UPGRADE OF
TERRAIN CLASSIFICATION, TERRAIN STABILITY, SURFACE EROSION POTENTIAL, AND SEDIMENT DELIVERY POTENTIAL OF
TRANQUILLE-WATCHING AND PETERSON-ROSEN COMMUNITY WATERSHEDS

PREPARED FOR:

WEYERHAEUSER COMPANY LIMITED
Kamloops Operating Unit

Kamloops, BC

PREPARED BY:

Denny Maynard, M.Sc., P.Geo
DENNY MAYNARD & ASSOCIATES LTD.
North Vancouver, BC

March 2002

UPGRADE OF
TERRAIN CLASSIFICATION, TERRAIN STABILITY, SURFACE EROSION POTENTIAL, AND SEDIMENT DELIVERY POTENTIAL OF
TRANQUILLE-WATCHING AND PETERSON-ROSEN COMMUNITY WATERSHEDS

PREPARED FOR:

WEYERHAEUSER COMPANY LIMITED
Kamloops Operating Unit

Kamloops, BC

PREPARED BY:

Denny Maynard, M.Sc., P.Geo
DENNY MAYNARD & ASSOCIATES LTD.
North Vancouver, BC

March 2002

PROFESSIONAL GEOSCIENTIST
PROVINCE OF BRITISH COLUMBIA
D. E. MAYNARD

TABLE OF CONTENTS

MAPS

Two map themes are portrayed on parts of the following 1:20,000 TRIM base maps: 92I 077, 078, 087, 088, 097, 098 and 92P 019, 020, 029, 030

The map themes are:

- Terrain Classification
- Terrain Stability, Surface Erosion Potential, and Sediment Delivery Potential

1.0 INTRODUCTION

Detailed terrain stability mapping previously done for community watersheds in the Kamloops-North Thompson area has not provided a consistent level of detail or reliability necessary for thorough and confident forestry planning. Within its Kamloops Operating Unit, Weyerhaeuser Company Limited identified some fairly significant problems in using this existing mapping in their forest license areas, which occur in the community watersheds of Tranquille River-Watching Creek and Peterson-Rosen creeks. At their request, Denny Maynard & Associates Ltd. carried out a program of re-mapping portions of these operating areas where potential terrain impacts were considered to be most significant. Discussions among Brian Nowicki, RPF, Weyerhaeuser Company Limited, Glenn Thiem, Forsite Forest Management Consultants, Tim Giles, P. Geo., Regional Geomorphologist, Kamloops Forest Region, and Denny Maynard, P. Geo. helped to define the areas to be re-mapped, which, for the most part, contained the steeper, potentially unstable and/or erodible ground in close proximity to watercourses. Gently to moderately sloping terrain on the plateau uplands and valley lowlands was mainly excluded from any thorough re-examination.

This report discusses the methods and results of this upgraded terrain stability mapping which consists of a 1:20,000-level analysis of the terrain landscape and an assessment of the potential effects of conventional forest harvesting on terrain stability, surface erosion, and sediment delivery to the main creeks, streams, and lakes within the community watersheds. Data and interpretations are presented at a level which are suitable for helping to plan forestry development, but are not usually detailed enough to substitute for site-specific, operational recommendations and decisions. The discussion mainly pertains to the re-mapping project but also provides some regional overview; little reference is made to the results of the original terrain stability mapping, which has been retained outside of the areas remapped.

Field work for the re-mapping project was carried out during August, 2001. Final interpretation of the aerial photographs and digital map production occurred between

October, 2001 and February, 2002. All GIS work and final map and report preparation were completed in March, 2002; the mapping has been submitted as both digital and hard copy (paper) products. The project was funded in its entirety by Forest Renewal BC.

2.0 PROJECT OBJECTIVES

The objectives of the project were the following:

1. To re-map, at Terrain Survey Intensity Level (TSIL) C, terrain (surficial materials, landforms, and geomorphic processes) at a scale of 1:20,000 for portions of the community watersheds of Tranquille River-Watching Creek and Peterson-Rosen creeks.

2. To produce derivative interpretations of terrain stability, surface erosion potential, and sediment delivery potential, which indicate an expected response of terrain in the re-mapped areas to conventional forestry operations (road construction and clearcut harvesting).

3. To capture all the new mapping and polygon attribute data in digital form which is fully compatible with provincial standards for terrain stability mapping; the newly mapped polygons will seamlessly merge with retained original polygons but original polygon attribute data is not to be modified.

4. To prepare a report describing the mapping project, including: survey methods and reliability, physical environment of the study area, surficial geology and materials, slope processes and hazards, and criteria for classifying terrain stability, surface erosion potential, and sediment delivery potential.

3.0 PROJECT AREA: LOCATION AND PHYSIOGRAPHY

The community watersheds of Tranquille River-Watching Creek and Peterson-Rosen creeks drain the plateau uplands north of Kamloops Lake and west of North Thompson River (figure 1). Much of this area falls within the Kamloops Operating Unit of Weyerhaeuser Company Limited although Tolko Industries Ltd. operates on the south-west side of Tranquille Valley and some small, scattered areas are operated by the Small Business Forest Enterprise Program (SBFEP). Tranquille River flows into Kamloops Lake about 15 km west of the city of Kamloops, BC. The confluence of Peterson Creek and North Thompson River is about 1 km north-west of the town of Barriere, BC.

The close proximity of these areas to transportation corridors and population and industrial centres has contributed to fairly extensive modification of the upland forest landscape; much of the lower elevations consist of dry grassland vegetation. Forestry activity has been on-going since the early 20th century, probably beginning with selective logging and agriculture-related land clearing, eventually expanding to more extensive clearcutting in recent times. This, combined with the natural fire history of interior forests, results in a mosaic of stand ages ranging from immature to mature. A short section of broad valley floor along mid Tranquille Valley (photo 1) and the lower end of Rosen watershed have been pre-empted for agricultural and rural-residential use.

As a consequence of the historical development in the region, an extensive network of roads exist which provide excellent access to most of these operating areas. Road quality ranges from the well-maintained mainline logging roads to old, overgrown and impassable (to vehicle) tracks.

The Thompson River system occupies major valleys cut deeply into the Thompson Plateau subdivision of the Interior Plateau physiographic region (Mathews, 1986). The upland surfaces consists of rounded mountains and ridges and rather uniform, low-relief plateau topography commonly ranging between about 1000 to 1500 m elevation.

Regional bedrock features a juxtaposition of very old (Paleozoic Age-about 300 million years old) metasediments and metavolcanics and young (late Tertiary Age- 10-25 million years old) volcanic lavas (Roddick et al, 1976). However, geomorphology of the region is mainly a product of geological events which occurred in the Tertiary and Quaternary Periods (the two most recent geologic time periods). This physiographic evolution began with uplift of the pre-Tertiary interior plateau causing erosional dissection of the raised surface to accelerate. With recurrent glacial erosion and deposition during the Pleisotcene Epoch, major valleys were further modified; glacial erosion in headwall valleys may have increased local relief and ruggedness, elsewhere surfaces were smoothed. Deposition of surficial deposits was usually most extensive along valley lowlands, often resulting in thick accumulations of pre-glacial, glacial, and/or post-glacial sediments. Bedrock-controlled uplands and valley walls are mainly covered with relatively thin surficial materials. Mass movement activity is concentrated on the steeper slopes, mainly the valley walls and creek and gully scarps.

Tranquille River and its main tributary, Watching Creek, drain southward into Kamloops Lake; their headwaters originate on the south side of Porcupine Ridge, about 25 km north of the lake. Total watershed area is about 42,700 ha. The upper reaches of these main drainages are narrowly entrenched in the plateau surface, confined by erosional scarps of varying height which consists of bedrock and/or thick surficial sediments. The mid to lower reaches take on more typical valley forms with wider, rounded floors bordered by higher, bedrock-controlled sidewalls (photo 1).

Peterson Creek drains a much smaller area (about 8700 ha) of plateau in a relatively short, easterly descent to North Thompson River. The western uplands consist of rounded bedrock ridges and depressions; numerous small creeks, lakes, and wetlands occupy the mostly broad, low-relief hollows with some short reaches more steeply confined in entrenched channels. Eastward from Allan Lake, Peterson Creek has downcut a deep, steep-sided canyon, mostly into bedrock (photo 2) although some scarp segments consist of thick surficial deposits. Over a channel distance of less than 15 km, the creek drops 850 m elevation from Allan Lake to its fan apex. Rosen Creek drains about 300 ha of the western valley wall bordering the floodplain of North Thompson River. The channel is not well entrenched on the moderate-gradient upper slopes but becomes more distinctly incised crossing the lower-slope terrace front.

Forest cover of the plateaus is primarily lodgepole pine with some engelmann spruce, subalpine fir, and Douglas fir occupying a transitional area between the Engelmann Spruce – Subalpine Fir and Montane Spruce biogeoclimatic zones. Interior Douglas Fir and Interior Cedar Hemlock zones occur on lower elevations, with the latter most prominent in Peterson Creek Watershed.

Mean annual precipitation in the region varies with elevation and geography. In very general terms, Farley (1979) shows less than 300 mm annual precipitation at Kamloops, increasing northward to about 400 mm in the valley near Barriere, and to greater than 500 mm on the plateau north of Porcupine Ridge. Much of the precipitation (greater than 50%) falls as snow, particularly at higher elevations; thus, peak runoff flows are primarily associated with snowmelt although annual extremes are often caused by rainfall on melting snow.

4.0 SURVEY METHODS AND RELIABILITY

In the late 1990's, Weyerhaeuser Company Limited commissioned terrain stability mapping (TSM) for much of its Kamloops Operating Unit. Detailed TSM for the community watersheds of Tranquille River-Watching Creek, Peterson Creek, and Rosen Creek was done by AGRA Earth and Environmental Ltd. (1998a and b). Weyerhaeuser encountered numerous difficulties with this stability-erosion interpretive mapping which impacted on their planning procedures and operating costs. As a consequence, it was decided that reclassifying terrain stability conditions within parts of these community watersheds would be beneficial both for company operations and for overview forestry-environmental planning; the operating areas of Tolko Industries Ltd. and SBFEP were also included in the remapping program.

Substantial parts of these watersheds consist of subdued to moderately sloping plateau surfaces and valley-floor lowlands which contain very little unstable terrain; thus re-examining the mapping in these areas in any detail would not provide much benefit. However, enough areas were outlined where terrain stability impacts could be significant (e.g. potentially unstable-erodible ground in close proximity to a watercourse) and therefore required more accurate and reliable mapping and interpretations. A program of re-mapping was decided upon which had the following scope:

- Reclassification of the existing stability mapping was to focus on areas originally designated as stability classes IV and/or V, also encompassing a certain amount of adjacent terrain to ensure that interpretations are consistent for the surrounding landscape. Previous experience (Maynard, 2001) has shown that the most efficient means of reassessing these areas is to fully re-map the larger areas of contiguous steepland, but where individual or small clusters of class IV and/or V polygons exist as isolated "islands" within stable terrain, only the specific polygons of interest are reassessed.

- Analysis of the AGRA mapping (T. Giles, P. Geo, personal communication) identified about 5850 ha (456 polygons) in Tranquille-Watching Watershed and 785 ha (136 polygons) in Peterson Watershed as originally mapped as class IV and V terrain. While isolated occurrences were scattered throughout the drainage basins, it was apparent that a large part of the remapping effort would concentrate along the deeply incised reaches of mid to upper Tranquille River and Watching Creek, the valley sidewalls of the mid to lower Tranquille-Watching system, and the main canyon area of Peterson Creek. In addition, in a few places the original mapping did not extend to the height-of-land or other tenure edges, thus creating gaps along the correct mapping boundary; new mapping was required to fill in these gaps which totaled about 1250 ha bordering both Tranquille-Watching and Peterson watersheds and for the missing area of lower Rosen Watershed.
- All the new mapping-polygon reclassification was to be seamlessly merged with the remaining original mapping (i.e. the adjacent class I, II, and III terrain). These newly created and/or modified polygons would be given new and unique identity numbers which tied to a newly created database; polygons and attribute data which were replaced would then be deleted from original map and database files. Hard-copy maps would consist of fully integrated polygons which seamlessly merge the new or reclassified mapping with the retained original polygons, but terrain and stability labels would only be produced for the new/reclassified polygons; the original retained polygons would only display their identity number. Minor differences in map-symbol usage and definitions may exist between products but these would be explained in the map legends.

Figure 1 shows a schematic outline of the re-mapped areas within the context of the operating forest-land which had previous terrain stability mapping. Note that the parts of Lac du Bois and Porcupine Meadows Protected Areas that fell within Tranquille-Watching Watershed were not reassessed as part of the study.

The following discussion applies to procedures followed by Denny Maynard & Associates Ltd. during the re-mapping program and is not necessarily all applicable to the earlier work carried out by AGRA Earth and Environmental Ltd. (1998a and b).

Terrain stability mapping involves inventorying existing features, conditions, and processes of the landscape by field observations and by map and aerial photographic analysis (Guidelines and Standards for Terrain Mapping in British Columbia, Resources Inventory Committee, 1996) and assessing these to make interpretations relating to the stability and erodibility of slopes following conventional logging (Mapping and Assessing Terrain Stability Guidebook, Second Edition, Forest Practices Code of BC, 1999). Terrain mapping was done according to the Terrain Classification System for British Columbia: Version 2, 1997). (Howes and Kenk, 1997). Additional data on slope gradient and soil drainage were noted according to The Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey, 1987).

Terrain units were stereoscopically delimited on 1992 and 1995, 1:15,000, colour aerial photographs. These units subdivide the land surface according to the origin and texture of surficial materials, landforms (surface expressions), and presence of modern geomorphic processes which modify the landscape. Drainage classes were mapped from soil and landscape characteristics and vegetation patterns; slope gradients were determined by a combination of field and contour-map measurements and aerial photo interpretation. On-site symbols are used to identify specific landscape features such as landslide scars and small terrace scarps.

Each terrain unit has been assessed as to its estimated stability, erosion, and sediment delivery potential following conventional logging. These types of classification indicate the expected response of the landscape to clearcut forest harvesting and road development. The likelihood of landslides initiating is based on terrain attribute criteria originally established from research by personnel of MacMillan Bloedel Ltd. and BC Ministry of Forests and modified by experience to adapt to conditions in the study region; these are explained in table 6.1 and appendix I. The rating of surface erosion potential is a qualitative assessment of the potential for erosion by running water, mainly associated with the location and construction of roads and bladed trails. Criteria used for this assessment are given in appendix II. Additional interpretive ratings are subjectively made to estimate the likelihood for causing sedimentation in a watercourse if either landslides or surface erosion were to occur in the polygon; appendix III describes these assessments.

Chartwell Consultants Ltd. (formerly Hugh Hamilton Ltd.) of North Vancouver, BC was subcontracted to transfer terrain polygon boundaries and on-site symbols from the aerial photographs to the map base and to enter the polygon data into GIS digital files. Topographic base mapping was extracted from provisional B.C.G.S. TRIM digital files; figure 1 shows the study area with-respect-to these map-sheet boundaries. Terrain classification and terrain stability attribute data from the new database were formatted into standardized symbols to create the mapped polygon labels.

Terrain polygons were digitized directly from the individual typed aerial photos tied to TRIM control using rigorous photogrammetric principles; the simulated photogrammetric technique uses a three-dimensional terrain model to solve for elevational (vertical) change. The Maps 3-D program (Monorestitution) runs simultaneously with Microstation in IGDS format. Polygons were numbered consecutively for each watershed unit. Attribute data for the terrain polygons, including all terrain characteristics and stability, erosion, and sedimentation interpretations, were entered into a database and processed to link with the numbered map units. The database files, digital map layers, and map legends were transferred into ArcInfo format according to specifications described in Standards for Digital Terrain Data Capture in British Columbia; Terrain Technical Standard and Database Manual, Version 1, June/98 Resources Inventory Committee, 1998).

Two map themes are portrayed on B.C.G.S. 1:20,000 TRIM maps (Tranquille-Watching Watershed – 921 077, 078, 087, 088, 097, 098 and Peterson-Rosen Watersheds – 92P 019, 020, 029, 030). Original paper copies of these maps, with the mapper's professional seal, are on file with Weyerhaeuser Company Limited, Kamloops Operating Unit and BC Ministry of Forests, Kamloops Region. Contour and planimetric features are screened or colour-toned to enhance the terrain polygon boundaries, on-site symbols, and labels. The Terrain Classification Maps contain polygon information for terrain component data, slope gradient, and soil drainage. All polygon observation sites and site landscape features are shown. Each mapsheet is accompanied by a legend which fully explains and describes all the component symbols and terms associated with this mapping system.

The Terrain Stability and Surface Erosion Potential Maps show the numbered terrain polygons with label components to indicate the four interpretive classifications. An example of this full polygon label is laid out below:

	143...........	polygon identity number
terrain stability class from I to V)	IV – 2........	potential for landslide debris to enter streams or lakes (1, 2, or 3)
surface erosion potential class (from VL to VH)......	H – m.........	potential for sediment delivery to streams or lakes from surface erosion sources (l, m, or h)

Those polygons with significant stability implications (i.e. classes V and IV) are graphically enhanced by colour shading (this shading is also reproduced on the Terrain Classification Maps). All on-site symbols and polygon observation sites are also shown on the interpretive maps. The legend accompanying each map provides descriptions and forest management implications for the various interpretations.

Field work was carried out from August 13-27, 2001 in accordance with standard terrain mapping procedures (Resources Inventory Committee, 1996). During this period of excellent weather, 12 days were spent in the Tranquille-Watching Watershed and 3 days in Peterson Watershed. Denny Maynard, P.Geo. assisted by Tedd Robertson, G.I.T. comprised the field crew, which frequently split up to ground check in different, but closely adjacent areas, thus providing a more thorough and efficient use of field time. Traverses and site inspections were selected to intersect representative terrain types in representative areas of actual and potential instability and areas previously described as having high to very high erosion potential. All the field work was ground-based; most of the areas of interest were closely accessible by vehicle from which hiking traverses could originate. This excellent ground access permitted very thorough field verification of terrain conditions.

Scale and quality of the aerial photography used for the mapping was optimal for detailed delimitation of terrain polygons and assessing stability criteria; all photo typing was done by Denny Maynard, P.Geo.

The reliability of the terrain re-mapping is considered very good; the map polygons are expected to reliably describe on-ground conditions and features. A total of 628 polygon observations (511 in Tranquille-Watching and 117 in Peterson) of terrain attributes were recorded, most of which (about 80%) were on-site ground checks, the rest being long-distance or cursory visual checks. The latter were only recorded where a reliable assessment could be made of at least material type, slope gradient, presence of geomorphic process, and stability class. Copies of the field notes are available upon request. Ground and visual observations are differentiated on the maps by different site symbols (different digital feature codes). The mapper's initials (i.e. DM or TR) precede the observation number. Some polygons (particularly the larger units or those of complex terrain) contain more than one observation note and, in other places, an observation was used to describe two or three adjacent polygons. No on-site field checks were done for the small area of new mapping (4 polygons) along lower Rosen Creek, all of which cover cleared agricultural land. The following table provides a summary of field-check data for the re-mapped polygons in the major watershed areas:

Table 4.1 Summary of Field Checks Per Watershed Area

Watershed	Number of New Terrain Polygons			Number and Percent of Polygons Field Checked		
	Total	Class V	Class IV	Total	Class V	Class IV
Tranquille-Watching	827	37	303	511 (62%)	32 (86%)	191 (63%)
Peterson	204	7	70	117 (57%)	5 (71%)	49 (70%)

The overall field checking exceeds the specifications (20-50% polygon checks) required for TSIL C detailed mapping (Table 1 – Forest Practices Code of BC, 1999). Close to 60% of the total number of newly mapped terrain polygons were verified in the field with a concentration on the potentially unstable and unstable areas (total field checks in the class IV and V polygons exceeded 65%). Additional site-specific data presented in Terrain Stability Field Assessment (T.S.F.A.) reports done for block and/or road layout (listed at the end of references) were consulted to help refine the new mapping; this information is not reflected in the field-check data of Table 4.1.

The assessment of terrain stability and erosion potential is presented with a high degree of confidence. The writer has carried out numerous, logging-related studies throughout the province including other Interior areas of similar physiographic and bedrock setting. The ratings for terrain stability and erosion potential originate from experience and criteria developed in wetter coastal areas (e.g. Howes, 1987, Rollerson et al, 1996, Rollerson et al, 1997, Rollerson et al, 2001); Pack (1994 and 1995) presented additional criteria data gathered in the Kamloops Forest Region. The terrain stability and erosion criteria used for this project conform to the established standards for the region (T. Giles, personal communication) and have been successfully applied in a similar remapping project in the Okanagan (Maynard, 2001). Nevertheless, it should be noted that terrain stability may be strongly influenced by subsurface conditions (e.g. characteristics of materials, subsurface hydrology) that are not apparent from surface observations or analysis of aerial photos, by events of unpredictable times of occurrence (e.g. extreme storms, earthquakes), and by land-management practices, and therefore, the stability interpretations do not provide an absolute guarantee of predicting the likelihood of the occurrence of mass movement events.

Assessments for surface erosion potential and sediment delivery potential rely largely on qualitative criteria and thus, are best considered as subjective interpretations, particularly when applied to 1:20,000-scale polygon attributes. The measure of reliability for the assessments can be best determined by ensuring that they are based on reasonable assumptions and consistent application of realistic criteria. Interpretations for surface erosion potential evolved from basic assumptions and criteria proposed by Rollerson (1986). Recent examples where this method has been applied to community watershed mapping include Maynard (1996, 1997, 2000, and 2001).

The determination of sediment delivery potential from landsliding and surface erosion is even more subjective and only highlights broad relative categories (i.e. high – moderate – low) based on proximity and landscape and hydrologic form between an applicable polygon and potential receiving water. Limited research has been done on landslide runout impacts (i.e. Howes, 1987 and Fannin and Rollerson, 1993), but this work is mainly applicable only to specific coastal areas. Nevertheless, concepts from these works provide a relevant framework for the interpretations as previously illustrated on other community watershed projects (Maynard, 1996, 1997, 2000, and 2001).

Accuracy of the map plotting is excellent. Digital transfer of the original terrain polygon boundaries from the aerial photographs to the TRIM files was done efficiently and with a high standard of photogrammetric control. Polygon boundaries are considered to be accurately aligned with respect to contour and planimetric features shown on the TRIM base.

It should be noted that localized topographic features are not always particularly well portrayed by the 1:20,000 digital contouring; therefore, not all landforms delimited by the detailed terrain mapping are accurately represented by the base topography. Large-scale features such as average gradients of long uniform slopes are satisfactorily represented, but micro-features such as small gullies, narrow or discontinuous scarps, and irregularly shaped landforms and benched surfaces are often missed entirely or are completely misrepresented by the contours.

A final statement of caution for the users of this project information is warranted. The new mapping done by Denny Maynard & Associates Ltd. only replaces the areas of mapping done by AGRA Earth & Environmental Ltd. (1998 a and b) where class IV and V terrain predominated. The reclassification is intended to provide more accurate delimitation of polygon boundaries and more reliable interpretation of terrain and stability attributes. New map polygons replace much of the original mapping in the areas of interest and seamlessly merge with the original polygons on stable ground which have been retained. Cursory examination of some of this retained original mapping confirms that many of the polygon boundaries and terrain and stability attributes are unreliable.

Denny Maynard P. Geo is solely responsible for all the new mapping, but assumes absolutely no responsibility for the accuracy or reliability of the original mapping.

5.0 GEOLOGY AND TERRAIN CLASSIFICATION

5.1 Bedrock Geology

Regional details of the bedrock geology of the area are shown on Geological Survey of Canada maps by Cockfield (1947) and Campbell and Tipper (1971). North from Kamloops Lake to the Bonaparte Lake area there is a pronounced east-west division of geologic units. To the east, flanking both sides of North Thompson Valley are Paleozoic age foliated rocks consisting of argillite, quartzite, greenstone, and minor schist, limestone and related volcanics and sedimentary facies. Tertiary age basaltic to rhyolitic flow lavas cover the western uplands, overlying the older bedrock units.

Most of Tranquille-Watching Watershed is underlain by the young plateau lavas. The old foliated rocks extend across upper Watching Creek to near the east end of Tranquille Lake. A belt of intermediate age (Cretaceous to Tertiary) volcanics and related sedimentary rocks separates the two main bedrock units in a narrow contact zone which trends southerly from mid Watching Creek along the Pass Lake – Lac du Bois lowland east of Opax Hill. Peterson and Rosen watersheds are mostly underlain by the foliated metasediments and metavolcanics with a central zone of intrusive granitics and andesite dykes in the south-central area around Gorman Lake; a large granitic batholith underlies the plateau to the north and west of Peterson Watershed.

Characteristics of the various **bedrock** types can noticeably influence the properties and processes of the surficial landscape. Granitic rock types are usually very hard and resistant to weathering. They tend to break mainly along fractures which are rarely closely spaced, favouring the formation of very coarse colluvial material (rubble and block-sized). However, isolated occurrences of highly fractured and/or altered zones will be encountered where these rocks have significantly reduced structural strength and are more susceptible to weathering and erosion, producing finer textured derivative materials. Sedimentary and volcanic rocks usually have more closely-spaced fracture and bedding planes resulting in easier breakage and greater susceptibility to weathering; thus, finer-textured derivative materials are more common on these rock types. Most of the glacial materials in the region are relatively coarse-textured, reflecting the dominance of hard, coarser-grained rock types over which the interior ice-sheet passed. Tills mainly have a high proportion of matrix sand and gravel clasts but inclusions of silt-dominant till will occur where finer-grained bedrock provided the main source for ice-entrained debris.

5.2 Geomorphic History

Evolution of this present landscape began several tens of millions of years ago (late Cretaceous - early Tertiary geologic time) with uplift of the interior mountain-plateau complex. During periods of tectonic quiescence, a low-relief landscape developed from on-going erosion and deposition; late Tertiary uplift reactivated more aggressive erosion causing established streams to incise relatively deeply and steeply into the more subdued upland surface. Remnants of this activity are represented by the juxtaposition of the deeply entrenched main valleys occupied by the Thompson River system with the surrounding rounded hillslopes on the Thompson Plateau.

The recurrent glacial erosion and deposition of the Pleistocene Epoch (the past million+ years) has further modified the area to its present-day form. Sediments and landforms generated during the last major (Fraser) glaciation and deglaciation are well preserved in the study area. Evidence of earlier glacial activity on the plateau has been largely removed or covered but some information has been reconstructed from events preserved along the flanks of the main valleys (Fulton, 1975). Post-glacial erosion and deposition over the past 10,000-12,000 years (Holocene Epoch) have also contributed to late-stage modification of the surficial landscape.

The on-set of the Fraser Glaciation began about 30,000 years ago with the formation of higher-elevation cirque glaciers. Piedmont glaciers continued to grow and thicken, coalescing into the southerly-flowing Cordilleran Ice Sheet where surface flow patterns became less controlled by ground-surface topography. At the glacial maximum, about

15,000 years ago, the ice covered even the highest plateau peaks. Associated with this ice flow was extensive deposition of sub-glacial sediment known as **till**; this was plastered onto the pre-existing surface as a mantle over the underlying topography or as thicker infills into valleys and depressions. In places, subglacial erosion dominated over deposition, resulting in little till being laid down and the surface smoothed and scoured to bedrock.

Deglaciation of the central interior icesheet must have commenced and progressed relatively quickly; Fulton (1975) indicates that it was underway at least by about 11,000 years ago and by about 9,000 years ago the southern interior was largely ice-free. Around about this latter date, ice still infilled the Thompson valleys and covered much of the plateau to the north-west, although higher elevations such as Porcupine Ridge may have been exposed. As deglaciation continued, the ice sheet probably separated into stagnating and retreating glaciers occupying the main valley systems with a downwasting cap of remnant ice on the upland plateaus which gradually dissolved into smaller bodies of detached, stagnating ice. This in-situ melting resulted in ice-entrained sediment being left as thin surface mantles or as chaotic hummocks of loose, coarse debris known as **ablation till.**

Considerable meltwater was also released, which eroded into the surficial and bedrock surface, creating well-defined meltwater channels; materials eroded and transported by the meltwater subsequently deposited along the temporary drainages. Deposits of sand and gravel (**glaciofluvial sediment**) of variable thickness are preserved as remnants of this deglacial activity. In some places, lakes and ponds were temporarily impounded, creating short-lived sites where fine sediment (sand to clay) accumulated to form deposits of **glaciolacustrine origin.**

Meltwater flows from the plateau surface concentrated along what were probably also pre-Fraser drainages; thus, formation of present-day incised reaches of main creeks and their tributary streams and gullies usually initiated with meltwater erosion which cut rapidly into the glacial and deglacial sediments that infilled older valleys and drainageway depressions, often through and into underlying bedrock. The main valleys occupied by Tranquille River, Watching and Cannell creeks, and Peterson Creek served as major spillways for meltwater draining from the uplands to the Thompson valleys.

During the transition from deglacial to post-glacial conditions the unvegetated land surface was most vulnerable to erosive processes and the downcutting of creeks accelerated. Erosion by surface runoff and mass movement processes would have been fairly active on the steeper slopes, particularly those which were developing in response to creek downcutting. Wind eroded fine sand and silt from exposed surface materials and re-deposited the fine sediment as thin, discontinuous **eolian** veneers across parts of the plateau surface.

Fluvial and slope erosion and deposition continued through post-glacial time but at decreased levels to that which immediately followed deglaciation. Common landforms representative of this later-stage **fluvial** activity include floodplains, tributary fans, and creek-side terraces.

Other common types of surficial materials and landforms produced in post-glacial time are **colluvial deposits** consisting of weathered bedrock on sloping surfaces or as accumulations of mass movement debris, in-situ veneers of **weathered bedrock** on subdued surfaces, and wetland depressions infilled by **organic** matter and/or fine **lacustrine** sediment.

5.3 Terrain Materials and Landforms

The distribution of surficial materials and their various textures, landforms, and modifying geomorphic processes are shown in detail on the Terrain Classification maps. The following discussion summarizes the main terrain characteristics of the map areas.

Bedrock is identified as a material type where rock outcrops occur at the surface or are mantled by less than 10 cm of surficial sediment (photo 3). Specific rock types are not indicated on the terrain maps but their generalized distribution and characteristics were discussed previously. Rock outcrops, while usually not extensive, can be found at all landscape positions in the various watersheds (photos 4-8). The plateau uplands and main-valley walls are all bedrock-controlled, mantled by variable thicknesses of continuous to discontinuous surficial deposits (mainly till and colluvium). Even where surficial cover appears extensive, underlying bedrock topography may be highly variable and rock hummocks occasionally protrude through a surface of thick sediment. Significant bedrock-dominated features scattered throughout the landscape are the abrupt lines of cliffs of plateau lavas (photos 5-8). Other notable rock exposures are seen in some deeply-incised canyons such as along Peterson Creek (photo 2).

Weathered Rock is mapped where the rock surface has disintegrated enough to significantly alter its physical properties yet fragments have not detached and moved away by gravity. This "in-situ" weathering usually occurs as a discontinuous or minor component on subdued surfaces of exposed, softer and/or highly fractured rock types, forming a surface veneer of small rubble in a loose, finer matrix. Bedrock exposed along erosional surfaces such as gullies and canyons may also show varying degrees of weathering as these features often concentrate in pre-existing zones of bedrock weakness.

Colluvium (products of mass wastage which transport by direct, gravity-induced movement) is the dominant surficial material mantling the major valley walls and ridge sideslopes, forming relatively thin, continuous to discontinuous mantles on mid to upper slope positions (photos 9 and 10) and thicker, more continuous aprons and blankets on lower slopes below bedrock-dominated sites (photo 11) and gully mouths. In places, sideslope colluvium may overrun the upper edges of lower-slope till deposits. Textures of colluvial soils typically range from silty rubbly where derived from volcanic and metasedimentary bedrock to sandy rubble and blocks where underlain by granitic rocks. Coarsest colluvium (blocky and rubbly fragments with little interstitial matrix – i.e. talus) occurs immediately below high bedrock cliffs (of all rock types, photo 12)and around sites of bedrock instability. Colluvial deposits are usually well to rapidly drained, but seepage and imperfectly drained soils may occur where slope gradients abruptly decrease and/or impermeable material (bedrock or till) is close to the ground surface. Evidence of soil creep and increased potential for surface erosion are usually associated with steeper slopes (photos 9 and 1~~0~~3), finer matrix textures, and/or wetter sites.

Other common colluvial landforms are the lower and toe-slope fans, cones, and aprons which have accumulated at the base of active slopes and mass movement sites. Characteristics of these deposits are dependent on their source and on the state of activity of the depositional processes. Coarse, angular, loose rock fragments accumulate below the more active bedrock slopes or may represent old rockslide debris. Where a high proportion of matrix material occurs it may indicate a longer period of weathering of the debris deposit.

Thick colluvial material accumulated along the eastern wall of Tranquille Valley, in the vicinity of the mainline bridge, appears to be old landslide debris. Thick exposures of loose, sandy rubble occur from the river scarp to a mid-slope bench (photo 13) suggesting that failure of the headwall cliffs may have caused recurrent deposition of debris against downwasting valley ice.

Colluvial debris derived from surficial materials will have textural characteristics reflective of the different parent sediments. Many debris flow deposits contain angular to subrounded clasts (mixed fragments) indicating that, while a landslide may have originated on upper-slope colluvium and bedrock (fresh angular fragments), it eroded through and incorporated materials (matrix and subrounded fragments) from lower-slope surficial deposits. Thick deposits of toe-slope colluvium may provide suitable sources of aggregate or ballast depending on clast size and any presence of mass movement hazard from upslope.

Glacial till (moraine) is material transported and deposited directly from glacier ice. It is a dense, compact, impervious sediment consisting of a poorly-sorted mixture of matrix and rock fragments. Basal till, plastered onto the surface by overriding ice, is typically highly consolidated with silty sandy to sandy silty matrix textures most common in the area (photo 14); in places, silt-clay dominant tills are exposed, but usually these are found at depth on erosional surfaces. Ablation till, which deposited supraglacially rather than subglacially, is a coarser-textured (more matrix sand and coarse fragments), less compact, and crudely stratified material commonly found as a surface mantle, particularly on the plateau uplands.

Till deposits are ubiquitous throughout the watersheds, occurring in a variety of landforms ranging from mantles of variable thickness (e.g. .5 – 3 m) on subdued uplands and gently to moderately steep valley walls to thick sections of valley-floor and lower-slope terraces and gully-and-ridge topography. Till is only subordinate to colluvium along the steeper, rockier sections of valley walls and higher-elevation ridges.

The thickest till deposits accumulated in pre-glacial plateau depressions and valleys but these are often of limited horizontal extent. In a number of places, creek banks and road cuts expose sequences of till in excess of 5 m thick which are closely adjacent to rock outcrops. The most continuous, thick till deposits are found along sections of the main creeks and tributaries where post-glacial downcutting into the valley infill has formed high (10m +) erosional scarps. These are also the steepest till landforms that occur; till mantles conforming to underlying bedrock topography are uncommon on slopes greater than 70%.

Drainage of moraine is largely dependent on topography and slope position. Till is typically well drained on sloping terrain but subdued and toe-slope landforms are often areas of seepage accumulation where soil drainage may be imperfect to poor. Areas of restricted drainage may be indicated by the presence of small depressional wetlands. Gully and creek banks incised into till deposits often contain seepage sites. Erosion potential may be significant on till-mantled terrain, particularly where deposits are thicker, slopes approach and exceed 40%, and surface runoff may concentrate. Mass movements (ranging from rapid flow slides to slow moving slumps) are common where thick till deposits have been undercut and oversteepened by fluvial erosion (photos 15-17).

Deglacial materials were deposited by glacial meltwater, at the edge of or in close proximity to ablating or retreating glacier ice. They consist mainly of **glaciofluvial** sands and gravels (may include abrupt textural changes and/or interlayers of till or silt) but, in places, may be in association with well-sorted, fine-textured (clay to fine sand and occasionally enclosing drop-stone pebbles) deposits which accumulated in temporary, meltwater-fed lakes and ponds (**glaciolacustrine or lacustrine sediments**). Deposits are thickest and most continuous along the major meltwater spillways (e.g. present-day valleys, photo 18) and in areas where extensive ice stagnation occurred (e.g. upland drainage divides).

Deglaciation patterns were probably fairly complex as the ice-sheet disintegrated. Areas of stagnant ice were left on the plateau uplands while separated tongues of ice retreated and downwasted in the valley lowlands. Substantial volumes of meltwater temporarily existed, so erosional downcutting, reworking of existing materials, and transportation and deposition of meltwater-entrained sediments remained highly active processes for a short time. Most of this meltwater activity occurred along the drainage ways now occupied by the main, present-day creeks although evidence of ice stagnation on the plateau surface occurs in the form of remnant sand and gravel ridges and hummocks (eskers and kames) and short, small meltwater channels which are now dry or contain underfit streams.

Downcutting of the ancestral creeks initiated with meltwater erosion, but as runoff regimes changed and deposition temporarily dominated, deglacial sediments accumulated along sections of these spillways and now remain as remnant deposits in close proximity to the present-day drainages. These mainly occur as mantles of variable thickness overlying till (and lesser bedrock) and as constructional forms (terraces, hummocks) of variable areal extent. Remnant fan and terrace deposits (photo 18), raised well above present base levels, provide evidence of typical valley-plateau glaciofluvial and isolated, intermixed, glaciolacustrine deposition.

The characteristics of deglacial materials are highly dependent on their mode of deposition. Lake-deposited fine sediments have low permeability and bearing strength and, particularly on gentle slopes, restricted subsurface drainage. Disturbed exposures are very susceptible to erosion from flowing water and are usually a point of weakness where exposed on steeper slopes or in deep excavations. Coarser sands and gravels deposited from flowing meltwater are free-draining, much less compressible and erodible, and are usually stable on slopes at least up to their angle of repose (about 65-75%) although they tend to ravel when exposed on oversteepened stream banks and road cuts. Deposits of post-glacial, granular sediment often provide good sources of aggregate; thick, dry, well-sorted outwash with favourable topography is most suitable. However, common characteristics which may reduce aggregate potential or create local problems of instability-erosion include highly variable textures and structure and till, bedrock, or finer-textured sediments at shallow depth. Glaciofluvial materials in the map areas consist predominantly of well sorted sand and pebbles along the main drainage systems (photo 19) with coarse, poorly-sorted deposits less common and usually occurring near areas of plateau ice stagnation and short-lived meltwater erosion.

Valley-floor fan, channel, floodplain, and low terrace deposits of granular sediment are mainly associated with post-glacial **fluvial** activity. These are materials transported and deposited by recent to present-day creek, stream, and gully regimes. Drainage of fluvial sediment is dependent on their texture and position of underlying water table or impervious layer. Coarse gravels occur along most active channels; overbank sands often cap the gravels on bordering low terraces and floodplain flats.

Slightly raised terrace and fan gravels border sections of most of the main channels, in places mantling toe-slope till (or lesser bedrock) to various thicknesses, reflecting earlier periods of deposition and subsequent downcutting. At the mouths of steep-gradient gullies, poorly-sorted deposits have usually resulted from a combination of debris flow-debris flood events which are transitional to mass movement or colluvial processes from purely fluvial activity. Sections of Tranquille River and Watching Creek have relatively broad, valley-floor fluvial surfaces (photo 1), but elsewhere on these creeks and for most of other main creeks, floodplains and low terraces are narrowly confined by high erosional scarps or canyon walls (photos 2, 16, and 18).

Over time, fluvial activity has become more erosional than depositional, resulting in further downcutting by main and tributary drainages into and through their ancestral deposits and into other surficial sediment and/or bedrock. These erosional scarps are significant landscape features because they have a higher instability and erosion potential and are closely adjacent to stream channels, thus providing ready sources of sediment. Excluding these scarps, most raised fluvial surfaces are subdued and well drained. However, depending on their proximity to an active channel, a flood or debris runout hazard may exist. Thick, raised, and dry gravels may provide potential sources of aggregate and are usually of low erosion and instability potential except where exposed on oversteepened scarps. Fluvial deposits associated with present-day flow regimes often are affected by high water tables and/or flooding which may restrict development.

Post-glacial depressional infilling by **organic** material and ponded fine sediment **(lacustrine** silt-sand) is most common on undulating surfaces of the upland plateaus and, to a lesser extent, broad, gentle toe-slopes and valley-floor enclosures. Deposits of intermixed fine sediments and organics are usually soft, wet accumulations which can be highly compressible, depending on thickness, and may become seasonally inundated, severely limiting development possibilities. They occur on low slope gradients so instability is not usually a concern but they may be erodible where fine sediment is exposed at the surface.

5.4 Geomorphic Processes

Geomorphic processes of weathering, mass movement, erosion, and deposition have contributed fairly significantly to post-glacial modification of some landscapes in the map areas. Process modifiers are attached to the terrain labels on the Terrain Classification Maps where geomorphic processes are active or have significantly affected or modified a landscape unit. Processes active during deglaciation (i.e. channeling by meltwater flows, formation of kettle holes by melting ice) modified the existing surface but are long inactive and not considered further in this discussion.

Gullying and **landsliding** are the main processes occurring on the forested slopes; these are affected by complex interactions of many factors, including climate, bedrock geology, topography, and characteristics of unconsolidated materials. **Snow avalanching** was not identified as an active process in the mapped areas although this does not preclude the occurrence of minor snow movements on isolated higher-elevation, sparsely vegetated, steeper slopes.

Large, individual **gullies** and intensely **gullied slopes** are important landscape features because they represent sites of previous to recurrent erosion and/or mass movement activity. They also have the potential to transport eroded debris long distances from mid and upper slopes to the valley floors. High and steep headwalls and sidewalls of deeply incised valley-wall gullies may be sites of bedrock-related instability. Evidence of debris transportation may exist at the gully mouths in the form of debris cones or fans (mapped as colluvial or fluvial depending on whether landsliding or stream flow was the main transportation agent). Many of these gully systems are formidable physical obstacles as well as being potentially active sources of sediment. Large sidewall gullies are most prominent along mid Tranquille (photo 8) and lower Watching valleys.

Gullies in surficial deposits are important sediment sources, particularly where banks have been destabilized. These usually occur on mid to lower valley slopes and, often, along high creek scarps. Where active gully channels directly connect to a floodplain the potential for sedimentation is highest. Inactive gullies, formed by processes no longer operating, are relatively common where thicker till and/or glaciofluvial deposits occur. These are considered to have a slightly higher instability and erosion potential than surrounding open slopes but their sedimentation potential will be determined by their connectivity to a watercourse.

Mass movement is the downslope transfer of earth materials under the influence of gravity. Landslide activity in the map areas is not extensive and is mainly restricted to very few landscape types. Scarps and canyon-like walls bordering deeply incised gullies and creeks contain the most evidence of historic to actively recurrent landslides which usually relates to lateral channel erosion or undermining scour that accompanies downcutting over time. Debris failures range from dry slides and ravels in granular sediment (photo 20), to slump-flow failures in finer-textured sediment and saturated till (photos 21 and 22), to a combination of such failure types (photos 15-18). These are most common where on-going erosion has created oversteepened sites and exposed stratigraphic discontinuities and subsurface seepage; because these are mostly closely adjacent to active channels, they pose a high risk for causing watercourse sedimentation. In places, where deep erosional incision intersects bedrock, banks of ravelling colluvium and crumbling rock faces also exist (photo 23). Sites of active or recurrent instability are, for the most part, readily apparent on the aerial photographs. Some of these are in unlogged areas, others are on logged portions of scarps and gully walls, and others appear to have a connection to diverted road drainage from above. Field evidence further confirms that even the thickly forested segments of the steeper and higher scarps and gully walls exhibit small-scale evidence (e.g. seepage, surface sloughing, rapid soil creep) suggesting moderate to high instability-erosion potential, particularly where surficial material is thick. Sections of these erosional slopes have been recurrently moving since post-glacial downcutting began and increased instability may be probable if they are excessively disturbed.

Landslides on forested, uniform, open slopes are very rare, but historic evidence (toe-slope debris fans, subtle vegetation changes) suggests that some failure events have initiated from valley-side headwall to mid-slope small basins. These are old (100-200 yrs +) events which could relate to unusual circumstances (e.g. intense rainfall after wildfire denudation); thus, it is difficult to absolutely link them to present-day conditions although it provides an indication of potential instability.

Many of the higher bedrock cliff exposures show some evidence of historical to recent instability. Rockfalls and cliff topples, originating at the weathered or fractured surface of the rock mass, are the main failure types. These often have little effect on forestry operations because such rock slopes are usually considered inoperable; downslope blockfields will indicate the area of potential hazard from rockfall runout. Examples of the more prominent cliff and talus landforms occur along sections of mid Tranquille-lower Watching valley walls; other discontinuous cliff exposures are scattered throughout the plateau surface. One very noticeable cliffed landform (photo 5), occurring on the west side of mid Watching Creek, north-west from Pass Lake, was mapped as a landslide feature by Fulton (1975). This appears to be a partial collapse-spread of the plateau lava front which likely caused slump-flow movement in the overlapping toe-slope surficial deposits. It may have occurred contemporaneously with ice-sheet disintegration because of the loss of lateral support the ice was providing to the cliff face. Thus, this landslide can be considered as a relict feature with a low likelihood for reactivation. Present-day hazards associated with these types of landforms are mainly from occasional rockfall off the headwall cliffs or possible collapse and ravel of talus piles (particularly if undercut by road construction); areas affected from these types of events are fairly isolated with limited downslope impacts.

6.0 TERRAIN STABILITY, SURFACE EROSION POTENTIAL, AND SEDIMENT DELIVERY POTENTIAL

Individual terrain units have been assessed according to their estimated stability, surface erosion potential, and sediment delivery potential following logging. These classifications, indicating the expected response of the landscape to clearcut forest harvesting and road development, are shown on the Terrain Stability and Surface Erosion Potential Maps. Explanations of the classifications and the criteria used in determining them are detailed in appendices I, II, and III with table 6.1 summarizing key interpretative criteria used as guidelines for assessing terrain stability.

Terrain stability rankings provide a relative assessment of the likelihood of mass movement initiation but give no indication of expected landslide frequency, magnitude, or impact. Ratings are intended to "flag" potential problem areas; actual decisions on logging or road construction should be based on careful field evaluation by appropriate terrain and forest engineering personnel. Problems of instability are expected to be most severe in classes V and IV. There is a high likelihood for landslide initiation within class V units during and following road construction and following conventional clearcutting. Class IV units have a lower likelihood for clearcut failures but bladed trail and road-associated problems are probable if special construction and maintenance techniques are not considered.

Usually there are only minor to no instability problems expected on classes I, II, and III units following logging. However, it should be noted that within class III terrain, small areas may occur which are potentially unstable; in effect these are inclusions of class IV ground which are too small to identify during 1:20,000-scale mapping. Similarly, inclusions of stable ground may occur within class IV and V units. In some areas, highly variable or complex terrain types are intermixed and are mapped as composite units which may have different instability potential. In these cases, the entire polygon will be labelled as the more severe class (Forest Practices Code of BC, 1999).

Guidelines (Table 6.1) for assigning terrain stability classes consider the important criteria of slope steepness and material characteristics, modified by other mapping factors such as slope morphology, slope drainage, and geomorphic processes. Generalized descriptions of the various terrain types assigned to each stability class are given in appendix I.

Ratings of surface erosion are a qualitative assessment of the likelihood for generating sediment by overland water flow during and after logging development and presume that mineral soil is exposed. Thus, areas of major concern are roads and bladed trails, recent landslide and gully scour and deposition, sensitive landforms (e.g. finer textured deposits), and excessively disturbed sites such as recent burns or ground heavily scoured by yarding or excavation; usually surface erosion is not a major concern in most clearcut areas where ground disturbance is minimal. The surface erosion ratings are not necessarily intended to restrict logging; rather, they should be used to "red flag" potential problem areas so that appropriate preventive or remedial action can be planned. Erosion potential is rated by a 5-class system ranging from very low to very high. The classes should only be considered as relative assessments of erosion potential if surface disturbance occurs.

Appendix II more thoroughly documents the linkage among the various terrain attributes that can be reliably identified by detailed mapping and the erosion potential interpretations. Most of the same factors considered for assessing slope stability are also considered for determining potential erodibility, albeit with somewhat different emphasis. The rational for assigning various attributes as class criteria follows these general assumptions:

- finer-textured sediments (clay to fine sand) will be more easily eroded than medium-textured materials (coarse sand to fine gravel); coarse materials (cobbles, boulders, rubble, and blocks) have low susceptibility to erosion by overland flow. Most types of intact bedrock are not erodible.

Table 6.1 Guidelines for Terrain Stability Classification

Stability Class	Dominant Gradient Range (%)	Material Characteristics and Landforms	Slope Process	Slope Drainage	Slope Morphology
I	less than 25	medium-coarse textures and organics; till, weathered rock, colluvium, (glacio)fluvial, bedrock	None		
	less than 10	fine textures; (glacio) lacustrine and (glacio) marine			
II	20-60	rock-dominated, irregular ground with discontinuous coarse textured veneers	None	wet slopes or those with prominent seepage sites and which have gradients dominantly within 5-8% of an upper gradient range, may be assigned to the next highest stability Class	Bedrock-controlled Slopes with irregular or benched topography have greater inherent stability; units with gradients dominantly close to a lower gradient range may be assigned to the next lowest stability class Erosional scarps and/or open-slope units which have, or contain prominent concave forms and which have gradients dominantly within 5-10% of an upper gradient range, may be assigned to the next highest stability class
	20-45	coarse-textured till, colluvium, (glacio) fluvial			
	10-40	medium to finer textured till, colluvium			
	10-30	fine-textured (glacio) lacustrine and (glacio) marine			
III	40-75	rock-controlled complexes of coarse-medium textured till, colluvium and/or (glacio) fluvial; talus slopes	inactive or minor gullying.		
	30-70	erosional, constructional, or mantled slopes of medium-coarse textured till, colluvium, and/or (glacio) fluvial			
	25-65	medium to finer textured till and colluvium			
	20-50	fine-textured (glacio) lacustrine and (glacio) marine			
IV	greater than 75	bedrock and coarse colluvial mantles	inactive or minor gullying; rockfall.		
	greater than 70	coarse-textured colluvium & (glacio) fluvial			
	greater than 65	coarse-textured till			
	greater than 55-60	medium to fine textured till, colluvium; (glacio) fluvial with finer interlayers	minor, small-scale sloughs; gullying		
	30-65	fine-textured (glacio) lacustrine and (glacio) marine	Inactive or minor gullying, small-scale slump-flows.		
V	any gradient	All	active and/or recurrent failures and/or readily identifiable small-scale instability		
	greater than 60	fine-textured (glacio) lacustrine and (glacio marine and clay-rich till	none		
	greater than 40		gullied		

- higher energy erosional environments are more probable on steeper and longer slope segments; also, on steeper slopes more surface area is likely to be disturbed by road and trail construction than on gentle slopes.
- thicker surficial deposits have a greater potential for sediment production because more material may be exposed in cuts and ditchlines (as opposed to thin deposits where excavations may be into bedrock).
- landscape position and slope drainage will influence erosion potential; receiving slopes may be more susceptible to erosion than shedding slopes because there is a greater likelihood of intercepting surface and near-surface runoff.
- gullied slopes have undergone erosion in the past and thus, may be more susceptible to future erosion, partly because runoff flows tend to concentrate.
- surficial-mantled slopes actively failing or with a high likelihood for post-logging failure are considered more susceptible to erosion because more bare material may be exposed.

Sediment delivery potential, either by direct landslide deposition or by water transport of sediment generated from surface erosion, is also an important concern when assessing post-logging disturbance impacts in a community watershed. At a mapping scale of 1:20,000, these interpretations have limited usefulness, at best providing very subjective assessments of the likelihood of any landslide debris and eroded sediment originating in a polygon to enter a downslope water body, depending on the proximity and linkage between them. Both sediment delivery interpretations are given as qualitative high-moderate-low rating systems. Factors used to assess the potential impacts of landslides and eroded sediment on receiving water are shown in tabular form in appendix III; these include slope angle and shape, the presence or absence of a landslide runout or depositional zone, the length of any runout zone, and the presence of small channels (ephemeral and non-mapped perennial) and gullies which may provide direct water-flow linkage between a polygon and receiving water.

In a community watershed the concern is potential sedimentation impacts which may affect water quality at an intake site. Yet, within the drainage network there may be lakes (reservoirs) and wetlands which act as filters or "sediment sinks", allowing most, if not all, sediment transported by incoming flows to settle out in the basin. Nevertheless, to simplify the sediment delivery interpretations, the filtering capability of these has been left to be considered as a management interpretation; therefore, for the purposes of assigning sediment delivery ratings in this project area, lakes, reservoirs, and wetlands have the same receiving water status as that of creeks. Also, note that a potential receiving water body is also considered by slightly different criteria depending on the sediment delivery process. For deposition by a landslide mass, the question is whether or not it will reach any well-defined perennial channel whereas sediment derived from surface erosion is primarily the finer fraction (sand to clay) which will transport with any concentrated flows of running water so this interpretation is concerned with delivery potential via the entire surface drainage network (i.e. includes small, valley-wall ephemeral streams to large valley-floor creeks).

Terrain stability concerns are greatest in those areas having actual or high likelihood for instability and/or surface erosion combined with close proximity to receiving water bodies. Accordingly, steep, failing and gullied slopes directly bordering the main creeks and their perennial-flow tributary streams and gullies, are considered as the most sensitive areas within the watersheds for forestry activity. These areas are denoted by a class V stability rating and a moderate (M) to very high (VH) surface erosion potential with high sediment delivery ratings (photos 15-18, 20, 21, 23). Dominant terrain types in this category are: high creek scarps and bordering gullied slopes consisting of failing thick till and stratigraphic complexes of granular fluvial-glaciofluvial and/or fine-textured glaciolacustrine sediment overlying (or possibly underlying) till; crumbling and ravelling colluvium and bedrock canyon walls bordering some creek reaches and steep-gradient gully tributaries; and high banks of surficial material (usually till, some gravel) overlying bedrock along tributary streams and gullies. Gullied and slump-deformed scarps, not actively failing but where there is sufficient micro-site field evidence to suggest that these areas are highly sensitive to disturbance, particularly if sites are wet and/or adjacent erosion has removed lateral support, are also rated as having high likelihood of post-logging instability and/or erosion potential.

Unstable and erodible scarps, gullies, and confining banks and slopes do not usually occupy large, continuous areas, but any erosion or mass movement activity on them may have a direct sedimentation impact on the adjacent water bodies. Their occurrence is relatively limited, but some segments of unstable/erodible scarps and gullied valley walls are identified along most of the main creeks and tributaries. In particular, concentrations of these are found throughout Peterson Creek canyon and bordering middle and lower reaches of Watching Creek with clusters also occurring along upper Tranquille River, above the Sylvester Creek confluence; other smaller and isolated unstable scarps are scattered along sections of upper Watching Creek, lower Tranquille River, and Sylvester and Cannell creeks. In places, past disturbance (i.e. logging, road building, fire) may have contributed to some of the recurrent failures. Future forestry activity should usually be precluded from these most sensitive areas, with any necessary development (e.g. limited road location) to be carefully scrutinized.

Other sensitive terrain types which may require restrictions to extensive forestry development are those slopes with moderate to high likelihood for instability (and usually erosion potential) that have high to moderate sediment delivery potential. This includes all the remaining deeply incised reaches of the above-named creeks and river, as well as some steeply-confined, smaller tributaries. These will mostly be rated as stability class IV with a landslide-induced sedimentation rating of 2 or 3; scarps displaying no obvious evidence of instability may be eroded entirely into till and/or gravels but also commonly include a significant rock component (photo 2). Development opportunities may be severely restricted by the slope steepness and sedimentation concerns. Areas of gully headwall and sidewall instability or potential instability (classes V or IV) that are slightly removed from the main drainage but remain somewhat connected by longer runout slopes and tributary channels also require careful scrutiny. The south-west valley side of mid to lower Tranquille River is the main example of this type of terrain. Sites of active instability (class V) are minor but steep-sided channels and upper-slope headwalls (photo 8) are ubiquitous (class IV) with the presence of some gully-mouth fans indicating that these are likely sites of historic debris deposition. Although the likelihood of any landslide directly impacting on Tranquille River from this valley wall is ~~s~~low to very low, any debris entrained in a steep-gradient tributary channel or finer sediment deposited where seasonal runoff concentrates will eventually transport to the valley floor. Controlled selective development (e.g. engineered roads, cable suspension yarding) is possible in places, but retention of forest buffers would be usual mitigative measures to help minimize sediment yield to the drainage systems. A unique concern to this area of Tranquille Valley exists because of potential safety hazards, albeit of relatively low risk, that any sizeable landslide could pose to downslope human activity and structures on the toe-slope runout zones beneath the areas of designated higher instability potential; any proposed development must assess downslope consequences which could result from valley-slope instability.

Open-slope stability class IV and V terrain that is completely disconnected from the drainage systems (i.e. low sediment delivery potential) is mainly associated with the steeper-gradient (over 65-70%), colluvial-bedrock landforms and the steeper, mid to upper slope till and/or colluvial mantles. The former include the rock-dominated valley walls, such as are evident on the north side of mid to lower Tranquille Valley (photos 3, 4, 9) and upstream into the Watching-Cannell confluence area, and the abrupt cliff zones along plateau and ridge edges scattered throughout the upland surface (photos 5, 6, 7, 12). Most of this terrain is rated as class IV, primarily because of road-related instability concerns. Class V rocky slopes are rare, limited to sites of concentrated crumbling rock and colluvial slide-ravels; erosion potential of this terrain type is usually low to very low. Landslides may not travel far from the initiation zone because they are usually dry and irregular surface gradients and morphology often create confined runout zones. Many of these sites have limited forestry values because of access difficulties and poor timber values so development impacts are lessened. The mid to upper slope, surficial mantled (till and/or colluvium) steeplands that are considered potentially unstable are mostly over 65% gradient where well drained, but may be as low as 55-60% where highly gullied or very wet. Erosion potential is low to moderate on most colluvium (depending on thickness, texture, and any site disturbance) but is usually rated high on the till (particularly where gullied and/or wet) and may be very high if gullied, fine-textured landforms exist. Development concerns are mostly road-related but harvesting may also be potentially damaging on wet or erodible sites. Open-slope surficial instability is rare in these watersheds; small class V polygons are isolated where small-scale debris slides and flows occur in association with seepage concentration and/or gullies on moderately-steep gradients. Such mass movement events usually remain relatively localized, as the size of existing and expected failures is small and the flattening downslope gradients that commonly occur usually do not facilitate long runout events. However, the proximity of such terrain types to any tributary gullies and small streams should be considered in the development plans. For future development in and around these and similar sensitive sites, selective logging may be considered an option where the slopes are definitely disconnected from all streams and thus sedimentation potential and downslope risk is minimal.

Terrain stability field assessments by a qualified registered professional are required prior to any ground-based or clearcut forestry development on class IV and V terrain in Interior community watersheds. Special conditions for road construction (e.g. full-bench cuts and endhauling) are commonly recommended and certain harvesting prescriptions or restrictions may also be applied in order for development to be approved where the on-site assessment determines that the landslide hazard is acceptable. Usually, forestry development will be considered as more feasible where the sedimentation potential is low. Consultation with a terrain stability specialist should also be considered for areas of high erosion potential and/or marginal stability (e.g. steeper class III ground) where high sedimentation concerns are identified (e.g. shallow gullies, low creek scarps, and for development closely adjacent to downslope areas of higher instability potential which could be adversely affected). Also, most importantly, potential consequences of landslide runout which may pose other downslope risks (e.g. to life and property) must be evaluated by a qualified registered professional if development is proposed for upslope class V and IV terrain.

A large proportion of the operable forest land , much of it previously logged, is on stability class II and III terrain. Where surface erosion potential is rated low to moderate, as for most well-drained colluvial and gravel slopes less than 65-70%, dry till-slope mantles less than 60-65%, and the bedrock-controlled ridged and hummocky terrain, there are few constraints to logging operations. Again, the most sensitive sites occur adjacent to creeks and streams, particularly where seepage or small surface channels occur on potentially erodible materials. Any logging development in areas rated stability class III with high erosion potential (i.e. silt and sand dominant sediments, wet till) or where minor inclusions of sensitive terrain (e.g. gullies, seepage sites) occur, should be carefully considered. Prudent layout of roads, landings, and block boundaries is important, as is a yarding plan which minimizes disturbance of the sensitive sites, particularly near active channels. Special conditions, such as avoidance of extreme wet periods, may be appropriate for yarding and/or road building in these areas, particularly if there may be significant downslope consequences.

Stability and erosion concerns are usually minimal on class I terrain. Subdued surfaces of dry fluvial and glaciofluvial landforms (raised fans and terraces) and till-mantled lowlands, broad benches, and upland plateaus are the main operable areas. Other class I types are mainly organic and depressional till or lacustrine wetlands and floodplains where logging activities are usually restricted by such factors as high water table, flooding, poor timber values, and/or high fish and wildlife values. Wet depressions or gentle slopes underlain by fine-textured surface material may be rated as having moderate erosion potential.

7.0 REFERENCES

AGRA Earth and Environmental Ltd., 1998a. Terrain Stability and Terrain Stability Mapping, Peterson Creek, Nelson Brook, and Rosen Brook Watersheds. Prepared for Weyerhaeuser Canada Ltd., Armstrong, BC.

AGRA Earth and Environmental Ltd., 1998b. Terrain Stability and Terrain Stability Mapping, Tranquille-Watching Watershed. Prepared for Weyerhaeuser Canada Ltd., Armstrong, BC.

Agriculture Canada Expert Committee on Soil Survey, 1987. The Canadian System of Soil Classification. Ottawa, Ont.

Campbell, R.B. and H.W. Tipper, 1971. Geology-Bonaparte Lake (92 P). Geological Survey of Canada Map 1278A. Ottawa, Ont.

Cockfield, W.E., 1947 (reprinted 1971). Geology-Nicola (92 I-east half). Geological Survey of Canada Map 886A. Ottawa, Ont.

Fannin, R.J. and T.P. Rollerson, 1993. Debris flows: some physical characteristics and behaviour. Canadian Geotechnical Journal 30: 71-81.

Farley, A.L., 1979. Atlas of British Columbia: people, environment, and resource use. University of BC Press, Vancouver, BC 136p.

Forest Practices Code of BC, 1999. Mapping and Assessing Terrain Stability Guidebook. Second Edition. BC Environment, Victoria, BC.

Fulton, R.J., 1975. Quaternary Geology and Geomorphology, Nicola-Vernon Area, BC. Geological Survey of Canada Memoir 380. Ottawa, Ont.

Howes, D.E., 1987. A terrain evaluation method for predicting terrain susceptible to post-logging landslide activity. Min. of Environment and Parks Technical Report 28, Recreational Fisheries Branch, Victoria, BC 38 p.

Howes, D.E. and E. Kenk (Eds.), 1997. Terrain Classification System for British Columbia: Version 2, 1997. MoE Manual 10. Update by Resource Inventory Branch, Ministry of Environment, Lands, and Parks. Victoria, BC 102 p.

Mathews, W.H. (compiler), 1986. Physiography of the Canadian Cordillera; Geological Survey of Canada Map 1701A, scale 1:5,000,000.

Maynard, D.E., 1996. Terrain Classification, Terrain Stability, Surface Erosion Potential, and Sedimentation Potential of Furry Creek Chart Area. Prepared for Terminal Forest Products Ltd., Richmond, BC.

Maynard, D.E.,1997. Terrain Classification, Terrain Stability, Surface Erosion Potential, and Sediment Delivery Potential of Canyon Creek Community Watershed. Prepared for BC Ministry of Forests, Prince Rupert Region and Bulkley Forest District, Smithers, BC.

Maynard, D.E., 1999. Reconnaissance Terrain Stability Mapping of Vaseux Creek and Shuttleworth Creek Watersheds. Prepared for Weyerhaeuser Canada Ltd., Okanagan Falls Unit.

Maynard, D.E., 2000. Terrain Classification, Terrain Stability, Surface Erosion Potential, and Sediment Delivery Potential of Sproat Lake Community Watershed. Prepared for Weyerhseuser, BC Coastal Group – Nanaimo Woodlands.

Maynard, D.E., 2001. Terrain Classification, Terrain Stability, Surface Erosion Potential, and Sediment Delivery Potential of Mission-Kelowna and Trout-Peachland Community Watersheds. Prepared for Riverside Forest Products Limited, Kelowna Operating Area, Kelowna, BC.

Monger, J.W.H., 1989. Geology, Hope, BC. (92H) Geological Survey of Canada Map 41-1989, scale 1:250,000.

Nasmith, H., 1962. Late glacial history and surficial deposits of the Okanagan Valley, British Columbia. BC Dept. of Mines and Petrol. Resources Bulletin, No. 46.

Pack, R.T., 1994. Inventory of landslide occurrences in the Kamloops Forest Region; Report prepared for BC Ministry of Forests, Kamloops Forest Region by Terratech Consulting Ltd., File 211-0.

Pack, R.T., 1995. Statistically-based terrain stability mapping methodology for the Kamloops Forest Region, BC; In: Proceedings of the 48th Canadian Geotechnical Conference, Canadian Geotechnical Society, Vancouver, BC, pp 617-624.

Resources Inventory Committee, 1996. Guidelines and Standards for Terrain Mapping in British Columbia. Government of BC, Victoria, BC.

Resources Inventory Committee, 1998. Standards for Digital Terrain Data Capture in British Columbia; Terrain Technical Standard and Database Manual, Version 1, June/98, Government of BC, Victoria, BC.

Roddick, J.A., J.E. Muller, and A.V. Okulitch (compilers), 1976. Geology-Fraser River (NTS Sheet 92), Scale 1:1,000,000. Geological Survey of Canada Map 1386A., Ottawa, Ont.

Rollerson, T.P., 1986. Hatchery Creek - Terrain Inventory. Prepared for Skeena Cellulose Inc. and BC Ministry of Forests and Lands.

Rollerson, T.P., D.E. Howes and M. Sondheim, 1986. An approach to predicting post-logging slope stability in coastal British Columbia. Presented at NCASI Coast Regional Meeting, Portland, Oregon, May 1986.

Rollerson, T.P., B. Thomson, and T.H. Millard, 1997. Identification of Coastal British Columbia Terrain Susceptible to Debris Flows. Manuscript for the first international conference, Debris-Flow Hazards Mitigation: Mechanics, Prediction, and Assessment. American Society of Civil Engineers, August 7-9, 1997. San Francisco, California.

Rollerson, T.P., T. Millard, C.Jones, K. Trainor, and B. Thomson, 2001. Predicting Post-Logging Landslide Activity Using Terrain Attributes: Coast Mountains, British Columbia. Forest Research Technical Report TR-011, Geomorphology. Vancouver Forest Region, Nanaimo, BC.

7.1 List of Terrain Stability Field Assessment Reports

Prepared by: Grainger and Associates Consulting Ltd.
Prepared for: Weyerhaeuser Company Ltd., Kamloops Operating Unit.

Watershed	Date	Site
Watching	August, 1999	C.P. 619, Blocks 5, 9, and 15: Road 2120.00
Watching	September,1999	C.P. 612, Block 4
Watching	October, 1999	C.P. 999, Block 9921
Watching-Cannell	November, 1999	C.P. 637, Blocks 1, 2, 3 and C.P. 999 Blocks 9915, 9916, 9917 Roads 1104.00, 1104.10, 1104.11, 1101.00
Tranquille	February, 2000	Tranquille Lake Road
Watching	June, 2000	C.P. 999, Block 9926A
Watching-Cannell	December, 2000	C.P. 641, Block 1; C.P. 642, Blocks 2 and 3; C.P. 999, Block 0012
Watching	July, 2001	C.P. 642, Block 6 and Road 2111.03 C.P. 999, Block 21
Tranquille	July, 2001	C.P. 643, Blocks 1 and 4 and Road 1118.00

8.0 ACKNOWLEDGEMENTS

This project was funded in its entirety by Forest Renewal BC under the contract identification KAM-RI-TSM-01-01. Administrative and technical details of the project were ably handled by Glenn Thiem of Forsite Forest Management Consultants Ltd. on behalf of Weyerhaeuser Company Limited. Brian Nowicki, R.P.F of Weyerhaeuser-Kamloops contributed important technical data in support of the project; Ryan Strank of the same office provided valuable mapping and digital data information. Tim Giles, P. Geo., Regional Geomorphologist for Kamloops Forest Region was involved throughout the duration of the project, providing administrative and technical advice and doing some field and office correlation.

Quality Assurance of the project was done by Terry Rollerson, P. Geo of Golder Assoicates Ltd.

Thanks to Tedd Robertson, G.I.T. for assisting in the field mapping.

The digital map production was done by Chartwell Consultants Ltd. of North Vancouver, BC under the very capable direction of Cherie Stutz.

APPENDIX I

TERRAIN STABILITY CLASSIFICATION AND CRITERIA

APPENDIX I

TERRAIN STABILITY CLASSIFICATION

Terrain units are qualitatively assessed according to their estimated stability following conventional logging. This type of classification indicates the expected response of the landscape to clearcut forest harvesting and road development. The rankings provide a relative assessment of mass movement potential, but give no indication of expected landslide frequency, magnitude, or impact. Terrain factors which are considered important in assessing this estimated stability are surficial material type and texture, slope gradient and morphology, soil drainage, geomorphic processes, landscape position, and bedrock properties. Based on the relative importance of each of these factors, individual terrain units are assigned to an appropriate stability class. Following is a description of expected stability and logging implications for each stability class:

Stability Class I

- No significant problems of instability expected.

Stability Class II

- Very low likelihood for forestry-induced instability; low probability of minor inclusions of sensitive terrain.
- Minor road-cut slumps and bank sloughing may occur leading to periodic maintenance of ditches.

Stability Class III

- Low likelihood for forestry-induced instability; minor inclusions of sensitive terrain are possible but no natural slope failures occur; field inspection by a terrain-stability specialist is usually not required.
- Minor stability and erosion problems should be expected, particularly with road construction on regular slopes greater than 50% and on wet or gullied slopes with gradients as low as 35%; regular road maintenance and inspection and repair of ditches and culverts recommended.

- Road planning may require an engineering review in potentially sensitive areas and provision for seasonal and/or semi-permanent deactivation when road-use is suspended or not regularly required.

- Clearcutting should not significantly reduce terrain stability; there is a low likelihood of post-logging failure, although small debris slides and slumps may be expected on wet or gullied slopes.

Stability Class IV

- Problems of instability are expected; marginally stable steep slopes and sensitive terrain. Natural landslides are rare but terrain conditions are either similar to nearby unstable slopes or show evidence of small-scale instability and/or excessive steepness.

- Moderate to high likelihood for road-associated landslides. On-site geotechnical evaluation is required. Avoid locating roads but, where they are necessary, special construction techniques and on-site supervision may be required. Critical terrain includes uniform slopes in excess of 65%, excessively wet slopes, and deeply-incised gullies. Regular road maintenance and inspection and repair of ditches and culverts required, particularly during all wet periods. When road use is discontinued a deactivation plan should be implemented.

- The potential for significant landsliding following clearcutting ranges from moderately low to moderately high. Sensitive terrain includes seepage and disturbed slopes, steep colluvial slopes, moderately steep till slopes and high gully and creek banks. Detailed geotechnical evaluation may recommend deferring logging from highly sensitive areas or use of alternative harvesting systems.

- A terrain stability field assessment is usually required to be made by a registered professional qualified to assess terrain stability prior to any development.

Stability Class V

- Significant problems of instability are expected; active or recurrent landslides initiate within mostly steep terrain. Also included are very sensitive terrain types such as steep-sided gullies, very wet slopes, and fine-textured sediments where small-scale mass movement and/or surface disturbance is significant.

- High likelihood for continued or accelerated mass movement in parts of the unit during and following road construction and following conventional clearcutting. Logging activity (road building and clearcutting) should normally be precluded from this unit, but any planned development must be preceded by a terrain stability field assessment by a registered professional qualified to assess terrain stability.

- On-site geotechnical evaluation may determine that locating specially constructed roads or careful logging of selective sites is feasible in some areas. Any such activity requires thorough planning, engineering, and supervising at all stages of operation through to complete deactivation and site rehabilitation.

TERRAIN STABILITY CLASS CRITERIA

Criteria for determining the various terrain stability classes have been developed from experience and research in numerous studies of predicting post-logging stability potential. Relevant published works include Howes (1987), Pack (1994 and 1995), Rollerson et al (1986), Rollerson et al (1997), and Rollerson et al, 2001. The writer has extensive experience in carrying out terrain stability studies in mountainous areas of British Columbia; particularly relevant are criteria used in areas of similar physiography and geology and for other Community Watersheds (Maynard, 1996, 1997, 1999, 2000, and 2001).

Following are the main terrain types and criteria assigned to each stability class:

Stability Class I

- Valley-lowland and plateau depressional floodplains, wetlands, and organics.
- Glaciofluvial, fluvial, and colluvial fans and terrace surfaces - well-drained slopes less than 25%.
- Other gentle-slope and enclosed depressional units less than 25% regardless of drainage; if fine textured sediments (silt-clay) are dominant then slope should be less than 10%.

Stability Class II

- Well drained morainal, fluvial, and glaciofluvial slopes mainly between 20-45%.
- Fine-textured glaciolacustrine-lacustrine surfaces with slope mainly 10-30%; restricted drainage.
- Uniform, well-drained colluvial slopes less than 50%; irregular slopes may contain localized steeper segments where small bedrock outcrops occur.
- Morainal-colluvial complexes with minor bedrock outcrops; well to moderately well drained with isolated rock-controlled slope segments up to 55%.
- Wet toe slopes or mid-slope seepage sites, usually moraine or finer-textured colluvial surface, with gradients mainly less than 40%.
- Irregular, hummocky to subdued surfaces, gradients mainly less than 50%, of old rockslide debris; textures variable but dominantly blocky.
- Benched or plateau areas with thin moraine, weathered rock, and small organics mantling bedrock; slopes range from 5-50% with variable drainage.
- Upper-elevation rock-controlled ridge crests; thin colluvium and weathered rock on well to rapidly drained 10-60% slopes.
- Any subdued or gently sloping areas located immediately above steeper slopes.

Stability Class III

- Well-drained morainal, fluvial, and glaciofluvial slopes mainly between 40-70%.
- Gullied or seepage-susceptible morainal slopes mainly between 30-60%; slightly steeper gradients are tolerable where gullies are inactive or drainage is better.
- Well-drained, relatively uniform glaciolacustrine deposits with no slopes exceeding 50% and dominantly below 40%.
- Well-drained morainal-colluvial complexes with minor bedrock on irregular slopes of 40-75%.
- Colluvial mantles on uniform, well-drained slopes between 45-70%; minor gullying and seepage may occur.
- Irregular slopes with near-surface bedrock; dominantly colluvium with lesser till veneers; slopes may range from 40-75% and drainage is well to rapid; small

bedrock gullies and cliffed outcrops may occur. Steep sites are isolated within hummocky to moderate gradients.

- Confined streams and gullies where bank sideslopes are less than about 7 m high and 65% gradient and channel gradient is low to moderate; usually incised into till, or gravel, often through to bedrock.
- Irregular, moderate to moderately steep slopes (40-70%) of blocky rockslide debris showing no evidence of recent movement.

Stability Class IV

- Well-drained morainal slopes ranging from 65-80%; little evidence of small-scale instability, but may contain inactive gullies. Wet till slopes and gully banks with gradients less than 65% are included, particularly where slow or small-scale movement indicators are suspected.
- Glaciofluvial and fluvial scarps in excess of 65-70%; well to rapidly drained; Where intensely gullied or interlayered with finer sediments gradients may be as low as 55%.
- All bedrock-controlled slopes, well to rapidly drained, in excess of 70-75% where there is no evidence of recent instability; small gullies incised in bedrock may occur along with isolated seepage sites or small-scale disturbances. Evidence of old landsliding may occur provided that most of the unit appears stable. Surficial material is mainly colluvium with minor, well-drained morainal veneers.
- Very steep, long bedrock slopes; 80-130% are common gradients; coarse colluvial veneers are subordinate components; occasional rockfall may occur.
- Deeply-incised, steep-sided, bedrock-controlled creek gullies and canyons with no active or recurrent mass movement; minor seepage, creep, and small sloughs may occur in isolated sites in colluvial veneers; channel gradients are low to high.
- Gully banks and creek scarps greater than 7-10 m in height with slopes exceeding 65%; eroded into surficial deposits, often through to bedrock. Minor seepage and surface sloughing but no significant evidence of active mass movement.
- Fine-textured glaciolacustrine deposits with some gullying but no significant evidence of instability; slopes are mainly 30-65% with seepage concentrated in channels.
- Erosional scraps or depositional accumulations of coarse-textured, well-drained colluvium with 65-90% slopes common. Thick deposits usually accumulate below sites of relict to recurrent bedrock instability and at the mouths of historically active gullies.

Stability Class V

- High scarps, often gullied, of thick glacial till or complex stratigraphy (till-gravel-fines) with recurrent failures or evidence of significant slow movement; slopes usually exceed 60% but may be terraced; in places, gravels and/or fine sediments may overlie or underlie the till.

- Erosional till gullies and till scarps with evidence of small-scale or slow instability on sideslopes; seepage sites are common; usually occurs where gradients approach 60%+.

- Gullied and slump-deformed deposits of fine-textured glaciolacustrine sediment; higher and steeper (greater than 60%) sidewalls often have active failures but lower gradients may only show evidence of slow, on-going movement.

- Bedrock canyons which experience rockfall, rock crumbling and colluvial sloughing.

- Incised, steep-sided bedrock gully headwalls where there is widespread evidence of small-scale instability on the sideslopes or headwalls creating a high potential for gully instability.

- Deep, steep-sided creek gullies and canyons eroded through surficial materials into fractured or weathered bedrock; evidence of instability may include crumbling bedrock, colluvial sloughing, and slump-flows of unconsolidated deposits which are undermined at the bank crest.

- Actively eroding or failing scarps of granular fan-terrace deposits or of oversteepened faces of coarse-textured, toe-slope colluvial deposits; usually undermined by lateral creek erosion.

- Actively ravelling colluvial veneers on steep bedrock ridge faces and valley slopes. Gradients are uniform and exceed 70%; considerable evidence of surface sloughing, rapid creep, and colluvial ravel.

- Bedrock cliffs which experience rockfall, rock crumbling, and ravelling of subordinate colluvium and/or display features such as tension cracks and detached blocks which indicate a high instability potential.

APPENDIX II

SURFACE EROSION POTENTIAL CLASSES AND CRITERIA

APPENDIX II

RATING SURFACE EROSION POTENTIAL

This rating is a highly qualitative, relative assessment of the potential for generating sediment by overland water flow during and after logging development and presumes that mineral soil is exposed. Usually surface erosion is not a major concern in undisturbed clearcut areas, except for roads and bladed trails, recent landslide and gully scour and deposition, sensitive landforms, and sites with extensive surface disturbance. Terrain units have been subjectively assessed according to their estimated erodibility in a manner similar to that done for determining terrain stability. Many of the same terrain factors (surficial material type and texture, slope gradient and morphology, soil drainage, geomorphic processes, landscape position, and thickness of deposit), albeit with different weightings, are considered when determining both erodibility and stability potential.

The surface erosion ratings are not necessarily intended to restrict logging; rather, they should be used to "red-flag" potential problem areas so that appropriate preventive or remedial action can be planned.

No definitive studies have been carried out on establishing mapping criteria for logging-related surface erosion. Previous terrain stability assessments in community watersheds (Maynard, 1996, 1997, 2000, and 2001) have included subjective interpretations for erosion potential of surface materials. The following assumptions form the basis of rating surface erosion potential (Rollerson, 1986); these presume that mapping attributes are generalized from the available site-specific data:

- fine-textured sediments (clay to fine sand) will have a higher potential for sediment generation than medium-textured materials. Coarse-textured, rubbly materials will have a relatively low potential for sediment production; most types of bedrock are not erodible.
- as slopes steepen, a higher energy erosional environment exists.

- gullied deposits have undergone erosion in the past and, thus, are considered more susceptible to future erosion, surface flows tend to be more concentrated.

- on steeper slopes more surface area is exposed during road construction than on gentle slopes.

- thicker deposits have a higher potential for total sediment yield.

- surficial-mantled slopes with a high likelihood for post-logging failure are ranked higher than areas of lower stability class; more sediment is available for erosion if sites are excessively disturbed or exposed by landsliding.

- landscape position and slope drainage will influence erosion potential; surface erosion is more probable on lower slopes receiving seepage than on similar terrain at an upper-slope shedding position.

SURFACE EROSION POTENTIAL CLASSES		
DESCRIPTION		FOREST MANAGEMENT IMPLICATIONS
VL	Very Low Potential No problems with erosion expected	Minor bank and channel erosion could be caused by disturbance of streams
L	Low Potential No significant problems with erosion expected	Minor erosion of fines from ditch lines and disturbed soils may occur; water should not be channelized onto sensitive sites
M	Moderate Potential Some problems with erosion expected	Water management is very important; erosion of ditches and across disturbed sites is expected. Plan preventive remedial actions for disturbed areas; road deactivation should be done in sensitive areas.
H	High Potential Significant problems with erosion expected	Major problems can be expected where water is channelled onto sensitive sites. Mitigative planning must be thorough to permit road development; disturbed sites should be immediately revegetated and all surface water controlled. Site inspection by a qualified terrain or soils specialist is recommended.
VH	Very High Potential Severe problems with erosion expected.	Severe surface and gully erosion problems exist which may preclude some logging development. Site inspection by a qualified terrain or soils specialist is recommended.

GENERALIZED CRITERIA FOR SURFACE EROSION POTENTIAL CLASSES

Very Low

- flat or gently sloping terrain.
- depressional wetlands - organics, coarser fluvial infillings on till-slopes less than 10%.
- blocky to bouldery textures - terrace or colluvial surfaces up to 27%.
- bedrock surfaces - no surficial cover on all slopes or minor components of blocky debris even on steeper gradients.

Low

- gentle slopes and steeper but short slope segments; mainly well drained.
- organic mantles on slopes of 10 - 27%.
- finer textures - clay to fine sand - on slope less than 10% which are not excessively wet.
- well-drained till mantles; slopes less than 27%. May be steeper (up to 40%) where deposits are thin or discontinuous, topography is irregular, or coarser textures (high clast content) predominate.
- Gravels with sand matrix - loose and well drained - on slopes mainly less than 27%.
- coarse colluvium - rubble to blocks - on well drained slopes up to 70% or steeper where deposits are thin, matrix component is minor, or a high proportion of rock outcrops occur. Where a high proportion of silt-sand matrix exists and/or bedrock is soft and friable, slopes should be less than 50% and deposits thin.

Moderate

- moderately steep slopes and long slopes; finer-textured, erodible soils on gentler gradients.
- finer textures - clay to fine sand - slopes mainly less than 27% but may be less than 10% on wet sites.

- well drained till mantles; slopes 27-50%; may be slightly steeper (short segments to 60%) where irregularly broken and where deposits are thin or discontinuous; wet or gullied till slopes should be less than 40% and may be as low as 10-15%.

- sands and gravels - loose and well drained on slopes up to 70% but only to 50% if significant inclusions of fines occur.

- thicker mantles of coarser-matrix colluvium on steep slopes, often in excess of 70%, and finer-matrix colluvium and/or soft, friable, easily weathered bedrock on slopes mainly 50-70%. Gullied colluvium or colluvium overlying till should also be on slopes less than 70%.

High

- moderately steep slopes and highly erodible soil textures or steep slopes with coarser materials.

- finer textures - clay to fine sand - slopes mainly 27-40% but may be less than 27% if wet.

- well-drained till mantles on slopes mainly in excess of 50%; wet or gullied till slopes may be as low as 30%. Also include lower slope angles where seasonal active creep-slumps-flows (i.e. related to spring thaw) is identified.

- sands and gravels - loose and well drained - on uniform slopes averaging close to 70% or as low as 50% if gullied or if there is a significant inclusion of fine-textured materials.

- finer-matrix colluvium and/or weathered bedrock on steep slopes where there is or has been extensive surface disturbance - landsliding, bedrock crumbling and bank ravelling, bank undercutting.

Very High

- steep slopes and erodible soil textures; evidence of active gully and/or surface erosion.

- finer textures - clay to fine sand - slopes in excess of 40%, particularly where gullied.

- moderately steep to steep till slopes which are usually gullied and show evidence of surface creep and slumping; high instability potential.

- high scarps of complex stratigraphy and/or thick till gullied and subject to seepage; unstable.

APPENDIX III

SEDIMENT DELIVERY POTENTIAL ASSESSMENTS

APPENDIX III

SEDIMENT DELIVERY POTENTIAL

The ratings for sediment delivery potential are highly qualitative assessments of the likelihood of landslide debris and eroded sediment originating in a terrain polygon to enter a downslope stream system. Landslide-induced sedimentation concerns the potential for direct deposition of landslide debris into a significant stream or lake. Sedimentation potential from surface-erosion sources concerns the ability of fine sediment to transport by surface runoff into the perennial drainage network. These assessments are done as 3-class rating system as follows:

POTENTIAL FOR LANDSLIDE-INDUCED STREAM SEDIMENTATION

RATINGS	DESCRIPTION
1	• Low likelihood that a landslide originating in the terrain polygon will enter a significant stream or lake. • Post-event erosion from a landslide will cause little or no surface water sedimentation
2	• Moderate likelihood that a landslide originating in the terrain polygon will enter a significant stream or lake. • Post-event erosion from a landslide will cause some additional surface water sedimentation.
3	• High likelihood that a landslide originating in the terrain polygon will enter a significant stream or lake. • Post-event erosion from a landslide will cause additional surface water sedimentation.

POTENTIAL FOR SEDIMENT DELIVERY FROM SURFACE EROSION SOURCES

RATINGS	DESCRIPTION
l	• Very low to low likelihood that any eroded sediment originating in the terrain polygon will reach a permanent stream or lake.
m	• Moderate likelihood that any eroded sediment originating in the terrain polygon will reach a permanent stream or lake.
h	• High to very high likelihood that eroded sediment originating in the terrain polygon will reach a permanent stream or lake.

GUIDELINES FOR ASSESSING SEDIMENT DELIVERY POTENTIAL

The assessments are essentially a subjective examination of the proximity and linkage between a terrain polygon and a potential receiving water body. Factors considered in these assessments include slope angle and shape, the presence or absence of landslide runout or depositional zone, the length of any runout zone, and the presence of small channels (ephemeral and perennial) and gullies which may provide direct water-flow-linkage between the polygon and water body.

No absolute criteria were established for these assessments because some important variables, such as wetness and fluidity of landslide debris and runoff conditions at the time of an event, may be very difficult to predict and yet such characteristics may, in some cases, be the significant factors affecting potential transport capability. Following are some subjective guidelines that were used during field and aerial photo examination to help assess sediment delivery potential. Much of this has been modified from example classifications proposed by Howes (1987), Fannin and Rollerson (1993), and Forest Practices Code of BC (1999).

SEDIMENT DELIVERY POTENTIAL	LANDSLIDE-INDUCED DELIVERY	DELIVERY FROM SURFACE EROSION SOURCES
Low	• No evidence of previous landslides entering the stream (includes all cl. I and II) • Runout slope below the polygon is gentle (less than 30-35%) and long (greater than about 150 m ±) • There are no gully channels connecting the polygon to the stream	• No perennial streams exist within or alongside the polygon • Ephemeral channels may drain the polygon on gentle slopes; distance to any perennial channel will vary depending on intervening slope gradient and morphology
Moderate	• Limited evidence of previous landslides entering the stream • Runout slope below the polygon is at least a moderate, uniform gradient (greater than 30-35%) and intermediate length (between about 50-150 m ±) or may be longer if gullied • Runout slope below the polygon is gentle and short (about 20-50 m ±)	• Ephemeral channels drain moderate to steep polygon slopes; distance to any perennial channel will vary depending on intervening slope gradient and morphology. • Perennial stream exists within or alongside gentle-gradient; no ephemeral tributary drainage.
High	• Obvious evidence of previous landslides entering the stream • Runout slope below the polygon is at least a moderate, uniform gradient and short (less than about 50 m ± or any gentle runout slope is less than about 20 m length. • Polygon is directly connected to a stream by gully channel(s) of at least moderate gradient.	• Moderate to steep slopes directly border a perennial channel with no intervening gentle gradients of substantial length. • Tributary ephemeral drainage connects to a perennial stream within about 100 – 150 m ± depending on intervening slope gradient and morphology.

APPENDIX IV

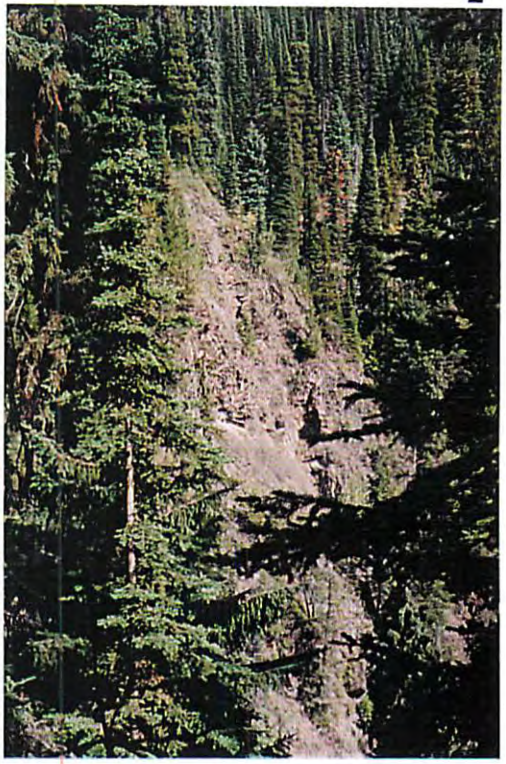
PHOTOGRAPHS

APPENDIX IV
PHOTOGRAPHS

Photo 1	Westerly view across mid Tranquille Valley.
Photo 2	High bedrock cliffs dominate sections of the canyon walls bordering Peterson Creek; View of site DM 256.
Photo 3	Hummocky to steep bedrock exposures have only thin, partial cover of colluvial rubble along the upper valley wall bordering the northern side of Tranquille Valley (site DM 132).
Photo 4	The bedrock-dominated northern valley wall bordering mid Tranquille River. The steep, rocky slopes with subordinate colluvium are rated stability class IV with the moderate to moderately steep colluvial toe-slopes mainly class III.
Photo 5	West of mid Watching Creek (site DM 42) this prominent plateau-lava cliff features a relict landslide. An apparent slump block of intact rock can be seen surrounded by talus; movement was probably in association with the loss of buttressing support during deglaciation. The steep rock-colluvial face is mapped as stability class IV.
Photo 6	Typical cliff-face exposure of plateau lava, bordered on top by subdued rocky terrain (usually class II) and at the toe slope by gentle to moderate-gradient surficial deposits (may be class I, II, or III). These cliffs are rated class IV because of steepness; this is site DM 211 along the south side of Porcupine Ridge.

1

2



3

4

6

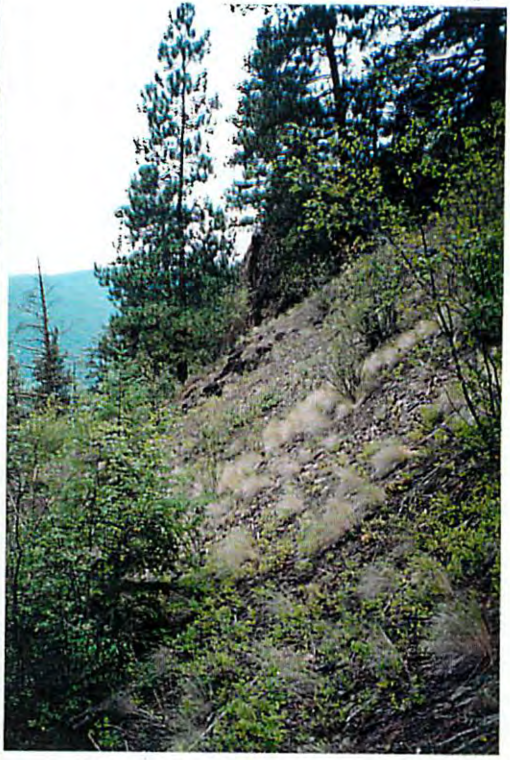
5

Photo 7	Horizontal view of a typical plateau-lava cliff line. Although this is a different location than in photo 6 (site TR 29), the terrain is similar with a subdued class II upland, a class IV steep cliff, and till-mantled class II-III toe-slopes.
Photo 8	High volcanic cliffs are exposed in the main tributary-gully headwalls along the southern side of mid Tranquille Valley (site DM 115). Some isolated rockfall occurs from these faces which are rated as stability class IV.
Photo 9	Finer colluvial rubble, subject to minor active ravelling, accumulates on steep slopes dominated by bedrock cliffs and ledges; site (DM 175) is along the upper slopes on the northern side of Tranquille Valley. This terrain type is stability class IV.
Photo 10	Moderate to moderately-steep gradient segments of Tranquille Valley sideslopes are common; mostly thin colluvium with minor bedrock ledges (site DM 122 on the southern side of the valley). This is typical class III terrain which was often included in class IV by the original mapping.
Photo 11	Coarse colluvial rubble and blocks are often found directly below higher cliffs. Minor rockfall may occur but the steep faces are considered to be class IV (site DM 249 near Peterson Creek). Uniform colluvial slopes at less than 70% gradient are stability class III.
Photo 12	Large blocks of volcanic rock have broken from the adjacent cliff creating a band of open talus. Much of this weathering was probably early deglacial and is not considered an active process.

7

8

9



10

11

12

Photo 13	Active creep on thick, sandy rubbly colluvium (site DM 147); slope gradient at site is only 45% and the amount of bare soil may be the result of high-use winter range on the south-westerly aspect, valley wall above Tranquille River.
Photo 14	Exposure of typical basal till (site DM 207) seen in a Tranquille Valley road-cut.
Photo 15	Headwall of a failure along Watching Creek scarp (site DM 39) exposes about 5 m of till (gray material in background) overlying weathered bedrock (brownish foreground); stability class V and high erosion potential.
Photo 16	Small landslides occur on both scarps of a gully tributary to Tranquille River (sites DM 204-206). The foreground bank is till at the crest overlying near-vertical bedrock down to the creek; the south bank (background) is all thick till. Gully walls are stability class V and highly erodible.
Photo 17	Prominent landslide headwall in thick till along the scarp bordering upper Tranquille River (site DM 228); stability class V and very high erosion potential occur in this area.
Photo 18	Thick sequence of gravels and sand in a high glaciofluvial terrace scarp bordering Tranquille River (Site TR71) is actively destabilized by seasonal undercutting during high flows.

13

14

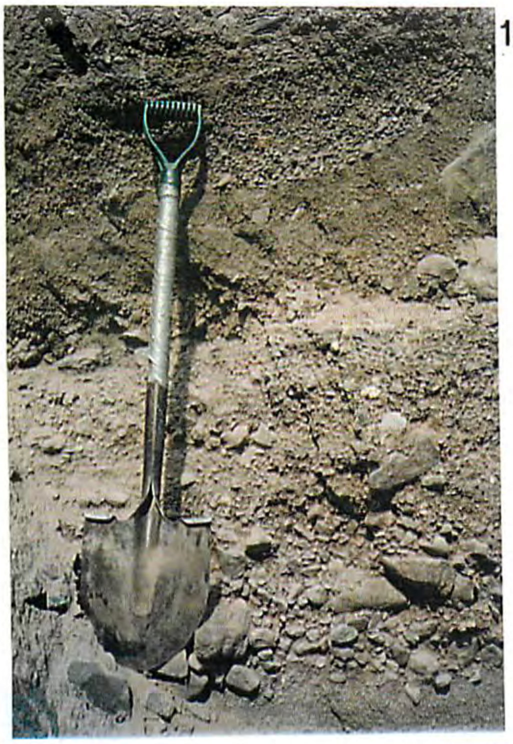
16

15

17

18

Photo 19	Sorted pebbles and sands occurring in the scarp seen in photo 18.
Photo 20	Small debris slide in a dry, but steep scarp segment of glaciofluvial gravels bordering mid Watching Creek (site TR 23); stability class V.
Photo 21	Small slump-flows initiate on steep, fine-textured till scarp bordering upper Watching Creek (site DM 32); stability class V.
Photo 22	Old slump scar on a low till scarp south of Tranquille Lake (site DM 76). Failure may have followed wildfire disturbance as slope gradients are not extreme nor is the site excessively wet; a small polygon is given a stability class IV rating.
Photo 23	High confining bank of Watching Creek (site DM 35, upstream from photo 21) is failing where being actively undercut. Ravelling colluvium and crumbling bedrock are undermining till at the scarp crest; stability class V.



19

20

22

21

23

Figure 1b.

Peterson-Rosen Community Watersheds

Scale approx 1:125,000

Previous Terrain Mapping	━━
PAS Boundary	-------
TFL 35 Boundary	▪▪▪▪▪
Area remapped by Denny Maynard & Assoc. Ltd.	▨