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ECOLOGY & EARTH SCIENCES

LEVEL 1 COASTAL WATERSHED ASSESSMENT PROCEDURE
Pemberton Creek Community Watershed
Ministry of Forests

for:

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EXECUTIVE SUMMARY

At the request of the Ministry of Forests, Squamish Forest District, Madrone Environmental Services Ltd. carried out a Level 1 Coastal Watershed Assessment Procedure (CWAP) for the Pemberton Creek Community Watershed (PCCW). The purpose of this CWAP is to:

1. Assess the cumulative effects of past forest development on the hydrology and aquatic resources.
2. Assess potential hydrological implications of proposed development.
3. Provide watershed recommendations based on the results of points 1 and 2.

This Level 1 assessment was an office- and field-based exercise that was used to assess the hydrological impact on the potential effects of changes to the four hazard indicators:

- Peak stream flow
- Surface erosion
- Landslide occurrences
- Riparian zones/channel morphology

The watershed was treated as one sub-basin for the purposes of this CWAP. Overall, past logging practices in the Pemberton Creek Community Watershed have had a LOW impact on the four hazard indicators, suggesting that forestry has had minimal impact on water quality and runoff volume. Current watershed condition results are summarized in Tables 6 and 7. Proposed development in the PCCW (2000-2004) is included in this CWAP. Forestry related activities will continue to have a LOW impact on water quality and quantity. Results for the Five-Year Development Plan are summarized in Tables 5 and 8. This LOW current and future impact of forestry related activities to the water quality and quantity in the PCCW are attributed to strict guidelines put forth in the PCCW Integrated Watershed Management Plan.

It is recommended that:

- Road R00542 be assessed for deactivation/maintenance where the sediment delivery hazard is MODERATE to HIGH. Deactivation should include adequate spacing and density of cross ditches in order not to overload ditches or natural watercourses.
- Proposed addition to Road R00542 be assessed for terrain stability hazards where it will cross potentially unstable (Class IV_R) terrain. Ensure proper water management along the road with the adequate spacing, density, and sizing of culverts. Drainage structures should be designed to handle peak flow conditions, and regular inspection for drainage structures should be carried out, especially after heavy flood events. Road construction across Class IV_R terrain should take place during the dry season.
- A sediment control plan be implemented for new roads.
- The next CWAP be completed in 2004 and should incorporate finalized results from recent terrain mapping and interpretations (erosion potential, risk of sediment delivery to streams and landslide delivery to streams).

LEVEL 1 COASTAL WATERSHED ASSESSMENT PROCEDURE
Pemberton Creek Community Watershed

INTRODUCTION

A watershed assessment is required before a forest development plan is prepared for a community watershed. In 1997, a Level 1 Coastal Watershed Assessment Procedure (CWAP) was executed in the Pemberton Creek Community Watershed (PCCW). This assessment concluded that there were likely no potential impacts to water quality and volume from past forest development, and recommended that the next CWAP be completed in the year 2000.

At the request of the Ministry of Forests, Squamish Forest District, Madrone Environmental Services Ltd. (Madrone) conducted a Level 1 CWAP in the PCCW. This CWAP was conducted in accordance with the *Coastal Watershed Assessment Procedure Guidebook (CWAP): Interior Watershed Assessment Procedure Guidebook (IWAP)* (Ministry of Forests, 1999).

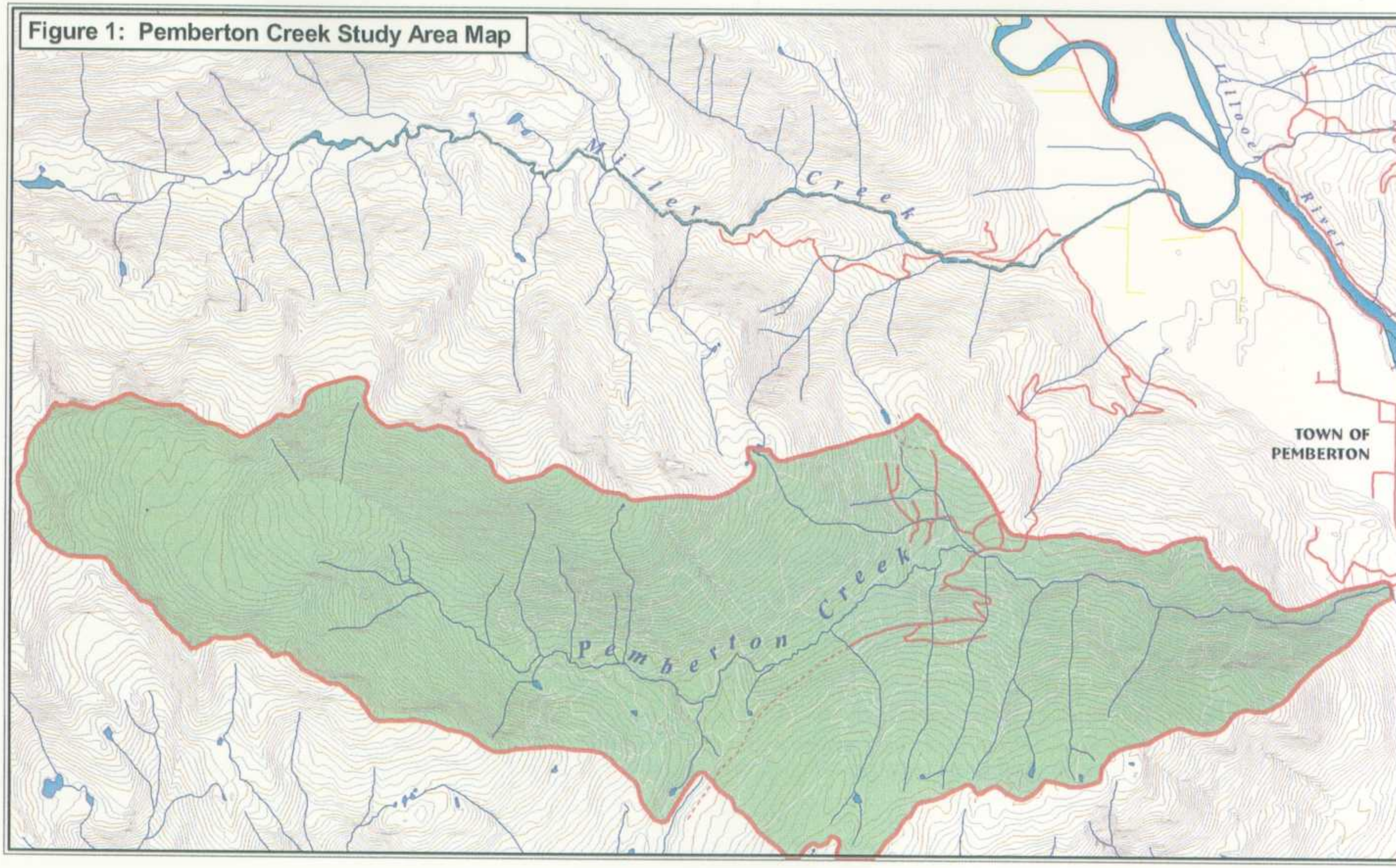
The purposes of this Level I assessment are:

1. To assess the cumulative effects of past forest practices on the hydrology and aquatic resources in the PCCW.
2. To assess the potential hydrological implications of proposed forestry related development in the PCCW.
3. Provide watershed-level recommendations for forest development plans based on points 1 and 2.

INTEGRATED WATERSHED MANAGEMENT PLAN (IWMP)

The IWMP (Ministry of Forests and Ministry of Environment, Lands and Parks, 1991) was created for the PCCW to provide guidelines for integrated resource development due to the demands on its water and timber. Government agencies and the local community expressed concerns over the potential impact of forest development on flooding and water quality. The plan allows for resource use in the watershed, while providing reasonable protection to the water supply. Specific resource development guidelines for the watershed have been developed based on terrain hazards and potential for stream impact. These guidelines require a high degree of planning and strict environmental procedures for sensitive terrain.

Figure 1: Pemberton Creek Study Area Map



REGIONAL SETTING

General Physiography

The PCCW is located immediately west of the town of Pemberton, approximately 30 km north of Whistler, in the Pacific Ranges of the Coast Mountains. The watershed is approximately 30 km^2 in area, with elevations ranging from 210 m to 2440 m.a.s.l. The watershed was treated as one sub-basin for the purposes of this report. The Ipsoot Glacier lies at the upper west end of the study area (Photo 1), with Ipsoot Peak located at the west boundary of the watershed. The Village of Pemberton is located on the Pemberton Creek fan.

Bedrock and Surficial Material

The bedrock within and surrounding the PCCW consists of Mesozoic and Tertiary-aged diorite, granite, and granodiorite of the Coast Plutonic Complex[1]. Bedrock outcrops are common at the upper end of the PCCW at higher elevations throughout the study area, and in the bed and banks of Pemberton Creek intermittently for its entire length. Where present at the surface, the outcrops are widely jointed and fractured. Colluvial cones, blankets, and veneers were observed below rock outcrops, consisting of angular, rubble to blocky sized fragments with less than 10% sandy matrix (Photos 3 and 4).

Much of the present appearance of the landscape surrounding Pemberton Creek is due to the glaciations during the Pleistocene Epoch of which the latest glaciation, the Fraser, has left the most extensive evidence. The headwaters of the basin have rugged to rounded bedrock peaks from which active rockfall is occurring. The middle and lower reaches intermittently flow through a shallow V-shaped gully that has been cut through bedrock since the last glaciation. The lowest reaches are more deeply incised in a bedrock-controlled gully. Erosional and depositional processes continue to shape the terrain within the watershed.

There are two types of till within the watershed. The first type is located at the upper end of the watershed and consists mainly of sub-rounded to angular rubble to block-sized fragments, with very little sandy matrix. This till was transported only a short distance from its source and represents the limit of the Little Ice Age (from 150-450 years ago). Distinct lateral moraines remain from the currently retreating Ipsoot Glacier (Photo 2). The till in middle and lower sections of the watershed shows more evidence of being reworked. The till here generally consists of approximately 40% sub-angular to rounded clasts in a silty, sandy matrix.

Fluvial deposits are also present in the watershed, mainly in the middle to upper sections, adjacent to Pemberton Creek. These deposits generally consist of approximately 70% to 80% rounded to subrounded clasts in a sandy matrix. Thin organic deposits overlie fluvial deposits in places at the upper end of the study area.

Active geomorphic processes within the PCCW consist of rockfall and rock sliding (Photos 3 and 4), debris slides in till and weathered bedrock, slow mass movement of till, avalanching,

[1] *British Columbia Geological Highway Map*, by British Columbia Ministry of Energy, Mines and Petroleum Resources, Victoria

debris torrenting, and gullying. However, the majority of the terrain within the PCCW is considered stable.

Fish Values

Pemberton Creek is designated S2 for its entire length within the study area (approximately 11 km); however, no fish have been found upstream of Reach 2, where slope gradients reach 63%. In community watersheds, streams are managed as fish bearing, regardless of whether fish have been found. A reserve zone is required on all streams except those designated S4. The lower reaches of Pemberton Creek, outside the study area, support coho salmon, coastal cutthroat trout, and whitefish (Fisheries and Oceans Canada, 2001). A run of Coho spawn every year in Pemberton Creek reaching just upstream of the railway bridge, which is located 400 m outside and to the east of the eastern study area boundary. During the summer months, when turbidity levels are high out of Pemberton Creek, fish are not seen in Pemberton Creek. They retreat to One Mile Lake and the creek draining One Mile Lake into Pemberton Creek. These two locations also support sockeye salmon and Dolly Varden char.

Climate

Although the PCCW falls in the rainshadow of the Coast Mountains, Pacific frontal systems bring a substantial amount of precipitation to the area. The closest meteorological station to the PCCW is in Pemberton Meadows (approximately 3 km NW of the PCCW, 223 m.a.s.l.). Pemberton Meadows receives 990.2 mm of precipitation per year with more than half falling between October and January. The mean basin elevation of the PCCW is approximately 1550 m; therefore, precipitation data from Pemberton Meadows is not representative of the true precipitation patterns of the PCCW. Based on trends seen elsewhere in B.C., it is likely that the annual precipitation is considerably greater in the PCCW than at Pemberton Meadows.

Hydrology

Because of mountainous topography combined with heavy snowfalls, the Pemberton Creek study area has a snowmelt and rain-on-snow dominated hydrologic regime. Water Survey Canada has gauged Pemberton Creek since 1987. The stream gauge is located downstream of the water intake and has not been corrected for stream withdrawals. Maximum creek flow normally occurs in May or June due to snowmelt. The average discharge for the months of May and June (1987 – present) are 3.37 m^3/sec and 3.47 m^3/sec, respectively. Even though precipitation is at its lowest in late summer, late summer 'low-flow' does not occur due to melting of the Ipsoot Glacier. Lowest flows occur from December to March (0.50 m^3/sec) when precipitation falls dominantly in the form of snow. The mean annual runoff is 1.66 m^3/sec.

Peak instantaneous flow, however, has occurred in some years during September to November because of heavy rain or rain-on-snow events. The small creeks in the watershed are responsive to these events. These short-term flood flows are significant in entraining sediment. The first large flows in the fall pick up and flush out much of the sediment stored in tributary creeks and gullies during the summer. Thus, sediment load probably reaches a peak during these September, October, or November rainstorms but tends to decline gradually with each subsequent storm over the winter as the sediment supply dwindles.

Land and Creek Use

Most of the PCCW remains undeveloped. Forestry is the primary land use at this time, with an allowed annual cut of 2500 m^3/yr, averaged over a five-year period. Harvesting has removed approximately 86 ha of timber in the PCCW, with another 44 ha planned for harvesting in the 2000-2004 development plan. Only blocks belonging to Talbot Logging are shown on the current development plan map; however, Category I blocks belonging to Western Forest Products and Weyerhaeuser located inside the PCCW have been included in this CWAP. Approximately 7.9 km of road has been built, with another 2.5 km planned for construction. The PCCW has relatively low recreation value at this time because of limited access. A heli-skiing operation based out of Whistler utilizes Ipsoot glacier at the Pemberton Creek headwaters.

Pemberton Creek serves as a backup water supply for the Village of Pemberton (1700 people) and residents of the Pemberton North area (200-300 people). The water intake is located 1060 m up from the east end of the study area on the mainstem channel. Pemberton Creek became the back-up water supply system in 1998-99 when Pemberton switched to a groundwater source for its primary water supply. Since then, Pemberton Creek has been used occasionally as a back-up water supply.

Water Quality

The Village of Pemberton occasionally measures water quality of the Pemberton groundwater system. Well Site 1 and Well Site 2 give information about the water coming out of Pemberton Creek (PSC Analytical Services, 2001). Both well sites plus four other sites were sampled in July 2001 for various parameters, including turbidity and total and fecal coliforms. Turbidity associated with melting of the Ipsoot Glacier is an ongoing water quality concern, especially in the summer months with a higher melt-out rate of fine sediments trapped in the glacier. Results from Well 1 indicate that water coming out of Pemberton Creek has a higher turbidity level than the remaining sampling stations. Well 1 indicates turbidity levels of 1.41 NTU while the remaining stations have a turbidity level of less than 0.21 NTU. An NTU of less than 2 is considered good, however the goal is an NTU of less than 1 for drinking water (British Columbia Approved Water Quality Guidelines [Criteria], 1998). Total and fecal coliforms are absent in both wells.

The water system does not use chlorination, as the water quality is generally good and the presence of chlorine is not desirable from a fisheries perspective.

EFFECTS OF LOGGING/DEVELOPMENT ON WATERSHEDS

The assessment of hydrological impacts in a Level I CWAP focuses on the potential for:

1. Changes to *peak stream flows.*
2. Accelerated *surface soil erosion.*
3. Accelerated *landslide activity.*
4. Change to *riparian zones and channel morphology.*

The following section describes the potential effects of changes to these four hazard indicators resulting from forestry and forestry-related activities:

Change to Peak Stream Flow

Peak flow is the maximum flow rate that occurs within a specified period, usually on an annual or event basis. Tree removal and road building by forestry can affect peak flow timing and volumes. By removing trees, not only is more precipitation able to reach the ground and infiltrate the soil, but the timing of the delivery may be altered. Generally, melting of the snowpack in spring and, to a lesser extent, heavy rainstorms or rain-on-snow events generate peak flows. Harvesting the forest reduces interception and increases the winter snowpack in openings up to 5H (H = tree height). This results in an increased rate of snowmelt in the spring.

The construction of logging roads can affect the pathway and the timing in which precipitation reaches the stream channel. Subsurface flow may be intercepted and directed down ditchlines as surface flow, reaching stream channels at an accelerated rate. Compacted surfaces of roads reduce infiltration, transferring surface flow to ditches, which also means that surface water reaches stream channels at an accelerated rate.

Accelerated Surface Soil Erosion

Surface soil erosion is defined as the detachment, entrainment, and transport of individual sediment particles due to falling or running water, or wind. It is a function of surface cover, mineral soil type, slope gradient, slope length and shape, and rainfall intensity.

The principal effect of forest practices on surface soil erosion results from road building in a watershed. Sediment generated from ditches, cut-and-fill slopes, and road surfaces is introduced to stream channels through ditches and at stream crossings. The greater the frequency of stream crossings, the higher the potential for sediment delivery to streams. This sediment can clog drainage ditches and stream channels, accelerate stream bank erosion, deposit fine sediments in reservoirs, cover fish spawning grounds, and reduce downstream water quality. Harvesting can also cause accelerated surface soil erosion due to exposing of soils with the removal of vegetation. However, roads are a far greater source of sediment than conventional harvesting done to current FPC standards.

Landslide Activity

Landslides are a natural process in the watershed and occur over time at a natural rate. Forest practices can accelerate this natural rate of landsliding by road construction and logging on unstable or potentially unstable terrain. The alteration of natural drainage patterns through road building can lead to large amounts of water concentrating on hillslopes, road fillslopes, and road beds, leading to a higher likelihood of landsliding.

Harvesting also alters slope hydrology. Removal of forest cover results in a reduction of transpiration and interception losses, leading to increased soil saturation, subsurface flow, and surface runoff. In addition, when trees are harvested, the roots of the stumps decay and begin to lose their strength so the soil loses its vertical and horizontal cohesion. The harvesting method can also lead to slope instability. Log yarding can disrupt natural pathways for water drainage, creating new pathways. Dragging logs across slopes and using heavy machinery can damage the soil surface and the roots that help hold the soil.

Change to Riparian Zone and Channel Morphology

The riparian area, or land adjacent to the high water line in water courses and standing bodies of water, has significant importance to stream ecosystems. Riparian areas help maintain water quality through controlling sedimentation and nutrient inputs. Excessive harvesting of riparian areas can destabilize stream banks, increase bank erosion and stream sedimentation, diminish supply of woody debris, and increase the size of sediment wedges of some stream reaches. Even if riparian vegetation is not removed, the riparian zone and channel morphology can be altered by landslide input or excessive sedimentation from roads. This can cause channel sedimentation or channel scouring and subsequent widening.

METHODOLOGY

Materials

The following materials were used in this assessment:

- 1:20,000-scale Forest Development Plan 2000-2004 map – 92J036, showing watershed boundaries, harvested and proposed cutblock (Talbot) locations, and built and proposed road locations.
- Map: *Pemberton Creek: Potential Clearcut Landslide And Stream Impact Rating* (Thomson, 1989).
- 1:20,000-scale map showing the location of Block TL0741, Block 800, and watershed boundaries (Weyerhaeuser).
- 1:20,000-scale map showing the location of blocks PW1 and PW2, proposed roads and watershed boundaries (Western).
- 1994 Black and White aerial photographs at a scale of approximately 1:18,000.
- *Coastal Watershed Assessment: Pemberton Creek Community Watershed* (MOELP, MOF – June 1997).
- The *Pemberton Creek Integrated Watershed Management Plan* (MOELP, MOF 1991).
- Terrain Stability Field Assessment (TSFA) for TSL A20485, Block 22 (Baumann Engineering, November 2000).
- TSFA for TSL A20485, Block 13 (as above, September 1997).
- TSFA for TL0741, Block 800 (as above, September 2001).
- GIS data supplied by the Ministry of Forests was used to calculate stand height and produce digital maps.

General

The first phase of the Level 1 CWAP involved an office-based review and interpretation of the above materials, and preparation for fieldwork. The second phase involved checking a sample of the terrain, roads, potential sediment sources, and Pemberton Creek channel using low-level helicopter survey and numerous ground checks. Fieldwork was carried out on July 5 and 6, 2001 by Scott Weston, *P.Geo.*, and Heather Stewart, *B.A.*, of Madrone. The third phase involves an office-based analysis of the background and field data, and final map production. Terrain stability mapping fieldwork occurred in conjunction with CWAP fieldwork. Unfinalized terrain stability mapping and interpretations (surface erosion potential, landslide-induced stream sedimentation, and risk of sediment delivery to streams) were used to define watershed conditions for this CWAP.

Information on nine environmental indicators was collected in the field and from watershed maps, and background data was entered into a spreadsheet to produce the Watershed Report Card (Table 6).

In Level 1 CWAPs, the following assessments are normally undertaken:

1. Peak stream flow and hydrological recovery.
2. Sediment source survey.
3. Reconnaissance channel assessment procedure (ReCAP).
4. Riparian assessment.

Peak Stream Flows and Hydrological Recovery

To determine *peak stream flow* hazard, we calculated the Equivalent Clearcut Area (ECA) index and the total non-deactivated road network in the watershed, based on elevation band. ECA is the area that has been clearcut within a watershed, with a reduction factor to account for the hydrologic recovery due to forest regeneration. For CWAPs, three elevation bands are chosen to represent the dominant streamflow generation process operating in the watershed. The elevations bands generally used at or near the south coast area of B.C. are 0-300 m (the 'rain-only zone'), 300-800 m (the 'rain-on-snow zone'), and >800 m (the 'snowmelt zone').

The calculation of ECA requires a determination of *hydrological recovery,* using the average stand height and canopy closure of regeneration of cutblocks and landslide scars. Hydrological recovery is the process by which regeneration restores the hydrology of an area to pre-logging conditions. To estimate stand height and canopy closure, we used digital forest cover data, adding 0.25 m/year of growth. Road lengths were measured using ArcView. The calculation and Form 2 within Appendix 2 of the CWAP guidebook were used to determine the current ECA.

Implications of proposed harvesting and road development on peak flow were determined by adding proposed cutblocks (approved and Category I) and roads from the five-year development plan onto the digital map. A future ECA was then determined (Table 5).

Current and future ECA is given a rating of LOW, MODERATE, or HIGH, defined in Table 1.

Table 1: ECA Rating Definitions

ECA (%)		
0-20	20-30	>30
Low	Moderate	High

An assessment of peak stream flow hazard also typically takes into account the frequency and timing of major flood events. We attempted to gather information on the flooding hazards for the Pemberton Creek fan in order to compare flood frequency and timing before and after logging occurred.

Sediment Source Survey

The *surface erosion potential* hazard is part of the sediment source survey, requiring information on erodible soils, sediment sources from the road network, and the number of active stream crossings. To obtain information on erodible soils, we consulted terrain stability mapping (Thomas, 1989) for soil textures where there was field verification. We also conducted Terrain Stability Mapping in conjunction with the fieldwork for the PCCW CWAP, enabling us to obtain more information on soil textures and to field verify potential sediment sources, particularly sources from roads.

The locations of stream crossings and sediment sources from open slopes and roads were determined from air photos. Stream crossings, most of the length of the road network in the PCCW, and most natural sources were then field checked.

Tables A3.1 and A3.2 from the CWAP guidebook (p. 35-38) were used to describe sediment production and sediment delivery from roads. Each road section was assigned a potential sediment production class and a classification of sediment delivery from forest roads to stream channels. With the values derived from Tables A3.1 and A3.2, Table A3.3 (p. 38 of the guidebook) was used to determine the sedimentation hazard. Only the road sections having MODERATE (M), HIGH (H), and VERY HIGH (VH) sedimentation hazard are shown on the map (Figure 2). Only sediment that is delivered to the streams is important for CWAP purposes.

Determining *landslide activity* is also part of the sediment source survey. The number, type, and size of landslides in the PCCW was initially determined from air photographs. This was supplemented by an aerial reconnaissance flight and ground verification, where possible. Previous Terrain Stability Mapping (Thomas, 1989) and Terrain Stability Field Assessments for proposed cutblocks were also used, and TSM mapping was done by Madrone in conjunction with the PCCW CWAP.

Each landslide was digitized from air photos to the base map (Figure 2).

Reconnaissance Channel Assessment Procedure (ReCAP)

Channel morphology is normally evaluated for CWAPs by doing *a* Reconnaissance Channel Assessment (ReCAP*)* of the mainstem and major tributaries. The purpose of a ReCAP is to determine changes in channel morphology after forestry related activities. The pre-fieldwork assessment of the Pemberton Creek mainstem was done using one set of air photos (1994) and 1:20,000-scale trim maps to identify channel reaches along the mainstem. Partitioning the creek into distinct reaches provides a framework within which to locate any reaches with obvious channel disturbances, natural and logging related, that are affecting creek morphology, or reaches that are potentially sensitive to increases in peak flow and sediment input. Channel reaches were defined by changes in channel gradient, stream bed/stream bank materials, channel confinement, channel width, and hillslope coupling (connectivity between the hillslopes and channel).

Reaches were classified based on methods described in *The Channel Assessment Procedure Guidebook* (Ministry of Forests, BC Environment, 1996). Reaches with gradients less than 8% normally have *Riffle-Pool (RP)* morphology, consisting of pools separated by riffles or extended rapids. Reaches with gradients greater than 8% up to 20% normally have

Step-Pool (SP) morphology, and reaches with gradients greater than 20% have either Step-Pool or *Cascade-Pool (CP)* morphology. Channels in erodible material are generally sensitive to disturbance. Channels in bedrock are generally insensitive to disturbance, especially those reaches that are entrenched. Each reach type along Pemberton Creek was given a ranking of sensitivity to disturbance (LOW, MODERATE, or HIGH). Hillslope and stream channel coupling were also noted. A channel is considered *decoupled* from a hillslope when sediment mobilized on the hillslope by a landslide normally would not enter the stream channel. *Partially coupled* channels occur where a portion of the sediment mobilized on the hillslope by a landslide directly enters the stream channel. A channel is considered *coupled* to a hillslope when sediment mobilized on the hillslope by landslide activity directly enters the stream channel.

An overview aerial survey of the entire main stem was then conducted in order to verify the reach classifications and locations of disturbances. Selected channel reaches were ground verified. Reach breaks and classifications were then digitized, and a reach break/classification map was then produced (Figure 2).

Riparian Assessment

A riparian assessment for a CWAP determines the role of riparian vegetation and wood debris in maintaining channel stability and channel structure, and how this role has been affected by logging. The pre-fieldwork assessment was done using air photos and the Forest Development Plan map to identify alluvial reaches either previously logged or identified on future plans. Certain logged riparian areas were then field checked to determine the extent of channel bank erosion.

RESULTS

Current Watershed Conditions

Peak Stream Flow and Hydrological Recovery

All past harvesting in the PCCW is located entirely within the >800 m elevation band, where snowmelt is the primary stream flow generation mechanism. The PCCW is assessed to have a **LOW** potential for increased peak flow because of timber harvesting and road construction. Harvesting has removed approximately 86 ha of the timber in the watershed, which accounts for 2.9% of the total watershed area. The ECA is 0.77 km^2. The ECA is approximately 2.6%. The road density in the watershed is LOW (0.27 km/km^2) and has a **LOW** potential for affecting peak flow increases.

Table 2: Area and Percentage of the Watershed Harvested Corrected for ECA

Block	Elevation Band	Area (km^2)	Stand height adjusted (m)	% Recovery	ECA (km^2)	ECA/total watershed area (km^2/km^2)	Weighted ECA (km^2/km^2)
A20485-1&2	800+	0.110	2.5	0	0.110		
A20485-1&2	800+	0.103	4.4	25	0.078		
A20485-1&2	800+	0.137	4.8	25	0.103		
A20485-10A	800+	0.128	3.3	25	0.096		
A20485-11A	800+	0.161	2.5	0	0.161		
A20485-12	800+	0.096	2.0 & 2.2	0	0.096		
A20485-13	800+	0.081	0.3	0	0.081		
A20485-32	800+	0.048	2.5	0	0.048		
Total for Watershed		**0.864**			**0.773**	**.0264 (2.6%)**	**.0264 (2.6%)**

At the time of writing this report, information on flood frequency and timing of significant major flood events was not available. The Village of Pemberton Creek has historically been flooded when snow avalanches within the watershed have blocked the channel and redirected flow on the fan. Thurber Engineering, subconsulting to Northwest Hydraulic Consultants Ltd., conducted a study of Pemberton Creek fan hazards. The report on this study was still in review when this report was written; therefore, it was not reviewed. However, with the small percentage of harvested area in the PCCW, harvesting has not and likely will not affect the frequency and timing of significant major flood events.

Sediment Source Survey

Surface Erosion

In the PCCW, there is a total of 7.9 km of built roads, with roads generally located on gentle to moderate slopes (less than 49%). Field checking of soil textures indicates that non-compacted fine sand and silt (sandy loam) textures predominate in the middle section and lower end of the watershed, where past and proposed harvesting and road construction are located. Sediment sources from roads include road surface and ditchline erosion, cutslope erosion at or near stream crossings of unstable fill slopes, and road sections with relatively steep grades (>15%) that connect to stream channels. There are 780 m of road that have a HIGH sedimentation hazard and another 500 m with a MODERATE sedimentation hazard. The percentage of the road network with a HIGH sedimentation hazard is **LOW** at 9.9%. The percentage of the road network with a MODERATE sedimentation hazard is also **LOW** at 6.3%.

There are erosion issues on Road R00542 and Branch Road B1-B. On Road R00542, the soil in the road cuts consists of non-compacted find sand and silt. From Stream Crossing 6 to Stream Crossing 8 (Figure 2), ditchline erosion is MODERATE to HIGH (Class 4), and road surface erosion is MODERATE (Class 3). In two locations along this road section, interception of surface water has created new stream channels (Figure 2). Creek 4 diverts from its original path and now flows to the northeast using a shorter route than the original to Pemberton Creek. Sediment delivery into Pemberton Creek is HIGH; therefore, the sedimentation hazard is also HIGH.

At the switchback below this stream diversion, the ditch line has diverted water at the bottom of the switchback into a more direct path to Pemberton Creek. A silt lens approximately 0.75 m deep is present at this location. Sediment delivery potential into Pemberton Creek is HIGH; therefore, the Sedimentation hazard is also HIGH. Below the switchback, road gradients decrease to 10% and the sedimentation hazard becomes MODERATE.

There are *eleven* active stream crossings in the PCCW. Minor erosion is to be expected at all crossings. There is potential for significant erosion and sedimentation hazard at Stream Crossing 4 on Branch Road B1-B. The road from the east slopes down the bridge at a gradient of 22%. The cutslope along this road consists of erodible, non-compacted, fine sand and silt (Photo 5). Potential cutslope and road surface erosion is MODERATE, sediment delivery potential into Creek 1 is HIGH; therefore, the sedimentation hazard is HIGH. The remainder of the road network has a **LOW** sedimentation hazard.

Landslide Activity

Five types of mass movements were observed in the PCCW, all being attributed to natural causes. Approximately ***sixteen*** landslides greater than 0.05 ha are located in the PCCW. Fifteen of them are a combination of rockfall/rock slide, and none of them reaches Pemberton Creek. Rockfall is an ongoing process throughout the entire watershed. There are numerous colluvial slopes consisting of rubbly and blocky fragments with very little sandy matrix to no matrix at all (Photos 3 and 4).

The surficial material at the upper end of the PCCW consists of rubbly and blocky till with very little sandy matrix, and rubbly and blocky colluvium with numerous bedrock outcrops. Raveling of lateral moraines is an ongoing process; however, only an insignificant amount of material is reaching Pemberton Creek (Photo 2). Slow mass movement of this till was observed on the south side of the watershed in a deep till blanket (Slide #16), indicated by numerous jack-strawed and pistol-butted trees. This process is not affecting Pemberton Creek or its tributaries. There is also evidence of past avalanche activity upslope of the main stem. Avalanche debris has likely reached Pemberton Creek, but evidence of this was not obvious.

There are only two gullies experiencing debris flows and one gully experiencing debris torrents in the study area. Debris flows and torrents are triggered by rockfall, gully sidewall failures, or debris slides. High runoff may also initiate debris flows or torrents by mobilizing channel material. Material from these movements likely reaches Pemberton Creek, with minimal impact. Gully sidewall erosion, sliding in weathered bedrock and till, and rockfall are ongoing processes in Creek 4 (Photo 6) and Creek 5 (Photo 7).

Slides in till along the banks of the lower reaches of Pemberton Creek are a source of sediment entering the Creek (Reach 4 – Figure 2). These slides and resulting creek sedimentation are located approximately 1600 m downstream of the closest cutblock. During a low level flight over the creek, boulders, cobbles, and large woody debris were observed in the creek below the slides and approximately 100 m downstream, indicating transport of the debris by the creek. The slide section extends for approximately 800 m along Pemberton Creek, with approximately eight small slides observed along this length. All slides are less than 0.05 ha. Creek undercutting appears to be the cause of the instability.

The sedimentation hazard from landslide activity for the entire PCCW is **LOW**. There are no slides initiated from logging-related activities, and natural mass movements are minimally impacting Pemberton Creek.

Reconnaissance Channel Assessment Procedure

From the preliminary ReCAP stage, we determined that the minimal logging that has taken place in the PCCW has not taken place along the mainstem or major tributaries. Therefore, a comparison between pre- and post-logging conditions of Pemberton Creek was not warranted. Channel reaches of the mainstem were still delineated, given a classification and ranking of disturbance (natural) (Figure 2). This information can be used as baseline data for future work in the watershed. There is one reach (Reach 4) where natural disturbance is moderately affecting channel morphology, where failures in till are directly entering Pemberton Creek (mentioned in the Landslide section above). Logging has had a **LOW** impact on channel morphology.

Twenty-one reaches were identified along Pemberton Creek, within the study area. Reaches identified as having a HIGH sensitivity to hydrologic change are those that are sensitive to scouring, infilling of pools, and/or destabilization of woody debris. Reaches that have a LOW sensitivity are those incised in bedrock, that are resistant to changes in channel morphology.

Reach 4 (R4) is the only reach within the study area located downstream of harvested cutblocks that has a HIGH sensitivity to increases in peak flow or sedimentation. The reach with the highest sensitivity to changes in hydrologic or sedimentation change is outside the study area, at the Pemberton Creek fan. Most of the Pemberton Creek fan has been dyked between the water supply intake at the apex of the fan and the Lillooet River due to flooding concerns.

Table 3: Reach Classification Results

Reach No.	Length (m)	Average Gradient (%)	Reach*** Type	Coupling	Channel Sensitivity	Notes
1	172.9	5.8	RPb	Decoupled	High	Reach just above fan
2	447.6	13.4	SPb	Partial	Low	In bedrock-entrenched gully
3	1165.1	27.5	CPb	Coupled	Low	Intake at 1060 m; in bedrock-entrenched gully
4	1050.9	12.4	SPb	Coupled	High	8 small slides in till from creek undercutting
5	962.8	7.3	RPb	Coupled	Moderate	
6	421.4	9.5	SPb	Coupled	Moderate	
7*	556.9	9.0	SPb	Decoupled	Moderate	Active stream crossing (Photo 9); bedrock exposed in banks
8	786.2	14.0	SPb	Partial	Low	Bedrock likely exposed in banks
9	221.4	9.0	SPb	Partial	Moderate	Bedrock likely exposed in banks
10*	1345.5	3.0	RPc	Coupled	High	Active fluvial plane (Photo 8)
11*	283.9	21.1	R**	Partial	Low	
12*	928.4	2.7	RPc	Partial	High	Active fluvial plane
13*	185.0	24.3	R	Partial	Low	
14	358.3	14.0	SPb	Partial	Moderate	Bedrock likely exposed in banks
15	580.7	3.4	RPc	Decoupled	High	Active fluvial plane with organics
16	272.6	11.0	SPc	Partial	Moderate	Bedrock likely exposed in banks
17	507.8	5.9	RPc	Decoupled	Moderate	Bedrock likely exposed in banks
18	560.5	12.5	SPc	Partial	Moderate	Bedrock likely exposed in banks
19	309.1	19.4	SPc	Coupled	Low	Bedrock exposed in bed and banks
20	466.5	6.4	RPc	Partial	Moderate	Bedrock exposed in bed
21	364.7	30.2	R	Decoupled	Low	

* Reach was ground inspected. The remaining reaches were inspected with a low-level helicopter flight.
** Bedrock
***Reach type: RPc – riffle pool; cobble
CPb – cascade pool; boulder
SPc – step pool; cobble
SPb – step pool; boulder

Riparian Assessment

There have been 1098 m of combined stream length logged in the PCCW, approximately 3.7% of the length of all streams in the watershed. All logged streams are short sections of small second and third order streams weakly incised in either till or bedrock, with the streams generally having LOW sediment delivery potential. No section of Pemberton Creek has been logged. No areas of significant channel bank erosion of logged alluvial reaches were noted with the exception of the point where Road R00542 intercepts Creek 4, redirecting it down another path. The road here has impacted the stability of the creek. Overall, the loss of riparian vegetation along the logged stream length is of **LOW** impact. Riparian vegetation and wood debris had little effect on channel stability and structure in these areas.

The mainstem has a Riparian Reserve Zone (RRZ) of greater than 60 m to any cutblock. The IWMP implemented a 100 m RRZ on Pemberton Creek in 1991, and this recommendation has been followed since.

Five Year Development Plan (2000-2004)

Table 4: Proposed Harvesting

Company	Block Number	Elevation Band (m)	Ha in the PCCW
Talbot	20	>800	5.2
Talbot	22	>800	6.2
Talbot	25	>800	5.0
Weyerhaeuser	800	>800	1.7
Weyerhaeuser	800	300-800	6.4
Pacific Western	PW1	>800	2.9
Pacific Western	PW2	>800	16.3

Table 5: Five-Year Development Plan (2000-2004): Predicted Area and % Watershed Harvested Corrected for ECA

	Block	Elevation Band	Area (km^2)	% Recovery	ECA (km^2)	ECA/total watershed area (km^2/km^2)	Weighted ECA (km^2/km^2)
Harvested	A20485-1&2	800+	0.110	25	0.082		
	A20485-1&2	800+	0.103	25	0.078		
	A20485-1&2	800+	0.137	50	0.069		
	A20485-10A	800+	0.128	25	0.096		
	A20485-11A	800+	0.161	25	0.120		
	A20485-12	800+	0.096	25	0.072		
	A20485-13	800+	0.081	0	0.081		
	A20485-32	800+	0.048	25	0.036		
Proposed	A20485-20	800+	0.052	0	0.052		
	A20485-22	800+	0.062	0	0.062		
	A20485-25	800+	0.050	0	0.050		
	TL0741-800	300-800	0.064	0	0.064		
	TL0741-800	800+	0.017	0	0.017		
	PW1	800+	0.029	0	0.029		
	PW2	800+	0.163	0	0.163		
Total for Watershed			**1.301**		**1.071**	**0.0366 (3.7%)**	**0.0366 (3.7%)**

All but 6.5 ha of proposed harvesting is in the >800 m elevation band. The 6.5 ha are located in the 300 m to 800 m elevation band, where rain-on-snow events tend to dominate peak stream flow. The proposed development in the PCCW is assessed to have a **LOW** potential for increased peak flow because of timber harvesting and road construction at the end of 2004. Harvesting will have potentially removed an additional 43.7 ha of timber in the watershed. Harvested terrain will account for 4.4% of the total watershed area. The ECA will be 1.071 km^2. The weighted ECA will be approximately 3.7%. The road density in the watershed will remain LOW (0.35 km/km^2) and will have a **LOW** potential for affecting peak flow increases.

There are 2.46 km of proposed Roads. Road development will potentially increase surface erosion. A section of proposed Branch Road 526 (informational only at this time) is currently planned to be located across potentially unstable terrain (Class IV_R) with HIGH erosion potential due to moderate slopes (30-50%) and active gullying. This section is located approximately 300 m upslope of Pemberton Creek, west of Block A20485-12 (Figure 2). This section is also located about a reach that has a HIGH sensitivity to changes in peak flow or sedimentation. However, with the LOW road density, soil erosion will be **LOW** for the watershed.

All proposed locations of cutblocks are on stable terrain with LOW or MODERATE erosion potential and LOW to MODERATE potential for sediment delivery to Pemberton Creek or a tributary. All proposed cutblock locations are also outside zones of avalanche activity. Forestry-related landslide effects will be **LOW**.

No further harvesting of riparian areas is planned. Block 20, currently deferred, is located approximately 25 m up from Creek 1, the closest a block is proposed to be to a creek. As recommended in the IWMP, all proposed cutblocks are located greater than 100 m from Pemberton Creek. In addition, all proposed block locations are downstream from reaches that have a HIGH sensitivity rating to increases in peak flow or sedimentation, with the exception of Reach 4. Proposed harvesting and road building has a **LOW** potential for riparian zone and/or channel disturbance.

Summary

Watershed Report Card

A Watershed Report Card (Table 6) was prepared for the PCCW that summarizes nine indicators of watershed condition.

Conclusions

Forestry related activities have had **LOW** effects on changes to the four hazard indicators in the PCCW (peak stream flow, surface erosion, landslides and riparian zones/channel morphology) (Table 7). This suggests that forestry has had very little impact on water quality and quantity. The low impact of forestry related activities can be attributed to the implementation of the recommendations put forth in the IWMP as well as the low rate of harvesting in the watershed. Future development in the watershed will follow the same strict guidelines in the IWMP and will have a **LOW** effect in changing any of the four hazard indicators (Table 8).

Table 6: Watershed Report Card – Current Conditions

1. Percentage Of Watershed Harvested, Corrected For ECA	2. ECA By >800 m Elevation Band	3. Road Density		4. Length Of Road With HIGH Sediment Delivery To Streams		5. Number Of Landslides >0.05 ha		6. Length Of Road On Unstable Slopes	7. Number Of Stream Crossings		8. High Riparian Impact – Stream Length	9. Length Of Mainstem With Disturbed Stream Channel (Natural)	
(%)	(%)	Length (Km)	Length/ Total Watershed Area (Km/Km^2)	Length (Km)	Length/ Total Length Of Road Network (%)	Total	Entering Streams	(M)	#	Density (Per Km^2)	(M)	(Km)	% Of Total Length
2.6	2.6	7.88	0.27	0.78	9.9	16	0	0	11	0.38	0	0.8	10%

Table 7: Summary of Forestry Effects in the PCCW

Total Area	Area Logged		ECA weighted		Forestry Effects			
(ha)	(ha)	%	(ha)	%	Peak flows	Surface Soil Erosion	Landslides	Riparian Zones & Channel Morphology
2992	86.4	2.9	77.3	2.6	LOW	LOW	LOW	LOW

Table 8: Summary of Potential Forestry Effects PCCW (2000-2004)

Total Area	Area Logged		ECA weighted		Forestry Effects			
(ha)	(ha)	%	(ha)	%	Peak Flows	Surface Soil Erosion	Landslides	Riparian Zones & Channel Morphology
2992	130.1	4.4	107.1	3.7	LOW	LOW	LOW	LOW

RECOMMENDATIONS

- Have Road R00542, where the sedimentation hazard is MODERATE to HIGH, assessed for deactivation/maintenance and a sediment control program. Deactivation should include adequate spacing and density of cross ditches in order not to overload ditches.

- Have proposed addition to Road R00542 assessed for terrain stability hazards where the road will cross Class IV_R terrain. Ensure proper water management along the road with the adequate spacing, density, and sizing of culverts. Drainage structures should be designed to handle peak flow conditions, and regular inspection of drainage structures should be carried out, especially after heavy flood events. Road construction across Class IV_R terrain should take place during the dry season.

- Develop and implement a sediment control plan for new roads, specifically addressing procedures to minimize the transport of road-related sediment into streams.

- The next CWAP should be completed in 2004 and should incorporate finalized results from recent terrain mapping and interpretations (erosion potential, risk of sediment delivery to streams and landslide delivery to streams).

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APPENDIX 1

Photographs

Photo 1: Ipsoot Glacier and west boundary of the study area.

Photo 2: Raveling of lateral moraines deposited during the Little Ice Age.

Photo 3: Colluvial slope below a bedrock outcrop (R"b) in the upper-middle section of the study area.

Photo 4: Colluvial cone located at the upper end of the study area. Colluvium is not reaching Pemberton Creek.

Photo 5: Non-compacted, silty, fine sand till in a recently constructed road cut located upslope of Stream Crossing #4.

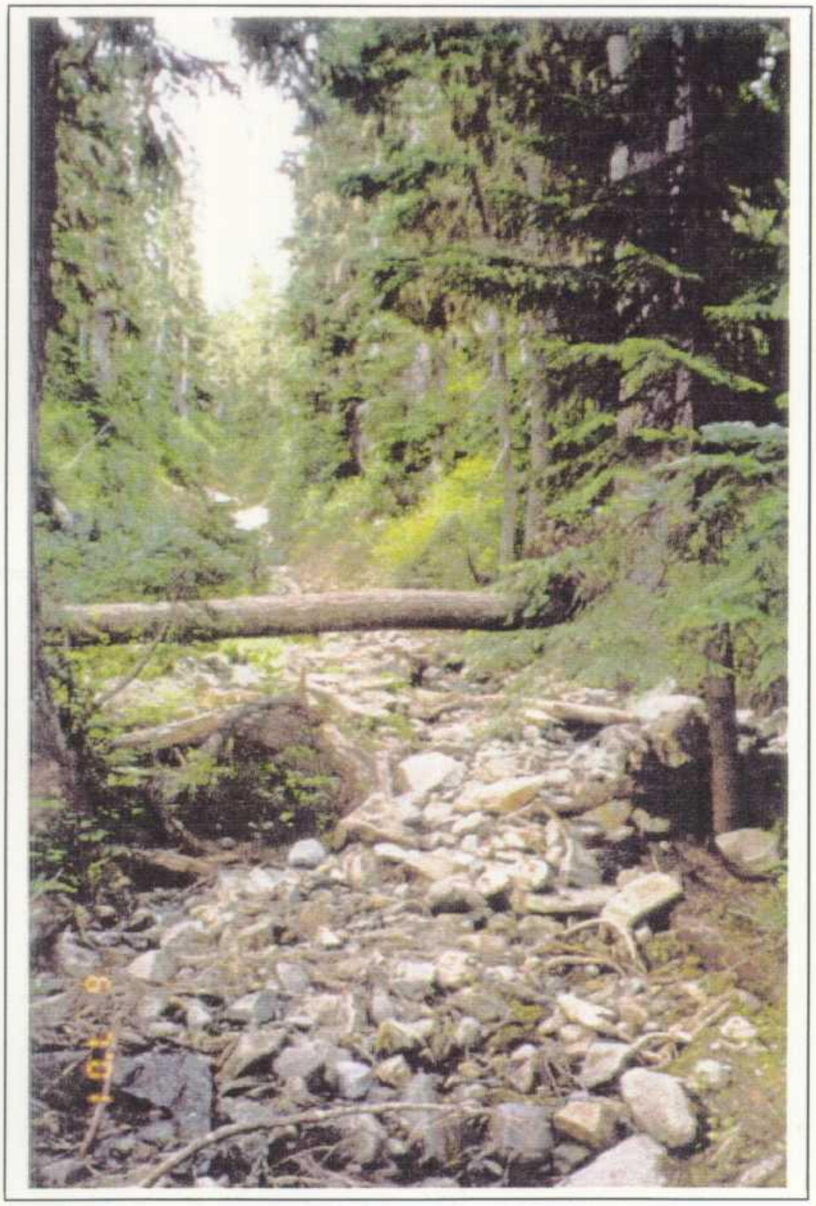

Photo 6: Debris torrent deposits and gully sidewall erosion in Creek 4.

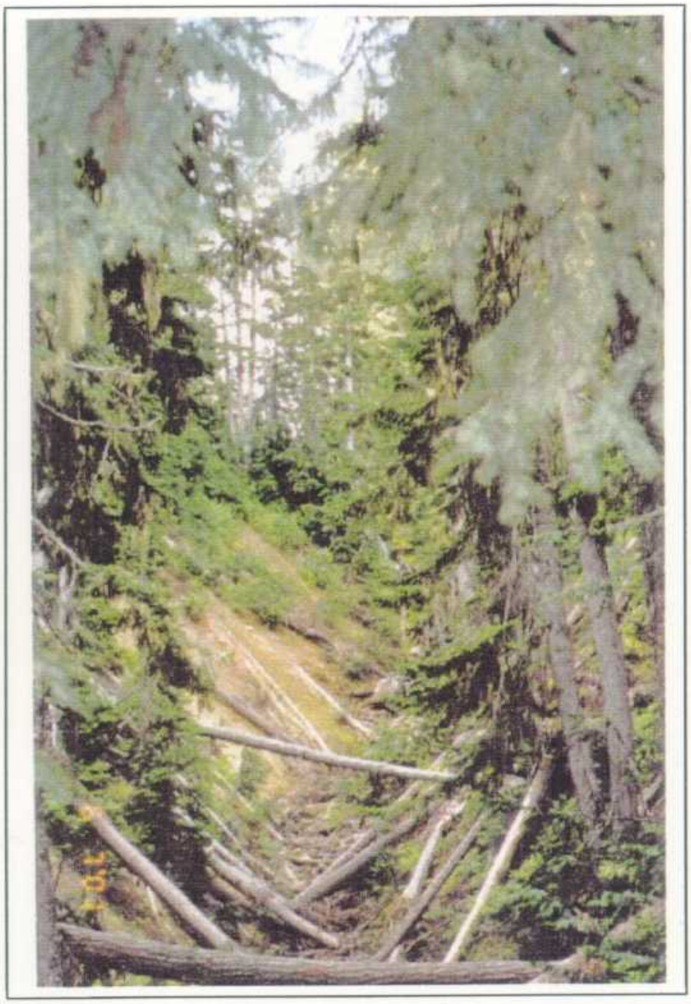

Photo 7: Gully sidewall erosion and slides in weathered bedrock and till in Creek 5.

Photo 8: Reach 10 with RP-c channel morphology.

Photo 9: Reach 7 with SPb channel morphology.

APPENDIX 2

Acronyms

ACRONYMS

IV_R	Terrain stability class where there is a LOW hazard with harvesting and MODERATE to HIGH hazard with conventional road construction.
CAP	Channel Assessment Procedure
ECA	Equivalent Clearcut Area
IWMP	Integrated Watershed Management Plan
LWD	Large Woody Debris
m.a.s.l.	Meters above sea level
MOELP	Ministry of Environment, Lands and Parks
MOF	Ministry of Forests
NTU	Nephelometric Turbidity Units
PCCW	Pemberton Creek Community Watershed
RMZ	Riparian Management Zone
TSFA	Terrain Stability Field Assessment
TSM	Terrain Stability Mapping