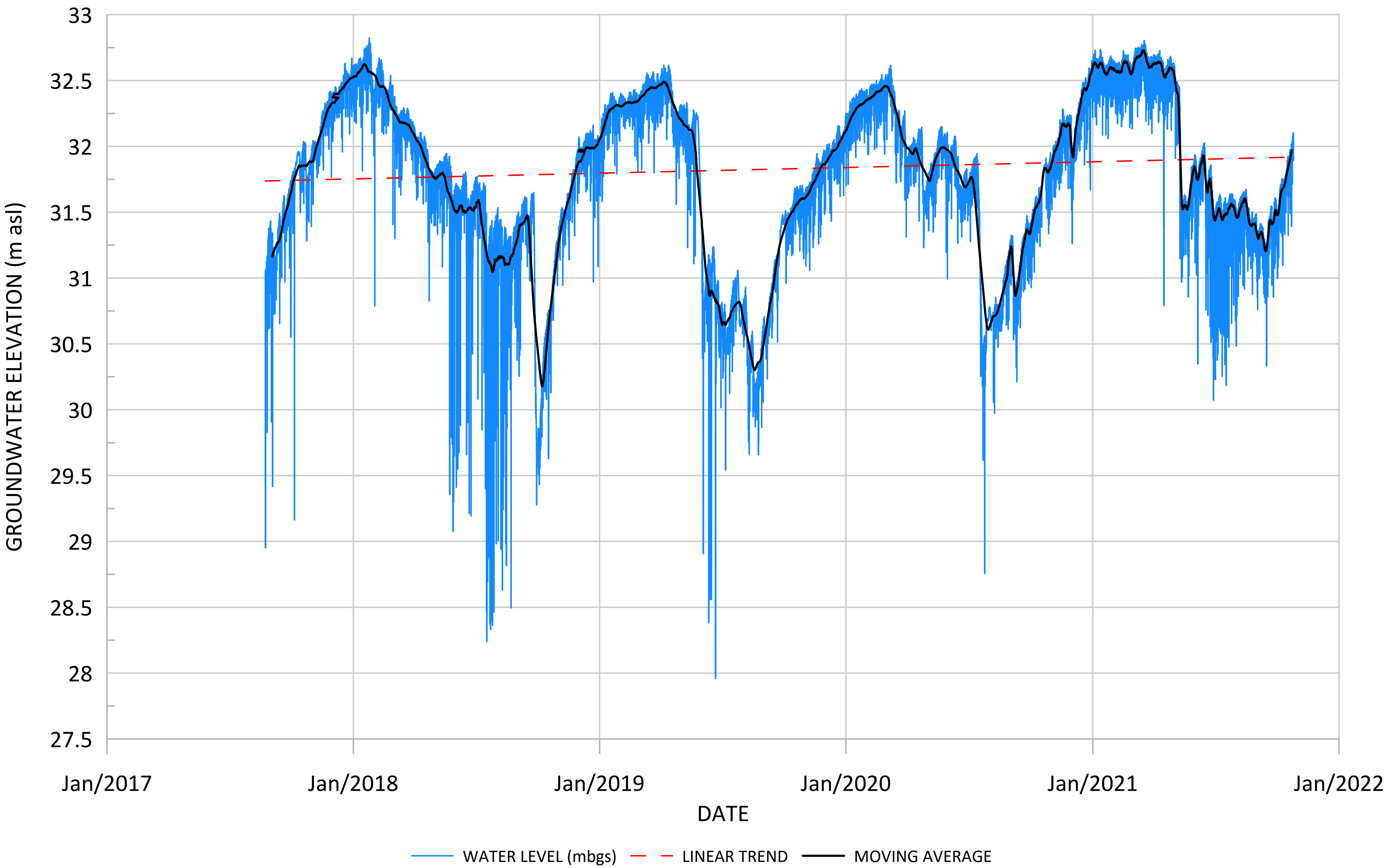
Groundwater Level Data from Aquarius Web Portal (http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CLIENT	REGIONAL DISTRICT OF NANAIMO
PROJECT	REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK
CONSULTANT	WSP
YYYY-MM-DD	2023-01-24
PREPARED	RKS
DESIGN	RKS
REVIEW	AP
APPROVED	MAB
TITLE	RDN VOLUNTARY WELL VOW 1 - WATER LEVELS (AQUIFER 216)
PROJECT No.	21487784
PHASE	5000
REV	0
FIGURE	B12



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 FRENCH CREEK	
CONSULTANT	YYYY-MM-DD: 2023-01-24 PREPARED: RKS DESIGN: RKS REVIEW: AP APPROVED: MAB	TITLE RDN VOLUNTARY WELL VOW 16 - WATER LEVELS (AQUIFER 217)	
		PROJECT No. 21487784	PHASE 5000 · REV 0 · FIGURE B13



CLIENT	PROJECT
REGIONAL DISTRICT OF NANAIMO	REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

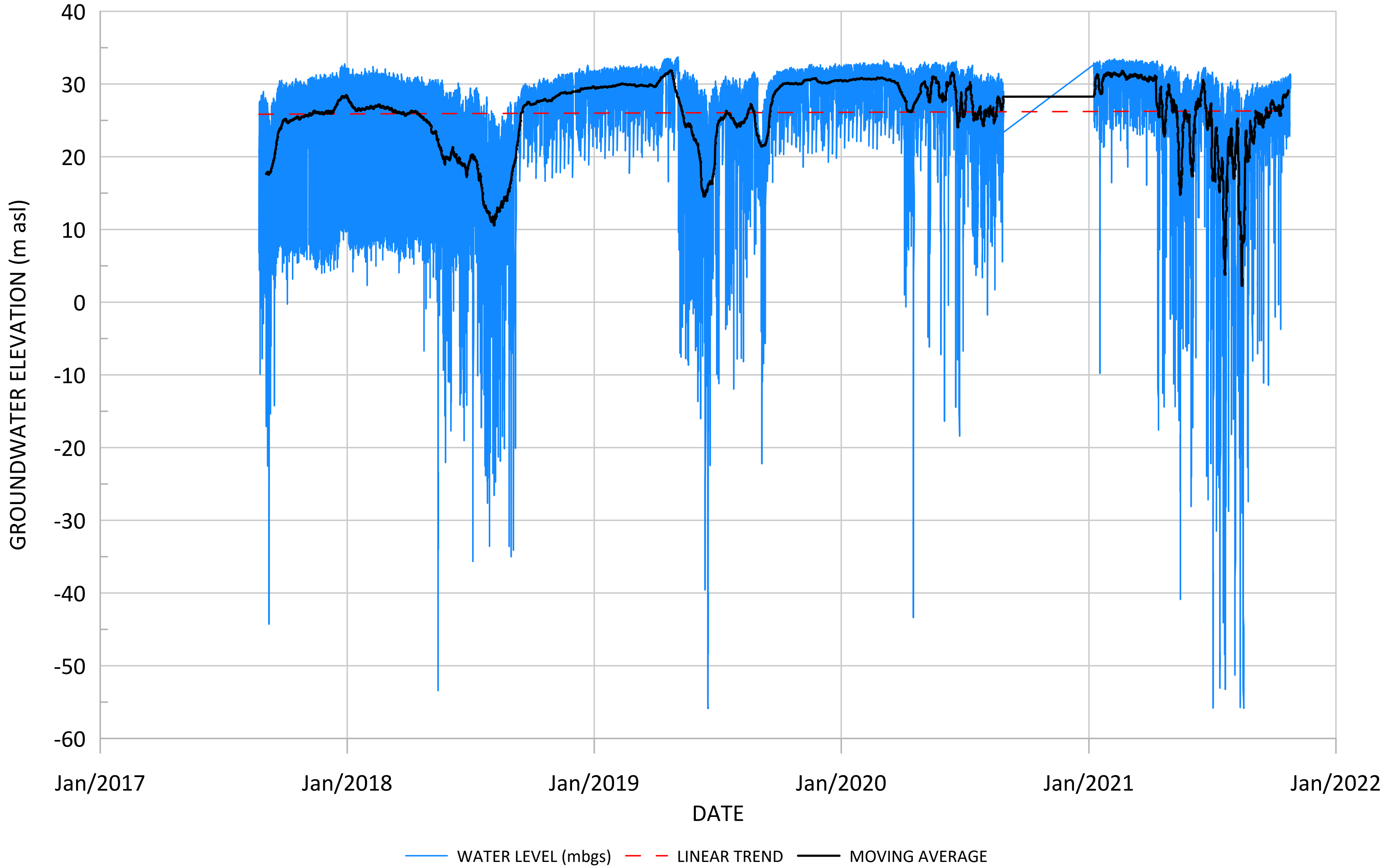
Groundwater Level Data from Aquarius Web Portal (http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CONSULTANT: wsp

YYYY-MM-DD	2023-01-24
PREPARED	RKS
DESIGN	RKS
REVIEW	AP
APPROVED	MAB

TITLE
RDN VOLUNTARY WELL VOW 14 - WATER LEVELS (AQUIFER 1250)

PROJECT No.	PHASE	REV	FIGURE
21487784	5000	0	B14



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

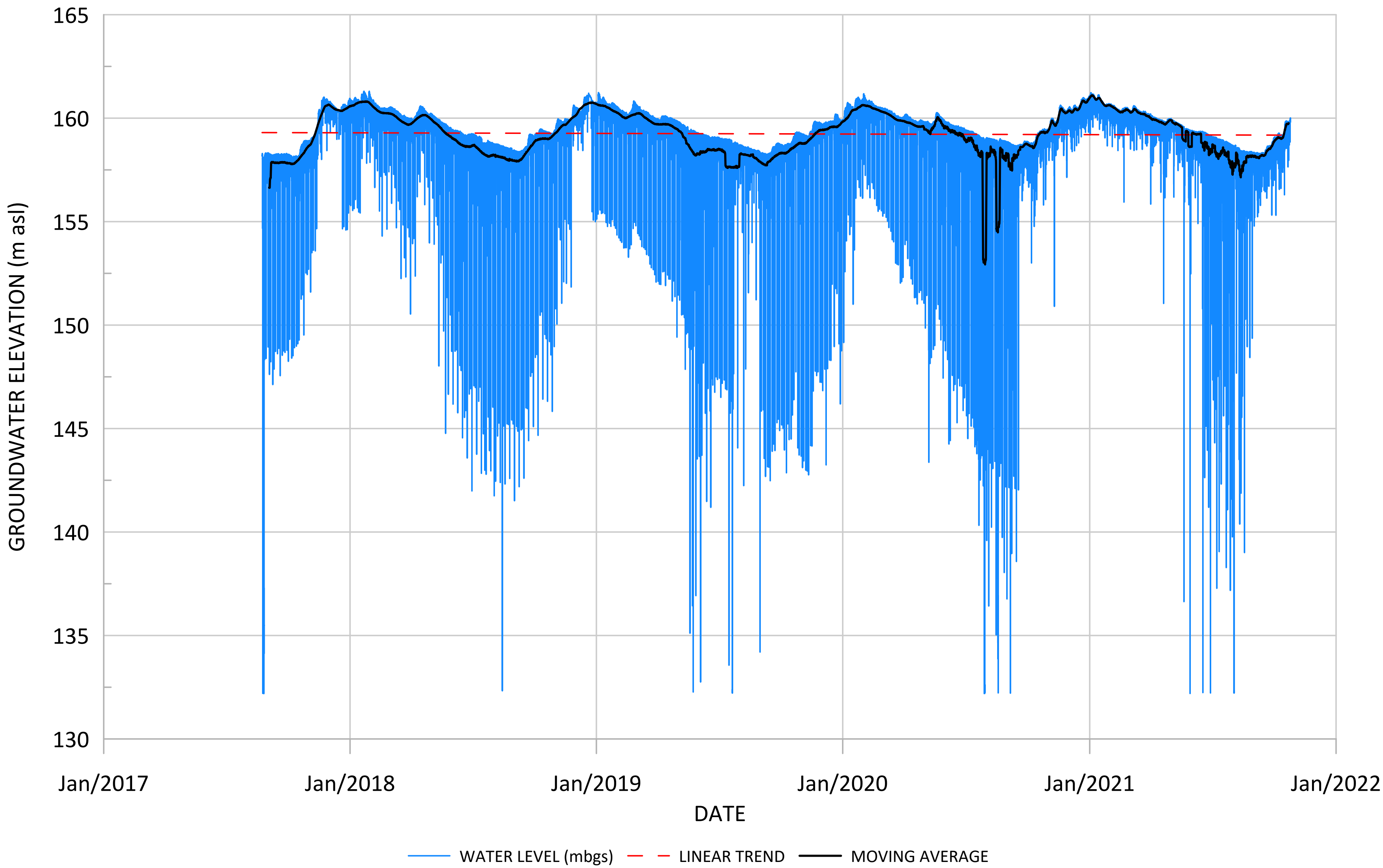
PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

CONSULTANT

YYYY-MM-DD	2023-01-24
PREPARED	RKS
DESIGN	RKS
REVIEW	AP
APPROVED	MAB

TITLE
RDN VOLUNTARY WELL VOW 15 - WATER LEVELS (AQUIFER 212)

PROJECT No.	PHASE	REV	FIGURE
21487784	5000	0	B15



CLIENT REGIONAL DISTRICT OF NANAIMO	PROJECT REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

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

CONSULTANT

YYYY-MM-DD	2023-01-24
PREPARED	RKS
DESIGN	RKS
REVIEW	AP
APPROVED	MAB

TITLE
RDN VOLUNTARY WELL VOW 18 - WATER LEVELS (AQUIFER 220)

PROJECT No.	PHASE	REV	FIGURE
21487784	5000	0	B16

APPENDIX C

Estimated Water Usage

Table C1: Metered Water Use Summary for Residential and Commercial Properties (2021)

2021	RDN French Creek [1]		
Account Type	Average Annual Consumption (L/day)	Average Winter Consumption (L/day)	Average Summer Consumption (L/day)
Residential	567	516	639
Commercial	-	-	-

2021	EPCOR		
Account Type	Average Annual Consumption (L/day)	Average Winter Consumption (L/day)	Average Summer Consumption (L/day)
Residential	-	-	577
Commercial	-	-	2862
Golf course only	-	-	3069

2021	Qualicum Beach		
Account Type	Average Annual Consumption (L/day)	Average Winter Consumption (L/day)	Average Summer Consumption (L/day)
Residential	840	524	1185
Commercial	2470	2165	3006

Notes

Summary of water use data for winter, summer and average derived from the metered water use data from residential and commerical properties provided:

1. Regional District of Nanaimo
2. EPCOR (North and South Well field)
3. Town of Qualicum Beach

Table C2: Properties Contained Within the Land Use Inventory and the Agricultural Land Use Inventory

Land Use Category	N. Parcels	Area (ha)
Agriculture	21	283
Commercial & service	4	12
Forestry	49	3134
Industrial	19	184
Institutional & community	11	27
Land in transition	1	2
No apparent use	138	1017
Protected area / park / reserve	3	136
Recreation & leisure	9	91
Recreation & leisure - golf	6	213
Residential	887	3970
Transportation	27	438
Transportation - airport	1	13
Utilities	12	174
Wildlife management	2	34

Notes
Land use and Land cover categories obtained from the Agricultural Land Use Inventory (ALUI; 2012) and the RDN Agricultural Water Demand Model (2013)

Coverage Type	N. Lots	Area (ha)
Anthropogenic - Artificial Waterbodies	164	36.0
Bare area	51	26.1
Blackberries	1	0.1
Blueberries	22	57.1
Bulbs	1	0.2
Cabin / cottage	4	0.3
Camp site / RV park	7	13.1
Church, cemetery	2	0.3
Closed	5	1.5
Club house	3	0.7
Community hall	1	0.2
Crop transition	1	0.2
Cucurbits	1	0.4
Cultivated land	1	5.9
Ditch	14	9.8
Duplex	27	2.6
Empty	1	0.1
Estate house	15	2.3
Exhibition hall	2	0.3
Extraction, mine	1	5.6
Fallow land	3	0.8
Farm	447	76.7
Fibre/pulp/veneer trees	2	12.6
Fire / police station	1	0.2
Floriculture	5	0.5
Forage corn	1	28.3
Golf fairway / green	76	28.0
Grapes	1	1.0
Grass	452	1371.9
Grass / open treed	21	20.9
Grassland	98	95.7
Hazelnut / filbert	1	1.8
Herbaceous	3	1.8
Hotel style	1	0.1
Incinerator, composting facility	2	11.9
Industrial equipment shop	2	0.5
Industrial storage	1	0.1
Junk yard	1	2.2
Kennels	3	0.3
Landscape lawn	315	193.7
Large house	115	14.7
Leafy vegetables	4	1.9
Lumber, log yard	1	0.7
Market shops	2	0.2
Medium house	802	82.5
Mill-type factory	1	0.2
Mixed berries	3	0.7
Mixed vegetables	11	6.4
Mobile home park	3	4.7
Museum, library	1	0.5

Table C3: 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:

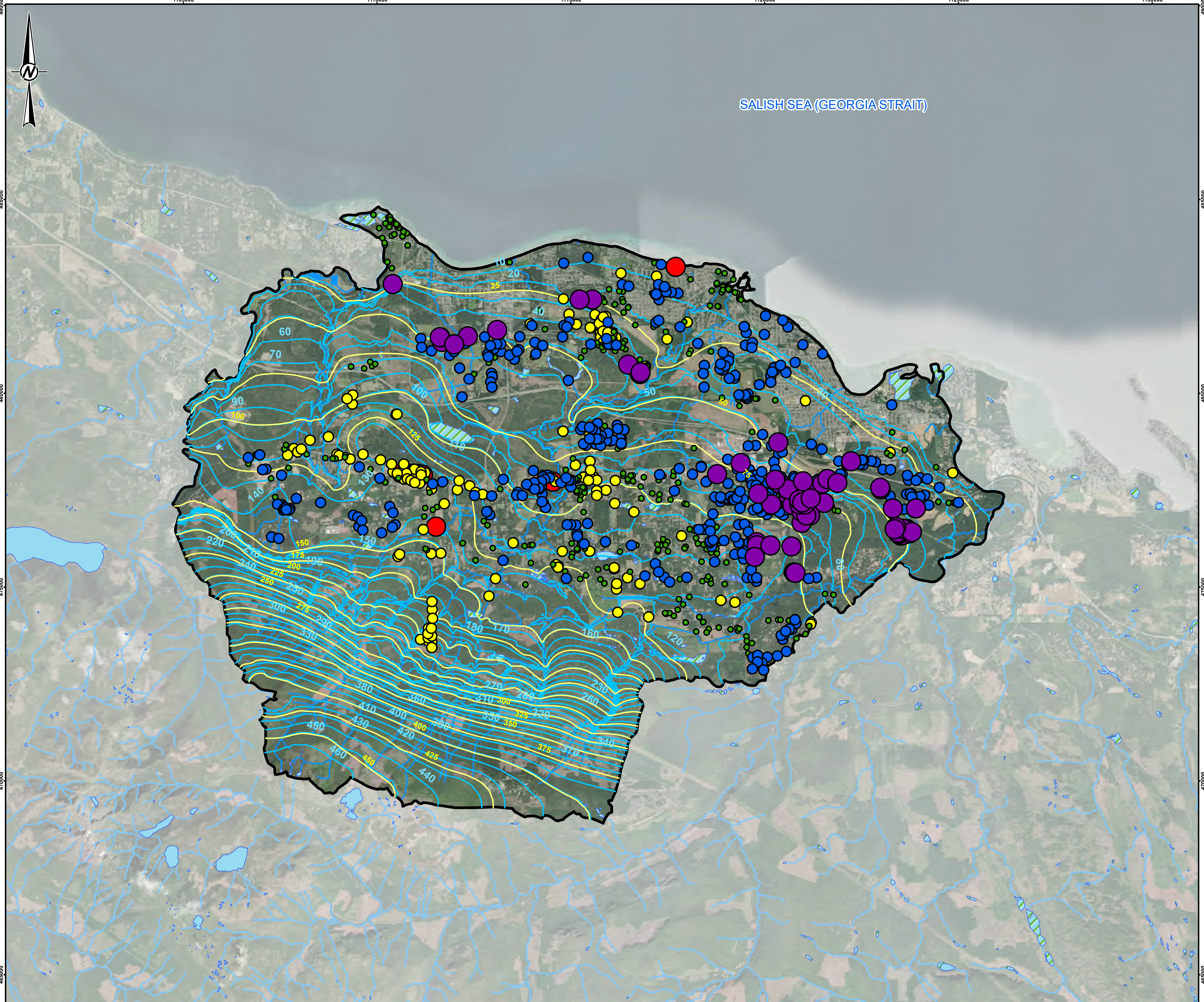
[1]Values from Appendix Table A and B (2003 and 1997 Water Demand by Crop with Average Management) of the RDN Agricultural Water Demand Study (May, 2013).
For the purpose of estimating water use in the non serviced properties, 2003 irrigation requirements values were used as conservative assumption.

[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

Model Calibration Residuals



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

Residual (Calculated - Observed)

- < -25 m
- -25 -to -5 m
- 5 to 5 m
- 5 to 25 m
- > 25 m
- Hydraulic Head Contour in Overbuden (masl)
- Hydraulic Head Contour in Bedrock (masl)

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
2. PROJECT AREA CREATED BY GOLDER ASSOCIATES LTD.
3. IMAGERY COPYRIGHT ESRI AND ITS LICENSORS. SOURCE: DITIGAL GLOBE. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE:20160912

COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

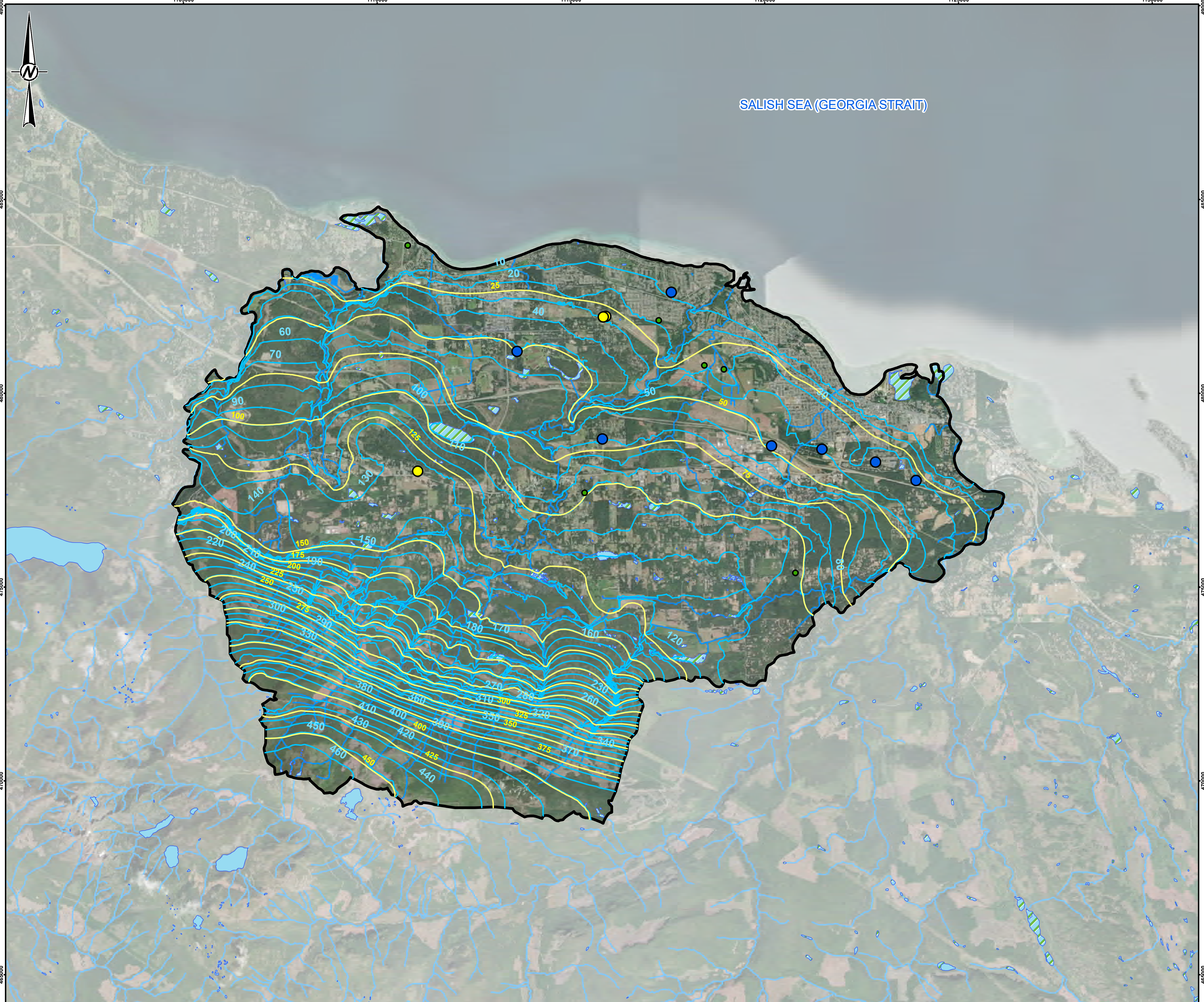
PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
CALIBRATED GROUNDWATER CONDITIONS AND RESIDUALS FOR WELLS IN STUDY AREA

CONSULTANT

YYYY-MM-DD	2023-07-13
DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	D1



LEGEND

- PROJECT AREA
- WETLANDS
- WATERBODIES
- WATERCOURSES

Residual (Calculated - Observed)

- < -25 m
- -25 -to -5 m
- 5 to 5 m
- 5 to 25 m
- > 25 m
- Hydraulic Head Contour in Overbuden (masl)
- Hydraulic Head Contour in Bedrock (masl)

0 2,000 4,000

1:100,000 METRES

NOTE(S)

1. WATERCOURSES, WATERBODIES AND WETLANDS OBTAINED FROM THE BC FRESH WATER ATLAS THROUGH DATA BC. DATA CONTAINS INFROMATION LICENSED UNDER THE OPEN GOVERNEMENT LICENSE - BRITISH COLUMBIA.
2. PROJECT AREA CREATED BY GOLDER ASSOCIATES LTD.
3. IMAGERY COPYRIGHT ESRI AND ITS LICENSORS. SOURCE: DITIGAL GLOBE. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE:20160912

COORDNATE SYSTEM: BC ALBERS

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR FRENCH CREEK

TITLE
CALIBRATED GROUNDWATER CONDITIONS AND RESIDUALS FOR PGOWN AND VOW WELLS IN STUDY AREA

CONSULTANT

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DESIGNED	RKS
PREPARED	RKS
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
21487784	5000	0	D2

APPENDIX E

Build-Out Information Provided by RDN

Files provided electronically

APPENDIX F

Water Budgets for Aquifers

Table F1: Water Budget Results
Current Conditions - Overburden Aquifers

Aquifer 1248	Average Conditions	End of Dry Season	End of Wet Season
Groundwater Inputs (m^3/day)			
Recharge from Surface Water	4402	4409	4399
Recharge	396	353	390
Flow from other units	3070	3100	3271
Total	7868	7863	8059
Groundwater Outputs (m^3/day)			
Discharge to Surface Water	1724	1692	1726
Flow to other units	6143	6116	6182
Private Users	1	1	1
Municipal Wells	0	0	0
Total	7868	7809	7909

Aquifer 216	Average Conditions	End of Dry Season	End of Wet Season
Groundwater Inputs (m^3/day)			
Recharge from Surface Water	0	0	0
Recharge	0	0	0
Flow from other units	11706	12034	11329
Total	11706	12034	11329
Groundwater Outputs (m^3/day)			
Discharge to Surface Water	0	0	0
Flow to other units	10077	11066	9978
Private Users	1629	2216	200
Municipal Wells	3119	3859	2192
Total	14825	17141	12371

Aquifer 1252	Average Conditions	End of Dry Season	End of Wet Season
Groundwater Inputs (m^3/day)			
Recharge from Surface Water	2010	2111	1825
Recharge	834	609	985
Flow from other units	1448	1457	1592
Total	4291	4177	4402
Groundwater Outputs (m^3/day)			
Discharge to Surface Water	73	67	100
Flow to other units	4207	4192	4233
Private Users	11	12	10
Municipal Wells	0	0	0
Total	4291	4270	4343

Aquifer 217	Average Conditions	End of Dry Season	End of Wet Season
Groundwater Inputs (m^3/day)			
Recharge from Surface Water	0	0	0
Recharge	0	0	0
Flow from other units	16001	15992	15511
Total	16001	15992	15511
Groundwater Outputs (m^3/day)			
Discharge to Surface Water	0	0	0
Flow to other units	13917	14712	13684
Private Users	1388	1914	88
Municipal Wells	695	1074	376
Total	16000	17700	14148

Aquifer 663	Average Conditions	End of Dry Season	End of Wet Season
Groundwater Inputs (m^3/day)			
Recharge from Surface Water	62656	62928	62347
Recharge	3679	2792	4300
Flow from other units	46676	46444	46658
Total	113011	112164	113305
Groundwater Outputs (m^3/day)			
Discharge to Surface Water	15244	15146	15396
Flow to other units	97626	97466	97577
Private Users	20	26	11
Municipal Wells	0	0	0
Total	112890	112638	112985

Aquifer 209	Average Conditions	End of Dry Season	End of Wet Season
Groundwater Inputs (m^3/day)			
Recharge from Surface Water	0	0	0
Recharge	0	0	0
Flow from other units	3211	3599	2829
Total	3211	3599	2829
Groundwater Outputs (m^3/day)			
Discharge to Surface Water	0	0	0
Flow to other units	1723	1621	2751
Private Users	1489	1995	68
Municipal Wells	0	0	0
Total	3211	3616	2819

Aquifer 664	Average Conditions	End of Dry Season	End of Wet Season
Groundwater Inputs (m^3/day)			
Recharge from Surface Water	5831	7048	4736
Recharge	553	444	576
Flow from other units	37128	36927	36921
Total	43512	44419	42232
Groundwater Outputs (m^3/day)			
Discharge to Surface Water	15637	15471	15640
Flow to other units	23946	23533	24008
Private Users	8	8	7
Municipal Wells	3918	5416	2573
Total	43508	44428	42228

Aquifer 1250	Average Conditions	End of Dry Season	End of Wet Season
Groundwater Inputs (m^3/day)			
Recharge from Surface Water	0	0	0
Recharge	0	0	0
Flow from other units	3434	4324	2903
Total	3434	4324	2903.31
Groundwater Outputs (m^3/day)			
Discharge to Surface Water	0	0	0
Flow to other units	2190	2330	2357
Private Users	134	176	28
Municipal Wells	1111	1864	497
Total	3434	4371	2882

Table F2: Water Budget Results
Current Conditions - Bedrock Aquifers

Aquifer 212	Average Conditions	End of Dry Season	End of Wet Season
Groundwater Inputs (m^3/day)			
Recharge from Surface Water	0	0	0
Recharge	0	0	0
Flow from other units	3494	3612	3422
Total	3494	3612	3422
Groundwater Outputs (m^3/day)			
Discharge to Surface Water	0	0	0
Flow to other units	3451	3586	3391
Private Users	44	57	7
Municipal Wells	0	0	0
Total	3494	3642	3398
Aquifer 220	**Average Conditions**	**End of Dry Season**	**End of Wet Season**
Groundwater Inputs (m^3/day)			
Recharge from Surface Water	0	0	0
Recharge	0	0	0
Flow from other units	36215	34523	35146
Total	36215	34523	35146
Groundwater Outputs (m^3/day)			
Discharge to Surface Water	0	0	0
Flow to other units	33713	31720	34460
Private Users	2502	3336	297
Municipal Wells	0	0	0
Total	36215	35056	34758

Table F3: Water Budget Results
Future Scenarios - Unconsolidated Aquifers

Aquifer 1248	**BASE CASE**		**Scenario 1 - CLIMATE CHANGE**		**Scenario 2 - FUTURE BUILD-OUT**		**Scenario 3 - CHANGE IN LAND COVER**		**Scenario 4 - 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**
Aquifer Fluid Volume (m^3)	**2.50E+06**	**2.50E+06**	**2.50E+06**	**2.50E+06**	**2.50E+06**	**2.50E+06**	**2.50E+06**	**2.50E+06**	**2.50E+06**	**2.50E+06**
% change			**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
	Groundwater Input (m^3/day)		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**	
Recharge from Surface Water	4417	4406	4424	4415	4414	4403	4425	4415	4420	4404
Recharge	356	390	357	390	321	392	309	316	311	402
Flow from other units	2914	3112	2713	2863	3020	3181	2826	3061	2792	2999
Total	7687	7908	7494	7667	7755	7976	7560	7792	7524	7804
	Groundwater Outputs (m3/day)		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**	
Discharge to Surface Water & Ocean	1670	1697	1647	1685	1672	1703	1665	1695	1645	1683
Flow to other units & Ocean	6018	6209	5926	6088	6042	6241	5940	6146	5930	6160
Private Users	1	1	1	1	5	4	1	1	5	4
Municipal Wells	0	0	0	0	0	0	0	0	0	0
Total	7689	7907	7574	7774	7719	7948	7606	7842	7580	7847
Range of water level change (m)[1]			0 to -2	0 to -2	0 to +/-2	0 to +2	0 to -2	0 to -2	0 to +/1	0 to +/1
Average Water level difference (m)[2]			0 to -2	0 to -2	0 to +2	0 to +2	0 to -2	0 to -2	0	0
Aquifer 1252	**BASE CASE**		**Scenario 1 - CLIMATE CHANGE**		**Scenario 2 - FUTURE BUILD-OUT**		**Scenario 3 - CHANGE IN LAND COVER**		**Scenario 4 - 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**
Aquifer Fluid Volume (m^3)	**7.46E+06**	**7.48E+06**	**7.45E+06**	**7.46E+06**	**7.46E+06**	**7.48E+06**	**7.46E+06**	**7.48E+06**	**7.44E+06**	**7.47E+06**
% change			**-0.1%**	**-0.2%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**-0.2%**	**-0.1%**
	Groundwater Input (m^3/day)		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**	
Recharge from Surface Water	2110	1824	2196	1937	2061	1816	2127	1842	2202	1867
Recharge	609	985	530	985	611	987	604	975	527	977
Flow from other units	1458	1593	1588	1540	1497	1600	1448	1577	1456	1584
Total	4177	4402	4314	4462	4169	4402	4179	4395	4185	4428
	Groundwater Outputs (m3/day)		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**	
Discharge to Surface Water	67	100	61	81	72	102	66	96	62	92
Flow to other units	4192	4233	4194	4217	4176	4234	4193	4231	4203	4227
Private Users	12	10	17	10	12	10	12	10	18	10
Municipal Wells	0	0	0	0	0	0	0	0	0	0
Total	4270	4343	4272	4308	4260	4346	4271	4336	4283	4329
Range of water level change (m)[1]			0 to -2	0 to -2	0 to +2	0 to +2	0 to -2	0 to -2	0 to -1	0 to -1
Average Water level difference (m)[2]			0 to -2	0	0 to +2	0 to +2	0 to -2	0 to -2	0 to -1	0 to -1
Aquifer 663	**BASE CASE**		**Scenario 1 - CLIMATE CHANGE**		**Scenario 2 - FUTURE BUILD-OUT**		**Scenario 3 - CHANGE IN LAND COVER**		**Scenario 4 - 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**
Aquifer Fluid Volume (m^3)	**4.55E+07**	**4.56E+07**	**4.54E+07**	**4.55E+07**	**4.55E+07**	**4.56E+07**	**4.54E+07**	**4.55E+07**	**4.53E+07**	**4.55E+07**
% change			**-0.1%**	**-0.2%**	**0.0%**	**0.0%**	**-0.1%**	**-0.1%**	**-0.3%**	**-0.3%**
	Groundwater Input (m^3/day)		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**	
Recharge from Surface Water	62909	62326	63098	62687	62917	62334	63121	62570	63505	62811
Recharge	2792	4300	2457	4300	2808	4310	2672	4114	2349	4121
Flow from other units	46471	46688	46848	46318	46473	46692	46296	46469	46085	46226
Total	112172	113313	112403	113305	112198	113335	112089	113152	111939	113158
	Groundwater Outputs (m3/day)		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**	
Discharge to Surface Water	15154	15405	15050	15232	15153	15402	15068	15304	14868	15164
Flow to other units	97469	97581	97303	97499	97474	97582	97447	97535	97461	97486
Private Users	26	11	40	11	51	35	26	11	65	35
Municipal Wells	0	0	0	0	0	0	0	0	0	0
Total	112649	112996	112393	112742	112677	113019	112540	112850	112395	112685
Range of water level change (m)[1]			0 to -2	0 to -2	0 to +/-2	0 to +2	0 to -2	0 to -2	0 to -5	0 to -1
Average Water level difference (m)[2]			0 to -2	0	0	0 to +2	0 to -2	0 to -2	0 to -1	0 to -1

Table F3: Water Budget Results
Future Scenarios - Unconsolidated Aquifers

Aquifer 664	BASE CASE		Scenario 1 - CLIMATE CHANGE		Scenario 2 - FUTURE BUILD-OUT		Scenario 3 - CHANGE IN LAND COVER		Scenario 4 - 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**
Aquifer Fluid Volume (m^3)	**5.13E+06**	**5.14E+06**	**5.13E+06**	**5.14E+06**	**5.13E+06**	**5.14E+06**	**5.13E+06**	**5.14E+06**	**5.13E+06**	**5.14E+06**
% change			**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
	Groundwater Input (m^3/day)		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**	
Recharge from Surface Water	7038	4728	6934	4841	7013	4707	7054	4743	7070	4748
Recharge	446	576	447	576	449	578	439	563	441	565
Flow from other units	36944	36939	36834	36624	36999	36987	36876	36865	36720	36777
Total	44428	42243	44215	42040	44461	42272	44369	42170	44231	42090
	Groundwater Outputs (m3/day)		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**	
Discharge to Surface Water & Ocean	15476	15645	15450	15550	15488	15659	15445	15606	15385	15571
Flow to other units & Ocean	23538	24015	23489	23883	23558	24031	23508	23981	23429	23935
Private Users	8	7	9	7	8	7	8	7	9	7
Municipal Wells	5416	2573	5416	2573	5416	2573	5416	2573	5416	2573
Total	44438	42239	44364	42013	44471	42269	44378	42166	44238	42085
Range of water level change (m)[1]			0 to -2	0 to -2	0 to +/-2	0 to +2	0 to -2	0 to -2	0 to -1	0 to -1
Average Water level difference (m)[2]			0 to -2	0	0 to +2	0 to +2	0 to -2	0 to -2	0 to -1	0 to -1
Aquifer 216	**BASE CASE**		**Scenario 1 - CLIMATE CHANGE**		**Scenario 2 - FUTURE BUILD-OUT**		**Scenario 3 - CHANGE IN LAND COVER**		**Scenario 4 - 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**
Aquifer Fluid Volume (m^3)	**7.90E+07**	**7.92E+07**	**7.60E+07**	**7.61E+07**	**8.01E+07**	**8.02E+07**	**7.79E+07**	**7.81E+07**	**7.75E+07**	**7.76E+07**
% change			**-3.8%**	**-3.8%**	**1.4%**	**1.3%**	**-1.4%**	**-1.3%**	**-2.0%**	**-2.0%**
	Groundwater Input (m^3/day)		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**	
Recharge from Surface Water	0	0	0	0	0	0	0	0	0	0
Recharge	0	0	0	0	0	0	0	0	0	0
Flow from other units	12169	11464	12315	10658	11718	11915	11732	10936	10602	10888
Total	12169	11464	12315	10658	11718	11915	11732	10936	10602	10888
	Groundwater Outputs (m3/day)		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**	
Discharge to Surface Water	0	0	0	0	0	0	0	0	0	0
Flow to other units	11253	10220	9813	9090	12179	10747	10892	9745	11192	9669
Private Users	2216	200	3260	200	540	272	2216	200	512	142
Municipal Wells	3859	2193	3859	2193	3859	2193	3859	2193	3859	2193
Total	17329	12613	16933	11483	16578	13212	16967	12138	15563	12004
Range of water level change (m)[1]			0 to -10	0 to -8	0 to > +10	0 to > +10	0 to -4	0 to -6	-5 to > +20	-5 to +20
Average Water level difference (m)[2]			-4 to -6	-4 to -6	+4 to +6	+4 to +6	0 to -2	-2 to -4	+1 to +5	+1 to +5
Aquifer 217	**BASE CASE**		**Scenario 1 - CLIMATE CHANGE**		**Scenario 2 - FUTURE BUILD-OUT**		**Scenario 3 - CHANGE IN LAND COVER**		**Scenario 4 - 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**
Aquifer Fluid Volume (m^3)	**1.43E+08**	**1.43E+08**	**1.40E+08**	**1.40E+08**	**1.44E+08**	**1.45E+08**	**1.41E+08**	**1.42E+08**	**1.40E+08**	**1.41E+08**
% change			**-2.1%**	**-2.2%**	**1.0%**	**0.9%**	**-1.2%**	**-1.2%**	**-1.8%**	**-1.8%**
	Groundwater Input (m^3/day)		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**	
Recharge from Surface Water	0	0	0	0	0	0	0	0	0	0
Recharge	0	0	0	0	0	0	0	0	0	0
Flow from other units	16202	15575	16618	15029	15640	15837	15618	14881	14362	14692
Total	16202	15575	16618	15029	15640	15837	15618	14881	14362	14692
	Groundwater Outputs (m3/day)		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**	
Discharge to Surface Water	0	0	0	0	0	0	0	0	0	0
Flow to other units	15037	13799	13680	12789	15314	14156	14497	13176	13944	12715
Private Users	1914	88	2855	88	641	214	1914	88	919	214
Municipal Wells	1074	376	1074	376	1074	376	1074	376	1074	376
Total	18025	14263	17609	13253	17030	14746	17486	13640	15936	13305
Range of water level change (m)[1]			-6 to -8	0 to -6	0 to +10	0 to +10	0 to -4	0 to -2	- 5 to +20	-5 to +5
Average Water level difference (m)[2]			-2 to -4	-2 to -4	0 to +2	0 to +2	0 to -2	0 to -2	0 to -1	0 to -1

Table F3: Water Budget Results
Future Scenarios - Unconsolidated Aquifers

Aquifer 209	**BASE CASE**		**Scenario 1 - CLIMATE CHANGE**		**Scenario 2 - FUTURE BUILD-OUT**		**Scenario 3 - CHANGE IN LAND COVER**		**Scenario 4 - 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**
Aquifer Fluid Volume (m^3)	**8.25E+06**	**8.25E+06**	**8.25E+06**	**8.25E+06**	**8.25E+06**	**8.25E+06**	**8.25E+06**	**8.25E+06**	**8.25E+06**	**8.25E+06**
% change			**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
	Groundwater Input (m^3/day)		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**	
Recharge from Surface Water	0	0	0	0	0	0	0	0	0	0
Recharge	0	0	0	0	0	0	0	0	0	0
Flow from other units	3601	2836	4556	2253	2892	2961	3539	2654	2963	2750
Total	3601	2836	4556	2253	2892	2961	3539	2654	2963	2750
	Groundwater Outputs (m3/day)		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**	
Discharge to Surface Water	0	0	0	0	0	0	0	0	0	0
Flow to other units	1623	2758	1566	2120	1939	2880	1561	2576	1562	2665
Private Users	1995	68	2993	68	963	76	1995	68	1412	75
Municipal Wells	0	0	0	0	0	0	0	0	0	0
Total	3619	2826	4559	2187	2902	2955	3556	2643	2974	2740
Range of water level change (m)[1]			0 to -8	0 to -2	0 to +10	0 to +10	0 to -2	0 to -2	-5 to +20	-5 to +10
Average Water level difference (m)[2]			-2 to -4	0	+2 to +4	+4 to +6	0 to -2	0 to -2	+1 to +5	0 to -1
Aquifer 1250	**BASE CASE**		**Scenario 1 - CLIMATE CHANGE**		**Scenario 2 - FUTURE BUILD-OUT**		**Scenario 3 - CHANGE IN LAND COVER**		**Scenario 4 - 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**
Aquifer Fluid Volume (m^3)	**1.91E+07**	**1.92E+07**	**1.91E+07**	**1.91E+07**	**1.91E+07**	**1.92E+07**	**1.91E+07**	**1.92E+07**	**1.91E+07**	**1.91E+07**
% change			**-0.1%**	**-0.1%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**-0.1%**	**-0.1%**
	Groundwater Input (m^3/day)		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**	
Recharge from Surface Water	0	0	0	0	0	0	0	0	0	0
Recharge	0	0	0	0	0	0	0	0	0	0
Flow from other units	4902	3127	4495	2941	5013	3220	4805	3012	4875	3049
Total	4902	3127	4495	2941	5013	3220	4805	3012	4875	3049
	Groundwater Outputs (m3/day)		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**	
Discharge to Surface Water	0	0	0	0	0	0	0	0	0	0
Flow to other units	2302	2294	2183	2056	2407	2387	2214	2180	2200	2200
Private Users	176	28	257	28	179	30	176	28	260	30
Municipal Wells	2487	777	2487	777	2487	777	2487	777	2487	777
Total	4965	3098	4927	2861	5073	3193	4877	2985	4947	3007
Range of water level change (m)[1]			0 to -6	0 to -4	0 to +10	0 to +10	0 to -4	0 to -2	- 5 to +20	-5 to +20
Average Water level difference (m)[2]			0 to -2	0 to -2	0 to +2	0 to +2	0 to -2	0 to -2	0 to -1	0 to -1

[1] Range in water level change estimated from drawdown contours for the end of wet and dry season from the numerical model

[2] Average water level difference was qualitatively estimated from drawdown contours for the end of wet and dry season from the numerical model

Table F4: Water Budget Results
Future Scenarios - Bedrock Aquifers

Aquifer 212	BASE CASE		Scenario 1 - CLIMATE CHANGE		Scenario 2 - FUTURE BUILD-OUT		Scenario 3 - CHANGE IN LAND COVER		Scenario 4 - 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**
Aquifer Fluid Volume (m^3)	**1.32E+07**	**1.32E+07**	**1.32E+07**	**1.32E+07**	**1.32E+07**	**1.32E+07**	**1.32E+07**	**1.32E+07**	**1.32E+07**	**1.32E+07**
% change			**-0.1%**	**-0.1%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
	Groundwater Input (m^3/day)		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**	
Recharge from Surface Water	0	0	0	0	0	0	0	0	0	0
Recharge	0	0	0	0	0	0	0	0	0	0
Flow from other units	3714	3486	3553	3248	3820	3635	3595	3346	3591	3394
Total	3714	3486	3553	3248	3820	3635	3595	3346	3591	3394
	Groundwater Outputs (m3/day)		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**	
Discharge to Surface Water	0	0	0	0	0	0	0	0	0	0
Flow to other units & Ocean	3689	3455	3473	3192	3748	3579	3567	3320	3516	3334
Private Users	57	7	83	7	96	39	57	7	96	39
Municipal Wells	0	0	0	0	0	0	0	0	0	0
Total	3746	3461	3556	3199	3844	3618	3624	3327	3612	3373
Range of water level change (m)			0 to > -10	0 to -8	0 to +10	0 to +10	0 to -2	0 to -2	-5 to > +10	-5 to > +10
Average Water level difference (m)			-2 to -4	0 to -2	+2 to +4	+2 to +4	0 to -2	0 to -2	+1 to +5	+1 to +5
Aquifer 220	**BASE CASE**		**Scenario 1 - CLIMATE CHANGE**		**Scenario 2 - FUTURE BUILD-OUT**		**Scenario 3 - CHANGE IN LAND COVER**		**Scenario 4 - 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**
Aquifer Fluid Volume (m^3)	**5.48E+07**	**5.48E+07**	**5.46E+07**	**5.46E+07**	**5.48E+07**	**5.48E+07**	**5.46E+07**	**5.47E+07**	**5.45E+07**	**5.45E+07**
% change			**-0.4%**	**-0.4%**	**0.0%**	**0.0%**	**-0.2%**	**-0.2%**	**-0.6%**	**-0.5%**
	Groundwater Input (m^3/day)		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**		**Groundwater Input (m^3/day)**	
Recharge from Surface Water	0	0	0	0	0	0	0	0	0	0
Recharge	0	0	0	0	0	0	0	0	0	0
Flow from other units	34689	35333	35092	33719	33018	35624	33505	33786	30340	33151
Total	34689	35333	35092	33719	33018	35624	33505	33786	30340	33151
	Groundwater Outputs (m3/day)		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**		**Groundwater Outputs (m3/day)**	
Discharge to Surface Water	0	0	0	0	0	0	0	0	0	0
Flow to other units	31898	34670	30251	32471	32198	34847	30705	33140	29155	32166
Private Users	3336	297	4948	297	1311	450	3336	297	1715	449
Municipal Wells	0	0	0	0	0	0	0	0	0	0
Total	35234	34967	35199	32768	33509	35297	34041	33437	30871	32615
Range of water level change (m)			0 to > -10	0 to 8	-2 to +10	0 to +10	0 to > -10	0 to > -10	> -20 to > +10	- >10 to +10
Average Water level difference (m)			-4 to -6	2 to 4	0	+2 to +4	-2 to -4	-2 to -4	-5 to -10	-1 to -5

[1] Range in water level change estimated from drawdown contours for the end of wet and dry season from the numerical model

[2] Average water level difference was qualitatively estimated from drawdown contours for the end of wet and dry season from the numerical model

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