APPENDIX 23-A

Tailings Dam Breach Analysis

IDM MINING LTD.

RED MOUNTAIN UNDERGROUND GOLD PROJECT



TAILINGS DAM BREACH ASSESSMENT

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IDM MINING LTD.
RED MOUNTAIN UNDERGROUND GOLD PROJECT

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EXECUTIVE SUMMARY

A tailings dam breach assessment for the Bromley Humps Tailings Management Facility (TMF) was conducted for the Red Mountain Underground Gold Project. The dam breach study presented herein is not a risk assessment and ignores the likelihood of occurrence of a breach. The purpose of the study was to generate inundation maps that are used for evaluating the downstream incremental impacts to population at risk (PAR) and potential loss of life, to environmental and cultural values (including consequences to wildlife and commercial, recreational, and aboriginal (CRA) fisheries), and to infrastructure and economics (CDA 2014). This report also supports the assessment of the "breach or failure of tailings dam or other containment structure" as identified in Section 9 – Accidents and Malfunctions of The Application Information Requirements for the Project (EAO 2017).

Two hypothetical failure scenarios were evaluated per the CDA (2007, revised 2013, and 2014) guidelines – a fair weather or "sunny day" scenario, which assumes normal operating conditions and a sudden failure due to any cause (e.g., earthquake, operational mismanagement, piping, etc.), and a flood-induced or "rainy day" failure, which could potentially occur due to an extreme flood. Flood routing and tailings slumping modelling was completed to assess the incremental impacts downstream of the Tailings Management Facility (TMF) for these scenarios. Inundation maps were prepared to illustrate the incremental flooding extent caused by a dam breach. In addition, comparisons between maximum flow depths, flow velocities, and depth-velocity products were generated to aid in the assessment of flood severity.

Although limited, the largest incremental impacts due to a dam breach are predicted to occur within Bitter Creek downstream of the TMF. These impacts are predicted to be primarily environmental, due to potentially severe geomorphic changes, with erosion resulting from increased depths and flow velocities, and deposition of tailings resulting from tailings slumping. The incremental impacts in the Bear River are expected to be smaller, because of the flood wave attenuation through the Bear River floodplain.

The incremental impacts to permanent PAR, potential loss of life, and infrastructure and economic values are predicted to be relatively limited for both the fair weather and flood-induced scenarios. The flood wave in a fair weather dam breach scenario attenuates quickly within the broad Bear River valley with the flows predicted to be similar to the mean annual flood in this river. In the case of a flood-induced scenario, the natural flooding prior to dam breach would inundate the entire Bear River valley including the entire town of Stewart. The potential impacts to the permanent PAR in Stewart may increase in the flood-induced dam breach, however, if adequate warning and evacuation times were not utilized.

Based on this analysis and considering the relatively limited incremental impacts during both the fair weather and flood-induced dam breach events, the hazard consequence classification of the Red Mountain TMF dams is assessed to be Very High (based on CDA 2014).

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ABBREVIATIONS

CRA	Commercial, Recreational, Aboriginal
DEM	Digital Elevation Model
DFO	Fisheries and Oceans Canada
DV	depth-velocity
EDF	Environmental Design Flood
HHWLT	higher high water large tide
LiDAR	Light Detection and Ranging
MAD	mean annual discharge
masl	meters above sea level
PAR	population at risk
PMP	Probable Maximum Precipitation
PMF	Probable Maximum Flood
TMF	Tailings Management Facility
WSC	Water Survey of Canada

1 – INTRODUCTION

1.1 PROJECT LOCATION

The Red Mountain Underground Gold Project (the Project) being developed by IDM Mining Ltd. (IDM) is situated in northwestern British Columbia, approximately 18 km east-northeast of Stewart, BC, as shown on Figure 1.1. The deposit area is located at 55° 57' N latitude and 129° 42' W longitude between the Cambria Ice Field and the Bromley Glacier, at elevations ranging from 1,500 m to 2,000 m. The TMF and Process Plant Site will be located on a plateau above Bitter Creek at Bromley Humps and to the north of Otter Creek, at elevations ranging from 400 m to 500 m. This area is characterized by steep, rugged terrain with sparse overburden cover, prevalent bedrock outcrops, and vegetation and weather conditions typical of the north costal mountains.

1.2 PURPOSE OF STUDY

The tailings dam breach assessment was conducted for the Bromley Humps Tailings Management Facility (TMF). This report summarizes the basic assumptions, methods and results of the study, conducted for the North TMF Embankment in the last year of operations (i.e., ultimate arrangement).

The dam breach study presented herein implicitly ignores the likelihood of occurrence of a breach and presents conservative mapping of potential inundation areas. It is intended to assist with the assessment of incremental consequences of a dam failure to downstream population at risk (PAR), environmental and cultural values, and infrastructure and economics, and can be used for developing emergency warning and response procedures in the future. This report also supports the assessment of the "breach or failure of tailings dam or other containment structure" as identified in Section 9 – Accidents and Malfunctions of The Application Information Requirements (EAO 2017). The potential inundation areas are based on forcing a hypothetical dam failure and subsequent hydrologic flood wave routing. This study is not a risk assessment and it does not account for design safety measures and management practices that will be implemented during various phases of the Project (i.e., construction, operation, reclamation and closure, and post-closure) to prevent a breach from occurring.

1.3 SCOPE OF WORK

The tailings dam breach assessment for the Project was completed for hypothetical failures under extreme and highly unlikely events. The results of the analysis do not reflect upon the structural integrity or safety of the dams.

The Canadian Dam Association (CDA) recommends that a dam breach analysis be undertaken to assess potential incremental consequences of failure as a basis for determining the Dam Classification in accordance with CDA "Dam Safety Guidelines" (CDA 2007, revised 2013, and CDA 2014). The incremental consequences are evaluated to assess potential impacts to downstream PAR and loss of life, environmental and cultural values, and infrastructure and economics.

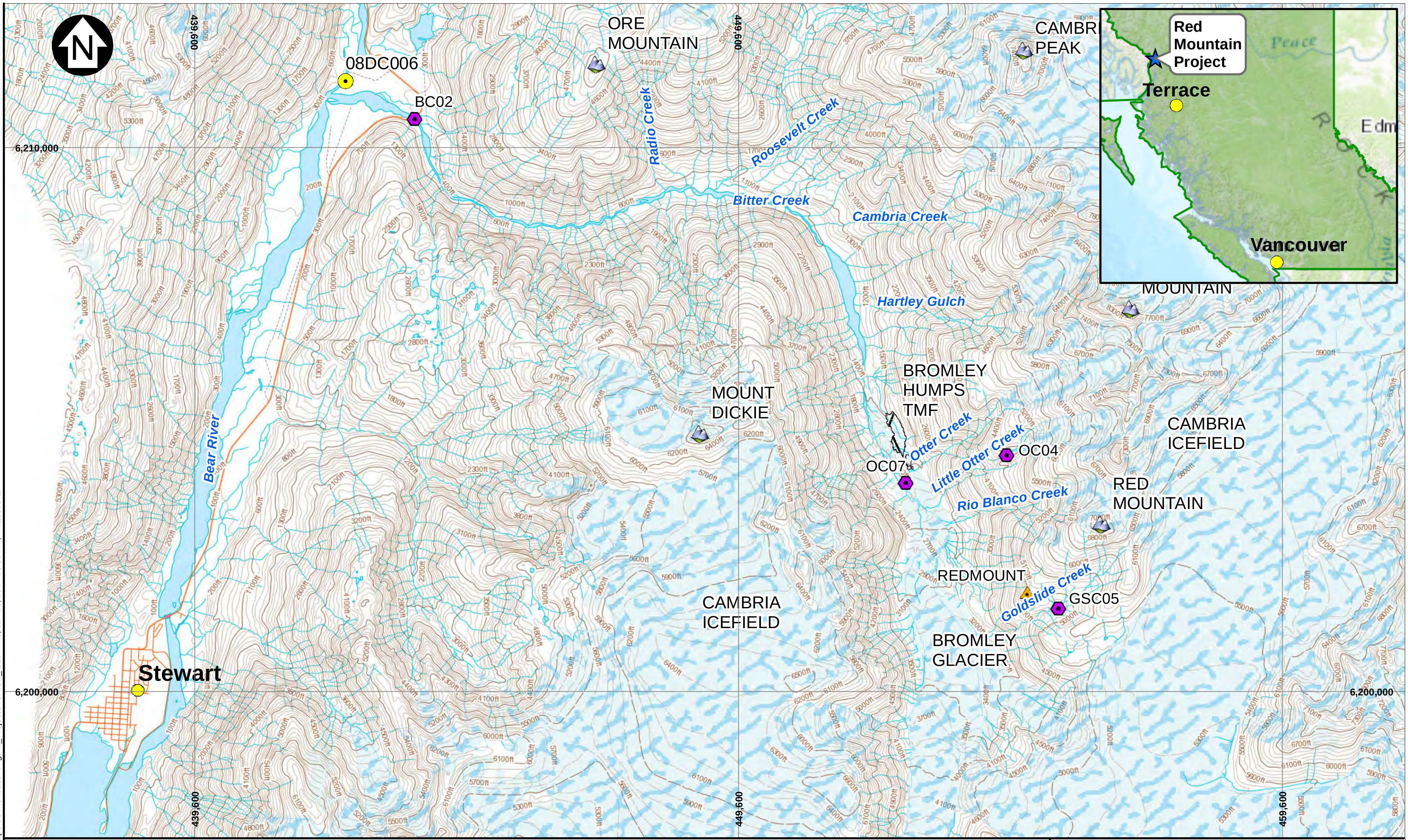
The tailings dam breach study was evaluated for two hydrologic conditions, as recommended by CDA (2007, revised 2013, and 2014):

- Fair weather or "sunny day" failure – a sudden dam failure that occurs during normal operations caused by internal erosion, piping, an extreme earthquake, mis-operation leading to overtopping, or another event; and

- Flood-induced or "rainy day" failure – a dam failure resulting from a natural flood of a magnitude greater than what the dam can safely pass.

The scope of work for this study included:

- Determination of critical dam locations to consider in the dam breach analysis;
- Determination of dam breach parameters for fair weather and flood-induced failure scenarios;
- Determination of outflow volumes and peak discharges for the two scenarios;
- Flood routing and inundation mapping for the two scenarios for areas downstream of the TMF;
- Modelling of tailings slumping and deposition extents downstream of the TMF;
- Assessment of geomorphic impacts caused by a potential dam breach; and
- Assessment of incremental consequences of a potential dam breach.



LEGEND:

- CITY/TOWN
- MTN
- CLIMATE STATION
- ACTIVE HYDROMETRIC AND SURFACE WATER QUALITY STATION
- INACTIVE WSC STREAMFLOW STATION

1 0.5 0 1 2 3 4 km

NOTES:

1. BASE MAP: TOPORAMA WMS SERVICE.

2. COORDINATE GRID IS IN METRES.
COORDINATE SYSTEM: NAD 1983 UTM ZONE 9N.

3. THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:100,000 FOR 8.5x11 (LETTER) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.

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IDM MINING LTD.

RED MOUNTAIN UNDERGROUND GOLD PROJECT

PROJECT LOCATION

Knight Piésold CONSULTING

P/A NO.	REF NO.
VA101-594/4	6

FIGURE 1.1 REV 0

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2 – DISCHARGE MECHANISMS FROM A BREACHED TAILINGS DAM

Two different discharge mechanisms are associated with tailings dam breaches for a TMF that has a supernatant pond: an *initial flood wave*, driven by the discharge of the supernatant pond, followed by *slumping of tailings*, in which additional tailings mass slumps through the breach opening and deposits closer to the dam.

An *initial flood wave* would occur in conjunction with the failure of the TMF dam. The supernatant pond water within the TMF would start to discharge through the developing breach and mobilize both tailings from the impoundment and construction materials from the dam. The flood wave would propagate downstream causing erosion and inundating the downstream receiving environment, with consequences potentially extending for long distances. The flood wave would carry the tailings solids and dam construction materials, as well as riverine and floodplain material eroded along the way, resulting in high solids concentrations within the flood wave. Some of the coarser material mobilized by the wave would deposit along the way, while the fine-sized tailings would be carried in suspension until the flow velocities are low enough for this material to settle (e.g., in a lake or on the flood plain during the receding limb of the flood wave).

Tailings slumping would occur following the initial flood wave, as some portion of the tailings mass remaining in the TMF would be expected to undergo static liquefaction resulting from the loss of containment and the local steepening of slopes created by the initial discharge. Tailings that are not mobilized in the initial flood wave may slump through the breach in a paste-like fashion and flow downstream, until the tailings mass stabilizes. The impact extent from the flow of liquefied tailings would be considerably less than the inundation extent from the initial flood wave, but this discharge mechanism would deposit far more solids closer to the dam.

In Sections 4 and 5 of this report, the mobilization of tailings in the initial flood wave is analyzed, and the associated peak discharges and dam breach outflow hydrographs are calculated for the fair weather and flood-induced scenarios. The flood wave resulting from the initial discharge of stored water and mobilized tailings is then routed downstream using a hydrodynamic model. The resulting depths and velocities are presented in Section 5. The potential volume of tailings slumping and the extent of tailings deposition are discussed in Section 6.

3 – FACILITY LAYOUT AND BASIC ASSUMPTIONS FOR THE DAM BREACH ANALYSIS

3.1 TAILINGS MANAGEMENT FACILITY DESCRIPTION

The proposed Bromley Humps TMF is designed to permanently store all tailings materials including potentially acid-generating (PAG) tailings over the six-year mine life. The TMF will be lined with a 100-mil HDPE geomembrane sandwiched between layers of non-woven geotextile. The liner system will be installed on the full TMF basin, with an underlying prepared sub-grade comprising processed bedding sand material. The tailings will be thickened to a slurry solids content of 50% by weight. Surplus water will be actively managed by pumping from the TMF supernatant pond to a water treatment plant for release to the environment to minimize the volume of water stored in the TMF during operations.

The TMF will have a storage capacity of 1.7 Mm^3, which will include approximately 1.5 Mm^3 of tailings (1.95 million tonnes at an average settled density of 1.3 t/m^3). The remaining storage is for the supernatant pond that will be reclaimed as plant process water, for the Environmental Design Flood (EDF), and for freeboard. The EDF of 0.16 Mm^3 was determined as the total runoff from the 1 in 50-year wet month plus the total runoff from a 1 in 200-year 24-hr precipitation event, which bypasses the non-contact water diversion channel (as per 2014 CDA guidelines). The non-contact water diversion channel is located on the east side of the TMF, and will function to collect runoff from the upstream catchment, safely divert around the TMF, and discharge to Bitter Creek. Flood events exceeding this volume, up to a peak runoff from a Probable Maximum Flood (PMF) event, will be safely conveyed from the TMF through an engineered emergency discharge spillway and will report to Bitter Creek.

The TMF has two embankments: the North TMF Embankment and the South TMF Embankment. The embankments allow for natural topographic containment with the steep slope to the east, and the Bromley Humps to the south and west of the facility. The TMF embankments will be constructed using material from local borrow sources, and are designed as zoned rockfill embankments. The upstream slopes of the embankments will be constructed at a 2.5H:1V slope to facilitate geomembrane placement, while the downstream slope will be constructed at a 2H:1V slope. The embankment crests will be 10 m wide to allow working space for tailings and reclaim water pipelines and traffic. The maximum vertical embankment height is approximately 35 m, while the maximum elevation difference between the dam crest and the lowest ground elevation at the toe of the North TMF Embankment is 60 m.

3.2 BREACH LOCATION AND BREACH HEIGHT

For this assessment, it was assumed that a hypothetical dam breach would develop in the North TMF Embankment, which is the higher of the two embankments. Conditions in the last year of operations are considered in this assessment only. The general arrangement of the TMF at the end of operations is illustrated in Figure 3.1.

The fair weather scenario was modelled as piping, while the flood-induced scenario was modelled as overtopping. In both cases, the breach was assumed to develop to the dam foundation at the lowest ground elevation, which results in the largest breach and subsequent peak discharge for this facility, and thus presents the worst case scenarios. The breach was assumed to be 60 m high from the top of the embankment at EL 470 masl (meters above sea level) to the ground level at the toe of the dam at EL 410 masl.

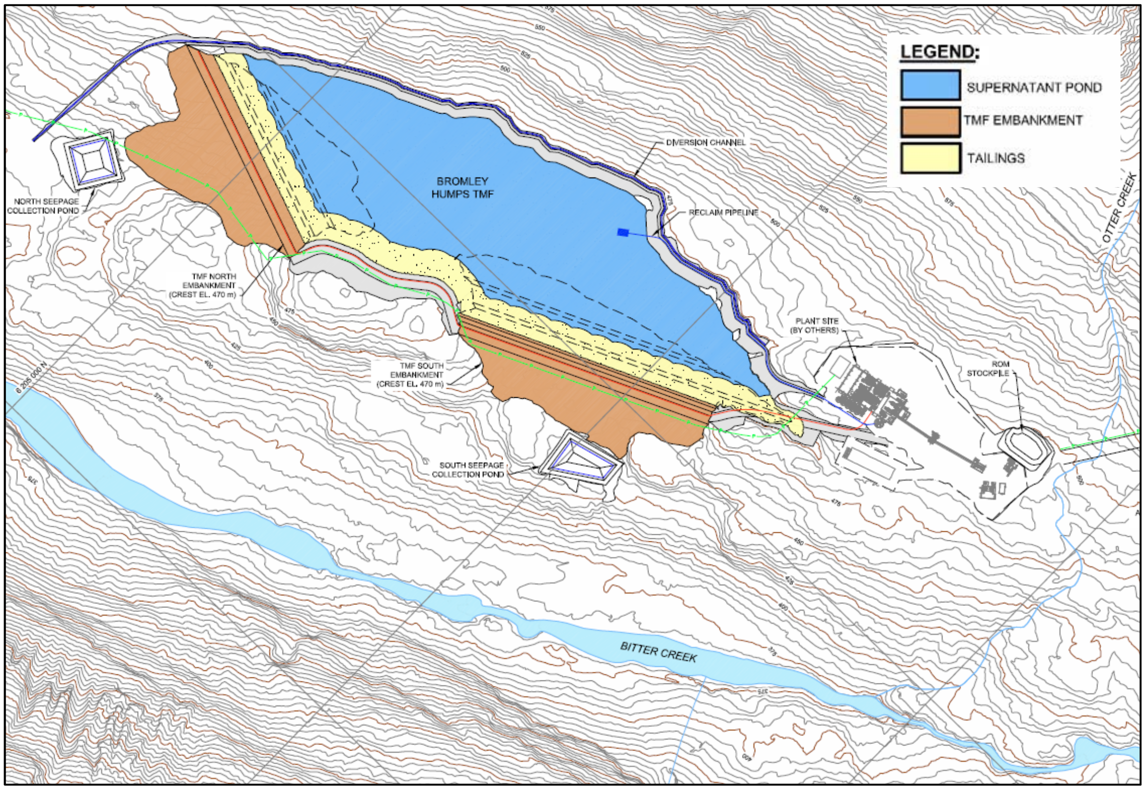


Figure 3.1 General Arrangement of the Bromley Humps TMF at the End of Operations

3.3 HYDROLOGIC CONDITIONS

The hydrologic conditions relevant to dam breach modelling pertain to the water storage within the TMF, the runoff from the upstream catchment reporting to the TMF, and the natural flows in the upstream and downstream drainage network. The available free water in the TMF, which includes the stored water in the TMF and the runoff from the upstream TMF catchment, would mobilize the tailings and dam construction materials in the case of a breach. The volume of free water is different for the fair weather and flood-induced scenarios. The natural flows in the upstream and downstream drainage network contribute to the flood wave routing subsequent to a dam breach.

3.3.1 Fair weather scenario

The volume of water in a fair weather scenario was determined based on the TMF filling schedule. This volume is equivalent to the volume of water associated with the maximum normal operating pond level of approximately 0.20 Mm^3. The non-contact diversion ditches upstream of the TMF are assumed to be fully functional, and hence, there is no additional runoff into the TMF during this event. The flows in Bitter Creek and Bear River are assumed to be equivalent to the Mean Annual Discharge (MAD) during a fair weather breach, as recommended by the CDA (CDA 2007b). The MAD for Bitter Creek was determined using the Project hydrometric monitoring stations, as presented in the "Red Mountain Underground Gold Project – Baseline Climate and Hydrology Report" (SRK 2017), while the mean annual flows for Bear River were determined from the Water Survey of Canada (WSC) hydrology station 08DC006 "Bear River Upstream of Bitter Creek". The additional flow between the WSC gauge and Stewart was estimated using drainage area proration between the WSC gauge and Stewart.

3.3.2 Flood-induced scenario

The PMF was evaluated for the flood-induced scenario, and the water level in the TMF was assumed to be at the spillway invert elevation at the start of the 24-hour PMF event. The PMF is based on a combined runoff from the Probable Maximum Precipitation (PMP) event and a snowmelt from a 100-year snow pack, as recommended by the CDA (CDA 2007a). The non-contact diversion ditches upstream of the TMF are assumed to fail during the PMF event. The total 24-hour PMF volume contributing to the TMF is approximately equivalent to 0.89 Mm^3, which is added to the volume of water already stored in the TMF at the start of the PMF event. Consequently, the total volume of free water available to mobilize the tailings solids in a flood-induced scenario is equal to 1.13 Mm^3.

The flows in the upstream and downstream drainage networks during the flood-induced scenario were calculated as follows:

- The PMP/PMF event is assumed to be centered over the TMF catchment area
- The concurrent flows elsewhere in Bitter Creek are based on pro-rated PMP calculated using Hansen *et al.* (1994); and
- The concurrent flows in Bear River are assumed to be coincident with a 500-year return period flood. The 500-year event was selected based on the size and vicinity of the remaining Bear River catchment outside of the Bitter Creek catchment.

The hydrologic conditions in Bitter Creek and Bear River are summarized in **Error! Reference source not found.**, and the key assumptions used in this tailings dam breach analysis are summarized in Table 3.2.

Table 3.1 Hydrologic Conditions in Bitter Creek and Bear River

Location		Fair Weather Failure Scenario	Flood-Induced Failure Scenario	
		Mean Annual Discharge (m^3/s)	1:500 Year Flood (m^3/s)	PMF[(1)] (m^3/s)
Bitter Creek	Bitter Creek upstream of the TMF	13.7	-	586
Bitter Creek	Bitter Creek at the mouth	19.7	-	900
Bear River	Bear River upstream of Bitter Creek	25.2	460	-
Bear River	Bear River at Stewart	28.8	524	-

NOTES:
1. FULL PMF OR PRO-RATED PMF BASED ON DISTANCE FROM THE TMF.

Table 3.2 Key Assumptions Used in the Tailings Dam Breach Analysis

Assumption	Dam Breach Scenario	
	Fair Weather	Flood-Induced
Water level in the TMF	Maximum operating pond level	At the spillway invert at start of PMF event, which fills the TMF to the dam crest and overtops; the spillway is non-operational
Upstream TMF diversion structures	Operational	Failed
Flows in Bitter Creek	MAD	PMF at the TMF, prorated with distance downstream
Flows in Bear River	MAD	500-year flood event

3.4 TAILINGS CHARACTERISTICS

The tailings characteristics used in this assessment, based on the values presented in the Design Basis Table (KP, 2017) for the end of operations, are as follows:

- Mass of tailings solids of 1,947,000 tonnes
- Average dry density of tailings mass of 1.3 tonnes/m^3; and
- Tailings specific gravity of 3.1.

Based on the values listed above and a degree of saturation assumed equal to 1.0 (representing the maximum normal operating conditions with full pond cover), the total volume of deposited tailings at the end of operations was calculated to be approximately 1.5 Mm^3, of which 0.63 Mm^3 represent the volume of tailings solids, and 0.87 Mm^3 the volume of interstitial water.

3.5 TAILINGS SOLIDS IN THE INITIAL FLOOD WAVE

The volume of mobilized tailings can be estimated assuming full mixing of available water with tailings solids to an assumed solids concentration, as discussed in Fontaine and Martin (2015). This approach is based on the potential of the available free water in the TMF to entrain and mix with tailings solids, while considering the physical characteristics of the deposited material (total mass of deposited solids, density of the tailings mass, degree of saturation, and average dry density).

A range of solids concentrations in the initial flood wave from 25% to 65% by weight was used to determine the range of potential outflow volumes in the initial flood wave, which is discussed further in the next section. This range of solids contents represents sediment laden flows with solids contents observed in water floods, mud floods, and hyperconcentrated flows (e.g., Pierson and Costa 1984, O'Brien 1986), as summarized in Table 3.3 (adapted from Bradley and McCuthcheon 1986, source: Gusman 2011).

Table 3.3 Flow Classification by Sediment Concentration (after Gusman 2011)

	Concentration percent by weight (100% by WT = 1,000,000 ppm)									
	23	40	52	63	72	80	87	93	97	100
	Concentration percent by volume (G. = 2.65)									
Source	10	20	30	40	50	60	70	80	90	100
Beverage and Culbertson (1964)	High	Extreme	Hyperconcentrated				Mud Flow			
Costa (1984)	Water Flood		Hyperconcentrated			Debris Flow				
O'Brien and Julien (1985) using National Research Council (1982)	Water Flood		Mud Flood		Mud Flow	Landslide				
Takahashi (1981)	Fluid Flow			Debris or Grain Flow				Fall, Landslide, Creep, Sturzstrom, Pyroclastic Flow		
Chinese Investigators (Fan And Dou, 1980)	←------------------Hyperconcentrated Flow--------------------→ Sediment Laden			←-----------------Debris or Mud Flow-------------------------------→						
Pierson and Costa (1984)	STREAMFLOW Normal: Hyperconcentrated				SLURRY FLOW (Debris Torrent), Debris Mud Flow, Solifluction			GRANULAR FLOW Sturzstrom, Debris Avalanche, Earthflow, Soil Creep		

NOTES:

1. GREEN SHADED RANGE INDICATES THE RANGE OF SUSPENDED SEDIMENT CONCENTRATION AND RESPECTIVE FLOW CHARACTERISTICS CONSIDERED IN THIS ANALYSIS.

4 – DAM BREACH CHARACTERISTICS

The quantitative assessment of the potential consequences of a flood resulting from the initial flood wave of a TMF dam breach requires estimates of the volume of water and tailings released in the breach, the peak outflow discharge, the physical characteristics of the breach (i.e., height, width, and side slopes), and the time for the breach to develop. These parameters were estimated using empirical methods, and then applied to develop dam breach hydrographs that are routed downstream to predict the extent of flooding in the downstream area.

4.1 TAILINGS OUTFLOW VOLUME DURING THE INITIAL FLOOD WAVE

The volume of the breach outflow in the initial flood wave includes the supernatant pond and the volume of tailings that would mobilize due to the discharge of the supernatant pond from the breached TMF. Using the inputs and assumptions outlined in Section 3, a range of outflow volumes was calculated based on the range of suspended sediment concentrations in the breach outflow, ranging from 25% to 65% solids mixing by weight.

The resulting range of outflow volumes is illustrated in Figure 4.1 for the fair weather failure scenario and in Figure 4.2 for the flood-induced failure scenario. The results are presented as a percent of a total impounded volume released that includes supernatant pond and flood waters, if applicable, the tailings solids and interstitial water, and also as a percentage of impounded tailings volume released that includes only the tailings solids and interstitial water.

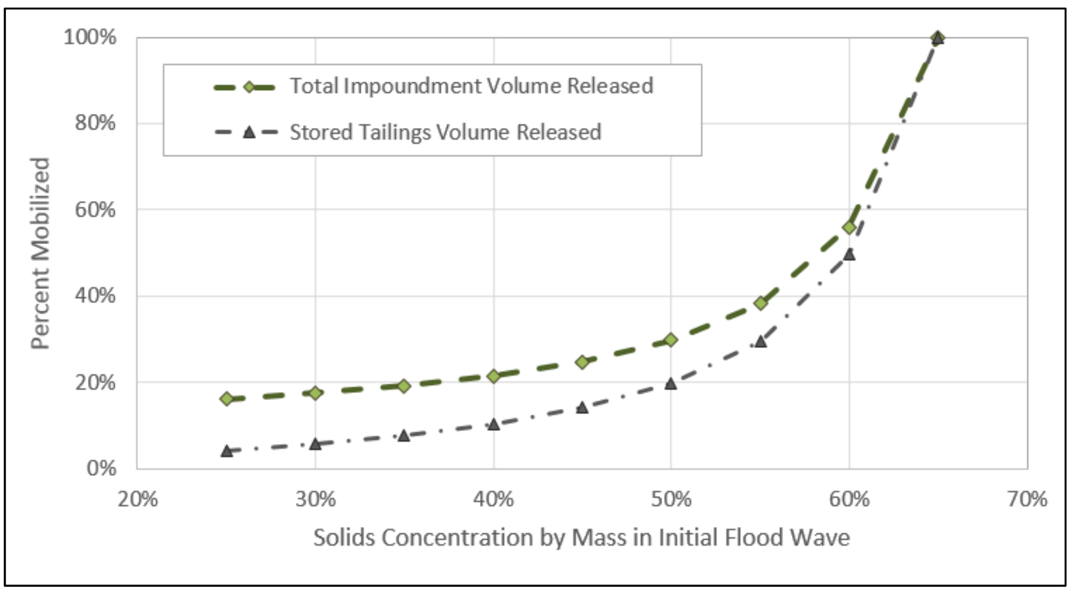


Figure 4.1 Fair Weather Scenario Outflow Volume Based on Mixed Solids Concentration

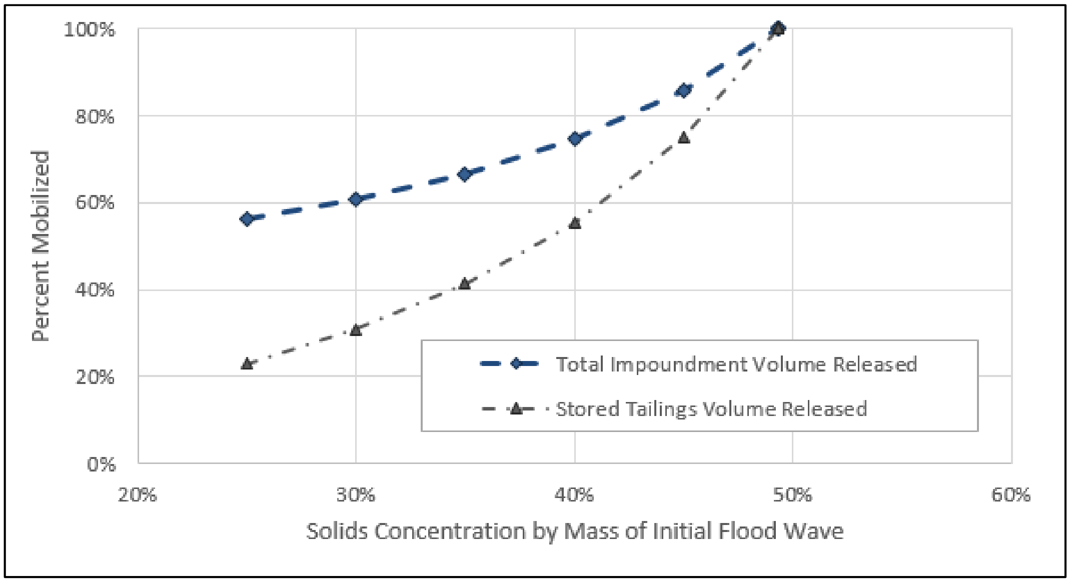


Figure 4.2 Flood-Induced Scenario Outflow Volume Based on Mixed Solids Concentration

The flood-induced scenario has more water available to mobilize the tailings and results in a larger mobilized volume of tailings than a fair weather scenario. The range of mobilized tailings volumes varies greatly, depending on the solids concentration assumed in the analysis. Considering that during the actual breach event, the solids concentration would vary through time, 50% solids content by weight was assumed to represent a reasonable average mixing percentage for the entire duration of the initial flood wave. In the fair weather scenario, 50% solids content in the initial flood wave mobilizes a tailings volume of 0.27 Mm^3, or 30% of the total impounded volume. In the flood-induced scenario, a 100% or the entire stored tailings volume of 1.5 Mm^3 is mobilized at 49% solids content, and thus higher solids content is not possible. The corresponding total breach outflow volume includes the water volume in the TMF at the time of the breach, and is carried forward to estimate the peak discharge and the relevant breach characteristics.

The volumes of mobilized tailings including interstitial water, and the percentages of the total impounded volume released in the breach outflow are provided in Table 4.1.

Table 4.1 Released Volumes in the Breach Outflow

TMF ARRANGEMENT	SCENARIO	VOLUME OF FREE WATER	VOLUME OF MOBILIZED TAILINGS	TOTAL VOLUME IN BREACH OUTFLOW	PERCENT OF STORED VOLUME RELEASED
ULTIMATE	Fair Weather	0.20 Mm^3	0.27 Mm^3	0.47 Mm^3	30%
ULTIMATE	Flood-Induced	1.13 Mm^3	1.50 Mm^3	2.63 Mm^3	100%

4.2 PEAK DISCHARGE AND BREACH CHARACTERISTICS

Breach parameters for a hypothetical dam breach scenario are challenging to define considering that there are no industry standards for tailings dams, and the equations typically referenced are empirical and largely based on past failures of water-retaining dams typically less than 30 m high. The selected parameters, however, have a considerable impact on the inundation extent and velocity of the resulting flood wave. Several commonly-used equations were considered in this assessment to determine a possible range of values for various breach parameters. The range of breach parameters for peak discharge, breach width, side slope, and time of failure were defined based on empirical formulas from the following methodology sources: Johnson and Illes (1976), Singh and Snorrason (1982, 1984), MacDonald and Langridge-Monopolis (1984), Costa (1985), Von Thun and Gillette (1990), FERC (1993), Froehlich (1995a, 1995b) as summarized in Wahl (1988), and Rico et al. (2008), Froehlich (2008), and Pierce (2010).

Table 4.2 and Table 4.3 summarize the range of breach parameters that were calculated for the fair weather and flood-induced scenarios, respectively. The empirical formulae are based on site characteristics that include breach outflow volume and dam height. The average peak discharge was then used in combination with the breach parameters to develop the breach outflow hydrographs discussed in the following section.

Table 4.2 Fair Weather Breach Parameters Based on Empirical Equations

Methodology	Peak Flow (m^3/s)	Time to Failure (hours)	Average Width (m)	Side Slope Ratio H:1V
Johnson and Illes, 1976	-	-	30 - 180	-
Singh and Snorrason, 1982, 1984	-	0.25 - 1.0	120 - 300	-
Macdonald, 1984	1,300	.56	2	0.50
Von Thon and Gillette, 1990	-	0.83	192	0.33 - 1.0
FERC Guidelines, 1993	-	0.1 - 1.0	60 - 300	0.25 - 1.0
Froehlich, 1995	4,110	0.06	26	0.9 - 1.4
Rico et. al., 2007 and Costa 1985	1,270	-	-	-
Froehlich, 2008	-	0.06	21	0.7 - 1
Pierce, 2010	550 – 1,480	-	-	-
Mean	**1,740**	**0.64**	**113**	**0.76**

Table 4.3 Flood-Induced Breach Parameters Based on Empirical Equations

Methodology	Peak Flow (m^3/s)	Time to Failure (hours)	Average Width (m)	Side Slope Ratio H:1V
Johnson and Illes, 1976	-	-	30 - 180	-
Singh and Snorrason, 1982, 1984	-	0.25 - 1.0	120 - 300	-
Macdonald, 1984	2,750	0.94	6	0.50
Von Thon and Gillette, 1990	-	0.90	205	0.33 - 1.0
FERC Guidelines, 1993	-	0.1 - 1.0	60 - 300	0.25 - 1.0
Froehlich, 1995	7,620	0.16	44	0.9 - 1.4
Rico et. al., 2007 and Costa 1985	2,720	-	-	-
Froehlich, 2008	-	0.15	36	0.7 - 1
Pierce, 2010	1,640 – 3,690	-	-	-
Mean	**3,690**	**0.76**	**121**	**0.76**

4.3 DAM BREACH OUTFLOW HYDROGRAPHS

Outflow breach hydrographs were modelled in HEC-HMS for each of the two failure scenarios, using the estimated physical characteristics of the breach and the peak discharges presented in Table 4.2 and Table 4.3. The fair weather and flood-induced scenario breach outflow hydrographs for the average peak discharges are illustrated in Figure 4.3 and Figure 4.4, respectively. The fair weather breach is a sudden failure due to any cause (e.g., earthquake, foundation failure, piping, etc.), and is assumed to start at time zero. In the flood-induced scenario, the PMP event starts at time zero and results in a PMF inflow into the TMF. The spillway is assumed to be blocked and non-functional during the PMF event, and hence the PMF results in overtopping, causing a dam breach initiated at the peak of the PMF inflow hydrograph.

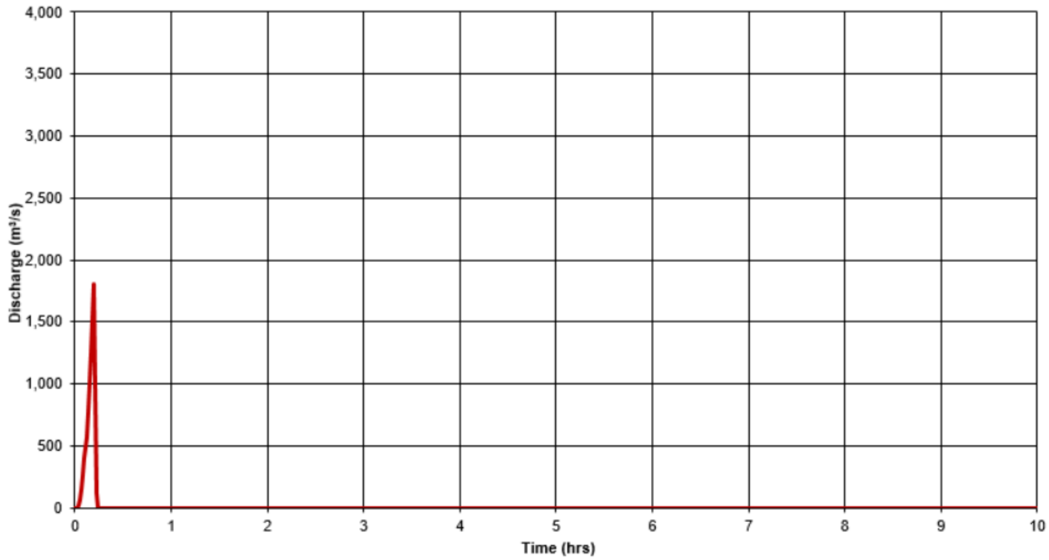


Figure 4.3 Breach Outflow Hydrograph for a Fair Weather Scenario

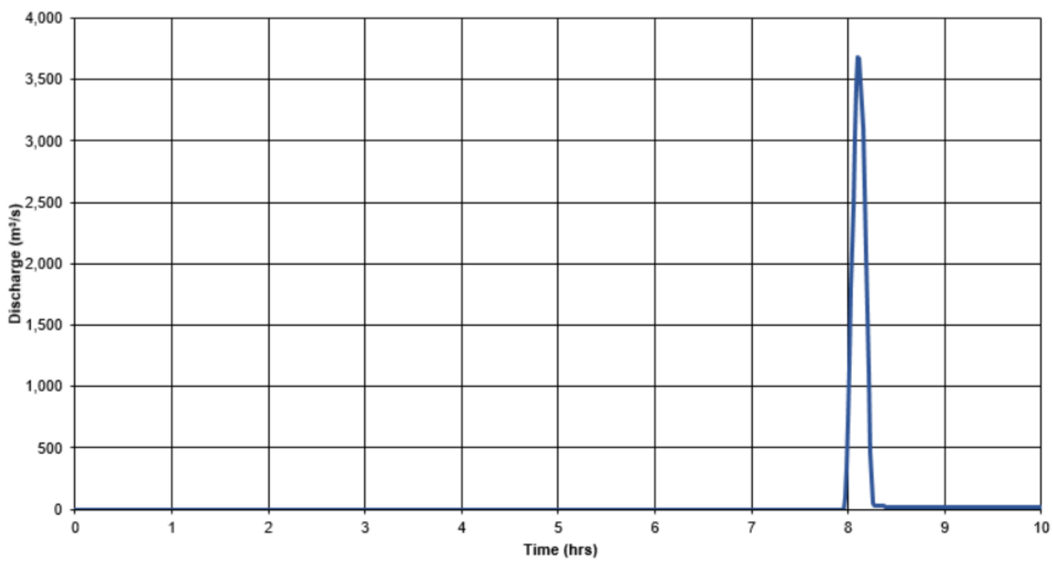


Figure 4.4 Breach Outflow Hydrograph for a Flood-Induced Scenario

5 – FLOOD WAVE ROUTING

The propagation of the initial flood wave and the routing of the breach outflow hydrographs were modeled using a two-dimensional hydrodynamic model, discussed in more detail below. The assessment of the flow and deposition of slumped tailings was carried out as a volumetric analysis using a three-dimensional volumetric model, discussed in Section 6.

5.1 INITIAL FLOOD WAVE PROPAGATION AND FLOOD WAVE ROUTING MODEL

The two-dimensional HEC-RAS 5.0.3 model was used to estimate the propagation of the initial flood wave from the TMF down Bitter Creek and the Bear River to the outlet of the Bear River at the Portland Canal near Stewart, BC. The model accounts for the attenuation of the flood wave as it propagates downstream for both the fair weather and flood-induced breach hydrographs. The HEC-RAS model extent is illustrated in Figure 5.1.

The flood wave propagation was modelled using a digital elevation model (DEM) generated from Light Detection and Ranging (LiDAR) data. Bear River has a braided streambed with a high sediment load, therefore an accurate calibration of the HEC-RAS model was not possible, as the bed elevation is constantly changing. A Manning's n value of 0.04 was selected for the main channel, and a higher value of 0.10 was selected for the overbanks. The higher high water large tide (HHWLT) was selected to represent the downstream boundary as this value represents the average of the annual highest high waters in the Portland Canal. A HHWLT value of 3.621 masl was used based on 19 years of predictions for Stewart, as provided by the Fisheries and Oceans Canada (DFO).

The fair weather scenario was assumed to occur in conjunction with the MAD on Bitter Creek and the Bear River, while the flood-induced scenario was assumed to occur in conjunction with a PMF event within the Bitter Creek catchment, and a 500-year flood event in the Bear River, as discussed in Section 3. The inflow locations for the HEC-RAS model are illustrated in Figure 5.1.

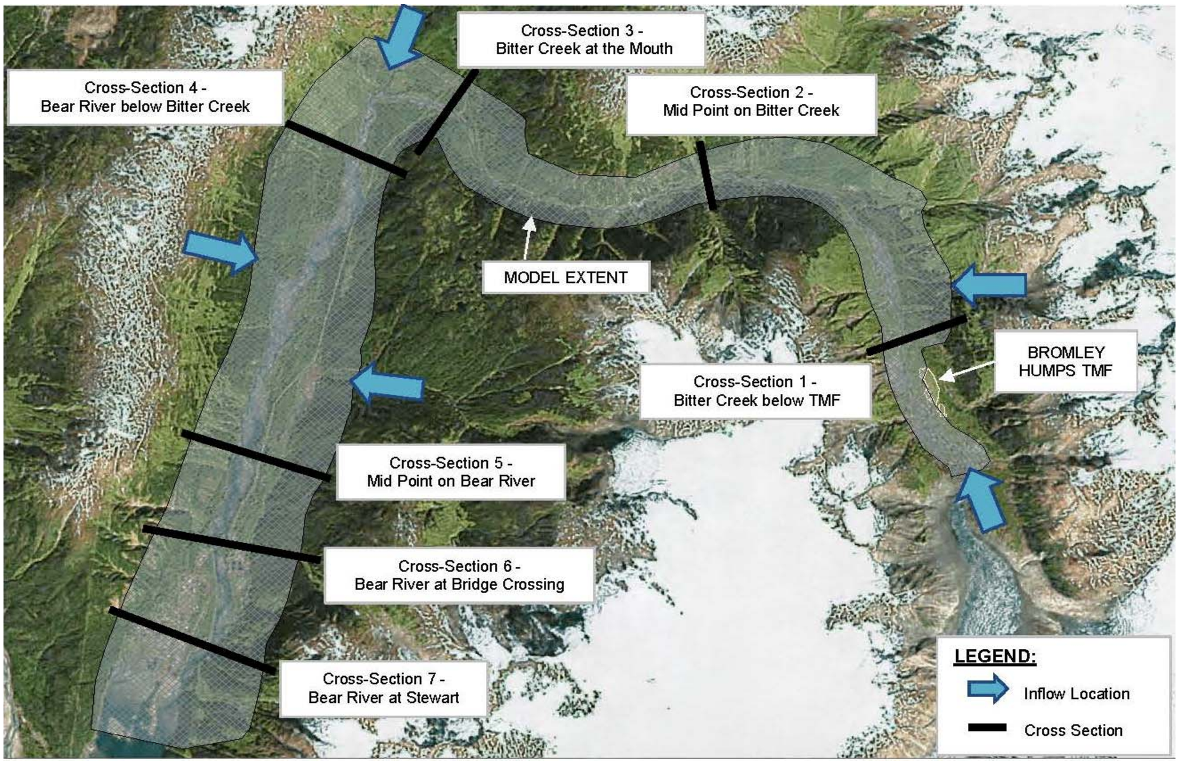


Figure 5.1 HEC-RAS Model Extent and Set-up with Cross-Section Locations

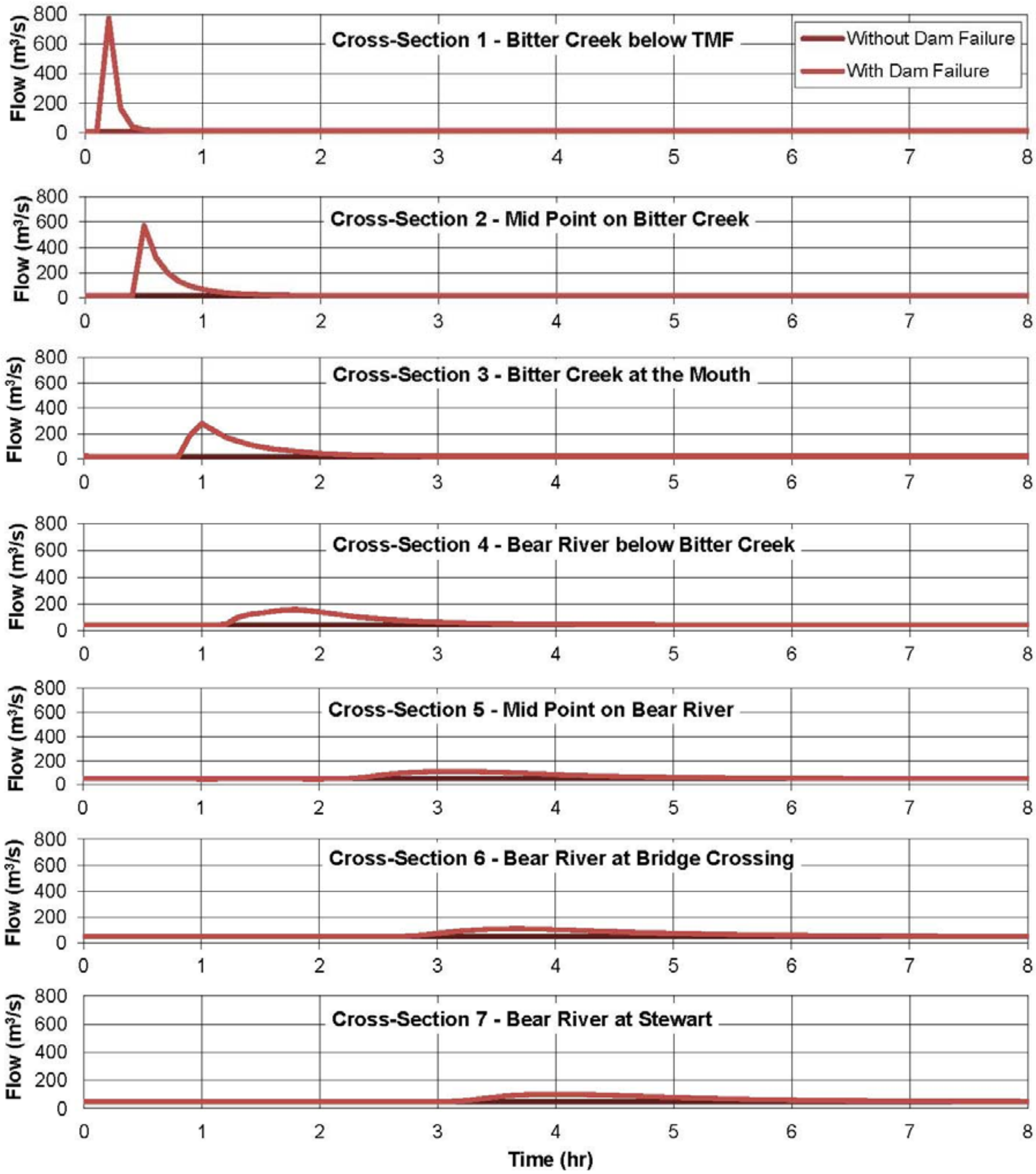
5.2 RESULTS OF THE INITIAL FLOOD WAVE ROUTING

5.2.1 Flood Hydrographs

Flow hydrographs are presented for various cross sections of interest downstream of the TMF for both the fair weather and flood-induced scenarios. The cross-section locations are illustrated in Figure 5.1. The values for peak flow, maximum depth and peak flood wave arrival time for these cross sections are illustrated on the inundation maps presented in Section 7.

5.2.1.1 Fair weather scenario

Figure 5.2 illustrates the modelled variation in discharge at various cross-sections as the flood wave propagates downstream of the TMF through Bitter Creek and the Bear River towards Stewart. The base flows prior to the dam breach are equivalent to the MAD in both watercourses. Flood wave attenuation through Bitter Creek is evident with the peak discharge decreasing from approximately 780 m^3/s a short distance downstream of the TMF to approximately 280 m^3/s at the mouth of Bitter Creek, which is approximately equivalent to the 10-year flood event at this location (based on SRK 2017). The flood wave is further attenuated when it reaches the wider floodplains of the Bear River, with the peak discharge decreasing from approximately 160 m^3/s just below Bitter Creek to approximately 100 m^3/s at Stewart. The flows in the Bear River are of the same order as the mean annual flood (i.e., spring freshet flow).

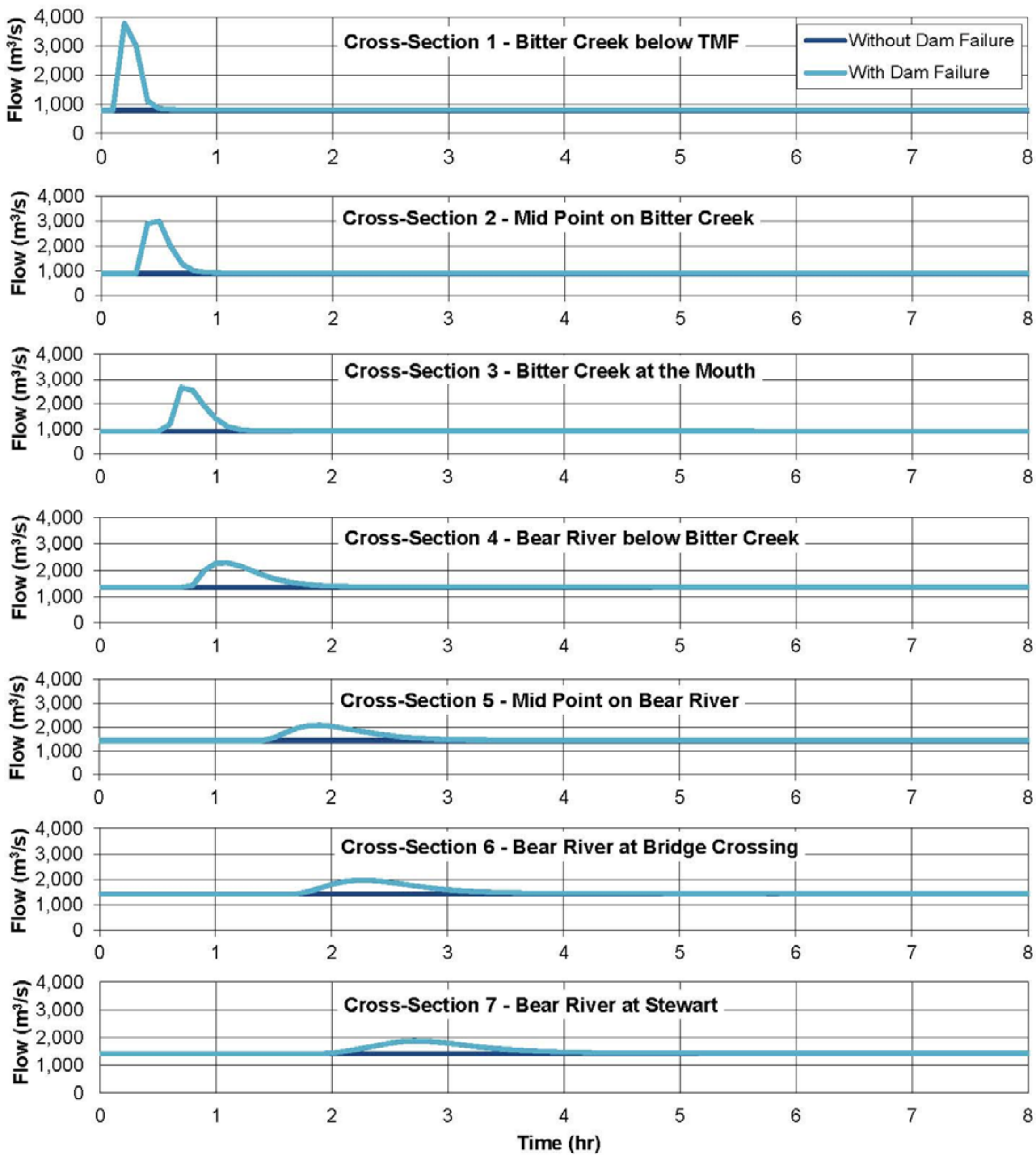


NOTES:
1. TIME 0 HOURS STARTS AT THE BEGINNING OF THE BREACH EVENT.

Figure 5.2 Modelled Fair Weather Scenario Hydrographs

5.2.1.2 Flood-induced scenario

Figure 5.3 illustrates the modelled variation in discharge at various cross-sections as the flood wave propagates downstream of the TMF through Bitter Creek and the Bear River towards Stewart. The base flows prior to the dam breach are equivalent to the PMF in Bitter Creek at the TMF location, and the 500-year flood in the Bear River. Similar to the fair weather scenario, the flood wave attenuation through Bitter Creek is evident with the peak discharge decreasing from approximately 3,800 m^3/s a short distance downstream of the TMF to approximately 2,660 m^3/s at the mouth of Bitter Creek. The flood wave is further attenuated when it reaches the wider floodplains of the Bear River, with the peak discharge decreasing from approximately 2,300 m^3/s just below Bitter Creek to approximately 1,880 m^3/s at Stewart.



NOTES:

1. TIME 0 HOURS STARTS AT THE BEGINNING OF THE BREACH EVENT. THE ONSET OF THE PMP STORM EVENT IS NOT SHOWN ON THE FIGURES, BUT OCCURS APPROXIMATELY 8 HOURS PRIOR TO THE BEGINNING OF THE BREACH EVENT.

Figure 5.3 Modelled Flood-Induced Scenario Hydrographs

5.2.2 Flow Depths

5.2.2.1 Fair weather scenario

Figure 5.4 illustrates the maximum flow depths for the fair weather scenario for both the MAD and dam breach results. Flow depths, as a result of the dam breach, are deeper through Bitter Creek than without the breach with maximum flow depths increasing by an average of 2.5 m throughout the creek. The incremental increase in depth is larger near the TMF at approximately 5.0 m, but decreases in the downstream direction as the flood wave is attenuated to approximately 1.0 m at the mouth of Bitter Creek. Similarly, the average incremental difference through the Bear River is approximately 0.6 m downstream of the confluence with Bitter Creek, decreasing to 0.3 m at Stewart. The flood wave is not predicted to noticeably raise the ocean levels at Stewart.

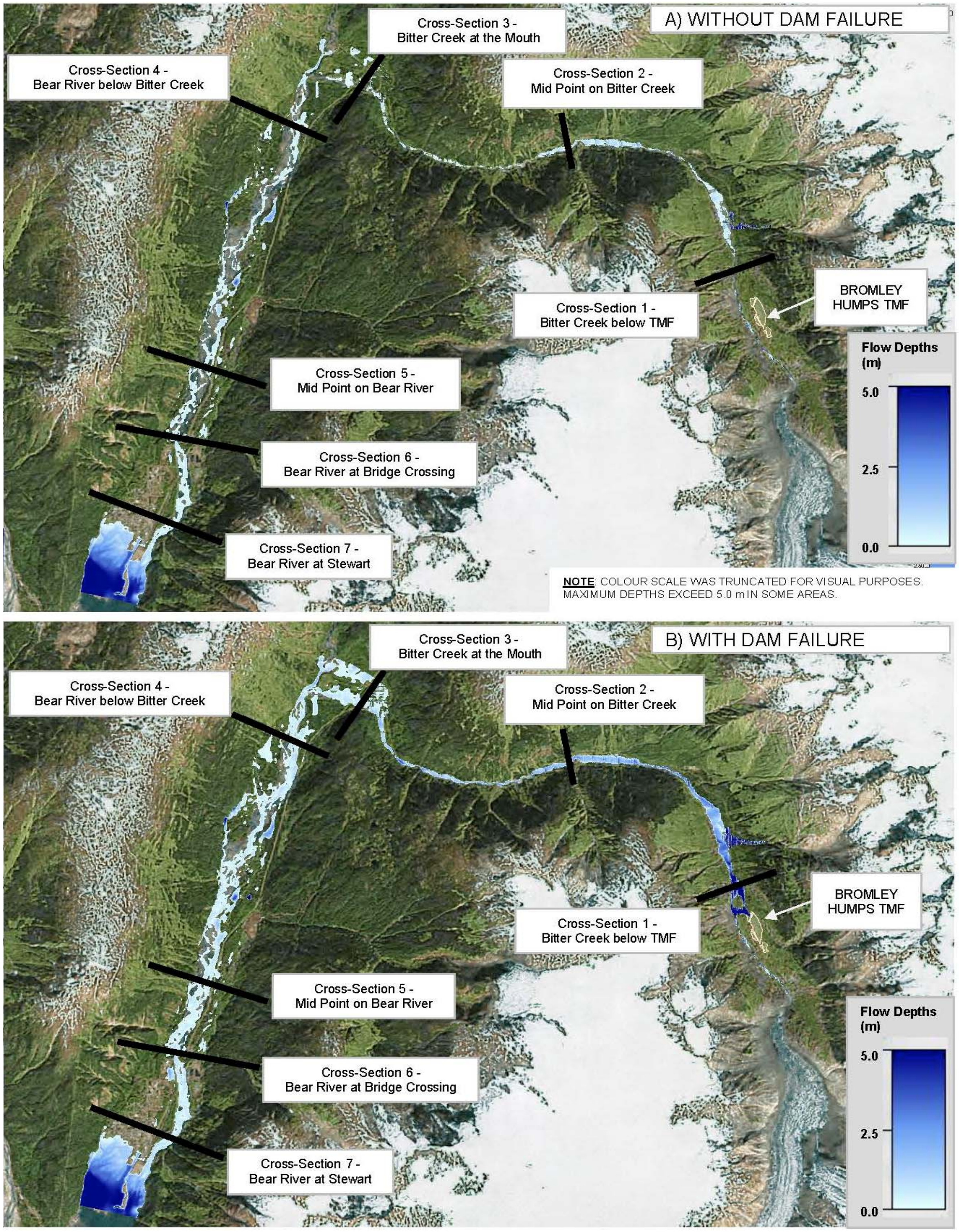


Figure 5.4 Modelled Flow Depths for Fair Weather Scenario

5.2.2.2 Flood-induced scenario

Figure 5.5 illustrates the maximum flow depths for the flood-induced scenario for both the natural flooding and dam breach results. Similar to the fair weather scenario results, the flow depths resulting from the flood-induced dam breach, are deeper through Bitter Creek than without a breach. The maximum flow depths increase by an average of 3.1 m throughout the creek. The incremental increase in depth is larger near the TMF at approximately 4.5 m, but decreases in the downstream direction as the flood wave is attenuated to approximately 1.1 m at the mouth of Bitter Creek. The average incremental difference through the Bear River is approximately 0.4 m downstream of the confluence with Bitter Creek, decreasing to 0.2 m at Stewart. The flood wave is not predicted to noticeably raise the ocean levels at Stewart.

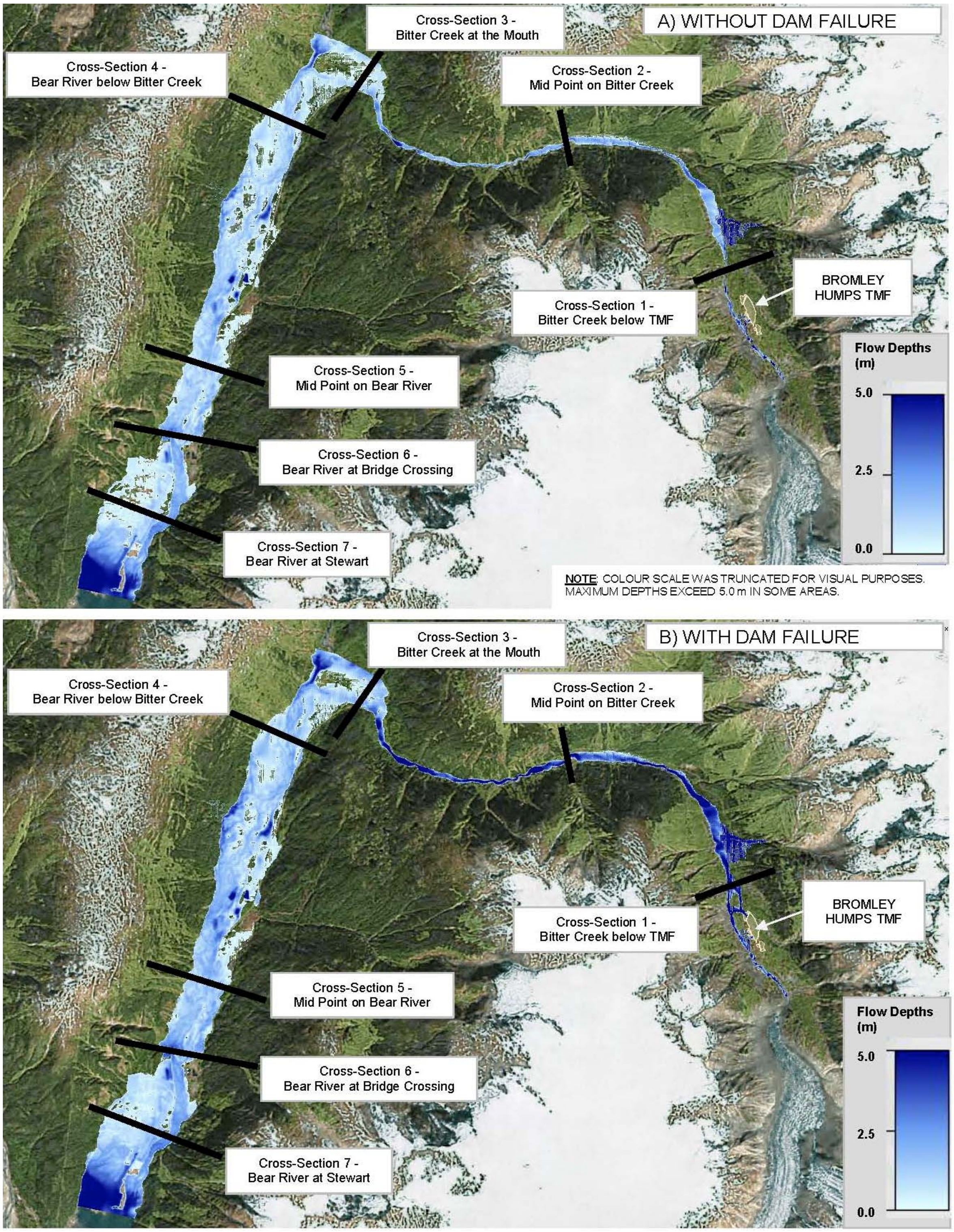


Figure 5.5 Modelled Flow Depths for Flood-Induced Scenario

5.2.3 Flow Velocities

5.2.3.1 Fair weather scenario

Figure 5.6 illustrates the maximum flow velocities for the fair weather scenario for both the MAD and dam breach results. Flow velocities, as a result of the dam breach, are faster through Bitter Creek than without the breach. Flow velocities through Bitter Creek without the dam breach range from approximately 0.75 m/s to 1.5 m/s, and under the dam breach scenario, the velocities increase to approximately 2.5 m/s to 5.0 m/s with velocities exceeding 20 m/s immediately downstream of the TMF. Similarly, the velocities through the Bear River are predicted to be higher with the dam breach than without, but the incremental increase is predicted to be smaller. Flow velocities without a dam breach range from approximately 0.75 m/s to 1.25 m/s and under the dam breach scenario the velocities increase to approximately 1.0 m/s to 1.5 m/s.

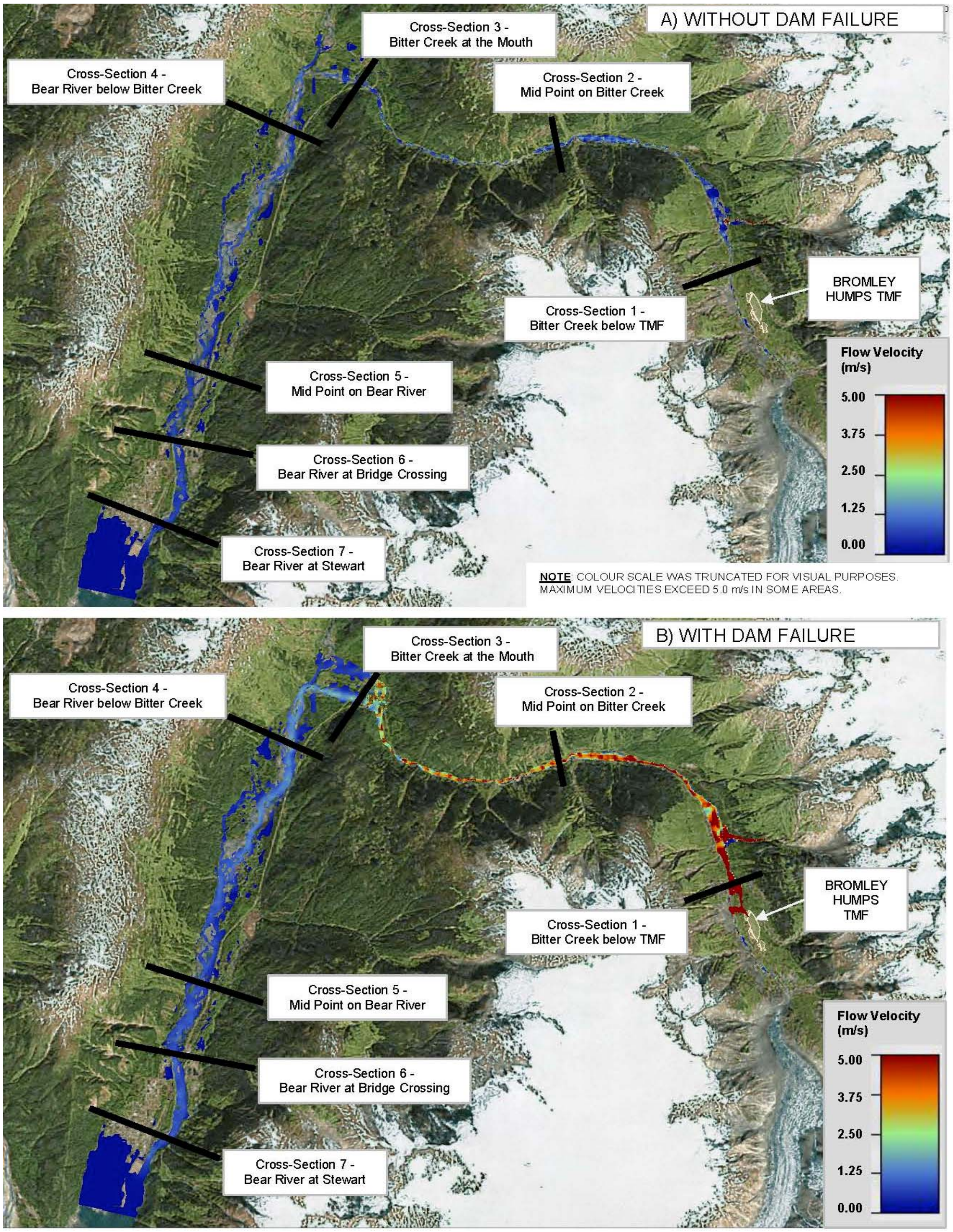


Figure 5.6 Modelled Flow Velocities for Fair Weather Scenario

5.2.3.2 Flood-induced scenario

Figure 5.7 illustrates the maximum flow velocities for the flood-induced scenario for both the natural PMF/500-year flood event without a dam breach and with dam breach. Flow velocities, as a result of the dam breach, are faster through Bitter Creek than without the breach. Flow velocities during natural flooding in Bitter Creek range from approximately 2.5 m/s to 5.0 m/s, while under the dam breach scenario the velocities increase to approximately 5.0 m/s to 10.0 m/s with velocities exceeding 20 m/s immediately downstream of the TMF. Similarly, the velocities through the Bear River are predicted to be higher with the dam breach than without, but the incremental increase is predicted to be smaller. Flow velocities due to natural flooding range from approximately 1.5 m/s to 3.0 m/s and under the dam breach scenario, the velocities increase to approximately 2.0 m/s to 3.5 m/s.

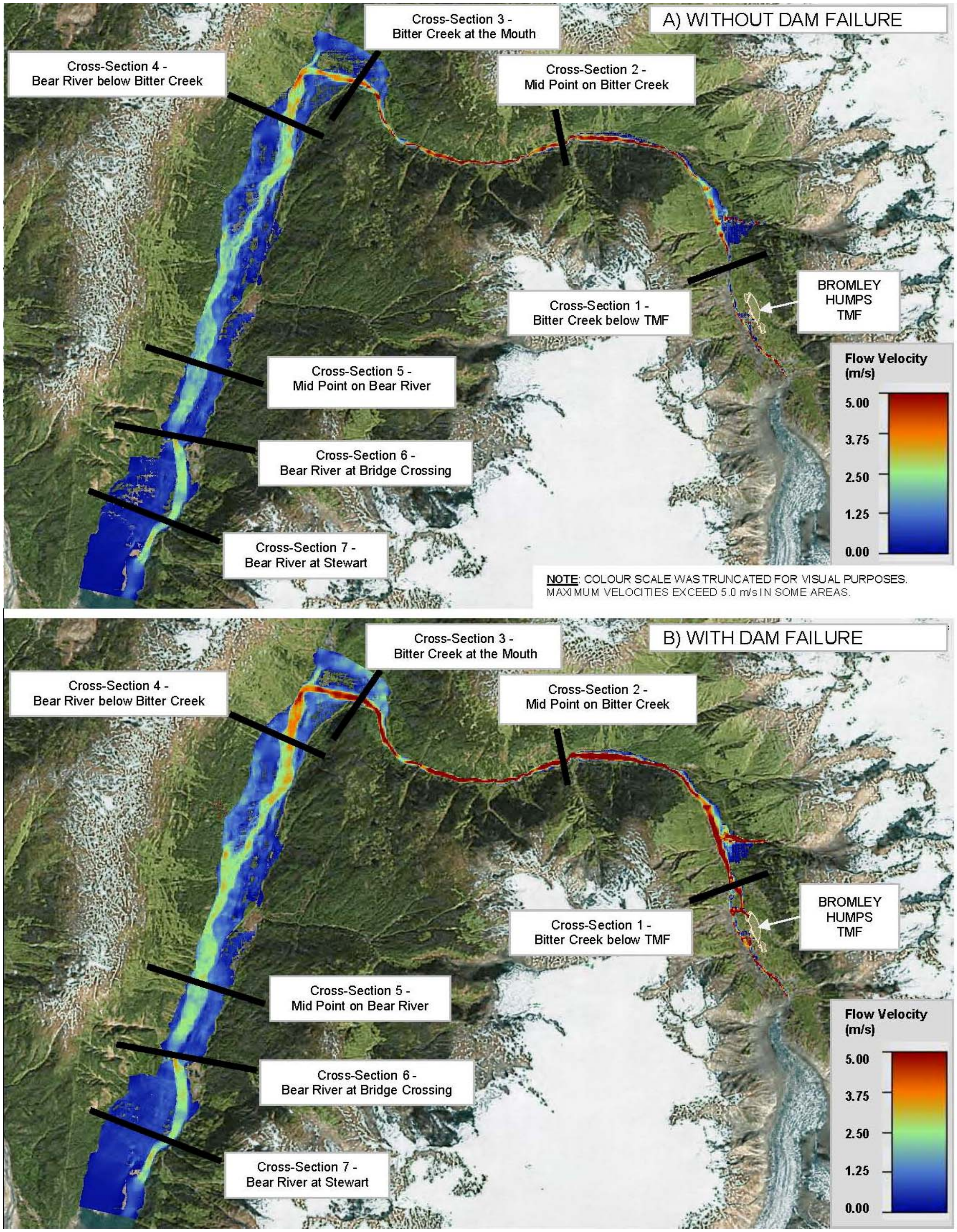


Figure 5.7 Modelled Flow Velocities for Flood-Induced Scenario

5.2.4 Depth-Velocity Product for Stewart

The depth-velocity (DV) product represents the flood severity for an area and can be communicated in categories of Low, Medium, High, Very High and Extreme Hazard, similar to the CDA dam hazard classification (CDA 2014). The DV product is derived from two-dimensional hydrodynamic models and is typically used to assess the potential for loss of life. Studies have been conducted in various countries to categorize the DV product into various flood severity classifications; however, similar guidelines are currently not available in British Columbia or Canada. The flood severity used in this dam breach assessment is based on studies completed in Australia (Hawkesbury-Nepean Floodplain Management Steering Committee 2006). The Australian guidelines have also been adopted by FEMA (2014). The DV severity categories from the Australian study are summarized in Table 5.1.

Table 5.1 Simplified Flood Depth-Velocity (DV) Severity Categories

Flood Severity Category	DV Product Range (m^2/s)
Low	< 0.2
Medium	0.2 – 0.5
High	0.5 – 1.5
Very High	1.5 – 2.5
Extreme	> 2.5

5.2.4.1 Flood-induced scenario

Figure 5.8 illustrates the flood-induced DV product at Stewart for both the natural flooding and dam breach scenarios (Note: a similar figure was not produced for the fair weather scenario, because a fair weather dam breach did not cause flooding in Stewart). The flood severity for Stewart under the natural flooding scenario is generally Low to Medium farthest away from the Bear River main channel. The flood severity increases to High and Very High closer to the riverbank. The Extreme flood severity is showing within the Bear River main channel (in which case, the severity category does not apply), and within a small area of the Bear River RV Park, just downstream of the Bear River bridge crossing. A similar pattern for flood severity is expected with the dam breach scenario; however, due to increased depths and velocities, regions that were previously Low are categorized as Medium to High. The extent of the Very High category has also increased, and covers the entire area along the riverbank, including the airport. The area of the Extreme flood hazard covers most of the RV park area.

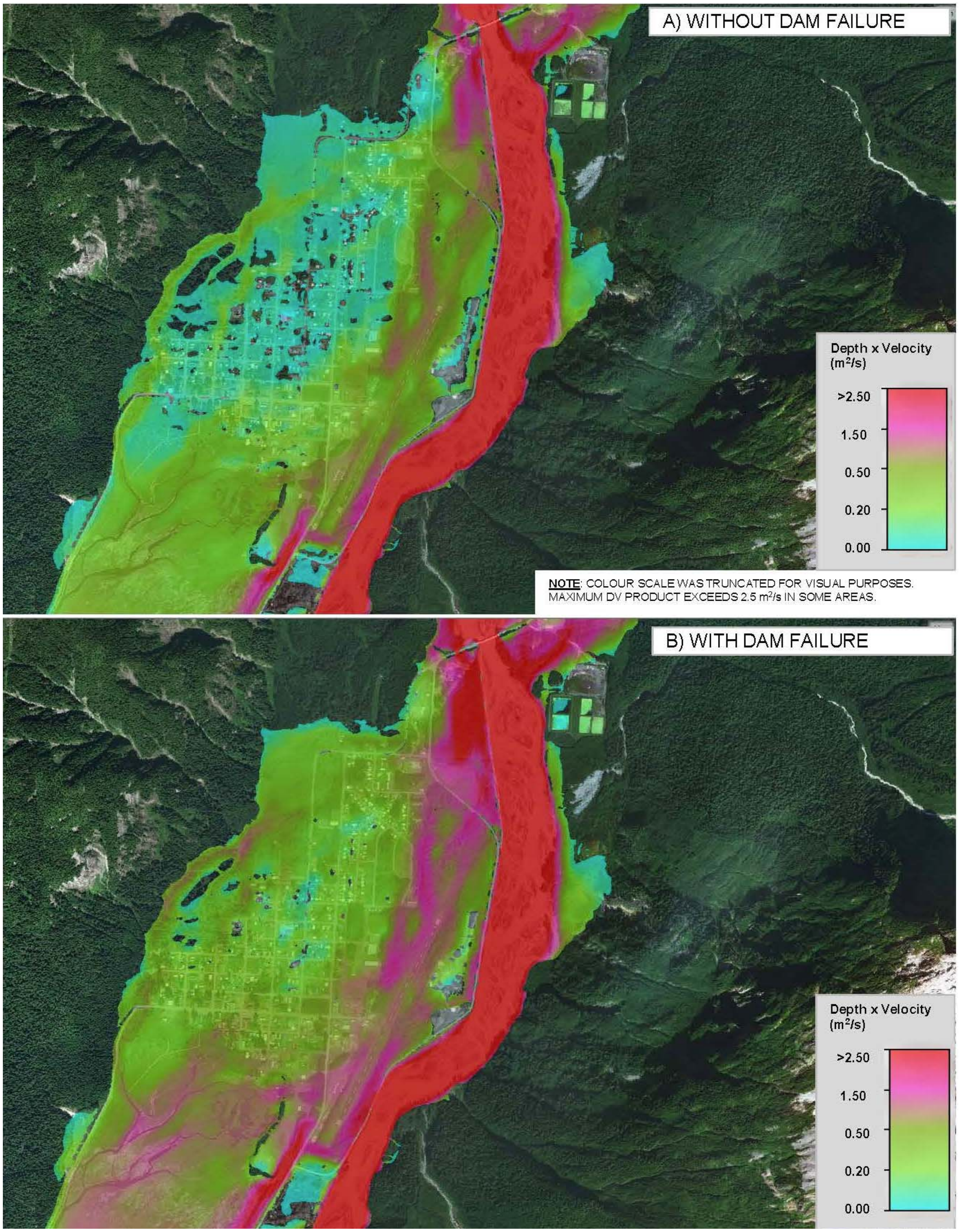


Figure 5.8 Modelled DV Product for Flood-Induced Scenario

6 – TAILINGS SLUMPING

The failure mechanism and breach scenarios in the preceding section considered tailings mobilized by free water with the initial flood wave. All of the stored tailings have a potential to mobilize in the flood-induced scenario with the initial flood wave due to the amount of water flowing into the TMF during a PMF. In the fair weather scenario, however, not all tailings would mobilize with the initial flood wave. It is expected that the tailings remaining in the facility would have the potential to undergo static liquefaction and slump, due to loss of confinement and local steepening of slopes created by the initial discharge. Two tailings slumping scenarios were investigated for the fair weather scenario to determine the volume of slumped tailings and the tailings deposition pattern downstream of the TMF: partial and full release of tailings.

Partial release of tailings

The first fair weather tailings slumping scenario considers a partial release of tailings. The total tailings volume in the breach outflow is based on Rico *et al.* (2008), who established an empirical relationship between the outflow volume (V_F) and the impounded volume (V_T) based on past tailings dam failures:

$$V_F = 0.354 \times V_T^{1.01}$$

This equation predicts that 37% of the impounded volume would be released during a dam breach. Considering that some of this volume would already be discharged with the initial flood wave and carried downstream, a tailings slumping volume of approximately 0.30 Mm^3 was used to model the deposition downstream of the TMF.

Full release of tailings

The second fair weather tailings slumping scenario assumed that the entire tailings volume remaining in the TMF would be released. Under extreme conditions and due to the small size of this facility, a volume of approximately 1.14 Mm^3, could potentially liquefy and discharge from the TMF, then deposit directly downstream. This condition would result in the maximum possible tailings deposition extent within Bitter Creek.

The review of historical tailings dam failures published online by Tailings.Info (2014) and in Rico *et al.* (2007) reveals that there is a considerable range of run-out distances from a few hundred meters to a few tens of kilometres to over a hundred kilometres. The same scatter is evident for outflow volumes. Both the outflow volume and the run-out distance depend on a number of factors including: the stored water volume, the type and volume of stored tailings, whether the tailings would liquefy, the construction method and dam height, the type and size of failure, and the downstream terrain topography. It is reasonable to assume that those solids that initially get mobilized at the onset of the breach when more water is available for mixing, would travel in suspension farther with the flood wave. The solids exiting at the tail end of the outflow hydrograph, would mix with much less water and creep through the breach to travel a much shorter distance, with the tailings rheology having a more pronounced effect at this stage.

Reviews of historic tailings dam failures by Lucia *et al.* (1981) and Blight and Fourie (2003) indicate that the post-failure tailings slope typically varies between 1˚ and 4˚ (1.7% to 7% grade), depending on the downstream terrain slope and on the type and properties of the stored tailings. For this study, a downstream slope of 3% was selected for settled tailings.

A 3D modelling software package (Muck3D) was used to estimate the resulting downstream deposition. The liquefied tailings typically remain mobile and continue flowing if the terrain is sloped at 3% or higher, and conversely, deposit on lower slopes. The deposition was assumed to occur at a slope of 3% both upstream and downstream of the location where the slumped tailings reached Bitter Creek. The modelled maximum tailings deposition is approximately 12 m and 16 m thick for the partial and full tailings slumping scenarios, respectively. The total extent of deposition is approximately 700 m and 2,000 m long for the partial and full tailings slumping scenarios, respectively.

The tailings deposition extent is illustrated in Figure 6.1 for the first slumping scenario based on partial release of tailings (Rico *et al.* 2008), and in Figure 6.2 for the most extreme tailings slumping condition assumed, based on full release of tailings.

Figure 6.1 Tailings Slumping Deposition Extent Based on Partial Release of Tailings

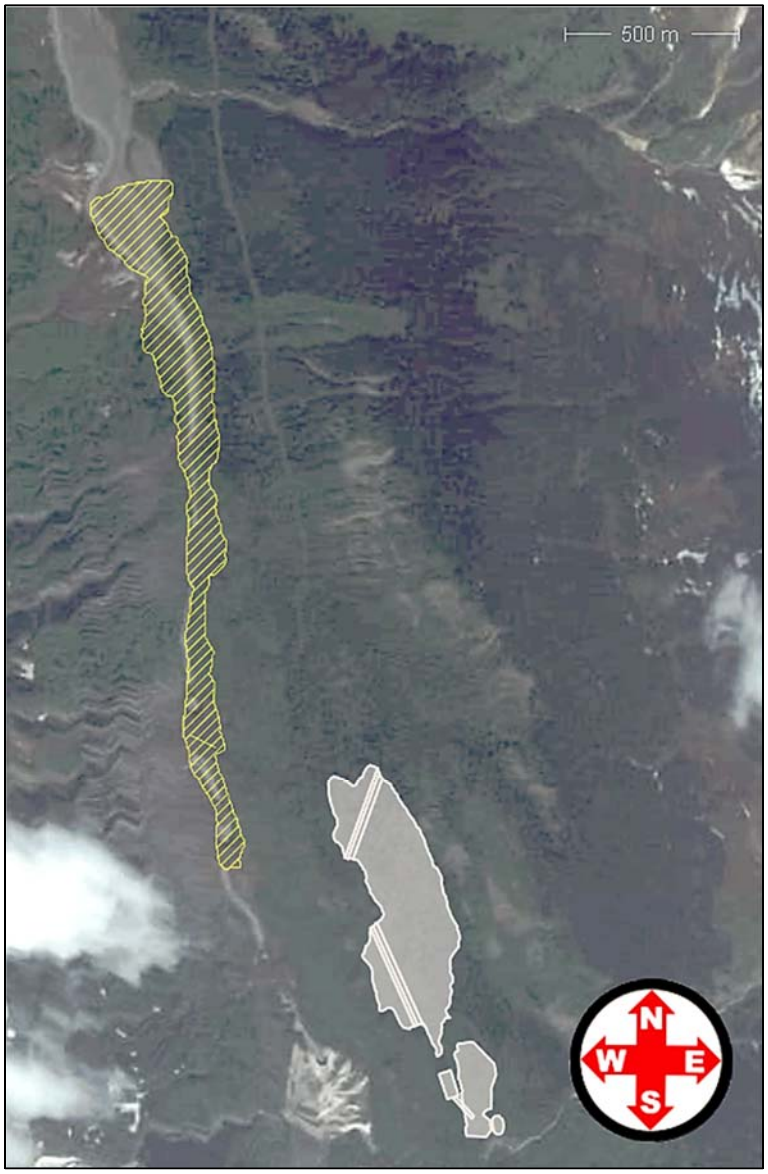


Figure 6.2 Tailings Slumping and Deposition Extent Based on Full Release of Tailings

7 – INUNDATION MAPPING AND CONSEQUENCE ASSESSMENT

Inundation maps were prepared using 1:70,000 scale and ESRI ArcGIS online Bing Maps Aerial imagery and show the maximum water surface extent for each modelled scenario. The maximum water surface extent without dam breach is plotted on top of the maximum water surface extent with dam breach, which allows for evaluation of the incremental impacts due to the breach.

The inundation maps and the incremental flooding due to the breach are used to assess the consequences to PAR and potential loss of life, to environmental and cultural values (including consequences to wildlife and CRA fisheries), and to infrastructure and economic values (CDA 2007, revised 2013, CDA 2014). In this report, we discuss the consequences of incremental flooding with respect to PAR, and impacts to infrastructure. The environmental impacts are discussed in terms of predicted geomorphic changes. Other disciplines responsible for other aspects of the EA will use this information to assess impacts to wildlife, CRA fisheries, and cultural values.

7.1 FAIR WEATHER INUNDATION MAP AND EXPECTED INCREMENTAL CONSEQUENCE

The inundation map for the hypothetical fair weather dam breach scenario is illustrated in Figure 7.1 for the ultimate TMF arrangement. The peak discharge magnitude, the peak flood arrival time, and the maximum depth of flow for both with and without dam breach scenarios are also illustrated in Figure 7.1 for various locations of interest.

Prior to the dam breach, there would be no flooding and the flows would be contained within the stream channels in both Bitter Creek and the Bear River. Following a dam breach, overbank flows and extensive flooding of the Bitter Creek “V”-shaped valley would be expected, particularly in the first 7 to 8 km downstream of the TMF, where the flood wave attenuation is relatively low. There would also be flooding within Bear River reaches; however, the flood wave would be attenuated within the broad “U”-shaped Bear River valley and the flooding would be similar to the mean annual flood that is experienced regularly in this river valley.

The flood wave from a fair weather dam breach may damage or wash out the Highway 37A bridge crossing on Bitter Creek near the confluence with the Bear River, considering that the peak flow due to a dam breach is approximately equivalent to a 10-year flood event at this location, and that it would carry considerable amounts of bed material and debris mobilized from upstream. The peak of the flood wave would reach this bridge in approximately 1 hour after the breach was initiated.

Limited flooding of several sections of Highway 37A along the Bear River is expected to occur during this event. Based on anecdotal evidence, the extent of the highway flooding is predicted to be similar to the flooding that occurs annually during high rainfall events and during the spring freshet season. Damage to the Highway 37A bridge crossing over the Bear River just upstream of Stewart is not expected during this event. The peak of the flood wave would reach this bridge in approximately 3.6 hours after the breach was initiated.

Flooding of the town of Stewart is not expected due to a fair weather dam breach event, and consequently, no loss of life is predicted to the permanent PAR in Stewart. However, industrial and recreational users may be temporarily present on or near watercourses, and may be impacted due to flooding along Bitter Creek. The potential for multiple losses of life is considered to be low for the fair weather scenario.

Environmental impacts are predicted to be limited to Bitter Creek, and the expected geomorphic changes with potential areas of erosion and sediment deposition are discussed further in Section 8.

In conclusion, the incremental impacts due to a fair weather dam breach scenario are predicted to be limited and low to both permanent PAR in Stewart, and infrastructure and economic values, but with potentially notable environmental impacts that would be limited to the Bitter Creek valley.

7.2 FLOOD-INDUCED INUNDATION MAP AND EXPECTED INCREMENTAL CONSEQUENCE

The inundation map for the hypothetical flood-induced dam breach scenario is illustrated in Figure 7.2 for the ultimate TMF arrangement. The peak discharge magnitude, the peak flood arrival time, and the maximum depth of flow are also indicated on Figure 7.2 for various locations of interest.

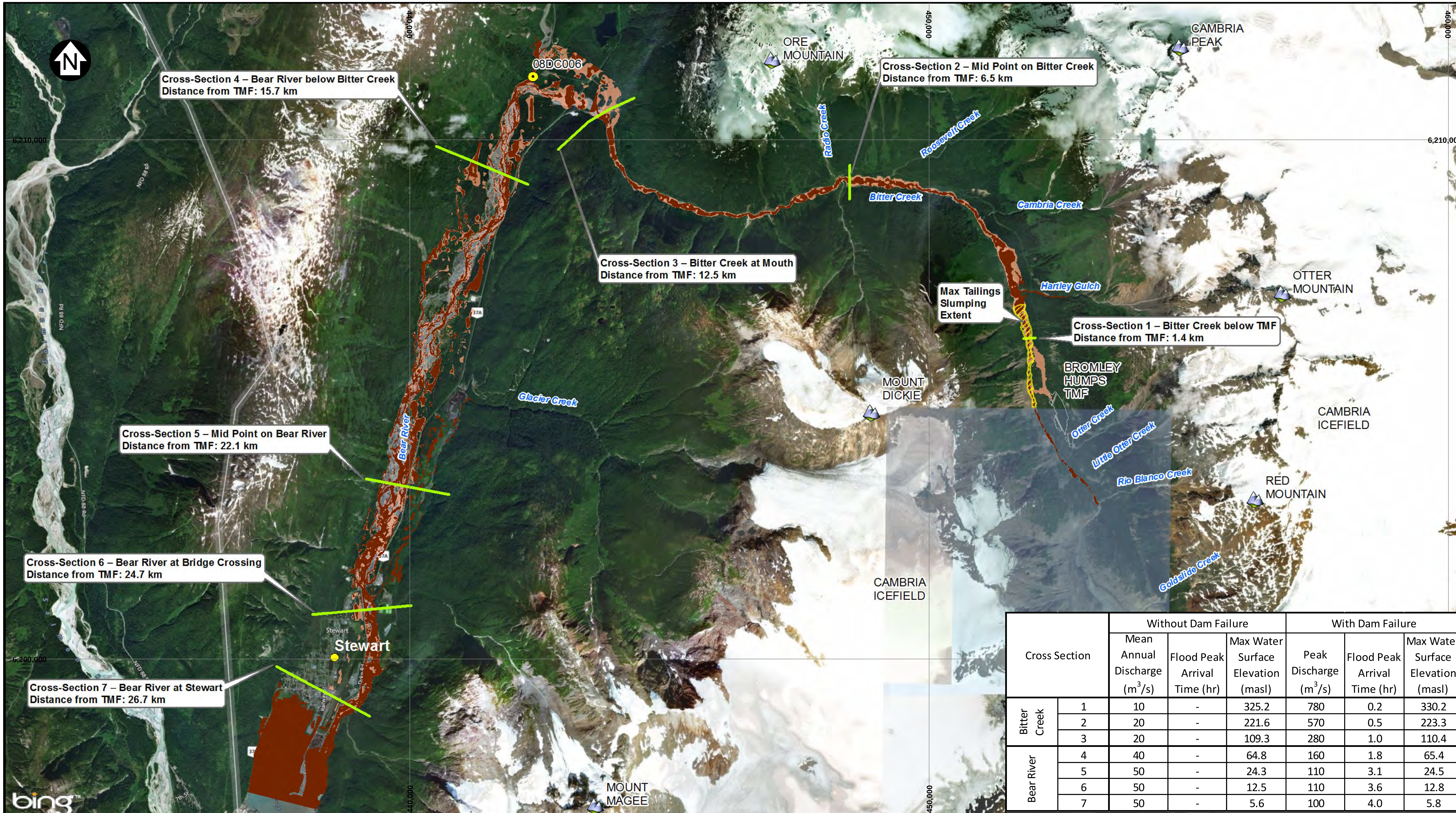
Prior to the dam breach, there would be extreme flooding in both Bitter Creek and the Bear River due to a PMF event occurring in the Bitter Creek catchment and a 500-year flood event occurring in the Bear River catchment. Following a dam breach, there would be incremental flooding of the Bitter Creek "V"-shaped valley, primarily reflected in deeper and faster flows, particularly in the first 7 to 8 km downstream of the TMF, where the flood wave attenuation is relatively low. There would also be extensive flooding within Bear River reaches prior to a dam breach, with flood waters filling the entire river valley bottom. The incremental flooding due to a dam breach would be low due to the flood wave attenuation within the broad "U"-shaped Bear River valley, and primarily reflected through changes in depths and flow velocities, rather than in the aerial extent of flooding.

There are two Highway 37A bridge crossings located downstream of the TMF, one crossing Bitter Creek near the mouth and the other crossing the Bear River at Stewart. The flood levels from the natural flooding occurring prior to a dam breach event are assumed to wash out both of these bridge crossings, as they are most likely not designed to withstand a PMF event. The incremental impact on these bridges due to a dam failure is therefore negligible.

Flooding of the town of Stewart would occur under the natural flood conditions used for the flood-induced scenario. The onset of natural flooding would occur over several hours or days, which would likely provide sufficient evacuation time for the residents of Stewart; however, potential for loss of life exists. The flooding covers the entire area of Stewart, and is worse in the case of a dam breach, particularly along the riverbank, including the airport. Incremental impacts are reflected in deeper and faster flows, as illustrated in Figure 5.8. Consequently, additional impacts to PAR and loss of life may occur if residents of Stewart were not evacuated prior to the dam breach. Temporary PAR such as industrial and recreational users are not expected to be present on or near watercourses (including the Bear River RV Park), or on the roads, due to natural flooding in Bitter Creek and the Bear River.

Environmental impacts are predicted to be extreme in both Bitter Creek and the Bear River due to extreme natural flooding, while the incremental impacts due to a dam breach are expected to be limited. The expected geomorphic changes are discussed further in Section 8.

In conclusion, the incremental impacts due to a flood-induced dam breach scenario are predicted to be limited due to the extreme PMF flooding prior to the breach, and due to the relatively small size of the TMF. The incremental impacts of a dam breach to environmental and cultural values, and to infrastructure and economic values, are predicted to be relatively low; however, potential incremental impacts to the permanent PAR in Stewart, are possible if adequate warning and evacuation times are not utilized.



Cross Section		Without Dam Failure			With Dam Failure		
		Mean Annual Discharge (m^3/s)	Flood Peak Arrival Time (hr)	Max Water Surface Elevation (masl)	Peak Discharge (m^3/s)	Flood Peak Arrival Time (hr)	Max Water Surface Elevation (masl)
Bitter Creek	1	10	-	325.2	780	0.2	330.2
	2	20	-	221.6	570	0.5	223.3
	3	20	-	109.3	280	1.0	110.4
Bear River	4	40	-	64.8	160	1.8	65.4
	5	50	-	24.3	110	3.1	24.5
	6	50	-	12.5	110	3.6	12.8
	7	50	-	5.6	100	4.0	5.8

LEGEND:

- INACTIVE WSC STREAMFLOW STATION
- CITY/TOWN
- CROSS-SECTION
- MOUNTAIN
- TAILINGS SLUMPING BOUNDARY
- FAIR WEATHER WITHOUT DAM FAILURE INUNDATION BOUNDARY
- FAIR WEATHER WITH DAM FAILURE INUNDATION BOUNDARY

1 0.5 0 1 2 3 4 5 Kilometers

NOTES:

1. BASE MAP: BING ONLINE.
2. COORDINATE GRID IS IN METRES. COORDINATE SYSTEM: NAD 1983 UTM ZONE 9N.
3. THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:70,000 FOR 11x17 (TABLOID) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.

IDM MINING LTD.

RED MOUNTAIN UNDERGROUND GOLD PROJECT

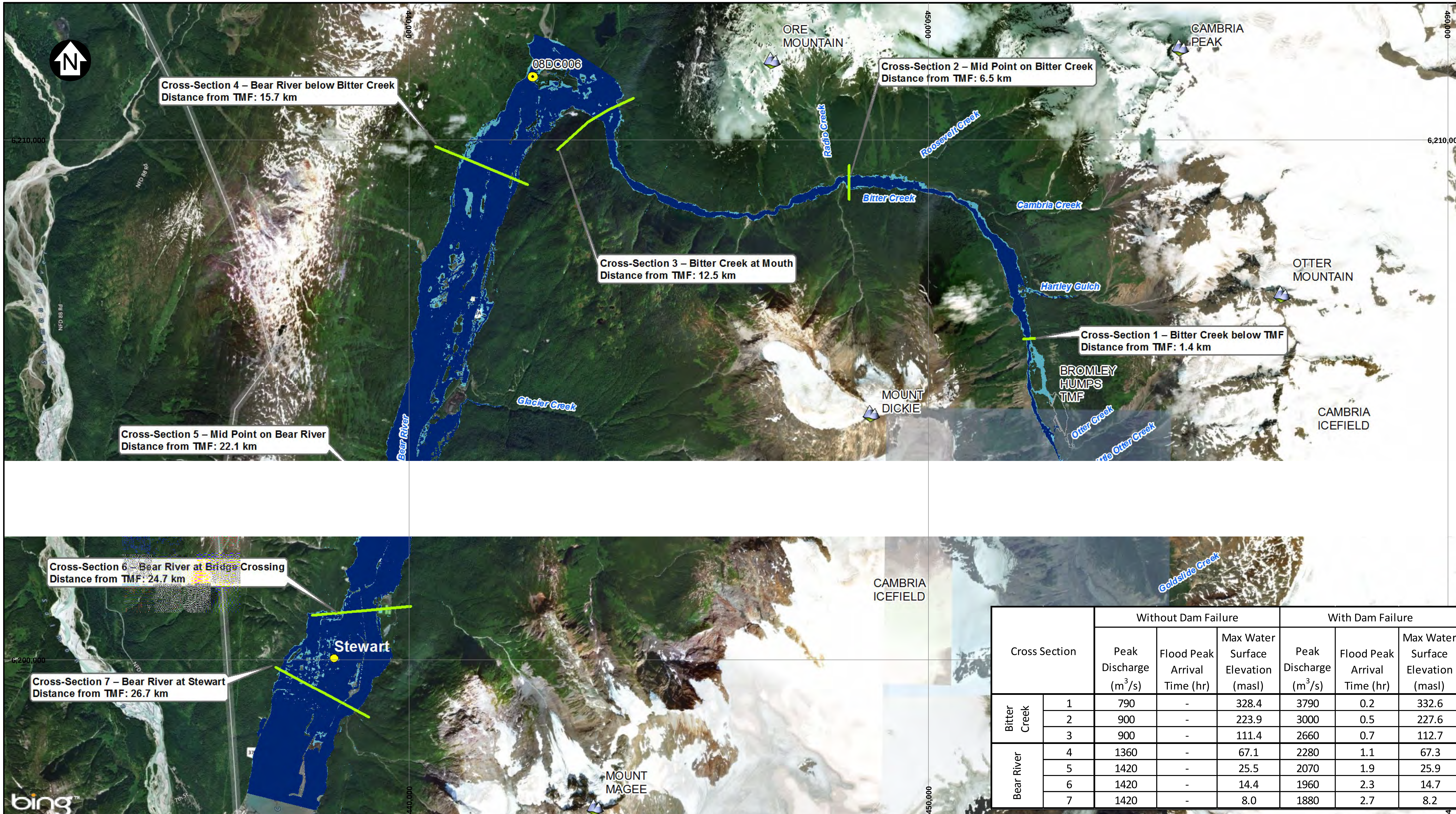
INUNDATION MAP
FAIR WEATHER FAILURE

Knight Piésold CONSULTING

P/A NO.	REF NO.
VA101-594/4	6

FIGURE 7.1 REV 0

REV	DATE	DESCRIPTION	DESIGNED	DRAWN	REVIEWED
0	15JUN'17	ISSUED WITH REPORT	AS1	KK	VM



Cross Section		Without Dam Failure: Peak Discharge (m^3/s)	Without Dam Failure: Flood Peak Arrival Time (hr)	Without Dam Failure: Max Water Surface Elevation (masl)	With Dam Failure: Peak Discharge (m^3/s)	With Dam Failure: Flood Peak Arrival Time (hr)	With Dam Failure: Max Water Surface Elevation (masl)
Bitter Creek	1	790	-	328.4	3790	0.2	332.6
	2	900	-	223.9	3000	0.5	227.6
	3	900	-	111.4	2660	0.7	112.7
Bear River	4	1360	-	67.1	2280	1.1	67.3
	5	1420	-	25.5	2070	1.9	25.9
	6	1420	-	14.4	1960	2.3	14.7
	7	1420	-	8.0	1880	2.7	8.2

LEGEND:

- INACTIVE WSC STREAMFLOW STATION
- CITY/TOWN
- CROSS-SECTION
- MOUNTAIN
- FLOOD INDUCED WITHOUT DAM FAILURE INUNDATION BOUNDARY
- FLOOD INDUCED WITH DAM FAILURE INUNDATION BOUNDARY

1 0.5 0 1 2 3 4 5 Kilometers

NOTES:

1. BASE MAP: BING ONLINE.
2. COORDINATE GRID IS IN METRES. COORDINATE SYSTEM: NAD 1983 UTM ZONE 9N.
3. THIS FIGURE IS PRODUCED AT A NOMINAL SCALE OF 1:70,000 FOR 11x17 (TABLOID) PAPER. ACTUAL SCALE MAY DIFFER ACCORDING TO CHANGES IN PRINTER SETTINGS OR PRINTED PAPER SIZE.

REV	DATE	DESCRIPTION	DESIGNED	DRAWN	REVIEWED
0	15JUN'17	ISSUED WITH REPORT	AS1	KK	VM

IDM MINING LTD.

RED MOUNTAIN UNDERGROUND GOLD PROJECT

INUNDATION MAP
FLOOD-INDUCED FAILURE

Knight Piésold CONSULTING

P/A NO. VA101-594/4 | REF NO. 6

FIGURE 7.2 | REV 0

7.3 POTENTIAL GEOMORPHIC EFFECTS

Past dam breach failures have indicated that the associated flood wave propagation and tailings deposition causes geomorphic changes to the waterbodies downstream of the breach. Potential geomorphic effects of a dam breach for the Project are discussed below in consideration of the observed effects from past tailings dam breaches.

The potential geomorphic effects are expected to be different for the riverine environments (e.g., Bitter Creek and the Bear River), compared to the Portland Canal estuarine environment, and as such, are discussed separately below.

7.3.1 Riverine Effects

Riverine environments where geomorphic effects could occur include Bitter Creek and the Bear River.

7.3.1.1 Geomorphic Setting

Bitter Creek flows through a confined "V"-shaped valley. The valley is constricted by tributary alluvial/colluvial fans in many places, likely composed of bouldery material. Alluvial wedges of finer bed material (e.g., gravel, cobble) have accumulated upstream from these constrictions. Bitter Creek has a large bed material load from active glacial and tributary sources. In short return period floods (i.e., return periods on the order of one to a few years), bed material is mobilized from the alluvial wedge reaches and works its way downstream. In longer return period floods (i.e., return periods on the order of decades to centuries), it is expected that the coarser bed material at the tributary fan constrictions is mobilized, causing channel destabilization and much greater bed material transport during such events.

The Bear River flows within a broad "U"-shaped valley, which was deeply scoured by glacial erosion during the Pleistocene Epoch (Ice Ages), and has since partially infilled with alluvial material built up by the river. The river has an active braided channel that occupies most of the valley bottom width. The braided character of the channel is indicative of the high bed material load of the river, and the fact that the channel is bounded by erodible alluvial material that is continually reworked during short and long return period floods.

The town of Stewart is situated on the Bear River floodplain near the mouth of the Bear River. The town site may be prone to erosion and/or deposition during naturally-occurring, long return period floods.

7.3.1.2 Fair weather scenario

The total volume of released material in the fair weather dam breach event is predicted to be equivalent to 0.2 Mm^3 of supernatant water and 0.27 Mm^3 of tailings materials including interstitial water.

A fair weather failure would have the following geomorphic effects in Bitter Creek:

- The peak flow of the flood wave generated by the dam breach would be similar in magnitude to a natural, long return period flood event in Bitter Creek, ranging from centuries (near the TMF) to a decade (near the Bear River confluence).
- A flood of this magnitude would likely mobilize coarse material in the tributary fan constrictions that is rarely mobilized, causing large-scale bed material mobilization.

- Coarser material (e.g., boulders) would accumulate in the alluvial wedge reaches while alluvial material (e.g., sand, gravel, cobbles) mobilized from the alluvial wedge reaches would be transported downstream to the Bear River.
- Large quantities of woody debris would be entrained by bank erosion and channel widening.
- Following the initial debris flood/flood wave, liquefied tailings would slump through the breach and deposit in the Bitter Creek valley, extending between a few hundred meters to about 2 km downstream of the dam, as indicated in Figure 6.1 and Figure 6.2. Some of this material would have the potential to be remobilized and deposited on bars and floodplains in Bitter Creek and the Bear River during subsequent natural flood events.

A fair weather failure would have the following geomorphic effects in the Bear River:

- The peak flow of the flood wave generated by the dam breach would be similar in magnitude to the natural, mean annual flood event in Bitter Creek (i.e., short return period).
- The erosional response in the river channel would be similar to a mean annual flood event.
- The large sediment source associated with the tailings material released from the TMF and scoured from the Bitter Creek valley would result in the development of an alluvial fan of coarser material (e.g., cobbles, boulders) at the Bitter Creek confluence, and extensive deposition of mid-sized material (e.g., sand, gravel) across the Bear River valley bottom.
- Sediment sizes finer than sand are expected to be transported further downstream as suspended sediment.

7.3.1.3 Flood-induced scenario

The total volume of released material in the hypothetical Red Mountain flood-induced dam breach event is predicted to be 1.1 Mm^3 of supernatant and flood waters, and 1.5 Mm^3 of tailings materials including interstitial water.

The natural, long return period flood conditions used as the basis for the flood-induced failure scenario would cause substantial erosion, sediment and debris transport, and deposition in the absence of a dam breach. The coarse material at the tributary confluences in Bitter Creek would be mobilized, causing large-scale bed material mobilization and channel erosion in Bitter Creek. The alluvial channel of the Bear River would experience substantial erosion, transport and deposition.

The flood-induced dam failure would cause even greater erosion, transport and deposition than would be experienced in the natural flood. It is likely that erosion in the Bitter Creek valley would be limited by scour to bedrock or very coarse boulders, such that incremental increases in peak flow would have limited capability to cause incremental erosional effects. In the Bear River, on the other hand, the alluvial valley fill provides a large source of erodible material and the flood wave would likely cause even greater erosion, transport and deposition than would occur in the natural flood.

7.3.2 Estuarine Effects

The estuarine environment in which geomorphic effects could occur, would be localized to the upstream end of the Portland Canal, just downstream of the town of Stewart. During a dam breach event, water, fine tailings and material entrained from the inundated floodplains will be transported to this estuary. Most of the coarser material (e.g., sand-sized and larger material) that reaches the Portland Canal is expected to settle rapidly in the estuary, while the fine sediments (e.g., silt and clay-sized particles) from the tailings and eroded floodplains are expected to remain in suspension temporarily and cause increased turbidity locally. The duration of these effects could be on the order of days to months, although water clarity will be influenced by the mixing dynamics in the estuary, water depths, and particle sizes of the settling sediment.

7.4 DAM CLASSIFICATION CONSIDERATIONS

The TMF dam classification considers the potential incremental consequences of an embankment failure defined as the total adverse effect from an event with dam failure compared to the adverse effect that would have resulted from the same event had the dam not failed. The incremental losses are defined in the 2014 CDA Guidelines, as illustrated in Table 7.1 (reproduced from Table 3-1 of CDA, 2014).

Table 7.1 Dam Classification (as per CDA, 2014)

Dam Class	Population at Risk[1]	Incremental Losses		
		Loss of Life[2]	Environmental and Cultural Values	Infrastructure and Economics
Low	None	0	Minimal short-term loss. No long-term loss.	Low economic losses; area contains limited infrastructure or services.
Significant	Temporary only	Unspecified	No significant loss or deterioration of fish or wildlife habitat. Loss of marginal habitat only. Restoration in kind highly possible.	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes.
High	Permanent	10 or fewer	Significant loss or deterioration of *important* fish or wildlife habitat. Restoration or compensation in kind highly possible.	High economic losses affecting infrastructure, public transportation, and commercial facilities.
Very High	Permanent	100 or fewer	Significant loss or deterioration of *critical* fish or wildlife habitat. Restoration or compensation in kind possible but impractical.	Very high economic losses affecting infrastructure or services (e.g., highway, industrial facility, storage facilities for dangerous substances).
Extreme	Permanent	More than 100	Major loss of *critical* fish or wildlife habitat. Restoration or compensation impossible.	Extreme losses affecting critical infrastructure or services (e.g. hospital, major industrial complex, major storage facilities for dangerous substances).

NOTES:

1. DEFINITIONS FOR POPULATION AT RISK:
   NONE – NO IDENTIFIABLE POPULATION AT RISK, NO POSSIBILITY OF LOSS OF LIFE OTHER THAN THROUGH UNFORESEEABLE MISADVENTURE.
   TEMPORARY – PEOPLE ARE ONLY TEMPORARILY IN THE DAM-BREACH INUNDATION ZONE (E.G. SEASONAL COTTAGE USE, TRANSPORTATION ROUTES, RECREATION)
   PERMANENT – POPULATION AT RISK IS ORDINARILY LOCATED IN THE DAM-BREACH INUNDATION ZONE (E.G. PERMANENT RESIDENTS)
2. IMPLICATIONS FOR LOSS OF LIFE:
   UNSPECIFIED – THE APPROPRIATE LEVEL OF SAFETY REQUIRED AT A DAM WHERE PEOPLE ARE TEMPORARILY AT RISK DEPENDS ON THE NUMBER OF PEOPLE, EXPOSURE TIME, NATURE OF ACTIVITY AND OTHER CONDITIONS. HIGHER CLASSES COULD BE APPROPRIATE DEPENDING ON REQUIREMENTS.

Based on this dam breach assessment, and considering the relatively limited incremental losses during both the fair weather and flood-induced dam breach events, the hazard consequence classification of the Red Mountain TMF dams is considered to be Very High (CDA 2014). The Very High classification is based on incremental losses defined as (Table 7-1):

- Loss of life – 100 or fewer
- Environmental and cultural values - Significant loss or deterioration of *critical* fish or wildlife habitat. Restoration or compensation in-kind possible but impractical; and
- Infrastructure and economics – Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities for dangerous substances).

Other disciplines responsible for other aspects of the EA are assessing impacts to wildlife, CRA fisheries, and cultural values in more detail to confirm this finding. Further discussion on the dam classification is provided in the feasibility report for this project (KP 2017).

8 – CONCLUSIONS

A tailings dam breach assessment was conducted for the Project and inundation maps were generated for evaluating the downstream incremental impacts to PAR and potential loss of life, to environmental and cultural values, and to infrastructure and economics (CDA 2014). This report discussed the predicted incremental consequences with respect to PAR, infrastructure, and environmental impacts in terms of possible geomorphic changes.

Two hypothetical failure scenarios were evaluated – a fair weather and a flood-induced failure. Flood routing and tailings slumping modelling were completed to assess incremental impacts downstream of the Tailings Management Facility (TMF). Inundation maps that show the incremental flooding extent due to a dam breach were prepared for both scenarios. Maximum flow depths and velocities were also compared to aid with the consequence assessment. Depth-velocity product maps were generated for the Stewart area, which indicate the flood severity and aid with the consequence assessment to PAR.

Although limited, the largest incremental impacts are expected to occur downstream of the TMF within Bitter Creek. These impacts are predicted to be primarily environmental, due to potentially severe geomorphic changes resulting from increased depths and flow velocities compared to conditions without a dam breach. The incremental impacts in the Bear River are expected to be small to negligible during a fair weather scenario, based on flood wave attenuation through the Bear River floodplain.

The incremental impacts to permanent PAR, and infrastructure and economic values are predicted to be relatively limited for both the fair weather and flood-induced scenarios; however, potential impacts to the permanent PAR and potential loss of life in Stewart may increase if adequate warning and evacuation times are not utilized. The predicted small incremental impacts are mostly related to the relatively small size of the TMF, as well as the severity of impacts that would be caused by the extreme natural flooding without a dam breach.

The incremental impacts related to tailings slumping and deposition are substantial, but would occur over a relatively short reach within Bitter Creek. Some of this material has the potential to be remobilized during subsequent natural flood events and deposited on bars and floodplains in Bitter Creek and the Bear River.

Based on this assessment, and considering the relatively limited incremental impacts during both the fair weather and flood-induced dam breach events, the hazard consequence classification of the Red Mountain TMF dams is considered to be Very High (based on CDA 2014; Table 3-1).

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10 – CERTIFICATION

This report was prepared and reviewed by the undersigned.

<Original signed by>

Prepared:

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Memorandum

Date: June 26, 2017

Project: P16002
Red Mountain
Underground Gold
Project_Fisheries

To: Max Brownhill, Brownhill Consulting Services Ltd.

From: Nicola Lower and Rick Palmer, Palmer Environmental Consulting Group Inc.

cc May Mason, Palmer Environmental Consulting Group Inc.

Subject: Evaluation of a Potential Tailings Dam Breach at the Red Mountain Underground Gold Project on Fisheries.

1 Introduction

IDM Mining Ltd. (IDM) proposes to develop the Red Mountain Underground Gold Project (the 'Project'), an underground gold mine in the Bitter Creek valley. The 17,125-hectare Project is located in northwestern B.C., 15 km northeast of the town of Stewart and in Nisg̲a'a traditional territory. The Project is composed of two main areas of activity with interconnecting Access and Haul Roads: the Mine Site with an underground mine and portal access at the upper elevations of Red Mountain (1950 metres above sea level [masl]); and Bromley Humps, situated in the Bitter Creek valley (500 masl), with a Process Plant and Tailings Management Facility (TMF).

The TMF has been designed to store runoff from an Environmental Design Flood (EDF) as per Canadian Dam Association Dam Safety Guidelines (CDA, 2013 & 2014). The EDF for the Bromley Humps TMF is equivalent to the runoff from a 1 in 50 year return period event with an event duration of one month. Flood volumes exceeding the EDF will be safely conveyed from the TMF through the use of an Emergency Discharge Spillway.

Knight Piesold (KP) has completed a tailings dam breach and inundation study for the Project TMF (KP 2017). Two hypothetical failure scenarios were evaluated as per the Canadian Dam Association (CDA) Guidelines (2007; revised 2013): A fair weather scenario which assumes normal operating conditions and a sudden failure due to any cause; and a flood-induced failure which occurs due to an extreme flood.

1.1 Purpose of the Assessment

The extent of impacts and the understanding of the potential failure of the dam are as outlined in the Tailings Dam Breach Assessment (Appendix 23-A). Pertinent results to fish and fish habitat from this assessment are summarized in this memo. The CDA Guidelines provide for the classification of dams in terms of the consequence of failure. The purpose of this technical memorandum is to support the classification of the Project TMF dam, by providing an evaluation of the potential effects of a hypothetical dam breach on commercial, recreational, and Aboriginal (CRA) fisheries in the area. The assessment also aims to address specific comments provided by Fisheries and Oceans Canada (DFO) as part of the Environmental Assessment Working Group Meeting (August 15, 2016):

DFO Comment: *An analysis of the effects to CRA fisheries in the event of a catastrophic failure of the Tailings Management Facility. This information will be used to inform Aboriginal consultation and to provide an understanding of potential effects to downstream CRA fisheries.*

DFO Comment: *The expectation for this analysis would be a robust assessment of potential impacts and risks to CRA Fisheries that would include modelling of wave inundation and erosional forces associated with an event that occurred during a dry (piping) or wet (precipitation) event. This assessment should include discussion of how far the inundation wave would travel, how far erosional forces would extend, and the range of potential effects (e.g. within Bitter Creek, extending downstream into the Bear River, and extending outside of the RSA into Portland Canal).*

The dam breach assessment (KP 2017) does not account for the design safety measures and management practices that will be implemented during all phases of the project to prevent a breach from occurring. As such, this assessment of potential effects to CRA fisheries is a conservative assessment.

2 Overview of Existing Conditions for Fish and Fish Habitat

The baseline studies completed in the study area include detailed review of historical and background information, data gap analysis, and field surveys. Initial baseline field surveys for Fish and Fish Habitat were conducted in 1993 to 1994 (Rescan 1995). The recent baseline programs to support the Application/EIS were carried out from 2014 to 2016 as described in the baseline report (Baseline Fisheries and Aquatic Resources; Appendix 18-A). The scope of the baseline surveys included fish habitat, fish communities, sediment quality, periphyton and benthic macroinvertebrates. For the purposes of the baseline surveys, and the Application/EIS, the study area was divided into a Local Study Area (LSA), and a Regional Study Area (RSA). The LSA was considered to contain watercourses that could be directly affected by mine development and operations, while the RSA represents the zone potentially influenced indirectly.

The LSA is characterized by a deeply-incised valley carved through rugged, rocky terrain. Bitter Creek is a highly turbid watercourse originating beneath Bromley Glacier. The fish habitat in Bitter Creek is generally considered low quality and is constrained by high velocity, heavy suspended sediment loads, and low habitat complexity. Fish habitat is confined to the lower reaches of Bitter Creek, downstream of a series of fish passage barriers that exist on the creek. Side channels in the lower reaches of Bitter Creek provide opportunities for spawning and rearing, although only two species of fish has been documented in Bitter Creek and its tributaries – Dolly Varden (*Salvelinus malma)*, and low numbers of coastrange sculpin (*Cottus aleuticus)* found only near the confluence of Bitter Creek with Bear River. All other fish species recorded are found within the RSA, namely Bear River and its tributaries (Table 1). Bitter Creek is the largest tributary to Bear River, and contains good quality fish habitat, including salmon spawning and rearing areas.

Table 1. Fish Species Documented in the Project Area

Common Name	Scientific Name	Presence	CRA species
Dolly Varden	*Salvelinus malma*	Observed in Bear River, Bitter Creek	X
Coho Salmon	*Oncorhynchus kisutch*	Observed in Bear River	X
Chinook Salmon	*O. tshawytscha*	Observed in Bear River	X
Chum Salmon	*O. keta*	Documented in Bear River	X
Pink Salmon	*O. gorbuscha*	Documented in Bear River	X
Steelhead	*O. mykiss*	Documented in Bear River	X
Rainbow Trout	*O. mykiss*	Documented in Bear River	X
Eulachon	*Thaleichthys pacificus*	Documented in Bear River	X
Coastrange Sculpin	*Cottus aleuticus*	Observed in Bear River, Bitter Creek	

2.1 CRA Fisheries

The only fish species of potential value to CRA fisheries identified in Bitter Creek is Dolly Varden. No known fisheries exist for this species in Bitter Creek. The Nass South Sustainable Resource Management Plan (MFLNRO 2012), which includes the Bear River watershed, has high fish values, including critical habitats for Pacific salmon and steelhead. These species can be considered as CRA fish species, although no commercial fishing fleet has existed in the Stewart area since 2000/2001 (Stoffels 2001). Given the decline of commercial fishing along the BC coast over the past 20 years and changes in the technology and economics of commercial fishing in general, it is unlikely that a commercial fleet will return to the area in the foreseeable future. The RSA falls into the BC's Fish and Wildlife Region 6 - Skeena and Water Body Management Units 6-14 and 6-16 (MFLNRO 2015). There is no fishing permitted in the Bear River watershed, including Bitter Creek. In the Stewart area, recreational fishing is limited to the upper reaches of the Portland Canal and the mouth of Bear River.

The Bear River watershed provides habitat for all five species of Pacific salmon, steelhead, and in the lower reaches of the Bear River and its estuary, Eulachon, all of which are extremely important to Nisg̲a'a citizens for food, social, and ceremonial purposes (MFLNRO 2012). Eulachon have been reported in the upper estuary and in the lower parts of Bear River, downstream of the Bitter Creek Bridge (Cleugh 1979; Noble and Challenger 2015). Although anecdotal information indicates large Eulachon runs up until the mid-2000's, there has been a substantial decline in the past decade which some suspect is a result of gravel extraction and beaver activity on the Bear and Rainy rivers, respectively (Noble and Challenger 2015).

According to comments received during consultation with the Nisg̲a'a Lisims Government (NLG), Nisg̲a'a citizens are not known to currently pursue salmon or Eulachon in the lower parts of the Bear River watershed, nor in the estuary or upper reaches of the Portland Canal. The reason is largely to do with location as the Nisg̲a'a villages are all situated along or near the Nass River, which has abundant runs of salmon actively harvested for food, social and ceremonial purposes. There is also a commercial Nisg̲a'a salmon fishery on the Nass and several well established Eulachon camps where families gather on a seasonal basis to harvest and process Eulachon grease. Currently there is no evidence to suggest that there are any Aboriginal fisheries on the lower reaches of the Bear River. Nonetheless, the Bear River lies within the Nass Wildlife Area where Nisg̲a'a Nation retains Treaty rights to harvest and manage fish.

3 Tailings Dam Breach Assessment

The TMF and Process Plant are located on a plateau above Bitter Creek at Bromley Humps and to the north of Otter Creek, at elevations ranging from 400 m to 500 m. Knight Piésold (KP) has completed a tailings dam assessment for the ultimate arrangement of the North TMF Embankment in the last year of operations (KP 2017).

The largest incremental impacts due to a dam breach are predicted to occur within Bitter Creek, downstream of the TMF. These impacts are predicted to be primarily environmental due to potentially severe geomorphic changes, with erosion resulting from increased depths and flow velocities, and deposition of tailings resulting from tailings slumping. The incremental impacts in Bear River are expected to be smaller, because of the flood wave attenuation through the Bear River floodplain.

The flood wave in a fair weather dam breach scenario attenuates quickly within the broad Bear River valley with the flows predicted to be similar to the mean annual flood in this river. In case of a flood induced scenario, the natural flooding prior to dam breach would inundate the entire Bear River valley.

Following a dam breach, an initial flood wave would occur. The supernatant pond water within the TMF would start to discharge through the developing breach and mobilize both tailings from the impoundment and construction materials from the dam. The flood wave would propagate downstream causing erosion and inundating the downstream environment. The flood wave would carry the tailings solids and dam construction materials, as well as riverine material eroded along the way, resulting in high solid concentrations within the flood wave. Some of the coarser material mobilized by the wave would deposit along the way, while the fine sized tailings would be carried in suspension until the flow velocities are low enough for this material to settle (KP 2017).

Tailings slumping would occur following the initial flood wave, as some portion of the tailings mass remaining in the TMF would be expected to undergo static liquefaction resulting from the loss of containment and the local steepening of slopes created by the initial discharge. The impact extent from the flow of liquefied tailings would be considerably less than the inundation extent from the initial flood wave, but this discharge mechanism would deposit far more solids closer to the dam (KP 2017).

Under the fair weather scenario, flood wave attenuation through Bitter Creek is evident with the peak discharge decreasing from approximately 780 m^3/s at the mouth of Bitter Creek, which is approximately equivalent to the 10 year flood event at this location. The flood wave is further attenuated when it reaches the wider floodplains of Bear River, with the peak discharge decreasing to approximately 100 m^3/s at Stewart, B.C. The flows in Bear River are of the same order as the mean annual flood (spring freshet flow) (KP 2017).

Similar to the fair weather scenario, the flood wave attenuation through Bitter Creek is evident within the peak discharge decreasing from approximately 3,800 m^3/s a short distance downstream of the TMF to approximately 2,660 m^3/s at the mouth of Bitter Creek. The flood wave is further attenuated when it reaches the wider floodplain of Bear River, with the peak discharge decreasing to approximately 1,880 m^3/s at Stewart (KP 2017).

Flow velocities through Bitter Creek without the dam breach range from approximately 0.75 m/s to 1.5 m/s. Under the fair weather dam breach scenario the velocities increase to approximately 2.5 m/s to 5.0 m/s with velocities exceeding 20 m/s immediately downstream of the TMF. The velocities through Bear River are predicted to be higher with the dam breach than without, but the incremental increase is predicted to be smaller. Flow velocities without a dam breach range from approximately 0.75 m/s to 1.25 m/s and under the dam breach scenario, the velocities increase to approximately 1.0 m/s to 1.5 m/s (KP 2017).

Flow velocities during natural flooding in Bitter Creek range from approximately 2.5 m/s to 5 m/s, while under the dam breach scenario the velocities increase to approximately 5.0 m/s to 10.0 m/s with velocities exceeding 20 m/s immediately downstream of the TMF. The velocities through Bear River are predicted to be higher with the dam breach than without, but the incremental increase is predicted to be smaller. Flow velocities due to natural flooding range from approximately 1.5 m/s to 3.0 m/s and under the dam breach scenario, the velocities increase to approximately 2.0 m/s to 3.5 m/s (KP 2017).

Under both scenarios, following a dam breach, overbank flows and extensive flooding of the Bitter Creek ‘V’ shaped valley would be expected, particularly in the first 7 to 8 km downstream of the TMF. There would also be flooding within Bear River reaches, however, the flood wave would be attenuated within the broad ‘U’ shaped Bear River valley, and the flooding would be similar to the mean annual flood that is experienced regularly in this river valley (KP 2017).

4 Effects to CRA Fish

A dam breach and subsequent release of sediment and water resulting in downstream flooding would cause a range of effects to CRA fish, depending on the magnitude, timing, and geographical extent of flooding, as well as the resiliency of resident fish species to adapt to habitat alteration or loss. While lotic fish have evolved within dynamic environmental and geomorphological conditions, and are relatively resilient to variable hydrological conditions, anthropogenic effects add an additional layer of complexity to projecting potential effects (Roghair *et al.* 2002; Milner *et al.* 2012). Examples of potential effects may include reductions of fish densities and biomass, changes in community composition, displacement-related mortality, smothering of incubating eggs, reduction of food availability (e.g. benthic invertebrates), or sub-lethal physiological effects resulting in reduced growth of reproductive rates (Roghair *et al.* 2002; Carline and McCullough 2003; Warren *et al.* 2009; Milner *et al.* 2012).

The following evaluation considers potential pathways of effects from a dam breach on CRA fish, using site-specific baseline information, such as species life history, distribution, and known habitat use.

4.1 Dolly Varden - Bitter Creek

Dolly Varden are found in the lower reaches of Bitter Creek, although suitable habitat is largely confirmed to side channels rather than the mainstem. Adult fish spawn in the fall in clear-water side channels, building a redd for egg incubation until hatching in the spring. Bitter Creek already experiences highly dynamic sediment transport, with seasonal freshets resulting in extreme increases in discharge volumes. These events tend to out-transport any woody debris introduced to the channel via debris torrents and frequent avalanches. As a result, habitat complexity is low and instream features are transitory at best. Side channels and tributaries provide refuge habitat for Dolly Varden, as well as some areas of spawning and rearing habitat (for example, Cambria Creek and Roosevelt Creek).

Under a dam failure scenario, the peak flow of the flood wave would be similar in magnitude to a natural, long return period flood event in Bitter Creek, ranging from centuries near the TMF to a decade near the Bear River confluence (KP 2017). Bitter Creek is non-fish bearing near the TMF, and so the flow event in the fish-bearing lower reaches (downstream of Reach 5) of Bitter Creek would be more comparable to the natural flood event. A flood of this magnitude would likely mobilize coarse material in the tributary fan constrictions, and large quantities of woody debris would be entrained by bank erosion and channel widening. Liquefied tailings would slump through the breach and deposit in the Bitter Creek valley extending to about 2 km downstream of the dam. Approximately the first 500 m downstream of the TMF are considered non-fish bearing, so approximately 1.5 km of fish habitat would be covered with tailings.

Effects to Dolly Varden in this habitat would likely include direct mortality from the force of the flood wave, smothering of gills with suspended materials, and stranding on the falling wave of the flood. Riparian vegetation, soil and alluvium adjacent to the stream channels may be eroded and instream fish habitat would be altered from high rates of erosion and sedimentation. Access to side channels may be restricted, which may alter the availability of spawning and rearing habitat. New channels would be expected to form in Bitter Creek after the event, although depending on the time of year of the dam breach, spawning habitat may be restricted for one season. The contribution of Bitter Creek habitat to the Dolly Varden population is not known, but given the low quality of the existing habitat; the existing dynamic system; and that the dam breach would be similar in magnitude to a natural, long return period, it is likely that the loss of habitat would not have any long-term effects on the productivity within the system.

4.2 Salmon Species - Bear River

The Bear River watershed within the confines of the RSA, extends 24 km from the estuary at Stewart to a short distance above the American Creek confluence. Within this distance, the channel width varies between 30 m to approximately 470 m, with the valley flat measuring close to 1,300 m at its widest point downstream of the Bitter Creek confluence. The RSA lies in the Mountain Hemlock Moist Maritime Parkland, and Windward Variant BEC Zones and is bounded by high, steep valleys to the east and west. High points within the valley include: Mt. Magee rising 1,990 masl on the east above Stewart, with Mt. Welker, Mt. Shorty Stevenson, and Mt. Bunting lining the western valley ridges at elevations of 1,570 m, 2,000 m, and 1,995 m, respectively.

The mainstem of Bear River is a wide, shallow channel that exhibits braiding and anastomosing on the ascending and descending shoulders of the hydrograph. Similar to Bitter Creek, Bear River experiences relatively high turbidity as a consequence of its glacial origins, frequency of torrent, avalanche, and mass wasting events. American and Bitter creeks represent the two most significant tributaries contributing perennial flows to Bear River. In 2014-2016, upstream of the RSA in the Bear mainstem, Coho and Dolly Varden are documented. Other species documented as occurring within the RSA included Rainbow Trout and Steelhead, whose presence is noted a short distance downstream of the American Creek confluence with Bear River, as well as in the Bear River estuary at the terminal end of Portland Canal south of Stewart.

Fisheries Inventory Summary System (FISS) records also indicate the presence of Chum and Pink salmon in the lower Bear River adjacent to the Stewart airport and upstream about 5 km along the left bank adjacent to Highway 37A. Given the spawning behaviour of both these species, it is reasonable to assume they may be present as far upstream as the mouth of American Creek, as river patterns and flow change little between their most upstream recorded distribution and this location. Above American Creek, the Bear mainstem narrows considerably and current velocity may preclude these species from ascending further. Coho and Dolly Varden presence are noted in American Creek from this programs' sampling as well as from the records. The absence of barriers and unchanging river morphology and flow patterns immediately upstream of the sample points suggest that these species are able to ascend further in this system. Below American Creek, Dolly Varden, Coho, Coastrange Sculpin, and Chinook were all observed at various locations. Chinook were observed in the lowest numbers, although similar habitat was noted above its most upstream location, and therefore its presence should also be assumed at least to the American Creek confluence. Coastrange Sculpin exhibit a wide range of habitat preferences and despite their reported high site fidelity, it is reasonable to assume that their distribution in this system extends beyond the limits of the RSA within the Bear River mainstem. Salmonid spawning and rearing areas, although not extensive through the Bear

River watershed, were widely distributed with the majority associated with right bank tributaries and side channels.

The peak flow of the flood wave generated by the dam breach would be similar in magnitude to the natural, mean annual flood event in Bitter Creek (i.e. a short return period). The erosional response in the river channel would be similar to a mean annual flood event (KP 2017). There would likely be extensive deposition of mid-sized material across the Bear River valley bottom, although this is not likely to significantly impact fish species as the river already has a braided streambed with a high sediment load. Given that the salmon species present in Bear River are adapted to the existing dynamic conditions, and that the flood wave would be similar in magnitude to the natural mean annual flood event, then significant effects at a population level are not expected. All salmon species will largely spawn and rear in the tributaries and side channels of the mainstem of Bear River, and these tributaries will be largely unaffected from the predicted flood wave. There may be some additional deposition of material at the confluences with Bear River, but considering the dynamic nature of the system, this is unlikely to restrict access for extended periods of time.

4.3 Eulachon - Bear River

Eulachon spend the majority of their life history in the ocean and only enter freshwater for spawning and incubating. Immediately after hatching, yolk sac larvae are rapidly flushed into coastal estuarine waters, meaning that generally speaking, eulachon are known to spawn in 'lower reaches of rivers' and not to penetrate far into freshwater (MFLRNO 2012). The arrival of Eulachon in the Nass River commences in late February or early March and spawning can continue as late as April with peak spawning thought to occur in mid to late March. Eulachon had been known to return to both the Bear and Rainy Rivers, and that the runs were large up to about the mid-2000's, at which point the run declined to a point a fishery was not sustainable. Despite anecdotal evidence, there are no formal record of Eulachon being present in freshwater at Stewart (MFLRNO 2012), although Bear River Eulachon are known by locals, to be present downstream of the highway bridge. The Eulachon COSEWIC Report (2011), notes that there is very little known about Eulachon in the Bear River, and the runs there are not regular.

As described for the salmon species in Bear River, the peak flow of the flood wave generated by the hypothetical dam breach would be similar in magnitude to the natural, mean annual flood event in Bitter Creek. Spawning habitat for Eulachon is not limiting in most river systems (COSEWIC 2011), and given that fertilized eggs are spatially dynamic and 'tumble' downstreams in rivers, there is little rationale that a hypothetical dam breach would result in significant impacts to the population.

5 Restoration Potential

Historically, watershed restoration efforts following catastrophic disturbance (*e.g.* a large flood) have sought a return to preexisting conditions, and this approach was typically equated to achieving "recovery;" (Bradshaw 1993; Norton *et al*. 2009), or, in this hypothetical case, a return to pre-dam breach conditions. Over the past three decades, however, a new understanding of disturbance and recovery has emerged:

that these processes are dynamic and site-specific, and re-attainment of pre-existing steady-state conditions may be unrealistic due to numerous complex and interacting factors (abiotic, biotic, and societal/anthropogenic) (Stanley *et al*. 2010).

George *et al*. (2015) recently investigated the effects of extreme floods on trout populations and fish communities in a Catskill Mountain river. Study findings indicated that within 10-11 months post-disturbance, that fish assemblages were not strongly impacted (density/biomass) and appeared highly resilient on a basinwide scale. Community composition did not differ significantly between years of the study or between the pre- and post-flood periods. These data provide evidence that resident fish species and their communities may be able to resist or recover rapidly from extreme flood events. Chance events play a large role in determining the effects and recovery from this major flood. George *et al.* (2015) determined that the seasonal timing of the flooding was significant: late summer floods may have been less damaging to stream fish communities than winter or spring floods because spawning activity is negligible and early life stages of many fish species are generally larger and less susceptible to displacement and mortality (George *et al.* 2015). The timing of any failure of the TMF dam will therefore be any important factor in the severity of any impacts to fisheries.

After the initial flood wave, and stabilization of the new channels, fisheries recolonization could occur due to seasonal migrations from the Bear River systems, back to Bitter Creek. Benthic macro-invertebrate recolonization could occur from downstream drift and tributaries downstream of the dam. However, restoration of the channel and riparian systems in the inundation area would be prolonged and it is unlikely that aquatic habitat will be restored to ‘previous conditions’. Complete restoration at Bitter Creek would be impractical given the change to unstable, fine-textured bed material and lack of riparian vegetation. The post-event soft muddy conditions would make channel restoration difficult.

Geomorphological processes, such as those occurring in a flood, can operate in sequence down gravitational flowpaths, forming a cascade of disturbance processes that can drastically alter stream and riparian ecosystems (Nakamura *et al*. 2000). In the aftermath of a catastrophic flood, the affected stream and its watershed can be viewed through time as a network containing a shifting mosaic of disturbance patches. In between patches of disturbance, the pockets of “biological refugia” that persist lend resilience by providing the organisms and energy sources for recolonizing degraded habitats, thereby promoting initial recovery of the disturbed stream network structure (Nakamura *et al*. 2000). This information indicates it would not likely be feasible to restore affected aquatic habitats to “previous conditions” in the event of a hypothetical TMF breach (for both rainy day and sunny day scenarios). Restoration objectives for aquatic habitats would need to be based on realistic expectations of recovery. Restoration to ‘previous conditions’ in Bitter Creek may be problematic, although Bear River is likely to recover relatively quickly, given the existing dynamic nature of the system, and the magnitude of the flooding within the natural mean annual flood event.

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6 Conclusion

Based on the known fisheries in the Project area, as well as the likely scenarios from the hypothetical dam breach, the impact on fisheries could range between 'High' and 'Very High' according to the CDA Guidelines. There are no known endangered fish species that would be displayed from the dam failure. Direct mortality of fish in the initial flood wave would likely be limited to the immediate downstream reaches of Bitter Creek, and be limited to one salmonid species – Dolly Varden. Bitter Creek has existing low fish productivity and the fish species are abundant in neighbouring streams and watersheds. This would facilitate any recolonization after the event. CRA fish in Bear River would likely not be affected to any significant degree, given that the hypothetical dam breach is within the magnitude of a natural mean annual flood event.

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