Terrain Stability Hazard Assessment

Block HM50

Halfmoon Bay, Sunshine Coast

Project Number: 19-205

April 6, 2020

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EARTH WATER LAND

RECOMMENDATIONS SUMMARY

Terrain

Terrain within Polygons A and C will have low terrain stability hazard for ground-based yarding methods. Polygon B will have low hazard for restricted ground-based yarding methods.

Roads

The hazard of road prism failure following conventional construction is low on all of the inspected road segments. Chartwell did not request an assessment of the existing Br. Road Spur 210.

Sedimentation Hazard

Harvesting within Block HM50 will have low sedimentation hazard due to the lack of connectivity to downslope sensitive receptors.

Roads also present low sedimentation hazard, again because of the lack of connectivity to sensitive receptors, however water management along the proposed roads will be required to prevent diverted runoff from flowing along the roads to cross outside the watershed boundary, or from flowing into the S4 stream at the stream crossing along Br. Road HM50-2.

Implementation of the general remedial measures prescribed in Section 6.4 will help minimize erosion potential and maintain low sedimentation hazard.

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1.0 INTRODUCTION

Chartwell Consultants Ltd. (Chartwell) working on behalf of Sunshine Coast Community Forest (SCCF) retained Statlu Environmental Consulting Ltd. (Statlu) to assess the terrain stability hazard for Block HM50 near Halfmoon Bay. An assessment was requested because the block is located within the Milne Creek Community Watershed. The block will be harvested using a combination of ground-based and restricted ground-based yarding methods.

Colton Cantner, B. Sc., GIT from Statlu assessed the block on November 27, 2019 with Rurik Muenter, RPF of Chartwell. There were clear sunny skies with cold temperatures and there were no barriers to normal visibility during the assessment. The assessment route is shown on Figure 1 (Appendix 1). We spent approximately 2 hours in the block.

Statlu's assessment methods and rationale are described in Appendices 2 and 3, commonly used terms are defined in Appendix 4, road cut and fill guidelines are provided in Appendix 5 and sedimentation hazard assessment methods are described in Appendix 6.

2.0 OVERVIEW OF SETTING AND DOWNSLOPE RESOURCES

Block HM50 is located on south- southwest-facing slopes at the edge of the Coast Mountains, approximately 9 km northwest of Sechelt. Elevations within the block range from approximately 200 m to 280 m above mean sea level.

2.1 Downslope Resources and Elements at Risk

Transmission Lines 2L047 and 1L035 parallel the lower block boundary. Trout Lake is located approximately 290 m to the southwest of Block HM50, on the other side of the transmission lines and contains three active water licenses. Identification of other downslope resources, including timber, recreational, archaeological, etc. is beyond the scope of this report.

2.2 Bedrock and Surficial Geology

The block is underlain by Late Jurassic-aged dioritic rocks (iMapBC, 2019). This rock is generally competent. I observed bedrock outcrops and colluvial blocks within Block HM50 that match this description.

Surficial material in the area consists of a till veneer to mantle with localized areas of fluvial and lacustrine sediments in low-lying areas, particularly near Trout Lake. The till consists of matrix-supported sandy-silty with 15% to 30% rubbly coarse fragment content. Soils range from imperfectly- to well-drained.

2.3 Weather and Climate

Climatic information is important for terrain stability studies because it describes general weather trends, including the frequency and intensity of precipitation that in turn, gives clues about possible antecedent moisture conditions and provides guidance for environmental shutdown of operations. Climate is difficult to describe in mountainous terrain because long-term weather stations are clustered in valley bottoms in populated areas of the province.

The nearest long-term climate station with data for the thirty-year period ending in 2010 is at Gibsons Gower Point, about 33 km southeast of the block (Environment Canada, 2019) at an elevation of 34 m above sea level. The mean annual precipitation is 1355 mm, with 72% falling between October and the end of March. Mean annual snowfall is 31 cm. Extreme daily precipitation was 66 mm of rainfall, in October 2003.

ClimateWNA is a climate model that uses data from western North America to predict climate characteristics for locations distant from weather stations (Wang *et al.*, 2016). Using data for the 30-year period ending in 2010, the model describes the climate at the block as 1371 mm mean annual precipitation with 67 cm as snow. Approximately 79% of total precipitation (1088 mm) arrives between October and April.

Peak flows near the block are probably caused by intense rainfall with rain-on-snow events at higher elevations.

3.0 TERRAIN OVERVIEW

Terrain near the block, as seen on Google™ Earth and digital orthophotos, is reflective of past glaciation with gentle slopes between rolling hillocks. Till blankets the area, overlying resistant bedrock while thin layers of colluvium are present across bedrock-controlled slopes and deposits of glaciofluvial sediments are localized to low-lying areas.

Near the block, rockfall appears to be the dominant mass movement process. Colluvial deposits derived from exposed bedrock across rounded ridges and scattered colluvial boulders are common. Previously harvested areas and existing roads adjacent to the block do not have evidence of widespread instability, suggesting forestry activity near the block has not reduced the surrounding terrain stability.

To the east of the block, landslides and debris flows have occurred. They are typically associated with old forestry roads that cross steep and gullied sideslopes of large and deeply incised streams that drain the Tetrahedron Plateau uplands near Sechelt.

3.1 Wind

The blocks are located near the southeastern coast of the Strait of Georgia, crossing low-relief terrain that offers little protection from damaging southeasterly winds blowing up the strait.

4.0 OBSERVATIONS, HAZARD EVALUATION, AND CONSEQUENCES

Block HM50 was divided into polygons based on homogenous terrain stability hazard, surficial materials, topography, and slope gradients (Figure 1).

4.1 Terrain Polygons

Polygon A comprises the majority of Block HM50. Terrain is planar to hummocky along contour with a slightly benchy profile. The slope gradients are between 0% and 35% with a few short bedrock slopes 45% steep in the middle sections of the block. The surficial material consists of an imperfectly to well-drained rubbly sandy till veneer to mantle.

Polygon A will have low terrain stability hazard for ground-based yarding methods. Small landslides, less than 20 m^3, could deposit within a few meters of the initiation site onto the surrounding gently sloped terrain.

Polygon B consists of upper sections of the block with one smaller area in the middle of the block. Slopes are bedrock controlled with uniform to irregular topography. Slope gradients range from 35% to 50%. In the northeastern corner of the block, there is a roughly 20 m wide bench with less than 30% slope gradients above the steeper irregular slopes. The surficial material consists of a well-drained rubbly sandy till veneer with exposed bedrock and a couple colluvial blocks up to 3 m in diameter.

Polygon B will have low terrain stability hazard for restricted ground-based yarding methods. Timber across greater than 40% slope gradients can be felled into lead. Landslides of less than 30 m^3 could deposit up to 25 m downslope onto gentle slope gradients within the block.

Polygon C is located in the northwestern corner of Block HM50. It consists of an undulating bench, up to 40 m wide with slope gradients of 15% to 25%, flanked by irregular slopes up to 40% steep. The surficial material consists of a well-drained rubbly sandy till veneer to mantle.

Polygon C presents low terrain stability hazard for ground-based yarding methods. Landslides could deposit within 10 m of the initiation site onto gently sloped terrain within the block.

4.2 Block HM50 Roads

Block HM50 will be accessed via the existing Br. Road Spur 210 and proposed Br. Roads HM50-2, HM50-3, and HM50-4. Chartwell only requested an assessment of the proposed branch roads.

The hazard analysis of the assessed roads for this report assumes that roads will be constructed using conventional cut and fill techniques. Construction options have been recommended for road segments where conventional methods would exceed low terrain stability hazard.

Branch Road HM50-2

Br. Road HM50-2 will be new construction. It branches off Spur 210 to crosses planar to hummocky topography with slope gradients between 5% and 35%. The surficial material consists of a moderately well- to well-drained rubbly to sandy till veneer to mantle. Conventional construction will result in low terrain stability hazard. A road failure could deposit within a few meters of the road.

Branch Road HM50-3

This road branches off the existing Spur 210 road. It will be new construction.

From the **POC** to **Sta. 0+083,** the proposed road crosses flat terrain with 0% to 5% slope gradients. The surficial material is a moderately well-drained sandy till mantle. Conventional construction presents a very low terrain stability hazard. A road failure could deposit within a couple meters of the road.

From **Sta. 0+083** to the **POT,** the remaining length of road crosses planar to undulating slopes with slope gradients of 5% to 25%. The surficial material consist of a rubbly sandy till veneer to mantle and soils range from imperfectly- to well-drained. Road failures could deposit within 5 m of the road.

Branch Road HM50-4

Br. Road HM50-4 branches off HM50-3. It will be new construction. Across its length, the proposed road crosses planar terrain with slope gradients of less than 15%. The surficial material is composed of a moderately well-drained rubbly sandy till veneer to mantle. A road failure could deposit within a few meters of the road.

5.0 SUMMARY OF CONSEQUENCES AND MITIGATION MEASURES

The following tables summarize the potential consequences of terrain instability and recommended mitigation measures.

Table 1: Downslope Consequence and Mitigation Measures – Terrain Polygons

Polygon	Hazard for Clearcut Timber Harvesting	Consequences of Terrain Instability	Recommended Mitigation Measures
A	Low	Landslides could deposit within 25 m of the initiation site onto gently sloped terrain within the block.	N/A
B	Low		Use restricted ground-based yarding methods.
C	Low		N/A

Table 2: Downslope Consequences and Mitigation Measures – Block HM50 Br. Roads

Road Segment		Hazard for Conventional Construction	Consequence of Terrain Instability	Recommended Mitigation Measures
From	To			
Br. Road HM50-2				
POC	POT	Low	A road failure could deposit within a few meters of the road.	N/A
Br. Road HM50-3				
POC	0+084	Very Low	Road failures could deposit within 5 m of the road.	N/A
0+084	POT	Low		
Br. Road HM50-4				
POC	POT	Low	A road failure could deposit within a few meters of the road.	N/A

5.1 Windthrow-Induced Terrain Instability

Windthrow has the potential to affect terrain stability. Widespread blowdown creates ground disturbance and immediate loss of root strength (Laird, 2001). If extensive windthrow occurs above unstable terrain near a gully or stream, slope failures could be triggered. Wind exposed edges of cutblocks should not be located on the edge of potentially unstable terrain such as gully edges.

The boundaries of Block HM50 are located adjacent to gentle to moderately sloped recently harvested or bedrock-controlled terrain, both of which are unlikely to be destabilized by post-harvest windthrow.

5.2 Worker Safety

Short rock outcrops and bedrock slopes up to 20 m long are present throughout Block HM50. Rockfall could occur and would presents a worker safety hazard. Workers should follow appropriate environmental shutdown guidelines[1] which contains clauses covering rockfall initiation (based on the presence of freeze/thaw conditions) as well as the standard rainfall based criteria.

[1] https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/bc-timber-sales/ems-sfm-certification/business-area/chinook/tch_tsg_wet_weather_shutdown_guidance_field_table_final.pdf

6.0 SEDIMENTATION HAZARD EVALUATION

Block HM50 and the proposed roads in the block were classified according to sedimentation hazard, based on surficial materials, slope form and gradient, and proximity to downslope sensitive receptors (Figure 2). The methods used in assessing sedimentation hazard are described in Appendix 6.

6.1 Observations

Block HM50 is located within the Milne Creek Community Watershed. There is a small and shallowly incised stream that has been classified as an S4 stream because it is located within a community watershed, in accordance with the Forest Practices and Planning Regulation Section 47(2)[2], near the northwestern corner of the block and one wet area with observed pools of standing water in the middle of the block.

Sedimentation hazard depends on several factors including slope gradient, surficial material depth and texture, and proximity to creeks and sensitive receptors. The sensitive receptors near Block HM50 is Trout Lake 290 m southwest of the block, however there does not appear to be any stream connectivity between the block and the lake.

6.2 Terrain

There are three sedimentation hazard polygons within Block HM50 (Figure 2).

Polygon 1 includes the majority of the terrain within Block HM50. The slope gradients are between 0% and 50%, with planar to hummocky morphology. Soils have a sandy texture with up to 30% rubbly coarse fragments and are moderately well- to well-drained. There are no streams in the polygon. The polygon has high soil erosion potential and low sediment delivery potential, which results in low sedimentation hazard.

[2] http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/12_14_2004#section62

Polygon 2 comprises a low-lying wet area within the middle section of the block where discontinuous pools of standing water were observed. Slope gradients are less than 15% and topography is planar with sandy loam soils with imperfect drainage. Bedrock forms a water restricting layer at 50 cm or more depth. This area appears to concentrate surface runoff and may act as a sediment sink, however it is not connected to any sensitive receptors. Therefore, it has high sediment erosion potential and low sediment delivery potential, so the overall sedimentation hazard is Low.

Polygon 3 represents the areas within 5 m of the S4 stream in the northwestern corner of the block. The stream is roughly 150 m long, extending from just above the upper block boundary to below Br. Road HM50-2 where surface flow within the stream channel becomes subsurface flow as it drains into the overlying surficial materials once it reaches flat terrain. The slopes on either side of the stream are uniform to irregular with slope gradients of 15% to 30%. Soils are a moderately well- to well-drained sandy loam with rubbly coarse fragments, similar to in the rest of the block. The stream terminates within the block and is not connected to any sensitive receptors. Polygon 3 therefore has high sediment erosion potential and low sediment delivery potential so the overall sedimentation hazard is low.

6.3 Roads

Sedimentation hazard for roads depends on soil erosion potential and sediment delivery potential. Soil erosion potential is high for roads. The sediment delivery potential depends on connectivity of the ditch system to creeks capable of transporting sediment or to other sensitive receptors. Since block roads have high erosion potential, the sedimentation hazard depends on the proximity to and size of streams and stream crossings and proximity to other sensitive receptors.

The road segments in Block HM50 have low sediment delivery potential because ditch networks are separated from streams. At Sta. 0+571, Br. Road HM50-2 crosses the S4 stream in Sedimentation Polygon 3. The stream did not appear to have constant water flow, as it was dry at the time of the assessment, it dewaters approximately 20 m below the road, and it is not connected to any sensitive receptors. Therefore, the road crossing has an overall low sedimentation hazard. To maintain this low hazard, ensure any water flowing within the road ditch near the stream crossing is not directed towards to the stream.

In addition, water management along the roads will be important to prevent surface runoff that is diverted either along the road surface or within the road ditch from flowing across the watershed boundary as the first 120 m of the proposed roads are located outside of the watershed.

Implementing the measures described in Sections 6.4 and 6.5 will maintain low sedimentation hazard, help minimize erosion, and prevent surface runoff diverted by roads from leaving the watershed.

6.4 General Erosion and Sediment Control Measures

It is important to minimize erosion potential and subsequent sedimentation in regions of the harvest area and along the proposed roads.

The following are general recommendations for reducing erosion potential and subsequent sedimentation during harvesting:

- Equipment operators should be adequately trained and experienced to mitigate ground disturbance.
- Use slash or brush matting to prevent soil disturbance during ground based harvesting.
- To prevent rutting and gouging, use tracked equipment rather than rubber tired equipment on steeper slopes greater than 40% and near areas of poorly-drained soils/standing water.

- Ground based harvesting should occur under dry conditions, particularly on slopes steeper than 30%. When harvesting within the low-lying wet area (Polygon 2), where concentration of surface runoff has resulted in discontinuous pools of standing water, ensure all equipment working in this area is tracked and implement 5 m wide machine free zones (MFZ) around any pooling water that may be present.
- While harvesting near the S4 stream (Polygon 3), implement a 5 m wide MFZ along both banks of the stream. To reduce channel disturbance and prevent overland flow from being directed or concentrated toward the stream, use fall away and yard away harvesting techniques. Do not cross-stream yard except where Br. Road HM50-2 crosses the stream at Sta. 0+571 or at designated stream crossing points with temporary drainage structures.
- After harvesting, cover any areas of exposed soil with slash and/or promote rapid revegetation of disturbed areas through seeding and/or planting an appropriate grass and legume seed mix.

For road construction, hazard and erosion mitigation options include:

- Construct roads and ditches under dry conditions. Dry conditions in this context refers to soil moisture and should not be confused with wet weather shutdown thresholds for terrain stability. Appropriate thresholds for precipitation for dry conditions are approximately 10 to 15 mm/24 hr for rainfall or a similar amount of snowmelt. Restarting operations after a shutdown will depend on soil drainage class; well-drained surficial material may take 12 hours to dry out after the rain. Operators should judge dry conditions on the ground. Visual indicators of dry conditions are a lack of runoff along road running surfaces or a lack of continuous flow in road ditches.
- Install sumps at culvert inflows to trap ditchline sediment.
- Armour seepage points along ditchlines and culvert outflows with coarse rock to prevent erosion.
- Install culverts parallel to and 20 m to 30 m from stream crossings, so that the majority of ditch water is dissipated onto adjacent slopes and is not directly connected to the stream.

- Use silt fences and/or straw bales during road construction to trap sediment generated during the construction process. Straw bales have lower maintenance requirements than silt fences.
- To prevent diverted runoff along the proposed roads from flowing across the watershed boundary, install appropriately sized culverts along the roads on the woods side of the boundary to allow diverted runoff to flow off the road before crossing the boundary. High points within the road surface and ditch line at those road segments near the boundary can also be constructed to help prevent flow from crossing the watershed boundary. The watershed boundary should be marked in the field so that equipment operators, road builders etc. are aware of its location.

7.0 CONCLUSION

7.1 Terrain

Terrain within Polygons A and C will have low terrain stability hazard for ground-based yarding methods. Polygon B will have low hazard for restricted ground-based yarding methods.

7.2 Roads

The hazard of road prism failure following conventional construction is low on all of the inspected road segments. Chartwell did not request an assessment of the existing Br. Road Spur210.

7.3 Sedimentation

Harvesting within Block HM50 will have low sedimentation hazard due to the lack of connectivity to downslope sensitive receptors.

Roads also present low sedimentation hazard, again because of the lack of connectivity to sensitive receptors, however water management along the proposed roads will be required to prevent diverted runoff from flowing along the roads to cross outside the watershed boundary, or from flowing into the S4 stream at the stream crossing along Br. Road HM50-2.

Implementation of the general remedial measures prescribed in Section 6.4 will help minimize erosion potential and maintain low sedimentation hazard.

8.0 LIMITATIONS

The recommendations provided in this report are based on observations made by Statlu and are supported by information Statlu gathered. Observations are inherently imprecise. Conditions other than those indicated above may exist on the site. If such conditions are observed or if additional information becomes available, Statlu should be contacted so that this report may be reviewed and amended accordingly.

This report was prepared considering circumstances applying specifically to the client. It is intended only for internal use by the client for the purposes for which it was commissioned and for use by government agencies regulating the specific activities to which it pertains. It is not reasonable for other parties to rely on the observations or conclusions contained herein.

Statlu prepared the report in a manner consistent with current provincial standards and on par or better than the level of care normally exercised by Professional Geoscientists and Professional Agrologists currently practicing in the area under similar conditions and budgetary constraints. Statlu offers no other warranties, either expressed or implied.

9.0 CLOSURE

Please contact me should you have any questions or if you require further clarification.

Yours truly,

Statlu Environmental Consulting Ltd.

2020-04-06

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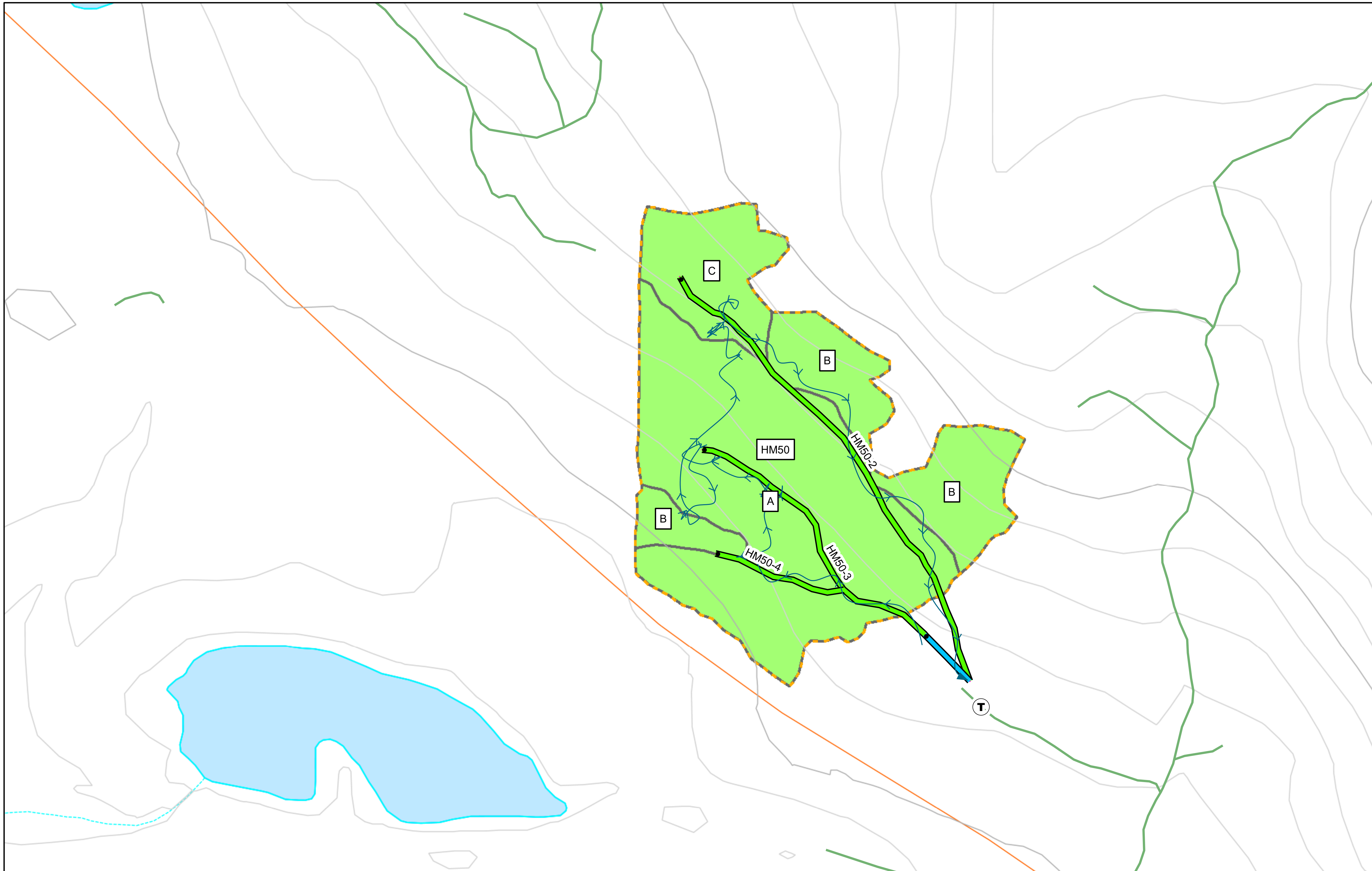

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Figure 1:
Road and Terrain
Hazard
Block HM50
Half Moon Bay

1:5,000

Client: SCCF
Project Number: 19-205

Legend

- Truck Location
- Creeks
- Traverse: November 27, 2019
- FTEN Roads
- Roads
- Block HM50

Road Hazard Rating

- Very High
- High
- Moderate
- Low
- Very Low
- Not Assessed

Terrain Hazard Rating

- Very High
- High
- Moderate
- Low
- Very Low
- Not Assessed

0 50 100 150 200
Meters

N

Author: R. Kremsat
Date Saved: Jan 09, 2020
NAD 1983 UTM Zone 10N

Terrain stability hazard ratings are depicted for the proposed harvesting method described in the accompanying report.
Road construction hazard ratings are depicted assuming all segments of road will be constructed using conventional methods.
Recommendations to reduce the road construction hazard to acceptable levels are provided in the report for segments rated higher than low.

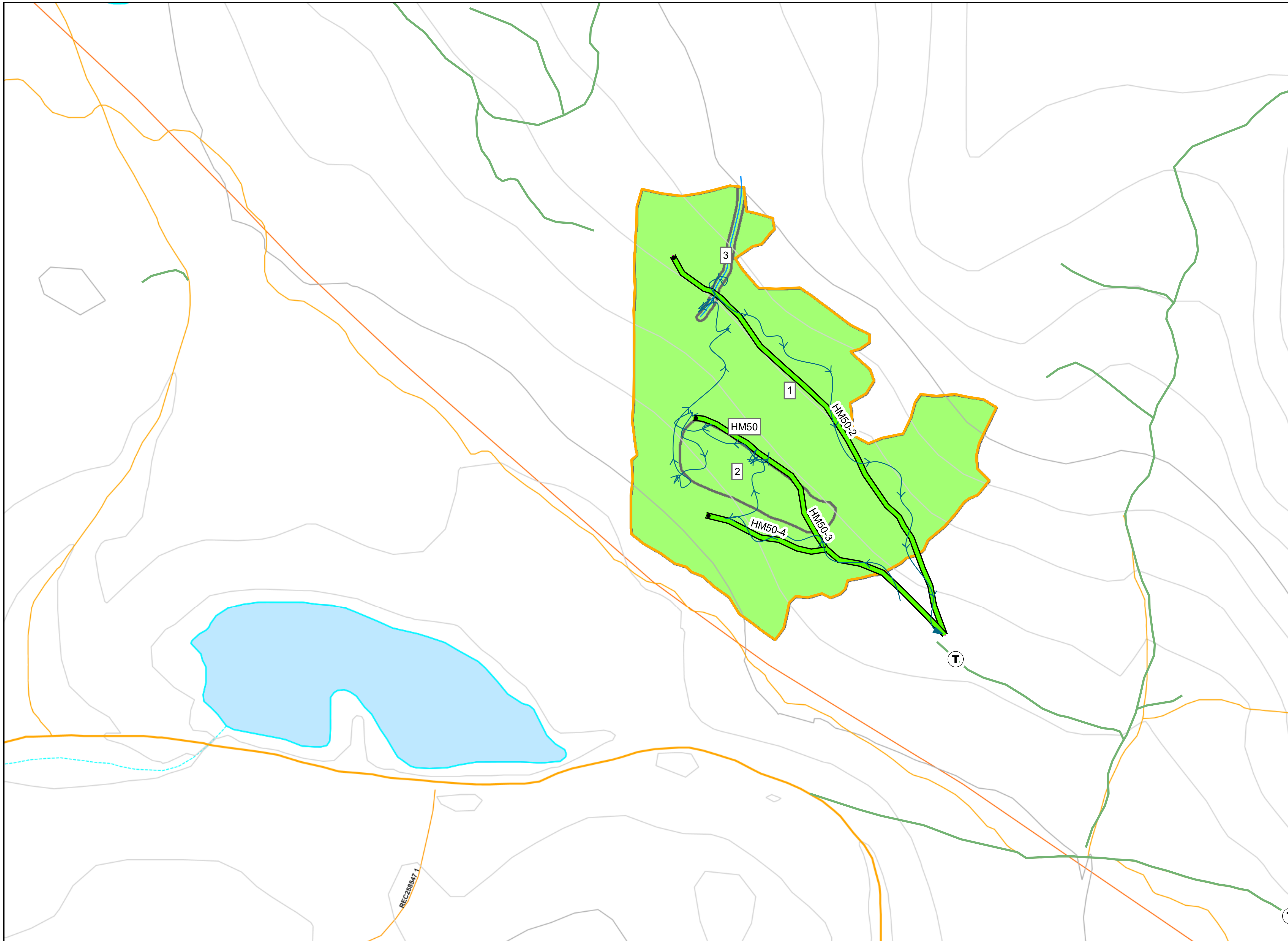

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Figure 2:
Sedimentation
Hazard
Block HM50
Half Moon Bay

1:5,000

Client: SCCF
Project Number: 19-205

Legend

- Truck Location
- Traverse: November 27, 2019
- Roads
- FTEN Roads
- Streams
- Block HM50

Road Sedimentation Hazard

- Very High
- High
- Moderate
- Low
- Not Assessed

Sedimentation Hazard Rating

- Very High
- High
- Moderate
- Low
- Not Assessed

0 50 100 150 200
Meters

N

Author: R. Kremsater
Date Saved: Jan 29, 2020
NAD 1983 UTM Zone 10N

APPENDIX 2: METHODOLOGY

The methods used in this assessment to evaluate and report on present or potential future geotechnical hazards, estimate their probability of occurrence, size and runout distance, and anticipate their probable consequences should they occur are based on accepted standards of professional geoscience current in the province of British Columbia. These methods follow the outline of recommended practice embodied in guidance documents, including:

- Guidelines for Professional Services in the Forest Sector – Terrain Stability Assessments (APEGBC, 2010);
- Mapping and Assessing Terrain Stability Guidebook (BC Ministry of Forests, 1999); and
- Similar publications.

The methods include insights for improved practice gained from current publications in peer-reviewed scientific literature.

My assessment included a consideration of the background information available for the area, including the area's climatic condition, topographic features, vegetation, bedrock, and surficial geology. I obtained and reviewed overview images for the area, including some or all of Google™ Earth imagery, digital orthophotos, and/or historic aerial photography, to provide historical perspective to my ground observations.

The field traverse was located using a combination of results from overview observations, discussion with the forest professional, and professional experience to located features of interest. The field traverse passed through and beyond the area(s) of interest to include areas of steep or potentially unstable ground within and adjacent to the proposed blocks and roads.

The field traverse is augmented by observations of terrain in the general vicinity of the block(s), looking particularly for evidence of past natural or logging- or road-related instability, especially activity that might have occurred more recently than the date of the most recent imagery covering the area in question.

During my field traverse, I observed and recorded details of surficial material type, drainage, topographic expression and position, stream courses, vegetation, bedrock geology, and evidence of past instability. I considered the proposed development (logging and/or road building) as well as the proposed size and location of drainage structures and the resultant potential for changes in runoff and subsurface hydrology. I made note of existing patterns of windthrow, including whether or not past windthrow had resulted in local instability.

Based on my overview and field investigations, and my professional experience and judgment, I divided the terrain and proposed roads within the study area into homogenous polygons or segments of road. I developed qualitative estimates of the likelihood of landslides or other terrain instability for the polygons and road segments that I assessed, both for existing conditions, and for post-harvest or post-construction conditions assuming that the development occurred using the construction, harvest, and yarding methods proposed by forest professionals for the block(s) and/or road(s) in question. In areas where the post-construction or post-harvest likelihood of instability was greater than low, I provided recommendations to mitigate the hazard.

I have evaluated the potential consequences of terrain instability and described those consequences to the best of my professional ability. Ultimately, the determination of acceptable risk is outside the scope of my assessment and must be made by forestry professionals and government land managers. This assessment is intended to provide information to assist those professionals with their decisions.

APPENDIX 3: RATIONALE FOR ASSESSMENT AND DEFINITION OF HAZARD AND CONSEQUENCE

Rationale for Assessment

The slope stability hazard ratings in this report are determined using a comparative analysis based on observations of terrain conditions near the cutblock and the results of previous logging and road building in adjacent areas. Studies of past occurrence, causes and impacts of natural and logging-related landslides in southwestern British Columbia are also taken into account, including Millard et al. (2002), Brayshaw and Hassan (2009), and Wolter et al. (2010)

Based on our professional experience and the discussion above, the main criteria leading to a moderate or high likelihood of landslides or debris flows are:

- Steep slope gradients generally greater than 75%;
- Imperfect or poorer soil drainage, and/or presence of springs and seepages;
- Slope morphology – gullies and slope concavities that concentrate drainage;
- Thick deposits of glaciogenic surficial materials, including till, glaciofluvial, and glaciolacustrine deposits, associated with steep slopes or gullies;
- Rapidly weathering or highly fractured bedrock; and,
- The presence of past landslides.

These factors act in combination and may not indicate slope hazard in isolation. The probability of the hazard occurring increases as more of the factors listed above occur in combination. A rapidly drained 80% gradient open slope with thin blocky colluvial deposits may have a low likelihood of post-logging terrain instability; a moderately well-drained 80% slope in deep silty till along a gully sidewall represents a high likelihood for post-harvest instability.

For roads, the most important factors in predicting slope failure are slope gradient, road construction and maintenance methods, water management, and nature and depth of the surficial materials exposed in the cutslope. Most road related failures are associated with oversteepened fill, poor water management, a lack of maintenance, or oversteepened cutslopes.

The frequency and magnitude of large bedrock landslides are generally unaffected by forest harvesting, and prediction of such events is beyond the scope of this report. However, where we have observed evidence of bedrock instability that could result in worker or public safety hazards, we have noted it in the report.

Definition and Classification of Terrain Stability Hazard

Hazards related to terrain instability depend on the frequency and magnitude of geomorphic events such as debris flows and landslides. Event frequency and magnitude are inversely related, that is, large landslides occur less frequently than small landslides. Statlu uses a qualitative rating system, based on pre-existing standards of practice embodied in legislation and used by professional geoscientists throughout British Columbia (*i.e.,* BC Ministry of Forests Mapping and Assessing Terrain Stability Guidebook, LMH 18, LMH 53, LMH 56), to express the probability of occurrence of landslides post-harvesting or post-road building (Table A1). These probabilities of occurrence are based on an expected magnitude for relatively small and consequently frequent landslides typical of slope instability within forestry operations – an area of 0.05 to 1.0 ha and a total failure volume of from hundreds to thousands of cubic meters of material.

Table A1: Definition of Terrain Stability Hazard Classes

Hazard Class	Expected Number of Failures Per 100 ha of Similar Terrain	Expected Probability of At Least One Failure over One Forest Rotation for 10 ha Polygon	Expected Number of Failures Per Km Length of Road
Very Low	<0.1	<0.8%	<0.01
Low	0.1-1	0.8%-5%	0.01-0.04
Moderate	1-5	5%-40%	0.04-1
High	5-50	40%-95%	1-5
Very High	>50	95%-100%	>5

Consequences of Terrain Instability and Partial Risk

Land Management Handbook 56 (Wise et al. 2004) and the BC Ministry of Forests Forest Road Engineering Guidebook (2002) define risk as the product of the probability of hazard and consequence. Consequence further depends on the nature of the element(s) at risk, the exposure of those elements to the hazard, and the vulnerability of those elements to the hazard. Statlu recognizes that the evaluation of the exposure and vulnerability of elements at risk to the identified hazards is difficult and may require specialized skills or additional information not available to professional geoscientists. Since the information is available or potentially available to land managers and statutory decision makers, we have concentrated on identifying and describing the geomorphic components of the consequence of terrain instability, specifically the expected runout distance and expected areas of deposition for landslides and their likelihood of reaching downslope identified elements and resources at risk. This is a partial risk analysis since it identifies the geomorphic components of a risk analysis without addressing the vulnerability of the elements at risk to the hazard.

As an example, consider a theoretical 10 ha cutblock planned for clearcut harvest on a steep mountain slope. There is a forest service road 400 m downslope and a S3 fish stream 600 m downslope. Statlu estimates that the post-harvest hazard of landsliding from the cutblock is low, and that if landslides occur, they are likely to reach and cross or deposit on the forest service road, and will likely deposit on the low-gradient terrain between the road and the stream, but could potentially reach the fish stream below the road.

To extend this geomorphic analysis to a full evaluation of the consequence of the potential landslide and the resultant risk requires information on the value of timber on the slopes below the block, the nature and frequency of use of the forest service road by industrial and recreational traffic, the quality of riparian habitat, species present and seasonality of use of the fish stream by those species, and other information beyond the purview of geoscience but available or potentially available to land managers and statutory decision makers.

Broadly speaking, the estimations of probability for runout and deposition determined by Statlu correspond to the following classes of consequence from the Forest Road Engineering Guidebook (Table A2). These correspondences are approximate and are provided only to help with decision-making.

Table A2: Definition of Probabilities of Consequence

Qualitative Probability of Consequence	Range of Quantitative Probabilities of Occurrence	Approximate Qualitative Consequence Class
Certain; Will Occur	>50%	Very High
Likely to Occur	25-50%	High
Probable; Could Occur	10-25%	Moderate
Unlikely to Occur	1-10%	Low
Remote or Will not Occur	<1%	Very Low

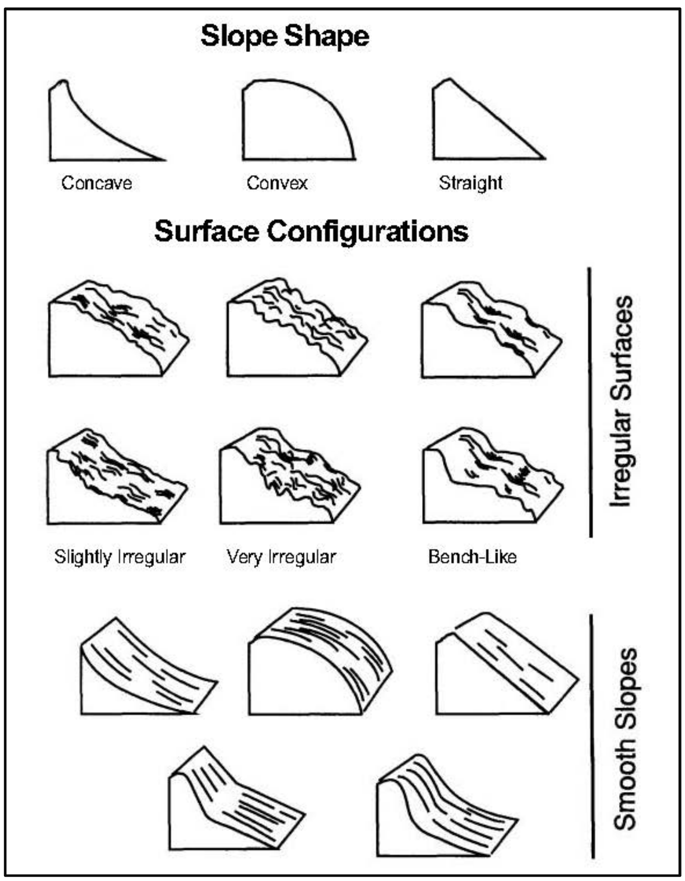
APPENDIX 4: DEFINITIONS

Statlu follows the Terrain Classification System for British Columbia, 2nd Version when describing terrain attributes (Howes and Kenk, 1997) and the Canadian System of Soil Classification, 3rd Ed. (SCWG, 1998) when describing soil drainage and forest soils.

Slope morphology: the shape of the slope, both along contour and in profile.

Term	Along Contour	In Profile
Concave	The contour converges	Slope gradient decreases downslope
Convex	The contour diverges	Slope gradient increases downslope
Irregular	No pattern to slope changes	Slope changes gradient with no pattern
Uniform/straight	Consistent shape	Slope has consistent gradient
	General Slope Descriptors	
Benched	A series of flat bench tops broken by steeper steps between benches, similar to terraces but not formed by fluvial processes	
Terraced	Slope pattern of step-like forms composed of flat tops or treads separated by shorter, steep pitches (risers); formed by fluvial processes	
Undulating	An assemblage of multidirectional slopes; regular slope variation along contour	

(From LMH 18)



Soil Drainage: the rate at which saturated surficial material reaches field capacity, the moisture content remaining after removal of water by gravity (usually 24 hours after saturation)

Soil Drainage Class	Description
Very rapid	Water removed rapidly in relation to supply. Water source is precipitation.
Rapid	Water removed rapidly in relation to supply. Water flows downward if material is pervious. Water source is precipitation. Soils are generally coarse textured.
Well-drained	Water readily removed from soil. Water flows downward or laterally.
Moderately well-drained	Water is removed from soil somewhat slowly in relation to supply.
Imperfect	Water is removed from the soil slowly. The soil remains wet for a significant portion of the growing season. Soils may be mottled.
Poor	Water is removed so slowly in relation to supply that the soil remains wet when it is not frozen. Soils may be mottled or gleyed.
Very Poor	Water is removed so slowly in relation to supply that the water table remains at or near the surface for most of the time the soil is not frozen. Associated with wetlands.

(From LMH 25)

Surface expression: the form and pattern expressed by a surficial material at the land surface. Figure B1 provides a general summary of terms commonly used to describe surface expression. In addition to common terms, we describe sediments thicker than approximately 5 m as "deep."

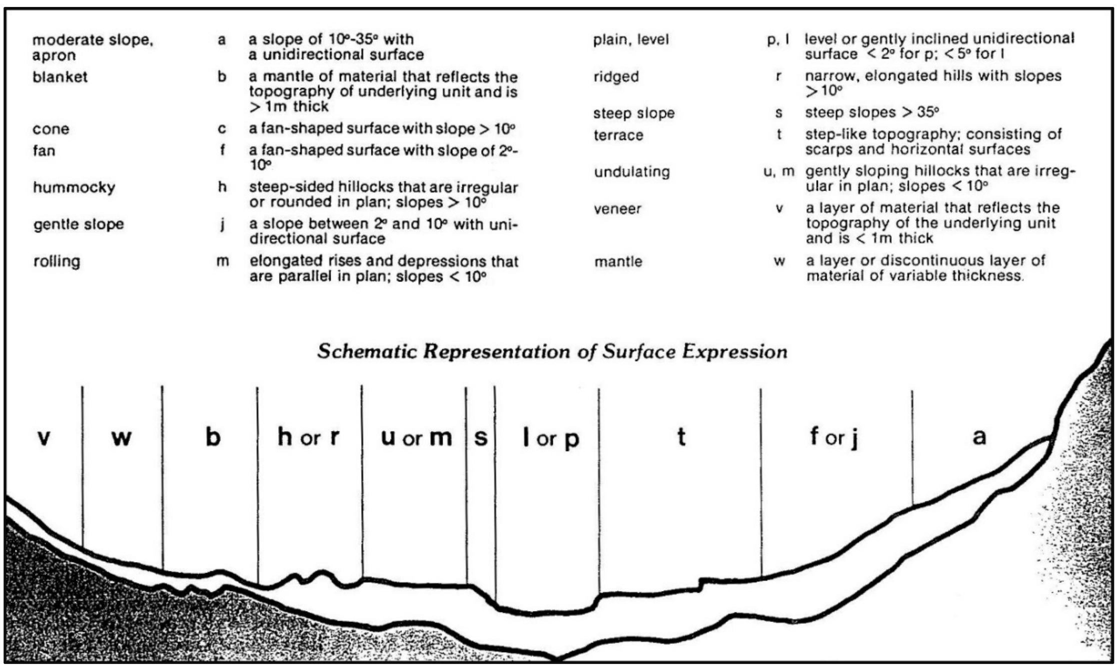


Figure B1: Common surface expression terms (Ryder and Howes, 1986)

Surficial materials: non-lithified, unconsolidated sediments that are classified by mode of deposition (*i.e.,* till, colluvium, glaciofluvial).

Surficial material texture: the size, shape, and sorting of particles in clastic sediments.

Single Particles		Mixtures	
Class Name	**Particle Size and Shape**	**Class Name**	**Particle Size and Shape**
clay	< 0.002 mm	gravel	> 2 mm, mix of round particles; pebbles, cobbles, boulders
silt	0.002 mm – 0.0625 mm	rubble	2 mm to 256 mm, mix of angular particles
sand	0.0625 mm - 2 mm	mud	mix of clay and silt; may include sand
pebbles	2 mm - 64 mm, round	angular fragments	> 2 mm, mix of angular particles; blocks and rubble
cobbles	64 mm - 256 mm, round	mixed fragments	> 2 mm, mix of round and angular particles
boulders	> 256 mm, round	diamicton	mix of materials with two or more distinct particle sizes
blocks	> 256 mm, angular		

Harvesting Methods

Harvesting systems include four phases: falling and bucking, yarding, loading, and hauling. Timber yarding methods have the greatest effect on terrain stability and are often modified to reduce the likelihood of increased post-harvest terrain instability (CSSP, 1995).

Ground-based yarding uses skidders, hoe forwarders, or other equipment to bring timber to the landing. Skidders drag timber on the ground, hoe forwarders carry timber or lift and swing it to a yarding or skidding corridor, landing, or roadside. Application of ground-based methods is limited by slope gradient, slope shape, soil sensitivity to erosion, and weather. Ground-based yarding with rubber tired or tracked machines is limited to slope gradients <40%. Restricted ground-based yarding uses ground-based machines on slope gradients between 40% and 60% by running machinery on cut and fill skid trails or from roads.

Cable yarding uses stationary yarders to move logs along cables from where they were felled to the roadside or landing. Cable yarding reduces soil disturbance and can be used on steep slopes. Skyline and highlead are two cable yarding methods.

Helicopter yarding is used to yard logs in sensitive or inaccessible terrain. Helicopters are used to fly logs from where they were felled to an accessible drop site. Helicopter yarding is both expensive and slow compared to other yarding methods.

Road Construction Terms

Conventional Construction: cut and fill is balanced; fill is sidecast on the downslope side of the road and will form a portion of the load-bearing road surface. Where conventional construction is described as a low-hazard option, other construction techniques that use more fill than cut, such as overlanding and full fill, are also low-hazard options unless otherwise specified.

Conventional Reconstruction: conventional reconstruction of an existing road consists of resurfacing the road, re-establishing a functional ditch line, and installing drainage structures with appropriate capacity and spacing.

Conventional Reconstruction with no sidecast is identical to regular conventional reconstruction, but prescribed in areas where existing roads cross steep slopes and where sidecast would result in oversteepened or unstable perched fills. Material which cannot be incorporated into the road surface during reconstruction operations must be endhauled to an appropriate spoil site.

Full Bench: the cut width is equal to the road width; none of the road prism is supported on fill. Sidecast may be hauled to a dump site, used for road ballast, or fully sidecast, as prescribed in the report and as defined below. Ditches are constructed on full bench road segments and where specifically recommended in the report.

Partial Bench (Sliverfill): 3/4 to full bench construction where fill is supported on rubbly material draped down hillslope. Used only in rock or coarse colluvium, or in locations where thin veneers of sidecast material will disperse downslope stably. Do not place material over organic material, soil, logs, etc.

Full Sidecast: Excavated material may be cast downslope but must not form a portion of the load-bearing road surface. Full bench with full sidecast is typically prescribed in locations where the slope is too steep for load-bearing fill to be stable but topographic features downslope of the road prism will capture and stabilize sidecast material.

No Sidecast: The sideslopes are too steep to support sidecast; therefore, all sidecast material must be hauled to a spoil site or spoiled in grade on adjacent road segments.

Keyed Fill: The ballast is composed of coarse pieces of angular rock placed on, and supported by, an excavated bench. The toe of the bench should be wide enough to support the lowest course of placed rock (generally 1.0 m to 1.5 m wide) and should be gently outsloped to facilitate drainage.

APPENDIX 5: GENERAL GUIDELINES FOR ROAD CUT AND FILL SLOPE ANGLES

Roads in sensitive areas (community watersheds, sensitive terrain, or areas where instability or erosion are unacceptable) should use flatter cut and fill slope angles than these general guidelines. These guidelines assume the cutslope height will be less than 6 m. Specific recommendations, if any, provided in the report take precedence over these general guidelines.

Texture	Example Material	Cutslope Angle (H:V)	Example Material	Fillslope Angle (H:V)
Coarse-grained soils	Loose to compact sands and gravels (glaciofluvial or fluvial; sandy till)	1½:1 (67%)	Sands, sands and gravels, or well-drained mixtures (glaciofluvial or fluvial; sandy till)	1½:1 (67%)
Coarse-grained sediments	Rubble (colluvium; scree slope	1½:1 (67%)	Placed angular rock, not dumped	1:1 (100%)
	Blocks (talus)	¼:1 to 1¼: 1 (80 to 100%)	Dumped angular or placed rounded rock	1¼:1 to 1½:1 (67-80%)
Fine grained soils	Loose silt, or soft cohesive soils such as silty clay, or clay	1½:1 (67%) for lower cuts 2:1 (50%) for higher cuts	Silts and clays	2:1 (50%)
	Hard, cohesive silty clays or clays	1:1 (100%)		
Dense till or cemented sands and gravels	Basal till, cemented sands and gravels	¾:1	Sands, sands and gravels, or mixtures of coarse- and fine-grained soils	1½:1 (67%)
Rock	Competent rock	¼:1 to vertical (100% to 400%)	Placed angular rock, not dumped	1:1 (100%)
	Weathered or fractured rock	¼:1 to 1¼: 1 (80 to 100%)	Dumped angular or placed rounded rock	1¼:1 to 1½:1 (67-80%)

(Ministry of Forests, 2002)

APPENDIX 6: SEDIMENTATION HAZARD ASSESSMENT METHODOLOGY

Statlu uses the *Hazard Assessment Keys for Evaluating Site Sensitivity to Soil Degrading Processes Guidebook, 2nd Ed.* (Ministry of Forests, 1999) to determine sedimentation hazard. The following keys have been modified from the guidebook.

Sedimentation hazard is the chance that eroded sediment will reach sensitive receptors. It depends on erosion potential and sediment delivery potential. Erosion potential is the ability for sediments to be eroded and it depends on precipitation, topography, sediment thickness and texture, etc. Sediment delivery potential describes the connectivity between sediment sources and sensitive receptors.

Erosion Potential

Erosion potential uses site factors to classify blocks and roads. The classification assumes that the soil is exposed to intense rainfall events. The erosion potential classification considers only the likelihood of sediment being displaced. It does not address the likelihood of eroded sediment reaching sensitive receptors.

Soil Erosion Hazard Key

Site factors	Degree of contribution of factors			
	Low	**Moderate**	**High**	**Very High**
Climate precipitation factor (points)	Low 2	Moderate 4	High 6	Very high 8
Slope Gradient (%) (points)	0-10 1	11-20 3	20-50 6	>50 9
Slope Length/Uniformity (points)	Short, broken 1	Short, uniform 2	Long, broken 3	Long, uniform 4
Depth to water-restriction (cm) (points)	>90 1	61-90 2	30-60 3	<30 4
Surface soil texture (0-15 cm)[a] (points)	SC, C, SiC 1	SiCL, CL, SCL 2	SL, L 4	Si, SiL, fSL, LS, S 8
Surface coarse fragments % (0 to 15 cm)[a] (points)	>60 1	31-60 2	16-30 3	<16 4
Subsoil texture (16 cm to 60 cm)[a] (points)	S, LS, SL, fSL 1	L, SiL, Si 2	CL, SCL, SiCL 3	C, SC, SiC 4
Soil erosion hazard rating [b] (point total)	**Low <16**	**Moderate 16-22**	**High 23-31**	**Very High >31**

[a] If two contrasting textures or coarse fragment contents occur in the depth, use the one with the highest point rating.

[b] Gently sloping areas with long, uniform slopes may rate as high soil erosion hazard since substantial erosion can occur, under the right conditions.

The climate precipitation factor is very high for southwest BC except for specific very dry ecosystem subclasses. All other site factors are classified according to field observations.

Sediment Delivery Potential

Sediment delivery potential describes the probability of displaced sediment reaching creeks with moderate or high sediment transport capacity. It is a classification that assumes sediment has been displaced by erosion, creeks are capable of transporting sediment to sensitive receptors, and the forest floor and understory vegetation remain relatively intact.

Sediment Delivery Potential Keys

Risk of sediment delivery to streams	Proximity and size of stream		
	No stream in or adjacent	Minor stream [a] in or adjacent	Major stream [b] in or adjacent
Low	>70% slopes[c]	< 25% slopes	
Moderate		25 to 70% slopes	< 25% slopes
High		> 70% slopes	25 to 70% slopes

[a] Perennial streams with channel widths ≤ 1.5 m, or ephemeral streams, or Class S4 or NCD streams.

[b] Perennial streams with channel widths > 1.5 m, or Class S1, S2, or S3 streams.

[c] Slope steepness downslope to stream channel.

Sedimentation Hazard

Sedimentation hazard is defined as the product of soil erosion potential and sediment delivery potential. The hazard is based on the probability of eroded sediments reaching a sensitive receptor.

		Sediment Delivery Potential		
		Low	Moderate	High
Erosion Potential	Low	Low	Low	Low
	Moderate	Low	Moderate	Moderate
	High	Low	Moderate	High
	Very High	Moderate	High	Very High