WINDERMERE CREEK HYDROTECHNICAL ASSESSMENT

Prepared for:

Regional District of East Kootenay
19 – 24th Avenue South
Cranbrook, BC V1C 3H8

Attn: Jim Maletta

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NHC 3000128

northwest hydraulic consultants

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Certification

Report prepared by:

PROFESSIONAL PROVINCE OF M. S. GELLIS # 33684 BRITISH COLUMBIA ENGINEER

21 Jan, 2013

Matt Gellis, M.S., P.Eng.

Rich McCleary

Richard McCleary, Ph.D., P.Bio.

Report reviewed by:

PROFESSIONAL PROVINCE OF A. E. ZIMMERMANN # 34226 BRITISH COLUMBIA SCIENTIST

Jan 28 2013

Andre Zimmermann, Ph.D., P.Geo.

PROFESSIONAL PROVINCE OF D.P. MUIR 27657 BRITISH COLUMBIA ENGINEER

2013 JAN 21

Dale Muir, M.Eng., P.Eng.

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EXECUTIVE SUMMARY

Windermere Creek is a steep mountain stream in the Rocky Mountains. Channel instabilities developed over the 2011 and 2012 freshet flows. The instabilities resulted in increased sediment generation in the reach between Windermere Loop Road and the Mine Road and deposition in downstream reaches, most notably upstream of Highway 93 crossing and at Windermere Lake.

Sedimentation in the lower reach of Windermere Creek reduced channel capacity resulting in overbank flooding and the Regional District of East Kootenay (RDEK) declaring a state of emergency August 5, 2011. Reduced channel depth following the aggradation has increased the risk of local icing problems within the channel which is expected to increase the risk of flooding during seasonal freeze and thaw.

Summer flow in 2012 was abnormally high across the Kootenays with numerous watersheds experiencing destabilisation and flooding; most notably the July 12 debris avalanche (in which three people died) and July 13 debris flow at Johnsons Landing, and the July 15 debris flow on nearby Fairmont Creek. High summer flow resulted in upstream degradation and downstream deposition of sediment increasing from that experienced in 2011. Sedimentation upstream of the Highway 93 culvert crossing blocked the culvert inlet in 2012. The upstream end of the culvert eventually floated and failed as water level rose above the culvert inlet. Sediment continued to deposit in the lower reach of the Windermere Creek and result in additional localised flooding.

Northwest Hydraulic Consultants Ltd. (NHC) teamed with Dr. Richard McCleary to provide a hydrotechnical assessment of Windermere Creek concentrating on the reach from the Mine Road downstream to Windermere Lake. Previous studies by BC Ministry of Forests, Lands, and Natural Resource Operations (FLNRO, 2011) and R. McCleary (2012) identified a destabilising reach located roughly 1 km upstream of Windermere Loop Road. Re-assessment of this and adjacent reaches following the 2012 freshet indicated that substantially more degradation and sediment mobilization had occurred in the 2012 freshet.

Following the destabilising events of 2011 and 2012 Windermere Creek has been left in a compromised state. Without mitigation work it is expected that the upper channel will continue to degrade, headcut, and widen increasing the sediment loading to downstream reaches. Increased sediment loading is expected to deposit in locations of lower shear stress, predominantly upstream of Highway 93 and at Windermere Lake. Recurring deposition in these areas will continue to lead to culvert or channel blockage and localised flooding.

Mitigation measures should address both the channel instability in the upper reach and the ongoing deposition of sediment downstream. No one solution is able to address both of these issues. Therefore, it is recommended that a series of grade controls be constructed to maintain vertical grade of the channel in the most destabilised reach - roughly 1 km upstream of Windermere Loop Road - and a sediment trap be constructed upstream of Highway 93 to intercept and allow controlled removal of transported sediment. It is expected that the middle grade controls also be used to re-establish flow along the north side channel limiting the stress on the south channel and potentially improve habitat value. Class D cost estimates for construction of the grade controls and sediment basin are $170,000 and $315,000, respectively. Five-year operations and maintenance costs are estimated at $17,000 for grade controls and $60,000 - $250,000 for the sediment basin.

CREDITS AND ACKNOWLEDGEMENTS

The work completed for this project is credited to the following Northwest Hydraulic Consultants staff:

• Dale Muir, P.Eng.	Project Manager
• Matt Gellis, P.Eng.	Lead Project Engineer
• Andre Zimmermann, Ph.D, P.Geo.	Lead Geoscientist
• Joe Drechsler	GIS Technician
• Piotr Kuras, R.P.F., P.Eng.	Hydrologist
• Barry Chilibeck, P.Eng.	Principal in Charge

Dr. Richard McCleary, Ph.D., P.Bio. worked in conjunction with NHC providing geomorphologic assessment, aquatic habitat considerations, and local familiarity with the site and its issues.

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Table of Contents

List of Tables

List of Figures

List of Photographs

List of Appendices

1 INTRODUCTION

Windermere Valley experienced higher than normal flows through the summer of 2011. Windermere Creek, which in recent history normally flows with minimal coarse sediment, transported substantial sand and gravel load resulting in deposition at the Highway 93 crossing and the development of a delta fan at Windermere Lake. Deposition at Windermere Lake forced flow overbank causing localised flooding. In response, RDEK declared a local state of emergency August 5, 2011, and sediment was dredged from the lower 150 m of channel for the next two days. A total of $15,290.78 has been submitted to Emergency Management BC (EMBC) to reimburse costs borne by RDEK during the 2011 cleanup. Following this event, investigations in the upper watershed (above Windermere Loop Road) revealed localised degradation of the channel (i.e. the generalized lowering of the channel due to ongoing scour of the bed) and the start of upstream progression of that degradation (i.e. head cutting) (FLNRO, 2011).

During the summer of 2012,the Kootenays experienced much greater flows than normal, which resulted in numerous extreme flow events, most notably the July 12 debris avalanche (in which three people died) and July 13 debris flow at Johnsons Landing, and the July 15 debris flow on nearby Fairmont Creek. Sustained high flow in Windermere Creek rapidly propagated the upstream degradation delivering roughly 10,000 to 20,000 m^3 of sediment to downstream reaches. This lead to the blockage and damage of the culvert under Highway 93 which was repaired by BC Ministry of Transportation and Infrastructure (MOTI) in the summer of 2012. As well additional aggradation and overbank flooding occurred within the lower reach of Windermere Creek. RDEK has submitted a further $44,344.20 to EMBC to cover costs incurred in the 2012 cleanup. Reduced channel depth following the aggradation has increased the risk of local icing problems which is expected to increase the risk of flooding during seasonal freeze and thaw.

The potential for the upstream degradation in the destabilized reach roughly 1 km upstream of Windermere Loop Road and subsequent downstream sedimentation to continue prompted the initiation of this hydrotechnical assessment of Windermere Creek. Northwest Hydraulic Consultants Ltd. (NHC) teamed with Dr. Richard McCleary were retained by the Regional District of East Kootenay (RDEK) to provide a hydrotechnical assessment of Windermere Creek, identifying potential causes of the recent channel instability, assessment of future instabilities, and identification of mitigation options. This report documents the study.

1.1 LOCAL SETTING

Windermere Creek is a steep mountain stream that flows west from the Stanford Range of the Rocky Mountains. The channel extends from a maximum elevation of approximately 2,600 m to Windermere Lake, elevation 800 m, at the town of Windermere, BC. The stream has a drainage area or roughly 90 km^2. According to BC Habitat Wizard, Windermere Creek supports Kokanee, Westlope (Yellowstone) cutthroat trout, brook trout, bull trout, and rainbow trout – although the Kootenay Highway culvert crossing (Hwy 93/95) roughly 1600 m upstream from Windermere Lake presents a barrier or partial barrier to upstream fish migration. The watershed has been subjected to intensive human impacts including forest harvesting, open pit gypsum mining, agriculture, water diversions and suburban development. **Drawing Sheets 1-3** (Appendix B) provide plan and profile view of the study area of Windermere Creek.

The lower most 100 to 200 metres of channel has low banks, flat gradient (i.e. slope), and is influenced by Windermere Lake levels. Historically not subject to much deposition, this reach has experienced substantial deposition and the development of a relatively large delta over the past two summers (2011 and 2012). The next four kilometres of channel has an average slope that is about twice as steep at approximately 3%. Sediment appears to move freely through this reach except for the Highway 93 culvert crossing near Station 1+550 (measured as km+m from Windermere Lake), where sediment - at least in the past two years - has deposited upstream.

The creek is over steepened, that is steeper than normally supported by the underlying materials, between Windermere Loop Road (Sta. 4+100) and the Mine Road crossing (Sta. 7+560). This reach has experienced severe degradation (i.e. down cutting erosion) over the past two years approximately 1000 m upstream of Windermere Loop Road. Upstream of this location the stream branches into two channels along the upper fan, approximately between Sta. 5+600 and 5+000, with the lower half of the south channel exhibiting the most severe degradation. Historically the over steepened slope appears to have been maintained by woody debris / beaver dams and an erosion resistant surface crust of deposited limestone referred to as tufa[1]. Both of these features are still present in an undisturbed state along the north channel and downstream. Failure of the grade control in the south channel over the past two years could be a result of gradual erosion of the tufa armour layer; changes in upstream sediment influx to the reach; longer than average duration of high flows; changes in water chemistry affecting the tufa layer; greater distribution of flows toward the south channel; or any combination of the above.

1.2 Regional Setting

In addition to the erosion in Windermere Creek, 2012 was an exceptional year for alluvial fan building in other small tributaries to the upper Columbia River. The following are three examples;

1. The Shuswap Creek watershed, located immediately adjacent and to the north of Windermere Creek watershed, enters Columbia River approximately 3 km downstream of the Athalmer bridge at the Lake Windermere outlet. The main channel avulsed on the fan and threatened the rail track that crosses the fan near its mouth at the Columbia River (pers. comm. Roger Dubielewicz, CP Rail).
2. The debris flow event in Fairmont Creek 20 km south of the town of Windermere (discussed above).
3. Marion Creek, a Columbia Lake tributary located on the west side of the valley and 30 km south of the town of Windermere, also experienced an exceptional fan building event (pers. comm. Roger Dubielewicz, CP Rail). To protect the railway, the channel upstream of the railway crossing was excavated on three separate occasions during the freshet. In Oct. 2012, extensive channel degradation and bank erosion were observed in the steep section of Marion Creek between the apex of the small fan and the Highway 93/95 crossing. The

[1] a chemical sedimentary rock composed of calcium carbonate – i.e. limestone - precipitated following groundwater emergence due to increasing pH resulting from $C0_2$ degassing and/or due to interaction with surface algae or bacteria

freshet was unusually long and the water was turbid well into the fall (pers. comm. Brian McKersie, Thunderhill Ranch).

1.3 Previous Studies

NHC has reviewed the following materials in preparation for our proposal submission:

- Windermere Creek Channel Condition and Prescription Assessment (AGRA Earth and Environmental Ltd., 1998)
- Water Resources Inventory Report: Physical, Chemical and Biological Characteristics of Windermere Creek (Fay Westcott et al., 2000)
- Windermere Creek Flooding (FLNRO, 2011)
- Windermere Creek Sediment Source Survey (Richard McCleary, 2012)

2 HYDROLOGY

2.1 STREAMFLOW

2.1.1 REGIONAL FLOW DATA

Water Survey of Canada (WSC) maintained a hydrometric station on Windermere Creek in the past. However, the station was not in operation during the primary study period; that is summer 2011 and summer 2012. All of the gauges in the Rocky Mountain Trench area were considered for comparison of historic flow conditions.

Table 1. Regional streamflow gauges

Name	Description	Watershed Area (km^3)	Record (years)
08NA024	Windermere Creek near Windermere	84.2	1914-1979
08NB012	Blaeberry River above Willowbank Cr	587	1970-2011
08NA002	Columbia River at Nicholson	6660	1903-2012
08NA006	Kicking Horse River at Golden	1850	1911-2012
08NF001	Kootenay River at Kootenay Crossing	416	1939-2012
08NG076	Mather Creek below Houle Cr	135	1972-2012
08NA011	Spillimacheen River near Spillamacheen	1460	1912-2012
08NB016	Split Creek at the mouth	80.5	1974-2012

2.1.2 DAILY FLOW RECORD

The initial hydrologic analysis was to compare the amount of flow in the summer of 2011 and 2012 with other years to determine if higher flows in 2011 and 2012 contributed to the degradation. Since Windermere Creek has not been gauged since 1979, a predictor site was found from the regional gauges from which to develop a transposition function and a synthetic daily flow record for the years of interest. Regression between summer Windermere Creek flow data and overlapping data sets from the other regional gauges was used to identify suitable predictor sites.

Two gauges were selected as potential candidates;

1. WSC Kootenay River
2. WSC Spillamacheen River

due to higher correlations with WSC Windermere daily flows and longer record lengths. These two gauges also have the closest proximity to Windermere Creek. The potential for seasonality in the WSC Kootenay and WSC Spillamacheen regressions with WSC Windermere was assessed with an Analysis of Variance (ANOVA) with month as a grouping variable.

A synthetic daily flow series was generated for Windermere Creek using both WSC Kootenay and WSC Spillamacheen as predictor sites for the period 1959 to 2012. Flow duration curves (sometimes referred to as flow exceedance plots) were generated for the intersecting data period, 1959 to 1979, (**Figure 1**).

WSC Kootenay was selected as the predictor for simulating flows at WSC Windermere since the weighted correlation for seasonal/monthly regressions was higher than WSC Spillamacheen, the watershed is closer to the size of WSC Windermere, and less variability is lost from the regression fit with this gauge. Using the developed transposition function, a synthetic data set was generated for Windermere Creek from WSC Kootenay. The highest flow years from this data set are shown in **Table 2**. 2012 and 2011 are in the top 10 for average summer flow (June, July, August). However, three summers out of the past 12 had greater average flow than 2012.

A comparison of select flow durations curves is presented in **Figure 2** to provide visual comparison of the flow in 2012, 2011, average flow duration for the summer period, and other high summer flow years.

Table 2. Highest Windermere Creek summer flow years from synthetic data sets, June, July, August 1959 to 2012

Rank	Year	Average Flow (m^3/s)
Average	-	0.90
1	1972	1.19
2	1990	1.15
3	1996	1.12
4	2012	1.11
5	1967	1.08
6	1991	1.06
7	1976	1.06
8	1974	1.05
9	1959	1.02
10	2011	1.02

Windermere Creek had a substantially longer duration of high flows in summer (June through August) of 2012 than in a typical year. Flow was equal to or greater than 1.5 m^3/s 26% of the summer; in summer 2011 the same flow was exceeded only 8% of the time. On average (1959-2012), summer flows exceeded 1.5 m^3/s less than 2% of the time. However, the flow duration curves also indicate that summer flows in 1972 and 1990 had similar or greater duration of high flows.

2.1.3 PEAK FLOW ANALYSIS

As a supplement to the above analysis, peak flows of 2012 and 2011 were compared to those experienced in recent history. Synthetic daily flows generated from a transposition function developed to closely predict the full range of annual or seasonal flows are typically poor predictors of annual peak flows, thus an alternative approach has been used for estimating annual peak daily flows at Windermere Creek.

The regional WSC gauges presented in **Table 1** were also considered for predictors of annual peak daily flows. WSC Kootenay and WSC Columbia, and WSC Mather were found to be the most suitable predictor sites for peak flows and were used to estimate annual peak flows for years that data did not exist for WSC Windermere. Using the Cunnane plotting position for the expanded WSC Windermere Creek flow record (1914 to 2012) and Log-Pearson Type III distribution a recurrence for Windermere Creek flood events were estimated (**Table 3**). Mean annual discharge (MAD) is also presented, although it is based solely on the Windermere Creek data (1914-1979).

Table 3. Annual peak daily flow frequency analysis, WSC Windermere Creek (08NA024)

Return Period	Daily Peak Flow (m^3/s)
MAD	0.6
2	1.3
5	1.9
10	2.2
20	2.4
25	2.5
50	2.7
100	2.9

Table 4 presents the highest daily flows between 1914 and 2012. The peak flow of 2012 (prior to November 2012) is estimated at 2.21 m^3/s; approximately a 10 year flow.

Table 4. Highest Windermere Creek annual daily peak flows, estimated from expanded peak flow dataset, 1914 to 2012

Rank	Annual Daily Max Flow (m^3/s)	Year
1	2.9	1972
2	2.8	1961
3	2.8	1967
4	2.5	1974
5	2.5	1916
6	2.5	1920
7	2.4	2002
8	2.3	1914
9	2.2	1956
10	2.2	2012

The maximum flow observed in 2012 (prior to November 2012) was the tenth largest flow in the past 99 years. 2011 had the 22nd largest flow in the same period.

2.2 RAINFALL

Precipitation data from the regional Environment Canada (EC) station Kootenay NP West Gate[2] (ID: 1154410) were analysed. Average summer rainfall was compared for the past 44 years and plotted in **Figure 3**. The total rainfall in 2011 does not appear to be extraordinarily high. However, the 2012 August rainfall as reported by this station was 50% greater than for the other years on record, except for 2005. The total summer (June through August) rainfall was also greater than the all other years except for 2005, but only by about 10%.

[2] Kootenay National Park West Gate, located off Highway 93 just east of Radium Hot Springs

3 FIELD ASSESSMENT

NHC inspected Windermere Creek with Rich McCleary in preparation of proposal for this work on September 15, 2012 and again from October 17 to 19, 2012.

The purpose of our October field assessment was to assess existing channel conditions and collect survey data for volume estimates and conceptual design. Observations from the field work are summarized in the following subsections. Stationing refer to valley distance (km+m) from Windermere Lake as measured from available GIS data (Province of British Columbia, 2012) and shown on **Drawing Sheets 1-3** (Appendix B).

3.1 NORTH AND SOUTH WINDERMERE CREEK CONFLUENCE (STA. 9+355)

Upstream of Station 9+355, North Windermere Creek branches off the main channel. A large wetland and lake (**Photo 1**) act as a sediment sump on the mainstem above the confluence. It is expected that the wetland also mitigates any water quality changes from upstream activities on the mainstem. Bedload influx from the north fork was observed as channel deposits of gravel and cobble with median diameter 25 mm, ranging up to 200 mm[3]. The channel between Sta. 9+355 and 7+560 was not inspected, however following the site inspection it was suggested by others that there are locations of minor degradation within this reach.

3.2 MINE ROAD CROSSING TO ALPINE RANCH DIVERSION (STA. 7+560 TO 5+605)

Through this reach much of the channel grade is maintained by a competent tufa layer. However, three nick points ranging from 0.2 m to approximately 1 m in height were located between the Mine Road Crossing and the Alpine Ranch Diversion (**Photo 3**, **Photo 4**, and **Photo 5**). The drops did not appear to be controlled by woody debris or bedrock; rather, they were local incisions through the tufa layer. The distribution of discrete points of localised degradation throughout the upper watershed indicates that channel incision is a watershed scale problem, and is not solely a result of flow re-allocation through the upper fan; i.e. near the Alpine Ranch Diversion.

A circular corrugated metal pipe (CMP) culvert at the Mine Road (**Photo 2**) crossing marks the upstream extent of degradation. Vertical banks downstream of the culvert indicate that the channel has likely degraded roughly 0.3 m.

3.3 ALPINE RANCH DIVERSION (STA. 5+605)

A weir at the apex of the upper fan diverts flow into a constructed diversion channel which supplies water to the Alpine Ranch south of Windermere Creek (**Photo 6**). The weir was damaged in 2011 and was rebuilt prior to the 2012 freshet (pers. comm. D. Wilfley). It does not appear to have been constructed with any scour protection; scour approximately 0.5 m in depth was noted downstream at the base of the weir plate (**Photo 7**).

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[3] Sediment grain size distributions were determined using SplitNet digital photo analysis software.

Downstream of the weir the channel has cut through what appears to be an otherwise continuous tufa layer. There is a nick point approximately 12 m downstream of the weir, about 1 m in height. Should the weir fail in future, the channel degradation is likely to propagate upstream.

3.4 South Channel (Sta. 5+605 to 5+030)

Downstream of the Alpine Ranch diversion, the channel has experienced recent degradation, leaving the channel incised 1 to 2 m deep. The incision deepens and widens downstream. A degree of vertical grade control is provided by tufa outcrops and woody debris, although over the past two years these have not been sufficient to stop channel incision.

Roughly 80 m downstream of the Alpine Ranch diversion (Station 5+520) channel depth is approximately 2 m and top width is 6 to 7 m (**Photo 8**). Previously at this location, flow was split between the active south channel and the beaver ponds in the floodplain to the right; i.e. the north channel. However, recent downcutting of the south channel has disconnected the wetland. It appears that prior to the degradation of the south channel, moderate to high flows would overtop the south channel's banks and enter the wetland that forms the head of the north channel. This is in contrast to flow entering the north channel through a defined or confined flow split. Debris and sand deposits provided evidence of overland flow on the floodplain, but a defined channel was not present.

Further downstream (approx. Sta. 5+460), the channel widens to approximately 14 m (top width) and is about 1.6 m deep. At about Sta. 5+400, there is a series of steps forming a nick point approximately 2 m in height (**Photo 9**). At this location, the channel has widened to 20 m following the recent degradation, and is left with vertical banks, as high as 4 m.

Another nick point was noted at approximate 100 m downstream, Sta. 5+360. A small terrace is visible throughout this reach, probably representing the pre-degradation (i.e pre-2011) bed level (**Photo 10)**. The downstream channel is deeper and wider, generally being more than 20 m wide and 5 m high (**Photo 11**). Another nick point approximately 1.5 m in height is located roughly 200 m downstream of the last one, at approximately Sta. 5+085 (**Photo 12**).

The downstream 100 m of the south channel was inaccessible from the floodplain. Immediately upstream of the confluence, a cut bank approximately 5 m high was noted on the left bank (**Photo 13**), remnant of the recent degradation.

3.5 North Channel (Sta. 5+625 to 5+030)

As described earlier, the north channel does not start with a defined channel, instead it initiates with a series of wetlands across a terraced right bank floodplain of the south channel (Sta. 5+625). The floodplain is dominated by abandoned beaver pond complexes with wood debris appearing to provide grade control between each terrace (**Photo 14**). Based on limited survey data, the floodplain appears to have a slight south-north component of slope, dropping at about 0.7% toward the north.

At the downstream end of the floodplain there are a number of small dry channels feeding toward the north channel. Flow eventually concentrates at the top of a tufa surfaced falls (Sta. 5+085), approximately 2.5 m high (**Photo 15**). At the falls, the gully is approximately 5.8 m wide at top of bank. The channel downstream of the falls is confined to a deeply incised gully. The channel follows a step-pool profile with partial woody debris control and an average gradient of approximately 6%. At the time of our field inspection the wetland and north channel were dry.

3.6 Confluence to Windermere Valley Golf Course Weir (STA. 5+030 to 4+605)

The channel downstream of the confluence has aggraded in recent years (i.e. generalized increase in channel elevation due to deposition of channel transported materials). The active channel is wider and shallower in the upstream portion of this reach, with sediment accumulation along tree roots and banks indications of the aggradation. The effect is compounded where wood debris retains transported sediment, as shown in **Photo 16** of a log step.

Average channel gradient in this reach is about 6%. A small tributary enters the creek just downstream of **Photo 16**, but is not expected to influence channel stability. The tributary was almost dry during the October field assessment (**Photo 17**).

The Windermere Valley Golf Course (WVGC) weir provides hydraulic control, likely backwatering some small extent of the upstream reach and increasing the likelihood of local sediment deposition. As such, channel aggradation is more pronounced closer to the weir. The piers supporting a wooden pedestrian bridge 20 m upstream of the weir appeared mostly buried by gravel during the October field assessment (**Photo 18**), but were apparently exposed by about 1 m more in previous years (pers. comm. R. McCleary).

GPS survey measurements in this reach were limited to one channel point at the confluence and a few points at the WVGC weir, due to satellite interference by the gully walls and canopy cover.

3.7 Windermere Valley Golf Course Weir (STA. 4+605)

The WVGC weir was apparently built on an existing waterfall, potentially composed of tufa or other calcium carbonate deposit. Water flowing over the weir drops 4 to 5 m to a plunge pool below then travels down a chute and over another step carved into the tufa (**Photo 19**). The tufa layer armouring the channel downstream of the falls appears to have deteriorated in recent years. Depending on the founding of the weir and the underlying falls, upstream progression of the deteriorated channel armouring could undermine the falls and weir and eventually result in the weir's failure.

The WVGC weir maintains the grade for the upstream reach. Failure of the weir and falls would result in degradation of the upstream channel . The degradation could be deeper than 4 to 5 m and propagate a large distance upstream. This would result in mobilization of large quantities of sediment and potentially de-stabilization of the adjacent hillside.

During the October field assessment, there was flow visible from the bed beneath concrete structure of the weir (**Photo 20**). At the time it was thought the flow was caused by piping through the structure, however anecdotal evidence suggests this may have been flow leaking from the low level outlet. Flow around the sides of the weir was also observed.

The present scope of work did not allow for detailed inspection of the weir. There appears to be a risk of failure with the consequence of destabilizing the upstream channel and supplying downstream reaches greater volumes of sediment than experienced in 2011 and 2012. It is recommend that a qualified professional be engaged to undertake a detailed safety assessment of the weir; primarily how it is supported and the likelihood for failure due to flow outflanking or the structure be undermined by scour.

The present height of the crest of the structure with respect to the natural downstream channel bed is approximately 6 m. Further downstream bed degradation and headcutting could increase the height beyond 7.5 m, the threshold for the weir being considered a dam under the British Columbia Dam Safety Regulation. Regardless of height, classification of the failure consequence of the weir as *significant* or greater due to the potential for economic or human losses could also result in classification as a dam. In either case the weir would be subject to dam design, maintenance, and inspection requirements.

3.8 WINDERMERE LOOP ROAD (STA. 4+140)

Windermere Creek crosses under Windermere Loop Road (WLR) through a culvert near Sta. 4+140. Upstream of the crossing the channel has a 3 to 5 m top width, an average gradient of approximately 3%, and an alluvial bed consisting primarily of cobble and gravel. Despite the relatively low flow at the time of the field assessment, gravel movement was still active. It is assumed that the mobilised material was tufa pebbles. Tufa has a lower density than the gravel typically found in BC, allowing reduced flow to initiate its transport[4].

An abandoned concrete diversion weir approximately 2 m high is located approximately 40 m upstream of the WLR culvert. The channel locally aggraded upstream of the structure (**Photo 21**). No evidence of outflanking or undermining of the structure was detected.

Further upstream of the weir, channel degradation on the order of 0.3 m has occurred. Anecdotal evidence suggests the incision occurred during the 2012 freshet. Another landowner apparently observed 1 m of degradation at his nearby property (pers. comm. Scott McDonald).

The WLR crossing is a partially embedded circular CMP culvert with a diameter of 4800 mm (**Photo 22**). The downstream end is hanging roughly 0.3 m above the bed; however steep banks and high velocity flow prevented access to verify. A second vertical drop of similar height is located about 5 m downstream of the culvert outlet (**Photo 23**).

Banks downstream of the crossing are vertical and undercut, with bank height varying from about 2 m at the culvert outlet to 0.3 m about 120 m downstream (**Photo 24**). Channel substrate downstream of the crossing is cobble and small boulders (**Photo 25**). Average channel gradient for the first 100 m downstream of the culvert is 6.5% transitioning to 4% over the next 30 m.

[4] This idea was illustrated by placing a round tufa boulder approximately 200 mm in diameter in the channel upstream of the WVGC weir. The depth of flow was on the order of 10 cm, and bed materials with median diameter of 31 mm were not moving. The tufa boulder, however, rolled relatively easily, getting stuck only twice before falling over the weir.

3.9 HIGHWAY 93 CULVERT (STA. 1+500)

At station 1+500 Windermere Creek crosses under Highway 93. The creek passes under the highway through a 1300 mm diameter CMP culvert set roughly 5 m below the highway surface. The culvert is undersized and partially embedded (**Photo 29**). During high flows, the reduced conveyance capacity of the culvert causes upstream water levels to increase. This backwatered condition results in sediment deposition, that extends about 75 m upstream of the crossing (**Photo 27**). Tufa deposits are visible in the channel bed and banks. The creek has incised 1 to 2 m through the recent sediment deposition and cut below the tufa armour layer in some places (**Photo 28**). Average gradients in the recently degraded channel are 3%, but the hydraulic gradient would be less steep during high water when the culvert backs up flow.

A wetland on the left overbank (facing downstream) drains to the creek at the culvert inlet. Vegetation in the wetland suggests that it has existed prior to 2011 (pers. comm. R. McLeary, **Photo 26**).

Downstream of the highway crossing the channel widens and is characterized by large woody debris (LWD) controlled steps and shallow banks (**Photo 30**). The shallow wide channel suggests this reach may be aggrading, although average gradient remained just under 3% (**Photo 31**).

3.10 VICTORIA AVE CULVERT TO WINDERMERE LAKE (STA. 0+410 TO 0+000)

Windermere Creek crosses under Victoria Avenue near Station 0+400 through an 8 m wide by 2.2 m high arch culvert (**Photo 33**). The channel immediately upstream of Victoria Avenue is well established with a width of approximately 3 m and banks about 2 m in height (**Photo 32**). The channel is somewhat incised in comparison to its local banks, but there is no evidence of recent degradation.

For approximately 200 m downstream of the culvert (to Sta. 0+210) the channel is confined by intermittent retaining walls, riprap, and mature trees that together narrow the channel to about 2.5 m, (**Photo 34**). Gradients downstream of the culvert transition from about 3% immediately downstream of the culvert to 1.5% at the delta. Detailed locations of grade breaks were not collected due to time constraints, but approximate breaks measured by clinometer and handheld GPS are:

- 2.5% STA. 0+250 to 0+210
- 2.0% STA. 0+120 to 0+140
- 1.5% STA. 0+000 to delta

The reach upstream of Sta. 0+150 - at least to just upstream of Victoria Drive - did not experience substantial sediment deposition in 2011 or 2012. Incoming bedload was transported through this reach and deposit downstream of Sta. 0+150.

Initiation of deposition is defined by channel width, bank height, channel gradient, and elevated lake elevations during freshet flow. At about Station 0+100, the channel emerges into an open area with low banks, allowing flow to spill over the banks. Channel gradients decrease to 2% slightly upstream of Station 0+100, and hydraulic grade is further reduced during high lake levels. NHC did not conduct a detailed survey of this reach, however fall 2012 survey data was provided by Mike Dubois

(Shadybrook Resort). Based on this survey, lake level does not appear to be the sole factor defining the upstream extent of the deposition.

4 GEOMORPHIC ANALYSIS

Rivers channels are commonly in one of three end states; at grade, degrading or aggrading. A channel at grade is more or less maintaining the same long profile slope and the amount of sediment entering the channel equals the amount leaving. A degrading channel is one that is scouring the bed and the channel is becoming lower over time; the input of sediment is less than the output. An aggrading channel is accumulating material and the bed elevation is rising over time, as such the input is greater than the output. Geomorphologists often attempt to classify a channel as one of these three types to help understand the types of responses that should be expected. In general, the classification is time based; i.e. the channel might be recognized as being at grade at the decadal to century time scale but aggrading at the millennia time scale.

The following section describes what is known about the past, current, and future trajectory of the channel.

4.1 GEOMORPHIC PROCESSES

4.1.1 PAST

Often alluvial channels in the Cordilleran mountain system of British Columbia are characterized by their gradual degradation through fan deposits deposited during the retreat of the glaciers, 7000 to 15000 years ago. This general pattern occurs because the post-glacial sediment supply, which created the fan, is larger than the contemporary supply. The contemporary supply is reduced as the readily mobile material left by the glaciers was removed with time and vegetation stabilizes the inputs. In these cases the fans are relatively stable and progressively more stable.

Windermere Creek on the other hand is not flowing through a historical fan, but instead appears to be reworking a contemporary fan. A piece of wood uncovered in 2011 during the recent channel degradation was radio carbon dated as 380 years A.D. (1632 years before 2012; wood was at bottom of bank near Sta. 5+100; pers. comm. R. McCleary). In addition, the bank stratigraphy consists of layers of coarse and fine alluvial sediments (**Photo 35**) that were likely deposited due to episodic channel migration and floodplain inundation caused by blockages such as beaver dams, log jams, or landslides.

Historically the lower fan that enters Windermere Lake has likely been aggrading, although the history of the lake level is not known and the subsurface stratigraphy was not investigated. Aggradation is common on lake fans and can result in development challenges when the rate is sufficient to cause regular flooding and avulsions.

4.1.2 PRESENT

Over the past two years Windermere Creek has become substantially less stable between Windermere Loop Road (Sta.4+130) and the Mine Road (7+558).

- During 2011 and 2012 above normal precipitation and flow occurred during the freshet period (Section 2.1); however, flows were not substantially greater than other years in the past century. It seems unlikely that high flows alone resulted in the observed changes.

- A partial or complete blockage of overbank flow from the south to the north channel (Sta. 5+600) may have resulted due to sediment deposition within the north channel/floodplain, beaver dams, or human activity across the floodplain. Such blockage may have concentrated the flows in the south channel more than in the past and overwhelmed the tufa and/or wood debris grade controls that naturally existed in the south channel. Once degradation was initiated in the south channel, the channel incised below and disconnected itself from the floodplain overflow to the north.
- Locations where tufa deposits armoured the channel and maintained its grade may have deteriorated due to change in water chemistry. Westcott (2000) reports a dilution of calcium during spring freshet with increasing concentration as flows lessen. Prolonged high flows of 2011 and 2012 likely resulted in decreased calcium or other ions concentration which may have impacted the resilience of the tufa layer.

The instability appears to have initiated during the summer of 2011. High flows during the summer of 2012 allowed rapid channel degradation and upstream propagation (i.e. headcut). The eroded material has been transported downstream, depositing primarily upstream of the Highway 93 crossing and within the lower 150 m (pers. comm. J. Maletta, 2012) of channel at Windermere Lake. Deposition of material at these locations required emergency dredging to limit flooding (near Windermere Lake) and culvert repairs at the highway crossing.

4.1.3 Future

Following high summer flows of 2012 the channel has been left in a compromised state. Without mitigation work it is expected that the channel will continue to degrade, headcut, and widen within the reach between WLR and the Mine Road. This will result in additional sediment loading downstream.

The following sub-section presents an estimate of the volume of material transported over the past two years and the amount expected without mitigation. Sediment transport was also analyzed to provide context for the expected rate of future sediment transport based on historic transport rates.

4.2 Sediment Volume Estimates

Sediment volumes associated with degradation in Windermere Creek (**Table 5**) have been estimated, and include:

- volume of sediment eroded in 2011 and 2012;
- volume of sediment likely to erode in future years with no mitigation;
- volume of sediment deposited upstream of Highway 93 in 2012; and
- volume of sediment deposited at the creek mouth in 2012.

Volumes are based on limited survey data, CDED topographic information; and site observations. The estimates are approximate only, and should not be relied upon for detailed design without corroborating information.

Table 5. **Estimated volumes of eroded sediments, future potential erosion and deposited sediments at various locations**

Location	Station (km+m)	Condition	Volume (m^3)
Mine Road downstream to WLR	4+000 to 7+200	Eroded in 2011-2012	35,000
Mine Road downstream to WLR	4+000 to 7+200	Remaining to erode under current conditions	140,000
Mine Road downstream to WVGC Weir	4+600 to 7+200	Remaining to erode in the case of weir failure	450,000
Upstream of Highway 93	1+510 to 1+600	Deposited 2012	1,600
Creek Mouth	0+000 to 0+100	Deposited 2012	5,300

4.2.1 Volume of Sediment Eroded in 2011-2012

Sediment volumes eroded in 2011-2012 were approximated by assuming pre-2011 channel form was similar to the stable channel form in adjacent upstream and downstream sections and using a coarse survey of the 2012 channel form conducted during the October field assessment. Channel alignment was taken from the BC Government Base Mapping (Province of British Columbia, 2012); the alignment goes through the floodplain adjacent to the south channel, introducing some error in channel length and volume estimates through that reach.

Topographic survey data was collected using a combination of RTK GPS and laser range finder, since access and satellite coverage issues prevented the collection of GPS data in most of the eroded channel. Channel cross-sections in the inaccessible areas were generally rectangular, allowing a reasonable approximation of areas using measured depth and width.

The total volume eroded from the channel in 2011 and 2012 is estimated at 35,000 m^3 (**Table 5**). To illustrate the relative contributions of various channel reaches we plotted the cumulative volume eroded against channel distance (**Figure 4**). The overwhelming majority (76%) of eroded sediment originated in the south channel (Sta. 5+030 to Sta. 5+600). One percent of the total volume originated upstream of WLR to the confluence (4+000 to 5+030). The remaining 13% was eroded from upstream of the Alpine diversion (Sta. 5+600).

4.2.2 Future Volume of Erosion

Current Conditions

We estimated the volume of sediment which would erode from the south channel if no mitigation were put in place. The estimate was derived using the profile from BC Government Base Mapping (Province of British Columbia, 2012). The Base Mapping elevations are derived from Canadian Digital Elevation Data (CDED), which itself is interpolated from 20 m contours. Comparison of NHC's survey elevations in short sections of eroded channel to the CDED profile (and accounting for the existing depth of degradation) suggests that in general the elevations of the two data sets are consistent within a few meters. However, a vertical discrepancy of approximately 14 m between surveyed elevation and CDED elevation was noted at the confluence between the north and south channel (Sta 5+030).

To determine volumes, we projected a stable slope of 3% upstream from various locations representing likely starting points for future headcut (**Drawing Sheet 2**). The gradient of the stable slope was selected to match the observed gradients of known sediment throughput reaches in the creek. The approximate volume of sediment likely to be eroded in the absence of mitigation was estimated at approximately 140,000 m^3; the confluence of the north and south channels (Sta. 5+000) to the Mine Road (Sta. 7+560).

Simplifications in the approximation include the sparseness of topographic data both in the degraded and presently stable reaches, neglect of future bank failures following degradation, and ignoring the potential for stable grades steeper than 3% due to wood debris, bedrock, or other stabilizing features.

WVGC WEIR FAILURE

If flow outflanks or produces undermining scour at the WVGC weir and results in its failure upwards of 450,000 m^3 of sediment could become erodible. This volume is estimated by projecting a stable slope of 3% upstream from a point 6 m below the weir crest (**Drawing Sheet 2**). It is expected that this estimate is conservative and would only occur over a number of years, however failure of the weir could easily double or triple the available erodible sediment and subsequent downstream sediment loading.

4.2.3 VOLUME OF SEDIMENT DEPOSITED UPSTREAM OF HIGHWAY 93 IN 2012

The sediment volume deposited upstream of Highway 93 in 2012 was estimated at 1600 m^3. Deposition in channel was estimated using a 3D topographic model, by calculating the volume between survey data collected during the October field assessment and an assumed pre-deposition surface. The pre-deposition surface we assumed using the 2012 bed profile, but with a wider channel and banks 1.5 m lower than surveyed in 2012 (4 m bed width, 0.3 m high vertical banks, 10H:1V sloped overbanks).

4.2.4 VOLUME OF SEDIMENT DEPOSITED AT THE CREEK MOUTH IN 2012

The sediment volume deposited at the creek mouth in 2012 was approximately 5300 m^3. This estimate is based on NHC's approximate measurements of the stockpiled and graded sediment, and RDEK's estimate of the materials removed from site by contractors. It does not account for materials removed by others, and does not include sediment deposited within the lake or its delta. Estimates of sediment deposition in the lake were not possible using available data.

4.3 SEDIMENT TRANSPORT ANALYSIS

The bedload transport capacity was analysed to estimate the expected rate of sediment supply. The transport capacity was used to verify the estimates of eroded and deposited sediments in 2011-2012. Annual bedload yield was also estimated. No estimates of suspended sediment load were undertaken, since fine sediments were transported into Windermere Lake and no suspended sediment data were available.

4.3.1 GRAIN SIZE DISTRIBUTION

Grain size distribution of transported material was estimated using digital photo analysis of substrate materials (**Figure 5** and **Table 6**). Size distributions were similar for the three upstream sites (above Sta. 4+605) and less for the lower two sites.

Table 6. Channel substrate sizes at various locations in Windermere Creek

Location	Station (km+m)	D_{50} (mm)	D_{100} (mm)
Upper Windermere Creek	9+355	25	191
Upstream end of south channel	5+605	30	140
WVGC weir	4+605	31	143
Upstream of Highway 93	1+510	23	75
Near the creek mouth	0+050	8	92

The grain size distribution from a sample collected at the upstream end of the south channel (Sta. 5+605) was selected for sediment transport modelling, since its location is within the actively eroding reach and grain size distribution is consistent with the next downstream sample location.

4.3.2 CRITICAL DISCHARGE

Critical discharge represents the threshold at which bedload begins to mobilize in the channel. Bedload transport equations generally under-estimate the critical discharge, and as a result they can over-estimate transport in the lower discharge ranges. To reduce this bias we modelled bedload transport only for discharges greater than critical discharge.

The critical discharge was estimated at 0.23 m^3/s based on Shields parameter of 0.045 for threshold of motion and the stage-discharge rating curve (**Figure 6**), approximated using a slope of 2.5%, channel bottom width of 2.5 m, near-vertical banks 1.5 - 2 m high, and moderate channel roughness represented by a Manning's n of 0.035.

4.3.3 BEDLOAD TRANSPORT RATING CURVE

To develop the bedload transport rating curve we applied four transport equations at a range of discharges greater than the critical discharge defined above. The average of the four transport rates was used to define the rating curve. The transport equations used in the analysis included:

- Meyer-Peter and Mueller (1948);
- Schoklitsch (1934);
- Meyer-Peter Mueller Corrected (Wong and Parker, 2006); and
- Recking (2008)

The first three equations use sub-surface grain size distributions. We approximated these by halving the sizes of our surface size distribution at the upstream end of the south channel. The Recking equation uses surface grain size distribution, so we applied the south channel distribution directly.

The rating curve (**Figure 7**) shows a definite break at around 2.2 m^3/s, where the yield-discharge relationship transitions from non-linear to linear. Two equations were fitted to the curve, and used to determine bedload yield.

4.3.4 BEDLOAD YIELD

Bedload yield was calculated by applying the transport rating equations to daily flows over the extended hydrologic record (1959-2012). Bedload yield in 2012 was estimated to be 33,000 Tonnes, the third greatest in the 54 year period (**Figure 8**). The yield estimates for 2011, 2012 and several other relevant years are listed in **Table 7**. Bedload transport calculations suggest that bedload is mobile every year at this watershed and provide a first order approximation of the amount of sediment transport that may occur in a year; that is 13,000 m^3 +/- 40%.

Table 7. Annual bedload yield estimates from select years (1959 – 2012)

Year	Bedload Yield (Tonnes)	Bedload Yield (m^3)	Rank
2012	33,000	18,000	3
2011	27,000	15,000	11
1972	24,000	13,000	22 (median)
1978	38,000	21,000	1 (largest)
2001	14,000	7,700	54 (smallest)

The calculated bedload yield assumes sediment supply is not limited. Prior to 2011 tufa channel armouring and wood debris grade stabilization likely limited the available sediment supply. Presently, following the recent degradation, available sediment volumes are not expected to be exhausted for a number of years.

5 PROPOSED MITIGATION

The impacts of channel instability between Windermere Loop Road (WLR) and the Mine Road have been felt at various locations between Windermere Lake and the Mine Road. Most notably, sediment deposition upstream of Highway 93 and near the creek mouth have resulted flooding and emergency repairs. The instability upstream of WLR has the potential to affect any location along the channel between Windermere Lake Road and the Mine Road.

The following mitigation options have been proposed to stabilize the upper reach and intercept sediment destined for deposition within the lower reach. **Drawing Sheets 1-3** show the locations of proposed options in plan and profile.

5.1 DESCRIPTION OF MITIGATION OPTIONS

5.1.1 GRADE CONTROL

Vertical grade control would consist of sills, weirs, or riffles keyed to the bed and banks of the creek that would function to slow the upstream progress of channel degradation. These structures would most likely be constructed of rock riprap but could be constructed from a range of materials, such as wood, logs, sheet pile, steel bin walls, gabions, or concrete (precast or formed on site). Since the degradation is a reach-scale issue, individual grade controls would not be capable of fully preventing further erosion. However a series of robust and well-placed grade controls may be able to retard erosion and limit the production and transport of excess sediment downstream.

Although grade controls will limit the influx of sediment downstream, sediment basins may still be desired to intercept the residual sediment influx.

Table 8. Advantages, disadvantages, and beneficiaries of grade control structures

Advantages	Relatively low cost; simple; reduction of sediment supply and hence deposition downstream; reduction of flood hazard downstream due to reduced deposition
Disadvantages	Vulnerable to undermining; short to medium term effectiveness; failure could contribute sediment pulses, potentially difficult access requirements for construction
Primary Beneficiaries	Reduced degradation potential, providing protection to upstream infrastructure from being undermined and reducing sediment loading to downstream properties and infrastructure; any habitat improvements from reduced lake shore sediment supply benefits regional population; reduced delta growth may provide benefit to recreational lake users; water license holders.

Potential locations for grade control structures include (**Drawing Sheets 1-3**):

1. Downstream of the Mine Road crossing (Station 7+170)
    - Close accessibility from Mine Road

- Grade control at this location would limit sediment supply and protect the Mine Road as it intercept degradation propagating upstream (i.e. headcuts)
- Potential cost sharing with mine operator
- Channel is presently not deeply incised, providing the option for a number of shallow grade controls rather than a single deep set control
- Relatively low cost

2. Alpine Ranch diversion (Station 5+600)
    - Close accessibility from gravel pit road
    - A deep structure is required to reduce the threat from present downstream incision propagating upstream and undermining the structure.
    - If incorporating the existing Alpine Ranch diversion, the diversion likely will require reconstruction to improve protection from downstream scour and outflanking.
    - Potential cost sharing with diversion owners.
    - Grade control could be designed to route a portion of flow to the north channel's beaver ponds/wetland.

3. At the upstream end of south channel (Station 5+520)
    - Moderately accessible, require roughly 100 m of road construction across north channel floodplain.
    - Would protect upstream grade control from being undermined by headcut propagation
    - Vulnerable to undermining from downstream degradation. A deep structure is required to reduce the threat from present downstream incision further propagating upstream and undermining the structure.

4. Upstream of the confluence (between Stations 5+030 and 5+460)
    - Difficult access
    - Much of the degradation between here and upstream proposed grade controls may have already occurred
    - Would protect upstream grade control from being undermined by headcut propagation

Structures at any of these sites would be vulnerable to undermining in the event of failure at the Windermere Valley Golf Club (WVGC) weir. Additional grade control(s) may be required to maintain grade on the north channel if flow is re-established along the north channel. Additional grade control may be required between the first and second grade control (Sta. 5+600 and 7+170) dependent on the ongoing natural stability of this reach.

5.1.2 Re-establish Flow to the North Channel (Beaver Ponds)

The floodplain downstream of the Alpine Ranch diversion was dry during the October field assessment. Present degradation of the south channel prevents flow from entering the north channel. It is unclear what fraction of flow the north channel transported prior to the 2011 degradation. The widespread sediment accumulation within the north channel suggest it transported at least a moderate amount of flow through some portion of the year. Re-establishing flow to the beaver ponds by diverting flow to the north channel would reduce the potential for degradation in the south channel.

Table 9. Advantages, disadvantages, and beneficiaries of re-establishing flow to the beaver ponds

Advantages	Could reduce erosion in south channel; minor to moderate reduction in peak flows may be realized through local storage during flow peaks; re-establish wetland habitat; depending on amount and seasonality of flow may reduce suspended sediment load downstream
Disadvantages	Existing channel is not well defined and flow could potentially re-divert to south channel (limited survey data collected suggests grades across the floodplain tilts at about 0.7% toward the north); uncertain benefit in terms of sediment reduction; could initiate destabilization of the north channel
Beneficiaries	Reduced degradation potential, providing protection to upstream infrastructure from being undermined and reducing sediment loading to downstream properties and infrastructure; reduction of flood peaks for downstream properties and infrastructure; any habitat improvements from increased wetland and reduced lake shore sediment supply benefits regional population; recreational lake users (reduced delta growth).

5.1.3 Sediment Basin Upstream of Highway 93

A sediment basin could be constructed upstream of the Highway 93 culvert to trap coarse sediments. The area currently functions as a sediment trap during high flows, due to backwater from the undersized highway culvert. Basin design will need to account for expected sediment yield, maintenance access, frequency and timing of monitoring and maintenance, disturbance limitations to habitat, and exclusion of fish during maintenance work.

Table 10. Advantages, disadvantages, and beneficiaries of constructing a sediment basin upstream of Highway 93

Advantages	Good access for construction and maintenance; existing sediment trap at high flows; reduction of sediment deposition and flood hazard downstream; reduced potential for blockage of Highway 93 culvert; potential addition of deep pool habitat
Disadvantages	Unlikely to capture entire sediment load (some deposition would probably still

	occur downstream); requires ongoing maintenance; habitat and spatial constraints from wetland on left bank; inline pond may impact water quality
Beneficiaries	Reduced sediment loading for MOTI's Highway 93 crossing and downstream landowners; recreational lake users (reduced delta growth); RDEK residents (habitat improvements at lake shore due to reduced sediment influx)

5.1.4 Containment Berms at Creek Mouth

Berms constructed along the creek banks at the mouth could sluice sediment to the lake and reduce or eliminate deposition within the lower reach of Windermere Creek. Flow would be confined to the current channel, and the berms would extend out onto the delta to carry sediment into the lake. Further design would be required to address the risk to the effectiveness and acceptance of this strategy, including effect of variable lake levels, the distance the containment berms would have to extend into Windermere Lake, potential navigation hazards, the fate of sluiced sediment (i.e. settlement), and the potential to increase upstream flooding during freshet flows and winter ice jams.

Table 11. Advantages, disadvantages, and beneficiaries of constructing a sediment containment berms near the creek mouth

Advantages	Good access for construction and maintenance; reduces short-term flood hazard at adjacent properties.
Disadvantages	Impacts riparian vegetation; may increase flood risk upstream; may increase flood risk adjacent to berm (i.e. failure of one side); benefits only downstream stakeholders; requires periodic maintenance; extends delta further into lake.
Beneficiaries	Only downstream most properties.

5.1.5 Sediment Basin at Creek Mouth

Construction of a sediment basin at the creek mouth could reduce or eliminate deposition on the adjacent properties. It would require substantial area and frequent maintenance. Basin design will need to account for expected sediment yield, maintenance access, frequency and timing of monitoring and maintenance, disturbance limitations to habitat, and exclusion of fish during maintenance work.

Table 12. Advantages, disadvantages, and beneficiaries of constructing a sediment basin near the creek mouth

Advantages	Accessible for construction and maintenance; eliminates sediment deposition on adjacent properties; may reduce short-term flood hazard for adjacent properties; reduction of delta growth and deposition at lake shore
Disadvantages	Would separate channel from riparian area; requires large area; benefits only downstream stakeholders; requires frequent maintenance.

Beneficiaries	Downstream most properties; recreational lake users.

5.1.6 WVGC Weir Stabilization

Although the risk of failure of the Windermere Creek Golf Club weir may be found to be low, its failure does present the greatest potential consequence for channel instabilities and sediment mobilization. It is recommended that the weir be inspected and a monitoring plan developed. Mitigation to address any deficiencies identified by the inspection should be considered. No specific mitigation is recommended for this site until an inspection has been carried out.

Table 13. Advantages, disadvantages, and beneficiaries of stabilising the WVGC weir

Advantages	Weir maintains current grade retaining upstream sediment.
Disadvantages	Difficult access; requires agreement with water license owner; does not address current upstream instabilities or downstream sedimentation.
Beneficiaries	Maintained grade benefits properties and infrastructure upstream to the Mine Road; retained sediment benefits downstream properties and infrastructure.

5.2 Cost of Mitigation Options

The above mitigation options have been presented at a conceptual level. Based on these concepts the costs for design, construction, and operation and maintenance (O&M) over the first five years has been presented in **Table 14**. Refer to **Appendix A** for detailed breakdown of the cost estimates of individual mitigation options.

A substantial component to the design cost of the grade control is the collection of detailed survey information within the reach. The risk of additional grade control being required has not been incorporated in the cost estimates. Additional grade control may be required in the north channel if flow is directed down this route, and additional grade control may be required between the proposed upper grade controls if this reach does not maintain its current natural stability.

Table 14. Summary of estimated costs for mitigation options

Option	Station (km+m)	Design Cost ($ 1,000's)	Construction Cost ($ 1,000's)	5-Yr O&M Cost ($ 1,000's)
1. Grade control (all)		$50	$165	$17
Mobilization			$5	
Grade control 1	7+170		$25	
Grade control 2	5+600		$35	
Grade control 3	5+520		$35	
Grade control 4	5+030 - 5+460		$65	
2. Re-establish flow to north channel		included in Cost for Grade Control 2 and 3		
3. Sediment basin upstream of Hwy 93		$20	$250 - $320	$60 - $250
4. Containment berms at creek mouth		$40	$50	$20
5. Sediment basin at creek mouth		$25	$250 - $320	$60 - $250

Variability in the cost for constructing and maintaining the sediment basins includes the cost of permitting sediment removal and potential cost recovery for removal of the sediment. Design requirements for containment berms at the creek mouth could be extensive, including bathymetric surveying and fate modelling of sediment.

6 CONCLUSIONS

Channel instabilities developed over the 2011 and 2012 freshet flows. The instabilities resulted in increased sediment generation in the reach between Windermere Loop Road and the Mine Road and deposition in downstream reaches, most notably upstream of Highway 93 crossing and at Windermere Lake. Sedimentation in the lower reach of Windermere Creek reduced channel capacity and both 2011 and 2012 freshets overflowed the banks causing localised flooding. Reduced channel depth following the aggradation increases the risk to local icing problems which is expected to also increase the risk of flooding during seasonal freeze and thaw.

Sedimentation at Highway 93 in 2012 resulted in a culvert inlet blockage and eventual floating and failure of the upstream end as water level rose above the obvert of the culvert inlet. Future sedimentation at this site could again plug the culvert and increase water level potentially stressing the culvert and fill as the hydraulic gradeline steepens through the road prism.

6.1 RECOMMENDED MITIGATION MEASURES

Mitigation measures should address both the channel instability between the WLR and the Mine Road and the ongoing deposition of sediment downstream. No one solution is able to address both of these issues. Therefore, it is recommended that mitigation includes the use of grade controls to stabilize the upstream channel and a sediment trap to intercept the majority of remaining sediment being transported downstream; that is,

i) Construct a series of grade control structures (listed as Grade Control 1 to 4 above) to stabilize the watershed. Implementation of the grade controls provides benefit to all properties adjacent to or crossing the creek downstream of the Mine Road. The grade controls limit the ongoing upstream progression of channel degradation that threatens upstream infrastructure such as the Alpine Ranch diversion weir and the Mine Road as well as reduces the amount of sediment expected to be transported downstream.

ii) Construct a sediment trap upstream of Highway 93. This location would take advantage of an existing deposition zone and site accessibility. Although expected to stabilize the reach, the grade controls proposed for the upstream reach are not expected to limit all sediment from being transported downstream. Sediment will be derived from the banks within the degraded reach as they return to a stable slope. It is expected that the sediment trap will require more frequent maintenance (i.e. removing deposited sediment) during the first five years and progressively require less maintenance as the degraded reach stabilizes (banks retreat and vegetation establishes). Because the instability is a watershed-scale problem, periodic destabilizing events are likely to occur outside of the reach primarily focussed on in this study, and the need for the sediment trap is expected to continue.

Figure 9 presents a map of the approximate service area for the recommended works, based on local topography, previous hazard analysis by RDEK (2011) and affected water licenses. Although the majority of sediment mobilized in 2011 and 2012 deposited upstream of the highway crossing and at the lake, unmitigated mobilization and transport of mass amounts of sediment as is expected from this reach has the potential to deposit sediment permanently or temporarily in any of the reaches downstream and possibly lead to flooding, localised bank erosion, or blockage and eventual failure of crossing structures.

The extent, nature of hazard, and probability of risk could be further evaluated and the map refined through detailed survey and modelling of various hazard scenarios, which could be undertaken as part of detailed design for a mitigation project. However, due to the generally confined channel form, it is expected that the changes resulting from such a study would be minor. The potential area of influence downstream of Highway 93 is consistent with previous public notification maps developed for potential failure of the Highway 93 crossing (RDEK, 2011).

NHC presented these recommendations to the Regional District of East Kootenay and BC Ministry of Forests, Lands, and Natural Resource Operations (FLNRO) via a teleconference on December 5 2012. From the meeting it was clear that there could be objection to proceeding with confining berms or a sediment trap near the lake due to the limited number of properties receiving benefit and the potential for increased flooding due to confinement or ice jams.

Interest in re-establishing flow in the north channel was expressed with an acknowledgement of the potential to add additional grade control on this reach if similar channel instabilities develop.

6.2 NEXT STEPS

This study assessed the channel from the Mine Road down to Windermere Lake, concentrating on sites of known instability, flooding, and hydrotechnical failure, that is the reach between Sta. 5+000 and 6+000, Highway 93 crossing, and the downstream most 300 m. Limited survey data was collected to assist in the assessment and mitigation options were identified. To proceed with implementing the recommended mitigation measures the following tasks are recommended.

1. **Detailed survey** of the proposed grade controls and the sediment trap is recommended. The detailed survey should capture the channel grade through this reach, channel sections, and topography of the overbank and potential access routes. Due to the dynamic state of the creek, implementation of the mitigation works should occur following the survey prior to spring freshet. The timing of the survey should be early enouh to allow for detailed designs to be developed and implemented prior to freshet.

   If flow is to be directed to the north channel, the north and south channel profiles should both be well captured by the survey and stability of the north channel investigated (i.e. define fraction and timing of flow to be directed to this site and determine need for additional grade control).
2. **Concept design** should be developed based on the detailed survey to define the location, extent, and access of the mitigation measures. At this stage aquatic habitat and fish passage considerations should be defined.
3. **Property rights** and ROW or easement acquisition should be initiated to ensure the mitigation measures can be constructed, monitored, and maintained.
4. **Permit and/or license application**, should proceed following or in conjunction with property right acquisitions

5. **Detailed design**, the concept design should be refined to provided increased detail to sections, details, notes, and specifications to allow for tender.
6. **Tender** preparation can be completed based on the drawings and specifications developed in the detailed design phase.
7. **Construction** should occur during a period of low flow based on the developed design and authorization/permit requirements.
8. **Monitoring and Maintenance** will be required the first couple years and following any extreme flow events. Monitoring will concentrate on identifying loss of stability of the structures or of the channel between or downstream of the structures. Maintenance requirements are expected to include periodic dredging of deposited sediment from the sediment trap (possibly every year for the first couple of years) and addition or rework of some grade controls following extreme flow events.

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FIGURES

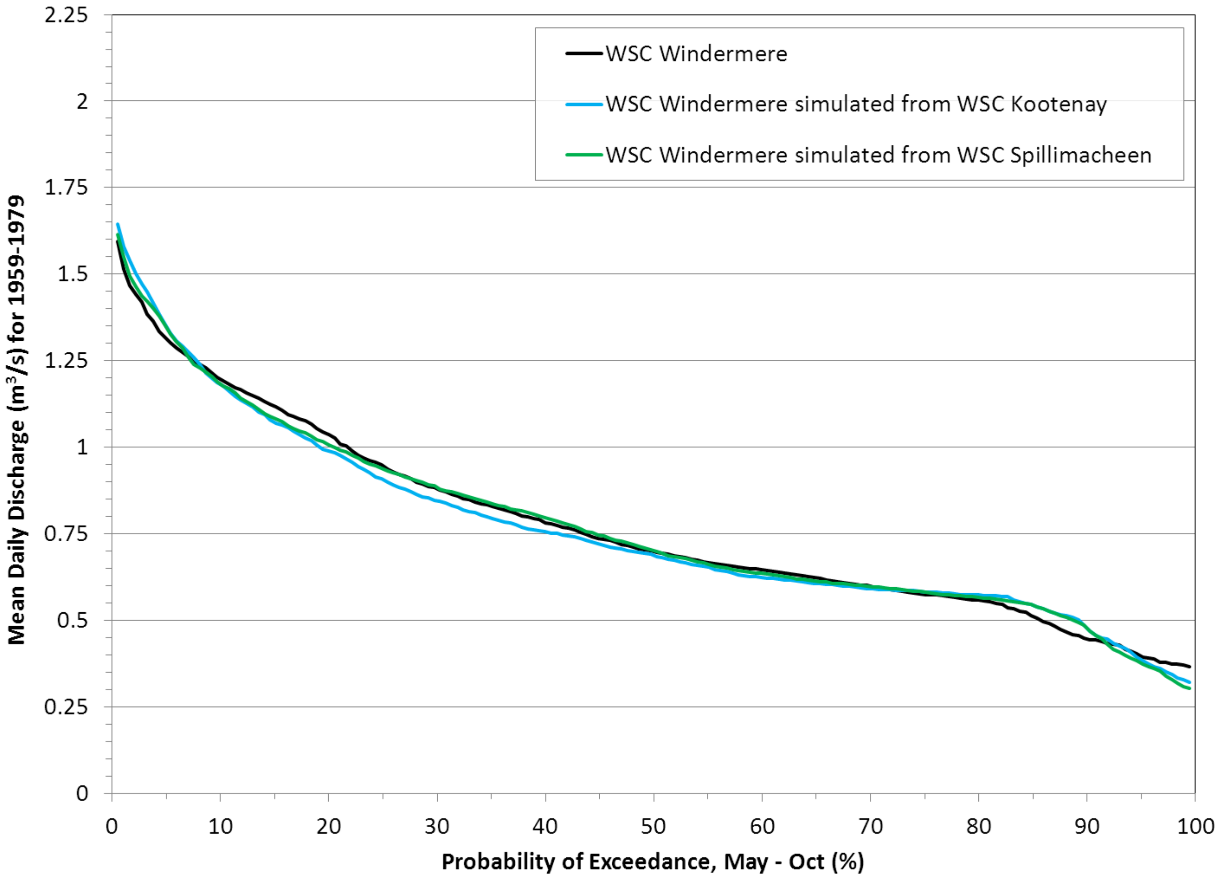


Figure 1. **Comparison of Windermere Creek flow duration curve (1959-1979) for flow based on Windermere Creek WSC and synthetic data generated from WSC Kootenay and WSC Spillamacheen**

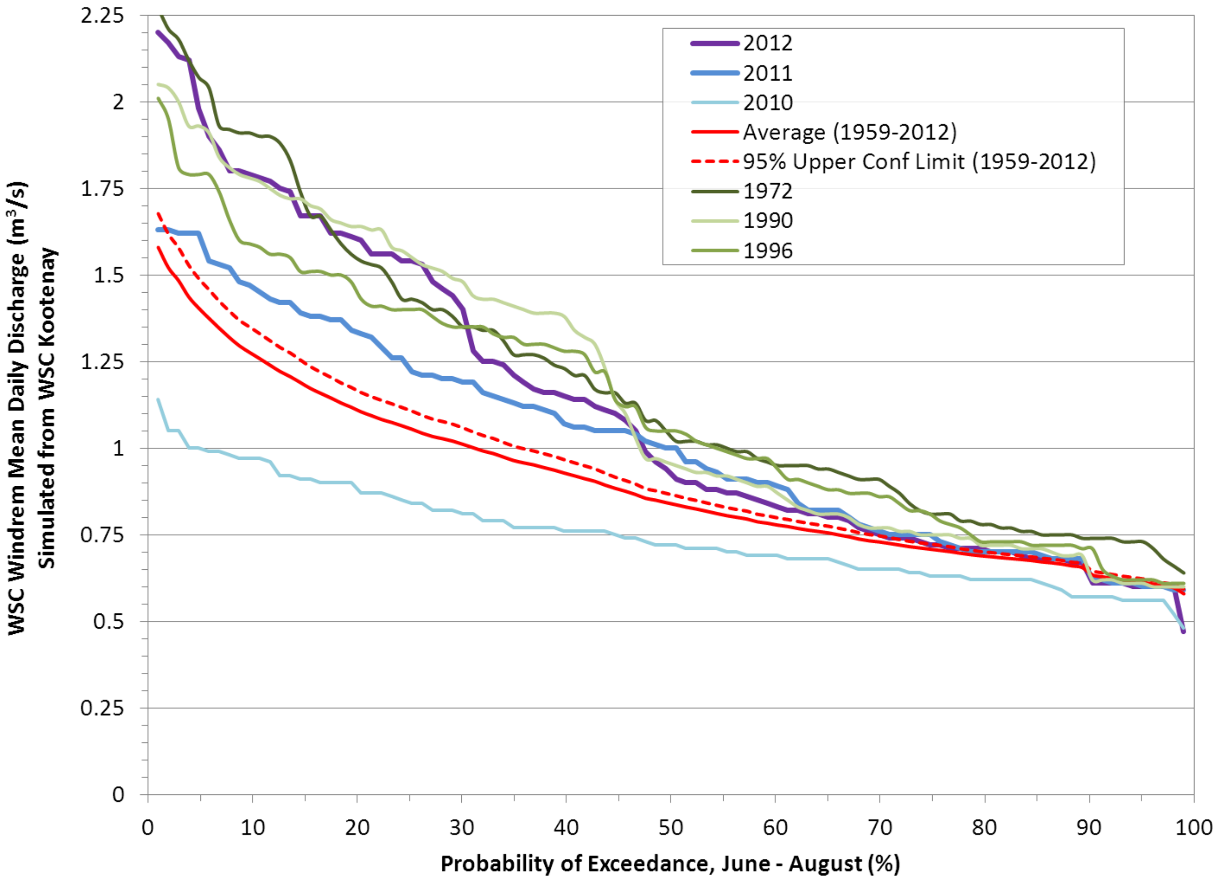


Figure 2. **Comparison of Windermere Creek flow duration curves for recent, average, and high summer flows (June, July, August) based on synthetic daily flow dataset**

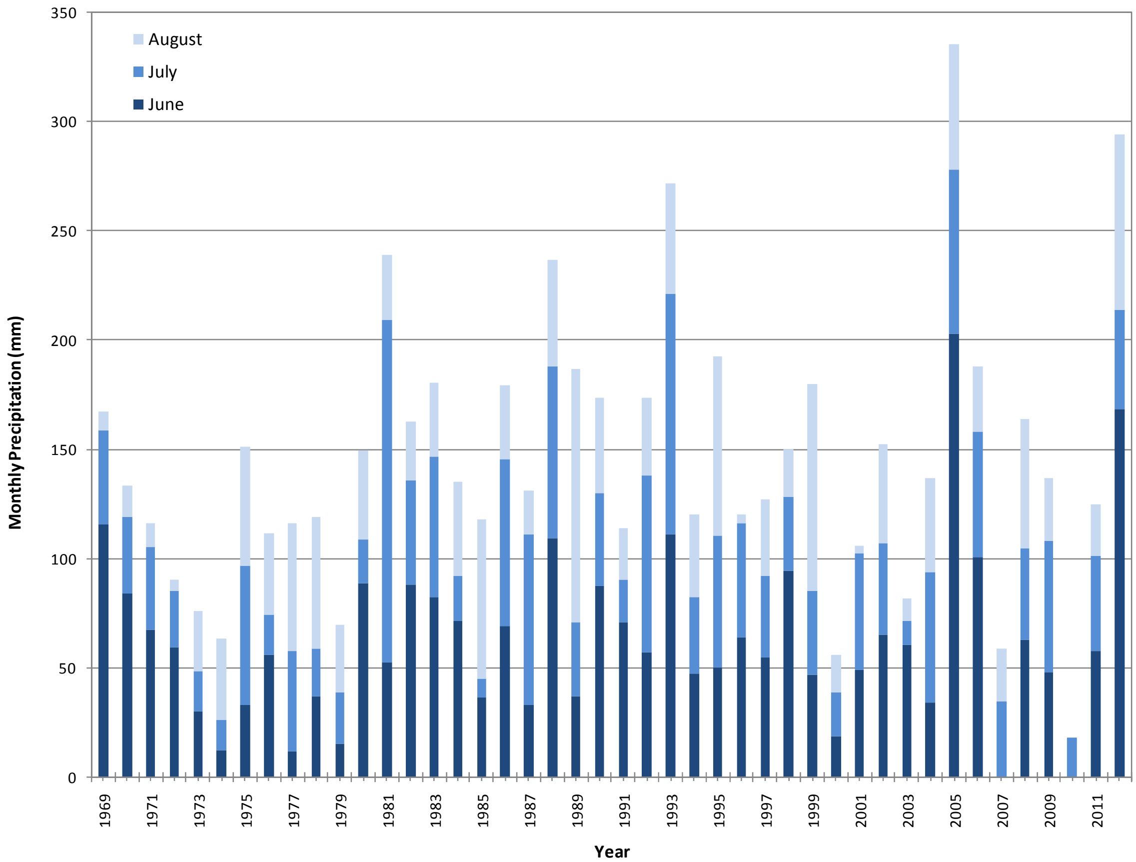


Figure 3. **Summer (June, July, August) precipitation as recorded at EC station Kootenay NP West Gate**

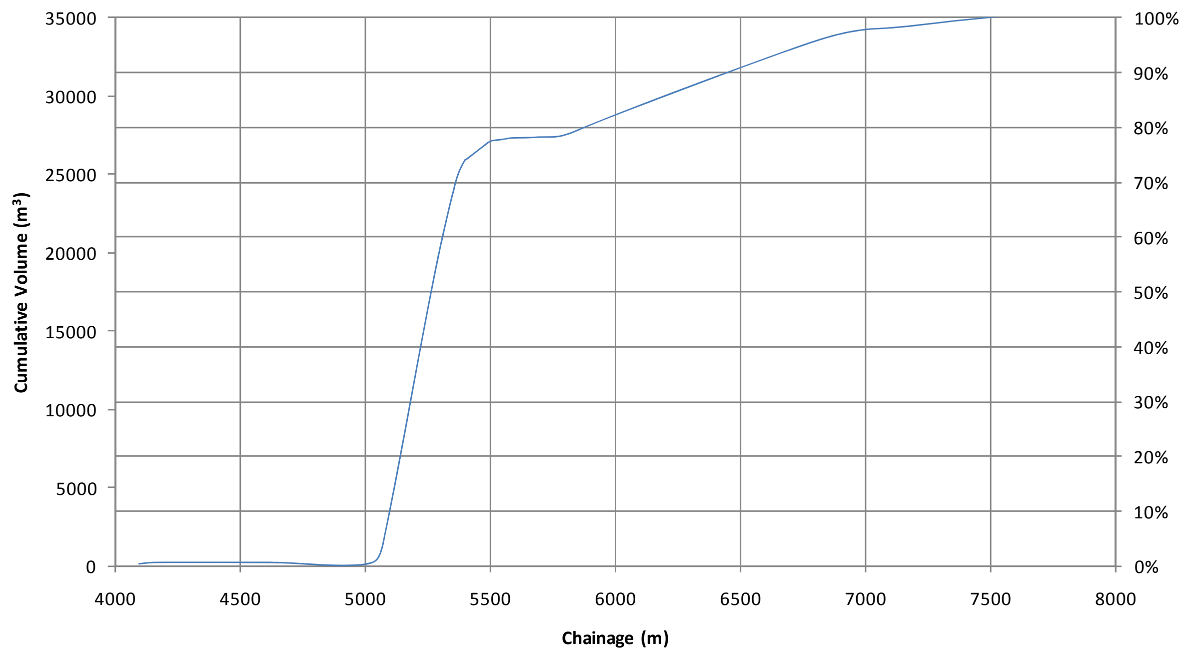


Figure 4. Cumulative volume of sediment eroded from the channel in 2011 and 2012.

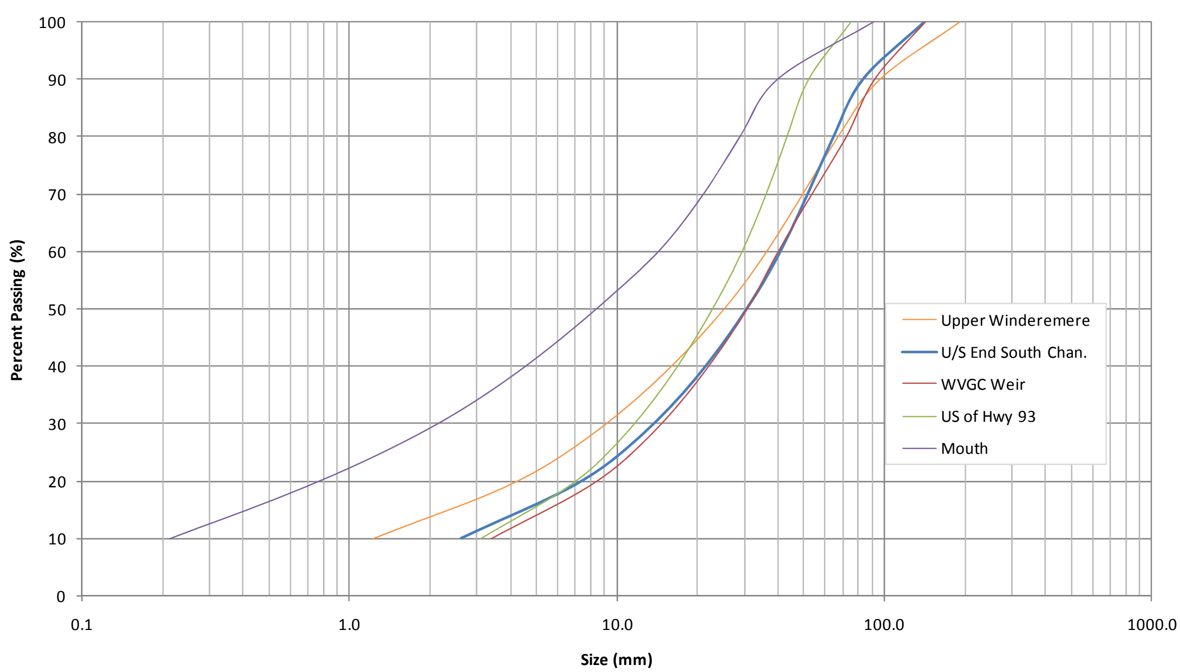


Figure 5. Channel substrate size distributions at various points along Windermere Creek.

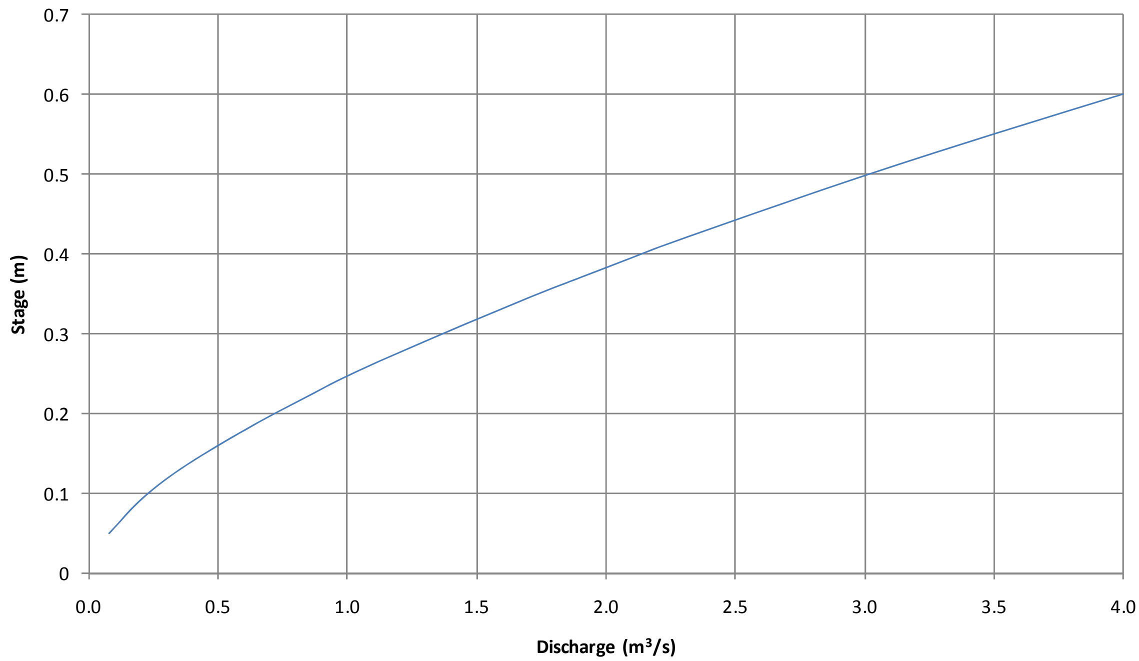


Figure 6. **Stage-discharge rating curve for Windermere Creek approximately 175 m downstream of Victoria Road.**

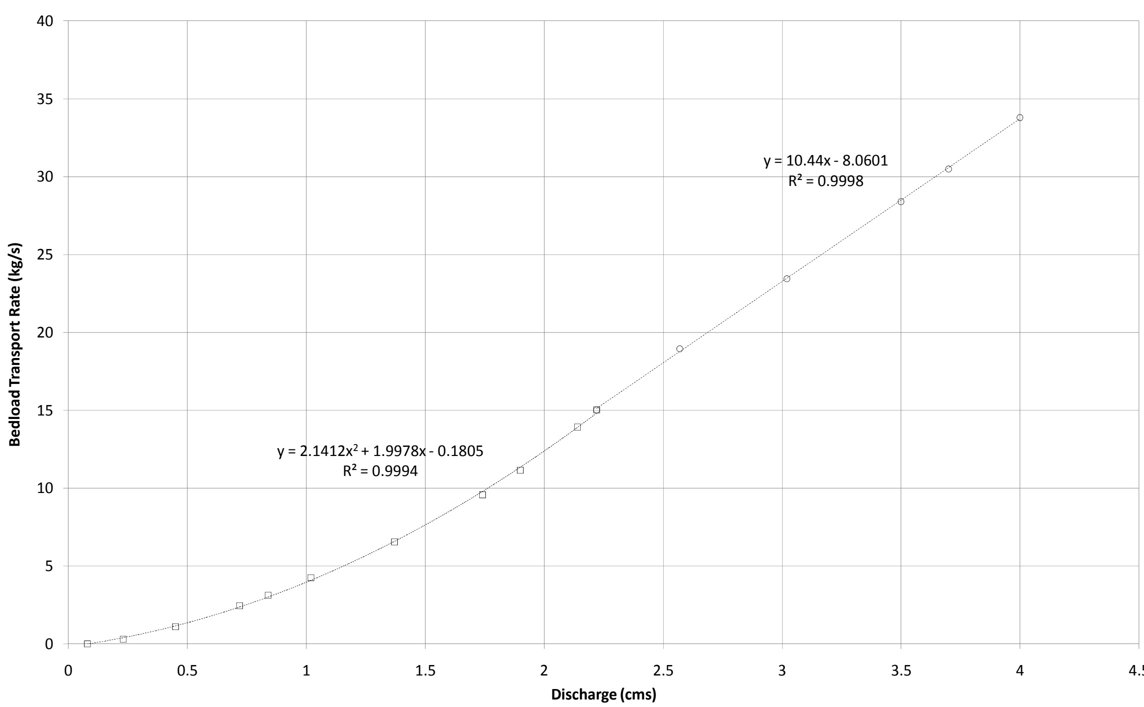


Figure 7. **Bedload transport rating curve for Windermere Creek.**

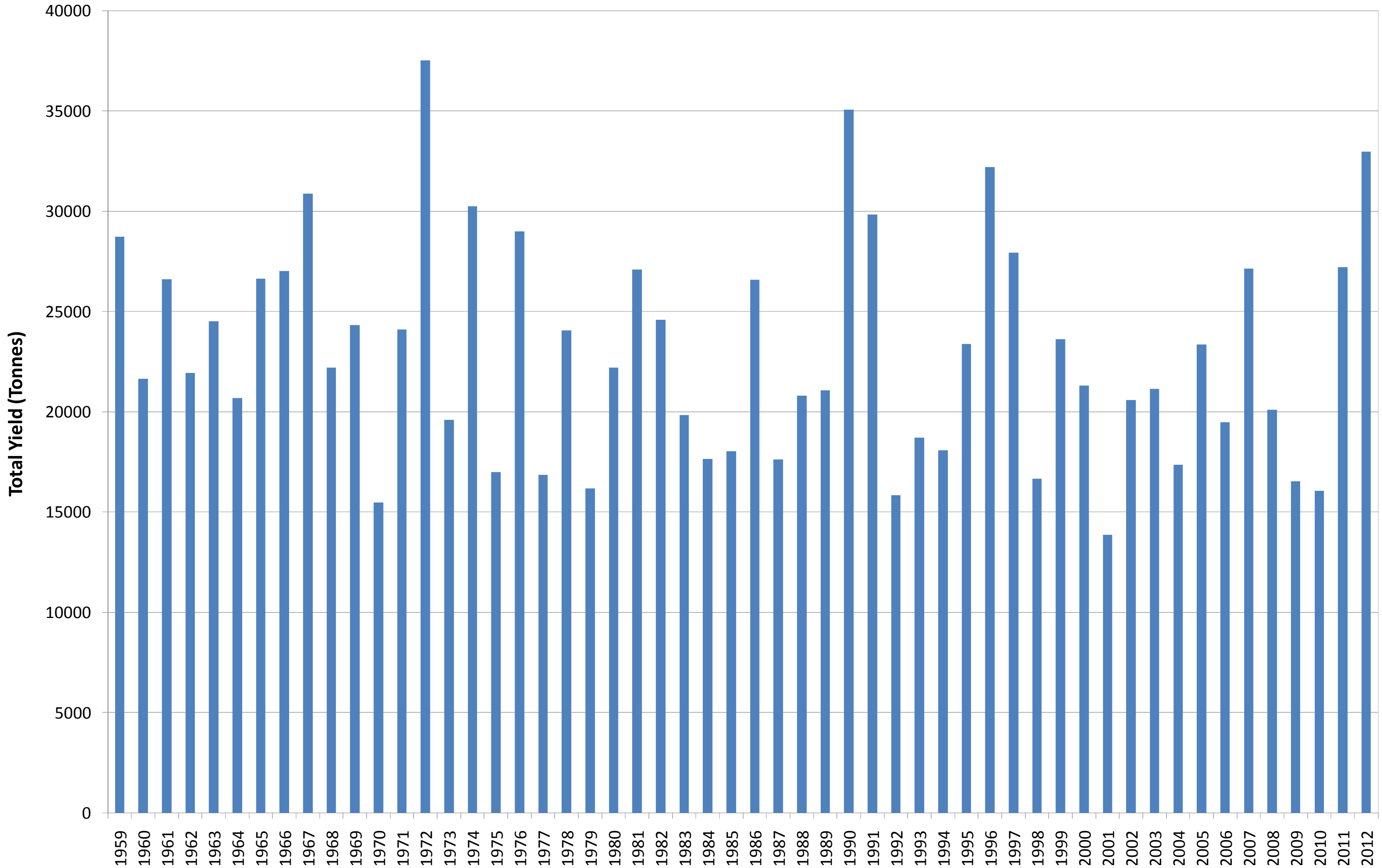
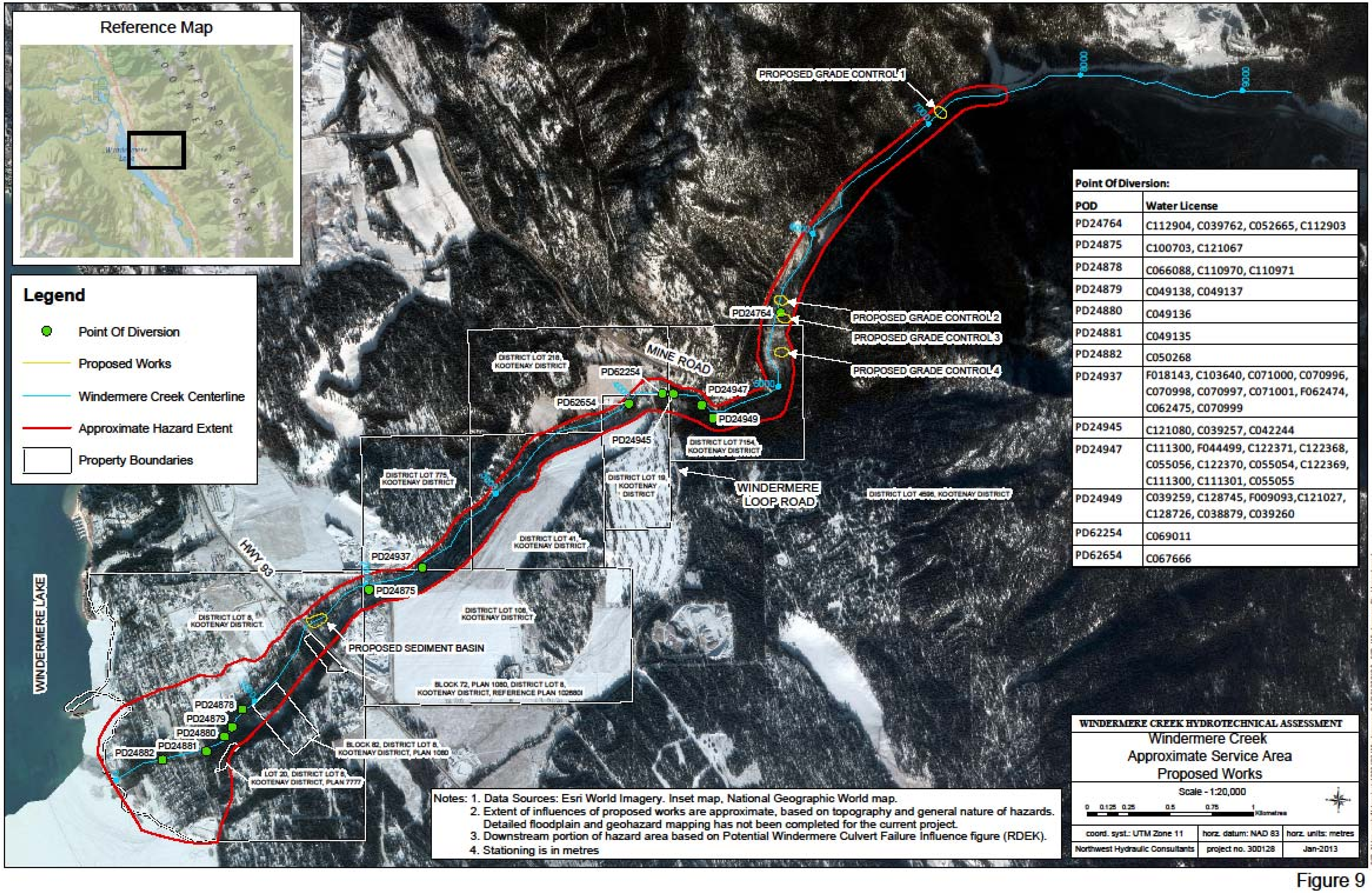


Figure 8. **Annual bedload yield estimates for Windermere Creek between 1959 and 2012.**



Point Of Diversion:	
POD	Water License
PD24764	C112904, C039762, C052665, C112903
PD24875	C100703, C121067
PD24878	C066088, C110970, C110971
PD24879	C049138, C049137
PD24880	C049136
PD24881	C049135
PD24882	C050268
PD24937	F018143, C103640, C071000, C070996, C070998, C070997, C071001, F062474, C062475, C070999
PD24945	C121080, C039257, C042244
PD24947	C111300, F044499, C122371, C122368, C055056, C122370, C055054, C122369, C111300, C111301, C055055
PD24949	C039259, C128745, F009093,C121027, C128726, C038879, C039260
PD62254	C069011
PD62654	C067666

Figure 9. Windermere Creek, approximate service area for recommended mitigation options.

PHOTOS

Photo 1. **South facing view of lake and wetland on south fork of upper Windermere Creek, Sta. 9+677**

Photo 2. **Downstream view of the culvert inlet at Mine Road crossing, Sta. 7+560**

Photo 3. **Upstream view of nick point in upper Windermere Creek, Sta. 7+170; tufa layer protruding from the bank in photo mid-ground.**

Photo 4. **Upstream view of small nick point in upper Windermere Creek, Sta. 6+830.**

Photo 5. **Upstream view of third nick point, upstream of the gravel pit and Alpine diversion, Sta. 5+800.**

Photo 6. View facing the left bank of the Alpine Ranch diversion weir, Sta. 5+600. The speed limit sign acts as a gate to control flow into the diversion channel.

Photo 7. Plunge pool at the base of the Alpine Ranch diversion weir, Sta. 5+600.

Photo 8. Downstream view of the upstream end of the South channel, Sta. 5+520. Water previously flowed into the beaver pond complex at on the right, but channel incision on the left has disconnected the floodplain.

Photo 9. **Upstream view of nick point at Sta.5+400; channel widens to about 20 m and deepens to 4-5 m downstream of this point.**

Photo 10. **Downstream view at Sta. 5+200; small terrace on right bank in photo mid-ground probably represents 2011 post-freshet bed level.**

Photo 11. Upstream view, Sta. 5+100,; south channel is more than 20 m wide and 5 m deep at this point, and for some distance downstream.

Photo 12. Downstream view, Sta. 5+080; nick point in south channel.

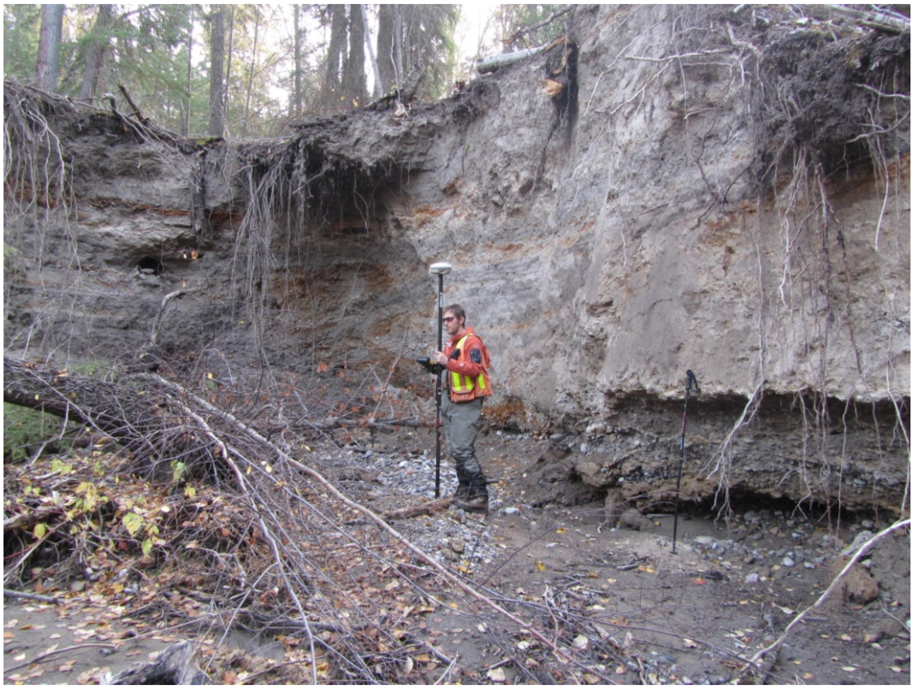


Photo 13. **Upstream view of severe erosion on left bank of south channel immediately upstream of confluence, Sta. 5+100. Height of bank in photo is approximately 4 m.**

Photo 14. **Eastward (upstream) view of a beaver dam in wetland. Ground level upstream of dam is roughly 0.5 m higher than downstream.**

Photo 15. **Upstream view of the tufa falls in the north channel near its confluence with the south channel, Sta. 5+000.**

Photo 16. **Upstream view of aggradation upstream of a small LWD grade control indicated by the buried roots of the wetted tree on the left bank (photo right); Sta. 4+980(immediately downstream of north-south channel confluence).**

Photo 17. **Downstream view toward small tributary entering Windermere Creek on left bank, approximately 25 m downstream of north and south channel confluence, Sta. 4+970.**

Photo 18. **Upstream view showing aggrading bed upstream of WVGC weir, Sta. 4+650. Note buried bridge piers.**

Photo 19. WVGC weir drops 6 – 7 m, Sta. 4+600; diversion pipe is visible in background.

Photo 20. Base of WVGC weir appears vulnerable to undermining erosion, Sta. 4+590. Water on photo right is mostly leakage from intake pipe, but some flow from beneath the weir structure is also visible, which may be a low level outlet.

Photo 21. Concrete diversion weir upstream of Windermere Loop Road culvert, Sta. 4+190.

Photo 22. Downstream view of Windermere Loop Road culvert inlet, Sta. 4+160.

Photo 23. Downstream view of Windermere Loop Road culvert outlet, Sta 4+120.

Photo 24. Incised channel downstream of Windermere Loop Road culvert, with undercut banks, Sta. 4+100.

Photo 25. **Channel substrate downstream of Windermere Loop Road culvert is cobble and small boulders, Sta. 4+000.**

Photo 26. **Downstream view of vegetation in the wetland on left bank of Windermere Creek upstream of Highway 93 suggests it has existed for a number of years, Sta. 1+700**

Photo 27. **Downstream view of sediment deposition in the reach upstream of Highway 93, Sta. 1+650.**

Photo 28. **Channel incision of 1 – 2 m through sediment deposit upstream of highway 93 has cut down through the tufa layer in some places, Sta. 1+550.**

Photo 29. Downstream view of Highway 93 culvert inlet, Sta. 1+510.

Photo 30. Upstream view of Highway 93 culvert outlet, Sta. 1+450.

Photo 31. **Downstream view of channel downstream of Highway 93 culvert, Sta. 1+450; channel is aggrading with shallow banks and woody debris steps.**

Photo 32. **Upstream view from Victoria Avenue culvert inlet, Sta. 0+410.**

Photo 33. Upstream view of Victoria Avenue culvert outlet, Sta. 0+370.

Photo 34. Upstream view of confined channel downstream of Victoria Avenue crossing, Sta. 0+370.

Photo 35. **Photo of left bank showing buried soil horizons and alternating coarse and fine substrate layers, Sta. 5+300.**

APPENDIX A

CLASS D COST ESTIMATES

Table A1. Class D cost estimate for construction and O&M of grade controls

	Rate	Units	Quantity	Cost	Subtotals	Constr. Totals	5-yr O&M
Mobilization and Demobilization							
Heavy Machinery							
20 tonne excavator	$ 1,040	day	2	$ 2,080			
trucks	$ 800	day	2	$ 1,600			
misc equipment	$ 1,500	day	1	$ 1,500			
Total Mob/Demob					$ 5,180	**$ 5,180**	
Location 1 - Downstream of Mine Road Crossing							
Materials							
Riprap	$ 50	m^3	153	$ 7,649			
Granular Filter	$ 10	m^3	38	$ 382			
Road Crush	$ 10	m^3	0	$ -			
Subtotal					$ 8,031		
Equipment							
20 tonne excavator	$ 1,040	day	5	$ 5,200			
trucks	$ 800	day	3	$ 2,400			
6 in. pump + 3 in. backup	$ 810	week	1	$ 810			
Sediment Barrier	$ 500	LS	1	$ 500			
Misc.	$ 500	LS	1	$ 500			
Subtotal					$ 9,410		
Planting and Site Restoration							
riparian planting	$ 20	m^2	40	$ 800			
erosion control blanket (ECB)	$ 3	m^2	40	$ 120			
Topsoil	$ 15	m^3	12	$ 180			
Subtotal					$ 1,100		
Construction Supervision							
Environmental Monitor	$ 640	day	5	$ 3,200			
Hydrotechnical Engineer	$ 1,120	day	3	$ 3,360			
Subtotal					$ 6,560		
Construction Location 1						**$ 25,101**	
5 Year O&M 10% of construction costs							**$ 2,510**
Location 2 - Alpine Ranch Diversion							
Materials							
Riprap	$ 50	m^3	199	$ 9,943			
Gravel	$ 10	m^3	50	$ 497			
Road Crush	$ 10	m^3	45	$ 450			
Diversion Gate	$ 1,000	LS	1	$ 1,000			
Subtotal					$ 11,890		
Equipment							
20 tonne excavator	$ 1,040	day	6	$ 6,240			

trucks	$	800	day	6	$	4,800				
6 in. pump + 3 in. backup	$	810	week	1	$	810				
Sediment Barrier	$	500	LS	1	$	500				
Misc.	$	500	LS	1	$	500				
Subtotal							$ 11,850			
Planting and Site Restoration										
riparian planting	$	20	m^2	40	$	800				
erosion control blanket (ECB)	$	3	m^2	40	$	120				
Topsoil	$	15	m^3	12	$	180				
Subtotal							$ 1,100			
Construction Supervision										
Environmental Monitor	$	640	day	6	$	3,840				
Hydrotechnical Engineer	$	1,120	day	6	$	6,720				
Subtotal							$ 10,560			
Construction Location 2								**$ 35,400**		
5 Year O&M 10% of construction costs									**$ 3,540**	
Location 3 - Upstream end of South Channel										
Materials										
Riprap	$	50	m^3	199	$	9,943				
Gravel	$	10	m^3	50	$	497				
Road Crush	$	10	m^3	90	$	900				
Subtotal							$ 11,340			
Equipment										
20 tonne excavator	$	1,040	day	6	$	6,240				
trucks	$	800	day	6	$	4,800				
6 in. pump + 3 in. backup	$	810	week	1	$	810				
Sediment Barrier	$	500	LS	1	$	500				
Misc.	$	500	LS	1	$	500				
Subtotal							$ 12,850			
Planting and Site Restoration										
riparian planting	$	20	m^2	64	$	1,280				
erosion control blanket (ECB)	$	3	m^2	64	$	192				
Topsoil	$	15	m^3	19	$	288				
Subtotal							$ 1,760			
Construction Supervision										
Environmental Monitor	$	640	day	6	$	3,840				
Hydrotechnical Engineer	$	1,120	day	6	$	6,720				
Subtotal							$ 10,560			
Construction Location 3								**$ 36,510**		
5 Year O&M 10% of construction costs									**$ 3,651**	
Location 4 - Upstream of the North and South Channel Confluence										
Materials										

Riprap	$ 50	m^3	413	$ 20,651			
Gravel	$ 10	m^3	103	$ 1,033			
Road Crush	$ 10	m^3	450	$ 4,500			
Subtotal					$ 26,184		
Equipment							
20 tonne excavator	$ 1,040	day	9	$ 9,360			
trucks	$ 800	day	9	$ 7,200			
Diversion Pipe	$ 3,000	LS	1	$ 3,000			
Sediment Barrier	$ 500	LS	1	$ 500			
Misc.	$ 500	LS	1	$ 500			
Subtotal					$ 20,560		
Planting and Site Restoration							
riparian planting	$ 20	m^2	96	$ 1,920			
erosion control blanket (ECB)	$ 3	m^2	96	$ 288			
Topsoil	$ 15	m^3	29	$ 432			
Subtotal					$ 2,640		
Construction Supervision							
Environmental Monitor	$ 640	day	9	$ 5,760			
Hydrotechnical Engineer	$ 1,120	day	9	$ 10,080			
Subtotal					$ 15,840		
Construction Location 4						**$ 65,224**	
5 Year O&M 10% of construction costs							**$ 6,522**
Total Construction - All Grade Controls						**$ 167,415**	
Total O&M 5 years							**$ 16,224**

Table A2. Class D cost estimate for construction and O&M of a sediment basin upstream of Highway 93

	Rate	Units	Quantity	Cost	Subtotals	Totals
Mobilization and Demobilization						
2 x 20 tonne excavator	$ 2,080	day	2	$ 4,160		
6 x trucks	$ 4,800	day	2	$ 9,600		
Subtotal					$ 13,760	
Materials						
Riprap	$ 50	m^3	80	$ 4,000		
Gravel	$ 10	m^3	24	$ 240		
Disposal of Excavated Material	$ 10	m^3	15,000	$ 150,000		
Road Crush	$ 10	m^3	90	$ 900		
Subtotal					$ 155,140	
Equipment						
2 x 20 tonne excavator	$ 2,080	day	17	$ 35,360		
6 x trucks	$ 4,800	day	15	$ 72,000		
6 in. pump + 3 in. backup	$ 810	week	3	$ 2,430		
Sediment Barrier	$ 500	LS	1	$ 500		
Misc.	$ 500	LS	1	$ 500		
Subtotal					$ 110,790	
Planting and Site Restoration						
riparian planting	$ 20	m^2	300	$ 6,000		
erosion control blanket (ECB)	$ 3	m^2	300	$ 900		
Topsoil	$ 15	m^3		$ -		
Subtotal					$ 6,900	
Construction Supervision						
Environmental Monitor	$ 640	day	17	$ 10,880		
Hydrotechnical Engineer	$ 1,120	day	17	$ 19,040		
Subtotal					$ 29,920	
Total Construction						**$ 316,510**
5 year O&M 10% of construction cost						**$ 31,651**

Table A3. Class D cost estimate for construction and O&M of containment berms at the mouth of Windermere Creek

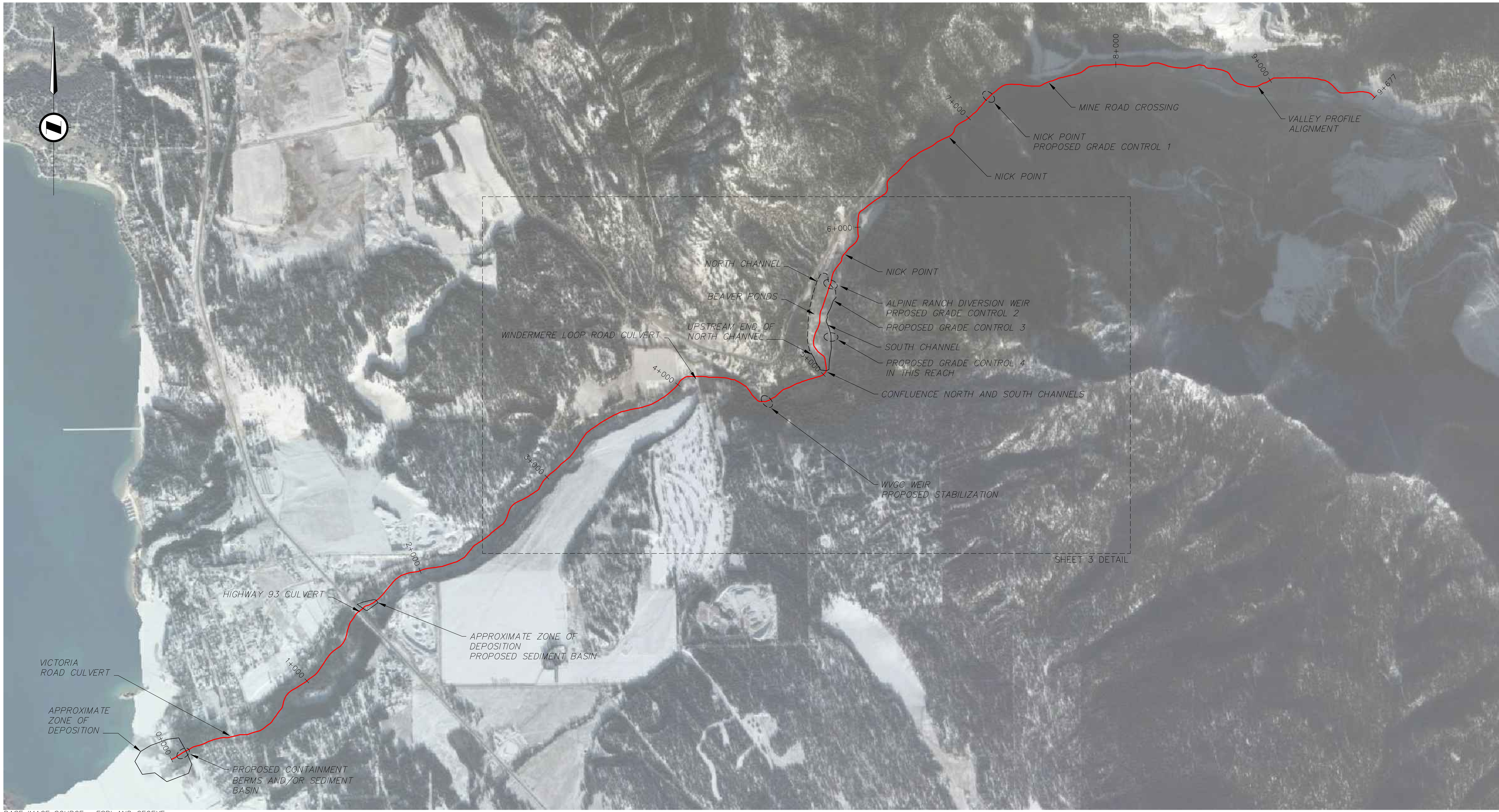
	Rate	Units	Quantity	Cost	Subtotals	Totals
Mobilization and Demobilization						
20 tonne excavator	$ 1,040	day	2	$ 2,080		
trucks	$ 800	day	2	$ 1,600		
Subtotal					$ 3,680	
Materials						
Riprap	$ 75	m^3		$ -		
Gravel	$ -	m^3	675	$ -		
Disposal of Excavated Material	$ 10	m^3		$ -		
Road Crush	$ 15	m^3		$ -		
Subtotal					$ -	
Equipment						
20 tonne excavator	$ 1,040	day	10	$ 9,880		
1 x truck	$ 800	day	8	$ 6,000		
6 in. pump + 3 in. backup	$ 810	week	2	$ 1,620		
Sediment Barrier	$ 500	LS	1	$ 500		
Misc.	$ 500	LS	1	$ 500		
Subtotal					$ 18,500	
Planting and Site Restoration						
riparian planting	$ 20	m^2	450	$ 9,000		
erosion control blanket (ECB)	$ 3	m^2	225	$ 675		
Topsoil	$ 15	m^3		$ -		
Subtotal					$ 9,675	
Construction Supervision						
Environmental Monitor	$ 640	day	10	$ 6,080		
Hydrotechnical Engineer	$ 1,120	day	10	$ 10,640		
Subtotal					$ 16,720	
Total						**$ 48,575**

Table A4. Class D cost estimate for construction and O&M of a sediment basin at the creek mouth

	Rate	Units	Quantity	Cost	Subtotals	Totals
Mobilization and Demobilization						
20 tonne excavator	$ 2,080	day	2	$ 4,160		
6 x trucks	$ 4,800	day	2	$ 9,600		
Subtotal					$ 13,760	
Materials						
Riprap	$ 75	m^3	40	$ 3,000		
Gravel		m^3	12	$ -		
Disposal of Excavated Material	$ 10	m^3	15,000	$ 150,000		
Road Crush	$ 15	m^3		$ -		
Subtotal					$ 153,000	
Equipment						
2 x 20 tonne excavator	$ 2,080	day	17	$ 35,360		
6 x trucks	$ 4,800	day	15	$ 72,000		
6 in. pump + 3 in. backup	$ 810	week	3	$ 2,430		
Sediment Barrier	$ 500	LS	1	$ 500		
Misc.	$ 500	LS	1	$ 500		
Subtotal					$ 110,790	
Planting and Site Restoration						
riparian planting	$ 20	m^2	300	$ 6,000		
erosion control blanket (ECB)	$ 3	m^2	300	$ 900		
Topsoil	$ 15	m^3		$ -		
Subtotal					$ 6,900	
Construction Supervision						
Environmental Monitor	$ 640	day	17	$ 10,880		
Hydrotechnical Engineer	$ 1,120	day	17	$ 19,040		
Subtotal					$ 29,920	
Total						**$ 314,370**

Appendix B

Drawings



BASE IMAGE SOURCE: ESRI AND GEOEYE
STATIONING IN m+m

Regional District of East Kootenay
19 - 24th Avenue South
Cranbrook, BC V1C 3H8

Columbia Basin Trust
Suite 201, 828 Baker Street
Cranbrook, BC V1C 1A2

nhc northwest hydraulic consultants
30 Gostick Place
North Vancouver, B.C. V7M 3G3
Canada
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com

Revisions		
No.	Date	Description

Drawing Information	
Date	14 December 2012
Status	FOR DISCUSSION
Designer	MSG
Drafter	BXH
Checked	
File Name	Windermere 2012-08-27 r0a.dwg
Plotted Scale	0 ½ 1

WINDERMERE CREEK SEDIMENT MITIGATION OPTIONS

Plan View

Job Number
300128

Sheet Number
1

Sheet 1 of 2

Regional District of East Kootenay
19 - 24th Avenue South
Cranbrook, BC V1C 3H8

Columbia Basin Trust
Suite 201, 828 Baker Street
Cranbrook, BC V1C 1A2

nhc northwest hydraulic consultants
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Revisions		
No.	Date	Description

Drawing Information	
Date	17 December 2012
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Designer	MSG
Drafter	BHO
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WINDERMERE CREEK SEDIMENT MITIGATION OPTIONS

Long Profiles

Job Number 300128

Sheet Number

2

BASE IMAGE SOURCE: ESRI AND GEOEYE
STATIONING IN m+m

Regional District of East Kootenay
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Cranbrook, BC V1C 3H8

Columbia Basin Trust
Suite 201, 828 Baker Street
Cranbrook, BC V1C 1A2

nhc northwest hydraulic consultants
30 Gostick Place
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Office: 604.980.6011
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Revisions		
No.	Date	Description

Drawing Information	
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Drafter	BXH
Checked	
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WINDERMERE CREEK
SEDIMENT MITIGATION OPTIONS

Detail View

Job Number
300128

Sheet Number
3

Sheet 1 of 2