5.6 Groundwater Resources

5.6.1 Introduction

This section of the Environmental Assessment Certificate (EAC) Application/Environmental Impact Statement (EIS) (hereafter referred to as the EA.) has been prepared by Golder Associates Ltd. (Golder). It addresses the effects of the Proposed BURNCO Aggregate Project (hereafter referred to as the 'Proposed Project') identified in the construction, operation, reclamation and closure phases on VCs related to Groundwater. Consideration has been given to mitigation measures proposed to mitigate any identified effects to acceptable levels and any residual effects have been characterized. Additionally consideration has also been given to cumulative effects of other reasonable foreseeable future projects in combination with the residual effects of the Proposed Project.

This section should be read in conjunction with the following technical report(s) provided in Volume 4, Part G - Section 22.0.

- Appendix 5.4-D – McNab Valley Project – Geological Setting and Description.
- Appendix 5.5-A – BURNCO Aggregate Project: Surface Water Hydrological Baseline.
- Appendix 5.5-D – Water Quality Modelling of the BURNCO Aggregate Project, BC.
- Appendix 5.6-A – Hydrogeology Characterization. McNab Valley Aggregate Project.
- Appendix 5.6-B – Geochemical Evaluation of Groundwater Samples Collected from the BURNCO Aggregate Project, BRUNCO Rock Products Ltd.
- Appendix 5.6-C – Geochemical Characterization at BURNCO Aggregate Project, BC.
- Appendix 5.6-D – Hydrogeological Modelling to Assess Proposed Mine Plan – McNab Valley Aggregate Project.
- Appendix 5.6-E – Geotechnical Assessment, Risk of Piping due to Changes in Groundwater Seepage Gradients, Proposed Gravel Pit, McNab Creek.
- Appendix 5.6-F – Groundwater Quality Predictions.

5.6.2 Regulatory and Policy Setting

This section provides a summary of the regulatory and policy setting of the Proposed Project as it relates to Groundwater quality and quantity.

5.6.2.1 Provincial Legislation

In the Province of British Columbia legislation on matters relating to use and flow of surface water and groundwater, and protection of water resources are governed by the *Water Sustainability Act* (WSA) (*Water Sustainability Act* SBC 2014). On February 29, 2016, the Regulations of the *Water Act* (*Water Act* RSBC 1996) were repealed and the WSA was brought into force, along with five new regulations, including the Water

Sustainability Regulation (B.C. Reg. 36/2016), the Water Sustainability Fees, Rentals and Charges Tariff Regulation (B.C. Reg. 37/2016), and the new Groundwater Protection Regulation (GWPR) (B.C. Reg. 39/2016). The Water Sustainability Regulation includes requirements for the licensing, diversion and use of groundwater and surface water to protect water resources and ecosystems, while the GWPR specifically addresses protection of the groundwater resource and identifies requirements for the construction of wells.

With respect to groundwater resources, requirements of the WSA and associated Regulations that are applicable to the Proposed Project will apply to a) the water supply well that is to provide make-up water for processing, b) the Site monitoring wells, and c) the potential for changes in groundwater quantity and quality as a result of Project Activities. Specifically, the requirements include, but are not limited to the following:

- Constructing and closing wells, installing well pumps and conducting flow tests are restricted activities that can only be performed by qualified well drillers, well pump installers or professional engineers and geoscientists.
- There are specific requirements for the construction, maintenance and decommissioning of water supply and monitoring wells, including requirements for submission of reports in relation to these activities.
- A water license must be obtained and rental fees must be paid for the diversion (extraction) and beneficial use of water from the supply well.
- The water license will establish water rights based on the system of First-in-Time, First-in-Right (FITFIR) that is currently in place for surface water licenses. For supply wells installed after the coming into force of the WSA, the priority date for the water license will be the date of the application for the water license. Under FITFIR, users with the earliest priority dates have precedence, regardless of the purpose for which the water is used. Thus, during times of water scarcity, users with older priority dates are entitled to their full allocation, even if this results in users with newer priority dates being unable to access any of their licensed allocation. The WSA makes exception to FITFIR for essential household uses, and to maintain environmental flows under specific types of “Orders”.
- Environmental flow needs must be considered in the application for a groundwater license where the source aquifer is hydraulically connected to a stream.
- There is a prohibition on the introduction of foreign matter into a stream or well.
- For the purpose of sustaining water quality, regulations may be made to establish water objectives for a stream, aquifer, or other specified area or environmental feature and specifying factors and criteria to apply for evaluating the impacts of a land use or resource use proposal.

The potential changes to groundwater quality and quantity as a result of the Proposed Project and the interaction of groundwater with a hydraulically connected stream are addressed as part of this EIS.

5.6.2.2 Federal Legislation

The Proposed Project may be subjected to the following Federal legislation:

- Groundwater may be indirectly regulated under the Federal *Fisheries Act* (R.S.C., 1985, c. F-14; last amended on 2013-11-25) that protects fish belonging to a commercial, recreational or Aboriginal fishery and their habitats with groundwater flow to steams a component of this habitat. Specifically, sections of the *Fisheries Act* that are pertinent to groundwater in the Proposed Project include the following:
  - Section 20 – relates to the passage of fish and in-stream flow needs of fish requiring sufficient groundwater flow occurs to the stream throughout the year.

5.6.3 Assessment Methodology

To assess effects to groundwater flow and quality, components of the study were developed as follows:

- Establish current baseline conditions including detailed measurement of groundwater levels and temperatures, water levels and tidal effects in Howe Sound, groundwater flow directions and velocities, groundwater and surface water quality and measurements of stream flow; and
- Use the baseline data to calibrate a three-dimensional numerical hydrogeological model of the Proposed Project site that can be used to predict effects of the Proposed Project on flows in McNab Creek.

In developing these components, the following documents were referenced:

- Framework for a Hydrogeologic Study in Support of an application for an Environmental Assessment Certificate under the *Environmental Assessment Act* and Regulations (BC Ministry of Environment 2015);
- Technical Guidance 6, *Environmental Management Act*, Applications Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators (BC Ministry of Environment 2012a); and
- Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities (BC Ministry of Environment 2012b).

5.6.3.1 Value Component (VC) Selection and Rationale

The VCs identified reflect issues and guidelines, potential Aboriginal concerns, issues identified by BC EAO and CEA Agency, First Nations, other stakeholders, professional judgment and key sensitive resources, species or social and heritage values. All identified candidate groundwater resources VCs were carried forward in the effects assessment (e.g. no groundwater resources VCs were excluded from the assessment). Additional details regarding the methods used to select VCs is provided in Part B, Volume 2 – Section 4.2.4.

The assessment of potential effects of the Proposed Project on Groundwater were determined using specific valued components or VCs. Valued components included environmental components considered to have the greatest relevance in terms of environmental value and which are most likely to be affected by the Proposed Project. Groundwater related VCs include the following:

- Groundwater flow (quantity); and
- Groundwater quality.

The overall assessment of effects from the Proposed Project on the VC's is predicted by use of quantitative or qualitative measurements of the amount of change of parameter(s) developed for each VC. For groundwater VCs, the change will assessed by the difference between existing groundwater conditions compared to those conditions predicted by a numerical hydrogeological model for groundwater quantity and a water quality model for groundwater quality that were developed for the Proposed Project.

Table 5.6-1 provides a summary of identified VCs, rationale for their inclusion in the assessment, and measurable parameters or endpoints that will be considered.

Table 5.6-1: Value Components and Measurable Indicators: Groundwater Resources

Value Component	Rationale	Measurable Indicators
Groundwater flow	Maintain groundwater flow quantity.	Monitor surface water flow in McNab Creek and streams along the marine shoreline throughout the year. Measure water level in pit lake. Install piezometer to measure hydraulic heads. Compare to baseline groundwater quantity.
Groundwater quality	Groundwater quality to meet applicable regulatory guidelines and/or not exceed background groundwater quality.	Sample groundwater in select monitoring wells every 3 months throughout the Proposed Project and compare to baseline groundwater quality.

5.6.3.2 Assessment Boundaries

5.6.3.2.1 Spatial Boundaries

The spatial boundaries for the EA have been selected to take into account the physical extent of the Proposed Project, physical extent of Proposed Project-related effects and the physical extent of any key environmental systems. The specific study areas for groundwater quality and quantity are provided in Table 5.6-2 and Figure 5.6-1.

Table 5.6-2: Spatial Boundaries: Groundwater Resources

Study Area	Description
Local Study Area (LSA)	It is the area of the Proposed Project that has a direct environmental effect on the groundwater. It primarily consists of the alluvial/deltaic aquifer of McNab Creek, but also includes alluvial sediment located to the north of the Project (and north of McNab Creek. McNab Creek east of the Project footprint flows on bedrock and bedrock is located east of McNab Creek. The constant head produced by McNab creek and the low hydraulic conductivity of the bedrock result in no direct effects to the east side of McNab Creek in this area. The effects to the bedrock slopes to the east of the Proposed Project footprint are also negligible and therefore are not included in LSA (Figure 5.6-1).
Regional Study Area (RSA)	Is the same as the surface hydrology RSA (i.e., the catchment area of McNab Creek as shown on Figure 5.6-1.

5.6.3.2.2 Temporal Boundaries

Based on the Proposed Project schedule, the temporal boundaries for the effects assessment for groundwater quality and quantity are as follows:

- Project construction – up to 2 years;
- Project operations – 16 years; and
- Project reclamation and closure – on-going and 1 year beyond operations.

See Volume 2, Part B - Section 4.0 for a full description of the temporal boundaries of the Proposed Project.

5.6.3.2.3 Administrative Boundaries

There are no administrative constraints on the groundwater resource assessment.

5.6.3.2.4 Technical Boundaries

There are no technical boundaries on the assessment of the baseline groundwater resource conditions. Field investigations, including installation of monitoring wells, groundwater sampling, continuous measurements of groundwater temperature and hydraulic heads were not limited.

Technical constraints would include the need to use a numerical groundwater model to predict future groundwater conditions. The numerical groundwater model was calibrated to considerable hydrogeological data collected on current groundwater conditions. Section 5.6.3.3.5 presents our assessment of the level of confidence in our predictions of groundwater flow rates and quality.

5.6.3.3 Assessment Methods

To assess the effects of the Proposed Project on the groundwater flow/quantities conditions a three-dimensional FEFLOW model (Diersch 2012) was developed for the LSA. The model was calibrated to the baseline groundwater conditions and then the calibrated model used to predict the effects of the Proposed Project. Sensitivity analyses were undertaken to assess the effect of uncertainties in the model parameters on the predicted changes to the groundwater conditions resulting from the Proposed Project. A full description of the numerical hydrogeological model is provided in Volume 4, Part G - Section 22.0: Appendix 5.6-D.

In developing the numerical hydrogeological model, the following document was referenced:

- Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities (BC Ministry of Environment 2012b).

To assess the effects of the Proposed Project on the groundwater quality, a mass-balance water quality model was developed using GoldSim Version 10.5. GoldSim is a graphical, object-oriented mathematical modelling program where all input parameters and functions are defined by the user and are built as individual objects or elements linked together by mathematical expressions. The object-based nature of the program is designed to facilitate an understanding of the various factors that control an engineered or natural system and predict potential changes to the system.

Simulated water qualities were determined in the groundwater and at several receiving environment assessment locations. The mass-balance model uses the site water balance to account for the magnitude of each natural flow (e.g., precipitation, stream flow) and Project-affected flow (e.g., runoff from fines, pit wall runoff) at each assessment location. Input water qualities were assigned to each source term. The inflow concentration of each modelled parameter was determined at each assessment location and at each time step in the water quality model. The calculated water quality represents the groundwater quality downstream of the pit lake.

A base case scenario was developed using median water quality inputs. In addition to the base case scenario, a conservative scenario was developed using a combination of 95th percentile and probabilistic inputs. The purpose of these scenarios was to generate a range of model predictions due to changes and uncertainties in the input water qualities. A full description of the GoldSim model used to predict groundwater quality is presented in Volume 4, Part G - Section 22.0: Appendix 5.5-D.

5.6.3.3.1 Existing Conditions

The information and methods used in this assessment for baseline characterisation of groundwater quality and quantity have been obtained from those sources listed below.

In assessing the baseline conditions at the Proposed Project the following document was referenced:

- Framework for a Hydrogeologic Study in Support of an application for an Environmental Assessment Certificate under the *Environmental Assessment Act* and Regulations (BC Ministry of Environment 2015).

The specific information and methods used in this assessment for baseline characterisation of groundwater for the Proposed Project are listed below.

Aquifer and Well Database

The BC Water Resources Atlas is an iMapBC application that displays information related to the water resources of BC, such as watersheds, water quantity and quality, monitoring sites, aquifers, water wells and flood protection works (BC Ministry of Environment 2014). The BC Water Resources Atlas was queried to assess the presence of water wells and aquifers that have been identified in the Proposed Project Area.

Field Investigations

The following provides a summary of the field methods used to assess the baseline groundwater conditions. A full description of these field methods is presented in Volume 4, Part G - Section 22.0: Appendix 5.6-A.

Monitoring Wells

Five monitoring wells (designated MW05-1 through MW05-5) were installed in 2005 under the supervision of EBA Engineering Consultants Ltd. (EBA) staff at the approximate locations shown on Figure 5.6-2. EBA wells MW05-1, MW05-2 and MW05-5 were located in the field. EBA wells MW05-3 and MW05-4 were not located in the field and were presumed to have been destroyed, as indicated on Figure 5.6-2.

In June 2010, Golder engineering and hydrogeology field staff supervised the drilling of five (5) exploratory boreholes to a maximum depth of 49.4 m-bg (metres below ground) below the valley floor at locations either within or adjacent to the proposed extraction area (Figure 5.6-2). The boreholes were designated DH10-01, DH10-02, DH10-05, DH10-06 and DH10-07. The completed monitoring wells were labelled using the above-noted DH-10 series designations, with an additional letter suffix “S” to identify the shallow standpipes and a “D” label to identify the deeper standpipes.

Initial Well Development and In-Situ Hydraulic Testing

During the period of June 30 to July 12, 2010, Golder staff completed standardized development of the five new DH10 series monitoring wells and three EBA MW05 series monitoring wells, to improve the hydraulic connectivity of the wells to the surrounding geological strata and remove water from the wells that was potentially affected by the drilling process.

Golder field personnel conducted standardized *in-situ* hydraulic tests (i.e., single well response tests) in the five DH10 series multi-level wells (shallow and deep) and two MW05 series wells. The hydraulic conductivity (*K*) of the granular sediments positioned adjacent to all monitoring well screens was estimated through analysis of the *in-situ* hydraulic testing data in AQTESOLV©, a commercially available software package for aquifer test analysis.

Groundwater and Surface Water Monitoring Program

In July 2010 Golder staff installed individual pressure transducers with automated dataloggers in all DH10 series monitoring wells (both shallow and deep) and also in MW05-02 and MW05-05. All devices were programmed to record water pressures and temperature at 15 minute intervals. Since initial installation, the recorded data has been downloaded at regular intervals, with the last download occurring in October 2014.

Four surface water monitoring stations were installed In the Project Area in August 2010 (Figure 5.6-2). Two surface water stations (Stations SW10-01, SW10-02) were installed in McNab Creek and two stations (SW10-03 and SW10-04) were installed in WC 2 (Figure 5.6-2). The four surface water monitoring stations (i.e., SW’s) were instrumented with automated pressure transducers to record water pressures at 15-minute intervals. Each SW was also outfitted with a graduated staff gauge surveyed by a Registered British Columbia Land Surveyor (BCLS). The automated pressure transducers were last downloaded in October 2014.

Groundwater Chemistry

Golder field staff obtained groundwater quality samples from all DH10 series monitoring wells (shallow and deep) and wells MW05-2 and MW05-3, during the 3-day period commencing July 20, 2010. Surface water quality samples were also obtained directly from McNab Creek at stations SW10-01 and SW10-02 and from WC 2 at station SW10-03. Groundwater quality sampling from the same well locations was conducted again during the period November 29 to 30, 2012 and February 17 to 19, 2014. Additional surface water stations were established and surface water samples were collected and these are reported in Volume 4, Part G - Section 22.0: Appendix 5.5-A

Golder's standard environmental sampling field procedures and protocols were employed during monitoring well sampling and surface water sampling, including maintenance of chain-of-custody (CoC) documentation. The requested analyses included a range of parameters based generally on BC Water Quality Guidelines for the Protection of Aquatic Life (BC Ministry of Environment 2010) to facilitate a relative comparison of surface water and groundwater quality.

5.6.3.3.2 Identifying Project Interactions

A preliminary evaluation of identified interactions between the various physical works and activities and the selected VCs across all spatial and temporal phases of the Proposed was undertaken to characterize interactions as:

a) Positive, none or negligible, requiring no further consideration; or

b) Potential effect requiring further consideration and possibly additional mitigation.

This evaluation is presented in Section 5.6.5. Rationale is provided for all determinations that there is no or negligible interaction and that no further consideration is required. For those Proposed Project-VC interactions that may result in a potential effects requiring further consideration, the nature of the effects (both adverse and positive) arising from those interactions is described. Potential effects include direct, indirect and induced effects.

5.6.3.3.3 Evaluating Residual Effects

Potential Proposed Project-related residual effects were characterized as the basis for determining the significance of potential residual adverse effects for each VC. The characterization of effects was undertaken following application of appropriate mitigation measures.

Potential residual effects were characterized using the following standard residual effects criteria:

- **Context** – the current and future sensitivity and resilience of the VC to change caused by the Proposed Project;
- **Magnitude** – the expected size or severity of the residual effect;

- **Extent** – the spatial scale over which the residual physical, biological and/or social effect is expected to occur;
- **Duration** – the length of time the residual effect persists;
- **Reversibility** - indicating whether the effect is fully reversible, partially reversible, or irreversible; and
- **Frequency** – how often the residual effect occurs.

The criteria defined in Table 5.6-3 have been used to characterise and determine the significance of potential effects of Groundwater VCs.

The likelihood of potential residual effects occurring was characterized for using appropriate quantitative or qualitative terms, with sufficient description of how conclusions were reached. The following scale was use for the assessment of likelihood:

- Low - likelihood of occurrence (0 to 40%) – Residual effect is possible but unlikely;
- Medium - likelihood of occurrence (41 to 80%) - Residual effect may occur, but is not certain to occur; and
- High - Likelihood of occurrence (81% to 100%) - Residual effect is likely to occur or is certain to occur.

Likelihood may be influenced by a variety of factors, such as the likelihood of a causal disturbance occurs or the likelihood of mitigation being successful.

5.6.3.3.4 Evaluating Significance of Residual Effects

The significance of potential residual adverse effects are determined for each VC based on the residual effects criteria and the likelihood of a potential residual effect occurring (Section 5.6.3.3) a review of background information and available field study results, consultation with government agencies and other experts, and professional judgement.

The rationale and determinations of the significance of potential residual effects on VCs are provided in Section 5.6.5.5.

5.6.3.3.5 Level of Confidence

The level of confidence for each predicted effect is discussed to characterize the level of uncertainty associated with both the significance and likelihood determinations. Level of confidence is typically based on expert judgement and is characterized as:

- Low: Limited evidence is available, models and calculations are highly uncertain, and/or evidence about potential effects is contradictory.
- Moderate: Sufficient evidence is available and generally supports the prediction.
- High: Sufficient evidence is available and most or all available evidence supports the prediction.

Table 5.6-3: Criteria for Characterizing Potential Residual Effects: Groundwater Resource VCs

VC	Context	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
Groundwater Flow	**Resilient:** The receiving groundwater environment has a high natural resilience to imposed stresses; **Moderately Resilient:** The receiving groundwater environment has a moderate natural resilience to imposed stresses; or **Sensitive:** The receiving groundwater environment has a low natural resilience to imposed stresses.	**Negligible:** Predicted % changes in total aquifer flow is less than 1%; **Low:** Predicted % change in total groundwater quantity is between 1% and 15%; **Moderate:** Predicted change in total groundwater quantity is between 15% and 30%; or **High:** Predicted change in total groundwater quantity is greater than 30%.	**Local:** Effect restricted to the LSA; **Regional:** Effect extends beyond the LSA into the RSA; or **Beyond Regional:** Effect extends beyond the RSA.	**Short-term:** <5 years; **Medium-term:** 5 years to life of Proposed Project; or **Long-term:** >life of Proposed Project.	**Fully reversible:** Effect reversible with reclamation and/or over time; **Partially Reversible:** Effect can be reversed partially; or **Irreversible:** Effect irreversible and cannot be reversed with reclamation and/or over time.	**Low:** Occurs rarely or during a specific period; **Medium:** Occurs intermittently; or **High:** Occurs continuously.

VC	Context	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
Groundwater Quality	**Resilient:** The receiving groundwater environment has a high natural resilience to imposed stresses; **Moderately Resilient:** The receiving groundwater environment has a moderate natural resilience to imposed stresses; or **Sensitive:** The receiving groundwater environment has a low natural resilience to imposed stresses.	**Negligible:** Releases do not cause exceedance of guidelines or cause exceedances that are less than background exceedances; **Low:** Releases contribute slightly to existing background exceedances; **Moderate:** Releases cause exceedance of guidelines (where guidelines were not previously exceeded); or **High:** Releases cause substantial exceedance of guidelines.	**Local:** Effect restricted to the LSA; **Regional:** Effect extends beyond the LSA into the RSA; or **Beyond Regional:** Effect extends beyond the RSA.	**Short-term:** <5 years; **Medium-term:** 5 years to life of Proposed Project; or **Long-term:** >life of Proposed Project.	**Fully reversible:** Effect reversible with reclamation and/or over time; **Partially Reversible:** Effect can be reversed partially; or **Irreversible:** Effect irreversible and cannot be reversed with reclamation and/or over time.	**Low:** Occurs rarely or during a specific period; **Medium:** Occurs intermittently; or **High:** Occurs continuously.

5.6.4 Baseline Conditions

Groundwater and surface water monitoring and testing at the Proposed Project Area between June 2010 and October 2014, together with the interpretation of Proposed Project Area geological and hydrological conditions (Volume 4, Part G - Section 22.0: Appendices 5.6-A and 5.5-A) has provided information to develop a characterization of the groundwater regime within the Proposed Project.

5.6.4.1 Traditional Ecological and Community Knowledge Incorporation

TEK/CK information was gathered from a Project-specific study undertaken by *Sḵwx̱wú7mesh* (Squamish Nation) and from publicly-available sources.

TEK/CK sources were reviewed for information that could contribute to an understanding of groundwater resources. The main sources of this information include:

- Occupation and Use Study (OUS) undertaken by Skwxwú7mesh (Traditions 2015 a,b)
- An expert report produced on behalf of Tsleil-Waututh Nation for another project (Morin 2015)
- Regulatory documents for other projects in close proximity to the Proposed Project Area (e.g., Eagle Mountain – WGP 2015 a,b; PMV 2015; WLNG 2015).

TEK/CK sources available at the time of writing provided no specific information on groundwater resources. .

5.6.4.2 Well and Aquifer Designation

There are no water wells and no aquifers have been identified in the BC Water Resources Atlas within the LSA or the RSA (BC Ministry of Environment 2014). Although the alluvial/deltaic deposits in the LSA have not yet been identified as an aquifer in the BC Water Resources Atlas, it is an unconfined aquifer and will be treated as such in the following effects assessment.

5.6.4.3 Hydrostratigraphy

There are three main hydrostratigraphic units, namely: valley-fill aquifer, till and bedrock. The granular glaciofluvial and alluvial sediments comprise a thick unconfined aquifer. The aquifer is at least 50 m think, but is likely much thicker particularly in the centre of the valley (potentially greater than 100 m). Single-well response testing indicates that the aquifer hydraulic conductivity is relatively high and ranging between 1×10^{-4} m/s and 2×10^{-3} m/s. Estimates of hydraulic conductivity based on grain size analysis were generally higher than the values obtained from the single-well-response testing, possibly due to washing-out of fines during sample collection. The hydraulic conductivity of the valley fill aquifer is decreasing with depth. The geometric mean of single-well-response tests conducted between 0 to 20 m depth interval and 20 m to 50 m depth interval is approximately 4×10^{-4} m/s and 2×10^{-4} m/s, respectively. The aquifer materials are likely anisotropic (i.e., vertical hydraulic conductivity is less than the horizontal hydraulic conductivity) due to inter-bedded and cross-bedded structures associated with the aquifer depositional environment.

Glacial till has been observed in the upper portion of the McNab valley. Hydrogeological properties of the till have not been measured at the Proposed Project Area; however, based on published values for similar materials its hydraulic conductivity is considered to be lower (perhaps on the order of 10^{-6} m/s to 10^{-7} m/s) than those estimated for the valley-fill aquifer.

No *in-situ* testing has been conducted in bedrock that underlies and flanks the valley fill aquifer. To the east of the McNab Creek valley the bedrock has a predominately granodiorite composition; whereas, to the west metamorphic rocks (meta-argillite, slate, and siltstone) dominate. The bulk hydraulic conductivity of the bedrock is likely at least three orders of magnitude less than those estimated for the valley fill aquifer (Maidment 1992). The hydrogeological properties of a possible fault structure within the bedrock that may parallel McNab Creek valley is also not know. However, the hydrogeological significance of this fault structure, if it exists, would only be high relative to the groundwater flow system in the valley fill aquifer if it is laterally continuous, highly permeable and of considerable width.

5.6.4.4 Groundwater Flow Directions and Gradients

Groundwater elevations recorded during the entire July 2010 to October 2014 monitoring period, exhibited consistently higher elevations during wet winter months and lower elevations during the remainder of the year. Increases in groundwater elevation in response to winter precipitation were recorded in all monitoring wells; however, the magnitude of these increases varied throughout the Proposed Project Area. The greatest increases of up to 5 m were observed in wells located closer to the west boundary of the valley fill aquifer; whereas, the lowest increases, those not exceeding approximately 2 m, were observed in remaining observation wells which are all located closer to the east portion of the property near McNab Creek. These lower increases compare relatively well with the range of creek level fluctuations observed during winter months, which suggest that the hydraulic head increases in the eastern portion of the Proposed Project Area are probably controlled to a larger degree by the creek level than by direct recharge. In the western portion of the Proposed Project Area direct recharge from rainfall events and run-off from the bedrock slope west and appears to be the main controlling factor in seasonal head fluctuations.

Despite these seasonal and short-term variations in hydraulic heads, the relative groundwater levels in the monitoring wells have remained constant. Therefore, groundwater flow directions and associated hydraulic gradients are interpreted to be similar throughout the year.

5.6.4.5 Horizontal Gradients

The valley floor groundwater regime during the summer months is interpreted to be characterized by an overall southward flow direction at gradients of 2% to 3% below the extreme northern end of the examined area. The gradients become progressively lower (i.e., flatter) toward the southern end of the valley floor (Figure 5.6-3). Within the central and southern portions of the valley floor, the groundwater regime is characterized by convergent southwestward and southeastward flow, toward Watercourse 2 (WC 2). The convergent flow is interpreted to be result of the hydraulic influence of the deeply excavated channel, which represents an artificial groundwater drainage pathway that has reduced groundwater levels in areas directly adjacent to the watercourse and altered both groundwater flow directions and flow gradients. The monitoring data indicates that, following construction of WC 2, permanent reductions of approximately 2 m to 3 m have potentially occurred within the central and northern reaches of this watercourse.

The groundwater flow pattern during the winter months (Figure 5.6-4) are similar to the one observed during the summer months; however, the hydraulic heads are overall higher, in particular in the west portion of the valley fill aquifer. This results in overall steepening of hydraulic gradients between the MW05-5 in the west and WC 2 that intersects the center of the aquifer.

5.6.4.6 Vertical Gradients

Upward groundwater flow gradients were identified in groundwater elevation data for all DH10 series monitoring wells. These upward hydraulic gradients persisted for the entire monitoring period, independently from the summer (dry) and winter (wet) seasons. The elevation differences are indicative of groundwater gradients that include a component of vertical flow. Accordingly, groundwater originating from the deeper valley floor sediments is partially conveyed upward, but not vertically upward, into the overlying shallower sediments.

The relatively higher groundwater elevations measured in deep monitoring wells are representative of regional-scale hydraulic influences. These include the presence of the large upland recharge areas to the west comprised of exposed bedrock that extends under the McNab Valley floor and likely conveys water under high piezometric pressure to the deeper valley floor sediments. Conversely, groundwater elevations measured in the relatively shallowly buried (i.e., near surface) valley floor sediments are more representative of localized hydraulic influences such as McNab Creek stage, recharge of incident rainfall and to a lesser extent by intermittent pressure gradients related to tidal stage. Lastly, these upward gradients are accentuated by WC 2, which lowered the hydraulic heads in the shallow portion of the aquifer from the pre-construction levels.

5.6.4.7 Surface Water-Groundwater Hydraulic Connectivity

Elevation data from the combined surface water and groundwater monitoring program indicate that the sediments underlying the valley floor have a direct hydraulic connection to McNab Creek. Water from McNab Creek flows southward (overall) into the valley floor sediments from both the east-west aligned and north-south aligned creek reaches. This interpretation is also generally supported through a comparison of water chemistry in McNab Creek with water chemistry in both WC 2 and shallow DH10 series monitoring wells.

Water loss from McNab Creek to the valley fill aquifer is further supported by the continuous temperature data that has been collected from the Proposed Project Area monitoring well network. When this information is compared to the continuous temperature record obtained from the surface water monitoring stations, it is possible to trace the movement of the thermal front through this aquifer in response to seasonally high temperatures in McNab Creek typically observed in the summer months. The temperature data was also used to calculate a bulk hydraulic conductivity of the valley-fill aquifer of approximately 7 x 10^{-4} m/s.

A calibrated numerical hydrogeological model developed for the Proposed Project Area estimates that the baseline total groundwater flow through the valley sediments (LSA) is about 58,000 m^3/day with and an uncertainty range of a factor of 2 (30,000 m^3/day to 120,000 m^3/day). A full description of the numerical hydrogeological model is presented in Volume 4, Part G - Section 22.0: Appendix 5.6-D.

5.6.4.8 Groundwater Quality

The results of the evaluation of the groundwater samples collected at the Proposed Project Area in 2010, 2012 and 2014 indicate that the local groundwater chemistry is influenced by the geographic location and depth from which the water originates, as well as by the lithology in which that the groundwater wells are completed. A detailed discussion of the methods used to characterise the baseline groundwater quality is presented in Volume 4, Part G - Section 22.0: Appendix 5.6-C.

Groundwater composition varied by location and the stratigraphic layer from which groundwater samples were collected:

- Most samples collected from MW05-01, DH10-06 and DH10-07, located down gradient of the steep, east facing slopes on the western boundary of the Proposed Project, and had a Ca-SO_4 type composition. Shallow groundwater samples collected from DH10-06 had a Ca-HCO_3 type composition. These wells were completed in shallow sand to deeper clayey silt;
- Deep groundwater collected from DH10-01 also had a Ca-SO_4 type composition. This well was completed in gravelly sand;
- Samples collected from DH10-05, MW05-02, MW05-05, DH10-02, and shallow water collected from DH10-01 had a Na-HCO_3 to Ca-HCO_3 type composition. These wells were completed in gravelly sand in the valley floor; and
- Groundwater samples collected from wells MW05-01, DH10-06, DH10-07 at the western edge of the Proposed Project were sulphate dominant. In general, most samples collected from monitoring wells completed in gravelly sand in the valley floor on the east edge of the Proposed Project had a bicarbonate dominant composition.

Groundwater sample analyses were compared to the Environmental Protection Division of British Columbia Water Quality (BCWQ) Guidelines (BC Ministry of Environment 2015a, 2015b) and the Canadian Council of Ministers of the Environment Environmental Quality (CCME) Guidelines (CCME 1999, with updates to 2015). Water quality trends of select parameters in groundwater collected from the Proposed Project Area include:

- **pH:** lab pH ranged from 5.8 to 8.8. Field pH values were outside the range of CCME guidelines (6.5 to 9.0) in seven samples collected from DH10-05S (2 samples), MW05-02 (1 sample), DH10-06S (1 sample), DH10-01S (1 sample), MW05-05 (1 sample), and DH10-02S (1 sample).
- **Ammonia (as N):** Ammonia concentrations ranged from less than the detection limit (<0.005) to 0.043 mg/L.
- **Chloride:** Chloride concentrations ranged from less than the detection limit (<0.50) to 8.0 mg/L.
- **Fluoride:** Fluoride concentrations ranged from less than the detection limit (<0.02) to 0.23 mg/L, exceeding the CCME guideline of 0.12 mg/L in five samples collected from DH10-06D (3 samples) and MW05-01 (2 samples).
- **Nitrate (as N):** Nitrate concentrations ranged from less than the detection limit (<0.005) to 0.49 mg/L.
- **Nitrite (as N):** Nitrite concentrations ranged from less than the detection limit (<0.001) to 0.0026 mg/L.

- **Sulphate:** Sulphate concentrations ranged from less than the detection limit (<0.50) to 120 mg/L.
- **Aluminum:**
  - Concentrations of dissolved aluminum ranged from less than the detection limit (<0.005) to 0.069 mg/L. Aluminum concentrations exceeded the hardness dependent BCWQ guideline in 14 samples collected from DH10-07S, DH10-07D, DH10-02S, DH10-05S, DH10-06S and DH10-06D. The CCME guideline was exceeded in 21 samples from DH10-07S, DH10-07D, DH10-02S, DH10-05S, MW05-02, DH10-06S, DH10-06D and DH10-01D.
  - Concentrations of total aluminum ranged from less than the detection limit (<0.005) to 124 mg/L and exceeded the BCWQ guideline of 0.011 mg/L in 30 samples, collected from all wells at the Project except MW05-05. Total aluminum concentrations exceeded the CCME guideline of 0.005 mg/L in 36 samples collected from all wells.
- **Arsenic:** Concentrations of dissolved arsenic ranged from less than the detection limit (<0.0005) to 0.0058 mg/L, exceeding both the CCME and BCWQ guidelines of 0.005 mg/L in 1 sample collected from DH10-06D. Concentrations of total arsenic ranged from less than the detection limit (<0.0005) to 0.045 mg/L, exceeding both the CCME and BCWQ guidelines in five samples collected from DH10-06S (1 sample), DH10-06D (3 samples) and DH10-01S (1 sample).
- **Beryllium:** Dissolved and total beryllium concentrations were all below detection limit. The detection limits used (<0.001 to <0.01 mg/L) exceeded the BCWQ guidelines of 0.00013 mg/L.
- **Cadmium:** Concentrations of dissolved cadmium ranged from less than the detection limit (<0.00001) to 0.000085 mg/L. Total cadmium ranged from less than the detection limit (<0.00001) to 0.00055 mg/L, exceeding the CCME and/or BCWQ guidelines in five samples collected from DH10-06S (1 sample), DH10-06D (2 samples), and DH10-01S (2 samples).
- **Chromium:** Dissolved chromium concentrations were less than the detection limit (<0.001 mg/L). Total chromium ranged from less than the detection limit (<0.001) to 0.097 mg/L and exceeded the hardness dependent CCME and BCWQ guidelines in five samples collected from DH10-06S (1 sample), DH10-06D (3 samples), and DH10-01S (1 sample).
- **Cobalt:** Dissolved cobalt concentrations were less than the detection limit (<0.0003 to <0.003 mg/L). Total cobalt concentrations ranged from less than the detection limit (<0.0003 mg/L) to 0.033 mg/L, exceeding the BCWQ guideline of 0.004 mg/L in four samples collected from DH10-06S (1 sample), DH10-06D (3 samples), and DH10-01S (1 sample).
- **Copper:** Dissolved copper concentrations were less than the detection limit (<0.001 to <0.01 mg/L). Total copper concentrations ranged from less than the detection limit (<0.001) to 0.16 mg/L and exceeded the hardness dependent BCWQ and CCME guidelines in seven samples collected from DH10-06S (2 samples), DH10-06D (2 samples), DH10-01S (1 sample), and DH10-01D (1 sample).
- **Iron:** Dissolved iron concentrations ranged from less than the detection limit (<0.03) to 0.14 mg/L. Total iron concentrations ranged from less than the detection limit (<0.03) to 75 mg/L and exceeded the CCME guideline of 0.3 mg/L in seven samples collected from MW05-02 (2 samples), DH10-06S (1 sample), DH10-06D (3 samples), and DH10-01S (1 sample).

- **Lead:** Dissolved lead concentrations were less than the detection limit (<0.0005 mg/L to <0.001). Total lead concentrations ranged from less than the detection limit (<0.0005) to 0.018 mg/L and exceeded the hardness dependent BCWQ and CCME guidelines in three samples collected from DH10-06S (1 sample), DH10-06D (2 samples), and the hardness dependent CCME guideline in 1 sample (DH10-01S).
- **Manganese:** Dissolved manganese concentrations ranged from less than the detection limit (<0.0003) to 0.20 mg/L. Total manganese concentrations ranged from less than the detection limit (<0.0003) to 1.2 mg/L, exceeding the hardness dependent BCWQ guideline in one sample collected from DH10-06D.
- **Mercury:** Dissolved mercury concentrations were less than the detection limit (<0.00001 to <0.0002 mg/L). Total mercury concentrations ranged were all less than the detection limit (<0.00001 to <0.0002 mg/L).
- **Nickel:** Dissolved nickel concentrations range from less than the detection limit (<0.001 to <0.01 mg/L) to 0.0012 mg/L. Total nickel concentrations ranged from less than the detection limit (<0.001) to 0.070 mg/L, exceeding the hardness dependent CCME guideline in one sample from DH10-06S.
- **Silver:** Dissolved silver concentrations were less than the detection limit (<0.00002 to <0.0002 mg/L). Total silver concentrations ranged from less than the detection limit (<0.00002) to 0.00035 mg/L, exceeding the hardness dependent BCWQ guideline and CCME guideline of 0.0001 mg/L in four samples collected from DH10-06S (1 sample), DH10-06D (2 samples), and DH10-01S (1 sample).
- **Titanium:** Dissolved titanium concentrations were less than the detection limit (<0.01 mg/L). Total titanium concentrations ranged from less than the detection limit (<0.01) to 5.0 mg/L.
- **Uranium:** Dissolved uranium concentrations were all below detection limit (<0.0002 to 0.002 mg/L). Total uranium concentrations ranged from below detection limit (<0.0002) to 0.014 mg/L, exceeding the BCWQ guideline of 0.0085 mg/L in one sample from DH10-06D.
- **Zinc:** Dissolved zinc concentrations were less than the detection limit (<0.005 mg/L). Total zinc concentrations ranged from less than the detection limit (<0.005) to 0.18 mg/L and exceeded the hardness dependent BCWQ guideline in eight samples collected from DH10-07S (1 sample), DH10-02D (1 sample), DH10-06S (1 sample), DH10-06D (3 samples), DH10-01S (1 sample), and DH10-02D (1 sample), and exceeded the CCME guideline of 0.03 mg/L in three samples collected from DH10-06S (1 sample), DH10-06D (2 samples).

Most samples with elevated metal concentrations were collected from wells down gradient of the steep east facing slopes on the western boundary of the Project (i.e., DH10-07, DH10-06, DH10-01S and MW05-01). At least one groundwater quality sample from these wells had elevated concentrations of total and dissolved aluminum, cadmium, and arsenic, and total chromium, cobalt, copper, iron, lead, lithium, nickel, silver, vanadium and zinc relative to the BCWQ and CCME criteria.

Samples collected from monitoring wells completed in the valley floor (i.e., DH10-05, MW05-02, MW05-05, and DH10-02) had fewer samples with elevated metal concentrations.

5.6.4.9 Tidal Influence and Saltwater Intrusion

On rare occasions between July and September of each monitoring year, tidal elevations exceeded groundwater elevations in monitoring wells located within 500 m of the marine shoreline. During these high tide intervals, there is an inferred northward gradient between the tidal regime and the inland groundwater regime in the immediate vicinity of the shoreline. However, the duration of the landward gradient is less than the corresponding periods of southward gradient associated with lower tidal position. Accordingly, the net groundwater flow direction during the entire monitoring period is confirmed to be southward toward the marine foreshore, despite the observed tidal influence in the nearest monitoring wells.

In coastal setting, intrusion of saltwater into the near shore sediments is expected due to density difference between fresh groundwater originating from on-shore recharge sites and seawater. Monitoring data indicated that the saltwater wedge, if present, is located at greater depths than approximately -30 m elevation. This observation is further supported by analytical calculations based on methodology presented in Domenico and Schwartz (1990). The salt water interface will deflect groundwater flow in the sediments upwards towards discharge sites on the foreshore.

5.6.4.10 Conceptual Model

A conceptual hydrogeological model was developed for the baseline groundwater conditions at the Proposed Project. A conceptual hydrogeological model is a representation of the groundwater regime that organizes and simplifies the Proposed Project Area hydrogeology, so that it can be modelled. The conceptual model must retain enough complexity such that it accounts, to the degree required to meet Proposed Project objectives, for the groundwater flow behavior. The conceptual model is then used in the development of a numerical groundwater model of the Proposed Project Area.

Figure 5.6-5 presents a schematic representation of the conceptual hydrogeological model used for the Proposed Project. Based on the information presented in the preceding sections, this model assumes that the unconsolidated sediments underlying the Proposed Project Area form a relatively permeable unconfined aquifer. This valley-fill aquifer is bounded at depth and laterally by bedrock and locally north of the Proposed Project Area by glacial till, both of which are considered to be much less permeable than the aquifer. The hydraulic conductivity of the valley fill aquifer to a depth of approximately 20 m is inferred to be in the mid 10^{-4} m/s range; whereas, at greater depth lower values are anticipated, likely in the low 10^{-4} m/s range. Considering observations made during drilling and general depositional setting, the aquifer is likely anisotropic with vertical hydraulic conductivity less than horizontal.

The dominant recharge source for this aquifer is McNab Creek. Other sources of recharge include inputs from direct precipitation, run-off from bedrock slopes west of the aquifer, and inflow from bedrock at depth. The main discharge from this aquifer is to Howe Sound, WC 2, and possibly the lower reaches of McNab Creek and other minor surface water features adjacent to the ocean shoreline. These hydrogeological boundaries result in the groundwater flow pattern that is generally from north to south, and converging near the Proposed Project Area center where WC 2 is located. Seasonal water table fluctuations are on the order of few meters; nevertheless, the overall groundwater flow pattern throughout the year is similar. The effects of ocean tides and saltwater intrusion are limited to the area in close proximity to the marine shoreline.

5.6.5 Effects Assessment

5.6.5.1 Project-VC Interactions

A preliminary evaluation of identified interactions between the various physical works and activities and the selected VCs across all spatial and temporal phases of the Proposed is presented in Table 5.6-4 and Table 5.6-5 for groundwater Potential Proposed Project-VC interactions are characterized as:

a) Positive, none or negligible, requiring no further consideration; or

b) Potential effect requiring further consideration and possibly additional mitigation.

Rationale is provided for all determinations that there is no or negligible interaction and that no further consideration is required.

For those Proposed Project-VC interactions that may result in a potential direct, indirect and induced effects requiring further consideration, the nature of the effects (both adverse and positive) arising from those interactions is described in Section 5.6.5.2 below.

Table 5.6-4: Project-VC Interaction Table: Groundwater Flow

Project Activities	Description	Groundwater Flow	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
Construction			
1. Crew and equipment transport	▪ Daily water taxi ▪ Tug and barge transport of machinery/materials (est. 8 loads) ▪ Barge household and industrial solid waste barged off-site	o	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.
2. Site preparation, including construction of the berms and dyke	▪ Logging, clearing and grubbing ▪ Grading ▪ Construction of the berms and dyke ▪ Compaction and laying of gravel base ▪ Limited improvements to existing on-site road infrastructure	o	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.
3. Processing area installation, including conveyors and materials handling system)	▪ Installation and use of portable concrete batch plant for construction ▪ Installation of concrete foundations ▪ Installation of screens, crushers, wash plant, conveyor system and automated materials-handling system (i.e., reclaim tunnels) ▪ Installation of groundwater well as a source of make-up water for the wash plant	o	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow. Groundwater well installation does not affect groundwater flow.
4. Substation construction and connection	▪ Construct electrical substation adjacent to existing BC Hydro transmission line ▪ Construct outdoor switchyard, electric building, and 100 m transmission line	o	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.
5. Marine loading facility installation	▪ Remove existing mooring dolphins ▪ Steel pile installation ▪ Installation of conveyor, barge movement winch and mooring dolphins	o	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.

Project Activities	Description	Groundwater Flow	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
6. Pit development	▪ Dry excavation to remove overburden/topsoil ▪ Installation of clamshell and floating conveyor	○	▪ Excavation has not penetrated down to the watertable; therefore, no effects to groundwater flow.
7. Other ancillary land-based construction works	▪ Temporary construction infrastructure set up (trailers, temporary power, etc.) ▪ Upgrades to the existing heavy equipment maintenance shop and warehouse ▪ Upgrades to the existing fuelling facility for the storage of diesel and gasoline for on-site equipment ▪ Construct site office, communications building, workers lunch/dry room, caretaker's cabin, first aid facility and helipad ▪ Install contained washroom facilities ▪ Construct pump room for well/stream intake water distribution and fire-fighting	○	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.
8. Other ancillary marine construction works	▪ Removal of existing small craft dock; install temporary dock for worker access ▪ Construct new floating small craft dock, the with tie-up area for a float plane, serviced with 30 amp (A) 125 volt (V) shore power ▪ Barge household and industrial solid waste off-site	○	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.

Project Activities	Description	Groundwater Flow	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
Operations			
9. Crew transport	▪ Daily water taxi	○	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.
10. Aggregate mining	▪ Use of electric powered floating clamshell dredge ▪ Primary screening and conveyance of extracted material to processing area ▪ Install channel plug in WC 2	●	▪ May increase groundwater flow due to presence of the pit acting as a groundwater sink. ▪ The plug may increase groundwater flow as discharge to WC 2 is reduced.
11. Processing (screening, crushing, washing)	▪ Screening to separate aggregate sizes ▪ Oversized gravels crushed ▪ Operation of wash plant fed using recycled water from two large storage tanks, supplemented with make-up water by a groundwater well. ▪ Drying and storage of fines and silt	●	▪ Make-up water from groundwater well will reduce groundwater flow.
12. Progressive reclamation	▪ Ongoing earth works (including site clearing, surface material removal) ▪ Fines and silt mixed with organic overburden material and used for infilling, re-vegetation and landscaping	○	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.
13. Stockpile storage	▪ Processed sand and gravel conveyed to stockpile area ▪ Storage of processed materials in stockpiles	○	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.
14. Marine loading	▪ Transfer of stored material using marine conveyor system ▪ Barge loading ▪ Site and navigational lighting	○	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.
15. Shipping	▪ Barge traffic (delivery/collection) in Howe Sound, Ramillies Channel, Thornbrough Channel, and Queen Charlotte Channel ▪ Tug and barge transport of fuel and consumables ▪ Navigational lighting	○	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.

Project Activities	Description	Groundwater Flow	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
16. Refueling and maintenance	▪ Refueling and maintenance of on-site equipment	○	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.
Reclamation and Closure			
17. Crew and equipment transport	▪ Daily water taxi ▪ Tug and barge transport of machinery/materials ▪ Barge household and industrial solid waste barged off-site	○	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.
18. Removal of land-based infrastructure	▪ Remove surface facilities, including clamshell dredge, conveyor system, screens, crushers, wash plant, automated materials-handling system, heavy equipment maintenance shop and warehouse, fuelling facility, site office, communications building, workers lunch/dry room, caretaker's cabin, first aid facility, helipad and contained washroom facilities	○	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.
19. Removal of marine infrastructure	▪ Remove marine facilities, in marine load out facility, jetty, conveyors and piles	○	▪ Activities will not affect groundwater flow. None of these activities inhibit or enhance groundwater flow.
20. Site reclamation	▪ Final completion of the pit lake, landscaping and re-vegetation to develop a functional ecosystem in the freshwater pit ▪ Landscaping and re-vegetation of processing area, berms and dyke	○	▪ Increase in groundwater flow from the baseline is expected at closure therefore this constitutes a positive effect.

Notes:
○ = Potential effect of Proposed Project activity on VC is positive, none or negligible; no further consideration warranted.
● = Potential effect of Proposed Project activity on VC that may require mitigation/benefit enhancement; warrants further consideration

Table 5.6-5: Project-VC Interaction Table: Groundwater Quality

Project Activities	Description	Groundwater Quality	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
Construction			
1. Crew and equipment transport	▪ Daily water taxi ▪ Tug and barge transport of machinery/materials (est. 8 loads) ▪ Barge household and industrial solid waste barged off-site	○	▪ Activities will not affect groundwater quality. None of these activities represent sources to alter groundwater quality.
2. Site preparation, including construction of the berms and dyke	▪ Logging, clearing and grubbing ▪ Grading ▪ Construction of the berms and dyke ▪ Compaction and laying of gravel base ▪ Limited improvements to existing on-site road infrastructure	●	▪ Activities may affect water quality due to incidental fuel leaks/ spills from vehicles/machinery. This is addressed in Volume 2, Part B - Section 5.5 under Surface Water Resources.
3. Processing area installation, including conveyors and materials handling system)	▪ Installation and use of portable concrete batch plant for construction ▪ Installation of concrete foundations ▪ Installation of screens, crushers, wash plant, conveyor system and automated materials-handling system (i.e., reclaim tunnels) ▪ Installation of groundwater well as a source of make-up water for the wash plant	○	▪ Activities will not affect groundwater quality. None of these activities represent sources to alter groundwater quality.
4. Substation construction and connection	▪ Construct electrical substation adjacent to existing BC Hydro transmission line ▪ Construct outdoor switchyard, electric building, and 100 m transmission line	○	▪ Activities will not affect groundwater quality. None of these activities represent sources to alter groundwater quality.
5. Marine loading facility installation	▪ Remove existing mooring dolphins ▪ Steel pile installation ▪ Installation of conveyor, barge movement winch and mooring dolphins	○	▪ Activities will not affect groundwater quality. None of these activities represent sources to alter groundwater quality.

Project Activities	Description	Groundwater Quality	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
6. Pit development	▪ Dry excavation to remove overburden/topsoil ▪ Installation of clamshell and floating conveyor	○	▪ Activities will not affect groundwater quality. None of these activities represent sources to alter groundwater quality.
7. Other ancillary land-based construction works	▪ Temporary construction infrastructure set up (trailers, temporary power, etc.) ▪ Upgrades to the existing heavy equipment maintenance shop and warehouse ▪ Upgrades to the existing fuelling facility for the storage of diesel and gasoline for on-site equipment ▪ Construct site office, communications building, workers lunch/dry room, caretaker's cabin, first aid facility and helipad ▪ ▪ Install contained washroom facilities ▪ Construct pump room for well/stream intake water distribution and fire-fighting	○	▪ Activities will not affect groundwater quality. None of these activities represent sources to alter groundwater quality.
8. Other ancillary marine construction works	▪ Removal of existing small craft dock; install temporary dock for worker access ▪ Construct new floating small craft dock, the with tie-up area for a float plane, serviced with 30 amp (A) 125 volt (V) shore power ▪ Barge household and industrial solid waste off-site	○	▪ Activities will not affect groundwater quality. None of these activities represent sources to alter groundwater quality.
Operations			
9. Crew transport	▪ Daily water taxi	○	▪ Activity will not affect groundwater quality. This activity is not a source to alter groundwater quality.

Project Activities	Description	Groundwater Quality	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
10. Aggregate mining	▪ Use of electric powered floating clamshell dredge ▪ Primary screening and conveyance of extracted material to processing area ▪ Install channel plug in WC 2	●	▪ Aggregate extraction may alter the groundwater quality.
11. Processing (screening, crushing, washing)	▪ Screening to separate aggregate sizes ▪ Oversized gravels crushed ▪ Operation of wash plant fed using recycled water from two large storage tanks, supplemented with make-up water by a groundwater well. ▪ Drying and storage of fines and silt	○	▪ Activities will not affect groundwater quality. None of these activities represent sources to alter groundwater quality.
12. Progressive reclamation	▪ Ongoing earth works (including site clearing, surface material removal) ▪ Fines and silt mixed with organic overburden material and used for infilling, re-vegetation and landscaping	●	▪ Deposit of fines around pit may alter the water recharging to groundwater thereby altering the groundwater quality.
13. Stockpile storage	▪ Processed sand and gravel conveyed to stockpile area ▪ Storage of processed materials in stockpiles	○	▪ Activities will not affect groundwater quality. None of these activities represent sources to alter groundwater quality.
14. Marine loading	▪ Transfer of stored material using marine conveyor system ▪ Barge loading ▪ Site and navigational lighting	○	▪ Activities will not affect groundwater quality. None of these activities represent sources to alter groundwater quality.
15. Shipping	▪ Barge traffic (delivery/collection) in Howe Sound, Ramillies Channel, Thornbrough Channel, and Queen Charlotte Channel ▪ Tug and barge transport of fuel and consumables ▪ Navigational lighting	○	▪ Activities will not affect groundwater quality. None of these activities represent sources to alter groundwater quality.
16. Refueling and maintenance	▪ Refueling and maintenance of on-site equipment	●	▪ Incidental leaks or spills may alter the groundwater quality. This is addressed in Volume 2, Part B - Section 5.5 under Surface Water Resources.

Project Activities	Description	Groundwater Quality	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
Reclamation and Closure			
17. Crew and equipment transport	▪ Daily water taxi ▪ Tug and barge transport of machinery/materials ▪ Barge household and industrial solid waste barged off-site	○	▪ Activities will not affect groundwater quality. None of these activities represent sources to alter groundwater quality.
18. Removal of land-based infrastructure	▪ Remove surface facilities, including clamshell dredge, conveyor system, screens, crushers, wash plant, automated materials-handling system, heavy equipment maintenance shop and warehouse, fuelling facility, site office, communications building, workers lunch/dry room, caretaker's cabin, first aid facility, helipad and contained washroom facilities	●	▪ Incidental leaks or spills may alter the groundwater quality. This is addressed in Volume 2, Part B Section 5.5 under Surface Water Resources.
19. Removal of marine infrastructure	▪ Remove marine facilities, in marine load out facility, jetty, conveyors and piles	○	▪ Activity does not affect groundwater quality. This activity does not represent a source to alter groundwater quality.
20. Site reclamation	▪ Final completion of the pit lake, landscaping and re-vegetation to develop a functional ecosystem in the freshwater pit ▪ Landscaping and re-vegetation of processing area, berms and dyke	●	▪ Pit lake development may result in alteration of the groundwater quality.

Notes:
O = Potential effect of Proposed Project activity on VC is positive, none or negligible; no further consideration warranted.
● = Potential effect of Proposed Project activity on VC that may require mitigation/benefit enhancement; warrants further consideration

5.6.5.2 Potential Project-Related Effects

5.6.5.2.1 Groundwater Flow

5.6.5.2.1.1 Construction

During construction, dry excavation to remove overburden/topsoil and installation of the clamshell and floating conveyer in the dry excavation. This excavation will be above the watertable; therefore, no effects to the groundwater flow are expected. A well will be installed for make-up water for washing of the aggregate, but it will not be operated during the construction phase; therefore, no effects to the groundwater flow are anticipated.

5.6.5.2.1.2 Operations

During operations, Proposed Project-related effects on groundwater flow may result from two activities:

- Aggregate mining; and
- Operation of the water well for make-up water.

Aggregate mining will be undertaken in the wet by clamshell and conveyor. As the pit expands, groundwater is induced to flow into the lake formed by excavation below the watertable. Table 5.6-6 presents the baseline estimate of groundwater together with the predicted groundwater flow during the life of the mine operations due to excavation of the pits below the watertable. Between the baseline and year 5 the groundwater flow will gradually decrease from the baseline to the year 5 flow rate. Groundwater flows will gradually increase between years 5 to 10, 10 to 15 and 15 to 16.

During operations, the water well installed during construction will be pumped to provide make-up water to the wash plant at a rate of approximately 160 m^3/day. This water will be removed from groundwater and represents a reduction in groundwater flow.

Table 5.6-6 presents the predicted effects to groundwater flow as a result of the aggregate mining and the pumping of the water well.

Table 5.6-6 Predicted Project-Related Effects to Groundwater Flow

Time	Groundwater Flow (m^3/day)	Well Groundwater (m^3/day)	Total Groundwater (m^3/day)	% Change from Baseline
Baseline	57,900	0	57,900	n/a
Year 5	53,300	160	53,140	-8%
Year 10	54,200	160	54,040	-7%
Year 15	57,400	160	57,240	-1%
Year 16	58,800	160	58,640	1%

5.6.5.2.1.3 Reclamation and Closure

During closure an over flow structure will be constructed that would allow a maximum elevation in the pit lake of about 5.2 m. Over much of an average year, the pit lake elevation would be similar to that predicted in the in the last year of operations; therefore, the water level in the pit lake would be at about 5.0 m elevation. In addition, the water well will no longer be pumped. The groundwater flow under these conditions is estimated to be 58,800 m^3/day or an increase of approximately 2% from the baseline. The groundwater flow rate will also be able to be controlled through adaptive management including raising or lowering of the height of the over flow structure allowing for a balance to be struck between losses from McNabb Creek, groundwater flow and water flow in down gradient aquatic habitat. This constitutes a positive effect on groundwater flow and is therefore not discussed further in the assessment. Potential adverse effects related to increases in groundwater flow related to surface water and fish and their habitat are addressed in Volume 2, Part B - Section 5.5 and Section 5.1.

5.6.5.2.1.4 Accidents and Malfunctions

An uncontrolled release of water from the pit lake could result during the installation of the overflow structure during construction. This would cause the water level in the pit lake to be lowered and reduce groundwater flow downstream. The invert of a cut to install the overflow structure would, in the worse-case scenario, extend down to an elevation of 4 m.

Surface flow discharging through this cut would lower the water level in the pit lake to about 4 m elevation. This will result in an estimated 35% reduction in groundwater flow downstream.

5.6.5.2.2 Groundwater Quality

5.6.5.2.2.1 Construction

During construction, no potential Proposed Project-related effects to groundwater quality have been identified.

5.6.5.2.2.2 Operations

During operations, a pit lake will form and the predicted quality of the pit lake is presented in Volume 4, Part G - Section 22.0: Appendix 5.5-D. The dissolved concentrations of constituents in the pit lake will define the groundwater quality in the foreshore area, south of the pit lake. The reason for using dissolved concentrations and not total is that, as presented in Volume 4, Part G - Section 22.0: Appendix 5.6-E, analyses using the grain-size of the aquifer and predicted groundwater gradients has shown that suspended particles will be filtered out during transport from the pit lake through the granular material.

Sources of the water quality in the pit lake are groundwater flow from McNab Creek, Infiltration through fines from wash reject that will be combined with organic material and placed around the pit, groundwater flow from the western slope and surface water inflow. Four tables are presented in Volume 4, Part G - Section 22.0: Appendix 5.6-F. Table 5.6-F1 provides the predicted monthly concentrations during operations when all the sources of groundwater are under median conditions compared to BCWQG; whereas, Table 5.6-F2 compares the predictions to CCME water quality guidelines. Table 5.6-F3 provides the predicted concentrations when all the sources are defined generally either by their respective 95 Percentile concentrations (except flow through the fines which is defined as the maximum concentrations as insufficient data are available to define the 95 percentile) or by probability distributions (for major ions and phosphorous) compared to BCWQ; whereas, Table 5.6-F4 compares the predicted concentrations to CCME guidelines. Maximum concentrations under median concentration conditions are considered to be closer to an expected case; whereas, the maximum predictions under 95 percentile or probability distributions are considered to be a conservative condition. It should be noted that the predicted minimum, median and maximum concentrations are predicted for each month of a given year of the Proposed Project under median and 95 percentile conditions. The maximum concentration of any one month in the year is conservatively used as the predicted maximum concentration for that entire year. Detailed descriptions of the source terms are provided in Volume 4, Part G - Section 22.0: Appendix 9.5-D.

To assess the significance of the Proposed Project related effects, the maximum predicted concentrations under 95 percentile or probability distribution conditions will be compared to the 95 percentile baseline groundwater quality. The conservative nature of this approach provides a high level of confidence that the effects to the groundwater resource have not been underestimated. Accordingly Tables 5.6-F3 and 5.6-F4 presents a comparison of these predictions to the BCGWQ guidelines and the CCME guidelines, respectively and these tables will be used in the environmental assessment.

Predicted Maximum Groundwater Quality Comparisons

No water quality parameters are predicted to be above the BCWQ or the CCME guidelines in the 95 percentile baseline or in the maximum predicted concentrations under 95 percentile or probability distribution conditions during operations.

5.6.5.2.2.3 Reclamation and Closure

During Reclamation and Closure, the groundwater chemistry is expected to be near the predicted concentrations in the last year of operations. In the last year of operations, No water quality parameters are predicted to be above the BCWQ or the CCME guidelines in the 95 percentile baseline or in the maximum predicted concentrations under 95 percentile or probability distribution conditions during reclamation and closure.

5.6.5.2.2.4 Accidents and Malfunctions

If fines to the north of the pit lake were not sufficiently reclaimed in a progressive manner, a larger area of the fines could be exposed to chemical dissolution. In the worst case scenario, all fines to the north of the pit lake could be exposed to chemical dissolution.

The results of chemical modelling of this event have already been accounted for in the water quality assessment. It has been assumed that reclamation will not be undertaken until closure; therefore, residual effects will be the same as predicted for operations.

5.6.5.3 Mitigation

The following measures are presented to mitigate potential Proposed Project-related effects to groundwater resources and to monitor groundwater so that any potential Proposed Project related effects can be identified in advance and corrective action undertaken through adaptive management (Table 5.6-7). These mitigative measures were developed during the assessment of potential effects to groundwater. Mitigation measure associated with the compensation/offsetting related to the removal of WC 2 are provided in Volume 2, Part B – Section 5.1: Fisheries and Freshwater Habitat. All measures were incorporated into the Proposed Project description and the evaluation of residual effects to groundwater VCs. The mitigation strategy outlined below forms the basis for the commitments that the Proposed Project is making with respect to groundwater resources. A detailed list of all commitments of the Proposed Project are provided in Volume 3, Part F – Section 19.

Monitoring of the groundwater flow rates, hydraulic heads and quality will be conducted during construction and reclamation and closure. Adaptive management will be undertaken if necessary. This monitoring will include the following:

- Monitoring wells located both up-stream and down-stream of the open pit. This will include existing wells that will not be removed as part of the aggregate extraction and additional wells installed to monitor groundwater levels during operations;
- Additional monitoring wells installed at the bottom of the east facing slopes to monitor water quality inputs from the west;
- Monitoring of the water levels in the pit lake; and
- Data collected on the flows in the creeks down gradient of the open pit undertaken as part of the surface water monitoring program will be reviewed to compare with assessment predictions.

Data will be reviewed and compared to the predictions of groundwater quantities and quality. If observed water quality is poorer than predicted and/or the water flows are less than predicted, than corrective action will be undertaken.

5.6.5.3.1 Construction

No mitigation is required during the construction period as no effects to groundwater VCs are expected.

5.6.5.3.2 Operations

The mitigative measure during operations is to limit excavation to the southern portion of the alluvial delta/fan so that water loss from McNab Creek is not increased from baseline, while still maintaining groundwater flow rates.

Rather than placing fines over the entire Fines Storage Area to the north of the pit lake, fines produced during each phase of aggregate processing will be dewatered and placed in small portions of the area (e.g., in a phased approach see Figure 5.5-2 in Volume 2, Part B – Section 5.5) thus minimizing the exposure area of fines to chemical dissolution. As the Proposed Project progresses and fines are placed, the placed fines will be contoured to the desired reclaimed topography. The top layer of the placed fines will be assessed for compaction and ripping done if required. Subsoil and then topsoil from the stockpiles in the northern portion of the soil deposit area will be placed over the fines to provide a growing medium. To reduce infiltration through the fines and down into the groundwater, the growing medium will be vegetated with a desired mix of native species. This reclamation of the fines storage area will occur progressively as the Proposed Project progresses through each of the phases. Additional details regarding soil management is provided in Volume 4, Part G - Section 22.0: Appendix 4 in the Reclamation and Effective Closure Plan.

5.6.5.3.3 Reclamation and Closure

The mitigative measure during closure is the construction of an overflow structure at an elevation of about 5.2 m. This structure maintains groundwater flow at near baseline rates. Based on monitoring data, adaptive management may include altering the elevation of this structure, either by raising or lowering it, to maintain the groundwater flow rates to near baseline rates. The fines deposited in the Fines Storage Area around the northern and eastern perimeter of the pit will be mixed with a growing medium and seeded, thereby stabilising the fines and reducing the chemical load form the fines.

Table 5.6-7: Identified Mitigation Measures: Groundwater Resources

Potential Effect	Mitigation	Anticipated effectiveness
Construction		
No effects anticipated		
Operations		
Changes in groundwater flow.	▪ Limit excavation to the southern portion of delta/fan. ▪ Implementation of a progressive Reclamation and Effective Closure Plan (Volume 4, Part G - Section 22.0: Appendix 4).	Reduced water loss from McNab Creek while maintaining groundwater flow to near baseflow.
Reclamation and Closure		
Changes in groundwater flow.	▪ Overflow structure at 5.2 m.	Maintains near baseflow groundwater flow rates.
Changes in groundwater quality.	▪ Fines deposited in the Fines Storage Area around the northern and eastern perimeter of the property but each year's deposition will be limited to small surface area. Fines will be mixed with a growing medium and seeded. ▪ Implementation of a progressive Reclamation and Effective Closure Plan (Volume 4, Part G - Section 22.0: Appendix 4).	Will stabilize soils and reduce chemical loading from fines to small annual areas of fresh fine deposition thereby improving groundwater quality.

5.6.5.4 Residual Effects Assessment

Potential Proposed Project-related residual effects have been characterized using the criteria for each VC identified in Table 5.6-3. The characterization of potential residual effects (i.e., following application of appropriate mitigation measures) is described below and summarized in Table 5.6-8.

5.6.5.4.1 Construction

No adverse residual effects to the groundwater flow are anticipated during construction.

5.6.5.4.2 Operations

5.6.5.4.2.1 Groundwater Flow

Table 5.6-8 characterizes the potential Proposed Project related effects to groundwater flow and quality during operations, based on a consideration of the criteria for these VCs presented in Table 5.6-3. The predicted effects are presented in Table 5.6-6. Groundwater flow is considered resilient as the system is expected to recover to near baseline conditions rapidly during excavation of the pit. The magnitude of the effects are predicted to be low (greater than 1% but less than 15%) throughout operations. They are expected to be local (confined to the LSA); are medium term (within the operation period); fully reversible (the effect is reversed in the last year of mining); and the frequency is considered low as it occurs during a specific period of operations.

5.6.5.4.2.2 Groundwater Quality

As discussed in Section 5.6.5.2.2.2, groundwater quality is predicted to be below CCME and BCWQ guidelines throughout operations. Table 5.6-8 presents the characterization of potential Proposed Project-related residual effects to groundwater quality during operations. Groundwater quality during operations is considered resilient as it is expected to recover rapidly to stresses caused to the system. The magnitude of the effect are predicted to be negligible because no water quality parameters are predicted to exceed the BCWQ or the CCME guidelines in the 95 percentile baseline, or in the maximum predicted concentrations under 95 percentile, or probability distribution conditions during operations. The extent of the effect is restricted to the local study area and short-term because the highest predicted concentrations of all parameters in any month are below BCWQ or CCME guidelines. The effects are considered fully reversible as effects are expected to be able to be reversed within a month (<5 years) and effects are considered to be of low frequency because they are rare.

5.6.5.4.3 Reclamation and Closure

5.6.5.4.3.1 Groundwater Flow

No adverse residual effects to the groundwater flow are anticipated.

5.6.5.4.3.2 Groundwater Quality

As discussed in Section 5.6.5.2.2.3, during reclamation and closure, groundwater quality is predicted to be below CCME and BCWQ guidelines; therefore, as presented in Table 5.6-8, the magnitude of the effect is considered negligible. The effect will be restricted to the local study area; it will be short-term (< 5 years), reversible and of low in frequency (rare).

5.6.5.4.4 Accidents and Malfunctions

5.6.5.4.4.1 Groundwater Flow

Table 5.6-8 characterizes the potential Proposed Project-related effects if this event occurs. The magnitude would be high because the modeled scenario resulted in a predicted 35% reduction in the groundwater flow downstream of the pit. The duration of the effects is considered short term, as repairs could be made over a short period of time to mitigate the effect. The effect is considered reversible as groundwater flow are expected to return to pre-event conditions soon after repairs have been made. The frequency of the effect is considered to be low as it would occur once during an event.

5.6.5.4.4.2 Groundwater Quality

If fines to the north of the pit lake were not sufficiently reclaimed in a progressive manner, a larger area of the fines could be exposed to chemical dissolution. In the worst case scenario, all fines in the Fines Storage Area to the north of the pit lake could be exposed to chemical dissolution.

The results of chemical modelling of this event have already been accounted for in the water quality assessment. It has been assumed that reclamation will not be undertaken until closure; therefore, residual effects will be the same as predicted for operations. Therefore, as presented in Table 5.6-8, during reclamation and closure, groundwater quality is predicted to be below CCME and BCWQ guidelines; therefore, the magnitude of the effect is considered negligible; the extent is restricted to the local study area: the duration is short term as it is occurs within a month (<5 years); reversible and frequency would be once.

Table 5.6-8: Characterization of Potential Project-Related Residual Effects to Groundwater Flow and Groundwater Quality

Proposed Project-Related Effect	Residual Effect Assessment Criteria					
	Context	Magnitude	Extent	Duration	Reversibility	Frequency
Construction						
None						
Operations						
Changes to groundwater flow	R	L	L	MT	FR	L
Changes to groundwater quality	R	N	L	ST	FR	L
Reclamation and Closure						
Changes to groundwater quality	R	N	L	ST	FR	L
Accidents and Malfunctions						
Changes to groundwater flow - Uncontrolled surface flow during construction of overflow structure at closure	R	H	L	ST	FR	L
Changes to groundwater quality - Insufficient progressive reclamation of fines leading to chemical dissolution	R	N	L	ST	FR	L

Assessment Criteria:
Context: R – Resilient, MR – Moderately Resilient; S - Sensitive;
Magnitude: N – Negligible, L – Low, M – Medium, H – High;
Geographic Extent: L – Local, R – Regional, BR – Beyond Regional;
Duration: ST – Short-term, MT – Medium-term, LT – Long-term;
Reversibility: FR – Fully Reversible, PR - Partially Reversible, IR - Irreversible;
Frequency: L – Low, M – Medium, H – High

5.6.5.5 Significance of Residual Effects

The significance of potential residual adverse effects will be determined for each VC based on the residual effects criteria and the likelihood of a potential residual effect occurring, a review of background information and available field study results, consultation with government agencies, First Nations, and other experts, and professional judgement. A summary of significance determinations is presented in Table 5.6-10.

The determination of significance of residual adverse effects is rated as negligible-not significant, non-significant, or significant, which are generally defined as follows:

- **Negligible – Not Significant:** The basis for determining that effects are negligible will be provided in the Application for each VC. Negligible effects will not be carried forward to the cumulative effects assessment
- **Not significant:** Effects determined to be not significant are residual effects greater than negligible that do not meet the definition of significant. Residual effects that are not significant will be carried forward to the cumulative effects assessment.
- **Significant:** The basis for determining that a residual effect is significant will be provided in the Application for each VC. Significant residual effects will be carried forward to the cumulative effects assessment.

5.6.5.5.1 Construction

No adverse residual effects to the groundwater flow are anticipated during construction.

5.6.5.5.2 Operations

5.6.5.5.2.1 Groundwater Flow

The likelihood that changes to groundwater flow rate will occur during operations is presented in Table 5.6-9 and is considered high. However, if the groundwater flow rate should exceed the predicted values it can be controlled through adaptive management techniques including raising or lowering the height of the over flow structure which would allow a balance between flow loses to McNab Creek, groundwater and water flow in down gradient aquatic habitat. After adaptive management techniques have been applied, the likelihood of the groundwater flow rates exceeding the predicted values is considered low. Table 5.6-10 presents the determination of the significance of changes to groundwater flow during operations. With the implementation of adaptive management techniques along with the low magnitude and local extent of the effect, changes to groundwater flow are considered to be negligible – not significant.

5.6.5.5.2.2 Groundwater Quality

The likelihood that groundwater quality could exceed these thresholds is predicted to be low as conservative assumptions were used to predict groundwater quality during reclamation and closure (e.g., 95% concentrations of the sources were used to generate predicted minimum, median and maximum monthly concentrations, and maximum concentrations in any month of a given year was used as the predicted value for that year). Considering the characterization of the effect the significance of potential effects to groundwater quality during operations (Table 5.6-10) has been determined to be negligible – not significant.

5.6.5.5.3 Reclamation and Closure

5.6.5.5.3.1 Groundwater Flow

No adverse residual effects to the groundwater flow are anticipated.

5.6.5.5.3.2 Groundwater Quality

The likelihood that groundwater quality could exceed these thresholds is therefore predicted to be low as conservative assumptions were used to predict groundwater quality during reclamation and closure. Based on the characterization of adverse effects to groundwater quality during closure and reclamation, the significance of potential residual effects is determined to be negligible – not significant.

5.6.5.5.4 Accidents and Malfunctions

5.6.5.5.4.1 Groundwater Flow

As presented in Table 5.6-9 the likelihood of this event is considered low as construction of the overflow structure will be supervised by an engineer and preventative measures, such as the construction of temporary containment structure at the location of the proposed breach, will be in place. As presented in Table 5.6-10, considering the characterization of the potential Proposed Project-related effect the significance is determined to be negligible – not significant.

5.6.5.5.4.2 Groundwater Quality

As presented in Table 5.6-9 the likelihood of such an event causing changes in the predicted groundwater quality is considered low as it is already assumed that reclamation will not occur until closure; whereas, progressive reclamation is planned throughout operations. As presented in Table 5.6-10, considering the characterization of the residual effect, the significance of potential residual effects is determined to be negligible – not significant.

Table 5.6-9: Likelihood of Occurrence of Potential Residual Effects: Groundwater Resources

VC	Residual Effect	Likelihood	Rationale
Construction			
No residual effects are anticipated.			
Operations			
Groundwater Flow	Changes to Groundwater Flow	High	The likelihood of changes in groundwater flow rate is high but the groundwater flow rate can be controlled through adaptive management including raising or lowering of the height of the over flow structure. A balance will be struck between losses from McNab Creek, groundwater flow and water flow in down gradient aquatic habitat.

VC	Residual Effect	Likelihood	Rationale
Groundwater Quality	Changes to Groundwater Quality - chemical parameter that was not above applicable guidelines in baseflow will above guidelines during operations/closure.	Low	The predicted groundwater quality during operations was based on conservative assumptions. The 95% concentrations of the sources or a probability distribution were used to generate predicted minimum, median and maximum monthly concentrations. The maximum concentration in any month of a given year was used as the predicted value for that year.
Reclamation and Closure			
Groundwater Quality	Changes to Groundwater Quality - parameters above guidelines that were not above guidelines in baseline.	Low	Conservative assumptions used to predict groundwater quality during reclamation and closure. The 95% concentrations of the sources were used to generate predicted minimum, median and maximum monthly concentrations. The maximum concentration in any month of a given year was used as the predicted value for that year.
Accidents and Malfunctions			
Groundwater Flow	Changes to Groundwater Flow	Low	The construction of the overflow structure will be undertaken the supervision of a geotechnical engineer. Measures will be in place to prevent uncontrolled flow through area of overflow structure.
Groundwater Quality	Changes to Groundwater Quality	Low	The water quality model assumes reclamation occurs at closure, however, progressive reclamation of the fines will occur through operations.

Table 5.6-10: Significance of Potential Residual Effects: Groundwater Flow and Groundwater Quality

VC	Residual Effect	Significance	Rationale
Construction			
None			
Operations			
Groundwater Flow	Changes to Groundwater Flow	Negligible – Not Significant	Magnitude of the potential Proposed Project related effects is determined to be low. Effect considered reversible through adaptive management.
Groundwater Quality	Changes to Groundwater Quality	Negligible – Not Significant	The magnitude of Proposed Project-related effects is determined to be negligible. Conservative approach has been used to predict groundwater quality.
Reclamation and Closure			
Groundwater Quality	Changes to Groundwater Quality	Negligible – Not Significant	The magnitude of Proposed Project-related effects is determined to be negligible. Conservative approach has been used to predict groundwater quality.
Accidents and Malfunctions			
Uncontrolled surface flow from pit lake during construction of overflow structure	Changes to Groundwater Flow	Negligible – Not Significant	Magnitude of the potential Proposed Project related effects is considered high, but reversible in a short period of time. Mitigation predicted to be effective: construction of the overflow structure will be supervised by an engineer.
Insufficient reclamation of the fines	Changes to Groundwater Quality	Negligible – Not Significant	The magnitude of the Proposed Project related effects is considered to be high but progressive reclamation is part of the mitigative strategy and will be stringently controlled and followed.

5.6.5.6 Level of Confidence

The level of confidence of predicted residual effects is provided in Table 5.6-11. The prediction confidence of the assessment on each VC is based on scientific information and statistical analysis, professional judgement and effectiveness of mitigation (rated as high, moderate and low).

5.6.5.6.1 Groundwater Flow

The FEFLOW model used to predict groundwater flow was calibrated to a number of observations including the following:

- Water levels in monitoring wells;
- Water flows in McNab Creek;
- Surface flow in WC 2: and
- The temperature plume from McNab Creek.

The level of confidence in the magnitude of groundwater flow are considered moderate; whereas, the confidence in the relative groundwater flows is considered to be high. Relative groundwater inflows are the percent difference between the predicted baseline groundwater flows and the predicted changes in these flows resulting from the Proposed Project; whereas, the magnitude of the groundwater flows are the predicted rates of groundwater flow expressed as m^3/day. For, example, if the magnitude of baseline groundwater flows are predicted to be 50,000 m^3/day, then a predicted increase in the groundwater flows resulting from the Proposed Project to 55,000 m^3/day would represent a 10% increase in groundwater flow. There is a high level of confidence that the groundwater flow would increase by 10%, but a moderate level of confidence in the magnitude of the baseline groundwater flows (50,000 m^3/day) and the magnitude of the predicted increase (5,000 m^3/day).

5.6.5.6.2 Groundwater Quality

Conservative methods have been used to assess changes in groundwater quality resulting from the Proposed Project. Therefore, there is a high level of confidence that the predicted changes to the groundwater quality have not been underestimated.

Table 5.6-11: Level of Confidence in Potential Residual Effect Predictions: Groundwater Resources

Residual Effect	Level of Confidence (LOC) in Residual Effect Prediction	LOC Rationale
Construction		
No residual effect		
Operations		
Changes to groundwater flow.	High level of confidence in relative changes in flows. Moderate level of confidence in magnitude of flows.	Considerable hydrogeological data that were incorporated into a numerical model and calibrated to observed conditions to predict changes in groundwater flow.
Changes to groundwater quality - copper above guidelines for first 2 years of operations, when not above guidelines in baseline.	High level of confidence that copper concentrations are not underestimated.	Conservative approach used to predict water quality. The 95% concentrations or probability distributions of the sources were used to generate predicted minimum, median and maximum monthly concentrations. The maximum concentration in any month of a given year was used as the predicted value for that year. No water quality parameters are predicted to be above the applicable guidelines.

Residual Effect	Level of Confidence (LOC) in Residual Effect Prediction	LOC Rationale
Reclamation and Closure		
Changes to groundwater quality.	High level of confidence.	The 95% concentrations or probability distributions of the sources were used to generate predicted minimum, median and maximum monthly concentrations. The maximum concentration in any month of a given year was used as the predicted value for that year. No water quality parameters were predicted to be above the applicable guidelines.

5.6.5.7 Cumulative Effects Assessment

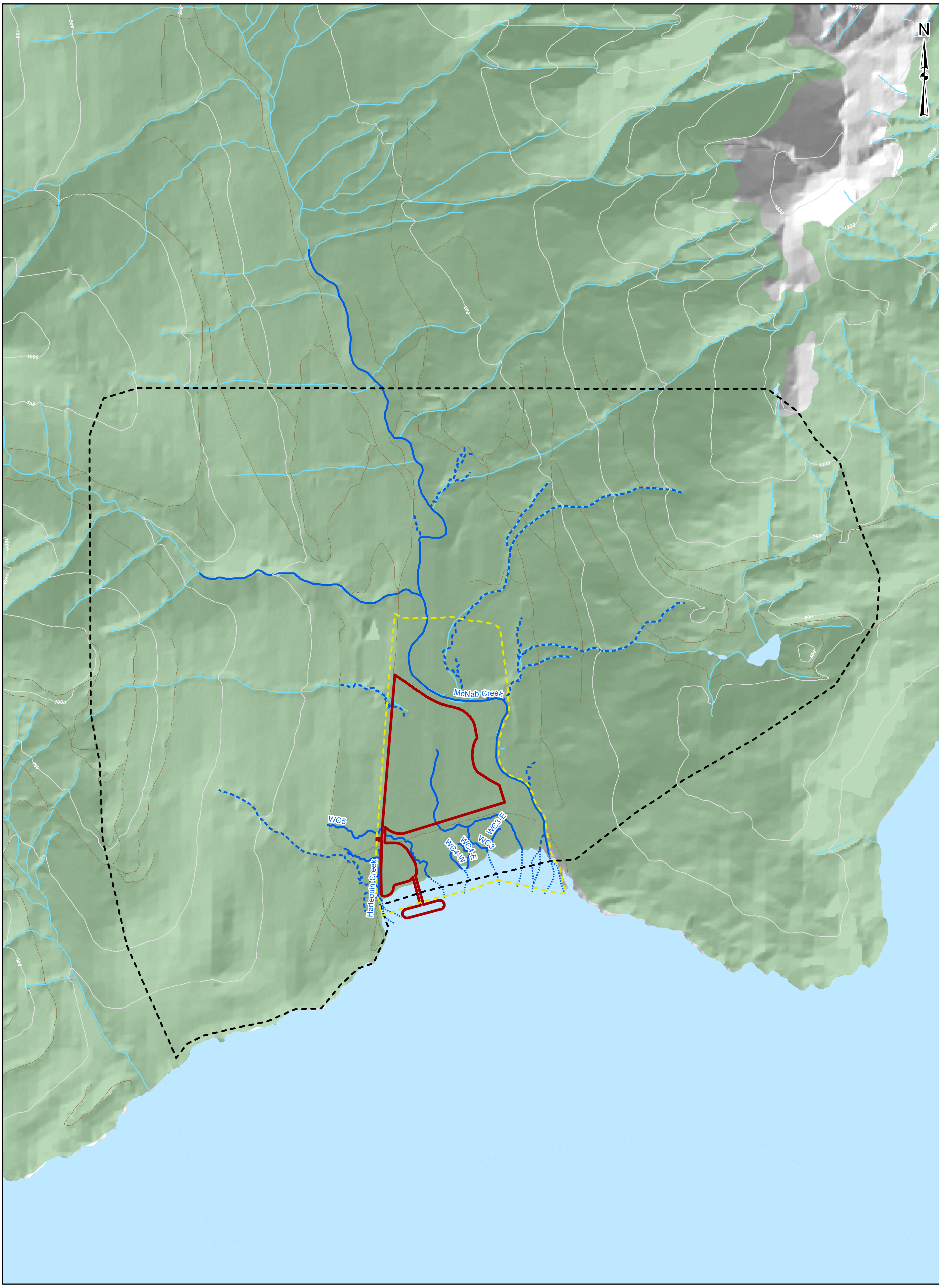
VCs that were determined to have not-significant or significant residual effects were carried forward in the cumulative effects assessment. All potential Project-related residual adverse effects were determined to be negligible – not significant and requiring no further consideration. No residual effects were carried forward to a cumulative effects assessment. Additional information on the methods used for the cumulative effects assessment is provided in Volume 2, Part B – Section 4.5.5. The text has been revised to include this additional information.

5.6.6 Conclusions

The significance of potential effects to groundwater flow and groundwater quality through construction, operations, and reclamation and closure are considered negligible – not significant. The assessment of significance used an approach that was conservative in nature so that there is a high level of confidence that the Proposed Project-related effects have not been underestimated.

Although groundwater flow is predicted to be less than the baseline during the first 15 years of operation, reduced groundwater loss from McNab Creek are predicted to result in an overall benefit to the environment. In the last year of operations and through to reclamation and closure, groundwater flow is expected to increase by 2% from the baseline. Effects to groundwater quality are considered to be negligible – not significant; no water quality parameters are predicted to exceed BCWQ or CCME guidelines throughout operations and reclamation and closure.

The suggested mitigation is considered effective and incorporates adaptive management techniques that can be undertaken if monitoring data indicates a different balance between losses from McNab Creek, changes in groundwater flow rates and the water flow in down gradient aquatic habitat need to be achieved.



LEGEND

- Project Area
- Local Study Area
- Regional Study Area
- Vegetation
- Waterbody
- Resource Road
- Contour (250m)
- Permanent / Perennial Watercourse
- Intermittent Watercourse
- Intertidal Watercourse
- Watercourse

REFERENCE

Elevation and indian reserves from Geobase. Vegetation from CanVec. Watercourses from the Province of British Columbia and field data. Base data from the Province of British Columbia. All rights reserved. Projection: UTM Zone 10 Datum: NAD 83

500 0 500

SCALE 1:25,000 METRES

PROJECT

BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE

GROUNDWATER RESOURCES STUDY AREAS

Golder Associates

PROJECT NO. 11-1422-0046			PHASE No.	
DESIGN	MD	14 May. 2014	SCALE AS SHOWN	REV. 1
GIS	DL	08 Mar. 2016	**FIGURE 5.6-1**	
CHECK	AS	10 Jun. 2014		
REVIEW	AC	10 Jun. 2014		

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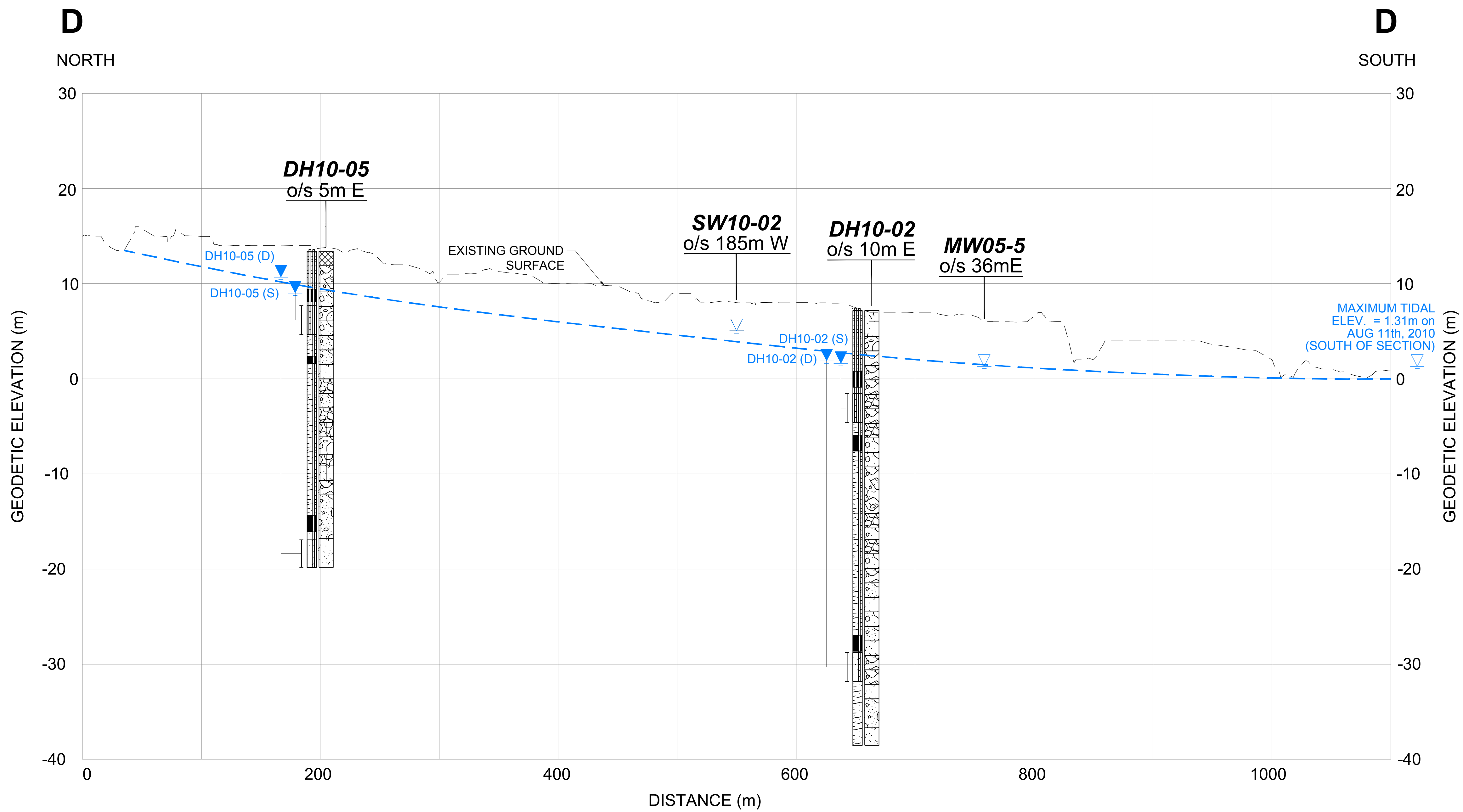


LEGEND

DH10-07	DENOTES TEST HOLE
o/s 5m N	DENOTES OFFSET AND DIRECTION FROM CROSS SECTION LOCATION
	DENOTES SOIL STRATIGRAPHY OBSERVED AT TEST HOLE LOCATION
	DENOTES MONITORING WELL INSTALLATION(S)
	(FOR DETAILED DESCRIPTIONS OF SOIL STRATIGRAPHY AND MONITORING WELL INSTALLATIONS REFER TO RECORD OF BOREHOLE LOGS)
	DENOTES GROUNDWATER MEASUREMENT ON AUGUST 11TH, 2010.
	DENOTES MONITORING WELL SCREEN INTERVAL
	DENOTES SURFACE WATER MEASUREMENT ON AUGUST 11TH, 2010.
	DENOTES INTERPRETED WATER TABLE POSITION ON AUGUST 11TH, 2010.

NOTES

1) MONITORING WELL AND STAFF GAUGE ELEVATIONS (TIDAL DATUM) PROVIDED BY PETER M GORDON LAND SURVEYING INC.
2) WATER ELEVATIONS BASED ON MANUAL MEASURED OBTAINED AUGUST 11TH, 2010.

0 80 160 240 m
SCALE

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
A	2014-11-13	ISSUED FOR FINAL REPORT	MM	MSH	AM	WZ

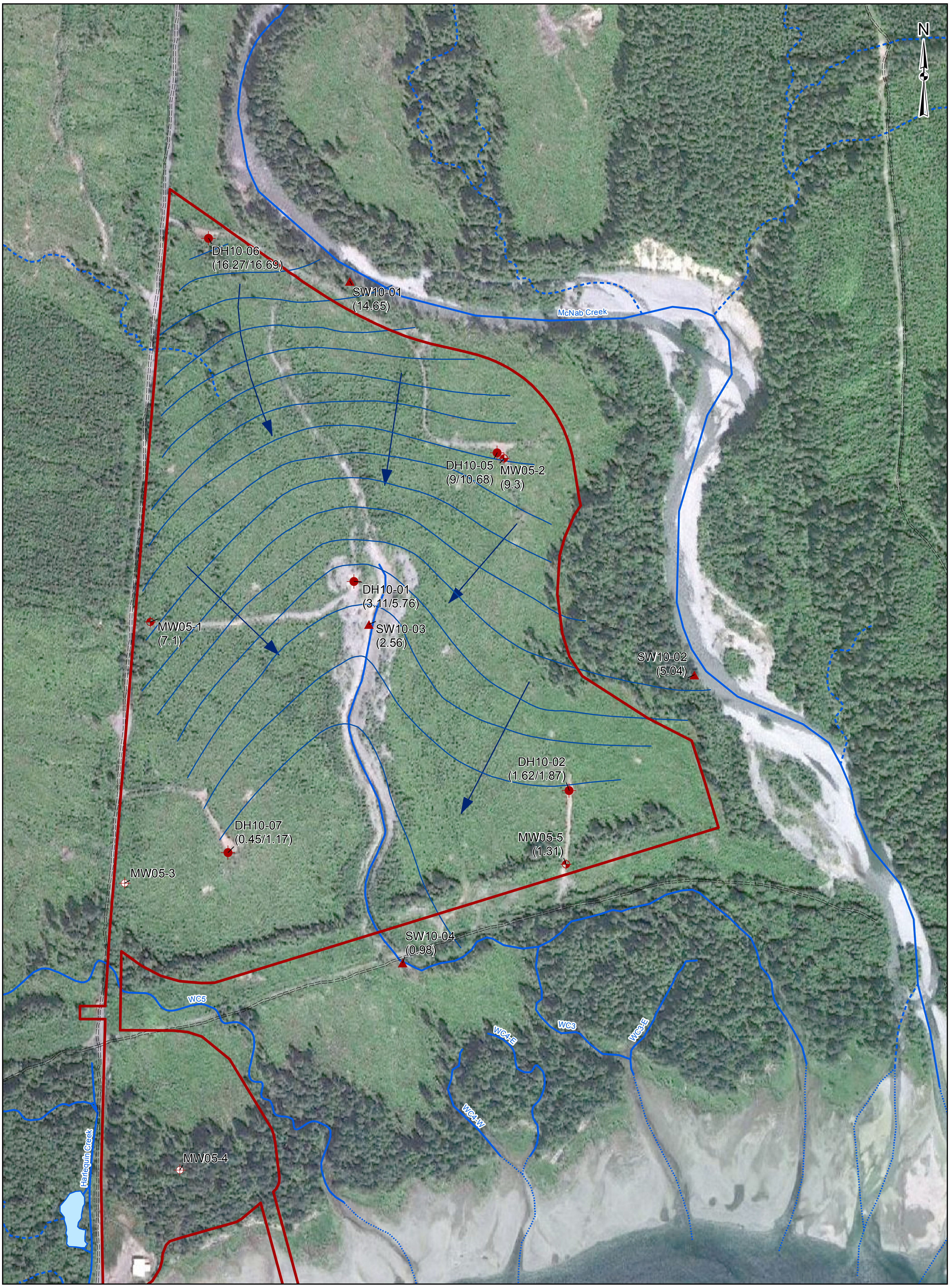
PROJECT
BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE
HYDROGEOLOGICAL CROSS SECTION D-D'

Golder Associates

PROJECT No.		1114220046-4600	FILE No.	1114220046-4600-5.6-2
DESIGN	MM	05OCT10	SCALE	AS SHOWN
CADD	MSH	13NOV14		
CHECKED	AM	07FEB13		
REVIEW	WZ	08FEB13		

FIGURE 5.6-2



LEGEND

- Monitoring Well with Two Nested Standpipe Piezometers (Golder, 2010)
- Surface Water Monitoring Station (Golder, 2010)
- Monitoring Well with One Standpipe Piezometer (EBA, 2005)
- Destroyed Monitoring Well (EBA, 2005) - Approximate location shown
- Interpreted Water Flow Direction
- Interpreted Water Table Contour (m)
- Project Area
- Permanent / Perennial Watercourse
- Intermittent Watercourse
- Intertidal Watercourse
- Road (Existing)

DH10-01 — Well/Station Label
(3.11/5.76) — Deep Piezometer (if applicable) — Shallow Piezometer

Water Elevations in Metres Recorded Aug. 11, 2010.

150 0 150

SCALE 1:5,000 METRES

REFERENCE

Watercourses from the Province of British Columbia and field data. Base data from the Province of British Columbia. All rights reserved. Well locations surveyed by Peter Gordon Surveys. Projection: UTM Zone 10 Datum: NAD 83

PROJECT

BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE

INTERPRETED WATER TABLE CONTOURS AUG. 11 2010

Golder Associates

PROJECT NO. 11-1422-0046			PHASE No. 4600	
DESIGN	MM	05 Oct. 2010	SCALE AS SHOWN	REV. 1
GIS	DL	08 Mar. 2016	**FIGURE 5.6-3**	
CHECK	AM	07 Feb. 2013		
REVIEW	WZ	08 Feb. 2013		

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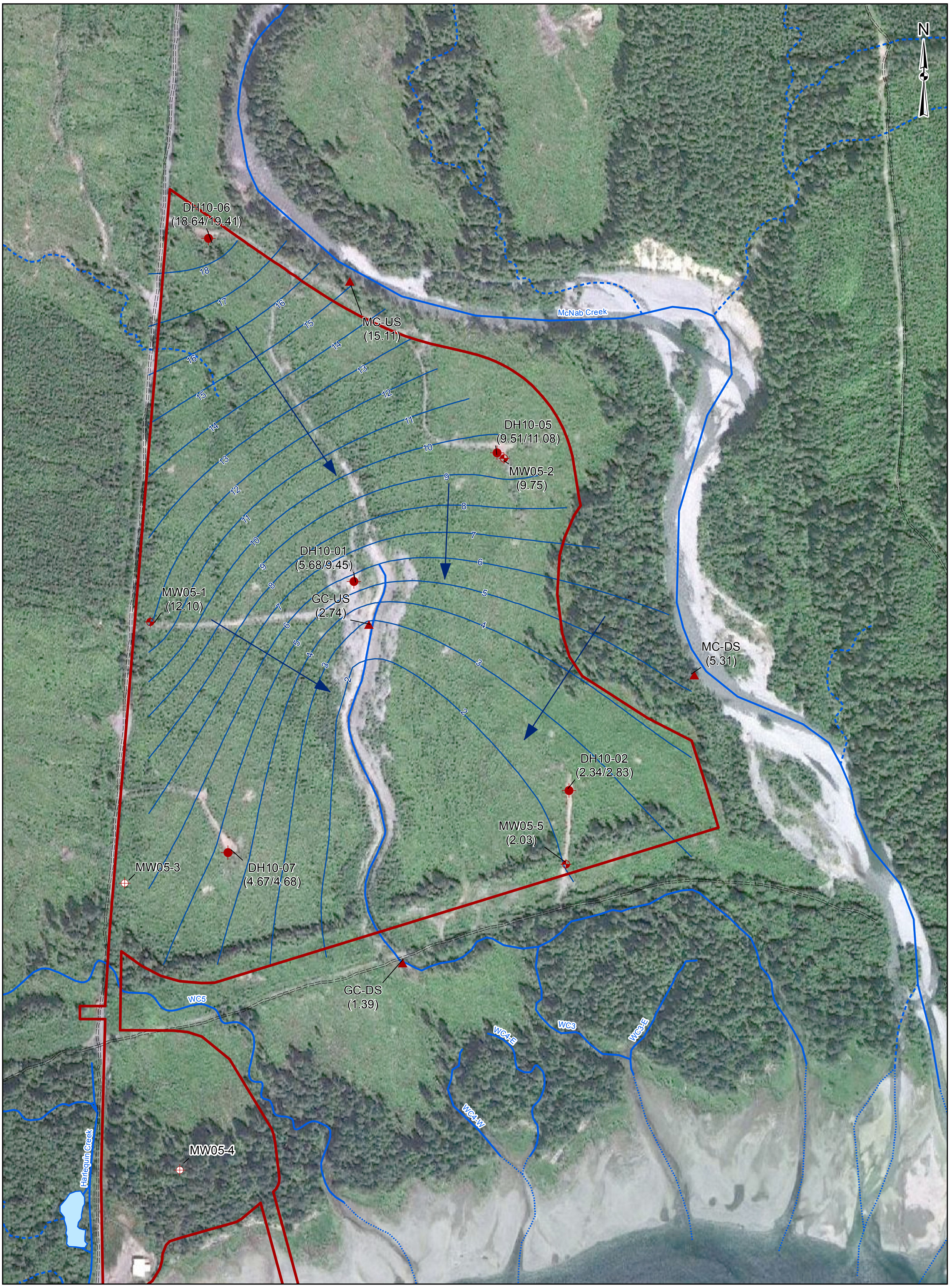


LEGEND

- Monitoring Well with Two Nested Standpipe Piezometers (Golder, 2010)
- Surface Water Monitoring Station (Golder, 2010)
- Monitoring Well with One Standpipe Piezometer (EBA, 2005)
- Destroyed Monitoring Well (EBA, 2005) - Approximate location shown
- Interpreted Water Flow Direction
- Interpreted Water Table Contour (m)
- Project Area
- Permanent / Perennial Watercourse
- Intermittent Watercourse
- Intertidal Watercourse
- Road (Existing)

DH10-01 — Well/Station Label
(5.68/9.45) — Deep Piezometer (if applicable) — Shallow Piezometer

Water Elevations in Metres Recorded Feb. 2, 2012.

150 0 150

SCALE 1:5,000 METRES

REFERENCE

Watercourses from the Province of British Columbia and field data. Base data from the Province of British Columbia. Well locations surveyed by Peter Gordon Surveys. Projection: UTM Zone 10 Datum: NAD 83

PROJECT

BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

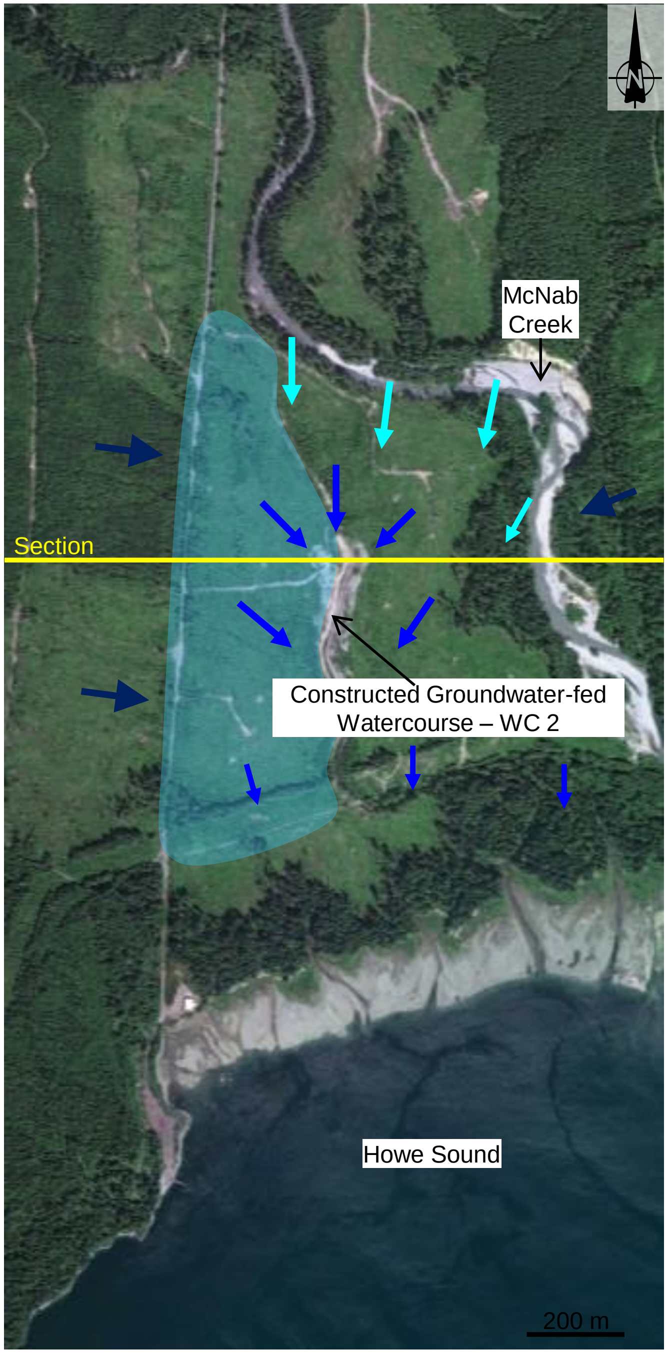
TITLE

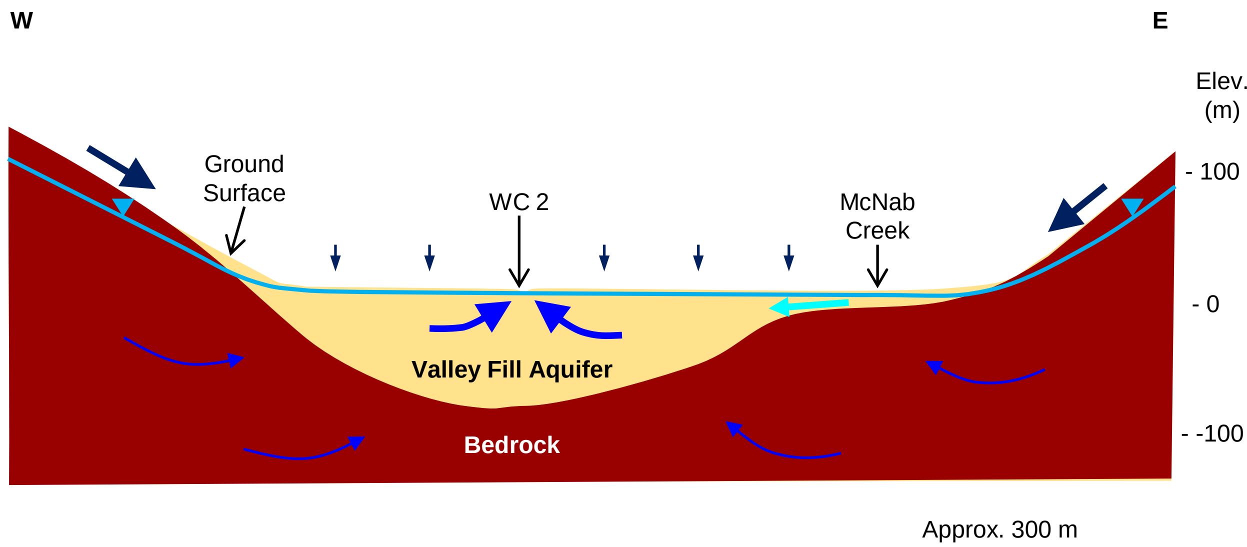
INTERPRETED WATER TABLE CONTOURS
FEB. 2, 2012

Golder Associates

PROJECT NO. 11-1422-0046			PHASE No. 4600	
DESIGN	MM	05 Oct. 2010	SCALE AS SHOWN	REV. 1
GIS	DL	08 Mar. 2016	**FIGURE 5.6-4**	
CHECK	AM	07 Feb. 2013		
REVIEW	WZ	08 Feb. 2013		

Path: X:\Project Data\BC\McNab\Figures\MXD\Hydrogeology\EA\BURNCO_HYDROGEOLOGY_Figure_5_6-4_Interpreted_Water_Table_Contours_2012.mxd





Legend

- Stream Loss
- Groundwater Flow Direction
- Direct Precipitation
- Run-off from Bedrock
- Area of Run-off Infiltration
- Watertable

PROJECT

BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT, HOWE SOUND, B.C.

TITLE

CONCEPTUAL HYDROGEOLOGICAL MODEL

Golder Associates

PROJECT No. 11-1422-0046			PHASE No. 4600
DESIGN	WZ	22OCT14	SCALE As Shown REV.
CADD	WZ	22OCT14	**FIGURE 5.6-5**
CHECK	DWC	22OCT14	
REVIEW	DWC	22OCT14	