PEMBERTON VALLEY
DYKING DISTRICT

Large Woody Debris Assessment and Mitigation Plan

Final Report
June 2011

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CONSULTING ENGINEERS

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KWL File No. 713.054

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EXECUTIVE SUMMARY

On August 6, 2010, a massive landslide occurred on Mount Meager, sending wood and sediment into Meager Creek and the Lillooet River. The landslide mobilized and transported a 46 Mm³ of material into the Lillooet River system raising concerns over the potential increase in risk to flood protection infrastructure and public safety in the downstream dyked reach of the Lillooet River. The Pemberton Valley Dyking District (PVDD) engaged Kerr Wood Leidal Associates Ltd. (KWL) to conduct a Large Woody Debris (LWD) assessment and to prepare a mitigation plan for increased flood risk from LWD on the Lillooet River.

LWD in river systems can create debris jams and increase flood hazard within a floodplain. The dyked reach of the Lillooet River is of particular concern, since development along the Lillooet River is concentrated in this reach.

The LWD assessment found that the potential LWD hazards within the dyked reach of the Lillooet River are less than expected given the scale of Capricorn Creek landslide. The 2010 landslide is estimated to have mobilized about 110,000 m³ of wood, however the braided reach of the Lillooet River (upstream of the dyked reach) acts as a storage area for LWD, and thereby mitigates some of the potential hazards downstream.

The channel in the dyked reach is relatively narrow, deep and straight, which promotes effective transport of LWD through the reach. There are relatively few locations where LWD jams could potentially form in the dyked reach. However, because the river channel is relatively confined within the dyked reach, this area is vulnerable to dyke breaches if large LWD jams do occur.

The LWD assessment identified 106 locations within the 31 km of dyked reach of the Lillooet River that could accumulate LWD and potentially form a jam. These locations were selected for general monitoring; however, given the uncertainty of predicting log jam formation, they should not be monitored exclusively. Of the larger list of general monitoring locations, 5 were considered to be high priority monitoring locations based on concern over the existing conditions and/or the high consequence of failure of the adjacent infrastructure.

An LWD mitigation plan was developed for the Pemberton Valley area of the Lillooet River, which has the following recommendations:

1. Monitor high priority locations.
2. Conduct general monitoring/LWD assessment updates.
3. Carry out emergency condition monitoring.
4. Plan and implement an early warning system.
5. Do not conduct LWD removals at this time.
6. Conduct a more detailed assessment of the hazard at the Miller Log Jam.
7. If potentially hazardous LWD jams form, assess the hazard and determine an appropriate response.
8. Consult with the local land owner regarding the potential removal of, or upgrade to, the footbridge upstream of Miller Creek.

Section 1

Introduction

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1. INTRODUCTION

1.1 SCOPE

Kerr Wood Leidal Associates Ltd. (KWL) was retained by the Pemberton Valley Dyking District (PVDD) in December 2010 to conduct a Large Woody Debris (LWD) assessment and to prepare a mitigation plan for increased flood risk from LWD in the lower Lillooet River.

The presence of wood and the potential for wood to create debris jams increases the flood hazard for developments within a river's floodplain. Debris and large wood jams can cause:

- localized constriction of the channel;
- localized elevation of the water level upstream of the jam;
- increase in velocities and scour around the jam;
- increase in sedimentation and gravel bar formation around the jam; and
- increase in force against bridges and other river crossings if LWD gets caught on piers and cables.

The LWD Assessment and Mitigation Plan Project was initiated by the PVDD in response to the landslide event in Meager Creek and Capricorn Creek. The landslide mobilized and transported millions of cubic meters of wood, rock and debris into the Lillooet River system raising concerns over the potential increase in risk to flood protection infrastructure and public safety in the downstream dyked reach of the Lillooet River. The assessment of LWD conditions, and associated mitigation plan are the first steps in addressing these concerns.

ENGINEERING WORK PROGRAM AND PROJECT DELIVERABLES

The work program consists of five primary tasks. The task descriptions and associated deliverables are summarized as follows:

- desktop review of Lillooet River LWD;
- field investigations of current LWD conditions in the Lillooet River, including a helicopter assessment of the Lillooet River;
- prepare updated mapping (updated from the Engineering Study for Lillooet River Corridor, prepared by KWL, December 2002);
- investigate options for an early warning system; and
- prepare an LWD Assessment and Mitigation Plan.

1.2 PROJECT TEAM

The KWL project team includes:

- Mike Currie, M.Eng., P.Eng., Senior Water Resources Engineer;
- Stefan Joyce, P.Eng., Project Manager;
- Erica Ellis, M.Sc., P.Geo., Project Geomorphologist;
- Sarah Lawrie, M.A.Sc., P.Eng., Project Engineer;
- Jason Miller, P.Eng., Project Engineer;
- Jack Lau, GIS Technologist; and
- Scott Cowan, Water Resources Technologist.

The KWL project team has been augmented through the addition of Dr. Richard Guthrie, P.Geo., a senior geohazards scientist and geomorphologist with Hemmera Environmental Service Consultants. Dr. Guthrie provided expertise on the Meager Creek landslide event and provided estimates of material mobilized by the landslide event.

Section 2

Background

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2. BACKGROUND

2.1 LWD AND FLOOD HAZARD

LWD jams may have an associated increased flood hazard as well as potential negative impacts on infrastructure. Possible issues include:

- Impacts to bridges and river crossings:
    - potential for LWD to get caught on river crossings and bridges, creating larger jams;
    - increased forces against bridge abutments and pillars, or cable crossings, causing failure of the structure;
    - increased localized scour causing failures; and
    - decreased channel conveyance at the crossing causing increased localized flood levels upstream and potential failure of adjacent or upstream flood protection works.
- Impacts to dykes:
    - jams create local increases in flood elevations reducing dyke freeboard; and
    - jams create areas of deposition and flow constriction decreasing flood conveyance and impacting dyke freeboard.
- Impacts to erosion protection:
    - jams create local scour undermining erosion protection and causing failure; and
    - floating debris can impact and abrade erosion protection and cause mechanical failures.

2.2 DYNAMICS OF LARGE WOOD IN RIVERS

The dynamics of large wood in rivers is dependant on both characteristics of the wood and the river (Gurnell *et al.* 2002)[1]. Wood and river characteristics that impact the dynamics of LWD in rivers include:

- wood supply;
- wood size, shape, and density;
- channel dimensions;
- channel geomorphology; and

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[1] Gurnell, A.M., H. Piegay, F.J. Swanson, and S.V. Gregory. 2002. *Large Wood and Fluvial Processes*. Freshwater Biology, vol. 47, pg 601-619.

- channel flow regime.

Wood is delivered into the river through a variety of processes including bank erosion, remobilization of wood stored in the floodplain, floatation from tributaries and slope failure processes such as landslides and avalanches (Gurnell *et al.* 2002).

LWD DIMENSIONS, FORM AND DENSITY

LWD has been defined as a piece of wood with a diameter of >0.1 m with length greater than 2 m (Johnston and Slaney, 1996)[2]. However, the dimensions of the wood relative to the channel dimensions are more indicative of how the wood will behave. Important relative dimensions include:

- the length of the wood piece compared to the width of the river; and
- the diameter of the wood piece (or water depth at which floatation occurs), compared to the average channel depth (Braudrick and Grant 2001)[3].

In general, a smaller piece of LWD will be more stable and have a larger effect on hydraulics in a small stream than the same-sized piece in a larger river.

Wood shape influences how wood is transported within the flow. Deciduous trees have a wider branch form that stays intact as it is being delivered to the river, and therefore is more likely to get caught on obstacles. Evergreen trees generally shatter on ground-impact, which tends to result in a more cylindrical form to the LWD that is conducive to downstream transport. Rootwads of any species provide increased roughness and will tend to anchor large pieces in rivers (Gurnell *et al.* 2002).

Typical wood densities are less than the density of water[4]. Waterlogging will increase the density of LWD, but in general, wood is buoyant. Wood density ranges from 300 kg/m³ to 700 kg/m³ for typical species in this area.

CHANNEL CHARACTERISTICS AND LWD DYNAMICS

Channel pattern (i.e., straight, meandering, braided) influences flow patterns and how wood is conveyed, as well as locations where log jams are formed. Straight channels are better able to transport wood as the LWD will become oriented parallel to the flow, and will tend to travel at approximately the same velocity as the flow (depending on interactions with the channel edge and bottom) (Braudrick and Grant 2001).

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[2] Johnston, N.T. and P.A. Slaney. 1996. *Fish Habitat Assessment Procedures*. Watershed Restoration Technical Circular No. 8. British Columbia Watershed Restoration Program. Ministry of Water, Land and Air Protection and Ministry of Forests.

[3] Braudrick, C.A. and G.E. Grant. 2001. *Transport and Deposition of Large Woody Debris in Streams: A Flume Experiment*. Geomorphology, vol. 40, pg 263-283.

[4] Density of water = 1,000 kg/m³.

Channel features that promote the deposition of LWD include:

- bar heads;
- the outsides of bends;
- shallow areas of flow;
- areas with increased roughness (vegetated islands, stable LWD, etc.); and
- areas of flow transition (Braudrick and Grant 2001, Gurnell *et al.* 2002).

Erosion of bed and bank material can mobilize LWD, while deposition patterns can act to bury and stabilize LWD in the channel.

Particularly in a braided channel, large floods greater than the 5-year return period flows ($>Q_5$) can occupy the entire width of the channel and can mobilize rafted wood and re-distribute and deposit wood during the falling limb of the hydrograph (Gurnell *et al.* 2002). Smaller floods can then re-mobilize the wood that has been deposited on lower-elevation bar surfaces. As a result, the amount of wood stored within a braided channel decreases with increasing time from the last large flood (Gurnell *et al*. 2002).

2.3 HOW NATURAL LOG JAMS FORM

Abbe and Montgomery (1996)[5] define three main types of wood debris jams through their work in the Pacific Northwest:

1. Bar Top Jams;
2. Bar Apex Jams; and
3. Meander Jams.

These three different debris jams reflect different structural components and are formed through different processes. All three of these log jam types are present in the Lillooet River. Characteristics of the three main types of debris jams are summarized in Table 2-1 and illustrated in Figure 2-1.

In general, bar top jams are the least stable and most transient type of log jam. Bar apex and meander jams, once established can persist for periods from decades to hundreds of years. This is particularly true if the key members become deeply buried and associated gravel bars become vegetated and stable under higher flows.

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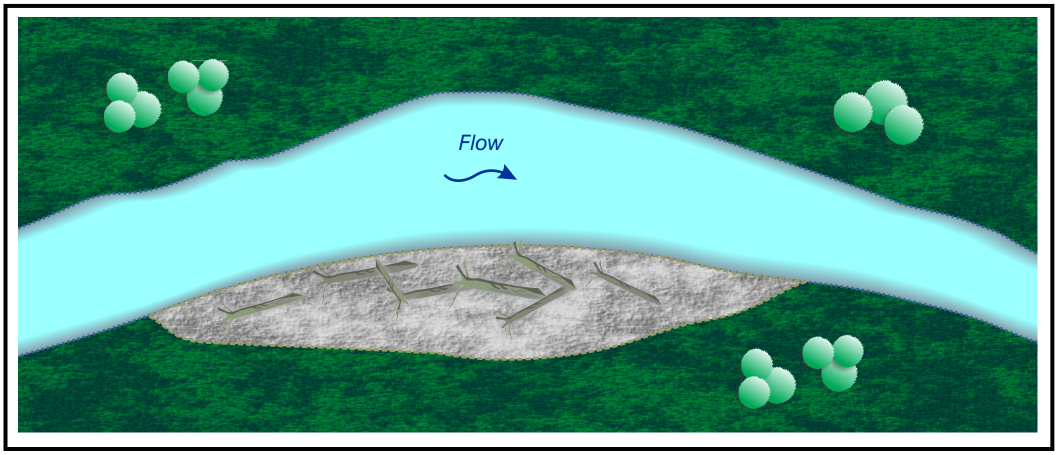
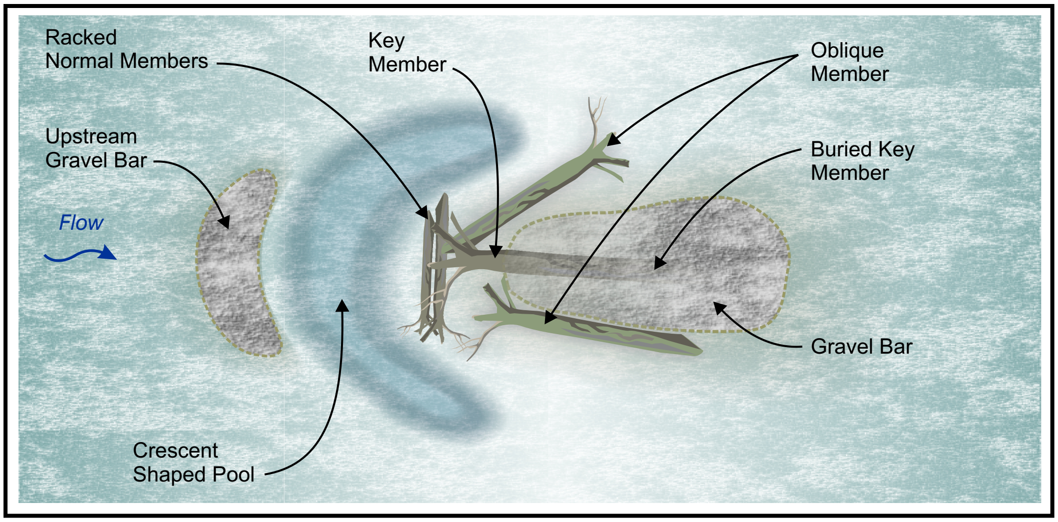
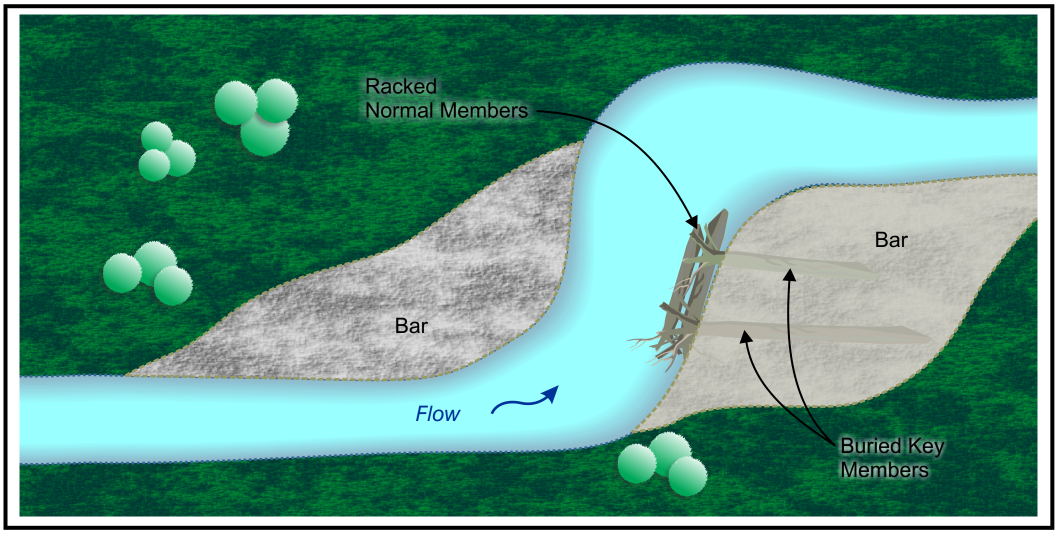
[5] Abbe, T.B. and D.R. Montgomery. 1996. *Large Woody Debris Jams, Channel Hydraulics and Habitat Formation in Large Rivers.* Regulated Rivers: Research and Management, vol. 12, pg 201-221.



Bar Top Jam



Bar Apex Jam



Meander Jam

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Large Woody Debris Assessment and Mitigation Plan

Project No.	Date
713-054	April 2011

Not to Scale

LWD Jams

Figure 2-1

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Table 2-1: Summary of Debris Jams

Type	Structural Components	Formation	Relative Jam Stability	Impact on Channel Morphology
Bar Top Jams	▪ Random accumulation of logs with little vertical stacking ▪ Most are oblique to the flow direction	▪ Loose mat deposited on the bar top during receding flows	**Relatively Unstable**	▪ Little impact on channel hydraulics
Bar Apex Jams	▪ Key member parallel to flow (large log with intact rootwad) ▪ Normal members orthogonal to flow ▪ Oblique members oriented 10 to 30° to flow ▪ Vertical stacking of five or more interwoven layers	▪ Key member is deposited in the flow ▪ Normal members racked up against the key member ▪ Oblique members deposit along the flank of the key member	**More Stable**	▪ Gravel bar formed upstream of the jam ▪ Crescent shaped pool formed at the upstream edge of the jam ▪ Gravel bar formed at the downstream end of the jam (often burying the key member and creating a more stable jam)
Meander Jams	▪ Two or more key members oriented parallel to flow (large logs with rootwads) ▪ Normal members orthogonal to flow ▪ Vertical stacking of interwoven layers	▪ Key members usually deposited at the upstream end of a point bar ▪ Key members are within approximately one rootwad diameter of each other ▪ Normal members rack up against the key members	**More Stable**	▪ Channel migrates laterally changing the orientation of the flow relative to the jam
Information from Abbe and Montgomery (1996).				

2.4 MOUNT MEAGER LANDSLIDE EVENTS

The Meager Creek watershed is a tributary to the Lillooet River. The Mount Meager massif is a volcanic complex with the last eruption occurring approximately 2360 years ago (Friele *et al.* 2008). Landslide activity in the Meager Creek watershed is not a new phenomenon: Mount Meager is recognized as one of the most unstable mountain massifs in Canada and has been the subject of numerous studies since the 1970s (Friele *et al.* 2008).

HISTORIC LANDSLIDE EVENTS

A summary of historical landslide activity in the Meager Creek watershed not associated with eruption events is shown in Table 2-2. As noted in Table 2-2, there have been ten major landslide events since 1850 (including the 2010 event), all of which are likely to have been associated with the transport of LWD to the Lillooet River. It is likely that landslide activity within the Lillooet River watershed has always played a significant role in the transport of LWD to the Lillooet River.

Table 2-2: Historical Mount Meager Landslide Events (Non-Eruptive)

Event	Source	Year	Volume (m³)
Debris Flow	Capricorn Creek	1850	1.3×10^6
Debris Flow	Capricorn Creek	1903	3×10^7
Debris Flow	Devastation Creek	1931	3×10^6
Rock Avalanche	Capricorn Creek	1933	5×10^5
Rock Avalanche	Devastation Creek	1947	3×10^6
Rock Avalanche	Devastation Creek	1975	1.2×10^7
Rock Avalanche	Mount Meager	1986	5×10^5
Debris Flow	Capricorn Creek	1998	1.3×10^6
Rock Avalanche	Capricorn Creek	2009	5×10^5
Rock Avalanche – Debris Flow	Mount Meager	2010	4.6×10^7
From R. Guthrie, pers comm.			

2010 MEAGER CREEK LANDSLIDE EVENT

The 2010 Meager Creek event is one of B.C.'s largest historical rock avalanches, and occurred at 03:27:30 August 6, 2010, in the Mount Meager Volcanic Complex. The landslide initiated as a rock fall, with the collapse of the mountain's secondary peak. The detached rock mass landed on the volcano's weathered and saturated flanks with a force visible on the seismic record (equivalent to a magnitude 2.6 earthquake).

Photos from the area shortly after the slide event courtesy of Dr. Guthrie are shown in Appendix A.

Undrained loading of the footslope caused the immediate and extremely rapid evacuation of the entire flank with a strong horizontal force, as the rock fall transformed into a massive rock avalanche (about 48 Mm³). The disintegrating mass travelled down Capricorn Creek at an average speed of 64 m/s (roughly equivalent to the average speed of a Formula 1 race car), with dramatic super-elevation in bends, to the intersection of Meager Creek, 7.8 km distant (Appendix A, Photos 1 through 8). The landslide material caused a temporary blockage of Meager Creek creating a dam with water ponding behind (Appendix A, Photos 9 and 10).

The Meager Creek impact caused a run-up of 270 m above the valley floor and the deflection of the landslide upstream for 3.7 km (Appendix A, Photos 11 and 12), and downstream into the Lillooet River valley (Appendix A, Photos 13 to 16) where it blocked the Lillooet River for a couple of hours. Deposition at the confluence also dammed Meager Creek for about 19 hours creating a lake 1.5 km long (Appendix A, Photos 8 and 9). The overtopping of the dam and the predicted outburst flood was the basis for a night-time evacuation of 1,500 residents in the town of Pemberton.

The 2010 event is the third major landslide in the Capricorn Creek watershed since 1998 and the tenth event greater than 0.5 Mm^3 since 1850. The 2010 Mount Meager rock avalanche is the second largest landslide to have occurred in British Columbia since 1900, along with the 1965 Hope Slide (48 Mm^3).

Direct impacts of the Mount Meager rock avalanche – debris flow include:

- the complete removal of timber in Capricorn Creek below the trim line (over 200 m above the valley floor in areas);
- loss of timber within the impact zone in Meager Creek and Lillooet River;
- the burial of 6 km of main forest road;
- the loss of several vehicles and industrial equipment; and
- the loss of two bridges.

In addition, there remains a substantial impact on the river systems, as sediment and large woody debris now make their way from the confluence of Meager Creek and Lillooet River, to Lillooet Lake over 60 km downstream.

Section 3

Large Woody Debris Inventory

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3. LARGE WOODY DEBRIS INVENTORY

The assessment of the pre-2010 landslide conditions for LWD in the Lillooet River is based on an evaluation of 2009 and 1999 orthophotos. Locations of individual log jams were mapped at approximately 1:2,000 scale between the Lillooet River delta (Lillooet Lake) and the braided reach upstream of the Hurley Forest Service Road Bridge (Forestry Bridge).

A summary of current (post-2010 landslide) conditions is also provided in the following sections. The post-2010 landslide inventory includes an assessment of the volume of wood generated by the 2010 landslide, as well as post-event conditions evaluated through oblique photographs collected since the landslide event.

For the LWD assessment and inventory, the Lillooet River has been divided into three characteristic reaches:

- ***Downstream of the dyked reach*** extends upstream from the Lillooet River delta at the lake upstream approximately 9 km to the Pemberton Airport;
- ***Dyked reach*** continues from the Pemberton Airport approximately 31 km upstream to the Forestry Bridge; and
- ***Upstream of the dyked reach*** which extends from the Forestry Bridge upstream to the Meager Creek confluence.

3.1 PRE-2010 LANDSLIDE LWD CONDITIONS

The following section presents the inventory of LWD preceding the 2010 landslide. Also included is a brief discussion of the stability of LWD and log jams following the 2003 flood event in the Lillooet River (as a comparison between the 1999 and 2009 orthophotos).

2003 FLOOD EVENT

In October 2003, the Lillooet River experienced a flow event at the Water Survey of Canada (WSC) station near Pemberton (08MG005) that was approximately equal to the estimated 200-year return period flood.

The availability of 1999 orthophotos, in combination with the severe 2003 flood, provides an opportunity to evaluate pre-flood LWD condition and post-flood LWD condition in the Lillooet River, and to allow for some comment on the stability of existing LWD jam structures in the river.

Photographs taken following the 2003 flood event are shown below. Photo 3-1 gives an indication of the amount of wood transported into the Lillooet Lake during the October 2003 event. Photo 3-2 shows a debris jam upstream of the Lillooet delta under high flow conditions following the 2003 flood event.

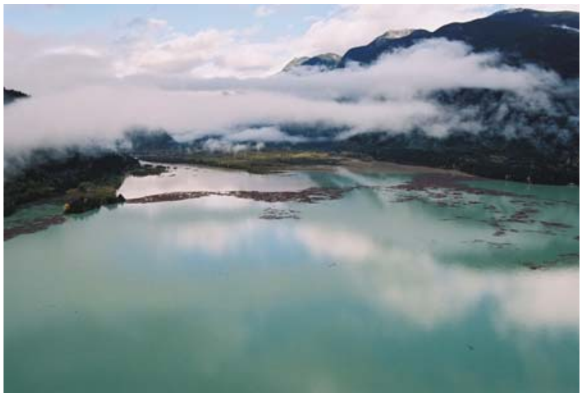

Photo 3-1
Wood in Lillooet Lake (November 5, 2003)

Photo 3-2
Back Channel and Bar Apex Jam Complex Upstream of the Lillooet Lake Delta (November 5, 2003)

LILLOOET RIVER LWD CONDITIONS PRE-2010 LANDSLIDE

LWD has been located and mapped based on the 1999 and 2009 orthophotos. Locations of identified LWD and log jams are shown on the updated maps in Appendix B.

The basemaps in Appendix B are from the Lillooet River Corridor Study[6], and have been updated to include:

- 2009 orthophotos, and
- dyke and erosion protection repairs and upgrades completed since 2002.

Examples of mapped LWD for different locations along the river are shown in Figures 3-1 through 3-4, and pre-2010 landslide LWD conditions are summarized by reach in the following sections.

Downstream of Dyked Reach

The reach between Pemberton Airport and the lake delta had a number of complex jam formations associated with vegetated islands and back channels (e.g. Figure 3-1).

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[6] Kerr Wood Leidal and Associates Ltd. (KWL). 2002. Engineering Study for Lillooet River Corridor. Prepared for Pemberton Valley Dyking District, Mount Currie Band, Indian and Northern Affairs Canada, and BC Ministry of Environment. December 2002.

A comparison of the 1999 and 2009 orthophotos indicates that the jam structures in the reach downstream of the Pemberton Airport are relatively stable, and that the jams did not recruit a significant amount of new material during the 2003 flood event (Figure 3-1). The log jams in this reach appear to have become more stable over the decade between 1999 and 2009, and the associated gravel bars have transitioned to vegetated islands. Some of the log jams identified in the 1999 orthophoto in Figure 3-1 are not identified in the 2009 photo as log jams per se because they appear to be functioning more as part of a vegetated island/bar complex, and less as a log-structure.

Dyked Reach

Development along the Lillooet River is concentrated within the dyked reach. The channel in this reach is relatively narrow, deep and straight, which promotes effective transport of LWD through the reach. However, because the river channel for the most part is confined by the dyke, this area is vulnerable to dyke breaches and erosion protection failure if large LWD jams do occur.

The dyked reach extends between the Pemberton Airport and the Forestry Bridge (approximately 40 km upstream of Lillooet Lake). In general, the 2009 photos show very little LWD within the dyked reach: the channel is relatively uniform and simple, with only a few back channels and island-bar complexes that recruit wood. Smaller jams are found at the head of vegetated bars and where the channel widens or where there are meanders (see Figures 3-2 and 3-3).

Within the dyked reach the following observations of LWD jams have been made:

- bar apex jams: 22 locations;
- back channel jams: 2 locations;
- bar top jams: 2 locations;
- fallen trees: 8 locations;
- single logs: 26 locations; and
- rafted logs: 12 locations.

Figures 3-2 and 3-3 show the 1999 and 2009 LWD mapping for two example locations along the dyked reach. In general, the amount of wood within the dyked reach did not increase significantly between 1999 and 2009 (e.g. Figure 3-2).

The largest change noted between 1999 and 2009 in the dyked reach is shown in Figure 3-3. At this location a single log is visible in the 1999 photos and a bar apex jam has formed in the 2009 photos. The single log (in combination with a small gravel bar) may have recruited more LWD to form a stable jam. This log jam, referred to as the ‘Miller Log Jam’, was examined in more detail during the May 2011 field investigations.

Upstream of Dyked Reach

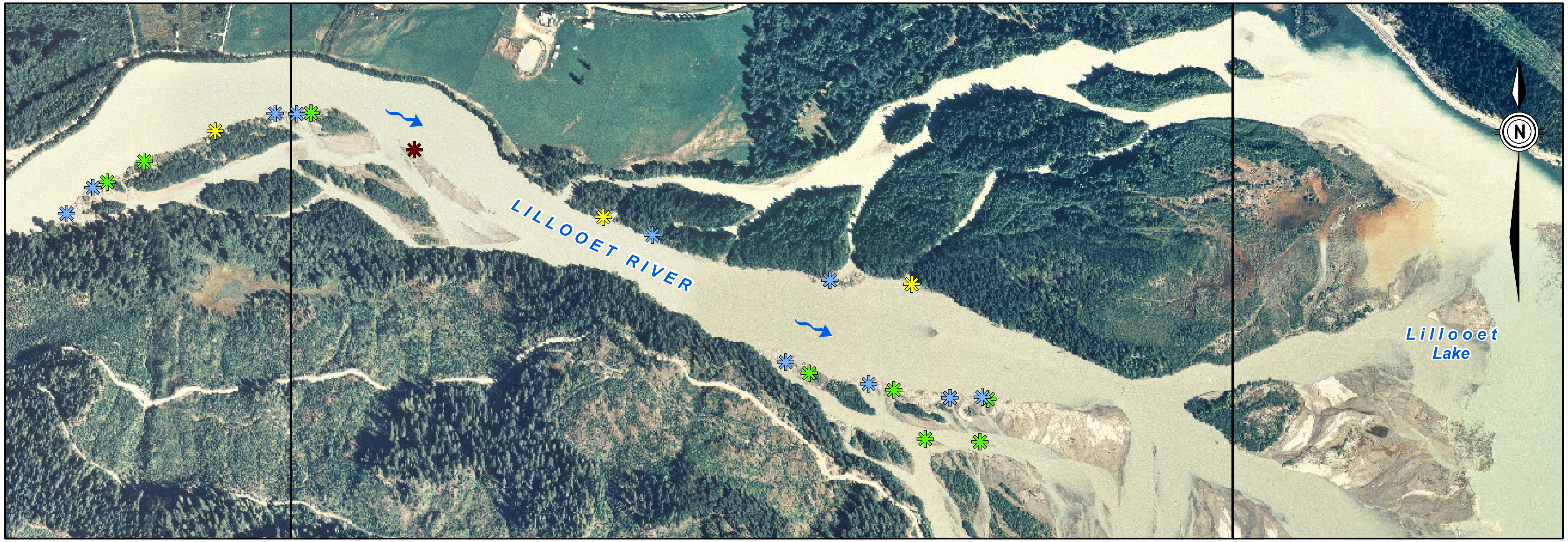
Upstream of the dyked reach, the river channel assumes a braided morphology starting about 2 km upstream of the Forestry Bridge. This reach of the river is shown in Appendix C using 2010 orthophotos as background imagery (photos were flown in July 2010, immediately before the 2010 landslide event).

The 1999 to 2009 LWD stability assessment could only be conducted for the 10 km of river upstream of the Forestry Bridge due to photo coverage; however, the results are likely to be characteristic of the entire reach.

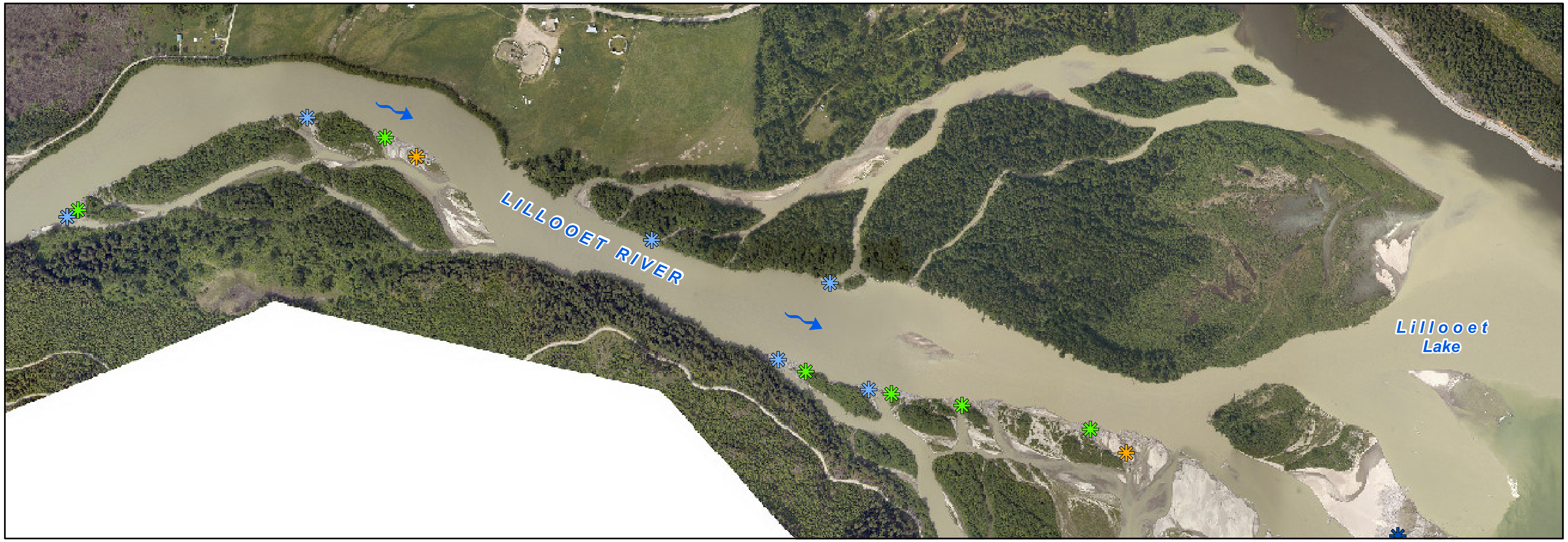
From the 1999, 2009 and 2010 orthophotos, it is evident that prior to the 2010 landslide event there was already a large amount of LWD stored within the active channel in the form of bar apex and bar top jams (e.g. Figure 3-4). Based on photo observations, this reach appears to function as a 'storage reach' for LWD.

Photo observations indicate that the braided reach upstream of the dyked reach is dynamic. Figure 3-4 shows a comparison of the 1999 and 2009 orthophotos that illustrates the shifting nature of the gravel bars within the channel and evidence of mobilization of rafted logs.

The number of log jams identified in Figure 3-4 between 1999 and 2009 has increased over that decade. Along the left bank (looking downstream) the bank has been eroded and two meanders have become more pronounced. It is likely that the increase in single logs and rafted logs immediately downstream of the erosion locations is the result of the mobilization and deposition of riparian vegetation within the river channel. In contrast, some of the log jams and key members appear to be relatively stable and have provided hard points that the channel has shifted around. Backchannels and vegetated island complexes also appear relatively stable and the photo comparison indicates growth of vegetation on a number of the stable island-bar complexes.



1999



2009

Pemberton Valley Dyking District
Large Woody Debris Assessment
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Legend

Large Woody Debris Inventory (Type)

- ✳ Back Channel Inlet Jam
- ✳ Bar Apex Jam
- ✳ Bar Top Jam
- ✳ Fallen Tree - Meander Jam Forming
- ✳ Meander Jam
- ✳ Rafted Logs
- ✳ Single Log

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Date
June 2011

Comparison of Wood Conditions Downstream of Dyked Reach

Figure 3-1

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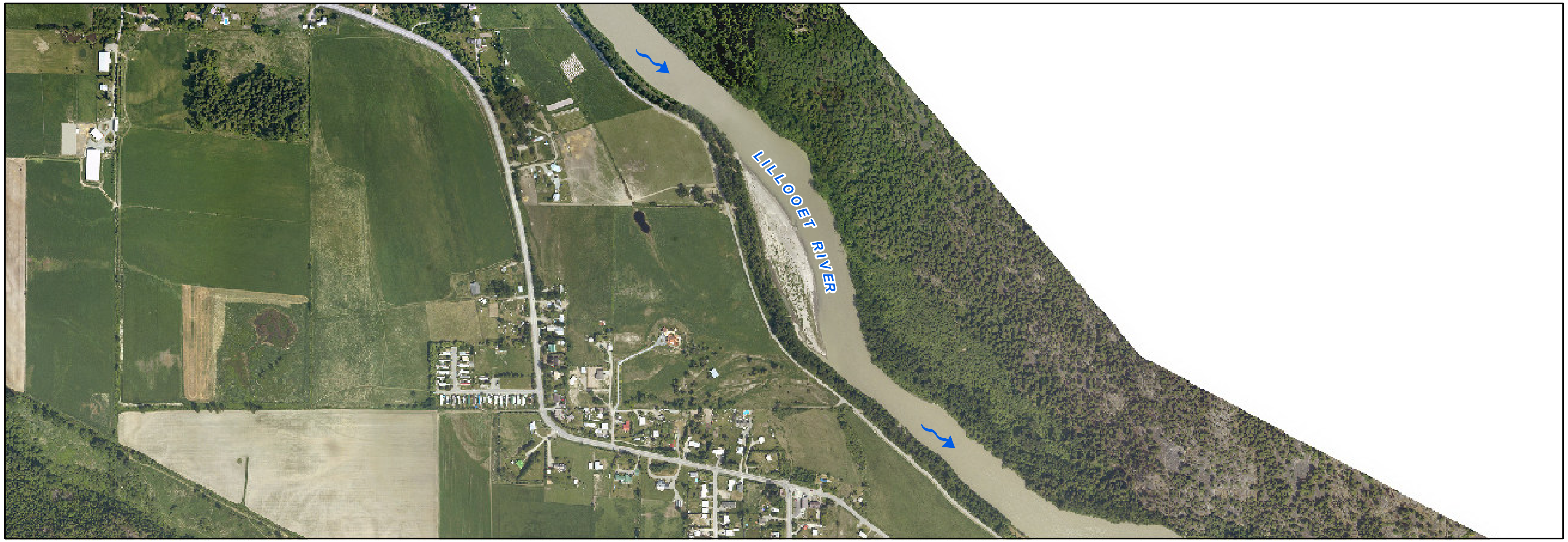
Author: JLau

1999



2009

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Author: JLau

Pemberton Valley Dyking District
Large Woody Debris Assessment
and Mitigation Plan

Legend

Large Woody Debris Inventory (Type)

✱ Back Channel Inlet Jam
✱ Bar Apex Jam
✱ Bar Top Jam
✱ Fallen Tree - Meander Jam Forming
✱ Meander Jam
✱ Rafted Logs
✱ Single Log

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Comparison of Wood Conditions in the Dyked Reach (1)

Figure 3-2

Pemberton Valley Dyking District
Large Woody Debris Assessment
and Mitigation Plan

1999

2009

Legend

Large Woody Debris Inventory (Type)

- ✳ Back Channel Inlet Jam
- ✳ Bar Apex Jam
- ✳ Bar Top Jam
- ✳ Fallen Tree - Meander Jam Forming
- ✳ Meander Jam
- ✳ Rafted Logs
- ✳ Single Log

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Comparison of Wood Conditions in the Dyked Reach (2)

Figure 3-3

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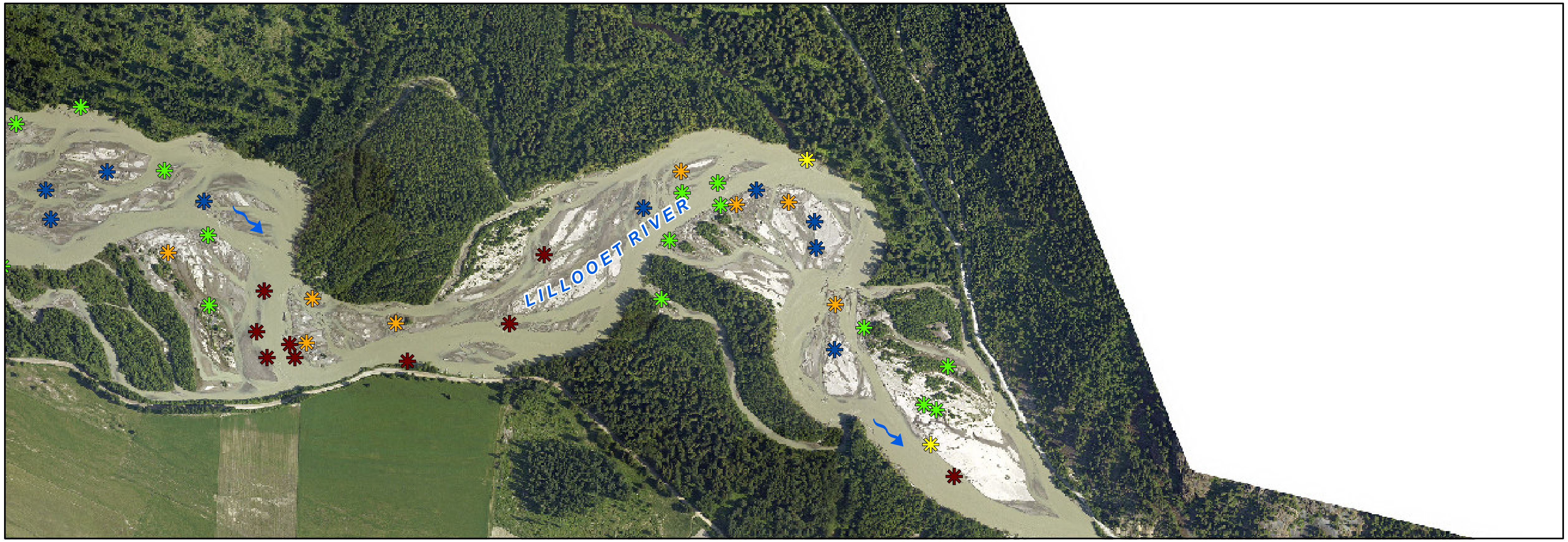
Author: JLau

1999



2009

Pemberton Valley Dyking District Large Woody Debris Assessment and Mitigation Plan

Legend

Large Woody Debris Inventory (Type)

- ✳ Back Channel Inlet Jam
- ✳ Bar Apex Jam
- ✳ Bar Top Jam
- ✳ Fallen Tree - Meander Jam Forming
- ✳ Meander Jam
- ✳ Rafted Logs
- ✳ Single Log

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Project No. 713-054

Date June 2011

Comparison of Wood Conditions Upstream of Dyked Reach

Figure 3-4

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Author: JLau

3.2 POST-2010 LANDSLIDE LWD CONDITIONS

LWD GENERATED FROM THE 2010 LANDSLIDE

Based on the GIS analysis, an estimated 110,000 m³ of wood was removed along the path of the August 6, 2010 Mount Meager landslide. This wood was either pulverized and incorporated into the mineral matrix of the landslide, or transported into the Lillooet River system as large woody debris. The wood is a mixture of deciduous and conifer species, although dominated by conifers. Additional details on the wood mobilized by the 2010 landslide are provided in Appendix D.

Of the 110,000 m³ of wood, much has been incorporated into the landslide deposit or was transported outside of the active channel. However, field investigations indicate that a large fraction of wood remains in the system as large woody debris. A portion of this material is likely to precede much of the sand wave that is expected to move through the Lillooet River over the next several years.

LILLOOET RIVER LWD CONDITIONS POST-2010 LANDSLIDE

The assessment of post-2010 landslide LWD conditions is based on site observations and oblique photos taken during August 2010 and May 2011 field investigations. At the time of writing, no air photographs have been flown of the Lillooet River following the landslide event.

Oblique air photographs were compared to the 2009 orthophotos from the Lillooet River delta to the Forestry Bridge and to the July 2010 orthophotos from the Forestry Bridge to Meager Creek.

Oblique photos were collected during two separate field investigations:

- helicopter and fixed wing aircraft flights on August 7 and 13, 2010, shortly after the landslide event (photos provided by PVDD); and
- helicopter flight on May 25, 2011, about 9 months post-landslide (photos by PVDD and KWL).

A selection of oblique photographs from the August 2010 and May 2011 flights are shown in Appendices E and F, respectively and discussed below.

Further investigations were conducted by boat on May 26, 2011 to visit specific locations of interest flagged during the overview flight.

September 2010 Flood Event

On September 28, 2010 (post-landslide), a 10- to 20-year return period flood event occurred on the Lillooet River. During the event, mobilization and transport of LWD was observed within the dyked reach (e.g. Photos 3-3 and 3-4 below). It is expected that some LWD material from the landslide event would have been mobilized and redistributed in the river or transported to the lake during the high flow event (and therefore would not have been observed during the May 2011 field investigations).

Photo 3-3
Airport Road (September 28, 2010)
(Photo courtesy of Jeff Westlake)

Photo 3-4
Footbridge (September 28, 2010)
(Photo courtesy of Jeff Westlake)

In addition to the September 2010 flood event on the Lillooet River, a second complicating factor is the smaller Capricorn Creek rock avalanche event that occurred in 2009 (see Table 2-2). This rock avalanche likely would have mobilized some wood into the channel which is difficult to distinguish from the 2010 landslide material. For this assessment, no attempt has been made to distinguish between 2009 and 2010 landslide material and new wood observed during the field investigations is assumed to have been generated as part of the much larger 2010 landslide event.

Downstream of Dyked Reach

Downstream of the dyked reach, very little change is evident between the 2009 orthophotos and 2011 conditions observed during field investigations. The LWD and log jams at back channel openings and at vegetated bars appear stable and do not appear to have recruited considerable volumes of wood since 2009 (Appendix C, Map 1 of 11; Appendix F, Photos F-1 and F-2).

Dyked Reach

In general, there is little change in LWD conditions detected pre- and post-landslide in the dyked reach. Some smaller wood material from the landslide event may have been transported into the dyked reach and been incorporated into the existing LWD jams;

however, it is difficult to determine if this material is from the 2010 landslide event or from other sources.

The existing gravel bars have little or no wood accumulation (Appendix F, Photos F-3 to F-5). Following the landslide, the Miller Log Jam appears to have accumulated sediment (Appendix F, Photo F-6). However the comparison of photos is influenced by the water levels at the time of investigations, which are lower in May 2011 than those captured by the 2009 orthophoto (and therefore will expose more of the gravel bar, all else being equal).

Upstream of Dyked Reach

In general, photos of the braided reach show wood evident on the gravel bars and within the floodplain both before and after the landslide event (Appendix F, Photos F-8 to F-12 and Appendix C).

2011 oblique photos show new (un-weathered) LWD material within the braided reach (Appendix E, Photo E-7 and Appendix F, Photo F-9). Some existing gravel bars and log jams have new racked logs or new wood incorporated into the bar top jams, which is likely sourced from either the 2010 landslide and/or the earlier (smaller) 2009 rock avalanche (Table 2-2). The approximate downstream extent of the newer, racked wood observed during the May 2011 flight is shown on Figure C5 in Appendix C.

Many of the larger, more intact trees from the 2010 landslide event appear to have been pushed to higher elevations along the floodplain (Appendix F, Photo F-10). As a result, these trees are unlikely to be mobilized by regular high flow events on the Lillooet River and are more likely to enter the active channel through slower weathering and erosion processes, or through less common events (e.g., landslide blockage and associated outburst flood).

Much of the wood that was transported into the Lillooet River channel by the 2010 landslide was shattered into smaller pieces and is part of the organic matter being trapped by existing bar top and other LWD jam structures (Appendix F, Photos F-11 and F-12). This material is easily mobilized and transported through the system.

Section 4

Large Woody Debris Assessment

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4. LARGE WOODY DEBRIS ASSESSMENT

4.1 WOOD STABILITY

Potential stability of LWD in the Lillooet River was assessed using a force-balance approach. This is an estimate of the stability of individual pieces of LWD on bar tops and within the active channel.

The existing hydraulic model of the Lillooet River has been used to estimate velocities and bankfull depths in the braided reach. As part of the emergency response to the 2010 landslide event, the hydraulic model was extended upstream from the Forestry Bridge to the Meager Creek confluence.

Based on modeled velocities and bankfull depths, an estimate has been made of the forces acting on logs in this reach. The size of stable logs (with attached rootwads) has been estimated using a force balance approach. Forces considered in the analysis include:

- buoyancy;
- lift;
- weight of the log; and
- the friction force between the log and the bed with the force of flow on the log.

Characteristic log dimensions are estimated based on representative measurements collected during field investigations. The analysis was conducted for a discharge of about 475 m^3/s (estimated bankfull discharge in braided reach).

The results of the force balance for different characteristic log dimensions are summarized in Table 4-1. The results indicate that at the estimated bankfull discharge, logs up to 0.83 m diameter at breast height (DBH) and 29 m in length would be mobilized.

It should be noted that the assessment does not take into consideration the interaction between logs and the effect of partial burial of key members on the stability of log jams. Interlocking logs (such as normal, racked members of a bar apex jam) and partially buried key members of the log jams are more stable than individual pieces.

Table 4-1: Log Stability Summary

Log Diameter (m)	Log Length (m)	Root Wad Diameter (m)	Mobilized at 475 m³/s? (Y/N)
0.83	18	1.8	Y
0.48	6	1.3	Y
0.54	14	1.7	Y
0.60	16	1.5	Y
0.38	29	2.6	Y
0.83	26	2.5	Y

4.2 POTENTIAL LOCATIONS OF CONCERN

GENERAL MONITORING LOCATIONS

General monitoring locations have been identified as part of the assessment and are shown in the updated mapping mentioned in Section 3.1 (Appendix B). The general monitoring locations within the dyked reach include:

- River Crossings (7 locations):
  - Forestry Bridge;
  - cable crossing;
  - pedestrian footbridge;
  - waterline crossing (2 locations);
  - Railway Bridge; and
  - Highway 99 Bridge;

- Gravel Bars / Islands (20 locations);

- Back Channels (7 locations – associated with gravel bars and islands);

- Existing LWD Locations:
  - bar apex jams: 22 locations;
  - back channel jams: 2 locations;
  - bar top jams: 2 locations;
  - fallen trees: 8 locations;
  - single logs: 26 locations; and
  - rafted logs: 12 locations.

The general monitoring locations are ones that do not appear to currently pose a hazard to existing flood and erosion protection. If these locations recruit a large amount of LWD, there is potential for them to become high priority locations and as such they should be monitored every 5 and 10 years (as discussed in the Mitigation Plan, Section 5).

HIGH PRIORITY LOCATIONS

There are five general monitoring locations within the dyked reach that are considered a higher priority for monitoring due to the consequence of failure and existing potential to cause failure of the flood and erosion protection. These locations will be identified and discussed in more detail in the Mitigation Plan (Section 5).

One existing jam was identified during the assessment that could potentially cause concern for increased flood risk is the Miller Log Jam, located about 14 km downstream of the Forestry Bridge (Figure 4-1). The Miller Log Jam is creating a channel constriction due to the jam and associated gravel bar. The jam is located downstream of a bedrock outcrop, the dyke is immediately adjacent to the river and the channel at this location is relatively narrow. The dyke is protected by riprap, and the left bank is lower than the right bank dyke, providing some potential overbank flow relief.

More information is needed to determine if the channel constriction caused by the log jam is sufficient to increase localized flood levels, and how flood levels might impact the right bank dyke. Currently, survey data is being collected along the Lillooet River including at this location and this information could be used to assess the local flood levels.

The Miller Log Jam should be monitored as one of the five high priority locations as part of the LWD mitigation plan.

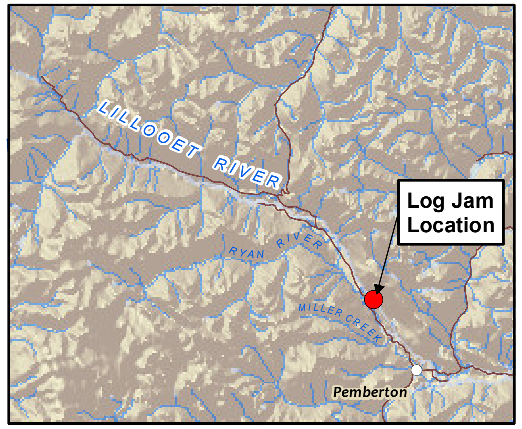
Pemberton Valley Dyking District Large Woody Debris Assessment and Mitigation Plan

Legend

● Photo Location

— Existing Dyke

Key Map



Reference: Orthophoto flown May 2009

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Project No.	Date
713-054	June 2011

Miller Bar Log Jam Location

Figure 4-1

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Author: JLau

Section 5

Large Woody Debris Mitigation Plan

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CONSULTING ENGINEERS

5. LARGE WOODY DEBRIS MITIGATION PLAN

The LWD mitigation plan is comprised of three main elements:

1. LWD monitoring within the dyked reach;
2. LWD response options; and
3. an early warning system for events in the upper watershed.

It is important to note that the mitigation plan cannot protect against all hazards associated with LWD within the Lillooet River system. The dynamic nature of the river flows, sediment and wood transport and uncertainties associated with the interaction between infrastructure and LWD make it difficult to predict all areas where LWD may cause a problem.

The monitoring locations identified as part of the mitigation plan reflect the LWD conditions of the Lillooet River at this time and should not be thought of as an exhaustive list. There is an unpredictable element to determining where log jams will ultimately form (especially during extreme flow events and given the interaction between bank erosion and mobilization or deposition of riparian trees into the river) so regular general monitoring of the Lillooet River and emergency monitoring are both necessary to mitigate LWD hazards.

5.1 LARGE WOODY DEBRIS MONITORING

Based on 1999, 2009, and 2010 orthophotos and 2011 oblique photos, there is a large volume of wood in the river upstream of the Forestry Bridge. However, large-scale removal of LWD would be impractical, both difficult and costly, and future landslide events and riparian processes would continue to mobilize more LWD into this reach. In addition, if all LWD were removed from this reach, it would likely increase the sediment transport into the dyked reach, since stable LWD provides roughness elements that change velocity patterns and encourage local deposition of sediment. Stable LWD jams also provide structural elements that anchor some gravel bars; removing this structure could de-stabilize these bars.

Instead, we propose that monitoring for hazardous accumulations of LWD within the dyked reach should be completed as part of the mitigation plan. Three general categories of monitoring activities are suggested for the dyked reach:

1. High priority location monitoring;
2. Emergency condition monitoring; and
3. General monitoring/LWD assessment updates.

HIGH PRIORITY MONITORING

High priority monitoring have been chosen due to the concern over the existing condition and/or the high consequence of failure of the adjacent infrastructure. The high priority monitoring falls into two categories:

1. High flow event monitoring; and
2. Repeat photo monitoring.

<u>Locations:</u>
The high priority monitoring locations are summarized in Figure 5-1. There are five high priority locations for monitoring:

- Highway 99 Bridge;
- Railway Bridge;
- Forestry Bridge;
- Footbridge (14 km downstream of the Forestry Bridge); and
- Miller Log Jam.

The Highway 99, Railway Bridge and Forestry Bridge crossings should be considered high priority monitoring locations due to the high consequence of failure. These structures have been designed for conveyance during high water events and the potential for failure is relatively low; however, the consequence of failure is high enough to warrant monitoring.

The footbridge crossing near the Miller Log Jam (Photos 5-1 and 5-2, Figure 5-1). This crossing is low and has a high potential to accumulate wood during a flood event (Photo 5-1). The PVDD should consult with the local land owner regarding the potential to remove the footbridge to prevent LWD accumulation and/or failure.

Photo 5-1
Footbridge Collecting LWD
(September 28, 2010)

Photo 5-2
Footbridge (May 26, 2011)

The Miller Log Jam (Appendix B, Map 7 of 11) creates a channel constriction that may result in increased flood levels. The erosion protection along the dyke should be monitored for signs of wear and possible failure.

High Flow Event Monitoring:
High flow event monitoring could be done during and after high flow events (where safety constraints allow), as part of high-water patrol activities. Flood events greater than a 5-year return period flow (>740 m^3/s instantaneous at WSC 08MG005), should be considered for high flow event LWD monitoring. Monitoring should also be conducted after large debris flow or landslide events within the upper watershed.

High flow event monitoring is recommended at the five locations identified above. This monitoring could be incorporated into the existing high water patrol activities currently undertaken by the PVDD.

Repeat Photo Monitoring:
A repeat photo monitoring location has been set up for Miller Log Jam (Figure 5-1). It is recommended that repeat photos be incorporated into the annual inspection of flood protection works carried out by PVDD.

Annual inspection of flood protection works should also include a visual inspection of the four high priority bridge crossings for increases in accumulating LWD and for wear and potential failure of associated erosion protection.

EMERGENCY CONDITION MONITORING

In addition to the high flow event monitoring of the five high priority locations, there is a separate emergency condition monitoring that should take place whenever emergency response measures are triggered. The emergency condition monitoring should include an areal survey (helicopter or fixed wing aircraft) of the Lillooet River system from the Lillooet Lake narrows to the Meager Creek confluence by PVDD, local and provincial emergency response authorities, and a qualified professional engineer with experience in emergency response and recovery.

GENERAL MONITORING/LWD ASSESSMENT UPDATES

The general monitoring locations are summarized in the updated mapping in Appendix B. These location do not appear to currently pose a hazard to existing flood and erosion protection. If LWD conditions change at these locations, there is potential for them to become high priority sites and as such they should be monitored regularly.

General monitoring comprises of two main components:

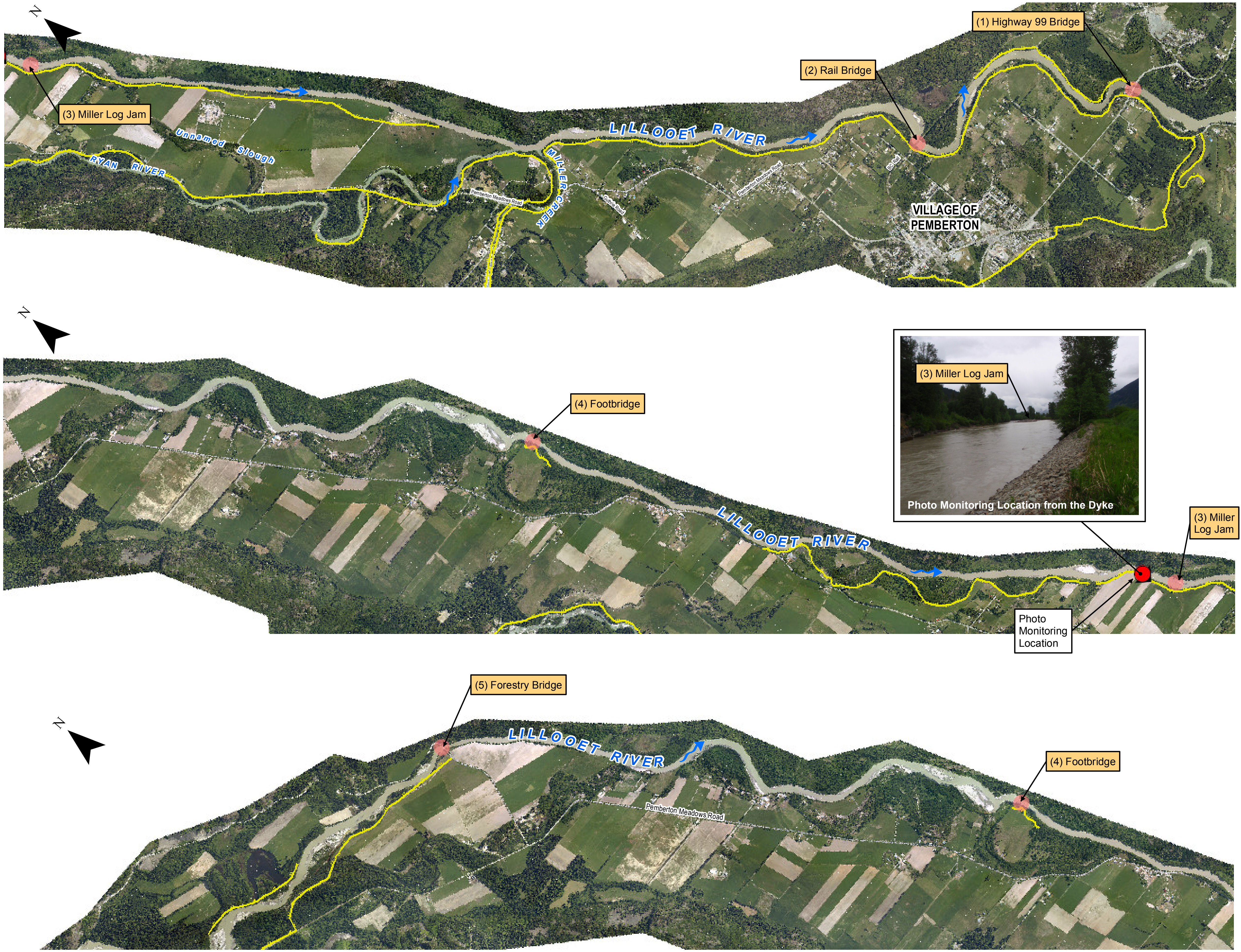
1. Helicopter monitoring; and
2. Orthophoto assessment.

It is recommended that a helicopter survey be completed every 5 years to evaluate LWD conditions in the Lillooet River between the Lillooet River delta and Meager Creek confluence.

Collecting and analyzing orthophotos every 10 years to compare LWD conditions and identify locations where LWD jams are forming or enlarging is also recommended. Table 5-1 presents a Class 'D' cost estimate for the repeat photo monitoring and helicopter monitoring recommended above.

Table 5-1: Class 'D' Cost Estimate for General Monitoring/LWD Assessment Updates

Description	Cost	Comments
Helicopter Monitoring (5 Year Cycle)	\$7,000 to \$10,000	Assumes a Jet Ranger or equivalent flying from Lillooet Lake delta to Meager Creek confluence. Assumes a water resource engineer and geomorphologist included in the flight.
Orthophoto Review (10 Year Cycle)	\$12,000 to \$15,000	For area between Lillooet Lake delta and Forestry Bridge. Office time for engineering and geomorphic analysis of LWD conditions within the dyked reach.



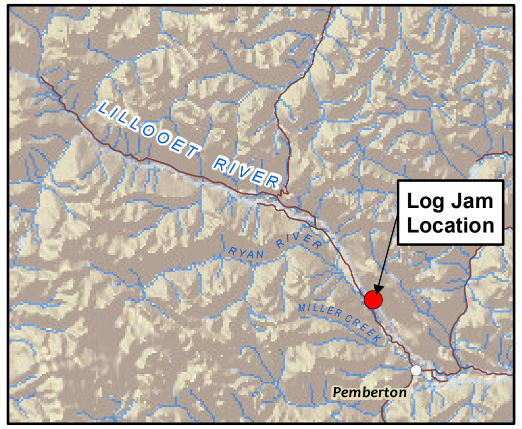
Pemberton Valley Dyking District
Large Woody Debris Assessment
and Mitigation Plan

Legend

● Photo Location

— Existing Dyke

Key Map



Reference: Orthophoto flown May 2009

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Project No.	Date
713-054	June 2011

High Priority Monitoring Locations

Figure 5-1

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Author: JLau

5.2 RESPONSE OPTIONS

In the event that high flow event or repeat photo monitoring indicates a LWD jam that is likely to become a hazard, there are a number of options as response measures. The response will depend on the situation, the immediacy of the threat or severity of the hazard and the river conditions at the site of the log jam.

Possible response includes:

- Removing the log jam using heavy machinery or helicopter (depending on access, logistics and safety).
- Removing the racked wood in the log jam to control the size of the channel constriction.
- Creating floodplain channels to provide flood conveyance where land availability and access permit.
- Constructing set-back dykes to allow for increased flood conveyance.
- Raising the dykes along a section to deal with increases in localized flood levels around a jam.

A cost estimate for response options for addressing hazardous log jams would have to be addressed on a case-by-case basis as the costs will be heavily dependant on local conditions, access and scale of the response.

5.3 EARLY WARNING SYSTEM

Early warning systems can be installed to warn of natural hazards such as earthquakes, tsunamis, floods and other hazards. The Village of Pemberton and local properties near the Lillooet River are subject to flooding due to several natural occurrences, which include floods from rainfall and snowmelt events, debris jams, and outburst floods due to landslides blocking the channel. A warning system could be employed to warn local community officials of these events.

Three types of hazards have been identified as candidates for monitoring by the early warning system, including:

- floods from rainfall and/or snowmelt;
- outburst floods from debris jams blocking the river; and
- debris jams located at the Forestry Bridge.

Debris jams located in other areas of the Lillooet River are not discussed as part of this work as they are very difficult to predict and would be best addressed through visual inspections. If debris jams impound water and subsequently break, they could be detected in a similar manner to outburst floods.

Appendix G outlines information regarding data needs and system components and technology for an early warning system. A Class 'D' cost estimate for system components is also presented in the appendix.

An early warning system should be installed at the Forestry Bridge, approximately 23 km upstream of the WSC hydrometric gauge (08MG005). This site is close to power and telephone lines and appears to have adequate line-of-sight for geostationary satellite telemetry. The early warning system could record water levels and collect photo data that would be easily accessible by the PVDD and local emergency response authorities remotely.

More discussion with PVDD should be held to determine the recommended system components and data needs for an early warning system incorporating the future plans for a WSC gauge near this location.

Section 6

Conclusions and Recommendations

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Although there have only been ten months since the 2010 landslide event on Mount Meager, the initial LWD assessment indicates that the potential LWD hazards within the dyked reach of the Lillooet River are not as bad as might have been expected given the size of the landslide.

The LWD inventory indicates that the braided reach of the Lillooet River (upstream of the dyked reach) has a large number of log jams and stores a large amount of wood. Although the 2010 landslide is estimated to have mobilized about 110,000 m^3 of wood, the nature of the braided reach upstream of the dyked reach to act as a storage location for LWD mitigates at least some of the potential associated downstream flood hazard.

When mobilized, wood travels at a similar velocity to river flow. However, much of the LWD in the Lillooet system is likely to move much more slowly downstream as it is stored and released from existing jams upstream of the dyked reach.

The dyked reach is of particular concern, since development along the Lillooet River is concentrated in this reach. The channel in the dyked reach is relatively narrow, deep and straight, which promotes effective transport of LWD through the reach. Based on the review of available orthophotos, there are comparitively few locations where LWD jams could potentially form in the dyked reach.

However, because the river channel is relatively confined by the dykes, this reach is vulnerable to dyke breaches if large LWD jams do occur. As part of the long-term planning for flood protection in this area, consideration should be given to constructing set-back dykes to allow the river more space to shift as necessary, which would be the river’s natural response to log jams.

The LWD assessment includes a summary of the most likely locations that could accumulate LWD and potentially form a jam within the dyked reach. These general monitoring locations represent the most likely log jam formation locations that can be identified at this time; however, there is a great deal of uncertainty when trying to predict where log jams might form. As such, these general monitoring locations should be incorporated into baseline monitoring of the larger river system.

The general monitoring locations within the dyked reach (approximately 106 locations in the 31 km between the Pemberton Airport and the Forestry Bridge) include:

- river crossings:
- gravel bars / islands;

- back channels; and
- existing LWD locations.

These locations, along with the entire river from Lillooet Lake to the Meager Creek confluence, should be part of a general monitoring program to help shape emergency response and long-term flood hazard mitigation planning, and provide better understanding of the LWD conditions of the river. This monitoring should be done not just in response to the landslide event.

From the larger list of general monitoring locations, five sites have been identified as being higher priority monitoring locations based on concern over the existing conditions and/or the high consequence of failure of the adjacent infrastructure.

Recommendations from the LWD assessment are summarized below.

6.2 RECOMMENDATIONS

A LWD mitigation plan has been developed for the Lillooet River. We recommend that the mitigation plan be implemented by the PVDD and local emergency response authorities:

1. Monitor high priority locations:
    - Perform high flow event monitoring at 5 high priority locations within the dyked reach. Look for changes to wood accumulation during and after events larger than a 5-year return period flow and as part of the annual dyke inspection.
    - Conduct repeat photo monitoring at Miller Log Jam annually, including inspection of the erosion protection works adjacent and upstream of the log jam.

2. Conduct general monitoring/LWD assessment updates:
    - Complete helicopter monitoring every 5 years of the general monitoring locations from the Meager Creek confluence to the Lillooet River delta to track evolving LWD conditions.
    - Complete an orthophoto review and LWD assessment update every 10 years within the dyked reach.

3. Carry out emergency condition monitoring:
    - Conduct helicopter monitoring of the system from the Meager Creek confluence to the Lillooet Lake Narrows whenever the emergency response measures are triggered for the Lillooet River.

4. Plan and implement an early warning system at the Forestry Bridge, in consultation with Water Survey Canada (WSC), to provide improved warning for future events.

5. Do not conduct LWD removals at this time:

- *Upstream of the Forestry Bridge* - large-scale removals of LWD are not recommended, as the costs would be prohibitive and might result in undesirable downstream impacts.
- *Within the dyked reach* - at this time there are no locations where site-specific log jam removals are recommended. This includes Miller Log Jam, as more information is required to determine the degree of hazard and appropriate response.

6. Engage a qualified professional engineer to conduct a hydraulic assessment (using new survey) at the Miller Log Jam to evaluate the degree of hazard to adjacent flood and erosion protection works and recommend appropriate response, if required.

7. If future monitoring identifies that a large LWD jam has formed within the dyked reach:
   - Determine the degree of hazard and appropriate response.
   - Consider response actions depending on local river conditions, environmental constraints, access, severity of the hazard and immediacy of failure of flood and erosion protection works.

8. Consult with the local land owner regarding the potential removal of the footbridge upstream of Miller Creek.

6.3 REPORT SUBMISSION

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

June 16, 2011
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June 16, 2011
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Reviewed by:

KERR WOOD LEIDAL ASSOCIATES LTD.

June 16, 2011
S. F. JOYCE
27627

Stefan Joyce, P.Eng.
Senior Water Resources Engineer

STATEMENT OF LIMITATIONS

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REVISION HISTORY

Revision #	Date	Status	Revision	Author
0	April 5, 2011	DRAFT		SJL / EE
1	June 15, 2011	FINAL	Updated to include results from the field investigations	SJL

Appendix A

Meager Creek Landslide Photos (August 2010),

Courtesy of R. Guthrie

KERR WOOD LEIDAL
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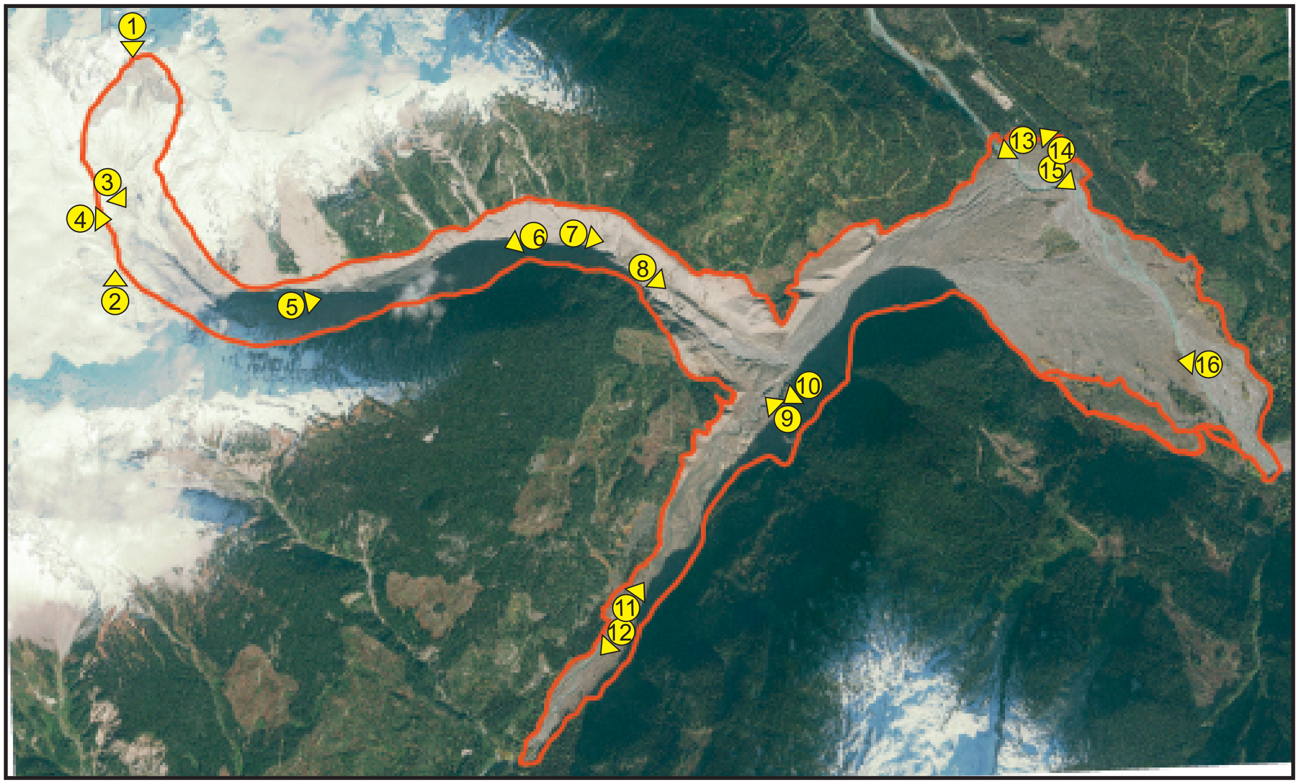
CONSULTING ENGINEERS



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Appendix B

Updated Mapping

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Notes	
Produced by:	Kerr Wood Leidal Associates Ltd.
Survey:	River Survey: (2000) by Atek Hydrographic Surveys Ltd Control Survey: RTK GPS by KWL and Bazett Land Surveying. Vertical Datum CVD 28
Sources:	2009 Digital Orthophoto provided by Mt. Currie Band. NAD 83 UTM (Zone 10), flown May 2009. Lillooet River discharge for orthophoto 204 m^3/s First Nations reserve boundary from NRCAN Canada Lands Digital Cadastral data.

Legend

- ▭ Reserve Boundary
- △△△ Riprap
- ▨ 2000 Modelled Area Boundary
- ---- Design Flood Level
- ⌖ Survey Monument
- ⑧ Floodplain Area (BC Ministry of Environment Report, 1985)

Constructed Dyke

- 🟪 Not Modelled
- 🟩 Q200 not within 0.3 m of Crest
- 🟧 Q200 within 0.3 m of Crest
- 🟥 Q200 Overtops Dyke

Cross Section

- 🟥 2001
- 🟦 Prior to 2001

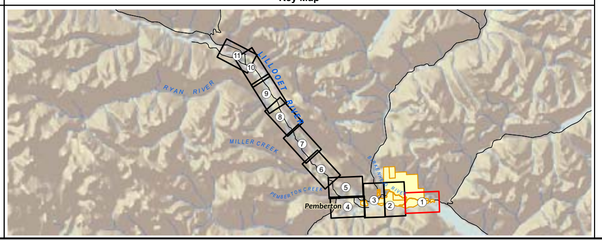
Large Woody Debris Inventory

- ✳ Back Channel Inlet Jam
- ✳ Bar Apex Jam
- ✳ Bar Top Jam
- ✳ Fallen Tree - Meander Jam Forming
- ✳ Meander Jam
- ✳ Rafted Logs
- ✳ Single Log

General Monitoring Locations

- ▲ Back Channels
- ▲ Bridge Crossings
- ▲ Cable Crossings
- ▲ Island/Bar

Key Map



KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Large Woody Debris Assessment
Updated Design Flood Levels
for Lillooet River and Birkenhead River

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Date	Project No.	Checked
June 2011	713-054	SL
Sheet No.	**Drawn**	**Approved**
1 of 11	JL	

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Author: JLau

Notes

Produced by: Kerr Wood Leidal Associates Ltd.

Survey: River Survey: (2000) by Atek Hydrographic Surveys Ltd
Control Survey: RTK GPS by KWL and Bazett Land Surveying. Vertical Datum CVD 28

Sources: 2009 Digital Orthophoto provided by Mt. Currie Band. NAD 83 UTM (Zone 10), flown May 2009.
Lillooet River discharge for orthophoto 204 m^3/s

First Nations reserve boundary from NRCAN Canada Lands Digital Cadastral data.

Legend

- ▭ Reserve Boundary
- △△△△ Riprap
- ▨ 2000 Modelled Area Boundary
- - - - - Design Flood Level
- ⌖ Survey Monument
- ⑧ Floodplain Area (BC Ministry of Environment Report, 1985)

Constructed Dyke

- 🟪 Not Modelled
- 🟩 Q200 not within 0.3 m of Crest
- 🟧 Q200 within 0.3 m of Crest
- 🟥 Q200 Overtops Dyke

Cross Section

- 🟥 2001
- 🟦 Prior to 2001

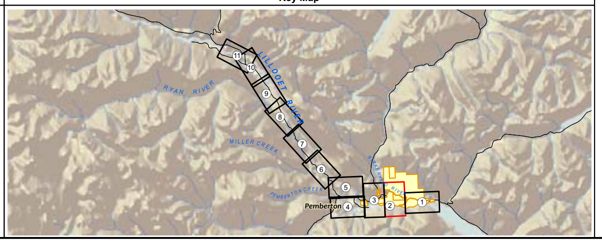
Large Woody Debris Inventory

- ✱ Back Channel Inlet Jam
- ✱ Bar Apex Jam
- ✱ Bar Top Jam
- ✱ Fallen Tree - Meander Jam Forming
- ✱ Meander Jam
- ✱ Rafted Logs
- ✱ Single Log

General Monitoring Locations

- ▲ Back Channels
- ▲ Bridge Crossings
- ▲ Cable Crossings
- ▲ Island/Bar

Key Map



KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Large Woody Debris Assessment
Updated Design Flood Levels
for Lillooet River and Birkenhead River

100 0 100 (m)
1:5,000

Date June 2011	**Project No.** 713-054	**Checked** SL
Sheet No. 2 of 11	**Drawn** JL	**Approved**

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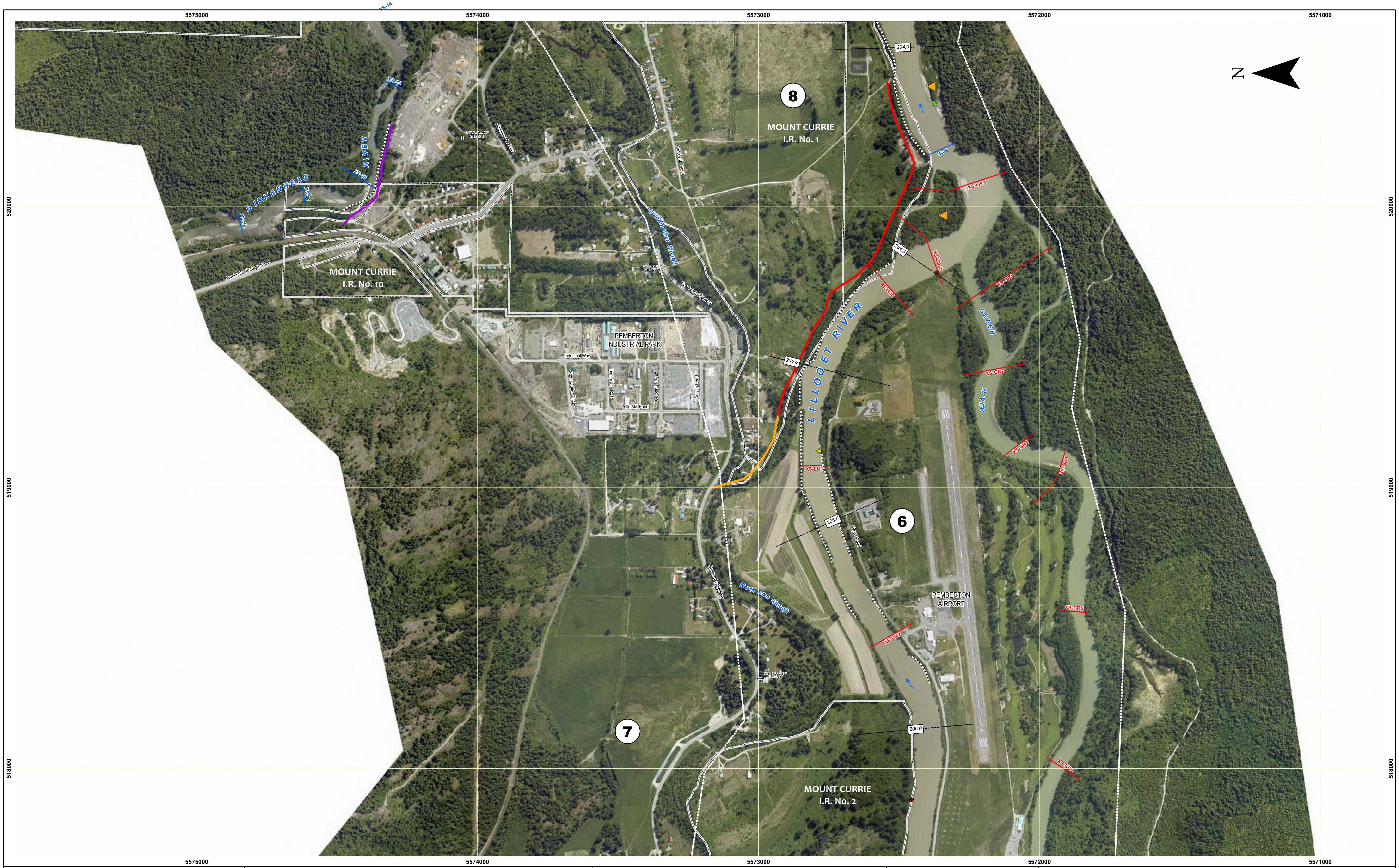


Notes

Produced by: Kerr Wood Leidal Associates Ltd.

Survey: River Survey: (2000) by Atek Hydrographic Surveys Ltd
Control Survey: RTK GPS by KWL and Bazett Land Surveying. Vertical Datum CVD 28

Sources: 2009 Digital Orthophoto provided by Mt. Currie Band. NAD 83 UTM (Zone 10), flown May 2009.
Lillooet River discharge for orthophoto 204 m^3/s

First Nations reserve boundary from NRCAN Canada Lands Digital Cadastral data.

Legend

- ▭ Reserve Boundary
- △△△△△ Riprap
- ▨ 2000 Modelled Area Boundary
- ----- Design Flood Level
- ⌖ Survey Monument
- ⑧ Floodplain Area (BC Ministry of Environment Erport, 1985)

Constructed Dyke

- 🟪 Not Modelled
- 🟩 Q200 not within 0.3 m of Crest
- 🟧 Q200 within 0.3 m of Crest
- 🟥 Q200 Overtops Dyke

Cross Section

- 🟥 2001
- 🟦 Prior to 2001

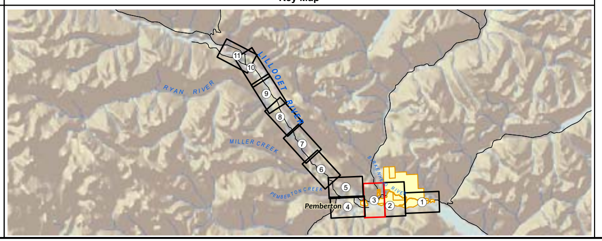
Large Woody Debris Inventory

- ✱ Back Channel Inlet Jam
- ✱ Bar Apex Jam
- ✱ Bar Top Jam
- ✱ Fallen Tree - Meander Jam Forming
- ✱ Meander Jam
- ✱ Rafted Logs
- ✱ Single Log

General Monitoring Locations

- ▲ Back Channels
- ▲ Bridge Crossings
- ▲ Cable Crossings
- ▲ Island/Bar

Key Map



KERR WOOD LEIDAL
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Large Woody Debris Assessment
Updated Design Flood Levels
for Lillooet River and Birkenhead River

100 0 100 (m)
1:5,000

Date June 2011
Project No. 713-054
Checked SL
Sheet No. 3 of 11
Drawn JL
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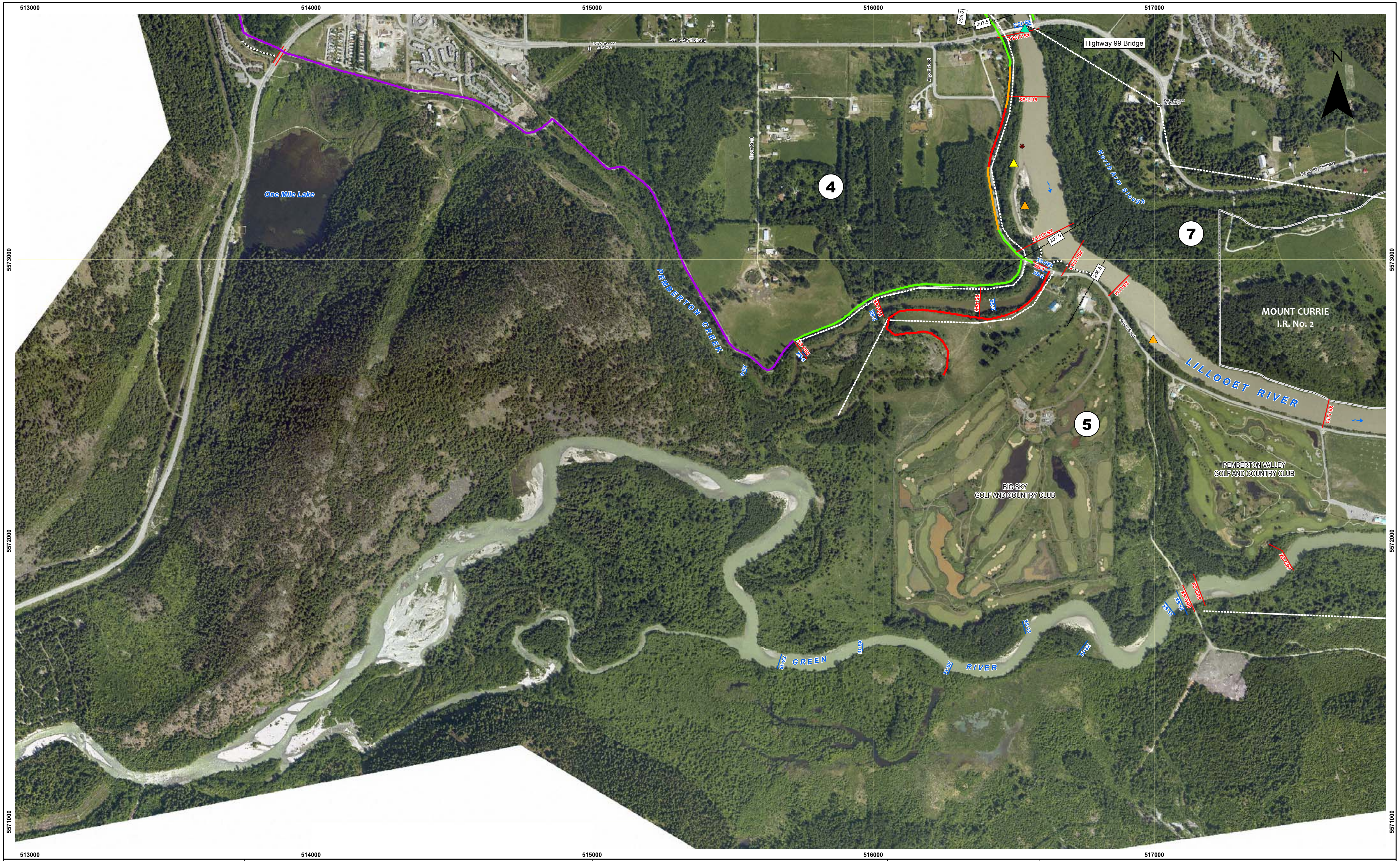

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Produced by: Kerr Wood Leidal Associates Ltd.

Survey: River Survey: (2000) by Atek Hydrographic Surveys Ltd
Control Survey: RTK GPS by KWL and Bazett Land Surveying. Vertical Datum CVD 28

Sources: 2009 Digital Orthophoto provided by Mt. Currie Band. NAD 83 UTM (Zone 10), flown May 2009.
Lillooet River discharge for orthophoto 204 m^3/s

First Nations reserve boundary from NRCAN Canada Lands Digital Cadastral data.

Legend

- ▭ Reserve Boundary
- △△△ Riprap
- ▨ 2000 Modelled Area Boundary
- ----- Design Flood Level Inventory
- ⌖ Survey Monument
- ⑧ Floodplain Area (BC Ministry of Environment Report, 1985)

Constructed Dyke

- 🟪 Not Modelled
- 🟩 Q200 not within 0.3 m of Crest
- 🟧 Q200 within 0.3 m of Crest
- 🟥 Q200 Overtops Dyke

Cross Section

- — 2001
- — Prior to 2001

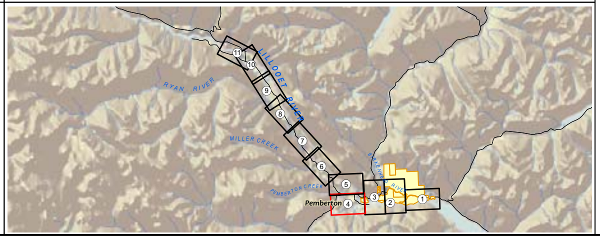
Large Woody Debris

- ✱ Back Channel Inlet Jam
- ✱ Bar Apex Jam
- ✱ Bar Top Jam
- ✱ Fallen Tree - Meander Jam Forming
- ✱ Meander Jam
- ✱ Rafted Logs
- ✱ Single Log

General Monitoring Locations

- ▲ Back Channels
- ▲ Bridge Crossings
- ▲ Cable Crossings
- ▲ Island/Bar

Key Map



KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Large Woody Debris Assessment
Updated Design Flood Levels
for Lillooet River and Birkenhead River

100 0 100 (m)
1:5,000

Date June 2011	**Project No.** 713-054	**Checked** SL
Sheet No. 4 of 11	**Drawn** JL	**Approved** SL

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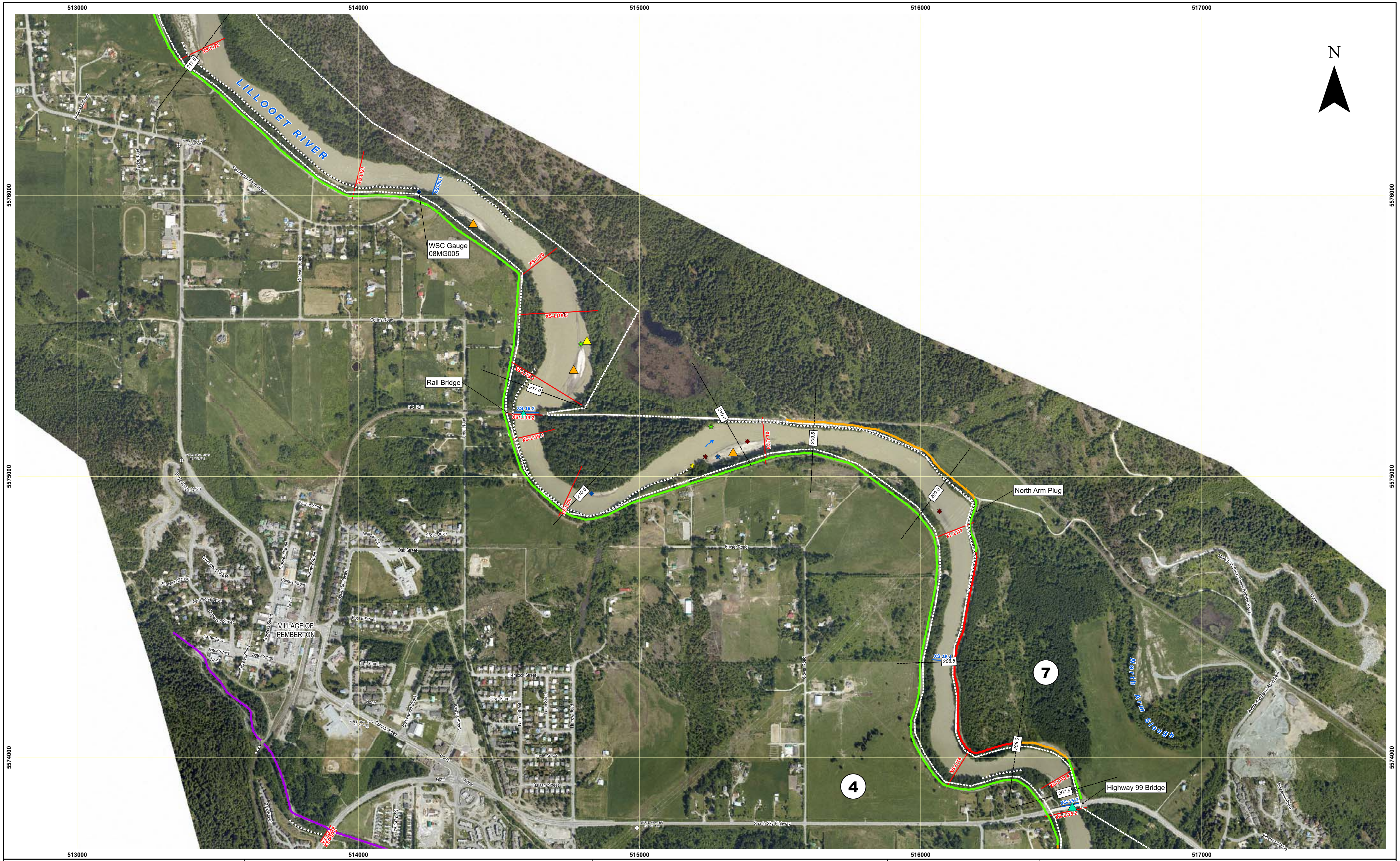


Notes

Produced by: Kerr Wood Leidal Associates Ltd.

Survey: River Survey: (2000) by Atek Hydrographic Surveys Ltd
Control Survey: RTK GPS by KWL and Bazett Land Surveying. Vertical Datum CVD 28

Sources: 2009 Digital Orthophoto provided by Mt. Currie Band. NAD 83 UTM (Zone 10), flown May 2009.
Lillooet River discharge for orthophoto 204 m^3/s

First Nations reserve boundary from NRCAN Canada Lands Digital Cadastral data.

Legend

- ⬚ Reserve Boundary
- △△△△△ Riprap
- ▨ 2000 Modelled Area Boundary
- ----- Design Flood Level
- ⌖ Survey Monument
- ⑧ Floodplain Area (BC Ministry of Environment Report, 1985)

Constructed Dyke

- Not Modelled
- Q200 not within 0.3 m of Crest
- Q200 within 0.3 m of Crest
- Q200 Overtops Dyke

Cross Section

- 2001
- Prior to 2001

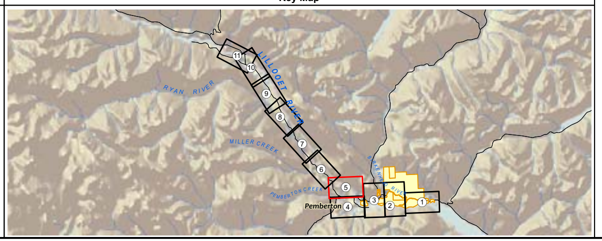
Large Woody Debris Inventory

- ✱ Back Channel Inlet Jam
- ✱ Bar Apex Jam
- ✱ Bar Top Jam
- ✱ Fallen Tree - Meander Jam Forming
- ✱ Meander Jam
- ✱ Rafted Logs
- ✱ Single Log

General Monitoring Locations

- △ Back Channels
- △ Bridge Crossings
- △ Cable Crossings
- △ Island/Bar

Key Map



KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Large Woody Debris Assessment
Updated Design Flood Levels
for Lillooet River and Birkenhead River

100 0 100 (m)
1:5,000

Date June 2011	**Project No.** 713-054	**Checked** SL
Sheet No. 5 of 11	**Drawn** JL	**Approved** SL

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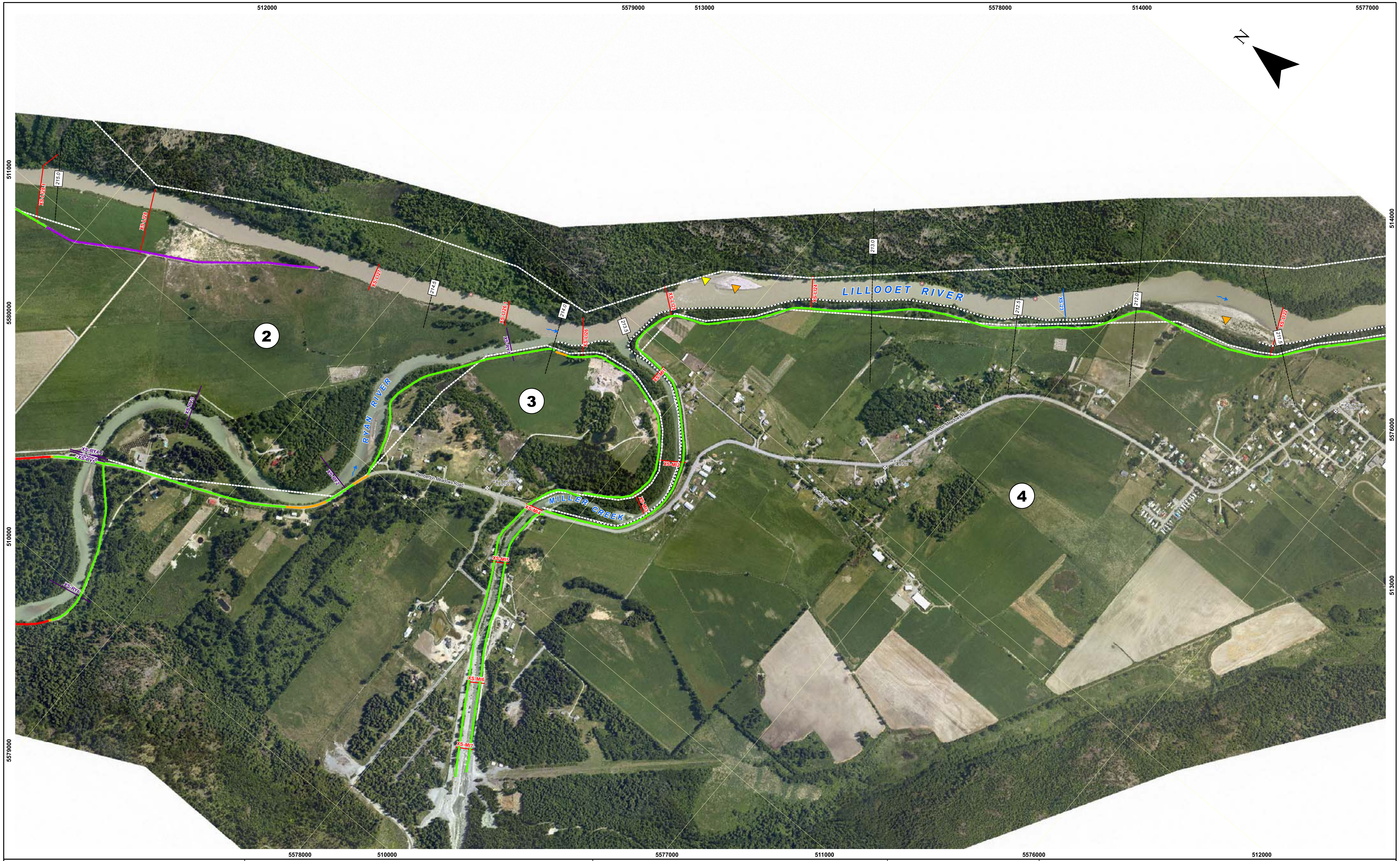
Author: JLau



Notes

Produced by: Kerr Wood Leidal Associates Ltd.

Survey: River Survey: (2000) by Atek Hydrographic Surveys Ltd
Control Survey: RTK GPS by KWL and Bazett Land Surveying. Vertical Datum CVD 28

Sources: 2009 Digital Orthophoto provided by Mt. Currie Band. NAD 83 UTM (Zone 10), flown May 2009.
Lillooet River discharge for orthophoto 204 m^3/s

First Nations reserve boundary from NRCAN Canada Lands Digital Cadastral data.

Legend

- ▭ Reserve Boundary
- △△△ Riprap
- ▨ 2000 Modelled Area Boundary
- ---- Design Flood Level
- ⌖ Survey Monument
- ⑧ Floodplain Area (BC Ministry of Environment Report, 1985)

Constructed Dyke

- 🟪 Not Modelled
- 🟩 Q200 not within 0.3 m of Crest
- 🟧 Q200 within 0.3 m of Crest
- 🟥 Q200 Overtops Dyke

Cross Section

- 🟥 2001
- 🟪 Post 2001
- 🟦 Prior to 2001

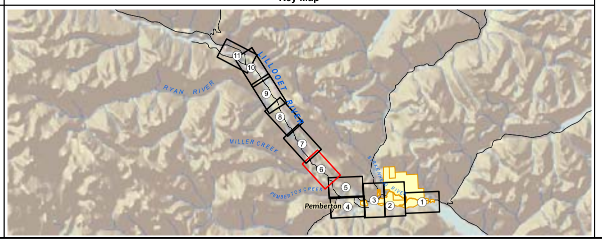
Large Woody Debris Inventory

- ✱ Back Channel Inlet Jam
- ✱ Bar Apex Jam
- ✱ Bar Top Jam
- ✱ Fallen Tree - Meander Jam Forming
- ✱ Meander Jam
- ✱ Rafted Logs
- ✱ Single Log

General Monitoring Locations

- ▲ Back Channels
- ▲ Bridge Crossings
- ▲ Cable Crossings
- ▲ Island/Bar

Key Map



KERR WOOD LEIDAL
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CONSULTING ENGINEERS

Large Woody Debris Assessment
Updated Design Flood Levels
for Lillooet River and Birkenhead River

100 0 100 (m)
1:5,000

Date June 2011	**Project No.** 713-054	**Checked** SL
Sheet No. 6 of 11	**Drawn** JL	**Approved** SL

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Author: JLau

Notes

Produced by: Kerr Wood Leidal Associates Ltd.

Survey: River Survey: (2000) by Atek Hydrographic Surveys Ltd
Control Survey: RTK GPS by KWL and Bazett Land Surveying. Vertical Datum CVD 28

Sources: 2009 Digital Orthophoto provided by Mt. Currie Band. NAD 83 UTM (Zone 10), flown May 2009.
Lillooet River discharge for orthophoto 204 m^3/s

First Nations reserve boundary from NRCAN Canada Lands Digital Cadastral data.

Legend

- ▭ Reserve Boundary
- △△△ Riprap
- ▬ 2000 Modelled Area Boundary
- ---- Design Flood Level
- ⌖ Survey Monument
- ⑧ Floodplain Area (BC Ministry of Environment Report, 1985)

Constructed Dyke

- 🟪 Not Modelled
- 🟩 Q200 not within 0.3 m of Crest
- 🟧 Q200 within 0.3 m of Crest
- 🟥 Q200 Overtops Dyke

Cross Section

- 🟥 2001
- 🟪 Post 2001
- 🟦 Prior to 2001

Large Woody Debris Inventory

- ✱ Back Channel Inlet Jam
- ✱ Bar Apex Jam
- ✱ Bar Top Jam
- ✱ Fallen Tree - Meander Jam Forming
- ✱ Meander Jam
- ✱ Rafted Logs
- ✱ Single Log

General Monitoring Locations

- ▲ Back Channels
- ▲ Bridge Crossings
- ▲ Cable Crossings
- ▲ Island/Bar

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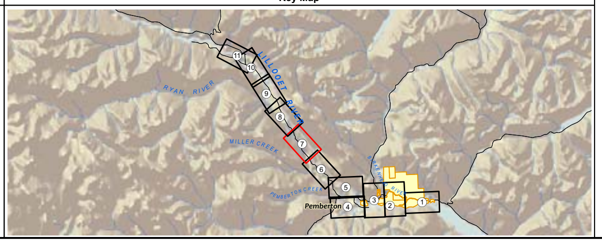
Key Map



KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Large Woody Debris Assessment
Updated Design Flood Levels
for Lillooet River and Birkenhead River

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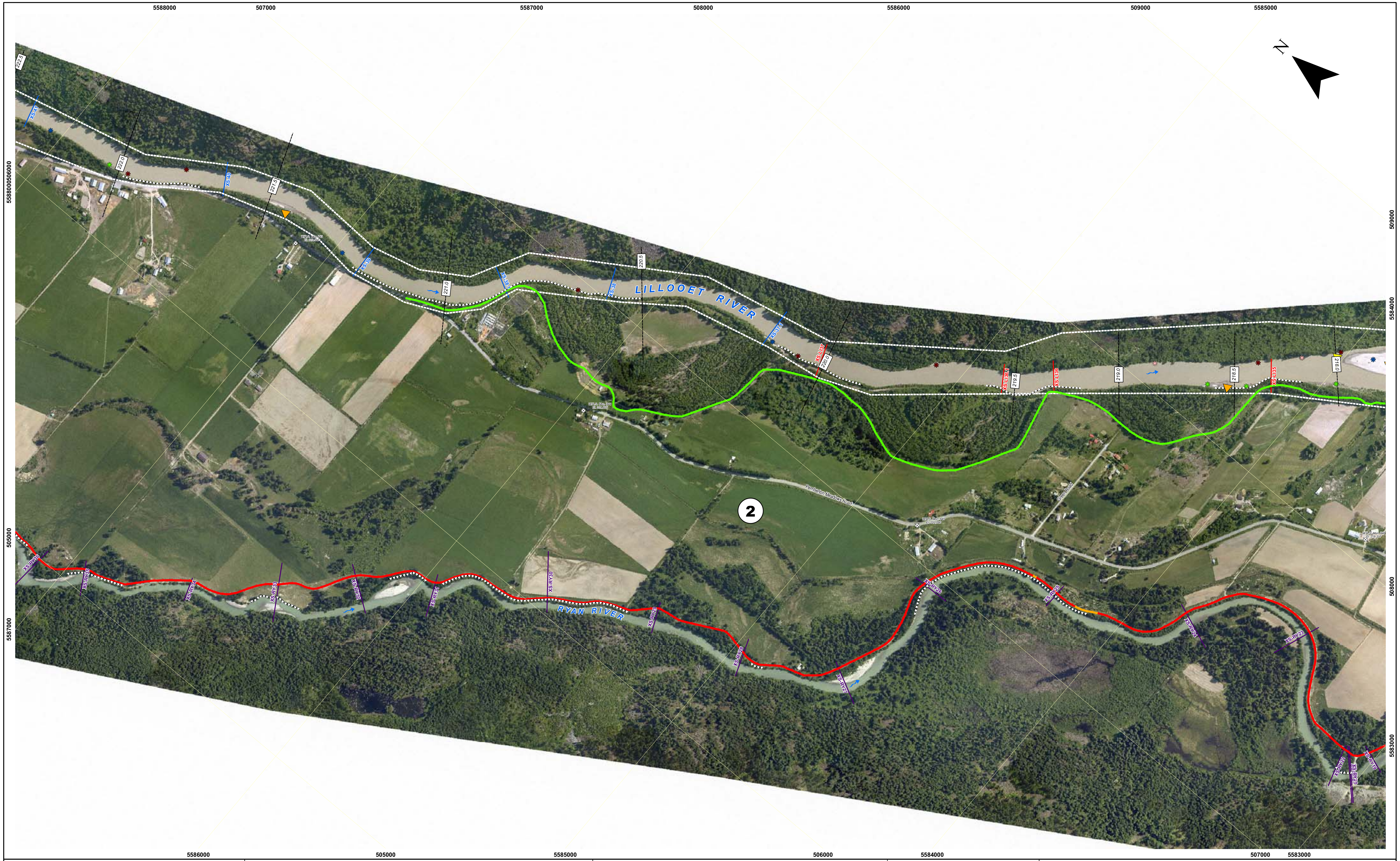
1:5,000

Date June 2011	**Project No.** 713-054	**Checked** SL
Sheet No. 7 of 11	**Drawn** JL	**Approved** SL



Notes

Produced by: Kerr Wood Leidal Associates Ltd.

Survey: River Survey: (2000) by Atek Hydrographic Surveys Ltd
Control Survey: RTK GPS by KWL and Bazett Land Surveying. Vertical Datum CVD 28

Sources: 2009 Digital Orthophoto provided by Mt. Currie Band. NAD 83 UTM (Zone 10), flown May 2009.
Lillooet River discharge for orthophoto 204 m^3/s

First Nations reserve boundary from NRCAN Canada Lands Digital Cadastral data.

Legend

- Reserve Boundary
- Riprap
- 2000 Modelled Area Boundary
- Design Flood Level
- Survey Monument
- ⑧ Floodplain Area (BC Ministry of Environment Report, 1985)

Constructed Dyke

- Not Modelled
- Q200 not within 0.3 m of Crest
- Q200 within 0.3 m of Crest
- Q200 Overtops Dyke

Cross Section

- 2001
- Post 2001
- Prior to 2001

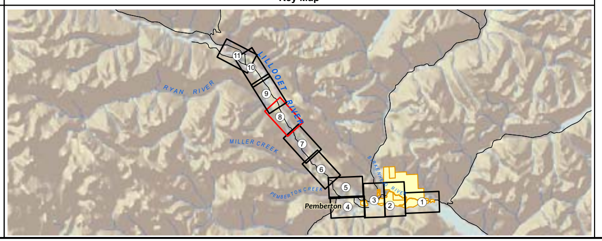
Large Woody Debris Inventory

- Back Channel Inlet Jam
- Bar Apex Jam
- Bar Top Jam
- Fallen Tree - Meander Jam Forming
- Meander Jam
- Rafted Logs
- Single Log

General Monitoring Locations

- Back Channels
- Bridge Crossings
- Cable Crossings
- Island/Bar

Key Map



KERR WOOD LEIDAL
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CONSULTING ENGINEERS

Large Woody Debris Assessment
Updated Design Flood Levels
for Lillooet River and Birkenhead River

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Date June 2011	**Project No.** 713-054	**Checked** SL
Sheet No. 8 of 11	**Drawn** JL	**Approved** SL

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Author: JLau

Notes

Produced by: Kerr Wood Leidal Associates Ltd.

Survey: River Survey: (2000) by Atek Hydrographic Surveys Ltd
Control Survey: RTK GPS by KWL and Bazett Land Surveying. Vertical Datum CVD 28

Sources: 2009 Digital Orthophoto provided by Mt. Currie Band. NAD 83 UTM (Zone 10), flown May 2009.
Lillooet River discharge for orthophoto 204 m^3/s

First Nations reserve boundary from NRCAN Canada Lands Digital Cadastral data.

Legend

- Reserve Boundary
- Riprap
- 2000 Modelled Area Boundary
- Design Flood Level
- Survey Monument
- ⑧ Floodplain Area (BC Ministry of Environment Report, 1985)

Constructed Dyke

- Not Modelled
- Q200 not within 0.3 m of Crest
- Q200 within 0.3 m of Crest
- Q200 Overtops Dyke

Cross Section

- 2001
- Post 2001
- Prior to 2001

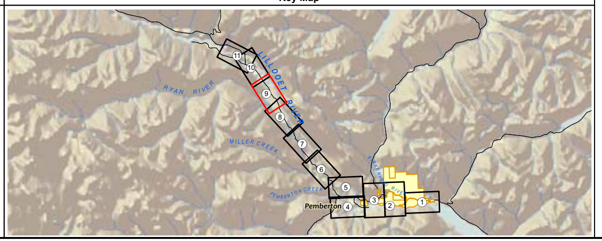
Large Woody Debris Inventory

- Back Channel Inlet Jam
- Bar Apex Jam
- Bar Top Jam
- Fallen Tree - Meander Jam Forming
- Meander Jam
- Rafted Logs
- Single Log

General Monitoring Locations

- Back Channels
- Bridge Crossings
- Cable Crossings
- Island/Bar

Key Map



KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Large Woody Debris Assessment
Updated Design Flood Levels
for Lillooet River and Birkenhead River

100 0 100 (m)
1:5,000

Date June 2011	**Project No.** 713-054	**Checked** SL
Sheet No. 9 of 11	**Drawn** JL	**Approved** SL

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Author: JLau

Notes

Produced by: Kerr Wood Leidal Associates Ltd.

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Control Survey: RTK GPS by KWL and Bazett Land Surveying. Vertical Datum CVD 28

Sources: 2009 Digital Orthophoto provided by Mt. Currie Band. NAD 83 UTM (Zone 10), flown May 2009.
Lillooet River discharge for orthophoto 204 m^3/s

First Nations reserve boundary from NRCAN Canada Lands Digital Cadastral data.

Legend

- Reserve Boundary
- Riprap
- 2000 Modelled Area Boundary
- Design Flood Level
- Survey Monument
- Floodplain Area (BC Ministry of Environment Report, 1985)

Constructed Dyke

- Not Modelled
- Q200 not within 0.3 m of Crest
- Q200 within 0.3 m of Crest
- Q200 Overtops Dyke

Cross Section

- 2001
- Prior to 2001

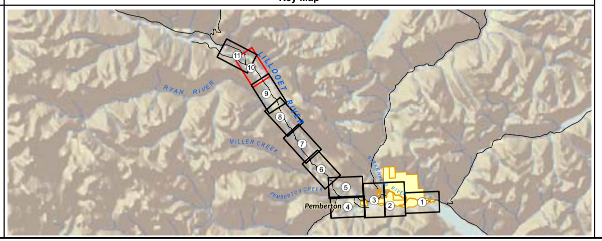
Large Woody Debris Inventory

- Back Channel Inlet Jam
- Bar Apex Jam
- Bar Top Jam
- Fallen Tree - Meander Jam Forming
- Meander Jam
- Rafted Logs
- Single Log

General Monitoring Locations

- Back Channels
- Bridge Crossings
- Cable Crossings
- Island/Bar

Key Map



KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Large Woody Debris Assessment
Updated Design Flood Levels
for Lillooet River and Birkenhead River

100 0 100 (m)
1:5,000

Date June 2011	**Project No.** 713-054	**Checked** SL
Sheet No. 10 of 11	**Drawn** JL	**Approved** SL

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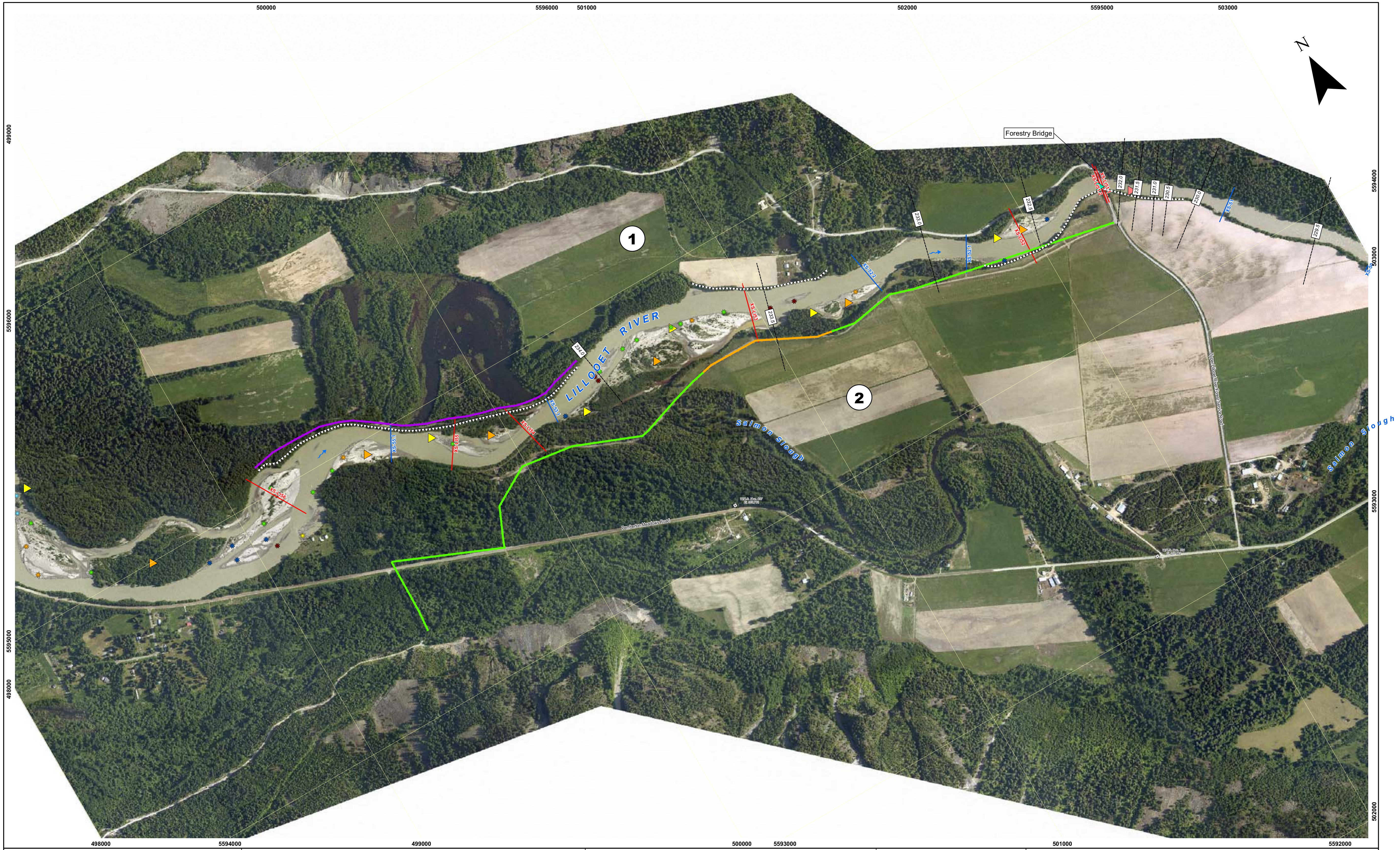
Author: JLau



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Produced by: Kerr Wood Leidal Associates Ltd.

Survey: River Survey: (2000) by Atek Hydrographic Surveys Ltd
Control Survey: RTK GPS by KWL and Bazett Land Surveying. Vertical Datum CVD 28

Sources: 2009 Digital Orthophoto provided by Mt. Currie Band. NAD 83 UTM (Zone 10), flown May 2009.
Lillooet River discharge for orthophoto 204 m^3/s

First Nations reserve boundary from NRCAN Canada Lands Digital Cadastral data.

Legend

- Reserve Boundary
- Riprap
- 2000 Modelled Area Boundary
- Design Flood Level
- Survey Monument
- Floodplain Area (BC Ministry of Environment Report, 1985)

Constructed Dyke

- Not Modelled
- Q200 not within 0.3 m of Crest
- Q200 within 0.3 m of Crest
- Q200 Overtops Dyke

Cross Section

- 2001
- Prior to 2001

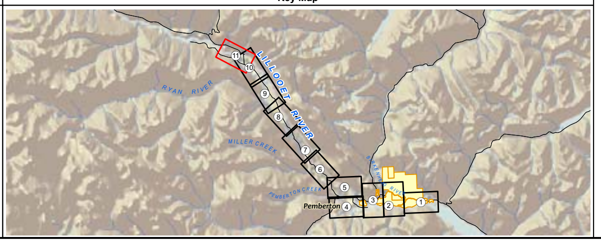
Large Woody Debris Inventory

- Back Channel Inlet Jam
- Bar Apex Jam
- Bar Top Jam
- Fallen Tree - Meander Jam Forming
- Meander Jam
- Rafted Logs
- Single Log

General Monitoring Locations

- Back Channels
- Bridge Crossings
- Cable Crossings
- Island/Bar

Key Map



KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Large Woody Debris Assessment
Updated Design Flood Levels
for Lillooet River and Birkenhead River

100 0 100 (m)
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Date	Project No.	Checked
June 2011	713-054	SL
Sheet No.	**Drawn**	**Approved**
11 of 11	JL	SL

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Author: JLau

Appendix C

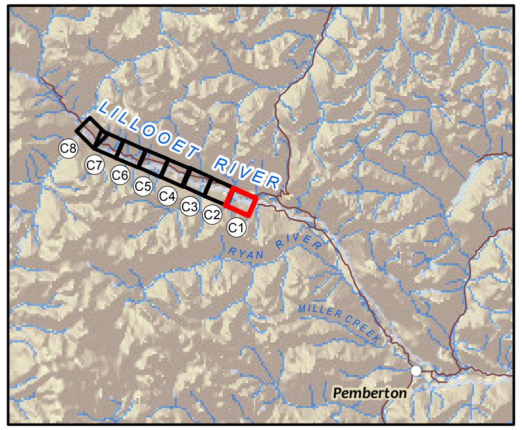
Upper Lillooet River Mapping

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Pemberton Valley Dyking District
Large Woody Debris Assessment
and Mitigation Plan

Legend

Key Map



Reference: Orthophoto from July 2010

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

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Project No.	Date
713.054	June 2011

Upper Lillooet River Photo Imagery

Figure C1

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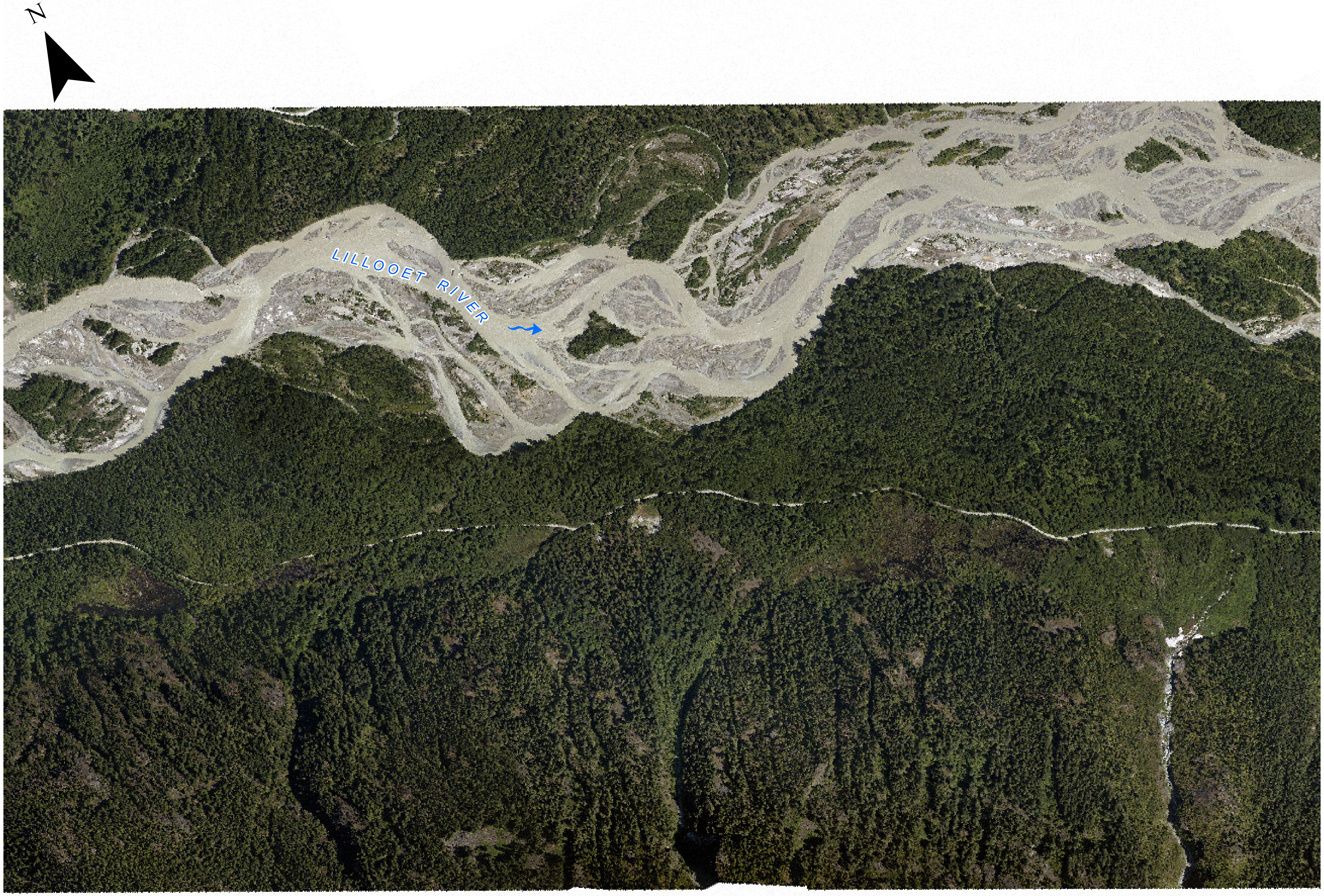
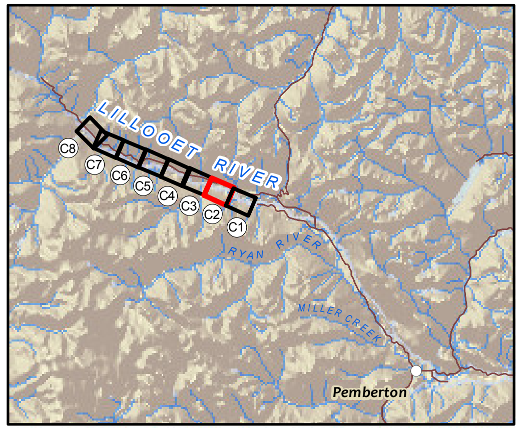


Pemberton Valley Dyking District
Large Woody Debris Assessment
and Mitigation Plan

Legend

Key Map



Reference: Orthophoto from July 2010

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

200 0 200 (m)
1:10,000

Project No.	Date
713.054	June 2011

Upper Lillooet River Photo Imagery

Figure C2

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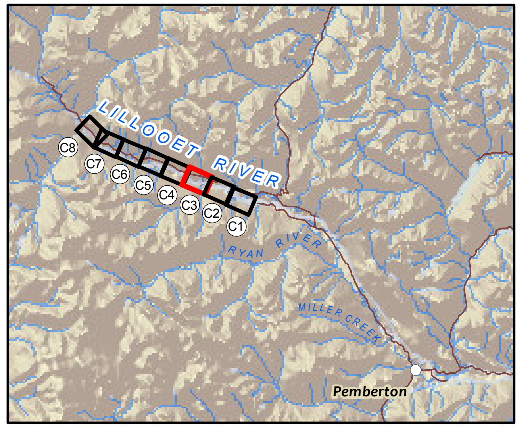
Author: JLau

Pemberton Valley Dyking District Large Woody Debris Assessment and Mitigation Plan

Legend

Key Map



Reference: Orthophoto from July 2010

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

200 0 200 (m)
1:10,000

Project No.	Date
713.054	June 2011

Upper Lillooet River Photo Imagery

Figure C3

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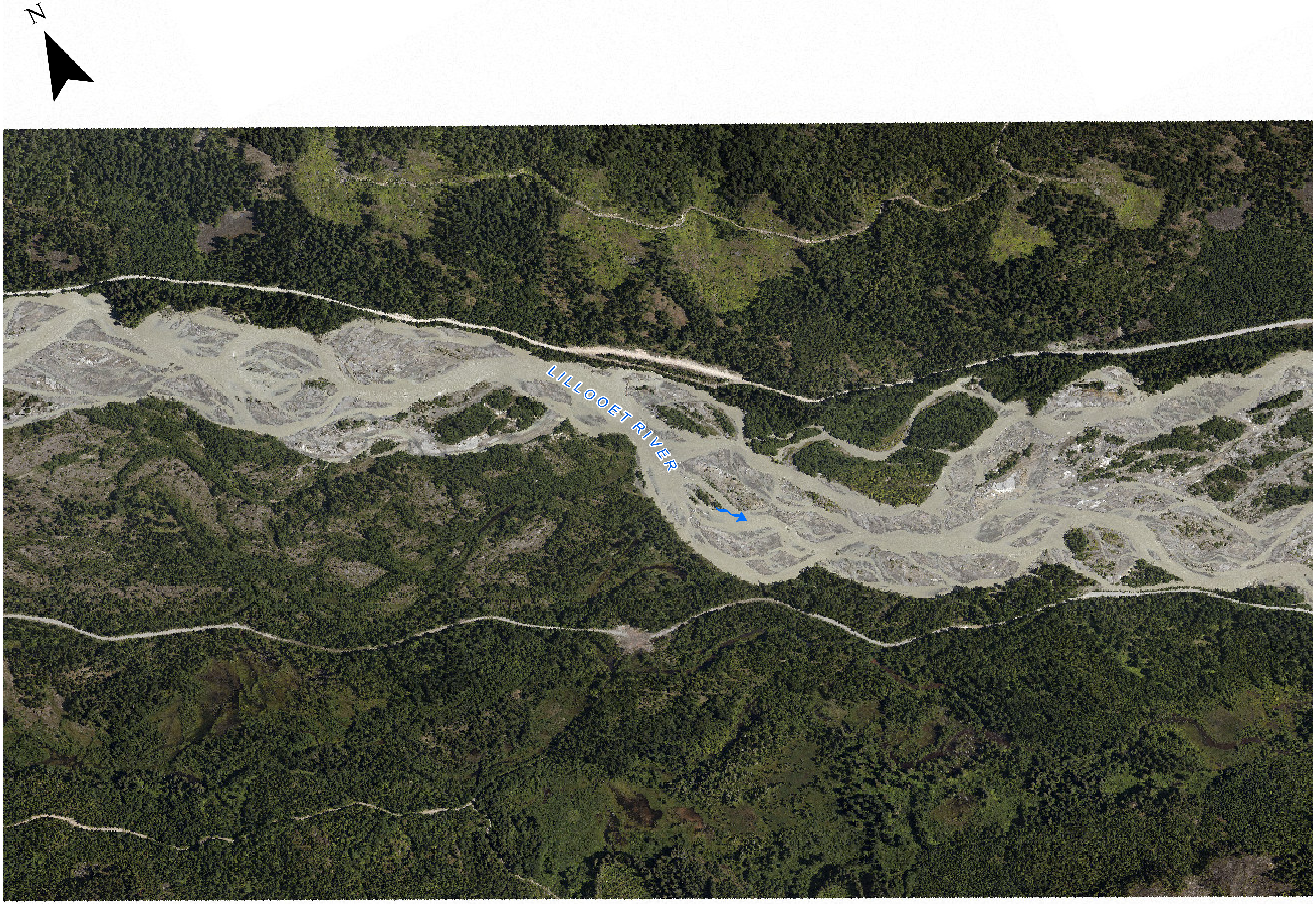
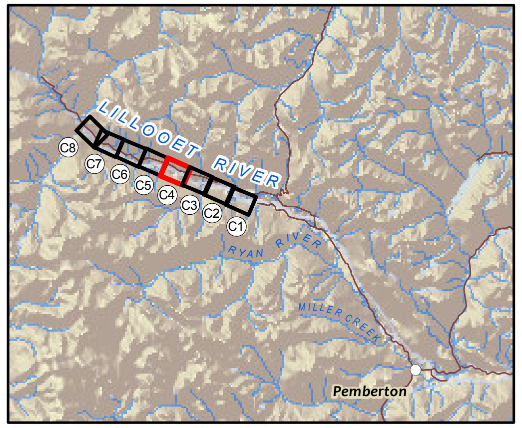
Author: JLau



Pemberton Valley Dyking District
Large Woody Debris Assessment
and Mitigation Plan

Legend

Key Map



Reference: Orthophoto from July 2010

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

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(m)
1:10,000

Project No.	Date
713.054	June 2011

Upper Lillooet River Photo Imagery

Figure C4

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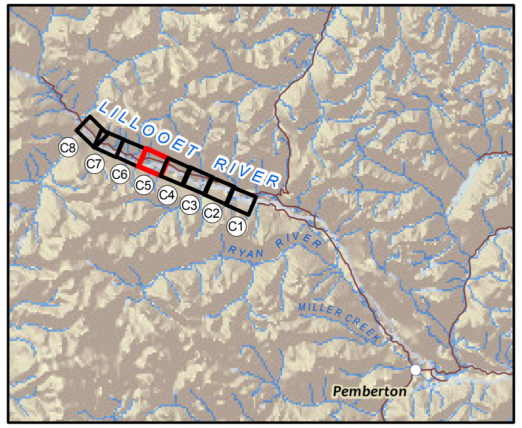
Pemberton Valley Dyking District
Large Woody Debris Assessment
and Mitigation Plan

Legend

Key Map



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associates limited
CONSULTING ENGINEERS

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Project No.	Date
713.054	June 2011

Upper Lillooet River Photo Imagery

Figure C5

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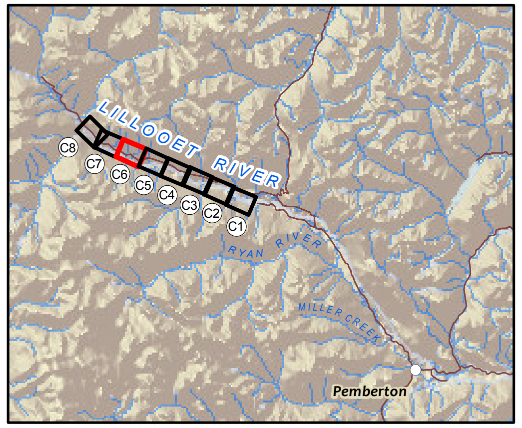
Pemberton Valley Dyking District
Large Woody Debris Assessment
and Mitigation Plan

Legend

Key Map



Reference: Orthophoto from July 2010

Reference: Orthophoto from July 2010

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

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Project No.	Date
713.054	June 2011

Upper Lillooet River
Photo Imagery

Figure C6

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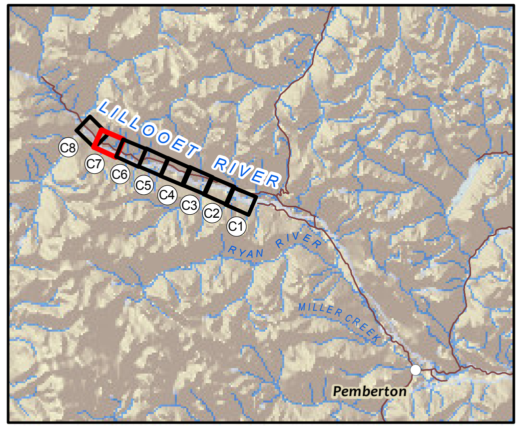
Author: JLau

Pemberton Valley Dyking District
Large Woody Debris Assessment
and Mitigation Plan

Legend

Key Map



Reference: Orthophoto from July 2010

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

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Project No.	Date
713.054	June 2011

Upper Lillooet River Photo Imagery

Figure C7

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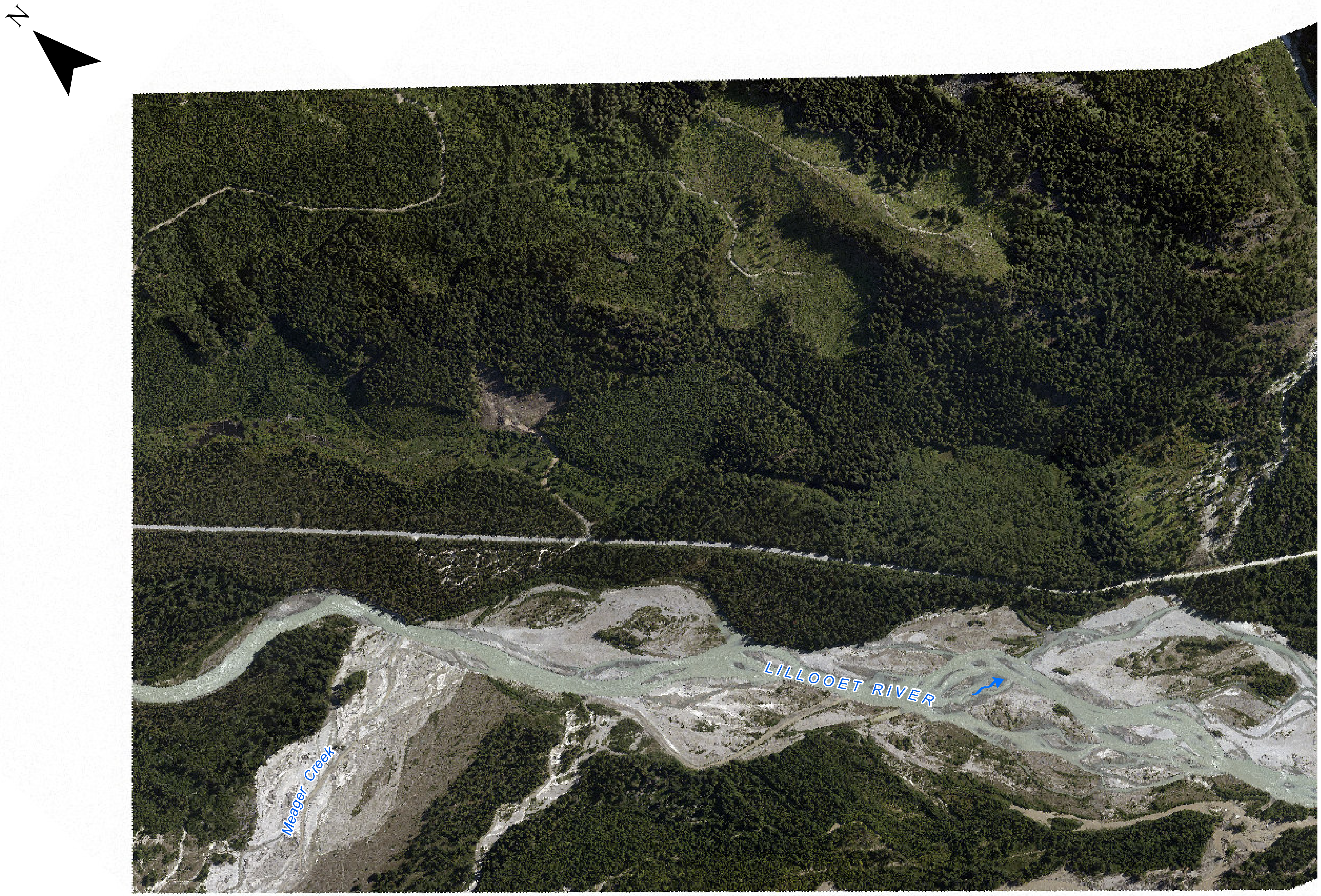
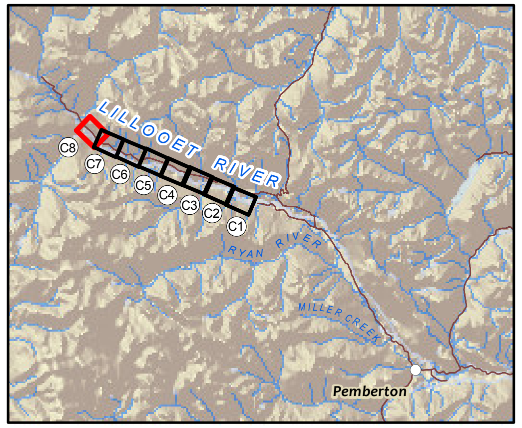


Pemberton Valley Dyking District Large Woody Debris Assessment and Mitigation Plan

Legend

Key Map



Reference: Orthophoto from July 2010

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

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Project No.	Date
713.054	June 2011

Upper Lillooet River Photo Imagery

Figure C8

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Author: JLau

Appendix D

Wood Volume Estimate, Meager Creek Landslide, B.C.

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

HEMMERA

June 15, 2011
File: 677-007.01

Kerr Wood Leidal
200 – 4185A Still Creek Drive
Burnaby, BC V5C 6G9

Attn: Stefan Joyce, P.Eng., Project Manager

Dear Stefan,

Re: Wood Volume Estimate, Meager Creek Landslide, BC

1.0 INTRODUCTION

One of BC's largest historical rock avalanches occurred at 03:27:30 August 06, 2010, in the Mount Meager Volcanic Complex southwest British Columbia. The landslide initiated as a rock fall in Pleistocene rhyodacitic volcanics, with the collapse of the mountain's secondary peak. The detached rock mass landed on the volcano's weathered and saturated flanks with a force clearly visible on the seismic record.

Undrained loading of the footslope caused the immediate and extremely rapid evacuation of the entire flank with a strong horizontal force, as the rock fall transformed into a massive rock avalanche. The disintegrating mass travelled down Capricorn Creek at an average speed of 64 m/s (roughly equivalent to the average speed of a Formula 1 race car), with dramatic super-elevation in bends, to the intersection of Meager Creek, 7.8 km distant.

The Meager Creek impact caused a runup of 270 m above the valley floor and the deflection of the landslide upstream for 3.7 km, and downstream into the Lillooet River valley where it blocked the Lillooet River for a couple of hours. Deposition at the confluence also dammed Meager Creek for about 19 hours creating a lake 1.5 km long. The overtopping of the dam and the predicted outburst flood was the basis for a night time evacuation of 1,500 residents in the town of Pemberton.

High-resolution GeoEye imagery obtained on October 16, 2010 was used to create a post-event digital elevation model. Comparing pre- and post-event topography we estimate the initial displaced volume from the flank of Mount Meager to be ca. 48 Mm^3, the height of the path (H) to be 2,078 m and the total length of the path (L) to be 12.6 km. This yields H/L = 0.165 and a fahrboschung of 9.4°. The movement was recorded on seismographs in British Columbia and Washington State with the initial impact, the rock avalanche travelling through bends in Capricorn Creek, and the impact with Meager Creek; all clearly evident on the seismic trace. The landslide had a seismic trace equivalent to a magnitude 2.6 earthquake. The landslide significantly impacted the fluvial regime of Meager Creek and Lillooet River.

The 2010 event is the third major landslide in the Capricorn Creek watershed since 1998 and the fifth large mass flow in the Meager Creek watershed since 1930. The 2010 Mount Meager rock avalanche is the tied as the largest landslide to have occurred in British Columbia since 1900, the other being the 1965 Hope Slide (48 Mm^3).

Direct impacts of the Mount Meager rock avalanche – debris flow included the complete removal of timber in Capricorn Creek below the trim line (over 200 m above the valley floor in areas), loss of timber within the impact zone in Meager Creek and Lillooet River, the burial of 6 km of main forest road, the loss of several vehicles and industrial equipment, and the loss of two bridges. In addition there remains a substantial impact on the river systems, as sediment and large woody debris now make their way from the confluence of Meager and Lillooet, to Lillooet Lake over 60 km downstream.

2.0 OBJECTIVES

This analysis attempts to determine the volume of wood stripped away from Capricorn Creek, Meager Creek and Lillooet River as a result of the August 06, 2010 landslide.

Further, it values the wood by dominant species to estimate the total lost market potential.

3.0 METHODS

The volume of wood lost by the landslide was estimated in the following manner:

- A polygon was created in Google Earth that delineated the previously un-vegetated portion of Capricorn Creek, Meager Creek and Lillooet River from a debris flow in 2009).
- The polygon was saved as a .kml file and imported into ArcMap® as a GIS shapefile.
- A polygon that covered the extent of the 2010 landslide was created from 0.5 m resolution GeoEye® color satellite imagery, and a new polygon created that showed the difference between the two years.
- Forest cover data was acquired for the region[1] and clipped to the new polygon to provide, in detail, forest species and wood volume along the path of the landslide.
- Wood volume was summed for all polygons and average market value was assigned for the wood based on dominant species within each polygon[2].
- Using the attribute table available on the forest cover map, different forest species were identified and the wood volume was calculated based on the predominant wood species and the wood density.

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[1] Government of British Columbia, GeoBC/ Geographic Data Discovery Service. Online resource: http;//www.for.gov.bc.ca/his/ datadmin/models/models.htm#models accessed March 2, 2011.

[2] Province of BC, 2010. Coast selling price system, average log prices for the 1 month period ending 2010-08-31. Province of British Columbia, Ministry of Forests, Mines and Lands. Online resource: http://www.for.gov.bc.ca/hva/logreports_coast.htm accessed March 4, 2011.

4.0 RESULTS

About 110,000 m^3 of wood (calculated as 108,000 m^3) was removed along the landslide path and either ground into the mineral matrix as fine organic material, or transported into the Lillooet River system as large woody debris. Based on forest cover, the following species were present before the landslide:

- Balsam poplar (Ac) located on Lillooet River Valley, downstream of Meager Creek and Capricorn Creek confluence;
- Amabilis fir (Ba) located mainly on the Meager Creek Valley, with a small patch on the Capricorn Creek;
- Western hemlock (Hw) a small area located at the confluence of Meager Creek and Capricorn Creek;
- Alpine fir (Bl) small areas located on the north slope of Meager Creek Valley;
- Western red cedar (Cw) located along Capricorn Creek Valley and the confluence and downstream of the confluence of Meager Creek and Capricorn Creek;
- White pine (Pl) located downstream of Meager Creek and Capricorn Creek Valleys, on the north side of the Lillooet River Valley; and
- Douglas fir (Fd) well represented along the Meager Creek Valley, Capricorn Creek Valley and the upstream area of Lillooet River Valley.

Distribution of species can be seen on **Figure 1**, attached.

Forest density and wood volume varied from less than 0.05 m^3/ha on steep areas located on the north slope of Meager Creek Valley, Capricorn Creek Valley and southeast area of the Lillooet River Valley, up to approximately 1,400 m^3/ha on areas located in the proximity of Meager Creek and Capricorn Creek confluence. High wood volume was found at the confluence of Capricorn Creek and Meager Creek and the north slope of the Lillooet River Valley.

Low forest density and low wood volume was attributed to alpine zones (including avalanche run-out zones, previous landslides, and a thinning tree line) and previous logging activity (clear-cuts). The distribution of wood volume is shown in **Figure 2**, and divided in three categories:

- Bare surface (no wood vegetation - bare rock and forest cut blocks);
- Immature forest (early stage second-growth forest); and
- Intact forest (old-growth forest).

The total potential loss based on the species specific average market values for August 10, 2010, was $8.7M. Only intact forest contributed substantially to the calculation of market value.

5.0 CONCLUSION

Based on data available and calculation performed, the lost wood volume is estimated to be approximately 110,000 m^3, with a potential market value of approximately $8.7 million. The majority of market value wood comes from small areas on the Lillooet, the south side of Capricorn Creek, and the confluence of Capricorn and Meager Creeks. Not all of that wood would be merchantable; however, the landslide has likely rendered additional merchantable timber inaccessible for the foreseeable future.

Of the 110,000 m^3 of wood, much has been incorporated into the landslide deposit; however, a significant volume remains in the system as large woody debris. This material will precede much of the sand wave that is expected to move through the Lillooet River over the next several years.

Report prepared by:
Hemmera

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Report peer reviewed by:
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Project Director
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6.0 STATEMENT OF LIMITATIONS

This report was prepared by Hemmera, based on fieldwork conducted by Hemmera, for the sole benefit and exclusive use of Kerr Wood Leidal. The material in it reflects Hemmera's best judgment in light of the information available to it at the time of preparing this Report. Any use that a third party makes of this Report, or any reliance on or decision made based on it, is the responsibility of such third parties. Hemmera accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this Report.

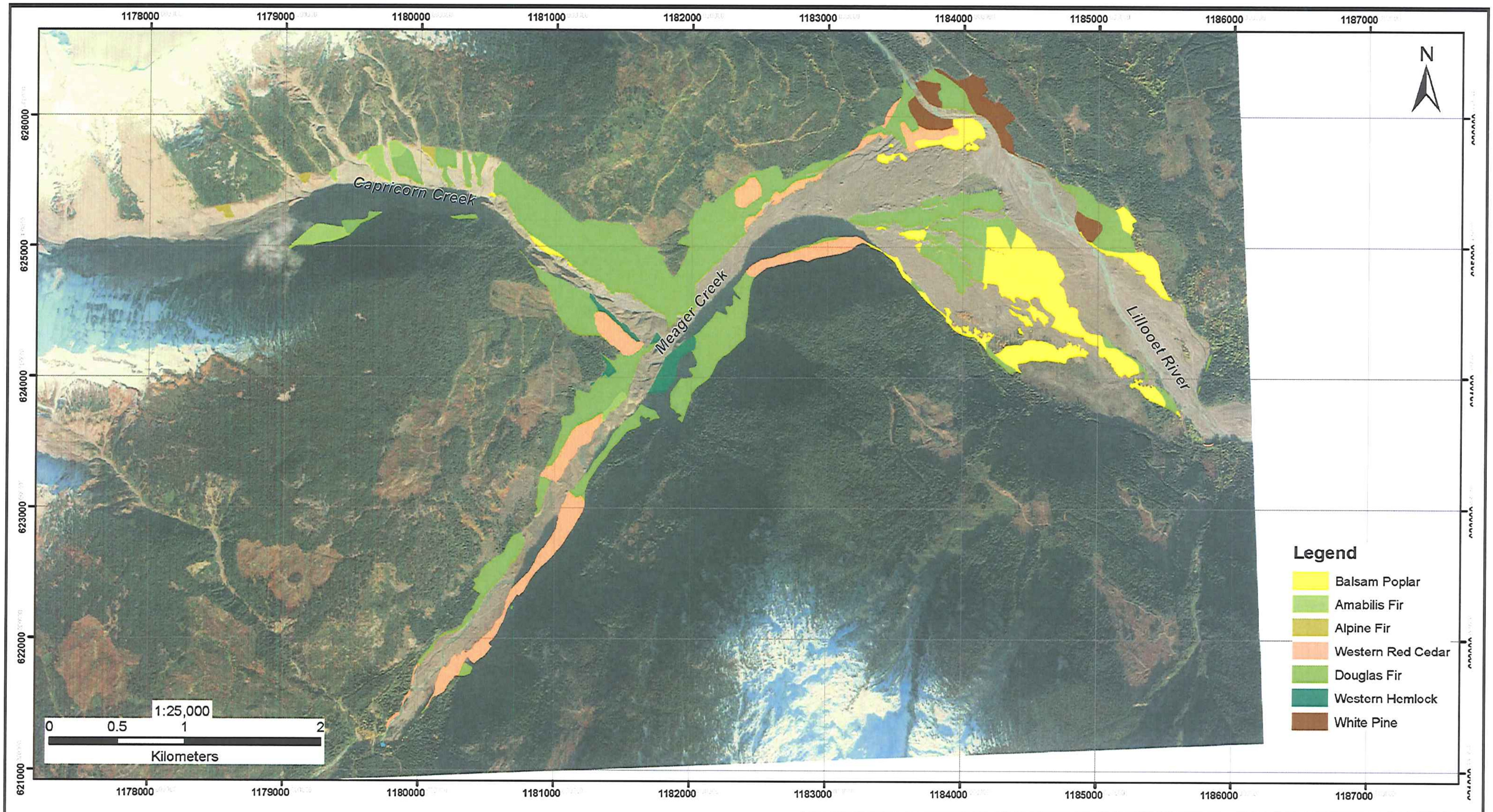
Hemmera has performed the work as described above and made the findings and conclusions set out in this Report in a manner consistent with the level of care and skill normally exercised by members of the environmental science profession practicing under similar conditions at the time the work was performed.

This Report represents a reasonable review of the information available to Hemmera within the established Scope, work schedule and budgetary constraints. It is possible that the levels of contamination or hazardous materials may vary across the Site, and hence currently unrecognised contamination or potentially hazardous materials may exist at the Site. No warranty, expressed or implied, is given concerning the presence or level of contamination on the Site, except as specifically noted in this Report. The conclusions and recommendations contained in this Report are based upon applicable legislation existing at the time the Report was drafted. Any changes in the legislation may alter the conclusions and/or recommendations contained in the Report. Regulatory implications discussed in this Report were based on the applicable legislation existing at the time this Report was written.

In preparing this Report, Hemmera has relied in good faith on information provided by others as noted in this Report, and has assumed that the information provided by those individuals is both factual and accurate. Hemmera accepts no responsibility for any deficiency, misstatement or inaccuracy in this Report resulting from the information provided by those individuals.

The liability of Hemmera to Kerr Wood Leidal shall be limited to injury or loss caused by the negligent acts of Hemmera. The total aggregate liability of Hemmera related to this agreement shall not exceed the lesser of the actual damages incurred, or the total fee of Hemmera for services rendered on this project.

FIGURES



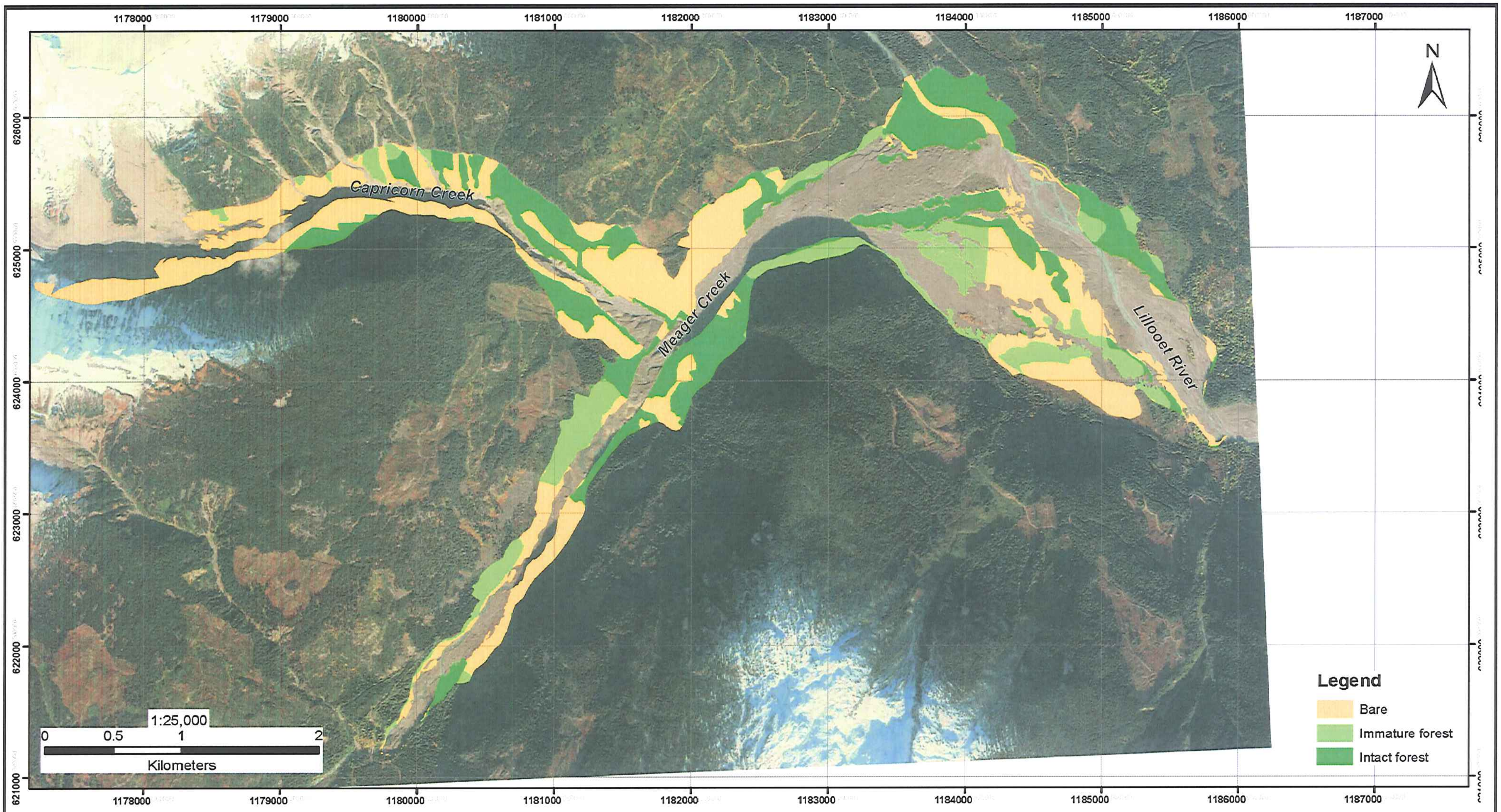
HEMMERA

CLIENT: **Kerr Wood Leidal**

Wood Volume Estimate
Meager Creek Landslide, BC

Dominant Species Distribution
Along Landslide Path

PROJECT No. 677-007.01	June 2011	FIGURE 1



HEMMERA

CLIENT: **Kerr Wood Leidal**

Wood Volume Estimate
Meager Creek Landslide, BC

Forest Cover
Along Landslide Path

PROJECT No. 677-007.01	June 2011	FIGURE 2

APPENDIX A

Calculations of Wood Volume and Value

[1]Species	[2]SITE INDEX	[3]Live wood volume (m^3/ha)	Polygon Area (ha)	Polygon live wood volume (m^3)	[4]Average market value (August 2010) of dominant species ($)	Volume x Market value ($)	Watershed
BlHm	5.0	82.6	0.42	34.63	87.00	3012.89	Capricorn Creek
Bl	4.5	2.4	0.04	0.10	87.00	9.07	Capricorn Creek
Bl	4.5	2.4	0.03	0.06	87.00	5.29	Capricorn Creek
Bl	4.5	2.4	0.58	1.37	87.00	119.48	Capricorn Creek
BaHwFd	8.4	52.8	0.31	16.51	46.40	766.25	Capricorn Creek
BaHwFd	8.4	52.8	4.18	220.56	46.40	10234.20	Capricorn Creek
Ba(Hm)	7.5	29.4	0.04	1.03	46.40	47.88	Capricorn Creek
FdCw(Ba)	15.9	458.6	0.00	0.50	87.00	43.52	Capricorn Creek
FdCw(Ba)	15.9	458.6	2.55	1168.32	87.00	101644.27	Capricorn Creek
BaFd(Hw)	10.6	343.6	0.14	48.43	46.40	2247.01	Capricorn Creek
Alpine	0.0	0.0	0.00	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.01	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.87	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	6.00	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	5.54	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	16.05	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.00	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.00	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.01	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.02	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.02	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.02	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.02	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.05	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.05	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.15	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	0.68	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	6.13	0.00	0.00	0.00	Capricorn Creek
Alpine	0.0	0.0	43.33	0.00	0.00	0.00	Capricorn Creek
BlHm	5.0	82.6	0.73	59.99	87.00	5219.55	Capricorn Creek
Ac	15.1	176.3	0.00	0.00	36.00	0.00	Capricorn Creek
Ac	15.1	176.3	0.00	0.00	36.00	0.01	Capricorn Creek
Ac	15.1	176.3	0.00	0.00	36.00	0.04	Capricorn Creek

[1]Species	[2]SITE INDEX	[3]Live wood volume (m^3/ha)	Polygon Area (ha)	Polygon live wood volume (m^3)	[4]Average market value (August 2010) of dominant species ($)	Volume x Market value ($)	Watershed
Ac	15.1	176.3	0.00	0.74	36.00	26.53	Capricorn Creek
Ac	15.1	176.3	1.05	185.37	36.00	6673.14	Capricorn Creek
FdCw(S)	26.0	0.0	3.84	0.00	87.00	0.00	Capricorn Creek
FdCw(Ba)	17.3	505.6	15.15	7658.59	87.00	666296.98	Capricorn Creek
FdCw	18.0	0.0	0.08	0.00	87.00	0.00	Capricorn Creek
FdCw(Ba)	15.9	458.6	3.10	1419.90	87.00	123531.07	Capricorn Creek
FdCw(Ba)	15.9	458.6	1.20	549.05	87.00	47767.15	Capricorn Creek
FdCw(Ba)	15.9	458.6	1.32	603.74	87.00	52525.81	Capricorn Creek
Fd	27.0	0.0	2.62	0.00	87.00	0.00	Capricorn Creek
HwFdCw	18.7	694.0	1.86	1291.98	46.40	59947.68	Capricorn Creek
CwHwFd	15.0	0.0	5.33	0.00	107.30	0.00	Capricorn Creek
Fd(HwCw)	24.9	1000.6	4.44	4445.72	87.00	386777.34	Capricorn Creek
FdHw(Ba)	24.0	0.0	9.28	0.00	87.00	0.00	Capricorn Creek
FdHwCw	22.1	600.5	0.03	15.90	87.00	1383.38	Capricorn Creek
Fd	18.0	0.0	2.42	0.00	87.00	0.00	Capricorn Creek
Fd(CwHw)	24.8	979.1	0.02	20.82	87.00	1811.37	Capricorn Creek
Fd(CwHw)	24.8	979.1	0.46	448.89	87.00	39053.80	Capricorn Creek
Fd(CwHw)	24.8	979.1	1.47	1443.84	87.00	125613.93	Capricorn Creek
Fd(CwHw)	24.8	979.1	8.26	8089.18	87.00	703758.25	Capricorn Creek
FdCw(HwBa)	25.0	0.0	0.49	0.00	87.00	0.00	Capricorn Creek
BaCw(Hw)	12.8	674.2	3.98	2686.28	46.40	124643.26	Capricorn Creek
FdCw(Hw)	26.6	1080.7	0.00	0.03	87.00	2.84	Capricorn Creek
FdCw(Hw)	26.6	1080.7	4.80	5192.21	87.00	451722.18	Capricorn Creek
FdCw	26.0	0.0	7.18	0.00	87.00	0.00	Capricorn Creek
Pl	14.6	209.9	9.14	1918.89	53.70	103044.38	Lillooet River
Fd(Cw)	20.7	598.6	3.84	2298.68	87.00	199984.97	Lillooet River
Pl(Fd)	14.6	208.0	0.60	125.17	53.70	6721.72	Lillooet River
CwAc	28.2	335.5	0.70	234.67	107.30	25180.52	Lillooet River
Ac(Cw)	32.2	421.0	4.82	2031.35	36.00	73128.49	Lillooet River
Fd(Cw)	20.7	598.6	1.20	715.54	87.00	62252.00	Lillooet River
River	0.0	0.0	2.16	0.00	0.00	0.00	Lillooet River
AcCw	18.3	445.9	0.81	362.03	36.00	13033.13	Lillooet River
CwAc	28.2	335.5	3.31	1111.42	107.30	119255.49	Lillooet River

[1]Species	[2]SITE INDEX	[3]Live wood volume (m^3/ha)	Polygon Area (ha)	Polygon live wood volume (m^3)	[4]Average market value (August 2010) of dominant species ($)	Volume x Market value ($)	Watershed
Ac(Cw)	32.2	421.0	0.86	363.64	36.00	13091.14	Lillooet River
FdCw	18.9	521.1	5.11	2664.02	87.00	231769.70	Lillooet River
Pl(Fd)	14.6	208.0	3.37	701.29	53.70	37659.18	Lillooet River
CwFd	24.0	0.0	0.60	0.00	107.30	0.00	Lillooet River
Pl(Fd)	14.6	208.0	2.38	494.95	53.70	26579.04	Lillooet River
AcDr	26.0	3.4	12.76	42.82	36.00	1541.35	Lillooet River
River	0.0	0.0	0.00	0.00	0.00	0.00	Lillooet River
River	0.0	0.0	0.00	0.00	0.00	0.00	Lillooet River
River	0.0	0.0	4.42	0.00	0.00	0.00	Lillooet River
River	0.0	0.0	4.98	0.00	0.00	0.00	Lillooet River
CwFd(Hw)	23.0	6.0	0.02	0.10	107.30	10.25	Lillooet River
AcCw(Fd)	18.0	17.0	1.47	25.01	36.00	900.45	Lillooet River
Bedrock	0.0	0.0	5.50	0.00	0.00	0.00	Lillooet River
Bedrock	0.0	0.0	9.85	0.00	0.00	0.00	Lillooet River
Ac	25.1	312.6	0.66	205.12	36.00	7384.14	Lillooet River
FdAcDr(CwBa)	27.0	37.0	5.94	219.78	87.00	19120.94	Lillooet River
FdAcDr(CwBa)	27.0	37.0	2.26	83.56	87.00	7269.53	Lillooet River
AcFdCw	3.0	0.0	19.88	0.00	36.00	0.00	Lillooet River
AcFd(Cw)	33.2	517.4	4.90	2535.67	36.00	91283.99	Lillooet River
Ac	33.1	239.5	3.69	884.11	36.00	31827.82	Lillooet River
FdAcDr(CwBa)	27.0	33.6	0.69	23.32	87.00	2029.04	Lillooet River
FdAcDr(CwBa)	27.0	33.6	1.28	42.82	87.00	3725.23	Lillooet River
AcDr	18.0	22.1	2.30	50.75	36.00	1827.13	Lillooet River
Ac	33.1	239.5	3.37	806.77	36.00	29043.81	Lillooet River
FdPl(PwBa)	17.8	307.0	10.06	3087.39	87.00	268602.83	Lillooet River
FdCwHw	14.1	627.4	3.40	2135.69	87.00	185804.93	Lillooet River
Pl	11.4	137.4	2.70	371.65	53.70	19957.61	Lillooet River
FdCwHw	14.1	627.4	1.79	1121.19	87.00	97543.51	Lillooet River
FdCwHw	14.1	627.4	3.88	2433.28	87.00	211695.57	Lillooet River
Fd	22.3	716.7	0.21	150.71	87.00	13111.78	Lillooet River
River	0.0	0.0	0.16	0.00	0.00	0.00	Lillooet River
River	0.0	0.0	0.69	0.00	0.00	0.00	Lillooet River
FdCwHw	14.1	627.4	8.46	5306.13	87.00	461633.21	Lillooet River

[1]Species	[2]SITE INDEX	[3]Live wood volume (m^3/ha)	Polygon Area (ha)	Polygon live wood volume (m^3)	[4]Average market value (August 2010) of dominant species ($)	Volume x Market value ($)	Watershed
FdCwHw	14.1	627.4	0.09	57.96	87.00	5042.55	Lillooet River
AcFd(CwHwBa)	20.0	16.6	0.95	15.81	36.00	569.32	Lillooet River
AcFd(CwHwBa)	20.0	16.6	1.19	19.73	36.00	710.14	Lillooet River
AcCw(Fd)	18.0	17.0	0.61	10.28	36.00	370.13	Lillooet River
FdAcDr(CwBa)	27.0	37.0	0.85	31.57	87.00	2746.18	Lillooet River
FdAcDr(CwBa)	27.0	37.0	3.04	112.63	87.00	9799.08	Lillooet River
FdCw	21.1	719.4	0.05	38.73	87.00	3369.83	Lillooet River
Fd(Ac)	20.7	505.1	0.05	25.10	87.00	2183.84	Lillooet River
Bedrock	0.0	0.0	0.02	0.00	0.00	0.00	Lillooet River
Bedrock	0.0	0.0	0.87	0.00	0.00	0.00	Lillooet River
FdHw(Cw)	26.8	983.2	0.00	1.36	87.00	117.98	Lillooet River
FdHw(Cw)	26.8	983.2	0.04	38.84	87.00	3379.44	Lillooet River
FdHw(Cw)	26.8	987.7	0.15	143.28	87.00	12465.53	Lillooet River
Ac(Cw)	20.0	0.9	1.83	1.66	36.00	59.60	Lillooet River
River	0.0	0.0	0.15	0.00	0.00	0.00	Lillooet River
Fd	27.0	0.0	0.95	0.00	87.00	0.00	Lillooet River
River	0.0	0.0	8.47	0.00	0.00	0.00	Lillooet River
River	0.0	0.0	0.51	0.00	0.00	0.00	Lillooet River
Ac(Cw)	20.0	0.9	3.41	3.09	36.00	111.29	Lillooet River
FdHwCw(Ac)	23.7	636.9	0.88	561.02	87.00	48808.91	Lillooet River
Cw	25.1	1385.4	0.05	69.96	107.30	7506.18	Lillooet River
AcDr	26.0	3.4	0.11	0.39	36.00	13.88	Lillooet River
Bedrock	0.0	0.0	0.36	0.00	0.00	0.00	Lillooet River
L	0.0	0.0	8.34	0.00	0.00	0.00	Lillooet River
FdHwCw(Ac)	23.7	636.9	0.97	616.91	87.00	53671.21	Lillooet River
River	0.0	0.0	0.00	0.00	0.00	0.00	Lillooet River
River	0.0	0.0	0.08	0.00	0.00	0.00	Lillooet River
River	0.0	0.0	1.69	0.00	0.00	0.00	Lillooet River
FdHw(Ba)	27.0	5.9	0.36	2.14	87.00	186.56	Meager Creek
Fd(Cw)	18.0	4.7	3.50	16.62	87.00	1446.08	Meager Creek
CwAc	23.0	26.2	0.80	21.05	107.30	2258.93	Meager Creek
Fd(CwHw)	24.8	979.1	4.85	4752.52	87.00	413469.46	Meager Creek
Fd	18.0	0.0	19.69	0.00	87.00	0.00	Meager Creek

[1]Species	[2]SITE INDEX	[3]Live wood volume (m^3/ha)	Polygon Area (ha)	Polygon live wood volume (m^3)	[4]Average market value (August 2010) of dominant species ($)	Volume x Market value ($)	Watershed
FdHwCw	22.1	600.5	1.49	894.57	87.00	77827.51	Meager Creek
Bedrock	0.0	0.0	3.30	0.00	0.00	0.00	Meager Creek
HwFdCw	14.3	704.7	5.07	3574.53	46.40	165858.26	Meager Creek
Fd	18.0	0.0	7.73	0.00	87.00	0.00	Meager Creek
River	0.0	0.0	0.01	0.00	0.00	0.00	Meager Creek
FdCw	26.0	0.0	1.37	0.00	87.00	0.00	Meager Creek
FdCw(Hw)	28.0	1202.0	4.74	5697.12	87.00	495649.72	Meager Creek
FdCwHw	16.2	417.3	2.83	1182.19	87.00	102850.94	Meager Creek
FdCwHw	22.9	800.9	15.31	12262.14	87.00	1066806.54	Meager Creek
Bedrock	0.0	0.0	1.22	0.00	0.00	0.00	Meager Creek
CwPl	28.0	0.0	2.87	0.00	107.30	0.00	Meager Creek
FdHw	10.9	23.9	0.05	1.16	87.00	100.62	Meager Creek
CwAc	20.9	688.2	2.35	1618.98	107.30	173716.70	Meager Creek
CwHw(Fd)	23.0	11.1	7.68	85.32	107.30	9154.65	Meager Creek
FdCw(Ac)	27.0	0.0	1.03	0.00	87.00	0.00	Meager Creek
FdCw(Hw)	27.0	11.9	3.67	43.72	87.00	3803.70	Meager Creek
HwCwFd	14.6	462.6	0.74	341.95	46.40	15866.52	Meager Creek
Bedrock	0.0	0.0	0.03	0.00	0.00	0.00	Meager Creek
CwFdHw	23.0	0.0	3.54	0.00	107.30	0.00	Meager Creek
Bedrock	0.0	0.0	3.73	0.00	0.00	0.00	Meager Creek
FdCw(S)	25.0	0.0	1.40	0.00	87.00	0.00	Meager Creek
Cw(Fd)	23.0	14.7	6.48	95.19	107.30	10214.38	Meager Creek
FdCw(Hw)	27.0	11.9	6.43	76.50	87.00	6655.25	Meager Creek
BaCwHw	23.0	0.0	0.70	0.00	46.40	0.00	Meager Creek
FdCwHw(Pw)	22.9	800.9	5.74	4599.13	87.00	400124.18	Meager Creek
Bedrock	0.0	0.0	0.34	0.00	0.00	0.00	Meager Creek
Bedrock	0.0	0.0	3.48	0.00	0.00	0.00	Meager Creek
FdCwHw	16.2	417.3	1.67	696.20	87.00	60569.55	Meager Creek
BaCwHw	23.0	0.0	0.27	0.00	46.40	0.00	Meager Creek
FdHwCw	18.9	532.0	0.02	8.96	87.00	779.17	Meager Creek
Bedrock	0.0	0.0	0.31	0.00	0.00	0.00	Meager Creek
CwFdHw	23.0	0.0	0.52	0.00	107.30	0.00	Meager Creek
CwBaFd(Hw)	23.0	0.0	7.34	0.00	107.30	0.00	Meager Creek

[1]Species	[2]SITE INDEX	[3]Live wood volume (m^3/ha)	Polygon Area (ha)	Polygon live wood volume (m^3)	[4]Average market value (August 2010) of dominant species ($)	Volume x Market value ($)	Watershed
Bedrock	0.0	0.0	1.30	0.00	0.00	0.00	Meager Creek
CwHw(Fd)	23.0	0.0	0.09	0.00	107.30	0.00	Meager Creek
CwFdHw	23.0	0.0	0.34	0.00	107.30	0.00	Meager Creek
Fd(Ba)	27.0	37.0	6.58	243.13	87.00	21152.67	Meager Creek
CwFd	23.0	4.7	0.00	0.00	107.30	0.03	Meager Creek
CwFd	23.0	4.7	0.43	2.04	107.30	218.70	Meager Creek
CwFd	31.7	826.8	0.00	1.18	107.30	126.81	Meager Creek
CwFd	31.7	826.8	0.01	5.58	107.30	598.62	Meager Creek
FdCw(Hw)	27.0	51.5	0.68	34.92	87.00	3038.33	Meager Creek
FdHw	18.0	5.7	1.31	7.43	87.00	646.63	Meager Creek
CwFd	31.7	826.8	3.19	2635.93	107.30	282835.00	Meager Creek
River	0.0	0.0	0.00	0.00	0.00	0.00	Meager Creek
River	0.0	0.0	0.01	0.00	0.00	0.00	Meager Creek
River	0.0	0.0	0.06	0.00	0.00	0.00	Meager Creek
River	0.0	0.0	1.53	0.00	0.00	0.00	Meager Creek
River	0.0	0.0	4.70	0.00	0.00	0.00	Meager Creek
Totals:			**509.17**	**108799.80**		**8747777.69**	

Notes:

[1] Species: Ba=Balsam; Fd=Douglas fir; Hw=Western hemlock; Cw=Western redcedar; Ac=cottonwood; Bl=Alpine fir; Hm=Mountain hemlock; S=spruce; Pl=White pine.

[2] Site Index is a measure of productive potential of the land.

[3] From: Government of British Columbia, GeoBC/ Geographic Data Discovery Service. Online resource: http;//www.for.gov.bc.ca/his/datadmin/models/models.htm#models accessed March 2, 2011.

[4] From: Province of BC, 2010. Coast selling price system, average log prices for the 1 month period ending 2010-08-31. Province of British Columbia, Ministry of Forests, Mines and Lands. Online resource: http://www.for.gov.bc.ca/hva/logreports_coast.htm accessed March 04, 2011.

Appendix E

Lillooet River Photos Post-Meager Creek Event: August 7 and 13, 2010

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Photo E-1
Braided Reach (August 7, 2010)

Photo E-2
Braided Reach (August 7, 2010)

Photo E-3
Braided Reach (August 7, 2010)

Photo E-4
Landslide LWD

Photo E-5
Braided Reach (August 7, 2010) (view towards Forestry Bridge)

Photo E-6
Log Jam Below the Forestry Bridge

Photo E-7
Braided Reach Upstream of the Forestry Bridge (August 13, 2010) Shows New and Older Racked Material

Photo E-8
Braided Reach Upstream of the Forestry Bridge (August 13, 2010)

Photo E-9
Meager/Lillooet Confluence (August 13, 2010)

Photo E-10
Forestry Road and Remnant Lake (August 13, 2010)

Photo E-11
Braided Reach Upstream of the Forestry Bridge (August 13, 2010) Shows New and Older Racked Material

Photo E-12
Wood in Lillooet Lake/Delta (August 13, 2010)

Photo E-13
View Upstream from the Delta (August 13, 2010)

Appendix F

Lillooet River Photos Post-Meager Creek Event: May 25, 2011

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Photo F-1
Log Jam Downstream of Dyked Reach (1)

Photo F-2
Log Jam Downstream of Dyked Reach (2)

Photo F-3
Highway 99 Bridge Crossing

Photo F-4
Simple Bars with Little or No Wood in Dyked Reach

Photo F-5
Single Log LWD in Dyked Reach

Photo F-6
Miller Log Jam

Photo F-7
More Complex Log Jams as Channel Widens in Dyked Reach

Photo F-8
Braided Channel Upstream of Forestry Bridge Showing Wood Storage in the Reach

Photo F-9
Log Jam Upstream of Forestry Bridge Showing Evidence of Newer Racked Wood

Photo F-10
LWD Pushed by the Landslide Higher Onto the Floodplain (Over the Forestry Road)

Photo F-11
Much of the Wood Material Appears to Have Shattered into Smaller Pieces During the Landslide Event (1)

Photo F-12
Much of the Wood Material Appears to Have Shattered into Smaller Pieces During the Landslide Event (2)

Appendix G

Early Warning System Information

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

APPENDIX G: EARLY WARNING SYSTEM

Early warning systems have been installed around the world to warn of natural hazards such as earthquakes, tsunamis, floods and other hazards. The Village of Pemberton and local properties near the Lillooet River are subject to flooding due to several natural occurrences, which include floods from rainfall and snowmelt events, debris jams, and outburst floods due to landslides blocking the channel. A warning system could be employed to warn local community officials of these events.

Three types of hazards have been reviewed as part of the early warning system, including:

- floods from rainfall and/or snowmelt;
- outburst floods from debris jams blocking the river; and
- debris jams located at the Forestry Bridge.

Debris jams located in other areas of the Lillooet River are not discussed as part of this work as they are very difficult to predict and would be best addressed through visual inspections. If debris jams impound water and subsequently break, they could be detected in a similar manner to outburst floods.

The following sections outline information regarding data needs and system components and technology for an early warning system.

1. DATA NEEDS

Data requirements for an early warning system depend on the type of hazard. The requirements can be simple (e.g. water level or discharge), to more complex (e.g. the rate of change of water level).

The general data requirement to warn of floods generated from rainfall and snowmelt events is a water level (or discharge). The water level would rise gradually during these events and warnings could be set at pre-determined thresholds to alert personnel that the river is nearing flood levels, in order to trigger the necessary flood response activities.

Outburst floods are different than rainfall or snowmelt floods in that they typically are generated following a blockage of the river and a subsequent breach or failure of the blockage. Initially there may be a noticeable drop in water level in the river after the blockage occurs, followed by a sharp rise in water level after the collapse of the blockage. Data requirements for warning of such events could be a water level that would result in flooding, or a rate of change of water level (increase or decrease of water level over a period of time) that would indicate an event of concern.

Data requirements to identify debris blockages are very different from floods. Debris blockages at the Forestry Bridge could be indicated by a difference in water level between the upstream side and downstream side of the bridge, impact loading on the bridge or a horizontal plane being broken by debris above a certain elevation.

2. SYSTEM COMPONENTS AND AVAILABLE TECHNOLOGIES

An emergency warning system has at least four major components, which include:

- power source;
- telemetry (how the system transmits data);
- logging system; and
- sensor technology.

Other considerations include processing data through a programmable logic controller (PLC), and a host system to store the data.
Different systems to record and transmit the data may be required based on the data requirements. In addition to recording and transmitting the data, redundant systems may be required to reduce the likelihood of a system failure during an event of concern. Ideally there would be redundancy in all systems with differing transmitting and receiving devices and hosting services.

System components and options are explored in more detail below.

2.1 POWER SOURCE

The most flexibility can be achieved through a constant electrical feed to the project site, and this is recommended to support the optimum telemetry for the early warning system (see following section). There is a powerline crossing at the Forestry Bridge that could be used for the early warning system.

A back-up power supply should also be considered even though the main power source would be direct AC power. Power outages are common during many storms, and this corresponds to the time when flooding and debris movement is most likely. The back-up system could consist of batteries and solar panels or a generator.

2.2 TELEMETRY

A number of different telemetry options are available to transmit data. Some of the more common systems include:

- telephone;

- satellite;
- radio signal; and
- internet.

An emergency warning system should have a constant connection between the logging instruments and the host service.

Data can be transferred by either a land-based telephone line (physical wiring) or a cellular network (SMS). A modem is used for the land-based telephone line to transfer the data to a host service. The power requirements for this are low and can be powered through batteries and solar panels if call-ins are less frequent. The powerline crossing at the Forestry Bridge appears to have a telephone cable; however, presently a cellular network connection is not available at the Forestry Bridge or upstream of this location.

One of the more reliable satellites is a geostationary satellite such as INFOSAT. The Forestry Bridge crossing on the Lillooet River appears to have a line of sight to the INFOSAT satellite so the data could be regularly transmitted as required, but the site would have to have constant power to operate the system.

Radio signals are often used to transmit data from SCADA and other monitoring systems that local operations and utilities use. VHF and UHF radio systems are common and could be employed to transmit data and warnings to a specified location.

The internet has become a major hub for transferring data. ADSL is widely used in areas with and without cable internet providers. A modem transfers the data to a host service through a wired or wireless connection. This option draws a moderate amount of power to send information regularly and would generally require power to the station.

2.3 SENSORS AND LOGGERS

There are a number of sensors on the market to record different types of data.

Water levels can be measured using pressure transducers, ultrasonic sensors and radar sensors. For this location, it is recommended that either an ultrasonic or radar sensor be used. These types of sensors could be placed along the bridge above the channel to detect the surface below. The sensors are vulnerable if directly impacted. Also, leaf-fall and/or material build up under the senor could produce false readings. However, they are less vulnerable to freezing and damage from debris than pressure transducers.

The same sensors used to calculate water level could be used to calculate the rate of change for the water level to warn against an outburst flood but a program is required to run calculations on the incoming water level data to obtain a change in level over a specified period of time. These calculations could be conducted by a PLC or the host service software.

Debris impact and build-up can be monitored several different ways including by impact sensors, trip mechanisms, water level differences and cameras. Likely the most practical debris build-up monitoring at the Forestry Bridge would be to monitor the difference between the water level upstream and downstream of the bridge by placing a second sensor at the bridge. A program could run calculations on the raw data and provide an alarm when the difference in water levels reaches a certain value. This could also provide redundancy in the water level monitoring.

Cameras could be used to take photos of the site regularly and upload images to the host service. These images could be viewed regularly to check for debris build up or during an alarm to check for false alarms and the potential magnitude of the alarm. An infrared camera has the ability to take pictures during the night and day. A normal camera could be used if adequate lighting is installed for the location the camera is pointing.

One of the most important components of a warning system is logging of the data. Depending on the setup of the telemetry and other components, it may be important to have a logger that is capable of “pushing” an alarm through. This means that when a certain threshold is achieved (either from raw data or calculated data from a PLC) the logger knows to “wake up” and call in to the host service. This would only be required if the host service was not in constant contact with the site. Preferably, the logger records the data and is a backup alarm device, with primary alarms generated by the data hosting service or a PLC.

2.4 HOST SERVICE

Once the data is logged and transmitted from site, a host service is required to store the data. The host service also may be required to process the raw data to check for alarm conditions, although this can only be achieved if there is continuous calling (i.e. every 15 minutes). In the case where the station is not in continuous contact with the host, a PLC would be required at the logging station to process the raw data.

Data storage and processing are usually software-based programs that have alarm/notification abilities and ideally can be accessed from multiple locations by multiple people. FlowWorks is an example of a service used for applications such as an early warning system. SCADA has also been used for similar applications; although this system typically has a high capital cost to setup if an existing system is not already in place.

3. CLASS 'D' COST ESTIMATE

Table 3-1 presents a summary of equipment costs for the various technologies discussed previously. More input from the PVDD is required to develop a full Class 'D' cost estimate to install an early warning system.

Table 3-1: Summary of Equipment Costs Associated with Early Warning System

Hardware Description	Unit	Cost	Comments
Sensors			
Pressure Transducer	ea.	$1,000.00	
Ultrasonic Sensor	ea.	$1,200.00	
Radar Sensor	ea.	$1,200.00	
Tiltmeter	ea.	$1,000.00	
Loggers			
Telog - 4 Analog, 3 Digital Channels	ea.	$2,700.00	
Telog - 8 Analog, 6 Digital Channels	ea.	$3,200.00	
Telemetry			
Geostationary Satellite	ea.	$1,200.00	
Low Orbit Earth Satellite	ea.	$1,500.00	Includes additional logger costs
Internet / Telephone	ea.	-	Included in the logger costs
Other			
Basic Kiosk	ea.	$,500.00	
Miscellaneous Hardware	L.S.	$500.00	Does not include specialty items
PLC	ea.	$1,000.00	very basic unit
Monthly Fees			
Geostationary Satellite	per month	$100.00	
Low Earth Orbit Satellite	per month	$55.00	Includes costs for other data collection (i.e., unidata)
Internet/ADSL Connection	per month	$40.00	
Telephone / Cellular (SMS)	per month	$30.00	