IDM MINING

Appendix IR1-11-D
Bitter Creek Hydrotechnical Assessment Report

Red Mountain Underground Gold Project
IDM Mining Ltd. Responses to
Canadian Environmental Assessment Information Request #1

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Integrated Watersheds

REPORT

Onsite Engineering

Bitter Creek
Hydrotechnical Assessment

October 2017

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1 Introduction

Bitter Creek is a steep watershed that drains out into the Bear River valley. It is located approximately 15 km north of Stewart, BC along Highway 37A. An abandoned resource access road interconnects with Highway 37A immediately north of the Bitter Creek bridge crossing. The road extends east of Highway 37A and is positioned on the north side of Bitter Creek. The existing road was designed and constructed during the mid-1990’s. Since construction, some road sections that are adjacent to the river channel have been significantly impacted or removed by flood-related erosion processes. As part of overall redevelopment of the resource access road by IDM Mining Ltd. to the proposed Red Mountain Gold Mine Project, new sections of the access road along the river are being redesigned by Onsite Engineering Ltd. (Onsite). At the request of Onsite, Integrated Watersheds conducted a hydrotechnical assessment of the river channel with the existing and the redeveloped road sections that will be adjacent to lower Bitter Creek. This area forms the project site for the hydrotechnical study (Figure 1-1).

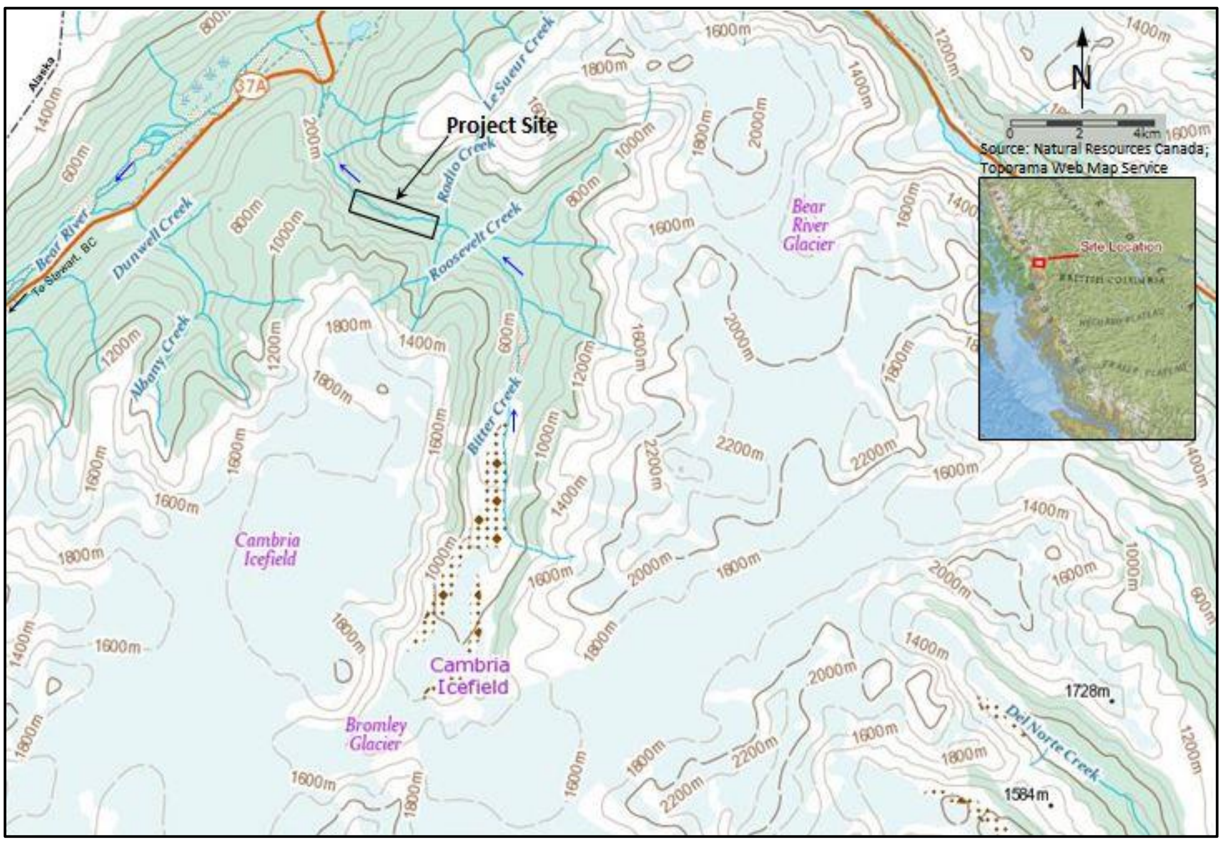

Figure 1-1: Location of the project site along lower Bitter Creek.

This report begins with a brief description of the objectives of the work for the project that was developed with Onsite. The methodology section provides an explanation of the procedures used for the hydrotechnical engineering assessment. Results and observations are presented for each aspect of the work, as well as for specific channel sections along lower Bitter Creek.

Four appendices accompany this report. Appendices A and B include copies of the Bitter Creek Hydrotechnical field inspection and Flood Frequency reports. Appendix C provides a listing of the estimated surface water elevation results for the 3,000 m of river channel that was assessed along lower Bitter Creek. Appendix D contains the rock riprap and fill material requirements for the road sections that will be constructed along and within Bitter Creek.

In this report, all station references are associated with geometric design that is being completed by Onsite for the Red Mountain access road. The left and right sides of channel sections are referenced as if one is facing in a downstream direction.

2 Purpose

The purpose of the hydrotechnical assessment was to conduct an analysis to estimate the flood magnitudes and the related surface water conditions during specified flood discharges along lower Bitter Creek. The intent was to evaluate the new road sections so that they are compatible with the river's channel's hydraulic geometry conditions and estimated water elevations during the flood events.

3 Methodology

The procedure used in the hydrotechnical assessment involved the completion of the following tasks:

1. Inspect the channel section along lower Bitter Creek and evaluate the hydrogeomorphic condition of the river channel.

2. Conduct a hydrologic flood frequency analysis in order to determine discharge estimates for flow events along lower Bitter Creek that varies from 1:2-year to 1:200-year return periods.

3. Develop a hydraulic model along lower Bitter Creek (within the project site) to estimate the mean surface water elevations for a range of flow discharge events. Version 5.0 of USACE's Hydrologic Engineering Centre (HEC) River Analysis System (RAS) was employed to carry out the analysis. HEC-RAS was used to calculate one-dimensional surface water profile calculations for steady gradually varied flow in the channel. HEC-RAS results for relative average depths, widths and flow velocities were compared for existing channel conditions and for the new road sections along lower Bitter Creek.

4. Provide a hydrotechnical report that summarizes the results and observations within the project site, as well as conclusions and recommendations for the hydrotechnical design criteria for the final Issued-for-Construction (IFC) requirements for the new road sections.

For the assessment, Onsite employed a LiDAR data set that was provided by IDM Mining Ltd. to develop a digital terrain model (DTM) of the project site using Softree's Terrain Tools© software. This was based on available 2013 LiDAR coverage and local site survey upgrades of current bank and water edge locations within the project site. A copy of the DTM was provided by Onsite to Integrated Watersheds. It was subsequently used in the HEC-RAS hydraulic model to estimate surface water elevations, the channel's related hydraulic geometry during flood conditions, and the development of the new road sections along lower Bitter Creek.

3.1 Site Inspection

The site conditions at the lower Bitter Creek project site were observed during a hydrotechnical inspection that was carried out on June 13 and 14, 2017 with Michael Foster, P. Eng., and Andrew Brabandt, C. Tech. from Onsite. The condition of the river channel, its channel banks and adjacent sideslopes were visually assessed during low flow conditions. During the inspection, water quality and clarity levels were poor due to high suspended sediment concentrations and turbidity levels. However, the water depths along the river were estimated to vary between 0.5 m to over 1.5 m in places.

The observed channel bed materials were associated with a coarse gravel bed river that had limited fine grain sediments (< 20%), and was dominated by a mixture of coarse gravels, large pebbles and cobbles, as well as rock boulders and semi-angular blocks in places. Both sides of the main channel, as well as the adjacent bank and hillslope sections were traversed. The representative composition and size distribution of the channel sediments was estimated by employing the Wolman-Miller sediment characterization procedure at several transects along the inspected sections of lower Bitter Creek. The transects were located spatially across the flood terrace areas, as well as along the perimeter of the main channel sections both upstream and downstream along Bitter Creek within the project site.

3.2 Representative Hydrology

A regional flood frequency analysis was undertaken to estimate the 200-year design flood for the project area along lower Bitter Creek. With no Environment Canada hydrometric stations present within the Bitter Creek watershed, all publically available data from Environment Canada's Water Survey of Canada (WSC) hydrometric stations (both active and inactive) within the region were reviewed to determine their suitability for estimating peak flows in Bitter Creek.

Once representative WSC hydrometric stations were determined, a flood frequency analysis was completed based on recorded maximum instantaneous peak discharges at each of the selected WSC stations. Four different frequency distributions (Pearson Type III, Log Pearson Type III, 3-parameter Log Normal, and Gumbel) were fitted to the sample flow data. The general procedure for estimating individual return periods involved visually inspecting each probability distribution for anomalies and outliers, as well as assessing and comparing the statistical dispersion parameters (coefficients of variation, skewness and kurtosis) for each distribution. The peak flow results for the ungauged watershed were adjusted to account for the regional variation in drainage area relative to Bitter Creek.

The hydrologic details of the flood frequency analysis are provided in Appendix A.

3.3 Hydraulic Model

A HEC-RAS hydraulic model was developed along Lower Bitter Creek. Based on the developed DTM for the project site, 198 cross-sections along a 3,000 m long reach were assessed (between Stations 2+000 to 5+000) at channel intervals that varied from 10 m along channel bends, to 20 – 50 m intervals along the river's wider flood terrace sections. All cross-sectional profiles were extended beyond the active channel banks, out across the adjacent flood terraces (where present), and up onto the adjacent hillslope sections.

Using the hydraulic model, the water surface elevations and average flow velocities were computed for each river cross-section. The assessment considered conditions both with and without the constructed road sections in place along lower Bitter Creek. The downstream boundary condition for the model was normal depth with a mean channel slope of 1.4 percent (0.014 m). Based on the observed variation in the channel's hydraulic geometry and bed materials, a Manning's roughness coefficient of 0.05 was used for the main river channel. Similarly, a roughness coefficient of 0.04 was used to account for the variation in the sediments across the overbank flood terraces and side channels. Expansion and contraction coefficients were also applied when channel and valley conditions changed along the lower Bitter Creek.

4 Results and Observations

This section describes the results of the hydrotechnical assessment for lower Bitter Creek. First a brief description of the basin and its channel conditions are provided. This is followed by the representative flood hydrology results, as well as related channel characteristics. The results are also referenced to the Bitter Creek Hydrotechnical Drawing set that has been produced by Onsite.

4.1 BASIN DESCRIPTION

Bitter Creek watershed is a mountainous watershed with a third-order drainage network. With an estimated drainage area of 247 km^2, the north-west facing watershed is a tributary to the Bear River watershed. Snow, ice and barren rock surfaces account for approximately 87% of the drainage area across the high elevation watershed.

Along the valley's lower elevation slopes, the overlying surficial sediments varied from colluvium to moraine-based glacial tills. In places, unconsolidated glacio-fluvial sediments and interbedded glacio-lacustrine clayey silts were also present along the lower valley sideslopes. Local bank erosion and slope instabilities were observed along the outside edges of channel bends. The riparian vegetation along the lower slopes was dominated by stands of Western Hemlock and Amabilis Fir trees. Along hillslopes that have been subjected to snow avalanches and slope instabilities, deciduous mountain Willows and red Alder trees were present. Alders were also seen along the old access road corridor that exists along the north side of lower Bitter Creek (Figure 4-1).

Lower Bitter Creek has developed along a well-defined regional fault that extends upstream from the channel confluence with the Bear River. The river valley is narrow and confined by steep-sided mountainous hillslopes. In general, the lower valley region is underlain by igneous intrusive quartz-based rocks associated with the Coast Plutonic complex (ECPqm), as well as sedimentary rocks from the Hazelton group of rocks (muJHs) from the mid-to-upper Jurassic geologic period (after BC Geologic Survey Geology Map for the Red Mountain Area).

Figure 4-1 Looking upvalley along lower Bitter Creek

4.2 FLOOD HYDROLOGY

The main source of surface water to Bitter Creek is the Bromley Glacier. It is an outlet glacier of the Cambria Ice field that has been retreating significantly during recent times. It provides glacial meltwater that maintains and augments surface water flows throughout the year. Peak flow events are associated with intense rainfall-runoff events, as well as temperature-dependent rain-on-snow events. Annual snowmelt freshets also contribute to surface water flows during the late spring-to-early summer periods.

Discharge estimates for Lower Bitter Creek are listed in Table 4-1. The estimates are derived from the completed statistical flood frequency analysis (see Appendix B). The results demonstrate the relationship that average peak flow discharges for each considered return period flow increase as the runoff events intensify along Bitter Creek. Compared to the average 1:2-year bankfull flows along the gravel bed channel, larger magnitude discharges will increase by factors that range from 2 (from Q_2 to Q_{10} flows) to 4 times (from Q_2 to Q_{200} flows) higher than 1:2-year flows. This indicates that Bitter Creek's hydrologic capacity to convey large amounts of water, sediment and debris downstream will elevate substantially during high energy flood events.

Table 4-1
Summary of estimated discharges for Lower Bitter Creek

Discharge Estimates (by Return Period)	Bitter Creek (ungauged) (m^3/s)
Q_2	127
Q_{10}	268
Q_{20}	330
Q_{50}	413
Q_{100}	476
Q_{200}	522

To account for the inherent risk and uncertainty associated with potential alterations to peak flows due to the occurrence of climate change, glacial outburst floods and sediment transport impacts, both the 100-year and 200-year design flood magnitudes were increased by 20% to 571 m^3/s and 626 m^3/s respectively (after APEGBC 2012 and IPCC 2014).

4.3 CHANNEL CHARACTERISTICS

In the confined lower valley, Bitter Creek has an irregular winding channel pattern as it shifts and deflects off the steep sideslopes. Large volumes of alluvial sediments were stored across the floodplain areas that are adjacent to the main channel. Along the outside channel bends, undercut and eroding banks were common features. Clusters of large woody debris were also present along the margins of the main channel and adjacent floodplain areas. The channel patterns ranged from meander-like channel bends to multiple braided channel sections in places (Figure 4-2).

Across the wider depositional flood terraces, the channel sediments were noted to be coarse sands and medium-to-fine pebble-size gravels, with cobble size clasts present in places. The median grain size diameter (D_{50}) was estimated to be 70 mm on average. In contrast, the channel bed materials along the main channel were larger and consisted of a more angular mixture of large cobbles, boulders and rock blocks. The median grain size diameter (D_{50}) was estimated to be 300 mm on average. These coarse bed materials were typically present along step-like channel profiles, and accounted for the naturally high hydraulic roughness and turbulence conditions that were consistently observed along lower Bitter Creek (Figure 4-2).

Channel flow widths during the field inspection varied on average between 10 m and 30 m. The depositional flood terrace areas were separated by narrower river sections associated with channel bends that were identified as transport reaches. Within the project site, the width of the river valley contracted along channel bends. These narrow sections had channel bed slopes that varied from 1% to over 3%. In places, the bends tended to behave as constrictions that promoted increased flow velocities within the channel sections. They also tended to facilitate the storage of alluvial sediments across the relatively wide flood terraces, as well as mid-channel, lateral and point bar deposits are present along the river (Figures 4-1 and 4-2).

4.4 CHANNEL HYDRAULICS

The estimated mean channel hydraulic results from the modeling of lower Bitter Creek are presented in Tables 4-2 and 4-3 for the 3,000 m long reach. The results are provided for two channel conditions that were considered: for existing road and channel conditions, and when the Red Mountain access road (as per the geometric design being completed by Onsite) is in place along the north bank of Bitter Creek. The results are provided per 500 m long channel sections for the estimated mean water surface elevation, top width, area and flow velocity results are shown for the 1:2-year, 1:100-year and 1:200-year maximum instantaneous peak discharge events.

Figure 4-2 Looking downvalley across a flood terrace along lower Bitter Creek

For the six 500 m long sections, the estimated mean flow conditions during flood discharge events show a proportional increase in channel hydraulic properties as flood widths expand across the wider flood terrace sections and along the narrower channel bends. They do not reflect the local variation in flow energy, water elevations and hydraulic roughness conditions as flow concentrations and super elevation effects will occur in places along the river.

Along the six 500 m long sections, the estimated mean flow velocities for 1:2 year flows range between 2.3 to 2.9 m/sec for existing channel conditions. At the higher discharges, the mean water depths proportionally increase. The 1:100 year and 1:200 year mean flow velocities reach and exceed 3 m/sec under both flow conditions. When higher flow conditions exist, the local scour depths along the outside channel bends exceed 3 m in places. In addition, superelevation effects greater than 1 m in places will be present along the outside channel bends.

Table 4-2
Mean channel hydraulic properties (per 500 m sections) for flow discharge events under current conditions along Bitter Creek

Channel Section (m)	Return Period (Q_n)	Estimated Discharge (m^3/s)	Mean Water Depth (m)	Mean Channel Flow Width (m)	Mean Channel Flow Area (m^2)	Mean Flow Velocity (m/s)
5000 – 4500	Q_2	127	1.6	47.3	47.8	2.7
	Q_{100}	571	3.6	58.3	154.2	3.9
	Q_{200}	626	3.8	58.9	164.3	4.1
4499 – 4000	Q_2	127	1.5	52.5	47.4	2.9
	Q_{100}	571	3.4	78.6	180.9	3.5
	Q_{200}	626	3.6	79.3	191.9	3.6
3999 – 3500	Q_2	127	1.5	52.0	49.5	2.7
	Q_{100}	571	3.0	60.5	135.7	4.4
	Q_{200}	626	3.2	61.1	144.7	4.6
3499 – 3000	Q_2	127	1.6	58.4	50.3	2.8
	Q_{100}	571	3.0	102.5	165.6	4.1
	Q_{200}	626	3.1	104.1	176.8	4.2
2999 – 2500	Q_2	127	1.4	80.7	64.3	2.3
	Q_{100}	571	2.6	138.3	194.4	3.5
	Q_{200}	626	2.7	139.7	206.8	3.6
2499 – 2000	Q_2	127	1.7	46.4	51.1	2.5
	Q_{100}	571	3.5	92.9	175.9	3.8
	Q_{200}	626	3.7	94.6	190.7	3.9

Table 4-3
Mean channel hydraulic properties (per 500 m sections) with Red Mountain access road Constructed along Bitter Creek

Channel Section (m)	Flow Event (Q_n)	Estimated Discharge (m^3/s)	Mean Water Depth (m)	Mean Channel Width (m)	Mean Flow Area (m^2)	Mean Flow Velocity (m/s)
5000 – 4500	Q_2	127	1.62	47.3	47.8	2.7
	Q_{100}	571	4.02	54.1	158.6	3.9
	Q_{200}	626	4.23	54.7	169.4	4.0
4499 – 4000	Q_2	127	1.52	52.5	47.4	2.9
	Q_{100}	571	3.45	74.5	177.4	3.5
	Q_{200}	626	3.61	75.2	188.2	3.7
3999 – 3500	Q_2	127	1.47	52.0	49.9	2.7
	Q_{100}	571	3.00	60.5	135.7	4.4
	Q_{200}	626	3.15	61.1	144.7	4.6
3499 – 3000	Q_2	127	1.6	58.1	50.2	2.8
	Q_{100}	571	3.0	101.9	166.2	4.1
	Q_{200}	626	3.13	103.5	177.6	4.2
2999 – 2500	Q_2	127	1.4	80.7	64.3	2.3
	Q_{100}	571	2.3	138.3	194.4	3.5
	Q_{200}	626	2.66	139.7	206.8	3.7
2499 – 2000	Q_2	127	1.66	46.4	51.1	2.5
	Q_{100}	571	3.48	92.9	175.9	3.8
	Q_{200}	626	3.7	94.6	190.7	3.9

4.5 CHANNEL BEND MODIFICATION

The resource access road is planned to encroach and expand onto the perimeter of Bitter Creek's flood terrace and river channel area between Stations 4+020 and 4+820. As the road prism proceeds east and upvalley, it will enter an alternating sequence of channel bends between Stations 4+600 and 4+820. The channel is confined through this section of the river, with the outside bends bordered by steep, bed-controlled slopes. The base of the right and left banks are oversteepened and have been undercut by bank erosion and local hydraulic scour processes (Figure 4.3 and Figure 4.4). In contrast, the inside channel bend along the left bank features mid-channel, lateral and point bar deposits of unconsolidated sediments (i.e., mixtures of coarse sands, gravels, cobbles, boulders and rock) that extend downstream.

Figure 4-3 Looking upstream along the right bank of Bitter Creek towards the channel bend that is present between Stations 4+600 and 4+820. The Alders shown on the bank (see arrow) shows the location of the previously constructed road elevation.

The construction of a road section along the north bank of Bitter Creek will reduce channel widths and produce a loss of available flow area in the order of 30% along the channel bend. This displacement of the channel will trigger a response whereby the river will likely have to redevelop its channel thalweg along the channel bed. Local erosion and scour of the channel bed and banks are also expected to increase along the channel perimeters of both channel bends. In addition, the loss of flow area will produce elevated flood water levels and superelevation effects as surface water volumes are concentrated through the alternating sequence of channel bends.

Figure 4-4 Looking along the downstream section of the channel bend's left bank between Stations 4+600 and 4+820

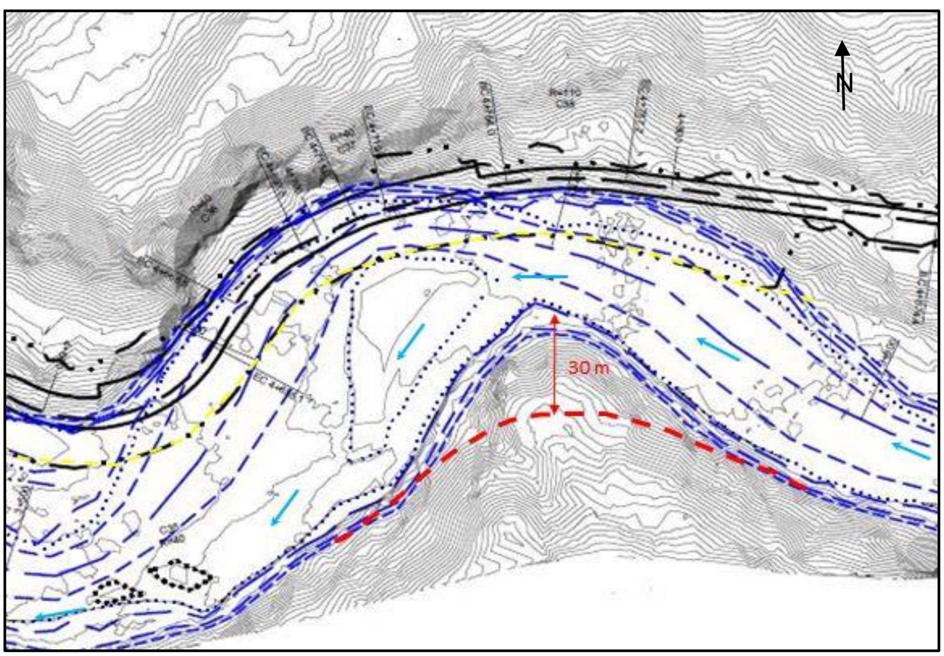

Figure 4-5 A 30m setback distance shown along the left bank of Bitter Creek As a potential bend realignment section between Stations 4+600 to 4+820. Note that the red dashed line represents the top of the cutslope.

To mitigate the loss of available channel area along the outside channel bend, the effect of shifting the inside channel bend back into the sideslopes along the left bank was assessed on an iterative basis. The boundary of the channel's left bank was setback so that it was consistent with the channel bend's natural turning radius (Figure 4.5).

The effect of applying a setback distance back from the inside bend's existing bank edge was assessed using the design 1:200 year design flood. The setback distance from the bank edge was increased until the amount of the flow area would be effectively recovered, and the water depths and surface elevations would be reduced between Station 4+600 and 4+820 m.

The results indicate that at a setback distance of 30 m from inside bend's bank edge, the effect of increasing the channel width was to reduce the estimated mean surface water elevations for the 1:200 year design flood to the point that the water elevations were consistent with the existing channel and road conditions through the alternating channel bends (Table 4-4).

Table 4-4 Estimated water elevations for Bitter Creek under varying channel bank conditions between Stations 4+600 and 4+820 during a 1:200 year flood discharge event

Station (m)	Existing Conditions (with Existing Road) (m)	With Redesigned Road in-place (m)	With Redesigned Road & 30 m setback in-place (m)
4820	193.6	194.7	193.5
4810	193.4	194.6	193.3
4800	193.3	194.5	192.1
4790	193.2	194.3	192.4
4780	193.0	194.3	192.4
4760	192.1	192.7	192.3
4750	192.4	193.1	192.3
4740	192.0	192.4	192.3
4730	192.1	192.7	192.2
4720	192.0	192.6	191.9
4710	191.0	191.3	190.9
4700	190.5	191.2	190.5

Station (m)	Existing Conditions (with Existing Road) (m)	With Redesigned Road in-place (m)	With Redesigned Road & 30 m setback in-place (m)
4690	190.3	191.3	189.7
4680	189.6	190.1	189.5
4670	189.2	189.6	189.0
4660	188.8	189.8	188.9
4650	188.7	188.7	189.0
4640	188.4	188.9	188.1
4630	188.4	188.1	188.0
4620	187.6	187.9	187.3
4610	187.8	188.0	187.3
4600	187.6	187.9	187.3

5 Conclusions and Recommendations

The completed Bitter Creek hydrotechnical assessment has provided estimates of the mean surface water elevations and hydraulic geometry conditions during specified flood discharge events. The assessment evaluated both the channel and the existing road in its current condition within the project site. The new road sections (as per the new geometric design being developed by Onsite) were also evaluated to determine if they will be compatible with the river's channel's and estimated water elevations during the flood events.

Based on the results, it is concluded that the redeveloped road sections that will be adjacent to lower Bitter Creek will be compatible with the river if constructed to the appropriate design elevations and the outside channel banks are protected with suitable erosion-resistant bank materials. For the section of Bitter Creek that is confined by the alternating sequence of channel bends between Stations 4+600 and 4+820, the results from an iterative assessment demonstrate that the effect of constructing a road section along the north bank of Bitter Creek can be mitigated by applying a setback distance back from the left bank to increase the channel width through the channel bends.

The following recommendations are put forward for your consideration

1. Construction of any road sections that will either encroach upon or be within the channel's flow area along lower Bitter Creek should be undertaken during low flow periods.

2. Where necessary, channel isolation and/or flow diversions should be implemented at active in-channel construction areas to prevent any disturbed surficial sediments from being eroded and transported downstream by surface water flows.

3. Where scour protection is required along the base of the riprap slopes along the outside of channel bends, a rock apron should be constructed so that it is keyed in a minimum depth of 1.5 m below the existing surface of the channel bed. The rock apron should support the base of the constructed riprap bank, and extend out a minimum of 3.0 m out from the base of the constructed riprap slope. During construction, the rock apron dimensions may vary due to changing channel bed material conditions.

4. A minimum Flood Construction Level (FCL) of 2.5 m above the estimated 1:200-year flood elevation should be applied to road sections that will be constructed within or adjacent to river channel bends within the project site. The FCL incorporates the hydraulic effects of superelevation and freeboard requirements for the design discharge events.

6 Closure

This report has been prepared based on and limited by the available information, as well as the related interpretation and conditions available at the time of completion of the assessment as referenced throughout the report. It has been prepared in accordance with generally accepted hydrotechnical engineering practices. No other warranty is provided. **Integrated Watersheds** accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

Respectfully submitted by;

<Original signed by>

Integrated Watersheds
R.W. (Bob) Askin, M.Sc., P.Geo, P.Eng.
(APEGBC Registration No. 18441)

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Appendix A - Bitter Creek Hydrotechnical Field Inspection Report

TO Michael Foster, P. Eng., Onsite Engineering Ltd.

FROM Bob Askin, M.Sc., P.Geo., P.Eng. FILE 20170601 DATE July 13, 2017

COPIES TO

SUBJECT **Bitter Creek: Hydrotechnical Field Inspection Report**

1. Introduction

A hydrotechnical field inspection of Bitter Creek was completed with you and Andrew Brabandt from June 12 to June 14, 2017. Travel to the field area was by helicopter from Stewart, BC to the Bitter Creek Watershed. Brief aerial overviews of the watershed's lower and upper channel sections of Bitter Creek up to the Bromley Glacier were also carried out on the afternoons of June 12th and June 13th respectively.

The purpose of the field work was to inspect and characterize the channel geomorphic conditions that are present within the vicinity of the resource road that will be redeveloped along the north side of Bitter Creek between Road L-Stations 5+500 and 2+200. Potential fish habitat compensation areas were also identified during the inspection period. The hydrotechnical information is to be incorporated into the planned hydrologic and hydraulic modeling of Bitter Creek.

Orthophoto-based topographic maps of Bitter Creek and its confining hillslopes were provided by Onsite Engineering Ltd. (OEL). The proposed layout of the resource road was superimposed onto the maps and the planned road stations was used for geographic reference purposes during the inspection period.

This report summarizes the observations made from the completion of the inspections of the Bitter Creek channel reaches. In this report, the left and right sides of the stream channels are referenced as if one is facing in a downstream direction.

Loation figures and representative photographs of the inspected Bitter Creek channel sections are provided in Appendix A.

2. Inspection Results

The inspection work was carried out under variable spring weather conditions that ranged from cloudy and drizzly to brief sunny intervals. During the three day period, low-to-moderate flow discharge conditions were present along Bitter Creek. Estimated water velocities ranged from 1 m/s to over 2 m/sec in places. Moderate-to-high sediment concentrations and turbidity levels were prevalent. This resulted in water visibility conditions that varied from murky to non-transparent conditions along Bitter Creek. Water temperatures were generally cold and varied between 5 ^{o}C and 10 ^{o}C.

The channel inspection work along Bitter Creek was completed in a downstream direction between Road L-Stations 5+500 and 2+200. The channel was inspected from Stations 5+500 and 4+200 on June 13, 2014. On June 14th, the lower 2,000 m of channel was inspected down to Station 2+200 (**Appendix A, Figures 1 and 2**).

Both sides of the main channel, as well as the adjacent bank and hillslope sections were traversed. The representative composition and size distribution of the channel sediments was characterized by employing the Wolman-Miller sediment characterization procedure at several transects along the inspected sections of Bitter Creek.

A brief summary of the inspection results follows:

- Bitter Creek is a major drainage tributary to the Bear River. Its fluvial geomorphic setting features channel transitions that alternate between transport and depositional reaches along a relatively narrow valley floor (**Appendix A, Figures 1 and 2**).
- Bitter Creek is confined by mountainous hillslopes that are relatively steep and extend down to the valley floor. The lower elevation slopes are forested and covered with stands of coniferous trees (**Appendix A, Photos 1 to 12**).
- Sediment availability and transport downstream along Bitter Creek is significant. Large volumes of sediment are stored as in-channel deposits of large gravel bars, mid-channel island complexes and relatively large flood terraces that are present across the wider valley floor sections. Cluster-like deposits of large woody debris were also observed in several places along the channel banks, gravel bars and flood terraces (**Appendix A, Photos 2, 3, 6 and 8**).
- In places, deposits of colluvium and rock fall were observed at the base of valley hillslopes, as well as within and along the margins of the main channel. Coarse, non-cohesive gravels and sand-size sediments were also present at the outlets of some of the steep hillslope streams that drain down into Bitter Creek. Remnant deposits of snow were also observed in places along the margins of the main channel (**Appendix A, Photos 1, 3, 5, 6 and 9**).
- There is a general downstream progression in the observed channel patterns, and sediment depositional features. The channel patterns varied from relatively long irregular meanders to short straight channel sections. Entrenched channel bends were present where the valley width narrows and is controlled by bedrock outcrops (**Appendix A, Photos 2, 4, 5, 8 to 10**).
- Bitter Creek's channel's bed was hydraulically rough, and consisted of medium-to-coarse textured sands and gravels that were intermixed with cobbles and rock boulders in places. (**Appendix A, Photos 1, 3, 6, 8 and 10**).
- During the inspection period, the average water depth was estimated to be 0.9 m, with observed depths varying from 0.5 m to over 1.5 m in places. The channel's average wetted width was estimated to be 8 m, and ranged from 6 m to over 10 m along generally concave channel cross-sectional profiles (**Appendix A, Photos 1 to 12**).
- Longitudinally, the channel gradients varied from 0.8% to over 2.0% along observed runs and riffle sequences along Bitter Creek. No significant pools were present along the main channel. But some small pool-like backwater areas were noted in places

(with finer grain sand deposits) along and behind any accumulations of woody debris or boulder cluster areas along the shoreline (**Appendix A, Photos 1 to 12**).

- In sections where the width of the valley floor expands, the presence of side, point, diagonal and mid-channel gravel bar deposits were present. The thickness of the alluvial sediments was high and was estimated to be over 2 m on average (**Appendix A, Photos 1, 2, 8 and 10**).
- Several flood channels were observed to extend laterally across and downstream along the broader flood terraces. The cross-sectional profiles varied between convex-shaped surfaces, with shallow concave sections present across the flood channel areas (**Appendix A, Photos 3, 7, 11 and 12**).
- The flood terraces are generally located between Road Stations 5+400 and 5+100; Stations 4+500 and 4+100; Stations 3+300 and 2+900; as well as Stations 2+800 and 2+300. Potentially suitable fish habitat compensation areas were identified along a few of the flood terraces along lower Bitter Creek (**Appendix A, Figure 2, Photos 3, 7, 11 and 12).**
- The flood terraces were observed to be up to 80 m wide in places. The flood terraces generally follow and are present along the inside regions of the irregular channel meanders. The alluvial sediments tended to be better sorted and displayed a wider distribution of sand and smaller size gravels across the exposed depositional surfaces. (**Appendix A, Figure 2 and Photos 11 to 12**).
- Bank erosion and evidence of hydraulic scour processes were observed along straight bank sections and at channel bends where lateral channel migration was being resisted and controlled by bedrock outcrops. This was most evident along the channel section that features three entrenched bends between Road Stations 5+000 and 4+500 (**Appendix A, Figure 2 and Photos 4 to 6**).
- Between Stations 5+000 and 4+500, Bitter Creek is predominately a canyon- like transport reach that is confining and redirecting surface water flows downstream along the channel bends. In places, the exposed bank sections were undercut, oversteepened and exposed to high energy shear and hydraulic scour processes (**Appendix A, Photos 4 to 6**).

3. Conclusions and Recommendations

The hydrotechnical inspection of Bitter Creek was completed between Road L-Stations 5+500 and 2+200, where the fluvial geomorphic conditions were characterized for planned hydrologic and hydraulic modeling purposes. Based on the results and observations, it is concluded that Bitter Creek is a dynamic, high energy basin. The gravel bed channel is generally steep and hydraulically rough. Bitter Creek has the capacity to mobilize and transport large volumes of sediment and woody debris downstream during significant flow discharge events. The basin's geomorphic setting indicates a downstream progression of coarse and medium size bedload materials in the form of migrating alluvial gravel bars, as well as broader flood terraces that have developed across the valley floor. The location of the flood terraces areas are likely controlled by the entrenched channel bends where the width of the valley floor narrows and is constricted by outcropping bedrock.

Where the new resource road sections are planned to be either within the channel or encroach upon the outside channel bends (between Road L-Stations 4+850 to 4+000; L-

Stations 3+500 to 3+300; and L-Stations 2+300 to 2+100), it is recommended that the detailed hydrotechnical river engineering analysis be completed to determine the estimated energy and water elevations during 100-year and 200-year flood events. Current channel conditions and planned alterations to the channel's hydraulic geometry along the bends should be included into the river modeling analysis. From this, the estimated hydraulic scour depths and bank protection requirements will be identified in conjunction with the required flood freeboard levels. This information will assist in the final determination of the final design elevations for the road sections along the channel reaches.

The benefits of any channel improvements from adding training works (e.g. guidebanks and tapered rock weir) should also be properly evaluated. Related fluvial geomorphic affects on the downstream flood terraces, and their long term sediment storage capabilities should be incorporated into the analyses. This should be evaluated in conjunction with any planned development of fish habitat compensation channels along the flood terrace areas.

4. Closure

In closing, I trust this hydrotechnical inspection report of the channel reaches along lower Bitter Creek meets with your expectations for this preliminary phase of the project. Please contact me if you have any questions or concerns. Thank you.

<Original signed by>

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R.W.(Bob) Askin, M.Sc., P.Eng., P.Geo.
Integrated Watersheds

Appendix A

Figures and Representative Photographs along Lower Bitter Creek

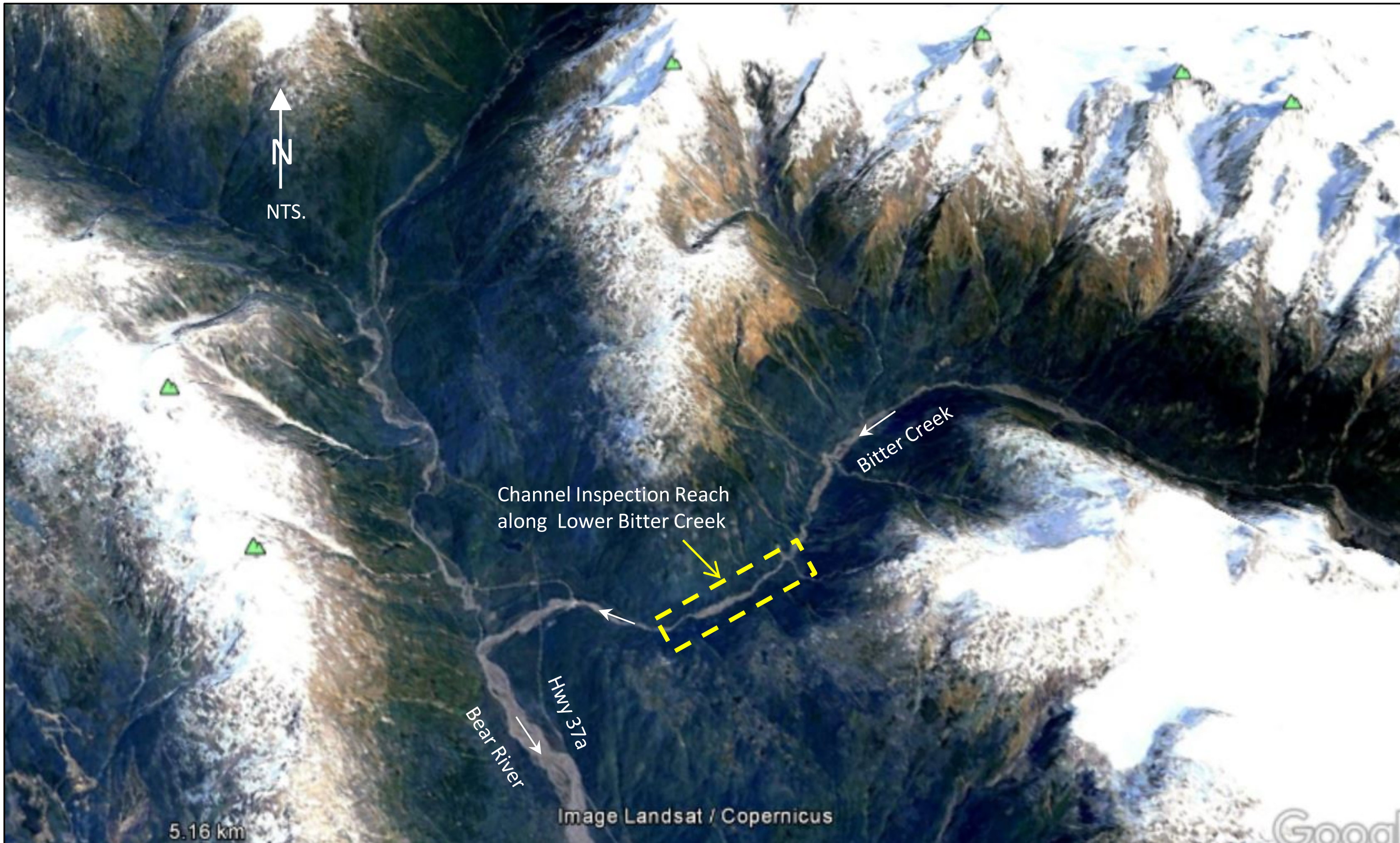

Figure 1: Location of Bitter Creek Watershed and Channel Inspection Reach

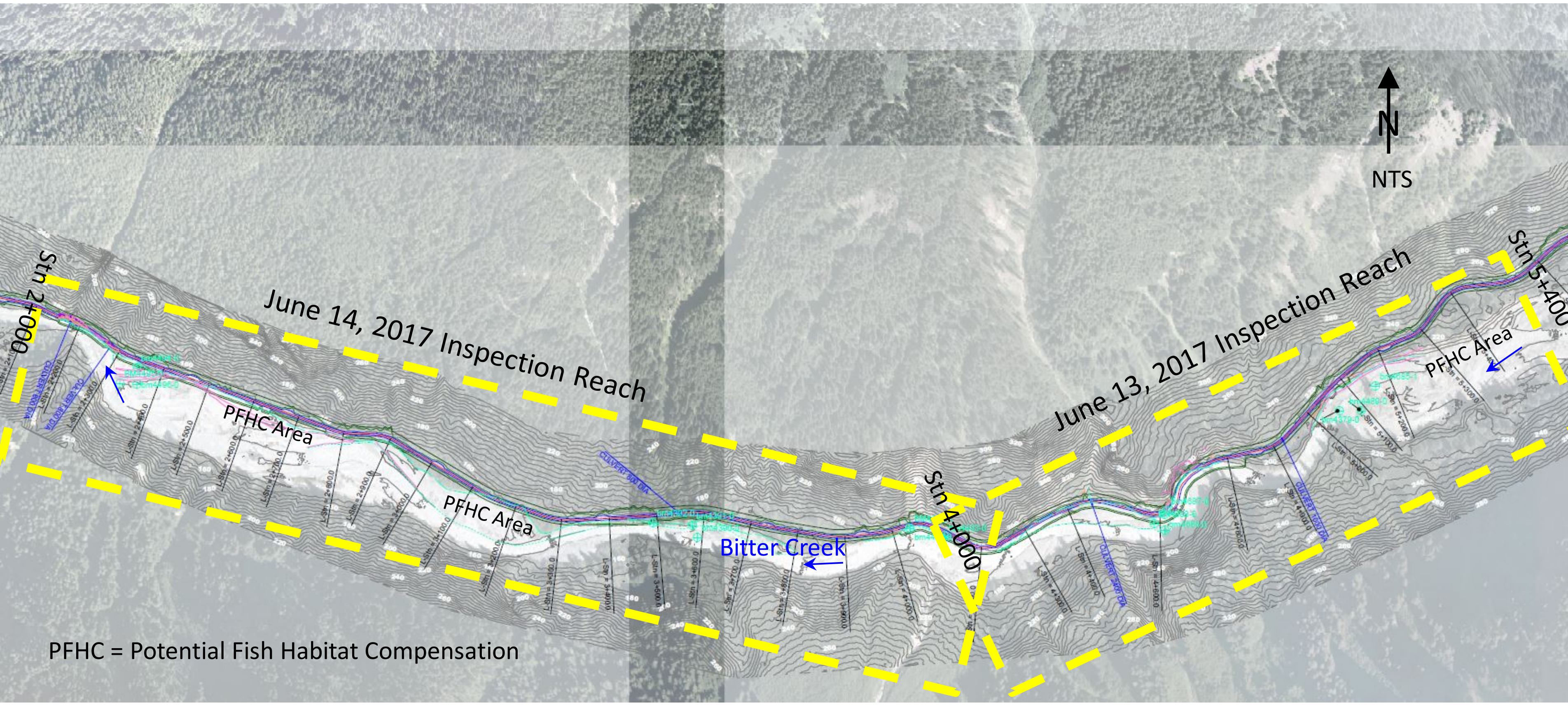

Figure 2: General position of channel inspection reaches along lower Bitter Creek on June 13 and June 14, 2017.

Lower Bitter Creek

Photo 1: Looking across Bitter Creek towards stream tributary outlet in the vicinity of Stn 5+600. June 13, 2017.

Photo 2: Looking upstream side, diagonal and mid-channel gravel bar deposits in the vicinity of Stn 5+350. June 13, 2017.

Photo 3: Looking downstream towards remnant flood channel and recent deposits of sediment & woody debris in the vicinity of Stn 5+200. June 13, 2017.

Photo 4: Looking downstream along left bank at existing bedrock outcrop that is deflecting flow across the channel in the vicinity of Stn 4+900. June 13, 2017.

<table>
<tr><th colspan="2">Lower Bitter Creek</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Photo 5: Looking upstream along bedrock controlled channel bend with eroding & over-steepened hillslopes in the vicinity of Stn 4+700. June 13, 2017</td><td>Photo 6: Looking upstream along left bank and steep partially undercut hillslopes in the vicinity of Stn 4+500. June 13, 2017.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Photo 7: Looking downstream at woody debris and flood terrace in the vicinity of Stn 4+300. June 14, 2017.</td><td>Photo 8: Looking upstream at side and mid-channel gravel bar deposits, with remnant snow deposits along the channel's left bank in the vicinity of Stn 4+100. June 14, 2017.</td></tr>
</table>

Lower Bitter Creek	
	
Photo 9: Looking upstream at gravel bar and woody debris deposits in the vicinity of Stn 3+800. June 14, 2017.	**Photo 10: Looking downstream along main channel & eroding bank section in the vicinity of Stn 3+100. June 14, 2017.**
	
Photo 11: Looking downstream along flood terrace at a remnant flood channel beside an old road section in the vicinity of Stn 2+700. June 14, 2017.	**Photo 12: Looking east along flood channel area that extends upstream in the vicinity of Stn 2+300. June 14, 2017.**

Appendix B - Bitter Creek Flood Frequency Analysis Report

TO Michael Foster, P. Eng., Onsite Engineering Ltd.

FROM RW (Bob) Askin, M.Sc., P.Geo., P.Eng. FILE 20170601 DATE August 23, 2017

COPIES TO

SUBJECT **Bitter Creek: Flood Frequency Analysis**

1. Introduction

This technical report provides the results of a flood frequency analysis that was completed for a project site within the lower Bitter Creek Watershed (Figure 1).

The purpose of the flood frequency analysis was to estimate the peak design flood from the basin area upstream of the Radio Creek tributary. The design flood is to be based on a corresponding upper flow magnitude associated with a 200-year return period. The peak design flood results are to be incorporated into the hydraulic channel analysis and flood assessment along lower Bitter Creek.

The 200-year design flood criteria are consistent with the BC Ministry of Transportation and Infrastructure's *Hydrotechnical Engineering Design Guidelines* (MOTI 2013), as well as the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) *Professional Practice Guidelines - Legislated Flood Assessments in BC (*APEGBC 2012*).* The BC Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) commissioned APEGBC to complete the BC Flood Assessment Guidelines.

2. Background

Bitter Creek is a steep and glacierized watershed that drains into Bear River. Bitter Creek is a gravel bed river that extends upvalley to its mountainous headwater region where Bromley Glacier is located. The Bromley Glacier is an outlet glacier that has been documented to be retreating upvalley to the Cambria Ice field for many years. It has the potential to produce glacial lake outburst events similar to what has been documented in the Pacific Northwest. The Bromley Glacier is a significant source of surface water and sediment supply for Bitter Creek (Figure 1).

An abandoned access road interconnects with BC Highway 37A immediately north of the Bitter Creek bridge crossing. The access road extends east of Highway 37A and is positioned on the north side of Bitter Creek. The existing resource road was designed and constructed during the mid-1990's. The project site is downstream of Roosevelt Creek. In this region of the watershed, Bitter Creek is incised and confined by steep-sided hillslopes. At this location, approximately 3 km of the access road is adjacent to lower Bitter Creek. Since construction, some road sections that are adjacent to the river have been significantly eroded and affected by channel migration and flood-related hydrogeomorphic processes. As a result, the damaged sections of the access road are being redesigned and upgraded as part of the redevelopment of the access road for the proposed Red Mountain Gold Mine Project.

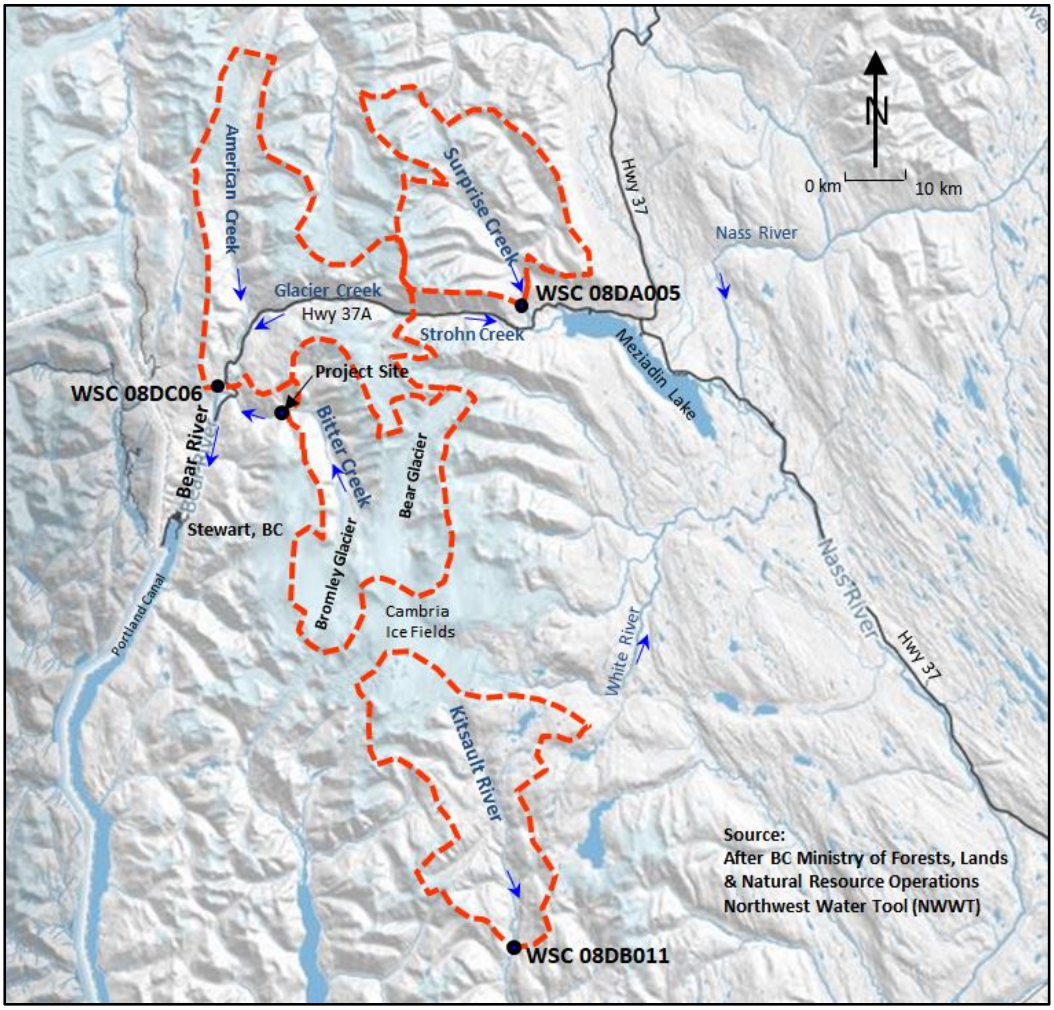

Figure 1. Regional location map showing the relative position of the project site along Bitter Creek, the watersheds and WSC hydrometric stations that were used in the FFA analysis.

The following hydrology-related investigations for Bitter Creek were reviewed:

- McElhanney Engineering Services (MES). 1993. Red Mountain Mining Property Access Route Hydrology Study. Prepared for Lac Minerals Ltd. April 1993.
- Northwest Hydraulic Consultants (NHC). 2012. Highway 37A Bitter Creek Bridge. Hydraulic assessment and design parameters for bridge replacement. Prepared for MOTI by MMM Group, Vancouver BC. June 2012.
- Kerr Wood Leidal (KWL). 2017. Bitter Creek Hydrology Assessment. Prepared for Bridge Power Hydro Developments Ltd. February 2017.

MES's1993 hydrology study for Bitter Creek was based on a single station frequency analysis using available data from Station 08DC006 (*Bear River above*

Bitter Creek). The 100-year design discharge for Bitter Creek was estimated to be 343 m^3/s.

NHC's 2012 hydraulic assessment of Bitter Creek was completed in response to a flood event that damaged BC Highway 37A Bridge in September 2011.NHC conducted a regional flood hydrology analysis and established the hydraulic design parameters for the replacement bridge. NHC estimated the 100-year and 200-year design discharges to be 472 m^3/s and 589 m^3/s respectively. To account for the uncertainty and risk associated with potential increases in flood elevation due to climate change, glacial outbursts floods, as well as sediment and debris aggradation, NHC recommended a 15% increase be appled to the 200-year design discharge.

In 2017, KWL completed a hydrology assessment for the proposed Bitter Creek Hydroelectric Project. The focus of the assessment was on developing the baseline hydrology for Bitter Creek for potential hydropower generation purposes. The hydrologic characterization of Bitter Creek was constructed by generating a long-term synthetic data series using developed regression relationships between short-term (2014 to 2016) hydrometric data collected in Bitter Creek and long-term hydrometric data from USGS Salmon River hydrometric station in Alaska, USA.

3. Methodology

No Environment Canada hydrometric station exists within the Bitter Creek Watershed. Thus, a peak flow regional flood frequency analysis was undertaken to estimate the 200-year design flood for the project area along lower Bitter Creek. The analysis was completed using a three-step process.

Step 1 involved reviewing all publically available data from Environment Canada's Water Survey of Canada (WSC) hydrometric stations (both active and inactive) that are located within the region (Figure 1). Using an assessment criteria, each station was qualitatively screened to determine its utility for estimating peak flows in Bitter Creek.

Similar to the other assessment reports (Northwest Hydraulic Consultants 2012 and the Kerr Wood Leidal 2017), the assessment criteria used in the review and selection of WSC stations for the flood frequency analysis was:

- Consider only WSC hydrometric station within the region located within or near to BC Environment's Hydrologic Zone 10 (i.e., the BC North Coast);
- Select inactive and currently active hydrometric stations within the region that have similar size drainage areas. Each station is to have greater than 10 years of recorded peak flow data from natural, non-regulated flow discharge regimes;
- The selected hydrometric stations are to be geographically located within a reasonable distance of each other so that Hydrometeorological processes can be assumed to be similar;
- For each selected hydrometric station, the area of snow accumulation and glaciers within the watershed should be equivalent

Once the representative WSC hydrometric stations were determined, Step 2 involved the completion of the flood frequency analysis. The analysis was based on recorded maximum instantaneous peak discharges (Q_{xi}), at each of the selected WSC stations.

Four different frequency distributions (Pearson Type III, Log Pearson Type III, 3-parameter Log Normal, and Gumbel) were fitted to the sample flow data. The general procedure for estimating individual return periods involved visually inspecting each probability distribution for anomalies and outliers, as well as assessing and comparing the statistical dispersion parameters (coefficients of variation, skewness and kurtosis) for each distribution. Any poor data fits were excluded.

In order to provide hydrologic context in the estimation of the design discharge event for lower Bitter Creek, a range of maximum instantaneous peak flows were estimated. That is, the 1 in 2-year (Q_{2i}), the 1 in 10-year (Q_{10i}), the 1 in 50-year (Q_{50i}), the 1 in 100-year (Q_{100i}), and the 1 in 200-year (Q_{200i}) return periods were estimated for each WSC station.

Step 3 involved an adjustment to the peak flow results to account for the regional variation in drainage area relative to Bitter Creek. The peak flow estimates for each WSC station were adjusted by an area ratio because basin size is the dominant determinant of flow discharge magnitudes. Regional analyses in British Columbia (Church 1997; Eaton et al., 2002) have demonstrated that for ungauged basins, the following power relationship can be used for adjusting flow discharge estimates as a function of drainage area:

$$Q_{xi} = WSC_{StnPeak} * (Area_{Bitter\ Ck} / Area_{WSC\ Stn})^{0.75}$$

where: $WSC_{StnPeak}$ = Peak discharge estimate from selected WSC Station

4. Results and Observations

From the regional review, three WSC hydrometric stations satisfied the selection criteria for completing the peak flood frequency analysis for Bitter Creek. The selected WSC stations and details are listed in Table 3.1.

WSC Hydrometric Station Name	Station Status	Drainage Area (km²)	Period of Record	Q_{xi} Record Length (years)
Bear River above Bitter Creek	Inactive	350	1967-1999	30
Surprise Creek near the Mouth	Active	221	1967-2014	43
Kitsault River above Klayduc Creek	Inactive	242	1981-1995	14

Table 3.1: WSC hydrometric stations used in the regional peak flow (Q_{xi}) analysis for Bitter Creek

All three watersheds are within close proximity to Bitter Creek, with Bear River and Surprise Creek basins located to the west and north of Bitter Creek. Kitsault River is located immediately south of the headwaters of Bitter Creek within the Cambria Ice Field. The Kitsault station was included because of its relative location, its basin size and its drainage connectivity to the upper Cambria Ice Fields (Appendix A, Figure A1).

Station Name (WSC Code)	Drainage Area (km²)	Max. Elevation (m)	Mean Elevation (m)	Min. Elevation (m)	*Basin Aspect (direction)*	*Glacier / Snow %*	*Barren Rock %*
Bear River (08DC006)	350	2,071	1,223	94	W-SW	44	30
Surprise Creek (08DA005)	221	2,014	1,272	301	S-SE	34	30
Kitsault River (08DB011)	242	1,917	967	87	S-SE	20	21
Bitter Creek	247	2,484	1,559	248	SE-NW	69	18

Table 3.2. Comparison of the basin characteristics of the selected regional WSC hydrometric stations with Bitter Creek (see Notes 1 - 3).

Notes:
1. *Source of physiographic attributes for each watershed listed is the BC Ministry of Forests, Lands and Natural Resource Operations' North West Water Tool (NWWT). 2017.*
2. *Basin aspect is generalized in terms of dominant and co-dominant compass directions.*
3. *The percent differences between barren rock and glacier-snow cover are only relative values and may not be accurate due to changing climatic conditions.*

Comparison of the physiographic differences between the four regional watersheds in Table 3.2 shows that the basins have equivalent drainage areas and topographic relief. While the basin aspect varies between the mountainous watersheds, Bitter Creek is the highest basin, with the greatest topographic relief. It also has the most amount of snow and ice cover, with over twice amount of surface area coverage of snow and ice than other watersheds. This reflects the presence and influence of the Cambria Ice Field and the Bromley Glacier.

The results of the peak flow regional flood frequency analysis indicated that each probability distribution fitted the sample data reasonably well. The log Pearson Type III distribution was selected for estimating the maximum instantaneous peak flows (Q_{xi}) because the distribution consistently showed the least statistical dispersion.

The estimated peak flow results in Table 3.3 show a distinction at the moderate-to-high flow magnitudes between the Kitsault WSC station and the other two stations. In comparison to the Bear River and Surprise Creek watersheds, this is likely to due to the physical differences in basin and channel conditions, as well as reduced percentages of barren rock, snow and glacier cover in the Kitsault River basin. The variation in the periods of record between the WSC Stations suggests that the peak flows from Kisault River may also represent different hydroclimatic conditions when compared to the estimated discharges from the Bear and Surprise WSC stations.

Peak Flow (Q_{xi}) Return Period	Bear River (WSC 08DC006) (m^3/sec)	Surprise Creek (WSC 08DA005) (m^3/sec)	Kitsault River (WSC 08DB011) (m^3/sec)
Q_2	165	110	163
Q_5	217	157	301
Q_{10}	248	190	407
Q_{20}	276	225	518
Q_{50}	311	272	672
Q_{100}	336	310	794
Q_{200}	359	351	922

Table 3.3 Estimated peak flow (Q_{xi}) results for each WSC hydrometric station based on the log Pearson Type III frequency probability distribution

The resulting peak flow estimates for each WSC station are presented following adjustment by the area ratio relationship (Table 3.4).

The results show a modest reduction in the discharge magnitudes when corrected for regional basin area differences. In addition, the calculated mean peak flows for each recurrence interval lowers the chance of introducing bias because of the range in the peak flow estimates. But the highlighted differences remain intact.

Maximum Instantaneous Peak Flow (Q_{xi}) Return Period	Bear River (WSC 08DC006) (m³/sec)	Surprise Creek (WSC 08DA005) (m³/sec)	Kitsault River (WSC 08DB011) (m³/sec)	*Bitter Creek Mean Q_{xi}* (m³/sec)
Q_2	116	117	144	127
Q_5	153	176	289	206
Q_{10}	176	218	409	268
Q_{20}	197	259	533	330
Q_{50}	222	315	701	413
Q_{100}	240	357	831	476
Q_{200}	257	348	961	522

Table 3.4: Estimated mean peak flows (Q_{xi}) for Bitter Creek *adjusted by a basin area scaling ratio, and regional mean peak flows (Q_{xi})*

4.0 Uncertainties and Limitations

The results from the Bitter Creek regional flood frequency analysis consider only surface water discharge events. They do not necessarily account for the complex hydrologic responses from the regional hydrometric stations that were considered. Differences in peak flow responses will be affected by varying channel and sediment transport conditions, specific hydrologic hazards, as well as changing climate conditions within the region. Each uncertainty is briefly discussed.

While all the regional watersheds have the potential for extreme discharge events, glacial outburst floods associated with the accelerated melt and the retreat of glaciers has not been accounted for in the flood frequency analysis. This limitation may likely be a significant flood discharge factor for Bitter Creek due to the presence and retreat of the Bromley Glacier within the upper watershed area. Other uncertainties are associated with any temporary channel blockages that may occur from snow avalanches or slope failures from along mountainous valley hillslopes of Bitter Creek.

Bitter Creek is a gravel bed river that contains large volumes of coarse-grained sediments and woody debris. As the Bromley Glacier retreats, loose, unconsolidated sediments and rocks are produced. These materials are entrained and transported downstream by melt water as the glacier continues to retreat upvalley. As a result, significant amounts of sediment are available for hydraulic entrainment and transport during significant flood discharge events. Uncertainty exists on what the appropriate sediment transport rate would likely be for Bitter Creek. It has not been accounted for in the flood frequency analysis. However, with continued deglaciation and erosion, more sediment will likely be produced and supplied to the channels downstream. Channel bed aggradation and degradation processes will also continue to occur as sediment is transported and reworked during flood discharge events. In addition, significant sediment accumulation and storage along the braided channel sections and flood terraces along Bitter Creek is expected to continue.

Climate change related scenarios provide a level of uncertainty that if occurred could result in larger and more frequent peak flow events occurring in Bitter Creek. Based on current global climate change projections (IPCC 2014), the regional climate may be warmer and somewhat wetter overall. Seasonally, the distribution of precipitation may change. For example, that portion of the precipitation that occurs as snow in the present-day climate may fall as rain in the future. Further, the Pacific Climate Impacts Consortium (PCIC) forecasts that mean annual temperatures in BC will be on average 1.4°C to 3.7°C higher by mid-century (2050s). The PCIC assessments also indicate that the majority of BC will likely receive more precipitation (up to 26 percent more in some locations) during the winter period. In summer, northern BC may be up to 15 percent wetter (after APEGBC 2017).

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5.0 Summary

A flood frequency analysis was undertaken to estimate the peak design flood along lower Bitter Creek where the resource access road for the proposed Red Mountain Gold Mine Project is being upgraded. The design floods associated with 100-year and 200-year return periods were estimated to be 476 m^3/s and 522 m^3/s respectively. These flow magnitudes are to be utilized in the hydraulic channel analysis to convey the design flood (plus freeboard) along lower Bitter Creek.

To account for the inherent risk and uncertainty associated with potential alterations of peak design floods due to the occurrence of climate change, glacial outburst floods and sediment transport impacts, it is recommended that the 100-year and 200-year design flood magnitudes be increased by 20% to 571 m^3/s and 626 m^3/s respectively. These elevated flow magnitudes should be used in the determination of appropriate flood construction levels, as well as the hydraulic scour and bank erosion protection requirements for the reconstructed resource road sections along lower Bitter Creek.

<Original signed by>

R.W.(Bob) Askin, M.Sc., P.Eng., P.Geo.
Integrated Watersheds

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Appendix C - Bitter Creek Estimated Surface Water Elevations

Estimated Surface Water Elevations along lower Bitter Creek

Bitter Creek: With Existing Channel and Road Conditions

Station (m)	2 yr Ws. Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
5000	195.86	197.31	197.5
4990	195.74	197.47	197.6
4980	195.27	197.00	197.2
4970	195.17	197.13	197.3
4960	194.76	196.98	197.2
4950	194.59	196.16	196.3
4940	193.96	195.60	195.8
4930	193.70	195.86	196.1
4920	193.45	195.68	195.9
4910	193.35	195.39	195.6
4900	192.71	195.48	195.7
4890	192.67	195.34	195.5
4880	191.56	194.52	194.7
4870	191.41	194.03	194.2
4860	191.23	193.57	193.8
4850	191.04	193.76	194.0
4840	190.87	193.57	193.8
4830	190.70	193.27	193.5
4820	190.62	193.34	193.6
4810	190.24	193.18	193.4
4800	190.01	193.05	193.3
4790	189.90	192.99	193.2
4780	189.59	192.80	193.0
4770	189.15	191.89	192.1
4760	188.92	192.20	192.4
4750	188.57	191.74	192.0
4740	188.30	191.90	192.1
4730	188.22	191.73	192.0
4720	187.71	190.81	191.0
4710	187.27	190.29	190.5
4700	186.82	190.14	190.3
4690	186.43	189.43	189.6
4680	186.14	189.05	189.2
4670	185.83	188.69	188.8
4660	185.52	188.56	188.7
4650	184.96	188.23	188.4
4640	184.21	188.21	188.4
4630	183.66	187.46	187.6

Bitter Creek: With Existing Channel and Road Conditions (cont'd)

Station (m)	2 yr Ws. Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
4620	183.10	187.65	187.8
4610	182.73	187.46	187.6
4600	182.74	186.09	186.3
4590	182.57	185.50	185.6
4580	182.13	185.21	185.4
4570	181.79	184.50	184.6
4560	181.39	184.52	184.7
4550	181.31	184.24	184.4
4540	181.23	184.26	184.4
4530	181.16	183.65	183.8
4520	181.13	183.42	183.6
4510	180.93	183.02	183.2
4500	180.61	183.11	183.3
4490	180.44	182.93	183.1
4480	180.29	182.96	183.1
4470	180.12	182.83	183.0
4460	179.88	182.78	182.9
4450	179.70	182.24	182.4
4440	179.52	181.83	181.9
4420	179.39	181.55	181.7
4400	179.11	181.61	181.7
4390	178.85	181.12	181.2
4380	178.63	180.87	181.0
4370	178.52	180.41	180.5
4360	178.44	180.03	180.2
4350	178.07	180.16	180.3
4340	177.93	180.03	180.2
4330	177.72	179.73	179.9
4320	177.63	179.77	179.9
4310	176.97	179.42	179.6
4300	176.55	179.46	179.6
4290	176.05	179.31	179.4
4280	175.66	178.87	179.1
4270	175.12	179.03	179.2
4260	174.81	178.92	179.1
4250	174.03	178.77	178.9
4240	173.55	178.08	178.2
4230	173.46	177.08	177.2
4220	173.41	177.01	177.2
4210	173.38	176.93	177.1

Bitter Creek: With Existing Channel and Road Conditions (cont'd)

Station (m)	2 yr Ws. Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
4200	173.36	176.83	177.0
4190	173.20	176.69	176.8
4180	172.78	176.10	176.2
4170	172.91	175.36	175.5
4160	172.86	175.27	175.4
4150	172.80	175.16	175.3
4140	172.77	175.01	175.1
4130	172.66	174.49	174.6
4120	172.59	174.45	174.6
4110	172.53	174.36	174.6
4100	172.48	174.24	174.4
4090	172.41	174.08	174.3
4080	172.12	173.83	174.1
4070	171.67	173.95	174.2
4060	171.64	173.88	174.1
4050	171.59	173.79	174.1
4040	171.27	173.70	174.0
4030	171.03	173.57	173.8
4020	170.85	173.49	173.7
4010	170.74	173.40	173.6
4000	170.65	173.29	173.51
3990	170.59	173.17	173.38
3980	170.39	173.01	173.22
3970	170.08	172.10	172.28
3960	169.70	171.14	171.31
3950	168.87	171.08	171.26
3940	168.74	171.02	171.20
3930	168.57	170.96	171.13
3920	168.51	170.89	171.06
3910	168.45	170.81	170.98
3900	168.33	170.72	170.89
3850	166.98	168.38	168.51
3800	165.43	166.91	167.05
3750	164.50	165.86	166.01
3700	163.74	164.99	165.12
3680	163.34	165.04	165.2
3660	162.94	164.25	164.38
3640	162.57	163.80	163.93
3620	162.14	163.46	163.58
3600	161.72	163.29	163.49

Bitter Creek: With Existing Channel and Road Conditions (cont'd)

Station (m)	2 yr Ws. Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
3580	161.20	163.08	163.28
3560	160.77	162.72	162.92
3540	160.55	162.28	162.36
3520	160.26	161.93	162.07
3500	159.89	161.69	161.84
3480	159.53	161.22	161.34
3460	159.32	160.78	160.9
3440	159.13	160.54	160.65
3420	158.49	160.31	160.42
3400	158.31	159.83	159.92
3380	158.15	159.59	159.69
3360	157.63	159.15	159.25
3340	157.36	158.66	158.76
3320	157.17	158.56	158.67
3300	156.87	158.18	158.26
3280	156.41	157.76	157.9
3260	156.20	157.35	157.45
3240	155.46	156.88	157.05
3220	154.96	156.15	156.26
3200	154.90	156.16	156.26
3150	154.29	155.27	155.36
3100	152.48	153.57	153.69
3050	151.35	152.82	152.89
3000	150.54	151.92	152.05
2980	150.29	151.56	151.65
2960	150.04	151.12	151.18
2940	149.61	150.73	150.81
2920	149.37	150.65	150.74
2900	149.08	150.30	150.39
2880	148.82	149.94	150.02
2860	148.45	149.60	149.7
2840	148.30	149.38	149.48
2820	148.25	149.35	149.44
2800	148.01	149.01	149.1
2750	147.36	148.35	148.44
2700	146.32	147.64	147.81
2650	145.69	146.74	146.8
2600	144.32	145.43	145.52
2550	143.41	144.73	144.83
2500	142.77	143.96	144.04

Bitter Creek: With Existing Channel and Road Conditions (cont'd)

Station (m)	2 yr Ws. Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
2450	141.49	142.81	142.91
2400	140.85	142.28	142.4
2380	140.47	141.60	141.68
2360	139.83	141.04	141.28
2340	139.32	141.00	141.24
2320	138.56	140.66	140.93
2300	138.08	140.44	140.69
2280	137.82	140.17	140.41
2260	137.57	140.15	140.4
2240	137.46	140.08	140.32
2220	137.24	139.59	139.8
2200	136.91	138.73	138.93
2180	136.63	138.57	138.69
2160	136.66	138.07	138.2
2140	135.96	137.71	137.82
2120	135.24	137.24	137.44
2100	135.12	136.86	136.97
2080	134.80	136.51	136.63
2060	134.68	136.10	136.14
2040	134.46	135.87	135.99
2020	133.93	135.83	136.03
2000	133.16	135.08	135.24

Estimated Surface Water Elevations along lower Bitter Creek

Bitter Creek: Existing Channel with Redesigned Road Geometry

Station (m)	2 yr Ws Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
5000	195.78	197.31	197.5
4990	195.74	197.47	197.6
4980	195.27	197.00	197.2
4970	195.17	197.13	197.3
4960	195.07	196.98	197.2
4950	194.59	196.16	196.3
4940	193.96	195.60	195.8
4930	193.64	195.86	196.1
4920	193.53	195.68	195.9
4910	193.35	195.39	195.6
4900	193.35	195.48	195.7
4890	193.24	195.34	195.5
4880	192.71	194.52	194.7
4870	192.05	194.52	194.8
4860	191.56	194.43	194.7
4850	191.66	194.50	194.8
4840	191.52	194.44	194.8
4830	191.13	194.37	194.7
4820	191.15	194.40	194.7
4810	191.14	194.32	194.6
4800	191.03	194.15	194.5
4790	191.00	194.01	194.3
4780	190.93	193.97	194.3
4770	190.25	192.50	192.7
4760	190.33	192.84	193.1
4750	189.74	192.16	192.4
4740	189.72	192.42	192.7
4730	189.62	192.32	192.6
4720	189.01	191.10	191.3
4710	188.87	191.00	191.2
4700	188.85	191.06	191.3
4690	188.33	189.96	190.1
4680	188.05	189.50	189.6
4670	187.53	189.57	189.8
4660	186.98	188.56	188.7
4650	186.75	188.68	188.9
4640	186.70	187.91	188.1
4630	186.30	187.73	187.9
4620	186.04	187.82	188.0

Bitter Creek: Existing Channel with Redesigned Road Geometry (cont'd)

Station (m)	2 yr Ws Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
4610	185.94	187.76	187.9
4600	184.65	186.33	186.5
4590	184.27	185.68	185.8
4580	183.68	185.44	185.6
4570	183.18	184.67	184.8
4560	182.87	184.48	184.6
4550	182.58	184.25	184.4
4540	182.56	184.23	184.4
4530	182.13	183.64	183.8
4520	181.65	183.48	183.6
4510	181.37	183.17	183.3
4500	181.39	183.17	183.3
4490	181.27	182.96	183.1
4480	181.25	183.04	183.2
4470	181.18	182.94	183.1
4460	181.10	182.82	183.0
4450	180.58	182.30	182.4
4440	180.29	181.89	182.0
4420	179.88	181.60	181.8
4400	179.94	181.67	181.8
4390	179.52	181.16	181.3
4380	179.32	180.86	181.0
4370	178.91	180.41	180.5
4360	178.63	180.03	180.2
4350	178.72	180.22	180.4
4340	178.63	180.07	180.2
4330	178.38	179.80	179.9
4320	178.36	179.84	180.0
4310	177.99	179.65	179.8
4300	178.05	179.60	179.8
4290	177.95	179.45	179.6
4280	177.52	178.80	178.9
4270	177.22	179.03	179.2
4260	177.15	178.94	179.1
4250	177.03	178.77	178.9
4240	176.55	178.10	178.2
4230	175.47	177.26	177.4
4220	175.39	177.10	177.2
4210	175.35	177.06	177.2
4200	175.26	176.89	177.0
4190	175.20	176.83	177.0

Bitter Creek: Existing Channel with Redesigned Road Geometry (cont'd)

Station (m)	2 yr Ws Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
4180	174.78	176.18	176.3
4170	173.91	175.35	175.5
4160	173.86	175.27	175.4
4150	173.80	175.16	175.3
4140	173.71	175.01	175.1
4130	173.36	174.49	174.6
4120	172.79	174.51	174.7
4110	172.73	174.40	174.6
4100	172.66	174.29	174.5
4090	172.56	174.14	174.4
4080	172.22	173.85	174.1
4070	171.96	173.99	174.2
4060	171.88	173.89	174.1
4050	171.79	173.81	174.1
4040	171.36	173.59	173.9
4030	171.13	173.52	173.7
4020	171.07	173.41	173.6
4010	171.04	173.39	173.6
4000	170.97	173.28	173.51
3990	170.89	173.17	173.38
3980	170.79	173.01	173.22
3970	170.24	172.10	172.28
3960	169.18	171.14	171.31
3950	169.14	171.08	171.26
3940	169.10	171.02	171.20
3930	169.06	170.96	171.13
3920	169.01	170.89	171.06
3910	168.95	170.81	170.98
3900	168.87	170.72	170.89
3850	166.98	168.38	168.51
3800	165.43	166.91	167.05
3750	164.50	165.86	166.01
3700	163.74	164.99	165.12
3680	163.34	165.04	165.20
3660	162.94	164.25	164.38
3640	162.57	163.80	163.93
3620	162.14	163.46	163.58
3600	161.72	163.29	163.49
3580	161.20	163.08	163.28
3560	160.77	162.72	162.92
3540	160.55	162.28	162.36

Bitter Creek: Existing Channel with Redesigned Road Geometry (cont'd)

Station (m)	2 yr Ws Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
3520	160.26	161.93	162.07
3500	160.07	161.69	161.84
3480	159.61	161.33	161.45
3460	159.40	160.89	161.02
3440	159.29	160.84	160.98
3420	158.61	160.41	160.52
3400	158.28	159.87	159.98
3380	158.15	159.59	159.69
3360	157.63	159.15	159.25
3340	157.36	158.66	158.76
3320	157.17	158.56	158.67
3300	156.87	158.18	158.26
3280	156.41	157.76	157.90
3260	156.20	157.35	157.45
3240	155.46	156.88	157.05
3220	154.96	156.15	156.26
3200	154.90	156.16	156.26
3150	154.29	155.27	155.36
3100	152.48	153.57	153.69
3050	151.35	152.82	152.89
3000	150.54	151.92	152.05
2980	150.29	151.56	151.65
2960	150.04	151.12	151.18
2940	149.61	150.73	150.81
2920	149.37	150.65	150.74
2900	149.08	150.30	150.39
2880	148.82	149.94	150.02
2860	148.45	149.60	149.70
2840	148.30	149.38	149.48
2820	148.25	149.35	149.44
2800	148.01	149.01	149.10
2750	147.36	148.35	148.44
2700	146.32	147.64	147.81
2650	145.69	146.74	146.80
2600	144.32	145.43	145.52
2550	143.41	144.73	144.83
2500	142.77	143.96	144.04
2450	141.49	142.81	142.91
2400	140.85	142.28	142.40
2380	140.47	141.60	141.68

Bitter Creek: Existing Channel with Redesigned Road Geometry (cont'd)

Station (m)	2 yr Ws Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
2360	139.83	141.04	141.28
2340	139.32	141.00	141.24
2320	138.56	140.66	140.93
2300	138.08	140.44	140.69
2280	137.82	140.17	140.41
2260	137.57	140.15	140.40
2240	137.46	140.08	140.32
2220	137.24	139.59	139.80
2200	136.91	138.73	138.93
2180	136.63	138.57	138.69
2160	136.66	138.07	138.20
2140	135.96	137.71	137.82
2120	135.24	137.24	137.44
2100	135.12	136.86	136.97
2080	134.80	136.51	136.63
2060	134.68	136.10	136.14
2040	134.46	135.87	135.99
2020	133.93	135.83	136.03
2000	133.16	135.08	135.24

Estimated Surface Water Elevations along lower Bitter Creek

Bitter Creek: Existing Channel with Redesigned Road Geometry & Modified Channel Bend between Stations 4+020 and 4+800

Station	2 yr Ws Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
5000	195.78	197.32	197.5
4990	195.73	197.48	197.6
4980	195.27	196.98	197.2
4970	195.16	197.12	197.3
4960	195.06	196.96	197.2
4950	194.58	196.15	196.3
4940	193.96	195.62	195.8
4930	193.66	195.84	196.0
4920	193.58	195.60	195.8
4910	193.38	195.52	195.7
4900	193.34	195.48	195.7
4890	193.25	195.34	195.5
4880	192.71	194.52	194.7
4870	192.05	194.13	194.3
4860	191.56	193.32	193.5
4850	191.49	193.40	193.6
4840	191.41	193.39	193.6
4830	190.88	193.19	193.4
4820	190.76	193.28	193.5
4810	190.69	193.02	193.3
4800	190.15	191.90	192.1
4790	189.99	192.20	192.4
4780	189.81	192.14	192.4
4770	189.72	192.03	192.3
4760	189.70	192.09	192.3
4750	189.68	192.07	192.3
4740	189.59	191.95	192.2
4730	189.47	191.69	191.9
4720	188.96	190.71	190.9
4710	188.41	190.34	190.5
4700	188.26	189.54	189.7
4690	187.87	189.39	189.5
4680	187.33	188.80	189.0
4670	186.88	188.74	188.9
4660	186.94	188.85	189.0
4650	186.40	187.95	188.1
4640	186.14	187.84	188.0
4630	185.73	187.18	187.3

Bitter Creek: Existing Channel with Redesigned Road Geometry & Modified Channel Bend between Stations 4+020 and 4+800 (cont'd)

Station	2 yr Ws Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
4620	185.34	187.12	187.3
4610	185.30	187.13	187.3
4600	184.33	186.01	186.2
4590	184.01	185.44	185.6
4580	183.72	185.64	185.8
4570	183.19	184.66	184.8
4560	182.87	184.52	184.7
4550	182.59	184.29	184.4
4540	182.56	184.28	184.4
4530	182.13	183.66	183.8
4520	181.65	183.51	183.7
4510	181.38	183.16	183.3
4500	181.39	183.17	183.3
4490	181.27	182.96	183.1
4480	181.25	183.04	183.2
4470	181.18	182.94	183.1
4460	181.10	182.82	183.0
4450	180.58	182.30	182.4
4440	180.29	181.89	182.0
4420	179.88	181.60	181.8
4400	179.94	181.67	181.8
4390	179.52	181.16	181.3
4380	179.32	180.86	181.0
4370	178.91	180.41	180.5
4360	178.63	180.12	180.3
4350	178.74	180.25	180.4
4340	178.64	180.10	180.2
4330	178.41	179.80	179.9
4320	178.36	179.85	180.0
4310	178.05	179.65	179.8
4300	178.06	179.57	179.7
4290	177.95	179.41	179.6
4280	177.53	178.79	178.9
4270	177.22	179.03	179.2
4260	177.15	178.94	179.1
4250	177.03	178.77	178.9
4240	176.55	178.10	178.2
4230	175.47	177.26	177.4
4220	175.39	177.10	177.2
4210	175.35	177.06	177.2

Bitter Creek: Existing Channel with Redesigned Road Geometry & Modified Channel Bend between Stations 4+020 and 4+800 (cont'd)

Station	2 yr Ws Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
4200	175.26	176.89	177.0
4190	175.20	176.83	177.0
4180	174.78	176.18	176.3
4170	173.91	175.35	175.5
4160	173.86	175.27	175.4
4150	173.80	175.16	175.3
4140	173.71	175.01	175.1
4130	173.36	174.49	174.6
4120	172.79	174.51	174.7
4110	172.73	174.40	174.6
4100	172.66	174.29	174.5
4090	172.56	174.14	174.4
4080	172.22	173.85	174.1
4070	171.96	173.99	174.2
4060	171.88	173.89	174.1
4050	171.79	173.81	174.1
4040	171.36	173.59	173.9
4030	171.13	173.52	173.7
4020	171.07	173.41	173.6
4010	171.04	173.39	173.6
4000	170.97	173.28	173.51
3990	170.89	173.17	173.38
3980	170.79	173.01	173.22
3970	170.24	172.10	172.28
3960	169.18	171.14	171.31
3950	169.14	171.08	171.26
3940	169.10	171.02	171.20
3930	169.06	170.96	171.13
3920	169.01	170.89	171.06
3910	168.95	170.81	170.98
3900	168.87	170.72	170.89
3850	166.98	168.38	168.51
3800	165.43	166.91	167.05
3750	164.50	165.86	166.01
3700	163.74	164.99	165.12
3680	163.34	165.04	165.20
3660	162.94	164.25	164.38
3640	162.57	163.80	163.93
3620	162.14	163.46	163.58
3600	161.72	163.29	163.49

Bitter Creek: Existing Channel with Redesigned Road Geometry & Modified Channel Bend between Stations 4+020 and 4+800 (cont'd)

Station	2 yr Ws Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
3580	161.20	163.08	163.28
3560	160.77	162.72	162.92
3540	160.55	162.28	162.36
3520	160.26	161.93	162.07
3500	160.07	161.69	161.84
3480	159.61	161.33	161.45
3460	159.40	160.89	161.02
3440	159.29	160.84	160.98
3420	158.61	160.41	160.52
3400	158.28	159.87	159.98
3380	158.15	159.59	159.69
3360	157.63	159.15	159.25
3340	157.36	158.66	158.76
3320	157.17	158.56	158.67
3300	156.87	158.18	158.26
3280	156.41	157.76	157.90
3260	156.20	157.35	157.45
3240	155.46	156.88	157.05
3220	154.96	156.15	156.26
3200	154.90	156.16	156.26
3150	154.29	155.27	155.36
3100	152.48	153.57	153.69
3050	151.35	152.82	152.89
3000	150.54	151.92	152.05
2980	150.29	151.56	151.65
2960	150.04	151.12	151.18
2940	149.61	150.73	150.81
2920	149.37	150.65	150.74
2900	149.08	150.30	150.39
2880	148.82	149.94	150.02
2860	148.45	149.60	149.70
2840	148.30	149.38	149.48
2820	148.25	149.35	149.44
2800	148.01	149.01	149.10
2750	147.36	148.35	148.44
2700	146.32	147.64	147.81
2650	145.69	146.74	146.80
2600	144.32	145.43	145.52
2550	143.41	144.73	144.83
2500	142.77	143.96	144.04

Bitter Creek: Existing Channel with Redesigned Road Geometry & Modified Channel Bend between Stations 4+020 and 4+800 (cont'd)

Station	2 yr Ws Elev. (m)	100 yr Ws Elev. (m)	200 yr Ws Elev. (m)
2450	141.49	142.81	142.91
2400	140.85	142.28	142.40
2380	140.47	141.60	141.68
2360	139.83	141.04	141.28
2340	139.32	141.00	141.24
2320	138.56	140.66	140.93
2300	138.08	140.44	140.69
2280	137.82	140.17	140.41
2260	137.57	140.15	140.40
2240	137.46	140.08	140.32
2220	137.24	139.59	139.80
2200	136.91	138.73	138.93
2180	136.63	138.57	138.69
2160	136.66	138.07	138.20
2140	135.96	137.71	137.82
2120	135.24	137.24	137.44
2100	135.12	136.86	136.97
2080	134.80	136.51	136.63
2060	134.68	136.10	136.14
2040	134.46	135.87	135.99
2020	133.93	135.83	136.03
2000	133.16	135.08	135.24

Appendix D - Bitter Creek Rock Riprap and Fill Specifications

Rock Riprap Specifications

Rock riprap corresponding to the BC Ministry of Transportation and Infrastructure Specifications (2013) for rock riprap dimensions and gradations should be followed to armour and protect constructed banks along and within the channel area of Bitter Creek.

1. Channel Bends

For road sections to be constructed where the banks will be on the outside of channel bends (including rock aprons) with impinging flow conditions, the rock riprap summary for Class 1000 Riprap in Table 1 should be followed:

Table 1: Channel Bend Rock Riprap Requirements

Criteria		Riprap Class 1000
None greater than	kg	3000
	or mm	1550
15% greater than	kg	1500
	or mm	1295
50%	kg	1000
	or mm	900
85% greater than	kg	415
	or mm	100

Percentages quoted are consistent with MOTI Tables 205A and 205B.

Sizes quoted are equivalent spherical diameters.

The design riprap slope is to be 1.5H:1.0V. If the slope must be increased in places, the Riprap Class requirements should be increased accordingly.

2. Scour Protection

Where scour protection is required along the base of the riprap slopes along the outside of channel bends, a rock apron should be provided. The rock apron should be constructed with large rock (that satisfies Class 1000 Riprap specifications for large rock) is placed and keyed in a minimum depth of 1.5 m below the existing surface of channel bed. The rock apron should support the base of the constructed riprap bank, and extend out a minimum of 3.0 m out from toe of the slope. During construction, the rock apron dimensions may vary due to varying channel bed conditions.

Riprap specifications and installation should conform to the attached BC Ministry of Transportation and Infrastructure Specifications guide (2013).

3. Channel Banks

For road sections to be constructed where the banks will be essentially parallel to the direction of flow along channel sections with no or limited impinging flow conditions, the rock riprap summary for Class 250 Riprap in Table 2 should be followed:

Table 3: Channel Bank Rock Riprap Requirements

Criteria		Riprap Class 250
100% Finer (none greater)	kg	1500
	or mm	1000
85% finer	kg	750
	or mm	600
50% finer	kg	250
	or mm	415
15% finer	kg	25
	or mm	260

Percentages quoted are consistent with MOTI Tables 205A and 205B.

Sizes quoted are equivalent spherical diameters.

Riprap specifications and installation should conform to the attached BC Ministry of Transportation and Infrastructure Specifications guide (2013).

4. Drainage Layer

Where required, drainage layers should be constructed with a well graded coarse granular fill that shall be clean and nonorganic. It should comply with the equivalent gradation limits provided in Table 4.

Table 4 Drainage Layer Gradations

US Standard Sieve Size	Percentage by Weight Passing
100.0 mm	100
75.0 mm	90-100
50.0 mm	80-100
37.5 mm	75-100
19.0 mm	65-100
10.0 mm	55-95
5.0 mm	35-75

5. Bulk Fill Materials

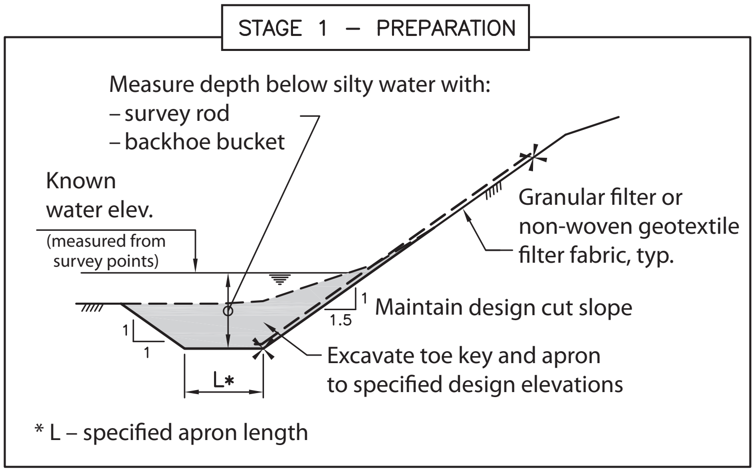
A well graded coarse granular material for the bulk fill shall comply with the gradation limits provided in Table 5.

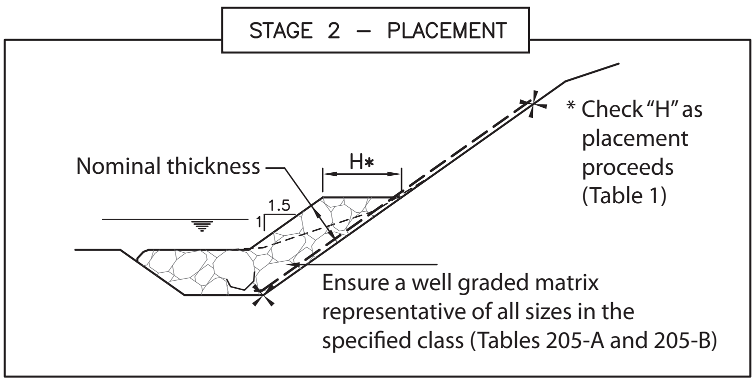
Table 5: Bulk Fill Layer Gradations

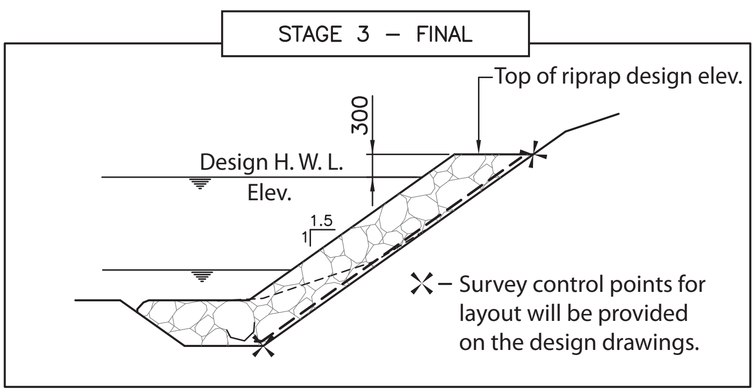
US Standard Sieve Size	Percentage by Weight Passing
300.0 mm	100
150.0 mm	85-100
75.0 mm	75-100
37.5 mm	80-100
19.0 mm	75-100
10.0 mm	64-100

Riprap Installation Guide – 1

BRITISH COLUMBIA
Ministry of Transportation and Infrastructure







WOLMAN EXAMPLE – CLASS 500 KG

For every 100 rocks set aside in Quarry, you need the following:

- From Table 205-B: 15%=330, 50%=715, 85%=1030mm, 100%=<1220mm
- The riprap has to meet ALL the following conditions

Class 500	330	715	1030	1220
15% (330mm)	15 rocks less than 330mm	85 rocks bigger than 330mm		
50% (715mm)	50 rocks less than 715mm		50 rocks bigger than 715mm	
85% (1030mm)	85 rocks less than 1030mm			15 rocks bigger than 1030mm
100% (<1220mm)	All 100 rocks less than 1220mm			

Table 1: Riprap Horizontal Dimensions

Class of Riprap (kg)	Nominal Riprap Thickness (mm)	Surface Width, H (mm)	
		2H : 1V Slope	1.5H : 1V Slope
10	350	783	631
25	450	1006	811
50	550	1230	992
100	700	1566	1262
250	1000	2236	1803
500	1200	2684	2163
1000	1500	3355	2704
2000	2000	4473	3606
4000	2500	5591	4507

Table 205-A: Gradation of Rock Sizes in Each Class of Riprap – **Mass (kg)**

Class of Riprap (kg)	Nominal Riprap Thickness (mm)	Rock Gradation Percentage Smaller Than Given Rock Mass (kg)		
		15%	50%	85%
10	350	1	10	30
25	450	2.5	25	75
50	550	5	50	150
100	700	10	100	300
250	1000	25	250	750
500	1200	50	500	1500
1000	1500	100	1000	3000
2000	2000	200	2000	6000
4000	2500	400	4000	12000

Table 205-B: Approximate Average Dimension of Each Specified Rock Class Mass (Sg=2.640) – **Equivalent Diameter (mm)**

Class of Riprap (kg)	Approximate Average Dimension (mm)			
	15%	50%	85%	<100%
10	90	195	280	330
25	120	260	380	450
50	155	330	475	565
100	195	415	600	715
250	260	565	815	965
500	330	715	1030	1220
1000	415	900	1295	1535
2000	525	1130	1630	1935
4000	660	1425	2055	2440

Riprap Installation Guide – 2

Ministry of Transportation and Infrastructure

CONSTRUCTION MONITORING

- Hold and Witness Points
  - Rock quality (hardness and gradation) (hold)
  - Stake-out (hold)
  - Clearing and grubbing (witness)
  - Toe/ Terminal end-key excavations (witness)
  - Preparation of back slope/ surface (witness)
  - Application of filter(s) (witness)
  - Toe construction (witness)
  - Front slope / H-width / thickness / gradation (witness)
  - Design height (witness)
- Getting the Right Size Riprap
  - by Visual Inspection with colour-coded samples from Tables 205-A and 205-B
  - one set at quarry and one at worksite
- Checking Gradation at Quarry and Worksite
  - Wolman Pebble Count (see example other side)
- Placement
  - Controlled placement on specified design slope (no end dumping)

POOR INSTALLATION

- Single rocks (not graded)
- Toe not keyed
- Inadequate thickness
- Steep slope (not visible)

GOOD INSTALLATION

- Environmental monitor
- Good site separation
- Toe and Terminal Ends are keyed
- Well graded matrix
- Design slope
- Sufficient thickness