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FINAL REPORT

Interior Watershed Assessment Procedure & Reconnaissance Stability Assessment of Structure Locations

Glade Creek

Prepared for:

KRM Associates Inc.
S31 C23 RR3
Nelson, B.C.
V1L 5P6

Prepared by:

M. Carver, Ph.D., P.Eng., P.Ag.
G. Utzig, P.Ag.
D. Putt, P.Geo., P.Ag.

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Carver Consulting

310 Houston Street, Nelson, B.C. CANADA V1L 5H4 TEL: (250)352-2892 FAX: (250)352-3892 E-MAIL: carver@netidea.com

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EXECUTIVE SUMMARY

This report presents the findings of an Interior Watershed Assessment of the Glade Creek watershed, a Community Watershed west of Nelson, B.C. The report also provides results of a reconnaissance terrain stability assessment for the proposed locations of powerline structures. Two hydrologic maps have been prepared as part of this study: *Hydrologic Features and Sediment Sources Map* and the *Hydrologic Recovery and Proposed Development Map*.

Indicator	Units	Existing			Proposed		
		Upper Glade	Lower Sub-Basin	Glade Total[1]	Upper Glade	Lower Sub-Basin	Glade Total[1]
Area	ha	1554.3	1309.3	2961.4			
Private land	%	0	4.2	2.0			
ECA[2] unweighted	%	13.0	11.1	12.9	13.4	11.4	13.2
ECA[2] weighted	%	15.5	15.9	16.3	15.9	16.2	16.7
Total road density	km/km^2	0.47	0.39	0.50	0.47	0.39	0.50
Very-high hazard roads	km	0.00	0.15	0.15	0.00	0.15	0.15
High hazard roads	km	0.00	1.17	2.45	0.00	1.17	2.45
Moderate hazard roads	km	1.43	1.47	3.21	1.43	1.47	3.21
Roads on Terrain Stability Class IV/V or above 60%	km/km^2	0.06	0.08	0.08	0.06	0.08	0.08
Density of TRIM stream crossings	no./km^2	0.32	0.31	0.37	0.32	0.31	0.37
Number of landslides	no.	10	3	17			
Length of disturbed mainstem	km	1.66	0.07	1.79			

[1] Total Glade includes the Upper Glade and Lower Sub-Basin areas in addition to a small area of face units near the Point of Interest. The Face Units have no proposed development and are not sub-basins hence they are not listed separately in this table.
[2] Equivalent Clearcut Area

Existing hazards are given in the following table in addition to the level of risk in each hazard class (and expected hazard) associated with the proposed development:

Indicator	Existing Hazard	Proposed Development	
		Associated Risk[1]	Resulting Hazard
Sediment Sources	M	(+)	M
Peak Flow	L-M	(+)	L-M
Channel Instability	L&H	(+)	L & H
Riparian Function	L-VH	o	L-vH

[1] Associated risk: o – none; (+) – insignificant increase; + – significant increase; ++ – major increase; (-) – insignificant decrease; "-" – significant decrease; "- -" – major decrease

The proposed development will create insignificant increases in hydrologic risks within the Glade Creek watershed. The terrain stability assessment supports the present choice of power-line alignment and justifies proceeding to the next step of detailed engineering design and ground-based assessment. Recommendations are provided to address the background risks already present in the watershed and include development of a drainage plan near the Lower Mainstem, sediment control in the headwaters of the Lower Tributary, and ECA management in the Upper Glade watershed.

1.0 INTRODUCTION

This report presents the findings of an Interior Watershed Assessment of the Glade Creek watershed, a Community Watershed west of Nelson, B.C. Glade Creek water is diverted by the Glade Creek Irrigation District, providing domestic and irrigation water to the rural community of Glade. This work has been completed in conjunction with a reconnaissance terrain stability assessment of the locations of proposed structures for the powerline. The report is prepared for Kevin Megale of KRM Associates Inc.

The terms of reference for this work were to conduct data collection and hydrologic assessments consistent with the requirements of the Interior Watershed Assessment Procedure (IWAP) Version 2 (Anonymous 1999). This work includes a sediment-source assessment, reconnaissance and riparian assessments, a peak-flow assessment including a detailed ECA determination, and calculation of other indicators of forest development. The reconnaissance terrain stability assessment focused on locations for proposed powerline structures identified by airphoto interpretation as having a potential for landsliding into a stream and showing the potential for threatening a powerline structure due to a failure above the structure.

Deliverables include one report and two maps: *Hydrologic Features and Sediment Sources Map and the Hydrologic Recovery and Proposed Development Map.* Field work was conducted during October and November (2000). Martin Carver carried out the reconnaissance channel and riparian assessments, a limited review of sediment sources, and field observations of hydrologic recovery. Greg Utzig provided the majority of the sediment-source descriptions. Dave Putt conducted the reconnaissance terrain stability assessment in relation to the proposed structure locations.

1.1 Limitations and Reliability

This report and accompanying maps are based on airphoto interpretation, literature review, and limited field checking. The hazard assessments and mapping completed in this project are of a reconnaissance nature and are not intended for road layout nor cutblock design. The maps are intended to fulfil part of the requirements of the Interior Watershed Assessment Procedure.

Given that this study's terms of reference did not include mapping of tributary streams, the streams shown on the maps cannot be considered reliable. In addition, the terms of reference did not allow the authors to view the watershed during the spring freshet, somewhat reducing the reliability of observations regarding road-related water diversions. The observations in the Lower Tributary were made difficult by late-season icy conditions and may be subject to some error.

Terrain mapping was available for only the eastern portion of the study area. For the western portion, "slopes over 60%" were used in the IWAP in place of Class IV/V ratings. The lack of terrain mapping also created a limitation for the reconnaissance terrain stability assessment. Additional limitations for the terrain stability assessment are provided in Section 5.3.3.

1.2 Previous Work

An Interior Watershed Assessment Procedure (first version) was completed for the Glade Creek Watershed (Timberland Consultants Ltd 1995). In addition, two terrain assessments have been carried out (Wehr and Salway 1991; Salway and Wehr 1994) in relation to Cutting Permit 41 in the headwaters of the Glade watershed . More recently, Apex (2000) has completed Level C terrain mapping for the eastern portion of the watershed, lying within Atco Lumber Ltd's chart area. Salway (1994) has provided channel observations following Pfankuch. Isaacson (1994) has provided comments on the potential impacts of Cutting Permit 41 on the hydrology of the Glade watershed. In addition, Jungen (1980) mapped the soils and terrain of the area at a scale of 1:100,000. Little (1960,1973) provided mapping of the area's geology.

Several other reports are available describing the nature of the proposed powerline under consideration in this study ("proposed development"). These reports include Bennett and Corbett (2000), Timberland Consultants Ltd (undated), KRM Associates (2000), and British Columbia Assets and Lands Corporation (2000).

2.0 STUDY AREA

The Glade Creek study area is shown in Figure 2.1. The watershed is 29.6 km^2 in area and is located 15-20 km west of Nelson, B.C.

2.1 Bedrock and Terrain

Bedrock geology has been compiled by Hoy and Dunne (1998) of the BCGS at a scale of 1:100,000 and summarised by Apex Geoscience (2000). Most of the study area is underlain by granite, granodiorite, quartz monzonite and tonalite of the Middle-to-Early Jurassic Connington Pluton (part of the Nelson intrusions). The extreme northern section of the study area is underlain by Early Jurassic Group argillite, siltstone, grit, impure limestone, minor chert, and wacke, generally rusty-weathering.

Apex Geoscience (2000) described the surficial materials of the eastern part (60%) of the study area. Till derived from the Bonnington Pluton rocks has a sandy matrix and in places consists entirely of sand with few coarse fragments. In contrast, till derived from the Ymir Group rocks (northern limit of study area) has a silty matrix. The silty till grades into the sandy till over a (circa) 1-km-wide zone south of the geological contact between the two Groups. Much of the area is underlain by an unconsolidated sandy gravel to gravelly sand ablation till. Very large erratic boulders to blocks are common, scattered throughout the area. Less commonly observed is highly consolidated sandy gravel to gravelly sand basal till (with up to 15% clay). Saprolite is common. The sandy nature of many of the surficial materials creates instability in deep road cuts and results in erodible materials throughout the area.

2.2 Climate and Hydrologic Regime

The study area lies within the Moist Climatic Region of the Nelson Forest Region (Braumandl and Curran 1992). Biogeoclimatic units range from the ICHdw in the extreme lower reaches through the ICHmw2 on lower slopes and in many valley bottoms to ESSFwc4 and ESSFwcp at middle-to-high elevations and Alpine Tundra at the highest elevations.

The study area is located in the southern portion of the "Interior Wet Belt". The general patterns of temperature and precipitation are typical for mountainous terrain with increases in mean annual precipitation and decreases in mean annual temperature coincident with increasing elevation. Precipitation increases with elevation to about 1500 m above which it often decreases slightly. (The inflection point moves higher in the summer.) The annual precipitation distribution is seasonal with a maximum during mid-winter (December-January) and a minimum in mid-summer (July-August). These temperature and precipitation patterns result in rapidly increasing snowpack with elevation. At the lower elevations, the winter maximum may be reached in January while at the higher elevations, it continues to collect until April. Nearby climate stations indicate total valley-bottom precipitation in the range of 500-800 mm/year and show an increasing trend over the past 75 years (based on long-term averages at Nelson, Deer Park, and New Denver stations).

The annual hydrograph is snowmelt-dominated with typically over 90% of the annual runoff occurring in April, May, and June. The Water Survey of Canada has collected water quantity data on Glade Creek:

- 08NJ149 Glade Creek near Shoreacres (1964-1968; latitude 49 22'35"; longitude 117 32'12")

These flow data were collected during April through September only, presumably due to difficult access/conditions during the winter months. The following information is extracted from these data:

- average mean daily flow in April (1968 only) = 0.42 m^3/s
- average mean daily flow in May (1968 only) = 2.54 m^3/s
- average mean daily flow in June (1968 only) = 3.60 m^3/s
- average mean daily flow in July (1966-1968) = 0.57 m^3/s
- average mean daily flow in August (1964-1968) = 0.19 m^3/s
- average mean daily flow in September (1964-1968) = 0.17 m^3/s
- annual maximum mean daily flow (based on 1968 only) = 10.9 m^3/s on June 3
- lowest annual minimum mean daily flow (1964-68) = 0.054 m^3/s
- date of annual low flow (1964-1968) = late-August to late-September

There are no data available on water quality.

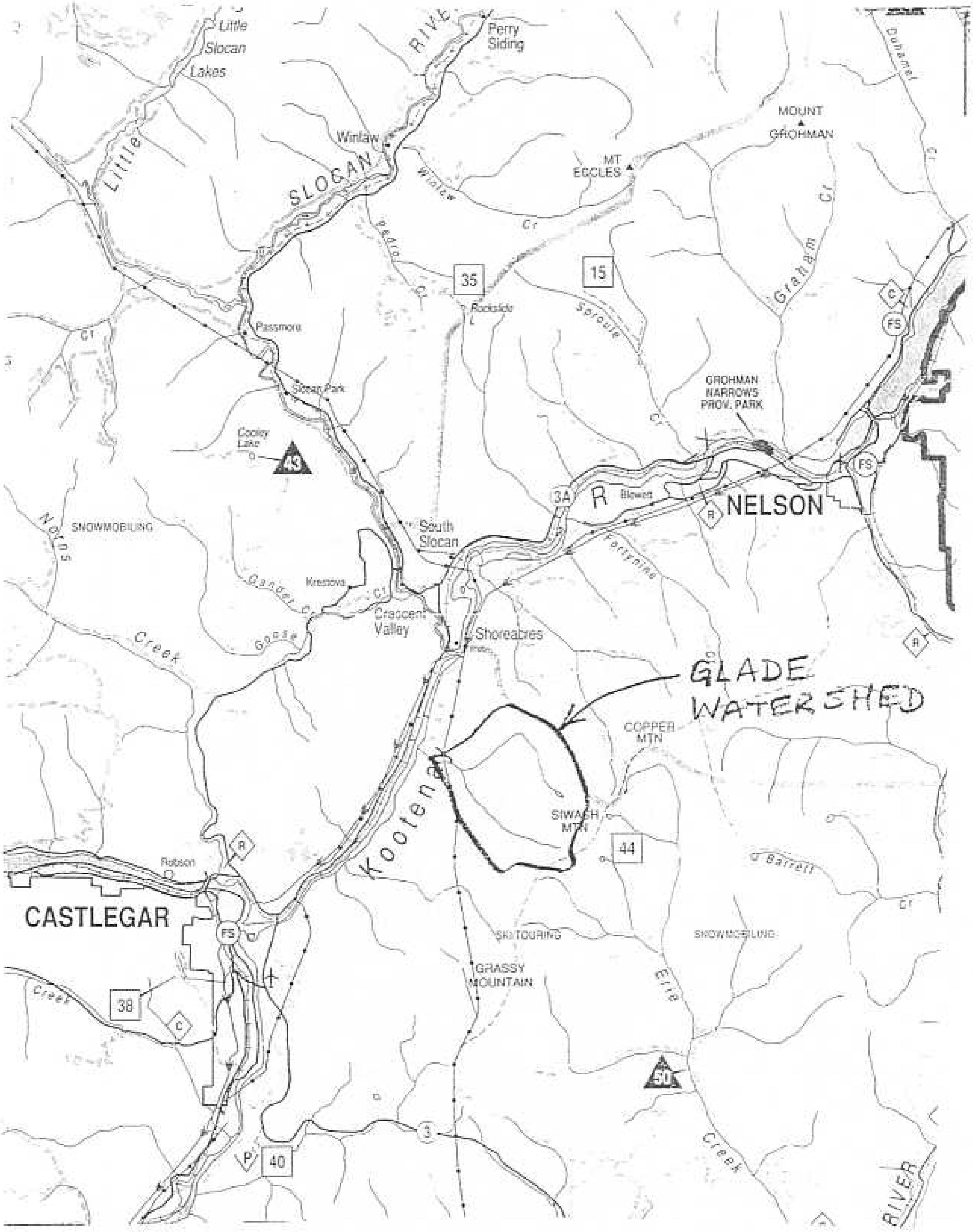

Figure 2.1. Study area location.

2.3 Water Licensing & Point of Interest

Table 2.1 summarizes water-licensing information for the study area as provided by the Water Management (MELP) website on September 24, 2000.

Table 2.1 Water licenses held on Glade Creek as of September 24, 2000.

Licence No	Licensee Name	Licensee Address	Purpose	Quantity	Unit	Status	Priority Date
C044909	Glade Irrigation District	SS2 C6 S3 Glade BC V1N 3L4	Irrigation Local Authority	300	AF	Current	Sept 1 1908
C044909	Glade Irrigation District	SS2 C6 S3 Glade BC V1N 3L4	Waterworks Local Authority	4015000	GY	Current	Sept 1 1908
C048637	Glade Irrigation District	SS2 C6 S3 Glade BC V1N 3L4	Waterworks Local Authority	25550000	GY	Current	July 24 1975

District/Precinct = Nelson-Castlegar; Water Rights map = 5132C (Intake "C")

According to Daryl Voiken (Trustee, Glade Irrigation District), domestic use for 100 households is served by this community intake. He described (personal communication) excellent water quality and quantity from Glade Creek. A variety of Glade residents was interviewed by phone in regard to the community water supply including Nick Dennisoff, John Dennisoff, Noni Tedesko, and Louella Bartlett.

There is only one intake on Glade Creek and as a result, the choice for Point of Interest is clear: Intake C on Water Rights map 5132C.

2.4 Disturbance History

This century's disturbance history in the Glade Creek watershed begins with early logging activities in the form of horse logging and hand-built trails. According to Bill Shlakoss (local resident) who frequented the watershed during this early period of logging, flumes (with catwalks) were constructed in 1927 overtop the mainstem Glade Creek to the upper end of reach 7 (1200 m – see section 4.2) where a sawmill was also located ("Camp 3"). In addition, a flume was constructed up the Lower Tributary to "Camp 4". The flumes merged at 775 m taking the cargo to a pond at the Kootenay River where logs were then floated to the nearby sawmill. Bill Shlakoss indicated that no machinery was involved in any of these logging activities. An extensive trail system was built to service these logging activities including a road along the mainstem to Camp 3 and a spur road across the centre nose and down into the Lower Tributary. At least two wooden bridges were in place across Glade Creek, along with log cribbing in the stream channel to enable fords in some locations. In addition, trails were constructed up most of the tributaries and hillslopes where conditions permitted. Many of these roads are now difficult to notice on the ground due to the lengthy period of disuse and recovery.

There are two persistent consequences of this early-century disturbance. The first is the lack of coniferous trees in many of the affected riparian areas. The gully bottoms were heavily logged and today many of these areas have poor regrowth and are often dominated by deciduous stands. In 1934, a forest fire of human origin (Bill Shlakoss personal communication) burned from the mouth of the Slocan River well into the Glade watershed, resulting in an equivalent clearcut area (ECA) estimated to have been in excess of 50%. Evidence of this fire persists today in the form of poorly-regenerated south-facing stands, now dominated by deciduous trees. According to Bill Shlakoss, runoff after the fire was too great, thereby ending the "flume era" in the watershed. The ECA continued to be very high on the 1958 airphotos, although recovery was underway.

Airphoto interpretation and a review of forest cover information indicates that the fire in 1934 which burned most of the mid- and lower-elevation areas of the watershed was likely the most extensive disturbance in the watershed this century. In much of the watershed forest regeneration and hydrologic recovery were well underway by the 1960s; however, southern aspects and shallow rocky soil areas were much slower to recover, as were the logged areas. A number of smaller isolated fires and windthrow events have occurred subsequently.

Airphoto interpretation also indicates the presence of a major channel disturbance (a debris flood?) of unknown cause in the Lower Tributary sometime before 1939, and its effects are still clearly visible in airphotos into the 1980s. The Glade Creek alluvial fan (below today's Point of Interest) exhibited major channel instability and erosional activity in the late 1940s or early 1950s. The cause is unknown, however it may have resulted from human disturbance on the fan, as there is no corresponding channel disturbance visible on the airphotos upstream of the fan. By 1968, fan instability appeared to have returned to pre-1940s levels.

By 1973, a portion of the earlier roads had been widened with bulldozers to accommodate modern machinery, and some new sections constructed, with at least three associated landslides. Based on the 1939 and 1958 airphoto coverage, there were no major landslides associated with the 1930s activities. According to David Grieve (Mines Branch, Cranbrook), there are no active claims anywhere in the Glade watershed nor are there any assessments or Minfile information available. Nick Dennisoff has described finding mining cores in this part of the watershed (personal communication). Mining exploration in the 1960s and 1970s remains the most likely reason for these road upgrades and the reason for various trails constructed in the northern portion of the watershed.

The first wood-pole line for BC Hydro was put in place in October 1975, followed by a second line in 1979 and the steel line in February 1980 (Geoff Clibbett personal communication). These BC Hydro lines cross the mainstem of Glade Creek only 0.5 km above the PoI. An access road was built in the fall of 1974 up to the height-of-land to the south of Glade mainstem. According to Goeff Clibbett, a landslide occurred between 1974 and 1982 which took out enough of the road that access was no longer possible.

Most recently, Atco Lumber Ltd. has constructed a road into the headwaters of the Lower Tributary sub-basin (from Granite Creek) and have harvested a number of cutblocks off this road.

3.0 METHODS

3.1 Determination of Equivalent Clearcut Area

Hydrologic recovery and equivalent clearcut area (ECA) were determined primarily by utilizing existing data on forest cover and regeneration, with confirmation during field work. The method follows that developed in Carver and Utzig (1999) and varied depending on data availability. The primary sources of information included:

- BC MoF Forest Cover Inventory (mapsheets 82F033)
- Airphotos (1939, 1958, 1973, 1983, 1997)
- Field transect notes

For the purposes of calculating ECA, six hydrologic recovery classes were defined as follows:

Table 3.1. Definition of classes of hydrologic recovery.

Recovery Class	Hydrologic Recovery (%)
5	100
4	90
3	75
2	50
1	25
0	0

Hydrologic recovery ratings were assigned to all existing forest cover polygons. In some areas, particularly those with a disturbance history in the last century, the detail and reliability could be significantly improved by redrafting the forest cover polygons (beyond the scope of this study).

Multi-layered stands were assigned the recovery class of the most-recovered layer, or a higher class if other layers were felt to make an additional contribution to overall recovery. Stand densities (total stems/ha) were discounted for deciduous components. Non-productive portions of the openings were assumed to be recovery class 0 but were generally insignificant portions of the openings.

For stands with tree heights greater than 10.4 m, and where no detailed stocking data were available (i.e., stands that had not been logged recently), preliminary recovery classes were determined using Table 3.2. The prevalence of shallow soils and subalpine climatic conditions in the upper elevations were accounted for by requiring less crown closure for full hydrologic recovery at elevations in excess of 1700 m.

All forested forest-cover polygons with a tree height of less than 10.4 m and without stocking data, or with a preliminary recovery class less than 5, were individually assessed on the 1997 airphotos to determine final recovery class. The general criteria used were soil characteristics and disturbance history. Airphoto interpretation of soil characteristics, site series, fire history, stand age, tree height and species composition was used to assign recovery classes for specific forest cover polygons. Open stands with ages greater than 100 years were generally considered fully recovered if located on excessively coarse-textured, shallow or poorly-drained soils. Younger stands on similar sites were assigned recovery classes similar to those on adjacent sites. Stands with previous harvesting and/or skidroad networks were also assigned recovery classes based on airphoto interpretation of crown closure. Rock outcrops, wetlands and other naturally occuring non-forested areas were always rated to be recovery class 5 (100%).

Table 3.2. Preliminary hydrologic recovery class for stands lacking detailed stocking data (not recently logged).

Recovery Class	Crown Closure (%)	
	Elev. ≤1700m	Elev. >1700m
5	> 50	>40
4	41-50	31-40
3	31-40	21-30
2	21-30	11-20
1	11-20	1-10
0	0-10	0

Forest cover polygons designated non-forested or non-productive were rated individually based on airphoto interpretation and information recorded during field transects. These included forest cover types such as: non-commercial brush, not satisfactorily restocked, non-commercial forest, alpine, alpine forest, non-productive, rock and burned. In areas with extensive fire history, especially at upper elevations, these forest cover designations were found to be generally unreliable. Based on field checks and terrain mapping, it was found that the areas were mistakenly classified as non-productive or non-forested designations because of slow regeneration, rather than an inherent inability to support closed canopy forest. For example the presence of deep soils and large stumps and/or coarse woody debris remaining from a stand pre-dating the last fire, clearly indicate an area which is capable of supporting a forest, not a non-productive site. These areas were rated according to the height and stocking of the present stand, in relation to the potential stand, rather than automatically rating them recovery class 5. Actual rock outcrops and other non-forested areas were still rated recovery class 5. Where the non-forested or non-productive areas were associated with fully-stocked stands with ages >100 years old, they were generally designated recovery class 4 or 5 (the assumption being that they had restocked to their capacity). When associated with fire-origin stands of <100 years in age, they were generally assigned a recovery class similar to the adjacent stands, based on airphoto interpretation as described above.

Fully stocked deciduous and mixed-deciduous stands were generally designated recovery class 5, as it was assumed they are a naturally-occurring portion of the landscape.

Cleared, cultivated or urban polygons were designated recovery class 0. Swamps and fens were designated recovery class 5. Clearing on private land was updated based on clearing visible on 1999 airphotos and field transect notes, with some forest polygons being pro-rated based on partial clearing. Full account may not have been made for very recent private-land harvesting and clearing.

The results were compared with observations of stocking and tree height from field transects. The correlation was found to be good overall. The ECA ratings for the "proposed development" scenarios do not include consideration of growth and recovery over the next five-year period.

3.2 Sediment Source Assessment

The sediment source assessment is built upon the description and rating of two classes of sediment sources– point sources (from any source) and surface erosion from the road prism. Each is treated separately.

3.2.1 Description and Rating of Sediment Sources

All point sources (description only)

Three types of point sediment sources are recognised and defined as follows:

Inactive Source: sources which have been active in the past but are now largely inactive

Active Source: sources with exposed material, generating sediment on an ongoing basis – these sources have a component which was active in the past and will be active in the future

Potential Source: locations with the potential to generate sediment but which have resulted in no production to date

The definition of source size varies with source type as described in Table 3.3. Table 3.4 provides the definitions of the size classes.

Table 3.3. Definition of source size in relation to source type.

Source Type	Size Definition
Inactive	total amount of sediment estimated to have been produced at the slide site
Active	total amount of additional sediment expected to be produced at the site if remediation action is not pursued.
Potential	total amount of sediment expected to be produced at the site if remediation action is not pursued (this can be the size of the potential landslide, the amount of vulnerable material at a bridge crossing with the potential to fail, the amount of material which may be mobilised as a result of an avulsion, etc.)

Table 3.4. Definition of size classes of point sediment sources.

Source Size Class	Size of Sediment Source (Volume, m^3)
Low	< 10
Moderate	10 – 99
High	100 – 499
Very High	> 500

Sediment source delivery refers to the extent to which mobilised material is delivered to a stream able to carry the material to the mainstem. Delivery classes are defined in Table 3.5.

Two types of potential sediment sources are distinguished as shown in Table 3.6.

Table 3.5 Definition of classes of sediment delivery.

Source Delivery Class	Percentage of Sediment Source Delivered to Stream Network
Low	< 10
Moderate	10 – 49
High	50 – 89
Very High	> 90

Note: Only point sources with direct connection to the stream network are included in the sediment-source inventory.

Table 3.6 Classes of potential sediment sources according to likelihood of occurrence.

Likelihood of Occurrence	Definition	Field Indicators
Probable (High)	Without remediation, expected to occur as a result of annual variability	Recent evidence of instability (recent tension cracks, nearby slide in same situation, newly-diverted drainage, high risk of further drainage diversion, etc.)
Possible (Moderate)	Situation that could be a problem but only with a significant event (eg 100-yr)	Past evidence of instability (old tension cracks, long-diverted drainage, etc.)

For each point source described, the following are provided:

- type
- cause
- size class
- delivery class

Road Sources (surface erosion only – description and rating)

Assessment of a road's surface erosion rating begins with road-segment descriptions carried out using the following steps:

1) Time permitting, identify all streams which (during freshet) have continuous overland connection to the watershed stream network.

2) Identify all road crossings of the streams from #1.

3) Identify road segments with both a cutbank and road surface which are less than 90% revegetated - airphoto interpretation can facilitate this step.

4) For those road lengths identified in #3:

a) Identify the connectivity of road lengths to the stream network according to Table 3.9.

b) For each of the road lengths with moderate, high, and very high connectivity, carry out a detailed description including the following factors:

- moisture regime
- cutbank height
- sideslope
- soil texture
- coarse fragment content
- soil depth
- road gradient
- percent revegetation (note separately for road surface and cutbank where different)

Depending on the specific road characteristics that are present, it may not be necessary to describe all of these factors for every segment.

c) Based on the findings of #4b, assemble the information into logical road segments with homogeneous (or near homogeneous) characteristics.

Designation of surface-erosion ratings of described road segments follows a scheme adapted partially from Thompson (2000):

1) Establish a preliminary hazard rating using Table 3.7. These preliminary ratings do not consider grading and use patterns. Heavy use and inappropriate grading can increase the ratings beyond those determined with this approach.

Table 3.7 Preliminary road surface-erosion rating for moist ESSF sites (modified from Thompson, 2000).

Site Moisture Regime	Cutbank Height (m. with soil)	Fine Texture	Road Gradient (%)	Segment Surface Erosion Rating[1]			
				Coarse Fragment Content (%)			
				< 20	21-50	51-70	> 70[2]
mesic,subhygric, hygric,hydric	<= 3	all	all	VH	H	H	M
	> 3 m			VH	VH	VH	M
submesic, subxeric, xeric	<= 3	all	0-12	VH	H	M	L
			>12	VH	H	H	L
	> 3 m	Si,S,LS, or loose	all	VH	H	H	L
		all others	0-12	VH	H	M	L
			>12	VH	H	H	L

1 Expected erosion rates by rating are (m^3/km/yr): Very High >10; High 7-10; Moderate 4-7; Low <4. [2] Includes bedrock.

2) Reduce the rating for those road segments with partial revegetation as indicated in Table 3.8.

Table 3.8. Hazard reductions applied to account for revegetation.

Revegetation[1] (%)	Change in Hazard Rating
0-35	no change
36-70	reduce hazard by one class
71-90	reduce hazard by two classes
> 90	low hazard

[1] Combined revegetation of cutbank and road surface.

3) Reduce the rating for those road segments with partial connectivity as indicated in Table 3.9.

Table 3.9. Hazard reductions applied to account for incomplete connectivity.

Delivery[1,2]		Typical Characteristics of Ditchline	Change in hazard Rating
Class	%		
VH	> 90	direct and visible connection to a stream	no change
H	50-89	direct/visible connection during high runoff years only; only silt/clay remain on sediment train; direct delivery to floodplain active annually	reduce hazard by one class
M	10-49	most of sediment train is deposited behind obstructions on the forest floor; direct delivery to a floodplain which is infrequently active	reduce hazard by two classes
L	< 10	no direct connection to a stream	low hazard

1. Delivery is defined as the percentage of fine sediment (clay, silt, sand and fine gravels <3mm) delivered to any part of the stream network during freshet.

3.2.2 Interpretation of Road Hazards

The assessment of road hazard - by segment – is based on the combination of the segment's surface erosion ratings in addition to its potential for point source *creation* as a result of segment characteristics (see Appendix A3 for typical causes). Where surface erosion is the primary concern of a segment, the surface erosion rating converts directly to the road hazard. Where the creation of new point sources is the primary concern (including the perpetuation of existing point sources), the criteria provided in Table 3.10 are used to designate the segment's hazard.

Table 3.10. Criteria used to assess road hazard classes for those segments where point sources are the primary sedimentation concern.

Hazard Class	Typical Characteristics
Low	• few point sources with any connection to stream network • no indication of drainage diversions with consequence for stream sediment yield • dry and rocky, far from streams
Moderate	• small active sediment sources with direct connection to stream or larger sources with partial connectivity • drainage diversions likely to result in landslides with partial stream connectivity
High	• large active sediment sources with high delivery • drainage diversions likely to result in landslides which can reach the creek • steep, gullied terrain; steep road gradient
Very High	• intensive frequency of "high hazard" characteristics

Note: not all characteristics apply to each road segment in a given hazard class.

In the Glade watershed, almost all assessed roads create sediment sources from either surface erosion or point sources (not both) hence hazards presented on the Hydrologic Features and Sediment Sources Map are derived from either of these mechanisms, not both. The one exception to this is the road to the southwest of the study area which accesses the BC Hydro powerline – see section 4.1.

3.3 Riparian Assessment

For each reach, riparian hazard is assessed based on channel hazard and floodplain hazard. Observations to determine these hazards were made during field transects and supplemented with airphoto interpretation.

Channel Hazard

Determination of the channel hazard is made based on two component hazards: channel-wood and channel-stability hazards. Each component hazard is determined by examining the channel for three indicators as outlined in Table 3.11.

Table 3.11. Indicators used to determine the channel-hazard components.

Channel Wood	Channel Stability
absence of wood	avulsion channels
abundant small wood	bank erosion
dysfunctional wood	bars

(See Anon (1996b) for description of indicators).

For each of these component hazards, if two or more of its indicators are observed to be significant in the channel, the result is High, if only one indicator is observed, the outcome is Moderate (otherwise, the hazard is Low). Observations from the ReCAP (see Appendix A2) are used here. Using the two component hazards, the channel hazard is determined from Table 3.12.

Table 3.12. Determination of channel hazard component of the riparian hazard assessment.

		Channel Wood		
		L	**M**	**H**
Channel Stability	**L**	L	L	M
	M	L	M	H
	H	M	H	H

Floodplain Hazard

The floodplain hazard is based on a qualitative judgment of floodplain condition. Determination of this component hazard (Low, Moderate, or High) is based on observation of the following:

- reduced stocking (generally from forest harvest)
- extent of landsliding onto the floodplain
- loss of productivity (generally from road building)

Riparian Hazard (Integration)

The channel and riparian component hazards are combined using the matrix shown in Table 3.13.

Table 3.13. Determination of riparian hazard based on floodplain and channel component hazards.

		Floodplain Hazard		
		L	**M**	**H**
Channel Hazard	**L**	L	L	M
	M	L	M	H
	H	M	H	VH

3.4 Reconnaissance Channel Assessment

A hybrid approach to reconnaissance channel assessment is used which supplements BC's Channel Assessment Procedure (CAP, Anonymous 1996a) with additional observations and definitions developed by the authors. The approach involves three steps: identifying reach breaks, conducting field observations, and carrying out interpretations.

Preliminary reach breaks were established in the office based on the TRIM maps and air photos. Reaches are sections of channel homogeneous in their physical characteristics – these characteristics include gradient, channel form, riparian vegetation, bed materials, bank materials, confinement, and hillslope-to-channel coupling. In addition, confluences and changes in sediment supply can result in reach breaks. Although tentative reach breaks can be defined in advance of field work, they are expected to be substantially revised as a result of field observations.

Field observations included an assessment of channel disturbance according to the indicators provided in the CAP and additional observations in the form of detailed channel descriptions for selected reaches. All observations were carried out by foot traverse due to poor access to Glade Creek. All major channels were traversed sufficiently that each reach could be characterized as to its level of disturbance. The field work was carried out On October 9, 12, and 15 and November 3 and 13, 2000. The frequency of disturbance indicators and the detailed descriptions were used to identify the extent of disturbance existing in each reach.

Interpretations followed the CAP, supplemented by other quantitative measurements of channel bed, banks, and riparian areas. Definitions of these other parameters are provided in Appendix A1. These data were interpreted to provide additional objective measures of channel condition. Table 3.14 describes four non-dimensional indices employed (where available) to provide further insight into channel stability.

Table 3.14. Indicators and indices for channel-stability interpretations.

Indicator	Description	Index
Storage Capacity	ratio of bankfull width to bankfull depth	w_b/d_b
Transport Capacity	ratio of surface to subsurface mean bed grain-size	$d_{50,sfc}/d_{50,subsfc}$
Bed Stability	ratio of bed grain-size to bankfull depth	$d_{90,sfc}/d_b$
Entrenchment	ratio of gully width (at 1 m) to bankfull channel width	w_{1m}/w_b

3.5 Indicator Information, Hazard Interpretations, and Risk Assessment

Selected indicators are calculated for the hydrologic units under study as defined in Table 3.15. Using these indicators and other observations, hazards are determined for each unit. Four hazards are assessed: sediment sources, peak flow, riparian function, and channel instability.

Hazards are rated in four classes (low, moderate, high, and very high). In addition, the risk is assessed of increasing the current hazards with implementation of the proposed development. The increase or decrease in risk is assessed as none, insignificant, significant, or major.

3.6 Terrain Stability Reconnaissance Assessment

The structure locations and proposed clearing areas were reviewed on 1958 and 1999 airphotos. Observations in this report on structure site nos. 36, 37 and 42 to 45 are based on airphoto observations only. Ground checks were made of structure sites 37 to 41 inclusive and of the areas proposed for clearing near these sites, as well as selected areas upslope. In the areas to be cleared all the trees may be removed or they may be topped to ensure a minimum clearance below the power lines. For the purposes of risk assessment, it is assumed all the trees are to be cleared. Areas downslope of the proposed clearings where stability could potentially be affected were also checked.

The structure sites and clearing areas were flagged on the ground by Timberland Consultants Ltd. prior to the present assessment. Labeling of structure numbers on the ground differed from that shown on the maps from this study. Structure nos. 37 to 41 on the map are flagged on the ground as Nos. 32 to 36. For the purposes of this report the structure numbers used are those shown on the maps produced in this study. The mapped locations of structures are based on GPS locations by Timberland Consultants Ltd.

Table 3.15 Definitions of watershed indicators.

Indicator		Definition
ECA – unweighted	%	Equivalent clearcut area without a weighting factor
ECA –weighted	%	Equivalent clearcut area with areas above the H60 weighted 1.5
Total Road Density	km/km^2	Total density of haul and spur roads
Very-High Hazard Roads	km	Total length of very-high hazard roads
High Hazard Roads	km	Total length of high hazard roads
Moderate Hazard Roads	km	Total length of moderate hazard roads
Roads on Terrain Stability Class IV/V or on slopes above 60%	km/km^2	Density of roads on terrain with Class IV/V stability or on slopes over 60% (available mapping not consistent over the entire study area)
Density of TRIM Stream Crossings	no/km^2	Total density of TRIM stream crossings of haul and spur roads
Number of Landslides	no	Total number of landslides connected to streams
Disturbed Mainstem Channel	km	Total length of moderately- and severely-disturbed mainstem channel

The ground checks for this review were carried out by the author on October 12 and November 3, 2000. Weather conditions were good. There was a light dusting of snow above 1400 m elevation on November 3 but it did not interfere with assessment.

Observations on the ground were tied to structure locations using hip-chain measurements. The power line route was walked from the north clearing boundary of structure 37 to the south clearing boundary of structure 41. Shallow soil pits (50-60 cm in depth) were dug near each tower location to determine soil and terrain types. At each structure site and in the intermediate areas to be cleared, observations were made of slope gradient, drainage conditions, signs of existing instability, soil type and other parameters which might affect terrain stability. Steep areas upslope and downslope of the right-of-way were also assessed - particularly gully sidewalls where stability might be affected by additional groundwater loading resulting from clearing. Ratings of landslide hazard and risk were made based on conventions and criteria outlined in the British Columbia Mapping and Assessing Terrain Stability Guidebook (BC MoF 1995) and provincial guidelines for terrain stability field assessment of forest cutblocks. The ratings incorporate the author's experience in terrain stability assessment in areas of similar geology and climate in other parts of southeastern BC. Drainage ratings are based on the classes defined by the Luttmerding et al. (1990) and are the same as those used in terrain mapping in British Columbia.

4.0 ASSESSMENT COMPONENTS (IWAP)

This chapter provides the basic assessments required under the Interior Watershed Assessment Procedure – Anonymous 1999. Chapter 5 provides an additional assessment carried out on terrain stability in the vicinity of the proposed structures.

4.1 Sediment Source Assessment

Note: the terms of the present study did not allow the authors to view the high and very high road segments during the spring freshet, somewhat reducing the reliability of observations regarding road-related water diversions.

This section provides an overview of the sediment source history in Glade watershed and a description of the sediment sources active today and important to channel stability and water quality. This section should be read in conjunction with 2.4.

The 1934 forest fire likely caused a short-term increase in surface erosion and fine sediment delivery. It may also have been a contributing factor in some minor landslide events and debris-flood events as soil moisture was increased due to reduced transpiration, as snags began to fall into stream channels, and as root systems of trees killed by the fire decayed. However, trail building associated with forest harvesting and mining exploration during that time also created a number of landslides and channel disturbances that were potentially more significant sediment sources (see Appendix A3). Most of these problems have not been persistent. Roads were upgraded with machinery in the 1960s and 1970s causing some larger landslides to be delivered to the mainstem of Glade Creek including several reaching the lower mainstem. The BC Hydro power-line access road built in circa 1974 has been perhaps the most significant source of sediment to the lower Glade mainstem in the past 30 years. Debris slides and debris flows from this road have been persistent occurrences including re-occurrences within the past ten years. Most recently, in 1999 and 2000, a forest access road has been constructed in the headwaters of the Lower sub-basin causing significant sedimentation to the headwaters of the Lower Tributary.

Appendix A3 provides a summary of the characteristics of the point sources (all landslides) located during this study. As many as 11 of the 17 point sources remain vulnerable to further activity. In particular, sites 1 through 4 present the greatest likelihood of delivering sediment directly to the creek near the community water intake. Sites 2 and 3 are debris flows: Site 2 actually crossed the creek whereas Site 3 delivered only secondary sediment to the creek. Sites 5 through 7 were not field visited. Based on airphoto review it is judged that, although these sources are of low (or moderate) size, these sites could be reactivated and therefore they should be field examined. The debris slides at Sites 10 and 11 reached the Middle Tributary, Site 11 occurring within the last 20 years. Sites 12 through 14 are of low size and largely inactive but under the right conditions, could also reactivate. Sites 15 and 16 resulted from fillslope failures and are largely inactive today. Site 17 is a cutbank slump on the forest access road in the headwaters of the Lower sub-basin.

Appendix A4 provides the preliminary and adjusted surface-erosion ratings for the new road in the headwaters of the Lower sub-basin based on a 4-hour reconnaissance of its road characteristics. These surface erosion ratings translate into 140 m of very high hazard and 600 m of high hazard road segments in these headwater areas. The reconnaissance channel assessment noted that the sediment plume from these road segments has travelled over 400 m down the Lower Tributary.

Table 4.1 summarises the road segments according to their hazard ratings and concerns present.

The ongoing concerns at Sites 1 through 4 have resulted in the high hazard rating for road segment 1 and the middle part of road segment 3. Road segment 1 has been the major sediment source over the last ten years, having contributed to two, or possibly three major landslides. The top portion of the road is located under the powerline, directly above steep slopes down into Glade Creek and just upstream of a series of waterfalls and the community intake. The road is partially vegetated, and waterbarred under the powerline (755m). The final road section under the powerline was likely used as a landing for clearing the powerline right-of-way, and a staging area for construction of the powerline, resulting in a wide bladed area and extensive sidecasting. Fill and/or sidecast material from this landing area, combined with concentrated drainage from the waterbars, has contributed to the initiation of two debris flows downslope (within the last 15 years). The upstream slide (#3) deposited significant material on the main Glade Creek road below and on the flood plain of Glade Creek. Secondary erosion of these deposits has contributed sediment to Glade Creek, but it is difficult to estimate the amount. The downstream slide (#2) deposited significant material directly into Glade Creek, and onto the floodplain across the creek. A slump has also occurred on the fill of the lower road near the western side of the powerline clearing, and deposited material on a bench immediately above Glade Creek (#1). Concentrated and diverted drainage from waterbars on the upper powerline road may have contributed to this slide. There is also a similar slump just downstream on the road (#4). This area requires a coordinated drainage plan to avoid additional problems in relation to the roads on this steep hillslope. Road segment 2, the steeply-climbing powerline access road up to segment 1, is actively eroding and rilling in places; however, it is partially outside the Glade watershed and most of the sediment is dispersed on the extensive terrace below.

Table 4.1 Summary description of road segments according to their sediment source hazards.

Road Segments	Hazard	Dominant Concerns and Causes
Segments 1 and part of 3 (to the south of the Lower Mainstem)	High	debris flows, debris slides, and slumps from oversteepened fills and drainage diversions; further erosion of existing slide paths and headwalls; some drainage concentration
Segments 17 through 31 (headwaters of the Lower Sub-basin)	Very High to Low	significant surface erosion on new road mainly due to unfavourable rock type – eroding cutbanks, poorly vegetated, numerous creek crossings
Segments 6, 8, 14, and 16 (central watershed)	Moderate	evidence of past problems in the form of drainage diversions, fillslope failures, and/or landslides – may warrant attention
Segments 2, part of 3, 4, 5, 7, 9-13, and 15 (various locations)	Low	few or no issues evident; localized minor seepage interception and drainage diversions

Additional issues evident on road segment 3 include: unstable fill/sidecasting on steep slopes (70-100%+) over Glade Creek, cut slope slumps blocking the ditchline, interception and diversion of cutslope seepage and tension cracks in fill material.

Segments 17 through 31 are surfaced with a highly-weathered granodiorite which crushes to sand with vehicle traffic and is easily eroded into ditch and adjacent streams. These segments have no significant vegetative cover (some areas may have been grass seeded) and needle ice was actively adding sediment from the cut banks into the ditch at the time of assessment. During assessment, all parts of this road were active and being regularly graded. Road characteristics and good delivery resulted in the hazard ratings for these road segments – many of which are high and very high. Ron Ozanne (Atco Lumber Ltd.) has indicated that the road has been recontoured from the northern boundary of Block 4 to the end of the road (segments 26 through 29). In addition, semi-permanent deactivation (water barring) has been undertaken to the south of the boundary of CP 41-4 and within the Glade Creek watershed (segments 17 through 25). Segments 29 and 31 were not yet constructed at the time the field assessment was carried out. Additional action is likely required in the form of sediment trapping, ditchline de-connection to the stream network, re-establishment of natural drainage patterns, re-vegetation and possible sediment removal from the stream channel. The failing cutbank in road segment 24 has contributed to its very high hazard rating, although connectivity is minimal.

The moderate hazard segments scattered about the watershed have been problems at various times in the past and may cause problems in the future particularly during high-runoff freshets. Of these, segment

8 which was not field visited during this study is the segment most in need of field investigation. Segment 6 has minor old cutbank slumps and fillslope debris slides in addition to old rills which are now generally inactive due to reasonable revegetation – the fills could be pulled back in places but it is likely not worth the cost. Segment 14 is revegetated but the remaining (minor) drainage diversions and old tension cracks indicate that there remains the potential for further landslides. Again, the fills could be pulled back but the moderate hazard is likely not worth the cost. Similarly, further instability along segment 16 could occur (two landslides to date) although the field visit to the southern section of this segment suggested that there remained only minor drainage diversions.

The old roads (segments 10 and 11) in the northeast corner of the Upper Face Unit residual area are assumed to be mining exploration roads. Some of these roads were walked and no issues were encountered. There are no issues evident for Segment 9 from airphotos and this segment was not field visited. Segments 5 and 7 are generally revegetated and present no issues. Segment 13 (between the two upper crossings) is totally vegetated – there were old rills and water running on the road but no active erosion. Segment 15 is on a flat-to-gentle ridge crest and is revegetated with no issues. Segment 12 has some sections where the road is immediately adjacent to Glade Creek or a flood channel, sections where fill has been eroded by the creek, and a few minor debris slides from fill into the stream channel; however, these are all generally re-vegetated and stable at present.

The Upper Mainstem of Glade Creek contains a distributed series of sediment wedges which is partly responsible for a cycle of instability persisting in that channel (see 4.2.1). Additional sediment sources are being created in the form of bank cutting and are present throughout reaches 4, 5, and 6. These sediment wedges are dynamic and relatively small in size. It is not recommended that these wedges be addressed as the cost is very high and the probability of any intervention success is very low.

4.2 Reconnaissance Channel Assessment

As shown in longitudinal profile in Figure 4.1, the Mainstem of Glade Creek originates in Siwash Lake in the northeastern part of the watershed and flows north to a minor confluence with a headwater tributary. As the channel then flows southwest/west trend to its mouth at 455 m (at the Kootenay River), two significant tributaries flow into Glade Creek ("Upper Mainstem"). The confluence with the Middle Tributaries at 900 m contributes a minor increase to the total flow. The addition of the Lower Tributary at 775 m almost doubles the flow and creates a distinctly different channel in this lower section of the Mainstem ("Lower Mainstem").

The following sections provide detailed reach descriptions for the entire Mainstem and the Lower Tributary. Generalised descriptions of the Middle and Headwater Tributaries are also provided. Appendix A2 provides the basic field data on which are based the interpretations found in this section.

4.2.1 Mainstem

Overview

Ten reaches were identified between Kootenay River and the basin headwaters. Physical characteristics of each reach are provided in Table 4.2 along with their disturbance ratings. Figure 4.1 provides this information on a longitudinal profile of Glade Creek. These results show that 40% of surveyed reaches are moderately or severely aggraded/degraded. The majority of these disturbed sections were in reaches 4 through 6. Table A2.1b provides details on the presence/absence of disturbance indicators as recorded in the field. The channel was observed to have very high width-to-depth ratios (10 to 50) indicative of a lack of storage capacity due to aggradation. The stream is expected to have SPb-w and CPb-w morphology though functioning wood was severely reduced in the upper mainstem channel (reaches 4-6).

Figure 4.1: Longitudinal Profile of Glade Creek

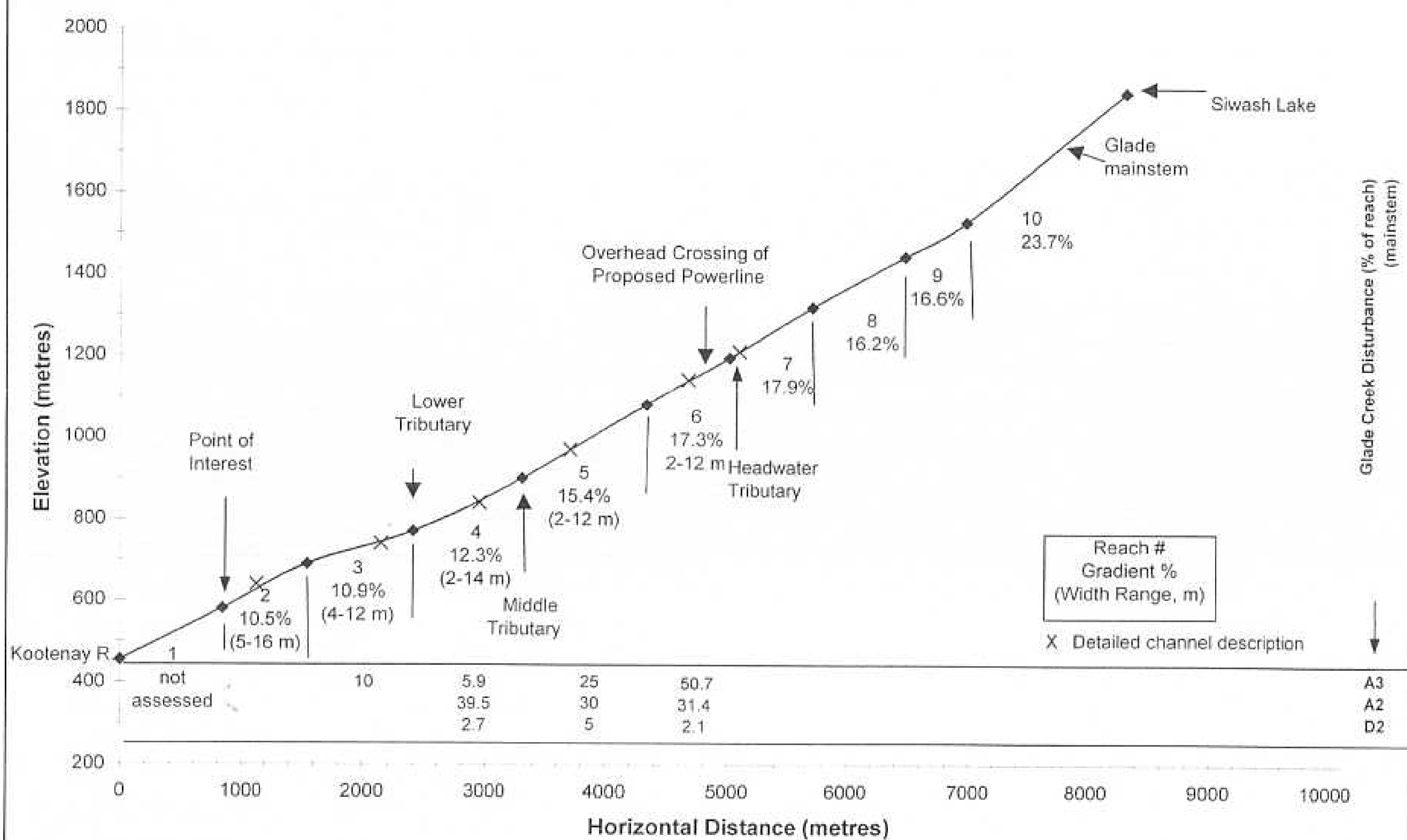

Table 4.2. Reach characteristics and disturbance levels for the Glade Creek mainstem.

Reach	Length	Elevation Range	Gradient (min,max)	Width (min,max)	Average Disturbance Ratings[1]						Descriptions Available
	m	m	%	m	A3	A2	A1	S	D1	D2	
1	1077	455-600	13.5	n/a							not assessed
2	726	600-690	10.5(8,120)	6.7(5,16)			18.3	76.7	5.0		1
3	604	690-770	10.9(5,16)	6.4(4,12)		10.0	24.3	60.7	5.0		2
4	910	770-900	12.3(5,22)	5.7(2,14)	5.9	39.5	27.3	18.6	5.9	2.7	3
5	1016	900-1080	15.4(5,28)	5.3(2,12)	25.0	30.0	22.3	10.0	7.7	5.0	4
6	657	1080-1195	17.3(10,25)	5.4(2,12)	50.7	31.4	12.1	1.4	2.1	2.1	5
7	700	1195-1320	17.9	n/a							6,7
8	770	1320-1445	16.2	n/a							not assessed
9	512	1445-1530	16.6	n/a							not assessed
10	1351	1530-1850	23.7	n/a							not assessed

[1] A3-severely aggraded; A2-moderately aggraded; A1-partially aggraded; S-stable; D1-partially aggraded; D2-moderately aggraded

<u>Reaches 8, 9, and 10</u>

These reaches were not field assessed.

<u>Reach 7</u>

Only the base of this reach was field visited in detail. The limited observations suggest a channel which has been disturbed in its lower sections (near reach 6) by forest harvest and road building in the gully bottom. (Channel Site 7 suggests that the condition of the channel improves considerably higher up however this is based on limited information.) A high mobile cobble load was observed in addition to limited step instability.

<u>Reach 6</u>

Channel condition deteriorates significantly below the confluence with the Headwater Tributary as it rapidly grows to a width of up to 12 m (average 6 m) with several threads. Many types of disturbance indicators are present as the step-pool channel migrates laterally on a wide gully bottom. The decline in channel stability begins at the former mill location (built in and adjacent to the creek) which is also the point where the gully bottom widens. Sediment wedges encourage avulsions while dysfunctional wood causes debris jams (and avulsions). Avulsion channels create bank cutting which contributes to the mobile sediment load. In addition, longterm wood recruitment is severely impaired due to extensive riparian harvest (probably from the 1930s). An old road (not field visited) lies above the right bank and providing former access to the vicinity of the confluence with the Headwater Tributary.

Channel stability improves somwehat through the reach. Average width actually declines steadily from 6 m at the top to 4.5 m at the base of the reach. There are occurrences of sections exhibiting good step-pool formation but these are regularly destabilised by the high mobile bed fraction and the problems with coarse woody debris noted above. The wide gully bottom is partly responsible for the continuation of this instability. It is common situation to see a well-formed step-pool channel on one side of the gully bottom, an active and unstable avulsion channel on the other side, and small channels connecting these two creating an, at times, problematic connection which tends to destabilise the formerly-stable step-pool channel. There is a wide range of step composition in this reach and about half of the steps are unstable. Old debris flow deposits may be present in the bottom of this reach.

Reach 5

There is a general improvement (over reach 6) with less of the bed affected by deposition and scour, clinging vegetation more common and bed packing slightly improved. Mobility continues to be high and about 25% of the steps are rated unstable (60% are composed of only rock). Bank cutting and slumping continue to be present with about 30% of the banks affected (see Chanel Site 4) – this helps to perpetuate the instability present in this channel.

The coupling of instability and stability is very clear in this reach. Gentler-gradient problematic sections alternate with pitches of steeper gradient where there is good and excellent step-pool formation. An unstable channel parallel to the stable channel is a common occurrence in the gentler-gradient sections. Pool extent is reasonable overall (15-35%).

The left bank rises steeply to the south. The right bank is open (to the north) with deciduous vegetation. This gully bottom has been heavily harvested (like reach 5) with a resulting reduced potential for longterm recruitment of coarse woody debris. At the top of this reach, there are several old landslides which have contributed material to the creek in decades past. A crossing was noted at the top of the reach with old roads likely present on both sides of the creek. These roads have tended to decrease bank stability through oversteepened fillslopes being undercut by the stream exacerbating the deficiency in recruitment of coarse woody debris. Bedrock was observed in the bed 375 m from the top of the reach.

Reach 4

This reach is situated between the confluences with the Middle and Lower Tributaries with many steep gullies rising on the left bank. The gully bottom is generally wider and flat in this reach with a lower average gradient (12%). These conditions encourage the lateral instability seen in reaches 5 and 6. In one location, two separate channel threads were observed stems (on a very wide gully bottom) with each stem separately avulsing. In other sections of the reach, a stable single stem was followed downstream by avulsions and instability.

Large boulders become more common at the base of the reach with a modest increase in stability. Bank cutting continues to be common as in the above reaches - the roots of large alder are undermined and delivered to the channel. Few large logs spans the creek and there remains little potential for this (from conifers) for about 100 years. There is evidence that suggests a significant sand load in transport at high flow.

Old roads are present in this gully bottom but present few issues of concern. The gully bottom has been heavily harvested and continues to be poorly-stocked. Old stumps can be seen being completely eroded out by avulsing channels. A crib in the channel immediately below the confluence with the Middle Tributary is failing progressively upstream.

Reach 3

A variety of factors change below the confluence with the Lower Tributary and bring a marked improvement in channel stability. Bed material coarsens significantly, steps become largely stable and composed of rock, the Entrenchment Ratio decreases, and the width-to-depth ratio declines to about 10. In addition, bank cutting is relatively minor and only 50% of the bed is now annually mobile. Dysfunctional wood and extensive bars remain common – here, however, they do not perpetuate a cycle of channel instability despite the doubling of the flowrate and the lower channel gradient. At the base of the reach, a large unstable bedrock failure reaches the creek on the right bank and contributes (potentially) stabilising angular material to the channel.

Old roads are again evident in this reach with little or no concerns in the present. The riparian areas have again been heavily harvested (with much reduced recruitment potential) but are in slightly better condition that in reach 4.

Reach 2

Improvement in channel condition continues in this reach with greater entrenchment and a width-to-depth ratio of only 9. The reduced access to this area likely meant that this area was not subject to the extensive riparian disturbance as seen in higher reaches. There is a much reduced frequency of indicators of instability. Some debris was observed and a reduction in the proportion of boulders on the bed. Old off-channel deposits, now vegetated with alder, suggest that this reach has seen greater material delivered to it in the past (10+ years ago) and that a period of relative decline in sediment movement may be underway. Bedrock occurrences are common in the bottom of this reach. The lowest 100 m of this reach (immediately above the community water intake) was not field visited. Several landslides have accessed the creek on the left bank near the top of the reach.

Reach 1 and the fan

Klohn Crippen (1996) provide a reconnaissance assessment for the Glade Creek fan based on airphoto interpretation. The following description is provided for this fan:

- length – 800 m; width – 650 m; average gradient – 8.75%; elevation range 440-510 m
- third order stream; active with several stream channels; incised; flat fan with steeper apex

Classified as fan type AD (a fluvial fan with a probability of being a debris torrent fan), it is interpreted as having a low hazard rating and a low damage rating (only 20% of the fan active). It was assigned an overall regional prioirty of low.

Only a portion of the reach below the Point of Interest was field visited and because the time made available for this was highly limited, these observations can only be considered preliminary. The first section is a bedrock section and includes the Glade Falls. There are no issues in this section as it is unaffected by channel instability. Below this, the fan is situated above the Kootenay River. The fan observations made here are generally consistent with the regional fan inventory. Multiple channels were common as was extensive bank erosion, channel migration, and levees. The fan appeared to have been active for many years. There is no development on or near these active and unstable channels.

4.2.2 Lower Tributary

Overview

Table 4.3 presents a morphological and disturbance summary of the Lower Tributary. The Lower Tributary extends from a small lake at 1870 m to its mouth with the Glade Creek Mainstem at 785 m. With a Storage Capacity Index of 13 to 17 (except in the first 400 m where there is sedimentation from the new forest access road), abundant clinging vegetation, and stoney banks, its characteristics suggest stability. Stability tends to increase downstream with the Entrenchment Index increasing and packing becoming tighter. In addition, the Bed Stability Index is highest in the lower four reaches, especially Reaches 2 through 4. About 50% of the bed material is lag material, probably from a combination of postglacial origin and debris-flood origin (late 1800s?). Bed stability is high despite a lack of recovery of riparian vegetation from logging in the mid-nineteenth century.

Reach 8

This reach is fed by a small lake at 1870 m and ends at the crossing of the recently-constructed forest access road. Although it was not field assessed, a brief examination of this channel immediately above the road crossing suggested a lag stream with little bed movement (heavily moss-covered, consistent with other channels viewed above the road). Its disturbance rating contrasts sharply with that of Reach 7 (just below the road crossing).

Table 4.3. Reach characteristics and disturbance levels for the Lower Tributary Creek.

Reach	Length	Elevation Range	Gradient (min,max)	Width (min,max)	Average Disturbance Ratings[1]						Descriptions Available
	m	m	%	m	A3	A2	A1	S	D1	D2	
1	1255	775-1000	16.1(9,23)	5.1(4,10)				100			8
2	1420	1000-1280	19(12,30)	4.7(2,10)			5.6	94.4			9,10
3	546	1280-1390	20.1	n/a				100			11
4	799	1390-1500	13.7(6,30)	3.6(2,7)				100			12,13
5	644	1500-1685	32.9(13,60)	4.1 (2,7)				100			
6	592	1685-1755	8.8(1,15)	3.9(2,6)		8.3	15.8	75.8			14
7	389	1755-1820	13.4(8,22)	3.2(.8,8)		66	21	13			15
8	547	1820-1970	27.4	n/a							not assessed

[1] A3-severely aggraded; A2-moderately aggraded; A1-partially aggraded; S-stable; D1-partially aggraded; D2-moderately aggraded

Reach 7

This headwater reach exhibits multi-channel behaviour with a mossy bouldery bed suggesting a prolonged state of bed stability. Flow is on a gentle gradient in an unconfined meandering stream. At times, there are several threads. Recent sand bars as a result of sedimentation from the newly-constructed road, are layered in and around these stable bed elements. Two tributaries flow in from the new block on the right bank. Channel Site 15 indicates about 25% of the bed is affected by deposition and all brightness (25%) is due to the recent activity of the mobile sand and fine gravels. Sedimentation from the new access road extends about 400 m down the channel.

Reach 6

This reach is similar to reach 7 however most threads have coalesced into one channel. Wood is abundant in this step-pool channel but is frequently not functioning as the stream lacks the power to move the wood. The channel continues to be resistant to instability due to the lag nature of the coarse bed and the stoney banks. The channel is sinuous and poorly confined. Sand bars from road construction continue in this reach. In addition, there are signs of earlier disturbance over the past few years (moss has been abraded off bed material). Lower in this reach, we see the development of an alluvial channel nested within a coarse stable bed substrate (see Channel Site 14). This remains a characteristic of the Lower Tributary throughout its length. The bed becomes coarser at the base of the reach.

Reach 5

Gradient steepens sharply in this reach (and to 50% in one location) as the channel flows across bedrock and large granitic (lag) boulders. The banks remain coarse and resistant to erosion. There are few or no signs of instability. There is abundant rotten wood unimportant, in this case, to channel stability. The canopy opens up over the creek in this reach. Alder is on both banks in many locations.

Reach 4

The channel gradient drops sharply in this reach consistent with the return to an alluvial channel (with far less lag material). Channel Sites 13 and 12 suggest an increase in mobile bed material with an attendant change from angular colluvially-derived material to sub-rounded and rounded fluvially-derived material (probably glaciofluvial). Steps are dominantly of stone composition and of high stability. There is little or no bank erosion due to the high cobble-boulder bank content. A tributary flows into this reach at 1435 m.

Reach 3

Only the top 100 m of this reach was field visited (Channel Site 11). Despite the almost-doubling in flow rate associated with the tributary at 1390 m, the characteristics of the channel appear to change very little from the reach above due to the lag nature of the bed material. Signs of earlier roads can be seen as high as the base of this reach.

Reach 2

This reach is characterised by extensive gullying in the till on the right gully sidewalls. Extensive lag deposits bring about multiple-thread behaviour as the channel routes around the deposits. Composed of rounded boulders and many glacial erratics, these deposits are highly stable and suggest an origin predating the period of logging. See Channel Site 10 for more details. Abandoned channels and small woody debris are present in the top half of the reach. Stumps are widespread in and near the gully bottom and have resulted in an open canopy over the creek. Stumps were observed atop levees. The canopy is open over the creek. Creek is confined among large boulders. Logging was particularly extensive on the right bank where the gully bottom extends out wide and flat. Limited wood is now available for recruitment however for channel stability this is not required due to the very coarse material in the channel and the entrenched nature of the flow. Roads are more clearly evident in the lower part of the reach but there are no concerns associated with these old trails, now barely visible. Also in the lower part of the reach we see multiple thread behaviour due to more deposits. Channel Site 9 is located at the base of this reach. The top 200 m of this channel were not field visited.

Reach 1

Disturbance indicators in this reach include multi-channel behaviour and a lack of functional wood however these have little effect on channel stability in this reach due to the continued presence of large lag material (about 50% of the bed). There is greater entrenchment here (than in reaches above) and a corresponding lower Storage Capacity Index (depth-to-width ratio). The Bed Stability Index and the Entrenchment Ratio both decrease suggesting a relatively deeper channel. A large amount of wood was observed spanning the channel in the lowest sections of the lowest kilometre of this reach. Excellent pool formation (from stone steps) was common despite the lack of functional wood. Debris piles were present throughout the reach. Roads were evident on both sides of the creek for large sections of this reach including spurs which may have crossed the creek. Several old landslide scars were found on the right bank which were a result of oversteepened road fills and drainage diversions. Time limitations meant that it was not possible to field visit this entire reach.

4.2.3 Middle Tributaries

Salway (1994) suggested using caution in managing the Middle Tributaries due to the high and extreme hazard interpretations which resulted from his channel and channel-gully field observations. Given this caution and the concentration of present proposed development within the vicinity of the Middle Tributaries, a reconnaissance field assessment was carried out for the Middle Tributaries. Channel Sites 16 through 21 are available as descriptions of the (main) Middle Tributary. Sites 22 through 25 provide descriptions of two of its side tributaries. Based on these observations, it was determined that reach delineation is unnecessary in the Middle Tributaries due to their homogeneous character and high degree of channel stability.

Most of the Middle Tributaries are entrenched colluvial lag channels with "underfit" streams: a large majority of the channel bed (of the Middle Tributaries viewed in the field) cannot be mobilised by contemporary flows. The Middle sub-basin was both harvested and burned earlier this century. The entire riparian zone was extensively logged. Highly-decomposed logging slash persists in the channels. In addition, evidence of roads (perhaps built without machinery) was found throughout most of the Middle tributaries visited. The limited streampower associated with these channels has resulted in gully bottoms with significant debris loads in terms of clastic colluvium and organic debris. At the higher-elevation sites on the main Middle Tributary, the Storage Capacity and Bed stability Indices both show increases while the Entrenchment Index decreases – these changes and others (angularity, packing, etc.) are consistent with the lag nature of the channel and an increasingly stable structure/bed. For the smaller tributaries, these indices generally have values which suggest even greater stability.

Scars from a few old debris slides were found in this area and patchy soil creep was noted (see Chapter 5). Bedrock was commonly observed at many locations on gully sidewalls (e.g., above site 18). No evidence of debris flows was observed anywhere in the Middle Tributary sub-basin.

Although dominantly lag channels, these gully bottoms also possess smaller alluvial channels intimately associated with the colluvium and organic debris. Particularly higher up the Middle Tributary itself, the bed of this "overstorey" channel sits atop unstable and rotting woody debris most of which is assumed to have derived from early logging slash. This creates an instability in the smaller channel as it breaks through its weak bed and as the unstable wood steps collapse. This instability of the overstorey channel has little consequence for Glade Creek due to the extensive sediment trapping opportunities in this diverse and coarse gully bottom. Although of limited significance with respect to the proposed development, the relative size of this nested alluvial channel grows closer to Channel Site 17.

The lowest 400 m of the Middle Tributary has a different character to the other assessed Middle Tributaries. Bed mobility is high at over 60% and the bed material is subangular/subrounded. The Entrenchment Index is higher suggesting a wider gully bottom. The significant bank cutting suggested a flashy response and/or more erodible banks perhaps consistent with the more U-shaped gully morphology. Step stability is, however, higher due to the greater frequency of stone steps and reduced frequency of rotten slash from early logging. Given the severe impacts on the riparian vegetation from last-century logging, it will be many decades before long-term wood recruitment is restored to natural levels. In summary, this short section of the Middle Tributary shows a slightly higher sensitivity to peak-flow changes (than the other Middle Tributaries) and is closer to the Glade mainstem, however, the concern here remains relatively unimportant and limited to only small potential impacts on water quality.

4.2.4 Headwater Tributary

Only 600 m of this channel was field reviewed. Channel Sites 26 and 27 are provided. There were signs of past disturbance in the form of mobile material and logging slash. The channel became less disturbed as it came closer to the Mainstem. The disturbance is assumed to be historic and related to mining and/or logging activities.

4.3 Riparian Assessment

Riparian hazards are provided in Table 4.4 for each reach which was field visited.

Extensive removal of riparian vegetation especially during the 1930s has been followed by spotty regrowth. As a result, there is a deficit recruitment of coarse woody debris to the channel in addition to a loss of long-term recruitment potential in the form of large coniferous trees. Riparian vegetation will take up to 150 years to recover to a cedar-hemlock stand consistent with its pre-disturbance condition. This contemporary condition has resulted in a moderate floodplain hazard for many of the study reaches. Reaches 4 through 6 of the Upper Mainstem have seen poor regrowth and a number landslides and as a result, is rated high. The Reaches 4 through 7 of the Lower Tributary have been relatively unlogged and maintain a low floodplain hazard.

In contrast to the low channel hazard of the Lower and Middle Tributaries, the Mainstem exhibits largely high and moderate channel hazards. With the associated floodplain hazards, there results very high and moderate riparian hazards in reaches 2 through 7.

Note that although the Middle Tributary is dominantly deciduous today due to heavy harvest and poor regeneration in the early part of the last century, the small flow rates and the entrenched and lag nature of this channel (and its side channels) means that coarse woody debris does not play a key role here. in addition, although there appears to have been extensive riparian road disturbance in this area, most or all of the road disturbance has rehabilitated itself naturally.

Table 4.4. Riparian hazards for field-assessed reaches.

Stream	Reach	Channel Hazard			Floodplain Hazard	Overall Riparian Hazard
		Stability	Wood	Overall		
Mainstem	2	L	L	L	L	**L**
	3	M	M	M	M	**M**
	4	H	H	H	H	**VH**
	5	H	H	H	H	**VH**
	6	H	H	H	H	**VH**
	7	M	M	M	M	**M**
Lower Tributary	1	L	M	L	M	**L**
	2	L	L	L	M	**L**
	3	L	L	L	M	**L**
	4	L	L	L	L	**L**
	5	L	L	L	L	**L**
	6	M	L	L	L	**L**
	7	M	L	L	L	**L**
Middle Tributaries	-	L	L	L	M	**L**
Headwater Tributary	-	M	M	M	M	**M**

4.4 Peak Flow Assessment

An extensive 1934 forest fire combined with forest harvest during the same period resulted in a weighted ECA in 1958 for the entire drainage of over 50% (according to the 1958 airphotos). The watershed continues to recover from this loss of forest cover with a weighted ECA today of 16.3% - refer to Table 6.1. Many of the burned and harvested areas are on south-facing exposures (particularly in the Upper Glade watershed) and have slow rates of regeneration to coniferous stands. These deciduous areas are contributing to a flashy hydrologic response in the Upper Glade watershed.

The Glade Mainstem is unstable particularly above its confluence with the Lower Tributary. This instability may persist for some time because the long-term potential recruitment of coarse woody debris has been severely reduced by riparian harvest. Other channels (e.g., the Lower Tributary and most of the Middle Tributaries) are not as sensitive to peak flow changes due to their channel characteristics which largely maintain stability. As a result, the Mainstem channel is sensitive to increases in the peak-flow regime: increases can be expected to cause an increased incidence of channel avulsions and likely contribute to maintaining mobile the in-channel sediment supply and creating new sources (e.g., bank erosion). Until the accessibility and/or mobility of these deposits decline and until the wood recruitment/function within this channel improves (natural channel processes), it is expected that increases in peak flow will be problematic. Some of the roads adjacent to the channel are contributing to the bank erosion through undercutting of steepened fillslopes. Also, bed re-mobilisation and the re-formation of sediment wedges can work to recruit new material due to bank erosion and in extreme cases, cause channel avulsions onto the floodplain, thereby prolonging the channel instability.

The Lower Mainstem is far more stable than the Upper Mainstem although reach 3 does exhibit signs of partial aggradation/degradation.

5.0 RECONNAISSANCE TERRAIN STABILITY ASSESSMENT

5.1 Introduction

This section describes a reconnaissance assessment (supplemental to the watershed assessment) of terrain stability within the Glade Creek watershed along the proposed power-line right-of-way. The objective of the assessment was twofold:

- To determine the risk to proposed structures of existing terrain instability.
- To determine the risk to the Glade watershed of terrain instability and surface erosion as a result of the proposed clearings.

The proposed power-line route is shown on the *Hydrologic Recovery and Proposed Development Map*. Also shown are the numbered locations of structures (steel pylons/towers) proposed for construction in the watershed (35 through 43) in addition to locations 44 and 45. The structures are to be constructed using a helicopter with long power-line spans.

Terrain stability in the area of structures 35, 36, 42, 43, 44 and 45 was reviewed based only on airphoto interpretation. The terrain in the vicinity of structures 37,38,39, 40 and 41 was field checked.

Level C terrain mapping of part the Glade drainage has completed by Apex Geoscience (2000) however, the right-of-way of the powerline is entirely outside the area mapped.

5.2 Observations

Observations of terrain materials, drainage, slope gradient and interpretations of landslide hazard at each structure site are summarized in Table 5.1. The table is supported by a discussion of the drainage and the few instability features seen in the areas where ground checks were made.

5.2.1 Instability Features

On the steep south sidewalls of the gullies 10 m and 90 m north of site 38 there have been minor, isolated, old, shallow (< 0.5-m deep) debris sloughs as indicated by thin Bf/Bm layers or the absence of developed soil layers. These were noted on the gully sidewalls both in the area to be cleared and downslope of the area to be cleared. Most of the sloughs predate the current forest rotation which is about 60-80 years old. There has also been very minor soil creep on the gully sidewalls, as indicated by occasional 'swept' and pistol-butted tree trunks, in isolated small patches. The soil creep and some of the sloughing occurred early following the last major fire in the area, when root strength would have been low.

No other significant instability features were seen at, or close to, structure sites 37 to 41. There are no indications on airphotos of significant instability in close vicinity to sites 35, 36 and 42 to 44.There are no indications of recent or historical debris flows in the gullies north of site 38 nor in the gullies of the tributaries to the Middle Tributary crossed by the right-of-way between sites 38 and 40.

5.2.2 Drainage

Drainage is rated "well" on sites 35 to 39 and in most of the areas between these sites. On site 41, it is rated rapid. In the areas to be cleared near sites 37 to 39 and from about 30 m north of site 41 to the south clearing boundary of site 41 drainage is mostly rated well. It is rated imperfect-to-poor at seepage sites in the bottom of the deeper gullies between the north clearing boundary of site 37 and site 38. Most of the section from the north clearing boundary of site 40 to 175 m south of site 40 is rated "well" but there are small areas of seepage where drainage is rated "imperfect" to "poor". These areas of poorer drainage are on moderate-gradient slopes, generally < 45%. There is a small pond at 65 m north of site 40 on slopes of only 10-20% gradient.

Table 5.1 Summary of observations from terrain stability assessment.

Structure No.	Field or Airphoto review	Slope	Aspect	Landform	Texture	Coarse Fragment Content[1]	Drain-age	Depth to Bedrock (est.)	Instability Features?[2]	Residual Landslide Hazard[3]	Comment
	(F/AP)	%,down	°			%		m	(Y/N)		
35	AP	>60	westerly	colluvium and bedrock		high	well	<.1.0m	N	low	
36	AP	>60	westerly	colluvium and bedrock		high	well	<.1.0m	N	low	
37	F	40-45	westerly	till blanket	silty sand; <2% clay	g: 15-20 c: 5-10	well	> 3.0 m	N	low	
38	F	55	315	gullied till blanket	silty sand; <2% clay	g: 15-20 c: 5	well	> 3.0 m	Y	low at site; moderate on gully wall 10-20 m north of site.	Slope break into deep gully 10-20 m north of structure site. South sidewall of gully has slopes of 70-90%. Minor >50-100 year old sloughs and soil creep on gully sidewall. Several other gullies between site 37 and 38
39	F	40-45	260	colluvial veneer (probably over till blanket)	silty sand	g: 40-45 ang & sub-ang c: 15-20	well	1-2 m	N	low	On ridge crest
40	F	55	355	colluvial blanket over bedrock	silty sand	g: 20 c: 30-35 b: 5	well	1-2 m	N	low	Bedrock is exposed about 10 m upslope of structure site. Bedrock is hard, has low fracture density
41	F	up15 dn55	240	colluvial and saprolitic veneer over bedrock	silty sand	angular rubble: 60	rapid	< 0.5 m	N	low	Bedrock is exposed at structure site, low fracture density
42	AP	45-60	NW-erly	till and colluvium?					N	low	
43	AP	<45	NW-erly	till					N	low	
44	AP	<45	NW-erly	till					N	low	
45	AP	<45	NW-erly	till					N	low	

[1] g – gravel; c – cobble; b – boulder [2] see text for details [3] following proposed clearing of the right of way

5.3 Risk Assessment

5.3.1 Terrain Stability

The structure sites and clearings are planned for areas which, in the system of terrain mapping used in British Columbia, are classed predominantly as terrain stability class II and III, with small areas of class IV. (There are five classes in this rating system ranging from I, most stable, to V, least stable.) The areas of class IV are the deep gullies between sites 37 and 38. Where the power-lines cross the Middle tributaries between sites 38 and 40 there are areas of class IV on the steep gully sidewalls. These areas however, are not areas planned for clearings or structures.

The landslide hazard at sites 37 to 41 and the adjacent areas to be cleared is rated low, except in some gullies near site 38 as described in the next paragraph. Based on airphoto interpretation, the landslide hazard is rated low at structure sites 35, 36 and 42 to 45. These ratings are subject to ground confirmation. Drainage is rated well in most of the steeper areas to be cleared from sites 37 to 41. The expected increase in snowpack resulting from the proposed clearing of the power-line right-of-way is not likely to significantly change the potential for groundwater saturation or landslide hazard.

The landslide hazard on the sidewalls of the major gullies 10 m and 90 m north of site 38 is rated moderate. Following clearing of the power-line right-of-way near site 38, there will be an insignificant increase in landslide hazard in the gullies. After the last major forest fire in the area, when there was higher groundwater loading due to the lack of forest cover, there were only very minor sloughs in the gullies. If a landslide were to occur on the gully sidewalls there is a very low probability that it would be large enough to destabilize structure site 38 or cause a debris flow able to reach tributaries of Glade Creek.

5.3.2 Surface Erosion and Sediment Delivery Hazards

The proposed clearing and tower construction will not cause any significant increase in surface erosion in areas with connection to the Glade Creek stream network.

5.3.3 Limitations and Reliability

The ratings in this report of landslide hazard and risk are estimates based on inferences made from soil pits and field observations at the structure sites and in areas which are to be cleared near the structures. Material textures and coarse fragment content as shown in this report are estimates based on field hand texturing and observation. Reasonable effort has been made to ensure that the observations are representative and that the critical areas were checked. There is a possibility that the inferences do not accurately reflect conditions because of natural variation in soil and geologic conditions.

The estimates of hazard are based on ground observations and this author's (Dave Putt) experience of landslide hazard in similar soils and terrain in other parts of southeastern British Columbia. The hazard ratings are considered to be at a reconnaissance level adequate for decisions about routing of the power-line. If it is decided to proceed with construction of the power-line, it is assumed that detailed engineering assessment of the structure locations will be completed as part of the design process.

This report has been prepared in accordance with generally accepted practices for assessment of terrain stability hazards and risk. No other warranty, expressed or implied, is made.

5.4 Conclusion and Recommendations

The results of this reconnaissance assessment support the present choice of power-line alignment and justify proceeding to the next step of detailed design and ground-based assessment. This next step would involve, in part, detailed assessment at each site, of the engineering properties of the surficial materials and bedrock using standard engineering design practices. During this next stage, it is recommended that the following be addressed:

- Carry out a field review to confirm the interpretations of terrain stability hazard at structure sites 36, 37, 42, 43, 44 and 45, which were not ground-checked in this study.

- Investigate moving structure 38 to a location about 20 m to the south of the location flagged in the field. This would provide additional distance from the steep-walled gully just north of the present location and provide an additional margin of safety to ensure that the structure site will remain stable.

6.0 INDICATORS, INTERPRETATIONS, & RECOMMENDATIONS

6.1 Indicator Results and Hazard Interpretations – Existing Condition

Table 6.1 summarizes development indicators for Glade Creek basin under existing and proposed development. Weighted ECA is calculated at 16.3% and would rise to 16.7% with the proposed development. This ECA derives from the residual effects of a forest fire in 1934 in addition to harvesting in the mid-twentieth century.

Road indicators are generally low-to-moderate. Total road density would not increase with the proposed development. There exist 148 m of roads with very-high hazard of sediment delivery, 1452 m of roads with high hazard of sediment delivery, and 2313 m of moderate hazard roads. In addition, there is currently 0.08 km/km^2 of roads on Class IV/V terrain (including slopes over 60%) which would remain unchanged with the proposed development.

Based on these indicators and on the observations of the channel reconnaissance, hydrologic hazards have been identified as summarized in Table 5.2. Peak Flow, Sediment Sources, Channel Instability, and Riparian hazards all rate between low and very high.

Table 6.2. Glade Creek Watershed hazard ratings and main causal factors.

Impact Category	Hazard Index	Main Causal Factors
Sediment Sources	Moderate	drainage diversions, fillslope failures below BC Hydro powerline access road; surface erosion from new access road in headwaters of Lower Tributary; Mainstem instability
Peak Flow	Low-Moderate	incomplete recovery from 1934 forest fire and riparian harvest; instability in mainstem particularly above the Lower Tributary confluence
Riparian Function	Low to Very High	widespread reduction in riparian forest cover due to forest harvest and poor recovery; major concern where channel stability is poor and recovery depends on recruitment of coarse woody debris
Channel Instability	Low & High	self-perpetuating disturbance in Mainstem (creating avulsions & sediment sources); impaired wood recruitment

The channel instability visible today in the Upper Mainstem above the Lower Tributary was likely initiated by riparian disturbance associated with forest harvest in the 1930s. The millsite in reach 6 and the landslides in reach 5 may have contributed further to this instability. The lack of recovery to a coniferous stand combined with the persistence of deciduous vegetation on south-facing slopes have likely reduced stability further and increased the speed of hydrologic response (locally-high ECA). The fan shows a history of instability although airphoto interpretation suggests that it may be largely a result of local fan land0use disturbance. Avoidance of further riparian disturbance including avoiding any further sediment inputs into the Mainstem would help speed recovery of this unstable channel.

Table 6.1. Report card for Glade Creek Watershed.

Indicator	Units	Existing							Proposed			
		Siwash Sub-Basin	Middle Sub-basin	Upper Face Units	Upper Glade	Lower Face Units	Lower Sub-Basin	Total Glade	Middle Sub-basin	Upper Glade	Lower Sub-Basin	Total Glade
Area	ha	555.1	272.1	727.1	1554.3	97.7	1309.3	2961.4				
Private Land	%	0	0	0	0	4.6	4.2	2.0				
ECA[1] – unweighted	%	5.1	7.7	21.1	13.0	34.9	11.1	12.9	8.9	13.4	11.4	13.2
ECA[1] –weighted	%	7.5	9.3	23.9	15.5	34.9	15.9	16.3	10.6	15.9	16.2	16.7
Total road density	km/km²	0.00	0.00	1.01	0.47	2.39	0.39	0.50	0.00	0.47	0.39	0.50
Very high hazard roads	km	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.00	0.00	0.15	0.15
High hazard roads	km	0.00	0.00	0.00	0.00	0.28	1.17	2.45	0.00	0.00	1.17	2.45
Moderate hazard roads	km	0.00	0.00	1.43	1.43	0.31	1.47	3.21	0.00	1.43	1.47	3.21
Roads on Terrain Stability Class IV/V or above 60%	km/km²	0.00	0.00	0.12	0.06	0.05	0.08	0.08	0.00	0.06	0.08	0.08
Density of TRIM Stream Crossings	no/km²	0.0	0.0	0.69	0.32	2.05	0.31	0.37	0.0	0.32	0.31	0.37
Number of Landslides	no.	2	2	6	10	4	3	17				
Length of Disturbed Mainstem[2]	km	0.0	0.0	1.66	1.66	0.06	0.07	1.79				

[1] Disturbed is defined as A2, A3, D2, or D3 – see Anonymous (1996b) for details.

In contrast, the Lower Tributary exhibits few signs of channel instability. Concerns with the Lower Tributary involve the movement of fine sediment (notably fine sand) from the headwaters through to the community intake. There are sedimentation problems associated with the new forest access road in its headwaters. If these are not addressed, they can be expected to show up in reduced water quality at the intake within 5-10 years. Although some riparian functions have been impaired by forest harvest (e.g., shading, recruitment of coarse woody debris), this deterioration does not have significant consequences for channel stability in this creek due to the stable nature of the existing bed material. ECA changes in the Lower sub-basin are most significant with respect to how they may affect the ECA for the lower Glade mainstem (rather than the Lower Tributary channel itself).

The Middle Tributaries, although most are physically stable, have been heavily impacted by riparian harvest. Avoiding riparian areas in these channels would speed the recovery of riparian functions in these lag tributaries and would facilitate the improvement of the lower Middle Tributary which is an alluvial channel. ECA changes in the Middle sub-basin are particularly important with respect to how they may affect the ECA for the Upper Mainstem (rather than the lower Middle Tributary channel itself).

Although the peak-flow hazard is now rated low-moderate, the upper mainstem is not stable and any changes in peak flow can have a potentially greater effect on the channel than they would under pre-disturbance channel-stability conditions.

6.2 Risk Assessment - Proposed Development

6.2.1 Description of Proposed Development

The proposed development consists of clearings in the Lower sub-basin (4.18 ha), the Middle sub-basin (4.05 ha), and the Upper Face Units (4.15 ha). In addition, nine structures are proposed to support a powerline including long lines of up to 1.8 km in length. In Chapter 5, it was found that the openings and the structures pose a low hazard for increased sedimentation from both surface erosion and terrain stability. The present risk assessment addresses only the risk of the proposed clearings and assumes that the structures and powerline can be put in place with no effect on the channel system. Of the total 12.38 ha proposed for clearings, 22.2% lies above the H60 line.

6.2.2 Risk Assessment

Table 5.3 provides the level of risk associated with the proposed development by hazard class. The increase in the risk of peak flows is rated as insignificant because the ECA goes up by only 0.4% and remains well below 20% (a "threshold" of potential concern).

Table 6.3. Risk due to development proposed for the Glade Creek drainage.

Indicator	Existing Hazard	Proposed Development	
		Associated Risk[1]	Resulting Hazard
Sediment Sources	M	(+)	M
Peak Flow	L-M	(+)	L-M
Channel Instability	L & H	(+)	L & H
Riparian Function	L-VH	o	L - VH

[1] Associated risk: o – none; (+) – insignificant increase; + – significant increase; ++ – major increase; (-) – insignificant decrease; "-" – significant decrease; "- -" – major decrease

The associated risk to channel instability is closely tied to the peak-flow risk (given the lack of proposed roads and of any proposed activities in riparian areas) and relates largely to the unstable Glade Creek mainstem. The riparian hazard is currently variable in the watershed and would remain unchanged with the proposed development. The associated risk to Sediment Sources would be insignificant due to the lack of proposed roads and the low probability that the proposed clearings would cause slope instability able to impact the Mainstem.

6.2.3 Specific Risk-Reduction Opportunities

The opportunities for reducing the risks associated specifically with the proposed development are limited because the proposed development presents minor incremental hydrological risks to the Glade Creek watershed. There are, however, existing background risks which can be reduced through time if certain activities are pursued. These may be especially attractive if and when additional forest development is pursued in the drainage.

1) Develop and implement a comprehensive hillslope drainage plan in the vicinity of road segments 1 & 3. Prevent drainage diversions which create hillslope instability. Include consideration of road rehabilitation where appropriate (e.g., pullback).

2) Develop and implement a sediment control plan for the forest access road in the headwaters of the Lower Tributary (segments 17 through 31). This plan could include various approaches such as deactivation, sediment trapping, modifying surfacing materials, and improved grading techniques. Consider hand cleaning the recent sand deposits from the channel.

3) Review the moderate hazard road sections to determine what steps, if any, are possible to reduce the likelihood of induced hillslope instability. If budget is limited, focus on road segment 8 near the existing unassessed landslides.

6.2.4 Development Strategies, Limitations, and Opportunities

Strategies

It is best to avoid development which involves the following:

* - harvesting in riparian areas of the Mainstem, notably within one tree-height on either side of the mainstem creek and within gully-bottom areas.
- the production of sediment sources which may reach the Mainstem (and Middle Tributary).

if it becomes necessary to carefully manage ECA increases, consider harvest below the H60 line (to limit the ECA contribution) and consider single-tree or group selection (preferably with >70% retention) to limit ECA increments especially in the Upper Glade watershed (above the Lower Tributary confluence)

Before further development is planned, it is recommended that Level B or C terrain mapping be completed for the watershed (western portion) and used to best locate development proposals in order to emphasise terrain outside areas of high and very high hazard of sediment yield and to avoid stream crossings in areas of high and very-high potential of sediment delivery or of landslide-induced stream sedimentation (or of both). Where it is not possible to avoid these areas, Level A Terrain Stability Field Assessments should be carried out to confirm the terrain mapping and prescribe detailed mitigation measures which prevent sediment delivery to the channel network.

In the future, improved monitoring of both channel condition (especially its lateral and vertical stability) and water quality can be helpful in evaluating the success and advisability of any further interventions. If pursued, selection of a channel segment upstream of the Lower Tributary confluence would maximise the sensitivity of the monitored reach. Immediately above the intake would be the best locations for water-quality monitoring.

If development is pursued in the Upper Glade watershed, use existing roads where possible. For instance, there are roads which can be accessed from Connor Creek which should help to limit the need to construct new road segments in the watershed. As greater channel stability returns to the Mainstem, this consideration becomes less important.

Limitations

Assuming that recovery of the channel is the highest priority and assuming that channel recovery will be the fastest without additional stress due to higher peak flows, it is suggested that an objective of maintaining weighted ECA of the Upper Glade watershed below 20% would allow maximum speed of channel recovery. (At 20%, changes to peak flows are often measurable.) The fan should be field assessed to determine its stability in relation to any land-use implications. Until that assessment is available, maintain an ECA for the entire Glade watershed below 20% - re-evaluate this limit in light of the fan assessment results. There are no suggested limits for the Lower Tributary though its ECA will factor into limits for the (total) Glade watershed. In addition, to limit any peak flow changes to the lower Middle Tributary (alluvial channel), it is suggested that the weighted ECA in the Middle sub-basin be maintained below 25%.

Opportunities

For future access, rather than reconstructing access in the lower part of the watershed near the main stream channels, use existing access at ridge crests and upper saddles from nearby adjacent watersheds (e.g. Connor Creek, Snowwater, Midas and McPhee Creeks).

6.3 Recommendations

1) Develop and implement a comprehensive hillslope drainage plan in the vicinity of road segments 1 & 3.

2) Develop and implement a sediment control plan for the forest access road in the headwaters of the Lower Tributary (road segments 17 through 31).

3) Encourage recovery of channel stability in the Upper Mainstem by:

- maintaining weighted ECA below 20% above the Lower Tributary confluence
- avoiding harvest and road building in riparian areas adjacent to the Mainstem; and
- avoid sediment delivery to the Mainstem.

4) Review the moderate hazard road sections to determine what steps, if any, are possible to reduce the likelihood of induced hillslope instability - focus on road segment 8 and the unassessed landslides.

5) Field assess the fan for stability and its implications. Until that assessment is available, maintain an ECA for the entire Glade watershed below 20% - re-evaluate this limit in light of the fan assessment results.

6) Complete the Level B or C terrain mapping for the eastern portion of the drainage. Use the complete mapping in planning any future development proposals.

7) Initiate comprehensive monitoring (and appropriate data analysis) of channel stability through detailed monitoring of sensitive sections of the Glade mainstem through time. For example, detailed assessment (CAP) on selected disturbed reaches (in reach 4) and use the observations to monitor creek recovery through time. Also consider water quality monitoring at the community intake.

8) If new road construction is planned, pursue "best pratices" for road location and construction to minimize the risk posed by new roads. For example:

- avoid locating roads and stream crossings in areas of high and very-high potential of either sediment delivery, or landslide-induced stream sedimentation, or both
- avoid locating roads in riparian areas
- avoid drainage interception and diversion
- minimize soil disturbance & revegetate promptly
- maintain roads or "put-them-to-bed"

The results of this study indicate that the proposed development does not significantly increase the existing hydrologic risk to Glade Creek and its water quantity, quality, and timing of flow. However, this study has identified significant ongoing and potential sediment sources that should be addressed to prevent further deterioration of the Glade Creek stream channel and water quality.

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Respectfully submitted, (January 8, 2001)

Martin Carver, Ph.D., P.Eng., P.Ag.
Carver Consulting

Greg Utzig, P.Ag.
Kutenai nature Investigations Ltd.

Dave J. Putt, P.Geo., P.Ag.
Forterra Consultants Ltd.

APPENDIX A1. DEFINITIONS OF CHANNEL DESCRIPTION VARIABLES

Gradient: Gradient of the reach as measured between its end points; a min or a max is recorded only where a departure exists for at least 10 m exists

Width and Depth (w_b and d_b): Both determined at bankfull height; bankfull height is based on a combination of changes in vegetation, gradient, and the surface

Channel Type: In their undisturbed state, the bed of these steep, alluvial channels is dominantly composed of boulders and cobbles. The definitions below generally follow Montgomery and Buffington (1997).

step pool (S): steps with pools; primary oscillation is vertical; mostly boulders and cobbles

cascade (C): stone lines with pools separated typically by at least one w_b; flow unable to concentrate; mostly cobbles and boulders

lag (L): material moved colluvially and not significantly reworked by streamflow (non-alluvial); there may be a mobile fraction of bed sediment finer than the colluvial bed material

bedrock (B): bed composed of bedrock; inerodible and non-alluvial

Bed Composition (by %): Bolded numbers indicate full-fraction mobility; italicized numbers indicate partial-fraction mobility. Mobile sizes are summed to determine the % of the bed that is mobile. The percentage of the bed composed of each of the following:

LB - large boulders (> 100 cm on the b axis)	S - sand
SB - small boulders (25 -100)	M - muck - includes silt, clay & fine organic matter
LC - large cobbles (15 - 25)	FF - forest floor
SC - small cobbles (7.5 -15)	W - wood
CG -coarse gravels (2.5 - 7.5)	BR - bedrock
FG - fine gravels (0.25 - 2.5)	Sub - subsurface flow

Brightness (%): percentage of the clastic bed which appears bright: newly exposed, lacking vegetation & organic stains

Clinging Vegetation: The abundance of the clastic bed that is covered with by moss or algae:

none (n) - clinging plants are rarely found anywhere in the reach.

sparse (s) - plants are found but their occurrence is spotty. They are almost totally absent from rocks in the swifter portions of the reach and may also be absent in some of the slow and still water areas.

common (c) - plants are quite common in the slower portions of the reach but thin out or are absent in the swift portions of the stream.

abundant (a) - Clinging plants are abundant throughout the reach from bank to bank. A continuous mat of vegetation is not required but moss and/or algae are readily seen in all directions across the stream.

Angularity 1, 2: Four classes of angularity observed in the reach:

angular (a) - flattened faces with sharp edges and corners; plane surfaces roughened

subangular (sa) - slightly rounded points of intersection of subrectangular faces; surfaces smooth and flat

subrounded (sr) - well rounded in two dimensions

rounded (r) - well-rounded in three dimensions; surfaces smooth

Deposition and Scour: The percentage of the area of the entire bed that is affected by each of scour & deposition (includes pools and bars on the channel margins)

Packing: The degree of imbrication/consolidation of the bed (of both the wood and the clasts):

none (n) - rocks in loose array, moved easily by less then high flow conditions and move underfoot while walking across the bottom

loose (l) - moderately loose without any pattern of overlapping. Most elements might be moved by average high flow conditions.

mixed (m) - moderately tight packing of particles with fast water parts of the cross-section protected by overlapping rocks. These might be dislodged by higher than average flow conditions, however.

tight (t) - an array of sizes are tightly packed and wedged with much overlapping which makes it difficult to dislodge by kicking.

Bed-Particle Mobility

annual surface d_{50} & d_{90}: The part of the clastic bed that appears bright is assumed to move in the mean annual flood ("Annual"). The d_{50} and d_{90} of this material is recorded as seen on the surface. The d_{50} is the b axis of the 50th percentile of the size distribution of this material by weight. (The d_{90} is larger, corresponding to the 90th percentile of the same distribution.)

subsurface d_{50}: The d_{50} of the bed material below the surface.

100-year surface d_{90}: The d_{90} of the material mobile during the 100-year flood.

Step Composition: The extent to which each of wood, stone, and mixtures form the steps.

Step Stability

Stable (s) – most steps require 100-year flood to be broken

Unstable (u) – most steps broken during annual flood

Entrenchment Width (w_{1m}): Width of the gully at a vertical position one metre above the channel bed (rep, min, and max)

Coupling: Coupling refers to sediment production/delivery within the reach width.

Coupled (C): Sediment produced on the sidewalls is expected to reach the creek:

Uncoupled (U): Sediment is not expected to reach the creek:

Partially Coupled (P): It is uncertain whether sediment will reach the creek:

Bank Erosion: % of total bank length with evidence of bank erosion in each class according to bank height:

Nil - no cutting is evident

$<$ 0.5 - cutting affects less than half of d_b

0.5 - 1.0 - cutting affects between a half and a full d_b

$>$ 1 - cutting affects a height more than d_b

APPENDIX A2. CHANNEL DESCRIPTION DATA

This appendix provides all the detailed channel data observed during the reconnaissance channel assessment. Three tables are provided. Table A2.1 provides morphology, disturbance indicators, and disturbance level estimates for each channel segment. Table A2.3 provides disturbance indicators and disturbance levels the detailed Channel Sites. Table A2.3 provides all other channel description information for all of the detailed Channel Sites.

Table A2.1a. Channel morphology data for channel segments as observed in the field.

Channel Name	Location (est.)	Reach	Site	gradient (%)			width (m)			depth (m)			w/d	width (1m)			step comp'n			stab'y		spanners
				rep	min	max	rep	min	max	rep	min	max		avg	min	max	W	M	R	U	S	
Upper Mainstem	0+000-0+200	6		20	15	25	6	4.5	12	25	20	40	24	20	10	30+	10	50	40	60	40	<5
Upper Mainstem	0+200-0+400	6		17	10	24	5.5	4	11	30	10	40	18	18	7	25+	10	30	60	40	60	5-10
Upper Mainstem	0+400-0+600	6		15	10	22	5	4	10	30	10	50	17	15	6	20+	30	20	50	50	50	5-10
Upper Mainstem	0+600-0+800	6/5		17	14	20	4.5	2	12	40	10	70	11	15	10	30+	25	10	65	35	65	5-10
Upper Mainstem	0+800-1+000	5		17	13	19	4	2	9	40	20	50	10	13	10	high	20	10	70	20	80	10-15
Upper Mainstem	1+000-1+200	5		20	16	28	5	3	10	36	10	60	14	13	10	high	20	20	60	25	75	5-10
Upper Mainstem	1+200-1+400	5		14	5	25	6	3	12	30	15	70	20	13	9	15	20	30	50	35	65	5-10
Upper Mainstem	1+400-1+600	5		12	8	17	6	4	12	30	15	70	20	15	10	25+	30	20	50	35	65	10-15
Upper Mainstem	1+600-1+800	5		13	7	20	6	2.5	11	30	10	60	20	12	10	25+	30	20	50	30	70	10-15
Upper Mainstem	1+800-2+000	4		12	5	22	5	3	12	30	10	70	17	15	10	25+	30	20	50	25	75	15-20
Upper Mainstem	2+000-2+200	4		13	8	20	5	4	11	30	10	60	17	20	15	25+	15	25	60	20	80	5-10
Upper Mainstem	2+200-2+400	4		13	9	18	5.5	3	12	30	10	70	18	30	20	40+	10	20	70	20	80	5-10
Upper Mainstem	2+400-2+600	4		13	10	18	7	2	14	40	15	100	18	20	15	30	20	80	2	18	80	5-10
Upper Mainstem	2+600-2+900	4		11	8	15	6	3	12	45	20	90	13	15	10	25	5	30	65	30	70	5-10
Lower Mainstem	2+900-3+100	3		12	8	14	6.5	4	10	60	40	100	11	12	10	15	10	30	60	20	80	10-15
Lower Mainstem	3+100+3+300	3		12	7	16	6.5	4	10	60	40	100	11	15	10	25	5	5	90	5	95	20-25
Lower Mainstem	3+300-3+500	3		10	8	16	6	4	12	70	35	100	9	10	8	15	5	5	90	5	95	10-15
Lower Mainstem	3+500-3+700	3/2		8	5	10	6.5	5	8	70	50	90	9	9	8	10	5	5	90	5	95	0-5
Lower Mainstem	3+700-3+900	2		12	9	14	6.5	5	10	70	50	90	9	10	9	15	5	0	95	5	95	0-5
Lower Mainstem	3+900-4+100	2		10	8	120	7	5	16	70	30	100	10	12	10	18	5	10	85	10	90	0-5
Lower Mainstem	4+100-4+200	2															5	10	85	10	90	5-10
Lower Tributary	0+000-0+200	7		12	8	22	2	0.8	4	8	5	15	25									
Lower Tributary	0+200-0+400	7	15	12	10	17	4	0.8	8	10	5	30	40									~15
Lower Tributary	0+400-0+600	7/6		19	15	22	4	3	8	25	5	40	16									0
Lower Tributary	0+600-0+800	6	14	6	1	12	4	3	7	20	10	50	20									2
Lower Tributary	0+800-1+000	6		6	3	10	4	2.5	6	20	10	50	20									0
Lower Tributary	1+000-1+100	6		10	8	15	3.5	2	5	25	10	50	14	15	10	25						0
Lower Tributary	1+100-1+200	5		30	25	35	4.5	3	6	30	10	60	15	12	8	20						0
Lower Tributary	1+200-1+400	5		45	30	60	4	2	6	30	5	70	13	14	8	25						0
Lower Tributary	1+400-1+600	5		20	13	25	4	2	7	25	5	60	16	15	8	20						0
Lower Tributary	1+600-1+800	5		35	13	60	4	3	7	20	5	60	20	15	7	25						0
Lower Tributary	1+800-2+000	4	13	13	10	16	3.5	2	6	20	10	50	18	12	6	15						0
Lower Tributary	2+000-2+200	4		10	6	12	3.5	2.5	5.5	20	5	50	18	12	6	15						0
Lower Tributary	2+200-2+400	4		14	12	30	3.5	2.5	5.5	20	5	50	18	10	6	15						1
Lower Tributary	2+400-2+650	4	12	17	15	25	4	3	7	30	10	90	13	10	8	15						0
Lower Tributary	2+650-2+750	3	11	20	n/a	n/a	4	2.5	6	30	10	80	13	10	7	15						0
Lower Tributary	2+750-3+500	3/2																				
Lower Tributary	3+500-3+700	2	10	17	12	20	4.5	3	6	30	10	50	15	13	10	18	20	20	60	5	95	0
Lower Tributary	3+700-3+900	2		19	15	30	6	5	8	35	10	50	17	11	10	15	20	20	60	5	95	7
Lower Tributary	3+900-4+100	2		22	18	30	4.5	2	9	35	10	50	13	10	3	14	10	20	70	5	95	6
Lower Tributary	4+100-4+300	2		20	15	25	5	4	10	35	10	50	14	14	10	20	10	20	70	5	95	2
Lower Tributary	4+300-4+500	2		18	15	21	4.5	4	9	35	10	50	13	13	10	20	10	20	70	5	95	3
Lower Tributary	4+500-4+700	2	9	16	14	18	5	4	9	35	10	50	14	14	10	20	10	20	70	5	95	4
Lower Tributary	4+700-4+900	2		20	18	23	5	4	10	35	10	50	14	13	11	18	10	20	70	5	95	1
Lower Tributary	4+900-5+100	1		17	15	23	5.5	4	10	35	10	60	16	12	10	15	20	20	60	5	95	9
Lower Tributary	5+100-5+300	1		14	9	18	5.5	4	10	40	10	70	14	11	10	13	20	20	60	5	95	7
Lower Tributary	5+300-5+500	1		19	18	21	5.5	4	10	40	10	70	14	11	10	14	10	20	70	5	95	20
Lower Tributary	5+500-5+700	1		16	14	19	5	4	9	40	10	70	13	10	8	12	10	20	70	5	95	37
Lower Tributary	5+700-5+900	1		18	16	23	5.5	4	10	35	10	70	16	10	8	12	10	20	70	5	95	27
Lower Tributary	5+900-6+100	1		20	18	23	6	4	10	40	10	70	15	11	8	13	10	20	70	5	95	20
Lower Tributary	6+100-6+300	1	8	18	16	20	5.5	4	10	40	10	70	14	10	8	12	10	20	70	5	95	19
Upper Mainstem			6	20	11	25	4	2	6	20	10	40	20	12	10	20	20	20	60	15	85	5-10
Headwater Tributary			26	18	15	24	1.5	0.8	3	10	8	25	15	8	6	10	40	30	30	10	90	10-15
Headwater Tributary			27	8	6	10	1.3	0.6	3	8	5	20	16	15	8	25	60	20	20	10	90	n/a

Table A2.1b. Disturbance indicators & disturbance-level interpretations (channel segments).

Channel Name	Location (est.)	Reach	Disturbance Indicators (2-active; 1-partially active)																Disturbance Ratings (%)						
			S1	S2	S3	S4	S5	C1	C2	C3	C4	C5	B1	B2	B3	D1	D2	D3	A3	A2	A1	S	D1	D2	D3
Upper Mainstem	0+000-0+200	6			2	2			1	2	2			2	2	2	2	2	80	20					
Upper Mainstem	0+200-0+400	6			2	2	1			2	2		1	2	2	2	2	2	60	30	10				
Upper Mainstem	0+400-0+600	6			2	2	2				2				2	2	1	2	30	40	20		5	5	
Upper Mainstem	0+600-0+800	6/5			2		1			1	1		1		1			2	15	40	25	10	5	5	
Upper Mainstem	0+800-1+000	5			2		1				2		2	1	2	2		2	20	30	30	10	5	5	
Upper Mainstem	1+000-1+200	5			2		1				2		2		2	2	1	2	25	25	20	20	5	5	
Upper Mainstem	1+200-1+400	5			2						2		2	2				2	25	30	20	10	10	5	
Upper Mainstem	1+400-1+600	5			2		1				2			2		2	2	2	30	30	20	5	10	5	
Upper Mainstem	1+600-1+800	5					1							2					30	30	20	5	10	5	
Upper Mainstem	1+800-2+000	4			2	2					2		2	2	2		1	2	10	40	25	10	10	5	
Upper Mainstem	2+000-2+200	4			2	2					2		2	2	2		2	1		50	30	15	5		
Upper Mainstem	2+200-2+400	4			2	2					2		2	2	2		2	1	5	40	25	20	5	5	
Upper Mainstem	2+400-2+600	4			2	2							2	2	2		2	2	10	35	25	20	5	5	
Upper Mainstem	2+600-2+900	4			2	2					2		2	2	2		1	1	5	35	30	25	5		
Lower Mainstem	2+900-3+100	3				1								2		1	2	1		5	20	65	10		
Lower Mainstem	3+100-3+300	3				2								1	2		2	1		15	25	55	5		
Lower Mainstem	3+300-3+500	3				1							2	1	2		2			15	30	55			
Lower Mainstem	3+500-3+700	3/2				2								1			2				20	75	5		
Lower Mainstem	3+700-3+900	2			1	1					1						1	1			15	80	5		
Lower Mainstem	3+900-4+100	2																			20	75	5		
Lower Mainstem	4+100-4+200	2																			20	75	5		
Lower Tributary	0+000-0+200	7				2			2	2	2									70	20	10			
Lower Tributary	0+200-0+400	7				2			2	2	2									70	20	10			
Lower Tributary	0+400-0+600	7/6				2			2	2	2									50	25	25			
Lower Tributary	0+600-0+800	6				1					1										25	75			
Lower Tributary	0+800-1+000	6																			10	90			
Lower Tributary	1+000-1+100	6																				100			
Lower Tributary	1+100-1+200	5																				100			
Lower Tributary	1+200-1+400	5																				100			
Lower Tributary	1+400-1+600	5																				100			
Lower Tributary	1+600-1+800	5																				100			
Lower Tributary	1+800-2+000	4																				100			
Lower Tributary	2+000-2+200	4																				100			
Lower Tributary	2+200-2+400	4																				100			
Lower Tributary	2+400-2+650	4																				100			
Lower Tributary	2+650-2+750	3																				100			
Lower Tributary	2+750-3+500	3/2																				100			
Lower Tributary	3+500-3+700	2									2		2			2	1				10	90			
Lower Tributary	3+700-3+900	2														1					5	95			
Lower Tributary	3+900-4+100	2														1					5	95			
Lower Tributary	4+100-4+300	2									2		2		1						20	80			
Lower Tributary	4+300-4+500	2									1										5	95			
Lower Tributary	4+500-4+700	2									2		1								5	95			
Lower Tributary	4+700-4+900	2									2											100			
Lower Tributary	4+900-5+100	1									2						2					100			
Lower Tributary	5+100-5+300	1									1						2					100			
Lower Tributary	5+300-5+500	1									1						2					100			
Lower Tributary	5+500-5+700	1									1						2					100			
Lower Tributary	5+700-5+900	1									2											100			
Lower Tributary	5+900-6+100	1									2											100			
Lower Tributary	6+100-6+300	1																				100			
Upper Mainstem					2	2				2	2		2			2				30	60	10			
Headwater Tributary																	2				20	80			
Headwater Tributary						2			2	2	1						2			30	70				

Table A2.2a. Channel description field data for detailed Channel Sites - morphology.

Channel Name	Site No.	Reach No.	Length m	Flow l/s	Gradient (%) rep	Gradient (%) min	Gradient (%) max	Width (m) rep	Width (m) min	Width (m) max	Depth (cm) rep	Depth (cm) min	Depth (cm) max	Ratio w/d	Bed Composition (% of total) LB	SB	LC	SC	CG	FG	S	M	FF	W	BR	SS	Mobile (%)	Brght (%)	Cling	Ang 1	Ang 2
Lower Mainstem	1	2	200	170	10	8	12	7	5	16	70	30	100	10	20	40	20	10	7	2	1						50	30	c	r	sr
Lower Mainstem	2	3	200	150	12	7	16	6.5	4	10	60	40	100	11	25	35	20	10	7	2	1						50	30	c	r	sr
Upper Mainstem	3	4	200	65	15	9	21	5.5	3	13	40	15	70	14	5	45	25	15	7	2	1						70	25	s	sr	sa/r
Upper Mainstem	4	5	100	70	15	5	18	5.5	3	12	35	10	70	16	5	35	20	15	5	4	1						62	25	c(s/a)	sr	sa
Upper Mainstem	5	6	100	30	22	15	29	5	3.5	11	30	5	60	17	10	40	25	15	5	3	1						69		s	sr	sa
Upper Mainstem	6	7	100	20	20	11	25	4	2	6	20	10	40	20	5	25	25	20	15	6	2			2			55	n/a	c	sa	a/sr
Upper Mainstem	7	7	50		18	14	22	3.2			30			11	20	35	25	15	4	1							35			r	sr
Lower Tributary	8	1	200	50	16	8	30	5	3.5	7.5	40	20	75	13	15	45	20	10	7	2	1						50	n/a	c->a	r	sr
Lower Tributary	9	2	200	70	16	14	18	5	4	9	35	10	60	14	10	50	20	10	5	4	1						55	20	a	sr	r(sa)
Lower Tributary	10	2	200		17	12	20	5	3.5	7.5	30	10	50	17	15	60	10	10	3	1	1						45	10	a	sr	r(sa)
Lower Tributary	11	3	100	60	20	19	21	4	2.5	6	30	10	80	13	8	22	25	25	10	8	2						70	15	a	sa/sr	r
Lower Tributary	12	4	100	45	17	12	22	3.5	2.5	7.5	25	15	50	14	3	37	20	20	10	9	1						50	15	a	sa/sr	r
Lower Tributary	13	4	100	25	13	11	15	3.5	2	5.5	40	10	80	9	5	40	25	15	8	5	2						30	15	a	r	sr
Lower Tributary	14	6	100	10	10	5	12	4	3	6	25	10	45	16	20	35	20	13	5	4	3						15	15	a		
Lower Tributary	15	7	50	8	14	11	17	2.5	1.5	4.2	10	5	15	25	10	30	15	15	10	10	10						30	25	a	a/sa	
Middle Tributary	16	n/a	100		20	10	30	2	1	3	20	10	50	10	0	15	34	30	15	5	1						70	30	n/c	sa	sr
Middle Tributary	17	n/a	100	6	21	10	35	2	1	4	15	5	40	13	1	14	20	30	20	15	2						55	35	c	sa	sr(a)
Middle Tributary	18	n/a	100	5	35	30	40	2	1	4	8	2	14	25	1	25	25	25	15	5	2						35		a	a	sa
Middle Tributary	19	n/a	100	3	25	20	33	1.7	1	2.8	6	2	10	28	0	15	15	15	20	20	5			5		5	45	20	a	a	sa
Middle Tributary	20	n/a	50	2	24	22	26	1.8	1.2	2.8	18	10	50	10													40				
Middle Tributary	21	n/a	100	3	34	30	38	1.5	0.9	2.5	6	2	10	25	0	15	15	15	15	15	5			10		10	35	20	a		
Middle Tributary	22	n/a	100	1	32	28	36	1.5	0.6	3.5	6	2	15	25	0	20	15	10	10	6	4						22		a	sa	a((sr))
Middle Tributary	23	n/a	50	< 1	37	30	45	0.9			15			6													25				
Middle Tributary	24	n/a	50	<0.1	30	15	35	0.3	0.15	0.5	10	0	20	3	0	0	3	2	0	0	1	39	30	10		15	~0	0	c	n/a	n/a
Middle Tributary	25	n/a	50	1	56	50	63	1.2			20			6	15	20	25	25	6	3	1				5		10		a	a	
Headwater Trib	26	n/a	100	6	18	15	24	1.5	0.8	3	10	8	25	15	0	50	25	20	15	5	1			4			43	10	a	sa	a(sr)
Headwater Trib	27	n/a	100	4	8	6	10	1.3	0.6	3	8	5	20	16	0	15	20	20	25	10	5			10			70	40	a	a	sa

Table A2.2b. Channel description field data for detailed Channel Sites (continued) – bed, banks, gully.

Channel Name	Site	Reach	Sco	Dep	Pack	Sfc (cm)		SubSfc	100yr	Ratio	Step Compositio			Unst	W1m (m)			Lag	Ratio	Coupling (%)			Bank Cutting (%)				Cut	Wood	Wood
	No.	No.	%	%		d50	d90	d50	Sfc d90	d/D	Wd	Mix	St	Step%	rep	min	max	%	w_{1m}/w_b	C	PC	Un	Nil	<.5	.5-1	>1	Ends	CDM	Span
Lower Mainstem	1	2	5	30	m/t	20	40	s/fg	50	0.57	5	10	85	10	12	10	18	50	1.7	10	30	60	90	2	6	2	a	m	5-10
Lower Mainstem	2	3	5	20	t->m	20	40	s/fg	50	0.67	5	5	90	5	15	10	30	60	2.3	50		50	95	0	5	0	a	m	
Upper Mainstem	3	4	10	25	n/a	20	30	2.5	45	0.75	5	15	80	25	25	15	40	15	4.5			100	65	10	20	5	a	c	0
Upper Mainstem	4	5	20	40	l->m	15	25			0.71	20	30	50	30	13	9	15	15	2.4	50	50		70	10	10	10	a	d	
Upper Mainstem	5	6	15	60	l->n	16	32	5	50	1.07	10	30	60	60	15	7	25	25	3.0	50		50	75	10	10	5	c	m	
Upper Mainstem	6	7	0	40	l	9	30	5	45	1.50	20	20	60	15	12	10	20	25	3.0	50	50		99	0	1	0	c	m	5-10
Upper Mainstem	7	7				20				0.00					12				3.8								c		
Lower Tributary	8	1	0	10	m/t	20	30		45	0.75	0	5	95	~90	10	8	40+	50	2.0	50		50	100	0	0	0	c	m	25
Lower Tributary	9	2	0	15	m/t	17	40			1.14	10	20	70	~90	14	10	20		2.8		25	50					a	m	4
Lower Tributary	10	2	0	10	m	15	40		60	1.33	20	20	60	~90	15	10	25		3.0		50	50	100	0	0	0	a	m	1
Lower Tributary	11	3	0		l/m	12	35			1.17				~75	12	7	15	40	3.0		20	20	100	0	0	0		c	0
Lower Tributary	12	4	0	15	l/t	10	30			1.20	0	20	80	~75	16	12	25	50	4.6		20	80	99	1	0	0		c	
Lower Tributary	13	4	0	5	l/t	7	20	sandy		0.50				~75	12	7	15	50	3.4		20	80	100	0	0	0	n	c	
Lower Tributary	14	6	0	15	l/t	3	12	sandy		0.48				~75	20	15	40	50	5.0			100	99	1	0	0	n	c	
Lower Tributary	15	7	0	25	n/t	1								~75								100	95	5	0	0	n	c	
Middle Tributary	16	n/a	0	15	m	10	20		30	1.00	40	20	40	70	15	8	>25	5	7.5		20	80	70	10	15	5	a		
Middle Tributary	17	n/a	0	30	l->m	5	15		20	1.00	15	35	50	30	10	6	18	25	5.0	30	40	30	90	5	5	0	a	m	
Middle Tributary	18	n/a	0	15	l->n	4	12	packed	15	1.50				10	7	5	10	75	3.5	100			98	0	1	1	a	m	low
Middle Tributary	19	n/a	0	15	l->n	3	10	sand	12?	1.67	50	40	10	20	10	8	12	65	5.9	80	20		100	0	0	0	a	m	l
Middle Tributary	20	n/a													6				3.3										
Middle Tributary	21	n/a	0	10		2	8	sand	10	1.33	20	70	10	10	9	7	11	65	6.0	100			100	0	0	0	a	m	h
Middle Tributary	22	n/a	0	30	l	3	7	sand	10	1.17	20	60	20	15	8	6	12	70	5.3	80	20		100	0	0	0	a	c	high
Middle Tributary	23	n/a													5				5.6										
Middle Tributary	24	n/a	60	0	n/a	0	0	0	n/a						13	10	16	~100	43.3	20	40	40	80	5	10	5	a	m	
Middle Tributary	25	n/a																											
Headwater Trib	26	n/a	0	20	l/t	7	20	sand	30	2.00	40	30	30	10	8	6	13		5.3	50	25	25	98	1	1		c	m	10-15
Headwater Trib	27	n/a	0	50	n/m	5	10	1	15	1.25	60	20	20	10	15	8	25		11.5			100	90	5	5	0	c	c	100

APPENDIX A3. DETAILED DESCRIPTIONS OF POINT SEDIMENT SOURCES

This appendix provides information on the point sediment sources which were field reviewed. The following abbreviations are used in these tables:

Types

BD Bed Destabilisation
CA Channel Avulsion
DF Debris Flow
DS Debris Slide
EG Erosion Gully
BE Bank Erosion
HF Headwall Failure
RE Road Erosion
SE Surface Erosion (landslide paths)
SL Slump

Causes

AR Avulsion onto Road
BC Bridge Collapse
CF Cutbank Failure
CB Culvert Blockage
DC Drainage Concentration
DD Drainage Diversion
FF Fillslope Failure
MC Machinery in Channel
NA Natural
SE Seepage
SP Slide Path erosion (existing landslide)
UT Undercut Toe

Table A3.1 Description of Point Sediment Sources.

No	Observer[1]	Active/Potential Sediment Production					Associated Past Production (if applicable)			
		type	cause	size	delivery	A/F[2]	type	cause	size	delivery
1	GU	SL	FF/DC/DD	L	M	F-H	SL	FF/DC/DD	M	L
2	GU	DF	FF/DC/DD	L	H	F-M	DS/DF?	FF/DC/DD	H	M-H
3	GU	DF	FF/DC/DD	M	M	F-M	DS/DF?	FF/DC/DD	M	M
4	GU	SL	FF/DC/DD	L	M	F-H	SI	FF/DC/DD	M	L
5	GU	DF	DC/DD	L	L	F-M[1]	DS/DF?	DC/DD	L	L
6	GU	DF	DC/DD	L	L	F-M[1]	DS/DF?	DC/DD	M	VH
7	GU	DF	DC/DD	L	L	F-M[1]	DS/DF?	DC/DD	L	L
8	AG[3]									
9	AG[3]									
10	MC						DS	NA	M	H
11	MC						DS	NA?	M	VH
12	GU	SL/DF	FF/SE	L	L	F-M	SL/DF	FF/SE	L	L
13	GU	SL/DF	FF/DD	L	L	F-M	SL/DF	FF/DD	L	L
14	GU	SL/DF	FF/DD	L	L	F-M	SL/DF	FF/DD	L	L
15	MC						DS	FF	L	VH
16	MC						DS	FF/SE?	M	H
17	GU	SL/DS	CF/SE	L	L	A	SL/DS	CF/SE	L	L

[1] GU – Greg Utzig MC – Martin Carver [2] M – moderate likelihood H – High Likelihood
[3] Most past sources vary in age between 5 and 60 years old.
[4] AG - Apex Geoscience –landslide locations only are available from Apex Geoscience (2000).

APPENDIX A4. DATA FOR ROAD SURFACE EROSION RATINGS AND ROAD HAZARDS

Table A4.1 Field descriptions of active forest road in the headwaters of the Lower Tributary.

NOTE: Data are based on a 4-hour rapid reconnaissance of the road, and should be considered preliminary.

Road Segment	Approx. Location[1] (km)	Moisture Regime[2]	Cut Depth (m)	Side Slope (%)	Terrain	Fine Fraction Texture	Coarse Fragments	Road Gradient (%)	Preliminary SE Rating[3]
17	0-0.5	M	1-2	0-30	sFGb/rsDv	LS - S	30% fg	4-8	H
18	0.5-0.8	M	3-6	50-60	srCv//gsMbv	LS	>60% (fg)	8-14	H
19	0.8-0.85	SHG	3-5	40-55	srCv/gsMbv	SL-LS	40-60+	8-12	VH
20	0.85-0.91	SHG(M)	1.5-5	20-30	gsMb	SL-LS	30-40(20)	<5	H(VH)
21	0.91-1.0	SHG	2-4	25-35	gsMb	SL-LS	35-60+	12-15	H-VH
22	1.0-1.24	SM(SHG)	2-4	25-35	gsMb	SL-LS	35-60+	12-15	H
23	1.24-1.38	SM	2-3	20-30	gsMb	SL-LS	35-60+	8	H(M)
24	1.38-1.65	M(SHG)	4	40-50	sgFGbv / gsMb	SL-LS	10-60+	5-10	VH
25	1.65-2.15	M/SM	1-2	0-10	srDvb	SL-LS	40-60	0-5	H
26	2.15-2.3	SM	4-7	65-70	srCvb	SL-LS	40-60	8-10	H
27	2.3-2.7	SM (SX-SHG)	0.5-2	0-20	srDv//gsMbv	SL-LS (fSL)	30-60	<5 (5-10)	H(M)
28	2.7-3.0	SHG/M	1-5	20-40	gsMb	SL (fSL)	30	0-10	H-VH
29	3.0-3.15	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
30	Spur 41-3-1 (0-0.5)	M/SM	2-3	15-30	gsMb	SL-LS	30	0-6	H
31	Spur 41-4-1	NA	NA	NA	n/a	n/a	n/a	n/a	n/a

[1] Segment 17 begins (0.0) where the road enters the Glade Creek watershed from the Granite Creek watershed.
[2] M-mesic; SM-submesic; SHG-subhygric; SX-subxeric
[3] Following Table 3.9.

Table A4.2. Sediment source information for new forest access road in headwaters of Lower Sub-basin.

Road Segment	Approx. Length (m)	Preliminary Surface Erosion Rating	Delivery Class	No. of Culverts (creeks)	Adjusted Surface Erosion Rating	Qualitative Comments
1[1]		L			L	Effective water bars and partially revegetated
2[1]		M	M		L	
3-16					L	Fully revegetated.
17[2,3]	500	H	H	3(1)	M	Significant ditch erosion in sandy material; 22 km sign
18	300	H	H	5(4)	M	Dry ravel; gravel weathering to sand
19	50	VH	VH	2(2)	VH	Erosion from both road cuts and in ditch
20	60	H(VH)	VH	4(2)	H	Dip in road with fill; significant sediment from fill into main creek
21	90	H-VH	VH	2(1)	VH	Supplies significant seepage to creek which carries sediment into large creek
22	240	H	VH	2(2)	H	Supplies significant seepage to creek, across spur road, and out into cutblock
23	140	H(M)	M	1	L	23 km sign;
24	270	VH	M	4(1)	M	Cutslope slump @ 1.5 (approx 100 m^2); some glaciofluvial materials
25	50	H	L	3	L	Flat ridge; significant ditch erosion with low connectivity
26	150	H	M	0	L	Dry ravel
27	400	H(M)	M	5(2)	L	Generally small ridges with interspersed small streams; effective sediment traps locally
28	300	H-VH	H	(?)	H	Most of segment is an active landing; corduroy sections
29	150	n/a	L	n/a	L	Recontoured
30	500 spur 41-3-1	H	M	4(2)	L	Seepage near main creek
31	430 spur 41-4-1	n/a	n/a	n/a	n/a	Not yet constructed

[1] Segments 1& 2 are partially vegetated roads with low surface erosion rating; segments 3 through 16 are well-vegetated inactive roads with a resulting Low Surface Erosion Rating.
[2] Segment 17 begins where the road enters the Glade Creek watershed from the Granite Creek watershed.
[3] Segments 17 through 31 are a new road therefore 100% unvegetated (all segments).