



TERRAIN STABILITY HAZARD ASSESSMENT

Blocks NK020, NK021, and NK022

Kookipi Creek

Project Number: 19-174

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Client:

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EARTH WATER LAND

RECOMMENDATIONS SUMMARY

Terrain

Terrain within Blocks NK020, NK021, and NK022 presents low terrain stability hazard for the proposed ground-based, restricted ground-based, and cable yarding methods.

Terrain with moderate terrain stability hazard is located outside Blocks NK020 and NK021.

Roads

The blocks will be accessed via reconstruction and new construction of several branch roads. The hazard of road prism failure following conventional construction and reconstruction is low on most of the inspected road segments. The following segments require specific reconstruction and construction techniques to either reduce the hazard to low, maintain low hazard, or to maintain worker safety hazard:

Br. Road NK1900

- Sta. 1+775 to Sta. 1+970
- Sta. 5+695 to Sta. 6+070

Br. Road NK1960

- Sta. 0+330 to the POT

Br. Road NK1970

- Sta. 0+594 to Sta. 0+633

Following the recommendations described in Section 4.4 and summarized in Section 5.0 for these segments will reduce the hazard to low.

Worker Safety

Rockfall, mobilization of large colluvial boulders, and snow avalanches present a worker safety hazard.

CONTENTS

1.0	Introduction	1
2.0	Overview of Setting and Downslope Resources.....	1
2.1	Downslope Resources an Elements at Risk.....	2
2.2	Bedrock and Surficial Geology	2
2.3	Weather and Climate	2
3.0	Terrain Overview	3
3.1	Wind	4
4.0	Observations, Hazard Evaluation, And Consequences.....	4
4.1	Block NK020	4
4.2	Block NK021	6
4.3	Block NK022	7
4.4	Roads.....	8
4.4.1	Branch Road NK1900.....	9
4.4.2	Branch Road NK1960.....	10
4.4.3	Branch Road NK1980.....	11
4.4.4	Branch Road NK1970.....	11
4.4.5	Branch Road NK1971.....	12
4.4.6	Branch Road NK1972.....	12
5.0	Consequence and Mitigation Measure Summary	13
5.1	Windthrow-Induced Terrain Instability	15
5.2	Worker Safety	16
6.0	Conclusion.....	17
6.1	Terrain	17
6.2	Roads.....	17
6.3	Worker Safety Hazard.....	17

7.0 Limitations.....	18
8.0 Closure	19
References	20

APPENDICES

Appendix 1: Figures.....	21
Appendix 2: Methodology	25
Appendix 3: Rationale for Assessment and Definition of Hazard and Consequence.....	26
Appendix 4: Definitions	28
Appendix 5: General Guidelines For Road Cut and Fill Slope Angles.....	32

1.0 INTRODUCTION

Infinity Pacific Stewardship Group Ltd. (IPSG) retained Statlu Environmental Consulting Ltd. (Statlu) to assess the terrain stability hazard for Blocks NK020, NK021, and NK022 in the Kookipi Creek drainage. IPSG requested Statlu's services because there is moderately steep to steep terrain within and near the blocks. The blocks will be harvested using a combination of ground-based, restricted ground-based, and cable yarding methods.

Colton Cantner, B. Sc., GIT of Statlu assessed the terrain stability hazard for Blocks NK020, NK021, NK022, and associated block roads on August 29, 2019 and September 6, 2019 with Sean O'Neal of IPSG. There were clear skies and warm temperatures during both days of the assessment and there were no barriers to normal visibility. The assessment route is shown on Figures 1, 2, 3, and 4 (Appendix 1). We spent approximately 13 hours in the blocks over the two days.

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 NK020, NK021, and NK022 cross west-facing slopes in the eastern fork of the main Kookipi Creek valley. The blocks are located in the Pacific Ranges of the Coast Mountains, approximately 18 km west of Boston Bar. Elevations across the blocks range from approximately 1200 m to 1360 m above mean sea level.

2.1 Downslope Resources and Elements at Risk

A tributary of Kookipi Creek, classified as an S2 stream in its reaches below the blocks, is located between 50 m and 200 m below Blocks NK020, NK021, and NK022. There are no points of diversion directly downstream of the blocks. A couple S6 and S5 streams flow between the blocks, eventually becoming fish bearing downstream of the blocks before flowing into Kookipi Creek.

The existing NK1900 branch road crosses the middle of Blocks NK020 and NK021. Identification of other downslope resources, including timber, recreational, archaeological, etc. is beyond the scope of this report.

2.2 Bedrock and Surficial Geology

The blocks are underlain by late-Cretaceous-aged granodioritic intrusive rock that is generally competent but varies in grain size (iMapBC, 2019). Bedrock outcrops and scattered colluvial boulders within and around the blocks match this description.

The surficial materials consist of a mix of till and colluvium with glaciofluvial and fluvial sediments in the valley bottom near the Kookipi Creek tributary. Till and colluvium have a veneer thickness with rubbly to bouldery sandy texture and sediments in the valley bottom have a cobbly to bouldery sandy silty texture. Soils range from well-drained to poorly-drained near streams and NCDs.

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 is Laidlaw, 58 km south of the blocks at an elevation of 37 m above sea level (Environment Canada, 2019). Data for the thirty-year period ending in 2010 describes mean annual precipitation as 2187 mm with 74% falling between September and the end of March. Mean annual snowfall was 78 cm and extreme daily precipitation was 131 mm /24h. Given its distance and elevation relative to the blocks, this station is likely not a good representation of climate near the blocks.

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 at an elevation of 1230 m above sea level as 2137 mm mean annual precipitation with 923 cm as snow. Approximately 80% of total precipitation (1716 mm) arrives between October and April.

The major runoff generation mechanism in the area is spring snowmelt. Rain-on-snow precipitation events can occur in early fall and late spring.

3.0 TERRAIN OVERVIEW

The blocks are located near the upper reaches of a tributary in the Kookipi Creek drainage valley, surrounded by mountainous terrain with tall snow covered peaks. The valley, as seen on Google™ Earth and digital orthophotos, is U-shaped in profile with gentle gradients in the valley bottom that steepen up the valley sides. The valley fill sediment is a mix of glaciofluvial and fluvial deposits that transition to a rubbly till blanket to veneer on lower- to mid-slopes. On steeper mid- to upper-slopes, the till is overlain by a blocky colluvial veneer.

Rockfall, snow avalanches, and debris flows are the dominant mass movement processes in the valley. Rockfall from steep bedrock bluffs is common, with talus patches beneath bedrock outcrops visible on the satellite imagery. Colluvial blocks dislodged and mobilized from steeper slopes are scattered in the area. Snow avalanches can also occur in the Kookipi Creek drainage valleys, with avalanche tracks often extending from just below mountain ridge tops down to lower to mid-slopes. Where these processes become concentrated within gullies, debris flows could result.

The blocks are located adjacent to cutblocks that were harvested sometime in the past 5 to 10 years. In these recently harvested blocks, young trees are growing in the harvested area, timber at the block edges remains standing, and stream channels are intact with sediment confined to the channels, suggesting that the surrounding terrain is stable.

3.1 Wind

Damaging winds in the vicinity of the blocks tend to be strong inflow and outflow winds that blow north and south through the Fraser Canyon, 20 km to the east or in the Harrison Lake/Lillooet River corridor, 30 km to the west. The valley where the blocks are located has a north-south orientation and is sheltered from inflow and outflow winds by Mount McEwan and Fraser Peak to the east, Mount Nesbit and Mount Snyder to the south, and smaller ridges and valley walls to the west.

4.0 OBSERVATIONS, HAZARD EVALUATION, AND CONSEQUENCES

Terrain in the blocks was divided into polygons based on homogenous terrain stability hazard, surficial materials, slope gradients, topography, and proposed harvesting method (Figures 1, 2, 3, and 4).

4.1 Block NK020

Polygon A comprises the majority of Block NK020. The topography is irregular with a straight to slightly convex profile and an undulating morphology across contour. The majority of slope gradients range from 45% to 70%. There are few bench tops up to 15 m wide with slope gradients of less than 40%, and the lower portions of Block NK020 have more planar to slightly undulating slopes with gradients between 10% and 30%. The surficial materials within the polygon include a well-drained rubbly to blocky sandy till veneer and patches of blocky colluvium with individual boulders up to 2 m in diameter.

This polygon presents low terrain stability hazard for the proposed cable yarding methods. Landslides smaller than 100 m³ could travel up to 100 m downslope, either depositing on gently sloped terrain within lower portions of the polygon, on the existing Br. Road NK1900, or in Polygon B.

Polygon B comprises the portion of Block NK020 adjacent to Br. Road NK1960. The terrain is benchy with 15 m to 40 m wide benches. Bench tops have an undulating morphology. Slope gradients within the polygon range from 10% to 40%. The surficial material consists of a well-drained rubbly sandy till veneer with scattered colluvial boulders up to 2 m in diameter.

Polygon B has low terrain stability hazard for the proposed ground-based yarding methods. A landslide initiating from the polygon would be less than 50 m³ and could deposit sandy and rubbly sediment within 20 m of the initiation site or up to 50 m downslope reaching Br. Road NK1900.

Polygon C consists of a gully located north of and outside Block NK020. The gully has slightly irregular sidewalls with heights between 10 m and 25 m. Sideslope gradients range from 55% to 75%. The surficial material is a well-drained rubbly sandy till veneer. An S5 stream flows through the gully with a 30% to 40% channel gradient. The stream flows over bedrock in places and transports up to boulder sized sediment. The stream becomes fish-bearing below the block before flowing into the Kookipi Creek tributary. The gully is forested with straight trees. The gully presents moderate terrain stability hazard.

The northern boundary of Block NK020, between Falling Corner (FC) 18 and FC 19, crosses the top of the southern gully sidewall. The boundary of a recently harvested cutblock, similar to NK020, follows the top of the northern gully sidewall. The northern gully sidewall is still forested, with little to no windthrow along the cutblock boundary, indicating the sidewall remained stable after harvesting. No boundary adjustments are required. Timber left standing along the boundary near the gully must be windfirm.

Landslides initiating from the gully sidewalls would deposit into the stream channel where material could become mobilized downstream as a debris flow. A debris flow could reach Br. Road NK1900, potentially damaging the road crossing. Finer sediment could be fluvially transported downstream, reaching fish-bearing portions of the stream and Kookipi Creek.

4.2 Block NK021

Polygon D comprises the majority of Block NK021. Topography is smooth to undulating with slope gradients less than 40%. The surficial material consists of a well-drained rubbly to blocky sandy till veneer. Polygon D presents low terrain stability hazard for the proposed ground-based yarding methods. Landslides would be less than 50 m³ in volume and deposit within 20 m of the initiation site.

Polygon E consists of irregular to benchy terrain above Br. Road NK1900. Bench tops are up to 20 m wide and are separated by short steps up to 10 m long. Slope gradients are 10% to 25% on bench tops and 35% to 65% on the steps between benches. The surficial material consists of a well-drained rubbly to blocky sandy till veneer.

Polygon E presents low terrain stability for the proposed cable yarding methods. Landslides initiating from Polygon E could deposit rubbly, blocky, sandy sediment up to 100 m downslope on Br. Road NK1900 or in the lower parts of the block.

Polygon F consists of a gully on the north side of Block NK021. The gully sideslope gradients are between 55% and 65% and extend 25 m to the stream channel. The surficial material consists of a well-drained rubbly sandy till veneer. The stream has a 35% channel gradient. Straight trees are growing on the sideslopes and alder is growing in the stream channel. The headwall is located just outside the northeastern corner of the block. An avalanche path, originating upslope of the block, eventually enters the gully.

Polygon F presents moderate terrain stability hazard. At the time of the assessment, a section of the northern block boundary, between FC 10 and FC 12, crossed the gully sidewall approximately 5 m from the S6 stream flowing within the gully. Harvesting the timber in the gully could destabilize the gully sidewall. The boundary was moved to the top of the gully sidewall. Timber standing next to the final block boundaries must be windfirm.

Landslides initiating from the gully sidewalls would deposit into the stream channel where material may become mobilized downstream as a debris flow. A debris flow could reach Br. Road NK1900 and Kookipi Creek.

4.3 Block NK022

Polygon G comprises the majority of Block NK022. Slopes are benchy in profile, with benches up to 30 m wide and bench tops separated by irregular steps up to 25 m long. Slope gradients range from 5% to 35% on bench tops and up to 65% steep on the steps between benches. The northern part of the polygon has ridge and swale morphology across contour with a well-drained rubbly sandy till veneer. In the southern portion of the polygon, the slope morphology becomes more undulating to hummocky across contour and the surficial material transitions to a blocky sandy colluvial veneer overlying a well-drained rubbly sandy till veneer. There are patches of blocky talus with individual blocks up to 4 m in diameter. Poorly-drained soils occur within a couple meters of streams and NCDs where the ground is flat.

Polygon G presents low terrain stability hazard for restricted ground-based yarding methods. Timber in steeper areas should be hand- or machine-felled into lead. If trails are constructed, rehabilitate them immediately after harvest. Landslides could deposit up to 50 m³ of sandy, rubbly, blocky till and colluvium within 25 m of the initiation site onto bench tops within the polygon.

Polygon H consists of the steep, rock-controlled upper parts of Block NK022. Slopes are irregular with a straight to slightly convex profile and a slightly undulating morphology across contour. Slope gradients are between 45% and 70%. The surficial material consists of a rubbly to blocky sandy colluvial veneer with individual blocks up to 3 m in diameter.

Polygon H will have low terrain stability hazard following clearcut harvesting using cable yarding methods. Landslides could deposit up to 100 m³ of blocky colluvium up to 150 m downslope onto broad bench tops within Polygon G.

Polygon I consists of an avalanche runout zone upslope of Block NK022. IPSG had concerns regarding a section of the upper boundary of Block NK022, between FC 31 and FC 34, because it crosses near the bottom of the avalanche track. The boundary segment is located on a broad bench with less than 30% slope gradients and lies at the edge of a 60 m wide clearing with scattered colluvial blocks and broken logs. A 100 m wide path of young coniferous trees, about 2 m in height, extends 200 m above the clearing. The slope is straight to convex with 65% to 75% gradients. Historic digital imagery shows that size 2 to 3 snow avalanches initiating from the rock-controlled slopes near mountain top occur here. The coarse woody debris, logs, and colluvium were deposited by a past snow avalanche.

Polygon I has low terrain stability hazard. No boundary adjustments are required. Debris from a snow avalanche will deposit on the gently sloped benchy terrain below the steep slope. Snow avalanches can pose a worker safety hazard, particularly during winter and spring months.

4.4 Roads

Blocks NK020, NK021, and NK022 will be accessed via reconstruction of Branch Road NK1900 and new construction of several branch roads within the blocks.

The hazard analysis assumes that roads will be constructed and reconstructed using conventional cut and fill techniques. Construction and reconstruction options have been recommended for road segments where conventional construction or reconstruction would exceed low terrain stability hazard.

4.4.1 Branch Road NK1900

Br. Road NK1900 will be reconstructed. The road width is between 5 m and 7 m and the fillslope is composed of coarse rock with gradients of 60% to 70%. Surficial materials are homogenous, consisting of a well-drained rubbly to bouldery sandy till veneer. Bedrock was observed in the cutslope in places. There are scattered colluvial blocks, up to 2 m in diameter above and below the road.

From the **POC** to **Sta. 1+775**, the existing road crosses irregular slopes with 30% to 60% gradients. Conventional reconstruction will result in low terrain stability hazard.

From **Sta. 1+775** to **Sta. 1+847**, the road crosses benchy terrain with 45% slope gradients or less. The cutslope is 5 m to 7 m high with a 65% slope gradient. The surficial material is loose cobbly sandy till. Sediment exposed in the cutslope has raveled and deposited on the road, extending 3 m onto the running surface. Conventional reconstruction will result in low terrain stability hazard. Place a coarse rock berm or line of logs between the ditch and the base of the cutslope to prevent raveled sediment from filling the ditch and depositing onto the road surface. Regular maintenance will be necessary to keep the ditch clear of sediment.

From **Sta. 1+847** to **Sta. 1+970**, the existing road crosses benchy terrain with 55% to 65% slope gradients for 20 m before shallowing to less than 50%. Conventional reconstruction would present moderate terrain stability hazard. The slopes below the road are too steep for the road prism to be supported on fill. For low hazard, use full sidecast reconstruction. If the road needs to be widened, do so by excavating into the cutslope a necessary amount. Excavated material may be cast downslope but must not form a portion of the load-bearing road surface. 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. Refer to Appendix 4 for definitions on various road construction and reconstruction prescriptions.

From **Sta. 1+970** to **Sta. 4+512**, the existing road crosses slightly irregular to benchy terrain with slope gradients between 20% and 55%. Conventional reconstruction will result in low terrain stability hazard. At **Sta. 4+094**, an S5 stream crosses the road at a coarse rock ford with twinned culverts. The inlets are buried by sandy sediment and the stream now flows through the coarse rock. The road surface is eroding at the crossing, likely as a result of water flowing over the road due to the blocked culverts. Remove the sediment blocking the culvert inlets and reconstruct the coarse rock ford. If the culverts are damaged, replace them.

From **Sta. 4+512** to the **POT**, the existing road crosses undulating to slightly benchy terrain with 45% or less slope gradients. Between **Sta. 5+695** and **Sta. 6+070**, there are a settling cracks approximately 5 m to 7 m long and 15 cm wide within the outer 1 m of road running surface. The cracks likely formed as a result of decayed organic material within the road fill (puncheon). The settling fill would present a worker safety hazard if it were to fail under a vehicle. Conventional reconstruction will result in low terrain stability hazard. To protect worker safety, pullback (P3) the fill to remove any remaining organic matter before reconstructing this segment.

Potential road failures initiating from Br. Road NK1900 could occur from oversteepened or cracked fill and oversteepened cutslopes. Stream crossings could lead to potential road failures if they are not properly maintained. Blocked or damaged culverts and ditches can intercept and divert natural drainages across and down the road, leading to erosion, road washouts and/or reduced stability of the surrounding terrain.

A road failure could be up to 30 m³ and could deposit coarse blocky and sandy road fill up to 40 m downslope.

4.4.2 Branch Road NK1960

This road branches off Br. Road NK1900 to enter Block NK020 and will be new construction.

From the **POC** to **Sta. 0+330**, the proposed road crosses a broad, undulating bench with 10% to 30% slope gradients. Conventional construction will have low terrain stability hazard.

A road failure would deposit within a few meters of the road on the surrounding bench tops.

From **Sta. 0+330** to the **POT**, the proposed road crosses onto a 15 m to 20 m wide bench above uniform to irregular topography with 55% to 65% slope gradients. Slope gradients on the bench top are between 40% and 50%. Conventional construction will result in low terrain stability as long as all sidecast is retained on the bench top. Sidecast over the bench edge onto the steep slopes below will result in moderate hazard.

A road failure could cross the steeper slopes below the bench and reach Br. Road NK1900, 50 m downslope.

4.4.3 Branch Road NK1980

This road branches off Br. Road NK1900 to cross into Block NK021. It will be reconstruction for the first 60 m of the road and will be new construction for the remaining road sections. It crosses undulating to benchy terrain with slope gradients between 10% and 40%. The surficial material consists of a well-drained rubbly to blocky sandy till veneer. Conventional construction will result in low terrain stability hazard along the entire road.

Failures from the road would be smaller than 20 m³ and could travel up to 15 m.

4.4.4 Branch Road NK1970

This road branches off Br. Road NK1900 to cross into Block NK022. It will be new construction.

From the **POC** to **Sta. 0+290**, the road crosses planar slopes within a recently harvested cutblock. The surficial material consists of a well-drained rubbly sandy silty till veneer and slope gradients are less than 10%. Conventional reconstruction and conventional construction presents very low terrain stability hazard.

From **Sta. 0+290** to **Sta. 0+594**, the proposed road enters Block NK022. The topography is benchy in profile with undulating to ridge and swale morphology along contour. Slope gradients are 5% to 45%. The surficial material consists of a well-drained rubbly sandy till veneer with localized areas of poorly-drained soils on gradients less than 5% near some stream and NCD channels. Conventional construction will have low terrain stability hazard.

From **Sta. 0+594 to Sta. 0+633**, the proposed road crosses the 60% to 70% gradient side of a uniform ridge, 10 m to 15 m above an S6 stream channel. Surficial materials along the ridge sideslope are similar to the previous segments. Conventional construction presents moderate terrain stability hazard. Use full bench construction with no sidecast for low hazard.

From **Sta. 0+633 to POT**, the road crosses the S6 stream channel, incised up to 2 m, and then continues across irregular to benchy terrain with a hummocky morphology along contour. Slope gradients range from 20% to 55% and surficial materials are a well-drained rubbly to blocky sandy till veneer that eventually transitions to a rapidly-drained blocky sandy colluvial veneer. There are discontinuous patches of blocky talus with individual boulders up to 4 m in diameter. Conventional construction presents low terrain stability hazard.

Road failures initiating from Br. Road NK1970 would be small ($<20 \text{ m}^3$) and could deposit debris up to 25 m below the road.

4.4.5 Branch Road NK1971

This road branches off Br. Road NK1970 and will be new construction. It crosses benchy slopes with an undulating to hummocky morphology along contour. The surficial material consists of a rubbly to blocky sandy till veneer. Slope gradients are between 20% and 50%. Conventional construction presents low terrain stability hazard.

Road failures could deposit up to 20 m^3 of blocky sandy sediment up to 20 m below the road.

4.4.6 Branch Road NK1972

This road branches off Br. Road NK1970 and will be new construction. The road crosses benchy slopes with 20% to 55% gradients. Surficial materials consist of a rapidly-drained blocky colluvial veneer overlying a well-drained rubbly sandy till veneer with scattered colluvial blocks up to 3 m in diameter. Conventional construction will have low terrain stability hazard along the road's entire length.

Road failures could deposit up to 20 m^3 of blocky sandy sediment up to 20 m below the road .

5.0 CONSEQUENCE AND MITIGATION MEASURE SUMMARY

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	Consequence of Terrain Instability	Recommended Mitigation Measures
A	Low	Landslides could travel up to 100 m downslope either depositing onto gently sloped terrain within the block or Br. Road NK1900.	Use cable yarding methods.
B	Low		None.
C	Moderate	Landslides would deposit into the stream channel where material could become mobilized downstream as a debris flow that could reach Br. Road NK1900, fish-bearing reaches of the stream, and the Kookipi Creek tributary.	None, polygon located outside of Block NK020.
D	Low	Landslides could deposit within 10 m to 20 m of the initiation site.	None.
E	Low	Landslides could deposit up to 100 m downslope either on to Br. Road NK1900 or onto undulating slopes in the lower portions of Block NK021.	Use cable yarding methods.
F	Moderate	Landslides would deposit into the stream channel where material may become mobilized downstream as a debris flow reaching Br. Road NK1900. Sediment could be fluvially transported downstream and reach Kookipi Creek.	None, IPSG moved the boundary to the top of gully sidewall.
G	Low	Landslides could deposit within 25 m on bench tops within Block NK022.	Use restricted ground-based yarding methods.
H	Low	Landslides could deposit up to 150 m downslope within Polygon G.	Use cable yarding methods.
I	Low	Debris from a snow avalanche will deposit onto the gently sloped benchy terrain above the block.	None, polygon located outside Block NK022.

Table 2: Downslope Consequences and Mitigation Measures – Br. Road NK1900

Road Segment		Hazard for Conventional (Re)Construction	Consequence of Terrain Instability	Recommended Mitigation Measures
From	To			
Br. Road NK1900				
POC	1+775	Low	Road failures could deposit up to 40 m below the road.	None.
1+775	1+847	Low		Place a coarse rock berm at base of the cutslope. Regular maintenance will be necessary to keep the ditch clear of raveled sediment.
1+847	1+970	Moderate	A road failure would deposit onto the benchy terrain 20 m below the road.	Use full sidecast reconstruction.
1+970	4+512	Low	Road failures could deposit up to 40 m below the road.	At 4+094, remove the sediment blocking the culvert inlets and reconstruct the coarse rock ford.
4+512	POT	Low		Between 5+695 and 6+070, where the fill has settled, remove any remaining organic matter and recompact before conventional reconstruction.

Table 3: Downslope Consequences and Mitigation Measures – Block NK020 Br. Roads

Road Segment		Hazard for Conventional (Re)Construction	Consequence of Terrain Instability	Recommended Mitigation Measures
From	To			
Br. Road NK1960				
POC	0+330	Low	A road failure would deposit within a few meters of the road.	None.
0+330	POT	Low	A potential road failure could reach Br. Road NK1900.	Retain sidecast on bench top. Do not sidecast over bench edge.

Table 3: Downslope Consequences and Mitigation Measures – Block NK021 Br. Roads

Road Segment		Hazard for Conventional (Re)Construction	Consequence of Terrain Instability	Recommended Mitigation Measures
From	To			
Br. Road NK1980				
POC	POT	Low	Potential road failures would deposit within 15 m of the road.	None.

Table 4: Downslope Consequences and Mitigation Measures – Block NK022 Br. Roads

Road Segment		Hazard for Conventional (Re)Construction	Consequence of Terrain Instability	Recommended Mitigation Measures
From	To			
Br. Road NK1970				
POC	0+290	Very Low	Road failures could deposit debris within 25 m of the road.	None.
0+290	0+594	Low		None.
0+594	0+633	Moderate		Use full bench construction with no sidecast.
0+633	POT	Low		None.
Br. Road NK1971				
POC	POT	Low	Road failures could deposit debris within 20 m of the road.	None.
Br. Road NK1972				
POC	POT	Low	Road failures could deposit debris between 15 m and 25 m of the road.	None.

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.

Polygons C and F consist of gullies located adjacent to the northern boundaries of Blocks NK020 and NK021, respectively. Increased post-harvest windthrow near the gullies could reduce the overall terrain stability of the gully sidewalls, increasing the terrain stability hazard.

Timber along the block boundaries adjacent to Polygons C and F should be assessed for windfirmness by a qualified professional. If the assessment indicates that post-harvest blowdown rates will significantly increase, windfirming strategies such as canopy treatment, feathering, or moving the boundary further away from the gullies should be applied to mitigate the potential for increased post-harvest blowdown.

5.2 Worker Safety

Rockfall from steep bedrock outcrops, and mobilization of large colluvial boulders, up to 4 m in diameter, present a worker safety hazard. In addition, snow avalanches can occur in Kookipi Creek. The avalanche prone terrain is located outside of the blocks but poses a worker safety hazard in the winter and spring months when snow is present upslope.

Workers in Blocks NK020, NK021, and NK022 should follow wet weather shutdown guidelines¹ which contains clauses covering rockfall initiation (based on the presence of freeze/thaw conditions) as well as the standard rainfall and snowmelt based criteria. Workers should be aware of the potential for falling and yarding operations to dislodge perched boulders and take appropriate precautions to prevent or avoid exposure to dislodged boulders.

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 CONCLUSION

6.1 Terrain

Terrain within Blocks NK020, NK021, and NK022 presents low terrain stability hazard for the proposed ground-based, restricted ground-based, and cable yarding methods.

Terrain with moderate terrain stability hazard is located outside Blocks NK020 and NK021.

6.2 Roads

The blocks will be accessed via reconstruction and new construction of several branch roads. The hazard of road prism failure following conventional construction and reconstruction is low on most of the inspected road segments. The following segments require specific reconstruction and construction techniques to either reduce the hazard to low, maintain low hazard, or to maintain worker safety hazard:

Br. Road NK1900

- Sta. 1+775 to Sta. 1+970
- Sta. 5+695 to Sta. 6+070

Br. Road NK1960

- Sta. 0+330 to the POT

Br. Road NK1970

- Sta. 0+594 to Sta. 0+633

Following the recommendations described in Section 4.4 and summarized in Section 5.0 for these segments will reduce the hazard to low.

6.3 Worker Safety Hazard

Rockfall, mobilization of large colluvial boulders, and snow avalanches present a worker safety hazard.

7.0 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.

8.0 CLOSURE

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

Yours truly,

Statlu Environmental Consulting Ltd.

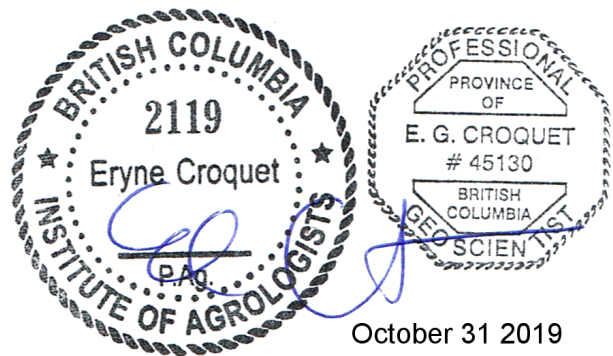


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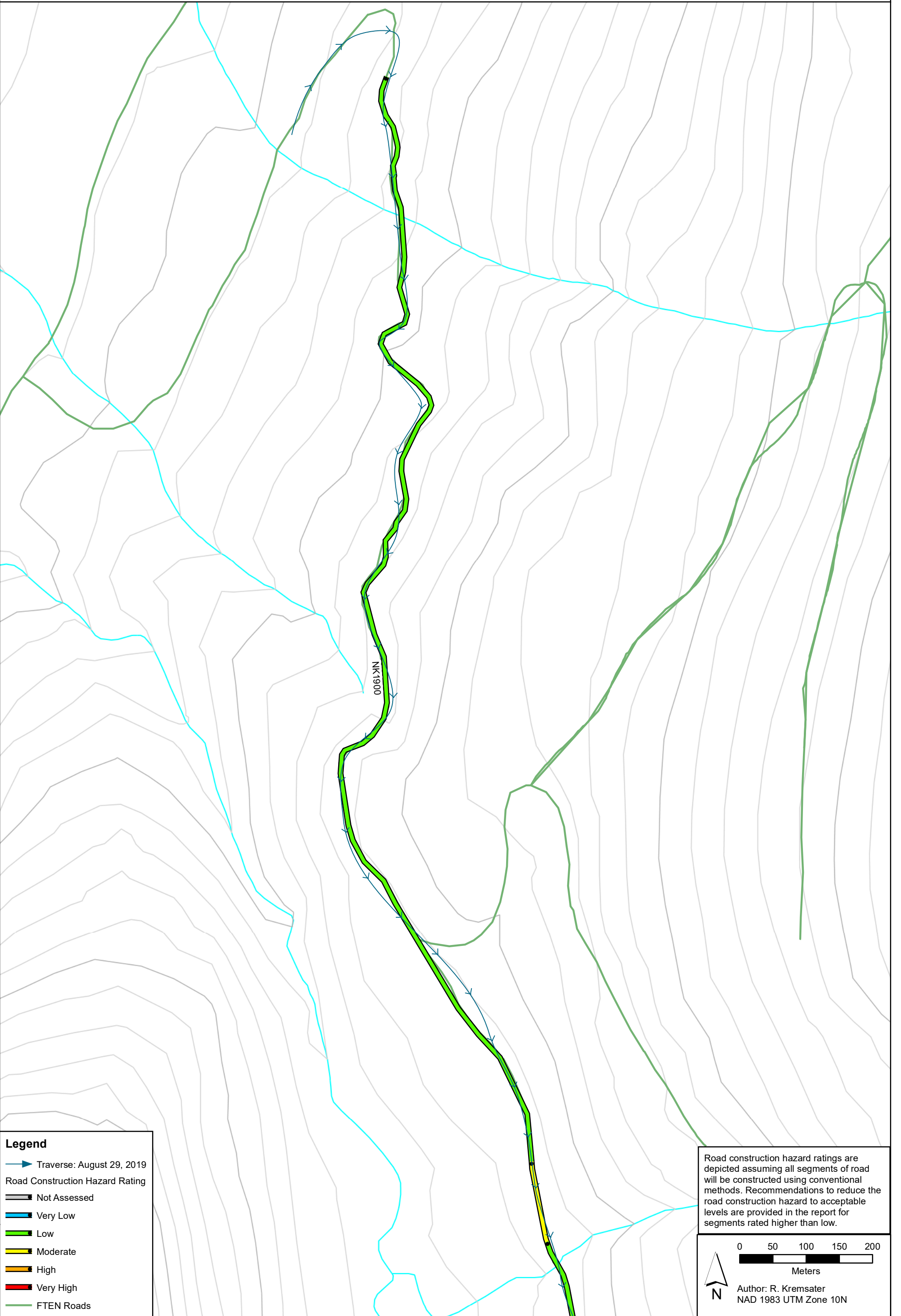
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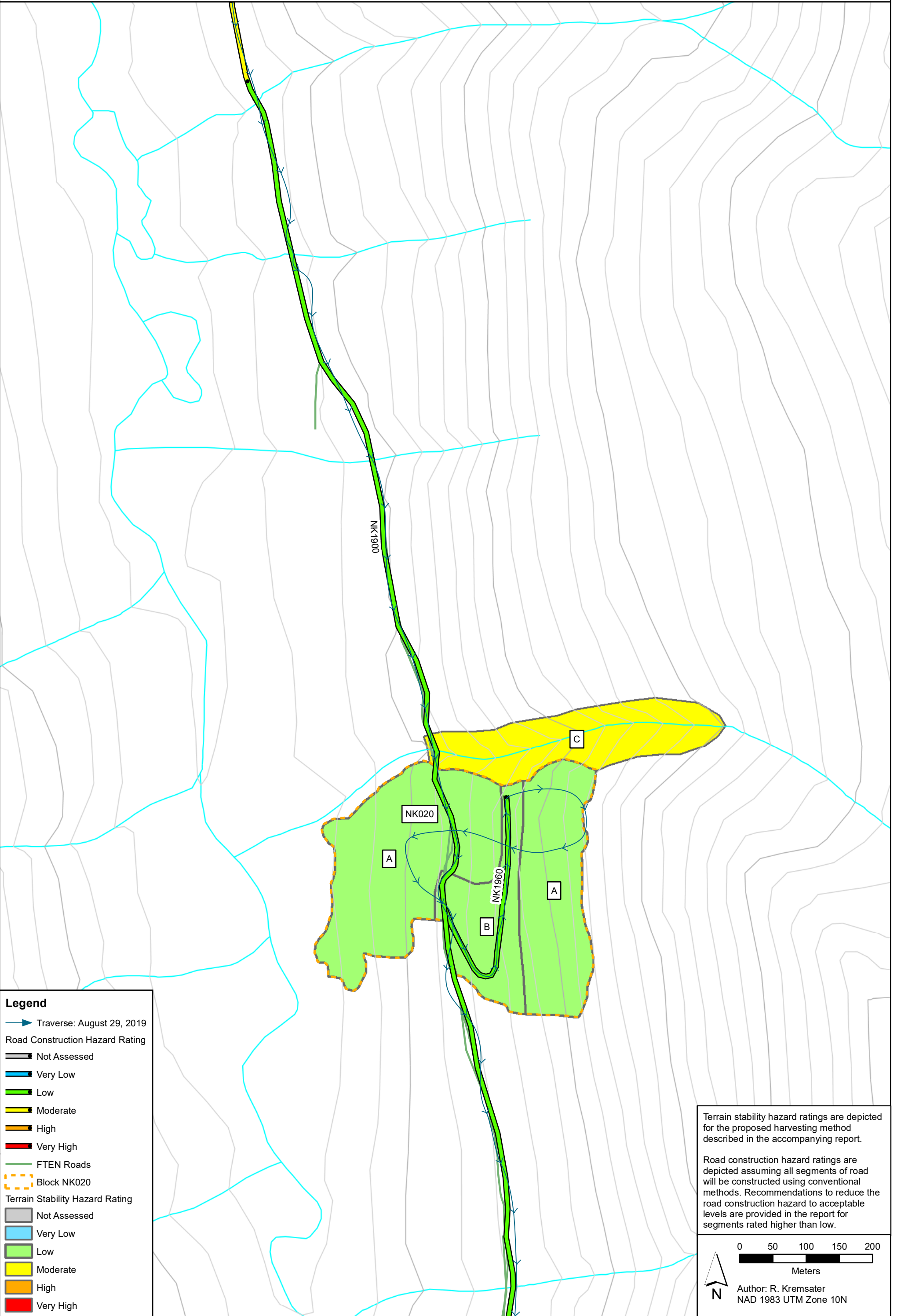
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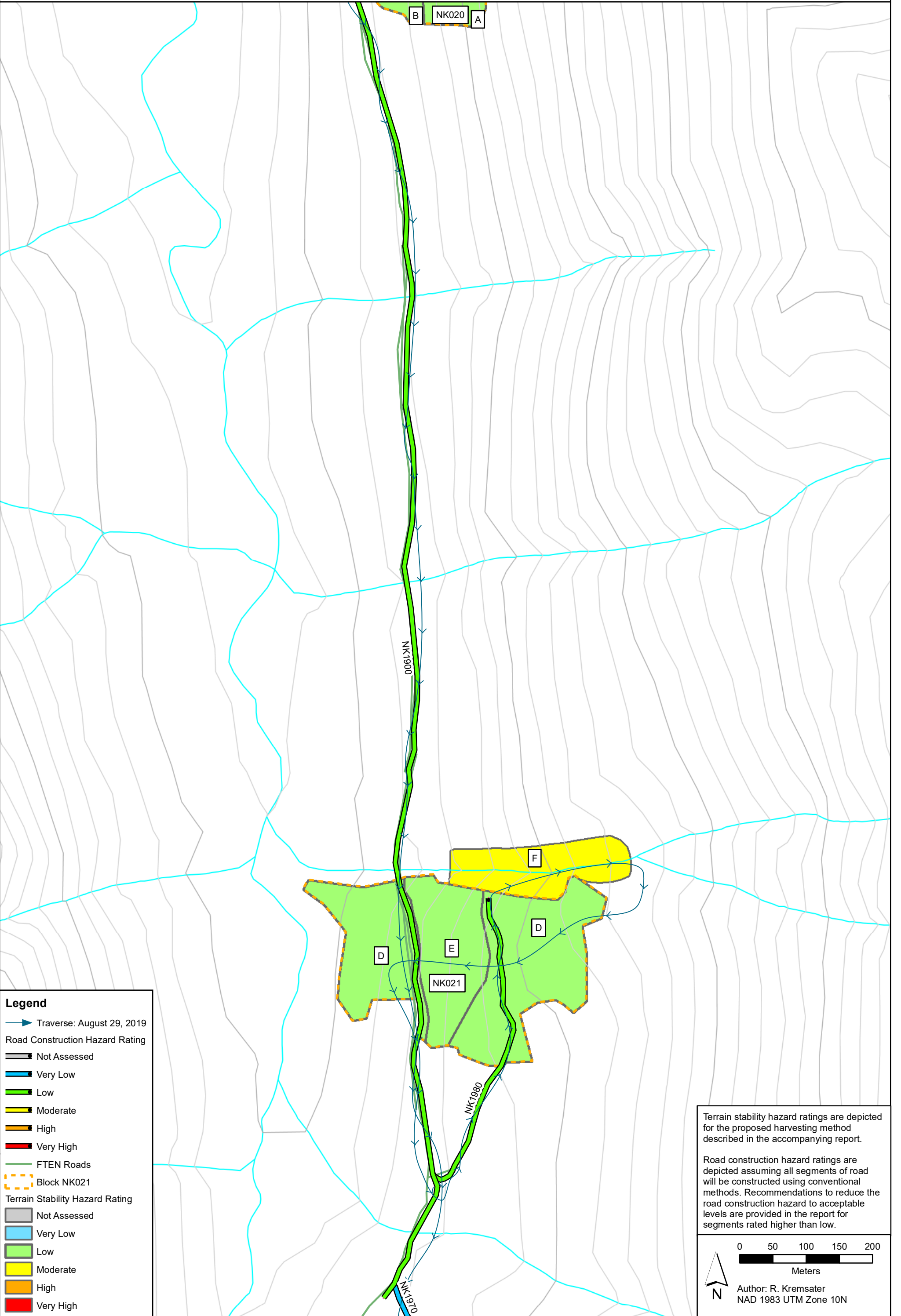
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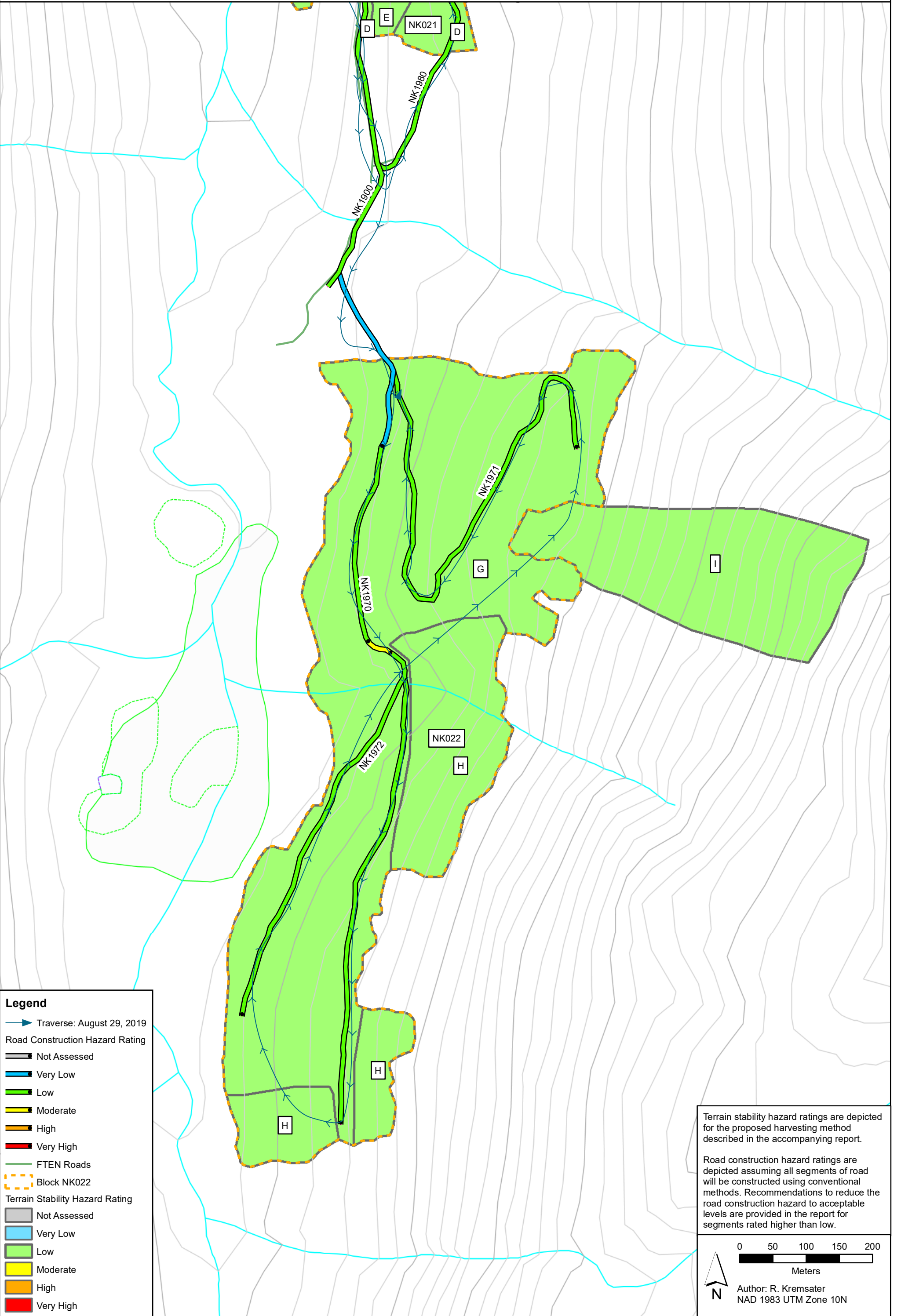
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APPENDIX 2: METHODOLOGY

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

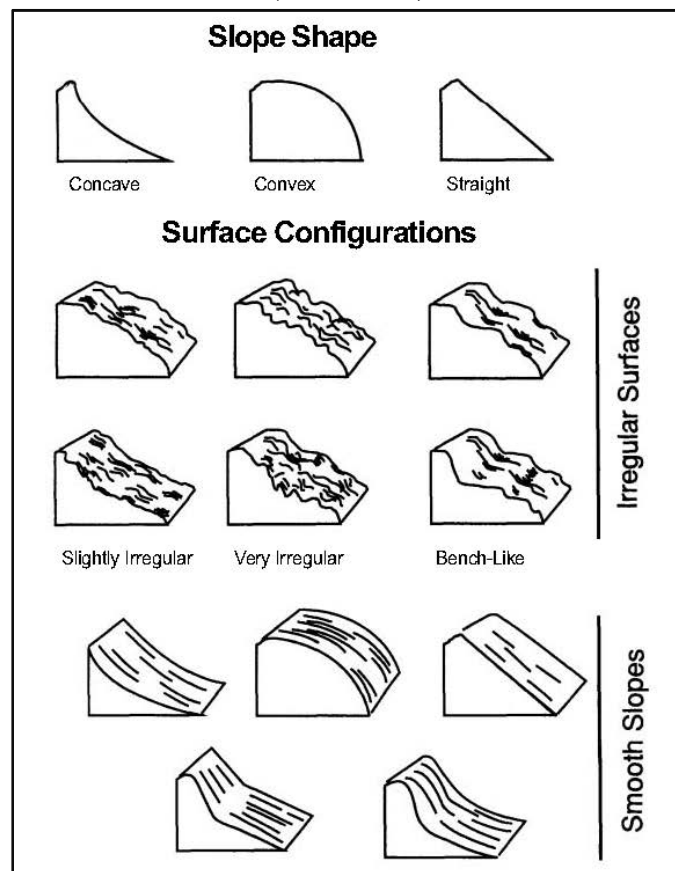
APPENDIX 4: DEFINITIONS

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.”

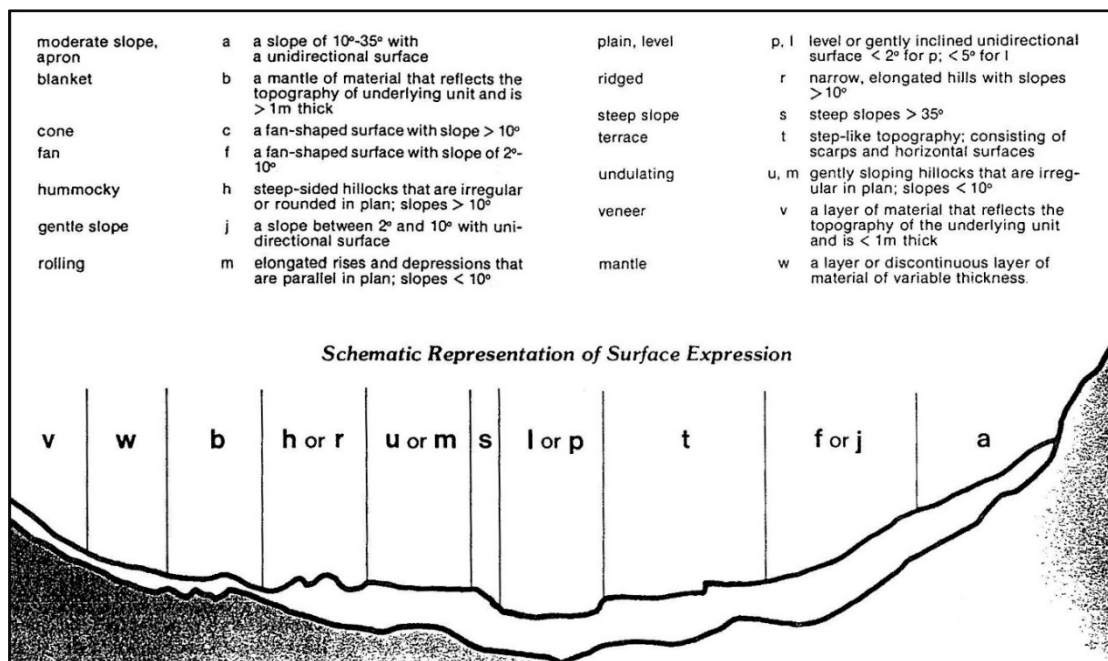


Figure B1: Common surface expression terms (Ryder and Howes, 1986)

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 outslopped 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)	¾:1 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	¾:1 to vertical (100% to 400%)	Placed angular rock, not dumped	1:1 (100%)
	Weathered or fractured rock	¾:1 to 1¼: 1 (80 to 100%)	Dumped angular or placed rounded rock	1¼:1 to 1½:1 (67-80%)

(Ministry of Forests, 2002)