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Technical Memorandum

DATE: December 22, 2011

TO: Steve Flynn, Pemberton Valley Dyking District

FROM: Erica Ellis, M.Sc., P.Geo.
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RE: **LILLOOET RIVER SURVEY**
Interpretation of 2011 River Survey
Our File 713.057-300

Kerr Wood Leidal Associates Ltd. (KWL) has been retained by the Pemberton Valley Dyking District (PVDD) to coordinate and interpret the 2011 Lillooet River bathymetric survey.

The comparison of 2000 and 2011 survey data indicates that most cross-sections have experienced net deposition (aggradation). Aggradation has reduced cross-sectional areas by amounts ranging from 0.2% to almost 15%. This will reduce the river's capacity to convey flood flows and decrease the available freeboard in the dyked reaches.

1. Background

In August 2010, a massive landslide occurred on Capricorn a tributary Meager Creek and the Lillooet River. The landslide provided the impetus to conduct a river survey to document existing conditions, and to compare with previous survey data. Although a comprehensive cross-section survey was conducted in 2000, a number of significant events have occurred in the intervening decade, including:

- A major flood in 2003; and
- Several smaller landslides within the watershed.

Therefore the updated survey provides a more representative 'baseline' for comparison with potential future sedimentation.

The 2011 Lillooet River survey is intended to document river conditions prior to the arrival of the majority of the coarse sediment generated during the 2010 landslide. As well, the updated survey can be compared with previous surveys, and can be used in future hydraulic modelling, analysis and for design purposes.

The survey was conducted by Atek Hydrographic Surveys Ltd. (Atek) between May and June, 2011, and included eighty-four cross-sections on the Lillooet River. The cross-sections are categorized in three groups as follows:

- Historic cross-sections repeated from 2000 survey (56 sections);
- Historic cross-sections repeated from pre-2000 survey (16 sections); and
- New cross-sections at key locations with no previous data (12 sections).

The survey extended from the Lillooet River delta at Lillooet Lake to about 3.5 km upstream of the Hurley forestry bridge, a distance of about 44 km.

The 2011 survey is documented in the December 2011 "Cross Section and Bathymetric Report" prepared by KWL for PVDD.

The purpose of this technical memorandum is to interpret the 2011 survey results for river management purposes.

2. Cross-section Changes

Table 1 in the "Cross Section and Bathymetric Report" presents a series of metrics measured from the cross-section data for 2011 survey, as well as previous years of survey. These metrics include:

- Channel width;
- Area;
- Average depth (calculated as area divided by width); and
- Maximum depth.

Changes in these metrics over time can be used to infer either aggradation or degradation at the cross-section. For example, an increase in area implies that degradation and/or bank erosion has occurred to enlarge the channel cross-section, whereas a decrease in area implies that aggradation has occurred.

Changes in the maximum depth are reflective of the thalweg elevation but do not, in and of themselves, fully describe the cross-section change since the overall shape of the cross-section may change without any loss of conveyance (e.g. from a more triangular shape, with flow concentrated in a deep thalweg, to a more rectangular shape, with a relatively flat bottom). The average depth reflects changes that have occurred in both the width and the area: a decrease in the average depth implies aggradation, while an increase in the average depth implies degradation.

With respect to management of the river for flood and erosion protection, aggradation of the bed (resulting in overall loss of conveyance) and bank erosion are of primary interest.

2.1 Historic Trends (2000 and prior)

Cross-section changes have previously been assessed by KWL, following the 2000 survey (KWL, 2002[1]). At this time, the decision was made to reference all cross-sections measurements to "bankfull" elevation, which was assessed on a cross-section by cross-section basis for each year of available survey. Cross-section survey data from 1969, 1971, 1978, 1985, 1993 and 2000 were included in the analysis.

[1] KWL, 2002. *Engineering Study for Lillooet River Corridor*. Report prepared for the Pemberton Valley Dyking District, the Mount Currie Band, the BC Ministry of Water Land and Air Protection, Public Works and Government Services Canada and Indian and Northern Affairs Canada. (KWL Project 713.002).

Although the 2002 report identified an estimated annual transport of 40,000 m^3 of gravel into the lower Lillooet River, the report also concludes "…there is no obvious trend toward reduced channel area at the cross sections". This is a counter-intuitive result, since over time the annual aggradation should gradually aggrade the bed and reduce the flow area. The following factors were presented to attempt to explain the apparent discrepancy:

- Over the river reach being considered, 10 years of 40,000 m^3/year aggradation represents about 12 cm of aggradation over that time period, which is relatively modest and therefore hard to detect in repeat surveys.
- The primary goal of the 2000 survey was to locate and replicate historical cross-sections, wherever they were located. However, deposition tends to occur in preferential locations (sedimentation 'zones'), which historic cross-sections happened not to intersect, for the most part.
- Gravel removals between 1980 and 2000 may have offset any aggradation occurring during the same time period.

In addition, as documented in KWL (2002), major engineering works constructed in the 1940s resulted in wide-scale channel degradation. These works included dredging a new channel to cut off 14 km of river meanders, and lowering Lillooet Lake by 2.5 m. It is assumed that the subsequent establishment of a new 'equilibrium' would take a number of decades due to the magnitude of the disturbance.

2.2 2000 to 2011 Trends

To facilitate the interpretation of cross-section changes, the width, area and maximum depth for the 2011 survey have been measured to the same vertical reference plane as used in the 2000 survey. Table 1 (attached) summarizes the 2000 to 2011 cross-section trends. Colour coding has been used to indicate which changes are associated with aggradation and which with degradation.

As indicated in Table 1, the majority of cross-sections indicate that aggradation has occurred between 2000 and 2011.

From about XS 37 to XS 29 (roughly 6 km) appears to be a reach of localized degradation. This impression may be somewhat biased by the lack of 2000-2011 comparative cross-sections downstream of the Forestry Bridge, and the fact that the cross-sections in this reach do not intersect the existing gravel bars (3 new sections were added in 2011, at existing bars). In addition, it is a relatively straight and simple reach, which would tend to promote transport of bed material, rather than deposition.

Table 2 summarizes the number of cross-sections in each time period that have indicated aggradation versus degradation based on cross-sectional area. As indicated in the table, there is a trend since 1969 of increasing numbers of cross-sections showing aggradation.

Table 2: Number of Cross-sections Showing Degradation or Aggradation Based on Area

Count	1969 to 1978	1978 to 1985	1985 to 2000	2000 to 2011
XS Showing Degradation	49	26	35	16
XS Showing Aggradation	2	27	19	40
Total XS Analyzed	**51**	**55**	**54**	**56**

Note: An increase in cross-sectional area implies degradation, while a decrease in cross-sectional area implies aggradation.

As previously mentioned, KWL (2002) estimated that, *on average*, about 40,000 m³/year of bed material (coarse sediment) is transported past the Forestry Bridge. The range of transport estimates was between 30,000 m³/year and 40,000 m³/year (KWL, 2002). The transport rate is not expected to increase significantly as a result of the Capricorn Creek landslide since the upper river already had abundant sediment sources, and the available sediment far exceeds the river's ability to transport it (leading to the characteristically braided form).

In any given year, the transport rate will vary depending on the distribution of flow. Sediment transport in gravel bed rivers is a non-linear process that is sensitive to the occurrence and magnitude of high flows: large floods tend to produce significant sediment transport, while very little transport of coarse material occurs during lower flows. In this respect, the 2003 flood (which has an estimated return period of about 200 years), is likely to have transported large volumes of sediment.

As summarized above, the 2000 to 2011 cross-section comparison indicates that many sections aggraded during this time period. The volume of aggradation experienced in the gravel reach would be of interest for management purposes.

Repeat cross-section surveys have been used in other gravel rivers to estimate the sediment budget (the net accumulation or loss of bed material). However, according to previous research, the spacing of the cross-sections greatly affects the precision of the resulting sediment budget. Results from the Vedder River suggest that cross-section spacing greater than about 2 times the average channel width is associated with high variability in the sediment budget results (Ashmore and Church, 1998[2]).

On the Lillooet River, the average channel width is about 120 m in the gravel-bed reach downstream of the Forestry Bridge. This implies that ideal cross-section spacing for sediment budget purposes would be less than about 250 m; in contrast, the average spacing of the surveyed cross sections (800 m) through the reach of concern is more than three times this ideal spacing. Given the length of survey required, a survey with 250 m cross section spacing would be extremely expensive to collect and repeat. Historic surveys for the Lillooet River have been completed primarily for hydraulic analysis, which does not require such a close spacing for cross sections.

The PVDD has been working towards better representation of sedimentation in the surveys they commission. Since 2000, the PVDD has been collecting detailed survey information at several gravel bars, and for the 2011 survey more cross-sections were added to better represent sedimentation. The additional cross-sections surveyed in 2011 can be used for comparison in future analyses.

Since the spacing of cross-sections common to the 2000 and 2011 surveys is not ideal for sediment budget purposes, there is uncertainty with estimating associated sediment volumes, which needs to be recognized in the interpretation of the results. It is thought that the larger than ideal cross-section spacing will likely result in an underestimation of the volume of deposition since locations of preferential deposition zones are less well represented.

In addition, a true sediment budget analysis must account for fine sediment (sand, silt and clay) differently than coarse sediment. Fine sediments tend to make up the upper portions of river banks, since they are deposited in overbank flood events. When these sediments are eroded back into the river, they are entrained into the water column and travel out of the reach (i.e. they are not deposited locally). Conversely, as gravel bars build up and begin to become vegetated, some of the vertical build-up on the top surface is fine sediment. The sediment budget is based on consideration of bedload only, so overbank sediments should be removed from the analysis. However, the primary purpose of the Lillooet

[2] Ashmore, P.E. and Church, M. 1998. Sediment transport and river morphology: a paradigm for study. In "Gravel Bed Rivers in the Environment". Klingeman, P., Beschta, R., Bradley, J., and Komar, P. (eds). Water Resources Press, Littleton, CO. pp 115-148.

River cross-section data has been to support a hydraulic model for flood profiling; a secondary goal has been to interpret repeat cross-sections to determine channel changes. A detailed sediment budget study has been beyond the scope of work conducted to date, and therefore, the depth of fine sediment at each cross-section is not known.

Bearing in mind the caveats made above, the net volumetric change has been estimated between XS 42.2 and XS 9.1. Cross-section 42.2 is about 6 km downstream of the Forestry Bridge. However, it was used as the upstream limit because significant changes have occurred at that cross-section that are not representative of the reach between that cross-section and the Forestry Bridge. The Green River confluence (XS 9.1) has been assumed to represent the approximate downstream limit of gravel transport, which occurs somewhere between kilometre 8 and kilometre 6. Downstream of this location it is assumed that the channel bed is dominantly sand.

The results of the analysis are summarized in Table 3, below.

Table 3: Estimated Net Volumetric Change Between 2000 and 2011

Reach	Average Distance Btw. XS (m)	Range in Net Volumetric Change [1,2,3] (m³)	Range in Annual Average (m³/year)	Previously Estimated Transport Rate [4] (m³/year)
6 km D/S of Forestry Bridge to Green River confluence (XS 42.2 to XS 9.1)	660	-70,000 to -210,000	-6,000 to -19,000	30,000 – 40,000 [5]
Miller Creek to Green River confluence (XS 25 to XS 9.1)	570	-145,000 to -435,000	-13,000 to -39,000	8,000 – 15,000

Notes:
1. Negative values represent net deposition (i.e. net loss of cross-sectional area).
2. Volumetric change calculated as the change in cross-sectional area multiplied by half the distance to each of the adjacent cross-sections (or representative distance). The change includes both erosion and deposition as identified in Table 1.
3. Range estimated by assuming that the associated uncertainty is at least ±50%.
4. Transport rates estimated in KWL (2002) and KWL (2007)[3].
5. Transport rate estimated for the reach downstream of the Forestry Bridge (i.e. downstream of XS 51.1).

As previously stated, the volumetric change estimated using the 2000 to 2011 cross-section data will be subject to relatively high uncertainty. As an indication of the potential magnitude of the uncertainty, an assumed range of ±50% has been assumed; however, the actual uncertainty could be greater.

As seen in Table 3 above, the portion of the Lillooet River between Miller Creek and the Green River confluence had a larger amount of net deposition (negative total net volume of change) than the entire reach of the Forestry Bridge to Green River confluence, which encompasses it. This is because there is net erosion between the Forestry Bridge and Miller Creek, which reduces the net deposition for the Forestry Bridge to Green River Confluence, see Tables 1 and 3.

[3] KWL, 2007. Lillooet River Gravel Management Plan. Report prepared for the Pemberton Valley Dyking District. (KWL Project 713.004).

It is also evident that the net volumetric changes estimated in Table 3 do not agree particularly well with previously estimated transport rates in KWL (2002) and KWL (2007). This is not surprising, for the following reasons:

- In using XS 42.2 as the starting point, about 20% of the reach is not represented in the calculation, compared with starting at the Forestry Bridge.
- Although the 2011 survey added 28 cross-sections to reduce the distance between cross-sections and to target known depositional areas, the comparative data in Table 3 are restricted to locations surveyed in 2000, which do not include many of the sedimentation zones.
- As mentioned earlier, the wide cross-section spacing introduces a high degree of uncertainty, since results at one cross-section are then assumed to be representative of conditions for several hundreds of metres upstream and downstream, which is unlikely to be accurate.

The first two factors will act to bias the result toward an underestimate of the “true” volumetric change, which explains in part why the estimated volumetric change between the Forestry Bridge and Green River is lower than previously estimated. The third factor could act as a low or high bias, depending on how “representative” the actual cross-sections are of the current conditions in the reach. It is not known whether additional cross-sections would also indicate erosion, or whether they would potentially reveal deposition that is not currently represented in the volume estimate (which would bring the volumetric change closer to the previous estimates).

The range of 2000 to 2011 estimated annual volumetric change between Miller Creek and Green River overlaps with the original range of estimated transport rates. If the “true” volumetric change is closer to the high end of the range this would imply that deposition is occurring preferentially in the lower part of the river. However, this cannot be established with certainty using the existing data.

In light of the uncertainty associated with using the 2000 to 2011 cross-section data to estimate volumes, the original range of estimated transport rates is still considered to be reasonable.

3. Implications for Flood Protection

The dyked reach of the Lillooet River extends from about XS 39 to about XS 8 (see map sheets in the “Cross Section and Bathymetric Report”, for reference). Between 2000 and 2011, the average channel area has decreased by 2% within the dyked reach[4]. A reduction in the cross-sectional area results in a decrease in the ability of that cross-section to convey flows for the same water surface elevation. This can increase the risk of adjacent dykes overtopping during flood events.

Areas where a reduction in conveyance would be of particular concern include: 1) locations where the dyke freeboard is 0.3 m or less, 2) areas not protected by dykes, 3) constrictions at bridge crossings, and 4) locations experiencing ongoing erosion. These areas were identified and compared to the aggradation and erosion observed at nearby cross sections, see Table 4 attached. The locations include:

[4] Average of available cross-section data covering the dyked reach: XS 9.1 to XS 37.

- Area 7/8 Dyke Near Pemberton Industrial Park and Mount Currie: The area does not have adequate flood protection.
- Area 6 Near Pemberton Airport: The area does not have adequate flood protection and it is an emergency access location to Pemberton.
- Road / Non-standard Dyke Access to Airport (Area 4): The area does not have adequate flood protection is the only vehicle access to the airport.
- Ayres Dyke Upstream of Highway 99 Bridge (Area 7): The area does not have adequate flood protection and has a major crossing (fixed constriction) of the Lillooet River. Location has had an emergency response bank erosion repair in 2011 and has an application to EMBC to raise the dyke.
- Rail Bridge Crossing (Area 4): A major crossing (fixed constriction) of the Lillooet River.
- Area 3 Dyke: The area does not have adequate flood protection.
- Denman Riprap (Area 2): Large channel changes and known bank protection failure location.
- Area 2 Dyke: The area does not have adequate flood protection.

In the areas of the dyked reach where the estimated 200-year return period water level could be within 0.3 m of the dyke crest or could overtop the dyke crest (based on the 2002 hydraulic model with the 2000 survey), the majority of the cross-sections indicate reduced cross-sectional area.

The Ayres Dyke upstream of the Highway 99 Bridge is of particular concern because, based on the 2002 model, the 200-year return period water levels could be within 0.3 m of the dyke crest and potentially overtop the dyke in some locations. In addition, the channel has lost between 4% and 10% of its cross-sectional area since 2000. Of note, XS 16 in this reach, has accumulated 34 m^2 since 2000, which is greater than 0.2 m deep if spread out over the distance between the dyke crests. Undoubtedly this will result in an increase in flood level in this reach, however it is not a one to one relationship on area reduction to flood level increase. Factors such as velocity increase, channel and bank roughness, and interaction with upstream and downstream sections will dictate what the resultant change in water level will be. In order estimate the increase in water level, the 2011 cross sections would need to be inputted into to the Mike 11 model.

In June 2011, a significant bank failure occurred along Ayres dyke which required emergency bank repair and protection. It is likely that this was, in part, caused by the sediment deposition and associated increased velocities in the reach.

In addition to this, there has been between 0.3 m and 1.1 m of deposition across the base of the channel (XS 15.2) at the Highway 99 bridge crossing. This will result in increased velocities and a higher water level at the bridge.

4. Gravel Management Plan

KWL has previously prepared a “Gravel Management Plan” for the Lillooet River (KWL, 2007). The purpose of the Plan is to mitigate the effects of progressive aggradation of the river channel such that the design flood levels in the vicinity of Pemberton will not increase, which could potentially result in flooding.

Based on an assumed decrease of the sediment transport rate downstream of the Forestry Bridge, the Plan recommends a removal of about 15,000 m^3 of sediment every 3 years to address aggradation. Specific removal sites are suggested to limit the associated habitat disturbance, rather than widespread dredging of the river. Suggested removal sites in the 2007 Plan include:

- Voyageur Bar;
- Beem Bar; and
- Big Sky Bar.

These bars have been shown to be aggrading, but the locally adjacent banks are either not dyked or have a 2000 modeled freeboard that equals or exceeds 0.3 m. A freeboard of 0.6 m was recommended in KWL (2002).

The Plan has been presented to regulatory agencies including the Ministry of Forests, Lands and Natural Resources Operations (MFLNRO) (which houses the Provincial Inspector of Dikes Office), and Fisheries and Oceans Canada (DFO). DFO has expressed concern that the approach to sediment management proposed in the 2007 Plan would not address site-specific hydraulic deficiencies, and that the Plan does not include alternate strategies for flood hazard mitigation (e.g. setback dykes, floodproofing, etc.).

The intent of the Plan is to provide a practical approach to gravel management on the Lillooet River. Although the results presented in Sections 2 and 3 of this technical memorandum demonstrate that the lower river is generally aggrading, the impact on the flood profile can only be quantified by hydraulic modeling using the 2011 survey cross-sections

Based on the results of the 2000 to 2011 survey comparison and the implications for flood protection presented above, it may be worth considering additional removal locations at bars that have demonstrated aggradation. These sites include:

- the left-bank gravel bar opposite the Green River confluence;
- the left-bank gravel bar adjacent to the airport; and
- the series of right-bank gravel bars extending from Beem Bar to Highway 99.

Of note, KWL (2007) recommends that an alternate, winter removal window be considered for the Lillooet River since the water levels in this high-elevation watershed tend to remain relatively high through the normal August-September in-stream works window. In order to visualize the very important effect the winter removal window would have on potential gravel removals, it is worthwhile comparing the map sheets included in the “Cross Section and Bathymetric Survey” report (2009 orthophotos; flow is about 200 m^3/s) with the Google Earth imagery (2009 orthophotos; flow is about 27 m^3/s). The Google Earth images represent the gravel bar exposure during the typical winter low flows.

5. Summary

In summary:

- The cross section comparison indicates aggradation over almost the entire surveyed reach of the Lillooet River (from upstream of the Forestry Bridge to Lillooet Lake). The observed aggradation has resulted in a loss of the river’s flow conveyance area ranging from 0.2% to almost 15% reduction.
- The reduced conveyance will result in:
  - an increase in the 200-year return period flood level;
  - a decrease in dyke freeboard; and
  - an increased potential for flooding in the Lillooet corridor near Pemberton and Mount Currie.
- Areas of concern were reviewed and the reach along the Ayres dyke and the Highway 99 bridge was identified as being of particular concern due to the quantity of deposition, the inadequate flood protection, and the recent large emergency response bank protection repair, which was likely aggravated by the deposition.

- In order to provide a significant local and immediately-realized hydraulic benefit, sediment removal in the wetted portion of the channel would be required in the Ayres dyke reach.
- Although the 2011 survey is not intended to support a comprehensive sediment budget, the estimated volumetric change is in the order of what would be expected based on previous sediment transport estimates presented in KWL (2002) and KWL (2007). The aggradation is generally widespread throughout the reach suggesting that if sediment management is pursued, additional sites beyond those presented in the Gravel Management Plan should be considered. As noted in the 2007 Plan, long term sediment management through gravel removals at large, accessible bars could be conducted primarily 'in the dry'.
- The results of the 2000 to 2011 cross-section comparison underscore the long-term and pervasive nature of aggradation on the Lillooet River that, if not addressed, ultimately will pose a significant hazard to the community. Sediment deposition in the channel will continue and, without sediment removals, the dykes will either need to be raised or set back from the river in order to achieve and maintain the surrounding community's required flood protection. As noted in the 2002 Corridor Study, a greater freeboard should be considered if gravel management is not implemented. There is however a practical limit to the height at which a dyke can be raised due to stability issues, which will constrain dyke raising in the long term. Many dykes in the Lillooet Corridor are already approaching the desirable practical limit of dyke height.

6. Recommendations

It is recommended that:

- PVDD consider viable long term approaches to address on-going aggradation in the Lillooet River. As presented in KWL (2002), sediment management, dyke raising and dyke setbacks continue to be recommended approaches.
- In light of the 2000 to 2011 survey comparison, PVDD meet with DFO, the Provincial Inspector of Dikes Office, and the Lil'Wat Nation to discuss sediment management for the Lillooet River. In particular, the meeting should address an application for 2012 sediment removal.
- In addition to the dyke-raising application that has already been submitted to the Province for funding, PVDD should consider adding the Ayres Dyke reach to the list of potential sediment removal sites. DFO has expressed a desire to see a local hydraulic rationale for sediment removal sites, and Ayres Dyke was already deficient in freeboard prior to the aggradation between 2000 and 2011, which will have exacerbated the situation.
- In light of significant changes to the channel and a severe flood in 2003, an updated flood profile is warranted to support future flood protection efforts. The existing MIKE11 hydraulic model of the Lillooet River should be updated with the 2011 surveyed cross-sections, and an updated design flood flow estimate.

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Revision History

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0	November 10, 2011	Draft	Draft for review.	EE / SFJ
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3	December 21, 2011	3rd Draft	Incorporate PVDD & MVC feedback.	EE / SFJ
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Table 1: Cross-sectional Changes Along Lower Reaches of Lillooet River - 2000 to 2011

Cross-section	Location	CHANGE IN AREA		CHANGE IN AVG. DEPTH		CHANGE IN MAX. DEPTH		CHANGE IN WIDTH	
		(m²)	(%)	(m)	(%)	(m)	(%)	(m)	(%)
0.3		-59	-3.3	-0.1	-3.3	0.5	8.7	0.0	0.0
1		-30	-3.3	-0.1	-3.3	0.6	7.9	0.1	0.0
1.1		-87	-7.6	-0.2	-7.6	0.8	11.8	0	0.0
3		14	2.1	0.1	1.2	0.2	2.6	1.3	1.0
5		-2	-0.3	-0.1	-1.5	0.3	5.1	2.2	1.2
6		-13	-1.9	-0.1	-1.2	-0.4	-7.6	-1.1	-0.7
7		-15	-2.6	-0.1	-2.7	-0.1	-2.3	0.2	0.2
9.1	Downstream of Green R confluence	-32	-4.4	0.0	-0.8	0.6	7.3	-6.7	-3.5
9.2	Upstream of Green R confluence	2	0.4	-0.3	-7.6	0.4	6.6	10.2	7.5
10		-42	-8.1	-0.2	-7.8	-0.4	-8.5	-0.5	-0.3
11		-12	-3.4	-0.1	-3.1	0.6	10.8	-0.2	-0.2
12		-10	-2.5	-0.1	-2.8	0.3	4.3	0.3	0.3
13		-10	-2.6	-0.1	-3.1	-0.4	-8.8	0.5	0.6
14		-19	-4.9	-0.2	-5.8	-0.9	-16.8	0.8	0.9
14.1	Downstream of Pemberton Ck confluence	-9	-2.2	-0.1	-1.4	-0.2	-3.3	-0.8	-0.8
14.2	Upstream of Pemberton Ck confluence	19	3.4	0.1	2.8	-1.0	-18.0	0.9	0.6
15		-7	-1.7	-0.1	-1.6	-0.2	-3.4	-0.1	-0.1
15.2	Highway 99 bridge, downstream	-33	-6.5	-0.3	-6.0	-0.5	-6.6	-0.5	-0.4
15.4		-35	-9.8	-0.3	-9.4	-1.3	-17.9	-0.4	-0.4
16		-34	-7.9	-0.3	-7.3	-2.0	-30.8	-0.6	-0.6
17		-25	-5.0	-0.2	-4.6	0.1	1.4	-0.4	-0.3
18	Downstream end of Beem Bar	-28	-4.2	-0.2	-4.2	-0.9	-11.8	-0.1	0.0
19		-26	-6.7	-0.2	-7.3	0.1	1.6	0.6	0.5
19.1		-32	-8.2	-0.2	-6.8	-1.1	-15.8	-1.4	-1.3
19.2	Railway bridge, downstream	36	4.9	0.3	4.7	1.0	9.1	0.3	0.2
19.4		39	5.6	0.2	5.3	1.0	16.7	0.6	0.3
19.5		-1	-0.2	0.0	-0.2	-1.2	-21.4	0.0	0.0
20		-21	-4.7	-0.2	-4.6	0.6	10.1	-0.1	-0.1
21	160 m upstream of WSC 08MG005	-28	-6.6	-0.2	-6.6	-0.2	-4.4	0.0	0.0
22	Downstream end of Voyageur Bar	-55	-11.1	-0.4	-14.0	-0.7	-14.6	3.9	2.5
24		-7	-1.8	-0.1	-1.7	-0.3	-5.3	-0.1	-0.1
25	Downstream of Miller Ck confluence	-38	-9.9	-0.4	-9.7	-1.2	-19.5	-0.1	-0.1
26	Upstream of Miller Ck Downstream of Ryan R. confluence	-6	-1.8	0.0	-1.2	-0.8	-15.6	-0.5	-0.6
26.1	Upstream of Ryan River confluence	1	0.3	-0.1	-1.6	-0.1	-1.3	1.3	1.9
27		-2	-0.5	0.0	-1.0	0.3	4.7	0.4	0.5
28		-6	-2.0	-0.1	-2.7	-0.6	-12.5	0.5	0.6
28.1		2	0.6	0.0	-0.8	-0.1	-1.9	1.1	1.4
29		-1	-0.3	0.0	0.4	-0.3	-6.5	-0.5	-0.7
30		1	0.3	0.0	-0.1	-0.1	-2.2	0.5	0.4
31		32	8.4	0.2	3.4	1.1	16.0	4.4	5.1
32		118	18.6	0.5	10.8	1.1	13.9	11.4	8.8
34		-26	-6.1	-0.3	-6.4	0.1	0.9	0.2	0.2
35		10	2.2	0.1	2.1	-0.1	-1.2	0.1	0.1
36		5	1.1	0.0	0.8	-0.2	-2.7	0.4	0.4
36.1		-7	-2.0	-0.1	-2.0	-0.3	-5.5	0.0	0.1
37		7	1.5	0.0	0.3	0.2	3.2	1.1	1.2
42		-4	-0.9	-0.1	-1.6	-0.4	-5.8	0.8	0.7
42.1		-79	-11.9	-0.6	-12.1	-1.0	-13.5	0.3	0.2
42.2		93	11.7	0.1	3.0	-1.2	-22.3	28.6	9.0
51.1	Forestry bridge, downstream	-18	-3.2	-0.2	-2.7	-0.4	-3.0	-0.3	-0.5
51.2	Forestry bridge, upstream	-5	-0.8	-0.1	-0.6	-0.8	-7.0	-0.1	-0.2
52		-38	-9.1	-0.2	-9.3	0.6	9.1	0.3	0.2
53		-57	-10.7	-0.3	-9.9	-0.8	-15.8	-1.2	-0.6
54		-45	-13.9	-0.3	-13.3	-0.3	-6.1	-0.7	-0.5
55		21	4.7	0.1	4.3	1.1	21.4	0.7	0.5
56		75	16.1	-0.2	-14.9	0.3	7.7	85.5	27.1

Notes:
Change calculated as (2011 - 2000). Percentage change is normalized to 2011 value.

(orange)	Change associated with aggradation.
(blue)	Change associated with degradation.

Table 4: Review of Potential Areas of Concern

Potential Concern	Location	Is the Reach Dyked?	Representative Cross-sections	2000 Q200 Model Result in Location of Concern	2000 to 2011 Cross-Section Change m^2 (%) — Erosion +, Deposition -
Area 7/8 Dyke - Pemberton Industrial Park & Mount Currie					
Dyke Overtopping	Near confluence Lillooet River and Green River. Roughly between XS 11 and XS 9	Yes (left bank, looking downstream (d/s))	XS 11	Within 0.3m of crest	-12 (-3.4%)
			XS 10	Overtops dyke	-42 (-8.1%)
			XS 9.2	Overtops dyke	2 (0.4%)
			XS 9.1	Overtops dyke	-32 (-4.4%)
Area 6 - Pemberton Airport					
Airport Flooding	Pemberton Airport (right bank, looking d/s)	Airport Road acts as a dyke (public road)	XS 12	Overtops road	-10 (-2.5%)
			XS 11	Overtops road	-12 (-3.4%)
Area 4 Road/Dyke - Access to Pemberton Airport					
Dyke Overtopping	d/s of Highway 99 Bridge. Roughly between XS 15 and XS 14.2	Yes (right bank, looking d/s)	XS 15	Within 0.3m of crest	-7 -1.7%)
Ayres Dyke Upstream of Highway 99 Bridge (protecting Area 7)					
Bridge & Dyke Overtopping	Upstream (u/s) of Highway 99 Bridge. Between XS 18 and XS 15.2	Yes (both banks)	XS 18 (representing upstream end of Ayres Dyke)	Within 0.3m of left bank dyke crest	-28 (-4.2%)
		Yes (both banks)	XS 17 (representing area of concern just u/s of North Arm Plug)	Within 0.3m of left bank dyke crest	-25 (-5%)
		Yes (both banks)	XS 16	Overtops left bank dyke Not within 0.3m of right bank dyke crest	-34 (-7.9%)
		Yes (both banks)	XS 15.4 (representing area of concern just u/s of XS 15.4)	Within 0.3m of left bank dyke crest	-35 (-9.8%)
Area 4 Dyke - Rail Bridge					
Bridge & Dyke Overtopping	Rail Bridge. XS 19.2	Yes (right bank, looking d/s)	XS 19.4	Not Within 0.3m of right bank dyke crest Overtops left bank	39 (5.6%)
			XS 19.2	Not Within 0.3m of right bank dyke crest or left bank	36 (4.9%)
Area 3 Dyke					
Dyke Overtopping	Immediately d/s of Lillooet River confluence with Ryan River. Small area between XS 26.1 and XS 26	Yes (right bank, looking d/s)	No XS available, XS 26 is just d/s but Q200 is not within 0.3m of dyke crest	Within 0.3m of crest	-6 (-1.8%)
Denman Riprap (Area 2)					
Bank Erosion Noted in Summer 2011	Denman Riprap Eroded Section. Roughly between XS 42.2 and XS 42.1	Private Berm / Dyke (right bank, looking d/s)	XS 42.2	Overtops right bank Not within 0.3 m of left bank crest	93 (11.7%)
			XS 42.1	Not within 0.3m of both bank crests	-79 (-11.9%)
Area 2 Dyke (constructed in 1987 by RPAP)					
Dyke Overtopping	XS 53	Yes (right bank, looking d/s)	XS 53	Within 0.3m of crest	-57 (-10.7%)