Technical Memo

Date: September 4, 2018

To: Kelli Bergh, (BMC Minerals (No.1) Ltd.)

From: [Name Redacted] (Minnow Environmental Inc.)

Ec: [Name Redacted] (Minnow Environmental Inc.)

RE: Assessment of the Impact of a Hypothetical Catastrophic Failure of the Proposed Water Management Ponds at the Kudz Ze Kayah Mine Site on Fish and Fish Habitat in the Finlayson River.

1 INTRODUCTION

1.1 Background

BMC Minerals Ltd. (BMC) is proposing to develop the Kudz Ze Kayah (KZK) Project, which is a copper-zinc-lead-gold-silver mine located approximately 250 km northeast of Whitehorse, Yukon Territory, Canada. A prefeasibility study (PFS) design of tailings, waste rock, and water management facilities for the site has been completed (KP 2016a). According to the PFS design of water management facilities, two water management ponds (WMPs), the lower water management pond (LWMP) and the upper water management pond (UWMP), will be located within the current alignment of Geona Creek downgradient of the Process Plant to manage contact runoff water and seepage during the operational phase of the mine. Site contact water will be routed to the UWMP for settling of sediments, and then decanted to the LWMP for additional storage prior to discharge to Geona Creek, which then flows into Finlayson Creek, and onwards to the Finlayson River. Both ponds have been designed to manage a 1-in-200 year, 24 hour storm event (including a 1 m freeboard allowance), and the dams of both ponds will be constructed with geosynthetic liners. The storage capacities of the UWMP and LWMP will be approximately 500,000 m^3 and 250,000 m^3 respectively. At closure, the UWMP will be removed, and the LWMP will be converted to a constructed wetland treatment system for site water discharge.

As part of Adequacy Review of the KZK Project by the Yukon Environmental and Socio-economic Assessment Board (YESAB), the board provided the following information request (IR; YESAB 2017a):

> *R274: In Accidents and Malfunctions a discussion of the impacts on fish and fish habitat and the associated affects to Commercial, Recreational or Aboriginal (CRA) Fisheries that would result from a catastrophic breach of the water management ponds on Genoa Creek should be provided. The expectations 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 or wet year in combination with a dry (piping) or wet (precipitation) event. This assessment would include discussion of how far the inundation wave would travel, how far erosional forces would extend, the range of potential effects.*

YESAB considered the response to the R274 to be insufficient, indicating that the Proponent provided a qualitative response focused on CRA fisheries. The response did not include inundation modelling study. In addition to CRA fisheries, the IR requested an assessment of the potential impacts on fish and fish habitat from a hypothetical failure of the water management ponds. As part of the second Adequacy Review of the KZK Project, the YESAB provided the following IR (YESAB 2017b):

> *R2-124: Provide an assessment of catastrophic failure of the water management ponds on Genoa Creek. This may be included in the response to R2-45 which requests an assessment of impacts associated with the Project on erosion, stream morphology, and riparian vegetation of all affected drainages from projected downstream flow changes during all Project phases.*
>
> *With respect to potential hydrologic/hydraulic impacts, there is potential, at least in Geona Creek, to result in an impact to stream morphology which could have a subsequent impact on fish and fish habitat. For instance, breach of the WMPs could result in (i) release of sediment downstream, (ii) erosion of sections of Geona Creek, (iii) sediment deposition in sections of Geona Creek, and (iv) change in stream morphology as a result of the erosion/sedimentation and alteration of natural erosion/sedimentation processes.*

A memorandum was submitted in response to R2-124, and the memo (henceforth, referred to as 'R2 Memo'; Minnow 2017; Appendix A) included an assessment of the potential impact of a hypothetical catastrophic failure of the proposed UWMP and LWMP to downstream fish and fish habitat in Geona Creek. The assessment summarized in the memorandum was focused on downstream Geona Creek and Finlayson Creek starting from the LWMP dam to station KZ-26, a water quality monitoring station in Lower Finlayson Creek, which is about 25.7 km from the LWMP. This spatial extent was consistent with the Project Local Study Area (LSA) utilized in the baseline monitoring of aquatic resources (Alexco 2016).

YESAB determined that the submitted memo was insufficient (based on feedback from the Fisheries and Oceans Canada (DFO)) and requested the information again in R3-14 (YESAB 2018) "*Provide a discussion of the impacts on fish and fish habitat and the associated effects to Commercial, Recreational or Aboriginal Fisheries that would result from catastrophic failure of the water management ponds in Genoa Creek*."

Given that this question had been previously addressed, BMC contacted DFO to see if they had reviewed Appendix R2-0. BMC subsequently sent Appendix R2-0 to DFO. DFO has acknowledged that they had not seen or reviewed the Appendix prior to re-submitting the question to YESAB for IR3. DFO has now seen and reviewed the memo and are expected to submit comments to YESAB concerning the response. To date via email DFO have indicated two new concerns:

i. The memo states that there is no CRA fishery within the area considered for the memo. As the systems involved are covered under the recreational fishery regulations for the Yukon, these systems are deemed by DFO to be part of a recreational fishery. This results in them being considered as a CRA fishery. Further, Indigenous community members have raised the issue of fish passage through the Robert Campbell Highway culvert crossing of Finlayson Creek. As there is a CRA fishery involved, the conclusions in the memo regarding impacts to CRA fisheries should be revisited.

ii. The memo only considers the watercourses down to the Robert Campbell Highway culvert crossing of Finlayson Creek despite the information indicating that the inundation wave and effects will still occur to this point. The areas that will be affected downstream and the effects that will have there should also be revisited.

With respect to concern 1, BMC agrees with DFO that the system should be regarded as or has potential to support recreational and aboriginal fisheries. This was recognized by BMC in the preparation of the Fisheries Offsetting Plan (Appendix E-4 of the Project Proposal).

With respect to concern 2, this memorandum has been prepared in response to IR R3-14, and includes an extended assessment of the potential impact of a hypothetical catastrophic failure of the proposed UWMP and LWMP in the Finlayson River, from Lower Finlayson Creek station KZ-26 (the last station of the earlier assessment; Minnow 2017; Appendix A) to a downstream station in the Finlayson River which is about 50 km from the LWMP dam (about 25 Km from

KZ-26; Figure 1). This memorandum outlines the approach, assumptions, and results of the assessment in the Finlayson River.

2 METHODS

Three locations on the Finlayson River downstream of KZ-26 were selected for the assessment (Figure 1). KZ-FR1 is an upstream location of the Finlayson River, and is closest to the confluence of Finlayson River and the outflow creek of Finlayson Lake. KZ-FR1 is about 4.5 km downstream of KZ-26, while KZ-FR2 and KZ-FR3 are about 10 km and 20 km farther downstream of KZ-FR1, respectively. The discharges corresponding to the 1-in-50 wet year scenario at these stations were estimated by pro-rating the discharge at KZ-26, which was predicted by the water balance model developed for KZK (Alexco 2017; Appendix D-6 of the Project Proposal). The 1-in-50 wet year scenario was used for the discharge in order to be consistent with the hypothetical catastrophic failure of the WMPs that was assumed to occur under a rainy day scenario (see R2 memo; included as Appendix A of this memo). The estimated discharge of 14.6 m^3/s at KZ-26 is consistent with the mean annual discharge of 16.5 m^3/s reported in a technical study for Yukon Energy Corporation (KP 2016b) presumably for a location farther downstream on the Finlayson River.

The same methodologies that were used for the earlier assessment (i.e., the R2 memo) were followed for the assessment in the Finlayson River. For a full account of these methods, please refer to R2 memo (Minnow 2017; Appendix A of this memo). Briefly, first, a worst-case scenario representing a hypothetical catastrophic failure of the WMPs was developed. The hypothetical catastrophic failure of the WMPs was assumed to occur under a rainy day scenario and a sequential dam failure case, in which the failure of the upstream dam of the UWMP caused the subsequent failure of the downstream dam of the LWMP.

The breach dimension, peak discharge, and the flood hydrograph were then estimated for the worst-case WMP failure scenario (as per methods in R2 memo). The attenuation of the dam breach peak discharge as the flood wave travels downstream was estimated. Subsequently, the potential geomorphological impacts of the dam breach peak flow discharge on downstream stations were analyzed based on stream power analysis. The stream power of a water flow indicates its ability to influence geomorphology, and is a measure of the main driving forces acting in the channel (i.e., the joint effect of channel gradient and discharge) (Bizzi and Lerner 2015). Stream power has also been widely used to assess sediment transport and channel geomorphic patterns (e.g., Bagnold 1977; Chang 1979; Ferguson 2005). Total stream power (TSP) and specific stream power (SSP) at the selected monitoring stations in Geona Creek, Finlayson Creek, and Finlayson River were calculated as (Bagnold 1966, 1977):

$$TSP = \gamma QS, \quad SSP = \frac{TSP}{W}$$

Where γ is the unit weight of water (9,800 N/m^2), *Q* is the estimated attenuated peak discharge, *S* is energy slope which was approximated as bed slope, and *W* is the channel bankfull width. The calculated stream power was compared with a threshold stream power value (referred to as 'critical stream power') to analyze the likelihood of downstream sections experiencing major erosional processes. When stream power exceeds the critical stream power, erosion dominates (Bull 1979). There have been a range of values of critical specific stream power in the literature; the following thresholds of SSP suggested by the United States Department of Agriculture (Yochum and Scott 2017; Yochum et al. 2017) were applied in this study:

- Highly likely (90% potential) and likely (50% potential) of major geomorphic change with avulsions, braiding, and elimination of roadway embankments due to erosion-dominated processes for SSP > 2400 W/m^2 and SSP > 990 W/m^2, respectively.

- Highly likely (90% potential) and likely (50% potential) of substantially widened channel due to erosion-dominated processes for SSP > 2000 W/m^2 and SSP > 790 W/m^2, respectively.

In the R2 memo, the estimation of attenuation of the dam breach peak discharge and the potential geomorphological impacts of the discharge were carried out until KZ-26, and this memo extends the analysis approximately 50 km downstream to KZ-FR3.

3 RESULTS

3.1 Inundation and Potential Sediment Erosion/Deposition in Finlayson River

The inundation analysis for the worst-case scenario of the failure of the proposed KZK WMPs resulted in the following (summarized in Table 1 and Figure 2):

- The attenuation analysis of the peak discharge showed that the peak discharge is expected to attenuate from 438 m^3/s at the LWMP dam (see R2 memo) to about 131 m^3/s within 25.7 km (at KZ-26), 108 m^3/s within 30.2 km (at KZ-FR1), 55 m^3/s within 40.1 km (at KZ-FR2), and 1.6 m^3/s within 50.2 km (at KZ-FR3) (Table 1). The peak discharge at KZ-FR3 is about 11% of 1-in-50 wet year discharge at KZ-FR3 (14.6 m^3/s). Hence, the effect of the peak discharge is expected to be negligible when the flood wave reaches KZ-FR3.

- The estimated potential maximum flood depth (Figure 2) corresponding to the peak flow is expected to be higher than the bankfull depth in KZ-FR1 and KZ-FR2 (i.e., the average bankfull depth in these locations is expected to be 1 - 2 m). However, the maximum flood depth is expected to be negligible (0.14 m) at KZ-FR3 (Table 1).

- The SSP for all three stations of Finlayson River (3 to 304 W/m^2) were less than 790 W/m^2 (Table 1), and so it is unlikely (i.e., <50%) that these locations may experience major geomorphic changes (e.g., avulsions, braiding, or elimination of roadway embankments) caused by erosion-dominated processes. As SSP is very low at KZ-FR3 (SSP = 3), most of the sediments that were carried out by the flood wave may be deposited in between KZ-FR2 to KZ-FR3.

3.2 Potential Impact on Fish and Fish Habitat

Predicted peak flows, specific stream power, and erosion potential in the Finlayson River are much lower than in Geona Creek and Finlayson Creek, as expected based on the size of these waterbodies (Table 2). Peak flows in the Finlayson River are predicted to be lower than swimming velocities for sub-carangiform[1] swimmers in general (e.g., Katopodis 1992[2]) and arctic grayling in particular (Omtzigt and Tobler 2008; Larocque et al. 2014). Specifically, arctic grayling are not found in velocities greater than 1.5 m/s (Larocque et al. 2014), maximum prolonged speed is 0.8 to 2.1 m/s, and maximum burst speed is 2.1-4.3 m/s (Omtzigt and Tobler 2008). This suggest that fish mortalities would be limited as fish can move to quiescent areas and stranding is unlikely. No erosion is expected in the Finlayson River, but deposition of suspended sediments is expected (Table 2).

Suspended particles from the upstream erosion have the potential to smother gills, as well as eggs and young-of-the-year (Minnow 2017). However, such effects in the Finlayson River would be temporary, and would not be a concern once the sediments settle out after the initial flood wave has passed through the system. High suspended sediment loads can also have some effect on growth, depending upon the duration and timing of high turbidity (>25 NTU or > 100 mg/L TSS). Possible reduction in growth rates of the under-yearling salmonids including arctic grayling was shown to occur at 25 NTU (BCMOE 1997; McLeay et al. 1984). However, TSS elevations would be expected to be of durations lower than those at which growth impacts have been observed (i.e., 3 to 6 weeks; McLeay et al. 1984). It is notable that the magnitude of potential effects associated with a failure would be dependent upon time of year. A failure and peak flood

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[1] Sub-carangiform swimmers are fish that propel themselves primarily by tail movement, with the vast majority of the work being done by the rear half of the fish (although the body of sub-carangiform swimmers is not completely rigid as with carangiform swimmers). Salmonids, including graylings, are sub-carangiform swimmers

[2] Burst speeds are the swimming velocities for escape and feeding that can be sustained for up to 165 sec (Katopodis 1992). Prolonged speeds are the swimming velocities that can be maintained for up to 200 min through difficult areas (Katopodis 1992).

event during critical periods of migration, spawning, egg incubation, and rearing would result in greater impact than failure outside of these periods.

Arctic grayling are a widespread species in the north, and are found in most waters throughout the Yukon. Although arctic grayling of the project area are considered to be part of CRA (Commercial, Recreational, and/or Aboriginal) fisheries (as indicated in the response to R3-14), arctic grayling populations of the region are generally secure, although some spring spawning runs have declined and monitoring is ongoing to determine the success of regulatory changes limiting harvest (Environment Yukon 2010). Thus, the Geona Creek, Finlayson Creek, and Finlayson River system does not provide unique or specialized habitat that provides critical life-history function.

4 CONCLUSIONS

An assessment of the potential impact of a hypothetical catastrophic failure of the proposed water management ponds at the Kudz Ze Kayah site to fish and fish habitat in Finlayson River was conducted. Erosional force resulting from peak water discharge from the failure is not expected to cause significant impact to the downstream channel morphology. The impact of peak water discharge and the maximum flood depth is expected to be negligible approximately 50 km downstream from the LWMP dam. Overall, effects of a failure of the Kudz Ze Kayah WMPs, which is of very low probability, are predicted to be limited and of short duration in the Finlayson River.

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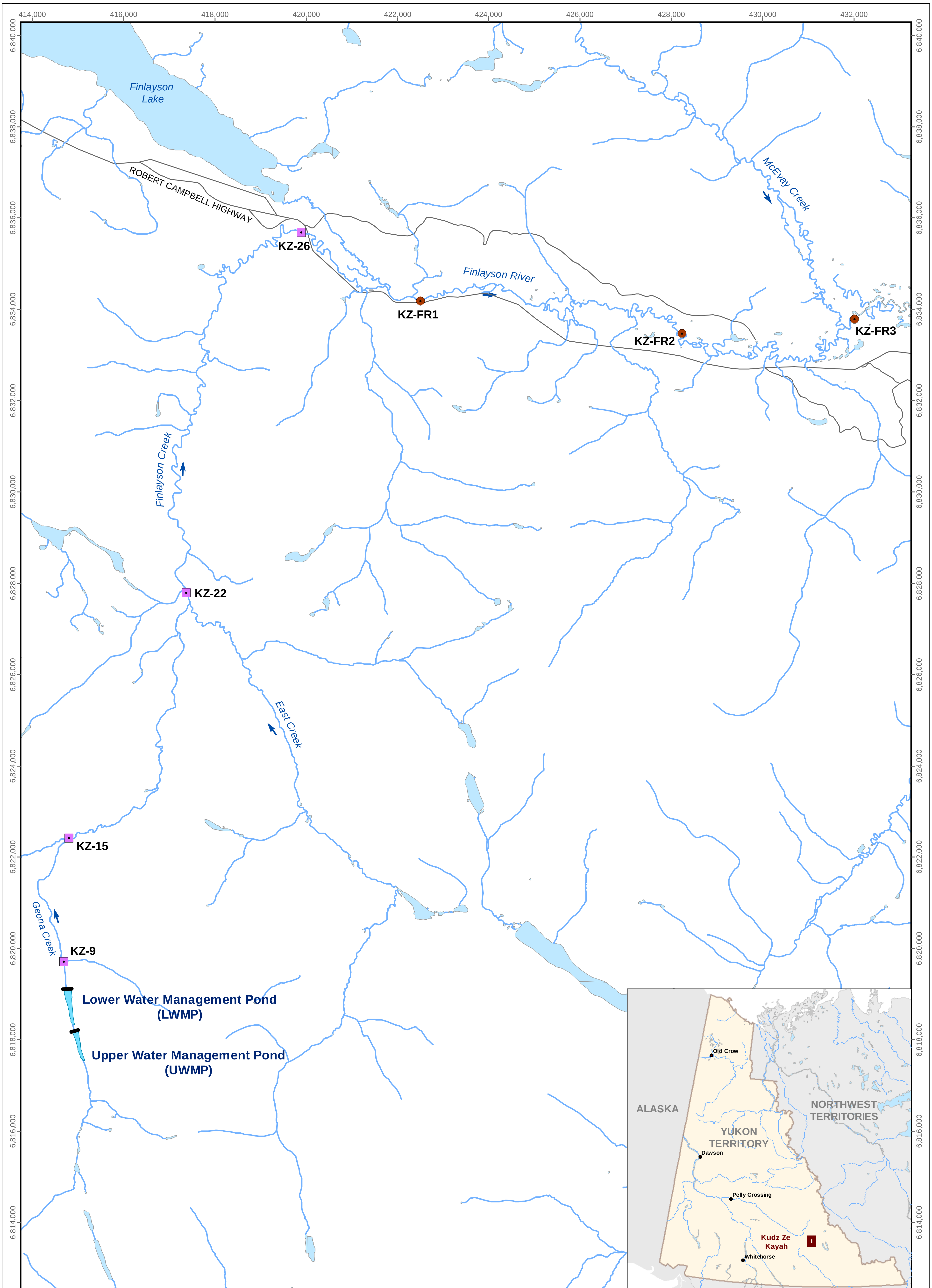

LEGEND

- Selected Station
- Water Quality Sampling Location

Selected Stations for the Inundation Analysis

0 1.25 2.5 5
km

N W E S

Map Projection: UTM Zone 9V NAD 1983
Data Source: Reproduced under licence from Her Majesty the Queen in Right of Canada, Department of Natural Resources Canada. All rights reserved.

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Figure 1

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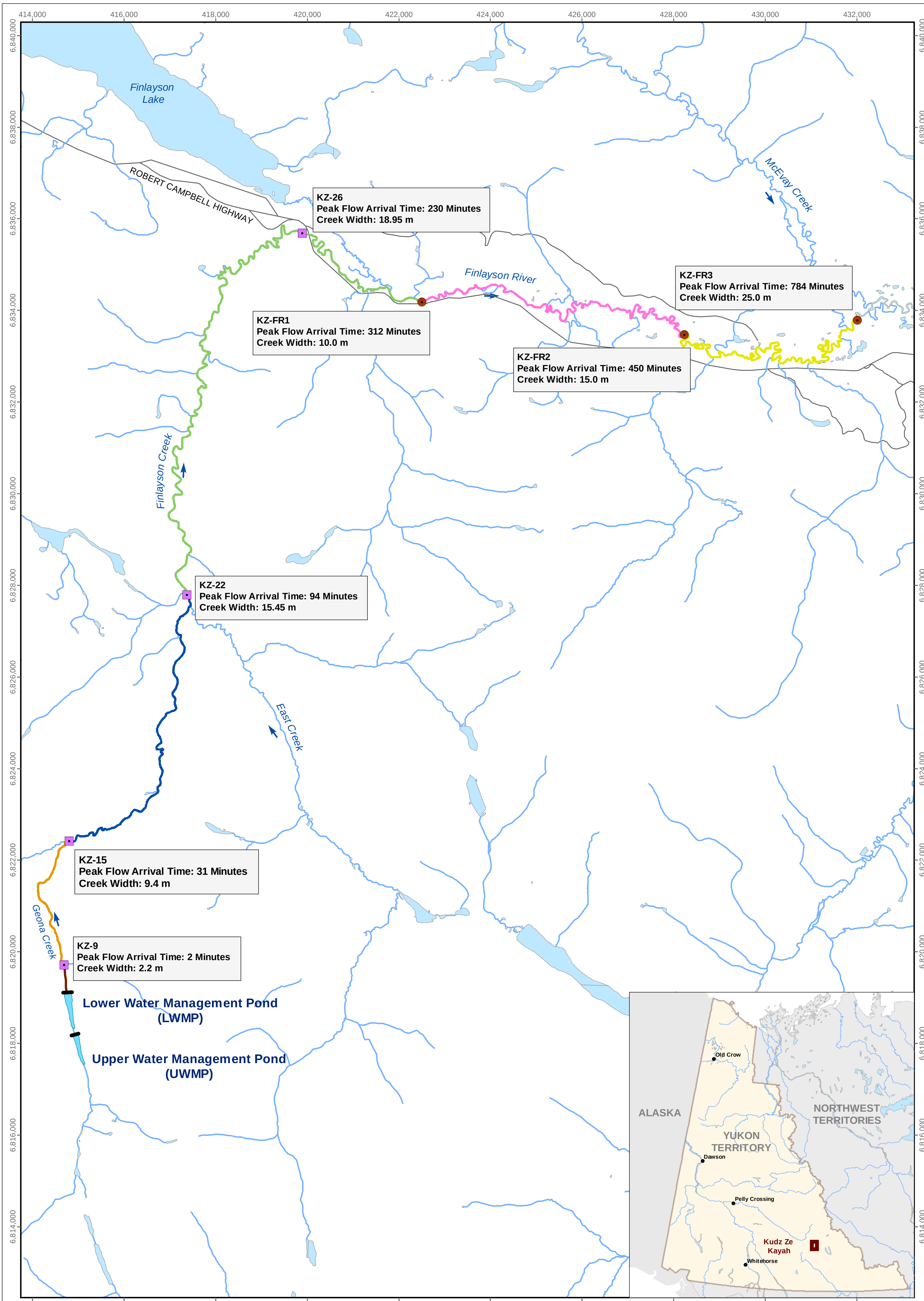
Table 1: Downstream Flow Characteristics Caused by the Hypothetical Failure of the Proposed WMPs Compared to the Pre-failure Condition

Parameters		**Unit**	**KZ-9**	**KZ-15**	**KZ-22**	**KZ-26**	**KZ-FR1**	**KZ-FR2**	**KZ-FR3**
Distance from the LWMP Dam		m	500	3,754	11,755	25,689	30,150	40,150	50,150
Pre-failure	Flow during 1/50 Wet Year	m^3/s	0.12	1.12	2.73	3.35	6.20	7.90	14.60
	Water Depth during 1/50 Wet Year	m	0.31	0.32	0.65	0.71	1.00	1.20	ND
	Mean Width	m	2.2	9.4	15.5	19	10	15	25
During Failure	Peak Flow	m^3/s	416	315	210	131	108	55	1.6
	Peak Flow Arrival Time	minute	3	35	113	250	312	450	784
	Velocity corresponding to the Peak Flow	m/s	2.62	1.7	1.7	1.7	1.2	1.2	0.5
	Potential Maximum Flood Depth	m	17	13	6	4.22	6.34	3.12	0.14
	Cross-sectional Area needed to Pass the Peak Flow	m^2	159	185	100	77	89	46	3
	Stream Power corresponding to the Peak Flow	W/m	101,944	30,905	20,603	12,877	5,278	2,678	77
	Specific Stream Power corresponding to the Peak Flow	W/m^2	46,338	3,287	1,333	679	304	166	3

Note: ND = Not Determined.



LEGEND

- Selected Station
- Water Quality Sampling Location

Maximum Channel Flood Depth (m)

- > 17
- 13 - 17
- 6 -13
- 4 - 6
- 3 - 4
- 0 - 3

Potential Maximum Channel Flood Depth for the Hypothetical Failure of the Proposed WMPs

0 1.25 2.5 5
km

N E S W

Map Projection: UTM Zone 9V NAD 1983
Data Source: Reproduced under licence from Her Majesty the Queen in Right of Canada, Department of Natural Resources Canada. All rights reserved.

Date: June 2018
Project 177202.0041

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Figure 2

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Table 2: **Summary of the Predicted Flood Waves and Effects on the Downstream Fish Habitat**

Evaluation Metric		Geona Creek	Finlayson Creek			Finlayson River		
		KZ-9	KZ-15	KZ-22	KZ-26	KZ-FR1	KZ-FR2	KZ-FR3
Distance from LWMP Dam (km)		0.5	3.75	11.8	25.7	30.2	40.2	50.2
Physical Characteristics								
	1-in-50 Wet Year Depth (m)	0.31	0.33	0.65	0.71	1	1.2	ND
	1-in-50 Wet Year Discharge (m^3/s) [a]	0.12	1.12	2.73	3.35	6.2	7.9	14.6
	Bankfull Width (m)	2.2	9.4	15.5	19	10	15	25
	Bankfull Depth (m)	1.38	1.07	1.36	1.85	ND	ND	ND
	Bankfull Discharge (m^3/s)	1.52	7.12	9.81	14.69	ND	ND	ND
Flood Wave Impact								
	Peak Flow Arrival (min)	3	35	113	250	312	450	784
	Peak Flow (m^3/s)	416	315	210	131	108	55	1.6
	Peak Flow / Bankfull Flow (ratio)	274 x	44 x	21 x	9 x	ND	ND	ND
	Peak Flow / 1-in-50 Wet Year Flow (ratio)	3467 x	281 x	77 x	39 x	17 x	7 x	0.1 x
	Maximum Flood Depth (m)	17	13	6	4.2	6.34	3.12	0.14
	Max / Bankfull Depth (ratio)	12.3 x	12.1 x	4.4 x	2.3 x	ND	ND	ND
Potential for Channel Widening by the Peak Flow [b]		Highly Likely	Highly Likely	Likely	Unlikely	Unlikely	Unlikely	Unlikely
Bed Sediment Erosion / Deposition by the Peak Flow [c]		Erosion - Very High, with scouring potential	Erosion - High	Erosion - High	Erosion - Moderate	Erosion - Very Low	Deposition - Moderate	Deposition - High

Note: ND = Not Determined (due to lack of required relevant data/information).

[a] Mean annual discharge corresponding to the 1-in-50 wet year scenario.

[b] Based on estimated specific stream power (SSP): SSP > 2000 W/m^2 (Highly likely), 790 W/m^2 < SSP < 2000 W/m^2 (Likely), and SSP < 790 W/m^2 (Unlikely).

[c] Based on estimated peak wave velocity (V_w) and SSP: SSP > 2000 W/m^2 and V_w > 2 m/s (Very High), 790 W/m^2 < SSP < 2000 W/m^2 and 1 m/s < V_w < 2 m/s (High), and SSP < 790 and 1 m/s < V_w < 2 m/s (Moderate).

APPENDIX A: R2 MEMO (Minnow 2017)

Technical Memo

Date: November 02, 2017

To: Kelli Bergh, (BMC Minerals (No.1) Ltd.)

Cc: Pierre Stecko, M.Sc., EP, R.P.Bio (Minnow Environmental Inc.) and T. Scott Keesey, B.Sc., EP (Alexco Environmental Group)

From: Mijanur R. Chowdhury, Ph.D. (Minnow Environmental Inc.), Nicola Lower, Ph.D. R.P.Bio (Minnow Environmental Inc.), and David Petkovich, B.Sc., P.Biol. (Alexco Environmental Group).

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1 INTRODUCTION

1.1 Background

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This memorandum has been prepared in response to IR R2-124 and includes an assessment of the potential impact of a hypothetical catastrophic failure of the proposed UWMP and LWMP to downstream fish and fish habitat in Geona Creek. This memorandum outlines the approach, assumptions, and results of the assessment.

1.2 Scope of the Study

The following was approach was used for the hypothetical catastrophic failure of the proposed WMPs:

- Estimation of flow and sediment load from the failure, and resulting downstream flood flow attenuation;
- Identifying downstream (Geona Creek) sediment erosion and/or accumulation based on the flow from the failure, and existing (i.e., pre-failure) creek flow and morphological information; and
- Evaluate the fish and fish habitat implications associated with potential changes in the Geona Creek.

The mandate for Minnow Environmental was to complete these tasks within a spatial boundary extending approximately 25 km downstream of the WMPs from Geona Creek to Lower Finlayson Creek (see Alexco 2016a, Figure 3-3). This spatial extent is consistent with the Project local study area utilized in the baseline monitoring of aquatic resources (Alexco 2016a).

2 ASSESSMENT SCENARIO AND ASSUMPTIONS

2.1 Catastrophic Failure Scenario of the Proposed WMPs

The assessment was focused on a worst-case scenario representing a hypothetical catastrophic failure of the WMPs. It was assumed that the catastrophic failure of the proposed WMPs would occur through their respective dams, and henceforth, the term ‘dam failure’ is used to represent the failures of the WMPs. In this study, the worst-case scenario of the dam failure for the proposed WMPs was considered to occur under a rainy day failure as it would cause the most severe downstream inundation and sediment erosion and/or deposition. In addition, it was assumed that the overtopping failure of the upstream dam of the UWMP would cause a sequential overtopping failure of the downstream dam of the LWMP. As such, the combined volume of both the UWMP and LWMP was used for inundation analysis, where the volume of the UWMP was considered as inflow to the LWMP. Then, the impact assessment was focused on downstream Geona Creek and Finlayson Creek starting from the LWMP dam (elevation 1317 masl, at the toe of the dam) to station KZ-26 (elevation 950 masl), a water quality monitoring station in Lower Finlayson Creek, which is about 25.7 km from the LWMP dam and with a 367 m lower elevation. Furthermore, the failure was assumed to occur with a maximum possible height (from the dam crest to the toe) of the dams. It was also considered that the failure would occur when both WMPs are at the final year of their operation (i.e., year 10) which represents the time of greatest contained sediment volume. Furthermore, the downstream channel (Geona Creek) before the failure was considered to be flowing at the maximum possible level (i.e. flood flow). The likelihood of all these conditions co-occurring to cause the worst-case scenario considered here is *extremely low*, and the WMPs will be carefully managed so that such a failure does not occur at any point. Nevertheless, the inundation analysis was carried out for the above described worst-case scenario with the following assumptions:

- The initial water levels, volume and surface area of both water management ponds just before the failure was assumed to be at their dam crest elevations (Table 2.1);
- The volumes of deposited sediment contained just before the failure were about 100 m^3 in the LWMP, and 48 m^3 in the UWMP. The accumulated sediment was estimated for the end of mine operations (i.e., 10 years) based on the predicted annual runoff rates for both WMPs during a mean precipitation year as reported by the water balance model (Alexco 2017), and representative total suspended solids concentrations (10 mg/L) in the runoff (Alexco 2016c);
- The deposited sediment was assumed to be released at the end of water flow from the dam failure (i.e., after all the water is released); and
- The maximum flow in the downstream receiving water bodies (see Section 2.2) before the failure was assumed to be equal to the predicted discharge during a 1-in-50 wet precipitation year as reported in the receiving water balance model (Alexco 2017).

2.2 Downstream Receiving Environment

The waterbody immediately downstream of the dams is Geona Creek, which flows into upper Finlayson Creek and then Lower Finlayson Creek. Finlayson Creek discharges into the Finlayson River. There are a number of water quality monitoring stations (KZ-9, KZ-15, KZ-22 and KZ-26) in the immediate downstream receiving environment which are routinely monitored (see Alexco 2016a, Figure 3-3). The geometric dimensions and estimated bankfull discharge in these monitoring stations (Table 2.2) indicate that the conveyance capacity of the downstream receiving waterbodies increases as the discharge flows from Geona Creek to Upper Finlayson Creek, and then to Lower Finlayson Creek (as expected). The bankfull discharge is much higher than the predicted discharge during a 1-in-50 wet year suggesting that the conveyance capacity would be more than enough for carrying discharge during a 1-in-50 wet year (Table 2.2). The dominant size of the stream sediments in these stations is less than 2 mm in diameter (i.e., sand and finer; see Alexco 2016a, Figure 4-8).

3 METHODS

3.1 Inundation Analysis

In the first step of the inundation analysis, the breach dimension, peak discharge, and the flood hydrograph were estimated for the worst-case WMP failure scenario described in Section 2. A simplified methodology developed by the Washington State Department of Ecology (Schaefer 1992, updated in 2007) was adopted for this purpose. The methodology was developed based on an extensive literature review and the author's practical dam safety experience (Schaefer 1992, updated in 2007). In order to facilitate the accurate use of the methodology, the Washington State Department of Ecology has developed a detailed technical note (Schaefer 1992, updated in 2007), a number of Microsoft Excel spreadsheets, and a guidance document for spreadsheet use (Walther 2007). As such, the methodology has been widely used for a general assessment of dam break inundation analysis, and is recommended by a number of regulatory bodies, such as by the State of Colorado (Dam Safety Branch of the State of Colorado 2010) and the province of British Columbia (BC Dam Safety Program 2001). The basic principles and equations that were adopted in the methodology and were used in this analysis are provided below:

- The dam breach parameters such as geometric dimensions of the breach, time of breach development, and volume of embankment material eroded were estimated using empirical procedures developed by MacDonald and Langridge-Monopolis (1984). Assuming a trapezoidal breach shape, this empirical procedure allows the estimation of dam-breach parameters based on the volume of water stored in the reservoir at the water surface elevation under consideration, and the height of water over the base elevation of the breach. The Washington State methodology selected this empirical procedure based on an extensive review of historical breaches of earthfill dams (Wahl 1998);

- The dam breach peak discharge and time of the peak discharge were estimated from the breach dimensions calculated above using a modified weir equation proposed by Fread (1981). The volume of water available in the LWMP (500,000 m^3) and the inflows from the UWMP dam (250,000 m^3) were used to estimate the peak discharge; and

- The dam breach hydrograph was estimated from the estimated peak discharge and time of the peak discharge using dimensionless exponential equation proposed by Barfield et al. (1981).

In the second step, the attenuation of the dam breach peak discharge as the flood wave travels downstream was estimated based on a family of curves included in the British Columbia dam break inundation guidance document (BC Dam Safety Program 2001, updated in 2016). The guidance document was developed by the dam safety program of British Columbia Ministry of Forests, Lands, and Natural Resource Operations, and intended for small dams with height less than 15 m. The dams of both LWMP and UWMP will be less than 15 m in height, and hence the guidelines are applicable for the analysis. The attenuation curves depict the relationship of the percentage of peak flow reduction versus the distance downstream for various reservoir storage volumes ranging from 10 to 2,000 acre-feet and average channel slope ranging from 0.1% to 5%. The following tasks were completed in the second step:

- The attenuation of the peak discharge from the catastrophic failure of the WMPs in the downstream receiving environment was estimated from the attenuation curves mentioned above. The representative curve corresponding to 600 acre-feet (740,088 m^3) which is close to the combined volume (750,000 m^3, 608 acre-feet) of the LWMP and UWMP, and a 1% average channel slope which best represents the slope of the major part of the downstream channels (Table 2.2) was used for the purpose.
- The cross-sectional channel area required to pass the attenuated peak discharge was estimated by dividing the attenuated peak discharge (determined in the previous step) at the monitoring stations by a representative breach wave velocity for stream bed slope and overbank cover type at the cross-section, following the guidance document (BC Dam Safety Program 2001, updated in 2016). The same techniques were also suggested by the Washington State Department of Ecology (Schaefer 1992, updated in 2007). The representative breach wave velocity was obtained from the tabulated data for different slope and cover type in the guidance document.
- For illustration purposes, an estimate of the potential maximum flood depth corresponding to the cross-sectional area required to pass the peak flow (determined in the previous step) from the standard relationship of the area of a trapezoidal cross-section with its depth and width (top width and base width) was determined. This calculation assumes that the same trapezoidal shape is applicable until the maximum flood depth occurs, while in practice the shape will change when flood depth is more than the bankfull depth. As such, these estimates of the maximum flood depth can be taken as conservative estimate of the maximum flood depth.

3.2 Downstream Sediment Erosion/Deposition Potential Analysis

The potential geomorphological impacts of the dam breach peak flow discharge in downstream Geona Creek were analyzed. The analysis was based on the following two methods:

i. Applying a threshold velocity of erosion, deposition, and transportation from the Hjulström graph (Hjulström 1935) for the prevalent stream sediment size.

ii. Using the stream power as an indicator of the channel sensitivity to erosion and deposition processes, and major geomorphic work such as channel widening, elimination of roadway embankment, avulsions, and/or braiding.

The Hjulström graph (Hjulström 1935) provides the boundaries among erosion, transportation, and deposition in a plot of flow velocity versus particle size. Stream sediment sampling results from the downstream monitoring stations (KZ-9, KZ-15, KZ-22, and KZ-26) shows that the dominant size of the stream sediment in these stations is less than 2 mm in diameter (see Alexco 2016a, Figure 4-8). Using the Hjulström graph, the following threshold velocities for 2 mm sediment size were obtained and used in the analysis of sediment erosion and/or deposition:

- Deposition may start to occur for stream velocity < 0.18 m/s;
- Erosion may start to occur for stream velocity > 0.5 m/s; and
- Transportation of sediment may occur for stream velocity in the range 0.18 – 0.5 m/s.

The stream power of a flow indicates its ability to influence geomorphology, and is a measure of the main driving forces acting in the channel (i.e., joint effect of channel gradient and discharge) (Bizzi and Lerner 2015). Stream power has also been widely used to assess sediment transport and channel geomorphic pattern (e.g., Bagnold 1977; Chang 1979; Ferguson 2005). Total stream power (TSP) and specific stream power (SSP) at the selected monitoring stations in Geona Creek and Finlayson Creek were calculated as (Bagnold 1966, 1977):

$$TSP = \gamma QS, \quad SSP = \frac{TSP}{W}$$

Where γ the unit weight of water (9,800 N/m^2), Q is the estimated attenuated peak discharge, S is energy slope which was approximated as bed slope, and W is the channel bankfull width. The calculated stream power was compared with a threshold stream power value (referred to as 'critical stream power') to analyze the likelihood of downstream sections experiencing major erosional processes. When stream power exceeds the critical stream power, erosion dominates (Bull 1979). There have been a range of values of critical specific stream power in the literature; the following thresholds of SSP suggested by the United States Department of Agriculture (Yochum and Scott 2017a; Yochum et al. 2017b) were applied in this study:

- Highly likely (90% potential) and likely (50% potential) of major geomorphic change with avulsions, braiding, and elimination of roadway embankments due to erosion-dominated processes for SSP > 2400 W/m^2 and SSP > 990 W/m^2 respectively.
- Highly likely (90% potential) and likely (50% potential) of substantially widened channel due to erosion-dominated processes for SSP > 2000 W/m^2 and SSP > 790 W/m^2 respectively.

4 RESULTS

4.1 Outflow and Downstream Inundation from the Hypothetical Failure of the WMPs

The inundation analysis for the worst-case scenario of the failure of the proposed KZK WMPs showed the following (summarized in Table 4.1 and Table 4.2):

- The prospective trapezoidal shaped breach is expected to fully form with a top width of 12 m and base width of 5.5 m. The maximum width (i.e. top width) of the breach is about 7% of dam crest length of LWMP. The height of the fully formed breach was considered as the height from the dam crest to its toe (13.2 m), a representative dam height for the worst-case scenario (Table 4.1).
- The hydrograph of the discharge through the breach suggests that the peak discharge would be 438 m^3/s, and would occur 44 minutes after the start of the failure (Figure 4.1). From the peak discharge of 438 m^3/s, the discharge is predicted to rapidly decrease to about 100 m^3/s at 60 minutes from the beginning of the failure, after which the discharge rate decreases at a slower rate (Figure 4.1). The outflow from the failure may continue for 1.5 hours before most of the stored water and sediment is released.
- The attenuation analysis of the peak discharge showed that the peak discharge is expected to attenuate from 438 m^3/s at the LWMP dam to about 315 m^3/s within 3.75 km (at KZ-15), 210 m^3/s within 11.75 km (at KZ-22), and 131 m^3/s within 25.7 km (at KZ-26) (Table 4.2).
- The peak flow and cross-sectional area needed to pass the peak flow at all the downstream stations are much higher than the bankfull discharge and cross-sectional area at bankfull depth respectively, indicating that the peak flow would cause overbank flooding (Table 4.2). The estimated potential maximum flood depth (Figure 4.2) corresponding to the peak flow is also expected to be much higher than the bankfull depth (Table 4.2).
- There is projected to be a total of 4,991 m^3 sediment released due to the WMP failure, of which the vast majority (4,843 m^3) would originate from the erosion of the embankment and the remainder (148 m^3) would be from the stored sediment in the two water management ponds.

This released sediment volume is expected to be much less than the total volume of water (750,000 m^3) that would be released during the breach. As such, the major downstream impact is expected to be caused by the water flow from the breach.

- The sediment from the dam materials would potentially be eroded during the initial breach development period and subsequently flow away due to continued water flow from the breach, while stored sediment would potentially be released after all the water was released (see Figure 4.1).

4.2 Potential Sediment Erosion/Deposition in the Downstream Waterbodies

The potential peak stream velocity in all monitoring locations (Table 4.2), which would occur when the peak discharge from the dam failure travels to the respective location, is expected to be much higher than the erosional threshold velocity (0.5 m/s) obtained from the Hjulström graph for the dominant sediment size present in those locations (see Section 3.2). The estimated specific stream power (Table 4.2) in a major part of the downstream waterbodies (from LWMP dam to 5 km upstream of KZ-26) would be much higher than the erosional threshold suggested by the United States Department of Agriculture (see Section 3.2). Consequently, the potential impact of dam breach peak discharge on downstream channel geomorphology would be the following:

- The downstream Geona Creek and Upper Finlayson Creek are expected to experience significant erosion when the peak flow travels through.
- The potential of substantially widened channel and major geomorphic change (e.g., avulsions, braiding, elimination of roadway embankments) is highly likely (90% potential) up to Station KZ-22.
- As SSP in KZ-26 is less than 790 W/m^2 (Table 4.2), KZ-26 and the stream section 5 km upstream of the KZ-26 may not experience major geomorphic change (e.g., avulsions, braiding, elimination of roadway embankments) caused by erosion-dominated processes. Deposition may not occur in these sections as the potential peak stream velocity in all monitoring stations is much higher than depositional threshold of Hjulström graph.
- As the dam breach peak flow would occur after the erosion of embankment sediment, most of the eroded embankment sediment would be carried away by the peak flow to beyond Station KZ-26.

The geomorphological impact summarized above was for the dam breach peak discharge, which is not expected to impact the fate of the stored sediment in the LWMP and UWMP as these deposited sediments would be released after the peak discharge ends, possibly at the end of the dam breach flow. Assuming that the entire 148 m^3 of deposited sediment would be released after all the water is released, it would flow downslope behaving like sediment-laden debris flows provided that there is a favorable condition of occurring such sediment-laden flows (Rickermann 1999). In general, debris flow does not occur as long as the downslope gradient is less than a certain critical value, and the critical gradient was reported to be more than 4% (Bathrust 1997, D'Agostino et al. 2010). The average slope from the LWMP dam toe to the immediate receiving environment (Geona Creek) is about 2.5% (Table 2.2). As such, it is highly likely that the stored sediment in the WMPs would not flow downslope at all, and rather stay in the LWMP. In the highly unlikely event of downslope sediment movement, the estimated runout distance for the stored sediment is about 80 m from the LWMP dam, with a maximum sediment depth of 0.84 m (Rickermann 1999).

4.3 Potential Impact on the Fish Habitat

4.3.1 Background Fish and Fish Habitat

The KZK Project area is located in the Geona Creek valley, and is characterized by a steep-sloped valley with discontinuous permafrost conditions and fine-grained glaciofluvial and morainal deposits (KP 2016). The valley drains to the north through Geona Creek into Finlayson Creek and Finlayson River, and to the south through South Creek into North River/Lakes system (Alexco 2016). Baseline environmental studies were completed in 1994-1995, and 2015-2016, and the results are outlined in Alexco (2016a). Full descriptions of the Fish and Fish Habitat in the Project area are also found in the Project Proposal submitted to YESAB, Chapter 10 – Aquatic Ecosystems and Resources, and Appendix E-4 – Fisheries Offsetting Plan. In summary, Geona Creek provides fish habitat, but at a low productivity level, and only to Arctic grayling (*Thymallus arcticus*). Most of the grayling found in the creek are fry and juveniles, with the highest numbers found in the headwater ponds (beaver ponds) of the creek. Very low numbers of adult grayling have been observed in the creek. Low numbers of grayling likely overwinter in the deepest pools of the creek, although this has not been confirmed.

Geona Creek was characterized into reaches as part of the baseline work (Alexco 2016a). Reach 1 is the downstream section that would be primarily affected by a failure of the WMPs. This reach was characterized as having an average channel width of 5.5 m, and average wetted width of 3.2 m. Both left and right banks are primarily undercut and composed of fines and gravels with intermittent cobbles. Riparian vegetation is dominated by shrubs and grasses, interspersed with some wetland species such as sedges. The reach is occasionally confined, with regular stream braiding with smaller channels branching off the main stem.

Historic and current beaver activity is the main driver of pond formation within the reach. The average pool depth is 0.8 m, and although investigations found that Geona Creek flowing water maintained dissolved oxygen concentrations high enough to sustain overwintering fish populations, the shallow ponds in the system freeze almost to the bottom. Therefore, Geona Creek provides marginal to no overwintering habitat, and possibly only for juveniles. Adult grayling likely move into Finlayson Creek, or even further downstream into Finlayson River, during the winter months. Beaver dams within the system have likely caused limited fish movement into and within the creek. Stream conditions within Reach 1 of Geona Creek, are therefore limited to providing suitable habitat for low-numbers of juvenile Arctic grayling rearing, and marginal habitat for spawning.

Finlayson Creek provides habitat for Arctic grayling, as well as slimy sculpin (*Cottus cognatus*). One burbot (*Lota lota*) was caught at KZ-26 in 2012, although this observation has not been replicated in any other fishing surveys, and may be an anomaly. Finlayson Creek flows through culverts under the Robert Campbell Highway. These culverts are barriers to fish passage, preventing fish from moving upstream. Any fish that move from Geona or Finlayson Creeks into the Finlayson River for overwintering are therefore currently unable to return to the upstream reaches. The baseline work concluded that no bull trout or Dolly Varden char (fall-spawners) are found in any of the creeks sampled. There are no resident salmonid species, other than Arctic grayling, in the creeks and beaver ponds within the Project area.

4.3.2 Potential Effects on Fish and Fish Habitat

As part of the KZK Project development, a Fisheries Offsetting Plan has been developed to enhance fisheries productivity in the system. A series of ponds will be developed in Reach 1 of Geona Creek, which will provide better overwintering habitat. Structural changes in Finlayson Creek at the Robert Campbell Highway are also proposed. This work will allow fish to migrate upstream into Lower Finlayson Creek, and ideally, facilitate a more typical seasonal movement pattern for Arctic grayling within the system. As these enhancements will be implemented at the same time as mine development, the hypothetical failure of the WMPs considers the potential effects on the system with these offsetting measures in place.

A summary of the predicted flood waves and effects on fish habitat are shown in Table 4.3. The modelling of the worse-case scenario of the failure of the WMP shows that the majority of the impacts would occur in Geona Creek, downstream of the LWMP. Peak flows would be immediate following a failure of the WMPs, with a peak flow of 416 m^3/s. This predicted flow is approximately 400 times the peak annual flood for Geona Creek (YESAB submission, Chapter 8, Surface Water Quality and Quantity). There would be no time for resident fish to move from the system, and a flood of this scale would flush the fish downstream, probably causing trauma and mortalities as the fish collide with substrate and debris in the system. Adult Arctic grayling have not been found in velocities greater than 1.5 m/s, which is significantly less than the predicted peak flows (Larocque et al. 2014). As the peak flow subsides, for surviving fish, there would be stranding of fish outside of the channel, or in isolated pools.

The additional pool habitat that will be created through offsetting measures may provide some refuge from the initial flood wave, particularly those that are created off the main channel. The inundation and sediment deposition following the initial flood wave would compromise the efficiency of some of this habitat, although some may still provide functional fish habitat. The proposed offsetting ponds will be approximately 2.0 ha in size with an average depth of about 2 m, providing a volume of 40,000 m^3. The inundation model indicates that less than 5,000 m^3 of sediment will be released due to the failure of the WMPs. Therefore, although the availability of the offsetting ponds would be reduced, not all would fill with sediment, and some deeper pools may still provide areas of refuge during the peak flow, and during the subsequent inundation.

The failure of the WMPs would result in a flood wave that would heavily scour Geona Creek where the channel is confined. Sediment deposition would be limited to the initial first approximately 80 m of Geona Creek downstream of the LWMP. The peak flow would result in major channel and bed erosion likely down to KZ-22 on Finlayson Creek. The suspended particles from this erosion have the potential to smother gills, as well as eggs and young of the year in spawning and rearing habitat.

The effects on fisheries productivity would depend on the timing of the WMP failure. Even with fully-functional offsetting measures, the immediate downstream reach of Geona Creek will likely not provide critical spawning habitat for grayling. A post-flood event inundation would therefore not remove large numbers of spawning adults from the population, and grayling would still be able to spawn in other watercourses, including Finlayson River and tributaries. A peak flood event during winter would likely have relatively greater impacts on the grayling population compared to the spring. Overwintering habitat is currently limited in the system, and offsetting measures will be in place that enhance pool habitat, and therefore, overwintering capacity. A peak flood event during the winter would displace fish during a season when overwintering habitat in neighbouring systems is also likely limited. Downstream movement to overwintering habitat primarily occurs in September (Craig and Poulin 1975), so a dam failure after September and before the spring, would have the greatest effect on the resident overwintering population. A failure of the WMP during the winter may therefore affect recruitment back into the population, until such time as overwintering habitat is functional again in the system. Although a dam failure after September and before the spring would have the greatest effect, the worst-case dam failure that was assumed to occur under a rainy day scenario (Section 2.1), and assessed here, is not likely to occur outside of the rainy season, and the WMPs and downstream waterbodies will be frozen in the winter.

As outlined in Table 4.3., the peak flow and erosion potential would be greatest in Geona Creek. As the flood moves down into Finlayson Creek, there would be some effects in this watercourse as well. The peak flow would be higher than the maximum sustained velocity for Arctic grayling, meaning that some fish mortalities and stranding may occur. Due to the closer proximity to Finlayson River, compared to Geona Creek, it is possible that fish would be flushed into the Finlayson River, where habitat would likely remain unaffected. Suspended sediments from the upstream channel scour and erosion may clog gills and smother spawning habitats. These effects would be temporary, and would not be a concern once the sediments settle out after the initial flood wave has passed through the system. The timing of the WMP failure would have the greatest influence on impacts to fisheries productivity. The offsetting measures are intended to facilitate fish upstream migration to spawning and rearing habitat in the spring and summer, and downstream migration to overwintering habitats in the fall (primarily September). A WMP failure and peak flood event during these critical life-cycles would have a greater influence on recruitment back into the population, than outside of the peak migration periods.

Arctic grayling are a widespread species in the north, and are found in most waters throughout the Yukon. Populations are generally secure, although some spring spawning runs have declined and monitoring is ongoing to determine the success of regulatory changes limiting harvest (Environment Yukon 2010). The Geona Creek system does not provide unique or specialized habitat that provides critical life-history function.

There are no commercial, recreational, or Aboriginal fisheries in Geona Creek, nor downstream in Finlayson Creek. This is likely due to low fisheries productivity throughout the system, as well as access restrictions. The implementation of the offsetting measures may enhance productivity within the system, although access to harvesting these fish is restricted as the Tote Road Lease does not permit public use to the road that runs parallel to the creek. This road will continue to have access restrictions during mine operations. For these reasons, the failure of the WMPs is not expected to affect CRA fisheries. Overall, Yukon fish populations are healthy and most fisheries are within sustainable limits (Environment Yukon 2010).

Geona Creek is an erosional creek system that is relatively straight in its alignment to Finlayson Creek. The flood wave would therefore not change the channel alignment substantially, and following inundation, it is expected that geomorphological processes would re-establish the creek to pre-inundation conditions. Riparian zones would be disturbed, however due to the low volume of sediment that would be mobilized, and the fact that peak sediment deposition would be limited to the immediate (<100 m) downstream section, this zone should recover within the short (months) to medium (<5 years) term. Even if the channel does not return to its exact pre-inundation conditions, it would return to a channel that provides fish habitat. Benthic drift from upstream, as well as fish colonization from adjacent watercourses (including from the Finlayson River), would help support natural restoration. Depending on the exact nature and location of sediment deposition and scour, restoration techniques could be used to facilitate a return to fish habitat. Although there would be impacts to the resident fish and fish habitat from the WMP inundation, a return to functional fish habitat within the Geona Creek is expected.

5 CONCLUSIONS

An assessment of the potential impact of a hypothetical catastrophic failure of the proposed water management ponds at the Kudz Ze Kayah site to downstream fish and fish habitat in Geona Creek was conducted. The hypothetical catastrophic failure of the WMPs was assumed to occur under a rainy day scenario through their dams with a sequential dam failure case, in which the failure of the upstream dam of the UWMP caused the subsequent failure of the downstream dam of the LWMP. The likelihood of this series of events co-occurring to produce this scenario is *extremely low*, and the consideration of the consequences and potential effects of this failure assessed herein should take this likelihood into account. The likelihood of a catastrophic failure of the WMPs during the most vulnerable overwintering period is even lower.

The major downstream impact of the failure of the proposed WMPs is expected to be caused mainly by the water flow from the breach, and sediment released by the failure would have minimal impact as there is projected to be less than 5,000 m^3 sediment released, compared to 750,000 m^3 water released due to the failure of the WMPs. The peak water discharge from the failure are expected to cause significant impact on the downstream channel morphology due to the erosional force from the discharge. Overall, the effects to the fish and fish habitat downstream of the WMPs are considered temporary, with a high restoration potential. Fish mortalities would be expected in Geona Creek in particular, with fish flushing and stranding. Recruitment back into the Arctic grayling population would be depressed until habitat becomes functional again. The downstream and adjacent waterbodies would still maintain viable populations, and the close proximity to Finlayson River, would facilitate a source of benthic macroinvertebrates and fish that would recolonize the system. Geona Creek, and to a lesser degree, Finlayson Creek, would likely experience scour of the channel and unstable channel banks and beds. Once the initial flood wave has passed, the system would start to stabilize, and restoration techniques could be used to speed-up the natural regeneration process. Overall, the failure of WMPs would be limited to temporary effects on up to two species, and no CRA fisheries.

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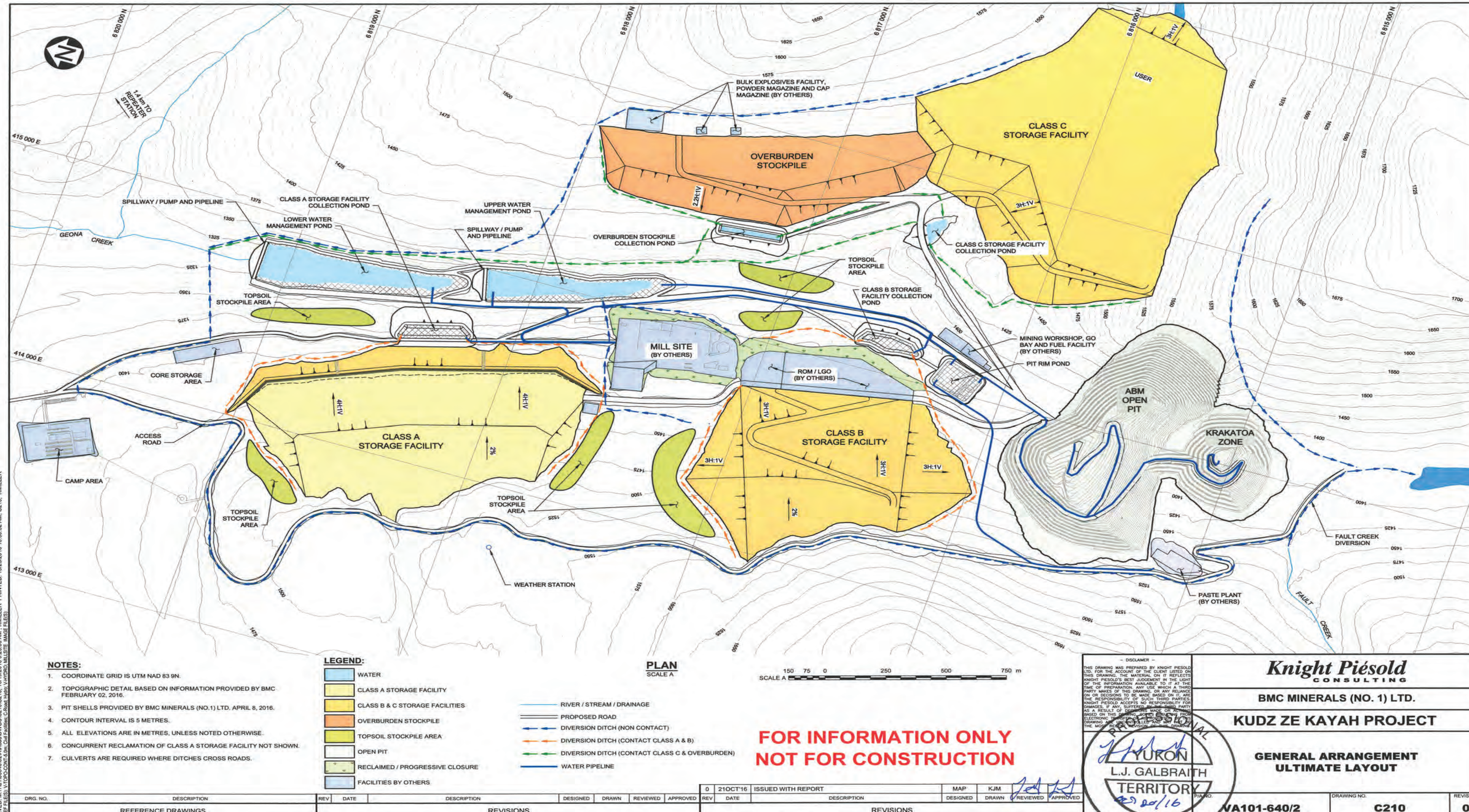

Layout of Kudz Ze Kayah Mine

Reproduced from the KZK PFS Report (KP,2016)

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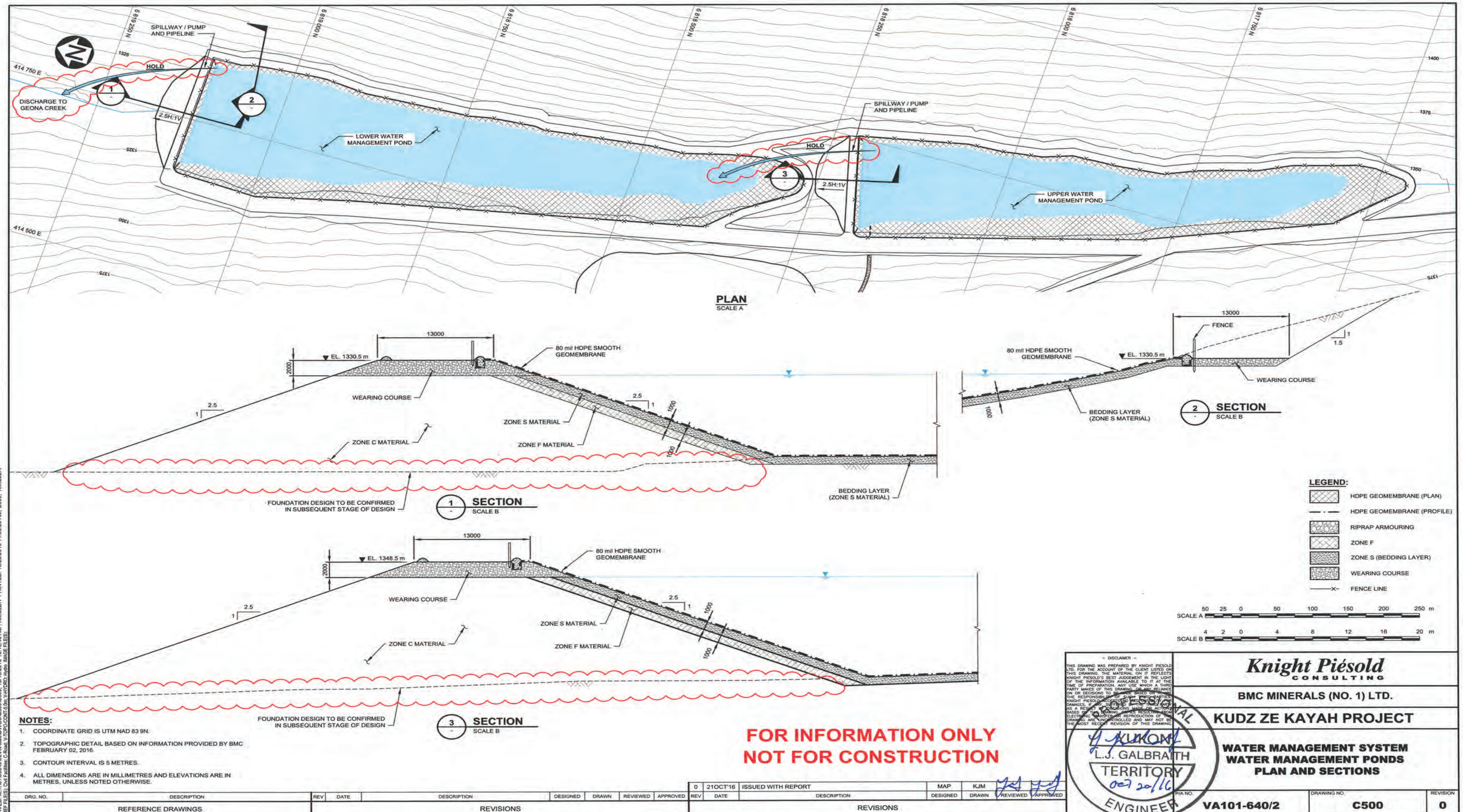
Figure 1.1



Layout of Proposed Water Management Ponds and Dams

Reproduced from the KZK PFS Report (KP,2016)

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Figure 1.2

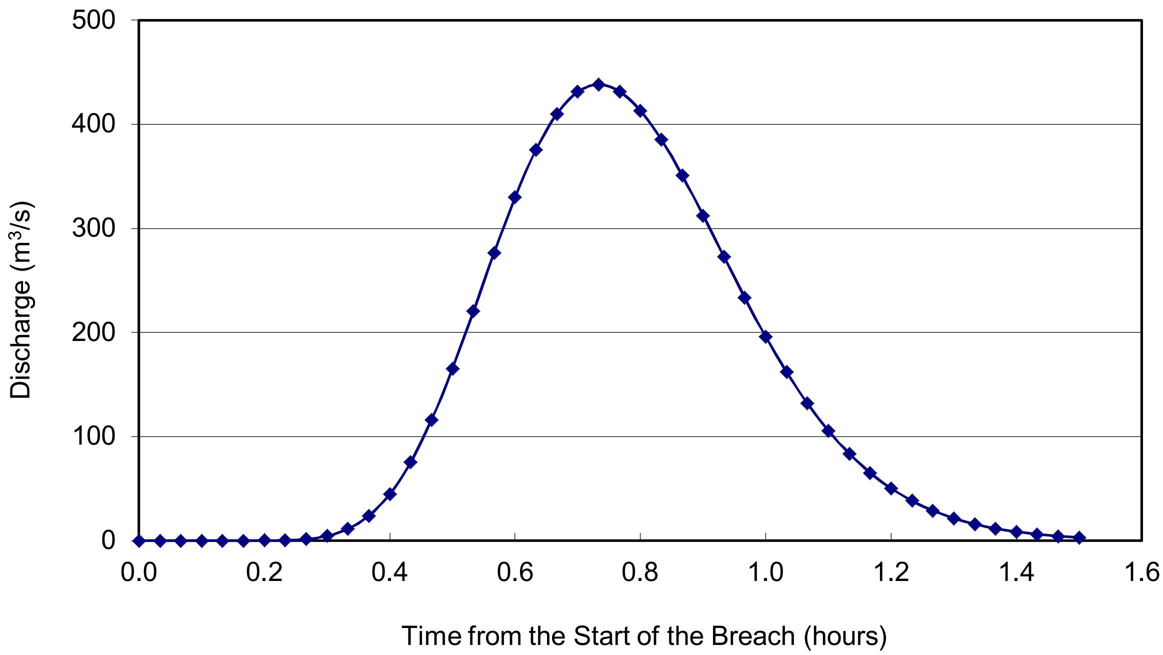
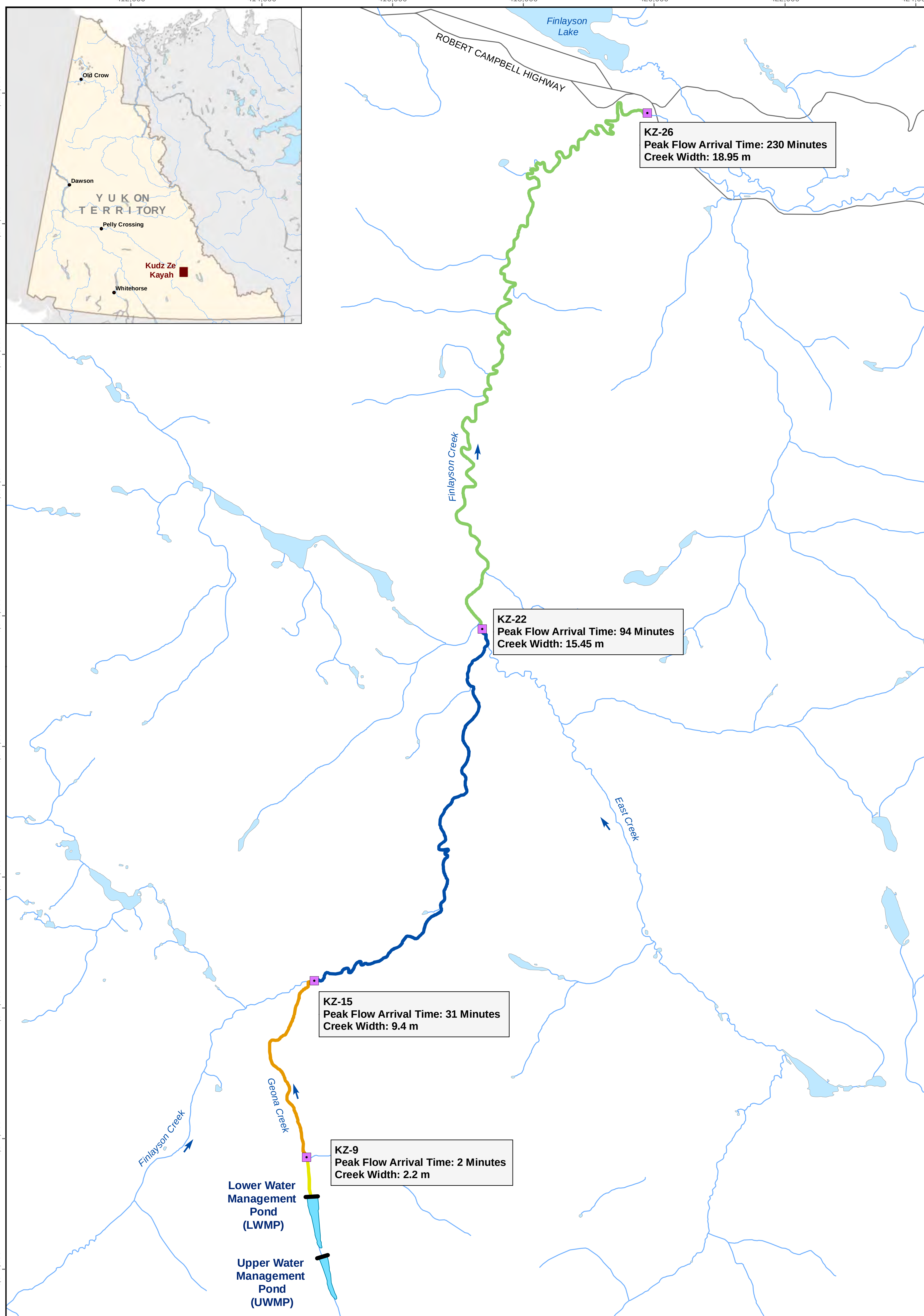


Figure 4.1: Discharge Hydrograph from the Hypothetical Catastrophic Failure of the Proposed WMPs



LEGEND

- Water Quality Sampling Location

Maximum Channel Flood Depth (m)

- > 17
- 13 - 17
- 6 -13
- 4 - 6

Potential Maximum Channel Flood Depth for the Hypothetical Failure of the Proposed WMPs

0 1 2 4 km

Map Projection: UTM Zone 9V NAD 1983
Data Source: Reproduced under licence from Her Majesty the Queen in Right of Canada, Department of Natural Resources Canada.

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Figure 4.2

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Table 2.1: Physical Characteristics of the Proposed Water Management Ponds

	Upper Water Management Pond	Lower Water Management Pond
Elevation at the Dam Crest	1,348.5 m	1,330.5 m
Volume at the Dam Crest	250,000 m^3	500,000 m^3
Elevation at Pond Bed	1,333.4 m	1,317.3 m
Maximum Depth	14.1 m	13.2 m
Surface Area at the Dam Crest	75,265 m^2	102,071 m^2
Dam Crest Length	151.5 m	178.8 m
Dam Crest Width	13 m	13 m
Downstream Dam Slope	2.5H:1V	2.5H:1V
Upstream Dam Slope	2.5H:1V	2.5H:1V
Accumulated Sediment	100 m^3	48 m^3

Table 2.2: Geometric Parameters and Discharge Capacity of the Downstream Receiving Waterbodies

Station	Description	Distance from the LWMP Dam (m)	Elevation (masl)	Average Slope (%)	Bankfull Parameters			During 1/50 Wet Year	
					Width (m)	Depth (m)	Discharge[a] (m^3/s)	Discharge[b] (m^3/s)	Depth[a] (m)
KZ-9	Geona Creek below the LWMP Dam	500	1,302	2.5	2.2	1.4	1.5	0.1	0.3
KZ-15	Finlayson Creek, 100 m downstream of the Confluence with Genoa Creek	3,754	1,203	1.0	9.4	1.1	7.1	1.1	0.3
KZ-22	Finlayson Creek below East Creek	11,755	1,091	1.0	15.5	1.4	9.8	2.7	0.7
KZ-26	Finlayson Creek just above the confluence with Finlayson River	25,689	950	1.0	19.0	1.9	14.7	3.3	0.7

[a]Estimated using calibrated stage-discharge rating curve (Alexco, 2016b).
[b]Discharge predicted by the water balance model (Alexco, 2017)

Table 4.1: Estimated WMP Failure Characteristics

Parameters	Results
Breach Shape	Trapezoidal
Breach Base Width	5.5 m
Breach Top Width	12 m
Breach Average Width	8.8 m
Breach Height	13.20 m
Time for Peak Discharge	44 min
Dam Breach Peak Discharge	438 m^3/s
Volume of Embankment Material Eroded	4,843 m^3

Table 4.2: Downstream Flow Characteristics caused by the Hypothetical Failure of the Proposed WMPs compared to the Pre-failure Condition

Parameters		Unit	KZ-9	KZ-15	KZ-22	KZ-26
Distance from the LWMP Dam		m	500	3,754	11,755	25,689
Pre-failure	Flow during 1/50 Wet Year	m^3/s	0.12	1.12	2.73	3.35
	Water Depth during 1/50 Wet Year	m	0.31	0.32	0.65	0.71
	Stream Velocity during 1/50 Wet Year	m/s	0.4	0.4	0.3	0.26
	Bankfull Depth	m	1.38	1.07	1.36	1.85
	Cross Sectional Area at Bankfull Depth	m^2	1.6	9.2	19.6	32.5
	Bankfull Discharge	m^3/s	1.52	7.12	9.8	14.7
During Failure	Peak Flow	m^3/s	416	315	210	131
	Peak Flow Arrival Time	minute	2	30	94	230
	Velocity corresponding to the Peak Flow	m/s	2.62	1.7	1.7	1.7
	Potential Maximum Flood Depth	m	17	13	6	4.22
	Cross-sectional Area needed to Pass the Peak Flow	m^2	159	185	100	77
	Stream Power corresponding to the Peak Flow	W/m	101,944	30,905	20,603	12,877
	Specific Stream Power corresponding to the Peak Flow	W/m^2	46,338	3,287	1,333	679

Table 4.3: Summary of the Predicted Flood Waves and Effects on the Downstream Fish Habitat

	Geona Creek	Finlayson Creek		
	KZ-9	KZ-15	KZ-22	KZ-26
Distance from LWMP Dam (km)	0.5	3.75	11.8	25.7
Physical Characteristics				
1-in-50 Wet Year Depth (m)	0.31	0.33	0.65	0.71
1-in-50 Wet Year Discharge (m^3/s) [1]	0.12	1.12	2.73	3.35
Bankfull Width (m)	2.2	9.4	15.5	19
Bankfull Depth (m)	1.38	1.07	1.36	1.85
Bankfull Discharge (m^3/s)	1.52	7.12	9.81	14.69
Flood Wave Impact				
Peak Flow Arrival (min)	2	30	94	230
Peak Flow (m^3/s)	416	315	210	131
Peak Flow / Bankfull Flow (ratio)	274 x	44 x	21 x	9 x
Peak Flow / 1-in-50 Wet Year Flow (ratio)	3467 x	281 x	77 x	39 x
Maximum Flood Depth (m)	17	13	6	4.2
Max / Bankful Depth (ratio)	12.3 x	12.1 x	4.4 x	2.3 x
Potential for Channel Widening by the Peak Flow[2]	Highly Likely	Highly Likely	Likely	Unlikely
Bed Sediment Erosion / Deposition by the Peak Flow[3]	Erosion - Very High, with scouring potential	Erosion - High	Erosion - High	Erosion - Moderate
Key Fish Habitat Notes	low productivity (but may expect more after barriers are removed as part of offsetting) low fish density very limited pool habitat, relatively straight run to Finlayson Creek	low productivity (but may expect more after barriers are removed as part of offsetting) low fish density very limited pool habitat	low productivity (but may expect more after barriers are removed as part of offsetting) low fish density very limited pool habitat	low productivity (but may expect more after barriers are removed as part of offsetting) low fish density very limited pool habitat
Key Fish Species Notes	Arctic Grayling. Juvenile grayling mainly present in headwater ponds. Low numbers of adults observed.	Arctic Grayling Slimy Sculpin		Arctic Grayling Slimy Sculpin Burbot (only 1 captured)
CRA Fisheries	None			
Seasonal Considerations	Limited over-wintering habitat. Marginal spawning habitat.	Over-wintering in Finlayson River - cannot return due to culvert barrier.		
Peak Flow Impact	Fish deaths, fish stranding, and temporary loss of fish habitat. Deeper pools may provide some refuge habitat.	Some fish deaths and stranding. Likely survival if fish are flushed to Finlayson River.		
Near-Term Impact [4]	eroded channel, short term food limitation, limited cover			sediment transport, seasonally elevated TSS, short term food limitation, limited cover
Long-Term Impact [5]	recovery expected - geomorphological, chemical, biological, riparian			

[1] mean annual discharge corresponding to the 1-in-50 wet year scenario

[2] Based on estimated specific stream power (SSP): SSP > 2000 W/m^2 (Highly likely), 790 W/m^2 < SSP < 2000 W/m^2 (Likely), and SSP < 790 W/m^2 (Unlikely)

[3] Based on estimated peak wave velocity (V_w) and SSP: SSP > 2000 W/m^2 and V_w > 2 m/s (Very High), 790 W/m^2 < SSP < 2000 W/m^2 and 1 m/s < V_w < 2 m/s (High), and SSP < 790 and 1 m/s < V_w < 2 m/s (Moderate).

[4] after failure-associated flow to 12 months post- failure

[5] 12 months post-failure to 10 years after failure