DETAILED TERRAIN STABILITY MAPPING OF THE FADEAR MOUNTAIN - MOOSE MEADOWS OPERATING AREA

Completed for:
Kamloops Forest District
Small Business Forestry Enterprise Program

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1.0 INTRODUCTION
The objective of this project was to prepare 1:20,000 scale maps of terrain, terrain stability, surface erosion potential and potential sediment delivery to major streams for the Fadear Mountain - Moose Meadows area. The study area is located approximately 50 kilometres (km) north-east of Kamloops in south-central British Columbia within the Kamloops Forest District (Figure 1). The study area is bound by Fraser and Sinmax Creeks on the north, Louis Creek to the west and Fadear Creek to the south; the south-east boundary crosses the uplands. The study boundary coincides with the Kamloops Forest District Small Business Forest Enterprise Program Fadear Mountain - Moose Meadows development area and is located entirely within Terrain Resource Inventory Map (TRIM) sheets 92P.010, 82M.001 and 011.

Detailed terrain mapping at terrain survey intensity level (TSIL) C and interpretations for terrain stability, surface erosion potential and potential sediment delivery to major streams were carried out in accordance with the Resource Inventory Committee Guidelines and Standards for Terrain Mapping in British Columbia (1996a). Terrain mapping consisted of aerial photographic interpretation of 1:15,000 scale (approximately) colour aerial photographs followed by field reconnaissance. The study area was divided into polygons of homogenous terrain (surficial materials, texture, surface expression and geomorphological processes), slope and drainage. Ratings for terrain stability, surface erosion potential and potential sediment delivery to major streams were the assigned to each of the terrain polygons.

This report accompanies a terrain map and an associated derivative map, at 1:20,000, completed as per the guidelines set forth in the Mapping and Assessing Terrain Stability (MATS) Guidebook (Ministry of Forests 1995). It provides a general overview of the physiography of the study area, descriptions of the terrain mapping methodology and mapping reliability, information about surficial materials and geomorphological processes, and criteria used for determining terrain stability, surface erosion potential and potential sediment delivery to major streams interpretations. A summary of the implications and recommendations for forestry planning and management that arise out of this terrain analysis are discussed in Section 8.0.

1.1 Report Limitations
The information presented in this report and on the accompanying map is intended for forest development purposes only. The terrain stability, surface erosion potential and potential sediment delivery to major streams ratings are not considered appropriate for other land use applications. Identification and classification of terrain polygons has been completed using the standards methods employed by professional terrain mappers throughout British Columbia. The reliability of this mapping is consistent with other TSIL C studies that largely rely on aerial photographic interpretation supplemented by field observations. Interpretations of terrain stability, surface erosion potential and potential sediment delivery to major streams are highly subjective because they are based mostly on aerial photographic interpretation. Accordingly, the exactness of the boundaries and the descriptions of the units shown on the accompanying map cannot be guaranteed. Subsequent, more detailed assessments should be undertaken for forest operational planning where required under the Forest Practices Code.
2.0 PHYSICAL SETTING

2.1 Physiography
The Fadear Mountain - Moose Meadows study area is located in the Shuswap Highlands of the Interior Plateau physiographic region (Holland 1976). The Shuswap Highlands consist of gently to moderately sloping plateaus of moderate relief dissected by major rivers, resulting in steep valley sides and a large total relief. The upland plateau lies at an elevation of approximately 1480-1620 metres above sea level (m asl). Elevation in the study area, ranges from 560 to 600 m asl in the valleys to 1680 m asl on top of Fadear Mountain. The west and south-west facing slopes above Louis and Fadear Creek are the steepest ground within the study area and consist of thin veneers of till and colluvium over bedrock which have been dissected by gullying. The north facing slope is covered with a morainal blanket which has been incised by several deep gullies (Plate 1). The plateau areas around Fadear Mountain have mostly tills mantling undulating or ridged bedrock and exposed bedrock faces with associated colluvium.

2.2 Bedrock Geology
Bedrock geology is covered by a British Columbia Ministry of Energy, Mines and Petroleum Resources map (Figure 2; Schiarizza and Preto 1984) and two Geological Survey of Canada maps (Campbell and Tipper 1971, Campbell 1963). In the east and central portions of the project area Schiarizza and Preto (1984) have mapped the primary bedrock types as grey and green phyllitic sandstone and grit as well as phyllite and quartzite. Occurring in less frequent amounts are limestone, dolostone, green chloritic phyllite, sericite-quartz phyllite and feldspathic sericite-quartz phyllite. The western parts consist primarily of dark grey phyllite and slate with interbedded siltstone, sandstone and grit with minor amounts of conglomerate, limestone and metatuff. A grey-green vesicular and pillow metabasalt, greenstone, chlorite schist with lesser amounts of bedded chert, siliceous phyllite and fine-grain quartzite runs through the western portion. Two small occurrences of light grey to white quartzite and limestone, dolostone and marble are found in the centre of the area. A thin unit of siderite-seracite-quartz phyllite and feldspathic phyllite occurs in the north-east. Olivine basalt, augite porphyry breccia, serpentinite and foliated diorite, quartz diorite and gabbro are also found in smaller portions within the project boundaries.

2.3 Quaternary Geology
Surficial geology mapping has been completed by the Geological Survey of Canada at 1:100,000 (Alley 1984) and 1:250,000 (Fulton et al. 1986). The BC Ministry of Environment produced a soil and terrain report (Kowall 1980), of the Seymour Arm area, which included the project area.

The distribution of surficial materials and the landforms that characterise the study area have largely been produced through bedrock weathering and the actions of glacial, fluvial and slope processes operating in the Quaternary Period (1.64 million years ago to present). The large scale features of the region are dominantly related to tectonic activity in the Tertiary Period (65 million to 1.64 million years ago) when the pre-glacial landscape was elevated. Subsequent stream incision into the plateau surface produced the plateaus and incised river valleys of the Shuswap Highland. During the Quaternary, glaciers repeatedly modified the landscape, smoothing the plateau and enlarging the valleys. There is stratigraphic evidence of only four major glaciations in southern British Columbia in the Quaternary Period (Fulton et al 1992), although there may have been as many as twenty glacial cycles.

The last glacial period, known as the Fraser Glaciation in British Columbia, was responsible for shaping much of the landscape as we know it today. The Fraser Glaciation occurred during the
Bedrock Geology Legend

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBS</td>
<td>gray and green phyllitic sandstone, grit, phyllite, quartzite</td>
</tr>
<tr>
<td>EBSq</td>
<td>light gray to white quartzite</td>
</tr>
<tr>
<td>EBSc</td>
<td>limestone, dolostone and marble</td>
</tr>
<tr>
<td>EBSt</td>
<td>siderite-sericite-quartz phyllite, feldspathic phyllite</td>
</tr>
<tr>
<td>EBP</td>
<td>dark gray phyllite, slate with interbedded silstone, sandstone, grit</td>
</tr>
<tr>
<td>EDM</td>
<td>gray and green vesicular, pillowved metabasalt, greenstone, chlorite schist</td>
</tr>
<tr>
<td>Tb</td>
<td>olivine basalt</td>
</tr>
<tr>
<td>TrJv</td>
<td>augite porphy breccia</td>
</tr>
<tr>
<td>ph</td>
<td>serpentine</td>
</tr>
<tr>
<td>di</td>
<td>foliated diorite, quartz diorite and gabbro</td>
</tr>
</tbody>
</table>

Scale 1:20 000

period of approximately 25,000 to 10,000 years before present and resulted in the land surface being covered by an ice sheet at least 1000 metres thick. Ice initially accumulated in cirques and icefields of the Monashee, Selkirk and Cariboo Mountains. Glaciers spread south and west along major valleys of the Thompson Plateau and Shuswap Highland. As the valley glaciers thickened, ice began to cover the plateaus, and eventually the entire area was covered by one large ice sheet. Deglaciation occurred by in situ ablation and stagnation on the plateaus where ice was thinnest (Clague 1989). Glaciers continued to move through the valleys but were retreating as the rate of melt exceeded the rate of replenishment. Meltwater from the plateaus was unable to drain freely to the Pacific Ocean and large lakes were impounded by valley ice.

During expansion of the glaciers, the active ice eroded bedrock and previously deposited sediment at its base. This debris was transported near the base of the ice and deposited as dense lodgement and basal tills far from the source. When the glacier stopped moving and started melting, ablation tills were deposited as ice melted out under the accumulated debris on the ice. Pre and post-glacially derived glaciofluvial (glacial river) or glaciolacustrine (glacial lake) sediments may be deposited along the margins of the ice. Terraces, kames, deltas and outwash plains of washed sand and gravel formed where glacial meltwater flowed. These often occur at the front of the advancing ice lobes, or on top of or marginal to the ice as it melts. Lakes formed where water was impounded by ice, which allowed the formation of glaciolacustrine deposits. In the Thompson region there were several lakes formed in the larger valleys. Other landforms indicative of glacial activity include parallel lineations, striations in bedrock and remnants of meltwater channels, all found on the plateau portion of the study area. Ice flow direction in the study area was determined to be to the south-east based on measurement of striations (Plate 2), drumlins and other elongated landforms.

During the Holocene Epoch (10,000 years ago to the present), the landscape in the study area has been modified by colluvial and fluvial processes. On the north face the morainal sediments have been eroded by running water and deeply incised creeks have developed. Fluvial sediments are found in the base of the draws with colluvial sediments accumulating over bedrock and till along the valley sides. The plateau areas are dominantly till covered, with gently rolling or undulating bedrock controlling the landform. Steeper bedrock ridges with minimal or no sedimentary cover are common. The majority of the north slope has experienced minimal change since the retreat of ice.

The steeper southern and western slopes of the study area are more open, drier and have thinner surficial sedimentary cover. Mass-wasting of sediments by debris slides and other gravity induced movements from the steeper slopes above Louis and Fadear Creek has resulted in colluvium accumulating at the foot of steep slopes or as fans at the outlet of gully systems. On the open slopes colluvial deposits are commonly deposited on top of morainal sediments and form a veneer over bedrock. The majority of the colluvial deposits were formed immediately following deglaciation when the land surface lacked vegetation and was at its most unstable and easiest to erode.

As the ice retreated or downwasted in the valleys, meltwaters deposited glaciofluvial sediments along the margins of the ice. The broad U-shaped valleys around the margin of the study area are infilled with thick glaciofluvial sediments. Lake sediments found in the Fadear Creek drainage suggest the presence of a localised ice dammed lake as ice stagnated. Fluvial sediments moved through the gullies by water have formed fans on top of the valley bottom sediments.
2.4 Soils
The Ministry of Environment published a soil and terrain report, including maps, of the Seymour Arm Area which covers the east portion of the project (Kowall 1980). The western segment is covered by a map entitled Bonaparte River - Canim Lake Map Area: soils and landforms (Gough 1978). The soils that have developed since deglaciation are primarily podsolos and brunisols depending on elevation and vegetation community (Kowall 1980). The plateau features humoferric podsolos derived from morainal or colluvial materials, having a gravelly sandy loam texture. The Louis Creek valley side has dystric brunisols, derived from colluvium, comprised of gravelly sandy loam.

2.5 Biogeoclimatic Classification
There are four biogeoclimatic zones in the Fadear Mountain - Moose Meadows study area. They include the Interior Douglas-Fir (IDF), Interior Cedar - Hemlock (ICH), Montane Spruce (MS) and the Engelmann Spruce - Subalpine Fir (ESSF) (Lloyd et al. 1990). The IDF is subdivided into two subzones, the dry-cool (dk) and the moist-mild (mm). The IDF is the dominant zone in the project area ranging from the valley floor to 1300 m asl. It is distinguishable by the presence of interior Douglas fir (*Pseudotsuga menziesii* var. *glauca*) and a pinegrass (*Calamagrostis rubescens*) understory. The ICH zone, ranging from the valley floor up to elevations of 1400 m asl, is located mostly in the south-eastern corner of the project area on sites with higher rainfall. The ICH is easily recognised by the presence of western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*). The MS zone (1275-1530 m asl) grades up from the IDF zone can be identified by subalpine fir, hybrid white spruce (*Picea engelmannii* x *glauca*), and the lack of the rhododendron and Sitka valerian. The ESSF zone is in the higher elevation ranges (above 1500 m asl) and is distinguished by the presence of white-flowered rhododendron (*Rhododendron albiflorum*) and Sitka valerian (*Valeriana sitchensis*) vegetation as well as subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*).

2.6 Climate
The closest climate station to the study area is located north-west in Barriere. Temperatures for the year are quite mild as they do not normally drop below -11 degrees Celsius (°C). January is the coldest month of the year with average high of -3 °C and a low of -10.7 °C. The warmest month of the year is in July having a monthly average high of 27.7 °C. The average precipitation for the year is 471.2 millimetres of which 124.8 centimetres falls as snow. The ESSF zone, at higher elevations, receives more snow than the average. The snow pack persists into the early spring months on some of the north aspect slopes.

3.0 METHODS

3.1 Pre-typing Aerial Photographs
Terrain mapping followed the British Columbia Terrain Classification System (Howes and Kenk 1997), Guidelines and Standards to Terrain Mapping in British Columbia (Resources Inventory Committee 1996a) and the MATS Guidebook (Ministry of Forests 1995). Preliminary terrain mapping was completed by interpretation of 1:15,000 scale aerial photographs prior to field assessment. The aerial photographs used were: BCC95115: 147-149; BCC95018: 12-18 and 66-70; and BCC95033: 103-105. Previous studies on the surficial and bedrock geology, soils and landform maps were reviewed prior to pre-typing.

Pre-typing involved placement of boundary lines around homogenous terrain, slope and drainage characteristics. Boundary lines are predominantly based on changes in slope gradient, surficial
materials and landforms, and geomorphological processes. A TRIM 1:20,000 topographic map with 20 metre contour interval was used to augment line placement decisions. Solid boundary lines were placed to indicate a definite boundary (well defined, sharp slope breaks or distinct surficial geology changes); dashed lines to indicate approximate boundaries (changes that are visible over a short distance, but cannot be precisely located); and dotted lines were used to indicate assumed boundaries (changes that occur very gradually). Pre-typing of the aerial photographs identified areas of potential instability, and efforts were made to ensure field checking of these areas if they were in proposed blocks or crossed by proposed road alignments.

3.2 Fieldwork
Field data was collected during vehicle and foot traverses (Figure 3) in July and August of 1996. Road access is via the Louis Creek road, and the Moose Meadows, Cedar Creek, Fadear Creek and Cicero Creek Forest Service Roads (FSR). There is also an old road that continues from the southern fork of the Moose Meadows FSR and links up with the Cicero Creek FSR to the south. All roads in the study area were reconnoitred and observation sites were located where good sections were available or different materials were noted. At each observation site, the following data was typically collected: texture of surficial materials, genesis of the deposit, surface expression, geomorphological processes, soil drainage, slope steepness, aspect, description of any exposed bedrock, and indicators of slope instability.

There were 94 field checks in the approximately 3900 hectare study area resulting in 2.4 checks per 100 hectares. Fifty-six of the 270 total polygons were ground checked which equals 21% polygon checks. The average polygon size in the study area was 14.4 hectares. Observation sites were established on all roads within the study area and also on foot traverses which descended from the plateau to the valley floor. The best exposures were found in road cuts, landings or gravel pits and the field traverses supplemented these with valuable information on the steeper, gullied terrain which has yet to be developed.

3.3 Editing of Aerial Photographs
Upon completion of fieldwork, terrain polygon lines on the aerial photographs were added or existing ones modified. Finalized polygons were labelled using standard mapping conventions (Howes and Kenk 1997). Terrain polygons were assigned a terrain stability hazard class, surface erosion potential class and potential sediment delivery to major streams class. Methodology for the derivative classification is described in Section 7. The finalized mapping on the aerial photographs was transferred to a 1:20,000 TRIM map base using mono-restitution by Hugh Hamilton Ltd. and linked to a terrain database spreadsheet containing the polygon information (Resources Inventory Committee 1996b). A preliminary map was produced and reviewed for line placement and labelling. Two final maps were produced, one showing basic terrain data and the second showing the classes for terrain stability, surface erosion potential and potential sediment delivery to major streams. The base for these maps are the 1:20,000 TRIM topographic maps 92P.010, 82M.001 and 011 which have been joined to display the entire Fadear Mountain - Moose Meadows operating area on one map.

4.0 SURFICIAL MATERIALS
The surficial materials that are present in the study area are described in the following sections. Colluvial and morainal sediments are the predominant surficial materials of the Fadear Mountain - Moose Meadows mapping area. Small areas of fluvial, glaciofluvial, organic and bedrock were also mapped.
4.1 Colluvium (C)
Colluvium is material that has reached its present position as a result of direct, gravity-induced movement; water or ice can assist in the mobilization of the material but it is not the chief transporting agent. Colluvial materials are generally poorly sorted, unconsolidated, and the clasts are quite angular due to the short distance of transport. Colluvium includes weathered rock debris that is subjected to slow creep, slope wash of underlying sediments, and deposits from landslides. Debris slides and slumps are mixed texture depending on the source, but generally are matrix-supported sandy silts or silty sands with mixed coarse clasts. Talus cones or aprons originating through individual rock fall or rock slides are clast-supported deposits of coarse angular rubble or blocks with a minor amount of interstitial sand or silt matrix.

In the project area, colluvial veneers and blankets are the second most common sedimentary deposit and are usually derived from underlying morainal sediments (Plate 3). Thicker colluvial deposits occur where mass movements, such as debris slides, slumps or flows, have accumulated in gullies and creek valley floors. Clast shape is angular to sub-rounded and the clast percentage varies from 15-70%. On the steep and dry west and south-west facing open slopes, where creep and slope wash are the dominant processes, the colluvial deposits are predominantly veneers over bedrock and the matrix materials are silt and sand. The gullies of the north, in contrast, are not as steep and the colluvial veneers are usually associated with morainal deposits. The study area contains areas of active rockfall (-Rb) below steep bedrock exposures in the gully systems that run west and south-west down the slopes into Fadear and Louis Creeks. A large talus apron, running the length of the exposed cliffs, is present below the major rock ridge of Fadear Mountain.

4.2 Fluvial Materials (F)
Fluvial materials have been transported and deposited by flowing water since the end of the last glaciation. Fluvial materials generally consist of moderately to well-sorted, stratified sand and/or gravel with minor amounts of silt. These deposits have a very porous structure and are highly permeable. They are usually well drained except when they are located on the floodplain or near stream level, where the water table may be high leading to poor or imperfect drainage. Within the study area, fluvial deposits are primarily found on the valley floor of Sinmax Creek. They also occur in the form of fans deposited at the downstream end of gullies. Minor fluvial deposits occur in the gully bottoms, but these areas are dominated by colluvial materials originating on the steep gully walls. There is also an interesting fluvial deposit, consisting of alternating layers of volcanic ash, calcium carbonate, silts, sands, clays and organic, found in a gully on the north facing slope (Plate 4). Weathering of bedrock or deposition of ash in the gully area has caused the deposits to move down slope and collect in the gullies.

4.3 Glaciofluvial Materials (FG)
Glaciofluvial materials exhibit evidence of having been deposited by glacial meltwater streams either directly in front of, or in contact with, glacier ice. They are generally coarse textured and well drained as a result of their high permeability and porosity. Sorting and stratification are variable depending on the type of material and depositional environment. They may occur as unsorted massive sand and gravel units or as discrete, well-sorted and well-stratified sand or gravel. Glaciofluvial deposits are uncommon in the Fadear Mountain - Moose Meadows study area. There is one deposit of well bedded sand and gravel and more than 1 m thick on the north side of Moose Meadows FSR. A second deposit of 3 to 4 m of alternating sand and gravel exists on the north side of Fadear Creek (Plate 5).
4.4 Morainal (Till) Materials (M)
Morainal materials or tills are those sediments deposited directly from glacial ice. Till materials in the study area generally consist of a matrix of fine materials (<2 mm) that surrounds and supports clasts (>2 mm) that vary in size and shape. Physical properties of tills are variable and based on the origin of the debris and the mode of deposition.

Three basic tills are commonly deposited from glaciers: lodgement, basal and ablation tills. Lodgement till is deposited by plastering of glacial debris from the sliding base of a moving glacier. These are unsorted sediments and are massive in structure. Typically this till has strongly developed sub-horizontal partings (platy appearance), is extremely dense and has a matrix of sand, silt and clay. Pebbles are dominantly oriented long axis parallel to flow direction and striations on clasts and on bedrock are parallel to flow. Lodgement tills are rarely observed on the surface, usually they are buried by other sedimentary deposits.

Basal till is deposited by a slow release of glacial debris from the ice that is not sliding or deforming internally. This till is characterised by debris banding and preservation of a well-developed orientation of clasts and striations on clasts. In comparison to lodgement till, basal till is less dense, has less well developed horizontal partings because it is not deposited by moving ice and usually has a slightly coarser matrix. Less pressure is exerted on this till and un lithified clasts of sediment (frozen sand, silt, clay, coal etc.) may be preserved in these sediments.

Ablation till (also called supraglacial till) is derived from any debris upon its release from glacier ice. Re-deposition is accomplished by gravitational slope process (gravity flows) and it may take place ice-marginally, supraglacially, subglacially, subaerially or subaquatically. These are not true tills in that they have been moved since deposition and no longer are purely a product of glacial ice deposition.

Tills are the most commonly occurring sediments in the study area and lodgement, basal and ablation tills were observed. The different types of till have not been identified on the maps as the survey intensity precluded this level of detail. Thin deposits of lodgement till may be found underneath the basal till in some of the deeper road cuts on the north facing slope and the highland areas. The finer-grained and denser lodgement tills have distinct subhorizontal partings (Plate 6) and numerous well striated and faceted clasts. The matrix of the lodgement tills is sandy silt with minor clay.

A typical section on the upland areas and on the north facing slope is a thick, dense basal till with a cap of looser ablation till. The matrix of basal and ablation tills is primarily sandy silt to silty sand; silt is usually the dominant component and minor (<5%) clay is present in most occurrences. Basal tills are slightly cohesive and well consolidated (Plate 7); ablation tills are non-cohesive due to lesser quantities of silt and clay and less consolidated as they were deposited on the surface of the ice. The undulatory nature of the plateau reflects the topography of the bedrock with a blanket of till smoothing the irregularities. Tills on the plateau are moderately drained, while those on the steeper slopes were moderately to well drained. There were 15 to 40% clasts, pebble to large boulder in size, which were sub-angular to sub-rounded and usually of local origin. On the steeper western facing slopes thinner exposures of basal and ablation till are found in association with colluvial veneers.
Gullies incised into till are common on the north facing slope. Basal tills are moderately dense and post-glacially water initially flows over the unvegetated surface in small rills. With time, a few of these rills develop into deeply incised gullies with steep sidewalls.

4.5 Organic Materials (O)
Organic deposits are found in depressions on the upper plateau surrounding Fadear Mountain. They are small waterlogged areas that generally overlie morainal materials or bedrock. They only comprise a moderate portion of the project area and are generally not treed, but are sensitive to harvesting disturbance.

4.6 Bedrock (R)
Bedrock controls the basic form of the landscape and is generally overlain by a veneer of till or colluvium. There are very few terrain units that are exclusively bedrock. Striations were noted on some outcrops on the plateau, and ice flow direction was measured at between 104° and 112° (reverse bearing 284° to 292°). These measurements reflect ice direction found by previous studies (Prest et al. 1967). Bedrock on the plateaus has undulating or ridged topography and outcrops sporadically, usually on ridgetops or as steeper sided hummocks (Plate 8). Further downslope as the ground becomes more dissected, rock occurs on steep ridges and gully sides.

5.0 SOIL DRAINAGE
Soil drainage refers to the rapidity and extent of water removal from a soil relative to additions (Luttmerding et al. 1990). Soil drainage is influenced by permeability, groundwater level and seepage, however these are not readily quantified in the field and are rarely used in these type of studies. Our assessment of the drainage of the soil was completed through recognition of the key diagnostic soil horizons, texture, vegetation associated with the area and the local terrain.

Six soil drainage classes were used rapidly drained (r), well drained (w), moderately drained (m), imperfectly drained (i), poorly drained (p), and very poorly drained (v). Abbreviated definitions of the soil drainage classes are provided in Table 1 (Luttmerding et al. 1990).

6.0 GEOMORPHOLOGICAL PROCESSES
Geomorphological processes are natural mechanisms of weathering, erosion or deposition that result in the modification of the surficial materials and landforms at the earth’s surface. These symbols are used to indicate a process is actively modifying the whole or portions of the polygon.

6.1 Rapid Mass Movement (-R)
This is the rapid downslope movement by falling, rolling, sliding or flowing of dry, moist or saturated debris derived from surficial material or bedrock. It can be applied to the initiation, transportation or depositional zone of the process. In the study area, only rock falls and debris slides have been identified.

Rock falls (-Rb)
Rock fall is the descent of a detached mass of bedrock by falling, bouncing or rolling. Rock fall is actively occurring on the dry west and south-west faces above Louis and Fadear Creeks, as well as derived from the main ridge of Fadear Mountain on the upland.

Debris slides (-Rs)
A debris slide is the rapid movement by sliding of a disintegrating mass of surficial material. The cause of these is commonly a plane of weakness in the surficial material which allow increased pore water pressures to develop and subsequently fail. Commonly the plane of weakness is a unweathered, denser till unit or a smooth bedrock surface. Three debris slides are located in the Fadear Mountain - Moose Meadows study area, these are all on the south and west facing slopes.
### Table 1: Soil Drainage Classes and Common Terrain Unit Associations

<table>
<thead>
<tr>
<th>Drainage Class</th>
<th>Definition</th>
<th>Common Terrain Unit Association</th>
</tr>
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<tr>
<td>Rapidly</td>
<td>Water is removed rapidly from the soil in relation to supply. Excess water flows downward into underlying material. Soils are usually coarse textured and shallow.</td>
<td>Steeper slopes in colluvium and rock. Talus cones are the most common example. Soils are mainly regosols.</td>
</tr>
<tr>
<td>Well</td>
<td>Water is removed from the soil readily, but not rapidly. Excess water flows downward into underlying material or laterally as subsurface flow. Soils are intermediate in texture and thickness.</td>
<td>Steeper slopes in till, moderate slopes in glaciofluvial or colluvial deposits. Soils are mainly brunisols or regosols.</td>
</tr>
<tr>
<td>Moderately Well</td>
<td>Water is removed from the soil somewhat slowly in relation to supply. Excess water is removed slowly due to low perviousness, shallow water table or lack of gradient. Soils are medium to fine textured.</td>
<td>Moderate slopes in till and gentle slopes in glaciofluvial, colluvial and fluvial sediments. Soils are predominantly brunisols.</td>
</tr>
<tr>
<td>Imperfectly</td>
<td>Water is removed from the soil sufficiently slowly in relation to supply such that the soil is kept wet for a significant part of the growing season. Soils have varied physical properties, but usually show gleyed horizon.</td>
<td>Gentle, undulatory and nearly flat slopes in all sediments. Evidence of standing water on the ground surface but minimal openings in forest cover. Mottles may be present.</td>
</tr>
<tr>
<td>Poorly</td>
<td>Water is removed from the soil so slowly in relation to supply that the soil remains wet for the majority of the time the soil is not frozen. Soils have varied physical properties but usually show gleyed horizons or fall within the Gleysolic or Organic soil orders.</td>
<td>Gentle slopes to flat ground in all sediments. Evidence of standing water on ground surface and openings in forest cover. Shallow water table usually indicated. Organic sediments common.</td>
</tr>
<tr>
<td>Very Poorly</td>
<td>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 that the soil is not frozen. Soils have varied physical properties and are either of the Gleysolic or Organic soil orders.</td>
<td>Flat ground with organic or very fine textured glaciolacustrine sediments. Open water may be present, large openings with well developed organic wetlands.</td>
</tr>
</tbody>
</table>

Adapted from Describing Ecosystems in the Field (Luttermading et al. 1990)

#### 6.2 Gully Erosion (-V)

Gully erosion is modification of a slope by the processes of running water in combination with mass movement resulting in formation of steep ravines. Gullying is the predominant geomorphic process occurring in the study area and is usually used to indicate a single large gully. On the west and south-west faces these gullies have active sidewall (rock or surficial material) sliding and falling and are considered to be quite active (Plate 9). On the north facing slope, a series of gullies on the open slope indicates erosion into a blanket of consolidated till (Plate 1). These gullies are well vegetated and most factors indicate that they are inactive, however they do indicate erosional action, and are susceptible to future erosion if appropriate harvesting and road building practices are not used. These gullies carry water for a large part of the year, however, the key period of flow is during snowmelt runoff and spring rains.
7.0 DERIVATIVE MAPS
Terrain polygons were classified for terrain stability, surface erosion potential and potential sediment delivery to major streams. The classifications are based on information found in the MATS Guidebook (Ministry of Forests 1995).

7.1 Terrain Stability
Terrain stability is a rating of the likelihood of a landslide initiating in a terrain polygon following timber harvesting or road construction (Ministry of Forests 1995). Factors that influence terrain stability are the physical attributes of surficial deposits, slope steepness and morphology, and the drainage or hydrological conditions. Terrain stability classes were initially assigned to each polygon based on physical attributes, slope steepness, and presence of obvious geomorphological processes (gullying or mass movement). Terrain stability classes range from I to V (Table 2) where I, II, and III designate areas with no or minor slope stability problems following road construction and timber harvesting. Class IV indicates a moderate likelihood of failure while Class V indicates a high likelihood of failure with presence of active failures. Table 2 is taken from the MATS Guidebook (Ministry of Forests 1995) and outlines the classes in general.

<table>
<thead>
<tr>
<th>Terrain Stability Class</th>
<th>Interpretation</th>
<th>Management Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>No significant stability problems exist.</td>
<td>None.</td>
</tr>
<tr>
<td>II</td>
<td>There is a very low likelihood of landslides following timber harvesting or road construction.</td>
<td>Minor slumping is expected along road cuts, especially for one or two years following construction.</td>
</tr>
<tr>
<td>III</td>
<td>Minor stability problems can develop. Timber harvesting should not significantly reduce terrain stability. There is a low likelihood of landslide initiation following timber harvesting or road construction.</td>
<td>Minor slumping is expected along road cuts, especially for one or two years following construction. A terrain stability field assessment by a registered professional is usually not required.</td>
</tr>
<tr>
<td>IV</td>
<td>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.</td>
<td>A terrain stability field assessment of these areas is usually required to be made by a registered professional qualified to assess terrain stability prior to any development.</td>
</tr>
<tr>
<td>V</td>
<td>Expected to contain areas with a high likelihood of landslide initiation following timber harvesting or road construction. Wet season construction will significantly increase the potential for road-related landslides.</td>
<td>A terrain stability field assessment of these areas is usually required to be made by a registered professional qualified to assess terrain stability prior to any development.</td>
</tr>
</tbody>
</table>

Adapted from: MATS Guidebook (Ministry of Forests 1995)

Following fieldwork the terrain stability ratings were modified as required to suit local conditions. Final terrain stability ratings take into account features which are not observable on aerial photographs such as drainage, texture, and small scale mass movements. The upland plateau areas are primarily Terrain Stability Class I, II or III as a result of the gentle topography. Only the steep cliff face of Fadear Mountain is rated as Terrain Stability Class V. The majority of the north facing slope above Fraser and Sinmax Creeks is Terrain Stability Class II and III; however, class IV and V terrain is found in the steeper and more gullied areas. The dry southwest and west slopes are typically Terrain Stability Class III, IV or V.
7.2 Surface Erosion Potential
Erosion is defined as the removal or wearing away of soil particles by surface water. The most influential factors on surface erosion are texture, slope steepness and soil density. Surface erosion potential is used to rate the susceptibility of an area to erosion when vegetation has been removed and mineral soil is exposed to the elements. Existing road cuts, landings, trails and naturally unvegetated slopes were reviewed for evidence of rilling or other feature which might indicate active surface erosion. Table 3 describes the surface erosion potential classes, varying from very low (VL) to very high (VH), which were applied to the terrain units.

During fieldwork sediments exposed in road cuts, landings and on logging trails were evaluated for the presence of indicators of active surface erosion. Very coarse textured colluvial deposits, organic sediments and bedrock exhibit very low surface erosion potential. The plateau areas have low to very low surface erosion potential due to the gentle topography. The moderate and moderately steep north facing till covered slopes and the moderately steep colluvium slopes are moderately susceptible to erosion when the sediments are exposed. High surface erosion potential polygons are located on steeper colluvial and rock slopes and gullied sites. The very high surface erosion potential is associated with the very steep colluvium veneered, bedrock cored south and west facing slopes and in the gullied areas on the north facing slope.

Table 3: Surface Erosion Potential Classification and Management Implications

<table>
<thead>
<tr>
<th>Rating</th>
<th>Example Criteria</th>
<th>Management Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low (VL)</td>
<td>Blocky colluvial deposits or terrain dominated by competent bedrock</td>
<td>None or only very minor surface erosion.</td>
</tr>
<tr>
<td>Low (L)</td>
<td>Morainal veneers and mostly rubby colluvial deposits with high coarse fragment content.</td>
<td>Expect minor erosion of fines from ditch lines and disturbed soils</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>Morainal blankets, glaciofluvial gravels and soft, friable bedrock.</td>
<td>Expect moderate surface erosion problems when water is channelled down road ditches.</td>
</tr>
<tr>
<td>High (H)</td>
<td>Morainal blankets on slopes steeper than 60% or steeper than 30% if gullied or poorly drained. Loose consolidated glaciofluvial or fluvial sands or colluvial sediments on slopes below 30%.</td>
<td>Significant erosion problems can be created when water is channelled onto or over these sites.</td>
</tr>
<tr>
<td>Very High (VH)</td>
<td>Loosely consolidated glaciofluvial or fluvial sands on slopes 30% or gullied or poorly drained sites.</td>
<td>Severe surface and gully erosion problems can be created when water is channelled onto or over these sites.</td>
</tr>
</tbody>
</table>

Adapted from: MATS Guidebook (Ministry of Forests 1995)

7.3 Potential Sediment Delivery to Major Streams
Potential sediment delivery to major streams is a rating of the likelihood that debris from landslides or other surface erosion sources will reach a major creek. This rating is a combination of the landslide induced stream sedimentation rating and the potential for sediment delivery from surface erosion sources rating that are outlined in the MATS Guidebook (Ministry of Forests 1995). Table 4 describes the potential sediment delivery to major streams classes, which vary from very low (1) to very high (5), applied to the terrain units.
TABLE 4: POTENTIAL SEDIMENT DELIVERY TO MAJOR STREAMS CLASSIFICATION AND MANAGEMENT IMPLICATIONS

<table>
<thead>
<tr>
<th>Rating</th>
<th>Example Criteria</th>
<th>Management Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low (1)</td>
<td>Gentle slope with no channel in or adjacent to polygon.</td>
<td>It is very unlikely that landslides or erosion will result in sediment input to a stream.</td>
</tr>
<tr>
<td>Low (2)</td>
<td>Gentle slope with a minor channel in or adjacent to polygon. Moderate slope with no channel adjacent to polygon.</td>
<td>Low likelihood that landslides or erosion will result in sediment input to a stream.</td>
</tr>
<tr>
<td>Moderate (3)</td>
<td>Gentle slope with a major channel in or adjacent to polygon. Moderate slope with a minor channel in or adjacent to polygon. Steep slope with no channel in or adjacent to polygon.</td>
<td>Moderate likelihood that landslides or erosion will result in sediment input to a stream.</td>
</tr>
<tr>
<td>High (4)</td>
<td>Moderate slope with a major channel in or adjacent to polygon. Steep slope with a minor channel in or adjacent to polygon.</td>
<td>High likelihood that landslides or erosion will result in sediment input to a stream.</td>
</tr>
<tr>
<td>Very High (5)</td>
<td>Steep slope with a major channel in or adjacent to polygon.</td>
<td>Very high likelihood that landslides or erosion will result in sediment input to a stream.</td>
</tr>
</tbody>
</table>

Adapted from: MATS Guidebook (Ministry of Forests 1995)

In rating each polygon for potential sediment delivery to major streams, two factors were assessed: proximity of a polygon to a major or minor creek and steepness of the slope between the creek and the sediment source. Presence of lower gradient slopes which would serve to arrest the passage of debris were accounted for in completing the assessment. Surface erosion sources include roads, logging trails and ditch lines as well as non-specific sources. Permanent streams were identified by aerial photograph interpretation and field work as ones that have running water during most of the year. Terrain units with a very low potential are separated from any stream by at least 20 m and will not create a direct avenue for any sediment input. Low, moderate and high potential units provide direct input into an ephemeral stream that is respectively ≥200 m, 100 to 200 m and <100 m away from a permanent stream. Very high potential units are located on gully side walls or stream escarpments that lead directly into a permanent stream.

With increasing gradient and decreasing distance, the probability that sediment will reach a creek is increased. Very high potential (5) for sediment delivery to major streams polygons are found along the deeply gullied stream channels down the north, west and south-west faces. Polygons of high potential (4) are noted on smaller gullied tributaries and steep slopes leading to stream channels. Most of the north face has moderate (3) or low (2) potential of sediment delivery to major streams. Plateau areas are primarily low potential (1 and 2), the presence of lakes and marshes that act as sediment traps reduces the chance of sediment reaching a major creek.

8.0 RECOMMENDATIONS AND CONCLUSIONS
Field and aerial photograph interpretation work indicates that there are areas within the Fadear Mountain - Moose Meadows study area that have a moderate to high likelihood of landslides, very high surface erosion potential or very high potential sediment delivery to major streams. These areas are found in the headwalls and transport zones of steep gullies along the north face and all along the west and south slopes above Louis and Fadear Creeks. Natural instability in the area, mostly rockfall and gully erosion, is more prevalent than instability associated with forest development. As timber harvesting continues the ground being developed will increasingly be on
steeper and more sensitive slopes. On the uplands, the undulating and gently sloping terrain poses few physical constraints to forest development. However, canopy removal and particularly road development on the plateau areas can have impacts on the stability of the steeper slopes below through drainage diversion and by increasing the amount and altering the timing of runoff. Therefore, it is equally important that development above areas mapped as Terrain Stability Class IV or V be as carefully planned as it would for areas within these polygons; detailed terrain and hydrological assessments of such areas would be prudent.

The following discussions and recommendations are provided to aid in reducing slope instability and minimizing erosion and delivery of sediment to creeks:

- Diverted drainage is a leading cause of forest development related landsliding in the interior of British Columbia (Pack 1994). Natural drainages have developed since glaciers retreated and are often in a finely balanced state of equilibrium. Road ditches can divert water into other drainages, thereby increasing the effective size of a catchment area. The amount of increased drainage is a combination of ground water and surface water intercepted by the road prism and redirected along ditches and through culverts. Instead of numerous small surface drainages and extensive subsurface groundwater flow, the water is directed through one culvert and then into one channel. An increase in water discharge by diversion may exceed the capacity of the natural drainage system and may result in landsliding. In general, it is recommended that existing natural drainage paths be maintained as much as possible and diversion of water be minimized.

- Seepage is present throughout the Fadear Mountain - Moose Meadows study area. Drainage must be dealt with wherever it is encountered in road cuts through the use of blanket drains, buttressing, extra culverts and trench drains. Deactivation should be considered where seepage is prevalent.

- Cut slopes in terrain with easily erodible material (high or very high surface erosion potential) may require stabilization. In the Fadear Mountain - Moose Meadows study area, such materials are loose rubbly colluvium, loose sandy glaciofluvial or fluvial sediments and moderately dense, coarse textured tills (Plate 10). Stabilization may require the use of bio-engineering techniques, or engineering solutions such as geotextiles, gabion walls, armouring or subsurface drains, or lock blocks. Cut slopes may have to be flattened to angles lower than industry practice, or other techniques used above and beyond conventional grass-seeding.

- Fill slopes on moderately steep or steep slopes (in general >60% gradients) should be avoided, particularly in wet or poorly drained areas. Fill slope failures may be a reflection of poor drainage in the sediments, poor drainage control of the road system, construction on unstable sediments, or use of organics within the road bed. Any road planned to cross slopes in excess of 50% must have a road location survey which includes plans, profiles and cross-sections. Generally, roads built by compacting materials will be less likely to fail than roads where the material is sidecast.

- Evidence of debris flows associated with gullies was not noted in the Fadear Mountain - Moose Meadows study area, however, most gully headwall systems are prone to failure if disturbed. When steep gully sidewalls and headwall systems are impacted by forest development they may fail as small debris slide events that impact the main gully. If sufficient conditions of slope and water are achieved, the slide translates into a flow which
moves rapidly through the gully system. Generally changes in peak flows through gully systems are not measurable below canopy removal of about 20%. It is recommended that for major gully systems, this level of canopy removal not be exceeded unless the development is reviewed by a qualified registered professional.

Information contained within this report and on the maps and aerial photographs are based on observations of land-surface conditions and current understanding of slope processes. The maps are provided as a tool to aid in forest development planning. However, because slope stability is strongly influenced by subsurface conditions that are not apparent from surface observations or aerial photograph 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 in this report, or other more detailed terrain stability field assessment reports that are done, will, however, reduce the risk of landslide and erosion.

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9.0 REFERENCES


APPENDIX 1: LIST OF AERIAL PHOTOGRAPHS

The aerial photographs listed below were used during completion of this project. They are listed by line from north to south and within the lines from west to east.

<table>
<thead>
<tr>
<th>Line Number</th>
<th>Flight Line</th>
<th>Photograph Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1</td>
<td>BCC95115</td>
<td>147-149</td>
</tr>
<tr>
<td>N2</td>
<td>BCC95018</td>
<td>12-18</td>
</tr>
<tr>
<td>N3</td>
<td>BCC95033</td>
<td>103-105</td>
</tr>
<tr>
<td>N4</td>
<td>BCC95018</td>
<td>66-70</td>
</tr>
</tbody>
</table>
Plate 1: View of the northern face of the Fadear Mountain - Moose Meadows study area. Forest Lake is at left centre and the Moose Meadows FSR can be seen uphill from the lake. Cut block at upper right is accessed via the Cicero FSR. Old logging areas along the mid-slope have regenerated as patchy deciduous with some conifers. The valley with the broad headwall and steep sidewalls to the centre right is Fraser Creek.
Plate 2: Striations on an outcropping of limestone bedrock on the north slope of the study area. Ice flow direction from these striations was measured at between 104° and 112° (reverse bearing 284° to 292°).
Plate 3: Typical loosely consolidated slope wash colluvial sediments overlying a dense till. Note the color variation from dark grey in the till to brown in the colluvium.
Plate 4: Observation site 15, alternating layers of volcanic ash, calcium carbonate, silts, sands, clays and organics, found in a gully on the north facing slope.
Plate 5: Observation site 24, road cut exposing crudely stratified coarse gravels at the base, interbedded with moderately well stratified fine gravels and well bedded sands.
Plate 6: Observation site 8, well defined horizontal partings and dense nature of this till indicate that it is a lodgement till. Note the horizontally aligned clasts which also indicate transportation and deposition under ice.
Plate 7: Observation site 58, dense grey till found on top of the plateau. This till is quite thick and lacks the well developed horizontal partings, suggesting that it is a basal till. Clasts at this site are moderately imbricated and many are striated or faceted.
Plate 8: View to the south-east from helicopter across the top of the plateau. Fadear Mountain is the ridge of bedrock on the left. An apron of colluvial venceer derived from the steep bedrock exposure grades into an undulating morainal blanket to the right.
Plate 9: Deeply incised gully on the southern face of the study area. Observation site 55 is in the harvested area to the left of the photograph. Note the bedrock outcropping along the margins of the channel.
Plate 10: Slumping road cut in well consolidated silty sand matrix till, observation site 18. The road has cut through a steep ridge of till, the slope is over 70% below, and the drainage control along this section of the road is poor. Note the tension cracks on the outside of the road prism where the fill slope is over-steepened and has been saturated by diverted drainage.