SPRUCE CREEK COMMUNITY WATERSHED

Detailed Terrain and Slope Stability Mapping

Prepared for
Squamish Forest District
Small Business Program

by

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September 1996

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October 3, 1996

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Dear Jim,

Detailed Terrain Stability Mapping (5-class) at TSIL C was completed for the Spruce Creek area. Mylar maps have already been sent to you and paper prints of the maps are in the back of this report. This report provides a general overview of the physiography of the study area, descriptions of terrain mapping methodology and criteria used for slope stability, erosion potential and sediment delivery interpretations, assessment of map reliability, information about surficial materials and processes, and recommendations for forest land management.

The information and analyses contained in this report are based on observations of land-surface conditions and current understanding of slope processes. However, because slope stability is strongly influenced by subsurface conditions that are not apparent from surface observations or air photo interpretation (e.g., characteristics of subsurface materials, subsurface hydrologic conditions), by events whose time of occurrence cannot be predicted (e.g., extreme storms, earthquakes), and by land management practices, the results and recommendations provided in this report cannot guarantee that no landslides will occur in areas affected by forestry activities. Appropriate use of terrain information and implementation of recommendations will, however, reduce the risk of landslides and erosion.

If you have any questions or comments please contact June or myself. Thank you for entrusting JMRATA with this terrain work.

Yours sincerely,

Claire Tweeddale, B.Sc., G.I.T. and June M. Ryder, Ph.D., P.Geo.

CONTENTS

(1) INTRODUCTION

The objective of this project was to upgrade reconnaissance terrain stability maps to detailed terrain stability maps at terrain survey intensity level (TSIL) C for Spruce Creek, located near D'Arcy. This work was carried out under the auspices of the Small Business program, Squamish Forest District. These maps will be used in planning forestry activities and for community watershed management. Mapping methodology is discussed in more detail below.

(2) PHYSIOGRAPHY

The map area lies in the southeastern part of the Pacific Ranges of the Coast Mountains (Holland, 1976). This is an entirely mountainous region lying east of the zone of high precipitation that characterizes the western side of the Coast Mountains (Roddick, 1973).

(2.1) General Topography and Distribution of Surficial Materials

The mountains in the Spruce Creek area rugged, with elevations ranging from slightly below 300 m a.s.l. at the confluence of Spruce Creek and Gates River to 2300 m a.s.l. at the local summits. The middle and upper parts of the Spruce Creek valley display the classic U-shaped profile typical of glacial scour. Elevation changes of 1000 m between the ridge crests and adjacent valley floors over distances less than 1.5 km, give rise to average slopes of 60-70%. Topography is bedrock controlled and surficial materials are thin. Lower Spruce and Haylmore creeks display moderately sloping (<50%), partially terraced terrain underlain by thicker surficial materials.

(2.2) Bedrock

Bedrock geology of the Pemberton area has been mapped at a scale of 1:250 000 by Roddick (1970). Most of the Spruce Creek area is underlain by the Hurley Formation. This consists of rocks of Upper Triassic Age, more than 450 m thick, including argillite, limestone, tuff and conglomerate beds, as well as coarse conglomerate strata and green andesitic flows several feet thick. A 1 km wide strip along the southwest boundary of the map area is underlain by quartz diorite of the Coast Plutonic Complex. Most outcrops of this rock type display a well developed northwest-trending foliation with vertical or steep northeasterly dips. The quartz diorite is medium to coarse grained, massive, and these characteristics are reflected in those of some surficial materials (e.g., see till below).

(2.3) Landscape History

The evolution of present day landforms and surficial materials is described briefly here to provide context for the discussions of surficial materials and slope stability that follow. Most terrain characteristics that are of significance to forestry operations date from events that have occurred during the past 30 000 years:

Fraser Glaciation and postglacial time. Prior to Fraser Glaciation, general topography of the area was probably very similar to the present: the major valleys and their tributaries were extant, and the mountains probably appeared pretty much the same as now. The landscape had already been affected by a dozen or more glaciations, each of which was probably similar to the most recent, Fraser Glaciation, about which we have a fair amount of information.

During Fraser Glaciation, ice began to expand from the high mountains of the Cordillera about 30 000 years ago. In the Pemberton area, glaciers expanded from cirques in the highest parts of the Coast Mountains, such as the Bendor, Cadwallader and Cayoosh ranges, forming valley glaciers in tributary valleys, such as Whitecap, McGillivray, and Spruce creeks. As these glaciers expanded, they coalesced with larger valley glaciers from the high icefields in the Coast Mountains flowing southeastward down Lillooet River valley, southward down Birkenhead River valley, and southwestward down Anderson Lake valley.

When the Cordilleran Ice Sheet attained its maximum extent about 15 000 years ago, the entire study area, except the highest peaks, was overridden by ice. Within the general ice cover, faster flowing streams of ice developed where subglacial valleys were parallel to ice flow direction, such as the Lillooet-Harrison ice stream, which flowed southeastward down the Lillooet valley and on into the Harrison Lake valley, scouring the valley sides and creating a U-shaped cross-profile.

Thick glaciofluvial terraces in the middle parts of Spruce and Haylmore Creeks were formed as outwash deposits while the ice melted back up these valleys. Near the mouth of Spruce Creek, these terraces end abruptly at steep north-facing scarps, formed where outwash deposits abutted thick glacier ice still occupying the main Gates valley.

Many parts of the present day landscape, especially the gentler slopes, have probably not changed significantly since deglaciation about 11 000 years ago. However, steeper slopes have been modified by gravitational processes (slides and debris flows, and snow avalanches). Steep gully walls have also been modified by slides and rockfall. The effects of erosion by running water are evident along most streams and rivers. Scarp slopes have developed where channels with relatively steep longitudinal gradients have cut-down into surficial materials and bedrock. Stream deposition has resulted in the formation of floodplains and low terraces, and a large alluvial fan at the mouth of Spruce Creek.

(3) METHODS

(3.1) Terrain Mapping

Reconnaissance terrain stability mapping of unstable and potentially unstable slopes was previously done by Blythe Killam (JMRATA). This mapping was upgraded to detailed terrain stability (5 class) mapping by Claire Tweeddale. The detailed mapping covers the whole area, and polygons formerly mapped as U (unstable areas) and P (potentially unstable areas) were changed to slope stability class V and IV, respectively. Preliminary terrain mapping was done on the 1:20 000 scale black and white air photos (30BCB 90046 Nos. 172-177; 90051 Nos. 64-68; 90052 Nos. 9-15) used for the original mapping, following the standard British Columbia procedures for terrain classification (Howes and Kenk, 1988), methodology (RIC, 1995) and stability mapping (FPC, 1995). The air photo interpretation was checked by June Ryder before field work.

Field work was carried out on August 7 and 8, 1996 by Claire Tweeddale and Jennifer Shypitka, Sid Tsang and Anthony Collett. We traversed the mid-slope regions, with attention focused on slopes designated as stability classes III, IV, and V. The first day we had a short overview flight of the study area to check the steep upper slopes, and then got dropped off at the upper end of the valley to traverse down to the road. The road follows Spruce Creek about half way into the study area, so, on the second day we checked the lower part of Spruce Creek valley from the road, using road cuts and short traverses off the road. Field observation sites are shown on the photos as either ground inspection sites or visual inspection sites. The latter were viewed from the helicopter or from across the valley. At ground inspection sites slope position, slope steepness, aspect, soil drainage, surficial material texture, local terrain symbol, slope stability, erosion potential and sediment deliverability to streams were recorded.

After fieldwork, the mapping on the air photos was corrected in accordance with field observations, and symbols for soil drainage and slope steepness were added. Interpretations were carried out for slope stability, erosion potential and sediment deliverability to streams, and symbols for these were added to the map. June Ryder then reviewed the photos again. Slope steepness classes were estimated partly from 1:20 000 scale TRIM maps (20m contour interval) and partly from field observations. Polygon boundaries for the new mapping were transferred by hand onto 1:20 000 scale TRIM maps, and polygons from the old mapping, which were also hand-transferred, were traced onto the same map. The completed map was sent to Hugh Hamilton Ltd. for digitizing. Terrain polygon information was compiled in a data base. A checkplot of the final map was returned to Claire Tweeddale for corrections.

(3.2) Slope Stability Criteria

Slope stability depends on numerous factors including slope steepness, morphology and position; material texture and thickness, and soil moisture characteristics. A single set of quantitative definitions for slope stability classes is not applicable to all areas. This is because local conditions, such as precipitation intensity and bedrock types, are variable, and also because there is insufficient information about slope failure processes. The criteria in Table 1 were used as guidelines, but judgement was applied to modify the guidelines as necessary, and each polygon was assessed individually.

Table 1: Guidelines for assessment of slope stability

Slope Stability Classes	Dominant Slope Class*	Material and Landforms	Dominant Texture	Active Processes	Soil Drainage	Slope Morphology
I	1 and 2	F^Gtu; Cf; Ff	g; sr, g	none	poorly drained and wet soils are relatively susceptible; polygons with slopes within 5 or 7% of an upper class boundary may be assigned to the next highest class	slopes with irregular or benched topography controlled by bedrock are relatively stable; polygons with slopes close to a lower class boundary may be assigned to the next lowest class.
	1&2 mixed	Mv, Mb; Cv; R	zs, s; sr	none		
II	2	Mv, Mb	sz	none		
	2 and 3	Cf; F^G; R	sr; g;	none		
III	3	Mv, Mb; Cv	zs; sr	none		
	4	Ca, Ck, R, F^G	sr, x; g	none		
IV	4 and 5	Mv, Mb, Cv, Cb	all	-V, -R"b		
	4 and 5	Rk, Rs				
V	any gradient	all	all	-F, -R"d, -R"s **		

* Slope classes are defined as follows: Class 1: 0-5% (0-3°); Class 2: 5-27% (3-15°); Class 3: 27-49% (15-26°); Class 4: 49-70% (26-35°); Class 5: over 70% (35°).

** Refers to the initiation zone of active gullies, rapid mass wasting and slow failure.

When using slope stability ratings, it is essential that map users note that conditions are locally variable. The ratings indicate the mapper's impression of typical conditions for each terrain polygon, however, locally steeper slopes, wetter soils and seepage zones may be more unstable than their surroundings. People marking cutblock boundaries or road alignments should recognize and take account of these local variations.

(3.3) Erosion Potential Criteria

Erosion potential indicates the susceptibility to erosion of surface materials where the vegetation has been removed by logging, fire, or insect kill, i.e., the erodibility of exposed soil. Erosion potential depends primarily on material type, texture and thickness; soil drainage; and slope position and steepness. The criteria in Table 2 were used as a guideline, but as in the case of slope stability, each polygon was assessed individually.

Table 2: Guidelines for assessment of erosion potential

Dominant Texture or Material	Typical Material	Slope Steepness Classes				
		1 (0-5%)	2 (5-27%)	3 (27-49%)	4 (49-70%)	5 (>70%)
organics	Op, Ob	VL	L	-	-	-
c, m	$W^{G}v$, $L^{G}v$	L,M	M	H	VH	VH
fine s, coarse z	L^{G}, Mv, Mw, Cv	L,M	M	H	VH	VH
coarse s, xs	Cv, F, F^{G}, Mv, Mw, Mb, Vv	VL,L	L,M	M,H	H	H,VH
dzs	Mw, Mb, Mv	VL,L	M	M	M,H	H
g, ds, r	F, F^{G}, Mv, Mb	VL,L	M	M	M,H	H,M
a, b	Ck, Cv, Cb	VL	VL	L	L	M,L
R (resistant rock)	R	VL	VL	VL	VL	VL

* slope position: upper -- decrease EP, lower -- increase EP

* soil drainage: poor -- increase EP, well -- increase EP

(3.4) Sediment Delivery Criteria

For each polygon, the potential for fine sediment delivery to Spruce Creek was rated. Sediment delivery depends on the proximity and size of the nearest channel, and the slope gradient downhill from the polygon (see Table 3).

Table 3: Guidelines for assessing potential for sediment delivery to Spruce Creek.

Steepness of slopes downslope from polygon	Proximity of channel to polygon		
	No channel (major or minor) in or alongside polygon	Minor channel in or alongside polygon	Major channel in or alongside polygon
gentle slope (class 1&2)	very low (1)	low (2)	moderate (3)
moderate slope (class 3)	low (2)	moderate (3)	high (4)
steep slope (class 4&5)	moderate (3)	high (4)	very high (5)

Since sediment delivery ratings are independant of erosion potential and slope stability ratings, all three should be considered when assessing polygon sensitivity to disturbance.

(3.5) Mapping Reliability

The accuracy of terrain mapping, and hence the reliability of slope stability interpretations, depends on numerous factors, including the scale and quality of the photos, type and density of the vegetation, field access and length of time spent in the field, quality of the base maps, and type of terrain and surficial materials. Mapping at 1:20 000 is the industry standard, and the photos provided were of excellent quality with few shadows. Out of 135 polygons, 43 were field checked (32%), which meets the criterion for TSIL C, which is defined as checking 25-50% of polygons.

The smallest polygon that can be mapped is 1 cm^2, which is 4 hectares on the ground. Thus any local variations in terrain over less than 200 m cannot be mapped. In a polygon mapped as stability class III, for example, there may be small areas of class II and class IV slopes. For forest management, this implies that detailed planning of road alignments and block lay-outs will require careful ground checking to identify sites that may be more sensitive to disturbance than the polygon as a whole.

The information and analyses contained in this report are based on observations of land-surface conditions and current understanding of slope processes. However, because slope stability is strongly influenced by subsurface conditions that are not apparent from surface observations or air photo interpretation (e.g., characteristics of subsurface materials, subsurface hydrologic conditions), by events whose time of occurance cannot be predicted (e.g., extreme storms, earthquakes), and by land management practices, the results and recommendations provided in this report cannot guarantee that no landslides will occur in areas affected by forestry activities. Appropriate use of terrain information and implementation of recommendations will, however, reduce the risk of landslides and erosion.

(4) SURFICIAL MATERIALS AND ASSOCIATED LANDFORMS

The following descriptions are based on observations of materials exposed in road cuts, terrace scarps, tree-throw hollows, and soil pits ranging in depth from 20 to 75 cm. Material characteristics were recorded at specific sites, and general observations were made continuously during traverses.

(4.1) Till (M)

Till (morainal material) was deposited directly by glacier ice. Basal till accumulated under the ice due to melting of the sole of the glacier. Typically, it is massive (non-stratified), poorly-sorted material, with clasts (particles >2 mm) supported by a fine grained matrix of sand, silt and clay. It is usually the most highly consolidated (densest) and strongest of all the surficial materials; and it is highly cohesive. The permeability of basal till is generally low.

In the study area, till consists of a matrix of silty sand with 40-55% clasts (e.g. dzsMb). It was found mainly on the mid-slopes of upper Spruce Creek, in between gullies and avalanche tracks, and in the area between Spruce and Haylmore Creeks. Near the surface, the till is weathered and quite loose, but till in road cuts is highly consolidated and very dense below a sharp weathering front. The contact between weathered and unweathered till is often a seepage site, since the compact till beneath is an effectively impermeable layer. The contact also functions as a slip plane for many debris slides.

In upper Spruce Creek, two polygons were mapped as "xM". The till in these polygons appears to be recently deposited, probably during the Little Ice Age of the 18th and 19th centuries. Recently deposited till tends to contain more angular fragments than Fraser Glaciation till, hence the texture 'x' -- angular fragments.

(4.2) Glaciofluvial Materials (F^G)

Glaciofluvial sediments were deposited by glacial meltwater streams during glacier advance and recession. Glaciofluvial ice-contact deposits accumulated against or on top of melting glacier ice, resulting in landforms with undulating, hummocky or ridged topography, such as eskers, kames and kame terraces. Proglacial deposits (outwash) were laid down by streams draining away from the ice, and resulted in deltas (if lakes were present) and outwash plains (which may now be terraces). In general, glaciofluvial materials consist predominantly of sands and gravels, and may contain a small portion of silt.

In the lower part of Spruce Creek valley and on the adjacent slopes of Gates River valley, glaciofluvial terraces are widespread (e.g., $gF^G tu$). The terraces slope gently down to the northwest and end abruptly at steep scarps that face toward Gates River (e.g., $F^G k$). These features probably formed where outwash deposits, laid down by meltwater from the glacier in Spruce Creek, came in contact with a larger glacier in the Gates River valley. Materials are well rounded bouldery gravels with interstitial sand. Raveling of the scarps has produced bouldery colluvium that forms a veneer over the thick glaciofluvial deposits. Where Spruce and Haylmore Creeks have cut down into the outwash deposits, steep scarps prone to debris slides have formed (e.g.,$F^G s$-F").

Glaciofluvial terraces are good sites for roads because they are well drained and dry, and stable unless interlayered with slowly permeable materials such as till or glaciolacustrine sediments. Terrace gravels are useful aggregate; this is exemplified by the gravel quarry located on the fan at the mouth of Haylmore creek.

(4.3) Colluvium (C)

Colluvium is material that has moved downslope due to any of a variety of gravitational processes, including rockfall, debris flows, landslides, and snow avalanches. Talus slopes are one type of colluvial landform, and are not prone to deep-seated instability, although subject to surface raveling. The texture of colluvium varies widely depending on its source.

Talus slopes are abundant in upper Spruce Creek at the base of steep rock outcrops. Colluvium in talus slopes is generally rubbly, with very few fines. At the base of avalanche tracks and debris flow gullies is colluvium derived from till and rock upslope. This consists of angular to sub-rounded clasts with interstitial silty sand. Along the lower reaches of Spruce Creek, colluvium has been derived from glaciofluvial terraces, and consists of rounded boulders (Photo 1).

In the Spruce Creek area, colluvium was most often found as veneers or blankets over till, rock and glaciofluvial materials. Where Spruce and Haylmore Creeks enter the Gates River valley, there are very large colluvial fans

(4.4) Bedrock (R)

Bedrock is exposed on ridge crests and steep slopes mostly at higher elevations in the Spruce Creek area.

(4.5) Fluvial Materials (F)

Fluvial sediments have been deposited by flowing water. They underlie floodplains, fluvial terraces and fluvial fans and deltas. Fluvial materials consist of loose gravel and sand that is well drained unless the water table is close to the surface, which is usually the case on floodplains.

In the Spruce Creek area, small floodplains and terraces were mapped along Spruce and Haylmore Creeks, and a large floodplain was mapped along Gates River. Fluvial fans are present where Spruce and Haylmore Creeks join Gates River.

(5) ACTIVE GEOMORPHOLOGICAL PROCESSES

(5.1) Rapid Mass Movement (-R, -R")

Rapid mass movement processes affect most of the upper slopes of the study area. Polygons that include initiation zones, indicated by -R" (e.g., Mv/Rs-R"d), are rated as stability class V because they include unstable ground and very likely to fail if the slope is disturbed. Mass movement processes in runout zones, mapped as -R (e.g., Mv/Cv-Rs) may pose a hazard to people and equipment, but logging activities are unlikely to increase the problem significantly. These polygons are rated as stability classes I-IV according to criteria listed in Table 1.

(5.1.1) Debris Slides (-R"s, -Rs)

Debris slides occur when a mass of sediment or weathered bedrock becomes detached from a slope and slides downslope along a shear plane. Failure occurs when water tables are high and the soil is saturated. In the study area, debris slides occur in areas where thin colluvium overlies rock, and on steep glaciofluvial scarps undercut by creeks. Photo 4 shows a debris slide on a glaciofluvial scarp beside Spruce Creek.

(5.1.2) Debris Flows (-R"d, -Rd)

Debris flows are rapid flows of saturated material, consisting of a mixture of sand, mud, stones, large boulders and organic debris, which travel down gullies. Material is derived from slides on the gully headwall or sidewalls. Debris flow deposits accumulate as fans at the base of gullies and in levees along the sides of channels. Site C10 on the sidewall of a gully is on the levee of a very old debris flow. Most of the gullies in the upper part of Spruce Creek valley show evidence of debris flow activity.

(5.1.3) Rockfall (-R"b, -Rb)

Rockfall is the downslope movement of small masses of rock by free fall, rolling and bouncing. In the Spruce Creek area, talus slopes at the base of steep rock cliffs are the result of rockfall.

(5.2) Snow Avalanches (-A, -Af)

Avalanches are common in upper and middle Spruce Creek valley, as indicated by the presence of numerous, clearly defined (treeless) avalanche tracks. Snow starts to slide on steep treeless areas below the ridge crests, and most avalanches travel all the way down to Spruce Creek. Removal of trees from steep, high elevation slopes that receive heavy snowfall could result in the extention of initiation and runout zones. Although snow avalanches are not a factor in the assessment of slope stability, they are a hazard to winter activities. Photo 5 shows a typical avalanche track.

(5.3) Slow Mass Movement (-F", -F"g)

Failing (-F") refers to slope failures where movement occurs slowly (imperceptibly) and/or where the displaced material moves only a short distance downslope. In the Spruce Creek area, -F" generally refers to slides on undercut stream banks, for example along the south side of Haylmore Creek.

In the upper part of the area, a rock glacier was identified (Cmb-F"g) (Photo 6). Rock glaciers are slow-moving, glacier-like tongues of blocks and rubble with interstitial ice, extending out from cirques in alpine areas. They are not usually a hazard to forestry activities.

(5.4) Gully Erosion (-V)

Gullies are small ravines with a V-shaped cross section formed in drift and bedrock. The symbol is usually applied to terrain polygons where more than one gully is present. Gullies are formed by the erosive effects of debris flows, small streams, snow avalanches and rockfall. In the study area, gullies formed by debris flows and avalanches in upper Spruce Creek extend down into mature forest.

(6) DISCUSSION AND RECOMMENDATIONS FOR MANAGEMENT

(6.1) Slope Stability

About half of the Spruce Creek area consists of slopes that have been rated as potentially unstable (class IV) and unstable (class V). Unstable slopes were mapped where evidence of present instability was noted on air photos or in the field. They were found along terrace scarps and steep mountainsides. Unstable terrace scarps are present along both Spruce and Haylmore Creeks, especially where the streams are presently undercutting and steepening slopes underlain by till and glaciofluvial materials. Small slides here probably result from a combination of steep slopes, weak materials, and lower-slope seepage. Unstable areas, chiefly slopes with small slides and associated debris flows, were mapped on glacially-steepened mountainsides in the upper Spruce Creek valley. For example, gullied, west-facing slopes on steep rock and colluvium near the headwaters of Spruce Creek display instability in the form of abundant debris flows and rockfall. As well, instability was noted on open slopes where thin till and colluvium overlie steeply sloping bedrock. Potentially unstable slopes are similarly distributed on scarps underlain by glacial drift and steeper mountainsides.

(6.2) General Recommendations

Management implications and recommendations based on ratings for slope stability, erosion potential and sediment delivery are listed in Tables 4, 5, and 6. Although much of the upper Spruce Creek area is mapped as unstable and potentially unstable, much of this terrain is inoperable, consisting of steep rock and colluvium, large gullies and avalanche tracks. The most significant unstable areas are the steep scarps of the glaciofluvial terraces beside Spruce and Haylmore Creeks. These slopes are being undercut by the creeks, leading to slides. Roads are often built on the relatively flat terrace surfaces above these scarps. Diversion of natural surface and shallow subsurface runoff by a road could lead to destabilization or erosion of the scarp, and the addition of sediment to the creek. Therefore it is important to control the release of water from ditches and road runoff, especially where the road is close to the upper edge of a scarp.

Table 4. Implications of Slope Stability Classes

Stability Class	Interpretation
I	• No significant problems exist
II	• There is a very low likelihood of landslides following timber harvesting or road construction. • Minor slumping is expected along road cuts, especially for one or two years following construction.
III	• Minor stability problems can develop. • Timber harvesting should not significantly reduce terrain stability. There is a low likelihood of landslide initiation following timber harvesting. • Minor slumping is expected along road cuts, especially for one or two years following construction. There is a low likelihood of landslide initiation following road-building. • A field inspection by a terrain specialist is usually not required.
IV	• Expected to contain areas with a moderate likelihood of landslide initiation following timber harvesting or road construction. Wet season construction will significantly increase the potential for road-related landslides. • A field inspection of these areas is to be made by a qualified terrain specialist prior to any development, to assess the stability of the affected area.
V	• Expected to contain areas with a high likelihood of landslide initiation following timber harvesting. • A field inspection of these areas is to be made by a qualified terrain specialist prior to any development, to assess the stability of the affected area.

From B.C. Ministry of Forests, Mapping and Assessing Terrain Stability Guidebook, April 1995

Table 5 Implications of erosion potential classes

Erosion Potential Class	Interpretation
VL (very low, none)	• No problems of erosion expected on flat or gently sloping terrain, organic soils and floodplains. Erosion of banks and channels may be initiated by the disturbance of streams.
L (low)	• Chances of rilling or sheet erosion and subsequent sedimentation of lakes and streams are generally low, although care is required to avoid erosion along ditches with steep gradients. No significant problems of erosion expected.
M (moderate)	• Problems of erosion associated with logging are similar to but less than terrain rated "high", although problems may develop if water flows unchecked along steep ditches, roadways, or on other bare soil surfaces. Avoid exposing fine textured till near creeks.
H (high)	• Expect problems of erosion to develop on bare soils and compacted surfaces along roads and ditches, cut slopes adjacent to landings, and disturbed soil in cut blocks. Take precautions necessary to minimize erosion as appropriate, such as immediate reseeding of exposed mineral soil. Site inspection by geomorphologist recommended.
VH (very high)	• Natural movement of fine sediments into adjacent creeks. Potential erosion more severe than in "high" category. Site inspection by geomorphologist recommended.

(Source: modified from Forest Practices Code, 1995).

Table 6 Potential for Fine Sediment Delivery to Major Streams

Sediment Delivery Class	Interpretation
1	• Very low potential: It is very unlikely that landslides or erosion in this polygon will result in sediment input to a stream
2	• Low potential: Low likelihood that landslides or erosion in this polygon will result in sediment input to a stream
3	• Moderate potential: Moderate likelihood that landslides and/or erosion in this polygon will result in sediment input to a stream
4	• High potential: High likelihood that landslides and/or erosion in this polygon will result in sediment input to a stream
5	• Very high potential: It is very likely that landslides and/or erosion in this polygon will result in sediment input to a stream

Note that ratings for sediment delivery to streams (Table 6) are based only on polygon steepness and its proximity to an ephemeral or major stream. For any polygon, to obtain an indication of the likelihood of fine sediment entering the nearest stream, consider the rating for fine sediment delivery *together with* the ratings for erosion potential and slope stability. Thus if the delivery rating is high, but erosion and (in)stability ratings are low, very little sediment can be expected to reach the stream.

ACKNOWLEDGEMENTS

The author would like to thank June Ryder and Sid Tsang for their advice and supervision throughout the project. Thanks to Jennifer Shypitka, Anthony Collett and Sid Tsang for help in the field and to Jim Gilliam of Squamish Forest District for giving us the job and providing maps and air photos.

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APPENDIX 1. STANDARD TERRAIN LEGEND - LONG VERSION

(1) TERRAIN UNIT SYMBOLS

Simple Terrain Units: e.g., texture ----> gFt - J <---- process
surficial material ____/ ____ surface expression

Note: Two or three letters may be used to describe any characteristic other than surficial material, or letters may be omitted if information is lacking.

Composite Units: Two or three groups of letters are used to indicate that two or three kinds of terrain are present within a map unit.

e.g., Mv · Rs indicates that "Mv" and "Rs" are of roughly equal extent

Mv/Rs indicates that "Mv" is more extensive than "Rs" (about 2/1 or 3/2)

Mv//Rs indicates that "Mv" is much more extensive than "Rs" (about 3/1 or 4/1)

Stratigraphic Units: Groups of letters are arranged one above the other where one or more kinds of surficial material overlie a different material or bedrock:

e.g., $\frac{\text{Mv}}{\text{Rr}}$ indicates that "Mv" overlies "Rr".

$\frac{\text{/Mv}}{\text{Rr}}$ indicates that "Rr" is partially buried by "Mv"

Slope Stability and Erosion Potential: Roman numerals for slope stability and upper case letters for erosion potential separated by a ".", e.g., **IV.M**

(2) MATERIALS

A	Anthropogenic materials	Artificial materials, and materials modified by human actions such that their original physical appearance and properties have been drastically altered.
C	Colluvium	Products of gravitational slope movements; materials derived from local bedrock and major deposits derived from drift; includes talus and landslide deposits.
D	Weathered bedrock	Bedrock modified *in situ* by mechanical and chemical weathering.
E	Eolian sediments	Sand and silt transported and deposited by wind; includes loess.
F	Fluvial materials	Sands and gravels transported and deposited by streams and rivers; floodplains, terraces and alluvial fans.
F^A	"Active" fluvial materials	Active deposition zone on modern floodplains and fans; active channel zone.

(2) MATERIALS cont'd

F^G	Glaciofluvial materials	Sands and gravels transported and deposited by meltwater streams; includes kames, eskers and outwash plains.
I	Ice	Permanent snow and ice; glaciers.
L	Lacustrine sediments	Fine sand, silt and clay deposited in lakes.
L^G	Glaciolacustrine sediments	Fine sand, silt and clay deposited in ice-dammed lakes.
M	Till	Material deposited by glaciers without modification by flowing water. Typically consists of a mixture of pebbles, cobbles and boulders in a matrix of sand, silt and clay; diamicton.
M'	Ablation till	Material accumulated on top of a melting glacier; coarse textured and less consolidated than basal till.
O	Organic materials	Material resulting from the accumulation of decaying vegetative matter; includes peat and organic soils.
R	Bedrock	Outcrops, and bedrock within a few centimetres of the surface.
U	Undifferentiated materials	Different surficial materials in such close proximity that they cannot be separated at the scale of the mapping.
V	Volcanic materials	Unconsolidated pyroclastic sediments.
W	Marine sediments	Sediments deposited by settling and gravity flows in brackish or marine waters, and beach sands and gravels.
W^G	Glaciomarine sediments	Sediments laid down in marine waters in close proximity to glacier ice.

(3) TEXTURE

Specific Clastic Terms

c	clay	< 2µm	k	cobbles	64 - 256 mm
z	silt	62.5 - 2µm	b	boulders	> 256 mm
s	sand	2 mm - 62.5µm	a	blocks	angular boulders
p	pebbles	2 - 64 mm			

Common Clastic Terms

f	fines	any or all of c, z, and fine s
d	mixed fragments	pebbles and larger clasts in a matrix of fines
g	gravel	any or both of p and k
r	rubble	angular gravel
x	angular fragments	mix of both r and a
m	mud	mix of both c and $
y	shells	shell or shell fragments

Organic Terms

e	fibric
u	mesic
h	humic

Bedrock Classification Codes

Sedimentary Rocks

	EITHER		OR	
Clastic, calcareous	fine grained	kf	calcareous siltstone calcareous mudstone calcareous shale	kz kd kh
	medium grained	km	calcareous sandstone calcareous greywacke calcareous arkose	ks kg ka
	coarse grained	kc	calcareous conglomerate calcareous breccia	kn kb
Clastic non-calcareous	fine grained	uf	siltstone mudstone shale	zl md sh
	medium grained	um	sandstone greywacke arkose	ss gk ak
	coarse grained	uc	conglomerate breccia	cg bx
Precipitates	calcareous	pk	travertine limestone dolomite	tv ls do
	non-calcareous	pu	gypsum limonite barite	gy li ba
Organic	calcareous	ok	marl	ma
	carbonaceous	oc	lignite coal	lg co

Igneous Rocks

	EITHER		OR	
Intrusive	acid (felsic)	ia	syenite granite quartz monzonite granodiorite	sy gr qm gd
	intermediate	ii	quartz diorite diorite	qd di
	basic	ib	quartz gabbro gabbro pyroxenite peridotite dunite	qg gb py pd du
Extrusive	acid (felsic)	ea	trachyte rhyolite dacite	tr rh da
	intermediate	ei	andesite	an
	basic	eb	quartz basalt basalt	qb bs
	recent lava flow	la		
	pyroclastic	ep	tuff volcanic breccia agglomerate	tu vb ag

Metamorphic Rocks

	EITHER		OR	
Foliated	fine grained	**ff**	slate phyllite	**sl** **ph**
	medium to coarse grained	**fm**	schist gneiss granite gneiss diorite gneiss	**sc** **gn** **gg** **dg**
	coarse grained	**fc**	migmatite	**mi**
Non-foliated	fine grained	**nf**	argillite serpentinite	**ar** **sp**
	medium to coarse grained	**nm**	granulite quartzite hornfels	**gl** **qt** **hf**
	coarse grained	**nc**	amphibolite hornblendite	**am** **hb**
	calcareous	**nk**	marble dolomite marble serpentine marble	**mb** **dm** **sm**

(4) SURFACE EXPRESSION

a	moderate slope(s)	predominantly planar slopes; 15-26^{o} (27-49%)
b	blanket	material >1-2m thick with topography derived from underlying bedrock (which may not be mapped) or surficial material
c	cone	a fan-shaped surface that is a sector of a cone; slopes 15^{o} (27%) and steeper
d	depression	enclosed depressions
f	fan	a fan-shaped surface that is a sector of a cone; slopes 3-15^{o} (5-27%)
h	hummocky	steep-sided hillocks and hollows; many slopes 15^{o} (27%) and steeper
j	gentle slope(s)	predominantly planar slopes; 3-15^{o} (5-27%)
k	moderately steep slope	predominantly planar slopes; 26-35^{o} (49-70%)
m	rolling topography	linear rises and depressions; <15^{o} (27%)
p	plain	0-3^{o} (0-5%)
r	ridges	linear rises and depressions with many slopes 15^{o} (27%) and steeper
s	steep slope(s)	slopes steeper than 35^{o} (70%)
t	terrace(s)	stepped topography and benchlands
u	undulating topography	hillocks and hollows; slopes predominantly <15^{o} (27%)
v	veneer	material <1-2m thick with topography derived from underlying bedrock (may not be mapped) or surficial material; may include outcrops of underlying material
w	variable thickness	material of variable thickness with topography derived from underlying bedrock (may not be mapped) or surficial material
x	thin veneer	a subset of v (veneer), where there is a dominance of surficial materials about 10-25 centimeters thick

(5) GEOLOGICAL PROCESSES AND MASS MOVEMENT SUB-CLASSES

A	Avalanches	Slopes modified by frequent snow avalanches.
Af	Avalanches: major tracks	In zones of coniferous forest: broad avalanche track(s) occupied by predominantly shrubby, deciduous vegetation.
Am	Avalanches: minor tracks	Similar to above, but generally narrower than the height of adjacent trees.
Aw	Avalanches: mixed	Includes both major and minor avalanche tracks.
Ao	Avalanches: old tracks	Clearly visible on air photos, but less well defined than active tracks because they are partly or completely occupied by young conifers.
B	Braiding channel	Channel zone with many diverging and rejoining channels; channels are laterally unstable.
C	Cryoturbation	Heaving and churning of soil and surficial materials due to frost action.
D	Deflation	Removal of sand and silt particles by wind action.
E	Glacial meltwater channels	Areas crossed by meltwater channels that are too small or too numerous to map individually.
F	Failing	Slope experiencing slow mass movement, such as sliding or slumping.
H	Kettled	Area includes numerous small depressions and/or lakes where buried blocks of ice melted.
I	Irregularly sinuous channel	Channel displays irregular turns and bends.
J	Anastamosing channel	Channels diverge and converge around semi-permanent islands.
K	Karst processes	Solution of carbonates (limestone, dolomite) resulting in development of collapse and subsidence features.
L	Surface seepage	Zones of active seepage often found along the base of slope positions.
M	Meandering channel	Channel characterized by regular turns and bends.
N	Nivation	Surface modified by hollows developed around semi-permanent snowbanks.
P	Piping	Subsurface erosion of silty sediments by flowing water resulting in the formation of underground conduits.
R	Rapid mass movement	Slope or parts of slope affected by processes such as debris flows, debris slides and avalanches, and rockfall.
S	Solifluction	Slope modified by slow downslope movement of seasonally unfrozen regolith.
U	Inundated	Areas submerged in standing water from a seasonally high watertable.
V	Gullying	Slope affected by gully erosion.
W	Washing	Winnowing of fines by flowing water resulting in development of lag deposits.
X	Permafrost processes	Processes related to the presence of permafrost; permafrost aggradation and degradation.
Z	Periglacial processes	Solifluction, nivation and cryoturbation occurring together in a single terrain unit.

Mass Movement Sub-Classes

-F"	Slow m.m. (initiation zone)	-Fx	Slump-earthflow
-Fc	Soil creep	-R"	Rapid m. m. (initiation zone)
-Fe	Earthflow	-Rb	Rockfall
-Fg	Rock creep	-Rd	Debris flow
-Fj	Lateral spread in surficial materials	-Rf	Debris fall
-Fk	Tension cracks	-Rr	Rockslide
-Fm	Slump in bedrock	-Rs	Debris slide
-Fp	Lateral spread in bedrock	-Rt	Debris torrent
-Fu	Slump in surficial material		

(6) SOIL DRAINAGE CLASSES

r	rapidly drained	water is removed from the soil rapidly in relation to supply
w	well drained	water is removed from the soil readily but not rapidly
m	moderately well drained	water is removed from the soil somewhat slowly in relation to supply
i	Iiperfectly drained	water is removed from the soil sufficiently slowly in relation to supply to keep the soil wet for a significant part of the growing season
p	poorly drained	water is removed so slowly in relation to supply that the soil remains wet for a comparatively large part of the time the soil is not frozen
v	very poorly drained	water is removed from the soil so slowly that the water table remains at or on the surface for the greater part of the time the soil is not frozen

Where two drainage classes are shown:
if the symbols are separated by a comma, e.g., "w,i", then no intermediate classes are present;
if the symbols are separated by a dash, e.g., "w-i", then all intermediate classes are present.

(7) SLOPE CLASSES

1	0-3^{o} (0-5%)	**3**	15-26^{o} (27-49%)	**5**	>35^{o} (>70%)
2	3-15^{o} (5-27%)	**4**	26-35^{o} (49-70%)		

(8) FIELD CHECK SYMBOLS AND BOUNDARY LINES

Boundary lines: definite boundary ——— ; indefinite boundary – – – – ; assumed or arbitrary boundary .... ; study area boundary ———

Field Check Symbols:

⊙ S10 ground inspection site

Δ B8 visual inspection site

APPENDIX 2: ANNOTATED PHOTOGRAPHS

Photo 1. Bouldery colluvium overlying glaciofluvial sediments near site C25.

Photo 2. Site S1 -- very thick glaciofluvial sediments. This is the edge of an old fan.

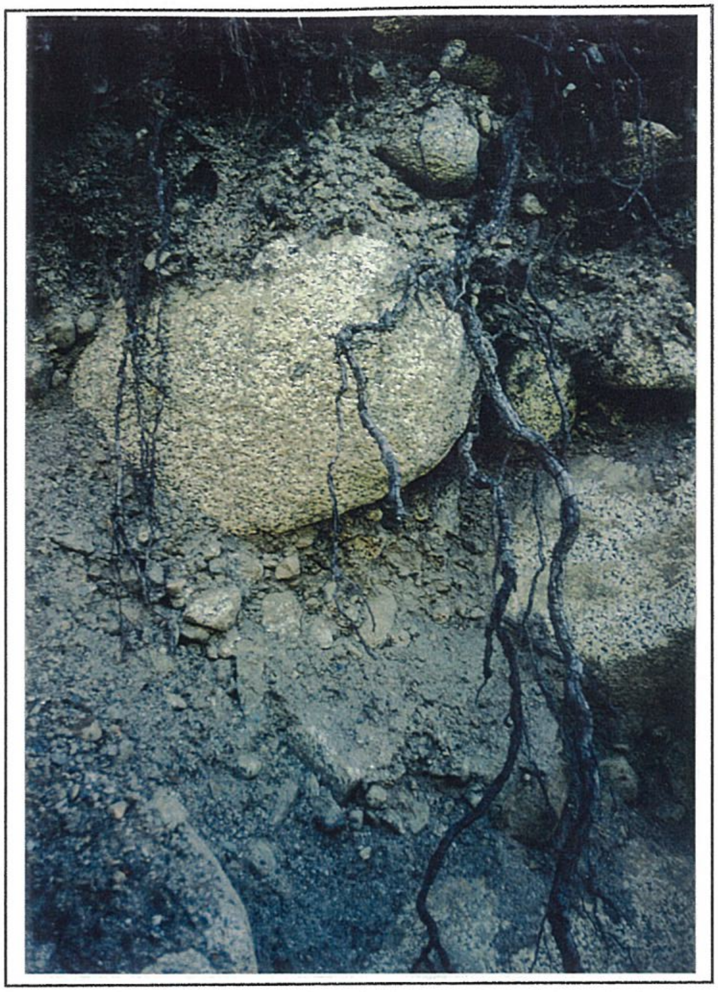

Photo 3. Close-up of glaciofluvial material in a road cut at site C24.

Photo 4. Failure in glaciofluvial terrace on the north side of Spruce Creek. This is possibly related to an old road.

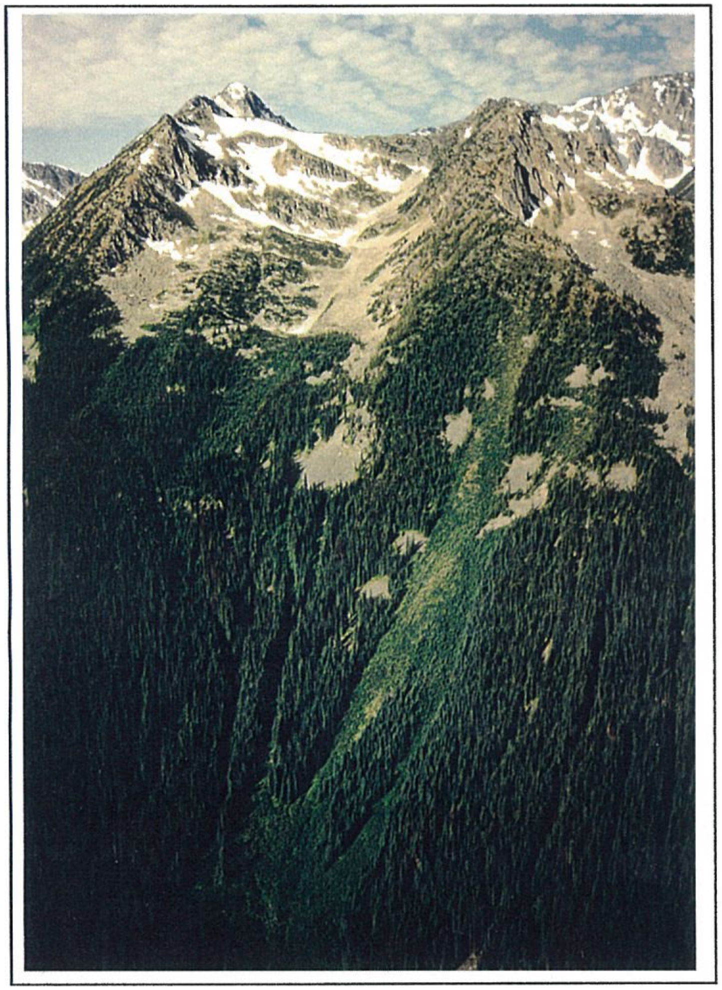

Photo 5. Large avalanche track in upper Spruce Creek.

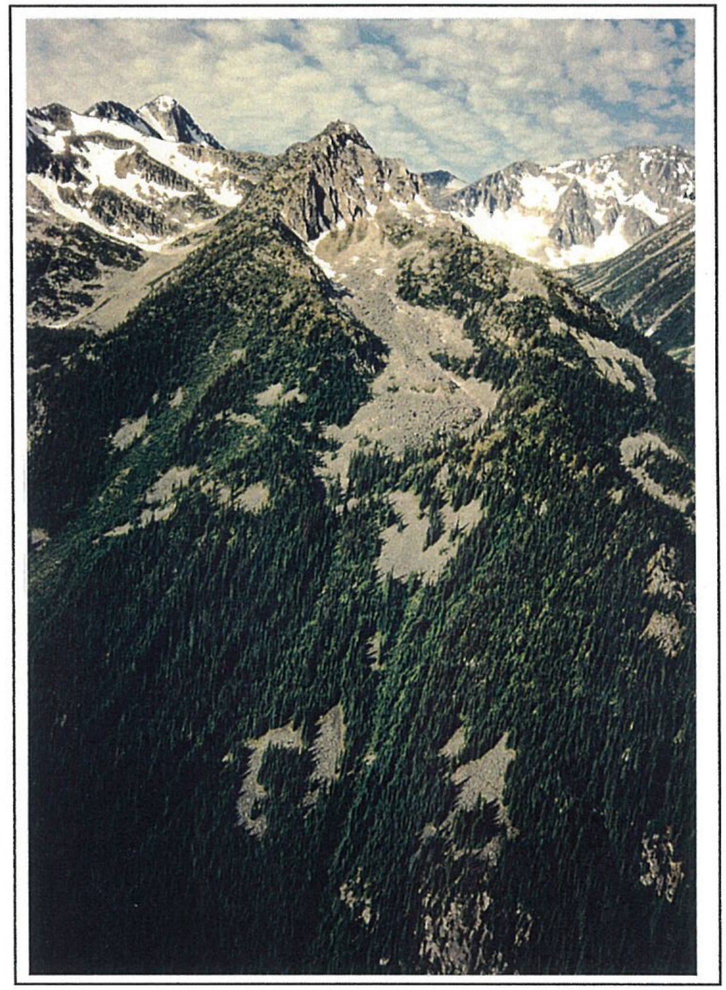

Photo 6. View of rock glacier in upper Spruce Creek

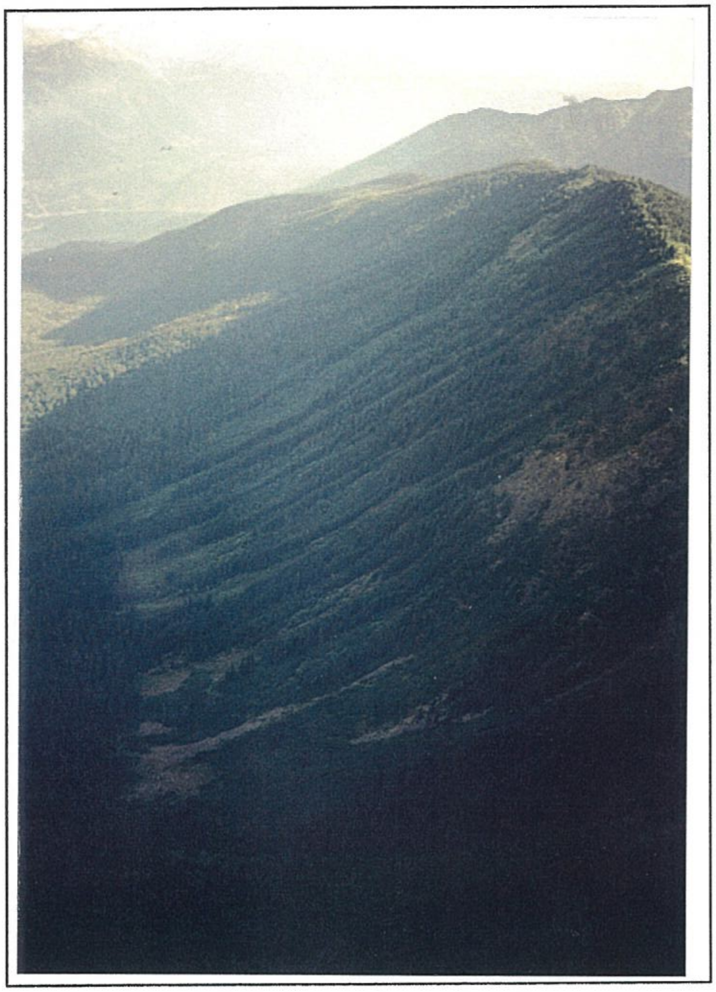

Photo 7. East side of upper Spruce Creek. Note numerous avalanche and debris flow tracks