Technical Memorandum

Prepared for: WSP Canada Group Limited
210-889 Harbourside Drive, North Vancouver, BC

Prepared by: Matt Vardal, MSc (Geology),
Dr. Gilles Wendling (P.Eng.)

Subject: CVRD Liquid Waste Management Plan – Preliminary Hydrogeological Assessment of Tunnel Options

1 INTRODUCTION

The Comox Valley Regional District (CVRD) has commissioned upgrades to the regional wastewater infrastructure, as part of the CVRD Liquid Waste Management Plan. Several routes are being considered for piping wastewater from the Courtenay Pump Station to the Treatment Plant on Brent Road. Due to local topography, the feasibility of tunneling versus pumping overland is being investigated.

GW Solutions conducted hydrogeological investigations (data analysis and field investigations) from 2015 to 2017 in the Balmoral Beach area (GW Solutions 2016 & 2017). Background information regarding study area wells, aquifers and stratigraphy can be found in these reports and are not reproduced here.

This memo summarizes our desktop investigation into the subsurface geology and groundwater conditions around the proposed tunnel alignment that traverses from the Courtenay Pump Station, inland from the Willemar Bluffs area, to the Comox Valley Water Pollution Control Centre (CVWPCC) on Brent Road. Available well information along the routes is illustrated in Figure 1. Of the two areas where tunneling is being considered (highlighted in Figure 1), only the eastern Lazo Hill portion has sufficient well data to enable a desktop investigation and is the area of focus in this memo.

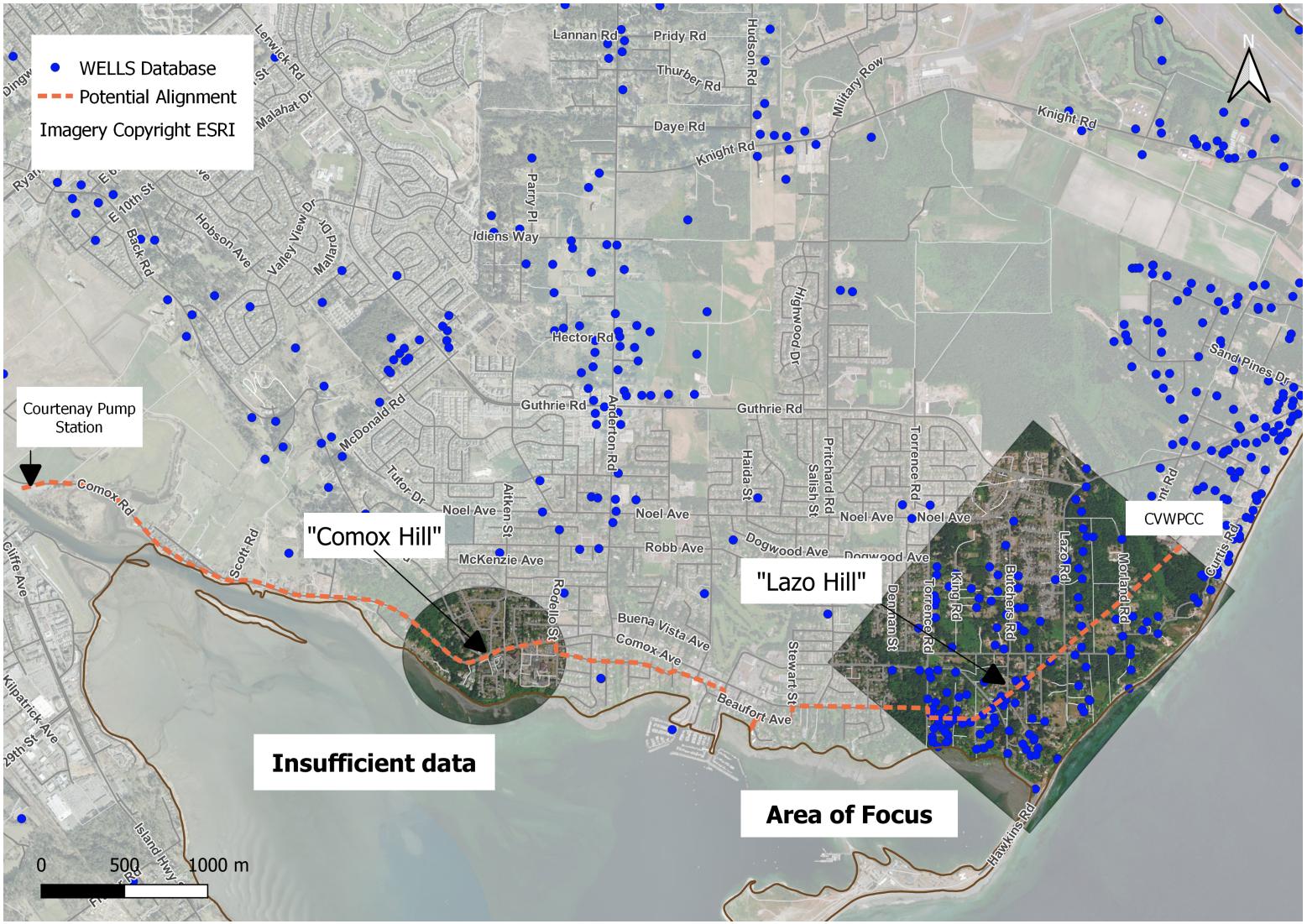


Figure 1. Route options, tunnel areas and area of focus for this memo

2 RESULTS

2.1 Data Visualization

The viability of tunneling is contingent on understanding where zones of saturation or elevated pore water pressures may exist in the subsurface. To investigate the depths and geometry of potential water-bearing strata in the tunneling area, GW Solutions completed a Leapfrog[1] 3D conceptual model that synthesizes the following:

- Well locations, water depths, and lithologies from the Provincial Wells Database;
- Interpolated water table and/or piezometric surfaces;
- Depths and thicknesses of interpreted non-saturated and saturated units; and
- Location of springs indicating possible "perched" zones of saturation within the Quadra Sand aquifer.

The 3D model of Lazo Hill is viewable online: https://lfview.com/embed/nvjjnlyqwtz09s0qkpnw/default/p9z1zwt25riqvhlkrlit

The Leapfrog model domain encompasses the area of proposed tunneling where supporting well data was sufficient. GW Solutions used a standardized version of the Provincial Wells Database, that includes lithologies (drill logs) that GW Solutions has correlated to a set of standard geological material classes. This greatly enhances characterization of the subsurface; however, the Provincial Wells Database is inherently messy and incomplete, and the following caveats must always be considered:

- Not all existing wells are in the database;
- Wells may not be accurately located on the land parcel;
- Large horizontal (X-Y) positional errors (greater than 50 m) will introduce errors in the vertical (Z) direction, since the well location will determine the ground elevation from the digital elevation model;
- Lithology descriptions may be inaccurate or incomplete; and

[1] Leapfrog, including Leapfrog Works, Geo and Viewer, refer to a suite of geological modelling software developed by ARANZ Geo Ltd., Christchurch New Zealand.

- Drillers' recorded water levels represent a snapshot in time (at time of drilling) and may not accurately reflect current groundwater elevations.

GW Solutions performed a review of the wells in the 3D model domain, correcting those wells suspected of having erroneous locations based on a selective review of the original driller's logs, available from the Provincial GWELLS web application. The corrected X-Y locations of wells had a corresponding improvement of the elevations of their downhole intervals and groundwater levels. GW Solutions underscores that the above does not lessen the importance of field verification of actual well locations and water level measurements in existing wells by a trained professional.

The main water-bearing strata (hydrogeological units) recognized in the local wells data are as follows (from shallow to deep):

- Capilano/Vashon Drift aquifer present at depths less than 20 m below ground, in areas blanketed by Vashon Drift (till). Water-bearing units are characterized by sand and gravel lenses within or below the Capilano/Vashon Drift.
- Quadra Sand (Aquifer # 408) is characterized by uniformly fine-grained, light brown to grey-coloured sand, with very little gravel content, and occasional silt/clay layers. This was readily distinguished in well logs in the study area.
- Croteau Aquifer (unofficially named herein) that occupies the lowlands beneath Hawkins Road south to the shoreline and is characterized by sand and gravel and gravel-only lenses.
- Pre-Quadra silts, clays and till (likely of the Cowichan Head formation).

2.2 Depths to Groundwater

Groundwater levels for known wells within 1 km of the proposed tunnel are depicted as coloured dots in Figure 2. Depths range from a few metres to approximately 50 m below ground level (approximately 0 to 20 m above sea level). Within each aquifer, groundwater depths are characterized as follows:

- Green points in Figure 2 denote water levels from wells drawing from the shallow groundwater system - characteristically from sand and gravel lenses within or below the Capilano/Vashon Drift.

- Purple points in Figure 2 are within the unconfined Quadra Sand. Groundwater levels in this part of the Quadra Sand aquifer are typically greater than 40 m below ground level. Points within the Quadra Sand at intermediate elevations may represent perched groundwater zones (in lenses); however, there is a paucity of wells where this may be observed.
- Blue points in Figure 2 denote water levels from the Croteau aquifer. The position of groundwater above upper limit of the saturated aquifer denotes a confined aquifer. Groundwater elevations in the Croteau aquifer are comparable to (or slightly higher than) those encountered in the unconfined Quadra Sand, suggesting a possible hydraulic connection between the two. The Croteau aquifer is consistently coarser-grained than the Quadra Sand, suggesting differing glacial depositional history.

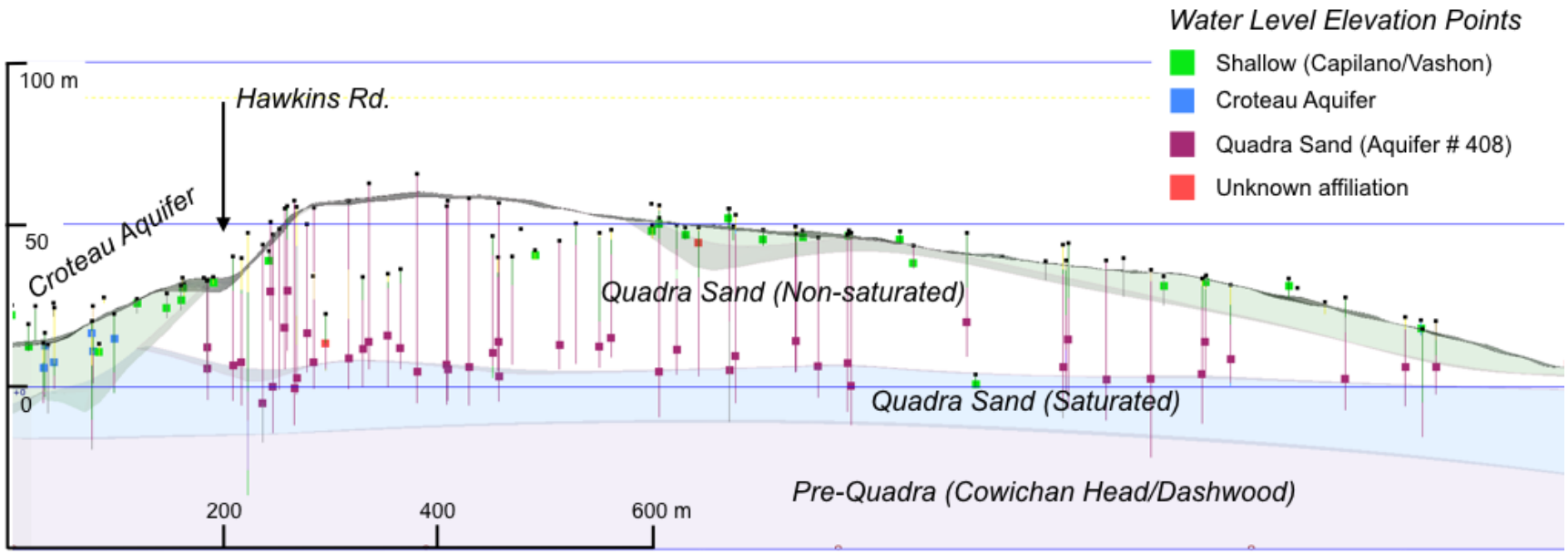


Figure 2. Groundwater elevations from wells within 1 km of tunnel alignment

- Water levels of "unknown affiliation" denote water levels from wells lacking subsurface information or identifiable geology.

The elevation of groundwater fluctuates seasonally and annually. It is important to underline that the water levels in Figure 2 were recorded at the time of drilling, and represent snapshots in time, taken over many years. The water levels in the Wells database may not accurately reflect groundwater elevations that exist in these wells today.

2.3 Springs and Seepage

Springs and seepage have been mapped in the study area (Figure 3 and 4, and these result from groundwater discharging at a local change in topography. Field verification and water sampling by GW Solutions (April and June 2017), on wells in the Balmoral Beach neighborhood revealed the following:

- Several shallow wells (less than 8 m deep), constructed at or near springs and seepage zones, are located immediately downgradient (southwest) of Hawkins Road (Red stars in Figure 3 and 4). These indicate that the water table here is relatively close to the surface (i.e. less than 5 meters).
- Contrasting water chemistry signatures exist between the shallow and deep groundwater systems in the Balmoral Beach neighborhood (area below Hawkins Rd). Total Dissolved Solids (TDS) is on average 1.7 times lower for shallow wells than for deep wells (GW Solutions 2017). Lower TDS values indicate that the water has spent less time in the ground travelling from the recharge area.

Wells and possible spring/seepage areas outside of the Balmoral Beach neighborhood (i.e., above/northeast of Hawkins Road) were not investigated as part of the 2017 field program. GW Solutions therefore cannot compare the water chemistry of groundwater discharging below Hawkins Road with that of wells above. The existing digital elevation model used in this study was a 1:50,000 elevation model available from NRCAN, with vertical inaccuracies in excess of +/-10m. This introduces uncertainty in determining the relationship between topography and the elevation of groundwater, either within the Quadra Sand or within the shallow Capilano/Vashon Drift. It is therefore beyond the scope of this study to determine the provenance of the groundwater discharging in the springs and seepage areas.

Figures 3 and 4 depict the distribution of wells in the relation to the approximate tunnel alignment, along with the recorded depths to water for each well. Quadra wells are denoted by "□". Here the depth to water is equal to the thickness of unsaturated sediment.

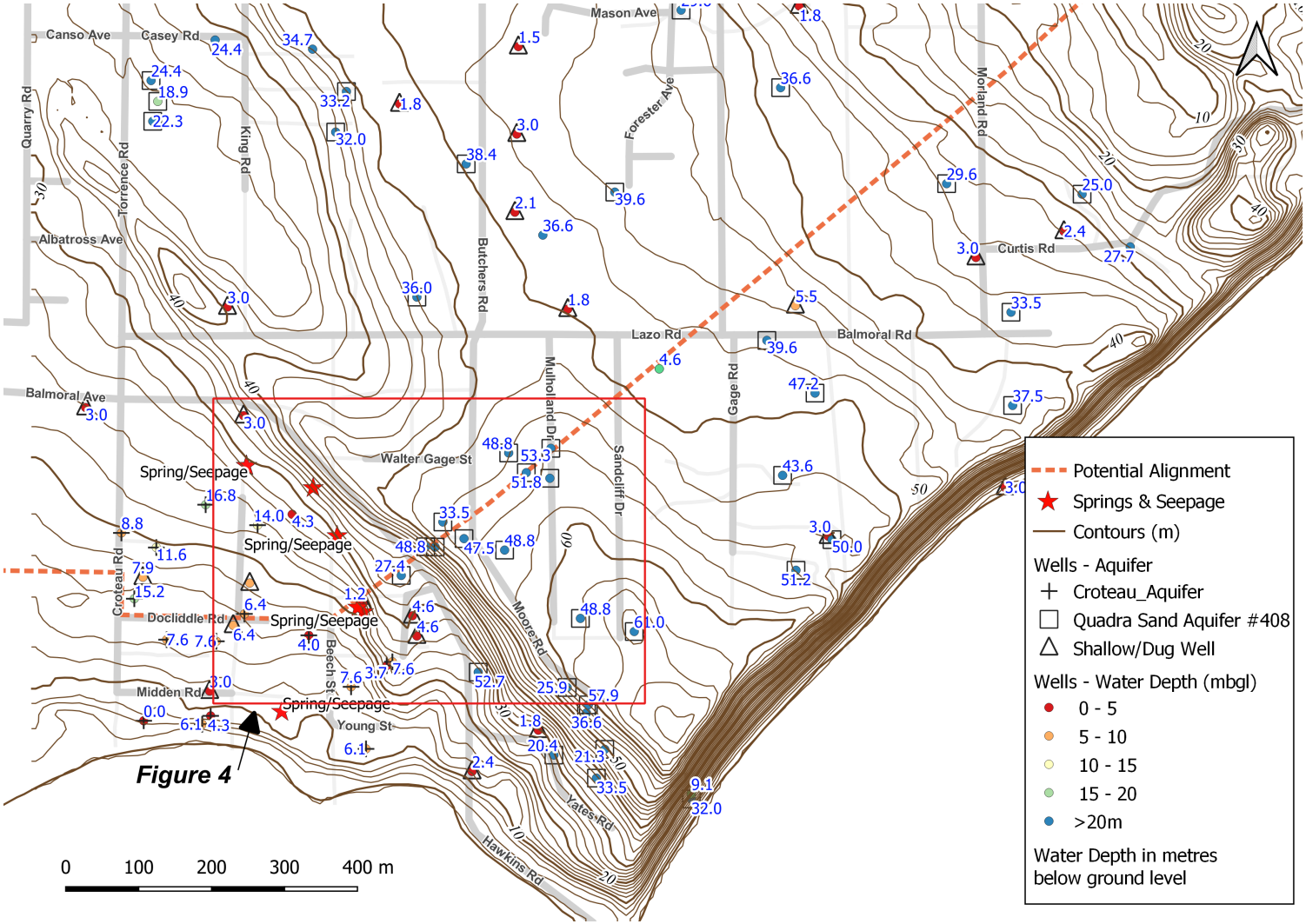


Figure 3. Depths to groundwater measured in various aquifers in the study area

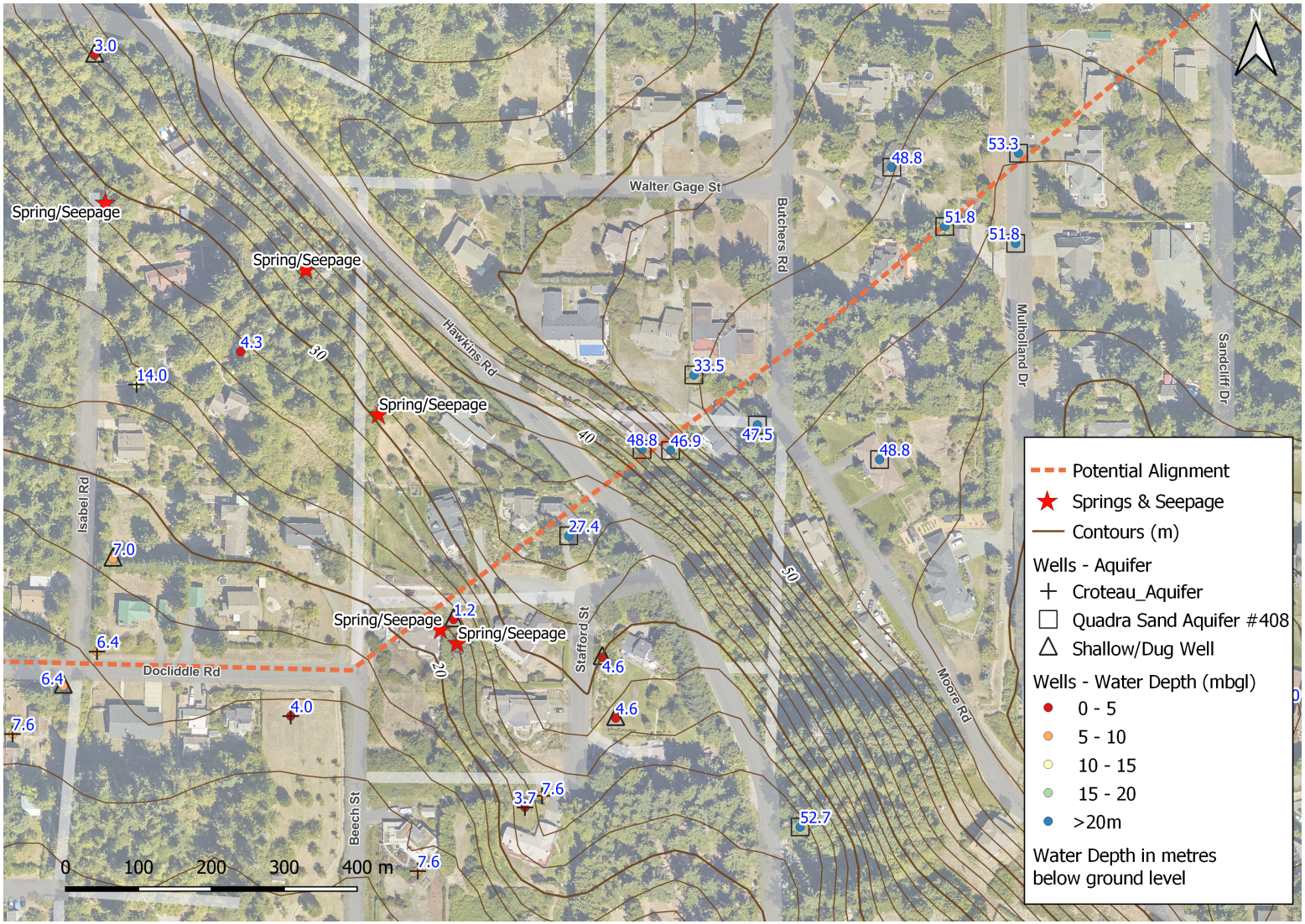


Figure 4. Closeup of Figure 3, near Lazo Hill

3 CONCLUSIONS

The Comox Hill area has no subsurface information available from the BC Wells Database. This likely stems from the historical reliance on municipal water versus groundwater by the community established in that area. Exploratory wells drilled in this area would provide much needed information on local geology and groundwater conditions.

In contrast, the Lazo Hill area has a sizeable population of wells in the database. Based on the work completed for this limited hydrogeological study of the Lazo Hill area, GW Solutions draws the following conclusions:

- Groundwater in wells drilled above (northeast of) Hawkins Road in the Quadra Sand Aquifer (#408) is greater than 40 m and as much as 60 m below ground level.
- The depth to groundwater in wells below (southwest) Hawkins Road is relatively shallow, typically less than 5 m below surface.
- Multiple seepage areas and springs exist below Hawkins Road. In these areas, groundwater discharges where local topography intercepts water-saturated horizons. It is not possible at this time to determine whether the groundwater discharging to surface at springs and seepage zones is being discharged from a perched water table within the Quadra Sand or from within the shallow Capilano/Vashon Drift.
- The Croteau aquifer is confined.

4 RECOMMENDATIONS

Should tunneling be accepted as a viable option and additional information be required to better define the hydrogeological conditions, GW Solutions makes the following recommendations:

1) Improve the quality and reliability of available information through the following steps:
   a) Obtain a higher definition digital elevation model (i.e. from LiDAR) that would greatly improve the definition of the geometry of the aquifers and springs/seeps.
   b) Map (elevations and coordinates) seepage areas and springs;

c) Seek access to residential wells near the tunnel alignment to obtain more accurate locations using handheld GPS or total station (with accurate elevation measurement);

d) Where possible, measure depths to water in existing domestic wells;

2) Drill and complete monitoring wells along the proposed route to adequately characterise groundwater conditions and tunnelling risks. Since no subsurface information is available for Comox Hill, drilling of at least three new monitoring wells along the alignment is recommended.

Following the gathering of new information in the above steps, GW Solutions recommends that the 3D Hydrogeological Conceptual Model of the tunneling area be updated, to better inform subsequent tunnel design steps.

5 STUDY LIMITATIONS

This document was prepared for the exclusive use of WSP Canada Group Limited. The inferences concerning the data, site and receiving environment conditions contained in this document are based on information obtained during investigations conducted at the site by GW Solutions and others and are based solely on the condition of the site at the time of the site studies. Soil, surface water and groundwater conditions may vary with location, depth, time, sampling methodology, analytical techniques and other factors.

In evaluating the subject study area and water quality data, GW Solutions has relied in good faith on information provided. The factual data, interpretations and recommendations pertain to a specific project as described in this document, based on the information obtained during the assessment by GW Solutions on the dates cited in the document, and are not applicable to any other project or site location. GW Solutions accepts no responsibility for any deficiency or inaccuracy contained in this document as a result of reliance on the aforementioned information.

The findings and conclusions documented in this document have been prepared for the specific application to this project and have been developed in a manner consistent with that level of care normally exercised by hydrogeologists currently practicing under similar conditions in the jurisdiction.

GW Solutions makes no other warranty, expressed or implied and assumes no liability with respect to the use of the information contained in this document at the subject site, or any other site, for other than its intended purpose. Any use which a third party makes of this document, or any reliance on or decisions to be made based on it, are the responsibility

of such third parties. GW Solutions accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or action based on this document. All third parties relying on this document do so at their own risk. Electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore no party can rely upon the electronic media versions of GW Solutions' document or other work product. GW Solutions is not responsible for any unauthorized use or modifications of this document.

GW Solutions makes no other representation whatsoever, including those concerning the legal significance of its findings, or as to other legal matters touched on in this document, including, but not limited to, ownership of any property, or the application of any law to the facts set forth herein.

If new information is discovered during future work, including excavations, sampling, soil boring, predictive geochemistry or other investigations, GW Solutions should be requested to re-evaluate the conclusions of this document and to provide amendments, as required, prior to any reliance upon the information presented herein. The validity of this document is affected by any change of site conditions, purpose, development plans or significant delay from the date of this document in initiating or completing the project.

The produced graphs, images, and maps have been generated to visualize results and assist in presenting information in a spatial and temporal context. The conclusions and recommendations presented in this document are based on the review of information available at the time the work was completed, and within the time and budget limitations of the scope of work.

WSP WSP Canada Group Limited may rely on the information contained in this memorandum subject to the above limitations.

6 CLOSURE

We hope that this provides a preliminary description of the groundwater system along the proposed works and we would be pleased to assist further, as required.

The conclusions and recommendations presented herein are based on available information at the time of the study. The work has been carried out in accordance with generally accepted engineering practice. No other warranty is made, either expressed or implied. Engineering judgment has been applied in producing this letter.

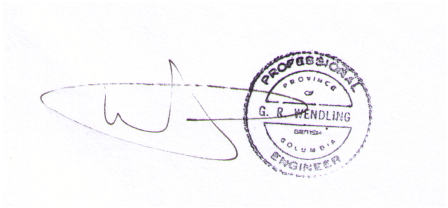
This letter was prepared by personnel with professional experience in the fields covered.

GW Solutions was pleased to produce this document. If you have any questions, please contact me.

Yours truly,

GW Solutions Inc.

Matt Vardal
MSc in Geology, GIS



Dr. Gilles Wendling
Ph.D., P.Eng.
President

7 REFERENCES

GW Solutions 2016. Hydrogeological Assessment of Future Wastewater Pump Station. Report submitted to Comox Valley Regional District.

GW Solutions 2017. Comox No.2 Pump Station - Groundwater Risk Assessment. Report submitted to Comox Valley Regional District.

NRCAN. Digital Elevation Model. Download from: https://open.canada.ca/data/en/dataset/7f245e4d-76c2-4caa-951a-45d1d2051333

Province of British Columbia (2019) GWELLS. Wells Database Download from: https://apps.nrs.gov.bc.ca/gwells/