FINAL REPORT

BAKER CREEK WATERSHED ASSESSMENT – PHASES 1 & 2

Volume 1: Report

Prepared for:

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Project 040-42.02

March 2007

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March 30, 2007

Reference: 040-42.02

Mr. Gerry Powell
Tolko Industries Ltd.
Quest Wood Division
1879 Brownmiller Road
Quesnel, B.C.
V2J 6R9

Dear Mr. Powell:

Re: Final Report – Baker Creek Watershed Assessment: Phases 1 & 2

Summit Environmental Consultants Ltd. is pleased to provide three (3) copies of the final report on the Baker Creek watershed assessment. The report summarizes our findings in the watershed, and provides recommendations to mitigate negative hydrologic impacts of pine mortality and/or forest development in the watershed.

I trust this completes our assignment to your satisfication. Please call me if you have any questions.

Yours truly,

Summit Environmental Consultants Ltd.

Lars Uunila, M.Sc., P.Geo., P.Geol., P.H., CPESC
Geoscientist

Attachments: Final Report (3 hardcopies with digital files)

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CD1 Digital files

1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

In the Baker Creek watershed (Figure 1.1), Mountain Pine Beetle (MPB) (*Dendroctonus ponderosae*) has caused the mortality of roughly 80% of the mature lodgepole pine *(Pinus contorta)* forest (Eng et al. 2005). Government agencies, forest licensees, and local stakeholders are concerned that such widespread pine mortality with or without extensive salvage harvesting may have potential negative impacts on watershed values, both on Crown and private land. In order to address these concerns and identify options to mitigate potential negative impacts, Tolko Industries Ltd. (Tolko), Quest Wood Division retained Summit Environmental Consultants Ltd. (Summit) in February 2006 to conduct a customized watershed assessment of Baker Creek. This report summarizes the assessment, which was conducted over two (2) phases, and supersedes an interim report (Summit 2006a) that was submitted following the completion of Phase 1 in March 2006.

1.2 PROJECT OBJECTIVES

The principal objectives of this watershed assessment are to:

- Assess water resource values with respect to impacts of beetle-kill and future potential forest development; and
- Provide recommendations to mitigate potential negative hydrologic impacts of pine mortality and/or forest development.

As outlined in Summit's January 31, 2006 work plan, the watershed assessment was organized into two (2) phases to accomplish the above objectives. Phase 1 included the following specific tasks:

1. Start-up call and meeting;
2. Stakeholder meeting;
3. Information compilation and review;
4. Aerial photo review;
5. Preliminary mapping; and

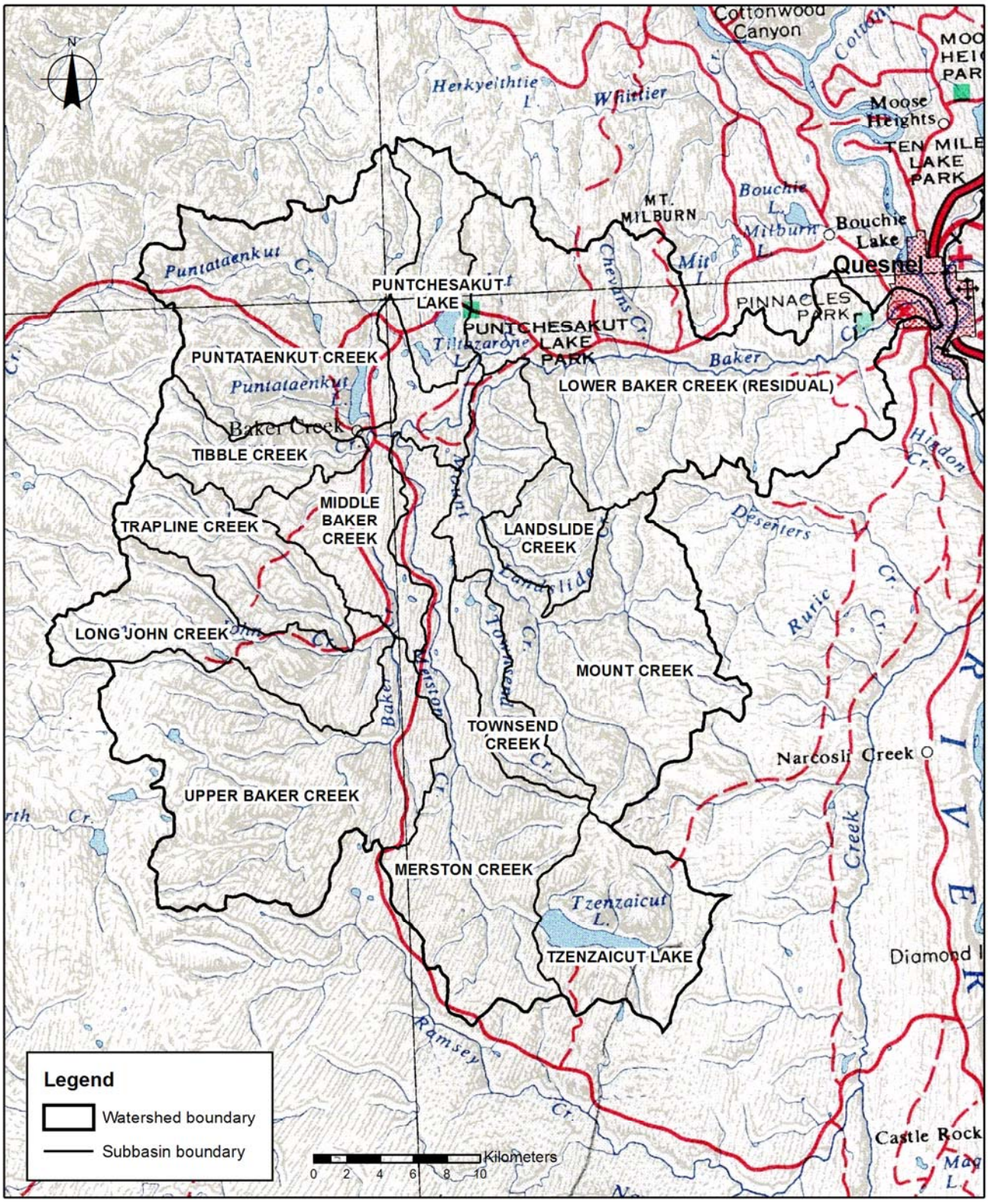


Figure 1.1 Baker Creek watershed and its major sub-basins.

6. Field planning and interim reporting.

Phase 2 included the following specific tasks:

1. Helicopter reconnaissance;
2. Ground-based inspection;
3. Analysis;
4. Draft reporting;
5. Stakeholder meeting #1;
6. Preparation of draft report;
7. Stakeholder meeting #2; and
8. Submission of final report.

1.3 REPORT ORGANIZATION

Section 1.0 of this report outlines the background and objectives of the study. Section 2.0 summarizes the methods used and the information compiled. To provide context to the study, Sections 3.0 and 4.0 briefly describe the Baker Creek watershed and the current knowledge on the potential hydrologic effects of Mountain Pine Beetle, respectively. A summary of the comments received from stakeholders during the study is provided in Section 5.0. Section 6.0 summarizes the current conditions in each of the principal sub-basins, provides an evaluation of the identified risks to watershed values from pine mortality and salvage harvesting, and identifies restoration opportunities. Recommendations on salvage harvesting in the watershed are provided in Section 7.0. Summary and conclusions are presented in Section 8.0. References and a glossary of technical terms are provided in Sections 9.0 and 10.0, respectively.

2.0 METHODS

2.1 PHASE 1

Specific objectives in Phase 1 were to obtain and review relevant background information, review aerial photographs, and develop a field plan for Phase 2. The following summarizes the key tasks completed during Phase 1 between February and March 2006.

2.1.1 Start-up Call and Meeting

Mr. Lars Uunila, P.Geo. (hydrologist) of Summit and Mr. Gerry Powell of Tolko conducted a conference call to discuss and confirm the project scope, budget and schedule. During this call, they identified relevant information sources and discussed the key issues facing the watershed. Mr. Uunila and Mr. Powell discussed which sub-basins should be delineated and which areas in the watershed were of most interest. Based on these discussions, it was agreed that the assessment would generally focus on the areas near and upstream of the major agricultural areas surrounding the Baker Creek community (i.e. Middle Baker Creek sub-basin). On March 8, 2006 Mr. Uunila met Mr. Powell at the Tolko offices in Quesnel to compile background information. Aerial photographs were also borrowed from the Quesnel office of the Ministry of Forests and Range (MOFR).

2.1.2 Stakeholder Meeting #1

A stakeholder meeting was held in the Baker Creek Hall on March 8, 2006 from 5 to 7 pm. The objective of this meeting was to inform stakeholders on the study and identify stakeholder concerns within the watershed. Mr. Powell introduced the study team to approximately 30 attendees and briefly described the scope and schedule of the watershed assessment. Mr. Uunila provided background biophysical information about the watershed and outlined the proposed work plan to identify the key issues. During the question and answer session, the private landowners and stakeholders present at the meeting identified potential areas of concern and provided some management suggestions. Maps of the watershed were available for the attendees to point out areas of concern. In addition, hydrometric station data for Baker Creek was presented to quantitatively illustrate historical

stream flows. The minutes of the meeting, as recorded by Ms. Kim Proulx of MOFR, are provided in Appendix A.

As a follow-up to the meeting, additional maps were sent to Mr. Joe Lisk, volunteer spokesperson for the landowners in the Baker Creek watershed, with a request to identify landownership and specific locations of concern relevant to the study. These maps were returned to Summit with comments following the completion of Phase 1.

2.1.3 Information Compilation and Review

A considerable amount of information relevant to the study of the Baker Creek watershed and the hydrologic effects of MPB was identified during the study (Table 2.1). During visits by Summit to Tolko and MOFR offices in Quesnel, several of the reports listed in Table 2.1 and aerial photographs listed in Table 2.2 were compiled. Several individuals from provincial agencies were also contacted to obtain digital map coverages of the watershed, including MPB mortality estimates. Professionals in the forestry industry were also contacted to discuss current research on MPB, particularly in the Baker Creek watershed. Of particular note, Dr. Younes Alila of the University of British Columbia, on behalf of the Forest Practices Board, has recently developed (and continues to refine) a hydrologic model[1] of the Baker Creek watershed to quantify the effects of various scenarios of MPB attack and treatments on peak flow and water yield (Luo et al. 2006; FPB 2007). Mr. Pat Teti, of the Ministry of Forests and Range (MOFR) is actively conducting stand level studies to research MPB mortality on snow processes. On behalf of the Ministry of Environment, Dobson Engineering Ltd. completed a screening-level assessment of selected tributaries in the Baker Creek watershed to prioritize where aquatic monitoring of MPB impacts would be most beneficial (Sabur, pers. comm. 2006). Attempts were made to contact the Baker Creek Enhancement Society (BCES), but we were unavailable to make contact during the study.

[1] Distributed Hydrological Soil Vegetation Model (DHSVM).

Table 2.1 Information sources identified for the Baker Creek watershed assessment.

Format / Type	Source
Maps and coverages	
Digital Trim 1 mapping	MOFR (2006)
Forest cover and fip files	Tolko (1999)
Forest health data	MOFR (2005b)
Existing and proposed blocks	BCTS[1] and LRDW[2] (2006)
Historical MPB Mortality coverage	CFS[3] (2005)
Proposed harvesting	MOFR (2006)
Licensee boundaries	MOFR (2006)
Points of diversion (PODs)	LWBC[4] (2006)
Forest development plans	MOFR (2001)
Aerial photographs	
Colour, Scale 1:15,000	Province of British Columbia (1996, 1997, 2005); refer to Table 2.2
Reports	
IWAP[5]	Cariboo Forest Consultants Ltd. (1996)
Hydrometric Records	Water Survey of Canada (2006)
Fish and Fish Habitat Inventory in the Baker Creek Watershed	RL & L Environmental Services Ltd. (2002)
Reconnaissance Fish and Fish Habitat Inventory of the Tibble Creek Planning Area	Triton Environmental Consultants Ltd. (2000a)
Reconnaissance Fish and Fish Habitat Inventory of the Long John Creek Planning Area	Triton Environmental Consultants Ltd. (1999)
Reconnaissance Fish and Fish Habitat Inventory of the Puntataenkut Lake Planning Area	Triton Environmental Consultants Ltd. (2000b)
Sediment Source Survey of Baker Creek and Pantage Creek	McElhanney Consulting Services Ltd. (1998)
Integrated Watershed Restoration Plan for the Baker and Pantage Creeks Watersheds	McElhanney Consulting Services Ltd. (1999)
Current Research and Other Studies	
DHVSM Modelling of Baker Creek[6]	Forest Practices Board (2007)
Aquatic Monitoring Screening Tool for Trapline & Tibble Creeks.	Dobson Engineering Ltd.
Snow Surveys, Upper Baker Creek	Mr. Pat Teti, MOFR

Notes:

1. BCTS is the British Columbia Timber Sales.
2. LRDW is the Land Resource Data Warehouse.
3. CFS is the Canadian Forest Service.
4. LWBC is Land and Water BC
5. IWAP is the Interior Watershed Assessment Procedure
6. DHVSM is the Distributed Hydrology Vegetation Soils Model

Based in part on the information sources noted above, an overview of the general hydrologic effects of MPB was prepared (Section 3.0).

2.1.4 Aerial Photo Review

Aerial photos were obtained from the MOFR office in Quesnel. Photos taken in 2005 cover the northern half of the watershed. The southern half of the watershed was covered by aerial photos flown in 1996 and 1997 (prior to widespread MPB infestation).

Table 2.2 List of aerial photos reviewed for the watershed assessment.

Date	Flight Line	Photo Numbers
August 2005	30BCC05061	135-150
	30BCC05068	30-51
	30BCC05140	38-48
	30BCC05068	127-145
	30BCC05068	85-110
	30BCC05067	27-55
	30BCC05066	240-268
	30BCC05066	57-75
	30BCC05069	67-90
	30BCC05069	125-144
August 1997	30BCC97185	195-205
	30BCC97185	140-165
	30BCC97156	204-215
	30BCC97187	1-17
	30BCC97156	158-183
	30BCC97136	151-176
	30BCC97136	40-64
	30BCC97136	195-200
	30BCC97136	1-20
	30BCC97136	150-167
	30BCC97115	10-46
	30BCC97085	170-206
	30BCC97116	99-116
	30BCC97115	190-116
	30BCC97116	64-84
	30BCC97115	209-223
	30BCC97070	103-130
	30BCC97069	120-150
	30BCC97069	70-100
September 1996	30BCC96159	120-150
	30BCC96159	75-100
	30BCC96158	115-145
	30BCC96158	10-40
	30BCC96153	155-185
	30BCC96153	10-40
	30BCC96149	12-39

Note: All aerial photographs are of a nominal scale of 1:15,000.

The aerial photo analysis was conducted to systematically review the entire Baker Creek watershed to confirm and identify key issues in the watershed. The review consisted of a customized channel and riparian assessment, and a sediment source survey. Stream reach breaks were identified and mapped for the mainstem of Baker Creek and its major tributaries. Channel reaches were based on several factors, including observed channel form and degree of confinement, stream flow, inferred sediment inputs, and stream gradient. A visual assessment of the area and significance of beetle-kill within riparian zones was also made for the northern portion of the watershed (where 2005 aerial photo coverage is available).

As part of the aerial photo review, a preliminary assessment of *channel disturbance* (e.g., degree of human impacts from landslides, increased sediment supply, or altered riparian zones), *channel stability* (or tendency for the channel to remain the same over time), and *channel sensitivity* (or potential for channel disturbance to result in decreased channel stability) was made for each identified reach. The aerial photo review also provided a means to identify any significant development-related slides, eroding banks or other point sources of sediment in the watershed. Based on the aerial photo review high priority areas were identified for field inspection in Phase 2.

2.1.5 Preliminary Mapping and Analysis

As noted above, Baker Creek watershed was divided into nine (9) principal sub-basins including two residual areas (Figure 1.1 and Map 1). The H_{60} elevation and watershed and sub-basin areas above and below this elevation were calculated using ArcGIS software. The mainstem of Baker Creek and all its principal tributaries were identified and reach breaks were mapped. Other watershed features that were identified and mapped included:

- Private lands;
- Indian reserves (none are located in the Baker Creek watershed);
- Licensee operating areas;
- Park or protected areas;
- Licensed points of water diversion and locations of groundwater wells; and
- City of Quesnel boundary.

Channel profiles of the main stem and its main tributaries were also developed and are presented in Appendix B.

To estimate beetle-kill severity in the watershed, Summit used historical MPB mortality coverage (CFS 2005), forest health data (MOFR 2005b), and forest cover and fip files (Tolko 1999). Table 2.3 and Map 2 were prepared to illustrate beetle-kill severity for the entire watershed from the forest health data coverage. The MOFR forest health data is based on aerial surveys and visual estimates of the percentage of red- or grey-attacked pine stands in each designated area (Ebata, pers. comm. 2006). MPB mortality percentages were then classified into five categories; "trace" (<1%), "light" (1-10%), "moderate" (11-30%), "severe" (31-50%), and "very severe" (50%). These categories are presented on Map 2. To simplify presentation, only areas mapped as "severe" and "very severe" are presented on detailed sub-basin maps (Maps 4 to 8).

Table 2.3 Areas of the principal sub-basins with beetle-kill classified as severe or very severe.

Sub-basin	Total sub-basin area (km^2)	Area of sub-basin with beetle-kill classified as "severe" or "very severe" (%)
1. Upper Baker Creek	210.5	40
2. Long John Creek (incl. Trapline Creek)	166.0	43
3. Tibble Creek	49.8	50
4. Puntataenkut Creek	182.5	32
5. Merston Creek (incl. Tzenzaicut Lake)	262.5	48
6. Punchesakut Creek	52.3	13
7. Mount Creek (incl. Townsend and Landslide Creeks)	283.1	47
8. Middle Baker Creek (residual)	89.9	11
9. Lower Baker Creek (residual)	285.5	29
BAKER CREEK WATERSHED	**1,582.1**	**43**

Notes:
1. See text for definition of "severe" and "very severe".

Recent observations suggest that MPB-has attacked stands as young as 20-40 years of age (MacLauchan 2006). Based on these findings, we have assumed beetle-kill will affect all

pine-leading stands with an age of 30 years or more. To illustrate how this would affect riparian zones in the watershed, Map 3 was prepared. It shows the expected mortality of trees within 30 m of all mapped stream channels based on TRIM and forest cover information. Expected pine mortality within riparian zones (or the risk that riparian zones will be affected by MPB) was classified and presented on Map 3 and Table 2.4 as "low" (1-50%), "moderate" (51-80%), and "high" (81-100%). The ranges in percentages for each classification were defined so that the riparian areas affected under each classification was roughly equivalent. For example, roughly one third of the total riparian zone falls in the low, one third in moderate category, and one third in the high category. To simplify presentation, detailed sub-basin maps (Maps 4 to 8) only present riparian zones at "high" risk.

Table 2.4 Estimated percentage of total riparian area at risk of beetle-kill in the Baker Creek watershed.

Sub-basin	Estimated total riparian area (ha)	Estimated percentage of riparian area at HIGH risk of beetle-kill (%)	Estimated percentage of riparian area at MODERATE risk of beetle-kill (%)	Estimated percentage of riparian area at LOW risk of beetle-kill (%)
1. Upper Baker Creek	2,287	49	10	11
2. Long John Creek (incl. Trapline Creek)	2,369	35	12	15
3. Tibble Creek	712	58	12	20
4. Puntataenkut Creek	2,179	46	11	14
5. Merston Creek (incl. Tzenzaicut Lake)	2,289	33	10	13
6. Punchesakut Creek	672	41	8	12
7. Mount Creek (incl. Townsend and Landslide Creeks)	3,955	34	15	22
8. Middle Baker Creek (residual)	1,283	26	16	15
9. Lower Baker Creek (residual)	4,088	20	30	15
BAKER CREEK WATERSHED	19,834	35	16	15

Notes:
1. Riparian areas assumed here encompass 30 m on either side of mapped streams of all sizes (based on TRIM mapping).
2. See text for definition of riparian area at "high", "moderate" and "low" risk of beetle kill.
3. Since some riparian areas are not at risk of beetle kill the totals of high, moderate, and low do not necessarily sum to 100%.

2.1.6 Field Planning

After compiling and reviewing background information, reviewing the aerial photographs, mapping preliminary features of the watershed; a field plan was developed for Phase 2. This included identifying high priority areas to be inspected by helicopter reconnaissance and ground inspections. In addition, several stakeholders that provided information at the stakeholder meeting or via correspondence with Mr. Joe Lisk were contacted by phone to arrange individual field meetings.

2.2 PHASE 2

A summary of Phase 2 activities, conducted after April 1, 2006, is outlined below.

2.2.1 Helicopter Reconnaissance

A helicopter reconnaissance was conducted on July 14th, 2006 to field-validate our findings of the aerial photo review, to qualitatively check stakeholder concerns, and ensure that all areas of the watershed were inspected. A slow-speed low-level flight over the watershed was completed in approximately five (5) hours. Areas of focus included the mainstem of Baker Creek and its principal tributaries, as well as areas of private land where issues were noted.

During the helicopter reconnaissance, channel conditions, sediment sources, and riparian conditions were noted, particularly in areas where considerable volumes of beetle-killed timber were within the riparian zone. Photographs were taken and a video of the flight path was recorded for reference purposes.

2.2.2 Meetings with Landowners

During June and July 2006, Summit attempted to contact a total of 23 residents of the Baker Creek watershed to obtain direct and specific comment on watershed and private land concerns. The list of local residents was compiled during the public meeting on March 8, 2006 (Appendix A). A minimum of two (2) attempts were made to call (or e-mail) each of the 23 residents prior to the field inspection. Of the 23 residents on the contact list, seven (7) provided direct comments over the phone regarding their property; many of these people also

provided written descriptions of issues on maps sent to Mr. Joe Lisk. During the ground reconnaissance, field meetings were arranged with three (3) of the seven (7) respondents interviewed by phone. These three (3) field meetings were in areas that covered the range of issues identified by stakeholders. A summary of the verbal and written comments from landowners is provided in Section 4.0.

2.2.3 Ground Reconnaissance

Mr. Uunila, P.Geo. and Ms. Tremain, G.I.T. conducted the ground-based reconnaissance between July 10th and 15th, 2006. During this period, inspections were focused at "high priority" locations based on the aerial photo review, stakeholder consultation, and preliminary mapping. These high priority locations included sites where potential risks from beetle-kill and or forest development to watershed values were high, and where major stakeholder concerns were identified. Representative locations were also visited throughout the watershed to confirm the preliminary assessment of channel morphology, channel stability, channel disturbance, channel sensitivity, and riparian conditions. In addition, the condition of roads and drainage works were noted throughout the watershed. Restoration opportunities were identified and ranked as high, moderate, or low priority based on the following factors:

1. risk to health and safety of watershed users;
2. existing and potential future level of disturbance;
3. restoration benefit (e.g. degree and type of habitat benefit, potential success, and duration of effectiveness);
4. potential restoration cost; and
5. accessibility to the restoration site.

2.2.4 Office Analysis

Following all data collection and reduction, information was organized and analysed on a sub-basin and watershed level. The risk to watershed values in the near future based on current and likely future conditions were assessed and organized as follows:

- Risk of increased peak flows;

- Risk of destabilizing stream channels; and
- Risk of affecting riparian function ; and
- Risk of sediment delivery to the stream network from point (i.e. slides) and non-point sediment sources (i.e. roads).

2.2.5 Status Report

Following completion of the field work, a small number of high priority restoration sites were brought to the immediate attention of the Dale Bubela, Tenures Officer of MOFR Quesnel, and Gerry Powell of Tolko. A memo outlining these sites with recommendations is attached in Appendix C.

2.2.6 Reporting and Stakeholder Meeting #2

This report summarizes both phases of the study and is intended for review and use by Tolko, MOFR, and interested stakeholders. Following a period for review of the draft report, a stakeholder meeting was held in the community of Baker Creek on March 22, 2007. The minutes of this meeting as recorded by Ms. Kim Proulx of MOFR and Ms. Jenna Hopkinson of Tolko are provided in Appendix A. The final report of the study was prepared following receipt of comments during and following the meeting.

3.0 BAKER CREEK WATERSHED

3.1 LOCATION AND PHYSIOGRAPHY

The Baker Creek watershed covers 1,582 km^2 of the Fraser Plateau west of Quesnel, B.C. (Figure 1.1 and Map 1). The watershed has been divided into nine (9) principal sub-basins, including two (2) residual[2] areas (Table 3.1).

The mainstem of Baker Creek is approximately 114 km in length and drains into the Fraser River at Quesnel, B.C. Elevations in the watershed range from about 475 m near the mouth of Baker Creek to approximately 1,500 m in the headwaters. The median elevation of the Baker Creek watershed is 1,100 m (Obedkoff 1999).

Table 3.1 Principal sub-basins in the Baker Creek watershed listed approximately in downstream order.

Sub-basin	Area above H_{60} (km^2)	Area below H_{60} (km^2)	Total Area (km^2)
1. Upper Baker Creek	191.7	18.8	210.5
2. Long John Creek (incl. Trapline Creek)	138.5	27.6	166.0
3. Tibble Creek	36.9	12.9	49.8
4. Puntataenkut Creek	81.3	101.2	182.5
5. Merston Creek (incl. Tzenzaicut Lake)	214.6	47.8	262.5
6. Punchesakut Creek	8.3	44.0	52.3
7. Mount Creek (incl. Townsend and Landslide Creeks)	188.2	94.9	283.1
8. Middle Baker Creek (residual)	13.0	76.9	89.9
9. Lower Baker Creek (residual)	60.4	225.1	285.5
BAKER CREEK WATERSHED	**932.9**	**649.2**	**1,582.1**

Notes:
1. Areas are based on TRIM mapping.
2. H_{60} refers to the elevation above which 60% of the watershed lies.

3.2 BEDROCK GEOLOGY, SURFICIAL GEOLOGY AND SOILS

The bedrock geology of the Baker Creek watershed is divided into volcanic rocks of the Endako Group in the higher elevations and marine sedimentary and volcanic rocks of the Cache Creek Complex in the valley bottoms. Upper elevation rock types include basalt,

[2] Residual areas are not discrete drainage units and thus may be affected by conditions in sub-basins upstream.

andesite, related tuff and breccia, minor dacite, rhyolite, conglomerate, sandstone, and shale. Lower elevation rock types include undivided phyllite, siliceous phyllite, ribbon and massive chert, argillite, tuff, mafic volcanic rocks, serpentinite, limestone, sandstone, and conglomerate.

Cutslope exposures along the valley sides suggest the surficial geology of the upper slopes throughout the watershed is dominantly colluvium overlying bedrock. Localized till exposures were identified at a few locations, however these exposures are uncommon. Gravelly sandy glaciofluvial deposits overlying extensive glaciolacustrine deposits occupy much of the valley bottoms. Soils represented in this area are of the Brunisolic and Luvisolic orders (B.C. Water Resources Atlas 2006).

3.3 BIOGEOCLIMATIC ZONES

The Baker Creek watershed is primarily located within the Sub-Boreal-Pine-Spruce (SBPS) biogeoclimatic zone. Lodgepole pine is the dominant tree species in this zone. The frequency of forest fire prevents the potential climax species (white spruce) from dominating forest cover. However, small areas of white spruce are found in relatively wet lowland sites. The relatively gentle topography combined with fine-textured soils results in poor drainage in many parts of the watershed, which is reflected by the presence of numerous wetlands.

The Sub-Boreal-Spruce (SBS) biogeoclimatic zone is found at middle elevations in the watershed. At higher elevations, in the southern portion of the watershed, the Montane-Spruce (MS) biogeoclimatic zone is also found.

3.4 CLIMATE

In general, the climate in the Baker Creek watershed is relatively cool and dry due to its interior location in the shadow of the Coast Mountains. There are two (2) long-term Environment Canada climate stations that are representative of the lower and middle elevations of the Baker Creek watershed. Climate station No. 1096630 is located at the Quesnel Airport (YQZ) at an elevation of 545 m, approximately 2 km north of the mouth of Baker Creek (Environment Canada 2006). Climate station No. 1086550 is located at

Punchesakut Lake at an elevation of 915 m (Environment Canada 2002). The long-term mean monthly temperature and precipitation from both stations are presented in Figure 3.1.

The climate data from both stations suggests a consistent annual pattern in temperatures from a low of near -10ºC in December and January to a high near 15ºC in July and August. In most months, the middle elevations of the watershed are approximately 1 to 2 ºC cooler than the lower elevations. Higher elevations (above about 915 m) are expected to be even cooler.

Mean annual precipitation at lower elevations in the watershed is approximately 511 mm; at middle elevations this increases to 540 mm. On average, 34% of the annual precipitation within the watershed is in the form of snow. With higher elevations (above about 915 m), it is expected precipitation will increase with a slightly higher proportion as snow. The annual pattern of monthly precipitation varies by season. Monthly precipitation is at a minimum in late winter (February to April). With convective storms on the plateau, precipitation tends to peak in June and July, and drop in late summer when high pressure systems are dominant. In fall and early winter, frontal systems typically increase or maintain precipitation at moderate levels. Extreme precipitation events (i.e. greater than 30 mm per day) can occur throughout the year.

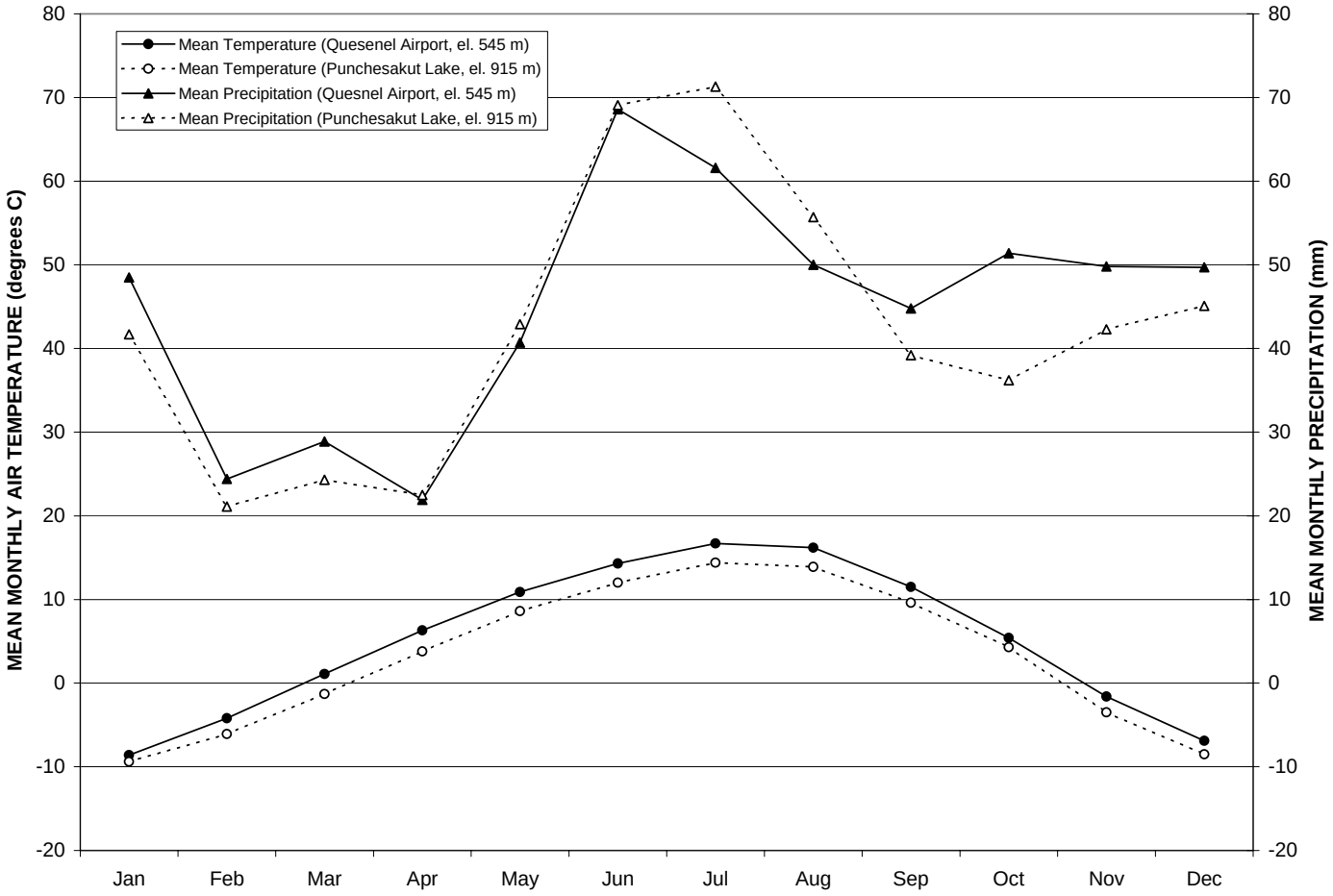


Figure 3.1 Mean monthly air temperature and precipitation from climate stations representative of the lower and middle elevations of the Baker Creek watershed.

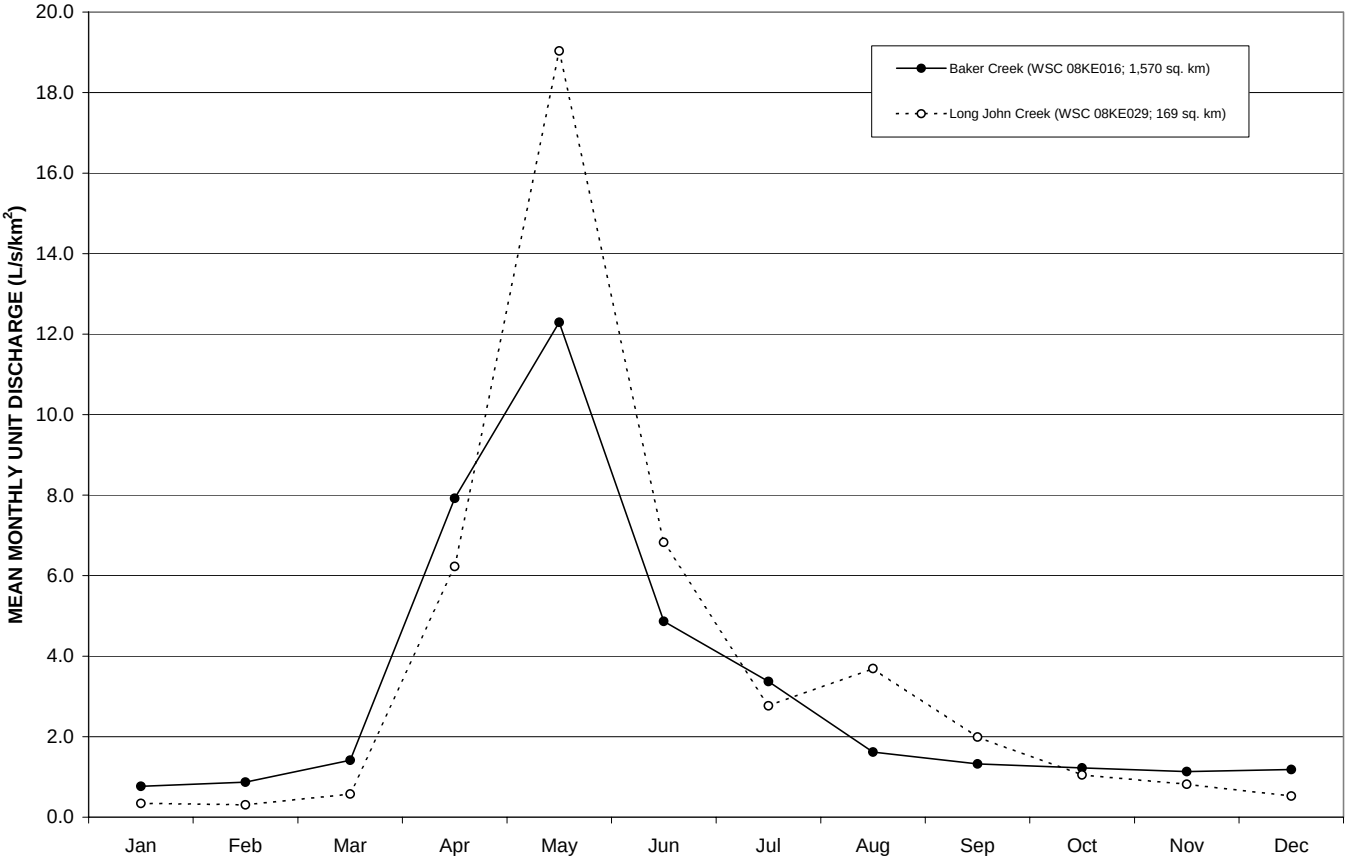
3.5 HYDROLOGY

The Baker Creek watershed is located on the relatively dry Fraser Plateau near the eastern edge of Hydrologic Subzone 12A (sub-zone e) (Obedkoff 1999). Hydrometric data has been collected by the Water Survey of Canada (WSC) at the following two (2) hydrometric stations in the watershed:

1. Baker Creek at Quesnel (WSC No. 08KE016; drainage area 1,570 km^2); and
2. Long John Creek at the mouth (WSC No. 08KE029; drainage area 169 km^2).

The former station is currently active and has an excellent long-term record of streamflows at the mouth of Baker Creek (since 1963). The later station operated only for a relatively short period between 1974 and 1981. Mean monthly unit discharge[3] (in $L/s/km^2$) for the period of record at both stations is presented in Figure 3.2. As shown on Figure 3.2, the annual hydrograph of streams in the watershed typically consists of a single snowmelt dominated peak in May, followed by a rapid recession in summer and fall. Rainstorms in late summer and fall often cause a minor secondary peak, but this is typically seen only in the tributary streams (e.g. Long John Creek) and not typically in the mainstem of Baker Creek near the mouth.

[3] Unit discharge refers to the volumetric runoff per unit area, typically reported as $L/s/km^2$. Unit discharge as opposed to discharge (in m^3/s) is used to facilitate the comparison of streamflows between watersheds of varying size.



Note the data cover different periods; they have not been normalized to a standard period.

Figure 3.2 Mean monthly unit discharge at the mouths of Baker Creek and Long John Creek.

The mean annual unit runoff at the mouth of Baker Creek over the period of record is 3.08 L/s/km^2 or 97 mm. This represents only 18% of the normal annual precipitation over the basin. Evapotranspiration, groundwater recharge, and/or off-stream uses account for the remaining 82% of the normal annual precipitation. Based on the relatively short record from Long John Creek, the mean annual unit runoff in the tributaries (within the upper portions of the watershed) are likely to be roughly 20% greater (i.e. 3.68 L/s/km^2 or 116 mm) than in the mainstem of Baker Creek near the mouth.

The 41-year record (1964 to 2004) of mean annual unit discharge of Baker Creek at the mouth is shown in Figure 3.3. A bold horizontal line indicates the long-term average annual unit discharge of 3.08 L/s/km^2 (noted above). This plot shows the large variability in annual streamflows about the long-term average. There have been several periods when flows were above average, and several periods when flows were below average. Visually, no systematic change in streamflows at the mouth of Baker Creek is apparent over time. This finding was confirmed statistically by analyzing the data using non-parametric tests (i.e. Mann-Kendall) incorporated in a statistical software package titled Trend (CRC for Catchment Hydrology 2005). This suggests that there is no long-term trend in annual streamflows at the mouth of Baker Creek over the period of record[4].

[4] Notwithstanding this finding at the mouth of Baker Creek, landowners in the middle portions of the watershed have reported increased flows in recent years (refer to Section 5.0).

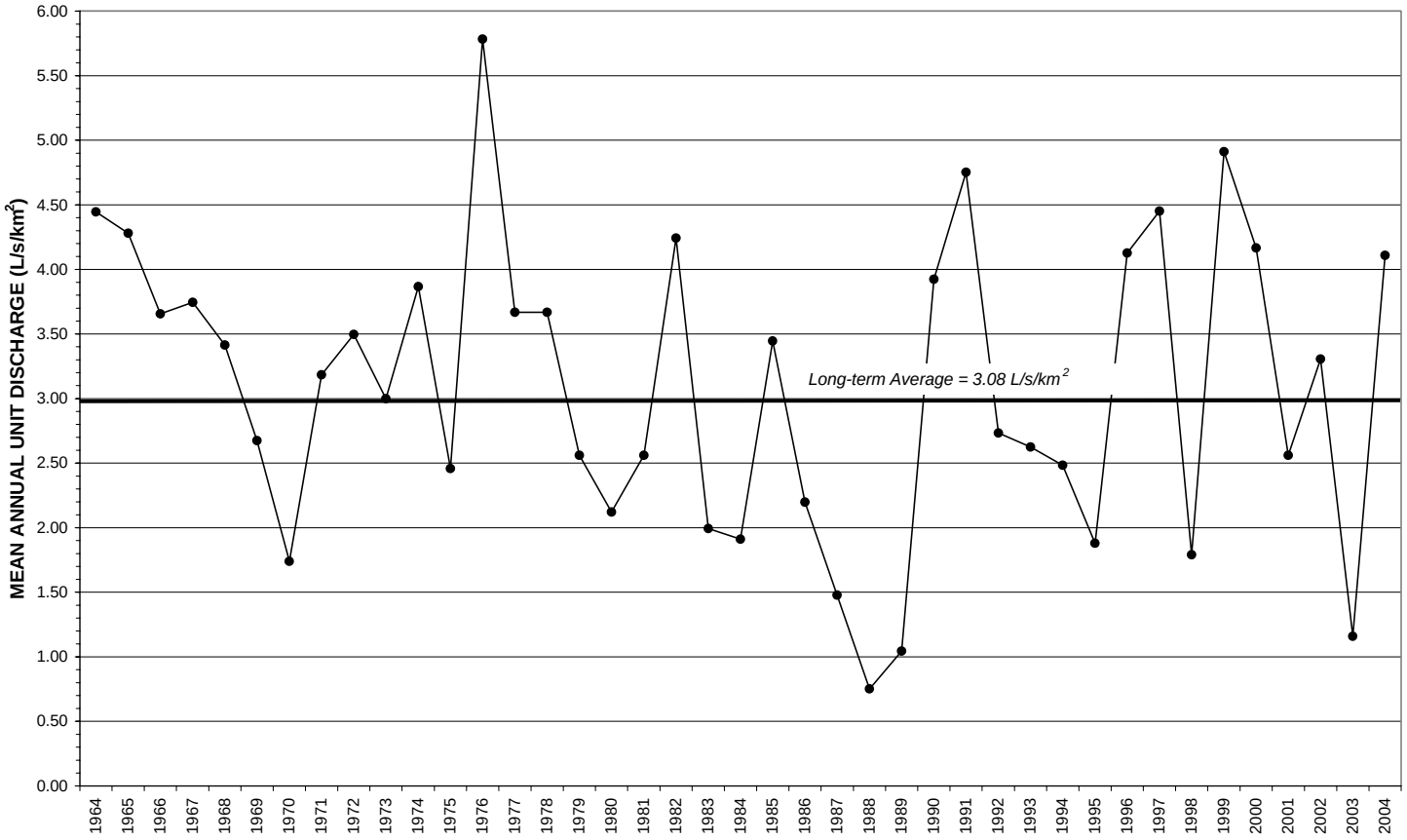


Figure 3.3 Mean annual unit discharge of Baker Creek at the mouth for the period 1964 to 2004.

As noted above, peak flows almost invariably occur in May in response to snowmelt. Figure 3.4 presents the maximum daily unit discharge for Baker Creek over the period 1964 to 2005. The plot shows the variability of annual peak flows about the long term average of 28.0 L/s/km^2. Inter-annual variability is similar to mean annual flows, but visually there appears to be a greater range in peak flows since 1990 than prior to 1990. Between 1964 and 1989, annual maximum daily unit peak flows averaged 23.6 L/s/km^2. Between 1990 and 2005, this value increased to 35.0 L/s/km^2; an increase of 48%. Furthermore, the six (6) highest peak flows on record all occurred after 1990, with the flood of 1991 the highest (Figure 3.4). Despite this, no statistical significant trend or shift in peak flows was identified using Trend statistical software (CRC for Catchment Hydrology 2005). Therefore, while not conclusive, the data are suggestive that peak flows in Baker Creek have generally increased in the last 15 years.

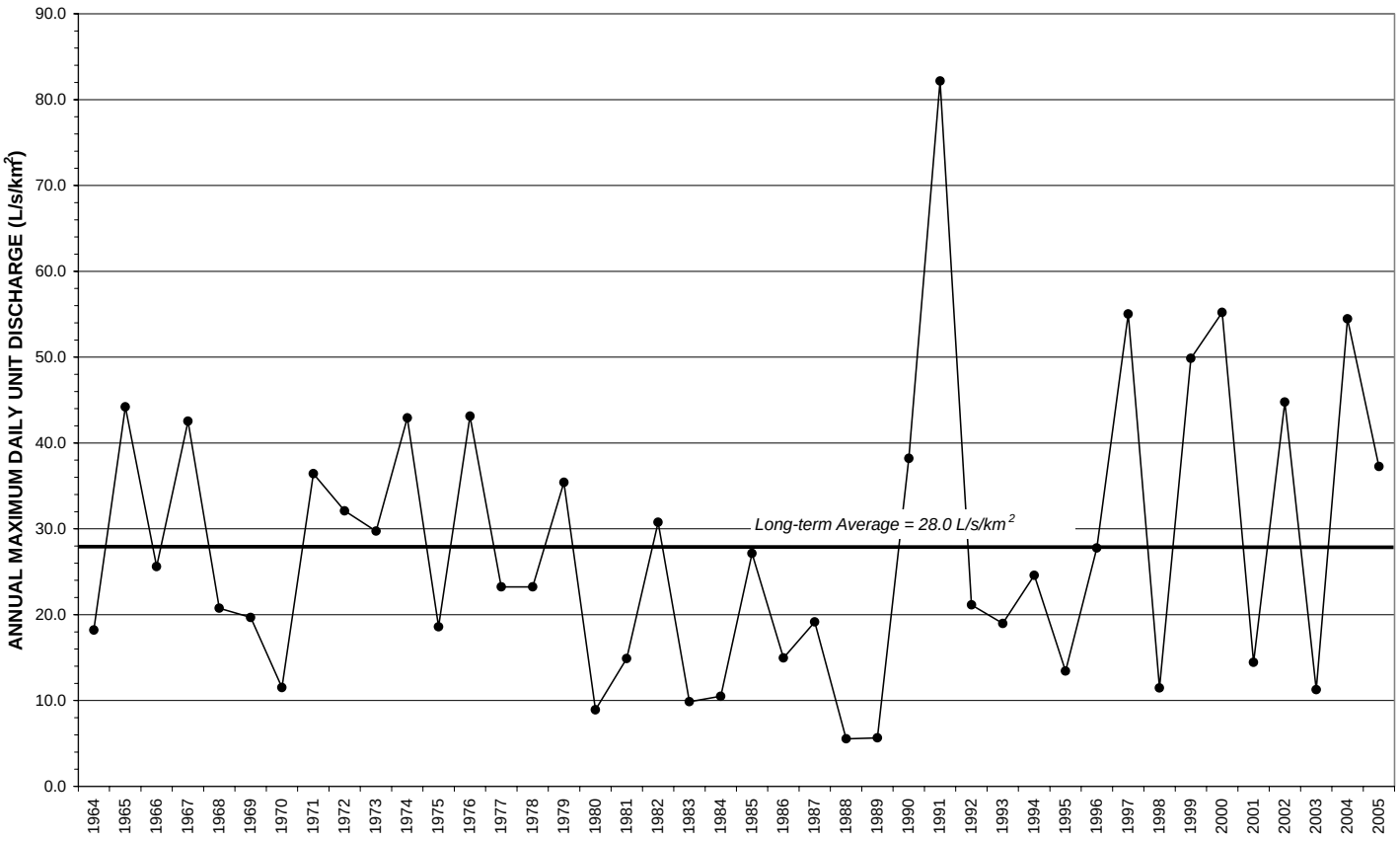


Figure 3.4 Annual maximum daily unit discharge of Baker Creek at the mouth for the period 1964 to 2005.

3.6 LAND USE

The Baker Creek watershed is a multiple-use watershed. Urban residential and commercial/light industrial development is located within the City of Quesnel near the mouth of Baker Creek. West of the city limits, rural residential and commercial land use extends along the Nazko Highway and is also concentrated near the community of Baker Creek. Ranching operations (primarily pasture and hay production) are found throughout the watershed, but are most concentrated on gentle terrain near the community of Baker Creek and along the Nazko Highway. Forestry is conducted throughout the watershed; the principal timber licensees include Tolko Industries Ltd., Canfor Corporation, and BC Timber Sales. An estimated 5.6% of the Baker Creek watershed is private land (Table 3.2), with the remaining 94.4% as Crown Land and parks.

Table 3.2 Areas of private land in the Baker Creek watershed organized by sub-basin.

Sub-basin	**Area of private land**	
	(km^2)	**% of sub-basin**
1. Upper Baker Creek	3.51	1.67
2. Long John Creek (incl. Trapline Creek)	0.776	0.467
3. Tibble Creek	0.078	0.156
4. Puntataenkut Creek	11.2	6.14
5. Merston Creek (incl. Tzenzaicut Lake)	7.49	2.85
6. Punchesakut Creek	11.9	22.7
7. Mount Creek (incl. Townsend Creek and Landslide Creek)	6.43	2.27
8. Middle Baker Creek (residual)	11.4	12.7
9. Lower Baker Creek (residual)	36.3	12.7
BAKER CREEK WATERSHED	**89.1**	**5.63**

3.7 SURFACE WATER AND GROUNDWATER USE

Surface Water

There are a total of 38 licences for surface water use in the Baker Creek watershed (MOE 2006a; Table 3.3). All but four (4) of these licences are for off-stream water use. On an annual basis, the 34 licences for off-stream uses in the watershed are authorized to withdraw 779,369 m^3, or 0.5% of the average annual runoff from the Baker Creek watershed. The majority of the licences for off-stream use are designated for irrigation (93%), with considerably less licensed for dust control (4%), and domestic use (3%). Although surface water is licensed in all sub-basins except Tibble Creek, most licences for off-stream use are

concentrated along the mainstem of Baker Creek in the Lower and Middle Baker residual areas, Punchesakut Creek sub-basin, and Mount Creek sub-basin. Water licences have also been granted to Ducks Unlimited for in-stream (wildlife and aquatic) use and conservation storage purposes in the Middle Baker Creek residual area and Puntataenkut Creek and Punchesakut Creek sub-basins.

Groundwater

According to the Ministry of Environment provincial well database (MOE 2006b), a total of 64 groundwater wells are located in the Baker Creek watershed (Table 3.4). The majority (37) of these wells are for private domestic use. Two (2) wells are listed for municipal waterworks (City of Quesnel), one (1) is for industrial use, and 24 are for unknown purposes. Based on the reported well yields, groundwater extraction on an annual basis is roughly estimated at 7.6 million m^3. Based on conversations with the Ministry of Environment staff responsible for the well database, it is understood that the actual number of wells may be as much as double that reported in the well database. Therefore, it is possible that groundwater extraction in the Baker Creek watershed may actually be on the order of 15 million m^3 per year.

Table 3.3 List of active surface water licences in the Baker Creek watershed, organized by sub-basin.

Sub-basin	Licence	Point-of-Diversion	Stream	Purpose	Quantity	Units	Annual quantity (m^3)	Licensee
1. Upper Baker Creek	C048828	PD41171	Baker Creek	Irrigation	50	AF	61,674	LISK JOE & URSULA
2. Long John Creek (including Trapline Creek)	C049006	PD40432	Trapline Creek	Irrigation	50	AF	61,674	LISK JOE
		PD40433	Bradley Creek					LISK JOE
3. Tibble Creek	No licences	-	-	-	-	-	-	-
4. Puntataenkut Creek	C117141	PD76724	Celby Marsh	Land Improve	0	TF	0	CEL-B HOLDINGS LTD
	C117204	PD76764	Engel Marsh	Land Improve	0	TF	0	ENGEL MATTHEW BRUCE & KELLY A
	C057061	PD40477	Keras Ditches	Land Improve	0	TF	0	LEADER ERNEST H
	C112055	PD72979	Little Ripley Creek	Dust Control	5000	GD	4,148	MOT
	C063241	PD40479	Madonna Springs	Domestic	500	GD	830	LEADER ERNEST H
	C063242			Ponds (instream use)	0.46	CS	410,778	
	C040429	PD40481	Puntataenkut Creek	Domestic	1500	GD	2,489	BOERSMA PETER & DIANA L
				Irrigation	1	AF	1,233	
	C066810	PD40483	Puntataenkut Creek	Conservation-Construction of Works (instream use)	0	TF	0	DUCKS UNLIMITED (CANADA)
				Conservation-Stored Water (instram use)	185	AF	228,195	
	C110873	PD71996	Puntataenkut Creek	Dust Control	1800000	GY	8,195	MOT
	C117204	PD40483	Puntataenkut Creek	Land Improve	0	TF	0	ENGEL MATTHEW BRUCE & KELLY A
	C122332	PD40471	Puntataenkut Creek	Irrigation	5	AF	6,167	SMART BRADLEY S
	C069195	PD58806	Puntataenkut Lake	Dust Control	5000	GD	4,148	MOT
5. Merston Creek (including Tzenzaicut Lake)	C102221	PD64122	Balfe Swamp	Irrigation	22	AF	27,137	FREEMAN KATHLEEN
	C043817	PD41169	Merston Creek	Domestic	2000	GD	3,319	MOFFAT KARL K & EVA M
	C043818	PD40681	Merston Creek	Domestic	2000	GD	3,319	BOMPAS DARRIN KENYON
	C106217	PD67415	Merston Creek	Dust Control	1050000	GY	4,773	MOT
	C112056	PD72976	Merston Creek	Dust Control	5000	GD	4,148	MOT

Table 3.3 cont'd.

Sub-basin	Licence	Point-of-Diversion	Stream	Purpose	Quantity	Units	Annual quantity (m^3)	Licensee
6. Punchesakut Creek	C119598	PD40690	Puntchesakut Creek	Irrigation	43	AF	53,040	ZEMANN ARAWAN
	C069197	PD58808	Puntchesakut Lake	Dust Control	5000	GD	4,148	MOT
	C101940	PD40492	Squamish Lake	Irrigation	56	AF	69,075	FOUTY GORDON E
	C063394	PD40688	Tiltzarone Lake	Conservation-Stored Water (instream use)	398	AF	490,929	DUCKS UNLIMITED (CANADA)
7. Mount Creek (including Townsend Creek and Landslide Creek)	C043568	PD41167	Mount Creek	Irrigation	80	AF	98,679	HAMZA HOLDINGS LTD.
		PD41166		Domestic	2000	GD	3,319	
	C054010	PD41163	Farnese Spring	Domestic	500	GD	830	WILSON TIMOTHY J & SANDRA A F
	C054009	PD41165	Townsend Creek	Domestic	500	GD	830	WILSON TIMOTHY J & SANDRA A F
8. Middle Baker Creek (residual)	C039878	PD40431	Baker Creek	Irrigation	70	AF	86,344	LISK JOE
	C069198	PD58805	Baker Creek	Dust Control	5000	GD	4,148	MOT
	C122333	PD40458	Baker Creek	Irrigation	4	AF	4,934	HILDEBRANDT LUTZ K
9. Lower Baker Creek (residual)	C063395	PD40686	Quanstrom Lake	Conservation-Stored Water (instream use)	83.8	AF	103,366	DUCKS UNLIMITED (CANADA)
	C066755	PD40691	Baker Creek	Irrigation	40	AF	49,340	CHERRY ROY
		PD40692						
	C101950	PD40682	Brailsford Creek	Irrigation	120	AF	148,019	CHERRY ROY
				Stockwatering	1000	GD	1,659	CHERRY ROY
	C049007	PD40679	Chevans Creek	Irrigation	40	AF	49,340	GRANHOLM ROBERT B & KATHLEEN A
	C043816	PD40674	Cox Creek	Domestic	2000	GD	3,319	SARGENT ERIC F
	C069066	PD40644	Hesketh Spring	Domestic	1000	GD	1,659	SAVAGE JAMES J
	C043816	PD40675	Munn Creek	Domestic	2000	GD	3,319	SARGENT ERIC F
		PD40677						
	C057062	PD40649	Peter Brook	Domestic	500	GD	830	HALL HAROLD F & SHIRLEY M
				Irrigation	2	AF	2,467	
BAKER CREEK WATERSHED	**Annual licensed quantity for offstream use:**						**779,369**	
	Annual licensed quantity for instream (conservation) use:						**410,778**	
	Annual licensed quantity for conservation storage:						**2,012,637**	

Table 3.4 List of groundwater wells located in the Baker Creek watershed that are reported in the Ministry of Environment well database.

Sub-basin	Well ID	Water Use	Reported Water Yield (GPM)	Estimated Annual Yield (m^3)
1. Upper Baker Creek	no wells in database	-	-	-
2. Long John Creek (including Trapline Creek)	no wells in database	-	-	-
3. Tibble Creek	no wells in database	-	-	
4. Puntataenkut Creek	60978	Domestic	7.5	14,919
	60980	Domestic	-	
5. Merston Creek (including Tzenzaicut Lake)	no wells in database	-	-	
6. Punchesakut Creek	45260	Domestic	4	7,957
	55556	Domestic	2.5	4,973
	27713	Unknown	6	11,936
	27710	Industrial (West Fraser Mills)	100	198,925
7. Mount Creek (including Townsend Creek and Landslide Creek)	41290	Unknown	1.5	2,984
8. Middle Baker Creek (residual)	47797	Domestic	6	11,936
	60979	Domestic	22	43,764
	27209	Unknown	600	1,193,550
9. Lower Baker Creek (residual)	06132	Domestic	-	-
	30857	Domestic	2	3,979
	33578	Domestic	100	198,925
	35314	Domestic	2.5	4,973
	36130	Domestic	15	29,839
	36693	Domestic	250	497,313
	36774	Domestic	5.5	10,941
	37358	Domestic	250	497,313
	37692	Domestic	1	1,989
	43692	Domestic	4	7,957
	43733	Domestic	2	3,979
	46384	Domestic	2	3,979
	47635	Domestic	6	11,936
	47975	Domestic	3	5,968
	48230	Domestic	6	11,936
	48286	Domestic	5	9,946
	49044	Domestic	3	5,968
	49436	Domestic	1	1,989
	49938	Domestic	4	7,957

Table 3.4 cont'd.

Sub-basin	Well ID	Water Use	Reported Water Yield (GPM)	Estimated Annual Yield (m^3)
9. Lower Baker Creek (residual)	50703	Domestic	2	3,979
	54086	Domestic	1	1,989
	54209	Domestic	2	3,979
	54633	Domestic	4	7,957
	55553	Domestic	2	3,979
	56050	Domestic	5	9,946
	57531	Domestic	6	11,936
	57959	Domestic	4	7,957
	60820	Domestic	10	19,893
	60981	Domestic	-	-
	61068	Domestic	2.5	4,973
	61070	Domestic	1	1,989
	15203	Municipal	400	795,700
	15269	Municipal	500	994,625
	06168	Unknown	-	-
	20890	Unknown	120	238,710
	20949	Unknown	60	119,355
	29781	Unknown	200	397,850
	29824	Unknown	150	298,388
	30282	Unknown	100	198,925
	30442	Unknown	500	994,625
	30443	Unknown	-	-
	31018	Unknown	5	9,946
	31039	Unknown	5	9,946
	31067	Unknown	-	-
	31795	Unknown	5	9,946
	31844	Unknown	3.5	6,962
	32522	Unknown	15	29,839
	32740	Unknown	4	7,957
	33581	Unknown	200	397,850
	34214	Unknown	100	198,925
	36045	Unknown	2	3,979
	41289	Unknown	4	7,957
	43406	Unknown	-	-
	43579	Unknown	5	9,946
BAKER CREEK WATERSHED (TOTAL)	-	-	-	7,617,833

4.0 OVERVIEW OF HYDROLOGIC EFFECTS OF MOUNTAIN PINE BEETLE

4.1 BACKGROUND

The mountain pine beetle (MPB; *Dendroctonus ponderosae Hopkins*) is the most damaging insect that affects lodgepole pine in western Canada. While not unprecedented as a natural phenomena (Burton 2006), the current mountain pine beetle outbreak in British Columbia's interior pine forests (that can be traced back to about 1993) is the largest on record in North America (BC Ministry of Finance 2005). The outbreak started in both the southern and northern portions of British Columbia and has since affected pine species throughout the interior of the province. Pine forests (i.e., lodgepole pine, ponderosa pine, and western white pine) account for approximately 1.2 billion m^3 of the provincial timber volume (Dobbin, pers. comm., 2006) and cover roughly 1/3 of British Columbia's 60 million hectare forest base (Eng 2005). Of the 20 million ha of forests containing pine in the province, roughly 22% is classified as pure pine (Eng 2005). The remaining 78% is mixed with other species.

By 2005, approximately 411 million m^3 or 35% of British Columbia's mature pine volume were affected by MPB (Dobbin, pers. comm. 2006). Current Ministry of Forests and Range predictions suggest the cumulative volume of beetle-killed timber will continue to increase provincially until about 2013. At that time, the volume of beetle-killed timber is projected to peak at 80% of the provincial volume of mature pine. Within many interior watersheds, including Baker Creek, beetle-kill has already peaked and has affected the majority (i.e. roughly 80%) of the forest.

Such large-scale disturbance could have a dramatic impact on forest hydrology (Alila 2005a and 2005b; FPB 2007). While some research on this topic is available, there is generally limited information available to help forest managers predict the hydrologic impacts at such a large scale. Much of the research available is based on beetle epidemics outside of British Columbia and at considerably smaller scales, so that direct application of these findings to the current problem is difficult (Alila 2005b). While several studies have been initiated in British Columbia, relatively few research results have been published to date. One study of

direct relevance that has recently been published by the Forests Practices Board documents the results of a hydrologic model developed for Baker Creek (FPB 2007). Based on the Forest Practices Board results, other relevant studies on hydrologic effects of beetle-killed stands, reference to relevant forest hydrology studies, and observations of stakeholders and forest professionals in beetle-affected areas an understanding of the potential hydrologic impacts of MPB and salvage harvesting can be developed.

In addition to the hydrologic regime, beetle-kill and salvage logging may affect sediment transport (including hillslope and channel processes), riparian function, and water quality (including stream temperature). This overview, however, focuses primarily on changes in water quantity and timing as a result of beetle-kill and salvage logging. This overview is adopted from recent papers by Uunila et al. (2006) and Uunila and Guy (2006) and outlines the nature of the forest disturbance caused by mountain pine beetle, some of the current management questions, and the previous hydrologic research on beetle infestation. This is followed by discussion of the potential hydrologic effects of mountain pine beetle with and without salvage logging.

4.2 CHARACTERISTICS OF THE MOUNTAIN PINE BEETLE DISTURBANCE IN B.C.

Insects, fire, windthrow, and drought play important and often interconnected roles in the natural disturbance and replacement of pine forests. Since fire control measures have been implemented in B.C. there is roughly three (3) times more mature (i.e., greater than 80 years old) pine now than there was in 1910 (Taylor and Carroll 2003). The relatively high proportion of "mature" pine currently in British Columbia is considered to be one of the most important controlling factors in the susceptibility of pine stands to beetle attack and ultimately the magnitude of the current beetle epidemic (MOF 2003). During the early stages of the current epidemic it was observed that pine trees roughly 60-80 years (or older) were generally susceptible. As the epidemic progressed, however, younger pine trees (roughly 20-40 years old) became susceptible to attack (MacLauchan 2006). Another important factor in the current epidemic is favourable weather in recent years that supports the survival and growth of beetle populations (i.e., warm summers and mild winters).

At endemic levels, mountain pine beetles infest weakened trees and may attack only a portion of the circumference of the tree (i.e., "strip attack"). The trees will continue to live and therefore there is little evidence of beetle attack. When climatic conditions are favourable and host trees are highly susceptible (i.e., old and/or stressed), the incipient stages of an outbreak may occur. At this stage, small groups of trees are typically attacked. Once incipient populations are established, the beetles expand and disperse to the surrounding pine forest, travelling up to 30 kilometres or more under favourable wind conditions and colonizing up to 30 hectares at a time (COFI 2004). The rate and pattern of attack varies depending on prevailing wind conditions during late summer when adult beetles usually take flight.

Mountain pine beetles kill mature trees by boring through the bark and mining the phloem – the layer between the bark and the wood of a tree. This effectively "girdles" the tree and prevents the upward flow of nutrients in the tree. In addition, beetles carry a blue staining fungus that causes dehydration and inhibits a tree's natural defences against beetle attacks (MOF, 2004). Both the "girdling" and the fungus kill the tree. This process takes about one year from initial attack, during which time the tree's foliage changes from green to red and trees begin to shed their needles. By the time the trees turn red, the beetles have moved on to colonize another tree or area. Approximately two (2) years after initial attack, pine needles turn dull red to grey. The needles continue to fall for up to five (5) years or more (Maloney, 2006). Trees at this stage are referred to as "grey attack". In this stage, trees begin to take on a ghost-like appearance, and unless salvaged will remain standing for some time. The timing and rate of tree fall following beetle-kill varies from stand to stand. Research suggests that trees may begin to fall 3 to 5 years after death, but that the majority of trees fall down within about 15 to 20 years, although resistant snags may stand for much longer (Lewis and Hartley 2006), particularly if the water table is lower than the root mat.

4.3 CURRENT FOREST MANAGEMENT QUESTIONS

There are many questions on how MPB affect hydrologic processes in forested watersheds. Common questions include:

- Will peak flows increase due to altered snow accumulation and melt processes?
- Will there be more water or less water flowing in the summer?
- Will water tables rise?
- Will stream temperatures increase?
- Will there be increased sediment inputs to streams or changes to large wood recruitment?
- Will stream channels become destabilized or will there be an increase in the rate of destabilization?
- Will riparian function and/or fish habitat be affected?
- How long will projected effects on hydrology last?

These questions in turn create many management questions for MPB affected areas. Uunila et al. (2006) presented a list of nine (9) key management questions:

- Is there a threshold at which the hydrologic effects of MPB are measurable?
- How do small group infestations compare in their hydrologic impact with larger infestations?
- How do location, elevation, aspect, physiography, and weather control the hydrologic impacts of MPB?
- How do the density, type, and extent of the forest understory affect hydrologic response and subsequently forest management?
- How do the hydrologic impacts of MPB vary with time?
- What is the impact of standing dead timber on key hydrologic processes? How does this compare with hydrologic impacts after salvage logging?
- How long will it take for non-salvaged beetle-kill stands to regenerate and hydrologically recover? Is regeneration faster or slower if salvage logging occurs in beetle-killed stands?

- Should forest managers approach salvage harvesting in the same manner as conventional harvesting?
- Will alternative silvicultural systems be required in non-salvaged MPB-affected stands to minimize impacts?

4.4 RESEARCH STUDIES

Relatively little research has been conducted on the effects of insect infestations in general, and mountain pine beetle infestations in particular, on forest hydrology. The research outlined below and summarized in Table 4.1 has traditionally involved paired-watershed or stand-scale studies. More recently, hydrologic modeling has become a focus given the urgency of the problem and the challenges in developing controlled watershed experiments.

One of the earliest relevant studies is that by Love (1955). Love (1955) described an Engelmann spruce beetle epidemic in the White River watershed in Colorado that began in 1939 (following a severe windthrow event) and lasted seven years, ultimately covering 30% of the study watersheds and killing up to 80% of the trees. Based on a review of streamflow and snowpack data, Love (1955) concluded that annual water yield increased by about 19% above pre-epidemic values. Love's study design was criticized by Bue et al. (1955) as being poorly controlled. Bue et al. (1955) claimed that it was not possible to conclude if streamflows increased in the infested watershed or decreased in the non-infested control watershed. However, a re-analysis of the White River data by Mitchell and Love (1973) indicated a water yield increase of 15% to 18%, which supported Love's (1955) conclusion.

The White River infestation was further investigated by Bethlahmy (1974) using additional data and another watershed (Yampa River). Based on an analysis of covariance on pre- and post-infestation data, Bethlahmy (1974) found that annual water yield increased on average about 12% over a 25 year period following infestation. While the data indicated that increases varied considerably from year to year, based on weather conditions, the maximum increase occurred 15-20 years post-infestation, after which time the process of forest regeneration tends to mitigate impacts. Further work by Bethlahmy (1975) was consistent

with the earlier research indicating that average increases in annual water yield post-infestation are about 15% and that the maximum increase (of up to 28%) occurred 15-20 years following infestation. The impacts were evident even 25 years after infestation - annual water yields were still 10% above pre-infestation levels. Bethlahmy (1975) also noted that monthly low flows increased 10-31% and monthly peak flows increased 14-22%. However, changes in instantaneous peak flows were variable; from no change to 27% increase.

A mountain pine beetle epidemic in southwestern Montana in the mid-1970's resulted in a 15% increase in annual water yield, a 10% increase in low flows, and a two-week advancement in the timing of spring runoff, but little change in peak flows (Potts 1984). These changes were associated with a watershed having 35% of the total timber killed by beetle. The observed changes resulted from reduced evapotranspiration losses, as well as alteration of winter snow accumulation and melt processes in winter and spring. However, the method used by Potts (1984) to infer the effect (i.e., double mass curve) is criticized by Hewlett (1982). Uunila et al. (2006) reanalyzed the Potts (1984) data and confirmed the validity of Hewlett's (1982) suspicion. Due to the small sample size (i.e., 4 years pre- and post-treatment), there was no statistically significant effect. Therefore, the results presented by Potts (1984) should be interpreted with caution.

Schmid et al. (1991) conducted a stand-scale investigation in Colorado and identified a complexity in beetle-infested forests that had not been widely considered. These authors identified the live understory (and needle retention to a lesser extent) in a beetle-killed stand as potentially important factors that mitigate the effects of beetle infestation on snowfall accumulation and rainfall interception. This finding is significant since understory vegetation, including well established conifers (e.g., spruce, sub-alpine fir, and Douglas fir), are common in many beetle-killed stands in British Columbia. According to Eng (2005), pure pine stands account for only 22% of the forests containing pine the province. Furthermore, over 40% of the stands dominated by pine within the north-central interior of the province have adequately stocked (600 stems/ha) understories (Burton 2006).

Troendle and Nankervis (2000) modelled a spruce bark beetle epidemic on spruce forests in Colorado and Wyoming assuming between 30% and 50% mortality over a 10-year period. Their results indicated an average water yield increase of 56 mm by the tenth year [comparable to Love's (1955) results] followed by a decrease to pre-infestation yields over the next 60 to 70 years.

Research at the University of British Columbia, Faculty of Forestry is currently investigating MPB effects and salvage harvesting on streamflow characteristics in selected watersheds in B.C. (Alila 2005a and 2005b; Luo et al. 2006). Both the Distributed Hydrology Soil Vegetation Model (DHSVM) and UBC Watershed Model (UBCWM) have been utilized in this research. The results of DHSVM modelling of Baker Creek have recently been published by the Forest Practices Board (FPB 2007). The results of this modelling suggest that if 80% of the mature pine in the watershed is attacked by MPB (and if past harvesting is accounted for), there could be annual water yield increases of about 30% and annual peak flow increases of about 60% (FPB 2007). Furthermore, the modelling suggests that if all pine-leading stands are salvaged (with 20% retention), annual peak flows could increase by 92% (FPB 2007). At the same time, flood frequency could increase; former 20-year return period floods would be anticipated every 3 years (FPB 2007). These model results suggest a possibility of a significant shift in the hydrologic regime as a result of beetle-kill and salvage harvesting. However, as the authors identify, the model "still reflects the limited state of knowledge of mountain pine beetle effects on hydrologic processes", so the reported values should be viewed cautiously. It is understood, that UBC researchers will continue to study Baker Creek to help refine the model in future.

Stand-scale and watershed-scale studies throughout the British Columbia interior are also being conducted by government agencies and academic institutions (e.g., Dubé et al. 2005). These studies are investigating the role of standing dead trees, partial retention, retention of advanced regeneration, recovery, and extensive forest cover loss on hydrologic processes (Winkler 2006).

Overall, the available research suggests that at the stand-scale the effects of MPB on forest hydrology may be roughly similar to the effects of forest harvesting. Within even-aged stands the effects include:

- increased annual water yield;
- increased summer low flow;
- variable changes to peak flow magnitude; and
- possibly earlier peak flows.

These effects, which may last upwards of 70 years, would likely be mitigated in uneven-aged stands containing live trees and understory vegetation.

Table 4.1 Summary of previous hydrologic research on effects of beetle infestation.

Location	Drainage area (km^2)	Dominant forest cover	% of watershed infested	Average change in annual water yield	Change in monthly low flow (late summer-fall)	Change in monthly high flow (spring)	Change in peak flow	Expected time for hydrologic recovery to pre-disturbance conditions	References
White River, Colorado	1,974	Engelmann spruce	80% of trees covering 30% of watershed	+50 mm (19%)	-	-	-	-	Love (1955)
				+40–48 mm (15–18%)	-	-	-	-	Mitchell and Love (1973)
				+31.8 mm (12%)	-	-	-	-	Bethlahmy (1974)
				+37.9 mm (15%)	+1.6 mm (31.4%)	+14.9 mm (22%)	+20.2 m^3/s (27%)	>25 years	Bethlahmy (1975)
Yampa River, Colorado	1,564	Engelmann spruce	80% of trees covering 30% of watershed	+23.6 mm (11%)	-	-	-	>25 years	Bethlahmy (1974)
				+35.2 mm (16%)	+1.2 mm (9.6%)	+12.0 mm (14%)	no significant change	>25 years	Bethlahmy (1975)
Jack Creek, Montana	133	Lodgepole pine	35% of trees (50–60% of trees > 18 cm diameter at breast height	+45 mm (15%)	+2 mm (10%)	+26 mm (52%)	no significant change to magnitude; peak 2 weeks earlier	>5 years	Potts (1984)
North Platte River, Wyoming & Colorado	1,978	Engelmann spruce	Assumed 30–50% tree mortality	+56 mm	-	-	-	60–70 years	Troendle and Nankervis (2000)
Baker Creek, BC	1,570	Lodgepole pine	80% of mature pine representing 53% of watershed area	+31%	-	-	+61%; peak 15 days earlier	-	FPB (2007)
			Salvage all beetle-kill with 20% retention	+52%	-	-	+92%; peak 16 days earlier	-	

Adapted from Uunila et al. (2006).

4.5 POTENTIAL HYDROLOGIC EFFECTS OF MPB AND SALVAGE LOGGING

The lack of controlled experiments and limited data preclude a quantitative assessment of the hydrologic impacts of MPB and the effects of salvage logging a MPB affected stand. However, based on existing knowledge of forest hydrology, it is possible to make initial hypotheses on the hydrologic effects of beetle-kill and salvage logging. The discussion below is organized by hydrologic processes at the stand-scale and at the watershed-scale. Throughout this discussion, it is assumed that dead pine will be salvaged using conventional forest harvesting techniques. Within each of key hydrologic processes discussed below, salvage-logging effects are introduced first. This is followed by discussion of the likely hydrologic effects of MPB assuming no salvage logging occurs.

4.5.1 Stand-scale Processes

Snow accumulation / interception

Many authors have documented an increase in snow accumulation in cutblocks compared with adjacent forest. Winkler (1999) summarized 16 previous studies of snow accumulation and melt in areas with a similar climate to the interior of B.C. These previous studies reported a range of from 0% to 67% (average 43%) more snow in cutblocks, compared with the adjacent forest, at the time of maximum snow accumulation. This phenomenon occurs for two reasons:

- Snow falls directly onto the ground, rather than being partially intercepted by a forest canopy - subsequent losses to the atmosphere by the process of sublimation are much smaller in the opening than in the adjacent forest; and
- Wind that occurs during snowfall favours deposition in cutblocks, and may also blow snow from the forest canopy into the openings near the stand edge.

Several factors govern the extent of the increase in snow accumulation in cutblocks, including the tree species, characteristics of the ground surface, wind characteristics, and cutblock characteristics.

Snow accumulation in a beetle-killed stand would likely be greater than in the surrounding live forest and approach that of a cutblock, since interception would be reduced (as crown cover is reduced once the foliage falls off). In the Vanderhoof area, Boon (2006) identified that peak snow water equivalent (SWE) in a dead stand was twice that of a comparable live stand and half that of a cutblock. P. Beaudry and Associates (2006) noted similar patterns of snow accumulation in beetle-affected stands southwest of Prince George. Based on one (1) season of snow surveys, P. Beaudry and Associates (2006) identified that red- and grey-attack stands had 47% and 69% more snow than undisturbed forest, while clearcuts had 105% to 132% more snow than in the undisturbed forest.

Boon (2006) suggested that the presence of understory vegetation would play a mitigating role – in its absence, accumulation under dead stands would be comparable to cutblocks. Standing dead timber would tend to protect the snowpack from the effects of wind (i.e., scour and sublimation). Within the first year of infestation (green stage), interception likely reflects natural conditions. One to two years following infestation (red stage) foliage largely remains, and trees still intercept precipitation similar to surrounding live trees (Schmid et al., 1991). Roughly two to four years after infestation (grey stage), most foliage is lost and interception is likely reduced to near zero (i.e., similar to a cutblock) until new trees become established.

Snowmelt

The general consensus in the research literature is that snow located in open cutblocks melts at a faster rate than snow in the forest. The reason for this difference is that solar energy is the dominant driver of melt, and snow in the openings is much more exposed to solar radiation than snow in the more shaded forest. In 16 studies reviewed by Winkler (1999), snowmelt rates ranged from 0% to 250% faster in the openings compared with the forest, with an average of 43% faster. The wide range of snowmelt rates reflects complex processes and several factors, including the tree species, the slope angle, the slope aspect, and the size, shape, and orientation of the cutblocks.

Preliminary study results in the Vanderhoof area based on one (1) year of data suggest that the energy balance and melt rates in a beetle-killed stand may be comparable to those in a live stand (Boon 2006). Considering the processes, snowmelt rate in a beetle-killed stand is likely to be transitional between the melt rate in a cutblock and the melt rate in the surrounding forest, given some shading afforded by the stand and reduced wind action (i.e., turbulent heat flux). Although standing dead trees emit long-wave radiation (leading to snowmelt), the increased long-wave radiation is likely outweighed by reduced solar radiation (due to shading).

Evapotranspiration

Evapotranspiration rates are reduced following forest harvesting and research in northern forests suggest this reduction ranges from 85 mm to 318 mm (Dubé et al. 2005). This leads to an increase in annual water yield, possibly increasing late summer streamflow and/or groundwater levels. Following the establishment of vegetation, however, evapotranspiration rates increase towards pre-harvest levels.

A substantial reduction in evapotranspiration also occurs following beetle-kill in even-aged stands with minimal understory vegetation (similar to clearcuts). The presence of mixed species and understory vegetation in the beetle-killed stand will however have a mitigating effect. The duration of the reduction will depend on the time it takes for vegetation and a new forest stand to establish and mature. Reduced evapotranspiration rates are speculated to continue over a longer time span than for cutblocks, as it will likely take longer for a new stand to establish, unless trees are planted to promote regeneration of beetle-killed stands.

Soil compaction

Soils are generally subject to compaction during forest harvesting and road construction. Soil compaction tends to reduce infiltration rates, increase bulk density, convert soil macro-pores to micro pores, alter overall drainage patterns, and promote surface runoff (Keppeler and Ziemer, 1990). Increased surface runoff could result in increased streamflows. The significance of this potential effect depends on how much harvesting actually occurs on soils

subject to compaction, and the extent of the surface disturbance that occurs during harvesting. If harvesting is conducted during winter on frozen ground and/or sufficiently deep snowpack (i.e. >0.5 m), impacts of harvesting on soil conditions can be minimized.

Assuming no heavy equipment accesses a beetle-kill area, soil compaction and associated hydrologic impacts from beetle-kill will not occur.

Roads

Roads and ditches associated with forest harvesting increase drainage density and create additional paths for the conveyance of surface water to streams, potentially resulting in a faster stream response to rainfall and snowmelt. In addition, cutslopes can intercept groundwater flow and route it to stream channels more quickly than if the water remained as groundwater. Finally, the surface compaction associated with roads and trails reduces infiltration, thus potentially increasing runoff to streams. Each of these factors tends to increase the volume of storm runoff reaching surface streams and the rate at which runoff becomes streamflow. In addition, cutslopes and ditches along roads can alter the natural drainage patterns of the hillslope below the road.

If no roads are developed to access beetle-kill area, the effects of roads on the hydrologic regime will not occur. However, if the length of roads in a watershed increases to facilitate salvage, then effects may occur.

Hydrologic Recovery

Hydrologic recovery occurs as the governing hydrologic processes affected by cutblocks and roads return to pre-harvest levels (e.g., interception, evapotranspiration, snow accumulation and melt, soil compaction). Several authors have addressed the longevity of the effects due to timber harvesting. Summit Environmental Consultants Ltd. (2001) summarized previous studies and concluded that the effects of harvesting can last from about 5 years to more than 35 years.

The time for hydrologic recovery is speculated to be greater for beetle-killed stands than for cutblocks that are harvested and planted. A dead pine forest with no live understory may take upwards of 60 years to hydrologically recover (Maloney 2005), particularly if the stand is not subject to fire. Modeling by Troendle and Nankervis (2000) suggests that recovery may take upwards of 70 years. Clearly, the time for hydrologic recovery will depend on stand characteristics (e.g., presence of non-pine species) and the vagaries of nature which control whether a dead stand will be subject to wind throw or fire.

4.5.2 Watershed-scale Processes

Peak flows

In snowmelt-dominated hydrologic regimes, many research studies have documented increases in total spring snowmelt runoff and increases in peak flow rates. Several (but not all studies) [Troendle and King (1985, 1987), Troendle and Stednick (1999), Troendle et al. (2001) and Van Haveren (1988)], have identified an advancement in the timing of peak flow following forest harvesting. These changes are attributable to an increase in snow accumulation in the cutblocks compared with the uncut forest and faster melt rates in the cutblocks. In a review of 40 studies by Scherer (2001), peak flows either increased or did not change following forest harvesting and the relations between the magnitude of change and peak flow following harvesting varied widely with the level of harvest.

Increased snow accumulation and more rapid melt rates in beetle-killed stands will likely result in higher and earlier peak flows than in the surrounding forest. However, due to mitigating effects of standing dead timber on snow accumulation and melt processes, and more importantly the lack of road development and soil compaction by heavy equipment in the beetle-killed area, the effects on peak flows associated with beetle-kill should be considerably less than the effects associated with cutblocks (assuming beetle-kill and harvesting are of comparable size). Based on one (1) year of snow survey data, P. Beaudry and Associates Ltd. (2006) suggested that the equivalent clearcut area (ECA) (i.e. an indicator of the potential affect of forest cover disturbance on peak flow) associated with red-

and grey-attacked stands is 45% and 52% of the ECA associated with a clearcut (with 100% basal area removed) of similar size.

In many watersheds, MPB has infested areas much larger than has been traditionally harvested. In such watersheds, MPB effects on peak flows could exceed those of traditional harvesting (i.e. with ECAs generally less than 20-30%). The research of P. Beaudry and Associates Ltd. (2006) suggests a watershed with 80-100% tree mortality would have an ECA of roughly 40-50%, although this should only be considered a rough estimate based on limited data. ECAs would be further increased if salvage harvesting occurred - ECAs could potentially reach 80-100% if all beetle-kill is salvaged. Salvage harvesting therefore has a greater potential to affect peak flows than watersheds affected by beetle-kill (and not harvested) as well as watersheds where traditional forest harvesting took place (only prior to MPB infestation) (FPB 2007). As noted above, the time for hydrologic recovery would however likely be shorter in watersheds where salvage harvesting occurs.

Annual Water Yield

In addition to many reports on the effects of forest harvesting on annual water yield, several comprehensive literature reviews on this subject have been conducted, including Hibbert (1967), Bosch and Hewlett (1982), and Stednick (1996). On the basis of these reviews, the following conclusions can be drawn:

- Forest harvesting increases the total annual water yield from a watershed;
- Re-establishment of forest cover decreases water yield; and
- The specific magnitude of the response to forest harvesting is difficult to predict.

None of the studies reported by Bosch and Hewlett (1982) demonstrated a decrease in yield following harvesting. Based on the work summarized in the above-noted studies, it is generally accepted that 15% to 20% of a watershed must be harvested before an increase in water yield can be noticed, although there is a wide range in this threshold. Once an effect is apparent, the increase in water yield is related to the percent of the watershed harvested. Bosch and Hewlett (1982) reported that in general, coniferous forests cause about a 40 mm

increase in annual water yield for every 10% decrease in forest cover. However, the nature of the relation between forest harvest and annual yield increase that has been reported in research studies varies widely.

An average increase in annual water yield of about 12-31% has been reported in beetle-infested watersheds where a varying proportion of the forest was affected (Table 4.1). In general, the increase in annual yield in beetle infested watersheds is expected to be less than in cutblocks due to mitigating effects of the standing dead timber on interception, snow accumulation, sublimation, and melt. FPB (2007) results suggest annual yields could increase by 52% following salvage harvesting (with 20% retention).

Groundwater and summer flows

Most of the available research indicates that late summer and fall streamflows are increased or not changed following forest harvesting (Scherer, 2001). The reason for this effect is that both rainfall interception by the forest canopy and summer evapotranspiration are reduced after trees have been removed and this volume of water is available to recharge groundwater as well as become runoff. Scherer and Pike (2003) summarized several studies on this topic that indicated transpiration rates from lodgepole pine, spruce, and fir stands can reach 3.3 mm per day during the growing season.

It is speculated that the effects of beetle-kill on low flows are similar to the effects of cutblocks, and involve a modest increase. Although unsupported statistically, the Potts (1984) study suggests that beetle-kill could result in increased low flows (by about 10%).

Recent observations in the Vanderhoof area suggest that reduced evapotranspiration has been responsible for elevated groundwater levels, which have affected forestry operations (MOF 2005a; Dubé et al. 2005). It is suspected that elevated groundwater levels in the Baker Creek watershed are responsible for many of the drainage issues that have been identified in the agricultural areas (see Section 5.0). Elevated groundwater levels can also result in more rapid streamflow response to storms (Winkler et al. 2007).

4.6 SUMMARY OF HYDROLOGIC IMPACTS OF MPB

The current MPB epidemic has a large potential to affect forest hydrology. Based on the overview presented above, a number of generalizations can be made. These include:

- The overall hydrologic impact of MPB will vary depending on the percentage of trees in a watershed that are affected by MPB and the spatial distribution of these trees. This is function of the species and age composition of the forest. Pure pine stands will generally be affected to a greater extent than mixed stands. In addition, watersheds with limited recent disturbance (i.e. by harvesting and/or fire) and high percentage of mature susceptible pines will likely be affected more than those which have had harvesting in the recent past and now have relatively young (i.e. less than 20 year old) plantations;
- At the stand-scale, the magnitude of MPB effects (in pure pine stands) is expected to be generally less than conventional forest harvesting. In mixed stands and in stands with considerable live understory vegetation, MPB effects are likely to be even less;
- At the watershed-scale, the hydrologic effects of MPB could potentially exceed those associated with traditional forest harvesting (i.e. when ECAs of 20-30% were common) given the large area of the beetle-kill in many watersheds (i.e. 80% or more);
- Salvage harvesting would likely increase the potential for hydrologic effects relative to beetle-kill alone. The magnitude of such an increase would depend on the percentage of the watershed that is planned for salvage harvesting. However, the duration (i.e. the time for hydrologic recovery) of these effects would likely be shorter than if beetle-killed stands were not salvaged, assuming salvage areas would be replanted while beetle-kill areas naturally regenerate. In summary, salvage harvesting would likely increase short- to medium-term hydrologic risks (relative to not salvaging beetle-killed stands), but with subsequent silvicultural activities, the long-term hydrologic risks of salvage harvesting would likely be less. Some evidence suggests that the hydrologic risks associated with salvage harvesting would be less

than not salvaging beetle-killed stands after about 20-25 years (P. Beaudry and Associates Ltd. 2006).

4.7 WATER QUALITY AND AQUATIC HABITAT IMPACTS OF MPB

As outlined in Summit (2006b), the MPB epidemic and subsequent salvage harvesting have the potential to affect water quality as well as aquatic habitat in the following ways:

- By increasing peak flows (Section 4.5.2);
- By spurring increased levels of harvesting, especially new road construction;
- By subsequent replanting techniques (e.g. disk trenching) that expose soils to surface erosion; and
- By potentially changing riparian areas, which play a role in sediment filtration, bank strength, woody debris recruitment, and shade.

In general, only changes in peak flows (not normal flows) cause bank erosion and transport large debris and sediment, and thus have undesirable implications for water quality, channel stability, and aquatic habitat. As outlined above, beetle-kill alone would not likely cause a significant increase in peak flow where there is significant understory present (and retained), and the results of both field observations and modeling indicate the potential for wide variation in peak flow effects. Part of the variation may be due to different densities and patterns of roads within affected watersheds. Roads facilitate the more-rapid routing of runoff through the watersheds, so watersheds affected by beetle-kill with a high road density would tend to be more likely to exhibit changes in peak flow with water quality implications. Increased peak flows are most likely to impact channels that are inherently sensitive. Sensitivity is a function of the combination of natural characteristics (i.e. an alluvial channel is more sensitive to changes in peak flow than a bedrock channel) and land use history (e.g. where riparian harvest has reduced the bank strength normally afforded by large trees).

Erosion from forest roads is generally a major development-related sediment source in a watershed, and any new roads established to facilitate the salvage beetle-killed timber would increase water quality hazards. Sediment delivery from new roads usually declines over time

as the road prism stabilizes (Elliot, 2000). Mass failures such as landslides caused by poor forest road design, construction, and/or maintenance can also be a major source of sediment where the slope is coupled to the stream network. Landslides not only contribute relatively large volumes of sediment over a short time frame, but unvegetated landslide scars can produce more sediment per unit area than do forest roads (McClelland et al. 1998).

Riparian zones help maintain water quality through a number of processes, including:

- The root masses of larger trees provide the bank strength necessary to resist bank erosion;
- Trees contribute large woody debris to the channel which acts to dissipate stream flow energy, reduce erosion and promoted overall channel stability;
- Shrubs and small plants filter sediment delivered from roads and upland areas;
- Shade moderates water temperatures; and
- Trees and woody debris in the riparian zone create hydraulic roughness that reduces the velocity of any floods that overtop the banks.

The potential for beetle-kill to directly impair these functions depends on the amount of pine in the riparian zone. Where MPB already has a significant presence in a watershed there may be little value in selectively removing pine from riparian areas, especially if it reduces the riparian functions listed above. The roots of dead pine trees would contribute to bank strength and hydraulic roughness for several years after they die, so affected trees retain their value to water quality for some time.

5.0 STAKEHOLDER CONCERNS

Based on the stakeholder meetings on March 8, 2006 and March 22, 2007 (see Appendix A), the following key concerns were noted:

- A concern that spring runoff and flooding has increased in magnitude and frequency in recent years;
- A concern that standing dead pine will increase the potential for forest fires;
- A concern that the woody debris loading of streams may increase the potential for flooding;
- A concern that increases in the beaver population may increase the potential for flooding;
- A concern that site preparation by disk-trenching, for example, may increase surface soil erosion and sediment inputs to the stream network and possibly route water more rapidly to the stream network;
- A concern that Visual Quality Objectives may not be incorporated into future licensees plans;
- A concern that in some areas road stability has been reduced; some noted "sinking roads", possibly as a result of elevated groundwater levels;
- A concern over deciduous species being eliminated from sites, especially with the use of herbicide;
- A concern that large woody debris may limit cattle movement in some areas; and
- A concern that all terrain vehicles (ATVs) are causing stream disturbance.

Furthermore, attendees wanted to know the current status of rehabilitation efforts, silviculture prescriptions, alternative harvesting methods, and options for protecting their land from flooding and erosion, and the impacts of MPB mortality on their properties.

Based on phone and written consultation by Summit during Phase 2 additional details from individual property owners were compiled. These details are summarized in Table 5.1 and are summarized by sub-basin in Section 6.0. The comments of stakeholders in the Baker Creek watershed are consistent and indicate that streamflow response to rainstorms has likely

become quicker in recent years and that flooding of valley bottom areas near the community of Baker Creek has increased in frequency and duration, thus imposing major constraints of agricultural activities (e.g. hay production).

Table 5.1 Summary of stakeholder comments received during consultation in Phase 2, organized alphabetically by property owner.

Property Owner(s)	Sub-basin(s) (refer to Maps 4 to 8 for location)	Comments / Issues
Cooper, Ted and Laurie	Middle Baker Creek	Flooding is an issue.
Engel, M.	Puntataenkut Creek	More flooding was noted on his property than in previous years.
Faloon, Celine	Punchesakut Creek; Middle Baker Creek	Flooding of fields is an issue.
Lisk, Joe and Ursula	Middle Baker Creek; Upper Baker Creek; Puntataenkut Creek; Trapline Creek	Joe and Ursula Lisk were interviewed at their home on July 10, 2006. Mr. Lisk has observed an increase in streamflow frequency, magnitude, and duration in the creeks that travel through his properties. These increases have resulted in flooded fields and erosion of stream banks. Mr. Lisk has indicated that flooding has reduced the area of useable fields more and more every year. Mr. Lisk has observed a significant increase in flooding and erosion of streambanks on several of his properties including district lot 3297 in the Trapline Creek sub-basin, district lots 9446, 9911, 9912, and 12429 in the Middle Baker Creek sub-basin, and district lot 6714 in the Upper Baker Creek sub-basin. He has also observed flooding on district lot 6703 in the Puntataenkut Creek sub-basin. Mr. Lisk believes increased flooding is due to MPB affected trees in the area and forest development (including harvesting, road maintenance, and disc trenching). Mr. Lisk indicated that in 2006 flooding was not as much of an issue due to the dry spring.
MacCrimmon, Scott	Punchesakut Creek	Mr. MacCrimmon has observed groundwater ponding in the middle of a hayfield in the last few years. Flooding normally occurs every year on his property in the spring. However in recent years, the flooded area does not dry out. Mr. MacCrimmon has observed a large beaver dam and pond at the upstream point of the creek on his property boundary and approximately 30 beaver dams in the creek. He noted that the beaver dams cause some flooding of his hayfields. He normally breaks up the beaver dams approximately two weeks prior to haying season. Mr. MacCrimmon has operated the property for the past three years and recalls that the hayfield has been actively used for the past 15 years. He observed that the area east and west of his property has been extensively logged over the years. In addition, he recently logged MPB affected trees of approximately 6-8 acres (approximately 3 hectares), and has removed the stumps to prepare it for a meadow.

Table 5.1 cont'd.

Property Owner(s)	Sub-basin(s) (refer to Maps 4 to 8 for location)	Comments / Issues
Moffat, Karl and Eva	Merston Creek	Flooding of fields is an issue.
McElroy, Dick	Middle Baker Creek	Flooding of fields is an issue
Moore, Mike	Middle Baker Creek; Merston Creek	Mike Moore was interviewed by Summit during a field inspection of his property on July 10, 2006. In general, Mr. Moore has observed an increase in flood magnitude, frequency and duration on his properties. Mr. Moore believes that his property in the Middle Baker Creek sub-basin has exhibited the most dramatic flooding. Baker Creek travels through his property and when it rains, creek levels increase and cause excessive streambank erosion. In the last two years, Mr. Moore has observed an increase in flooding in the fall. He has also observed a reduction in the time between significant rainstorms and subsequent flooding. He has noticed that in the past his fields would flood a few days after a rain event. In the last year, his field flooded very soon after rain events, suggesting elevated groundwater levels. He also identified that forest development in MPB affected areas is occurring upstream of his property. Due to the changes in the hydrology on his property, Mr. Moore has increased the number of ditches in his fields. However, flooding still is a major constraint to his ranching operations. He has observed increased ponding of water on his fields and standing water in numerous ditches. Mr. Moore indicated that his property in the Merson Creek sub-basin is located at a higher elevation and the flooding is not as significant. However, he has noticed an increase in siltation in Merston Creek.
Potts, Bill and Barb	Upper Baker Creek	Mr. Bill and Mrs. Barb Potts were interviewed by Summit at their home property on July 10, 2006. *Home Property:* Mr. and Mrs. Potts have lived on their "home" property since 1996 and believe that flooding became an issue approximately four (4) years ago. Their main issue is concenr is an increase in runoff onto their properties resulting in flooding of fields. In spring 2006, Mr. and Mrs. Potts indicated that runoff was "faster" than previous years. This particular property has no erosion problems. *Baker Meadow:* In the fall of 2005, they could not harvest the hay fields in "Baker" meadow due to the presence of standing water. Three (3) culverts drain onto the fields and they believe that ditching and road maintenance is required to use the property for future hay production. *Cooper Meadow:* This property has experienced flooding. One culvert diverts water into the field. According to Mr. and Mrs. Potts, Tolko has a right-of-way through their property and maintains the culvert.

Table 5.1 cont'd.

Property Owner(s)	Sub-basin(s) (refer to Maps 4 to 8 for location)	Comments / Issues
Paley, Mike and S. Wilson	Mount Creek	Mr. Paley has observed an increase in the magnitude and frequency of flooding on his property since the fall of 2003. He has observed approximately 7-8 floods each year including flooding in January. He has observed approximately 60 acres (24 ha) on the southwest corner of his property flood during spring runoff or during a rain event. He has observed up to 2" (5 cm) of water on his fields within two days of a rain event. According to Mr. Paley the creek through his property is not channelized and has very little riparian vegetation. He also has indicated that up to 90% of the surrounding forest is affected by MPB and there has been no logging directly upstream from his property since 2003. Mr. Paley is concerned that the increase of flooding could affect egg and nest habitat for sandhill cranes on his property.
Strachan, Terry	Mount Creek	Flooding of fields is an issue.
Way, Jesse	Puntataenkut Creek	Mr. Way has noticed rapid and heavy spring runoff. He has observed no forest development activities upstream of his property. Mr. Way indicated that last fall his fields were abnormally wet and he could not harvest in the hay fields.
Way, John and Rosemarie	Puntataenkut Creek	Mr. John Way indicated that he has no significant issues on his property. His son Mr. Jesse Way has potential issues on his property. In general, Mr. Way has observed an increase in beaver dams in the area around his property. Mr. Engel's property drains onto Mr. Jesse Way's property. He has observed logging east of his son's property. In addition, Mr. Way recalls that before 1980, Tibbles Lake was utilized as a reservoir and had a power station at the mouth of Baker Creek near Quesnel. During the operation of the reservoir, Mr. Way said that the lake level was approximately 3-4 feet (1 m) higher than present. At present, Mr. Way describes the lake having high tannin and peat discoloring, and he has observed a significant amount of silt from runoff of all the tributary creeks entering the lake. Mr. Way claims that the lake circulation is approximately every 15 years. He has observed an increase in lakeshore damage in recent years

6.0 WATERSHED CONDITIONS

The conditions of the nine (9) principal sub-basins of the Baker Creek watershed as of summer 2006 are summarized in Sections 6.1 through 6.9. The summaries for each sub-basin are organized into nine (9) sections:

1. Physiography;
2. Forest cover and forest development;
3. Private land;
4. Channel conditions;
5. Sediment sources;
6. Roads;
7. Risk ratings; and
8. Restoration opportunities.

Recommendations for future forest development (i.e. salvage harvesting) in the Baker Creek watershed and its sub-basins are outlined in Section 7.0.

6.1 UPPER BAKER CREEK

6.1.1 Physiography

Upper Baker Creek sub-basin has a total area of 210.5 km^2 with 91% of this area above the Baker Creek watershed H_{60} elevation. This sub-basin represents the headwaters of Baker Creek and is located in the southwest corner of the watershed (Figure 1.1 and Map 8). The sub-basin has rolling topography with several generally unconfined tributaries to Baker Creek. Numerous wetlands and meadows are scattered throughout the sub-basin, including one major unnamed wetland at the western edge of the sub-basin, Baker Meadow, Cooper Meadow, and meadows near the lower end of the sub-basin near the Lisk and Potts properties.

6.1.2 Forest Cover and Forest Development

In general, the Upper Baker Creek sub-basin is dominated by pine-leading stands. Spruce leads some high elevation stands and is mixed with pine in much of the riparian zone. Approximately

40% of the sub-basin has stands with severe and very severe MPB disturbance (Map 2). Approximately 49% of the total riparian zone in the sub-basin is at high risk of beetle-kill (Map 3). Beetle-kill is throughout the sub-basin but is most severe in the western (higher elevation) end of the sub-basin and the lower (eastern) end of the sub-basin (Map 8). Approximately 10% of the sub-basin, located in the northern portion of the basin was also affected by wildfire in the past. Aerial photos suggest that this area has recovered largely with pine, approximately 30 to 60 years old; these trees however have since been affected by MPB.

The majority of forest development activities, which have occurred over about 15% of the sub-basin, are located in the central and eastern areas of the sub-basin near established roads. The proposed forest development (in 2006) accounts for approximately 5% of the sub-basin area and it is distributed throughout the sub-basin. In 1996, ECA values projected to 2001 (prior to MPB attack) were calculated to be 22% (Cariboo 1996)[5]. Considering the degree of MPB attack, current ECAs are likely to be at least double that value.

6.1.3 Private Land

Two (2) landowners have properties in the Upper Baker Creek sub-basin (refer to Map 8). The Lisk family has one (1) property in the sub-basin adjacent to Reach 14 of Baker Creek. The Potts family has three (3) properties: district lot 2928 adjacent to Reach 15; district lots 9921 and 2324 adjacent to Reach 2 of Tributary 8 of Baker Creek; and district lot 9422 adjacent to Reach 22 of Baker Creek.

Mr. and Mrs. Lisk have observed an increase in frequency, magnitude, and duration of flooding on their property known as the "Burnstead" homestead (district lot 6714). These hydrologic changes have resulted in flooding of fields and eroded streambanks. Mr. Lisk has also indicated that the flooding has reduced the area of useable fields more and more every year. Mr. Lisk also noted that in 2006 flooding was not much of an issue due to the drier spring conditions.

[5] Note that the calculation of existing ECAs is beyond the scope of work for this study.

During the site visit, Mr. Lisk explained that the increased amount of water in the fields and beaver activity has made it difficult to maintain ditches.

Mr. and Mrs. Potts have three (3) properties in the Upper Baker creek sub-basin. They have lived on their home property (district lot 9916) since 1996. They believe that the flooding issues began approximately four (4) years ago. They stated that the main issue on each of their properties is the increase of water draining from roads and upland areas onto their properties and subsequently flooding the fields. Mr. and Mrs. Potts indicated that in spring 2006 runoff was "faster" than previous years. They have also observed a significant number of beaver dams in neighbouring areas. Mr. and Mrs. Potts commented that trapping has been done in the area but they have not observed a significant change or reduction in beaver activity.

Another property owned by the Potts family with flooding issues is Cooper Meadow (Photo 1, Appendix D) (district lots 9921 and 12324). According to the Potts, Tolko has a right-of-way through the property and maintains culverts that drain water into the fields. The third Potts property is Baker Meadow (district lot 9422). In the fall of 2005, they could not harvest the hay fields due to standing water. They indicated that three (3) culverts drain onto the fields from neighbouring roads. They believe that ditching and road maintenance is required to use the property for future hay production.

6.1.4 Channel Conditions

A total of 13 reaches of Baker Creek and six (6) tributaries were identified in the Upper Baker Creek sub-basin (Map 8). Baker Creek reaches 14 to 16 flow across the lower gradient valley bottom, while reaches 17 to 20 are found on moderate gradient hillslopes. Reaches 21 to 24 have relatively low gradients and are located on the upper plateau.

A summary of the channel conditions as noted from the aerial photograph review, helicopter survey, and ground reconnaissance is provided below. The reach locations are identified on Map 8 and the longitudinal profile in Appendix B.

Table 6.1 Summary of channel conditions in the Upper Baker sub-basin.

Stream	Reach	Summary
Baker Creek	14	Reach 14 is located between the Lisk and Potts properties and is characterized by a low-gradient riffle-pool channel with sand and gravel bed and banks. Reach 14 flows through large wetland areas. The channel shows signs of instability with several banks exhibiting excessive erosion. In addition, sediment accumulation in the channel appears excessive. This reach has evidence of cattle and human disturbance and portions of the riparian zone (not in the wetland areas) have high levels of beetle-kill. Channel sensitivity is rated as **high**.
Baker Creek	15	Reach 15 is a highly sinuous riffle-pool channel with a sand and gravel bed. Functioning woody debris is present in the reach but the recruitment potential is low as much of the land adjacent to the reach is private land used for cattle grazing and hay production. The left bank contains a dense mix of willows and has disturbed sections due to cattle accessing the creek (Photo 2, Appendix D). The right bank is disturbed from previous cattle access and willow browse. This area is now fenced and creek access is now limited to a smaller area of riparian zone. Several beaver dams were identified in this reach, however, it is unclear how these factor into the reported flooding on the Potts property. The channel is stable and has a **moderate** sensitivity.
Baker Creek	16	Reach 16 is a highly sinuous riffle-pool channel that flows partly through low-gradient wetland areas with minimal riparian vegetation and fine-grained bed and banks. These areas are generally unstable and are responsible for sediment delivery to the creek. No direct disturbance to this reach was noted however, the riparian zone (in non wetland sections) has approximately 40% pine affected by MPB. The sensitivity of Reach 16 is **high**.
Baker Creek	17	Reach 17 has a partly confined riffle-pool and cascade-pool morphology with a sand-gravel-cobble bed. Functioning large woody debris is present with high recruitment potential and small woody debris volumes and recruitment potential are moderate. Both banks of the reach contain a mature mixed forest of spruce, aspen, and cottonwood with a live understory of willows and herbaceous plants. Despite some evidence of high flows causing undercutting, the functioning condition of the riparian zone has maintained a stable channel that shows no signs of disturbance. Channel sensitivity is **low**.

Table 6.1 cont'd.

Stream	Reach	Summary
Baker Creek	18	Reach 18 has a cascade-pool morphology with natural riparian conditions consisting of mixed species. Large woody debris volumes and recruitment potential are moderate. The reach is stable and has no evidence of disturbance. Channel sensitivity is **low**.
Baker Creek	19	Reach 19 has a riffle-pool morphology with natural riparian conditions (with mixed species) and a moderate volume of large woody debris. The channel is stable and there is no evidence of disturbance. Channel sensitivity is **low**.
Baker Creek	20	Reach 20 has a meandering riffle-pool morphology with natural riparian conditions and low volume of woody debris. The channel is stable and there are no signs of disturbance. Channel sensitivity is **low**.
Baker Creek	21	Reach 21 has a riffle-pool morphology with natural riparian conditions and a low volume of woody debris. Portions of the reach lie within low gradient wetland areas with fine-grained bed and banks. The channel is stable and no signs of disturbance were noted. Channel sensitivity is **moderate**.
Baker Creek	22	Reach 22, which flows through Baker Meadow (Potts property) has a riffle-pool morphology with minimal riparian vegetation and a low volumes of large woody debris. This reach was identified as stable although historic clearing of riparian vegetation has likely affected channel conditions. Channel sensitivity is **moderate**.
Baker Creek	23	Reach 23 has riffle-pool morphology with natural riparian conditions and low volume of large woody debris. Most of Reach 23 flows through a natural low gradient wetland area. Overall the reach is stable and shows no signs of disturbance. Channel sensitivity is **low**.
Baker Creek	24	Reach 24 has riffle-pool and cascade-pool morphology with a low volume of large woody debris. The channel is stable and no signs of disturbance were noted. Channel sensitivity is **low**.
Baker Tributary 8	1-3	Baker Tributary 8 is a partly confined channel with a low-gradient sand and gravel bed and riffle-pool morphology. Tributary 8 connects several wetlands and meadows. Woody debris volumes vary considerably. In Reach 2 excessive woody debris was noted, however in many other areas woody debris volumes are low. Tributary 8 flows through Cooper Meadow (Potts property) where there is little or no riparian vegetation. The riparian zone overall is largely intact, however impacts of beetle-kill on the upper portions of Tributary 8 will likely be significant. While disturbance was identified in Cooper Meadow associated with the hay field, overall evidence of disturbance is low and the channel is stable. Channel sensitivity is **moderate** overall.

Table 6.1 cont'd.

Stream	Reach	Summary
Baker Tributary 9	1	Baker Tributary 9 has a riffle-pool and cascade-pool morphology with a sand, gravel and cobble bed. The riparian zone is heavily forested with mixed species. Evidence of natural instability was noted, however no signs of direct disturbance was identified. Channel sensitivity is **low**.
Baker Tributary 10	1-3	Baker Tributary 10 has a sinuous riffle-pool morphology with a sand-gravel bed and is generally unconfined. Portions of Tributary 10 flow through low-gradient wetland areas with fine-grained bed and banks. Woody debris volumes are generally low. The riparian zone along Tributary 10 is natural with mixed species along the lower portions. The riparian zone in upper portions of Tributary 10 are dominated by pine-leading stands, which are largely affected by beetle-kill. Small sections of the channel show signs of natural instability, however, overall the channel is stable and disturbance is currently not detectable. Channel sensitivity is **low**.
Baker Tributary 11	1-2	Baker Tributary 11 has a riffle-pool morphology with a sand and gravel bed and is largely unconfined. Woody debris volumes are low. Portions of the riparian zone along Tributary 11 have been logged but have been substantially revegetated. Beetle-kill within the riparian zone is high. The channel is stable and no evidence of disturbance was noted. Channel sensitivity is **low**.
Baker Tributary 12	1-2	Baker Tributary 12 has a riffle-pool morphology with a sand and gravel bed. Portions of Tributary 12 have been logged to the bank but have been substantially revegetated. At Baker Meadow (Potts property) Tributary 12 has been diverted around an agricultural field in a channel with no riparian vegetation. Other than this direct disturbance, the channel shows no evidence of other disturbance and is stable. Channel sensitivity is **low**.
Baker Tributary 13		Tributary 13 has riffle-pool morphology with a natural riparian zone comprised of mixed species. Beetle-kill within the riparian zone is high. The channel is stable and shows no signs of disturbance. Channel sensitivity is **low**.

6.1.5 Sediment Sources

No significant development-related sediment sources were identified in the Upper Baker creek sub-basin.

Site preparation in some parts of the sub-basin have included disk-trenching (Photo 3, Appendix D). It was noted at several sites that such practices were completed parallel to the fall-line likely constrained by equipment and safe practices. There is potential that this practice could increase the rate of runoff in some areas by providing direct pathways for runoff downslope to the drainage and stream network, particularly if runoff occurs during frozen ground conditions

in spring. In some areas this practice may also be contributing to increased surface erosion potential through increased soil exposure.

6.1.6 Roads

In general, all active roads in the Upper Baker sub-basin were in good condition and present a low potential for surface erosion. Only two (2) locations warrant discussion (further details are provided in Section 6.1.8):

- On Lavington Road at km 23 (Site UB1 on Map 8), erosion along 50 m of roadcut had caused infilling of the ditch with sediment (Photo 4, Appendix D) thus reducing the effectiveness of the ditch. Ditch maintenance and armouring is recommended at this location; and
- Recent roadcut rehabilitation was noted upstream of the 3800 Road crossing of Baker Creek (Site UB2 on Map2) (Photo 5, Appendix D). It appears that gravel was spread along the cutbank upslope of the stream crossing to reduce sediment delivery to creek. While the works are functioning satisfactorily, silt fences in the ditch have fallen down and should be removed and replaced with rock weirs and small catch basins to reduce the risk of sediment delivery to Baker Creek.

6.1.7 Risk Assessment

This section summarizes an overview risk assessment of the Upper Baker Creek sub-basin. The types of risk summarized in this section are those associated with **peak flows**, **channel stability**, **riparian function**, and **sediment delivery.** These risks are evaluated using a consistent risk analysis framework to facilitate comparison among sub-basins and the assignment of priorities for future work. The risk analysis considers the impact of past conditions and activities (i.e. harvesting) in the watershed and the current state of the watershed (i.e. channel conditions, extent of beetle-kill) in developing estimates of risk for the near-future. It should be noted that widespread salvage harvesting is not addressed in this analysis given that these such plans were unavailable at the time of the study. However, the implications of

salvaging are discussed in Section 4.0. A summary of the risks for the Upper Baker Creek sub-basin is provided in Table 6.2.

Table 6.2 Summary of watershed risks in the Upper Baker sub-basin.

Risk type	Identified risk level	Comment
Peak Flow	High	While there are several reports of private land being flooded more frequently or for longer durations, there is little physical evidence to indicate peak flows magnitude has yet increased as a result of past harvesting and beetle-kill in the sub-basin. The incidents of flooding are likely related to general increases in runoff along with chronically higher groundwater levels in the lowland areas. Approximately 40% of the Upper Baker sub-basin has severe or very severe beetle-kill. Although ECAs calculations were beyond the scope of work, current ECAs considering beetle-kill probably exceed 50% in the sub-basin. Based on the literature and recent hydrologic modeling by UBC, the extent of beetle-kill poses a high risk to increased peak flows. It however may take a few years for the full impacts associated with beetle-kill to be witnessed as trees die and fall and for the right meteorological conditions to trigger channel-changing floods.
Channel Stability	High	Overall channel conditions in the Upper Baker Creek sub-basin are currently stable, however there are sections of Reaches 14 and 16 of Baker Creek that are unstable. Considering the high potential for increased peak flows in the near future, and the moderate and high sensitivity of several reaches (particularly lower in the sub-basin), the risk to near future channel stability is high.
Riparian Function	Moderate	Most riparian zones are either mixed pine and spruce stands or second growth pine stands. The four (4) privately owned properties in the sub-basin exhibited little or no riparian zones since they are utilized for pasture and hay production. A relatively large percentage of the mainstem of Baker Creek is at low risk of beetle-kill given the extensive wetlands and meadows supporting shrubby vegetation and mixed stands. The smaller tributaries at generally higher elevations are at high risk however – along these tributaries, dead pine dominate the riparian zone. Based on weighting the riparian conditions in the sub-basin, the overall risk to riparian function in the Upper Baker sub-basin is moderate.
Sediment	Low	Overall, there are few natural and/or human development related sediment sources (including those from roads) in the Upper Baker Creek sub-basin. Therefore, the sediment risk in the Upper Baker sub-basin is low.

6.1.8 Restoration Opportunities

Table 6.3 summarizes the locations where restoration opportunities have been identified in the Upper Baker Creek sub-basin. While addressing these locations will reduce the impacts of past activities, it will also serve to minimize the risk associated with future conditions (e.g. increased peak flows) and activities in the watershed. Priorities have been assigned based on the potential impact and risk to aquatic habitat, water quality, or infrastructure. The locations of the recommended restoration sites are identified on Map 8.

Table 6.3 Summary of restoration sites identified in the Upper Baker sub-basin.

Restoration Site[1]	Location	Summary of recommended restoration activities	Priority
UB1	Lavington Road km 23	Ditch maintenance and armouring to minimize erosion potential are recommended.	High
UB2	Road 3800 near crossing of Baker Creek	Remove non-functional silt fencing and install rock check dams and small catch basin to collect sediment prior to entering Baker Creek.	Moderate
UB3	Baker Creek Reach 14	Retain an experienced professional to develop site specific restoration prescriptions to stabilize sections of Reach 14 to reduce potential for erosion, land loss and sediment delivery.	Moderate
UB4	Baker Creek Reach 15	Retain an experienced professional to identify site specific opportunities to increase riparian vegetation along Reach 15 where it is lacking and affecting stream values. In addition, an examination of the role of beaver dams on the flood regime in Reach 15 should be undertaken to determine if beaver and beaver dam management is justified.	Moderate
UB5	Baker Creek Reach 16	Retain an experienced professional to develop site specific restoration prescriptions to stabilize sections of Reach 16 to reduce potential for erosion, land loss and sediment delivery.	Moderate

Notes
1. Refer to Map 8 for location.

6.2 LONG JOHN CREEK

6.2.1 Physiography

The Long John Creek sub-basin has a total area of 166.0 km^2, 83% of which is above the Baker Creek H_{60} elevation. Long John Creek drains in an eastward direction into Baker Creek at the arbitrary break between Upper and Middle Baker Creek (Figure 1.1 and Map 8). Trapline Creek and Bradley Creek are aligned roughly parallel to and flow into Long John Creek approximately three (3) km upstream of the mouth. The Long John Creek sub-basin has moderately rolling topography with generally unconfined tributaries. Occasional wetlands are present in the headwaters of Long John, Trapline, and Bradley Creeks. Near the mouth of Trapline and Long John Creeks, however, wetlands are extensive.

6.2.2 Forest Cover and Forest Development

In general, the Long John Creek sub-basin is dominated by pine-leading stands. Spruce lead in some high elevation stands and are mixed with pine in riparian zones. Approximately 43% of the sub-basin has beetle-kill classified as "severe" or "very severe" (Map 2) and approximately 35% of the riparian zones in the sub-basin are at high risk of beetle-kill (Map 3). The affected trees are located throughout the sub-basin. Approximately 10% of the sub-basin has been affected by wildfire located in the central area of the sub-basin. An aerial photo review indicates that this wildfire area recovered with mostly pine approximately 30 to 60 years old – however, much of this has likely been affected by MPB.

The majority of forest development activities have occurred in the central and western areas of the sub-basin. Forest development has historically covered approximately 26% of the sub-basin area. The proposed forest development (end-2006) accounts for an additional 5% of the area - distributed throughout the sub-basin. In 1996, ECA values for existing and proposed development projected to 2001 were calculated to be 31% of the total sub-basin (Cariboo 1996). Considering the development since 1996 and the extent of beetle-kill, it is likely that ECA levels currently exceed 50%.

6.2.3 Private Land

One private property (district lot 3297) owned by Mr. Joe Lisk is located in the Trapline Creek sub-sub-basin (Map 8). Reach 1 of Bradley Creek and Reach 2 of Trapline Creek flow through this property, which is locally referred to as "Moose Horn".

6.2.4 Channel Conditions

Table 6.4 summarizes the channel conditions noted in the Long John sub-basin for the following streams:

- Long John Creek;
- Tributary 1;
- Long John Tributary 2;
- Trapline Creek; and
- Bradley Creek.

Reaches locations are identified on Map 8 and on the longitudinal profile in Appendix B

Table 6.4 Summary of channel conditions in the Long John sub-basin.

Stream	Reach	Summary
Long John Creek	1	Reach 1 has a highly sinuous dune-ripple morphology with a sand-and gravel bed and scarce amounts of large woody debris. The floodplain is wide as the channel flows through an extensive wetland area. Although there are high levels of beetle-kill in the adjacent forest, the width of the floodplain limits the potential recruitment of dead pine. Sections of reach 1 show evidence of bank erosion and aggradation suggesting the channel is unstable. Evidence of direct disturbance however was not identified. Channel sensitivity is **high**.
Long John Creek	2	Reach 2 has a dune-ripple morphology with a sand-gravel bed and variable amounts of large woody debris. Lower portions of the reach through wetland areas have limited woody debris, however, considerable volumes of wood were identified upstream of the wetland area. Although there was no evidence of disturbance (the stream has a buffer adjacent to harvested areas), the channel appears to be actively adjusting and is unstable. The riparian zone in upper portions of Reach 2 are highly impacted by beetle-kill. Overall channel sensitivity is **high**.

Table 6.4 cont'd.

Stream	Reach	Summary
Long John Creek	3	Reach 3 has riffle-pool and cascade-pool morphology with a sand, gravel, and cobble bed and low volumes of large woody debris. Both banks have been logged in the past but have substantially revegetated (mostly pine). The channel decreases in sinuosity and the floodplain narrows in the upstream direction. The channel appears stable and shows no evidence of disturbance. The channel sensitivity is **moderate**.
Long John Creek	4	Reach 4 has riffle-pool and cascade-pool morphology with a sand, gravel, and cobble bed, scarce amounts of woody debris and has been logged to both left and right banks with substantial revegetation. The left bank was logged to the streambank and the right bank has an extensive buffer with mixed species. The channel is stable and shows no evidence of direct disturbance. Channel sensitivity is **moderate**.
Long John Creek	5	Reach 5 has riffle-pool and cascade-pool morphology with a sand, gravel, and cobble bed, scarce amounts of woody debris with low recruitment potential and has been logged to both left and right banks with substantial revegatation. The left and right banks have been re-established with pine after a wildfire. The reach travels through a floodplain with mixed species. The channel is stable and shows no evidence of direct disturbance. Channel sensitivity is **moderate**.
Long John Creek	6	Reach 6 has cascade-pool morphology with a gravel and cobble bed and scarce amounts of woody debris. The riparian zone is contains a mix of species. The channel is stable and there are no detectable signs of disturbance. Channel sensitivity is **low**.
Long John Creek	7	Reach 7 has cascade-pool morphology with a gravel bed. A moderate quantity of functioning large woody debris is present in the reach, which appears to have been at least partly responsible for maintaining channel stability. The riparian zone consists of spruce with approximately 20% pine on the left bank and open wet meadow adjacent to healthy pine on the right bank. Direct disturbance to the channel is undetectable. Channel sensitivity is **low**.
Long John Creek	8	Reach 8 is a wetland and lake complex.
Long John Creek	9	Reach 9 has riffle-pool morphology with a sand and gravel bed with low volumes of large wood debris. Logging in the past has occurred to the banks; in some locations the riparian vegetation has been slow to establish. MPB has affected considerable portions of the riparian zone. No signs of direct disturbance has been noted and the channel is stable. Channel sensitivity is **low**.
Long John Tributary 1		Tributary 1 joins Long John Creek at Reach 2. Tributary 1 has riffle-pool morphology and a sand and gravel bed. There are low volumes of woody debris along this reach which passes through several wetland areas. The riparian zone is natural on the left bank and has an extensive buffer with selective logging on the right bank. The channel is stable and there are no detectable levels of disturbance. Channel sensitivity is **moderate**.

Table 6.4 cont'd.

Stream	Reach	Summary
Long John Tributary 2		Tributary 2 joins Long John Creek at Reach 4. Tributary 2 has cascade-pool morphology, a gravel and sand bed, and has functioning LWD. There is a high quantity of woody debris in the reach. The riparian zone consists of mixed spruce and willow on the left bank and spruce and willow intermixed with pine. The level of disturbance is low, the channel is stable, and channel sensitivity is **moderate**.
Trapline Creek	1	Reach 1 has riffle-pool morphology with a sand and gravel bed. There is a high quantity of large and small woody debris present in the reach. The riparian zone is dominated by spruce with willow and minor amounts of pine. Although the channel is stable, there is evidence of high flows causing streambank undercutting and slumping. No direct disturbance to the channel was identified. Channel sensitivity is **moderate**.
Trapline Creek	2	Reach 2 flows through the area known locally as "Moose Horn" and has riffle-pool morphology with a sand and gravel bed and a low volume of woody debris. The riparian zone consists of a partial buffer in some locations. Ranching activities on private land have affected riparian function along this reach, which is unstable. Channel sensitivity is **high**.
Trapline Creek	3	Reach 3 has a riffle-pool morphology with a sand-gravel bed, and low volume of large woody debris. The riparian area consists of a mixed pine and spruce. Although beaver activity was noted in the upper portion of the reach, there are no detectable levels of disturbance and the channel is stable. Channel sensitivity is **moderate**.
Trapline Creek	4	Reach 4 is characterized by riffle-pool morphology with a sand-gravel bed, and low volumes of large woody debris. The riparian area consists of a partial buffer with intact banks on the left side of the reach and a natural zone on the right side of the reach. There are no detectable levels of disturbance the channel is stable. Channel sensitivity is **moderate**.
Trapline Creek	5	Reach 5 has a cascade-pool morphology with a sand, gravel, and cobble bed. There is a high quantity of large and small woody debris present in the reach. The riparian zone is dominated by mature spruce and willows, although there is a high level of beetle-killed pine also. The channel is stable, and only minor disturbance was noted at the Road 2000 crossing. The channel has a moderate **sensitivity**.
Trapline Creek	6	Reach 6 has a cascade-pool morphology with a gravel and cobble bed. There is a high quantity of large and small woody debris present in the reach. The left bank riparian zone is narrow with small pine (<3 m), a small amount of spruce and beetle-killed pine. The right bank is a mature mixed forest of pine and spruce. The channel is stable and shows no signs of disturbance. Channel sensitivity is **low**.
Trapline Creek	7	Reach 7 has a riffle-pool morphology with a sand and gravel bed. Functioning woody debris volumes are low. The left and right banks contain a mix of pine and spruce adjacent to the open meadow the reach flows through. The channel is stable with no detectable level of disturbance. Channel sensitivity is **moderate**.

Table 6.4 cont'd.

Stream	Reach	Summary
Bradley Creek	1	Reach 1 of Bradley Creek flows through the "Moose Horn" area and has riffle-pool morphology with a sand-gravel bed. The reach has scarce amounts of woody debris. The riparian zone has a partial buffer with intact left and right banks. The channel has a high sinuosity and travels through private agricultural land where there is some evidence of loss of riparian vegetation. The channel is unstable and has a **high** sensitivity.
Bradley Creek	2	Reach 2 has riffle-pool and cascade-pool morphology with a sand, gravel, and cobble bed. The reach has low volumes of woody debris. The riparian zone is natural along wide floodplains with a young pine forest adjacent to the floodplain. The reach is stable and there are no detectable signs of disturbance. The channel sensitivity is **low**.
Bradley Creek	3	Reach 3 has riffle-pool and cascade-pool morphology with a sand, gravel and cobble bed. The reach has low volumes of woody debris. The riparian zone is natural with spruce mixed with young pine forest. The reach is stable and there are no detectable signs of disturbance. The channel sensitivity is **low**.
Bradley Creek	4	Reach 4 has a cascade-pool morphology with a gravel and cobble bed. The reach has low volumes of woody debris. The riparian zone has an extensive buffer with selective logging on the left bank and a natural area on the right bank. The riparian zone contains mixed pine and spruce. The channel is stable and there are no detectable signs of disturbance. Channel sensitivity is **low**.

6.2.5 Sediment Sources

No significant development-related sediment sources were identified in the Long John sub-basin.

6.2.6 Roads

In general, all the roads driven in the Long John sub-basin were in good condition and posed a low sediment risk. Only four (4) road locations were identified that warrant discussion and remediation (these are further discussed under Section 6.2.8):

- Tibbles Road crossing of Trapline Creek at km 13 (LJ1 on Map 8);
- Tibbles Road at km 14 (LJ2 on Map 8);
- Road 2400 at km 11 (LJ3 on Map 8); and
- Road 2000 crossing of Trapline Creek at km 6.5 (LJ4 on Map 8).

6.2.7 Risk Assessment

A summary of the risks for the Long John Creek sub-basin is provided in Table 6.5.

Table 6.5 Summary of watershed risks in the Long John sub-basin.

Risk type	Identified risk level	Comment
Peak Flow	High	While one land owner reported private land being flooded more frequently and over longer durations, there was only little evidence to indicate peak flow magnitude has increased as a result of past harvesting and beetle-kill in the sub-basin. The incidents of flooding are likely related to overall increases in annual runoff along with chronically higher groundwater levels in the lowland areas. Approximately 43% of the sub-basin has severe or very severe beetle-kill. Although ECAs calculations were beyond the scope of work, current ECAs considering beetle-kill probably exceed 50% in the sub-basin. Based on the literature and recent hydrologic modeling by UBC, the extent of beetle-kill poses a high risk to increased peak flows. It however may take a few years for the full impacts associated with beetle-kill to be witnessed as trees die and fall and for the right meteorological conditions to trigger flooding of sufficient magnitude to trigger channel changes.
Channel Stability	High	Overall, channels in the Long John Creek sub-basin are currently stable, however there four reaches identified as unstable, including Reaches 1 and 2 of Long John Creek, Reach 2 of Trapline Creek, and Reach 1 of Bradley Creek. Based on the current number of unstable reaches, considering the high probability of increased peak flows in the near future, and the number of moderate and high sensitivity reaches, the overall risk to near future channel stability is high.
Riparian Function	Moderate	Most riparian zones in the Long John sub-basin are either mixed pine and spruce stands or second-growth pine stands. The privately owned properties in the sub-basin generally exhibited little or no riparian vegetation since they are utilized for pasture and hay production. Large percentages of the mainstems of Long John, Trapline and Bradley Creeks are at low risk of beetle-kill given the extensive wetlands and meadows supporting shrubby vegetation and mixed stands. The smaller tributaries are however at much higher risk as shown on Map 3 – along these tributaries, dead pine dominates the riparian zone. Overall, the risk to riparian function in the Long John Creek sub-basin is moderate.
Sediment	Low	Overall, there are few natural and/or development-related sediment sources in the Long John Creek sub-basin and roads were in good condition. Therefore, the sediment risk in the sub-basin is low.

6.2.8 Restoration Opportunities

Table 6.6 summarizes the locations where restoration opportunities have been identified in the Long John Creek sub-basin. The locations of the recommended restoration sites are identified on Map 8.

Table 6.6 Summary of restoration sites identified in the Long John sub-basin.

Restoration Site[1]	Location	Summary of recommended restoration activities	Priority
LJ1	Tibbles Road crossing of Trapline Creek near km 13	A ditch on the west side of the road is slumping. Previous efforts to use hay bales and silt fencing are currently non-functional. We recommend that the ditch be cleared of excess sediment and that small rock check dams be installed along the ditch to reduce flow velocity and promote settling of sediment; this will reduce the potential for sediment input to creek.	High
LJ2	Tibbles Road at km 14	The road fill is failing above a 400 mm culvert (Photo 6, Appendix D), excessive ditch erosion was noted in all ditches (both sides of road - 300 m total). Past sediment control measures are currently non-functional (Photo 7, Appendix D). We recommend clearing ditches, armouring the ditch with rock and installing small rock check dams to reduce flow velocity and promote settling of sediment. The road should be repaired and should be graded to promote drainage off the running surface (i.e. crown the road).	High
LJ3	Road 2400 at km 11	A short (5 m) length of eroded road surface was noted that requires minor repairs.	Low
LJ4	Road 2000 crossing of Trapline Creek at km 6.5	At a relatively new culvert installation, road fill on downstream side of the culvert is ravelling into the creek (Photo 8, Appendix D). We recommend pulling back the material and installing a small structure (e.g. lock block retaining wall) to prevent sediment from entering the creek.	Low

Notes
1. Refer to Map 8 for location.

6.3 TIBBLE CREEK

6.3.1 Physiography

The Tibble Creek sub-basin has a total area of 49.8 km^2 with 74% above the Baker Creek H_{60} elevation. This sub-basin drains eastward into Middle Baker Creek approximately two (2) km south of Puntataenkut (Tibbles) Lake (Figure 1.1 and Map 8). The headwater streams of the sub-basin are relatively steep and confined while the middle and lower portions of the mainstem has low gradients. Approximately half way along its length, Tibbles Creek becomes unconfined as it flows through occasional wetlands, the largest of which is located near the mouth.

6.3.2 Forest Cover and Forest Development

The Tibble Creek sub-basin is dominated by pine-leading stands with relatively small amounts of spruce mixed with pine in the low lying riparian zones. Approximately 50% of the sub-basin area has severe or very severe beetle-kill (Map 2), primarily in the upper (western) portion of the sub-basin. In addition, nearly all of the remaining area is classified as moderate risk of beetle-kill. Furthermore, a total of 58% of the riparian zone has been classified as high risk of beetle-kill (Map 3). Approximately 1% of the sub-basin, located in the lower portion of the sub-basin, has been affected by wildfire.

The majority of past forest development has occurred in the central and western areas of the sub-basin. In 1996, ECA values projected to 2001 were calculated to be about 3% (Cariboo 1996). Based on a review of current maps, there appears to have been a modest increase in harvesting since 1996. Proposed forest development (end-2006) amounts to approximately 7% of the sub-basin area and it is distributed throughout the sub-basin. Considering 2006 proposed harvesting and the extent of beetle-kill, ECAs are speculated to be approaching 50%.

6.3.3 Private Land

There is a very small portion of private land in the Tibble Creek sub-basin near the mouth of the creek. However, conditions in Tibble Creek likely do not constrain activities on the small portion of land and therefore are not discussed here.

6.3.4 Channel Conditions

Table 6.7 summarizes the channel conditions noted in the Tibble Creek sub-basin.

Table 6.7 Summary of channel conditions in the Tibble Creek sub-basin.

Stream	Reach	Summary
Tibble Creek	1	Reach 1 of Tibble Creek has a riffle-pool morphology with a sand and gravel bed. The reach generally has low volumes of woody debris. The lower portion of the reach flows through an unconfined wetland area dominated by shrubby vegetation and fine-grained banks. Further upstream in Reach 1, dead pine dominates the riparian zone. The channel appears stable and there are currently no signs of direct disturbance other than a private stream crossing that was washed out near the mouth of the creek. Channel sensitivity is **high**.
Tibble Creek	2	Reach 2 has riffle-pool morphology with a sand and gravel bed. Functioning woody debris is scarce and the recruitment potential is low. The riparian zone has an extensive buffer with selective logging on the left bank and a natural area on the right bank. Beetle-kill dominates the riparian zone. The channel is currently stable and no disturbance was detected. Channel sensitivity is **moderate**.
Tibble Creek	3	Reach 3 has a sinuous riffle-pool morphology with a sand and gravel bed. Functioning woody debris volumes are low. The riparian zone has a partial buffer with intact banks on the left bank and a natural riparian zone on the right bank. This reach has a wide floodplain over much of its length. Beetle-kill varies within the riparian zone. There is no detectable disturbance and the channel is stable. Channel sensitivity is **moderate**.
Tibble Creek	4	Reach 4 has riffle-pool morphology with a gravel bed. The riparian zone has an extensive buffer on both banks with selective logging having occurred in the past. This reach has a wide floodplain and a sinuous channel. The forest has a high degree of beetle-kill, although there remain portions of the riparian zone with mixed aspen and spruce. The channel is stable and there is no evidence of direct disturbance. Channel sensitivity is **moderate**.

Table 6.7 cont'd.

Stream	Reach	Summary
Tibble Creek	5	Reach 5 has cascade-pool and step-pool morphology with a cobble and boulder bed. The riparian zone remains intact, however, beetle kill is severe. Reach 5 is stable and there is no detectable level of disturbance. Channel sensitivity is **low**.
Tibble Tributary 1		Tributary 1 of Tibble Creek has cascade-pool morphology with a cobble and gravel bed. The riparian zone has and extensive buffer on both banks with selective logging having occurred in the past. The reach is stable and there is no detectable level of disturbance. Channel sensitivity is **low**.

6.3.5 Sediment Sources

No significant natural or development related sediment sources were identified in the Tibble Creek sub-basin.

6.3.6 Roads

In general, all the roads in the Tibble Creek sub-basin are in good condition. However, three (3) issues were noted (which are further discussed in Section 6.3.8):

- A washed out culvert on private property was identified near the mouth of Tibbles Creek (TB1 on Map 8);
- 2100 Road near km 6 had recently been constructed and graded (TB2 on Map 8; Photo 9, Appendix D). This exposes large areas that may be susceptible to surface erosion; measures to minimize such erosion here (and in all areas of new road construction) are recommended.

6.3.7 Risk Assessment

A summary of the risks for the Tibbles Creek sub-basin is provided in Table 6.5.

Table 6.8 Summary of watershed risks in the Tibble Creek sub-basin.

Risk type	Identified risk level	Comment
Peak Flow	High	Approximately 50% of the sub-basin has severe or very severe beetle-kill. Although ECAs calculations were beyond the scope of work, current ECAs considering beetle-kill probably are approaching 50% in the sub-basin. Based on the literature and recent hydrologic modeling by UBC, the extent of beetle-kill likely poses a high risk to increased peak flows. It however may take a few years for the full impacts associated with beetle-kill to be witnessed as trees die and fall and for the right meteorological conditions to trigger flooding of sufficient magnitude to trigger channel changes.
Channel Stability	Moderate	Several reaches of Tibble Creek are moderately sensitive and one is highly sensitive. While there is a high risk of increased peak flows, all reaches of Tibble Creek are stable. Therefore, the risk to near future channel stability is moderate.
Riparian Function	High	About half of the length of Tibble Creek is at low risk of beetle-kill given the extensive wetlands and meadows supporting shrubby vegetation and mixed stands. The remainder of Tibble Creek (upper reaches especially) as well as numerous tributaries are however at high risk of beetle-kill as shown on Map 3 – along these tributaries, dead pine dominates the riparian zone. Considering the extent of beetle kill in riparian areas, the risk to riparian function in the riparian function is high.
Sediment	Low	No significant development-related sediment sources were identified in the Tibble Creek sub-basin and roads were in good condition. Therefore, the sediment risk in the sub-basin is low.

6.3.8 Restoration Opportunities

Table 6.9 summarizes the locations where restoration opportunities have been identified in the Tibbles Creek sub-basin. The locations of the recommended restoration sites are identified on Map 8.

Table 6.9 Summary of restoration sites identified in the Tibble Creek sub-basin.

Restoration Site[1]	Location	Summary of recommended restoration activities	Priority
TB1	Tibbles Creek near the mouth	A washed out culvert was identified on private land near the mouth of Tibbles Creek. It is recommended that the crossing be properly deactivated by removing the non-functional culvert and pulling back and armouring the exposed banks.	Moderate
TB2	Road 2100 near km 6	Recent road construction along relatively steep terrain represents a moderate risk of surface erosion and delivery to the stream network. We recommend that all exposed cut slopes be grass-seeded to minimize the potential for surface erosion.	Moderate

Notes
1. Refer to Map 8 for location.

6.4 PUNTATAENKUT CREEK

6.4.1 Physiography

Puntataenkut Creek drains a total area of 182.5 km^2, 44% of which is above the Baker Creek H_{60} elevation. This sub-basin is located in the northwest corner of the Baker Creek watershed (Figure 1.1 and Map 5). With the exception of the western portion of the sub-basin, the sub-basin is characterized by rolling terrain with several low gradient tributaries that feed Puntataenkut (Tibbles) Lake. Puntataenkut Lake drains into Middle Baker Creek near the Tibbles Road crossing. Numerous wetlands are located along the lower reaches of most streams entering the lake. Several small lakes are also located in the northern portion of the sub-basin. In addition to Puntataenkut Creek, four (4) significant tributaries were identified draining into Puntataenkut Lake.

6.4.2 Forest Cover and Forest Development

The Puntataenkut Creek sub-basin is dominated by pine-leading stands; however, spruce is present in many locations of the watershed and is mixed with pine in riparian zones and in moister sites. Approximately 32% of the sub-basin area has severe and very severe beetle-kill (Map 2), and approximately 46% of the total riparian area is at high risk of beetle-kill (Map 3).

The majority of the affected trees are located in the southwest corner of the sub-basin. Less than 1% of the sub-basin above has been affected by wildfire.

The majority of past forest development has occurred in the northern and western areas of the sub-basin. According to Cariboo (1996), the ECA projected to 2001 was 17%. Proposed forest development (end-2006) would increase this by about 3%. Considering the extent of beetle-kill, overall ECAs in the sub-basin are speculated to be approaching 40%.

6.4.3 Private Land

There are several privately owned properties in Puntataenkut Creek sub-basin. The majority of properties are used for agricultural purposes, and properties adjacent to Puntataenkut (Tibbles) Lake are used primarily for recreation. Approximately 20 private properties are located in the sub-basin. During the course of this study, four (4) property owners provided comment to the study team: Mr. John Way, Mr. Jesse Way, Mr. and Mrs. Joe Lisk, and Mr. Engel. Each owner identified specific issues on their properties (outlined in Section 5.0). In summary, more frequent flooding of fields is the main concern.

6.4.4 Channel Conditions

Table 6.10 summarizes the channel conditions noted for Puntataenkut Creek and four (4) of its major tributaries. Reach locations are identified on Map 5 and on the longitudinal profile in Appendix B.

Table 6.10 Summary of channel conditions in the Puntataenkut Creek sub-basin.

Stream	Reach	Summary
Puntataenkut Creek	1	Reach 1 of Puntataenkut Creek connects Puntataenkut (Tibbles) Lake to Baker Creek and is a very low gradient dune-ripple channel with sand bed lined by dense shrubs. A dam that was formerly located in Reach 1 has long since been removed and the channel appears stable and shows little signs of disturbance. Channel sensitivity is **moderate**.
Puntataenkut Creek	2	Reach 2 is Puntataenkut Lake. The lakeshore is heavily forested and consists of mainly private land on the east side. Several roads access the lake on the west side. Agricultural activity is present on adjacent properties. There is little sign of sediment input to the lake.
Puntataenkut Creek	3	Reach 3 has dune-ripple and riffle-pool morphology with a sand and gravel bed. Functioning large woody debris is common. The riparian zone contains a mix of spruce and beetle-kill pine. The channel is stable, and there is a low level of disturbance, associated with private land activities. Beaver activity is common and is responsible for backwatering the Nazko Highway crossing. Channel sensitivity is **high**.
Puntataenkut Creek	4	Reach 4 crosses private land used for agricultural purposes and has dune-ripple and riffle-pool morphology with a sand and gravel bed. A portion of the reach crosses a large wetland area. Woody debris volumes are variable and generally low. The riparian zone has been heavily altered on the private land and the stream appears to have been partially channelized. Evidence of flooding was noted. The channel is currently stable, however, channel sensitivity is **high**.
Puntataenkut Creek	5	Reach 5 has riffle-pool morphology with a gravel and sand bed. Functioning woody debris is present. The riparian zone is characterized by open meadow with spruce, willow and pine. The riparian area has been logged on both sides of the reach. Overall, disturbance to the reach is low and the channel is stable. Channel sensitivity is **moderate**.
Puntataenkut Creek	6	Reach 6 flows almost entirely across private land in a large wetland complex. Channel morphology is riffle-pool with sand and gravel bed. Woody debris volumes are low, and the riparian zone is characterized by a partial buffer from the agricultural fields. Evidence of flooding was noted. The channel appears stable and has low levels of disturbance. Channel sensitivity is **moderate**.
Puntataenkut Creek	7	Reach 7 has riffle-pool morphology with a gravel bed. Large woody debris is common and the riparian zone consists of willows with spruce and relatively low levels of beetle-killed pine. The channel is stable and has a low level of disturbance. Beaver activity was noted in the reach. Channel sensitivity is **moderate**.

Table 6.10 cont'd.

Stream	Reach	Summary
Puntataenkut Creek	8	Reach 8 is a confined cascade-pool channel with gravel and cobble bed. Functioning woody debris is common. The riparian zone is dominated by mature spruce with willow and aspen on both left and right banks. Relatively low levels of beetle-killed pine are found in the riparian zone. The channel is stable and no signs of disturbance were noted. Channel sensitivity is **low**.
Puntataenkut Creek	9	Reach 9 includes a small lake with a relatively short length of cascade-pool channel upstream. The riparian zone has a mix of spruce and pine and there is an extensive buffer on the left bank from prior logging. The channel is stable and there are no detectable levels of disturbance. Channel sensitivity is **low**.
Crimen Creek	1	Reach 1 of Crimen Creek is a low gradient dune-ripple and riffle pool channel that flows through an extensive wetland with dense shrubs. The channel is stable and there is no evidence of disturbance. Channel sensitivity is **moderate**.
Crimen Creek	2	Reach 2 is characterized by riffle-pool morphology with a relatively wide floodplain dominated by shrubby vegetation. Beetle-killed pine is located adjacent to the floodplain but is generally not coupled to the riparian zone. The channel is stable and there is no evidence of disturbance. Channel sensitivity is **moderate**.
Crimen Creek	3	Reach 3 is a wetland and small lake located primarily on private land. The short length of channel has a dune-ripple morphology with fine-grained bed and banks. The channel is stable with no evidence of disturbance. Channel sensitivity is **moderate**.
Puntataenkut Tributary 1	1	Reach 1 crosses a low-gradient wetland area and has a riffle-pool morphology with a sand gravel bed. The riparian zone is natural with a wide floodplain of mixed forest. The channel is stable and there are low levels of disturbance. Channel sensitivity is **moderate**.
Puntataenkut Tributary 1	2	Reach 2 has riffle-pool morphology with a sand gravel bed. Functioning large woody debris volumes are low. The riparian zone is largely natural with mixed species and relatively low levels of beetle-kill. However, beetle-kill levels are high in the adjacent upland areas. The reach is stable and there is no detectable levels of disturbance. Channel sensitivity is **moderate**.
Puntataenkut Tributary 1	3	Reach 3 has riffle-pool morphology with a gravel and sand bed. Functioning woody debris is present in high quantities. The riparian zone consists of mixed species and moderate levels of beetle-kill; however beetle-kill in adjacent upland areas is significant. The channel is stable, and there is no detectable level of disturbance. Channel sensitivity is **moderate**.

Table 6.10 cont'd.

Stream	Reach	Summary
Puntataenkut Tributary 2	1	Reach 1 of Tributary 2 joins Puntataenkut Lake on the west side of the lakeshore. The reach has riffle-pool morphology with a sand and gravel bed. Woody debris is scarce. The riparian zone includes mixed species with relatively low levels of beetle-kill. The channel is presently stable and no detectable disturbance. Channel sensitivity is **moderate**.
Puntataenkut Tributary 2	2	Reach 2 has riffle-pool morphology with a sand and gravel bed. Woody debris is scarce as it flows through wetlands dominated by shrubby vegetation. The channel is presently stable and has low level of disturbance. Channel sensitivity is **moderate**.
Puntataenkut Tributary 2	3	Reach 3 has riffle-pool and cascade-pool morphology with a sand, gravel and cobble bed. Functioning woody debris is present in high quantities. The riparian zone is dominated by spruce with some shrubs and low levels of beetle-killed pine. The channel is stable, and the level of disturbance is low. Beaver activity in the reach was noted. Channel sensitivity is **moderate**.
Puntataenkut Tributary 2	4	Reach 4 is generally characterized by confined cascade-pool morphology. The riparian zone consists of mixed species and has been partially affected by previous harvesting. Minor natural slides were noted along the reach. The channel is stable and there is no detectable level of disturbance. Channel sensitivity if **low**.
Puntataenkut Tributary 3		Tributary 3 joins on the east side of Puntataenkut Lake. It has riffle-pool morphology with a sand and gravel bed, and has low levels of woody debris. The riparian zone is logged to both banks with substantial revegetation and the channel has been straightened through the private agricultural land. Although there was a high level of disturbance, the channel is stable. Channel sensitivity is **moderate**.

6.4.5 Sediment Sources

No significant development related sediment sources were identified in the Puntataenkut Creek sub-basin. Some issues associated with roads are identified in Section 6.4.6.

6.4.6 Roads

In general, all the roads in the Puntataenkut Creek sub-basin were in good condition and presented low sediment-related risks. However, five (5) issues were noted (which are further discussed in Section 6.4.8):

- At the Road 1200 crossing of Puntataenkut Creek (Reach 7) at km 6 a 1,500 mm diameter culvert is partially blocked by beavers (PT1 on Map 5) (Photo 10, Appendix D). Maintenance is recommended to clear the blockage;

- At the Nazko Highway crossing of Puntataenkut Creek (PT2 on Map 5) road fill erosion and rilling was noted delivering sediment to creek (Photo 11, Appendix D). Work is recommended to protect the roadfill from erosion;
- At the Nazko Highway crossing of Crimen Creek there is a 2 m diameter hanging culvert that possible represents a fish barrier (PT3 on Map 5). In addition, the inlet is damaged and is partly plugged and there is piping in the roadfill. Maintenance is recommended to address these issues;
- On Road 3100 near km 1 (PT4 on Map 5), a spur road into a cutblock was constructed in highly erodible materials. As a result ditches have filled up and are non-functional (Photo 12, Appendix D). Maintenance of the ditches is recommended; and
- On an unnamed road off Road 3100 at km 4 there is a considerable surface erosion along about 50 m of road surface (Photo 13, Appendix D). Road grading is recommended.

6.4.7 Risk Assessment

A summary of the risks for the Puntataenkut Creek sub-basin is provided in Table 6.11.

Table 6.11 Summary of watershed risks in the Puntataenkut Creek sub-basin.

Risk type	Identified risk level	Comment
Peak Flow	High	Approximately 32% of the sub-basin has severe or very severe beetle-kill. Although ECAs calculations were beyond the scope of work, current ECAs considering beetle-kill probably are approaching 40% in the sub-basin. The extent of beetle-kill poses a high risk to increased peak flows, particularly in the small tributaries in the southwest corner of the sub-basin. It however may take a few years for the full impacts associated with beetle-kill to be witnessed as trees die and fall and for the right meteorological conditions to trigger flooding of sufficient magnitude to trigger channel changes.
Channel Stability	Moderate	Despite being currently stable, streams in the Puntataenkut Creek sub-basin are moderately or highly sensitive. While there is a high risk of increased peak flows, there are considerable wetland areas and lakes that would act to partially buffer impacts on channels. Therefore, the risk to near future channel stability is considered moderate.

Table 6.11 cont'd.

Risk type	Identified risk level	Comment
Riparian Function	High	The majority of the mainstem and principal tributaries of Puntataenkut Creek are at low risk of beetle-kill given the extensive (relatively wide) wetlands and meadows supporting dominantly shrubby vegetation and mixed stands. The majority of the smaller tributaries however are at high risk of beetle-kill as shown on Map 3 – along these tributaries, dead pine dominates the riparian zone. Considering the spatial extent of beetle kill in riparian areas, and the present level of riparian disturbance on private land, the risk to riparian function in the riparian function is high.
Sediment	Low	No significant development-related sediment sources were identified in the Puntataenkut Creek sub-basin and roads were generally in good condition. Therefore, the sediment risk in the sub-basin is low.

6.4.8 Restoration Opportunities

Table 6.12 summarizes the locations where restoration opportunities have been identified in the Puntataenkut Creek sub-basin. The locations of the recommended restoration sites are identified on Map 5.

Table 6.12 Summary of restoration sites identified in the Puntataenkut Creek sub-basin.

Restoration Site[1]	Location	Summary of recommended restoration activities	Priority
PT1	Road 1200 crossing of Puntataenkut Creek at km 6	A 1,500 mm diameter culvert is partially blocked by beavers and required clearing.	Moderate
PT2	Nazko Highway crossing of Puntataenkut Creek	Erosion of highway roadfill was noted delivering sediment to creek. Work is recommended to protect the roadfill from erosion. This could include rerouting road drainage away from materials susceptible to surface erosion and/or armouring or seeding the roadfill material.	High
PT3	Nazko Highway crossing of Crimen Creek	A 2 m diameter hanging culvert possibly represents a fish barrier. This potential issue should be confirmed with fisheries agencies. In addition, the inlet of the culvert is damaged and is partly plugged and there is piping in the roadfill. Maintenance is recommended to address these issues.	High

Table 6.12 cont'd.

Restoration Site[1]	Location	Summary of recommended restoration activities	Priority
PT4	Road 3100 near km 1	A spur road into a cutblock was constructed in highly erodible materials. As a result ditches have filled up and are non-functional. Maintenance of the ditches is recommended.	High
PT5	Road 3100 at km 4	Surface erosion was noted along about 50 m of road surface. Road grading is recommended at this location.	Low

Notes
1. Refer to Map 5 for location.

6.5 MERSTON CREEK

6.5.1 Physiography

The Merston Creek sub-basin has a total area of 262.5 km^2 with 82% above the Baker Creek watershed H_{60} elevation. This sub-basin is located largely in the southern portion of the Baker Creek watershed and includes Tzenzaicut Lake and its contributing area (Figure 1.1 and Map 7). From the lake, Merston Creek flows west and then north along a relatively narrow watershed bounded by Baker Creek to the west and Townsend and Mount Creek to the east. The Merston Creek sub-basin is dominated by wetlands along the valley bottom that generally increase in number and size in the downstream direction. Topography in the sub-basin is characterized by moderate sloping and rolling terrain in the south and gentle terrain in the north. Merston Creek flows into Baker Creek between the confluences with Puntataenkut and Punchesakut Creeks.

6.5.2 Forest Cover and Forest Development

In general, the Merston Creek sub-basin is dominated by pine-leading stands. Spruce is common in lower moister sites and is typically mixed with pine in riparian zones at lower elevations. Beetle-kill has been classified as severe or very severe in 48% of the sub-basin (Map 2). Most of this is located in the southern portion of the sub-basin near Tzenzicut Lake. Furthermore, 33% of total riparian area in the sub-basin is at high risk of beetle-kill (Map 3);

most if this is along relatively small tributaries. Approximately 2% of the sub-basin has been affected by wildfire in the past.

Forest development has occurred throughout much of the sub-basin with the exception of some areas around Tzenzicut Lake. Cariboo (1996) identified ECAs in the sub-basin ranging from about 28% to 50% depending on area of the sub-basin. Specific harvesting proposals (end-2006), including some recent blocks north of Tzenziacut Lake, would account for an additional 6%. Considering the extent of beetle-kill, ECAs in the watershed are speculated to be currently in excess of 50%.

6.5.3 Private Land

There are several private properties in Merston Creek sub-basin. The majority of properties are used for agricultural purposes in the north, and recreation near Tzenzaicut Lake (including Fish Lake Resort). Approximately 15 private properties were identified; two (2) property owners provided comments during this study. Mr. Moore identified flooding as an ongoing issue, but not as great a problem as in the Middle Baker sub-basin where he also owns property. Mr. Moffat also indicated that flooding of his fields near the mouth of Merston Creek is an issue.

6.5.4 Channel Conditions

Table 6.13 summarizes the channel conditions noted for Merson Creek. Reach locations are identified on Map 7 and on the longitudinal profile in Appendix B.

Table 6.13 Summary of channel conditions in the Merston Creek sub-basin.

Stream	Reach	Summary
Merston Creek	1	Reach 1is a relatively short channel with riffle-pool morphology and a gravel and sand bed. Woody debris volumes are high and the riparian zone consists mainly of spruce. The channel is stable and disturbance is not detectable. Channel sensitivity is **moderate**.
Merston Creek	2	Reach 2 crosses private land and has riffle-pool morphology with a sand and gravel bed. Woody debris volumes are low and the riparian zone has been logged on both banks, although there is some remaining functional riparian vegetation. The removal of riparian vegetation and agricultural activities has disturbed sections of the creek, and evidence of channel instability in the form of excessive bank erosion and sediment delivery to the creek is evident. Channel sensitivity is **high**.
Merston Creek	3	Reach 3 is a low gradient riffle-pool channel with a sand and gravel bed. A low quantity of functioning woody debris is present given the wide floodplain area dominated by shrubby vegetation (e.g. willows). Adjacent to the floodplain, the forest is mixed pine and spruce on the left bank and mostly beetle-killed pine on the right bank. However, most of the beetle-kill is outside of the riparian zone. The channel is stable and there are no detectable signs of disturbance. Channel sensitivity is **moderate**.
Merston Creek	4	Reach 4 crosses private agricultural land and has riffle-pool morphology with a sand and gravel bed. The quantity of woody debris is scarce and the recruitment potential is low given that the riparian zone has been largely cleared of vegetation. Portions of the channel have been modified through the property and extensive ditching exists to promote drainage of the area. Bank erosion within Reach 4 is considerable and is partially related to ranching activities on the property. The channel is unstable and channel sensitivity is **high**.
Merston Creek	5	Reach 5 is a riffle-pool channel with sandy bed that flows through an extensive wetland area with dense willows. The floodplain width varies; where it is narrow there is some potential for recruitment of mature timber. There is some potential for direct input of beetle-killed timber, but most timber is spruce. The channel is stable and there is no evidence of disturbance other than some minor localized impacts near the Road 37-1 crossing. Channel sensitivity is **moderate**.
Merston Creek	6	Reach 6 is similar in morphology to Reach 5, however, Reach 6 flows through a wide extensive wetland with dense willow. Large woody debris is generally scarce along this reach. Beavers are active and have constructed several dams that backwater the channel. The channel is currently stable. Channel sensitivity is **moderate**.
Merston Creek	7	Reach 7 has a riffle-pool morphology with a gravel bed. The riparian zone consists of mature pine and spruce with approximately 80% beetle-killed trees on the right bank and mature willows on the left bank. The channel is stable and disturbance is low (associated with an old stream crossing). Channel sensitivity is **moderate**.

Table 6.13 cont'd.

Stream	Reach	Summary
Merston Creek	8	Reach 8 has a riffle-pool morphology with a sand and gravel bed. The riparian zone consists of mature pine, spruce, and young willows on the left bank and willows with open agricultural land on the right bank. The channel is stable, and disturbance is moderate (associated with cattle access to the creek on the right bank). Also, portions of the creek have been diverted across private land. Nevertheless, the channel is stable. Channel sensitivity is **moderate**.
Merston Creek	9	Reach 9 is a sinuous low gradient riffle-pool channel that connects numerous wetlands. The riparian zone consists of open meadows with dense willows and grasses with spruce-leading stands on the adjacent upland areas. Beetle-killed timber is scatted along the length of the creek. There is a moderate level of disturbance associated with cattle access and crossing of the creek. Nevertheless, the channel is stable. Channel sensitivity is **moderate**.
Merston Creek	10	Reach 10 crosses private land and has a riffle-pool morphology with a sandy and gravel bed. A moderate quantity of functioning woody debris is present in the reach. The riparian zone is dominated by dense willow. Disturbance to the reach is moderate as a considerable portion of the private land has been logged to the bank, and cattle have access to the creek. The channel is unstable as shown by several undercut banks and flow paths indicating former channel avulsions. Channel sensitivity is **high**.
Merston Creek	11	Reach 11 has a riffle-pool morphology and a sand and gravel bed. The riparian zone is natural with mixed tree species, and the channel is highly sinuous and passes through several wetlands with dense willows. High levels of beetle-kill are found uplslope, but generally this timber will not have direct influence on the creek. Beaver activity was noted. The channel is stable and there are no detectable signs of disturbance. Channel sensitivity is **moderate**.
Merston Creek	12	Reach 12 has riffle-pool morphology with a sand gravel bed. It is similar in many respects to Reach 11, however Reach 12 flows through larger wetland areas. The riparian zone is generally natural on the left bank and has an extensive buffer with selective logging adjacent to the right bank. High levels of beetle-kill are found upslope but typically this timber will not have a direct influence on the creek. The channel is stable and there is low disturbance other than some beaver activity. Channel sensitivity is **moderate**.
Merston Creek	13	Reach 13 has a riffle-pool morphology with a gravel and sand bed. There is a low quantity of large woody debris present in the reach and the riparian zone consists of low shrubs and grass along the banks and mixed forest, approximately half affected by MPB. The channel is stable and the disturbance level is low. There is considerable beaver activity in the reach. Channel sensitivity is **moderate**.
Merston Creek	14	Tzenzaicut Lake (Reach 14) has a gravely lakeshore with a dense mixed forest of spruce, aspen, and willows adjacent to the foreshore and mature pine upslope of the lake.

Table 6.13 cont'd.

Stream	Reach	Summary
Merston Creek	15	Reach 15 upstream of Tzenzaicut Lake flows through private land and has a riffle-pool morphology with a sand and gravel bed. The riparian zone has been harvested on both banks however there is substantial revegetation. Beaver activity was noted. The channel is stable and there is low level of disturbance. Channel sensitivity is **moderate**.
Merston Creek	16	Reach 16 flows across a boggy area with dense shrubs. The channel has a riffle-pool morphology with a sandy bed. The channel is stable, and there is no detectable level of disturbance. Channel sensitivity is **moderate**.

6.5.5 Sediment Sources

No significant development related sediment sources were identified in the Merston Creek sub-basin. Some issues associated with roads are identified in Section 6.4.6. Dispersed across the sub-basin were signs of cattle disturbance to streambanks. This was specifically observed in Reaches 8, 9 and 10, but there are likely other areas also affected. It is recommended that future range access management planning consider minimizing stream impacts by placing restrictions on watering locations. In addition, private land owners should be informed on the benefits and encouraged to practice improved riparian management on their own properties (e.g. reduced land loss through erosion, improved water quality).

6.5.6 Roads

In general, all the roads in the Merston sub-basin were in good condition and presented a low risk of sediment delivery to the stream network. Two (2) sites however were identified that warrant discussion (also discussed in Section 6.5.8):

- Ditches along Road 34-5 approximately 2 km west of the junction with Road 1700 are filled in with sediment and require clearing to maintain their functionality (ME1 on Map 7); and
- On Lavington Road at km 14, a ditch on the west side of road has evidence of severe erosion for 150 m (ME 2 on Map 7; Photo 14, Appendix D). A large area of sediment has deposited on upslope side of road and a 400 mm culvert is damaged and is non-functional. Restoration of this site is recommended.

6.5.7 Risk Assessment

A summary of the risks for the Merston Creek sub-basin is provided in Table 6.14.

Table 6.14 Summary of watershed risks in the Merston Creek sub-basin.

Risk type	Identified risk level	Comment
Peak Flow	High	Approximately 48% of the sub-basin has severe or very severe beetle-kill. Although ECAs calculations were beyond the scope of work, current ECAs considering beetle-kill probably are likely exceeding 50% in the sub-basin. The extent of beetle-kill poses a high risk to increased peak flows. It however may take a few years for the full impacts associated with beetle-kill to be witnessed as trees die and fall and for the right meteorological conditions to trigger flooding of sufficient magnitude to trigger channel changes.
Channel Stability	Moderate	Despite being currently stable, streams in the Merston Creek sub-basin are moderately or highly sensitive. While there is a high risk of increased peak flows, there are considerable wetland areas and some lakes that would act to partially buffer impacts on channels. Therefore, the risk to near future channel stability is considered moderate overall.
Riparian Function	Moderate	The majority of the mainstem and principal tributaries of Merston Creek are at low risk of beetle-kill given the extensive (relatively wide) wetlands and meadows supporting dominantly shrubby vegetation and mixed stands. The majority of the smaller tributaries however are at high risk of beetle-kill as shown on Map 3 – along these tributaries, dead pine dominates the riparian zone. Considering the spatial extent of beetle kill in riparian areas, and the present level of riparian disturbance on private land, the risk to riparian function in the riparian function is moderate.
Sediment	Low	No significant development-related sediment sources were identified in the Merston Creek sub-basin and roads were generally in good condition. Therefore, the sediment risk in the sub-basin is low.

6.5.8 Restoration Opportunities

Table 6.15 summarizes the locations where restoration opportunities have been identified in the Merston Creek sub-basin. The locations of the recommended restoration sites are identified on Map 7.

Table 6.15 Summary of restoration sites identified in the Merston Creek sub-basin.

Restoration Site[1]	Location	Summary of recommended restoration activities	Priority
ME1	Road 34-5 approximately 2 km west of the junction with Road 1700	Ditches are filled in with sediment and require clearing.	Low
ME2	Lavington Road at km 14	A ditch on the west side of the road has evidence of severe erosion for 150 m. A large area of sediment has deposited on the upslope side of road and a 400 mm culvert is damaged and is non-functional. We recommend that the ditch be re-graded, and armoured with coarse rock that is underlain by a suitable geotextile. The culvert should be repaired and a small catch basin on the upslope side of the road could be constructed to promote settling out of sediment.	High
ME3	Moffat property, district lot 12267 (Reach 4 of Merston Creek)	Excessive bank erosion is occurring along private land where riparian vegetation is lacking. It is recommended that with the cooperation of the land owner, site specific restoration plans be developed and implemented by experienced professionals to minimize the risk of further channel instability, particularly in light of the high risk of increased peak flows. For long-term benefits, the channel could be fenced off in order to restore vegetation.	Moderate
ME4	District lot 2454 (Reach 2 of Merston Creek)	Excessive bank erosion is occurring along private land where the functional riparian vegetation is lacking. It is recommended that with the cooperation of the land owner, site specific restoration plans be developed and implemented by experienced professionals to minimize the risk of further channel instability, particularly in light of the high risk of increased peak flows. For long-term benefits, the channel could be fenced off in order to restore vegetation.	Moderate
Future range management in the sub-basin should consider restricting the number and locations of watering locations, particularly along moderate and high sensitive stream reaches. If possible, watering should be off-stream or at locations armoured to prevent excessive erosion.			Moderate

Notes
1. Refer to Map 7 for location.

6.6 PUNTCHESAKUT CREEK

6.6.1 Physiography

Puntchesakut Creek sub-basin has a total area of 52.3 km^2 with only 16% above the Baker Creek watershed H_{60} elevation. This sub-basin is located in the north-central part of the Baker Creek watershed and includes Squamish Lake, Tiltzarone and Punchesakut Lakes. The sub-basin generally has low relief with rolling hills in the north and gently sloping terrain along Jordan Creek and Punchesakut Creek. Large wetlands are located north and south of Squamish Lake and east of Puntchesakut Lake. Puntchesakut Creek flows into Baker Creek at the arbitrary break between Middle and Lower Baker Creek sub-basins.

6.6.2 Forest Cover and Forest Development

The Puntchesakut Creek sub-basin is dominated by pine-leading stands in the northern portion of the sub-basin and mixed stands in the south. Only 13% of the sub-basin has beetle-killed classified as severe or very severe (Map 2), however a considerable portion of the sub-basin has at least some (lower level of) beetle-killed timber. An estimated 41% of the riparian zone in the sub-basin is at high risk of beetle-kill, mostly in the northern portion of the sub-basin (Map 3).

Most forest development within the sub-basin has occurred in the northern half. Cariboo (1996) projected 2001 ECAs to be 23%. Proposed forest development (end-2006) comprises about 6% of the sub-basin. Considering the level of beetle-kill, the current ECA in the sub-basin is speculated to be approximately 30%.

6.6.3 Private Land

There are several privately owned properties in Puntchesakut Creek sub-basin. The majority of properties are used for agricultural purposes, and properties adjacent to Puntchesakut Lake are used for recreation. Puntchesakut Lake Provincial Park is also located on the east side of the lake. Of approximately 15 private land parcels, only one (1) property owner provided comments to the study team. Mrs. Falloon identified flooding of fields as an issue of concern.

6.6.4 Channel Conditions

Table 6.16 summarizes the channel conditions noted for Punchesakut Creek. Reach locations are identified on Map 5 and on the longitudinal profile in Appendix B.

Table 6.16 Summary of channel conditions in the Puntchesakut Creek sub-basin.

Stream	Reach	Summary
Puntchesakut Creek	1	Reach 1 has riffle-pool morphology with a sand and gravel bed. Large woody debris is present in low quantities. The riparian zone consists of an extensive buffer on the left bank and a uniform pine forest (approximately 60% beetle-kill) on the right bank. The channel is stable and there are no detectable signs of disturbance. Channel sensitivity is **moderate**.
Puntchesakut Creek	2	Reach 2 is a low gradient riffle-pool channel with a sand and gravel bed that flows across a wetland area. Riparian vegetation is predominantly shrubby vegetation with a partial buffer of mature timber on the left bank and logged to the right bank with substantial revegetation. The reach is stable and there are no detectable signs of disturbance. Channel sensitivity is **moderate**.
Puntchesakut Creek	3	Puntchesakut Lake (Reach 3) foreshore consists of an extensive buffer on the east side with mixed forest species and a partial buffer on the west side with several lots of recreational and agricultural land.
Jordan Creek	4	Jordan Creek is the principal tributary to Punchesakut Lake. Reach numbering continues from Punchesakut Creek. Reach 4 flows across wetland and has a dune-ripple and riffle-pool morphology with a sand and gravel bed. Large woody debris volumes are low. The riparian zone consists of mostly grass with sparse willows. The meandering channel exhibited downcutting and undercutting downstream of the Grevatt Road crossing. Evidence of recent flooding in the wet meadow (stressed vegetation, fine sediment) was noted. Cattle access to this reach and the removal of the riparian vegetation may have exacerbated flooding and erosion in the reach (Photo 15, Appendix D). Despite the high level of disturbance, the channel is stable overall. Channel sensitivity is **moderate**.

Table 6.16 cont'd.

Stream	Reach	Summary
Jordan Creek	5	Reach 5 flows almost entirely across private land and has a riffle-pool morphology with a sand and gravel bed. The riparian area and the channel has been heavily disturbed across agricultural land, and much of its length the reach has been straightened. Despite high levels of disturbance, the channel is stable. Channel sensitivity is **moderate**.
Jordan Creek	6	Reach 6 has dune-ripple and riffle-pool morphology with a sand bed. Woody debris is present in low quantities and the riparian zone consists of a very wide open meadow with grass and low shrubs. The channel is stable and there is no detectable level of disturbance. Channel sensitivity is **moderate**.
Jordan Creek	7	Squamish Lake (Reach 7) is downgradient of the headwaters for Puntchesakut Creek. The lake foreshore consists of dense mixed forest with logged areas upslope on the east and west sides of the lake. Small ponds are located adjacent and east of the lake.
Jordan Creek	8	Reach 8 upstream of Squamish Lake is dominated by small low gradient riffle-pool channels in an extensive wetland area. The channel is stable and there is no detectable level of disturbance. Channel sensitivity is **moderate**.

6.6.5 Sediment Sources

No significant development related sediment sources were identified in the Puntchesakut Creek sub-basin. Dispersed across the sub-basin was evidence of cattle disturbance to streambanks. This was specifically in Reaches 4 (Jordan Creek) where both a combination of riparian disturbance and cattle access on private land caused significant impacts to the stream values. It is recommended that future range management planning consider stream impacts and place restrictions for watering locations. In addition, private land owners should be informed on the benefits (e.g. reduced land loss through erosion, improved water quality) and encouraged to practice improved riparian management on their own properties.

6.6.6 Roads

In general, all the roads are in good condition and present a low risk of sediment delivery to the stream network.

6.6.7 Risk Assessment

A summary of the risks for the Puntchesakut Creek sub-basin is provided in Table 6.17.

Table 6.17 Summary of watershed risks in the Punchesakut Creek sub-basin.

Risk type	Identified risk level	Comment
Peak Flow	Moderate	Approximately 13% of the sub-basin has severe or very severe beetle-kill. Although ECAs calculations were beyond the scope of work, current ECAs considering beetle-kill probably are likely approaching 30% in the sub-basin. This overall ECA poses a moderate risk to increased peak flows.
Channel Stability	Low	Despite being currently stable, streams in the Punchesakut Creek sub-basin are moderately sensitive. Given the moderate risk of increased peak flows and the extensive nature of the wetlands and lakes in the sub-basin that act to reduce the rate of runoff reaching the mainstem, the risk to near-future channel stability is low.
Riparian Function	Moderate	The majority of the mainstem and principal tributaries of Punchesakut Creek are at low risk of beetle-kill given the extensive (relatively wide) wetlands and meadows supporting shrubby vegetation and mixed stands. Most smaller tributaries in the northern portion of the sub-basin in particular are at high risk of beetle-kill as shown on Map 3 – along these tributaries, dead pine stands dominate the riparian zone. Considering the spatial extent of beetle kill in riparian areas, and the present level of riparian disturbance on private land, the risk to riparian function in the riparian function is moderate.
Sediment	Low	No significant development-related sediment sources were identified in the Puntchesakut Creek sub-basin and roads were generally in good condition. Therefore, the sediment risk in the sub-basin is low.

6.6.8 Restoration Opportunities

No restoration opportunities were identified specifically for the Punchesakut sub-basin. However, as noted in Section 6.6.5, future range management in the sub-basin should consider restricting the number and locations of watering locations, and armouring such locations to minimize erosion and sediment delivery to the stream network, particularly along moderate and high sensitive stream reaches.

6.7 MOUNT CREEK

6.7.1 Physiography

Mount Creek sub-basin has a total area of 283.1 km^2, 66% of which is above the Baker Creek H_{60} elevation. This sub-basin is located in the east-central portion of the watershed, and includes Townsend and Landslide Creeks. The topography varies from moderately sloping hills

in the east that become gentler towards the west. Along the valley bottom, low gradient streams meander through extensive wetlands with a few small lakes. Mount Creek joins Lower Baker Creek east of its confluence with Punchesakut Creek.

6.7.2 Forest Cover and Forest Development

The Mount Creek sub-basin is dominated by pine-leading stands, particularly in the southeastern portion of the sub-basin. Spruce is common in moist sites and is typically found along the riparian zones at lower elevations. Beetle-kill is classified as severe or very severe in 47% of the sub-basin (Map 2). High risk of MPB mortality has been identified in 34% of the riparian zone within the sub-basin. The majority of the affected trees are located in the central and southeastern areas of the sub-basin – areas that have largely been undeveloped to date (Photo 16, Appendix D). Approximately 1% of the sub-basin has been affected by wildfire.

Most forest development to date has occurred in the western half of the sub-basin. ECAs in the sub-basin projected to 2001 were 17% (Cariboo 1996). Specific harvest proposals (to end-2006) amount to an additional 8% of the sub-basin. Considering the extent of beetle-kill in the sub-basin, it is speculated that ECAs are currently about 50%.

6.7.3 Private Land

Approximately 10 private properties are located within in Mount Creek sub-basin. Most of the properties are used for agricultural purposes and the majority are located in the western half of the sub-basin. Owners of two properties provided comment during the study (Section 5.0). Mr. Strachan, owner of district lot 6711, indicated flooding was an issue. Mr. Paley and Ms. Wilson, owners of district lot 6710, indicated they observed an increase in the magnitude and frequency of flooding (Townsend Creek) on their property since the fall of 2003. In some cases, 7 to 8 floods each year occurred, including flooding in January. Mr Paley has observed up to 2 inches (5 cm) of water on his fields within two (2) days of a rain event. According to Mr. Paley, the creek through his property is not channelized and has very little riparian vegetation. He also indicated that up to 90% of the surrounding forest has been killed by MPB.

6.7.4 Channel Conditions

Table 6.18 summarizes the channel conditions noted for Mount Creek. Reach locations are identified on Map 6 and on the longitudinal profile in Appendix B.

Table 6.18 Summary of channel conditions in the Mount Creek sub-basin.

Stream	Reach	Summary
Mount Creek	1	Reach 1 of Mount Creek is a highly sinuous riffle-pool channel with gravel and sand bed and abundant woody debris. The riparian zone consists of mixed spruce, willow, and minor amounts of pine. The channel is stable and has low levels of disturbance. Given the nature of the bed and bank materials and the unconfined nature of the channel, sensitivity is **high**.
Mount Creek	2	Reach 2 is a highly sinuous unconfined ripple-dune and riffle-pool channel that flows through an extensive wetland. Bed material varies but is dominated by sand. Woody debris is abundant and log jams were noted near the lower end of the reach (Photo 17, Appendix D). The riparian zone consists of dense willows and grasses. Upslope, the majority of the forest has been harvested with a riparian buffer. Beetle-kill is moderate along the reach and will generally not contribute wood directly to the creek. The channel is stable and there are low levels of disturbance. Channel sensitivity is **high**.
Mount Creek	3	Reach 3 is a sinuous riffle-pool channel with a sand and gravel bed that flows across private land. Woody debris volumes are variable. The riparian zone varies considerably as it flows through a lengthy wetland area. Where the stream is adjacent to mature forest, a partial buffer is in place. The channel is stable and there is no indication of disturbance. Channel sensitivity is **moderate**.
Mount Creek	4	Reach 4, upstream of the confluence with Landslide Creek, is similar in morphology and conditions to Reach 3. The riparian zone consists of mixed forest with spruce, willow, and pine with relatively low levels of beetle-kill. There is a low level of disturbance associated with a bridge crossing and some disturbance to streambanks along private land, however, the channel is stable. Channel sensitivity is **moderate**.
Mount Creek	5	Reach 5 has a similar morphology as reaches 3 and 4 and has a riparian zone dominated by shrubby vegetation and spruce-leading stands. Some beetle-kill was noted in these stands, but the potential for direct input of wood is low. There is no detectable level of disturbance and the channel is stable. Channel sensitivity is **moderate**.

Table 6.18 cont'd.

Stream	Reach	Summary
Mount Creek	6	Reach 6 is a sinuous riffle-pool channel with sand and gravel bed that flows through a wide wetland on private land. Large woody debris volumes are variable and some log jams were noted. The riparian zone is dominated by shrubby vegetation but in a few locations the vegetation has been removed. The channel appears unstable, however the cause of disturbance was not specifically identified. Channel sensitivity is **high**.
Mount Creek	7	Reach 7 is a highly sinuous riffle-pool channel that flows through a few small wetlands. The riparian zone consists of mixed species on both banks. Considerable beetle-killed timber is found within the riparian zone, but is generally not likely to directly provide wood to the creek. The reach is stable and there are no detectable levels of disturbance. Channel sensitivity is **moderate**.
Mount Creek	8	Reach 8 flows largely across a meadow on private land and has a riffle-pool morphology with a sand and gravel bed. The reach has a low volumes of woody debris and the riparian zone has been harvested in the past but has substantially revegetated. Cattle have access to the creek and have disturbed the willows lining the banks. Despite moderate disturbance, the channel is stable. Channel sensitivity is **moderate**.
Mount Creek	9	Reach 9 of Mount Creek has a dune-ripple morphology with a silt and sand bed. Woody debris volumes are generally low as this low gradient channel is located primarily in a wetland. The riparian zone consists of mostly grass with willow shrubs. High levels of beetle-kill were noted upslope, but most of this timber will not directly impact the creek. Cattle access to the creek has caused high levels of disturbance including compaction of soils, willow browse, bed degradation, and bank erosion (Photo 18, Appendix D). Despite this, the channel remains stable. Channel sensitivity is **high**.
Mount Creek	10	Reach 10 crosses private land and has a riffle-pool morphology with sand and gravel bed. Woody debris volumes are low and are a result of the low gradients and open meadow with mostly shrubby vegetation along the banks. The channel appears stable, however there is evidence of flooding in the area. It appears the property owner has recently constructed a series of drainage ditches around the property (Photo 19, Appendix D). Disturbance to the reach is moderate. Channel sensitivity is **moderate**.
Mount Creek	11	Reach 11 flows partly across a wetland and partly within mature forest with high levels of beetle-kill. The morphology of the reach is riffle-pool. The channel has no detectable levels of disturbance and is stable. Channel sensitivity is **moderate**.
Mount Creek	12	Reach 12 is a generally unconfined and has riffle-pool morphology with a sand and gravel bed. The riparian zone has an extensive buffer with selective logging upslope. Near the upper end of the reach, beetle-killed timber has some potential to enter the creek. The reach is stable and there are no detectable levels of disturbance. Channel sensitivity is **moderate**.

Table 6.18 cont'd.

Stream	Reach	Summary
Mount Creek	13	Reach 13 has a cascade-pool morphology with a cobble and gravel bed. The riparian zone consists of second growth forest with young pine plantations upslope of the reach. There are no detectable levels of disturbance. The channel is stable and has a **low** sensitivity.
Landslide Creek	1	Reach 1 of Landslide Creek has riffle-pool and cascade-pool morphology with gravel and cobble bed. Moderate quantities of functioning woody debris were noted. The riparian zone consists of spruce and willow and little beetle-kill. Beaver activity was noted. Disturbance to the reach was high as noted by recently scoured banks and sediment deposits. The principal cause of this appears to be a sudden breach of a culvert crossing on Road 3800 at km 8 in early 2006, likely caused by beavers plugging the culverts. The breach released water from a relatively large pond dammed by roadfill. Overall, the channel is unstable and is currently adjusting to the effects of the "dam-break" flood. The channel is **highly** sensitive.
Landslide Creek	2	Reach 2 of Landslide Creek is a generally confined cascade-pool channel with a gravel and cobble bed. Woody debris volumes are variable. The riparian zone has not been harvested and is largely affected by beetle-kill. The reach is stable and there are no detectable levels of disturbance. Channel sensitivity is **low**.
Landslide Creek	3	Reach 3 of Landslide Creek has cascade-pool and step-pool morphology and is generally confined. Both banks of the reach are lined by pine-leading stands that are highly affected by beetle-kill. Although there is no detectable level of disturbance the channel is stable. Channel sensitivity is **low**.
Townsend Creek	1	Reach 1 of Townsend Creek flows across private land and has a sinuous riffle-pool morphology with sand and gravel bed and predominantly shrubby and grassy riparian vegetation, some of which has been cleared for ranching. Evidence of cattle disturbance along the banks and flooding was noted. The channel is moderately disturbed but is stable. Channel sensitivity is **high**.
Townsend Creek	2	Reach 2 of Townsend Creek has a cascade-pool morphology with gravel and cobble bed. Woody debris is common. The riparian zone consists of mixed spruce and aspen with dense understory and approximately 20% beetle-kill. The channel is stable and there is no detectable level of disturbance. Channel sensitivity is **low**.
Townsend Creek	3	Reach 3 of Townsend Creek includes a lake, wetland and meadow on private land. Channel morphology is riffle-pool with gravel bed. Woody debris is common. The riparian zone consists of mixed spruce and aspen with dense understory and approximately 20% beetle-kill. Harvesting and substantial revegetation has occurred along the reach. Drainage ditches appear to have been constructed to drain marshy areas to increase the agricultural potential of the area. The channel is stable and there is no detectable level of disturbance. Channel sensitivity is **moderate.**

Table 6.18 cont'd.

Stream	Reach	Summary
Townsend Creek	4	Reach 4 of Townsend Creek has riffle-pool and cascade-pool morphology with a sand, gravel, and cobble bed. The reach passes through several small wetlands with shrubby vegetation. Riparian vegetation consists of mixed pine and spruce with some potential for potential for recruitment into the creek. The channel is stable and there is no detectable level of disturbance. Channel sensitivity is **moderate**.
Townsend Creek	5	Reach 5 of Townsend Creek has cascade-pool morphology with a gravel and cobble bed. The reach is confined and the riparian zone is natural and consists of mixed pine and spruce with high levels of beetle-kill. The channel is currently stable with no detectable levels of disturbance. Channel sensitivity is **low**.

6.7.5 Sediment Sources

Other than some road issues identified in Section 6.7.6, no significant development related sediment sources (i.e. slides) were identified in the Mount Creek sub-basin. In the lower portion of the basin there was evidence of cattle disturbance to streambanks. It is recommended that future range management consider minimizing stream impacts by placing restrictions on watering locations. In addition, private land owners should be informed of the benefits of improved riparian management on their own properties (e.g. reduced land loss through erosion, improved water quality).

6.7.6 Roads

In general, roads in the Mount Creek sub-basin were in good condition and posed a low risk of sediment delivery to the stream network. A total of six (6) sites require maintenance or restoration work (outlined also under Section 6.7.8):

- On Mount Creek Road (Road 8800), ditch maintenance is recommended for about 50 m near a gravel pit (MT1 on Map 6);
- On Road 3700 at km 8 there was a washout in Landslide Creek in early 2006 (MT2 on Map 6; Photos 20-22, Appendix D). An urgent memo was sent to MOF and Tolko in July 2006 (copy in Appendix C) outlining the conditions of the road. Recommendations to limit access to the site until the crossing could be re-established (if access is required) were provided;

- Moderate levels of surface erosion were noted on Road 3750 at km 2+. In addition, waterbars were non-functional and should be cleared to minimize further road surface erosion (MT3 on Map 6);
- On Road 14A near km 3 there is poor drainage and moderate levels of surface erosion (MT 4 on Map 6; Photo 23, Appendix D). If the road is not planned to use in the near-term, it is recommended that it be deactivated with functional water bars. If access is required, improved ditching and drainage works are needed;
- At the Road 10A-3 crossing of Mount Creek (Reach 12) there is a damaged culvert that should be repaired to make it functional (MT5 on Map 6);
- At Road 37-1 near km 6, the culvert crossing of Landslide Creek was partially plugged with small woody debris causing a widening and erosion of the channel upstream (MT6 on Map 6). Beaver activity and high flows likely were contributing factors. We recommend a secondary overflow culvert be installed to convey flows in the event of beaver-related or other culvert blockages. Screens should be considered at the inlet to limit the influence of beaver-related woody debris.

6.7.7 Risk Assessment

A summary of the risks for the Mount Creek sub-basin is provided in Table 6.19.

Table 6.19 Summary of watershed risks in the Mount Creek sub-basin.

Risk type	Identified risk level	Comment
Peak Flow	High	Approximately 47% of the sub-basin has severe or very severe beetle-kill. Although ECAs calculations were beyond the scope of work, current ECAs considering beetle-kill probably are likely at or above 50% in the sub-basin. This overall ECA poses a high risk to increased peak flows. It however may take a few years for the full impacts associated with beetle-kill to be witnessed as trees die and fall and for the right meteorological conditions to trigger flooding of sufficient magnitude to cause channel changes.

Table 6.19 cont'd.

Risk type	Identified risk level	Comment
Channel Stability	High	Other than two reaches, streams in the Mount Creek sub-basin are generally stable. However, most reaches are moderately sensitive and five reaches are highly sensitive. As a result, the risk to near-future channel stability overall is high.
Riparian Function	High	Much of the mainstem and principal tributaries of Mount Creek are at low risk of beetle-kill given the extensive (relatively wide) wetlands and meadows supporting shrubby vegetation and mixed stands. Smaller tributaries in the sub-basin however are at high risk of beetle-kill as shown on Map 3 – along these tributaries, dead pine stands dominate the riparian zone. Considering the spatial extent of beetle kill in riparian areas, and the present level of riparian disturbance on private land, the risk to riparian function in the riparian function is high.
Sediment	Moderate	No significant development-related sediment sources (i.e. slides) were identified in the Mount Creek sub-basin and roads were generally in good condition. However there are a small number of issues associated with drainage and surface erosion along roads. Therefore, the sediment risk in the sub-basin is moderate.

6.7.8 Restoration Opportunities

Table 6.20 summarizes the locations where restoration opportunities have been identified in the Mount Creek sub-basin. The locations of the recommended restoration sites are identified on Map 6.

Table 6.20 Summary of restoration sites identified in the Mount Creek sub-basin.

Restoration Site[1]	Location	Summary of recommended restoration activities	Priority
MT1	Mount Creek Road (Road 8800)	Due to infilling with sediment, ditch maintenance is recommended for about 50 m near a gravel pit.	Low

Table 6.20 cont'd.

Restoration Site[1]	Location	Summary of recommended restoration activities	Priority
MT2	Road 3700 at km 8	A major washout of the road occurred in early 2006 after the blockage of culverts (likely by beaver-related woody debris) caused overtopping and a breach of the road fill that effectively controlled the water in a beaver pond upstream. An urgent memo was sent to MOF and Tolko in July 2006 (copy in Appendix C) outlining the conditions of the road at the time. If access past this point is a management priority, it is recommended that the road be reconstructed in such a manner to minimize the risk of future "dam-break" events. This could include reducing the level of road fill, providing a sufficient number of secondary culverts (in case of culvert blockage), screening of culvert inlets to minimize blockages, and engineering the road surface such that it can withstand overtopping for brief periods.	High
MT3	Road 3750 at km 2+	Non-functional waterbars were identified causing excessive surface erosion along the road surface. It is recommended that the waterbars be cleared.	Low
MT4	Road 14A near km 3	Poor drainage and moderate levels of surface erosion were identified. If the road is not planned for use in the near-term, it is recommended that it be deactivated with functional water bars. If access is required in the near-future, improved ditches and drainage works are recommended.	Moderate
MT5	Road 10A-3 crossing of Mount Creek	It is recommended a damaged culvert at the crossing should be repaired to make it functional.	Moderate
MT6	Road 37-1 near km 6	A culvert crossing of Landslide Creek was partially plugged with small woody debris causing channel erosion. Beaver activity and high flows likely were contributing factors. We recommend a secondary overflow culvert be installed to convey flows in the event of beaver-related or other culvert blockages. Screens should be considered at the inlet to limit the influence of beaver-related woody debris.	Moderate
Future range management in the sub-basin should consider restricting the number and locations of watering locations, particularly along moderate and high sensitive stream reaches. If possible, watering should be off-stream or at locations armoured to prevent excessive erosion.			Moderate

Notes
1. Refer to Map 6 for location.

6.8 MIDDLE BAKER CREEK (RESIDUAL AREA)

6.8.1 Physiography

The Middle Baker Creek Residual covers an area of 89.9 km^2 with 14% above the total Baker Creek watershed H_{60} elevation. This residual area is located in the central portion of the

watershed and includes all contributing areas draining into Baker Creek between Long John Creek and Puntchesakut Creek (not including the Tibbles and Puntataenkut Creeks). The Middle Baker residual includes relatively low gradient tributaries, numerous wetlands and a wide valley flat along Baker Creek where private land, used for ranching is located.

6.8.2 Forest Cover and Forest Development

In general, the Middle Baker Creek residual area is dominated by low lying wetlands and wide valleys dominated by spruce and shrub species. Most of the pine-leading stands occur in the southern end of the residual area near the confluence with Long John Creek. Only 11% of the residual area has beetle-kill classified as severe or very severe (Map 2), and 26% of the riparian zone is considered to be at high risk from beetle-kill (Map3). Less than 1% of the sub-basin has been affected by wildfire.

The majority of forest development activities have occurred in the western half of the sub-basin. In 1996, ECAs projected to 2001 were estimated to be 19% (Cariboo, 1996). Current mapping suggests that in total about 21% of the residual area has been harvested, with an additional 8% of the basin proposed for harvesting (as of 2006).

It is important to note that conditions in residual areas are affected by all areas upstream and upslope. At the southern end of Middle Baker Creek, conditions along Baker Creek are influenced by Upper Baker Creek and Long John Creek. At the north end of the Middle Baker residual area, conditions are also affected by the Tibble Creek and Puntataenkut Creek. Considering the conditions of the forest (past harvesting and beetle-kill) upstream and upslope, ECAs in the Middle Baker residual area are speculated to range from about 40 to 50%.

6.8.3 Private Land

There are about ten (10) privately owned properties in Middle Baker residual area. Most of properties are used for agricultural purposes and the majority are located in the central and northern portions of the residual area. Four (4) property owners were contacted during the

course of this study: Mr. and Mrs. Lisk, Mr. Moore, Mr. Cooper, and Ms. Falloon. (Section 5.0).

Both Mr. Cooper and Ms. Faloon identified flooding as an issue of concern. Mr. and Mrs. Lisk reiterated the same concern and indicated they have observed increased flooding and erosion at all four (4) properties in the Middle Baker residual area. This has constrained their ranch operations more and more each year. Mr. Moore further reinforced the concern of property owners and explained that flooding has increased in magnitude, frequency and duration and now occurs rapidly following rainstorms. In addition to the constraint this places on ranch operations (e.g. in 2005 no hay could be harvested), Mr. Moore noted that excessive streambank erosion has occurred.

6.8.4 Channel Conditions

Table 6.21 summarizes the channel conditions noted for Middle Baker residual area. Reach locations are identified on Map 5 and on the longitudinal profile in Appendix B.

Table 6.21 Summary of channel conditions in the Middle Baker Creek residual area.

Stream	Reach	Summary
Baker Creek	8	Reach 8 of Baker Creek as an irregularly meandering riffle-pool channel with gravel bed and relatively low volumes of functional woody debris. The riparian zone is natural with mixed species – mostly willows and spruce; beetle-killed pine are upslope but generally do not directly influence the creek. The Baker Creek falls, located near the upper end of the reach, are bedrock controlled and are several metres high. This feature strongly controls the stream gradient upslope and is a major factor in the channel morphology and groundwater and flood regime in the Middle Baker residual area. Reach 8 is stable with no detectable signs of disturbance. Channel sensitivity is **moderate**.

Table 6.21 cont'd.

Stream	Reach	Summary
Baker Creek	9	Reach 9 is a highly sinuous unconfined dune-ripple sand-bed channel that zigzags across a wetland upslope of the Baker Creek falls. Due to the low gradient, sediment tends to deposit in this reach causing the formation of bars. Some of this sediment likely comes from Merston Creek, which joins Baker Creek at the upper end of Reach 9. The riparian zone is natural with mixed species; beetle-killed pine are located upslope generally outside of the riparian zone. The channel is unstable and there is no evidence of direct disturbance. Channel sensitivity is **high**.
Baker Creek	10	Reach 10 is a low gradient dune-ripple channel with silt sand bed. Low quantities of functioning woody debris are present in the reach The riparian zone generally consists of a dense willows although some areas on private land are vegetated only with grass. Old pilings were noted in the channel near the Tibbles Road bridge. Overall, the channel is stable and there is a low level of disturbance. Channel sensitivity is **moderate**.
Baker Creek	11	Reach 11 is a highly sinuous ripple-dune and riffle-pool channel with sand and gravel bed. Woody debris volumes are moderate (with some log jams) and the riparian zone is characterized by dense willows. Some disturbance to the riparian zone was noted on private land, however channel disturbance was low. The channel is stable and has a **moderate** sensitivity.
Baker Creek	12	Reach 12 of Baker Creek flows through one of the most concentrated areas of ranching in the Baker Creek watershed and is characterized by a highly sinuous riffle-pool channel with sand bed and banks (Photo 24, Appendix D). Stream gradients are very low, stream banks are relatively low and thus the potential for flooding is high. When flooding occurs, much of the floodplain, which is about 2 km wide, may be inundated. In efforts to reduce flooding and promote drainage, a series of drainage ditches have been constructed by individual property owners. While most ditching is in the center of the valley, some ditching also has been constructed along the base of the hillslopes (i.e. near district lots 12429, 9911, 9912). Riparian conditions vary greatly along Reach 12. In some areas there is a fringe of dense shrubs, but in many areas all functional riparian vegetation has been removed during preparation of fields or by cattle access the creek. As a result, many banks have limited bank strength and are prone to slumping and erosion (Photo 25, Appendix D). Evidence of channel avulsions is widespread. The channel is therefore unstable and is highly disturbed. Channel sensitivity if **high**.
Baker Creek	13	Although gradients are slightly higher, Reach 13 is similar in morphology to Reach 12. However, the channel is on Crown land and has little evidence of disturbance to the riparian zone of the channel. The riparian zone is characterized by dense shrubs and the channel has moderate levels of woody debris (and some log jams). There is a high level of beetle-kill upslope, but most of these trees are not likely to directly affect the channel. The channel is stable and has a **moderate** sensitivity.

6.8.5 Sediment Sources

No significant development related sediment sources (i.e. slides) were identified in the Middle Baker Creek residual area. However, there is a considerable length of channel where bank

erosion and slumping was noted along Baker Creek. The majority of such channel instability was located on private land. Recommendations to initiate restoration of these areas are outlined in Section 6.8.8. Such restoration is the most logical means to mitigate the observed and potential impacts of beetle-kill in the watershed.

6.8.6 Roads

In general, all the roads in the Middle Baker residual area were in good condition and posed a low risk of sediment delivery to the stream network.

6.8.7 Risk Assessment

A summary of the risks for the Middle Baker Creek residual area is provided in Table 6.22. Given that flows in this residual area are affected by sub-basins upstream, consideration of conditions in these sub-basins is necessary in the designation of the peak flow risk in the Middle Baker Creek residual area. The sub-basins that were considered include:

- Upper Baker Creek sub-basin;
- Long John Creek sub-basin; and
- Tibbles Creek sub-basin; and
- Puntataenkut Creek sub-basin.

The risks outlined in Table 6.22 apply to the downstream end of the Middle Baker residual area.

Table 6.22 Summary of watershed risks in the Middle Baker residual area.

Risk type	Identified risk level	Comment
Peak Flow	High	Although ECAs calculations were beyond the scope of work, current ECAs above the point-of-interest considering beetle-kill are likely between 40% and 50%. This overall ECA poses a high risk to increased peak flows. Based on anecdotal evidence and field observations, some of this increase may have already occurred. Based on the scientific literature, further increases are likely in the next few years.
Channel Stability	High	Reaches in the Middle Baker residual are moderately or highly sensitive. Given the high risk of increased peak flows and the current channel instability in some reaches, the risk to near-future channel stability is considered to be high.
Riparian Function	Moderate	Most of the riparian zone along Baker Creek in the Middle Baker residual is at low risk of beetle-kill given the wide floodplain and wetlands (dominated by shrubs) through which it flows. Smaller tributaries in the sub-basin are at higher risk of beetle-kill as shown on Map 3 – along these tributaries, dead pine stands dominate the riparian zone. Considering the spatial extent of beetle kill in riparian areas, and the present level of riparian disturbance on private land, the risk to riparian function in the riparian function is moderate.
Sediment	Low	No significant development-related sediment sources (i.e. slides) were identified in the Middle Baker residual area. Furthermore, roads were generally in good condition. Therefore, the sediment risk in the sub-basin is low.

6.8.8 Restoration Opportunities

Sites MB1 and MB2 are two of the key locations where landowners have identified concerns in the watershed (Map 5). Site MB1 covers approximately 7.1 km in reaches 11 and 12 of Baker Creek and is located on private property owned by Falloon, Cooper, Moore, and Lisk. Site MB2 covers the upper 2.5 km of Reach 12 of Baker Creek along the Lisk property. Both sites have been heavily disturbed by ranching, are sensitive to future disturbance and are currently experiencing flood and drainage problems that constrain ranch operations.

Drainage conditions in the fields at these locations has apparently deteriorated in recent years as a result of the increased flooding, at least partially attributable to pine mortality in the watershed upstream. Much of the problem is not likely due to an actual increase in peak flow magnitude (as there is little evidence to suggest such increases have occurred in the watershed yet) but rather an increase in overall runoff combined with high groundwater levels. With the dramatic

reduction of evapotranspiration in the watershed, a considerably greater proportion of precipitation is contributing to runoff and groundwater. The result is that the groundwater table is remaining at or near the surface much of the year. Therefore, relatively low intensity rainstorms quickly result in ponding of water at the surface (i.e. flooding) since the ground is effectively saturated year-round. The scientific literature suggests that these problems will tend to get worse in the short- to medium-term (about 5 to 20 years; see Section 4.0). Furthermore, salvage harvesting will likely further increase the hydrologic risks in the short-term; however, these risks could decline in the medium-term if salvaged areas are promptly reforested.

In order to ranch on the properties at MB1 and MB2, ranchers will likely have to adapt or modify their practices to the new hydrologic regime – at least over the short- to medium-term (i.e. about 20 years).

It is suggested as a first step that an integrated drainage management plan be developed at sites MB1 and MB2 on Map 5. In the past, each property owner appears to have developed their own network of drainage ditches in a piecemeal fashion as necessary. It is clear that while these structures may have adequately functioned in the past, it is likely they will only prove satisfactory during relatively dry years in the near-future. As drainage conditions in the valley are often only as good as the "weakest" link it is important that any future drainage plan should be developed amongst all relevant property owners.

Development of the plan should be coordinated by an experienced professional knowledgeable in agricultural drainage practices and familiar with Ministry of Agriculture, Food and Fisheries Agricultural Drainage Criteria (e.g. MAFF 2002). It is recommended that the plan be phased, with the first phase including feasibility and scoping studies. The goal of this would be to identify specifically which areas could reasonably be expected to be drained adequately in light of the projected increases in runoff. It is possible that some areas may not be feasible for hay production in the near-future. A number of options should then be identified to improve drainage conditions and costs estimated for each. Landowners can then use this information to decide if the costs of drainage improvements are justified.

Since an integrated drainage plan could indirectly benefit many stakeholders, it is suggested that the affected landowners communicate with forest licensees as well as government agencies to identify potential funding assistance and support for the project.

In addition to drainage improvements, it would also be beneficial at sites MB1 and MB2 to identify opportunities for stream channel and riparian restoration. Approximately 7.1 km of (highly sinuous) channel should be reviewed at MB1, and 2.5 km at MB2. Many locations have degraded riparian vegetation, slumping banks and relatively high levels of sediment delivery to the creek. It is recommended that an experienced professional develop and coordinate implementation of a restoration plan for these high sensitive areas. This will serve to improve the channel stability and water quality as well as other watershed values. Again options for funding and support should be discussed among all stakeholders, since it is unreasonable to expect private land owners to single-handedly finance the work, which will provide wide-ranging benefits in the watershed.

6.9 LOWER BAKER CREEK (RESIDUAL AREA)

6.9.1 Physiography

The Lower Baker Creek residual area covers 285.5 km^2 with 21% above the Baker Creek watershed H_{60} elevation. This residual area is located in the eastern portion of the watershed between the mouth of Punchesakut Creek and the mouth of Baker Creek. Within this residual area, Baker Creek flows generally from west to east and is generally unconfined along the upper reaches (Reaches 5-7) and confined in the middle and lower reaches (Reaches 1-4) where it cuts through the Fraser Plateau on its route to the Fraser River. Moderately and steeply sloping terrain flanks both the north and south sides of the creek. Many natural slides are present along the incised reaches of Baker Creek and numerous small tributaries and gullies feed the creek on both banks.

6.9.2 Forest Cover and Forest Development

The Lower Baker Creek residual area has a relatively large proportion of mixed stands relative to the remainder of the Baker Creek watershed, however, significant pine-leading stands are located in the western portion of the residual area at higher elevations. Beetle-kill is classified as severe or very severe in 29% of the residual area (Map 2), and 20% of the riparian zones are at high risk of beetle-kill (Map 3). Less than 1% of the sub-basin has been affected by wildfire.

Forest development has been distributed throughout the central and western portions of the residual area. Currently, approximately 21% of the sub-basin area has been affected by forest harvesting, however precise ECAs are unknown. Proposed forest development (end-2006) would increase the areas harvested by about 8% of the residual area.

As in the Middle Baker residual area, hydrologic conditions in Lower Baker residual area are affected by all areas upstream and upslope. Considering the conditions of the forest (past harvesting and beetle-kill) of the entire watershed, current ECAs are speculated to range from about 30 to 50%.

6.9.3 Private Land

There are many rural and urban (i.e. City of Quesnel) private properties in the Lower Baker sub-basin. Given the primary focus of the study, near the community of Baker Creek, no property owners from the Lower Baker were contacted during the study.

6.9.4 Channel Conditions

Table 6.23 summarizes the channel conditions of Lower Baker Creek. Reach locations are identified on Map 4 and on the longitudinal profile in Appendix B.

Table 6.23 Summary of channel conditions in the Lower Baker Creek residual area.

Stream	Reach	Summary
Baker Creek	1	Reach 1 of Baker Creek flows through the City of Quesnel and has riffle-pool morphology with a gravel and cobble bed (Photo 26, Appendix D). The reach is partially confined and is lined by a narrow fringe of mature balsam poplar and shrubby vegetation. Given the proximity of development, several banks have been ripraped to protect from erosion. Overall, the channel is stable and disturbance is moderate. Channel sensitivity is **moderate**.
Baker Creek	2	Reach 2 of Baker Creek is deeply incised and has a has riffle-pool morphology with a gravel bed. Woody debris volumes are low and the riparian zone consists of dense mixed forest. There are a considerable number of natural slide paths that have exposing underlying bedrock along the reach. Overall the channel is stable and the level of disturbance is low. The channel sensitivity is **low**.
Baker Creek	3	Reach 3 of Baker Creek is a partially confined irregularly meandering riffle-pool channel with a gravel bed. Woody debris volumes are low and the riparian zone consists a mixed deciduous and coniferous species. Natural sediment sources supply fine and coarse sediment to the reach, some of which is exposed on bars. The reach is naturally unstable. Human-related disturbance was not identified. Channel sensitivity is **moderate**.
Baker Creek	4	Reach 4 of Baker Creek has a riffle-pool and cascade-pool morphology with gravel bed. The channel is partially confined and has irregular meanders. One natural slide path was noted on the left bank. The riparian zone consists of mixed spruce and pine as well as deciduous species. The reach is stable and there is no detectable level of disturbance. Channel sensitivity is **low**.
Baker Creek	5	Reach 5 is a riffle-pool channel that crosses through private land and includes a large entrenched meander. The riparian buffer remaining along the reach is narrow on both the inside and outside of the meander. The bend is very tight and it is likely over the long-term that, unless protected, natural erosion through the "neck" of the meander could result in a cutoff channel and oxbow. The channel is currently stable and there is a low level of disturbance. Channel sensitivity is **moderate**.
Baker Creek	6	Reach 6 has riffle-pool morphology with a sand and gravel bed. Woody debris volumes are low and the riparian zone consists of mixed species. Several small natural slides enter the reach causing localized aggradation. The channel is stable and there is a low level of disturbance. Channel sensitivity is **moderate**.
Baker Creek	7	Reach 7 of Baker Creek has riffle-pool morphology with a gravel and sand bed. There are low volumes of woody debris, although a log jam was identified at the lower end of the reach. The reach includes a relatively straight entrenched section as well as irregular meanders. The riparian zone consists of a relatively wide valley flat occupied by spruce and willow. Natural bank erosion and slumping was noted along the reach. The channel is stable and there no detectable level of disturbance. Channel sensitivity is **moderate**.

6.9.5 Sediment Sources

Although there are a considerable number of natural slide areas in the Lower Baker Creek residual area (Photo 27, Appendix D), particularly along Reaches 2 and 3, there were no significant development-related sediment sources identified.

6.9.6 Roads

In general, all the roads were in good condition and posed a low risk of sediment delivery to the stream network.

6.9.7 Risk Assessment

A summary of the risks for the Lower Baker Creek residual area is provided in Table 6.24. Since hydrologic conditions along the mainstem of Baker Creek within the Lower Baker residual area are influenced by the conditions upstream and upslope, conditions in the entire Baker Creek watershed were considered in identifying the peak flow risk in Table 6.24.

Table 6.24 Summary of watershed risks in the Lower Baker Creek residual area.

Risk type	Identified risk level	Comment
Peak Flow	High	Although ECAs calculations were beyond the scope of work, current ECAs considering beetle-kill probably are in the range of 30 to 50%. This overall ECA poses a high risk to increased peak flows. It however may take a few years for the full impacts associated with beetle-kill to be witnessed as trees die and fall and for the right meteorological conditions to trigger flooding of sufficient magnitude to trigger channel changes.
Channel Stability	Moderate	Most reaches of Baker Creek are currently stable in the Lower Baker residual area. However, overall Baker Creek is moderately sensitive. Although risk of increased peak flows is high, the risk to near-future channel stability is considered to be moderate.

Table 6.24 cont'd.

Risk type	Identified risk level	Comment
Riparian Function	Moderate	The majority of the mainstem and principal tributaries of the Lower Baker residual area are at low risk of beetle-kill given species present along Baker Creek. Most smaller tributaries in the residual area, particularly in the western portion of the sub-basin are at high risk of beetle-kill as shown on Map 3. Along these tributaries dead pine stands dominate the riparian zone. Considering the spatial extent of beetle kill in riparian areas, and the present level of riparian disturbance currently, the risk to riparian function in the riparian function is moderate.
Sediment	Low	Although there are a considerable number of natural sediment sources, no significant development-related sediment sources were identified in the Lower Baker residual area, Furthermore, all roads inspected were generally in good condition. Therefore, the sediment risk in the residual area is low.

6.9.8 Restoration Opportunities

No restoration sites were identified in the Lower Baker residual area.

7.0 MINIMIZING IMPACTS OF FUTURE FOREST DEVELOPMENT

7.1 INTRODUCTION

One of the principal objectives of this assessment is to provide recommendations to mitigate potential negative hydrologic impacts of pine mortality and/or forest development. Throughout Section 6.0, recommendations are provided to address or restore site-specific issues that were identified in the watershed. These items (e.g. culvert, ditch improvements, etc.) are intended not only to address past impacts but also to safeguard against future impacts. Section 7.0 provides stand- and landscape-level recommendations to minimize near-future impacts on water resources (as well as other non-timber values). These recommendations apply throughout the watershed and should be considered in all future salvaging. Section 7.0 builds upon MPB watershed management recommendations initially identified in Summit (2006b).

General recommendations and guidelines for harvesting activities that may mitigate the effects of MPB (as well as fire damage) in British Columbia have been made by a number of authors (Hughes and Drever 2001; Douglas 2002, 2003; Bunnell et al. 2004; Winkler 2005b; Snetsinger 2005, Timberline 2006, Quesnel Forest District Enhanced Retention Strategy Committee 2006). These recommendations are varied, and can be applied at both the landscape and stand levels. These recommendations are provided below.

7.2 LANDSCAPE (WATERSHED) LEVEL PLANNING

Despite increases in the allowable annual cut (AAC), MPB has far outpaced salvage harvesting in the region. While it is economically important to recover as much value from the dead pine as possible, harvesting all dead pine will not be possible, nor is it feasible, practical, or ecologically sound (Eng 2004). As it is impossible to salvage all MPB-killed pine, it is important that forest managers strategically retain live and dead stands by considering non-timber resource values (e.g., recreation, biodiversity, water resources, stand and landscape functionality, fish and wildlife) on both stand and landscape levels (Snetsinger 2005).

To assist with landscape-level planning, Timberline (2006) has prepared maps that identify areas recommended for retention in the Vanderhoof and Quesnel Management Units based on consideration of several non-timber and timber values. Areas for retention were given priority based on a selected set of indicators of timber and non-timber resource values. These indicators included:

- proximity to existing areas of retention (ranking increases the closer an area is to existing retention);
- species composition (ranking increases roughly proportional to percentage of non-pine species);
- age class (the closer the stand is to being mature or merchantable the lower the ranking);
- polygon size (ranking increases with size);
- site potential (the poorer the site the higher the ranking);
- habitat potential (higher ranking for higher habitat potential);
- regeneration potential (the lower the potential for natural regeneration the lower the ranking);
- watershed sensitivity (ranking increases with increasing sensitivity); and
- riparian management zones (ranking is higher for riparian zones than for upland sites).

Further details on the methodology and ranking system are outlined in Timberline (2006). For the purposes of this study, the following areas mapped by Timberline (2006) are of primary interest:

1. Very high priority for retention;
2. High priority for retention;
3. Moderate priority for retention;
4. Low priority for retention;
5. Legislated retention;
6. Legislated constrained retention (i.e. constraints on harvesting); and
7. Non-pine leading stands.

This information provides a solid basis for strategic-level planning in the watershed, however as noted by the authors this is only a first step that should be refined with field observations and local knowledge. A simplified version of Timberline's (2006) mapping is provided on Map 9 for the Baker Creek watershed. Map 9 identifies three (3) principal areas in the watershed:

- Red - legislated and "high" priority areas for retention that should not be salvaged in order to minimize impacts on non-timber values (including water resources). This includes areas 1, 2, 5, 6, and 7 noted above. Salvage harvesting of these areas is either illegal (for legislated retention areas) or is strongly discouraged since these areas likely have high non-timber values (unless proved otherwise with ground truthing);
- Yellow – Moderate priority retention areas. This includes area 3 noted above. Salvage harvesting is generally discouraged from these areas given there is some risk to non-timber values; and
- Green – Low priority retention areas. This includes area 4 noted above. These are areas where salvage harvesting presents the lowest risk to non-timber values (until proved otherwise) and therefore salvage harvest should initially focus on these areas.

Table 7.1 summarizes the areas recommended for retention in the Baker Creek watershed and presented on Map 9. Overall, 28% of the watershed is rated as "high" priority for retention, while 58% is rated as "moderate" and 11% is rated as "low"[6]. As a first step, it is recommended that forest managers focus salvage harvesting in the low and moderate priority areas. Unless ground inspections suggests otherwise, harvesting in the "high" priority areas should be avoided.

[6] The sum of the high, moderate, and low priority areas do not equal 100% since there are portions of the watershed covered by lake, wetlands and other non-timber areas.

Table 7.1 Summary of recommended areas for retention in the Baker Creek watershed.

	Area of sub-basin (km^2)	Percentage of sub-basin with high priority retention (%)	Percentage of sub-basin with moderate priority retention (%)	Percentage of sub-basin with low priority retention (%)
Sub-basin				
1. Upper Baker Creek	210.5	21	62	11
2. Long John Creek (incl. Trapline Creek)	166.0	29	55	14
3. Tibble Creek	49.8	25	68	6
4. Puntataenkut Creek	182.5	22	61	12
5. Merston Creek (incl. Tzenzaicut Lake)	262.5	20	63	10
6. Punchesakut Creek	52.3	21	56	13
7. Mount Creek (incl. Townsend and Landslide Creeks)	283.1	26	59	11
8. Middle Baker Creek (residual)	89.9	24	62	11
9. Lower Baker Creek (residual)	285.5	46	44	8
BAKER CREEK WATERSHED	**1,582.1**	**28**	**58**	**11**

Notes:
1. Based on mapping from Timberline (2006)

In addition to landscape-level retention, impacts of salvage harvesting on non-timber values (including water resources) can also be minimized by the following means:

- Maintaining a diversity of forest cover types and minimize reforestation delays through retention and protection of advanced regeneration;
- Avoiding salvage harvesting in areas where intermixed pine represents <30% of the species mix;
- Salvaging in stages using a variety of harvest intensities and retention strategies to desynchronize runoff;
- Minimizing new road construction (i.e. road density and potential erosion hazards);
- Maintaining natural drainage patterns and ensuring the drainage network on permanent roads can accommodate any changes in flow resulting from large-scale harvest;
- Considering alternative silvicultural systems; and
- Considering leaving pine stands in place where their role in maintaining water quality and aquatic habitat is judged to be greater than the hazards associated with beetle kill.

7.3 STAND LEVEL RETENTION

Stand-level retention within cutblocks is a way to reduce the hydrological effects of pine mortality and/or salvage, with the proportion of retention increasing with the size of harvested block. Recommended retention levels as suggested by the B.C. Chief Forester (Snetsinger 2005) are listed in Table 7.2.

Table 7.2 Recommended levels of retention within large-scale harvesting areas.

Opening Size	Percent of harvest block to be retained
<50 ha	10%
50-250 ha	15%
250-1,000 ha	25
> 1,000 ha	>25%

From Snetsinger (2005).

The retention guidelines in Table 7.1 should be considered minimum guidelines for general forest harvesting and salvage; if possible retention levels should exceed these values to reflect the higher conservation values expected within the Baker Creek watershed. Retention should include:

- stands of live non-pine species (e.g. spruce and deciduous species) both on upland and riparian sites;
- live understory vegetation;
- groups of dead pine (>0.2 ha), particularly very large snags, which when retained will provide wildlife tree habitat and woody debris into the future;
- buffers of dead pine around retained inclusions of other tree species;
- large live and dead trees; and
- all vegetation within riparian reserve zones (RRZs) and (if feasible) riparian management zones (RMZs).

7.4 RIPARIAN ZONES

Functioning riparian zones are important to minimizing impacts of MPB and salvage harvesting. Given the current state of the watershed, a conservative approach to riparian

management is justified. Except where there are special circumstances, such as beetle-killed trees excessively blocking streams and affecting channel morphology (no areas have yet been identified in the Baker Creek watershed), harvesting should be avoided in riparian reserve zones (RRZs). Furthermore, as outlined in the Quesnel Enhanced Retention Strategy, we recommend considering the entire Riparian Management Zone (RMZ) of all riparian features as a Riparian Reserve Zone (RRZ) and seeking opportunities to increase the size of the RRZ, but only if it is suitable to enhance the protection of fisheries habitat or watershed values (Quesnel Forest District Enhanced Retention Strategy 2006).

Table 7.3 Riparian Management Zone (RMZ) widths.

Stream type	Riparian Management Zone (RMZ) Width (m)[1]
S1	70
S2	50
S3	40
S4	30
S5	30
S6	20

Notes:
1. RRZ applies to each side of the stream and is the greater of: 1) the slope distance (perpendicular to the stream) as measured from the top of the streambank; 2) the top of the inner gorge of an incised channel; 3) the outer edge of the active floodplain; or 4) the outer edge of non-classified wetlands.

This means that in many, but not necessarily all streams, there will remain some form of riparian buffer. Where disturbance of the RMZ cannot be avoided, forest licensees should clearly identify reasons for this and develop plans to ensure minimal impact on riparian function.

As part of an adaptive management strategy (see Section 7.11), it is recommended that selected riparian management zones covering a number of stand types (e.g. live and dead pine-leading stands with and without significant understory vegetation, other coniferous stands, and deciduous stands) be monitored in future to assess their functioning status (e.g. “filtering” effect) under a number of riparian management scenarios. Such monitoring would provide a basis to determine if riparian management is or is not minimizing impacts to riparian values. This information should be incorporated into harvest plans as it becomes available.

7.5 SALVAGE OPERATIONS

If disturbance to the watershed can be minimized during salvage operations then less restoration work will ultimately be required. Therefore, it is most efficient (both economically and operationally) to undertake salvage operations in a way that minimizes disturbance, particular to watercourses, riparian areas, and potentially unstable terrain. Every action taken within the watershed should be performed with this preventative framework in mind. This would include the use of Best Management Practices (BMPs) for all road and trail construction and careful consideration of the factors that can exacerbate the impacts of forest harvesting, including the timing of operations, terrain, soil conditions, and proximity to riparian areas. Logging contractors should be qualified and experienced in appropriate and ecologically-sensitive harvesting techniques, using harvesting equipment and systems suited to the block size and layout, terrain, stem size, and volume to be removed. The use of a logging contractor with a demonstrated commitment to achieving the desired results is essential for successful operations in particularly sensitive systems (Richardson et al. 1999).

It is important that as much fine and coarse woody debris is retained in salvage blocks as possible and be dispersed across the site rather than be hauled to piles (Klenner 2006). This material will delay surface runoff by slowing snow melt, reducing wind speed, maintaining soil moisture and aid in site regeneration (Winkler et al. 2007). It will also reduce the potential for surface erosion.

7.6 REFORESTATION

To accelerate hydrologic recovery in the watershed, it is important that re-forestation be initiated as soon as possible. Site preparation should be conducted in a manner that considers the potential for increased runoff, groundwater levels and surface erosion. It is also important to ensure that seedling orders are placed as soon as estimates for seedling requirements are reliable, with new seedlings in production during the first growing season after harvest. To meet hydrologic goals, these seedlings should be planted the spring following seedling production (second growing season following harvest).

Where feasible, cutover sites should be restocked with non-MPB-susceptible species to break up the previously existing large, contiguous stands of pine. This will introduce mosaic patterns on the landscape and reduce the potential speed and spread of future beetle attack or fire.

Following reforestation, regularly scheduled silviculture surveys should be completed in the watershed to assess regeneration progress. The surveys would be used to develop prescriptions to address any lagging plantations. This could include in-fill planting and fertilizer applications [i.e. where suitable environmental conditions exist as defined by the Forest Fertilization Guidebook (MOF 1995)]. Fertilization must follow the requirements of FRPA which state that no fertilizer must be applied within 100 m of the point of diversion for a community water supply or within 10 m of a perennial stream; unless an alternative strategy that meets FRPA objectives is proposed.

7.7 ROADS

All road construction should be accompanied by erosion and sediment control plans developed by a qualified specialist. Such plans should address road construction, maintenance, and (where necessary) deactivation.

If temporary roads are to be built to facilitate salvage harvest, the roads should be built to facilitate their prompt deconstruction. Use of corduroy (log) methods of road base construction in wetter areas will reduce the need to excessively cut in side slopes and limit the interception of possibly elevated ground water flow (Dobson pers. com. 2006). In an effort to minimize impacts during spring melt/break-up period, smaller temporary stream crossings should be removed prior to freshet, even if the rest of the temporary road network will continue to be utilized following the spring break-up period.

Road deactivation (i.e. culvert removal and cross ditching, often accompanied by seeding of exposed soils) or complete rehabilitation and slope contouring within cutblocks should be done immediately following harvest (while machines are still on site) to maintain natural surface and

near-surface drainage patterns (Winkler et al. 2007). If this is done before spring break-up, it also reduces the amount of potentially erodible material available prior to peak flows. It is also more efficient to do all these works while equipment is at the site finishing up their other tasks (reduces the costs of additional mobilization and demobilization).

7.8 RETENTION OF STRUCTURAL COMPONENTS OF HISTORICAL STANDS

Although their effect on watershed hydrology may be minor, the retention of components of dying and dead pine stands, as well as large components of the non-pine stands are important considerations in the conservation of biodiversity and healthy ecosystem functioning at both the local and landscape levels. It is critical to ensure that the planning and practices associated with protecting biodiversity values are in step with the increased rate of salvage harvesting (Snetzinger 2005). The conservation of biodiversity and multi-storied structural stand complexity across the landscape will provide a greater probability of continued ecosystem health and function, which contributes to riparian health and function.

The increased retention of affected stands (even dead ones) in wetter areas reduces the likelihood of disturbance and damage to these sensitive systems, preserving their functional integrity. It would also minimize soil disturbance and erosion potential. These undisturbed areas will help offset the risks associated with increased harvesting rates, and provide continued sources of large woody debris (LWD) and important habitat.

The quality of advanced regeneration, understory vegetation, and structure of retained stands should be assessed for proper function. In particularly sensitive areas with high mortality and inadequate advanced regeneration and shrub cover, under planting of the retained stands with appropriate species (deciduous or conifers) may be warranted to accelerate hydrologic recovery and function. Similarly, advanced regeneration and minor vegetation should be conserved where possible during salvage harvesting operations.

The retention of dead pine around living stand cohorts may assist in reducing the risk of the live trees succumbing to high velocity wind events. The dead pine will protect the live trees as a

buffer against the wind, providing the area with a supply of large woody debris as these snags slowly deteriorate and eventually fall to the ground. Using these dead tree buffers to protect relatively small stands of live trees from wind throw will help avoid increases in ECA beyond those caused by the salvage hazard, which has implications for peak flow hazards.

Stands with less than 30% mortality can be expected to provide similar old forest habitat values as pre-disturbance stands, and are good targets for retention in old growth management areas (OGMAs) and riparian areas (Douglas 2003). The retention of both live and dead trees within the riparian reserve zones will provide continued streambank stability, supplies of LWD in and around the channel, and appropriate habitat for many species displaced by fire and harvesting activity.

7.9 RANGE MANAGEMENT CONSIDERATIONS

Cattle grazing and other agricultural activities are important economic uses of the watershed. However, excessive cattle disturbance in sensitive riparian areas can cause significant damage to channel banks and vegetation, increase sediment loads within the flowing water, and introduce contamination (e.g. fecal coliform bacteria and cryptosporidium). Due to the current and future expectation of increased stand mortality and harvesting activity within the watershed, a conservative approach to the number of livestock permitted within these watersheds and livestock access to streams should be considered.

Currently, as required by section 33 of FRPA, ranchers develop a Range Stewardship Plan [RSP – formerly Range Use Plans (RUP)] that provides a map of the areas their livestock will utilize and a schedule of livestock movement. It is recommended that livestock be discouraged from moderately and highly sensitive stream reaches (by using natural barriers or fencing), and where this is not possible, watering should be provided off-stream or at armoured stream locations.

Because RSPs/RUPs have been very flexible and approvals are discretionary to the MOFR, it is recommended that as future RSPs come under review, livestock activity within riparian areas of moderately and highly sensitive stream channels be minimized (see Section 6.0). In riparian

areas where natural barriers to livestock access were destroyed by MPB, directional falling of killed timber may be able to produce new barriers to cattle movement, acting to protect riparian integrity and water quality. This activity should effectively restrict livestock from entering sensitive areas where natural barriers have been destroyed, without the full expense of constructing extensive new fencing.

7.10 DRAINAGE MANAGEMENT

As outlined in Section 4.0, a substantial loss of forest cover by beetle-kill has potential to affect the hydrologic regime. Within even-aged stands of beetle-killed pine annual water yield and low flows are expected to increase while peak flows may increase and occur earlier in the spring. Such impacts have implications on near-surface groundwater (and soil moisture) conditions and on drainage infrastructure in a watershed.

7.10.1 Groundwater

General increases in the level of the water table or lengthening of the period over which elevated ground water levels occur have the potential to impact forest operations during harvesting and regeneration. For example, in the Vanderhoof Forest District groundwater levels have reportedly risen in MPB-affected areas, requiring the use of low ground pressure harvesting equipment and a shift in logging operations from summer to winter (MOF 2005a). Operators in the watersheds should consider these options in order to minimize ground disturbance, particularly in sensitive riparian areas or areas directly coupled to the stream network. Additional site preparation (i.e. mounding) may also be necessary to ensure restocking success if sites exhibit elevated moisture levels. In areas previously dominated by lodgepole pine, elevated groundwater levels or soil moisture conditions may require operators to consider restocking harvested areas with more water tolerant species (such as spruce). Along lowlands and riparian zones, the feasibility of planting native deciduous species that rapidly grow should be considered. Such initial rapid growth (relative to most conifers) will increase the rate of hydrologic recovery and along riparian zones improve root strength and bank stability. The planting of deciduous species will also benefit the forest since they will tend to act as natural firebreaks and/or beetle barriers.

7.10.2 Surface Water

While the available research suggests that beetle-kill alone has a variable effect (i.e., no change or increase) on peak flows (Section 4.0), (salvage) harvesting is generally associated with an increase in peak flows if the total ECA exceeds about 15-20%. Due to the dominant role of snow accumulation and melt processes in driving peak flows in the watershed, losses of forest cover in the upper portions of the watershed will tend to result in greater increases in peak flows, than the equivalent losses in the lower portions of the watershed (Winkler 2005). Since solar radiation is a major driver of melt processes, loss of forest cover on south-facing aspects tends to produce greater peak flow increases than north-facing aspects (Bethlahmy 1975). It is therefore recommended that harvesting be minimized on south-facing slopes if possible.

An increase in peak flows has a direct effect on the performance of drainage infrastructure. The specifications of ditches and culverts based on design flows under pre-disturbance conditions may be inadequate under post-disturbance conditions. This may result in ditches overflowing and eroding excessively, and culverts having insufficient capacity thereby causing roadway overtopping and/or stream crossing failure. This suggests that drainage infrastructure in sub-basins with a high peak flow risk (i.e. the majority of sub-basins in the watershed), may need to be upgraded or be supplemented with secondary structures (e.g., high flow culverts) or additional armour (ie. rock). Based on this study it appears that most drainage infrastructure in the watershed is satisfactory at present; however, annual inspections are recommended to monitor the situation.

7.11 ADAPTIVE MANAGEMENT

Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs (MOF, no date). It is therefore paramount that as the conditions in Baker Creek evolve, forest managers monitor conditions and if necessary refine strategies to minimize impacts on non-timber values. By using the findings of this study as a baseline, monitoring of the watershed (e.g. road conditions, stream conditions) will at a minimum provide a qualitative sense whether forest management

practices should be refined or not. To quantify changes, however it is recommended that a program of surface and groundwater monitoring be initiated. This would include wells and hydrometric stations located at strategic locations (e.g. near Site MB1).

7.12 COMMUNICATION

Communication among forest licensees, government agencies and the public is important and will be key in moving forward with restoration and/or MPB mitigation initiatives. Communication will also be key in adaptive management since land owners are often the first identify issues or hazards in the watershed.

8.0 SUMMARY AND CONCLUSIONS

A customized watershed assessment of the Baker Creek watershed has been completed. The study methodology was designed to address issues raised by local stakeholders, government agencies, and forest licensees and also be consistent with Watershed Assessment Proceedure guidelines. The assessment combined an office review of background information and aerial photos with the findings of a field inspection of the watershed in the air and on the ground. During the field inspection, channel conditions, sediment sources, and restoration sites were identified. Finally, the hydrologic risks associated with the current conditions (i.e. beetle-kill) in the watershed were assessed.

8.1 CURRENT WATERSHED RISKS

The following conclusions on the current watershed risks are drawn (Table 8.1):

- As a result of the high levels of beetle-kill, there is a high risk that peak flows will increase in the near-future. This applies to all portions of the watershed, with the exception of the Punchesakut Creek sub-basin, where the risk is moderate;
- Stream channels in the Baker Creek watershed are for the most part stable, however channel sensitivity varies from low to high. The risk of channels becoming unstable in the near-future varies by sub-basin but is generally moderate or high (Table 8.1);
- Beetle-kill is widespread in the Baker Creek watershed. However, it's impact on riparian function is greatest along the smaller upland tributaries. Mainstem channels in the watershed tend to be fringed by wide floodplains or flow through wetlands that are dominated by shrubby vegetation and/or mixed stands only partially impacted by beetle-kill. The risk that riparian function will be impacted in the near-future varies from moderate to high (Table 8.1); and
- With the exception of the Mount Creek sub-basin, the risk of sediment delivery in the watershed is low (Table 8.1).

Table 8.1 Summary of near-future risks in the Baker Creek watershed.

Sub-basin	Peak Flow	Channel Stability	Riparian Function	Sediment
1. Upper Baker Creek	High	High	Moderate	Low
2. Long John Creek (incl. Trapline Creek)	High	High	Moderate	Low
3. Tibble Creek	High	Moderate	High	Low
4. Puntataenkut Creek	High	Moderate	High	Low
5. Merston Creek (incl. Tzenzaicut Lake)	High	Moderate	Moderate	Low
6. Punchesakut Creek	Moderate	Low	Moderate	Low
7. Mount Creek (incl. Townsend and Landslide Creeks)	High	High	High	Moderate
8. Middle Baker Creek (residual)	High	High	Moderate	Low
9. Lower Baker Creek (residual)	High	Moderate	Moderate	Low

8.2 RESTORATION OPPORTUNITIES

The present work focussed on impacts on the stream network. It did not focus on issues such as roads that do not affect the stream network, although roads causing stream impacts were identified. We identified 29 potential restoration sites in the watershed. Of these sites, 10 are high priority, 13 are moderate priority, and 6 are low priority. All restoration sites are described in Section 6.0. It is recommended that action be taken with respect to all high priority sites as soon as possible. Moderate priority sites should be addressed in the next 6 – 8 months and low priority sites within a year.

8.3 FUTURE FOREST DEVELOPMENT

In order to mitigate the potential direct impacts of future forest development on streams, aquatic habitat and water quality, we have provided recommendations for restoration by sub-basin (Section 6.0). In addition, based on the current scientific literature we have identified several general recommendations for forest management in beetle-affected areas that apply equally across the watershed (Section 7.0).

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10.0 GLOSSARY

Aggradation Upbuilding of the bed of a stream channel by continued deposition of bed load.

Alluvial Channels Alluvial channels flow through sediments transported and deposited by the stream under the current hydrologic regime. Alluvial channels are classified as follows:

- **Dune-ripple** channels have a sand bed with typical bedforms being lower-regime plane beds, ripples, sand waves and dunes. Point bars may also be present.
- **Riffle-Pool** channels are characterized by alternating sequences of pools, bars and riffles typically spaced every 5 to 7 channel widths. They are typically associated with a floodplain and a meandering pattern. The bed is typically composed of sand, gravel and cobble sized particles.
- **Cascade-Pool** channels encompass the "glide", "riffle", and "rapid" morphologies used in the fisheries literature, and are generally featureless and straight. The bed may be composed of sand, gravel, cobble and boulder sized particles.
- **Step-Pool** channels are confined by valley sides, and are characterized by longitudinal steps formed by large particles which dissipate much of the water's kinetic energy in the form of turbulence. Flow is subcritical at the pools, and supercritical over the steps.
- **Steep Cascade** channels are confined and have a bed composed of large, randomly placed particles producing jet-and-wake flow.
-

Alluvium Any sediment transported and deposited by running water.

Annual Maximum Instantaneous Discharge The highest daily discharge in a stream recorded over a period of one year.

Anthropogenic Adjective describing actions caused by human activity.

Anthropogenic Impact Rating An estimate of the existing disturbance to the watershed determined to be as a result of human-related activity, such as forest, agricultural, or urban development. See also Peak Flow Impact Rating, Channel Stability Impact Rating, Riparian Function Impact Rating, and Sediment Impact Rating.

Bank Erosion Removal of material from the side of a stream channel. This may be the result of particle by particle removal, frost heave, groundwater movement and the dislodgement and fall of material and the subsequent entrainment of particles by flowing water, abrasion by ice, and mass failure of the bank.

Bankfull Flow The discharge that fills a channel but does not spill out onto the floodplain. Bankfull flows are often assumed to recur with a return period of about 1.5 to 2 years.

Bed Load That portion of the stream load moving close to the stream bed by rolling, sliding and low leaps.

Bedrock Channels Bedrock channels lack a continuous alluvial bed, and have little or no valley fill. They are the result of a transport capacity much higher than sediment supply, and are often the result of catastrophic scouring as a result of a debris flow.

Biogeoclimatic Zone

A geographic area with broadly homogeneous macro-climate and associated vegetation, soils and animals. In British Columbia, each forested zone occurs under a broadly similar macro-climate and is usually named by one or more of the dominant tree species which are capable of self-regeneration on most of the zone's habitats (e.g., Coastal Western Hemlock, Interior Douglas fir). In B.C., the biogeoclimatic zones are further subdivided into sub-zones, variants, and Phases.

Channel Confinement

The degree to which the valley sides restrict the lateral movement of the stream channel.

Channel Coupling

The degree to which sediment produced on the hillslopes is delivered (by landslides or surface wash) to the stream channel without intervening storage on the river floodplain.

Channel Disturbance

Channel disturbance is an assessment of the level of anthropogenic disturbance to the stream channel. Channel disturbance is classified as follows:

- **Not detectable:** There is no physical evidence of anthropogenic disturbance to the stream channel.
- **Low:** While spatially limited disturbances are identifiable, the large majority of the stream Reach is undisturbed. Disturbances upslope of the stream channel that may or may not have impacted the channel may be present. This may include such disturbances as stream crossings and logging adjacent to the stream but with a suitable riparian management area retained.
- **Moderate:** Anthropogenic disturbance is widespread throughout the Reach, affecting more than ¼ of the Reach length. Disturbances upslope of the stream channel, where present, likely have impacted the channel. This may include roads parallel to the stream channel, selective logging of the riparian area and/or logging of one stream bank, and occasional landslides Reaching the stream channel.
- **High:** Disturbance is both widespread and severe, affecting more than ½ of the Reach length. This may include logging of the riparian area, skidding or yarding across the stream channel, channel diversions due to failed or improperly placed culverts, or frequent landslides Reaching the stream channel.

Channel Morphology

The characteristic shape and organization of the landforms within the stream channel.

Channel Response Potential

The degree of potential impact from indirect (i.e., ECA-related) effects, based on channel sensitivity and watershed routing efficiency according to the following table.

Channel Sensitivity	Watershed Routing Efficiency		
	Low	**Moderate**	**High**
Not sensitive or slight	Low	Low	Low
Moderate	Low	Moderate	Moderate
High or Very High	Low	Moderate	High

Channel Pattern

The characteristic shape of a river channel, as seen from above (i.e. plan view).

Channel Sensitivity This is an assessment of the potential for the channel to change in response to future disturbance. Channel sensitivity is classified as follows:

- **Not sensitive:** The channel is unlikely to change its channel pattern, cross-section, or slope as a result of any level of disturbance.
- **Low:** The channel may undergo changes in channel pattern, cross-section, or slope when subject to a high level of disturbance. However, the extent of channel changes will be limited due to immobile boundaries (e.g. bedrock) and/or small volumes of stored alluvial sediment.
- **Moderate:** The channel may undergo changes in channel pattern, cross-section, or slope when subject to moderate or high levels of disturbance. The extent of the channel changes may be limited in places due to immobile boundaries and/or small volumes of stored alluvial sediment.
- **High:** The channel may undergo changes in channel pattern, cross-section, or slope when subject to moderate or high levels of disturbance. The extent of the channel changes increases with the degree of disturbance, and it not generally limited by immobile boundaries or the extent of alluvial sediment.

Channel Stability Refers to the average channel width, depth, slope, and sinuosity; these parameters do not change over time in a **stable** channel, but one or more of them may change in an **unstable** channel.

Channel Stability Risk Rating Channel stability risk rating is defined as the combined impact of forest development and beetle-kill on near-future channel stability (this is not the same as "channel stability" per se). This risk rating incorporates the influence of both direct disturbance (such as road crossings and riparian logging) and indirect disturbance (such as increased fine sediment supply from roads, and increased peak flows). Note that a naturally unstable channel would receive a low rating if it had not been impacted by human activity. Additionally, a channel that was disturbed by human activity in the past but which has recovered to the pre-disturbance stability level would receive a low rating. The channel stability risk rating is determined by aerial photo examination and field observation. A "low" rating means that human and beetle-related changes in stability affect a small proportion of the mainstem length and/or that the change in overall basin channel stability is small. A "high" rating means that a substantial proportion of the mainstem has been affected, and that the channel stability in the basin has been altered.

Clast A coarse sediment particle, usually larger than 4 mm in diameter.

Colluvium Material transported across and deposited on slopes as a result of mass movement processes (i.e. primarily by gravity, not running water).

Colluvial Channels Exhibit only minor sediment transport by fluvial processes, and fluvial processes are not considered to govern the deposition, transport or sorting of the sediment. Debris flows and/or avalanches dominate the sediment transport regime

Competence The largest particle size transported by flowing water under the current hydrologic regime in a stream.

Consequence	The effect on human well being, property, the environment, or other elements of value; or a combination of these. Consequence is composed of spatial probability, temporal probability, and vulnerability (probability of loss of life, or proportion of loss, or damage to, property, the environment and other elements of value). For an element other than human life, an element's worth can be introduced and a consequence value determined (CSA, 1997).
Discharge	Rate of fluid flow expressed as a volume per unit of time (e.g. m^3/s).
Equivalent Clearcut Area (ECA)	The total area clearcut reduced by an amount that accounts for the hydrologic effects of forest regrowth.
Floodplain	Belt of low, flat ground, present on one or both sides of a stream channel, subject to inundation by a flood and underlain by alluvium.
Glaciofluvial Deposit	Material moved by glaciers and subsequently sorted and deposited by streams flowing from the melting ice. The deposits are stratified and may occur in the form of outwash plains, deltas, kames, eskers, and kame terraces.
Hazard	A source of potential harm, or a situation with a potential for causing harm, in terms of human injury; damage to health, property, the environment, and other things of value; or some combination of these (CSA, 1997).
H_{60}	The elevation in a watershed above which lies 60% of the watershed area. Peak flows are thought to be more sensitive to forest harvest above H_{60}. This concept is based on a 1950s Colorado study in a snowmelt-dominated mountain watershed, and has been confirmed in recent research in a similar watershed in the Kootenays. Its applicability to plateau environments is less certain.
IWAP	Interior Watershed Assessment Procedure: a process for assessing the risk that prior harvesting-related activities have impacted a watershed; outlined in a guidebook developed by Ministry of Forests.
Large Woody Debris (LWD)	Fallen trees or pieces of wood with diameter greater than 10 cm (trunk sections, branches or roots) situated in streams or lakes.
Mass Wasting	Spontaneous downward movement of soil, surficial materials, and bedrock under the influence of gravity; does not include the action of fluid agents.
Peak Flow Risk Rating	Peak flow risk rating is defined as the likelihood that peak flows (equal to or greater than the annual maximum daily discharge) have or will be increased in the near-future as a result of changes to forest cover either through forest harvesting of beetle-kill. Factors taken into account in the Peak Flow Impact Rating are ECA and Watershed Routing Efficiency. This risk rating does not imply channel change as a consequence.
Reach	A relatively homogeneous length of stream having a sequence of repeating structural characteristics (or processes) and fish habitat types. The key factors used to discriminate between Reaches are discharge, sediment load, channel pattern, channel confinement, gradient, streambed material and bank material.

Riparian Area	An area of land adjacent to a stream, river, lake or wetland that contains vegetation that, due to the presence of water, is distinctly different from the vegetation of adjacent upland areas.
Riparian Condition	The degree to which the riparian area has been altered; a riparian area may be **natural**, may exhibit an **extensive buffer** or equivalently have been subjected to **selective logging**, may exhibit a **partial buffer**, or may have been **logged to bank**.
Riparian Function Risk Rating	The degree to which the current and near-future natural riparian function has/will be disturbed. This risk rating incorporates both the level of past disturbance, the level of recovery of the riparian vegetation, and the impacts of beetle-kill.
Risk	The chance of injury or loss as defined as a measure of the probability and severity of an adverse effect to health, property, the environment, or other things of value (CSA, 1997).
Salmonid	Fish of the family Salmonidae, including salmon, trout, chars, whitefish, ciscoes, and grayling. It generally refers to salmon, trout and chars.
Sediment Delivery Potential	The potential for sediment to be delivered to the stream network. There are three sediment delivery potential classes: **Low**: No or minimal delivery of sediment from roads to any stream system, sediment commonly delivered to forest floor, with no surface runoff during the wet season. **Moderate**: Sediment delivery is partially disconnected from the stream network, disconnected by flat terrain and/or discontinuous drainage routes. **High**: Sediment is delivered to stream network directly or via ditch drainage or surface runoff routes.
Sediment Erosion Potential	The potential for soil erosion including erosion of road cut and fill and the running surface. There are three sediment erosion potential classes: **Low**: The road surface is armoured and/or re-vegetated and ditches are functional and stable. Cutslopes are stable and/or vegetated and fillslopes are vegetated. This is typical of low-use roads and/or highly erosion-resistant road prism materials. **Moderate**: The road surface is stable with little or no rutting on the road surface. The cutslope is stable with only localized cutslope erosion. The fillslope is generally stable and erosion localized. This is typical of active forest roads and/or recent temporarily deactivated road sections. **High**: The rates of erosion of the road surface, cutslope and/or fillslope are substantial and little or no stabilizing vegetation is on the cutslope or fillslope. This is typical of roads through unstable terrain, roads on erosion-prone surficial materials, roads through seepage zones, and new roads.
Sediment Hazard	This is the combination of the sediment delivery potential and the sediment erosion potential used to describe the likelihood that sediment produced from a road section is delivered to the stream network. Sediment hazard can be **Low**, **Moderate** or **High**.

Sediment Risk Rating	Sediment risk rating is defined as the combined impact of forest development and beetle-kill on the rate of sediment supply to the stream channel, relative to background rates. Sources of anthropogenically-derived sediment include landslides, roads, range areas, and areas in agricultural production. A "low" rating means that the proportion of total sediment delivered to the channel has not been changed by human activity or beetle-kill. Where a previous anthropogenic sediment source has been stabilized (e.g. through re-vegetation), a low impact rating would be given. A "high" rating means that the proportion of the total sediment delivered to the channel related to anthropogenic activities has increased. This could have occurred for example through an increase in the frequency and/or magnitude of mass movement events.
Sediment Size	Refers to the b-axis diameter of a particle. Sediments are classified as: silt (>0.004-0.062 mm), sand (>0.062-2 mm), gravel (>2-64 mm), cobble (>64-256 mm), and boulder (>256 mm).
Stream	A stream is any Reach with a continuous bed scoured by water or contain observable deposits of mineral alluvium. Note that the bed or banks can be locally obscured.
Sub-basin	A sub-unit of a watershed, usually defined as the watershed of a tributary channel.
Surficial Material	Layer of non-lithified mineral particles overlying the bedrock. It may be derived by weathering of underlying bedrock or by transportation and deposition from other locations by fluid agents. These geologically young materials, usually of Quaternary age, are classified as to their genesis, hence the terms alluvium, colluvium, glaciolacustrine sediments, and till.
Talus	Accumulation of loose rock fragments derived by rock fall from a cliff.
Till	Material deposited by moving ice sheets or glaciers, without subsequent modification by other transport processes. Till is often a diamicton, consisting of a fine matrix (usually sand or silt) and larger clasts (gravel, cobble and boulder-sized particles).
Watershed	An area of land that collects and discharges water into a single main stream through a series of smaller tributaries. Watershed is synonymous with catchment or drainage basin.
Watershed Advisory Committee	A technical group formed to provide specific watershed information and make land-use recommendations.
Watershed Routing Efficiency	Watershed routing efficiency is defined as the relative rate of transmission of runoff from an arbitrary point in a watershed to the mainstem channel. It is used in conjunction with channel sensitivity to assess the potential for ECA impacts on the mainstem channel. It is an intrinsic property of a watershed, i.e. it is not related to a particular forest development plan. It is assessed by considering relevant watershed characteristics, including: presence and extent of lakes and wetlands, potential for losses to groundwater (a function of soil permeability and depth), slope gradient, extent of stream network, and extent and location of road network. Watershed routing efficiency is assigned a value of Low, Moderate or High.

Appendix A

BAKER CREEK DETAILED WATERSHED ASSESSMENT: PUBLIC MEETING MINUTES (March 8, 2006 and March 22, 2007)

Baker Creek Detailed Watershed Assessment Public Meeting Minutes
March 8, 2006, Wednesday, Baker Creek Community Hall, 5:00 pm – 7:00 pm

36 Attendees:

Name	Phone	Mail/email
Lars Uunila, Summit	545-3672	lu@summit-environmental.com
Gerry Powell, Tolko	992-1754	Gerry.Powell@tolko.com
Dale Bubela, MoFR	992-4400	Dale.Bubela@gov.bc.ca
Kim Proulx, MoFR	992-4400	Kimberly.Proulx@gov.bc.ca
Jaime Giesbrecht, MoFR	992-4400	Jaime.Giesbrecht@gov.bc.ca
Scott MacCrimmon	249-0224	scottannalisa_maccrimmon@yahoo.com
John & Rosemarie Way	249-5358	wayco@goldcity.net
Terry & Wendy Strachan	991-8270	R.R. 5, Box 48, Tibbles Site, Quesnel, V2J 3H9
Bruce L. Engel	991-7039	tbengel@direcway.com
Mike Moore	991-9085	
Bill & Barb Potts	249-0166	
Karl Moffat	No phone	R.R. 5, Box 1, Tibbles Site, Quesnel, V2J 3H9
Sue & Cam Lylick	249-5058	R.R. 5, Box 29, Tibbles Site, Quesnel, V2J 3H9
Steve Lasure	No phone	R.R. 5, Box 67, Tibbles Site, Quesnel, V2J 3H9
Dennis Gordon	249-0271	R.R.5, Box 15, Tibbles Site, Quesnel, V2J 3H9 csb@uniserve.com,
Breanna Harbidge	249-5779	
Peter Spruyt	249-5779	pjspruyt@myway.com
Fred Clements	249-5112	
Jason & Krista Shopa	249-0003	
Dan Gibbons	249-5393	R.R. 5, Box 21, Tibbles Site, Quesnel, V2J 3H9
Todd Birch & SandeeMackinnon	249-0171	msmack9@telus.net
Elsa Falloon	249-0279	epj@telus.net
Celine Falloon	249-0279	baeblu@hotmail.com
Mike Paley	249-5194	
Joe & Ursula Lisk	249-5951	ulisk@telus.net
Dawn Barl	249-5069	cluna@uniserv.com
Laurie & Ted Cooper	249-5005	
Jesse Way	249-5358	R.R. 5, Box 2, Tibbles Site, Quesnel, V2J 3H9

Minutes:

- Gerry Powell of Tolko made the introductions and explained that through Tolko and Summit Environmental Consultants, a Detailed Watershed Assessment for Baker Creek would be conducted this spring/ summer. Gerry mentioned that Mountain Pine Beetle (MPB) and the lack of live lodgepole pine stems may be contributing to the recently observed changes in the hydrology of Baker Creek.

- Lars Uunila explained the purpose of the Baker Creek Detailed Watershed Assessment. The purpose of the assessment is: 1) to determine the current condition of the Baker Creek watershed; 2) To identify opportunities to mitigate past and present land-use related effects on water quality and water quantity, 3) To review proposed and potential forest development

on the crown land portion of the watershed, and 4) Describe expected effects on water resources, and provide recommendations to address water-related issues where possible.

- Lars explained that this watershed is a large one (about 150,000 ha) and research is needed to identify and understand the issues. He will look at the big picture with air photos to identify issues such as slides, unstable banks and washed-out roads. Within a month he'll have a sense of the issues and where they are. He'll fly most of the watershed and identify important sub-basins – there are ~10-15 sub-basins. He'll videotape the flights.

- As mentioned above, Lars will study the area through air photos, orthophotos, he will fly the area, and ground checks the area when the snow is gone.

- Lars will provide a draft copy of the assessment report to concerned stakeholders for review and comment before the finalized report is completed by the fall.

- Lars asked that people point out where they are seeing problems with the creek and their property.

- Lars will assess risks for MPB and harvesting: stream stability, riparian vegetation, and sediment inputs.

- Lars will make recommendations on what could be done to mitigate risks – guidance on constraints and opportunities for harvesting activities, and how to protect properties.

Concerns as Outlined by Private Landowners/Stakeholders Present at the Meeting:

Fire – People in the Baker Creek community are quite concerned about the fire hazard that exists with standing dead pine. They wonder if firebreaks are considered by licensees when developing cutblock proposals. No one from this community has been contacted by the Cariboo Fire Protection Planning group to be involved in a community plan.

Debris In Creeks – Could creeks be cleared off to enable proper runoff? Lars commented that cleaning out creeks may not help the situation a great deal. It's more of an issue to do with rising groundwater and the need for green trees to be present to "soak' up water. Landowners have seen an increase in blowdown in streams.

Quality, Quantity and Timing of Water – Siltation is a problem. Baker Creek has changed location. Landowners have experienced flooding, channel infilling, change of course, and siltation of their fields over the past few years.

Silviculture Practices – Landowners have seen disc-trenching practices that appear to be detrimental (i.e., soil erosion as a result). They want to know if this could contribute sediment to Baker Creek.

Alternative Species for Planting - Landowners wonder if there are faster growing species (i.e., hybrids) available to 'soak' up groundwater to help prevent flooding. Could alternative, non-commercial species be planted such as willow that could establish quickly while the commercial species such as pine and spruce take their time to establish? Could we underplant with pine and spruce, and then remove the non-commercial species at a later date when the pine and spruce are established? Could there be a diversity of ages in plantations to help ensure a constant source of trees that can control the water table?

Herbiciding – There is concern that non-commercial species that help to control groundwater are being eradicated.

Visual Quality – Landowners wonder if visual quality is considered by licences. There are Visual Quality Objectives in place in the Quesnel Forest District.

'Waterboils' – The representative of the Bible school identified a problem with roads sinking and reduced foundation stability.

Beavers – Beavers are not in the scope of this assessment, but are a concern. Landowners have noticed a lot of beavers in the area and feel that they may be contributing to flooding. This could be exacerbated by blowdown of dead pine in the future.

Rehabilitation Efforts – Landowners want to know if dead stands will be re-planted and how trees will grow within dead stands. There is some money available for rehabilitation, but this is in the planning stages currently. Such rehabilitation efforts are a focus of the MoFR Stewardship section.

Changes Over the Past 3 Years – Flooding has always occurred in the Baker Creek area, but it's happening more now than in the past. In the past, areas would flood 3-4 times a year and now they are flooding 7-8 times a year. Furthermore, flooding is generally more severe and has caused drainage pattern changes along some lowlands, particularly south of Tibbles Lake.

Private Land – Landowners want to know what options they have to manage MPB on their land and perhaps on surrounding Crown Land. Surface erosion was noted as an issue that has been mitigated through grass-seeding in the past, but currently there appears to be no funding for this. Many landowners are keen to address problems (i.e., flooding and erosion) on their land but, have limited funds. Landowners would like to hear about ways to slow down water during peak flows to protect their property on low lying areas. Are there choices they can make to protect their property if required?

Harvest Methods – Landowners asked if horse logging is an option for selective harvesting. It may be possible to use strategically in limited sensitive areas with large diameter timber.

Landowners also asked about being able to harvest right to the edge of streams and lakes to remove beetle killed trees if it makes sense.

Baker Creek Watershed Assessment - Community Meeting
March 22, 2007
Location – Baker Creek Community Hall

Attendees:

Summit Environmental Consultants Ltd.
Lars Uunila

Ministry of Forests and Range
Gerry Grant
Dale Bubela
Kim Proulx

B.C. Timber Sales
Bob Merta

Canfor
Steve Day

Tolko Industries Ltd.
Gerry Powell
Lindsay Anderson
Ryan Weltz
Jenna Hopkinson

Baker Creek Residents
Dennis Gordon
Sage Gordon
Mike Moore
Todd Birch
Roy Richmond
Bill Potts
Joe Lisk
Ursula Lisk
Celine Falloon

Study Objectives

- To assess the watershed with respect to impacts of beetle-kill and future forest development.
- To create a tool for stakeholders to mitigate hydrological impacts from these disturbances.

Study Process

- As per summary.

Background Information / Current Research

- We are at the forefront of research regarding this issue – consequently adaptive management is required to improve our practices as we go.
- Hydrologic recovery may occur faster where harvesting and planting have taken place.
- Forest Practices Board (FPB) Report / UBC Hydrological Studies
    - UBC will be in Baker Creek for eight years (subject to funding) to create a model of the hydrology of the area
    - The parameters entered into the model drive the outcome – this is a best guess at this stage and do not necessarily represent reality.
    - Information gathered in the FPB report compliments this report, however it does not appear to clarify the level of uncertainty, and consequently the limitations of results derived from such a young model.
    - Over time this model will improve as it is calibrated with more data**.**

Stakeholder Issues

- Fire is a concern - most residents support harvesting in area to reduce fire risk.
- Disc-trenching
    - When following pattern with the fall line trenches have been observed to change natural drainage patterns – water accumulations in areas that did not previously experience them.
    - The Summit representative noted that trenches running up and down the slope can increase erosion potential and sediment transport – however he is not aware of any specific studies to support the observation. There is a decreased impact on drainage when trenches follow the contour of a slope.
    - This method of site preparation is not preferable for cattle movement/grazing.
    - Tolko offered to field tour with any concerned parties over trenching from the past to address potential issues.
- Brush Management/Herbicide
    - Some residents expressed concern over deciduous species being eliminated from sites – especially with the use of herbicide.
- Coarse Woody Debris (CWD)

    - Concern was expressed over the limitation of cattle movement within areas that have heavy CWD.
    - It was suggested that leaving CWD can be helpful in decreasing runoff in general, erosion, and subsequent runoff from snowmelt.
- Four Wheelers
    - Concern that four wheelers go through streams and cause damage.

Watershed Conditions

- Peak Flows
    - Definition: The highest peak in any given year. In the interior, snowmelt dominates the hydrographs, and while peaks can happen throughout the year the interior peak flow typically refers to the spring freshet.
    - Peak flows are the greatest risk in our current situation.
    - The majority of the streambanks in the watershed remain stable, this is an indication that extreme peak flows have not yet occurred.
    - Expect increased frequency and severity of flooding.
    - Deep snowpacks and fast warming will create these peaks.
    - We've experienced more frequent flooding at low levels, rather than frequent flooding at high levels.
    - There is a need to ensure that structures (ex. culverts & bridges) will be capable of supporting both current and future peak flows.
- Channel Stability
    - Currently channel stability is in fair condition throughout the watershed.
    - The watershed has both high and moderately sensitive channels due to fine soils that are easily eroded by high peak flows.
- Riparian Function
    - Provides aquatic habitat, channel stability, as well as acting as a filter to upland activities and conditions.
    - Pine mortality has higher impacts on upslope streams as pine dominates the streamside vegetation.
    - Lower basins are less affected as wetland vegetation dominates streambanks.
- Sedimentation
    - Not a high risk at this point in time – some issues noted with roads that require addressing within specified time period.
    - This may become more of an issue with increased peak flows – road management programs to assess the capabilities of the current structures to handle increased water will be necessary.

Private Land

- Issues noted throughout, especially in the middle Baker sub-basin.
- Stream restoration recommended on a number of reaches within private land – this includes re-vegetating streambanks and blocking cattle access.
- Current drainage infrastructure around fields will not be sufficient to address current and future issues – cost/benefit analysis to direct potential

restoration/drainage infrastructure projects is required. May need an integration plan between government agencies to achieve this, but there is uncertainty around whether funding exists for these kinds of projects.

Forest Management

- In addition to recommendations noted on the summary sheet:
    - Stagger harvesting schedules within areas of close proximity, similar elevations and aspects – this will help to distribute snowmelt rates and water delivery between catchment areas.
    - Leaving increased slash loads dispersed on harvested blocks is a recommended method to slow snowmelt.
        - Public concern over the creation of range barriers due to processing at the stump – preference expressed for leaving slash in rows to allow passage between for cattle.
    - Maintain natural drainage patterns.
    - Reforestation
        - Increasing deciduous species composition – fast growing species that will transpire water during the summer season to mitigate summer storm events.
        - Prompt reforestation within 2 yrs of harvest.
    - Road Management
        - Assess crossing structures to ensure that they are sufficient for future peak flows
        - Emphasis on removing temporary crossings prior to spring freshet.
        - Fix culverts that are currently failing within the watershed.
    - Monitoring
        - It is very important to monitor the condition of the watershed with regard to forest management. Issues can be cleared up in a more timely manner this way. Adaptive management will be more successful with monitoring.

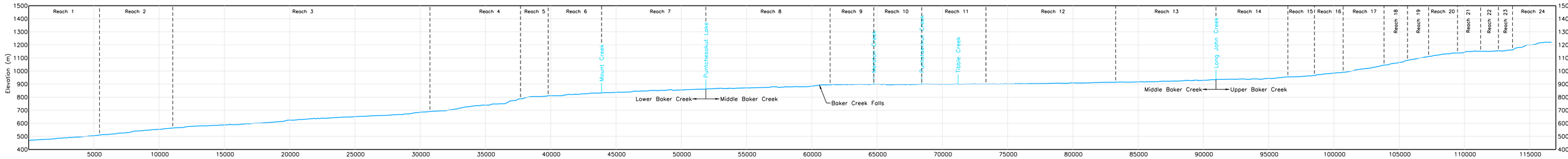
Further Public Comments

- *Is there a benchmark that indicates we are close to hydrologic recovery?*
    - There is no signal as to where that threshold of achievement is measured.
    - Variability, on average, has increased in the last five years.
    - Recovery is tied to the forest stand.
        - Old growth is considered 100% recovery
        - various tree heights have an associated level of recovery.
        - 9m trees are considered ~90% recovered, which is considered the peak recovery of a managed stand.
- Flooding used to be experienced once or twice per year, usually in the spring. Now they occur more frequently at any time of year.

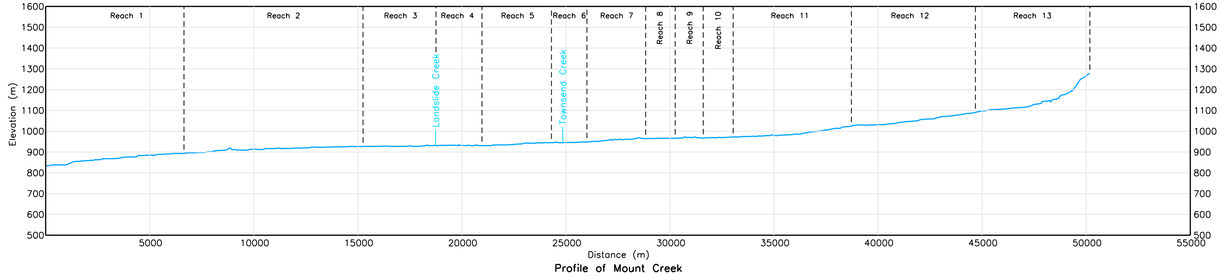
    - The loss of water pumps means that the water table is rising providing less available space within the “sponge” to absorb inputs from weather events – therefore the system cannot handle extra inputs.
- Grass seed used to be provided to the farmers and they would seed roadsides and landings for the licensees. This provided very good grazing potential for the cattle and kept them on higher ground and out of the lowlands. *Is there opportunity for this to happen again?*
    - Roadsides are still grass seeded as a standard practice by licensees; however with logging practices having changed, large landings are no longer utilized. The actual practice of seeding is contracted out.
- *What is the expected time limit on standing timber?*
  No one knows – the longevity of the standing timber depends on the degree of root saturation caused by increased water tables. (Lars Uunila)
- ATV’s are a major disturbance factor in streams – they create trails that cattle follow as the path of least resistance.
- There is a concern that logging and silviculture practices are carrying on “business as usual” – without adaptation to the current situation.
  Responses from Licensees:
    - Fiber is changing and becoming more fragile – different methods (ex. processing at the stump) are going to be required simply to get the wood to roadside.
    - Increased water tables are requiring soft-touch machinery.
    - Site specific changes in fiber are changing the strategies of where we can do business.
    - *Will private landowners have more access to timber on crown land adjacent to properties? Companies pay salvage rates for poor quality stands while landowners pay more.*
      There are some tenures available for small amounts of timber (i.e. free use permits) – cash sales are also possible for small volumes.

Appendix B

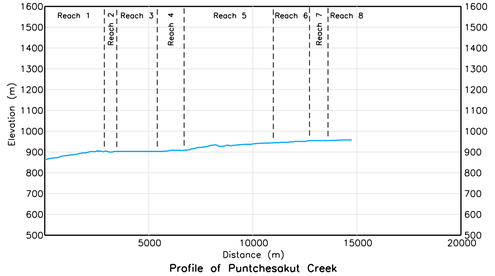
LONGITUDINAL CHANNEL PROFILES OF BAKER CREEK AND PRINCIPAL TRIBUTARIES



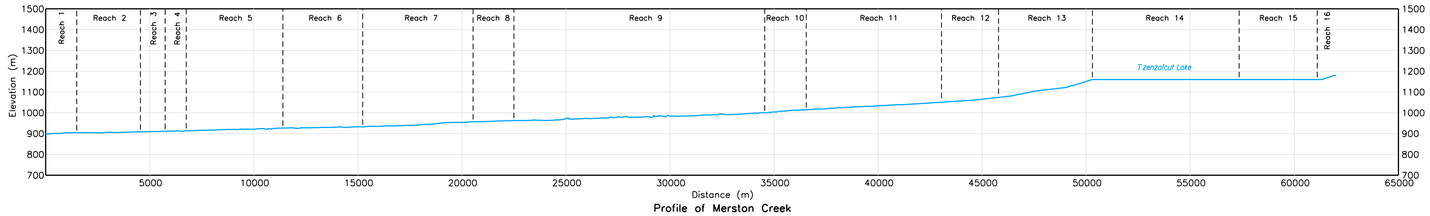
Profile of Baker Creek



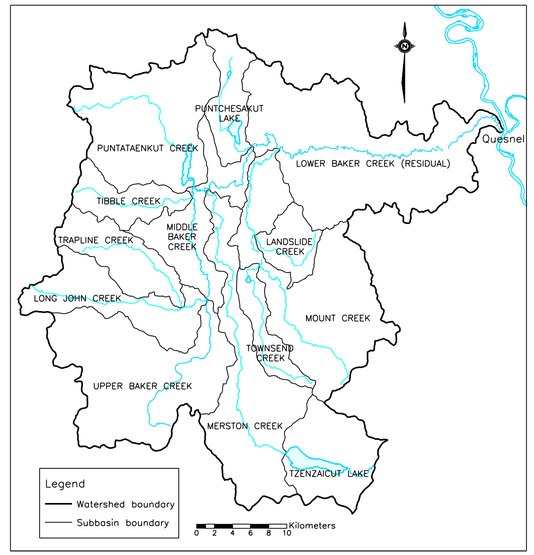
Profile of Mount Creek

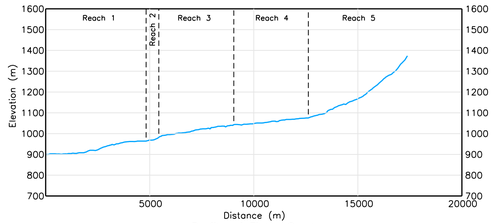


Profile of Puntchesakut Creek

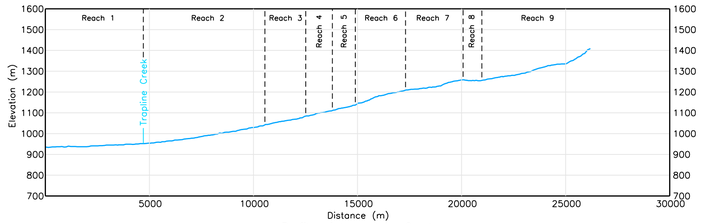


Profile of Merston Creek

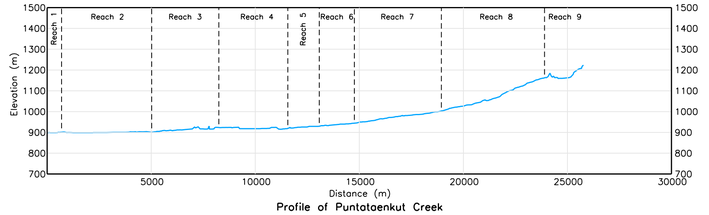




Profile of Tibble Creek



Profile of Long John Creek



Profile of Puntataenkut Creek

Prepared for:

TOLKO INDUSTRIES LTD.

Quest Wood Division

LONGITUDINAL CHANNEL PROFILES OF BAKER CREEK AND PRINCIPAL TRIBUTARIES

Drawn by: BdJ	Date: Jan. 2007	File: profiles.dgn

SUMMIT Environmental Consultants Ltd.

Appendix C

MEMOS IDENTIFYING URGENT RESTORATION

Lars Uunila

From: "Lars Uunila" <lu@summit-environmental.com>
To: "Gerry Powell" <Gerry.Powell@Tolko.com>
Cc: "Dale Bubela" <dale.bubela@gov.bc.ca>
Sent: Monday, July 17, 2006 3:03 PM
Attach: IMGP2446-2448.JPG; IMGP2459.JPG; IMGP2441.JPG
Subject: Baker Creek watershed

Hi Gerry,

Back in the office, I just wanted to let you know the field work went quite smoothly. We met with the Potts family, Lisk family, and Mike Moore and went over their concerns. As you heard in our phone message our scheduled helicopter flight was cancelled on tuesday, but we scrambled and found one for Friday. It went well despite a very close encounter with a high flying eagle. We covered all significant tributaries and roads by air and/or ground and in general we found relatively few items of immediate concern. Most roads are well graded with satisfactory drainage works, and culverts and bridges are functioning well. We will be outlining the range of issues identified at a later date, but there was one issue that I'd like to bring to you immediate attention. A road was washed out no long ago at the lower end of Landslide Creek. It is at Road 3700 at km 6+. It appears beavers plugged the culvert(s) causing a substantial rise in the pond causing overtopping and erosion of the road. The road, which acted as a dam, burst causing a breach 5 m wide by 2.5 m high. Currently there is some flagging across the road, but given the hazard to the public, the road should be blocked by something more substantial until repaired. I met shortly with Dale Bubela on Friday to inform him of this, and he indicated he would follow it up with his engineering staff since he was unaware of it. I also left with him all air photos we borrowed. We will still need them for the project, but we can get by without them for 2-3 weeks.

If you have any questions let me know.

Regards

Lars Uunila, M.Sc., P.Geo., P.Geol., P.H., CPESC
Geoscientist
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Cell (250) 938-5546
lu@summit-environmental.com
www.summit-environmental.com

IMGP2441.JPG

IMGP2446-2448.JPG

IMGP2459.JPG

SUMMIT Environmental Consultants Ltd.

ISO 9001 AND 14001 CERTIFIED

MEMORANDUM

DATE: **JULY 25, 2006**

TO: Gerry Powell

FROM: Lars Uunila

RE: **PRIORITY AREAS FOR ROAD MAINTENANCE**

FILE: **040-42.02**

The field assessment of the watershed identified two additional priority areas that require road maintenance.

1. This high priority site is located on Tibbles Road at km 14+ near the mouth of Trapline Creek. The attached photographs (0406-0416) illustrate road erosion and excessive ditch erosion in all ditches (approximately 300 m in total) leading to an unnamed tributary of Trapline Creek. Sediment control measures (silt fences) are non-functioning and currently sediment is being delivered to the creek. Recommendations include clearing and armouring the ditches, installing rock check dams (removing the silt fences) in each ditch, regrading the road crown and embankment, and repairing the fill adjacent to the culvert.
2. This moderate priority site is located at the entrance of a secondary cutblock road at km 1+ Crimen Creek (3100) Road. The attached photographs (2519-2522) illustrate the excessive surface erosion on the road and the non-functioning culvert. Recommendations include regrading the road, ditch and culvert clearing.

17A-100 Kalamalka Lake Road. Vernon, B.C. V1T 7M3 *Web*: www summit-environmental.com
Phone: (250) 545-3672 *Fax:* (250) 545-3654 *e-mail*: info@summit-environmental.com

IMG_0406.jpg

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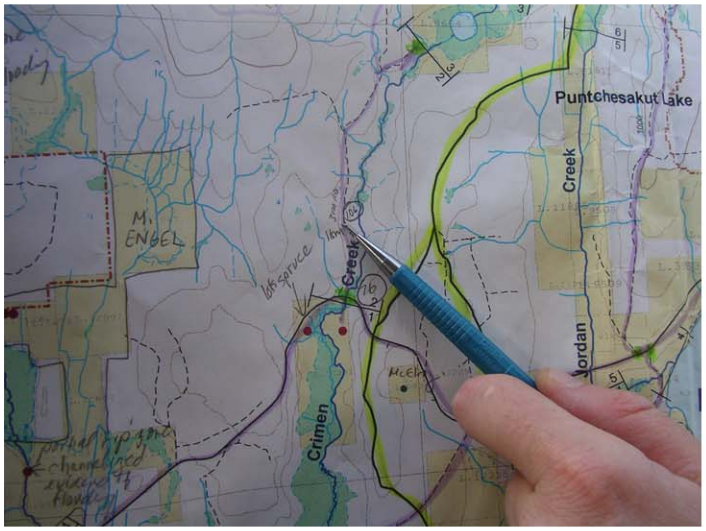

IMGP2519.JPG

IMGP2520.JPG

IMGP2521.JPG

IMGP2522.JPG

Appendix D

SELECTED PHOTOS ORGANIZED BY SUB-BASIN

Upper Baker Creek Sub-basin (refer to text for descriptions)

Photo 1 (July 10, 2006)

Photo 2 (July 10, 2006)

Photo 3 (July 12, 2006)

Photo 4 (July 10, 2006)

Photo 5 (July 10, 2006)

Long John Creek Sub-basin (refer to text for descriptions)

Photo 6 (July 12, 2006)

Photo 7 (July 12, 2006)

Photo 8 (July 12, 2006)

Tibble Creek Sub-basin (refer to text for descriptions)

Photo 9 (July 12, 2006)

Puntataenkut Creek Sub-basin (refer to text for descriptions)

Photo 10 (July 13, 2006)

Photo 11 (July 12, 2006)

Photo 12 (July 13, 2006)

Photo 13 (July 13, 2006)

Merston Creek Sub-basin (refer to text for descriptions)

Photo 14 (July 11, 2006)

Punchesakut Creek Sub-basin (refer to text for descriptions)

Photo 15 (July 13, 2006)

Mount Creek Sub-basin (refer to text for descriptions)

Photo 16 (July 14, 2006)

Photo 17 (July 13, 2006)

Photo 18 (July 13, 2006)

Photo 19 (July 14, 2006)

Photo 20 (July 14, 2006)

Photo 21 (July 13, 2006)

Photo 22 (July 13, 2006)

Photo 23 (July 15, 2006)

Middle Baker Creek Residual Area (refer to text for descriptions)

Photo 24 (July 11, 2006)

Photo 25 (July 10, 2006)

Lower Baker Creek Residual Area (refer to text for descriptions)

Photo 26 (July 15, 2006)

Photo 27 (July 13, 2006)