TERRAIN STABILITY HAZARD ASSESSMENT

Blocks AN03, AN3A, and AN15

Grey Creek

Project Number: 21-187

August 9, 2022

Client:
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EARTH WATER LAND

RECOMMENDATIONS SUMMARY

Terrain

The proposed ground-based and restricted ground-based harvesting in Blocks AN03, AN3A, and AN15 will result in low terrain stability hazard.

Terrain in Polygon E, outside Block AN15, has moderate terrain stability hazard. The boundary between Falling Corner (FC) 17 and FC 17-3 was adjusted in the field to exclude this from Block AN15. No other boundary adjustments are recommended.

Roads

The hazard of road prism failure following conventional construction or reconstruction is very low to low on all of the inspected segments. Follow the recommendations described in Section 4.2.1 and summarized in Section 7.0 to reconstruct the Stream A and Stream B crossing for the segment of Br. Road AN15-1 between Sta. 0+585 and Sta. 0+620.

Windthrow

Increased windthrow near Stream A could increase the potential for and the runout distance of a channel avulsion or reduce terrain stability above the channel. The boundaries of Block AN15 from FC 8 to FC 19, and FC 10 to FC 17, and the boundary of Block AN03 from FC 24 to FC 27 should be assessed for windthrow susceptibility by a qualified professional.

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APPENDICES

1.0 INTRODUCTION

Chartwell Resource Group Ltd. (Chartwell), working on behalf of Sunshine Coast Community Forest (SCCF), retained Statlu Environmental Consulting Ltd. (Statlu) to assess the terrain stability hazard for Blocks AN03, AN3A, and AN15, north of Sechelt. Chartwell requested Statlu's services because steep terrain is located near the blocks. The blocks will be harvested using ground-based and restricted ground-based yarding methods.

Colton Cantner, B. Sc., GIT from Statlu assessed the blocks on December 9, 2021, with Callum Fallis, FIT, of Chartwell. The weather was cloudy with cold temperatures and it began to snow as we were walking out of the blocks at the end of our assessment. There were no barriers to normal visibility within the blocks. The assessment route is shown on Figure 1 (Appendix 1). We spent approximately 3 hours assessing the blocks.

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

2.0 OVERVIEW OF SETTING AND DOWNSLOPE RESOURCES

Blocks AN03, AN3A, and AN15 are located on west-facing slopes above Sechelt Inlet at the edge of the Coast Mountains, 6 km north-northeast of Sechelt (Figure 1). Elevations within the blocks range from approximately 280 m to 440 m above mean sea level.

2.1 Downslope Resources and Elements at Risk

Several resources are located downslope or downstream of the blocks. Stream A (S5) flows between the patches of Block AN15 and continues to flow 10 m to 30 m downslope of Block AN03 to join Gray Creek (S2) 950 m downstream of the blocks. A fish hatchery is located on Gray Creek 1.2 km downstream of the blocks, approximately 900 m upstream of Sechelt Inlet. The blocks are 50 m to 550 m upslope of the Sechelt-Dakota Forest Service Road (FSR). The lower boundary of Block AN3A follows the Sechelt-Angus FSR. An above-ground transmission line 1L044 is 330 m to 700 m downslope of the blocks. Identification of other downslope resources, including timber, recreational, archaeological, etc., is beyond the scope of this assessment.

2.2 Bedrock and Surficial Geology

Bedrock in the area is Jurassic to Cretaceous-aged granodioritic intrusive rocks (iMapBC, 2022). Bedrock outcrops in the blocks is generally competent, with some fracturing in places.

The surficial material in the area consists of two units. The first and most common unit is a mantle of silty-sand diamictic till with angular coarse fragment content. The second and less extensive unit is a discontinuous blocky colluvial veneer, predominately occurring below bedrock outcrops. The surficial materials are moderately well to rapidly 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 30-year period ending in 2010 is at Gower Point, 20 km southeast of the blocks at an elevation of 34 m above sea level (Environment Canada, 2022). The mean annual precipitation was 1355 mm, with 72% falling between October and the end of March. Mean annual snowfall was 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 near the blocks as 1793 mm mean annual precipitation with 121 cm as snow. Approximately 80% of total precipitation (1428 mm) arrives between October and April.

The blocks are located near the edge of the rain/rain-on-snow transition zone. Intense rainfall and rain-on-snow events can cause peak flows in Gray Creek.

2.4 Wind

Winds blowing up the Salish Sea from the southeast will be the most probable damaging winds as they are funneled up Sechelt Inlet.

3.0 TERRAIN OVERVIEW

Blocks AN03, AN3A, and AN15 lie above Sechelt Inlet below the Tetrahedron Plateau uplands. It generally has low relief with uniform to undulating topography and rolling bedrock ridges, reflective of past glaciation as coalescing glaciers flowed southward along the Georgia Depression (Holland, 1976). Thin layers of till and colluvium overlay resistant bedrock. Large streams eroded into the plateau by postglacial runoff and created V-shaped, steeply sided valleys.

Rockfall is the dominant mass movement process near the blocks. Colluvial deposits from bedrock outcrops are common. The nearest landslides visible on Google™ Earth imagery are 3 km away. The slides initiated from old forestry roads that cross steep and gullied terrain. The frequency of human-caused instability has decreased since the mid-1990s following improvements in forest management practices and deactivation of old logging roads.

4.0 OBSERVATIONS AND HAZARD EVALUATION

The terrain in the blocks was divided into polygons based on homogenous terrain stability hazard, surficial materials, topography, drainage, and slope gradients (Figure 1). The block boundaries were not used as part of my terrain mapping because the blocks are close to each other; therefore, terrain polygons may sometimes occur in more than one block.

4.1 Terrain Description and Hazard Analysis

The terrain in **Polygon A** includes smooth to slightly hummocky topography with mostly 5% to 30% slope gradients and some 2 m to 3 m high steps with 45% to 50% slope gradients. The surficial material is a mantle of moderately well- to well-drained rubbly sandy till, with some scattered colluvial blocks. The proposed ground-based yarding will result in low terrain stability hazard.

Landslides could deposit up to 30 m^3 of colluvium, derived from rubbly sandy till, onto surrounding gently sloped terrain within 10 m of the initiation site.

The terrain in **Polygon B** is slightly benchy with hummocky morphology. Slope gradients are up to 60%, with the steepest gradients on 5 m to 15 m high straight steps. The surficial material is a mantle of well-drained rubbly sandy till, with some imperfectly drained areas near shallow NCDs. Using restricted ground-based yarding will result in low terrain stability hazard.

Most landslides could be up to 50 m^3 in volume and could deposit up to 20 m downslope. Slides initiating near the northern boundary of Block AN03 could deposit into Stream A below the block. Landslides that reach the stream could cause a debris flow that could reach the Sechelt-Dakota FSR up to 450 m downslope. A debris flow could be up to 1500 m^3 in volume.

The terrain in **Polygon C** includes uniform topography with a straight to slightly concave profile and 40% to 60% slope gradients. The surficial material is a discontinuous veneer of blocky colluvium overlying a veneer of well-drained sandy till, with a few bedrock outcrops up to 1 m high. Restricted ground-based yarding will result in low terrain stability hazard.

Landslides could be up to 50 m^3 in volume and could deposit up to 30 m downslope onto gently sloped terrain or roads within the blocks.

The terrain in **Polygon D** has slightly ridge-and-swale morphology. Slope gradients are up to 25% in the swale bottoms and 40% to 60% on 10 m to 20 m high sideslopes. The surficial material is a mantle of moderately well- to well-drained sandy till, with some localized imperfectly drained sediments in the swale bottoms. Using restricted ground-based yarding will result in low terrain stability hazard.

Landslides could be up to 50 m^3 in volume and could deposit up to 30 m downslope onto gently sloped terrain within Block AN15.

The terrain in **Polygon E** includes the area around Stream A, outside the patches of Block AN15. The surrounding morphology is hummocky. Slope gradients are 10% to 55%. The surficial material is a mantle of imperfectly to moderately well-drained rubbly till.

Stream A has a 1 m deep channel with 5% to 20% channel gradients. A recent debris flow deposited coarse rock and woody debris 20 m upslope of Br. Road AN15-1. It caused an avulsion into a secondary stream channel (Stream B), 5 m to 10 m south of Stream A. Stream B is incised 30 cm to 50 cm with 10% to 20% channel gradients. Stream B eventually flows back into Stream A, 30 m below Br. Road AN15-1.

An old skid trail is located 2 m directly above Stream A. The trail follows the southern stream bank and slopes downhill towards Br. Road AN15-1. At the time of the field assessment, the boundary segment between FC 17 and FC 17-3 followed the skid trail directly above the stream.

The terrain in Polygon E has moderate terrain stability hazard. Harvesting the trees up to the skid trail above the stream could result in potential stream avulsions that would flow down the old skid trail. An avulsion would reach Br. Road AN15-1 and cause a road washout. The boundary segment between FC 17 and FC 17-3 was moved 20 m to the south, away from Stream A to reduce the potential for channel avulsions after harvest.

4.2 Block Roads

Access to the blocks will be via the Sechelt-Dakota FSR, the Sechelt-Angus FSR, an existing branch road, and several proposed branch roads. Chartwell only requested an assessment of the existing Br. Road AN15-1 and the proposed Br. Roads AN03-1, AN03-2, and AN15-2 within the blocks. I did not assess Br. Roads AN3A-1 and AN3A-2 because those roads were added after my field visit to the blocks.

The assessed roads were divided into segments based on slope gradient, terrain stability hazard, and recommended construction and reconstruction methods. The hazard analysis assumes that roads will be constructed or reconstructed using conventional techniques.

4.2.1 Br. Road AN15-1

Br. Road AN15-1 road will be reconstructed.

From **the PoC to Sta. 0+589,** the road crosses smooth to slightly hummocky morphology with 0% to 30% slope gradients. The surficial material is a mantle of moderately well- to well-drained rubbly sandy till. The road crosses NCDs and small S6 streams, with cross-ditches at the crossings. The streams are incised up to 30 cm into the surrounding terrain with 15% to 20% channel gradients. Conventional reconstruction will result in low terrain stability hazard.

From **Sta. 0+585 to Sta. 0+620,** the road climbs uphill. The road fillslope is up to 6 m long and rests on up to 20% slope gradients. The surrounding surficial material is a mantle of moderately well-drained sandy till with a mix of rubbly to blocky coarse fragments. The road crosses Stream B at Sta. 0+589 and Stream A at Sta. 0+614. A recent debris flow in Stream A deposited blocky colluvium 20 m upslope of the road and diverted water from Stream A into Stream B, which is a secondary channel of Stream A. The road crosses Stream B with a 50 cm deep cross-ditch. The road crosses Stream A with a 1 m to 1.5 m deep cross-ditch. The stream channel gradients are 15% to 25%.

Conventional reconstruction will maintain a low terrain stability hazard. Cross Stream A using a modified coarse rock ford with an appropriately sized culvert. Cross Stream B using a coarse rock ford with no culvert. Reconstruct the road segment and add a swale across the road to prevent avulsions from diverting down the road. Do not sidecast into the stream channels below the road.

From **Sta. 0+620 to Sta. 0+726 (the PoT),** the existing road crosses undulating terrain with 20% slope gradients. The surficial material is a mantle of well-drained sandy till. Conventional reconstruction will result in low terrain stability hazard.

Landslides from Br. Road AN15-1 could be up to 20 m^3 in volume and could deposit up to 20 m downslope. A debris flow or channel avulsion at the Stream A and Stream B crossings could led to a road washout or sediment depositing on the road.

4.2.2 Br. Road AN03-1

This road branches off the Sechelt-Dakota FSR. It will be new construction. The road crosses a mantle of imperfectly to well-drained rubbly sandy till along its entire length.

From **the PoC to Sta. 0+254,** the road crosses uniform terrain with a slight ridge-and swale morphology along contour. Slope gradients are mostly 10% to 50%, but some segments reach 55% to 65%. The steeper terrain extends up to 8 m above gently sloped terrain. Conventional construction will result in low terrain stability hazard because fill and sidecast will be supported below the road.

From **Sta. 0+251 to Sta. 0+281,** the road crosses a swale with an S6 stream. The swale sideslopes are 10 m high with 45% to 60% slope gradients. The swale bottom has 25% slope gradients. The stream channel gradient is 20%. Conventional construction will result in low terrain stability hazard.

From **Sta. 0+281 to the PoT,** the road enters Block AN03 and crosses slightly benchy terrain with a uniform to hummocky morphology. The slope gradients are 0% to 55%. Conventional construction will result in low terrain stability hazard.

Landslides initiating from Br. Road AN03-1 could be 10 m^3 in volume and could deposit within 10 m of the road.

4.2.3 Br. Road AN03-2

Br. Road AN03-2 branches off Br. Road AN03-1. The road will be new construction. It is a short spur that crosses a bench top with up to 15% slope gradients. The surficial material is a mantle of well-drained sandy till. Conventional construction will result in very low terrain stability hazard. A landslide initiating from the road could be 5 m^3 in volume and could deposit within a few meters of the road.

4.2.4 Br. Road AN15-2

Br. Road AN15-2 branches off Br. Road AN15-1. It will be new construction. The road crosses undulating topography with up to 25% slope gradients. The surficial material is a mantle of moderately well- to well-drained rubbly sandy till. Conventional construction will result in low terrain stability hazard. A landslide could be 10 m^3 in volume and could deposit within 10 m of the road.

5.0 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.

Increased windthrow near Stream A could increase the potential for and the runout distance of a channel avulsion or reduce terrain stability above the channel. The boundaries of Block AN15 from FC 8 to FC 19, and FC 10 to FC 17, and the boundary of Block AN03 from FC 24 to FC 27 should be assessed for windfirmness by a qualified professional. If the assessment indicates that post-harvest blowdown rates will significantly increase along the edge, windfirming strategies such as canopy treatment, feathering, or moving the boundaries further away from Stream A should be applied to mitigate the potential for blowdown to reduce terrain stability and increase channel avulsion potential and runout distance.

6.0 WORKER SAFETY

Workers should follow appropriate wet weather shutdown guidelines[1] when working in the block. Workers should be prepared to use their own best judgement and stop work if unsafe conditions are observed or if conditions become unsafe even if wet weather shutdown criteria have not been exceeded.

7.0 SUMMARY OF HAZARD MITIGATION MEASURES

The following tables summarize the recommended hazard mitigation measures for polygons and road segments.

[1] https://www2.gov.bc.ca/gov/content/industry/forestry/bc-timber-sales/forest-certification/ems-sfm

Table 1: Downslope Consequence and Hazard Mitigation Measures – Terrain Polygons

<table>
<tr><th>Polygon</th><th>Hazard for Clearcut Timber Harvesting</th><th>Downslope Consequences</th><th>Recommended Hazard Mitigation Measures</th></tr>
<tr><td>A</td><td rowspan="4">Low</td><td>Landslides could travel up to 300 m downslope to deposit about 100 m³ of sediment in Wray Creek.</td><td>N/A</td></tr>
<tr><td>B</td><td>Landslides could deposit within 20 m. Slides near the northern boundary of Block AN03 could deposit into Stream A and result in a debris flow that could reach Sechelt-Dakota FSR.</td><td rowspan="3">Use restricted ground-based yarding methods.</td></tr>
<tr><td>C</td><td rowspan="2">Landslides could deposit up to 30 m downslope.</td></tr>
<tr><td>D</td></tr>
<tr><td>E</td><td>Moderate</td><td>Channel avulsions would reach Br. Road AN15-1 and cause a road washout.</td><td>None. The block boundary was adjusted in the field.</td></tr>
</table>

Table 2: Downslope Consequences and Hazard Mitigation Measures – Blocks AN03, AN3A, and AN15 Roads

<table>
<tr><th colspan="2">Road Segment</th><th rowspan="2">Hazard for Conventional (Re)Construction</th><th rowspan="2">Downslope Consequences</th><th rowspan="2">Recommended Hazard Mitigation Measures</th></tr>
<tr><th>From</th><th>To</th></tr>
<tr><td colspan="5">Br. Road AN15-1</td></tr>
<tr><td>PoC</td><td>0+585</td><td>Low</td><td>Landslides would deposit within 20 m of the road.</td><td>None.</td></tr>
<tr><td>0+585</td><td>0+620</td><td>Low</td><td>A debris flow or channel avulsion could lead to a road washout.</td><td>Use a modified coarse rock ford with an appropriately sized culvert at Stream A and a coarse rock ford with no culvert at Stream B. Add a swale across the road. Do not sidecast into the stream channels below the road.</td></tr>
<tr><td>0+620</td><td>PoT (0+726)</td><td>Low</td><td>Landslides would deposit within 20 m of the road.</td><td>None.</td></tr>
<tr><td colspan="5">Br. Road AN03-1</td></tr>
<tr><td>PoC</td><td>PoT (0+530)</td><td>Low</td><td>Landslides could deposit 10 m downslope of the road.</td><td>None.</td></tr>
<tr><td colspan="5">Br. Road AN03-2</td></tr>
<tr><td>PoC</td><td>PoT</td><td>Very Low</td><td>A landslide would deposit within a few meters of the road.</td><td>None.</td></tr>
<tr><td colspan="5">Br. Road AN15-2</td></tr>
<tr><td>PoC</td><td>PoT (0+081)</td><td>Low</td><td>Landslides could deposit 10 m downslope of the road.</td><td>None.</td></tr>
</table>

8.0 CONCLUSION

8.1 Terrain

The proposed ground-based and restricted ground-based harvesting in Blocks AN03, AN3A, and AN15 will result in low terrain stability hazard.

Terrain in Polygon E, outside Block AN15, has moderate terrain stability hazard. The boundary between Falling Corner (FC) 17 and FC 17-3 was adjusted in the field to exclude this from Block AN15. No other boundary adjustments are recommended.

8.2 Roads

The hazard of road prism failure following conventional construction or reconstruction is very low to low on all of the inspected segments. Follow the recommendations described in Section 4.2.1 and summarized in Section 7.0 to reconstruct the Stream A and Stream B crossing for the segment of Br. Road AN15-1 between Sta. 0+585 and Sta. 0+620.

8.3 Windthrow

Increased windthrow near Stream A could increase the potential for and the runout distance of a channel avulsion or reduce terrain stability above the channel. The boundaries of Block AN15 from FC 8 to FC 19, and FC 10 to FC 17, and the boundary of Block AN03 from FC 24 to FC 27 should be assessed for windthrow susceptibility by a qualified professional.

9.0 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.

10.0 CLOSURE

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

Yours truly,

Statlu Environmental Consulting Ltd.

2022-08-09

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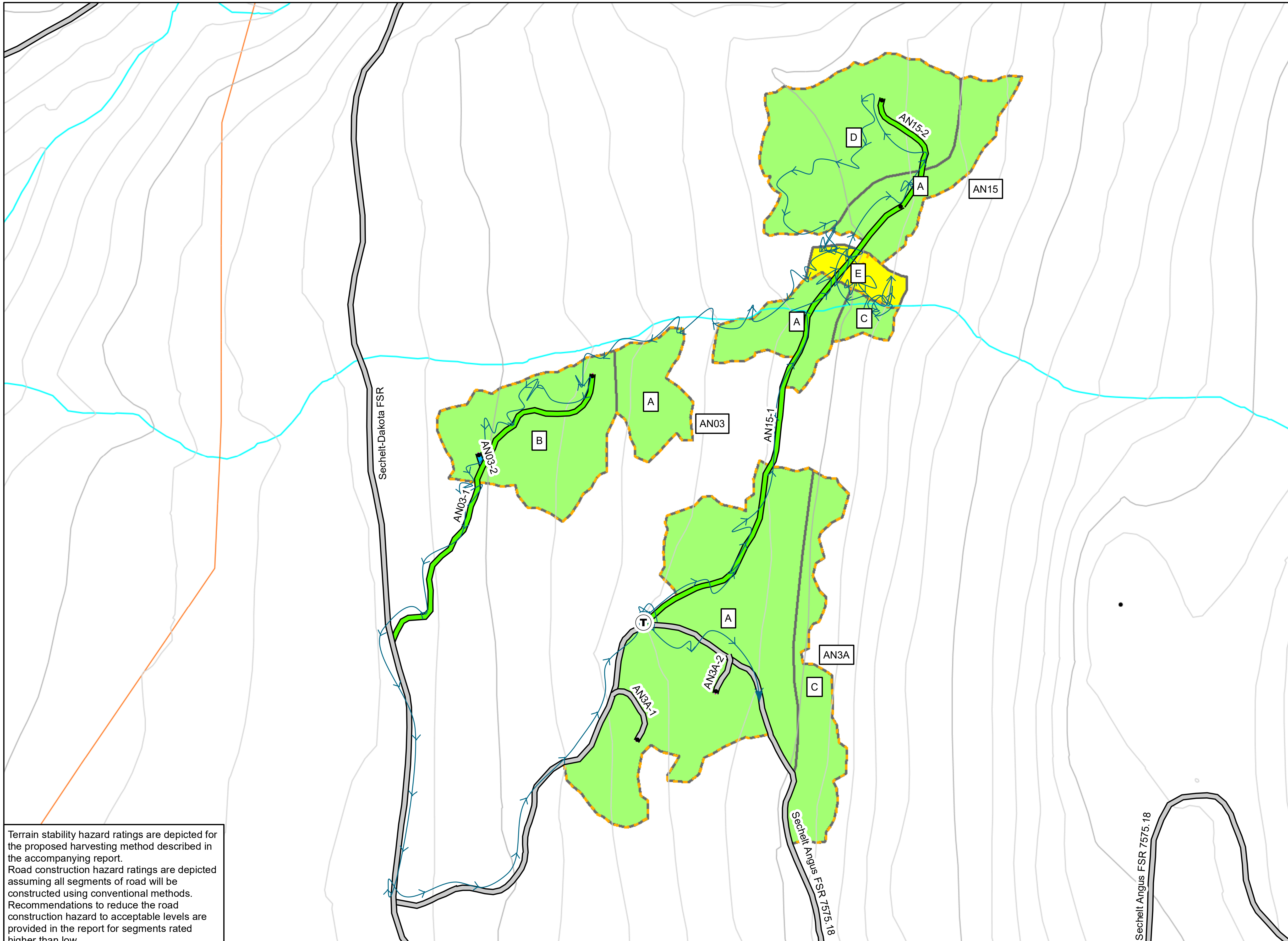

Terrain stability hazard ratings are depicted for the proposed harvesting method described in the accompanying report.
Road construction hazard ratings are depicted assuming all segments of road will be constructed using conventional methods. Recommendations to reduce the road construction hazard to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

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Figure 1: Road and Terrain Hazard Blocks AN03, AN3A, & AN15 Angus Creek

1:5,000

Client: SCCF
Project Number: 21-187

Legend

- Truck Location
- Creeks
- Traverse: December 9, 2021
- Roads
- Blocks AN03, AN3A, & AN15

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. Kremsater
Date Saved: May 30, 2022
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, oversteepened cutslopes, or a combination of these factors. The assessed hazard assumes that the road will be constructed in accordance with standard practices described in the FLNRO Engineering Manual unless it is specifically stated otherwise (MFLNRORD, 2022).

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

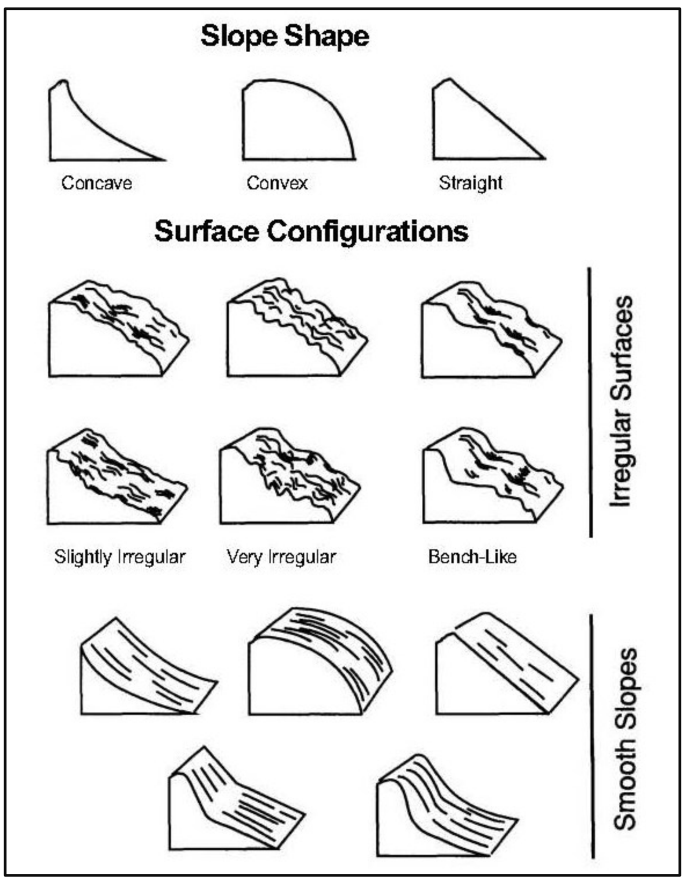
APPENDIX 4: DEFINITIONS

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."

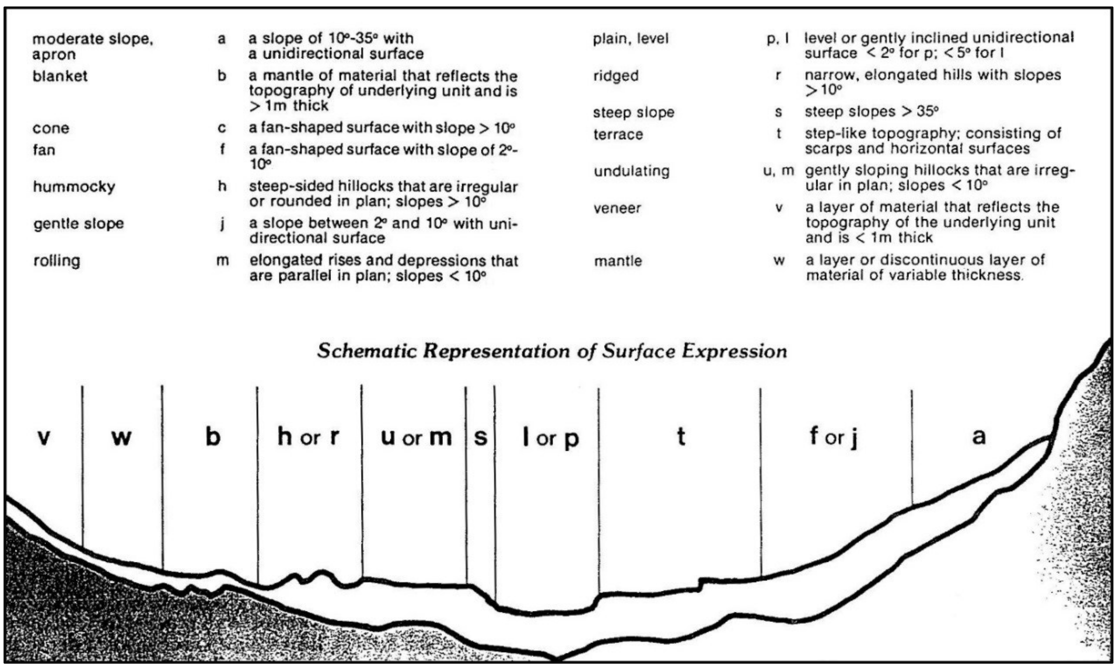


Figure B1: Common surface expression terms (Ryder and Howes, 1986)

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. A functional ditch line with appropriately sized and spaced drainage structures (e.g., culverts) will be installed. 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)