5.4 Geotechnical and Natural Hazards

5.4.1 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 Geotechnical Hazards and Natural Hazards. Geotechnical and Natural Hazards are discussed in terms of alteration of the physical terrain that could detrimentally impact ground stability conditions or increase the potential for landslide or avalanche initiation in the watershed.

For this assessment, "Geotechnical Hazards" refer to how the Proposed Project could impact earthquake induced liquefaction and fault ruptures. The "Natural Hazards" portion of the assessment refers to how the Proposed Project could impact land based terrain stability and mass movement processes that result in events such as landslides, debris flows/floods, and snow avalanches. Natural Hazards will refer to Terrain Stability for the purpose of this report. As noted in the AIR, Natural Hazards also includes "Climate" as a VC. Proposed Project related impacts on climate change is assessed in Volume 2, Part B - Section 5.8. Potential effects of climate change on the Proposed Project (sea level-rise and increased precipitation events) are discussed in Volume 3, Part D – Section 15.0: Federal Information Requirement.

Figures for the Natural Hazard Assessment (Figure 5.4-1 to Figure 5.4-7 and Geotechnical Assessment (Figure 5.4-8 to Figure 5.4-12) can be found at the end of this section.

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

- Appendix 5.4-A – Assessment of Avulsion Risk on McNab Creek, BC.
- Appendix 5.4-B – Geotechnical Stability Assessment Compensation Groundwater Channel McNab Valley Project, BC.
- Appendix 5.4-C – Hydrologic and Hydraulic Characterization McNab Valley Aggregate Project, Howe Sound, BC.
- Appendix 5.4-D – McNab Valley Project – Geological Setting and Description.
- Appendix 5.4-E – McNab Creek Gravel Deposit.
- Appendix 5.4-F – Concrete Aggregate Assessment McNab Creek British Columbia.
- Appendix 5.4-G – Summary Report on Sub-Surface Geology – Particle Size Distribution, BURNCO, McNab Creek.
- Appendix 5.4-H – Rationale for 2011 Geophysical Survey of Fan-Delta, McNab Valley Aggregate Project.
- Appendix 5.4-I – Report on Bathymetric and Sub-bottom Acoustic Profiling Survey McNab Creek Docking Facilities Howe Sound Area, B.C.

- Appendix 5.4-J – Terrain Stability Assessments for TSL A79510 - Cutblocks MB060 and Additional Area Added to C34M.
- Appendix 5.4-K – Terrain Stability Assessment: TSL A79510 Cutblock MB060, McNab Creek, BC.
- Appendix 5.4-L – Terrain Stability Assessment for cutblocks C3UX, C3H8 & C2XU, McNab Creek area, BCTS License A90229 – McNab Creek, BC.
- Appendix 5.4-M – McNab Creek Project: Blocks G063C3UW, G053C39P-A, B, C and Associated Access Roads - McNab Creek, BC.
- Appendix 5.4-N – Aerial Photograph Reference List.
- Appendix 5.4-O – Terrain Label Definitions.
- Appendix 5.4-P – Terrain Stability Classification Criteria.
- Appendix 5.4-Q – Geotechnical Stability Analysis of Pit Slopes.

This assessment is intended to provide an inventory of existing geotechnical hazard and natural hazard site conditions and how they relate to potential impacts from the Proposed Project. This assessment is also intended to be used for identification of areas for additional investigation to more fully characterise and mitigate geotechnical and natural hazards.

The objectives of this assessment were to identify and evaluate static and seismic ground conditions (geotechnical hazards) and potential landslide, debris flow/flood, and snow avalanche hazards (terrain and terrain stability, or natural hazards) that could be impacted by the Proposed Project, or could impact the Proposed Project.

The geotechnical and natural hazard factors assessed were associated with the following:

- Stability evaluations of the Proposed Project for both static and seismic cases, considering options or alternatives for development / sequencing of the site to confirm facilities are developed in a safe manner including;
- Evaluation of existing or potential natural hazard conditions which could impact the sequencing of excavation and development of the pit slopes, stockpile locations or heights, and the stability of the adjacent McNab Creek channel sides slopes;
- A review of the potential impact of changes in surface water and groundwater seepage into or from the Proposed Project site;
- Marine and shoreline assessments;
- Earthquake related assessments;
- Characterisation of existing baseline conditions of the Regional Study Area (RSA) and Local Study Area (LSA) (described below), via terrain and terrain stability mapping in the McNab Creek watershed;
- Identify and assess potential run-out (depositional) zones;

- Identify areas prone to mass wasting events (landslides, debris flows/floods, snow avalanches), that could affect the Proposed Project Area, or could be affected by the Proposed Project;
- Provide recommendations for further detailed studies if required; and
- Recommend general mitigation measures where applicable.

Assessment of slope stability and confirmation of suitable Factors of Safety (FOS) for aggregate pit slopes will be addressed in the *Mines Act* Permit Application. General comments regarding these geotechnical aspects are outlined in the general Best Management Practices section of this document.

Based on the results of geotechnical and natural hazard assessment process described above, a qualitative hazard assessment was conducted to evaluate adverse effects from seismic or mass wasting events, within the Proposed Project Area (defined below), as well as the RSA and LSA.

Consideration has been given to mitigation measures proposed to mitigate identified effects to acceptable levels and 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.

5.4.2 Regulatory and Policy Setting

This section provides a summary of the regulatory and policy setting of the Proposed Project as it relates to Geotechnical and Natural Hazards.

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 *Dam Safety Regulation* (B.C. Reg. 40/2016). The *Dam Safety Regulation* sets requirements and best practices for all aspects of dam design, construction, operation, maintenance, removal and decommissioning of dams.

5.4.2.1 Engineers and Geoscientists Act

Current provincial and federal standards, and approved criteria were followed for characterising and mapping terrain. This includes professional guidelines used for terrain, terrain stability, landslide and flood assessments developed by the Association of Professional Engineers and Geoscientists of BC (APEGBC). As professional due diligence under the *Engineers and Geoscientists Act*, the National and British Columbia Building Codes (BCBC) were followed, since the BCBC Code directive now requires slope stability assessments to be addressed for the 1:2,475 year earthquake.

5.4.3 Assessment Methodology

This section provides a description of the assessment methodology used in preparing the EA related Geotechnical and Natural Hazards.

Please refer to Volume 2, Part B - Section 4.0: Assessment Methods of this EA. for full description of the assessment methodology and scope including: selection value components, establishing boundaries, describing existing conditions, identification of Proposed Project VC interactions, identifying mitigation measures, evaluating residual effects and assessing cumulative effects.

5.4.3.1 Value Component (VC) Selection and Rationale

This section describes the VCs and measureable indicators identified for this assessment related to Geotechnical and Natural Hazards. 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 geotechnical and natural hazards VCs were carried forward in the effects assessment (e.g. no geotechnical and natural hazards 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.

Geotechnical and natural hazards (land based terrain stability) were selected as a VC because there is potential for Proposed Project related activities to affect or be affected by the marine environment (e.g., marine slope stability, shoreline morphology, marine habitat). There is also a potential for Proposed Project-related activities to affect or be affected by ground movement in the land based environment (e.g., earthquake induced soil liquefaction, changes to slope morphology and loss of ground cover that could lead to landslide and/or snow avalanche initiation).

The Proposed Project Area is located within the zone of moderate to high earthquake risk of coastal British Columbia (BC), along the shoreline of Howe Sound, and within the McNab Creek watershed with active and historic mass wasting events and potentially unstable terrain. Proposed Project facilities will be designed and constructed to achieve life safety and performance criteria of the National and BC Building Codes, or as otherwise required for the Proposed Project.

The potential for damage or loss of proposed on-shore and marine facilities associated with the following geotechnical and natural hazards have been considered in Volume 3, Part D – Section 14.0: Federal Information Requirement:

- Failures of steep delta-fan slopes and steep onshore slopes;
- Earthquake-related ground shaking, soil liquefaction-induced loss of strength and foundation support, lateral spreading movements and potential ground surface ruptures from faulting at depth; and
- Naturally occurring mass movements (i.e., landslides and snow avalanches) within the McNab Creek watershed that may directly or indirectly affect the Proposed Project Area.

This section focuses on the potential effects associated with natural hazards and land disturbance potentially resulting from the Proposed Project. Proposed Project design will incorporate applicable standards and follow existing engineering and geoscience practices appropriate to development projects in BC.

Table 5.4-1 provides a summary of identified VCs, rationale for their inclusion in the assessment, and measurable Indicators that will be considered.

Table 5.4-1: Value Components and Measurable Indicators: Geotechnical and Natural Hazards

Value Component	Rationale	Measurable Indicators
Earthquakes and Tsunamis – Proposed Project activities increasing detrimental effects of earthquakes, tsunamis, and the initiation of submarine landslides.	Proposed Project activities could increase ground movement typically experienced during an earthquake event. This could result in increased effects of liquefaction, settlement, lateral movement, ground surface ruptures, landslides. Proposed Project activities may increase the extent of shoreline erosion and instability or increase offshore debris deposition (via landslide initiation). This could potentially accelerate the effects of an earthquake or landslide generated tsunami. Proposed Project activities may initiate a submarine landslide and perpetuate tsunami events. These events could result in substantial damage to Proposed Project offshore and shoreline structures and facilities and public/private infrastructure as well as risk to persons.	Increased ground movement resulting in changes in site conditions (i.e., sand "boils", subsidence and slumps, lateral movements and cracking or scarp formations). Increase in mass movement events in the LSA or RSA, such as rockfalls, soil slumps in areas within potentially unstable terrain. Change in shoreline conditions (i.e., debris above normal high tide level, recent or ongoing erosion).
Terrain Stability – Proposed Project activities increasing the potential mass movement events (e.g., landslides, snow avalanches, debris flows, debris floods).	Proposed Project activities could adversely impact current stable site conditions with changes to slope morphology and drainage characteristics. This could lead to the initiation of mass movement events that could impact the Proposed Project Area directly or alter adjacent water courses. This could result in damage to public/private infrastructure or natural resources (e.g., aquatic habitat, sensitive ecosystems, forestry operations and timber resources).	Change to slope morphology (e.g., removing natural slope stabilizers, undercutting unstable slopes, altering transport and run out zones). Change in drainage characteristics in areas with unstable or potentially unstable terrain (e.g., increase water flow to unstable creek side banks).

5.4.3.2 Assessment Boundaries

5.4.3.2.1 Spatial Boundaries

The spatial boundaries for the EA have been selected to take into account the physical extent of the Proposed Project, the Proposed Project-related effects, and the extent of any key environmental systems. The specific spatial boundaries for Geotechnical and Natural Hazards are provided in Table 5.4-2.

For a full description of the temporal boundaries of the Proposed Project please refer to Volume 2, Part B - Section 4.3.2 of this EA.

The LSA was established to encompass the area within which the Proposed Project is expected to interact with, and potentially change the conditions of, geotechnical and natural hazards. In determining LSA boundaries, consideration was given to the nature and characteristics of geotechnical and natural hazards, its potential exposure to various influences, and the maximum extent of potential changes on the geotechnical VC.

The RSA was established to provide a regional context for the consideration of changes to the IC that may cause adverse Proposed Project effects to a VC. The RSA was also established to encompass the area within which the residual effects of the Proposed Project are likely to overlap with the residual effects of other existing or reasonably foreseeable projects and activities.

Table 5.4-2: Spatial Boundaries: Geotechnical and Natural Hazards

Study Area	Description
Proposed Project Area	The Proposed Project Area (Figure 5.4-1) includes areas in which modifications to current vegetation cover, site grades and surface or groundwater conditions are expected and where proposed development plans are located.
Local Study Area (LSA)	The LSA (Figure 5.4-1) will encompass the Proposed Project Area and include adjacent areas that could potentially be affected by activities or changes in geotechnical or natural hazards conditions. This includes the area along McNab Creek to the northeast, slope breaks to the west, and the Howe Sound shoreline buffer zone and offshore facilities to the south.
Regional Study Area (RSA)	The RSA (Figure 5.4-1) includes the Proposed Project Area, the LSA and the McNab Creek watershed and portions of the adjacent sub-watersheds and marine environments.

5.4.3.2.2 Temporal Boundaries

Based on the Proposed Project schedule, the temporal boundaries for the effects assessment for Geotechnical and Natural Hazards 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.

Temporal characteristics of the Proposed Project's construction (including decommissioning of temporary construction-related facilities), operation and reclamation and closure phases of the Proposed Project are described in Volume 2, Part B - Section 4.3.2 of this EA. The temporal boundaries for Geotechnical and Natural Hazards are summarized below:

- **Construction** – The scope includes all pre-construction activities such as site preparation, ancillary work and construction activities. Additional potential effects from construction may occur from geotechnical testing, excavation of existing fills and natural soils or rock, development of temporary or permanent cut slopes, ground improvement, the addition of fill, heavy equipment traffic, road construction, and berm and dyke construction and through installation or construction of infrastructure. Infrastructure may include but is not limited to processing facilities, an office building, an electrical substation, underground tunnels and above-ground conveyors, the barge load out jetty with mooring appurtenances, and habitat compensation areas, among others;
- **Operation** - The scope of adverse interaction between the Proposed Project and geotechnical or terrain stability conditions is anticipated to be low during the operation phase, generally limited to the potential increases in adverse effects of earthquakes and tsunamis should an event occur. On-going erosion, vibration and compression from aggregate excavation, processing and handling, vehicle and vessel traffic or machinery on natural conditions may have potential effects during an earthquake or tsunami event; and

- **Reclamation and Closure** - The scope for interaction during this phase is generally limited to the potential for Proposed Project activities increasing ground movement and erosion / deposition during an earthquake or tsunami event. In addition, on-going erosion, vibration and compression from vehicle and vessel traffic or machinery on natural conditions may have potential effects.

5.4.3.2.3 Administrative Boundaries

There are no administrative boundaries applicable to the Geotechnical and Natural Hazards VCs.

5.4.3.2.4 Technical Boundaries

The technical boundaries for the Geotechnical and Natural Hazards assessment include the RSA and LSA, as well as the submarine foreshore area.

5.4.3.3 Assessment Methods

5.4.3.3.1 Existing Conditions

The Geotechnical and Natural Hazards (Terrain Stability) assessment (increased effects of earthquakes and tsunamis, and land based terrain stability) included a desktop review of existing information, preliminary terrain base map production (including terrain stability classification), and summaries of site conditions and recommendations. Refer to Volume 2, Part B - Section 5.8 for a detailed assessment of climate change.

Below is a summary of the existing sources of information used for the geotechnical and natural hazards assessment, followed by brief methodologies for each component.

5.4.3.3.1.1 Summary of Existing Information Sources

Previous studies undertaken on and in proximity to the Proposed Project Area are listed as follows:

Environmental Baseline and Technical Reports for McNab Creek and Surrounding Watersheds:

- Golder and other consultant Environmental Baseline and Technical Reports in the McNab creek watershed and foreshore areas (as listed in the Section 5.4.1)

Publically available studies and reports on the Proposed Project Area and surrounding areas:

- 1:50,000 Detailed Surficial Geology Map for Squamish (Thomson 1980);
- Surficial geology and landslide inventory of the lower Sea to Sky Corridor (Blais-Stevens 2008);
- Quaternary stratigraphy and history of south-coastal BC (Clague 1994);
- Geomorphology of Slope Instability Features: Squamish Harbour (Prior and Bornhold 1984a, b and c);
- Land resource inventory of Mill and Woodfibre Creeks, BC (Moon and Brierley, 1988);

- Sunshine Coast Aggregate Potential Mapping Project (Bichler et al. 2001);
- Physiography of BC (Church and Ryder 2010);
- Bulletin 65: Surficial Geology and Sand and Gravel Deposits of Sunshine Coast, Powell River, and Campbell River Areas (McCammon, 1977); and
- Tsunami Probability and Magnitude Study (Westmar 2005).

Publically available digital files:

- Ministry of Environment Terrestrial Ecosystem Information (TEI) Geodatabase based on 1:50,000 scale reconnaissance surficial geology mapping and linework for Terrestrial Ecosystem Mapping (TEM);
- Digital (Bedrock) Map of BC: Tile NM10 Southwest BC (Massey et al. 2005);
- CanVEC topographic layers (water course and lakes, roads, feature names, contours);
- Surficial Geology and Sand and Gravel Deposits of Sunshine Coast, Powell River, and Campbell River Areas, (Ministry of Mines and Petroleum Resources 1977);
- Environmental and Engineering Applications of the Surficial Geology of the Fraser Lowland, British Columbia Armstrong 1984);
- Sand and Gravel in the Strait of Georgia Area (Leaming, 1968); and
- Vancouver North, Coquitlam, and Pitt Lake Map-Areas, British Columbia (Roddick).

Imagery:

- 2003 colour aerial photographs (listed in Volume 4, Part G – Section 22.0: Appendix 5.4-N) converted to digital files;
- Client provided 2013 orthophotograph covering the LSA;
- Client provided 2013 High Resolution Digital Elevation Model Light Detection and Ranging (HRDEM), Light Detection and Ranging (LiDAR) data from airborne laser scanning covering the LSA;
- Publicly available Bing and ESRI Imagery; and
- GoogleEarthTM Imagery dated July 8, 2010 and August 9, 2012.

BC terrain and terrain stability classification methods and mapping standards:

- Guidelines for Legislated Landslide Assessments for Proposed Residential Development in British Columbia (APEGBC 2010)

- Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC. (APEGBC 2012)
- Guidelines for Terrain Stability Assessments in the Forest Sector (APEGBC and ABCFP 2003)
- Terrain Classification System for British Columbia (Howes and Kenk 1997)
- Mapping and assessing terrain stability guidebook (Ministry of Forests, Lands and Natural Resource Operations 1999)
- Best management practices handbook (Ministry of Forests, Lands and Natural Resources 2001)
- Flood Hazard Area Land Use Management Guidelines (Ministry of Water, Land and Air Protection 2004)
- A Landslide Classification and Inventory System for British Columbia with Digital Data Capture Standards (BC MoE 2007)
- Terrestrial Ecosystems Information Guidelines for Developing a Project Plan (BC MoE 2010)
- Field Manual for Describing Terrestrial Ecosystems (British Columbia Ministry of Forests and Range and British Columbia Ministry of Environment 2010)
- Guidelines and Standards to Terrain Mapping in British Columbia (RIC 1996)
- Standard for Digital Terrain Data Capture in British Columbia, Terrain Technical Standard and Database Manual (RIC 1998)
- Quality assurance Guidelines Terrain Stability Mapping (TSM) (RIC 2010)
- Soil Inventory Methods for British Columbia (RISC 1995)
- Standard for Terrestrial Ecosystem Mapping in British Columbia (RISC 1998)
- Terrestrial Ecosystem Information Digital Data Submission Standard –Draft for Field Testing Database and GIS Data Standards (RISC 2010)
- Field Manual for Describing Terrestrial Ecosystems (Luttmerding et al 1998)
- Canadian System of Soil Classification, 3rd Edition (Soil Classification Working Group 1998)

5.4.3.3.1.2 Geotechnical Hazards Assessment

The geotechnical hazards assessment consisted of a review and discussion of site specific geotechnical considerations related to the potential for the Proposed Project to initiate or increase the frequency of earthquake events; earthquake related ground movement, shoreline erosion and offshore debris deposition during tsunami events, and submarine landslides. This assessment included a desktop review of existing information, along with a summary of site conditions and recommendations. Specific documents reviewed for this assessment includes general geotechnical and geological information previously completed by Golder (Volume 4, Part G – Section 22.0: Appendix 5.4-B and 5.4-D), information on a series of sampled boreholes and monitoring wells conducted within the proposed conceptual aggregate pit area (Volume 4, Part G – Section 22.0: Appendix 5.4-E, F, and G), topographic and bathymetry mapping of the Proposed Project Area and LSA (Volume 4, Part G – Section 22.0: Appendix 5.4-G, H, and I), and tsunami probability and magnitude studies for surrounding area (Westmar 2005).

5.4.3.3.1.3 Terrain Stability Assessment

This assessment consisted of assessing areas with unstable terrain and if those areas could potentially be impacted by Proposed Project activities, resulting in a mass movement event. This involved preparing a terrain map with stability classifications (rating criteria for unstable to stable terrain) for the RSA. Two main tasks were undertaken as part of the terrain and terrain stability mapping assessment:

1. Desktop review of existing information from existing studies in the McNab Creek and adjacent watersheds in the Howe Sound area (as noted above and found in the References at the end of this document); and
2. Production of a RSA terrain stability map identifying potentially unstable and unstable terrain and areas in the LSA that may be impacted by landslides, snow avalanches, debris flows and debris floods.

5.4.3.3.1.3.1 Terrain Mapping

Terrain mapping was completed at Terrain Survey Intensity Level (TSIL) C at a 1:20,000 scale. Background data was incorporated into digital map layers using ArcGIS 10.2 (ArcMap) and analysed via digital interpretation/mapping using ArcGIS 10.2 (ArcMap), HRDEM interpretations (i.e., hillshade and slope elevation models created from LiDAR), interpretation of other digital layers (i.e., existing surficial geology and bedrock information), and stereoscopic air photo analysis using PurVIEW (digital mapping program).

Base map production includes delineation of terrain “polygons” that represent areas of relatively homogenous terrain attributes (surficial geology, geomorphic processes, and terrain stability classification ratings). Linework and labels from the existing TEI 1:50,000 surficial geology map (Thomson 1980) were revised accordingly by making minor adjustments to existing linework, creating new polygons where warranted; and adding terrain stability ratings, drainage and erosion susceptibility codes to each polygon.

Publically available information noted in Section 5.4.3.3.1.1, including reports, studies and maps on local physiography and geomorphology; surficial geology and Quaternary stratigraphy; landslides and slope stability; land resource inventories, and existing aggregate deposits was reviewed and incorporated into terrain analysis

Each polygon was assigned current BC terrain code attributes that were entered into a geospatially-linked ArcGIS, government standard TEI database. Polygon delineation and labeling, including terrain stability ratings, incorporated and adhered to the guidelines and standards found in the noted in Section 5.4.3.3.1.1- BC terrain and terrain stability classification methods and mapping standards.

Refer to Volume 4, Part G - Section 22.0: Appendix 5.4-O of this environmental assessment for an overview of terrain label definitions and drainage codes used in the mapping.

5.4.3.3.1.3.2 Terrain Stability Mapping

Terrain stability classification for the RSA was completed in conjunction with terrain base map production at a 1:20,000 scale. The purpose of terrain stability mapping for the Proposed Project was to identify terrain that may experience landslides related to proposed development and identify the types of terrain that are likely to be more prone to landslides than others (Ministry of Forests, Lands and Natural Resource Operations 1999).

The criteria used for the terrain stability class ratings (i.e., the expected likelihood or frequency of development-related landslide activity) are based on the terrain guidelines noted in this report as well as the experience of the mapper. Refer to Volume 2, Part B - Section 22.0: Appendix 5.4-P of this environmental assessment for an outline of the stability rating classifications criteria used for this assessment.

A single terrain stability classification rating (Class I, II, II, IV or V) was assigned to each polygon. The ratings range from Class I indicating a very low probability that unstable terrain exists in a polygon and a low probability that a landslide will occur within that polygon; to Class V, where unstable terrain has a high probability of being located in the polygon and will potentially impact terrain/resources.

Class III polygons may contain small areas of unstable ground, and Class IV and Class V polygons can contain some stable ground. For the purpose of this baseline study, Class IVR (road specific classifications) was not used in this assessment.

Terrain stability field assessments for proposed forestry cutblocks and access roads in the watershed (Volume 4, Part G – Section 22.0: Appendix 5.4-J, K, L, and M), were also reviewed and taken into consideration when assigning terrain stability classification ratings to polygons.

5.4.3.3.2 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.

Potential effects include direct, indirect and induced effects. This evaluation is presented in Section 5.4.5. 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 briefly below.

The LSA would be susceptible to Proposed Project-related interactions during the construction phase. Interactions causing direct effects or Proposed Project-induced changes may occur as a result of excavation of fill materials and natural surficial deposits or soils, fill placement, and other ground disturbing activities related to various new-builds and infrastructure upgrades implemented during construction.

Less obvious ground disturbances that have the potential to cause direct effects may come from site clearing (i.e., exposing shallow sediments); the addition of material to the ground surface (surcharging) such as waste material; pile driving; re-vegetation activities; and wave-generated erosion along shorelines resulting from coastal modifications.

During the operational phase, Proposed Project related interactions that may directly or indirectly change the context or integrity of ground conditions are likely to be limited to ground disturbance activities, resulting from modifications or additions to the Proposed Project Area and the aggregate excavation, handling, processing, storage operations, and marine facilities.

The reclamation and closure phase is unlikely to affect geotechnical and natural hazard conditions at the Proposed Project Area. Activities such as foundation removal may result in additional ground disturbance beyond that related to the initial construction phase.

5.4.3.3.3 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 5.4-3 Criteria for Characterizing Potential Residual Effects: Geotechnical and Natural Hazards have been used to characterise and determine the significance of potential effects of Geotechnical and Natural Hazards VCs.

Where possible, definitions have taken into account the technical guidance that has been produced. Documents relevant to the geotechnical and natural hazard (terrain stability) assessment are noted in the Summary of Existing Information Sources of this report section.

Please refer to Volume 2, Part B - Section 4.0: Assessment Methods of this EA. for a description of the criteria used to characterise potential effects for all disciplines.

The likelihood of potential residual effects occurring was also characterized for each VC using appropriate quantitative or qualitative terms. To derive a likelihood rating that indicates the probability of a certain effect to occur, implementation of mitigation measures were considered. For example, the likelihood of a certain effect is low, if there is a low potential of the event leading to the effect to occur, or if there are effective controls in place that can eliminate or reduce the magnitude or frequency of the effect. The following criteria were used to define 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.

5.4.3.3.4 Evaluating Significance of Residual Effects

The rationale and determinations of the significance of potential residual effects on VCs are provided in Section 5.4.5.5. A conclusion about the significance of predicted residual adverse effects (i.e., after mitigation) of the Proposed Project is provided for each VC based on:

- Residual effects criteria described above;
- A review of background information and available field study results;
- Consultation with government agencies and other experts; and
- Professional judgment.

Potential adverse residual effects on selected VCs are characterized as negligible – not significant, not significant, or significant:

a) Negligible – Not significant - requiring no further consideration;

b) Not Significant - Potential residual effect is not considered to be substantially impacted by the Proposed Project; and

c) Significant - Potential effect requiring further consideration and possibly additional mitigation.

Negligible residual effects are either not measurable, within the range of natural variability, or so small they may be safely disregarded. They do not warrant further consideration and are not carried forward into a cumulative effects assessment.

Residual effects may be characterized as not significant if they are determined to be measurable but not likely to result in substantial changes to the viability of the VC.

Residual effects may be characterized as significant if there is a reasonable expectation that the effect of the Proposed Project would:

- Exceed established environmental standards, guidelines, or objectives;
- Be beyond the natural variability of the environmental or social conditions; and/or
- Affect the viability of the VC (i.e., the ability of the population, ecosystem or community to work and function over time within the defined spatial and temporal boundary).

All non-negligible residual adverse effects (i.e., significant and not significant) will be considered for inclusion in a cumulative effects assessment.

5.4.3.3.5 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 background information, field studies, knowledge of types of effects potentially resulting from various Proposed Project-activities, professional judgement, and effectiveness of mitigation 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.

Uncertainties and assumptions associated with the geotechnical and natural hazard assessment are primarily associated with the following:

- Limitations in the currently available information on subsurface conditions;
- Variations or uncertainties in the subsurface conditions within and adjacent to the Proposed Project Area;
- Preliminary or concept level mitigative measures presented in these documents. Interpretations of surficial geology and geomorphological processes are limited to areas covered by existing maps and reports and previous studies;
- Terrain mapping and identification of terrain stability related (i.e., natural) hazards are based solely on desktop methods and have not been verified in the field;
- Terrain mapping accuracy may be affected by the quality of digital data transfers and uploads to ArcGIS 10.2; and
- Tonal differences among and across air photo and orthophoto data acquisition lines may reduce the accurate definition of polygon boundaries and interpretation of geomorphic processes.

Based on the above, the level of confidence of this geotechnical and natural hazards VC assessment is considered moderate.

Table 5.4-3: Criteria for Characterizing Potential Residual Effects: Geotechnical Hazards and (Terrain Stability)

VC	Context	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
Earthquakes and Tsunamis – Increasing earthquake-related ground movements, increasing shoreline erosion and offshore debris deposition during a tsunami event (generated by landslide and/or earthquake activity), and initiation of submarine landslides from Proposed Project activities.	**Resilient:** The geotechnical hazards have low susceptibility to potential changes caused by the Proposed Project; **Moderately Resilient**: The geotechnical hazards have moderately susceptibility to potential changes caused by the Proposed Project; or **Sensitive:** The geotechnical hazards (increase in earthquake induced liquefaction and ground movement, slope instability debris deposition, shoreline erosion due to tsunamis, and submarine landslides) are susceptible to potential changes caused by the Proposed Project.	**Negligible:** Proposed Project will have no measurable effect; **Low**: Proposed Project will result in changes in geotechnical hazards that will not exceed Canadian or BC guidelines or Code requirements; **Medium:** Proposed Project will result in changes in geotechnical hazards that will exceed Canadian or BC guidelines or Code requirements; or **High:** Proposed Project will result in large ground movements and slope failures, damage or failure of facilities, injury or loss of life.	**Local:** Effect restricted to LSA; **Regional:** Effect extends beyond the LSA into the RSA; or **Beyond Regional:** Effect extends beyond the RSA.	**Short-term:** <1 year; **Medium-term:** 1 year to life of Proposed Project; or **Long-Term:** > life of Proposed Project.	**Fully Reversible:** Effect can be avoided by appropriate design and construction measures; **Partially Reversible:** Effect can be minimized or mitigated by appropriate design and construction measures as well as operations and emergency response plans; or **Irreversible:** Effect is permanent.	**Low:** Occurs rarely; **Medium:** Occurs intermittently; or **High:** Occurs continuously.

VC	Context	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
Terrain Stability – Initiation of land based mass movement events. Project activities increase potential for unstable conditions to arise (e.g., landslides, snow avalanches, debris flows, debris floods)	**Resilient:** the terrain conditions have low susceptibility to potential changes caused by the Proposed Project; **Moderately Resilient**: The geotechnical hazards have moderately susceptibility to potential changes caused by the Proposed Project; or **Sensitive:** the terrain conditions **(**slope morphology and potentially unstable and currently unstable ground conditions) are susceptible to mass movement initiation with potential changes caused by the Proposed Project.	**Negligible:** Proposed Project will have no measurable effects on the unstable or potentially unstable terrain. **Low:** Proposed Project will result in changes in unstable or potentially unstable terrain parameters but will not directly impact the LSA. **Medium:** Proposed Project will result in initiation of a mass wasting event but will not directly impact the LSA. **High:** Proposed Project will result in initiation of a mass wasting event that will directly impact the LSA.	**Local:** Effect restricted to LSA. **Regional:** Effect extends beyond the LSA into the RSA. **Beyond Regional:** Effect extends beyond the RSA.	**Short-term**: <1 year. **Medium-term**: 1 year to life of Proposed Project. **Long-term**: >life of Proposed Project.	**Fully Reversible:** Effect can be avoided by appropriate design and construction measures; **Partially Reversible:** Effect can be minimized or mitigated by appropriate design and construction measures as well as operations and emergency response plans; or **Irreversible:** Effect is permanent.	**Low:** occurs rarely or during a specific period **Medium:** occurs intermittently **High:** occurs continuously

5.4.4 Baseline Conditions

5.4.4.1 Introduction

The ground (subsurface) conditions related to Earthquake and Tsunami baseline conditions have been presented in previous Golder reports: Geologic Setting and Description (Volume 4, Part G – Section 22.0: Appendix 5.4-D); Geotechnical Stability Assessment Compensation Groundwater Channel McNab Valley Project (Appendix 5.4-B); McNab Creek Avulsion Risk Assessment (Appendix 5.4-A); McNab Valley Aggregate Project Howe Sound BC (Volume 4, Part G – Section 22.0: Appendix 5.4-H); Concrete Aggregate Assessment McNab Creek British Columbia (Volume 4, Part G – Section 22.0: Appendix 5.4-F) and are summarized in Section 5.4.3.3.1 above and in Figure 5.4-8 to Figure 5.4-12 found at the end of this section. The natural hazards baseline conditions was completed by conducting a terrain and terrain stability mapping assessment comprising a desktop review of existing information, production of a terrain base map, and analysis of the potential for the terrain hazards to affect the Proposed Project facilities. Below is an overview of the general geologic setting and results of the baseline studies.

The geologic setting, physiography, and surficial geology and bedrock descriptions have been detailed in previous Golder reports (Geologic Setting and Description (Volume 4, Part G – Section 22.0: Appendix 5.4-D); Geotechnical Stability Assessment Compensation Groundwater Channel McNab Valley Project (Volume 4, Part G – Section 22.0: Appendix 5.4-B); McNab Creek Avulsion Risk Assessment (Volume 4, Part G – Section 22.0: Appendix 5.4-A); Geophysical Survey of Fan-Delta (Appendix 5.4-H). The McNab Creek watershed is located on the west side of Howe Sound, and is characterized by a south-flowing drainage approximately 12.7 km long, that drains to the marine environment (Volume 4, Part G – Section 22.0: Appendix 5.4-D). The U-shaped valley consists of rugged Coast Mountain topography, with elevations reaching 1500 m. The glaciated McNab Creek watershed consists of thick valley bottom sediments (glacial outwash, terraces, and fan-delta complexes), with thinner surficial materials (till and colluvial materials) along valley walls leading to exposed bedrock outcrops along steep and irregular ridges. Active and historic avalanching and landslide events are also common along the middle to upper reaches of the watershed.

Bedrock along the western valley was previously mapped as metamorphic (primarily a low grade slate of metasiltstone) of the Coast Plutonic Complex (Volume 4, Part G – Section 22.0: Appendix 5.4-D). The western ridge and upper slope area have been mapped as plutonic rocks (granodiorites) of the Coast Plutonic Complex. A mix of volcanic rocks (dykes and xenolithithic rock) has also been previously mapped throughout the watershed (Volume 4, Part G – Section 22.0: Appendix 5.4-D). Volume 4, Part G – Section 22.0: Appendix 5.4-F noted that McNab Creek may be the surface expression of a fault system that separates the metamorphic rocks from the plutonic rocks.

The watershed has been actively logged (road systems and cut blocks) over the last fifty years and there are several residential sites located at the mouth of the valley in the watershed.

5.4.4.2 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 geotechnical hazards. The main sources of this information include:

- Occupation and Use Study (OUS) undertaken by *Sḵwx̱wú7mesh* (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 geotechnical hazards.

5.4.4.3 Surficial Geology and Geotechnical Conditions

The sediments in the valley and underlying the Proposed Project exhibit characteristics of glaciofluvial outwash sediments for the most part, and have formed a valley fill that has encouraged the development of a U-shape to the McNab valley. The valley fill sediments are present as a series of terraces of varying elevation, with generally gentle slopes within the Proposed Project Area. In the upper terraces, the valley fill sediments are capped by till. In the lower terraces, the sediments appear to have an alluvial veneer (Geologic Setting and Description (Volume 4, Part G – Section 22.0: Appendix 5.4-D); Geotechnical Stability Assessment Compensation Groundwater Channel McNab Valley Project (Volume 4, Part G – Section 22.0: Appendix 5.4-B); McNab Creek Avulsion Risk Assessment (Volume 4, Part G – Section 22.0: Appendix 5.4-A); Geophysical Survey of Fan-Delta (Volume 4, Part G – Section 22.0: Appendix 5.4 - H).

Interpretation of the sedimentary sequences observable in the terraces indicates a geologic history in which McNab Creek has incised into glaciofluvial valley fill over the post-glacial period (i.e., the last 10,000 years), leaving till capped glaciofluvial deposits exposed at or near surface or overlain by more recent alluvial deposits along the past and current creek channels. Sediments from local erosion of the glaciofluvial deposits as well as more recent alluvial sediments have been deposited in the lower reach as a fan-delta structure.

Glacial/post-glacial outwash during the time of glacial decay within the valley is projected to have resulted in high water volumes and accompanying greater sediment transport capacity, such that thick deposits of quite coarse-textured glaciofluvial materials resulted. Exposures of some of these former glaciofluvial deposits over shallow bedrock are observed on the flanks of the valley, and at the location of the first major bend in the creek upstream of its mouth. At this site, the creek has cut through these earlier glacial outwash deposits, exposing them and transporting the sediments downstream.

In the lower reaches of McNab Creek, the creek has deposited a bed of alluvial sediments derived from erosion of the terraces upstream. This has formed a fan-delta at the mouth of the stream. The alluvial material associated with the stream overlies the glaciofluvial valley fill. McNab Creek is presently reworking these alluvial sediments and continues to build the fan-delta into Howe Sound at the creek mouth. Based on a bathymetric and sub-bottom marine geophysical investigation (Volume 4, Part G – Section 22.0: Appendix 5.4-I), the surface of the fan-delta is generally flat lying to gently sloping at shallow depth below mean sea level and extends 500 m or more locally to the crest of the offshore delta front slope along the shoreline of the Proposed Project.

The bedrock surface on which the valley fill and subsequent fan-delta sediments has accumulated is likely to be undulating and irregular, and the thickness of the deposit may range from approximately 50 to 100 m. Fan-delta deposits that are progressively built up in these settings tend to begin with the initial deposition of very fine sediments at depth. Hydraulic sorting dictates that the fine sediments will be deposited further out as additional sediment is supplied to the fan-delta, and that coarser material will be deposited in shallower water. This pro-graded structure is typical of river system fan-deltas, such that fines are often located near the bottom of a sequence, and coarser materials are deposited atop of the finer sediments. As the pro-grading stream transports additional materials into the area, the fan-delta develops further into deeper water. The stream providing sediment also tends to wander or migrate across the width of the fan-delta surface that it is developing. As a result, it is frequently observed that an inter-bedded, cross-bedded structure evolves.

5.4.4.4 Results- Terrain and Terrain Stability

Mapped terrain units and terrain stability characteristics and classifications are summarized in the following sections. An overview of the terrain mapping results for the RSA at 1:50,000 scale is presented on Figure 5.4-1 at the end of this section. The 1:20, 000 scale TSIL Level C results are based on terrain mapping labels presented on the Figure 5.4-2 to Figure 5.4-6. Note, results are based on the LSA land areas only, and do not include the marine environments. Land based LSA areas are 191 ha out of the total 254 ha (which includes marine foreshore environments).

Terrain mapping includes surficial materials (noted as capital letters the label); surficial material expressions (noted as lower case letters in the label) that describe landform and estimated thicknesses of deposits); delimiters (backslashes indicating relative proportions of each material type); geomorphological processes (capital letter noted after the "dash" in the label); and subclasses to these processes (lower case letter adjacent to the process label).

The example presented in Figure 5.4-7 provides an overview of label definitions.

5.4.4.4.1 Surficial Materials

Surficial materials consist of generally poorly consolidated, non-lithified sediments that develop through processes of weathering, deposition, biological accumulation, or human activity. Specific processes, which are used to classify surficial materials include: erosion, transportation, deposition, mass wasting and weathering. Surficial materials can further be classified based on surface expression, landforms and depositional patterns.

Five distinct surficial materials were mapped within the 2014 RSA (see Figure 5.4-2 to Figure 5.4-6). The surficial material types and their estimated areal coverage relative to the LSA and RSA are summarized in Table 5.4-4 and described in the following sections of this report.

Table 5.4-4: Summary of Dominant Surficial Material Types Mapped in the RSA and LSA

Surficial Material (present as dominant material type)	Total Area in RSA (ha)	Percent of RSA (%)	Total Area in Land-based LSA (ha)	Percent of Land-based LSA (%)
Colluvium (C)	4,659	64	0	0
Fluvial (F)	922	13	186.5	98
Bedrock Outcrops (R)	893	12	0	0
Moraine/Till (M)	760	10	4	2
TOTAL	**7,245**	**100**	**191**	**100**

5.4.4.4.1.1 Colluvium (C)

Colluvium is material that has been deposited as a result of gravity-induced movement on slopes. It is generally poorly sorted to unsorted deposits, and contains a wide range of class sizes, typically composed of a combination of rubble and angular blocks, and is well drained materials. Colluvium is the most dominant surficial material, and covers 4659 ha or 64% of the RSA. Colluvium was not mapped in the LSA.

Colluvial materials in the RSA are primarily the result of mass wasting events (discussed below in the Geomorphological Processes section).

In the RSA, colluvial materials typically occur on slopes with gradients greater than 50%. On slopes with gradients greater than 70%, colluvium was mapped as veneers (Cv) or thin veneers (Cv), ranging in thickness from 0.2 m to typically less than 1.0 m. Thin and discontinuous colluvial deposits were mapped along ridges and upper slopes and where exposed bedrock outcrops are common, with estimated thickness of 0.1 m to 0.5 m (Cxv). Along upper, uniform slopes with gradients between 50% and 70%, colluvium thicknesses are expected to be between 0.5 m to 1 m (Cv), and likely overlying morainal (till) or fluvial deposits.

Along these middle to upper slopes (including steep uniform slopes with gullies, gully sidewalls, areas with fractured bedrock bluffs), colluvial deposits were commonly associated with avalanching (Cv-A); soil creep (Cv-Fc), rockfalls and rockslides (Cv- Rbr), and debris slides (Cv-Rs) are occurring along steep slopes as well

Colluvium was also commonly mapped as cones and fans where steep valley slopes transition to gentle valley bottom slopes. Colluvial deposits in mid-slope areas near the lower slopes and in debris avalanche and mass wasting run out zones (i.e., cone and fan landforms) may be up to 3 m to 5 m thick. These types of deposits likely have a greater component of coarse sub-angular materials.

5.4.4.4.1.2 Fluvial (F) and Active Fluvial (FA) Materials

Fluvial materials are stream transported sediments that are typically composed of unconsolidated gravel and sand, with variable amounts of silt, cobbles and boulders. The fluvial materials in McNab watershed consist of sediment deposited by meltwater streams beyond ice contact (outwash), as well as more recent fluvial erosion, transport, and depositional sequences.

Fluvial materials covered 922 ha or 13% in the RSA. Fluvial materials covered 187 ha or 98% of the land based LSA. Fluvial materials have been mapped within the McNab Creek, along lower valley areas from the foreshore to approximately half way up the valley, and within actively incising, well developed mountain stream tributaries. Within the small floodplain sections of McNab Creek, there are likely reaches that periodically flood, resulting in erosion and generation of sediment that is likely transported downstream. These deposits are considered to be active (FAp).

The morphology and details of these valley fill deposits are characterized in the Golder Technical Memorandum – Geological Setting and Descriptions (Volume 4, Part G – Section 22.0: Appendix 5.4-D). In general, the mapped fluvial materials consists of a series of outwash terraces (Ft) in the upper valley (typically mixed with till deposits) as well as more recent, lower elevation terrace sequences in the mid-valley area. The morphology of the fluvial channels has been modified by colluvial fans and cones where they have reached the creek valley bottoms. These colluvial deposits have also affected the sediment flux of some of the creeks.

Within the LSA and the lower reaches of McNab Creek, a well-developed fan-delta (Ff) has been mapped, with the fan-delta structure and development presented in Volume 4, Part G – Section 22.0: Appendix 5.4-B. The fan materials consist of thick outwash deposits of sand and gravel currently being reworked by McNab Creek, which continues to build the fan-delta into Howe Sound.

5.4.4.4.1.3 Bedrock (R)

Exposed bedrock rock was mapped in 893 ha or 12% of the RSA only. Bedrock was not mapped in the LSA. Mapped bedrock polygons include previously mapped meta-sedimentary, plutonic, and to a lesser extent meta-volcanic rocks located along high elevation ridges, peaks, and forming short, steep bluffs located in avalanche and landslide initiation zones.

While bedrock exposures are common in the alpine and upper slope areas, there are mid to lower slope areas dominated by till and colluvium (irregular terrain with short, irregular slope breaks) where bedrock hummocks were mapped as a secondary component. These polygons were not extensive or typical of the terrain polygon as a whole.

5.4.4.4.1.4 Morainal (Till) (M)

Morainal material (till) is transported and deposited by glaciers and is characterized by poor sorting and a wide range of particle sizes, including boulders, blocks, gravel, sand, silt and clay. Till is typically dense and non-stratified.

Till was mapped in 10% or 760 ha of the RSA and in 2% or 4 ha in the LSA. Till generally occurs as mantles over bedrock on the mid to upper slopes, and is likely exposed along incised streams and in gullies. Till in these areas are inferred to be generally less than 2m thick (Mv), with drainage properties that vary from poorly drained to moderately well drained. Till has also been mapped adjacent to McNab Creek on the lower valley walls and is overlain by fluvial deposits along and is likely greater than 1m in depth (Mb).

5.4.4.4.2 Geomorphological Processes

Geomorphological processes modify surficial materials and landforms through processes of weathering, erosion and deposition. Steep slopes, surficial materials and bedrock lithology along with climate factors affecting the Coast Mountains physiographic region contribute to a variety of geomorphological processes. The role of these processes in the study is discussed in the following sections. A summary of the dominant geomorphological processes in the land based RSA and LSA are provided in Table 5.4-5 and Table 5.4-6 (summary of secondary geomorphological processes) noted below and presented in Volume 4, Part G - Section 22.0: Appendix 5.4-P. The discussions following provide an overview of the multiple processes occurring in the RSA. Refer to Volume 4, Part G - Section 22.0: Appendix 5.4-O for geomorphological terms based on terrain mapping definitions and labels.

Table 5.4-5: Summary of Dominant Geomorphological Processes for LSA and RSA

Geomorphological Processes	RSA Area (ha)	RSA % polygons	LSA Area (ha)	LSA % polygons
No Processes Mapped	2,854	39	166.5	65.6
Avalanching (-A)	2,051	28	0	0
Gullying (-V)	1,163	16	0	0
Rapid Mass Movement (-R)	734	10	0	0
Surface Seepage (-L)	372	5	3.7	1.5
Irregularly Sinuous Channel (-I)	60	1	20.3	8.0
Totals	**7,234**	**100**	**190.5**	**75.1**

Table 5.4-6: Summary of Secondary Geomorphic Processes for LSA and RSA

Geomorphological Processes	RSA Area (ha)	RSA % polygons	LSA Area (ha)	LSA % polygons
No Secondary Processes Mapped	3,868	53	0	0
Rapid Mass Movement (-R)	1,889	26	0	0
Avalanching (-A)	1,087	15	0	0
Gullying (-V)	278	4	0	0
Slow Mass Movement (-F)	61	1	0	0
Irregularly Sinuous Channel (-I)	51	1	0	0
Totals	**7,234**	**100**	**190.5**	**75.1**

A total of 4,379 ha or 61% of the RSA had mapped geomorphological processes. The LSA only had 9.5% or 24 ha mapped as having geomorphological processes.

5.4.4.4.2.1 Mass Movement Processes

5.4.4.4.2.1.1 Snow Avalanches (-A)

Approximately 28% or 1051 ha of the RSA was mapped as having snow avalanche as a dominant process. As a secondary process, avalanching was mapped in an additional 15% or 1087 ha in the RSA. Snow avalanches are rapid downslope movements (i.e., flowing or sliding) of snow and ice that can incorporate rock, surficial material and vegetation. This process is applied to terrain with snow avalanche tracks as well as initiation and run out zones.

The mapped polygons are associated with areas of high local relief and inferred moderate to heavy snowfall, and are characterised by linear vegetation patterns characteristic of avalanche prone terrain. Initiation zones mapped in the RSA are typically located along ridges or in "*bowls*" on leeward slopes where snowpack accumulates. Several run out zones in the upper valleys (specifically in the Mill Creek watershed) appear to extend from the initiation zones at high elevations to the valley bottom, running out along the edge of McNab Creek.

High precipitation levels in the region combined with the Coast Mountains physiography support deep snow packs at high elevations within the RSA, which result in varying sizes and track-types of avalanche paths. Geomorphological sub-classes of snow avalanches including active major tracks (-Af), minor tracks (-Am), mixed tracks (-Aw), and older tracks (-Ao) were mapped throughout the upper to mid-slopes in the RSA.

Snow avalanches are commonly associated with rapid mass movement processes (i.e., mixed with debris slides and less commonly debris flows, or torrents along gully systems) resulting in larger volumes of accumulated debris along avalanche tracks. In some cases, large debris loads can form a stream "*plug*", which can later be overwhelmed by spring run-off or storm events. This has the potential to create a rapid mass movement event in the form of a debris flow along steeper slopes, and possible debris floods along lower gradient main river valleys. These types of mixed, large avalanche deposits were not commonly observed in the lower valley area.

5.4.4.4.2.1.2 Rapid Mass Movement (-R)

Approximately 10% or 734 ha of the RSA were mapped as having rapid mass movement as the dominant processes. Rapid mass movement was mapped as the secondary process in an additional 1889 ha or 26% of the RSA. Terrain stability Class IV and Class V terrain were associated with these polygons, and include both existing natural landslide hazards and terrain where construction activity may increase landslide initiation.

This process includes rapid downslope movement by falling, rolling, sliding or flowing of dry, moist or saturated debris derived from surficial material and/or bedrock. Rapid mass movements were generally mapped in upslope areas where ridge crests break to steep valley slopes; in areas where steep, fractured bedrock and weathered bedrock outcrops are actively raveling downslope; where debris slides and (and less commonly debris flows) are concentrated along gully systems; or where surficial materials are undercut by fluvial action and side banks of steam channels appear to be unstable.

When identifiable on air photos, subclasses of mass wasting processes mapped in the area include rockfall (- Rb), rock slides (-Rs), debris slides (s), debris torrents (t) and debris fall (f). The majority of these deposits were observed in the form of colluvial cones (slope gradients typically greater than 15%) or fans (slope gradient less than 15%) at the base of bedrock outcrops and bluffs.

Rockfalls and rockslides were also observed in small gully systems where the material accumulates in the channel and is eventually transported downstream during episodes of high stream discharge. Rockslides were commonly associated with weathered bedrock exposures and areas with avalanching.

Rockfall and rockslide (-Rb, -Rr) events are typically small and have traveled less than 100 m running out on mid-to-lower slopes. Rockfall and rockslides were observed at avalanche initiation zones, and less commonly in small gully system sidewalls.

Debris slides (-Rs) involve sliding of disintegrating masses of surficial materials and bedrock and typically occur along steep, open slopes. In the RSA, debris slides are observed along mid-to-upper slopes where avalanches or rockslides have incorporated and entrained the underlying till and colluvial material. This includes steep gully sidewalls, along gradient breaks transitioning from steep mid-valley slopes to lower valley slopes, along upper cutblock boundaries transitioning to steeper upper slope gradients, and on old logging road fill slopes. The majority of the mapped debris slides along middle slopes are covered by second growth stands, with upper elevations slides having exposed headscarps with partially vegetated transport zones. The majority of debris slides terminated along mid to lower valley or side valley slopes. Exceptions included road-related fillslope slides along the western side of the valley that have reached the side valley tributary creek. Debris flows did not appear to have been initiated from the debris slide material reaching the creek. Small scale debris slides and less commonly slumps (-Ru, sliding of internally cohesive masses of surficial material along a concave upward or planar slip plane) were observed along McNab Creek side banks.

Debris flows (–Rd) occur when a mixture of water, earth and vegetation debris rapidly flows downslope. In the RSA, they are likely associated with material that has accumulated in gullies or an avalanche track and is eventually transported downstream during episodes of high discharge during periods of heavy stream flow or high precipitation events. There is evidence of possible historic debris flow deposits, primarily along the eastern slopes of the valley. These areas are mapped as colluvial fans (Cf) and are generally located at the mouths of steep gully systems. There is a recent debris flow mapped approximately 3.5 km up the valley from the LSA on the eastern side of McNab Creek. The debris flow appears to have initiated along headwater areas of gullies at the ride, and incorporated debris slide material from sidewalls and possible avalanche debris. The runout zone (Cf) is located on the mid to lower valley slopes above McNab Creek.

5.4.4.4.2.1.3 Slow Mass Movement (-F)

The process involves the slow downslope movement of masses of cohesive or non-cohesive surficial materials and/or bedrock by creeping, flowing or sliding (-Fc). This was mapped as a secondary component in polygons covering 61 ha or 1% of the RSA. Terrain affected by slow mass movement was displayed as irregular, chaotic or hummocky topography along upper slopes in the RSA where thick colluvial materials and seepage were common.

Debris Floods

Based on terrain mapping interpretations, and previous Golder assessments regarding the avulsion risk on McNab Creek (Volume 4, Part G – Section 22.0: Appendix 5.4-A) and the hydraulic characterization of the McNab Creek Valley (Volume 4, Part G – Section 22.0: Appendix 5.4-C), there is little evidence that recent or large scale debris floods have occurred in this valley. Also, scour and debris jams were not observed, indicating that there is little evidence to suggest that periodic debris flood events have occurred in the recent past (i.e., <200 years, based on assumed timber ages).

A debris flood is defined as a very rapid flow of water, heavily charged with debris, in a steep channel. Peak discharge is comparable to that of a water flood (Hungr et al. 2013). Due to water drag, debris flood deposits can extend further downslope and deposit on lower channel gradients. With annual peak flows, extreme weather events, an "outburst" flood associated with a debris plug being overwhelmed, may result in hyper-concentrated flow due to debris flows entering the creek system (and converting to a debris flood), or combinations of these.

It is possible that debris flood deposits may be present within the McNab Creek valley; detailed investigations regarding historic debris flow or debris flood events have not been addressed in this report.

5.4.4.4.2.2 Erosional Processes

5.4.4.4.2.2.1 Gullying (-V)

Approximately 1163 ha or 16% of the RSA was mapped as having gully erosion processes (-V). Gully erosion was mapped where there is active down-cutting and erosion in more than one discrete location within a terrain polygon. Gullies can provide significant conduits for transporting material downslope and are important to sediment supplies to McNab Creek.

There are generally four types of gullies observed in the RSA; broad gully systems starting at ridges, with several creek headwater areas coalescing at mid-valley creek systems; narrow, steep gully channels and sidewalls incised between bedrock outcrops (likely associated with weaker, more erodible bedrock layers or sections of highly fractured and jointed, or faulted outcrops with larger volumes of weathered bedrock); shallow and less incised gullies cutting into thin till and colluvial deposits along mid-to-upper valley sidewalls; and lower valley gullies that are incising through thick fluvial and till deposits with lower channel gradients.

Active rapid mass movement processes are also evident in gullies and are associated with avalanche tracks, debris slides, rockslides and rockfalls with persistent raveling.

The majority of the gully systems in the RSA start at the top of ridges along slopes greater than 70%, and dissipate along middle slope "hanging valley" tributary systems, where the gullies coalesce with channels having less than 50% gradients. Lower valley gullies are erosional features and are actively down cutting through thick deposits, with little to no evidence of significant debris flow activity.

5.4.4.4.2.3 Hydrologic Processes

5.4.4.4.2.3.1 Surface Seepage (-L)

Surface seepage is a hydrological process where abundant surface discharge or seasonal seepage occurs (Mb-L). Surface seepage was mapped over 372 ha or 5% of the RSA. Within the LSA, it covered 4 ha or 1.5% of the area. Surface seepage was mapped as processes where the surficial material and overburden is expected to have slow soil infiltration rates and high water storage capacity. These areas were identified in the RSA by wet vegetation indicators and poorly incised creek channels.

Polygons mapped with this process are located on middle-to-lower slopes, and along the out-most edges of colluvial toe deposits (Mb, Cf-L).

5.4.4.4.3 Fluvial Processes

5.4.4.4.3.1.1 Irregularly Sinuous Channel (-I)

Irregularly sinuous channels are clearly defined creeks or rivers with a main channel that has irregular turns and bends with no repetition of similar features. This fluvial process was mapped as a dominant and secondary processes in 101 ha, or 2% of the RSA. Within the LSA this channel type covered 20 ha or 8% of the area.

McNab Creek and a few smaller tributaries along the lower valley slopes were mapped as having this process. Along McNab Creek, a few minor back channels and small side channels with small bars and islands were also observed.

5.4.4.4.4 Terrain Stability Classification

Terrain stability classes are used to indicate the probability that areas of unstable ground exist within a polygon. The probability of unstable ground being present in a polygon increases with increasing terrain stability numerical class (i.e., highest probability occurs in Class V). These classes and their occurrence in the RSA are presented below in Table 5.4-7 and on Figures 1-1 through 1-6 in Volume 4, Part G – Section 22.0: Appendix 5.4-P and summarised in the following sections.

Table 5.4-7: Summary of Terrain Stability Classes Mapped in RSA and LSA

Stability Rating	Total Area in RSA (ha)	Percent of RSA (%)	Total Area in Land Based LSA (ha)	Percent of Land- Based LSA (%)
Class I	416	6	157.3	62.0
Class II	1,626	22	3.7	1.5
Class III	1,817	25	29.5	11.6
Class IV	1,836	25	0.0	0.0
Class V	1,538	21	0.0	0.0
TOTALS	**7,234**	**100**	**190.5**	**75.1**

5.4.4.4.4.1 Terrain Stability Class V

Polygons with terrain stability Class V covered 21% or 1538 ha of the RSA. Class V was not mapped in or adjacent to the LSA. All of the Class V polygons include active rapid mass movement process, avalanching, or gullying, or a combination of the three. Most of the polygons also exhibited historic instability, which is the basis for assignment of stability class.

The majority of the terrain stability Class V polygons were identified on steep upper slopes and near headwaters and landslide or avalanche initiation zones near ridges. Slope gradients of the Class V polygons range from 50% to 150%, most fall into the 50% to 70% slope range.

Polygons mapped with terrain stability Class V typically show exposed, “fresh” weathered headscarps along upper slopes with seepage zones and rockslide/rockfall zones consisting of fractured and loose bedrock and raveling rubbly weathered bedrock along upper slopes leading to a colluvial cone with large blocks and rubble depositing on benched terrain adjacent to McNab Creek.

Other terrain stability Class V polygons included the recent debris flow mapped along the eastern valley side wall, as well as smaller, fairly recent debris slides that initiated along mid-slope seepage zones and have run out on lower slope terrain.

5.4.4.4.4.2 Terrain Stability Class IV

Polygons with terrain stability Class IV covered approximately 25% or 1836 ha of the mapped area within the RSA. Class IV terrain was not mapped within the LSA.

Terrain stability Class IV polygons are located primarily along upper slopes at breaks to ridge crests. Surficial materials present in Class IV terrain in the RSA include a mix of weathered bedrock and bedrock, colluvium, and, to a lesser extent, thin till deposits. The typical slope gradient range is 50% to 70%, with lesser areas of undulating or hummocky terrain (40% to 70%).

Polygons were mapped as terrain stability Class IV where small rockfall or rockslide (i.e., one small slide over a large area), or minor ravelling of loose material in gullied terrain was observed. In these cases, there did not appear to be any evidence of widespread inherent instability or large run out deposits at the base of slopes.

Terrain stability Class IV areas included areas where road related slides were observed on otherwise stable terrain (western upslope access roads to cut blocks). Unstable side banks where active slumping, ravelling, and debris slides were occurring (i.e., along lower reaches of McNab Creek) were also given Class IV terrain stability classifications.

5.4.4.4.4.3 Terrain Stability Class III

Terrain stability Class III polygons contain potentially unstable terrain, but generally lack evidence of active or historical instability. Polygons with Class III terrain stability classification covers 1817 ha or 25% of the RSA, with 30 ha or 12% of those areas located within the LSA.

Terrain stability Class III was correlated with middle to upper slopes with gradients typically ranging between 40% and 70%. Surficial material in these polygons is expected to be less than 1 m thick, with no evidence of seepage, and no evidence of inherent instability or significant gullying. These areas were associated with till mantles, thin colluvial deposits and hummocky bedrock outcrops along convex to irregular shaped topography along valley slopes.

5.4.4.4.4.4 Terrain Stability Class II and Class I

1626 ha (22%) of the RSA was mapped as terrain stability Class II, with 4 ha or 1.5% of that area located within the LSA. Terrain stability Class II polygons have relatively low inherent instability and display no evidence of historic or active slope failures. These polygons were identified along mid to lower slopes with less than 40% slope gradients, and areas of undulating topography dominated by thick (inactive) fluvial materials and undulating till mantles with no evidence of gullying or significant erosion.

Polygons with terrain stability Class I covered 416 ha (6%) of the RSA, with 157 ha or 62% of those polygons located in the LSA. Class I terrain was mapped along planar to gently sloping valley bottoms, and undulating and irregular bedrock ridges. Evidence of instability or active degradation is lacking and there is no evidence for deep seated failure of low angel/slope slide initiation.

5.4.4.5 Discussion

Results from the terrain base mapping assessment generally correlate with existing surficial geology maps and information from previous site reports.

Interpretation of the terrain and terrain stability mapping was used to identify areas susceptible to natural hazards and geomorphic processes that could affect the RSA and the LSA and Proposed Project Area. In this assessment, terrain stability hazards, both recent and historic, do not appear to directly affect the LSA or the Proposed Project Area and facility locations.

Unstable and potentially unstable terrain was identified in the RSA (e.g., snow avalanches, debris slides and debris flows along valley sidewalls). Natural Hazards (terrain stability Class IV and V; unstable and potentially unstable terrain) mapped in the RSA are further up valley and are not directly connected to the LSA. Geologic phenomena such as avalanches and various types of terrain stability concerns such as landslides have historically occurred and are currently occurring in the RSA. The potentially unstable terrain is a result of avalanche conditions and recent and active, naturally occurring slides (gully sidewalls and along steep bedrock slopes); road-related debris slides, and older (natural) debris flows. Existing slides at road fill slopes are likely to continue to occur, with ongoing ravelling, and possible larger scale slides reaching side valley tributary systems (i.e., Box Canyon Creek) that are indirectly connected to the LSA. These possible events can be managed with detailed site reviews and recommendations.

The likelihood of these events to continue will remain the same throughout the Proposed Project life. Although avalanching and steep valley sidewall debris and rock slides are common in the McNab Creek watershed, they are not expected to directly affect the LSA. Activities associated with the Proposed Project Area are not anticipated to increase the potential for initiating mass wasting (i.e., landslide) events.

In the past (greater than ~ 200 years based on forest stands), landslide-related material has been deposited in McNab Creek, with an influx of sediment being deposited into the channel and transported downstream towards the LSA. These types of events could lead to shifting avulsion patterns further downstream; which in turn can potentially lead to active erosion of unstable side banks and initiation of debris slides along the channel banks.

Landslides and snow avalanches can transport debris and sediment to creeks, increase water volumes, increase fine sediment transport, and in some cases debris jams can cause outburst floods (as seen with debris flood events). Evidence for significant debris flows and debris floods (including outburst floods) was not identified in this desktop assessment. This is based on the current topography, results from the terrain mapping assessment, and reviews of previous Golder studies. There is a possibility that such events may have originated upstream of the LSA; however, there does not appear to be any evidence of recent (i.e., <100 years ago based on assumed intact tree ages) scour or debris jams to indicate periodic debris flood events. Further investigation and assessment will be required to evaluate the debris flood/debris flow potential and determine if engineering designs are required to mitigate potential risks.

There is no evidence for debris flood/debris flows that could potentially impact the Project area. Therefore no further investigations or assessments for debris floods / flows are required and engineering designs are expected to mitigate the potential risks.

5.4.4.6 Results - Geotechnical Hazards

In June 2010, a drilling program was undertaken, with samples collected for laboratory analyses (Volume 4, Part G – Section 22.0: Appendix 5.4-E, Appendix 5.4-F and Appendix 5.4-G). Drilling results indicated at least 50 m depth of sediments within the onshore portion of the Proposed Project. Overall, the drilling exploration encountered sand and sand and gravel units throughout much of the proposed aggregate extraction area, with sand:gravel ratios in the order of 1:1, and minimal silt/fines content. In general, the surficial geologic data indicates that the upper portion of the deposit can be generally characterized as very coarse granular material, with boulders to 1.5 m diameter or more. Zones of high silt content were encountered within the upper 10 m of the deposit in some drill holes. The texture and composition of the fan-delta deposits vary as a result of the prevailing sedimentological and hydraulic conditions at the time of deposition.

A series of geophysical seismic refraction lines, drill holes and test pits, combined with visual mapping indicates that the slopes of the valley are underlain by these granular materials, with the depth of materials ranging up to several meters in thickness, in some locations.

Preliminary assessment of the drill hole and geophysical data indicates that portions of the thick glaciofluvial, alluvial and fan-delta deposits are potentially subject to liquefaction induced loss of strength, settlements and lateral spreading when subject to large earthquake events, such as the BC Building Code 1:2,475 year design event. During large earthquake events, slumping and instability of the steeper fan-delta front slopes and other moderate to steep natural or constructed slopes within or adjacent to the Proposed Project may occur. However, under static conditions, moderate to steep natural and man-made excavation slopes (Appendix 5.4-B) are expected to be stable. On and off site components and structures, including aggregate pit slopes and containment berms, and proposed processing infrastructure will be constructed and operated to engineered design standards. Based above noted subsurface conditions and engineered design requirements, components have been determined to not have a high failure consequence. To address the potential for pit wall stability, a detailed Geotechnical and Pit Slope Stability Monitoring Plan has been prepared (Volume 3, Part E - Section 16.0).

5.4.5 Effects Assessment

5.4.5.1 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 5.4-8.

Potential 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.

Table 5.4-8: Project-VC Interaction Geotechnical and Natural Hazard VCs

Project Activities	Description	Geotechnical and Natural Hazard VCs: Terrain Stability and Earthquakes/Tsunamis	
		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	○	▪ Transport of personnel and materials and supplies by water or air will have no interaction with geotechnical and natural hazards.
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	●	▪ Changing slope morphology along toe deposits of potentially unstable slopes could increase potential for unstable conditions. ▪ Proposed Project activities could increase the effect of ground movement related to earthquake events or induce slope instability along constructed slopes in the LSA. ▪ The Proposed Project activities could contribute to or increase shoreline erosion and offshore debris deposition if a landslide or earthquake generated tsunami occurred. ▪ The Proposed Project could cause or contribute to initiation of submarine landslides within the offshore area impacted by the Proposed Project. ▪ Modifications to existing site grades and slopes onshore will not likely impact land based slope stability conditions. ▪ Site clearing could change drainage conditions and increase surface soil erosion. ▪ Near bank site preparation and construction could directly impact side channel banks of McNab Creek, or indirectly impact the banks with drainage changes. This could potentially increase instability along the banks. ▪ Proposed roads are restricted to the level valley bottom and do not encroach on steep or potentially unstable slopes or mass wasting run out zones. ▪ Land based infrastructure is not located on, adjacent to, or downslope of unstable terrain (landslides, gullies, avalanche tracks).

Project Activities	Description	Geotechnical and Natural Hazard VCs: Terrain Stability and Earthquakes/Tsunamis	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
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	●	▪ Potential increase of surface erosion. ▪ Proposed roads are restricted to the level valley bottom and do not encroach on steep or potentially unstable slopes or mass wasting run out zones. ▪ Land based infrastructure is not located on, adjacent to, or downslope of unstable terrain (landslides, gullies, avalanche tracks).
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	●	▪ No or negligible interaction with geotechnical and natural hazards will occur as part of such measures. ▪ Potential increase of surface erosion. ▪ Proposed roads are restricted to the level valley bottom and do not encroach on steep or potentially unstable slopes or mass wasting run out zones. ▪ Land based infrastructure is not located on, adjacent to, or downslope of unstable terrain (landslides, gullies, avalanche tracks).
5. Marine loading facility installation	▪ Remove existing mooring dolphins ▪ Steel pile installation ▪ Installation of conveyor, barge movement winch and mooring dolphins	●	▪ The Proposed Project could increase earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes within the LSA areas. ▪ The Proposed Project activities could contribute to or increase shoreline erosion and offshore debris deposition if a landslide or earthquake generated tsunami occurred. ▪ The Proposed Project could cause or contribute to initiation of submarine landslides within the offshore area impacted by the Proposed Project.

Project Activities	Description	Geotechnical and Natural Hazard VCs: Terrain Stability and Earthquakes/Tsunamis	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
6. Pit development	▪ Dry excavation to remove overburden/topsoil ▪ Installation of clamshell and floating conveyor	●	▪ The Proposed Project could increase earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes within the LSA areas. ▪ The Proposed Project could initiate land based mass movement processes in the LSA (e.g., debris slides, rock slides, rock falls, debris flows, debris floods, and snow avalanches).
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	●	▪ Site clearing could increase erosion resulting in increased earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes within the LSA areas. ▪ Site clearing could contribute to or increase shoreline erosion and offshore debris deposition if a landslide or earthquake generated tsunami occurred. ▪ Proposed roads are restricted to the level valley bottom and do not encroach on steep or potentially unstable slopes or mass wasting run out zones. ▪ Land based infrastructure is not located on, adjacent to, or downslope of unstable terrain (landslides, gullies, avalanche tracks).
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	●	▪ Pile driving and dredging could increase earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes within the LSA areas. ▪ Pile driving and dredging could contribute to or increase shoreline erosion and offshore debris deposition if a landslide or earthquake generated tsunami occurred. ▪ Pile driving and dredging could cause or contribute to initiation of submarine landslides within the offshore area impacted by the Proposed Project.

Project Activities	Description	Geotechnical and Natural Hazard VCs: Terrain Stability and Earthquakes/Tsunamis	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
Operations			
9. Crew transport	▪ Daily water taxi	○	▪ Transport of personnel and materials and supplies by water or air will have no interaction with geotechnical and terrain stability.
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	●	▪ Dredging, handling and processing of extracted material activities could increase earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes within the LSA areas. ▪ Dredging, handling and processing of extracted material activities could contribute to or increase shoreline erosion and offshore debris deposition if a landslide or earthquake generated tsunami occurred. ▪ Dredging, handling and processing of extracted material could cause or contribute to initiation of submarine landslides within the offshore area impacted by the Proposed Project.
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	●	▪ The Proposed Project could increase earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes within the LSA areas. ▪ The Proposed Project activities could contribute to or increase shoreline erosion and offshore debris deposition if a landslide or earthquake generated tsunami occurred.

Project Activities	Description	Geotechnical and Natural Hazard VCs: Terrain Stability and Earthquakes/Tsunamis	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
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	●	▪ Ongoing earthworks and berm and dyke construction could increase earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes within the LSA areas. ▪ Ongoing earthworks and berm and dyke construction could contribute to or increase shoreline erosion and offshore debris deposition if a landslide or earthquake generated tsunami occurred. ▪ Ongoing earthworks and berm and dyke construction could cause or contribute to initiation of submarine landslides within the offshore area impacted by the Proposed Project. ▪ Proposed roads (road deactivation) are restricted to the level valley bottom and do not encroach steep or potentially unstable slopes or mass wasting run out zones. ▪ Land based infrastructure is not located on, adjacent to, or downslope of unstable terrain (landslides, gullies, avalanche tracks).

Project Activities	Description	Geotechnical and Natural Hazard VCs: Terrain Stability and Earthquakes/Tsunamis	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
13. Stockpile storage	▪ Processed sand and gravel conveyed to stockpile area ▪ Storage of processed materials in stockpiles	●	▪ Stockpile construction and maintenance will adhere to MEMPR for slope stability and Factor of Safety criteria and are not expected to be unstable ▪ Ground loading, and surface soil erosion could increase earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes within the LSA areas. ▪ Ground loading, and surface soil erosion could contribute to or increase shoreline erosion and offshore debris deposition if a landslide or earthquake generated tsunami occurred. ▪ Ground loading and surface soil erosion could cause or contribute to initiation of submarine landslides within the offshore area impacted by the Proposed Project. ▪ Stockpiles will not be located on, adjacent to, or downslope of unstable terrain (landslides, gullies, avalanche tracks) and are not expected to initiate mass movement events.
14. Marine loading	▪ Transfer of stored material using marine conveyor system ▪ Barge loading ▪ Site and navigational lighting	○	▪ Marine loading is not expected to have an interaction with geotechnical and terrain stability hazards.
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	○	▪ Transport of materials and supplies by water will have no interaction with geotechnical and terrain stability hazards.
16. Refueling and maintenance	▪ Refueling and maintenance of on-site equipment	○	▪ Refueling and maintenance will have no interaction with geotechnical and terrain stability hazards.

Project Activities	Description	Geotechnical and Natural Hazard VCs: Terrain Stability and Earthquakes/Tsunamis	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
Reclamation and Closure			
17. Crew and equipment transport	▪ Daily water taxi movements ▪ Tug and barge transport of machinery/materials ▪ Barge household and industrial solid waste barged off-site	○	▪ Transport of personnel and materials and supplies by water will have no interaction with geotechnical and terrain stability hazards.
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	●	▪ Removal of surface facilities could increase earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes within the LSA areas.
19. Removal of marine infrastructure	▪ Remove marine facilities, in marine load out facility, jetty, conveyors and piles	●	▪ Removal of marine infrastructure could increase earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes within the LSA areas. ▪ Removal of marine infrastructure could contribute to or increase shoreline erosion and offshore debris deposition if a landslide or earthquake generated tsunami occurred. ▪ Removal of marine infrastructure could cause or contribute to initiation of submarine landslides within the offshore area impacted by the Proposed Project.

Project Activities	Description	Geotechnical and Natural Hazard VCs: Terrain Stability and Earthquakes/Tsunamis	
		Potential Interaction (See Notes)	Potential Effect / Rationale for Exclusion
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	●	▪ Site reclamation could increase earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes within the LSA areas. ▪ Site reclamation could contribute to or increase shoreline erosion and offshore debris deposition if a landslide or earthquake generated tsunami occurred. ▪ Site reclamation could cause or contribute to initiation of submarine landslides within the offshore area impacted by the Proposed Project. ▪ Proposed roads are restricted to the level valley bottom and do not encroach on steep or potentially unstable slopes or mass wasting run out zones. ▪ Land based infrastructure is not located on, adjacent to, or downslope of unstable terrain (landslides, gullies, avalanche tracks).

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

5.4.5.2 Potential Project-Related Effects

Proposed Project development impacts to the following geotechnical hazards were addressed:

- The Proposed Project could increase earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes within the LSA areas;
- The Proposed Project activities could contribute to or increase shoreline erosion and offshore debris deposition if a landslide or earthquake generated tsunami occurred; and
- The Proposed Project could cause or contribute to initiation of submarine landslides within the offshore area impacted by the Proposed Project.

Proposed Project development impacts to the following natural hazards (terrain stability) were addressed:

- The Proposed Project could initiate land based mass movement processes in the LSA (e.g., debris slides, rock slides, rock falls, debris flows, debris floods, and snow avalanches); and
- The Proposed Project could initiate land based mass movement processes in the RSA that could impact the LSA.

Potential effects of the Proposed Project on climate change are assessed in Volume 2, Part B - Section 5.8 and will not be discussed further in this section. Potential effects of the environment from earthquakes, tsunamis, geotechnical and natural hazards and climate change (sea-level rise and increased precipitation events) on the Proposed Project is discussed in Volume 3, Part D – Section 15.0: Federal Information Requirement and will not be discussed further in this section.

5.4.5.2.1 Construction

5.4.5.2.1.1 Increased Ground Movement

Proposed Project activities are not expected to initiate or increase the frequency of earthquake events during any phase of the Propose Project however, in the event of an earthquake, ground movement could increase as a result of Proposed Project activities. Construction activities that could increase the effects of earthquake related ground movement (liquefaction, settlement, lateral ground movements, surface rupture) or induce slope instability along constructed slopes related to the Proposed Project are: pit excavation, fill placement, infrastructure construction and upgrades, site clearing (exploring shallow sediments), addition of material (ex. waste material) to ground surface (surcharging), and pile driving.

Steepening and/or increasing the height of excavation and fill slopes or increase in loading from construction activities and fill placement could affect the stability of these slopes and adjacent terrain and facilities, as well as increased settlements and potential for lateral movements during earthquake events.

The results of previous geotechnical investigations at other sites underlain by comparable subsurface conditions have identified the potential for liquefaction of the less dense, upper portions of the unconsolidated fluvial and fan-delta deposits both onshore and offshore within the Proposed Project Area and LSA. Liquefaction of these deposits may introduce excessive settlements, ground movements and slope instability. However, as illustrated in Figure 5.4-11 and Figure 5.4-12, due to the offset distance (500 m or more) and generally flat to gently sloping ground and shoreline seabed surface between the steep fan/delta slopes and onshore processing plant and other facilities, as well as the aggregate pit excavation zone, excessive lateral ground movements and slope instability affecting the onshore site and facilities is not expected. Also, as identified by previous studies, there is no evidence of existing fault and ground rupture within the generally strong metamorphic and granitic bedrock.

5.4.5.2.1.2 Increased Shoreline Erosion and Offshore Debris Deposition during Earthquake or Landslide Generated Tsunami

Construction activities that could increase shoreline erosion and debris deposition during an earthquake or landslide generated tsunami event include near shore excavation, fill placement, infrastructure upgrades, site clearing, pile driving, road construction and activities that could redirect drainage to foreshore area.

The disturbances noted above will affect/impact the erosion/deposition by removal or modification of the existing vegetation and tree cover in those shoreline and stream or drainage channel areas subject to tsunami events and by instability of excavation or fill slopes during an earthquake event. These events could affect the Proposed Project Area directly or alter adjacent water courses, resulting in damage to public/private infrastructure or natural resources (i.e., aquatic habitats, sensitive ecosystems, forestry-based lands).

5.4.5.2.1.3 Initiation of Submarine Landslides

Proposed Project activities could initiate submarine landslides. Construction activities that could initiate submarine landslides include pile driving, dredging or fill placement for marine infrastructure and other offshore facilities.

The construction activities noted above will affect/impact initiation of submarine landslides primarily by the design and construction of structures, including pile driving at the offshore berth and other facilities located on or close to the steep fan-delta front slope. These events could affect the Proposed Project Area directly, resulting in damage to public/private infrastructure or natural resources (i.e., aquatic habitats, sensitive ecosystems, forestry-based lands).

5.4.5.2.1.4 Land Based Mass Movement (Terrain Stability)

Effects associated with terrain stability related to Proposed Project physical works and activities are typically connected to changes to slope morphology (e.g., through excavation, material addition or slope re-contouring) and changes in drainage characteristics (e.g., redirecting water onto potentially unstable terrain). These types of changes can lead to the initiation of mass movement events (e.g., local slope failures, rockslides, debris flows) depending on interaction of the activities with potentially unstable or unstable slopes.

Terrain stability effects consist of changes to slope morphology and drainage patterns could lead to increases in mass movement events. These events could affect the Proposed Project Area directly or alter adjacent water courses, resulting in damage to public/private infrastructure or natural resources (i.e., aquatic habitats, sensitive ecosystems, forestry-based lands).

Changes to steep slopes, changes to the base of steep slopes, or alteration of existing transport and deposition zones of landslides or snow avalanches could lead to initiation of mass movement events. Excavation, material addition or slope re-contouring could potentially destabilize slopes and initiate rapid or slow mass wasting events that such as debris slides, debris flows, rockslides, and slumps. Typically, construction of access roads along steep or potentially unstable terrain could induce road-failures that could impact downslope environments. As such, proposed roads are restricted to the level valley bottom and do not encroach on steep or potentially unstable slopes or mass wasting run out zones Therefore potential effects from road construction on terrain stability are considered negligible and are not carried forward in the assessment.

Changes in drainage characteristics connected to unstable or potentially unstable terrain could initiate mass movement events. Activities related to earthworks in the LSA could redirect drainage patterns or increase volume of flow onto potentially unstable side banks of McNab Creek, initiating side bank debris slides and slumps. Effects related to watercourse bank stability caused by direct activity or changes in drainage in the LSA are carried forward in construction discussions below. Changes in drainage characteristics along access roads in steep terrain or at the base of steep slopes could initiate road related failures such as cutslope or fillslopes debris slides.

Although not expected, naturally occurring mass wasting events initiating in the RSA such as landslides or snow avalanches could reach watercourses and the main channel of McNab Creek. This in turn could lead to debris flows or debris floods reaching the LSA creating debris material transport or deposition zones. Proposed Project earth works activities altering potential debris flow-debris flood transport or deposition zones could resulting in unstable site conditions such as active debris levee erosion and alteration of drainage patterns directing water to potentially unstable slopes along McNab Creek. However, neither recent nor historic debris flow/debris flood transport and deposition zones were observed in the LSA.

The LSA is located on level to undulating valley bottom, outside of areas identified as being unstable or potentially; and is not located in landslides or snow avalanche run out zones therefore, Proposed Project facilities, structures, and roads are not directly connected with unstable or potentially unstable terrain within or upslope of the LSA. As Proposed Project Activities associated with potential effects on terrain stability are located solely within the LSA it is unlikely the Proposed Project will change slope morphology or drainage characteristics, or initiate mass movement events.

5.4.5.2.2 Operations

5.4.5.2.2.1 Increased Ground Movement

Operation activities that could increase earthquake related ground movements and adversely affect/impact constructed slope instability include ground disturbance activities resulting from processing and handling of the aggregate materials, modifications or additions to the Proposed Project Area and the aggregate plant, and storage and marine facilities.

The operational activities noted above could affect/impact constructed slope instability, settlement, and lateral ground movements. Ongoing maintenance including steepening and/or increasing the height of excavation and fill slopes, or increasing loading and fill placement could change ground conditions. These events could affect the Proposed Project Area directly or alter adjacent water courses, resulting in damage to public/private infrastructure or natural resources (i.e., aquatic habitats, sensitive ecosystems, forestry-based lands).

5.4.5.2.2.2 Increased Shoreline Erosion and Offshore Debris Deposition during Earthquake or Landslide Generated Tsunami

The operational activities could remove or modify existing vegetation and tree cover along the shoreline, and along watercourse or drainage channel areas. This could affect stability to shorelines causing increases in erosion and deposition.

Operational activities that could increase shoreline erosion and debris deposition include processing and handling of the aggregate materials, modifications or additions to the Proposed Project Area and the aggregate plant, storage, and marine facilities. Instability along excavated slopes and fill slopes could also lead to erosion and debris deposition.

During an earthquake or landslide generated tsunami event, additional sediment loads from activities inducing erosion and deposition could increase the expected effects of a tsunami.

These events could affect the Proposed Project Area directly or alter adjacent water courses, resulting in damage to public/private infrastructure or natural resources (i.e., aquatic habitats, sensitive ecosystems, forestry-based lands).

5.4.5.2.2.3 Initiation of Submarine Landslides

Operational activities that could initiate submarine landslides include processing and handling of the aggregate materials, modifications or additions to the Proposed Project Area and the aggregate plant, and storage and marine facilities other offshore facilities.

The operational activities noted above will affect/impact initiation of submarine landslides primarily by the design and construction of structures, including pile driving at the offshore berth and other facilities located on or close to the steep fan-delta front slope.

These events could affect the Proposed Project Area directly, resulting in damage to public/private infrastructure or natural resources (i.e., aquatic habitats, sensitive ecosystems, forestry-based lands).

5.4.5.2.2.4 Land-based Mass Movement (Terrain Stability)

During the operational phase, Proposed Project related interactions that may directly or indirectly change the context or integrity of ground conditions are likely to be limited to ground disturbance activities, resulting from modifications or additions to the Proposed Project Area and the aggregate facilities.

No unstable or potentially unstable terrain was identified in the LSA. Therefore it is unlikely that operational earthworks could destabilize slopes and initiate rapid or slow mass wasting events. Changes in drainage characteristics to the site, and adjacent activity along potentially unstable McNab Creek side bank areas could initiate mass movement events. Activities related to earthworks in the LSA could redirect drainage patterns or increase volume of flow onto potentially unstable side banks of McNab Creek, initiating side bank debris slides and slumps.

In general, unmaintained roads and inappropriate water control related to inadequate culvert and ditch maintenance along steep or potentially unstable terrain can lead to road-failures such as fillslope or cutslope debris slides and debris flows. Roads are not located in or adjacent to steep slopes or potentially unstable or unstable terrain.

There is a potential debris flow-debris flood event to result in creation of new transport or deposition zones in the LSA. Operation activities could alter site conditions that may lead to debris levee erosion and alteration of drainage patterns directing water to potentially unstable slopes along McNab Creek.

5.4.5.2.3 Reclamation and Closure

5.4.5.2.3.1 Increased Ground Movements

Reclamation and closure activities that could increase earthquake related ground movement or adversely affect constructed slope instability include excavation, fill and stockpile placement, demolition and removal of infrastructure upgrades.

The disturbances noted above will affect/impact slope instability, settlement, and lateral ground movements by steepening and/or increasing the height of excavation areas fill slopes or stock piles, or increase loading from fill placement during reclamation activities.

These events could affect the Proposed Project Area directly or alter adjacent water courses, resulting in damage to public/private infrastructure or natural resources (i.e., aquatic habitats, sensitive ecosystems, forestry-based lands).

5.4.5.2.3.2 Increased Shoreline Erosion and Offshore Debris Deposition during Earthquake or Landslide Generated Tsunami

Reclamation and closure activities that could increase shoreline erosion and debris deposition include demolition or removal of marine infrastructure and other shoreline facilities.

The reclamation and closure activities noted above will affect/impact the erosion/deposition by removal or modification of the existing vegetation and tree cover in those shoreline and stream or drainage channel areas subject to tsunami events and by instability of excavation or fill slopes during an earthquake event.

These events could affect the Proposed Project Area directly or alter adjacent water courses, resulting in damage to public/private infrastructure or natural resources (i.e., aquatic habitats, sensitive ecosystems, forestry-based lands).

5.4.5.2.3.3 Initiation of Submarine Landslides

Reclamation and closure activities that could initiate submarine landslides include demolition or removal of marine infrastructure and other shoreline facilities, dredging or fill placement within the offshore fan-delta area.

The reclamation and closure activities noted above will affect/impact initiation of submarine landslides primarily by reclamation activities, including pile removal, dredging or fill placement at the offshore berth and other facilities located on or close to the steep fan-delta front slope.

These events could affect the Proposed Project Area directly, resulting in damage to public/private infrastructure or natural resources (i.e., aquatic habitats, sensitive ecosystems, forestry-based lands).

5.4.5.2.3.4 Land-based Mass Movement (Terrain Stability)

The reclamation and closure phase is unlikely to affect terrain stability conditions in the LSA. Structures, facilities and roads are not located in or directly connected to potentially unstable or unstable terrain within or upslope of the LSA.

Decommissioning roads and restoring site facility areas are limited to gently sloped and undulating terrain with no evidence of active or historic landslide or snow avalanche deposition zones. The LSA, including access roads, is not located at the base of steep slopes where re-contouring could potentially initiate a mass movement event.

However, during soil stockpiling, and active reclamation earth works, site drainage patterns may get altered and redirect and possibly increase flow to potentially unstable side bank slopes along McNab Creek. This could potentially lead to initiation of side bank debris slides, flows, or slumps.

5.4.5.3 Mitigation

This section provides a description of the proposed mitigation measures specifically related to Proposed Project effects on VCs for Geotechnical and Natural Hazards (Terrain Stability). The suite of measures proposed to mitigate potential geotechnical and natural hazards effects is presented in Table 5.4-9.

5.4.5.3.1 Construction

Task specific detailed geotechnical investigations such as subsurface drilling and geophysics imaging would be developed. These investigations would guide preventive measures to reduce and monitor potential alterations of the subsurface environment or constructed slopes that could increase the effects noted in Section 5.4.5.

This would include appropriate onsite assessments to identify: areas with potential slope instability along constructed slopes and in pit excavation area; current ground conditions to address subsurface changes related to infrastructure construction; increased erosion/deposition related to site clearing (exploring shallow sediments); loading the ground surface (e.g., waste material, leading to surcharging); pile driving in the marine environment; and addressing facility and site earth works connectivity to watercourses. Investigations would include approved engineered designs where applicable.

Design level earthquakes in the LSA (and RSA) are expected to occur with 2,475 to more than 5,000 year return periods. Onsite assessments and engineering plans will be designed to meet the standards applicable to this return period.

Other than watercourse side bank erosion and instability, and the potential for Proposed Project activities to impact potential debris flow / debris flood deposits along McNab Creek, there are no mass wasting hazards in the LSA. An appropriate debris flow/ flood hazard effect assessments including a hydrotechnical investigation to determine peak discharge and sediment concentration estimates would address if there is a potential for debris flows / floods to occur along McNab Creek. If there is a potential for a debris flow / flood to occur, further detailed assessments specific to construction plans would be implemented.

Geotechnical and terrain stability investigations, plans, and engineering designs would be prepared in accordance with:

- The former *Canadian Environmental Assessment Act* (CEAA 1992);
- British *Columbia Environmental Assessment Act* (BCEAA 2002);
- The *Dam Safety Regulations* (B.C. Reg. 40/2016);
- The Association of Professional Engineers and Geoscientists of BC (APEGBC) *Engineers and Geoscientists Act*;
- the National and British Columbia Building Codes (BCBC) were followed, since the BCBC Code directive now requires slope stability assessments to be addressed for the 1:2,475 year earthquake;
- Aggregate Operators Best Management Practices Handbook for BC (Ministry of Energy and Mines 2002); and
- Other relevant Best Management Practices (BMPs) noted in Section 5.4.3.3.1.1 Summary of Existing Information sources (BC terrain and terrain stability classification methods and mapping standards).

These plans would be prepared, implemented, reviewed, and monitored by qualified registered engineers and geoscientists. Compliance with the objectives of the plans will be performance based.

5.4.5.3.2 Operations

Effects include increases to soil erosion and depositions, initiating debris slides and slumps along watercourse side banks, and potential detrimental changes to ground conditions from structures and facilities (aggregate plant, and storage and marine facilities. and ongoing processing and handling from the aggregate materials).

Operational activities could remove or modify existing vegetation and tree cover along the shoreline, and along watercourse or drainage channel areas. This could affect stability of shorelines due to increases in erosion and sediment deposition that could affect/impact initiation of submarine landslides. Other operational activities that could impact the stability of shorelines are primarily related to the design and construction of structures, including pile driving at the offshore berth and other facilities located on or close to the steep fan-delta front slope.

Changes in drainage characteristics to the site, and adjacent activity along potentially unstable McNab Creek side bank areas could initiate localized, small mass movement events. Activities related to ongoing earthworks in the LSA could redirect drainage patterns or increase volume of flow onto potentially unstable side banks of McNab Creek, initiating side bank debris slides and slumps. Operational activities could alter site conditions that may lead to existing debris flow levee erosion and alteration of drainage patterns directing water to potentially unstable slopes along McNab Creek.

Ongoing monitoring of ground conditions and soil erosion mitigation measures would be carried out throughout operations and the analysis would be periodically refined. Mitigation measures associated with soil erosion and deposition, structural support of facilities and support structures, and ongoing earth works are consistent with those described above for construction in Section 5.4.5.3.1 above. Ongoing geotechnical and terrain stability assessments may be required to address changing conditions, with possible updated engineering designs, as conducted by qualified registered engineers and geoscientists.

The extent or development of the proposed pit would be modified if the refined analysis indicates that it is necessary to do so in order to prevent negative impacts related to constructed slopes and potential soil erosion.

5.4.5.3.3 Reclamation and Closure

Reclamation and closure activities and design will include provisions to address and control the potential for local aggregate pit slope, watercourse side banks, and shoreline and marine instability events consistent with that of other comparable sites.

In addition to those measures described above for construction, progressive reclamation activities such as re-vegetation of disturbed areas will be carried out throughout operations to minimize or prevent potential soil erosion effects.

Mitigative measures such as maintenance or enhancement of natural shoreline vegetation, erosion control measures and other potential engineered solutions that may be put in place to prevent or resist marine and shoreline erosion, sediment transport and deposition, will be designed by qualified and experienced professionals, based on detailed, site-specific geotechnical investigations

Monitoring would be carried out throughout reclamation activities to provide additional data that will be used to refine the Soil Management Plan (Volume 3, Part E - Section 16.0) within the Reclamation and Effective Closure Plan (Volume 4, Part G - Section 22.0: Appendix 4), and other engineered designs (e.g., overflow structure designs that require limited maintenance and monitoring).

Table 5.4-9: Identified Mitigation Measures: Geotechnical and Terrain Stability Hazards

Potential Effect	Mitigation	Anticipated effectiveness
Construction		
Increased ground movement during earthquake event.	▪ Conduct detailed geotechnical subsurface investigations (drilling and geophysical programs) where required; ▪ Prepare approved engineered design and plans to achieve Proposed Project engineering design and performance requirements and for mitigation, as required by provincial and federal accepted standards	Earthworks and land and marine based facilities and structures will be planned, designed and monitored by professional engineers and geoscientist following accepted standards and guidelines. The geotechnical plans and recommendations will reduce potential residual effects to acceptable levels.

Potential Effect	Mitigation	Anticipated effectiveness
Increased shoreline erosion and offshore debris deposition during earthquake or landslide generated tsunami.	▪ Conduct detailed geotechnical subsurface investigations (drilling and geophysical programs) where required; ▪ Prepare approved engineered design and plans to achieve Proposed Project engineering design and performance requirements and for mitigation, as required by provincial and federal accepted standards	Earthworks and land and marine based facilities and structures will be planned, designed and monitored by professional engineers and geoscientist following accepted standards and guidelines. The geotechnical plans and recommendations will reduce potential residual effects to acceptable levels.
Initiation of submarine landslides	▪ Conduct detailed geotechnical subsurface investigations (drilling and geophysical programs) where required; ▪ Prepare approved engineered design and plans to achieve Proposed Project engineering design and performance requirements and for mitigation, as required by provincial and federal accepted standards	Earthworks and land and marine based facilities and structures will be planned, designed and monitored by professional engineers and geoscientist following accepted standards and guidelines. The geotechnical plans and recommendations will reduce potential residual effects to acceptable levels.
Land-based Mass Movement - Terrain Stability: changes to slope morphology or drainage conditions.	▪ Conduct appropriate detailed investigations of terrain stability and geotechnical conditions; ▪ Prepare approved engineered design and plans to achieve Proposed Project performance requirements and for mitigation, as required; and ▪ Conduct appropriate onsite assessments to identify connectivity of site earth works to watercourses.	Mitigation measures will reduce potential residual effects to acceptable levels.
Land-based Mass Movement - Terrain Stability: changes to debris flow-debris flood transport or run out zones.	▪ Conduct onsite assessment of terrain stability conditions along watercourse banks and connectivity to planned site activities; ▪ Conduct appropriate debris flow/ flood hazard and effect assessments including hydrotechnical assessments that would include peak discharge and sediment concentration estimates; and ▪ Prepare engineered designs and plans by qualified and experienced professionals for mitigation (e.g., diversion and catchment structures), as required.	On site terrain stability assessments conducted by professional engineers and geoscientist following accepted standards and guidelines will reduce potential residual effects to acceptable levels.

Potential Effect	Mitigation	Anticipated effectiveness
Operations		
Increased ground movement during earthquake event.	▪ Conduct operations in conformance with detailed geotechnical designs; and ▪ Monitor performance during operations and update or modify designs if required to achieve Proposed Project performance requirements and for mitigation, as required.	Prescribed monitoring and design updates if required will reduce potential residual effects to acceptable levels.
Increased shoreline erosion and offshore debris deposition during earthquake or landslide generated tsunami.	▪ Conduct operations in conformance with detailed geotechnical designs; and ▪ Monitor performance during operations and update or modify designs if required to achieve Proposed Project performance requirements and for mitigation, as required.	Prescribed monitoring and design updates if required will reduce potential residual effects to acceptable levels.
Initiation of Submarine Landslides	▪ Conduct operations in conformance with detailed geotechnical designs, monitor performance during operations and update or modify designs if required to achieve Proposed Project performance requirements and for mitigation, as required.	Prescribed monitoring and design updates if required will reduce potential residual effects to acceptable levels.
Land-based Mass Movement - Terrain Stability: changes to slope morphology or drainage conditions.	▪ Conduct appropriate monitoring and ongoing investigations of terrain stability and geotechnical conditions to achieve Proposed Project performance requirements and for mitigation, as required.	Prescribed monitoring and design updates if required will reduce potential residual effects to acceptable levels.
Land-based Mass Movement - Terrain Stability: changes to debris flow-debris flood transport or run out zones.	▪ Conduct recommended monitoring and ongoing debris flow/ flood hazard assessments of watercourse side banks and drainage of changing site conditions were warranted.	As prescribed monitoring of watercourse side bank stability and debris flow / flood hazards will reduce potential residual effects to acceptable levels.
Reclamation and Closure		
Increased Ground Movement during earthquake event	▪ Conduct reclamation and closure in conformance based on detailed geotechnical designs, monitor performance during reclamation and update or modify designs if required to achieve Proposed Project performance requirements and for mitigation, as required.	Detailed Geotechnical and Pit Slope Stability Monitoring Plan (Volume 3, Part E - Section 16.0) will reduce potential residual effects to acceptable levels

Potential Effect	Mitigation	Anticipated effectiveness
Increased Shoreline Erosion and Offshore Debris Deposition during Earthquake or Landslide Generated Tsunami	▪ Conduct reclamation and closure in conformance based on detailed geotechnical designs, monitor performance during reclamation and update or modify designs if required to achieve Proposed Project performance requirements and for mitigation, as required	Detailed Geotechnical and Pit Slope Stability Monitoring Plan (Volume 3, Part E - Section 16.0) will reduce potential residual effects to acceptable levels
Initiation of Submarine Landslides	▪ Conduct reclamation and closure in conformance based on detailed geotechnical designs, monitor performance during reclamation and update or modify designs if required to achieve Proposed Project performance requirements and for mitigation, as required	Detailed Geotechnical and Pit Slope Stability Monitoring Plan (Volume 3, Part E - Section 16.0) will reduce potential residual effects to acceptable levels
Land-based Mass Movement - Terrain Stability: changes to slope morphology or drainage conditions and changes to debris flow-debris flood transport or run out zones	▪ Based on stockpile location and earth works affecting or indirectly connected to side banks of watercourses, conduct site assessment of terrain stability conditions and soil erosion plans. ▪ Includes conducting appropriate onsite assessments to identify connectivity of site earth works to watercourses. For potential debris flow / flood catchment structures, conduct appropriate decommissioning or ongoing monitoring of structures where warranted. ▪ As required, prepare engineered designs and plans by qualified and experienced professionals for removal or ongoing mitigation of site.	Detailed Geotechnical and Pit Slope Stability Monitoring Plan (Volume 3, Part E - Section 16.0) will reduce potential residual effects to acceptable levels

5.4.5.4 Residual Effects Assessment

Potential Project-related effects on geotechnical hazards and terrain stability following the application of appropriate mitigation measures are described in Section 5.4.5.3 and presented below in Table 5.4-10 and Table 5.4-11. Residual effects have been characterized using the criteria defined in Table 5.4-3.

Geotechnical hazard residual effects include Proposed Project related increased ground movement during an earthquake event, impacts to shoreline erosion, and initiation of submarine landslides. Terrain stability residual effects include Proposed Project induced initiation of land-based mass movement events such as landslides, snow avalanches, and debris flows and floods.

Following applicable and accepted provincial and federal engineering guidelines, and professionally accepted Best Management Practices (BMPs), prescribed mitigation measures will reduce potential residual effects to acceptable levels.

Magnitude and frequency were deemed to be the main criteria for assessing residual effects, and are presented first. This is followed by a general evaluation of the other assessment criteria, where applicable, that form the basis for determining significance of effect. The likelihood of occurrence is then discussed for each residual effect.

5.4.5.4.1 Construction

Site preparation, facility and structure installations, and pit development could change slope morphology and subsurface ground conditions, resulting in the residual effects discussed below.

5.4.5.4.1.1 Increased Ground Movement

General construction activities and facility construction could increase ground movement during an earthquake event by altering subsurface conditions. Altering subsurface conditions could potentially lead to rapid loss of soil strength resulting in amplified liquefaction, ground settlement or lateral shifts. Potentially detrimental changes to subsurface and stability conditions can be minimized or mitigated by appropriate design and construction measures as well as operations and Emergency Response Plans (Volume 3, Part E - Section 16.0).

Mitigation measures would be implemented during site preparation and construction of the Proposed Project to minimize potential residual effects. Ground improvement or other stabilization and foundation support measures will be designed by qualified and experienced professionals based on detailed, site specific subsurface geotechnical and geophysical investigations. As required, engineering designs and plans will follow the National and BC Building Code and other applicable earthquake building requirements.

The Proposed Project may result in changes that could exceed Canadian or BC guidelines or Code requirements. Subsurface changes will be minimized through mitigation, using appropriate construction techniques to stabilize facilities and structures. Therefore the expected size and severity of increased ground movement during an earthquake event will be reduced and would be limited to site specific locations. The resulting magnitude has therefore been rated as low.

Frequency is based on how often the residual effect occurs and is therefore connected to when earthquake events are expected. The return period of expected design level earthquake events affecting the LSA and RSA are anticipated to have a low return period of 2,475 to more than 5,000 years. With mitigation measures, increased ground movement during an earthquake event has been deemed as low and expected to rarely occur.

The duration is the length of time increased ground movement effects during an earthquake event are expected to persist. Duration of these effects will be from start of construction to life of the Proposed Project, and therefore has a low to medium rating.

Context is an assessment of the current and future ground movement conditions and the sensitivity and resilience to having increased effects of the caused by the Proposed Project. By applying Building Code requirements for design and construction, the residual effects as geotechnical hazards will likely be resilient to imposed stresses, resulting in a low susceptibility to potential changes caused by the Proposed Project.

The geographic extent is local and restricted to the LSA.

Increased ground movements are partially reversible. This is based on the limited amount of increased ground movement that is expected after mitigation measures have been applied. During construction of facilities and structures, Canadian and BC guidelines and earthquake building Code requirements will minimize the effects of subsurface static loading changes. Therefore increases in liquefaction, surface rupture, or lateral movement can be managed and are not expected to result in permanent effects.

With appropriate mitigation measures addressing subsurface changes that could increase ground movement during earthquake event, the likelihood of potential residual effects occurring is low. Construction activities will be designed to appropriate engineering performance requirements.

5.4.5.4.1.2 Increased Shoreline Erosion and Offshore Debris Deposition during Earthquake or Landslide Generated Tsunami

General construction activities and construction of facilities/structures could alter subsurface conditions and impact the volume of erodible shoreline soils during an earthquake or landslide initiated tsunami related event. Potential soil displacement during construction could result in increased sedimentation of the marine environment; accelerating the effect of erosion and deposition during tsunami related events.

Soil erosion assessments and soil control methods, geotechnical and geophysical subsurface investigations and engineered designs will minimize the effects of erosion along the shoreline, and subsequent offshore debris deposition. The expected size and severity of increased shoreline erosion and offshore deposition will be minimal with mitigation, and limited to site specific locations. The magnitude is considered negligible as mitigation will reduce erosion potential and the amount of material available for transport and deposition offshore.

The duration is the length of time increased shoreline erosion and offshore deposition during an earthquake will persist. Duration of these effects will be from start of construction to life of the Proposed Project, and therefore has a low to medium rating.

The frequency of increased erosion / deposition has been rated low and is expected to rarely occur. Mitigation is expected to primarily manage for soil erosion / off shore deposition and landslide or earthquake induced tsunamis are not expected in the LSA and RSA (given the 1:2,475 to greater than 1:5,000 year design earthquake return period).

Context has been deemed low or resilient, as engineering plans are expected to reduce soil erosion and soil transport in the shoreline and off shore fan area. The geotechnical hazards of increased soil erosion and debris deposition impacting, amplifying, or initiating a tsunami event has a low susceptibility to potential changes caused by the Proposed Project. Although activities may take place in sensitive marine or land base ecosystems, the BC building code and engineering designs would result in planned facilities, structures, and earth works being resilient to imposed stresses.

The geographic extent is local and restricted to the LSA.

Reversibility of increasing erosion and deposition effects during a tsunami event in the LSA is rated as partially reversible. Under Canadian or BC guidelines or Code requirements, an increase in soil erosion and offshore deposition during a Tsunami event is not expected and not expected to result in permanent effects. Changes to subsurface and stability conditions can be minimized or mitigated by appropriate design and construction measures as well as operations and Emergency Response Plans (Volume 3, Part E - Section 16.0).

With appropriate mitigation measures, the likelihood of potential residual effects occurring is low. Construction will be designed to appropriate engineering performance requirements.

5.4.5.4.1.3 Initiation of Submarine Landslides

Mitigation includes design of facility and structures to be built to specified building code for design level earthquakes with 1:2,475 to more than 1:5,000 year return periods. During earthquake events, slumping and instability of the steep fan-delta front submarine slopes may occur. However, under static loading conditions, the submarine slopes are assumed to be stable (Volume 4, Part G – Section 22.0: Appendix 5.4-B). Geotechnical and geophysical subsurface investigations, engineered designs, and construction monitoring will be conducted where static loading conditions may be affected.

Although not expected, a submarine landslide initiated by the Proposed Project could result in changes in geotechnical hazards that will exceed Canadian or BC guidelines or Code requirements. A submarine landslide could potentially have severe effects on marine habitat and existing structures. Subsurface changes in the marine environment will be minimized through mitigation using appropriate construction techniques to stabilize facilities and structures. Therefore the expected size and severity of a potentially submarine landslide will be reduced and likely limited to site specific locations. Therefore, the magnitude associated with the potential changes and effects has been rated as medium.

Frequency is a measure of how often a submarine landslide would be initiated from Proposed Project construction activities with mitigation in place. Residual effects such as changes to static ground conditions are not expected if facilities and structures are built and monitored under federal and provincial guidelines and the required building Codes. Appropriate design and construction will minimize changes to the subsurface and submarine environment and therefore lowering the potential for submarine landslide initiation. The frequency has therefore been rated as low, as residual effects could occur intermittently throughout the life of the Proposed Project.

The duration is the length of time when Proposed Project activities could initiate a submarine landslide. Duration will be from start of construction to life of the Proposed Project, and therefore has a low to medium rating.

Context has been deemed low or resilient, as engineering designs under federal and provincial guidelines and building Codes are expected to reduce detrimental changes to the submarine static loading conditions resulting in resiliency to imposed stresses. The geotechnical hazards of initiating a submarine landslide have a low susceptibility to potential changes caused by the Proposed Project.

The geographic extent is local and restricted to the LSA.

Depending on the size of the submarine tsunami event, reversibility during this phase is medium assuming appropriate and operational and emergency response planning (Volume 3, Part E - Section 16.0) are undertaken.

Initiation of a submarine landslide is not expected, and with appropriate mitigation and Emergency Response Plan (Volume 3, Part E - Section 16.0), permanent effects are not anticipated. Reversibility of submarine landslide initiation after mitigation measures have been applied is rated as partially reversible. Potential detrimental changes to the submarine static conditions can be minimized or mitigated by appropriate design and construction measures under Canadian or BC guidelines or Code requirements as well as operations and Emergency Response Plan (Volume 3, Part E - Section 16.0). Material transported during an event could possibly be recovered with dredging operations or submarine restoration works, and damage to or loss of structures could be repaired or replaced.

With appropriate mitigation measures, the likelihood of potential residual effects occurring is low. Construction will be designed to appropriate engineering performance requirements.

5.4.5.4.1.4 Land-based Mass Movement - Terrain Stability

Construction activities such as excavation, material addition or slope re-contouring can change slope morphology at the base of steep slopes and changes in drainage characteristics (e.g., redirecting water onto potentially unstable side banks of McNab Creek) could initiation of mass movement events (e.g., local slope failures, side bank slumps and slides). Construction activities could also alter run out zones of existing or possibly imminent debris flows or floods along McNab Creek. Altering existing or future run out zones could result in an increase of erosion along existing debris deposits and levees, or could result in debris from an event being transported to areas within the LSA where they might not have originally travelled.

Mitigation includes on site earthworks and soil erosion assessments and monitoring plans to address site connectivity (minimize machine activity and manage drainage conditions) to unstable and potentially unstable watercourse side banks such as along McNab Creek. To manage earthworks and siting locations near McNab Creek, an on-site assessment for existing potential future debris flow / debris flood run out zones will be conducted and may include proposed engineered plans for diversion and catchment structures.

Due to the subdued topography and stable terrain mapped in the LSA, mass wasting initiation is not expected in the LSA. Other than possible small side bank slides and slumps along McNab Creek (comparable to naturally occurring failures observed), steep slopes with unstable or potentially unstable terrain were not identified within the LSA. The LSA is not located immediately downslope of potentially unstable terrain or unstable terrain or within landslide or snow avalanche run out zones. There did not appear to be major evidence of historic, recent, or impending debris flows or debris floods along McNab Creek. Detailed debris flow / flood studies will address this, and will provide mitigation plans for maintenance of existing debris deposits if required.

With mitigation measures noted above, the residual effect are limited to small side bank slides and slumps along McNab Creek and degradation of potential debris run out zone deposits. With mitigation efforts, the expected size of debris levee slope failures or McNab Creek side bank slides and slumps is expected to be relatively small, and similar to naturally occurring failures observed along the channel. Therefore the magnitude has been rated as negligible. With mitigation, construction activities for the Proposed Project will have no measurable effects on the unstable or potentially unstable terrain.

The duration of the residual effect is considered medium-term as earthworks and potential for soil erosion and drainage changes are likely to persist from the construction phases to life of the Proposed Project.

Frequency is based on how often land based mass movement events are expected to occur with applied mitigation. Landslide, snow avalanche, and debris flow / flood events in the LSA are not expected. However, watercourse side bank slides and slumps may occur intermittently comparable to naturally ongoing side bank failures. Therefore a medium frequency has been applied to this effect.

The extent is regional as construction activities could increase the potential for unstable conditions to arise by changing mass wasting depositional areas that are connected to the RSA.

Context is the current and future terrain stability conditions sensitivity and resilience to changes from Proposed Project activities. With mitigation, the residual effects are resilient as unstable watercourse side bank protection and debris flow / flood deposition areas will have a low susceptibility to potential earthwork and drainage changes.

Reversibility is medium as effects of initiation of watercourse side bank stability and potential debris flow /flood deposit erosion and sediment transport can be minimized and mitigated and monitored; slope restoration can be addressed if required. Therefore, permanent effects are not expected.

With appropriate mitigation measures, operational activities for the Proposed Project will have none to minimal measurable effects on the unstable or potentially unstable terrain.terrain stability conditions have low susceptibility to potential changes during the Proposed Project operations and therefore a low likelihood of occurrence.

5.4.5.4.2 Operations

During the operations phase, progressive reclamation and stockpile storage could impact surface and subsurface ground conditions, resulting in the residual effects discussed below.

5.4.5.4.2.1 Increased Ground Movement

Surface material handling and subsurface facility/structure modifications could change the ground conditions and foundation supports; and could induce erosion and sediment transport. Mitigation measures would consist of ground improvement or other stabilization and foundation support designed by qualified and experienced professionals based on detailed, site specific geotechnical investigations. These mitigation measures, implemented during site preparation and construction of the Proposed Project, with potential modifications or upgrades during operation, will limit the effect of increased ground movement to acceptable levels.

Operational activities may result in changes that could exceed Canadian or BC guidelines or Code requirements. Potential facility and structure upgrades or stabilization efforts may result in subsurface changes. These changes will be minimized through mitigation. Therefore the expected size and severity of increased ground movement during an earthquake event will be reduced and would be limited to site specific locations. The resulting magnitude has therefore been rated as low.

Operational activities that could increase ground motions such as liquefaction, settlement events and lateral ground movement during an earthquake. Building Code designs will be based on a long, 2,475 to more than 5,000 year, earthquake return period. With mitigation measures, operational activities leading to increased ground movement during an earthquake event has been deemed as low and expected to rarely occur.

The duration is the length of time where operational activities will lead to an increase in ground movement during an earthquake. Duration will be from start of construction, through the operational phase, to life of the Proposed Project, and therefore has a low to medium rating.

Context is the current and future sensitivity and resilience of the VC to change caused by Proposed Project operational activities. With mitigation, the residual effects are expected to be resilient as the geotechnical hazards of increased ground movement will likely be resistant to imposed stresses and have a low susceptibility to potential changes.

The geographic extent is local and restricted to the LSA.

Reversibility of the effect is partially reversible. Under Canadian or BC guidelines or Code requirements, operational activities are not expected to increase in ground movement during an earthquake event. Therefore increases in liquefaction, surface rupture, or lateral movement can be managed and are not expected to result in permanent effects.

With appropriate mitigation measures addressing subsurface changes that could increase ground movement during earthquake event, the likelihood of potential residual effects occurring is low. Operation activities will be designed to appropriate engineering performance requirements.

5.4.5.4.2.2 Increased Shoreline Erosion and Offshore Debris Deposition during Earthquake or Landslide Generated Tsunami

During the operations phase, ongoing maintenance or upgrades of facilities and structures could alter subsurface conditions and impact the volume of erodible shoreline soils during a tsunami related event. Potential soil displacement could result in increased sedimentation of the marine environment; accelerating the effect of erosion and deposition during tsunami related events.

An increase in offshore debris deposition has a negligible magnitude as landslide prone terrain was not observed along the foreshore/offshore slopes and naturally occurring or earthquake induced landslides generating a tsunami are not expected.

Residual effects for increased shoreline erosion and offshore debris deposition have a negligible magnitude. The Erosion and Sediment Control Plan (Volume 4, Part G – Section 22.0: Appendix 3) will be applied through ongoing earthwork operations, and potential upgrades to structures and facilities will be completed under required federal and provincial guidelines and building Codes. The expected size and severity of increased shoreline erosion and offshore deposition will be minimal with mitigation, and limited to site specific locations. Therefore, the magnitude is considered negligible as mitigation will reduce erosion potential and the amount of material available for transport and deposition offshore.

The frequency of increased erosion / deposition during operational activities has been rated low and is expected to rarely occur. Mitigation is expected to primarily manage for soil erosion / off shore deposition and landslide or earthquake induced tsunamis are not expected in the LSA and RSA (given the 2,475 to greater than 5,000 year design build earthquake return period).

Duration reflects length of time in the operational phase where increased shoreline erosion and offshore deposition during an earthquake will persist. Duration of these effects will be from start of construction, through the operation phase and to life of the Proposed Project; and therefore has a low to medium rating.

Context has been deemed low or resilient, as engineering plans are expected to reduce soil erosion and soil transport in the shoreline and off shore fan area during operational activities. The geotechnical hazards of increased soil erosion and debris deposition impacting, amplifying, or initiating a tsunami event has a low susceptibility to potential changes caused by the Proposed Project during the operational phase. Although activities may take place in sensitive marine or land base ecosystems, application of the BC building code and engineering designs during the construction phase would result in operations phase facilities, structures, and earth works being resilient to imposed stresses.

The geographic extent is local and restricted to the LSA.

Reversibility of increased erosion and deposition effects during a tsunami event in the LSA is rated as partially reversible. As soil erosion cannot be avoided, but it can be minimized during operational activities based on conformance with detailed geotechnical designs, approved monitoring of performance during operations, including updates or modification to designs as required to achieve Proposed Project performance requirements. This will in turn reduce the volume of sediment and debris reaching the submarine area; which could increase the detrimental effects of a tsunami. Changes to subsurface and soil erosion conditions during operations can be minimized or mitigated by appropriate design and construction measures as well as operations and Emergency Response Plan (Volume 3, Part E - Section 16.0).

With appropriate mitigation measures, the likelihood of potential residual effects occurring is low. Construction will be designed to appropriate engineering performance requirements and will be carried through the operational phase.

5.4.5.4.2.3 Initiation of Submarine Landslides

If mitigation measures are followed and appropriate monitoring is implemented; operational activities are not expected to disturb subsurface conditions and initiate a submarine landslide. Residual effects such as changes to static ground conditions are not expected if facilities and structures are built and monitored under federal and provincial guidelines and the required building Codes.

During the operational phase, it is assumed the structures in the marine environment will conform to stable static loading conditions (Volume 4, Part G – Section 22.0: Appendix 5.4-B) and will be constructed as per the Canadian or BC guidelines and Code requirements. Previous and additional, if required, geotechnical and geophysical subsurface investigations, engineered designs, and ongoing monitoring will be conducted where static loading conditions may be affected. During earthquake events, naturally occurring slumping and general instability of the steep fan-delta front submarine slopes may occur. This may require updates to structure integrity; with appropriate engineered designs, monitoring and updates where required, activities and structures in the marine environment are not expected to initiate a submarine slide.

Changes to submarine conditions may occur during the operational phase, it is unlikely that the as built marine structures and facilities would exceed design codes and regulations. However, if a submarine landslide was initiated, it could result in changes in geotechnical hazards that would exceed Canadian or BC guidelines or Code requirements. Also, a submarine landslide could potentially have severe effects on marine habitat and existing structures. The expected size and severity of a potentially submarine landslide will likely be limited to site specific locations. Therefore, the magnitude associated with the potential changes and effects has been rated as medium.

Frequency is a measure of how often a submarine landslide would be initiated from Proposed Project operational activities with mitigation in place. The frequency is Low based on the assumption that the above noted mitigation measures will protect the submarine environment. Residual effects could occur intermittently throughout the life of the Proposed Project.

Duration of the potential for submarine landslide initiation will be from start of construction, through the operational phase and to life of the Proposed Project. Therefore there is a low to medium Duration rating.

Context has been deemed low or resilient. Through the operations phase, structures in the marine environment or activities associated with the submarine area that could have the potential to initiation submarine landslides via changes to submarine static loading conditions will be maintained and monitored following federal and provincial guidelines and building Codes.

The effect is local as it is located in the foreshore, submarine area and therefore restricted to the LSA.

Reversibility of submarine landslide initiation after mitigation measures have been applied is rated as partially reversible. Material transported during and event could possibly be recovered with dredging operations or submarine restoration works, and damage to or loss of structures could be repaired or replaced. With appropriate building design and subsurface and structure and site conditions monitoring during operations, initiation of a submarine landslide is not expected and therefore not expected to result in permanent effects.

With appropriate mitigation measures, the likelihood of potential residual effects occurring is low. Structures would have been designed to appropriate engineering performance requirements and ongoing monitoring on site conditions will reduce the potential effects from occurring.

5.4.5.4.2.4 Land-based Mass Movement - Terrain Stability

Other than areas along and connected to McNab Creek, the LSA is locate along gentle terrain with no substantial evidence of snow avalanche or landslide run out zones. Altering runout or debris deposition zones can in some cases lead to increase instability along deposits or increases in soil erosion. Loading near unstable or potentially unstable side banks of watercourses, or altering site drainage to increase flow to these side banks can result in initiation of debris slides and slumps and increased side bank erosion. With onsite monitoring of earthworks and proper management of drainage, mitigation measures will reduce detrimental changes to side bank conditions.

Operation activities such as ongoing earth works and progressive stock pile storage could result in surficial materials being located near unstable slopes along McNab Creek or could detrimentally affect run out zones of debris flows or floods along McNab Creek. Ongoing site earthworks and facility and pit locations may alter drainage conditions. Surface water could be redirected towards McNab Creek and could impact unstable or potentially unstable side walls

With mitigation measures, surficial materials will not be located on, adjacent to, or downslope of unstable terrain and therefore, mass movement initiation (e.g., local slope failures, side bank slumps and slides) are not expected to be initiated by operational activities. With mitigation measures noted above, the residual effect are limited to small side bank slides and slumps along McNab Creek and degradation of potential debris run out zone deposits. With mitigation efforts, the expected size of debris levee slope failures or McNab Creek side bank slides and slumps is expected to be relatively small, and similar to naturally occurring failures observed along the channel. Therefore the magnitude has been rated as negligible. With mitigation, construction activities for the Proposed Project will have no measurable effects on the unstable or potentially unstable terrain.

Frequency is based on how often land based mass movement events are expected to occur with applied mitigation. Initiation of landslides, snow avalanche, and debris flow / flood events in the LSA are not expected.

Earthworks and changes to topography, slopes and drainage along McNab Creek side banks may result in intermittent, small slides or slumps along the creek side bank (similar to naturally occurring slides along banks). Therefore a medium rating frequency has been applied to this effect.

The duration of the residual effect is considered medium-term as earthworks and potential for soil erosion and drainage changes are likely to persist from the construction phase, through the operational phase and to life of the Proposed Project.

The extent is regional as operational activities such as earthworks and drainage alteration may impact debris flood or debris flow transport and deposition zones that are indirectly connected to the RSA

Context is a measure of the current and future terrain stability conditions sensitivity and resilience to change from operational activities. The residual effects of operational activities are resilient; drainage, near bank loading, and soil erosion control, protection of unstable side banks, and monitoring of potential changes to debris flow / flood deposition areas will have a low susceptibility to ongoing operations. Drainage and soil erosion measures, and potential changes to watercourse side bank integrity will be monitored and updated based on the Proposed Project Erosion and Sediment Control Plan that will be prepared during the construction phase. A draft of this plan is provided in Volume 4, Part G – Section 22.0: Appendix 3.

Reversibility is medium as effects of initiation of watercourse side bank stability and potential debris flow /flood deposit erosion and sediment transport can be minimized and mitigated and monitored; slope restoration can be addressed if required. Therefore, permanent effects are not expected.

With appropriate mitigation measures, operational activities for the Proposed Project will have none to minimal measurable effects on the unstable or potentially unstable terrain.terrain stability conditions have low susceptibility to potential changes during the Proposed Project operations and therefore a low likelihood of occurrence.

5.4.5.4.3 Reclamation and Closure

During the reclamation and closure phase, removal of land and marine-based infrastructure and site reclamation could impact surface and subsurface ground conditions, resulting in the residual effects discussed below.

5.4.5.4.3.1 Increased Ground Movement

Site reclamation and removal of infrastructure may result in changes to the surface and subsurface environment, potentially increasing ground movement during an earthquake event. The Emergency Response Plan (outline provided in Volume 3, Part E - Section 16.0) and the decommissioning of engineered structures and facilities will reduce detrimental changes.

During the reclamation stage, the Proposed Project may result in changes that could exceed Canadian or BC guidelines or Code requirements. Decommissioning and removal of facilities and structures where ground disturbance has occurred will be managed by qualified and experienced professionals based on detailed, site specific subsurface data. Appropriate reclamation plans will be written at the time of decommissioning and will reduce the effects of ground movement during an earthquake event. The expected size and severity of increased ground movement during an earthquake event will therefore be reduced and would be limited to site decommissioning locations. This results in a low magnitude.

Frequency is based on how often the residual effect of increased ground movement during earthquakes occurs, and is therefore connected to when earthquake events are expected. The return period of expected design level earthquake events affecting the LSA and RSA are anticipated to have a low return period of 2,475 to more than 5,000 years. Based on this return period and with mitigation measures in place during closure and decommissioning activities, increased ground movement during an earthquake event is expected to rarely occur, with a low frequency rating.

The duration is the length of time increased ground movement during an earthquake will persist throughout the decommissioning, reclamation, and closure phase. Duration of these effects will be from start of construction to life of the Proposed Project, and therefore has a low to medium rating. Effects of previous ground and subsurface disturbance are not expected to continue once the site has been reclaimed.

The effects of earthworks and facility / structure decommissioning on increased ground movement during an earthquake may have an impact if they occur in ecologically sensitive areas or where subsurface ground conditions have less resilience to imposed stresses. With mitigation, increased ground movement during an earthquake event will likely be resilient to imposed stresses and have a low susceptibility to potential changes caused by the Proposed Project.

The geographic extent of increased ground movement during an earthquake is local and restricted to the LSA.

Reversibility of the effect is partially reversible. As facility and structure decommissioned will be following the Canadian and BC guidelines and building Code requirements, increased ground movement during an earthquake event is not expected. Liquefaction, surface rupture, or lateral movement can be mitigated with appropriate decommissioning and removal plans, and are not expected to result in permanent effects.

With appropriate mitigation measures addressing subsurface changes that could increase ground movement during earthquake event, the likelihood of potential residual effects occurring is low. Reclamation and closure activities will be designed to appropriate engineering performance requirements.

5.4.5.4.3.2 Increased Shoreline Erosion and Offshore Debris Deposition during Earthquake or Landslide Generated Tsunami

With appropriate mitigation and monitoring, site reclamation and removal of infrastructure is not expected to increase shoreline erosion or offshore deposition.

Soil reclamation (details provided in the Reclamation and Effective Closure Plan in Volume 4, Part G - Section 22.0: Appendix 4) and facility and structure decommissioning are not expect to detrimentally increase the volume of erodible shoreline soils or increase debris deposition off shore, which could be incorporated during an earthquake or landslide tsunami related event. Appropriate erosion control measures and decommissioning monitoring will minimize the effects of erosion along the shoreline, and subsequent offshore debris deposition. The expected volume and severity of increased shoreline erosion and offshore deposition will be minimal with mitigation, and limited to shoreline periphery stock pile storage locations, and facility and structure decommissioning sites. The magnitude is therefore considered negligible as mitigation will reduce erosion potential and the amount of material available for transport and deposition offshore.

Soil reclamation and engineering decommissioning design plans are expected to manage for soil erosion / off shore deposition. Landslide induced tsunamis are not expected in the LSA based on the lack of evidence for landslide prone terrain that would impact the LSA. Also, earthquake induced tsunamis are not expected in the LSA and RSA (given the 2,475 to greater than 5,000 year design build earthquake return period). With erosion/deposition controls in place, and the low expectancy for tsunamis to occur, the frequency has been rated low and is expected to rarely occur

The duration for increased shoreline erosion and offshore deposition to impact a tsunami event has been rated low to medium. Effects are expected to be mitigated from construction to life of the Proposed Project.

Context has been deemed low or resilient, as engineering plans are expected to reduce soil erosion and soil transport in the shoreline and off shore fan area. The geotechnical hazards of increased soil erosion and debris deposition impacting, amplifying, or initiating a tsunami event has a low susceptibility to potential changes during the reclamation and closure phase. Although activities may take place in sensitive marine or land base ecosystems, the BC building code and engineering designs would result in planned facilities, structures, and earth works being resilient to imposed stresses.

The geographic extent is local and restricted to the LSA.

There is a Medium reversibility based on conformance with detailed geotechnical designs, approved monitoring of performance during operations, and updates or modification to designs if required to achieve Proposed Project performance requirements and for mitigation. Reversibility of increased erosion and deposition effects during a tsunami event in the LSA is rated as partially reversible. Following recommendations under Canadian and BC guidelines and building Code decommissioning requirements, an increase in soil erosion and offshore deposition is not expected. Therefore if no substantial increases in erosion / deposition occur, then the effects of a tsunami event will not be amplified. Changes to erosive and depositional conditions can be minimized or mitigated by appropriate reclamation plans and decommissioning measures as well as emergency response plans. Details of what will be provided in in the Reclamation and Effective Closure Plan and the Emergency Response Plans are provided in Volume 4, Part G – Section 22.0.

With appropriate mitigation measures and reclamation plans, the likelihood of potential residual effects occurring is low. Decommissioning of facilities and structures will be designed to appropriate engineering performance requirements.

5.4.5.4.3.3 Initiation of Submarine Landslides

Site conditions are not conducive to submarine landslides, and initiation of slides from reclamation and closure activity can be minimized though mitigation efforts. Removal of marine and foreshore infrastructure and foreshore connected site reclamation may change the submarine subsurface environments. With appropriate engineering designs and mitigation measures, the marine and foreshore delta fan areas will revert to static loading conditions and stable submarine slopes (Volume 4, Part G – Section 22.0: Appendix 5.4-B). With appropriate decommissioning and reclamation plans; initiation of submarine landslides is not expected.

Although not expected, a submarine landslide initiated by decommissioning and removal efforts could result in changes in geotechnical hazards that will exceed Canadian or BC guidelines or Code requirements. A submarine landslide could potentially have severe effects on marine habitat. Stabilizing submarine environments via applicable engineered decommissioning plans and techniques will result in minimized changes to static conditions. Therefore the expected size and severity of a potentially submarine landslide will be reduced and likely limited to site specific locations. This results in a medium magnitude rating.

The effect is local as it is located in the foreshore, submarine area.

The duration is Medium-term as Proposed Project activities will be incurred throughout the Proposed Project lifetime.

Frequency is a measure of how often a submarine landslide would be initiated from operational activities with mitigation in place. Frequency of submarine initiation is based on existing and altered conditions of the submarine delta fan. There is no significant evidence of previous submarine landslides, and phased alterations of the subsurface conditions will be mitigated during reclamation and closure. Changes to static submarine delta-fan are not expected if facilities and structures are decommissioned under federal and provincial guidelines and building Code requirements. Appropriate engineered decommissioning plans will minimize changes to the submarine environment therefore lowering the potential for submarine landslide initiation. The frequency has therefore been rated as low as there will still be a potential for submarine slides to occur intermittently throughout the life closure phase.

Context has been deemed low or resilient, as engineering designs under federal and provincial guidelines and building Codes are expected to reduce detrimental changes to the submarine static loading conditions resulting in resiliency to imposed stresses. The geotechnical hazards of initiating a submarine landslide have a low susceptibility to potential changes caused by the Proposed Project.

The geographic extent is local and restricted to the LSA.

Reversibility of submarine landslide initiation after mitigation measures have been applied is rated as partially reversible. Potential detrimental impacts to the submarine static conditions can be minimized or mitigated by appropriate decommissioning measures under Canadian and BC guidelines or Code requirements as well as emergency response plans. Impacts to the submarine environments could likely be partially reversible in that submarine restoration works may be undertaken.

With appropriate mitigation measures, the likelihood of potential for submarine landslide initiation occurring is low. Construction will be designed to appropriate engineering performance requirements.

5.4.5.4.3.4 Land-based Mass Movement - Terrain Stability

Reclamation and closure activities such as soil reclamation planning for stripping and stock piling, general earth works, and road decommissioning will not be located on, adjacent to, or downslope of unstable terrain. Stockpiling soil near creek edges, or redirecting water onto potentially unstable side banks of McNab Creek could initiation of mass movement events such as localized side bank slumps and slides. Reclamation activities could also alter erosion and stability conditions of existing or possibly imminent debris flows or flood deposits along McNab Creek. Mitigation includes implementing a Soil Management Plan (Provided in the Volume 4, Part G - Section 22:

Appendix 4, Reclamation and Effective Closure Plan) and Erosion and Sediment Control Plan (Volume 4, Part G – Section 22.0: Appendix 3) to minimize changes to the currently stable conditions, and removing any debris flow / flood catchment structures that exist.

With mitigation efforts, the expected size of debris levee slope or McNab Creek side bank slides and slumps is expected to be relatively small, and similar to naturally occurring failures observed along the channel. Therefore the magnitude has been rated as low.

Landslide, avalanche, and debris flow / flood events in the LSA are not expected. The frequency for reclamation and closure activities initiating land based mass movements along debris flow / flood deposit slopes or alongside banks of McNab Creek after mitigation has been applied is medium. Reclamation plans for soil stockpile location, drainage control and potential sidebank protection will reduce these effects (Volume 4, Part G - Section 22.0: Appendix 3). Initiation of small slides, similar to naturally occurring slides along McNab Creek side bank is expected to intermittently occur during reclamation phase activities.

The duration of the residual effect is considered medium-term as earthworks and potential for soil erosion and drainage changes are likely to persist throughout the life of the Proposed Project.

The extent is regional as closure activities could increase the potential for unstable conditions to arise by changing debris flow / flood depositional areas that are connected to the RSA.

Context is a measure of the current and future terrain stability conditions sensitivity and resilience to changes inflicted by the Soil Management Plan and the Erosion and Sediment Control Plans. The residual effects will be resilient to changes based on the following: natural drainage conditions will be re-established; near bank loading from stockpiling and machine works will be monitored; soil erosion control measures will be implemented; unstable creek side protection will be utilized until reclamation activities are completed; and monitoring of potential changes to debris flow / flood deposition areas will be conducted. These mitigation measures will result in a low susceptibility of mass movement initiation during reclamation and closure activities.

Reversibility is medium as effects of initiation of watercourse side bank stability and potential debris flow /flood deposit erosion and sediment transport can be minimized and mitigated and monitored; slope restoration can be addressed if required. Therefore, permanent effects are not expected.

With appropriate mitigation measures, operational activities for the Proposed Project will have none to minimal measurable effects on the unstable or potentially unstable terrain.terrain stability conditions have low susceptibility to potential changes during the Project reclamation and closures plans. Therefore a low likelihood of occurrence is anticipated.

Table 5.4-10: Characterization of Potential Project-Related Residual Effects: Geotechnical Conditions - Earthquakes and Tsunamis

Project-Related Effect	Residual Effect Assessment Criteria					
	Context	Magnitude	Extent	Duration	Reversibility	Frequency
Construction						
Increased ground movement during earthquake event.	R	L	L	ST to MT	PR	L
Increased Shoreline Erosion and Offshore Debris Deposition during Earthquake or Landslide Generated Tsunami	R	N	L	ST to MT	PR	L
Initiation of Submarine Landslides	R	L	L	ST to MT	PR	L
Operations						
Increased ground movement during earthquake event.	R	L	L	ST to MT	PR	L
Increased Shoreline Erosion and Offshore Debris Deposition during Earthquake or Landslide Generated Tsunami	R	N	L	ST to MT	PR	L
Initiation of Submarine Landslides	R	L	L	ST to MT	PR	L

Project-Related Effect	Residual Effect Assessment Criteria					
	Context	Magnitude	Extent	Duration	Reversibility	Frequency
Reclamation and Closure						
Increased ground movement during earthquake event. (liquefaction, settlement, lateral movement, rupture)	R	L	L	ST to MT	PR	L
Increased Shoreline Erosion and Offshore Debris Deposition during Earthquake or Landslide Generated Tsunami	R	N	L	ST to MT	PR	L
Initiation of Submarine Landslides	R	L	L	ST to MT	PR	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-tern, MT – Medium-term, LT – Long-term;
Reversibility: FR – Fully Reversible, PR - Partially Reversible, IR - Irreversible;
Frequency: L – Low, M – Medium, H – High.

Table 5.4-11: Characterization of Potential Project-Related Residual Effects: Land Based Mass Movements - Terrain Stability

Project-Related Effect	Residual Effect Assessment Criteria					
	Context	Magnitude	Extent	Duration	Reversibility	Frequency
Construction						
Land-based Mass Movement - Terrain Stability	R	N	R	MT	PR	M
Operations						
Land-based Mass Movement – Terrain Stability	R	N	R	MT	PR	M
Reclamation and Closure						
Land-based Mass Movement – Terrain Stability	R	N	R	ST	FR	M

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-tern, MT – Medium-term, LT – Long-term;
Reversibility: FR – Fully Reversible, PR - Partially Reversible, IR - Irreversible;
Frequency: L – Low, M – Medium, H – High.

Table 5.4-12: Likelihood of Occurrence of Potential Residual Effects: Geotechnical Hazards and Terrain Stability

VC	Potential Residual Effect	Likelihood	Rationale
Construction			
Earthquakes and Tsunamis	Increased ground movement during earthquake event. (liquefaction, settlement, lateral movement, rupture)	Low	Subsurface changes where ground movements can be affected will be addressed through engineering designs under federal and provincial guidelines and building Codes. This is expected to reduce detrimental changes the currently stable static loading conditions resulting in resiliency to imposed stresses.
	Proposed Project related increase in earthquake or tsunami related Shoreline Erosion and Debris Deposition	Low	Events impacting shoreline erosion (earthwork) and offshore debris deposition (from foreshore erosion and transport or structure related erosion in submarine environment, or landslide related debris transport), will be addressed through Soil Management Plans and Sediment Erosion and Drainage Control Plans , and engineering designs under federal and provincial guidelines and building Codes. This is expected to reduce the effects of erosion and deposition that could increase the effect of tsunami events. .
	Proposed Project-related initiation of Submarine Landslides	Low	The submarine environment has been deemed to be stable. Works conducted the submarine environment will follow engineering designs under federal and provincial guidelines and building Codes. This is expected to reduce detrimental changes to the submarine static loading conditions resulting in resiliency to imposed stresses. The geotechnical hazards of initiating a submarine landslide have a low susceptibility to potential changes caused by the Proposed Project.
Terrain Stability	Proposed Project related initiation of land-based Mass Movement Event	Low	No unstable terrain identified in the LSA; soil (earthworks) erosion and drainage management will address potentially connectivity to unstable and potentially unstable McNab Creek side banks Terrain stability concerns in RSA that could indirectly affect the LSA can be managed via appropriate mitigation measures.

VC	Potential Residual Effect	Likelihood	Rationale
Operations			
Earthquakes and Tsunamis	Increased ground movement during earthquake event.	Low	Subsurface changes where ground movements can be affected will be addressed through engineering designs under federal and provincial guidelines and building Codes. This is expected to reduce detrimental changes the currently stable static loading conditions resulting in resiliency to imposed stresses.
	Proposed Project related increase in earthquake or tsunami related Shoreline Erosion and Debris Deposition	Low	Events impacting shoreline erosion (earthwork) and offshore debris deposition (from foreshore erosion and transport or structure related erosion in submarine environment, or landslide related debris transport), will be addressed through soil and drainage management, and engineering designs under federal and provincial guidelines and building Codes. This is expected to reduce the effects of erosion and deposition that could increase the effect of tsunami events.
	Proposed Project-related initiation of Submarine Landslides	Low	The submarine environment has been deemed to be stable. Works conducted the submarine environment will follow engineering designs under federal and provincial guidelines and building Codes. This is expected to reduce detrimental changes to the submarine static loading conditions resulting in resiliency to imposed stresses. The geotechnical hazards of initiating a submarine landslide have a low susceptibility to potential changes caused by the Proposed Project.
Terrain Stability	Proposed Project-related initiation of land-based Mass Movement Event	Low	No unstable terrain identified in the LSA; soil (earthworks) erosion and drainage management will address potentially connectivity to unstable and potentially unstable McNab Creek side banks. Terrain stability concerns in RSA that could indirectly affect the LSA can be managed via appropriate mitigation measures.

VC	Potential Residual Effect	Likelihood	Rationale
Reclamation and Closure			
Earthquakes and Tsunamis	Increased ground movement during earthquake event.	Low	Subsurface changes where ground movements can be affected will be addressed through engineering designs under federal and provincial guidelines and building Codes. This is expected to reduce detrimental changes the currently stable static loading conditions resulting in resiliency to imposed stresses.
	Proposed Project related increase in earthquake or tsunami related Shoreline Erosion and Debris Deposition	Low	Events impacting shoreline erosion (earthwork) and offshore debris deposition (from foreshore erosion and transport or structure related erosion in submarine environment, or landslide related debris transport), will be addressed through soil and drainage management, and engineering designs under federal and provincial guidelines and building Codes. This is expected to reduce the effects of erosion and deposition that could increase the effect of tsunami events.
	Proposed Project related initiation of Submarine Landslides	Low	The submarine environment has been deemed to be stable. Works conducted the submarine environment will follow engineering designs under federal and provincial guidelines and building Codes. This is expected to reduce detrimental changes to the submarine static loading conditions resulting in resiliency to imposed stresses. The geotechnical hazards of initiating a submarine landslide have a low susceptibility to potential changes caused by the Proposed Project.
Terrain Stability	Proposed Project-related initiation of land-based Mass Movement Event	Low	No unstable terrain identified in the LSA; soil (earthworks) erosion and drainage management will address potentially connectivity to unstable and potentially unstable McNab Creek side banks. Terrain stability concerns in RSA that could indirectly affect the LSA can be managed via appropriate mitigation measures.

5.4.5.5 Significance of Residual Effects

The significance of potential residual adverse effects was determined based on the effects criteria ratings presented in Table 5.4-10 and Table 5.4-11 review of background information, and professional judgement. A summary of significance determinations is presented in Table 5.4-13 along with rationale for the determination of significance for the operations and closure time periods.

For all potential interactions, negligible (and not significant) residual effects of geotechnical hazards and terrain stability conditions are expected during construction, operations and during reclamation and closure. Potential residual effects on the geotechnical hazards and terrain stability conditions were considered negligible (and not significant) because:

- Landslides, snow avalanches, and submarine landslide conditions are not present in the LSA;
- With mitigation measures, site geotechnical conditions will not diverge from baseline conditions; and
- Anticipated engineering designs and mitigation measures would minimize and manage for potential adverse effects.

Based on the negligible to not significant rating for all residual effects, no residual effects were carried forward into a cumulative effects assessment.

Table 5.4-13: Significance of Potential Residual Effects: Geotechnical and Natural Hazards

VC	Potential Residual Effect	Significance	Rationale
Construction			
Earthquakes and Tsunamis	Increased ground movement during earthquake event. (liquefaction, settlement, lateral movement, rupture)	Negligible- Not Significant	Taking into account subsurface changes where ground movements can be affected by Proposed Project related construction, these will be addressed through engineering designs under federal and provincial guidelines and building Codes. Design and mitigative measures will incorporate a 2,475 to greater than 5,000 year design build earthquake return period. This is expected to reduce detrimental changes to the currently stable static loading conditions resulting in resiliency to imposed stresses.
	Proposed Project-related increase in earthquake or tsunami related Shoreline Erosion and Debris Deposition	Negligible- Not Significant	Events impacting shoreline erosion and offshore debris deposition will be mitigated under soil and drainage management. Engineering designs following federal and provincial guidelines and building Codes will maintain structural integrity and static loading conditions of offshore structures. Landslide initiated debris deposition is not expected.

VC	Potential Residual Effect	Significance	Rationale
	Proposed Project-related initiation of Submarine Landslides	Negligible- Not Significant	The submarine environment has been deemed to be stable; engineered submarine structures will be designed and maintained following federal and provincial guidelines and building Codes. Submarine fan-delta static loading conditions are expected to be resilient to imposed stresses.
Terrain Stability	Proposed Project initiation of Land-based Mass Movement	Negligible- Not Significant	No land based mass movement events or unstable or potentially unstable terrain (Class IV and V) were identified within LSA. Proposed Project activities are not expected to initiate land based mass movement events However, existing unstable and potentially unstable terrain (terrain Class IV and V) was identified in the RSA with indirect connectivity to the LSA (via McNab Creek and tributaries). Although unlikely, naturally occurring debris flow and debris flood events could reach the LSA and impact the Proposed Project. Detailed debris flow/flood studies and mitigation measures could account for potential and adverse erosion effects beyond current conditions.
Operations			
Earthquakes and Tsunamis	Increased ground movement during earthquake event.	Negligible- Not Significant	Taking into account subsurface changes where ground movements can be affected by Proposed Project operations, these will be addressed through engineering designs under federal and provincial guidelines and building Codes. Design and mitigative measures will incorporate a 2,475 to greater than 5,000 year design build earthquake return period. This is expected to reduce detrimental changes the currently stable static loading conditions resulting in resiliency to imposed stresses.
	Proposed Project-related increase in earthquake or tsunami related Shoreline Erosion and Debris Deposition	Negligible- Not Significant	Events impacting shoreline erosion and offshore debris deposition will be mitigated under soil and drainage management. Engineering designs following federal and provincial guidelines and building Codes will maintain structural integrity and static loading conditions of offshore structures. Landslide initiated debris deposition is not expected.

VC	Potential Residual Effect	Significance	Rationale
	Proposed Project-related initiation of Submarine Landslides	Negligible- Not Significant	The submarine environment has been deemed to be stable; engineered submarine structures will be designed and maintained following federal and provincial guidelines and building Codes. Submarine fan-delta static loading conditions are expected to be resilient to imposed stresses.
Terrain Stability	Proposed Project initiation of Land-based Mass Movement	Negligible- Not Significant	No land based mass movement events or unstable or potentially unstable terrain (Class IV and V) were identified within LSA. Proposed Project activities are not expected to initiate land based mass movement events However, existing unstable and potentially unstable terrain (terrain Class IV and V) was identified in the RSA with indirect connectivity to the LSA (via McNab Creek and tributaries). Although unlikely, naturally occurring debris flow and debris flood events could reach the LSA and impact the Proposed Project. Detailed debris flow/flood studies and mitigation measures could account for potential and adverse erosion effects beyond current conditions.
Reclamation and Closure			
Earthquakes and Tsunamis	Increased ground movement during earthquake event.	Negligible-Not Significant	Taking into account subsurface changes where ground movements can be affected by reclamation and closure measures, these will be addressed through engineering designs under federal and provincial guidelines and building Codes. Design and mitigative measures will incorporate a 2,475 to greater than 5,000 year design build earthquake return period. This is expected to reduce detrimental changes the currently stable static loading conditions resulting in resiliency to imposed stresses.
	Proposed Project-related increase in earthquake or tsunami related Shoreline Erosion and Debris Deposition	Negligible- Not Significant	Events impacting shoreline erosion and offshore debris deposition will be mitigated under soil and drainage management. Engineering designs following federal and provincial guidelines and building Codes will maintain structural integrity and static loading conditions of offshore structures. Landslide initiated debris deposition is not expected.

VC	Potential Residual Effect	Significance	Rationale
	Proposed Project-related initiation of Submarine Landslides	Negligible- Not Significant	The submarine environment has been deemed to be stable; engineered submarine structures will be designed and maintained following federal and provincial guidelines and building Codes. Submarine fan-delta static loading conditions are expected to be resilient to imposed stresses.
Terrain Stability	Proposed Project initiation of Land-based Mass Movement (landslides, snow avalanches, debris flows/floods)	Negligible- Not Significant	No land based mass movement events or unstable or potentially unstable terrain (Class IV and V) were identified within LSA. Proposed Project activities are not expected to initiate land based mass movement events However, existing unstable and potentially unstable terrain (terrain Class IV and V) was identified in the RSA with indirect connectivity to the LSA (via McNab Creek and tributaries). Although unlikely, naturally occurring debris flow and debris flood events could reach the LSA and impact the Proposed Project. Detailed debris flow/flood studies and mitigation measures could account for potential and adverse erosion effects beyond current conditions.

5.4.5.6 Level of Confidence

This assessment was, in part, conducted to predict whether or not the Proposed Project will result in significant adverse effects related to geotechnical hazards and terrain stability conditions. It is important to identify the major uncertainties associated with the predictive assessment and to consider the implications of these uncertainties on the level of confidence in determination of significance. The identification of uncertainties will assist in developing mitigation and monitoring programs during all phases of the Proposed Project.

The level of confidence of predicted residual effects is provided in Table 5.4-14.

Table 5.4-14: Level of Confidence in Potential Residual Effect Predictions: Geotechnical and Natural Hazards

Residual Effect	Level of Confidence (LOC) in Residual Effect Prediction	LOC Rationale
Construction		
Increased ground movement during earthquake event.	Moderate	Proposed Project Area is flat to gently sloping and offset significant distance from the steep fan-delta slope. Potential adverse effects would be mitigated by appropriate design and mitigative measures
Proposed Project-related increase in earthquake or tsunami related Shoreline Erosion and Debris Deposition	Moderate	Residual effects can be managed by appropriate design and mitigative measures
Proposed Project-related initiation of Submarine Landslides	Moderate	Residual effects can be managed by appropriate design and mitigative measures
Proposed Project-related initiation of land-based Mass Movement Event	Moderate	No terrain stability hazards identified within LSA. There is a low likelihood that the Proposed Project will induce mass movement events. Terrain Class IV and V unstable and potentially unstable terrain within the RSA would be subject to potential mitigation measures to account for debris flow/flood potential erosion beyond current conditions.
Operations		
Increased ground movement during earthquake event.	Moderate	Proposed Project Area is flat to gently sloping and offset significant distance from the steep fan-delta slope. Potential adverse effects would be mitigated by appropriate design and mitigative measures
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Proposed Project-related initiation of land-based Mass Movement Event	Moderate	No terrain stability hazards identified within LSA. There is a low likelihood that the Proposed Project will induce mass movement events. Terrain Class IV and V, and unstable and potentially unstable terrain within the RSA would be subject to potential mitigation measures to account for debris flow/flood potential erosion beyond current conditions.

Residual Effect	Level of Confidence (LOC) in Residual Effect Prediction	LOC Rationale
Reclamation and Closure		
Increased ground movement during earthquake event.	Moderate	Proposed Project Area is flat to gently sloping and offset significant distance from the steep fan-delta slope. Potential adverse effects would be mitigated by appropriate design and mitigative measures
Proposed Project-related increase in earthquake or tsunami related Shoreline Erosion and Debris Deposition	Moderate	Frequency of earthquake and tsunami events is low. Residual effects can be managed by appropriate design and mitigative measures
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Proposed Project-related initiation of land-based Mass Movement Event	Moderate	No terrain stability hazards identified within LSA. There is a low likelihood that the Proposed Project will induce mass movement events. Terrain Class IV and V, and unstable and potentially unstable terrain within the RSA would be subject to potential mitigation measures to account for debris flow/flood potential erosion beyond current conditions.

5.4.6 Cumulative Effects Assessment

All potential Project-related residual adverse effects were determined to be negligible and requiring no further consideration. No residual effects were carried forward to a cumulative effects assessment.

5.4.7 Conclusions

5.4.7.1 Geotechnical Hazards

Proposed Project activities are not expected to initiate earthquakes or tsunamis throughout and after the Proposed Project life. Tsunami and earthquake events will remain the same throughout and after the Proposed Project life. The likelihood of earthquake or tsunami occurrences (earthquake or landslide induced) in Howe Sound was considered. In general, the frequency of earthquake and tsunami events occurring is low. Residual effects can be managed by appropriate design and mitigative measures. Once mitigation measures have been implemented; no further consideration for shoreline erosion and debris deposition and initiation of submarine landslides will be required.

5.4.7.2 Terrain Stability

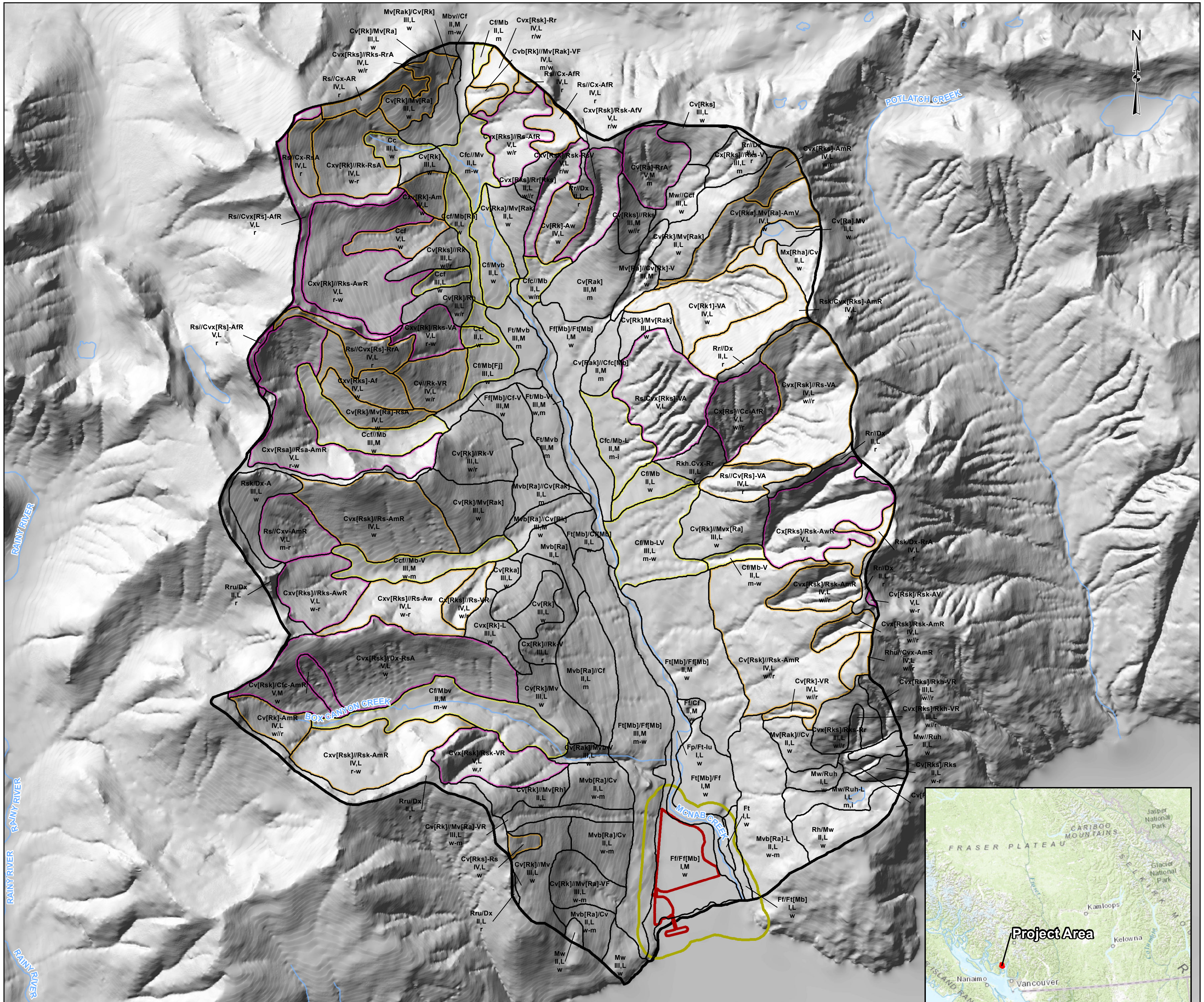
No terrain stability concerns have been identified within the LSA. Proposed Project activities are not expected to induce land based mass wasting events such as landslides, snow avalanches, and debris flows and debris floods. Geologic phenomena related to terrain stability such as landslides and snow avalanches have historically occurred and are currently occurring in the RSA. The likelihood of these events to continue will remain the same throughout the Proposed Project life. Although avalanching and steep valley sidewall debris and rock slides are common in the McNab Creek watershed, they are not expected to directly affect the LSA and Proposed Project Area. Activities associated with the Proposed Project Area are not anticipated to increase the potential for initiating mass movement processes (landslides and snow avalanches).

It is unlikely that there is a significant potential for debris flows and debris floods to occur upstream of the Proposed Project Area, which could affect the LSA. Further investigation and assessment will be required to evaluate the debris flood/debris flow potential and determine if engineering designs are required to mitigate potential risks.

5.4.7.3 Recommendations

Based on the existing geotechnical and natural hazards conditions, the following monitoring and investigation programs are suggested:

- Field review of desktop terrain mapping and terrain stability assessment to confirm interpretations of surficial materials, bedrock, slopes and geomorphological processes to be carried out by original map compilers before detailed designs are completed;
- Supplemental debris flow and debris flood investigations to analyse potential for events to occur and if engineered mitigation plans and designs are warranted;
- Supplementary geotechnical investigations and analyses to delineate the extent and depths of potentially liquefiable fills or soils both onshore and offshore within the Proposed Project Area; and
- Stability and ground movement analyses of the Proposed Project Area and the fan-delta slopes.



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TERRAIN UNITS
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- Depositional Area (Colluvial Fans and Cones)
- Terrain Stablity Class IV
- Terrain Stablity Class V

TERRAIN CLASSIFICATION SYMBOL

Mvb[Rak]//Cfc[Rak]-RsV
IV, M
i . p

- surficial material
- surface expression
- underlying material
- underlying surface expression
- delimiters
- geomorphological process
- geomorphological process subclass
- terrain stability class
- drainage
- surface erosion potential

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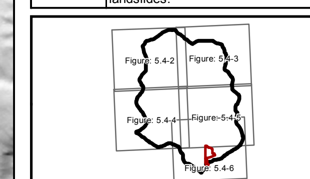

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DATUM: NAD83 PROJECTION: UTM ZONE 10.

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SCALE 1:50,000 METRES

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

TITLE
DESKTOP ANALYSIS:
TERRAIN AND TERRAIN STABILITY MAPPING
OVERVIEW

Golder Associates

PROJECT	11-1422-0046		FILE No.
DESIGN	WM	19 Aug. 2014	SCALE AS SHOWN REV. 0
GIS	DL	04 Mar. 2016	
CHECK	WM	04 Mar. 2016	**FIGURE 5.4-1**
REVIEW	JF	04 Mar. 2016	

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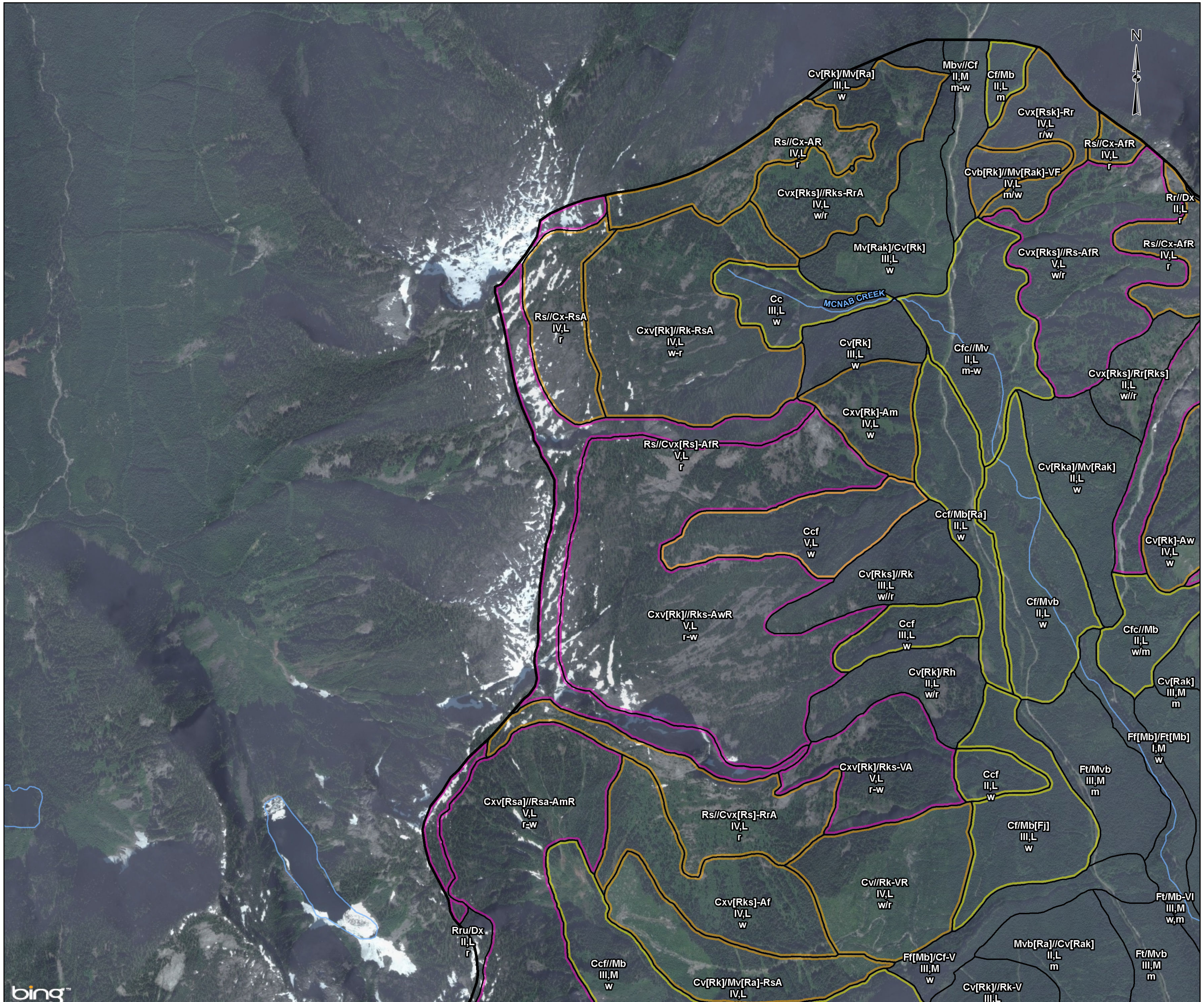

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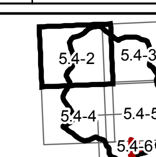

REFERENCE

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SCALE 1:20,000 METRES

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

TITLE
DESKTOP ANALYSIS:
TERRAIN AND TERRAIN STABILITY MAPPING

Golder Associates

PROJECT	11-1422-0046	FILE No.	
DESIGN	WM	19 Aug. 2014	SCALE AS SHOWN REV. 0
GIS	DL	04 Mar. 2016	
CHECK	WM	04 Mar. 2016	**FIGURE: 5.4-2**
REVIEW	JF	04 Mar. 2016	

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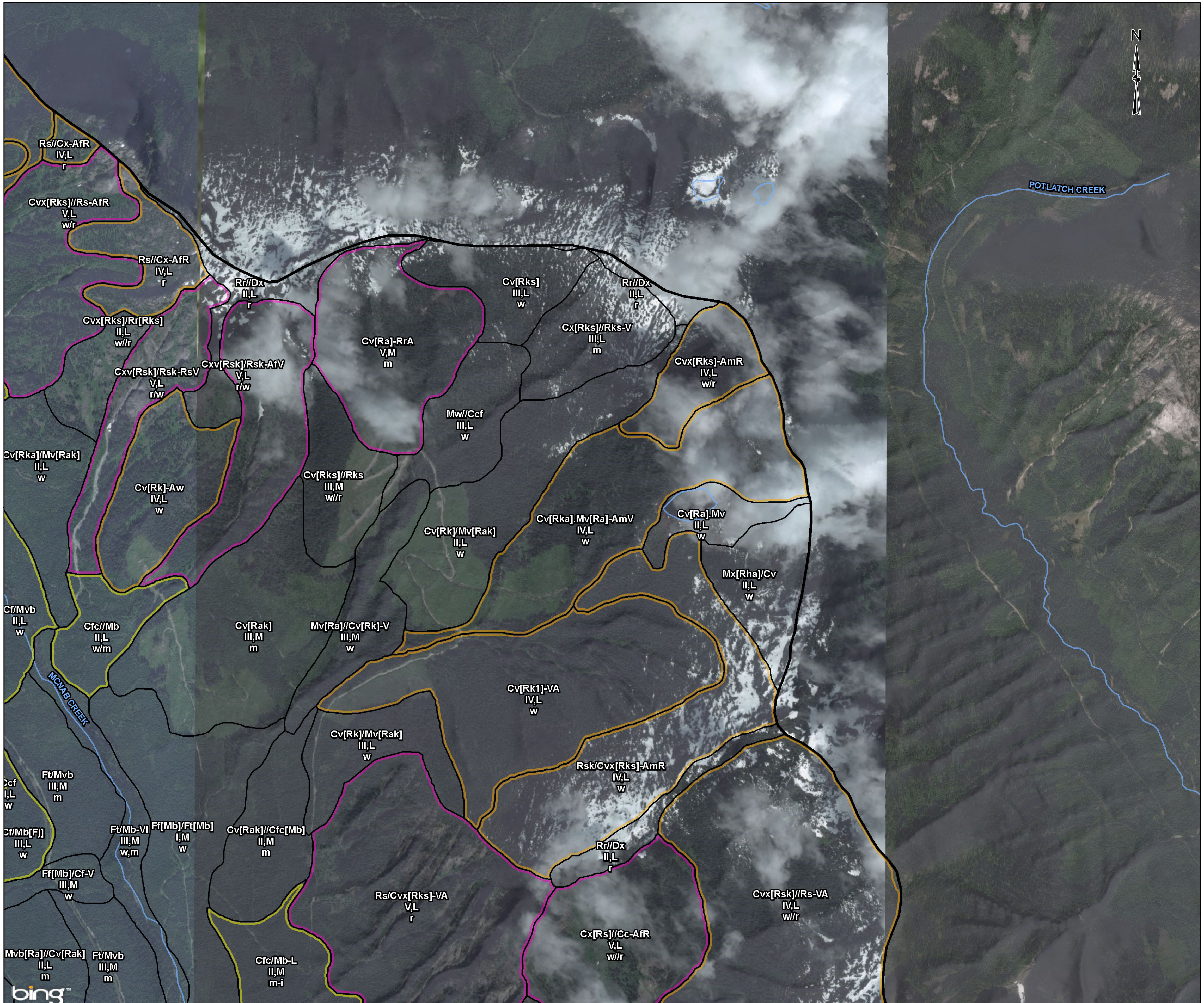

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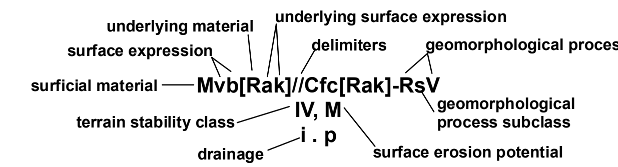

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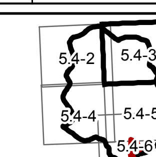

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600 0 600

SCALE 1:20,000 METRES

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GIS	DL	04 Mar. 2016		
CHECK	WM	04 Mar. 2016	**FIGURE: 5.4-3**	
REVIEW	JF	04 Mar. 2016		

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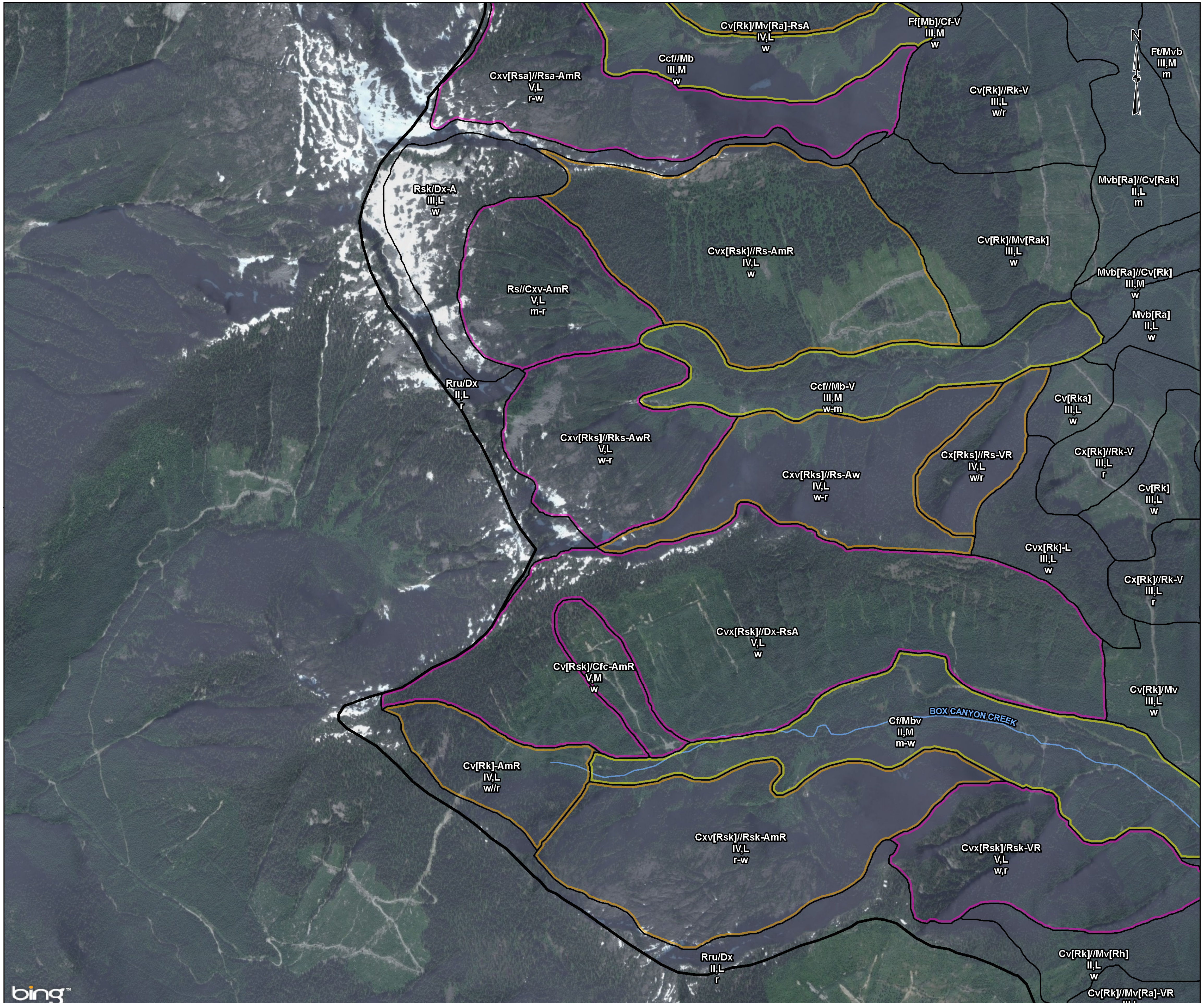

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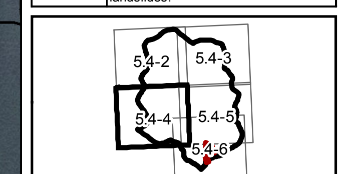

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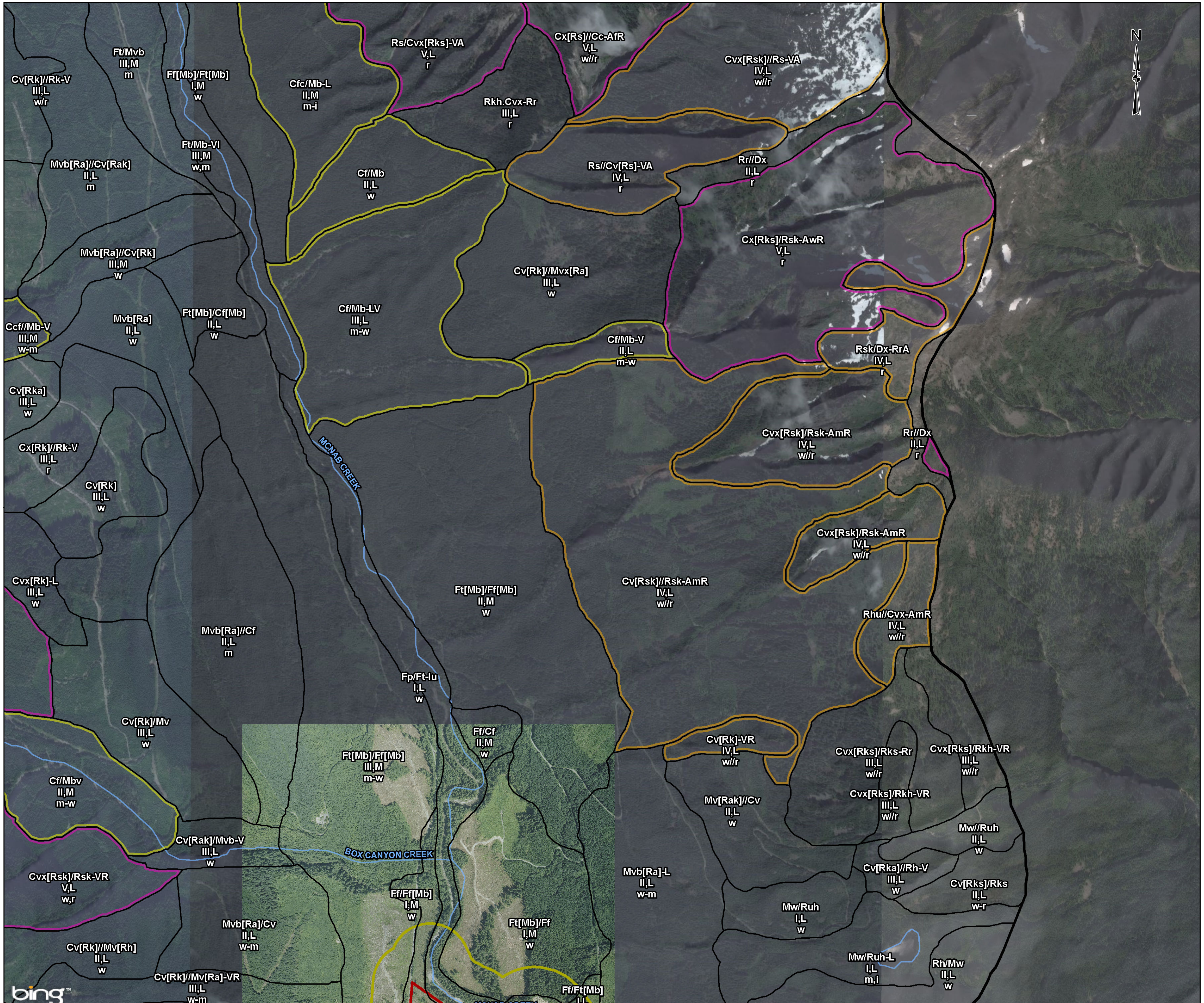


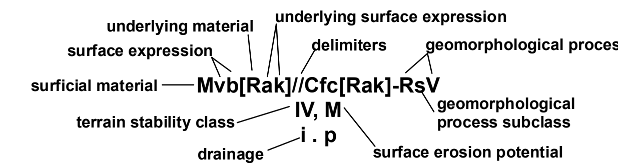
LEGEND

PROJECT BOUNDARIES
- Project Area
- Local Study Area (LSA)
- Regional Study Area (RSA)

BASE MAP
- Waterbody
- Watercourse

TERRAIN UNITS
- Polygon Boundary (Label)
- Depositional Area (Colluvial Fans and Cones)
- Terrain Stability Class IV
- Terrain Stability Class V

TERRAIN CLASSIFICATION SYMBOL



TERRAIN MAPPING LABEL LEGEND

Terrain Stability Classification (Adapted from the Mapping and Assessing Terrain Stability Guidebook, 1999)	
Terrain Stability Class	Interpretation
I	No evidence of significant stability problems is observed.
II	There is a very low likelihood of landslides following timber harvesting, general land clearing, and road construction. Minor slumping is expected along cut slopes, especially for 1 or 2 years following construction.
III	Minor stability problems can develop. Minor slumping is expected along cut slopes, especially for 1 or 2 years following construction. There is a low likelihood of landslide initiation following timber harvesting, general land clearing, or road construction.
IV	Expected to contain areas with a moderate likelihood of landslide initiation following timber harvesting, general land clearing, or road construction.
V	Expected to contain areas with a high likelihood of landslide initiation following timber harvesting, general land clearing, or road construction. May includes areas with evidence of current instability and/or active landslides.

Terrain Symbol Legend
(Annotated List from Howes & Kenk (1998))

Surficial Parent Materials
- **C** Colluvium (gravity induced movements)
- **D** Weathered Bedrock (insitu decomposed bedrock)
- **F** Fluvial Material
- **M** Morainal/Till (deposited directly by glacial ice)
- **R** Bedrock

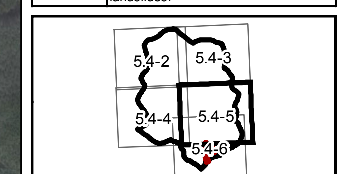
Surface Expression
- **a** Moderate Slope (27-49%)
- **b** Blanket (>1m thickness)
- **c** Cones(S)
- **f** Fan (fan shaped landform with <26% gradients)
- **h** Hummocks (non-linear rises >26%)
- **j** Gentle Slope (6-26%)
- **k** Moderately Steep Slope (50-70%)
- **P** Plain (Unidirectional surface up to 30°)
- **r** Ridges (S) (elongate rises >26%)
- **s** Steep Slope (>705)
- **t** Terrace (Step-like topography)
- **u** Undulating Topography (non-linear rises <26%)
- **v** Veneer (<1m thickness)
- **w** Mantle (fills depression and irregular substrate)
- **x** Very Thin Veneer (<0.3m)

Geomorphological Process
- **A** Snow Avalanches
- **F** Slow Mass Movements
- **J** Anastomosing Channel
- **M** Meandering Channel
- **R** Rapid Mass Movements
- **V** Gully Erosion

Geomorphological Subclasses
- **a** Abrupt Channel Diversion; Avulsion
- **d** Ephemeral Tributary-Fed Backchannels
- **e** Ephemeral,River-Fed Backchannels
- **f** Major Avalanche Tracks; Active
- **m** Minor Avalanche Tracks; Active
- **o** Old Avalanche Tracks
- **r** Patterned Ground
- **s** Debris Slide
- **t** Thermokarst: Subsidence
- **u** Slump in surficial
- **w** Ice Wedge Polygons

Soil Erosion Potential (SEP)
- **VL** Very Low
- **L** Low
- **M** Medium
- **H** High
- **VH** Very High

Drainage
- **x** very rapid
- **r** rapid
- **w** well
- **m** moderate
- **i** imperfect
- **p** poor
- **v** very poor



REFERENCE

DATUM: NAD83 PROJECTION: UTM ZONE 10.

600 0 600

SCALE 1:20,000 METRES

PROJECT

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

TITLE

DESKTOP ANALYSIS:
TERRAIN AND TERRAIN STABILITY MAPPING

Golder Associates

PROJECT		11-1422-0046	FILE No.
DESIGN	WM	19 Aug. 2014	SCALE AS SHOWN REV. 0
GIS	DL	04 Mar. 2016	
CHECK	WM	04 Mar. 2016	FIGURE: 5.4-5
REVIEW	JF	04 Mar. 2016	

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LEGEND

PROJECT BOUNDARIES

- Project Area
- Local Study Area (LSA)
- Regional Study Area (RSA)

BASE MAP

- Waterbody
- Watercourse

TERRAIN UNITS

- Polygon Boundary (Label)
- Depositional Area (Colluvial Fans and Cones)
- Terrain Stability Class IV
- Terrain Stability Class V

TERRAIN CLASSIFICATION SYMBOL

Mvb[Rak]//Cfc[Rak]-RsV
IV, M
i . p

surficial material; surface expression; underlying material; underlying surface expression; delimiters; geomorphological process; geomorphological process subclass; terrain stability class; surface erosion potential; drainage

TERRAIN MAPPING LABEL LEGEND

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(Annotated List from Howes & Kenk (1998))

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- **x** very rapid
- **r** rapid
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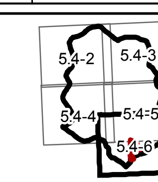

REFERENCE

CONTOURS OBTAINED FROM CANVEC © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED. ROADS AND HYDROLOGY OBTAINED FROM IHS ENERGY INC. ROADS ALSO OBTAINED FROM NATIONAL ROAD NETWORK DATA OBTAINED FROM GEOBASE®. SERVICE LAYER CREDITS: © 2016 DIGITALGLOBE IMAGE COURTESY OF USGS © 2016 GEOEYE © PROVINCE OF BRITISH COLUMBIA EARTHSTAR GEOGRAPHICS SIO © 2016 MICROSOFT CORPORATION
DATUM: NAD83 PROJECTION: UTM ZONE 10.

600 0 600

SCALE 1:20,000 METRES

PROJECT

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

TITLE

DESKTOP ANALYSIS: TERRAIN AND TERRAIN STABILITY MAPPING

Golder Associates

PROJECT	11-1422-0046		FILE No.
DESIGN	WM	19 Aug. 2014	SCALE AS SHOWN REV. 0
GIS	DL	04 Mar. 2016	
CHECK	WM	04 Mar. 2016	FIGURE: 5.4-6
REVIEW	JF	04 Mar. 2016	

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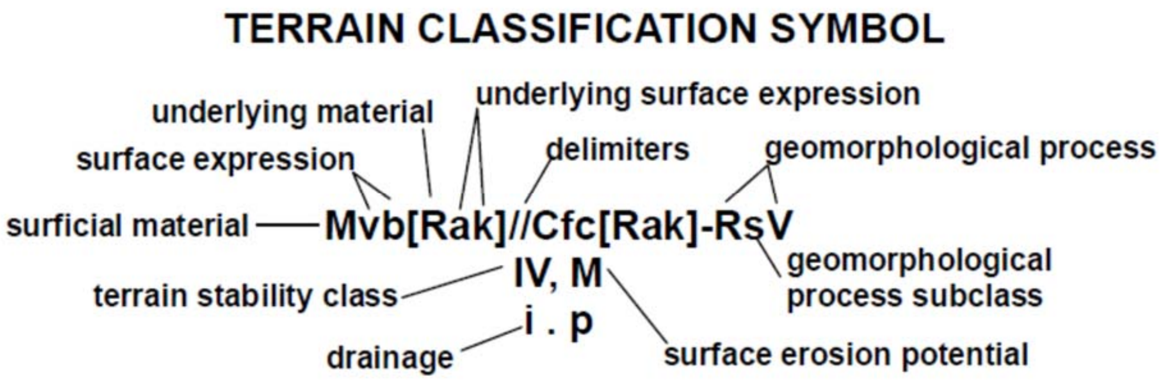
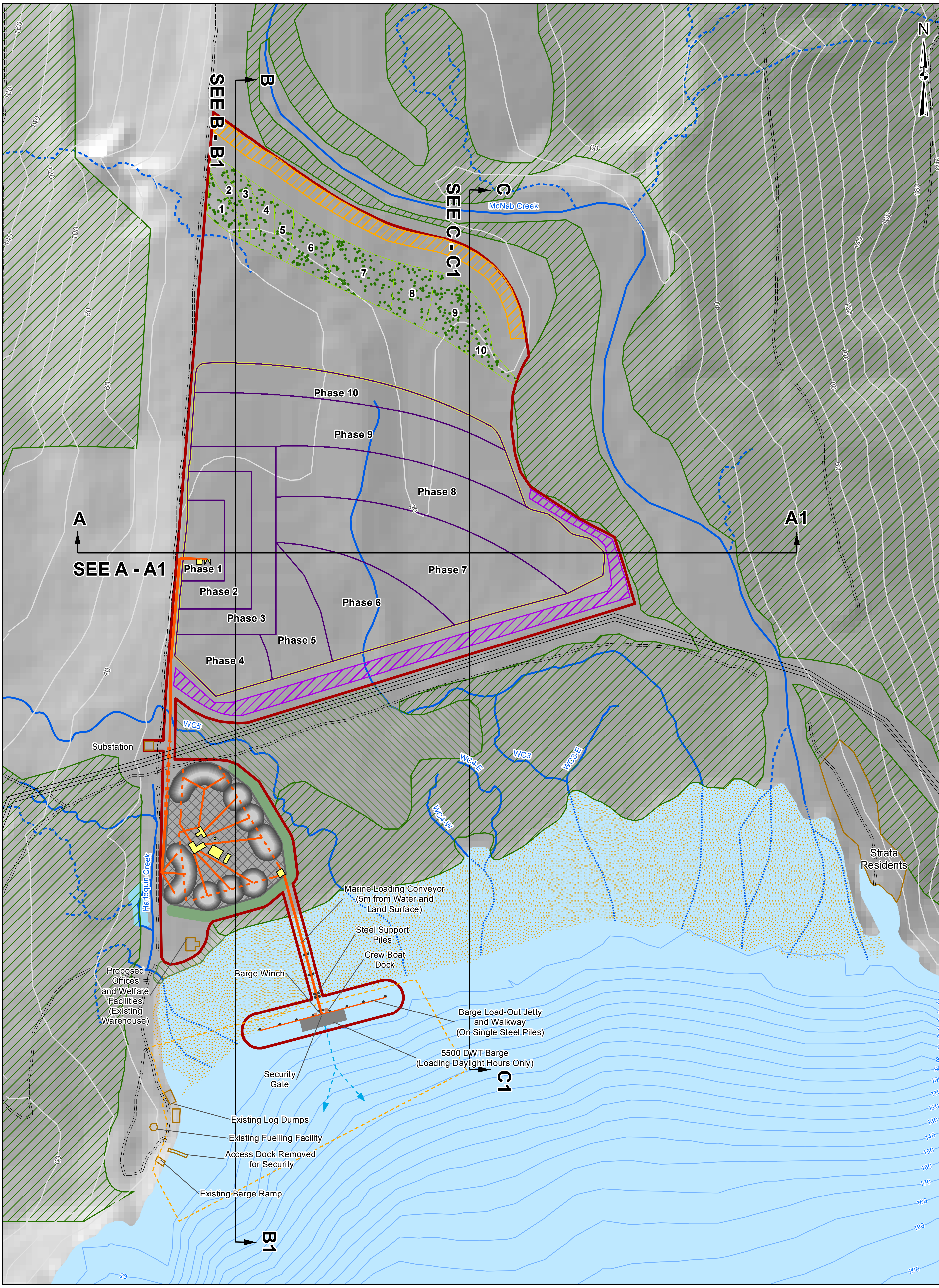


Figure 5.4-7: Terrain Classification Symbol (adapted from Howes and Kenk 1997)



LEGEND

- Project Area
- Proposed Aggregate Pit Phase
- Final Pit Lake Outline
- Product Stockpile
- Processing Area
- Existing Feature
- Existing Log Tenure Area
- Fines Storage Area
- McNab Creek Flood Protection Dyke
- Pit Lake Containment Berm
- Possible Processing Plant Configuration
- Processing Area Berm
- Mature 2nd Growth Forest
- New Planting Area
- Intertidal Zone
- Elevated Conveyor
- Underground Conveyor
- Barge Load-out
- Transmission Line
- Road (Existing)
- Contour (20m)
- Bathymetry (10m)
- Permanent / Perennial Watercourse
- Intermittent Watercourse
- Intertidal Watercourse
- Barge Route
- Cross Section Line
- Pile

200 0 200

SCALE 1:6,500 METRES

REFERENCE

Projection: UTM Zone 10 Datum: NAD 83

PROJECT

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

TITLE

PROPOSED CONCEPTUAL SITE LAYOUT AND CROSS SECTIONS

Golder Associates

PROJECT NO. 11-1422-0046			PHASE No.	
DESIGN	RB	10 Oct. 2014	SCALE AS SHOWN	REV. 0
GIS	DL	08 Mar. 2016		
CHECK	WM	08 Mar. 2016		
REVIEW	JF	08 Mar. 2016		

FIGURE 5.4-8

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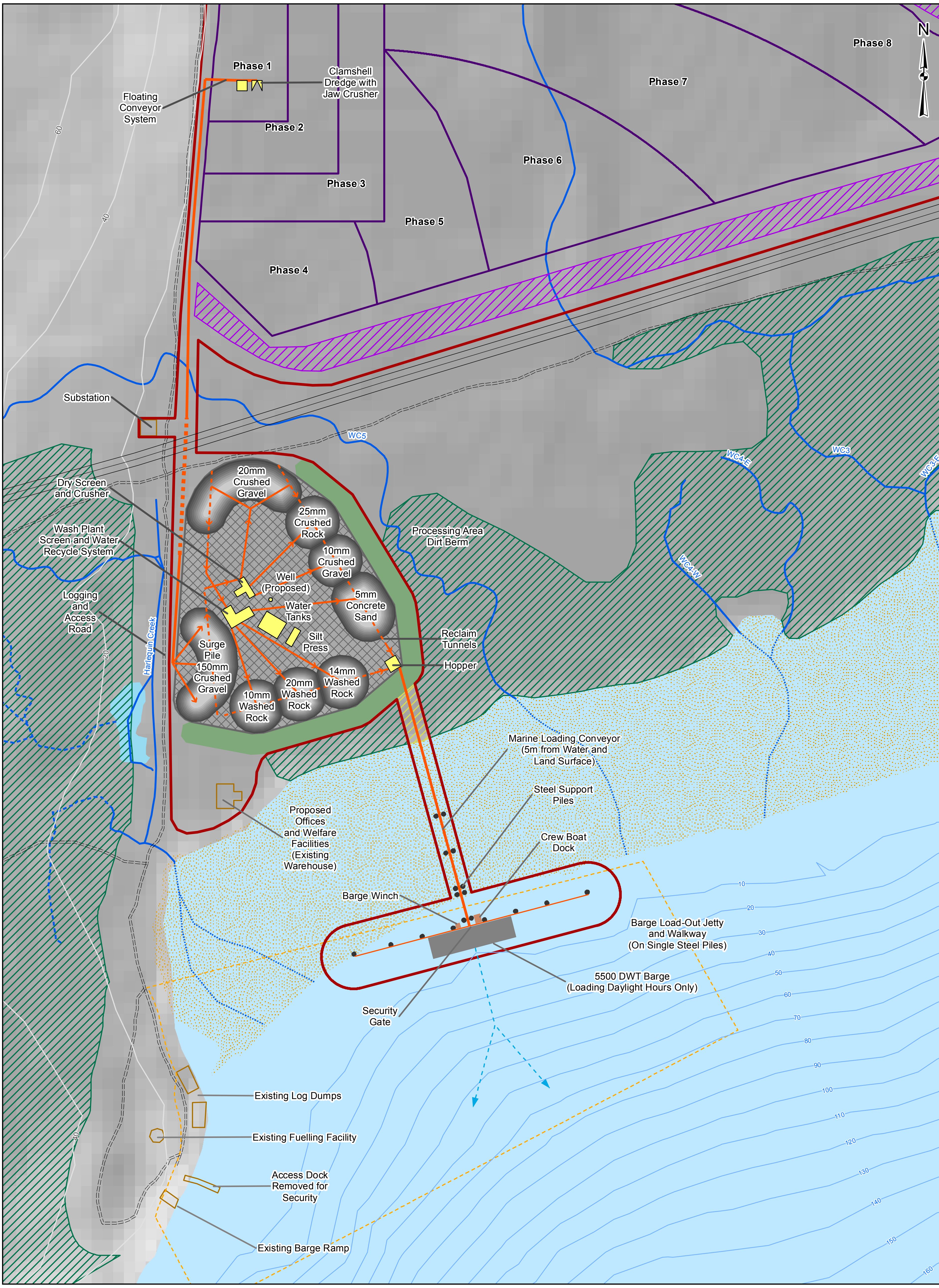

LEGEND

- Project Area
- Proposed Aggregate Pit Phase
- Possible Processing Plant Configuration
- Product Stockpile
- Processing Area
- Existing Feature
- Existing Log Tenure Area
- Pit Lake Containment Berm
- Conveyor Buffer
- Processing Area Berm
- Mature 2nd Growth Forest
- Intertidal Zone
- Elevated Conveyor
- Underground Conveyor
- Barge Load-out
- Transmission Line
- Road (Existing)
- Contour (20m)
- Bathymetry (10m)
- Permanent / Perennial Watercourse
- Intermittent Watercourse
- Intertidal Watercourse
- Barge Route
- Pile

100 0 100

SCALE 1:3,500 METRES

REFERENCE

DEM from Geobase. Watercourses from the Province of British Columbia and field data. Base data from the Province of British Columbia. Contours from TRIM positional data. Additional detailed site features provided by McElhanney.
Projection: UTM Zone 10 Datum: NAD 83

PROJECT

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

TITLE

CONCEPTUAL OPERATIONAL SITE LAYOUT

Golder Associates

PROJECT NO. 11-1422-0046			PHASE No.	
DESIGN	MJ	5 Jan. 2013	SCALE AS SHOWN	REV. 0
GIS	DL	08 Mar. 2016		
CHECK	WM	08 Mar. 2016	FIGURE 5.4-9	
REVIEW	JF	08 Mar. 2016		

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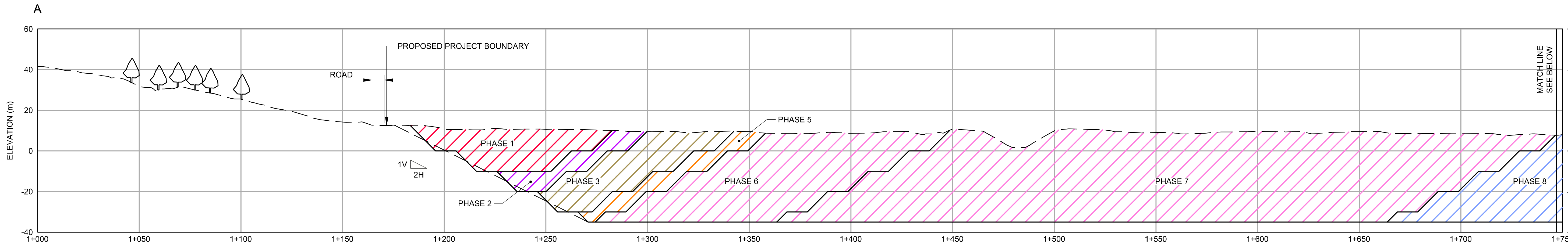
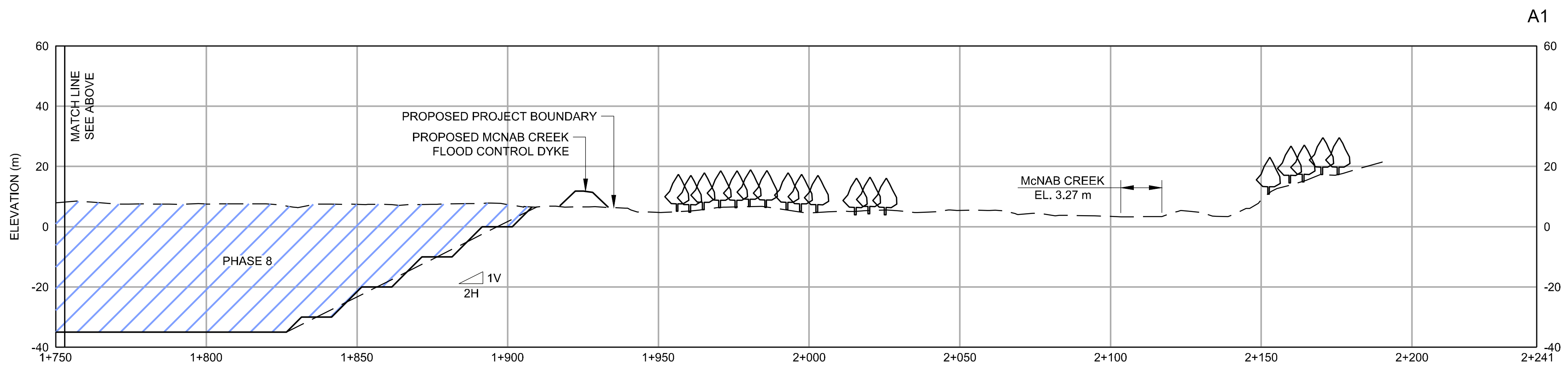




0 50 100

1:2,000 METRES

NOTES

1. PHASE BOUNDARIES ARE CONCEPTUAL IN PLAN.

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
1	2016-03-07	FINAL	FHS	MSH	FHS	RCB
A	2014-04-11	ISSUED FOR REVIEW	FHS	MSH	-	-

PROJECT

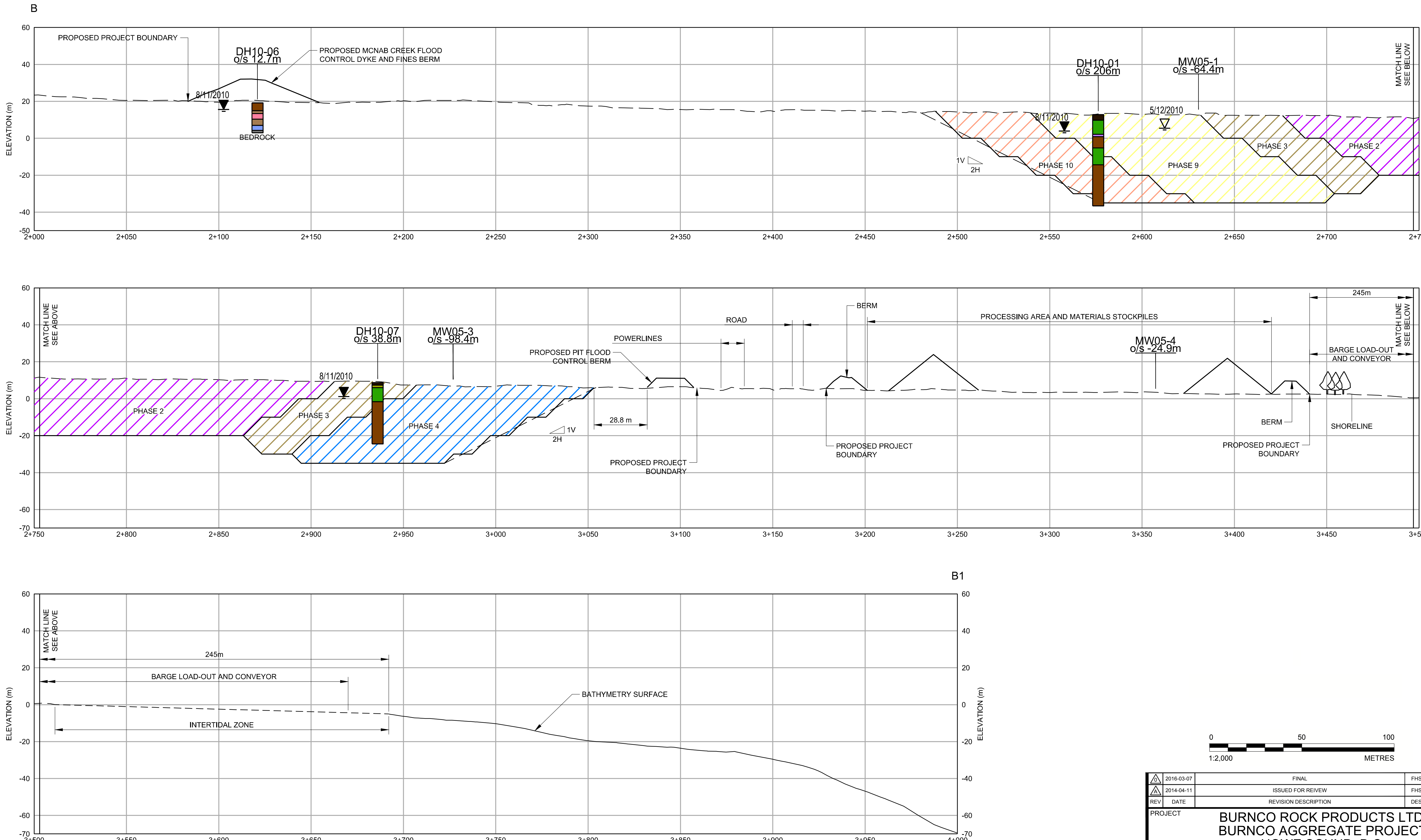
BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT
HOWE SOUND, B.C.

TITLE

SUBSURFACE CONDITIONS AND CONCEPTUAL MINING AND OPERATIONAL SITE LAYOUT SECTION A-A1

Golder Associates

PROJECT No.	11-1422-0046.3100		FILE No.	1114220046-3100-5.4-10
DESIGN	FHS	2014-04-11	SCALE	AS SHOWN
CADD	MSH	2014-04-11	FIGURE	
CHECK	FHS	2016-03-07		5.4-10
REVIEW	RCB	2016-03-07		



NOTES

1. PHASE BOUNDARIES ARE CONCEPTUAL IN PLAN.

STRATIGRAPHY LEGEND

- BEDROCK
- CLAYEY SILT SOME SAND AND GRAVEL
- FILL
- GRAVEL AND COBBLES, SOME SAND
- GRAVEL, SOME SAND
- SAND
- SAND AND SANDY GRAVEL WITH COBBLES
- SILT TO CLAYEY SILT
- SILT, SOME SAND

0 50 100
1:2,000 METRES

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
	2016-03-07	FINAL	FHS	MSH	FHS	RCB
	2014-04-11	ISSUED FOR REIVEW	FHS	MSH	-	-

PROJECT

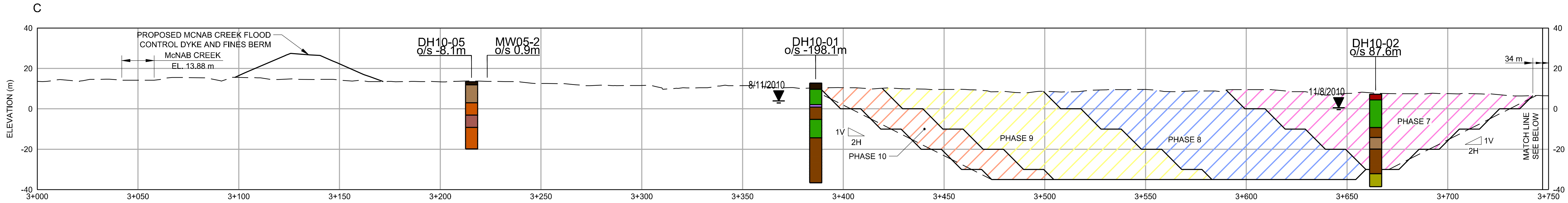
BURNCO ROCK PRODUCTS LTD.
BURNCO AGGREGATE PROJECT
HOWE SOUND, B.C.

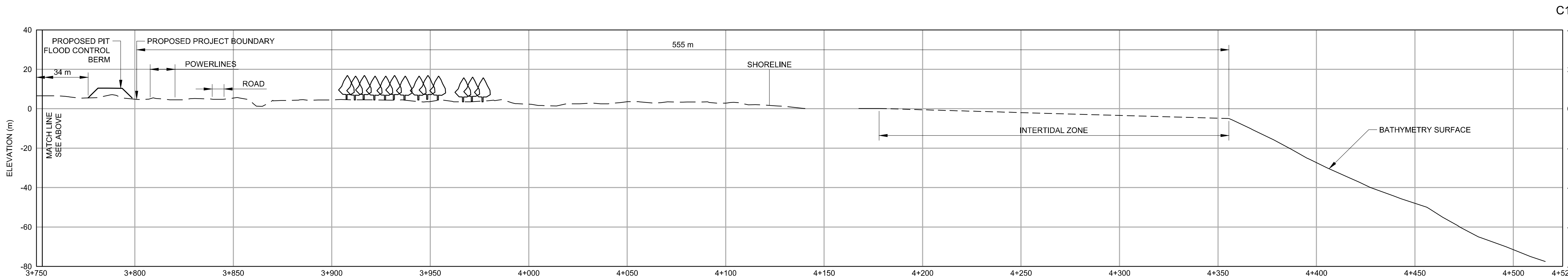
TITLE

SUBSURFACE CONDITIONS AND CONCEPTUAL MINING AND OPERATIONAL SITE LAYOUT SECTION B-B1

Golder Associates

PROJECT No.	11-1422-0046.3100	FILE No.	1114220046-3100-5.4-11
DESIGN	FHS	2014-04-11	SCALE AS SHOWN
CADD	MSH	2014-04-11	FIGURE
CHECK	FHS	2016-03-07	5.4-11
REVIEW	RCB	2016-03-07	





0 50 100

1:2,000 METRES

NOTES

1. PHASE BOUNDARIES ARE CONCEPTUAL IN PLAN.

STRATIGRAPHY LEGEND

- BEDROCK
- CLAYEY SILT SOME SAND AND GRAVEL
- FILL
- GRAVEL AND COBBLES, SOME SAND
- GRAVEL, SOME SAND
- ORGANIC FILL
- SAND
- SAND TO SANDY GRAVEL
- SAND AND SANDY GRAVEL WITH COBBLES
- SILT TO CLAYEY SILT
- SILT, SOME SAND

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
	2016-03-07	FINAL	FHS	MSH	FHS	RCB
	2014-04-11	ISSUED FOR REIVEW	FHS	MSH	-	-

PROJECT

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

TITLE

SUBSURFACE CONDITIONS AND CONCEPTUAL MINING AND OPERATIONAL SITE LAYOUT SECTION C-C1

Golder Associates

PROJECT No.	11-1422-0046.3100	
DESIGN	FHS	2014-04-11
CADD	MSH	2014-04-11
CHECK	FHS	2016-03-07
REVIEW	RCB	2016-03-07

FILE No. 1114220046-3100-5.4-12

SCALE AS SHOWN

FIGURE 5.4-12