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December 14, 2016

RDN Water Services
Regional District of Nanaimo
6300 Hammond Bay Road
Nanaimo, BC V9T 6N2

Attention: Ms. Julie Pisani
Drinking Water & Watershed Protection Program Coordinator

Dear Ms. Pisani:

Re: Scoping for Phase 2 Water Budgets in Priority Areas in French Creek and Cedar-Yellowpoint

Piteau Associates Engineering Ltd. (Piteau) was retained by the Regional District of Nanaimo (RDN) to provide hydrogeological consulting services in support of Phase 2 of their Water Budget Analysis strategy. The intent of the work has been to recommend data collection measures in support of producing water budgets and numerical groundwater flow models for the French Creek and Cedar-Yellowpoint areas. Ultimately, the water budgets will be used as aids in local area based water sustainability planning and integrated watershed management.

1.0 BACKGROUND AND OBJECTIVES

The work described in this letter report forms part of Phase 2 of the RDN's Water Budget Assessment strategy. Phase 1 was completed by Waterline Resources Inc. (2013), and involved compiling existing data to develop conceptual water budget models and relative stress assessments for each of the aquifers/surface water bodies within the six water regions on the Vancouver Island portion of the RDN. French Creek (Water Region 3) and Cedar-Yellowpoint (sub-area of Water Region 6) were identified as priority areas for additional work. The basis for prioritization was surface water/groundwater interaction and development pressures at French Creek, and saline intrusion risk in the fractured bedrock aquifer at Cedar-Yellowpoint.

Phase 2 of the process involves the implementation of expanded data collection to facilitate development of water budgets and numerical hydrological models as part of Phase 3.

Piteau's assessment represents the first part of Phase 2, and has involved identification of data needed in support of the water budget analyses and numerical modelling for the French Creek and Cedar-Yellowpoint areas. We understand that the RDN is considering the use of other analysis methods as opposed to numerical modelling in order to estimate flows. For example, an enhanced conceptual model based on analytical calculations could be considered. For such analytical calculations to yield realistic results, the data requirements will be similar to those presented in this report to support modelling.

2.0 STUDY AREAS AND AQUIFERS

Aquifer mapping by the Province was used to identify the study areas. The French Creek Study Area includes Aquifer Nos. 209, 216, and 217, which comprise unconsolidated sediments (sand and gravel), and Aquifer No. 220, which comprises fractured sedimentary bedrock. The extents of these aquifers are shown on Figure 1.

The Cedar-Yellowpoint Study Area includes Aquifer 162, which is hosted in fractured sedimentary bedrock (Figure 2). A map of bedrock geology in the area was published by BC Ministry of Energy and Mines (1998).

3.0 METHODOLOGY

The purpose of the scoping project was to identify the information that the RDN should endeavour to obtain in support of the development of water balances, which in turn could be used as inputs to numerical models. Accordingly, the first step in the data gap analysis was to review what fundamental inputs would be required to complete a water balance and numerical model.

The information required in support of a water balance and model has been organized according to *hydrogeology* and *surface water hydrology*, and these are in turn subdivided into the following categories.

3.1 Hydrogeology

3.1.1 Groundwater Levels

By mapping groundwater levels at various points across an area, groundwater flow directions and hydraulic gradients can be determined. This information in turn can be used to estimate groundwater flow rates. Repeated water level measurements made in a well over time can also be used to identify seasonal fluctuations that correspond to changes in aquifer storage.

3.1.2 Groundwater Use

Groundwater is pumped from wells in aquifers in both study areas and must be accounted for in a water balance.

3.1.3 Hydraulic Properties

The transmissivity of a geological formation quantifies how readily groundwater can move through the formation. It is often obtained from aquifer pumping tests. In the absence of values derived from tests, typical values for various rock types are available in the literature. Modelling based on literature derived values should consider an upper and lower probable limit of transmissivity for each formation type.

3.1.4 Groundwater Recharge Areas and Rates

Both water balance calculations and numerical flow modelling require an understanding of the spatial distribution of recharge by infiltration of precipitation, and the rates at which such recharge occurs.

3.1.5 Recharge/Discharge Zonation

Both study areas include zones where groundwater is replenished from surface water sources, and zones where groundwater discharges to the surface as springs or seepages. The extent of these zones, approximate exchange rates and seasonal changes, if applicable, are needed.

3.2 Surface Water Hydrology

3.2.1 Surface Water Connectivity to Aquifer

Locations where streams, lakes, and ponds lie in contact with a permeable formations (unconsolidated or bedrock) should be mapped.

3.2.2 Stream Base Flow and Surface Water/Groundwater Interaction

Monitoring of stream flows and lake stages will allow seasonal fluctuations and temporal response to precipitation to be quantified.

3.2.3 Surface Water Use

Surface water removed for consumptive uses or for storage should be accounted for in a water balance.

Data available from the BC Government (aquifer mapping, well logs, consultants reports), Natural Resources Canada (hydrostratigraphic modelling), the Geological Survey of Canada (geology maps), Environment Canada (climate data), Water Survey of Canada (stream flow monitoring), and Piteau files (background on aquifers) were reviewed to identify data that is already available. The data requirements were then assigned to one of two classes: those that are available, and those that have yet to be acquired.

4.0 RESULTS

Availability of information in each classification/category is summarized for French Creek and Cedar/Yellowpoint in Table I and Table II, respectively. Background information and a rationale for the table entries are discussed in the following sections.

4.1 French Creek

4.1.1 Groundwater Levels

Water levels are available for many of the wells in the BC WELLS database (Ministry of Environment, 2016) that is maintained by the Province. However, the water level information is limited to single measurements or estimates, typically made immediately following construction. Since seasonal variation and long-term trends cannot be reliably separated, the resulting data set has a low resolution. Accuracy is further reduced by a lack of datum elevations.

Long-term water level monitoring is available for the municipal well fields identified on Figure 1, including Berwick, Springwood, Railway, Chartwell, and the three well fields operated by Epcor (Church Rd., Springhill, and Hills of Columbia). These data sets are valuable as they display seasonal fluctuations. However, water levels reported for these locations will be affected by localized drawdown caused by pumping and well losses. Additional water level monitoring data will be required to facilitate development of a refined water balance. The points to be monitored should be distributed across the study area. Where feasible, manual measurements should be supplemented by continuous records obtained using transducer-data loggers.

The minimum monitoring duration to discern the magnitude of seasonal fluctuation is one year. However, to account for annual variability, monitoring should continue for multiple years. Planning for a five-year monitoring program is therefore recommended.

Monitoring of water levels at the locations indicated by green circles on Figure 1 would allow hydrogeologic cross sections to be drawn in concert with existing provincial groundwater observation wells. If budgetary limitations or well accessibility preclude monitoring at all sites, the circles are numbered in order of priority based on the anticipated benefit of each. Sets of circles with the same priority number would provide the most valuable data if the entire set is monitored. Elevations of all monitoring wells would have to be surveyed. The most cost-effective method for surveying most wells would be by differentially corrected GPS survey (DGPS). Alternatively, wellhead elevations may be available from LIDAR mapping, if available. Such elevations will not be as accurate as a DGPS, but given the distances between the proposed well locations, elevations established using LIDAR mapping may be acceptable.

An excellent example of a long-term groundwater level monitoring program using volunteer wells has been in place in Errington (Figure 1) since about 2010 (GW Solutions, 2012). The program is coordinated by the Mid-Vancouver Island Habitat Enhancement Society (MVIHES) and is designed to monitor water levels in dozens of water wells drawing from aquifers hosted in both bedrock and unconsolidated sediment. If available, this data set should be incorporated into the French Creek water budget study. However, since it covers only a portion of the study area, it would need to be expanded by recruiting additional volunteer wells.

The RDN obtains water level data from a volunteer well on Fourneau Way and this information should also be incorporated into the recommended five-year monitoring program.

4.1.2 Groundwater Use

Pumping records can be used to estimate groundwater use by municipal and commercial systems. Groundwater use by residents outside water service areas can be estimated using GIS resources such as cadastral mapping and aerial images to identify inhabited parcels. An average groundwater consumption rate would be assigned to each parcel.

Groundwater use for irrigation can be based on pumping records, or possibly a review of cadastral zoning and a review of cultivated land cover on airphotos combined with estimates of crop water demand. The Agriculture Water Demand Model that has been developed in the study areas (Agriculture and Agri-Food Canada, 2013) may be useful for this purpose.

4.1.3 Hydraulic Properties

The hydraulic properties (transmissivity and storativity) of Aquifer 216 and Aquifer 217 (unconsolidated) have been assessed in various consultant reports. Roughly 33 transmissivity values are available (Waterline, 2013; BC Ministry of Environment, 2013). No data on hydraulic properties are available for wells in Aquifer 220.

As the available data for aquifers 216 and 217 are clustered in a few areas and no data are available for Aquifer 220, hydraulic properties at additional sites dispersed across the study area would be valuable. Two locations in each of aquifers 216 and 217 and six in Aquifer 220 are recommended for pumping tests to determine aquifer hydraulic properties at existing water wells. Such data could be obtained by completing brief (two to four-hour) pumping tests with volunteer wells using currently installed well pumps.

4.1.4 Groundwater Recharge Rates

Available recharge estimates (Waterline, 2013) could be refined using information from existing Environment Canada climate stations at Coombs, Qualicum River, Nanoose Bay, and Ballenas Island to estimate recharge from precipitation for the French Creek Study Area. Data from the combination of active and historic stations is likely adequate for the purposes of water balance calculations and numerical flow modelling. Recharge from over-irrigation in agricultural areas can be estimated from data compiled by Agriculture and Agri-Food Canada (2013). Recharge from septic fields located outside municipal-sewered areas could be estimated in conjunction with an estimate of groundwater used by residents (discussed above), and can be based on an average discharge per dwelling.

4.1.5 Recharge/Discharge Zonation

Recharge areas and rates of infiltration from surface water, including French Creek, have not been defined. Areas of recharge for aquifers can be identified based on airphoto interpretation and verification in the field. Such areas are likely to include transition zones from bedrock to alluvium at ground surface, locations where streams cease to flow. Surficial sediment modelling (Natural Resources Canada, 2015) may be helpful for this task. Lateral groundwater seepage into the study area through fractured bedrock, including Mountain Block Recharge, could be estimated based on available groundwater gradients and this estimate refined during model calibration.

4.1.6 Surface Water Connectivity to Aquifers

Interactions between groundwater and streams can be assessed using existing mapping, reconnaissance, and surface water flow monitoring data. Seasonal, discontinuous, or ephemeral streams should be mapped, and local Streamkeepers or other groups may provide input. Particular attention should be paid to stream courses at the transition between areas of shallow bedrock and thick sediment deposits. Springs could be mapped based on surface water licenses, interviews with local residents, and reconnaissance.

4.1.7 Stream Base Flow and Surface/Groundwater Interaction

Flows in French Creek were monitored by the Water Survey of Canada from 1990 to 1996, and by BC Conservation Foundation (BCCF) from 2012 to 2015. Grandon Creek flows were monitored by BCCF from 2012 to 2014. Continued monitoring and installation of additional monitoring stations on each of these streams are recommended. Hydrometric scoping (Kerr Wood Leidal, 2015) recommends re-establishing a station on French Creek, but multiple stations (as depicted on Figure 1) would allow changes in flows to be assessed. Flow measurements for Morningstar, Romney, and Swane creeks would also be useful. Base flow separation analysis would be required to estimate the proportion of stream flow supplied by groundwater. Water level monitoring in Hamilton Marsh would be helpful in assessing aquifer confinement.

Ideally, surface flow would be monitored at all sites indicated on Figure 1 (blue circle). If budgetary limitations preclude monitoring at all sites, the circles are numbered in order of priority based on the anticipated benefit of each. Sets of circles with the same priority number would provide the most valuable data if the entire set is monitored.

To establish a stage-discharge rating curve, at least four manual flow measurements will be required under different flow conditions at each station. Continual stage monitoring using transducer-data loggers is required to allow analysis of the response to precipitation events. As with groundwater monitoring, the minimum duration for automated stage monitoring is one year, but to account for variability, monitoring should continue for multiple years. Planning for a five-year monitoring program is therefore recommended.

4.1.8 Surface Water Use

Although surface water use has long been regulated in BC, actual flows may differ significantly from licensed flows. Initially, preparing a meaningful water balance will require that actual surface water usage is determined. This information will help reconcile flow changes along the course of a stream in response to abstractions by licence holders. Information for some municipal suppliers can be obtained from the online Water Use Reporting Centre (RDN, 2016), and information for other users could be obtained by interviewing other license holders. In combination with information on groundwater usage, detailed information on surface water use may help identify where changes in infiltrative losses from streams to aquifers are occurring. These changes could result from changes in geology or pumping from adjacent wells. Once a balance has been calibrated using actual flows, predictive scenarios could be modelled to assess conditions of increased diversions corresponding to licensed amounts.

4.2 Cedar-Yellowpoint

4.2.1 Groundwater Levels

Groundwater level information covering the Cedar-Yellowpoint area is available as spot measurements from well construction logs. These were suitable for the conceptual water budget model, but are of insufficient accuracy and temporal consistency for numerical modelling. More accurate and continuous measurements are available from provincial observation wells and water suppliers, including and North Cedar Improvement District, RDN supply well (De Courcy), RDN volunteer observation wells (Pylades). Monitoring data may also be available for the Aquila Estates wells at Woodley Range. Additional monitoring points distributed across the study area are required, and these could be obtained in a network of volunteer wells such as the RDN Volunteer Observation Well network or the MVIHES study in Errington (GW Solutions, 2012). Monitoring at the locations suggested by green circles on Figure 2 would allow hydrogeologic cross sections to be drawn in concert with existing MOE Observation Wells. A detail map for the Quennell Lake area is shown on Figure 3. Surveyed elevations of all monitoring wells would be necessary. An initial monitoring duration of five years is recommended, with a review at the end of this interval to select sites for continued monitoring.

4.2.2 Hydraulic Properties

Little information on hydraulic properties in Aquifer 162 is currently available. As the groundwater seepage through Aquifer 162 is through bedrock fractures, hydraulic properties of the rock mass will vary substantially based on proximity to faults and through-going fracture sets. Accordingly, obtaining a representative data set encompassing the range in hydraulic values would require completion of aquifer pumping tests on many wells throughout the study area. While some such tests are justified to assess local properties, only a limited number of pumping tests are justified on the basis that hydraulic conductivity values determined from aquifer pumping test will be positively biased, since only wells intersecting more permeable fractures are likely to be preserved). Additionally, it will not be feasible to reliably map locations and hydraulic characteristics of all individual faults and fractures to the extent that they can all be appropriately represented in a numerical model. It may be more practical to estimate overall “bulk” properties (i.e., average properties for zones of the bedrock aquifer) during calibration and validation of the model.

4.2.3 Groundwater Use

As described for the French Creek Study Area, groundwater use can be estimated from pumping records maintained by municipal and commercial suppliers. Groundwater use by residents outside water service areas can be estimated using GIS resources and assigning an average use.

If applicable, groundwater use for irrigation can be based on pumping records, or as described previously, based on the area of irrigated land and an assumed crop water demand. Additionally, the Agriculture Water Demand Model (Agriculture and Agri-Food Canada, 2013) may be useful.

4.2.4 Groundwater Recharge Rates

Recharge rates from precipitation estimated for the study area (Waterline, 2013) could be refined using existing precipitation data from Environment Canada stations at Nanaimo Airport and Stuart Channel Boat Harbour. Recharge from lakes and streams, however, has not been quantified.

Monitoring of lake levels and flows in selected streams can provide data on which estimates of the magnitude of recharge from surface water can be based. Recharge from over-irrigation (irrigation return flow) in agricultural areas can be estimated from the Agriculture and Agri-Food Canada (2013) compilation, while recharge from septic fields would have to be estimated based on the number of drain fields in operation. This could be assessed by identifying inhabited parcels not serviced by community sewer based on airphoto/GIS interpretation.

4.2.5 Recharge/Discharge Zonation

As with the French Creek Study Area, recharge and discharge zonation will be important in preparing a model for the Cedar-Yellowpoint Study Area. The groundwater recharge area for Aquifer 162 needs to be defined. Assessing the zonation could be done using a combination of map reviews, field reconnaissance, hydrometric mapping, and interviews with local residents.

Lateral groundwater seepage into the study area through fractured bedrock, could be estimated based on available groundwater gradients. Such estimates are likely to be refined during model calibration.

4.2.6 Surface Water Connectivity to Aquifer

Map review in concert with field ground-truthing is required to confirm the locations where aquifers are in contact with surface water bodies.

4.2.7 Stream Base Flow and Surface/Groundwater Interaction

We are not aware of any ongoing flow monitoring for streams flowing within the footprint area of Aquifer 162. Recent flow monitoring data for Haslam Creek is useful for correlating stream flow with water levels in Aquifer 161, but is of little use for model calibration since only a single gauging station is available. As the water flows along the common boundary with the aquifer, changes in stream flow cannot be assessed.

Flow monitoring is recommended for Hokkanen Creek and the unnamed creeks draining the study area north to Nanaimo Harbour, and south to Kulleet Bay (Figure 2). A station on Hokkanen Creek has been identified as a priority for monitoring in the hydrometric scoping study (Kerr Wood Leidal, 2015), but two stations would be preferred to detect how flows vary along the stream's course. Base flow separation analysis is also recommended to separate groundwater contribution to flow.

The interaction between lakes and the aquifer will need to be investigated to quantify recharge to the aquifer, or conversely groundwater losses from the aquifer (discharge). Bathymetry charts available for Holden Lake and Quennell Lake (Nanaimo River Salmonid Enhancement Project, 1980) will enable the bottom profile of each lake to be projected onto geologic cross sections. The monitoring of lake water levels will enable comparison against aquifer water levels in nearby monitoring points. Flow monitoring at lake outlets will be useful for differentiating the proportion of lake water contributing to aquifer recharge.

Stream flow monitoring should include at least four manual discharge measurements to establish a rating curve. This should be augmented with continual stage measurements obtained with transducer-data loggers. An initial monitoring duration of five years is recommended, with a review at the end to select sites for continued monitoring.

4.2.8 Surface Water Use

As noted for the French Creek Study Area, actual surface water abstractions likely differ from licenced flows. Actual consumption for the North Cedar Improvement District could be estimated from the online Water Use Reporting Centre. Data for other licence holders could be obtained by interviewing licence holders.

5.0 PRIORITIZATION

Since the costs associated with the proposed data collection are substantial, a phased approach is recommended for implementing data collection. Priority is assigned to tasks in Tables I and II, and the rationale for the assignment of each is given in this section.

5.1 First Priority

The highest priority is recommended for long-term data collection initiatives such as aquifer water level and stream flow monitoring.

5.2 Second Priority

Tasks with lower costs and shorter lead times that provide information of first-order importance should be considered as the next highest priority. These include field reconnaissance for basic data collection and subsequent analysis to estimate groundwater and surface water consumption and return flows via sewage infiltration.

5.3 Third Priority

Tasks with shorter lead times and relatively high costs should be considered as the third priority. It may be possible to defer these tasks, so that they can be conducted concurrently with water balance and numerical flow model development, specifically on an as-needed basis.

5.4 Fourth Priority

A fourth priority is assigned to obtaining other information that could potentially add value to the understanding of aquifer dynamics and water balance. This could include analyses of water samples to classify or date groundwater, and/or establishing additional climate monitoring stations to supplement data collected from existing stations operated by Environment Canada. As there is no clear need for these types of data at the present time, collection and analysis can be deferred until a specific need has been identified.

Within tasks, further prioritization is provided on Figure 1 and Figure 2. Each monitoring site, designated by a green or blue circle, is assigned a number representing priority. The highest priority is identified as 1, and lower priorities are assigned successively higher numbers.

6.0 COSTS AND TIMING

Anticipated time requirements and Class 4 (concept study/feasibility) cost estimates are presented in Tables I and II. The costs assume different rates for work that would be completed by RDN staff, contractors, or consultants.

The estimated cost to implement all recommended investigations is in the order of $110,000 for each of the French Creek and Cedar-Yellowpoint study areas. Estimated annual monitoring costs would be roughly $25,000 for each.

7.0 CONCLUSIONS AND RECOMMENDATIONS

1) This report presents an assessment of the data gaps to be filled to assist with the preparation of numerical groundwater flow models and water balances for the French Creek and Cedar/Yellowpoint study areas.

2) Modelling will require groundwater gradients and flow directions, and an understanding of groundwater vs. surface water interaction. Data could be obtained by a combination of mapping/GIS reviews, field reconnaissance, and the monitoring of groundwater levels and creek flows.

3) The RDN should consider implementation of data collection programs that are summarized in Table I and Table II for the French Creek and Cedar/Yellowpoint study areas, respectively. Relative priorities for each of the data collection tasks are discussed in Section 5, and indicated in the tables.

8.0 LIMITATIONS

This investigation has been conducted using a standard of care consistent with that expected of scientific and engineering professionals undertaking similar work under similar conditions in BC. No warranty is expressed or implied.

This report is prepared for the sole use of the Regional District of Nanaimo. Any use, interpretation, or reliance on this information by any third party is at the sole risk of that party, and Piteau accepts no liability for such unauthorized use.

9.0 CLOSURE

We trust that this report is sufficient for your current needs. If you have any questions or comments, please contact the undersigned.

Yours truly,

PITEAU ASSOCIATES ENGINEERING LTD.

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Att.

10.0 REFERENCES

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TABLES

TABLE I
DATA GAP ANALYSIS: FRENCH CREEK STUDY AREA

Hydrogeology								
Prior-ity	**Description**	**Information/Data required**	**Available Data**	**Comments**	**Recommended Investigation**	**Timeline**	**Estimated Implemen-tation Cost**	**Estimated Annual Monitoring Cost**
1	**Groundwater levels**	Spatial distribution and temporal variations in groundwater levels, flow directions, flow rates.	Aquifer 216 (Quadra Sands) number of wells = 214 well density = 0.08 wells/Ha wells with a single water level record = 194 wells with water level monitoring to discern seasonal fluctuations: Springwood and Railway fields and Obs 287, Obs 304, Obs 314, Obs 398.	Aquifer water levels (potentiometric surface) are of primary importance for defining groundwater flow regimes, and for configuration and calibration of a numerical flow model.	Gather existing water level information from available sources (e.g., municipal & MVIHES monitoring data). Expand volunteer well monitoring network (6 monitoring sites as depicted on Fig. 1).	Implement-ation: 2 months; Monitoring: ongoing	$ 13,590	$ 3,990
			Aquifer 217 (Quadra Sands) number of wells = 272 well density = 0.06 wells/Ha wells with a single water level record = 214 wells with water level monitoring to discern seasonal fluctuations: 6 incl. 5 in French Creek well field and Obs 295, Obs 303, Obs 321, Obs 434.		Collate available data from existing sources and expand volunteer well monitoring network (3 sites).	Implement-ation: 2 months; Monitoring: ongoing	$ 7,740	$ 2,010
			Aquifer 220 (bedrock) number of wells = 564 well density = 0.10 wells/Ha wells with a single water level record = 385 wells with water level monitoring to discern seasonal fluctuations: 1 MOE Obs Well (287), plus MVIHES monitoring data if available.		Collate available data from existing sources and expand volunteer well monitoring network (9 sites).	Implement-ation: 2 months; Monitoring: ongoing	$ 19,440	$ 6,030
2	**Groundwater use**	Pumpage from aquifer	Provincial Wells database is incomplete. Some data may be available from Agriculture Study. Flow monitoring may be available for established well fields.	Approximate locations for all residential wells in service is required. Flow quantity can be estimated based on assumed usage per well. Pumpage by larger users (well fields) to be quantified on a case-by-case basis.	Use cadastre/ photo interpretation to infer locations of residential wells. Obtain records from well field operators.	1 month	$ 7,840	$ -
2	**Groundwater recharge rates**	Climate data to support monthly soil water budget to estimate infiltration. Properties of soil near-surface soils, and soil in contact with surficial aquifers or surface water.	Topographic, surficial geology, and soils mapping. Active Environment Canada weather stations at Coombs (1960 - 2010), Little Qualicum Hatchery (1981 - 2015), and Ballenas Island (1966 - 2016).	Estimates of recharge from precipitation are available (Waterline, 2013). Estimates of recharge from surface water, irrigation, and septic fields are required.	Desktop review in concert with reconnaissance (see Items 5 & 6 below).	1 month	$ 5,500	$ -
2	**Recharge/ discharge zonation**	Extent of surface areas contributing to aquifer recharge, and areas where discharge occurs.	Topographic mapping, aerial photography, surficial geology mapping, soils mapping. NRCAN model includes isopach layers for sediment layers.	The underlying bedrock aquifer interacts with aquifers 216 and 217. Role of Mountain Block Recharge not known. Estimate recharge and discharge areas from groundwater and surface water levels, airphoto analysis, and field ground-truthing.	Reconfiguration of NRCAN model in concert with one reconnaissance visit.	1 month	$ 5,500	$ -
3	**Hydraulic properties**	Spatial distribution of hydraulic properties (hydraulic conductivity, transmissivity, & storativity), and range in values for aquifers and aquitards of interest; correlation to lithology.	Aquifer 216 transmissivity values = 5; poor distribution.	Hydraulic properties are of primary importance for defining groundwater flow regimes, and for configuration and calibration of a numerical flow model.	Collate available data from existing sources; complete 4-hour pumping tests with 10 volunteer wells at locations throughout study area. Data analysis.	2 months	$ 4,000	$ -
			Aquifer 217 transmissivity values = 28; poor distribution.			2 months	$ 4,000	$ -
			Aquifer 220 = no data			2 months	$ 12,000	$ -

TABLE I
DATA GAP ANALYSIS: FRENCH CREEK STUDY AREA

Surface Water Hydrology								
Prior-ity	**Description**	**Information/Data required**	**Available Data**	**Comments**	**Recommended Investigation**	**Timeline**	**Estimated Implemen-tation Cost**	**Estimated Annual Monitoring Cost**
1	**Creek flow and surface water/ groundwater interaction**	Quantify surface water flows and flows between surface water and aquifer.	French Creek discharge 1990 - 1996 (WSC) and 2012 - 2015 (BCCF); Grandon Crk. discharge 2012 - 2014 (BCCF).	Establish pond level monitoring station in Hamilton Marsh. FoFC/ MVIHES/ BCCF might assist in measuring flows.	Collate available flow data; establish flow gauging stations on Morningstar (x1), Romney (x1), Grandon (x1), Swane (x3), and French creeks (x5). Establish stage monitoring station on Hamilton Marsh (x1).	Implement-ation: 6 months; Monitoring: ongoing	$ 18,690	$ 13,170
2	**Surface water connectivity to aquifers 216 and 217**	Quantify hydraulic connection between surface water bodies and aquifers.	none	Require information on groundwater-surface water interaction for Little Qualicum River, Grandon Crk., French Crk., Hamilton Marsh, French Crk., Morningstar Crk., Romney Crk., & Shelley Crk. To be based on relative aquifer and surface water levels and field observations.	Field reconnaissance.	1 month	$ 5,500	$ -
2	**Surface water use**	Surface water use by type (agricultural, domestic etc.); amount/volume; and when it is used (seasonal fluctuations).	Aquifer 216: current surface water licenses: 29; Aquifer 217: current surface water licenses: 15; Aquifer 212: current surface water licenses: 2; Aquifer 220: current surface water licenses: 42. No actual consumption data.	Domestic use can be estimated based on typical consumption observed for metered homes in other jurisdictions. Non-domestic use can be obtained by interviewing licensees.	Confirm domestic and non-domestic water license data and plot.	1 month	$ 2,800	$ -
							$ 106,600	$ 25,200

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TABLE I
DATA GAP ANALYSIS: FRENCH CREEK STUDY AREA

TABLE II
DATA GAP ANALYSIS: CEDAR/YELLOWPOINT STUDY AREA

Hydrogeology								
Prior-ity	**Description**	**Information/Data required**	**Available Data**	**Comments**	**Recommended Investigation**	**Timeline**	**Estimated Implemen-tation Cost**	**Estimated Annual Monitoring Cost**
1	**Groundwater levels**	Spatial distributions and temporal variations in groundwater levels, flow directions, flow rates.	entire Aquifer 162 number of wells = 1,673 well density = 0.27 wells/Ha wells with a single water level record = 1,198 wells with water level monitoring to discern seasonal fluctuations = 8: De Courcy, Pylades, Butler, Obs 315, 337, 390. De Courcy Sandstone subsection number of wells = 853 well density = 0.18 wells/Ha. shale and mudstone subsection number of wells = 1,490 well density = 0.35 wells/Ha.	Aquifer water levels (potentiometric surface) are of primary importance for defining groundwater flow regimes, and for configuration and calibration of a numerical flow model.	Gather existing water level information and expand volunteer well monitoring network. Deploy data loggers in 13 volunteer wells at locations indicated on Fig. 2.	Implement-ation: 2 months; Monitoring: ongoing	$ 30,940	$ 9,425
2	**Groundwater use**	Pumpage from aquifer	Provincial Wells database is incomplete. Some data may be available from Agriculture Study. Flow monitoring may be available for established well fields.	Approximate locations for all residential wells in service is required. Flow quantity can be estimated based on assumed usage per well. Pumpage by larger users (well fields) to be quantified on a case-by-case basis.	Use cadastre/ photo interpretation to infer locations of residential wells. Obtain records from well field operators.	1 month	$ 7,840	$ -
2	**Groundwater recharge rates**	Climate data to support monthly soil water budget to estimate infiltration. Properties of soil near-surface soils, and soil in contact with surficial aquifers or surface water.	Topographic mapping, surficial geology mapping, soils mapping. Environment Canada weather stations: Nanaimo A (1947 - 2016) and Stuart Channel Boat Hrbr (1987 - 2006).	Environment Canada precipitation data available. Estimates of recharge from surface water, irrigation, and septic fields are required.	Map and water level analysis in concert with one reconnaissance visit (see Items 5 & 6 below).	1 month	$ 5,500	$ -
2	**Recharge/ Discharge zonation**	Extent of surface areas contributing to aquifer recharge, and areas where discharge occurs.	Topographic mapping, aerial photography, surficial geology mapping, soils mapping.	Unconsolidated aquifers interact with Aquifer 162. Estimate recharge and discharge areas from airphoto analysis and field ground-truthing.	Desktop/GIS review in concert with groundwater level analysis and one reconnaissance visit.	1 month	$ 5,500	$ -
3	**Hydraulic properties**	Spatial distribution of hydraulic properties (hydraulic conductivity, transmissivity, & storativity), and range in values for aquifers and aquitards of interest; correlation to lithology.	None identified within Aquifer 162 by Waterline (2013).	Hydraulic properties are of primary importance for defining groundwater flow regimes, and for configuration and calibration of a numerical flow model. As these vary substantially in a fractured bedrock setting, measurements at multiple locations are required. Could break out De Courcy sandstone and shale/siltstone from Cathyl-Bickford geology map.	Collate available data from existing sources; complete 4-hour pumping tests with 10 volunteer wells at locations throughout study area. Data analysis.	2 months	$ 23,920	$ -

TABLE II
DATA GAP ANALYSIS: CEDAR/YELLOWPOINT STUDY AREA

Surface Water Hydrology								
Prior-ity	**Description**	**Information/Data required**	**Available Data**	**Comments**	**Recommended Investigation**	**Timeline**	**Estimated Implemen-tation Cost**	**Estimated Annual Monitoring Cost**
1	**Creek flow and surface water/ groundwater interaction**	Quantify surface water flows and flows between surface water and aquifer.	No stream flow data available for streams within the study area. Historical lake stage monitoring for brief intervals at 3 sites: Holden Lake (WSC) 1980-1985; Quennell Lake (WSC) 1976-1979; Priest Lake (WSC) 1979-1980.	Quennell Lake, Holden Lake, Michael Lake, Hokkanen Creek, and smaller wetlands, ponds, and streams are present in the Study Area.	Initiate 8 stream discharge gauging stations at locations indicated on Fig. 2. Initiate lake stage gauging stations at 9 locations indicated on Fig. 2.	Implement-ation: 6 months; Monitoring: ongoing	$ 23,800	$ 11,800
2	**Surface water connectivity to Aquifer 162**	Quantify hydraulic connection between surface water bodies and aquifers.	No known mapping of locations of bedrock outcrops lying in contact with surface water and sea water.	Required to model groundwater-surface water interaction. Confirm Michael Lake discharge: Waterline database indicates SE to Kulleet Bay; NTS map and TRIM map indicate NW to Hokkanen Crk.	Reconnaissance along Nanaimo River, Haslam Creek, Hokkanen Creek, and lakes to map surface water in contact with bedrock. Construct multi-level monitoring wells.	1 month	$ 5,500	$ -
2	**Surface water use**	Surface water use by type (agricultural, domestic etc.); amount/volume; and when it is used (seasonal fluctuations).	256 current surface water licenses within Aquifer 162 footprint. No actual consumption data.	Surface water use may be consumptive or non-consumptive.	Confirm domestic and non-domestic water license data and plot.	1 month	$ 2,800	$ -
							$ 105,800	$ 21,225

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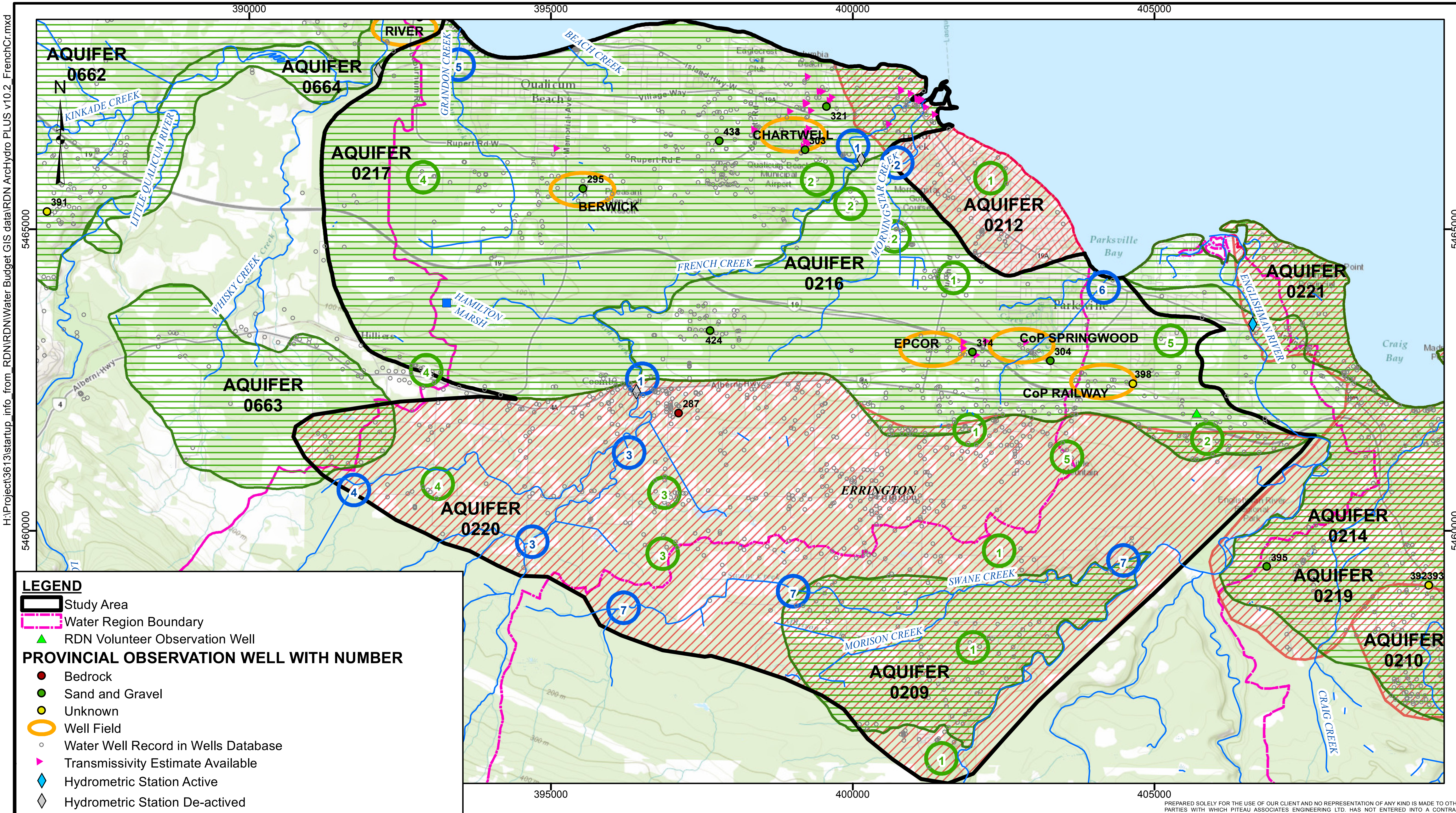
TABLE II
DATA GAP ANALYSIS: CEDAR/YELLOWPOINT STUDY AREA

FIGURES



REGIONAL DISTRICT OF NANAIMO
SCOPING FOR PHASE 2 DATA COLLECTION
FRENCH CREEK AND CEDAR-YELLOWPOINT

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

FRENCH CREEK STUDY AREA WITH RECOMMENDED MONITORING SITES

BY:	DATE:
AB	DEC 16
APPROVED:	FIG:
RA	1

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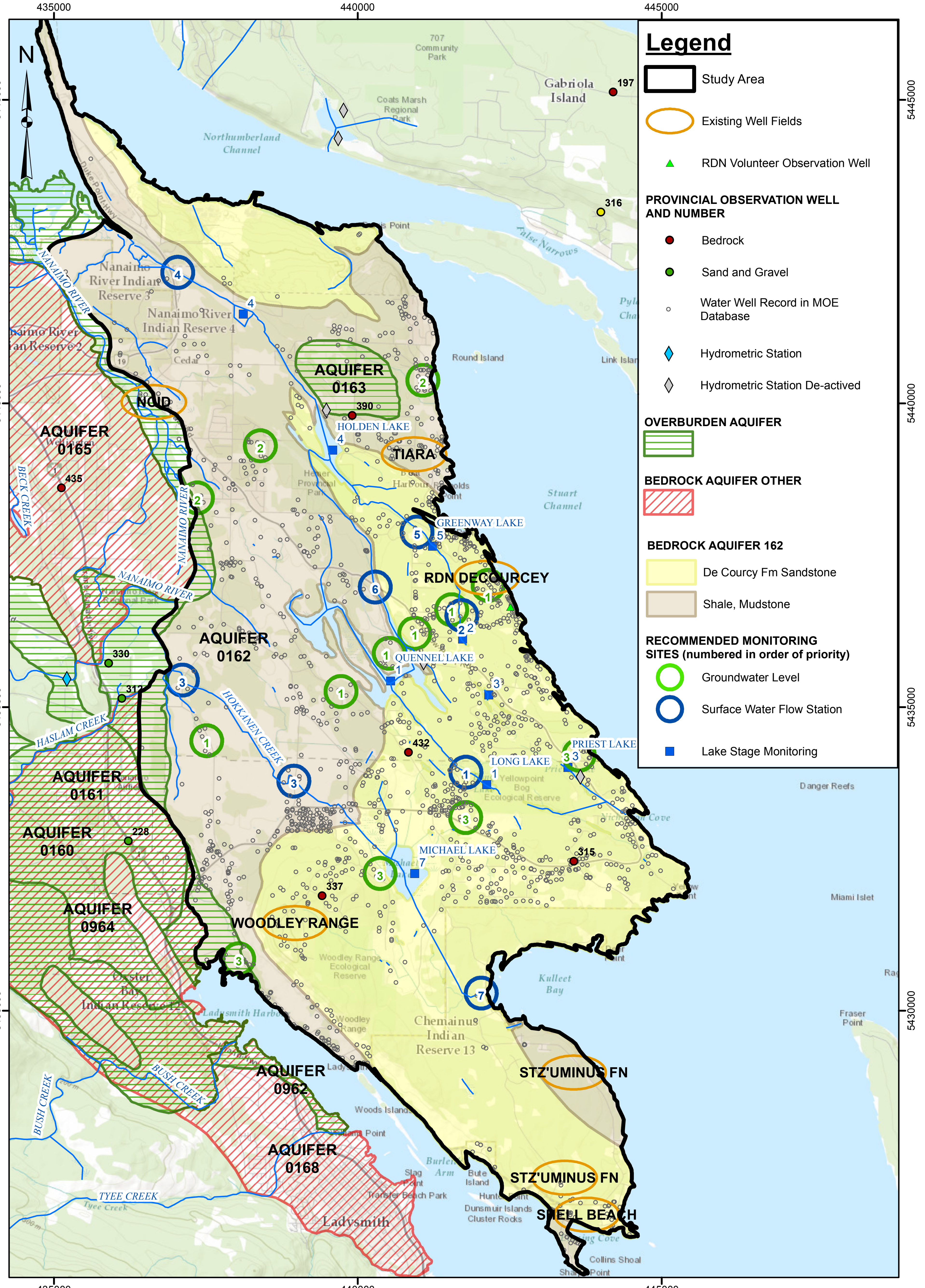


0 1,000 2,000 m
SCALE: 1:60,000

Bedrock geology mapping:
BC Ministry of Energy and Mines, 1998.

Aquifer mapping and numbering: MOE.

PREPARED SOLELY FOR THE USE OF OUR CLIENT AND NO REPRESENTATION OF ANY KIND IS MADE TO OTHER PARTIES WITH WHICH PITEAU ASSOCIATES ENGINEERING LTD. HAS NOT ENTERED INTO A CONTRACT.

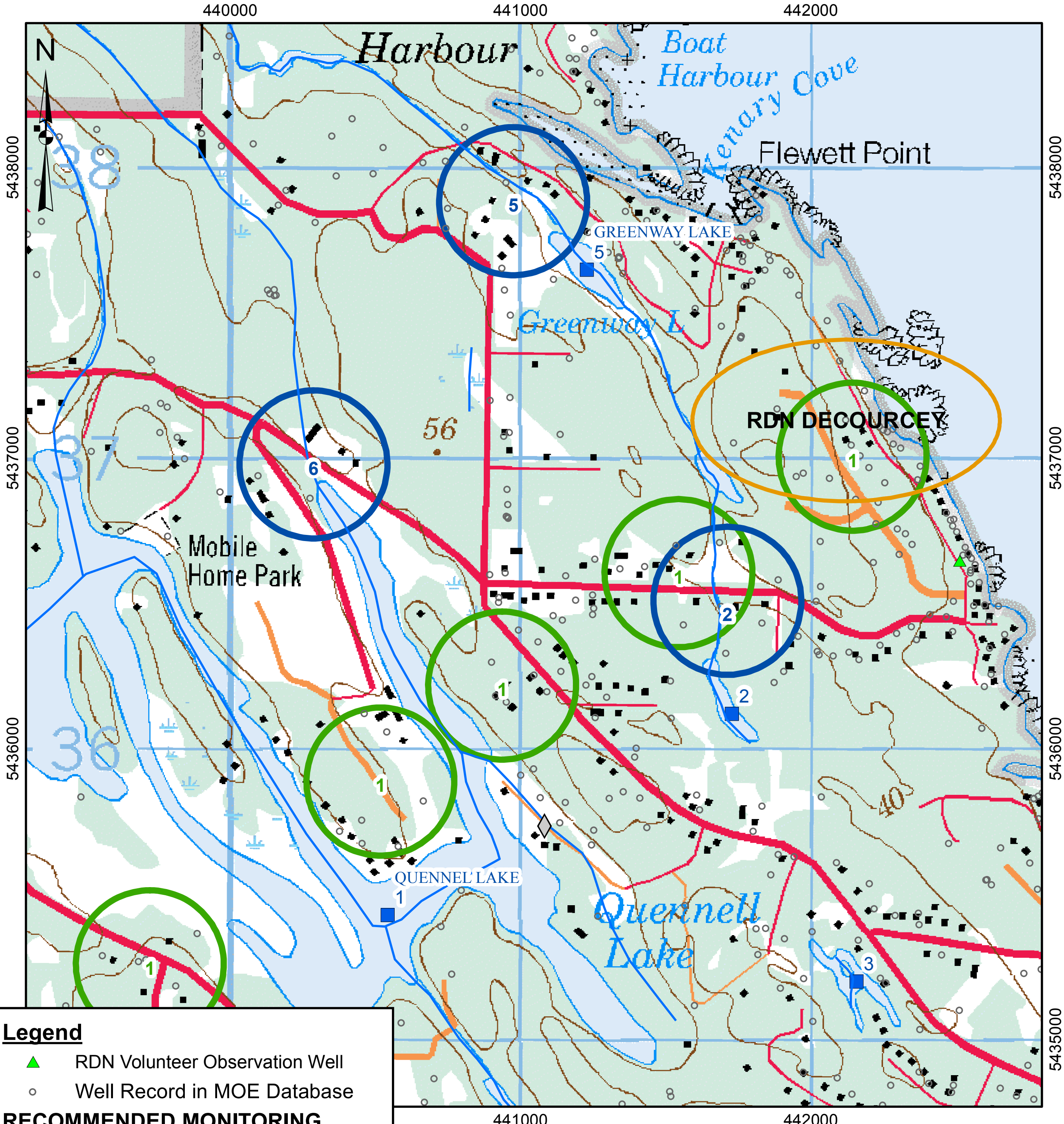
REGIONAL DISTRICT OF NANAIMO
SCOPING PHASE 2 WATER BUDGETS
FRENCH CREEK AND CEDAR-YELLOWPOINT

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

CEDAR-YELLOWPOINT STUDY AREA AND RECOMMENDED MONITORING PROGRAM

BY: AB
DATE: DEC 16
APPROVED: RA
FIG: 2

H:\Project\3613\startup_info_from_RDN\RDN\Water Budget GIS data\RDN ArcHydro PLUS v10.2_CedarYP_Detail.mxd



Legend

- RDN Volunteer Observation Well
- Well Record in MOE Database

RECOMMENDED MONITORING SITES (numbered in order of priority)

- Groundwater Level
- Surface Water Flow Station
- Lake Stage Monitoring

0 250 500 750 1,000 m

SCALE: 1:20,000

REGIONAL DISTRICT OF NANAIMO
SCOPING PHASE 2 WATER BUDGETS
FRENCH CREEK AND CEDAR-YELLOWPOINT

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

CEDAR-YELLOWPOINT STUDY AREA
RECOMMENDED MONITORING PROGRAM
QUENNELL LAKE DETAIL

BY:	DATE:
AB	DEC 16
APPROVED:	FIG:
RA	3