BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

HUCKLEBERRY MINES LTD.

TMF-3 DAM

DAM BREACH AND INUNDATION STUDY

FINAL

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November 28, 2014
Project No.: 1193004-M

Mr. Kent Christensen, P.Eng.
General Manager
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3394 – Highway 16 East
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Dear Kent,

Re: TMF-3 Dam Breach and Inundation Study – FINAL REPORT

Please find enclosed under cover of this letter four (4) copies of our aforementioned final report. The dam breach and inundation study is to inform the updating of the overall emergency preparedness and response plan for the Huckleberry Mine site.

Yours sincerely,

BGC ENGINEERING INC.
per:

Daryl Dufault, P.Eng.
Project Manager

EXECUTIVE SUMMARY

Huckleberry Mine is located in west central British Columbia, approximately 85 km southwest of Houston, B.C., as shown on Drawing 01. The mine site is on the south flank of Huckleberry Mountain overlooking Tahtsa Reach, which is part of the Nechako Reservoir impounded by Kenney Dam, located about 200 km to the east of the Huckleberry Mine site.

The Huckleberry open pit mine is currently in its eighteenth year of production, which began in the fall of 1997. The mine produces copper, gold, and silver through a hard rock mining process which involves the grinding of the mined rock into fine particles, sand size and smaller, such that copper, gold, and silver concentrate can be extracted via a conventional flotation process. The fine material left after the metals are extracted is called tailings, which are transported from the mill to the tailings impoundment as a slurry (a mixture of fine particles and water) by pipelines.

The TMF-3 Dam will attain a projected ultimate height of 90 m and will extend the life of the mine through to 2021. The planned mill throughput rate will vary between 16,400 and 18,000 tonnes per day, and the TMF-3 impoundment will, in its final projected configuration, store 46.8 million tonnes of waste rock, and 63 million tonnes of tailings.

Dam Breach and Inundation Study

The Canadian Dam Association (CDA) published dam safety guidelines (CDA, 2007) that recommend dam breach and inundation studies for all major water and tailings dams. These studies are to model potential consequences of hypothetical dam failures on areas downstream of the dam. The consequences are evaluated in terms of incremental impacts, which are defined in the CDA guidelines as the damage above and beyond the damage that would have occurred in the same conditions had a breach of the dam not occurred. The consequences of failure are divided into three categories: loss of life; loss of environmental and cultural values; and infrastructure and economic losses. The results of the dam breach and inundation analyses are generally used for two purposes:

1. To establish the failure consequence classification of the dam.
2. To inform the development of emergency preparedness and response plans (EPRP), which would be activated in the event of an incident at the dam.

This study was undertaken only to inform EPRP development, as the consequence classification of the dam has been established previously as “High”. However, the design criteria adopted for the dam are consistent with an “Extreme” consequence classification, and the dam will be constructed and operated accordingly. The results of the dam breach and inundation modelling therefore primarily inform EPRP; there are no implications for design criteria

At the time of issuance of this report, the starter embankment for the TMF-3 dam had been constructed to elevation 945 m. This report presents the dam breach and inundation study for the TMF-3 Dam at its final projected configuration and maximum projected height, 50 m higher than the dam as of November 2014.

Analyses used to simulate downstream consequences were intentionally conservative so that emergency response plans derived on the basis of these analyses err on the side of caution. The dam breach and inundation analyses completed for the TMF-3 Dam were based on hypothetical modes of failure under highly unlikely conditions, and the results of the analyses presented herein in no way reflect upon the structural integrity or safety of the dams.

The routing of floods released from hypothetical breaches of the TMF-3 Dam is as follows, and as illustrated on Drawing 02:

- Approximately 0.5 km from the downstream toe of the TMF-3 Dam to Tahtsa Narrows (part of the Nechako Reservoir)
- Approximately 2 km west along the Tahtsa Narrows to Tahtsa Lake
- Approximately 1 km east along the Tahtsa Narrows to Tahtsa Reach

The flood modelling was extended downstream of the dam up to the point where the modelled flood was predicted to have attenuated to the degree that water level increases in the Nechako Reservoir due to a hypothetical dam breach were negligible.

There are no people residing or personnel stationed directly below the TMF-3 dam. However, lodges, cabins, and boat launch facilities are known to exist along Tahtsa Reach and further to the east in the Nechako Reservoir.

Tahtsa Intake is a concrete structure located within the model domain at the west end of Tahtsa Lake. This structure is the inlet to the power tunnel for the Kemano hydroelectric generating station, operated by Rio Tinto Alcan. The flow of water from the Nechako Reservoir through the Tahtsa Intake is controlled at the Kemano Powerhouse, located at the downstream end of the penstock in Kemano, which is approximately 20 km west of Tahtsa Lake.

Computer Model Analyses

The dam breach and downstream flood analyses were carried out using computer model packages recognized as being among industry standards for such analyses. The models yielded estimates of:

- Areas that could be flooded
- Maximum water level rise in the reservoir at any given location
- Time for the flood wave to reach any given location
- Time for the water level to rise to its maximum level at any given location.

These estimates are used for EPRP development purposes.

The models for the TMF-3 Dam were extended to the western end of Tahtsa Lake and the eastern end of Tahtsa Reach. The computer models for the downstream flooding were terminated at these limits because there are no connecting water bodies downstream of the western end of Tahtsa Lake and the results of the dam breach and inundation analyses indicate that the dam breach flood is attenuated to only show a water level increase of less than 0.2 m by the time it reaches the eastern end of Tahtsa Reach.

To account for the many uncertainties and assumptions involved in this type of modelling, a range of assumptions and input parameters was used in the models to evaluate the effect on the results. Conservative assumptions were adopted for key parameters and model inputs so as to yield a conservative basis for emergency planning.

Modelled Dam Breach Scenarios

As outlined in the CDA (2007) guidelines, two dam breach scenarios were assessed for each of the dams: a "sunny-day" scenario; and a "rainy-day" scenario. Sunny-day breach scenarios are assumed to occur when the water behind the dam is at its normal (non-flood) operating level. Examples of sunny-day scenarios include a breach of the dam caused by internal erosion of fill or foundation soils, or a slope failure of the dam causing overtopping.

Rainy-day scenarios occur when rain and/or snowmelt inflows to the pond are so large that it causes the pond water level to rise above a level that the dam can safely accommodate, and thus overwhelms the flood storage, freeboard, and spillway release capacity incorporated into the design and operation of the dam. Under rainy-day scenarios the water bodies downstream of the dam were assumed to be under flood conditions consistent with those required to overtop the dam.

During its operational phase (with annual dam raises), the TMF-3 impoundment will not have an open channel spillway. An open channel spillway capable of passing the 4-day Probable Maximum Flood (PMF) will be constructed upon closure at the east abutment of the dam. Prior to closure, with no overflow spillway, the TMF-3 impoundment will be operated to store the 4-day PMF, with at least 1 m of extra allowance (called freeboard) between the highest expected flood storage level and the top of the dam. The dam will generally be raised a year in advance of actual tailings and flood storage requirements so the available freeboard will generally exceed the PMF storage and freeboard requirements cited above. For the dams to overtop, inflows would therefore have to be well above the estimated PMF volume, a highly unlikely occurrence. Moreover, at closure, the overflow spillway would have to be non-functional for overtopping to occur.

To identify the maximum effects of flooding, the dam breach flood was combined with the Nechako Reservoir at its highest permitted operating level.

Results of Analyses

The modelling results are illustrated on Drawing 03, in the figures provided in Appendices A and B, and in the summary tables provided in Section 5.0. The results presented include:

- Breach hydrograph – this is the rate of flow versus time at the modelled breach in the dam
- Hydrographs at the locations where the dam breach flows enter Tahtsa Narrows downstream of the modelled dam breach

- Plans showing the modelled inundation areas downstream of the modelled dam breach, the maximum water level rise above assumed PMF levels, and the estimated time taken for the maximum water level rise to occur at five reference locations in the reservoir.

The results of the rainy-day (overtopping) analyses are summarized in the table below.

Summary of TMF-3 Rainy-day (Overtopping) Dam Breach Analysis Results

		Key Locations Between the TMF-3 Dam and Tahtsa Narrows				Reference Locations in the Nechako Reservoir				
Scenario	**Analysis Output**	**Breach Location**	**Easternmost Stream Outlet to Tahtsa Narrows**	**Middle Stream Outlet to Tahtsa Narrows**	**Westernmost Stream Outlet to Tahtsa Narrows**	**1 – Tahtsa Narrows directly downstream of TMF-3**	**2 – Tahtsa Narrows near Tahtsa Reach**	**3 – Tahtsa Narrows near Tahtsa Lake**	**4 – Tahtsa Reach**	**5 – Tahtsa Lake**
Downstream Distance (km)		0	0.6	0.9	1.5	~0	~2	~2	~20	~20
Rainy-day scenario Over-topping 2° back-scarp	Peak Breach Flow (m^3/s)	37,000	22,000	14,000	<10	--	--	--	--	--
	Local Maximum Water Level Rise (m)	--	--	--	--	4.4	1.9	3.4	0.2	0.1
	Time for Local Maximum Water Level Rise to Occur (hr)	--	--	--	--	0.4	0.7	0.5	14.3	72[1]

[1]The presented time for the maximum water level rise to occur at the Tahtsa Lake reference location reflects a 72-hour model duration and is not the true time taken for the maximum water level rise to occur (see Section 4.5.12).

The greatest water level rise was predicted for Tahtsa Narrows, where the model predicted a water level rise of between 2 m and 4.4 m for the rainy-day (overtopping) scenario. As shown on Drawing 03, the water level rise in Tahtsa Lake and Tahtsa Reach was modelled to be less than 2 m, and was reduced to less than 0.25 m in the eastern and western portions of the model domain.

Limitations

The dam breach and inundation analyses are based on hypothetical scenarios. The conditions under which these scenarios occur are considered to be significantly less likely than those for an “Extreme” consequence category. Based on the use of industry standard modelling methods and software, conservative assumptions, and unlikely scenarios, the inundation predictions for a rainy-day scenario occurring during a PMF are considered upper bound and a suitable basis for EPRP.

The results of the dam breach and inundation analysis are not an indication of the structural integrity or safety of the TMF-3 Dam. Furthermore, the analyses do not predict the spatial distribution and deposition of tailings sediment after a breach event. Tailings run out deposition in Tahtsa Narrows could potentially isolate the Tahtsa Lake portion of the reservoir to the west from the Tahtsa Reach portion of the reservoir to the east. Given the volume of tailings considered for release in the scenarios modelled herein, and the dimensions of Tahtsa Narrows, EPRP plans should include contingency planning for mitigating isolation of the Tahtsa Lake portion of the reservoir in the event of a blockage of Tahtsa Narrows.

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LIMITATIONS

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1.0 INTRODUCTION

1.1. Objectives and Scope

BGC Engineering Inc. (BGC) was retained by Huckleberry Mines Ltd. (HML) to perform a tailings dam breach and inundation study for the TMF-3 dam. The mine operation comprises conventional open pit mining and flotation process operations and is currently in its eighteenth year of production, which began in the fall of 1997. The mine site is located in west central British Columbia, approximately 85 km southwest of Houston, B.C. (see Drawing 01).

Three tailings management facilities have been constructed as part of the HML operation (see Drawing 02). The TMF-2 impoundment is contained by the TMF-2 Dam, the Orica Saddle Dam, and the East Dam. The containment dams for the TMF-2 impoundment were completed to their final configuration, apart from downstream shell slope re-grading and on-going reclamation activities, in 2007. The East Zone Pit (EZP) impoundment located to the east of the TMF-2 impoundment, is contained by the East Pit Plug Dam (EPPD), constructed at the southeast rim of the EZP. The EZP impoundment was filled to capacity with waste rock and tailings in August 2013, with some capacity reserved for emergency tailings discharge. An inundation study was completed by AMEC in 2009 for both the TMF-2 and EZP facilities.

TMF-3 is the third tailings management facility constructed as part of the HML operation and is located to the west of the TMF-2 impoundment. Construction of the TMF-3 Starter Dam was completed in 2013. It is expected to store tailings and waste rock for a mine expansion that was initiated in 2011, which will extend the life of the mine through to 2021. Dam breach and inundation modelling for TMF-3 is presented in this report using the projected final (closure) configuration, representing the maximum height and retaining the maximum amount of tailings.

The objective of this dam breach and inundation study was to produce dam breach inundation maps to inform emergency preparedness and response planning (EPRP). Such analyses are recommended for all water and tailings dams in the dam safety guidelines published by the Canadian Dam Association (CDA) in 2007 (CDA, 2007). They are also mandated by the B.C. Ministry of Energy and Mines (MEM) for tailings dams in British Columbia.

To inform EPRP, dam breach and inundation studies typically estimate the following key outputs:

1. Potential inundation area
2. Maximum flood flow depth and, where relevant, flow velocity along the path
3. Arrival time of the flow front along the path
4. Arrival time of the peak flow along the path
5. The incremental height of the dam breach water level above the ambient river flow and reservoir water level conditions that would be expected at the time had the dam breach not occurred.

In the specific instance of the TMF-3 study, with no permanent population at risk in the area between the dam and the Nechako Reservoir the key outputs required to support EPRP reduce to the following:

- Areas that could be flooded
- Maximum water level rise in the reservoir at any given location
- Time for the flood wave to reach any given location
- Time for the water level to rise to its maximum level at any given location.

The analyses presented herein do not indicate the downstream distribution of released tailings following a hypothetical dam breach. Furthermore, the report only addresses the potential inundation extent in the event of a hypothetical breach of the TMF-3 dam under ultimate design elevation conditions, which will not be attained until the end of 2021. It does not attempt to quantify the consequences to facilities, calculate economic losses, address potential loss of life within the inundation area, or suggest potential risk management strategies. The results of the analyses documented herein are intended to inform assessments to support EPRP, which represents the next step upon completion of these analyses. The EPRP should include some contingency plans for mitigating tailings deposition within Tahtsa Narrows, which could potentially isolate the Tahtsa Lake portion from the remainder of the Nechako Reservoir.

1.2. Report Outline

The dam breach and inundation study report is organized as follows.

- Section 2.0 describes the project setting.
- Section 3.0 discusses the modelling framework and scenarios in the context of the CDA (2007) guidelines.
- Section 4.0 presents the dam breach methodology, discusses model assumptions, and outlines model inputs.
- Section 5.0 presents the results of the dam breach and inundation modelling, including modelling uncertainties and limitations.
- Section 6.0 outlines the recommended next steps involved in use of the modelling results documented herein.

2.0 PROJECT SETTING

2.1. Tailings Management Facility Setting

Huckleberry Mine is located in west central British Columbia, approximately 85 km southwest of Houston, B.C. The mine site is on the south flank of Huckleberry Mountain, overlooking Tahtsa Reach. The mine site lies in a transitional zone between the Coast Mountains to the west and the Interior Nechako Plateau to the east. The site lies in an east-west trending basin, or draw, bounded by Huckleberry Mountain to the north and a rock hill to the south. Huckleberry Mountain rises to El. 1543 m, and Tahtsa Reach has an elevation of about 860 m. The mine site and location plan are shown on Drawings 01 and 02.

The TMF-3 impoundment is the westernmost tailings management facility at the mine, located west of Huckleberry Mountain and north of Tahtsa Reach. The TMF-3 Dam will attain a final design crest elevation of about 995 m in 2021 (AMEC, 2011). It will be a centreline-raised, zoned earth fill and rockfill embankment, with downstream slopes of 2H:1V. The Starter Dam was constructed in 2013 to crest El. 945 m, and comprises the main approximately east-west section and a smaller north-south saddle dam, separated from the main embankment by high ground to the south for the first four years of operation. The Starter Dam comprises an upstream slope of 1.5H:1V and a downstream slope of 2H:1V. The TMF-3 Dam will include a central compacted till core and will attain an ultimate projected dam height of 90 m.

The TMF-3 impoundment will provide both waste rock and tailings storage. Per the AMEC design report (2011), the TMF-3 impoundment is projected to include 46.8 million tonnes of waste rock, 53.1 million tonnes of mill tailings deposited in slurry form, and 9.9 million tonnes of re-handled legacy tailings, hauled via truck. To achieve full submergence upon closure, the waste rock and legacy tailings will be primarily stored in the northern part of the impoundment, within a platform that will reach a maximum elevation of 990 m. The mill tailings will be primarily stored between the waste rock platform and the TMF-3 dam, although some tailings would be deposited over the El. 990 m platform.

An open-channel spillway will be constructed upon closure and will be capable of routing, in combination with the attenuation capacity of the TMF-3 impoundment, the peak inflow resulting from the 4-day duration Probable Maximum Flood (PMF), which comprises a 4-day Probable Maximum Precipitation on top of a snowmelt component. The analyses presented in this report conservatively assume that the closure spillway is blocked or otherwise inoperable.

2.2. Setting Downstream of TMF-3 Dam

The flood route downstream of TMF-3 would be as follows (see Drawing 02):

- Approximately 0.5 km from the downstream toe of the TMF-3 Dam to Tahtsa Narrows (part of the Nechako Reservoir)
- Approximately 2 km west along Tahtsa Narrows to Tahtsa Lake
- Approximately 1 km east along Tahtsa Narrows to Tahtsa Reach.

Tahtsa Reach forms an upper reach of the Nechako Reservoir, which was created by construction of the Kenney Dam in the early 1950's. Kenney Dam is located approximately 200 km downstream (east) of the TMF-3 Dam.

Tahtsa Intake is a concrete structure at the west end of Tahtsa Lake, about 35 km west of the TMF-3 Dam. This structure is the inlet to the power tunnel for the Kemano hydroelectric generating station, operated by Rio Tinto Alcan. The flow of water from the Nechako Reservoir via the Tahtsa Intake is controlled at the Kemano Powerhouse, located at the downstream end of the penstock in Kemano, which is approximately 20 km west of Tahtsa Lake. Natural drainage of Tahtsa Reach was to the east, but with the construction of Kenney Dam approximately 200 km to the east and the Kemano power intake tunnel at the west end of Tahtsa Lake, flow now occurs to the west through Tahtsa Narrows.

The surface area, mean depth, and maximum depth of Tahtsa Lake were obtained from a bathymetric map provided by the British Columbia Ministry of Environment and are summarized in Table 2-1 below. No detailed bathymetric information data were available for Tahtsa Narrows or Tahtsa Reach; mean depths were estimated using available reports (Alcan, 2007; "Tahtsa Narrows Dredging", date unknown).

Table 2-1. Physical Characteristics of Water Bodies in Model Domain

Lake Name	Surface Area (km^2)	Mean Depth (m)	Maximum Depth (m)
Tahtsa Lake (assuming water level at 852 masl)	53	60	217
Tahtsa Narrows[1]	~ 3	3	17
Tahtsa Reach[1]	~ 40	20	--
Nechako Reservoir (assuming water level at 853.5 masl)	910	--	--

[1]Detailed bathymetry unavailable for Tahtsa Narrows or Tahtsa Reach. Mean depths were estimated using available reports. Surface areas were calculated using Google Earth Pro.

2.3. Population and Infrastructure

There are no people residing or personnel stationed below the TMF-3 dam. However, lodges, cabins, and boat launch facilities are known to exist along Tahtsa Reach and further downstream to the east in the Nechako Reservoir.

No major transportation corridors exist within the study area.

3.0 BREACH MODELLING FRAMEWORK

3.1. CDA Guidelines

Dam breach and inundation studies are recommended for all major tailings and water dams under the CDA (2007) dam safety guidelines. The guidelines are based on a risk-based approach and classify dams based on failure consequences. The failure consequence classification is then used to determine the appropriate design criteria in terms of the maximum design earthquake (MDE) and the inflow design flood (IDF). The higher the consequence classification, the more stringent the design criteria that are applied to the dams.

The CDA Dam Safety Guidelines define the term “consequence” to mean incremental damage above and beyond the damage that would have occurred in the same event or conditions had the dam not failed. These may also be called “incremental consequences” of failure.

The consequence classification also informs the frequency at which formal dam safety reviews (DSR’s) are to be carried out.

Table 3-1 provides the consequence classification scheme per the CDA (2007) guidelines. On the basis of this scheme and the setting of the TMF-3 tailings impoundment, the TMF-3 dam was assigned a “High” consequence classification (AMEC, 2011).

Despite the “High” consequence classification, the design of the TMF-3 dam is based on the 10,000 year return period earthquake as the MDE ground motions, and the PMF as the IDF, which are applicable for the “Extreme” consequence classification. The results of this dam breach and inundation therefore have no bearing on the design criteria for the TMF-3 dam because the most stringent criteria have already been adopted.

Table 3-1. CDA (2007) Consequence Classification Scheme

Dam Class	Population at Risk [note 1]	Incremental Losses		
		Loss of Life [note 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 or compensation 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 important 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 in kind impossible	Extreme losses affecting critical infrastructure or services (e.g. hospital, major industrial complex, major storage facilities for dangerous substances)

Note 1. Definitions for population at risk:

None – There is no identifiable population at risk, so there is 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, passing through on transportation routes, participating in recreational activities).

Permanent – The population at risk is ordinarily located in the dam-breach inundation zone (e.g. as permanent residents); three consequence classes (high, very high, extreme) are proposed to allow for more detailed estimates of potential loss of life (to assist in decision-making if the appropriate analysis is carried out).

Note 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, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.

3.2. Breach Modelling Scenarios

In accordance with the CDA guidelines (2007) the following dam breach scenarios were assessed for the TMF-3 dam (see Figure 3-1):

- Rainy-day dam failure:
    - Flood-induced dam failures are referred to as rainy-day failures. A rainy-day or overtopping type failure may occur during large flood inflow conditions when the pond water level rises high enough to overtop the dam.
- Sunny-day dam failure:
    - Sunny-day failures are assumed to occur when the pond is at its normal operating level. Examples of sunny-day failures include dam slope failure due to static or earthquake loading, or piping-induced dam failure (internal erosion).

CDA (2007) indicates that "*typically, for earthfill dams, both overtopping failure and piping failure are included in the analysis*". Figure 3-1 provides an overview of the dam breach scenarios modelled in this study. Both sunny-day and rainy-day failure scenarios were simulated considering a range of back-scarp angles in the tailings not released in the modelled breach, as discussed further in Section 4.4. The 3^{o} failure back-scarp case was not carried forward to inundation modelling as dam breach modelling results indicated the 3^{o} case was nearly identical to the 2^{o} failure back-scarp case. Dam breach wave propagation modelling in the reservoir was only completed for the rainy-day (overtopping) case as this represents the most conservative scenario for EPRP purposes.

The dam breach analyses and results presented in this report are based on hypothetical failures and in no way reflect the structural integrity or safety (i.e. probability of failure) of the dams.

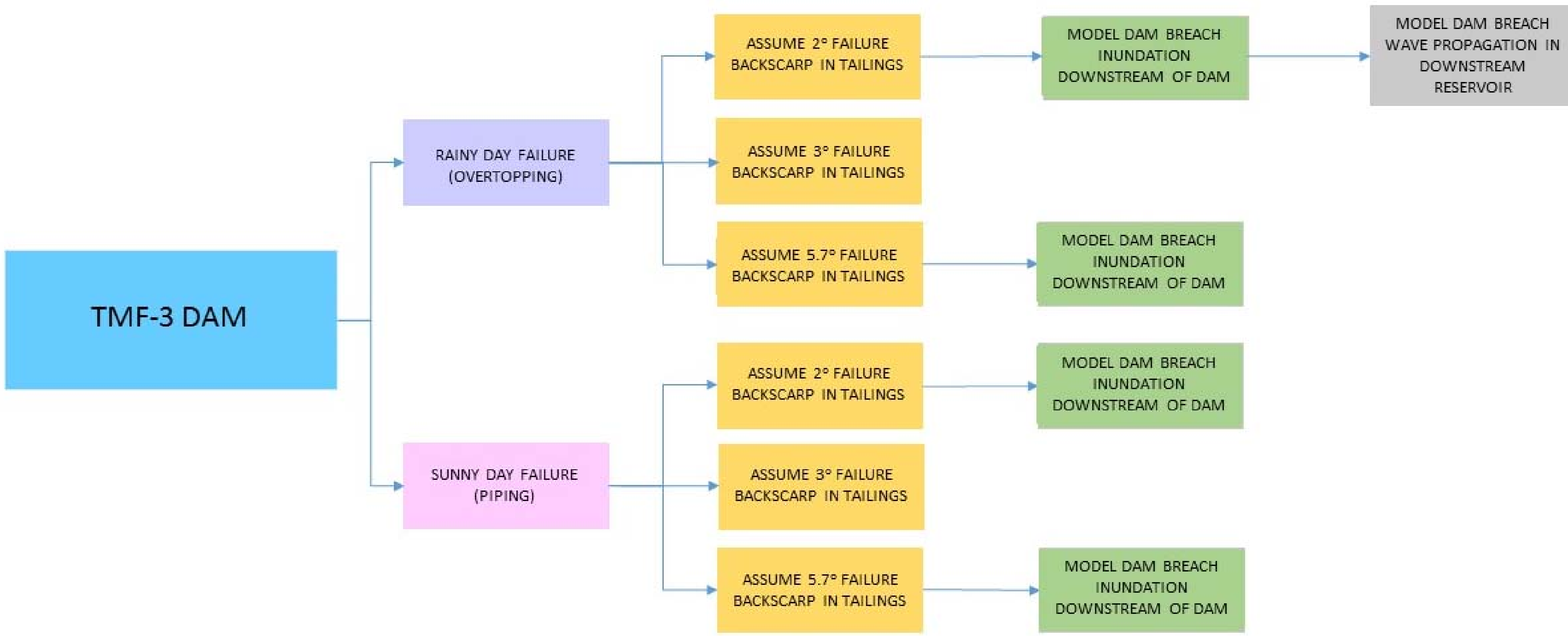

Figure 3-1. Overview of Modelled Dam Breach Scenarios

4.0 DAM BREACH METHODOLOGY AND ASSUMPTIONS

4.1. Overview of Dam Breach Modelling Practice

In practice, breach and inundation modelling for tailings dams is performed using a two-step approach. The first step involves breach modelling to estimate the outflow rate from the tailings dam breach. The second step involves inundation modelling to simulate slurry flow wave propagation processes downstream of the breach with hydrodynamic models that incorporate the assumed rheological properties of tailings flow.

The software packages used for the work presented in this report are industry accepted models. They were judged to be the most appropriate models for this project site and the downstream conditions, as described in Section 4.2 and Section 4.3. The limitations and uncertainties of the modelling approach are discussed in Section 5.3.

4.2. Breach Modelling

The numerical model BREACH (Fread, 1991) was used to simulate dam breaches in this study. BREACH was selected over other comparable numerical models, including DAMBRK, FLDWAV, MIKE 11, and HEC-RAS, because it is physically based (as opposed to empirical-parametric). This means that the breach rate, which is typically the source of the greatest uncertainty in empirical-parametric modelling, is an output of the model rather than an input. Furthermore, the physical processes simulated by BREACH provide a physical basis for interpreting the model results.

Given the geometry and physical properties of the dam and pond in question, BREACH simulates the physical processes of overtopping or piping using the principles of hydraulics, sediment transport, and slope stability. These physical processes, which are extremely complex and variable in reality, are, out of necessity, simplified in the numerical model.

In a typical overtopping breach analysis, BREACH simulates the following process:

1. Flow of water over the dam crest initiates erosion of a narrow channel on the downstream dam face.
2. The channel down-cuts parallel with the dam face and expands laterally through a combination of continuous erosion and episodic bank failures.
3. After intersection with the upstream dam crest, the channel begins to down-cut vertically and continues to expand laterally.

The start of step 3 above typically coincides with a significant increase in the simulated outflow discharge. Beyond this point, an overtopping breach is considered to be fully developed. This critical point is notable because it defines time t = 0 in the inundation analyses described in Section 4.3, and therefore affects the simulated arrival times along a flow path. Steps 1 and 2 above may become redundant if it is assumed that a mass movement (i.e., a slump or foundation failure) of the dam triggers the breach. In this case, rapid down-cutting may begin immediately.

In a typical piping breach analysis, BREACH simulates the following process:

1. Given a user-specified initial breach elevation, a narrow horizontal pipe is formed which joins the upstream and downstream dam faces.
2. The diameter of the pipe increases through continuous erosion until a critical point is reached and the pipe collapses.
3. If the top of the collapsed material is lower than the elevation of the pond surface at the time of collapse, overtopping follows as described above.

The main limitation of BREACH is that the breaching fluid is assumed to be clear water, meaning that the sediment concentration (i.e., solids content by volume) of the actual flow is neglected. This may influence the calculated breach rate and the resulting outflow hydrograph, although this influence is not well understood at present. For typical tailings dam breach analyses, treating the breaching fluid as clear water (i.e., a fluid with a relatively high sediment transport capacity) is likely a conservative assumption resulting in comparatively higher estimated peak discharges.

4.3. Inundation Modelling

The numerical model FLO-2D (FLO-2D Software Inc., 2007) was used to simulate the tailings flow run-out from the simulated dam breach. FLO-2D is on the U.S. Federal Emergency Management Agency's list of approved hydraulic models for this type of study, and has been used in practice for more than 15 years.

FLO-2D is a depth-averaged volume conservation based flood routing model that was developed specifically for the analysis of muddy flows travelling over complex three-dimensional terrain, making it well-suited to tailings run-out analysis. For flows with volumetric sediment concentrations greater than 20%, the flow resistance of the tailings slurry is governed by a non-Newtonian quadratic rheological model. For flows with volumetric sediment concentrations less than 20%, the influence of the solids component on the rheology of the breaching fluid is negligible and the material is expected to flow like water. In this case, FLO-2D reverts to a conventional clear water flood routing model, in which the breaching fluid is treated as clear water and flow resistance is governed by surface roughness along the path.

FLO-2D does not account for the influence of deep standing or flowing water along the path, including displacement waves which might occur upon impact by the flow front. In this study, a simplified approach was used to simulate changes in lake water levels due to inflow and outflow of breach material.

4.4. Modelling Assumptions

The closure configuration of the TMF-3 Dam (crest El. 995 m) was assumed for the dam breach and inundation analyses, therefore incorporating the maximum dam height and the maximum volume of impounded tailings.

The modelling required a considerable number of inputs and assumptions, which in turn required engineering judgment. Given the assumptions involved in modelling of the complex processes involved in dam breaching and flood wave propagation, this type of modelling is inherently uncertain. In the face of that uncertainty, and given the objective of informing conservative emergency response and preparedness planning, it is appropriate to adopt conservative assumptions. Key uncertainties are discussed in Section 5.3. Some of the model assumptions were as follows:

- The initial water level in the tailings impoundment for rainy-day scenarios was assumed to be equivalent to the ultimate dam crest elevation. The volume of water required to raise the pond level from the closure spillway invert elevation (El. 992.5 m) to the dam crest (El. 995 m) is 3.5 Mm^3, equivalent to 1.6, 4-day duration PMF's, with no release.
- The initial water level for sunny-day scenarios was assumed to be at the nominal pond level of 992.5 m, with a pond volume of about 2.5 Mm^3.
- The initial piping failure location was modelled near the toe of the maximum (highest) portion of the dam.
- The TMF-3 Dam design comprises a till core with a downstream shell of compacted cyclone sand and NAG rockfill, and an upstream starter dam shell of PAG waste rock, but BREACH is unable to model complex internal geometries. For BREACH modelling purposes, the TMF-3 Dam was modelled as a central till core dam with a compacted cyclone sand downstream shell.
- The waste rock stored in the northern part of the impoundment does contain fines and is generally well graded, which suggests that erosion of the waste rock could occur during a breach event as the tailings and water above the top of the waste rock dump are mobilized. However, the volume of waste rock that could be mobilized by erosion is expected to be negligible relative to the volume of tailings and water released. Furthermore, unlike the water and tailings, the waste rock would not be expected to liquefy during a breach event.
- Case studies indicate that, following the breach of a tailings dam, typically only a portion of the impounded tailings are released. Rico et al. (2008) estimated an average tailings release volume of approximately 35%; Lucia (2001) estimated an average tailings release volume of approximately 20%. However, depending on the site conditions, the released volume is documented to range from 10% to 100%. A post failure tailings surface profile of 2° from the upstream toe of the breach through the tailings was assumed as an upper bound for a released volume estimate based on case studies from the El Cobre, Merriespruit, Bafokeng, Arcturus and Saaiplaas tailings dam failures (Blight and Fourie, 2003); 3° was assumed as an average value; and 5.7° (10%) was assumed as a lower bound (Lucia, 2001). In this study sensitivity analysis for released volumes were performed by considering a back-scarp range of 2° to 5.7°.
- The deposited tailings were assumed to be fully consolidated at the closure condition, meaning that the time-dependent consolidation process of the tailings was considered complete, so there would be no further increase in the density of the tailings. The initial tailings concentration by volume was assumed to be vertically uniform.

- Because bathymetric data for Tahtsa Narrows and Tahtsa Reach are not available, average depths of 3 m and 20 m, respectively, were assumed in the model, based on information gleaned from Alcan (2007) and the “Tahtsa Narrows Dredging” report (date unknown). The modelling results presented herein also assumed a mean depth of 20 m in Tahtsa Lake for modelling efficiency. The sensitivity of the model to assumed mean depth is described in Section 5.2.4.
- To account for PMF conditions for the rainy-day (overtopping) failure scenario, the initial water level in the reservoir downstream of the TMF-3 Dam was set at 854 m, which is very close to the highest permitted elevation of the reservoir of 853.44 m (Alcan, 2007). As discussed in Section 3.2, the sunny-day (piping) scenario modelling was not extended into the reservoir, as the rainy-day (overtopping) scenario represents the most conservative case for EPRP purposes. The invert elevation of the Skins Lake Spillway, which is located approximately 90 km downstream of the TMF-3 dam is unknown, however Alcan (2007) suggests that if the reservoir level rises above 853.44 m, water is discharged from the reservoir via the spillway.

4.5. Model Inputs

4.5.1. Breach Geometries

Design cross sections showing the ultimate dam geometry were obtained from AMEC’s design report (AMEC, 2011). The geometrical inputs to the BREACH model are summarized in Table 4-1.

The TMF-3 dam is centreline-raised, so there is no upstream slope. In the BREACH model, the upstream slope was adjusted to generate peak flows that were within the range of empirical-statistical estimates, as discussed in detail in Section 4.5.7. The model was therefore forced via adjustment of a key parameter to yield a peak breach flow in line with documented case record experience.

Table 4-1. Breach Geometry Inputs

<table>
<tr><th>Dam</th><th>Failure Mode</th><th>Initial Water Level (m)</th><th>Tailings Level at Closure (m)</th><th>Dam Crest Elevation (m)</th><th>Dam Toe Elevation (m)</th><th>Downstream Dam Slope</th><th>Initial Design Crest Width (m)</th></tr>
<tr><td rowspan="2">TMF-3 Dam</td><td>Overtopping</td><td>995</td><td rowspan="2">990.5</td><td>995</td><td rowspan="2">905</td><td rowspan="2">2H:1V</td><td rowspan="2">25</td></tr>
<tr><td>Piping</td><td>992.5</td><td>995</td></tr>
</table>

4.5.2. Dam Material Parameters

The dam material parameter values used in the BREACH analyses are shown in Table 4-2. The values are based on information from AMEC (2011).

Table 4-2. TMF-3 Dam Material Properties

Parameter	Till Core	Cyclone Sand Shell
D_{50} Grain Size (mm)	0.1	1
D_{90} to D_{30} Grain Size Ratio	10	10
Porosity	0.45	0.45
Density (kN/m^3)	21.5	19
Internal Friction Angle, ϕ_i (°)	30	35
Cohesion (kPa)	0	0

4.5.3. Released Tailings and Water Volumes

As discussed in Section 4.4, the average post failure angle in the tailings remaining within the impoundment is one of the key assumptions for modelling. Three different post failure angles were selected to evaluate the impact of this parameter on the model results. Post failure angles in the tailings of 2^o, 3^o, and 5.7^o were assumed for both the rainy-day (overtopping) and sunny-day (piping) failure cases. This range was considered to evaluate the degree to which different volumes of tailings release could affect the attenuation of the flood wave in the Nechako Reservoir.

MUCK-3D (MineBridge Software, 2014) was used to develop volume-elevation curves that projected the assumed post failure angles from the breach location of the TMF-3 Dam. A summary of the modelled outflow volumes is presented in Table 4-3.

Table 4-3. Outflow Volumes for Modelled Scenarios

Dam	Failure Mode	Post Failure Angle (degrees)	Total Released Volume (Water + Tailings)[1] (Mm^3)	Released Free Water Volume (Mm^3)	Released Tailings Volume (Mm^3)	Percentage of Tailings Released (Mm^3)
TMF-3	Overtopping	2	29	6	23	92%
	Piping	2	26	2.5	23	92%
	Overtopping	3	29	6	23	91%
	Piping	3	26	2.5	23	91%
	Overtopping	5.7	24	6	17	70%
	Piping	5.7	21	2.5	17	70%

Note:
1. Water volume released refers to the free water pond, all of which is released under any breach scenario. Tailings volume released represents the volume of the tailings solids and the porewater within the tailings.

As shown in Table 4-3, the 2^o and 3^o failure back-scarp cases yielded nearly identical released volumes with approximately 90% tailings release volume. This high percentage of released tailings can be explained by the geometry of the TMF-3 impoundment. The toe of the waste rock platform internal to the TMF-3 impoundment is located approximately 100 m upstream of the TMF-3 Starter Dam toe, meaning that the projection of the tailings back-scarp angle is truncated at the dump within a short distance. Furthermore, natural ground slopes upstream at approximately 1° to 2°, which essentially parallels the 2° and 3° tailings back-scarp projections, resulting in near full release of tailings. Given the similarity of the 2° and 3° cases, only the 2° and 5.7° failure back-scarp cases were carried forward to inundation modelling within the Nechako Reservoir.

4.5.4. Pond Elevation vs. Surface Area

To estimate the volume of stored tailings remaining in the impoundment at any given time during a breach analysis, BREACH requires estimates of the tailings pond surface area as a function of pond surface elevation. Pond surface areas were estimated using volume-elevation curves developed from the topographic data and the MUCK-3D generated post failure surfaces.

4.5.5. TMF-3 Inflow Rates

The estimated average 4-day PMF flow rate of 6.5 m^3/s was derived using the 4-day PMP and the TMF-3 impoundment catchment area (AMEC, 2011). This value was assumed as inflow into the TMF-3 impoundment to initiate a simulated overtopping failure (rainy-day scenario). No base flow into the TMF-3 impoundment was assumed for the piping failure scenario (sunny-day scenario).

4.5.6. Topography

The following digital topographic data was used for the study:

- 17 m resolution Canadian Digital Elevation Data (CDED) provided by GeoBase
- 1 m resolution LiDAR data provided by HML (2013)
- Bathymetry for Tahtsa Lake provided by the British Columbia Ministry of Environment (2014).

The LiDAR data were used for dam breach and inundation modelling from the TMF-3 Dam to just upstream of Tahtsa Narrows. The GeoBase data were used for modelling in the Nechako Reservoir.

The data were input into the Grid Developer System (GDS) pre-processing program included with FLO-2D. The computational domain was then clipped around the main area of interest to improve model efficiency. The grid size for modelling between the TMF-3 Dam and the Tahtsa Narrows was 20 m; the grid size for modelling in the reservoir was 100 m. The resolution of the grid size for each model domain was chosen based on a combination of factors, including DEM resolution and the computing time.

4.5.7. Peak Discharge Estimate

Peak flow is a key output of BREACH modelling and affects the flow depth and propagation velocity along the flood route. Given that the TMF-3 Dam is centreline-raised, which means there is no upstream slope, and the simplifications of the physical processes applied in modelling, BREACH tends to output extremely high peak discharge values compared to peak flow estimated based on case studies. This required that the upstream slope of the dam modelled within BREACH be adjusted such that the model yielded a predicted peak discharge in line with empirical-statistical estimates, so as to better conform to documented case record experience.

4.5.8. Hydrographs

The BREACH outflow hydrographs for the 2^{o} and 5.7^{o} cases shown in Figure 5-2 and Figure 5-3 were used as input into the FLO-2D model of the area between the TMF-3 Dam and Tahtsa Narrows, and the Nechako Reservoir. Inundation model time t=0 was reset to correspond with the start of a significant rise in the outflow discharge, representing the onset of full breach development, as discussed in Section 4.2.

4.5.9. Tailings Concentration

The breach flows analyzed in this study for the TMF-3 Dams assumed a uniform solids content of 73% by weight and 47% by volume for the saturated tailings. This solids content was derived using the following tailings property assumptions from AMEC (2011), which were derived from annual soundings and surveys of the other Huckleberry tailings impoundments:

- Average void ratio for settled tailings, e = 1.0
- Specific gravity of tailings solids, G_s = 2.69
- Average Settled Dry Density, ρ_d = 1.35 tonnes/m^3.

Erosion and entrainment of dam material, impounded waste rock, and surficial material downstream was assumed to contribute a relatively small volume of additional solids to the breach flows.

4.5.10. Tailings Rheological Parameters

To model the released non-Newtonian slurry flow, FLO-2D requires the input of several rheological parameters including the yield stress and viscosity of the slurry. The parameters in Table 4-4, based on typical values for gold tailings from the FLO-2D manual (2007), were applied while routing the outflow from the TMF-3 Dam. Copper tailings tend to be of somewhat coarser gradation, so the use of parameters for finer grained tailings is judged conservative in terms of the mobility of the tailings following the modelled dam breach.

Table 4-4. Yield Stress and Viscosity Parameters for Tailings

Resistance Component	Estimated Parameter (per FLO-2D manual)	
	α	β
Yield Stress (Pa)	0.0473	21.1
Viscosity (Pa-s)	0.128	12.0

4.5.11. Resistance Parameters

FLO-2D requires estimates of Manning's coefficient, *n*, which characterizes the surface roughness along the flood path downstream of the dam. Given the overall site conditions with generally dense brush cover in the area between the TMF-3 Dam and Tahtsa Narrows, a uniform Manning's *n* number of 0.075 was assigned to the grid cells in FLO-2D. This value was selected from tables presented in Chow (1959).

4.5.12. Duration of Simulation

The duration of each simulation was determined by the time required for the peak flow to pass through the model domain from the inflow to the outflow boundary. Ultimately, it is the model domain area that defines the duration of simulation, which was set as 72 hours for the inundation modelling in the reservoir.

The water level in Tahtsa Reach was still rising in the model at the end of the 72-hour model duration. However the water level rise was negligible and given the size of the reservoir compared to the volume of released tailings and water, the model duration was deemed adequate.

4.5.13. Selected Reference Locations

To evaluate the potential consequences of the modelled dam breach events, several reference locations were defined in the inundation models. Table 4-5 summarizes these locations, indicated with stars on Drawing 03. The results at each reference location are discussed in Section 5.2

Table 4-5. Reference Locations in Model Domain

Reference Locations		UTM Easting (m)	UTM Northing (m)
1	Tahtsa Narrows directly downstream of TMF-3 Dam	616561	5949139
2	Tahtsa Narrows near Tahtsa Reach	618561	5947639
3	Tahtsa Narrows near Tahtsa Lake	613861	5949339
4	Tahtsa Reach	636261	5954539
5	Tahtsa Lake	596061	5948039

5.0 MODEL RESULTS AND DISCUSSION

5.1. Breach Outflows

Outflow hydrographs developed in BREACH present the modelled discharge rate versus time at the downstream toe of the dam. The area under the breach hydrograph represents the total volume of released material. The hydrographs reflect several factors, including the bathymetry of the pond, the breach development process (i.e. overtopping vs. piping), the tailings/water volumes released, and the final breach dimensions. Relatively steep and narrow hydrographs are typical for higher dams in narrow valleys (with smaller pond surface areas), whereas relatively flat and broad hydrographs are typical for smaller dams in wider valleys (with larger pond surface areas). For overtopping failures, the breach mechanics are dominated by the down-cutting process, resulting in a single peak in the hydrograph. For piping failures, there are sometimes two peaks in the hydrograph separated by a low that represents collapse of the pipe, which may temporarily stem the breach and be followed by overtopping of the collapsed material and a second peak.

The sections below discuss the peak discharge estimate and the BREACH hydrographs obtained for the various modelling scenarios developed for the TMF-3 Dam. The hydrographs were used as input into the FLO-2D inundation modelling.

5.1.1. Peak Discharge Estimate

Using dam failure case records, a number of empirical equations have been developed relating peak discharge to dam height and/or breach volume for water and tailings dams (e.g., Walder et al., 1997; Froehlich, 2008; Rico et al., 2008). Figure 5-1 plots peak discharge rate values against dam factor. Dam factor, which is the product of the dam height (H) in units of m, and reservoir volume (V) in units of Mm^3, is an index of the energy expenditure at the dam when it fails. This index was developed by Hagen and the Committee on the Safety of Existing Dams to estimate peak discharge based on reservoir characteristics (Rico et al., 2008).

The upstream slope input parameter for the TMF-3 Dam was adjusted in BREACH so that the simulated peak discharges obtained with BREACH, shown in Figure 5-1, are consistent with the typical range of empirically-calculated values.

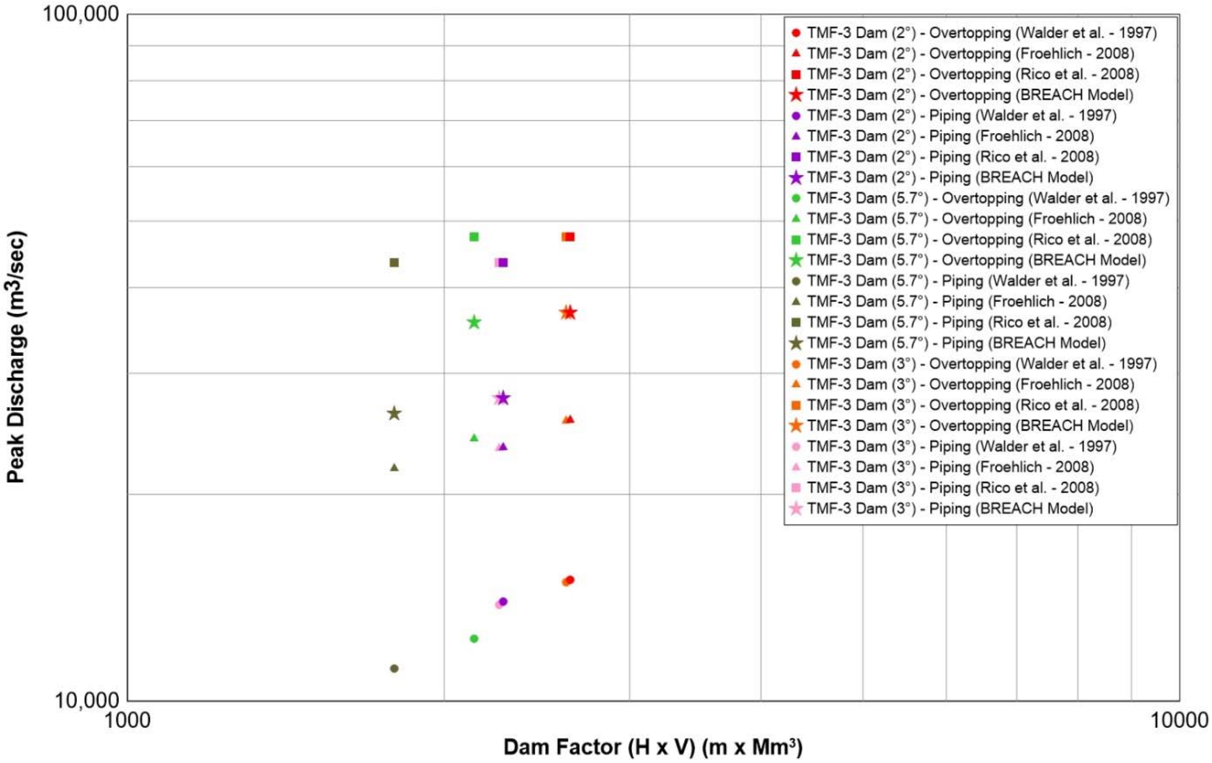

Figure 5-1. Comparison of Empirical Relationships with BREACH Model Output

5.1.2. Breach Hydrographs

Figure 5-2 shows the BREACH analysis results for the rainy-day (overtopping) scenario at the TMF-3 dam. The hydrograph shows multiple lines: the black lines represent the discharge rate for tailings and water combined for the three failure back-scarp angles; the orange lines represent the discharge rate for tailings (and associated porewater) alone for the three failure back-scarp angles. Tailings discharge is delayed by approximately 0.1 hours because initially only water is released from the pond (between the ultimate crest elevation of 995 m to the tailings elevation of 990.5 m). Once the pond level drops below 990.5 m, tailings discharge is initiated. Using the model assumptions for the rainy day scenario, approximately 29 Mm^3 of tailings and water would be released from the TMF-3 Dam for the 2^o and 3^o scenarios in approximately 0.8 hours and approximately 24 Mm^3 of tailings and water would be released for the 5.7^o scenario in approximately 0.8 hours.

Figure 5-3 shows the BREACH analysis results for the sunny-day (piping) scenario at the TMF-3 Dam. The simulated peak discharge for piping failure for water and tailings release combined is approximately 28,000 m^3/s for the 2^o and 3^o failure back-scarp cases and approximately 26,000 m^3/s for the 5.7^o failure back-scarp case. The orange line represents the discharge rate for tailings (and associated porewater) alone. Based on the assumption that the initial piping elevation is located near the toe of the dam, both tailings and water are released at the onset of discharge. Using the model assumptions for the sunny-day (piping) scenario, approximately 26 Mm^3 of tailings and water would be released from the TMF-3 Dam for the 2° and 3° scenarios in approximately 0.4 hours and approximately 21 Mm^3 of tailings and water would be released for the 5.7° scenario in approximately 0.4 hours. The hydrograph drops off abruptly at the end due to collapse of the overlying dam material onto the formed pipe.

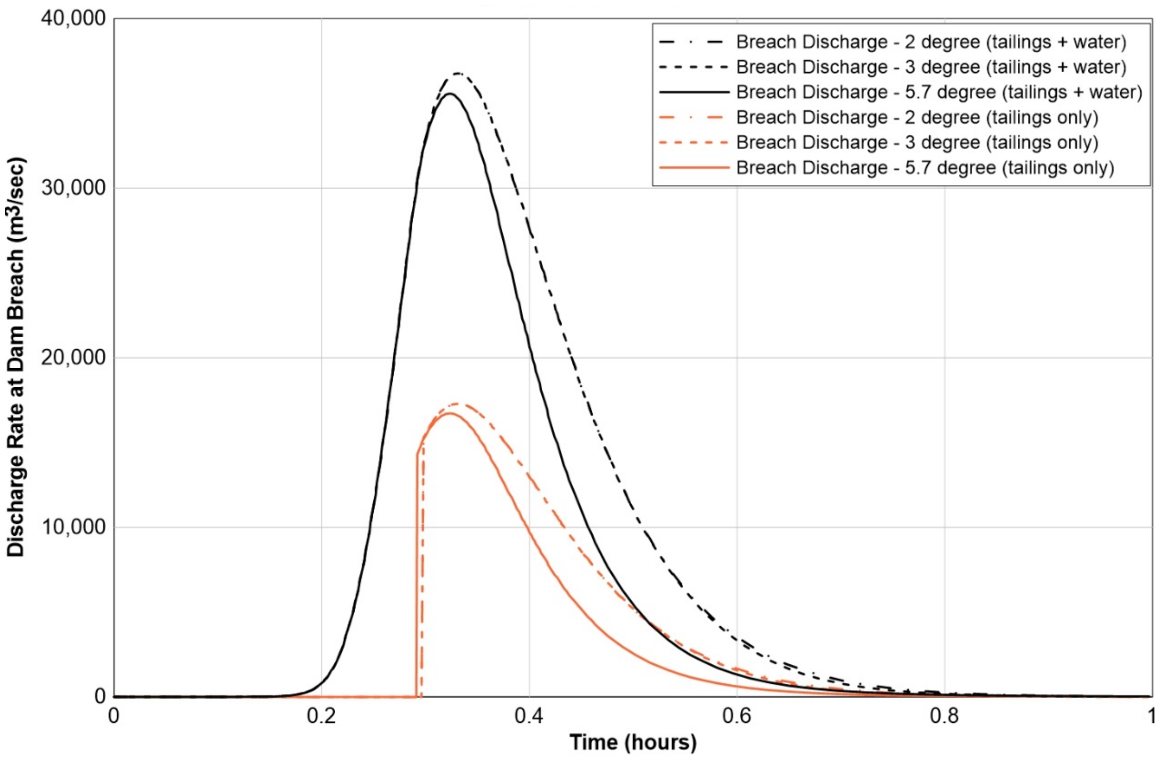

Figure 5-2. TMF-3 Dam Rainy-day (Overtopping) BREACH Hydrographs

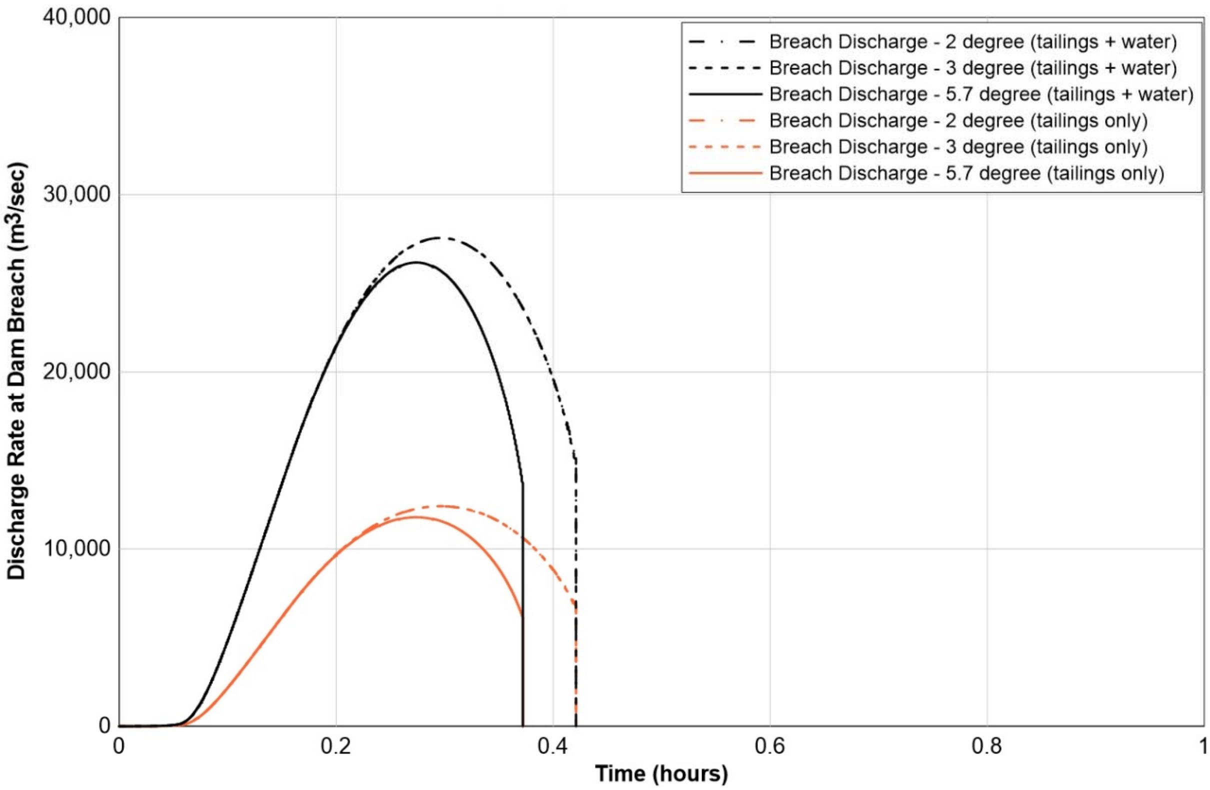

Figure 5-3. TMF-3 Dam Sunny-day (Piping) BREACH Hydrographs

5.1.3. Sensitivity Analysis

In general, the BREACH results are not very sensitive to the input parameter values shown in Table 4-2. Lessons from modelling on other projects show that variations in D_{50} grain size, porosity, unit weight, and Manning's *n* value produce a change of less than +/- 2% in the simulated peak discharge rates and have a negligible influence on the duration of the rising limb of the hydrograph.

The BREACH results were also relatively insensitive to the specified internal friction angle of the dam material, which was modelled as a till core with a compacted cyclone sand downstream shell as the base case. To evaluate the sensitivity of the results to this assumption, the BREACH modelling was also carried out assuming a rockfill downstream shell. The simulated peak discharge using the assumed friction angle of 35^{o} for compacted cyclone sand was approximately 3% higher than the simulated peak discharge obtained using a friction angle of 50^{o} for rockfill. The shell gradation was also varied to evaluate the effect of different shell materials on BREACH results. Changing the D_{50} value from 1 mm (assumed for compacted cyclone sand) to 100 mm (assumed for rockfill) decreased the peak flow by approximately 1%.

The BREACH results were somewhat sensitive to pipe initiation location. The results presented herein were based on piping having been initiated at the downstream toe of the maximum (highest) section of the TMF-3 Dam. Sensitivity analyses indicate that pipe initiation at a point on the downstream face of the dam above the dam fill to foundation contact, at El. 945 m (starter dam crest elevation) yielded an approximately 40% lower peak discharge than that from the case with piping initiated at the toe, which therefore represents the most conservative piping scenario in terms of predicted downstream inundation.

The BREACH results were not very sensitive to the tailings back-scarp angle for the TMF-3 Dam. The 2°, 3°, and 5.7° cases yielded relatively similar peak flow estimates for both the rainy-day (overtopping) and sunny-day (piping) scenarios and similarly shaped hydrographs. Hence, the 2° and 5.7° degree cases were carried forward to inundation modelling from the TMF-3 Dam to the Tahtsa Narrows. The 2° case was carried forward for the inundation modelling in Tahtsa Narrows, Tahtsa Lake, and Tahtsa Reach, as this represented the highest outflow volume and most conservative case.

5.2. Flood Inundation

The flood inundation results are presented in the sections below according to inundation area, flood hydrographs downstream of the dam, and maximum water level rise above the assumed reservoir level, as detailed in the following sections.

The analysis results for water level rise in the Nechako Reservoir are illustrated on Drawing 03. The results for the most conservative modelling case (largest released volume, based on the 2° back-scarp case) are presented on the drawing to form the basis of emergency response planning. Inundation maps for the area between the TMF-3 Dam and Tahtsa Narrows are presented in Appendix A.

5.2.1. Inundation Area

The modelled inundation area for the area downstream of the TMF-3 Dam to Tahtsa Narrows is presented for the 2° back-scarp rainy-day (overtopping) case on Drawing 03. Modelled inundation areas and maximum flow depths for the area downstream of the TMF-3 Dam to Tahtsa Narrows for all of the modelled cases are presented in Appendix A. The sensitivity of the model to the breach location is detailed in Section 5.2.4.

A summary of the inundation results for the 2° back-scarp scenarios is presented in Table 5-1.

Table 5-1. Summary of Modelling Results for the 2° Back-scarp Case

Scenario	Inundation Impact Description
TMF-3 Dam rainy-day (overtopping) See Drawing 03	• The maximum breach flow depth is approximately 17 m near the downstream toe of the dam • Flow depths in the creeks and ground downstream of the dam but before Tahtsa Narrows can reach up to approximately 17 m. • The maximum predicted water level rise above the assumed PMF reservoir level of 854 masl in Tahtsa Narrows is 4.4 m • The predicted maximum water level rise (above the assumed PMF reservoir level of 854 masl) approximately 20 km west of Tahtsa Narrows in Tahtsa Lake is 0.1 m; the predicted maximum water level rise (above the assumed PMF reservoir level of 854 masl) approximately 20 km east Tahtsa Narrows in Tahtsa Reach is 0.2 m.
TMF-3 Dam sunny-day (piping) See Figures A2 and A4	• The maximum breach flow depth is approximately 16 m near the downstream toe of the dam • Flow depths in the creeks and ground downstream of the dam but before Tahtsa Narrows can reach up to approximately 16 m.

5.2.2. Flood Hydrographs Downstream of the TMF-3 Dam

Figure 5-4 shows the rainy-day (overtopping) hydrographs for the 2^{o} back-scarp case at key locations downstream of the TMF-3 Dam and upstream of Tahtsa Narrows. The modelled dam breach flood enters Tahtsa Narrows at three locations, along three stream channels. As shown by the blue and green lines on Figure 5-4, most of the flow is concentrated in the easternmost and middle streams. Table 5-2 summarizes the peak discharge at the stream outlets to Tahtsa Narrows. The sensitivity of the model to the breach location is evaluated in Section 5.2.4

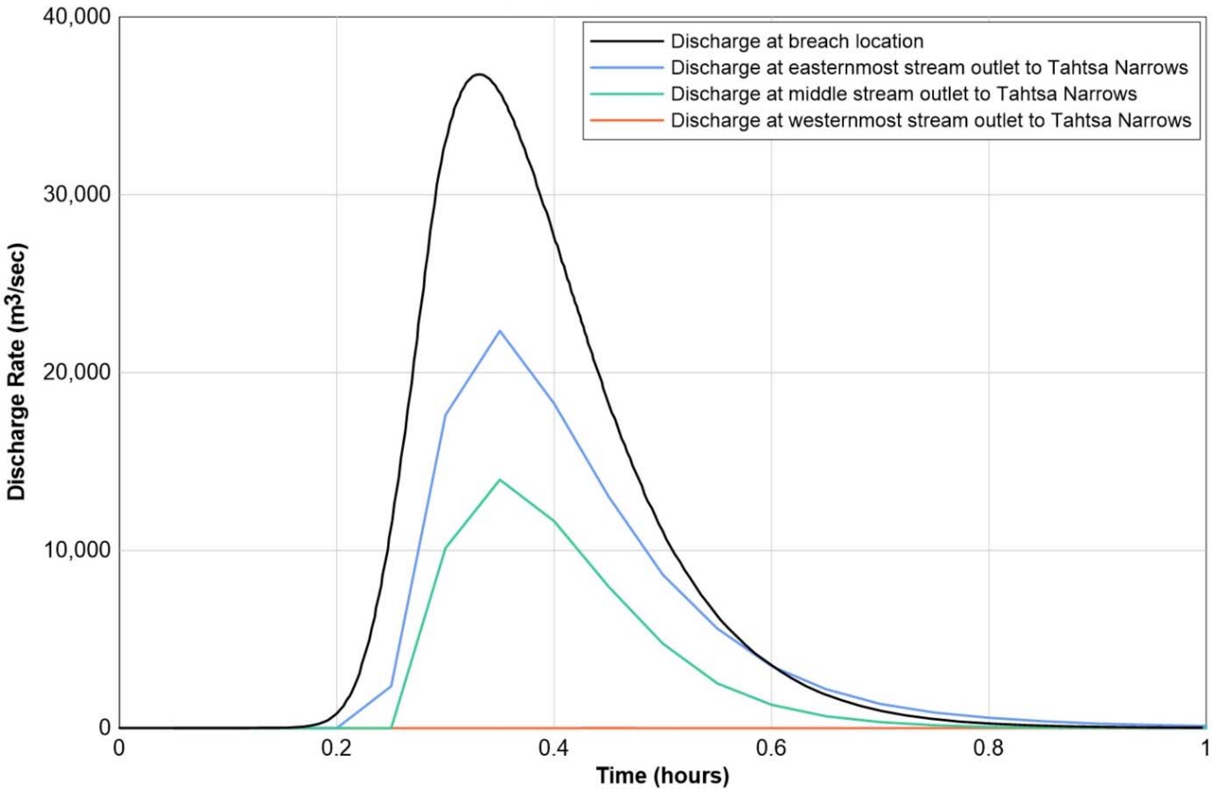

Figure 5-4. TMF-3 Dam Rainy-day (Overtopping) Hydrographs (2° back-scarp) at Key Locations for Tailings and Water Combined

Table 5-2. Summary of Peak Flows at Key Locations Downstream of the TMF-3 Dam for the Rainy-day (Overtopping) 2° Back-scarp Scenario

Scenario	Category	Breach Location	Easternmost Stream Outlet to Tahtsa Narrows	Middle Stream Outlet to Tahtsa Narrows	Westernmost Stream Outlet to Tahtsa Narrows
Downstream Distance (km)		0	0.6	0.9	1.5
Rainy-day (Overtopping) 2° back-scarp	Peak Breach Flow (m^3/s)	37,000	22,000	14,000	<10

5.2.3. Maximum Water Level Rise

The modelled maximum water level increases in the reservoir are summarized in Table 5-3 and are shown on Drawing 03 and Figure 5-4. The values in Table 5-3 show that the water level increases predicted for the 2° rainy-day (overtopping) scenario were reduced to 0.1 m in Tahtsa Lake, approximately 20 km west of Tahtsa Narrows and to 0.2 m in Tahtsa Reach, approximately 20 km east of Tahtsa Narrows. A maximum water level rise of 4.4 m was predicted in Tahtsa Narrows.

Table 5-3. Summary of Maximum Water Level Rise at the Reference Locations for the Rainy-day (Overtopping) 2° Back-scarp Scenario

Model Output	1 - Tahtsa Narrows directly downstream of TMF-3 Dam	2 - Tahtsa Narrows near Tahtsa Reach	3 - Tahtsa Narrows near Tahtsa Lake	4 - Tahtsa Reach	5 - Tahtsa Lake
Distance Downstream of Tahtsa Narrows (km)	0	2	2	20	20
Local Maximum Water Level Rise above the assumed PMF reservoir level of 854 masl (m)	4.4	1.9	3.4	0.2	0.1
Time for Local Maximum Water Level Rise to occur above the assumed PMF reservoir level of 854 masl (hr)	0.4	0.7	0.5	14.3	72[1]

[1]The presented time for the maximum water level rise to occur at the Tahtsa Lake reference location reflects a 72-hour model duration and is not the true time taken for the maximum water level rise to occur (see Section 4.5.12).

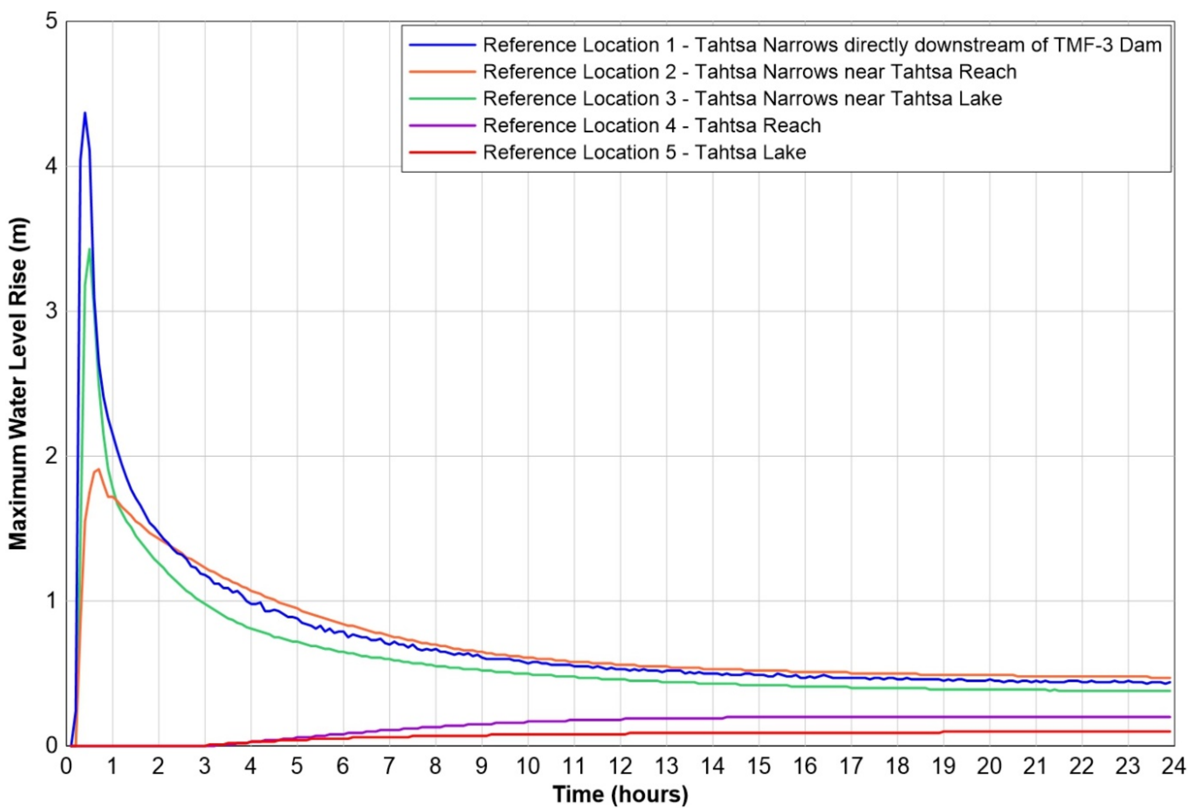

Figure 5-4. Maximum Water Level Rise in Tahtsa Lake, Tahtsa Narrows, and Tahtsa Reach for the Rainy-day (Overtopping) 2° Back-scarp Scenario

5.2.4. Sensitivity Analysis

Breach Location

To better understand the sensitivity of the inundation model results to the breach location, two additional breach locations were modelled. The first additional breach location was modelled at the southwest corner of the ultimate dam; the second additional breach location was modelled at the west side of the ultimate dam, which corresponds to the location of the smaller north-south saddle dam for the starter configuration. The base case location (maximum dam height) 2^{o} back-scarp release volume was assumed for both of the additional breach locations. For the breach at the southwest corner the released volume will be similar to that at the base case location. For the breach at the west side of the impoundment, the released volume would be slightly smaller than that at the base case location. The presented results, which are based on the same release volume as for the two other breach locations where the dam is higher, are therefore judged conservative estimates of flow depth and inundation area for the west side breach scenario.

Inundation maps for these two dam breach locations are presented in Appendix B. The figures show that the flood will be spread over a larger inundation area compared to the assumed base case breach location at the maximum dam height. As a result, the flow discharge rate to the reservoir will be smaller and the water level rise caused by the breach will also be smaller. Furthermore, dam breaches at the southwest corner and at the west side of the dam will divert flow primarily into Tahtsa Lake, which is a deeper water body than Tahtsa Narrows. This means a reduced potential for isolation of the Tahtsa Lake portion of the reservoir relative to the base case breach location scenario, directly above Tahtsa Narrows.

Reservoir Depth

To better understand the sensitivity of the inundation model results to the assumed depth of Tahtsa Lake and Tahtsa Reach, two scenarios were modelled. One scenario assumed a depth of 10 m in the two water bodies and the second scenario assumed a depth of 20 m in the two water bodies. Results indicate that the water level rise is not very sensitive to the assumed depth of the water bodies. A water level rise difference of approximately 0.5 m was noted in Tahtsa Narrows directly downstream of the TMF-3 Dam and a water level rise difference of approximately 0.1 m was noted in Tahtsa Lake and Tahtsa Reach, approximately 20 km to the west and east of Tahtsa Narrows, respectively. The 20 m depth results are presented on Drawing 03.

5.3. Uncertainties

There are numerous uncertainties inherent to dam breach modelling and routing of extreme floods caused by a dam breach. Sources of uncertainty include, but are not limited to, the following:

- BREACH assumes the breaching fluid is clear water, meaning that the sediment concentration (i.e., solids content by volume) of the actual flow is neglected. This may influence the calculated breach rate and the resulting outflow hydrograph, although this influence is not well understood at present. Treating the tailings dam breaching fluid as clear water (i.e., a fluid with a relatively high sediment transport capacity) is likely a conservative assumption since the viscosity of the liquefied tailings is higher than that of pure water, liquefied tailings does have a residual, non-zero shear strength, and pure water breaches most likely have comparatively higher peak discharges.
- There is uncertainty in the published values of peak discharge that were used to develop the empirical equations cited in Section 5.1.1 due to the difficulty in measuring these values.
- Flood wave propagation involves complex and dynamic physical processes, which are not all captured by the inundation modelling. These complexities include sediment transport processes, including deposition and erosion, the rheological behavior of the slurry flow and the roll wave propagation process. The uncertainties and simplifications cited above for developing the breach hydrographs also influence the inundation modelling results.

Because of the uncertainties involved with dam breach modelling, and as discussed previously, conservative assumptions were applied to provide conservative inundation scenarios as the basis for EPRP.

6.0 LIMITATIONS AND RECOMMENDED NEXT STEPS

The dam breach and inundation analyses completed for the TMF-3 Dam are based on hypothetical modes of failure under extreme or highly unlikely conditions, and are intended only to inform EPRP. The analyses only address the potential flood characteristics in the event of a breach under ultimate design elevation conditions.

This report does not attempt to quantify the consequences to facilities, calculate economic losses, address life loss potential to people within the inundation area or suggest potential risk management strategies. Furthermore, the analyses do not predict the spatial distribution and deposition of tailings sediment after a breach event. Tailings run-out deposition in Tahtsa Narrows could potentially isolate the Tahtsa Lake portion of the reservoir to the west from the Tahtsa Reach portion of the reservoir to the east. Given the volume of tailings considered for release in the scenarios modelled herein, and the dimensions of Tahtsa Narrows, EPRP plans should include contingency planning for mitigating isolation of the Tahtsa Lake portion of the reservoir in the event of a blockage of Tahtsa Narrows.

7.0 CLOSURE

We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

BGC ENGINEERING INC.
per:

Shielan Liu, Ph.D.
Numerical Modeler

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T. E. MARTIN
BRITISH COLUMBIA
ENGINEER

Nov/28/14

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SL-TM-CB/ SM/ igb/sjk

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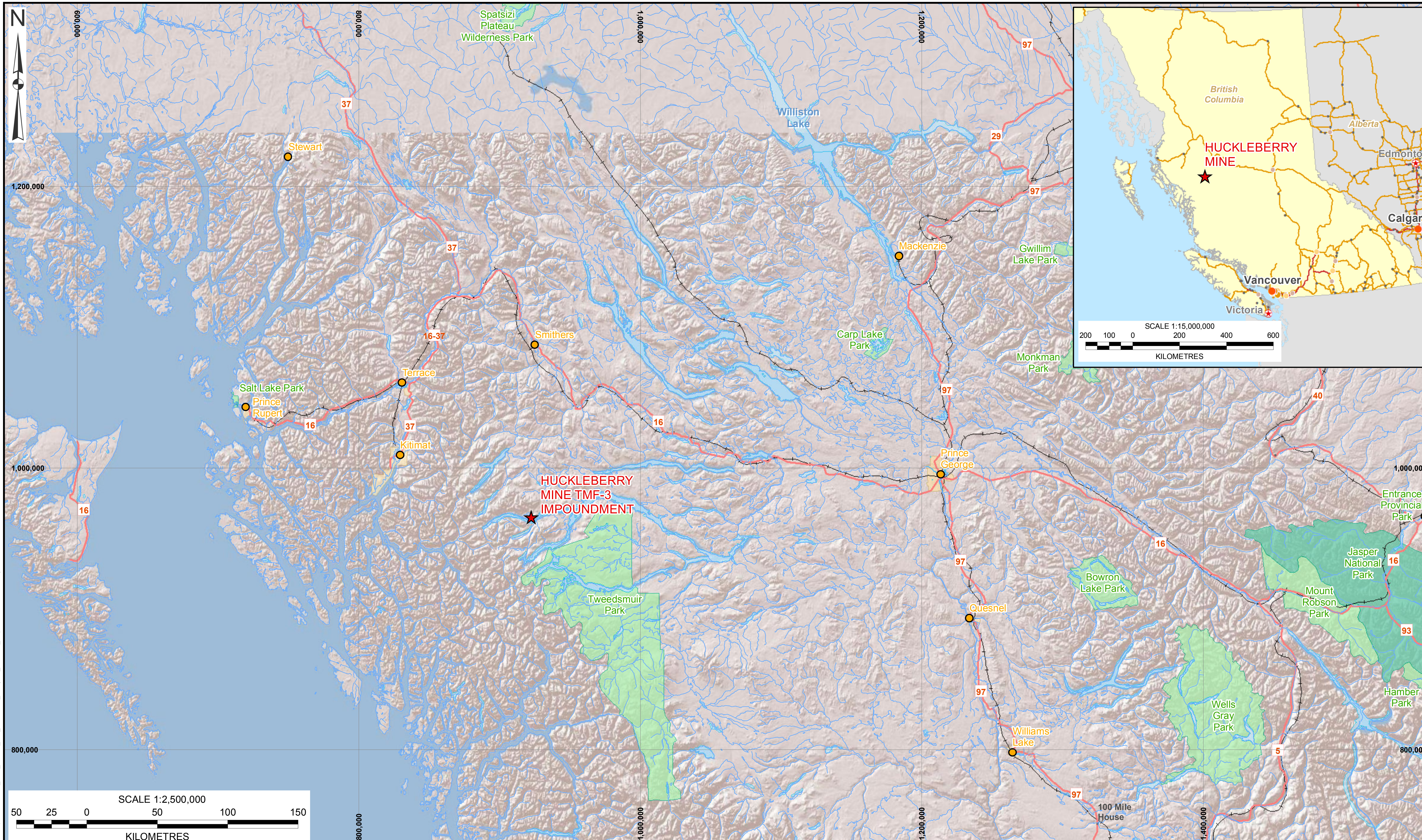
DRAWINGS



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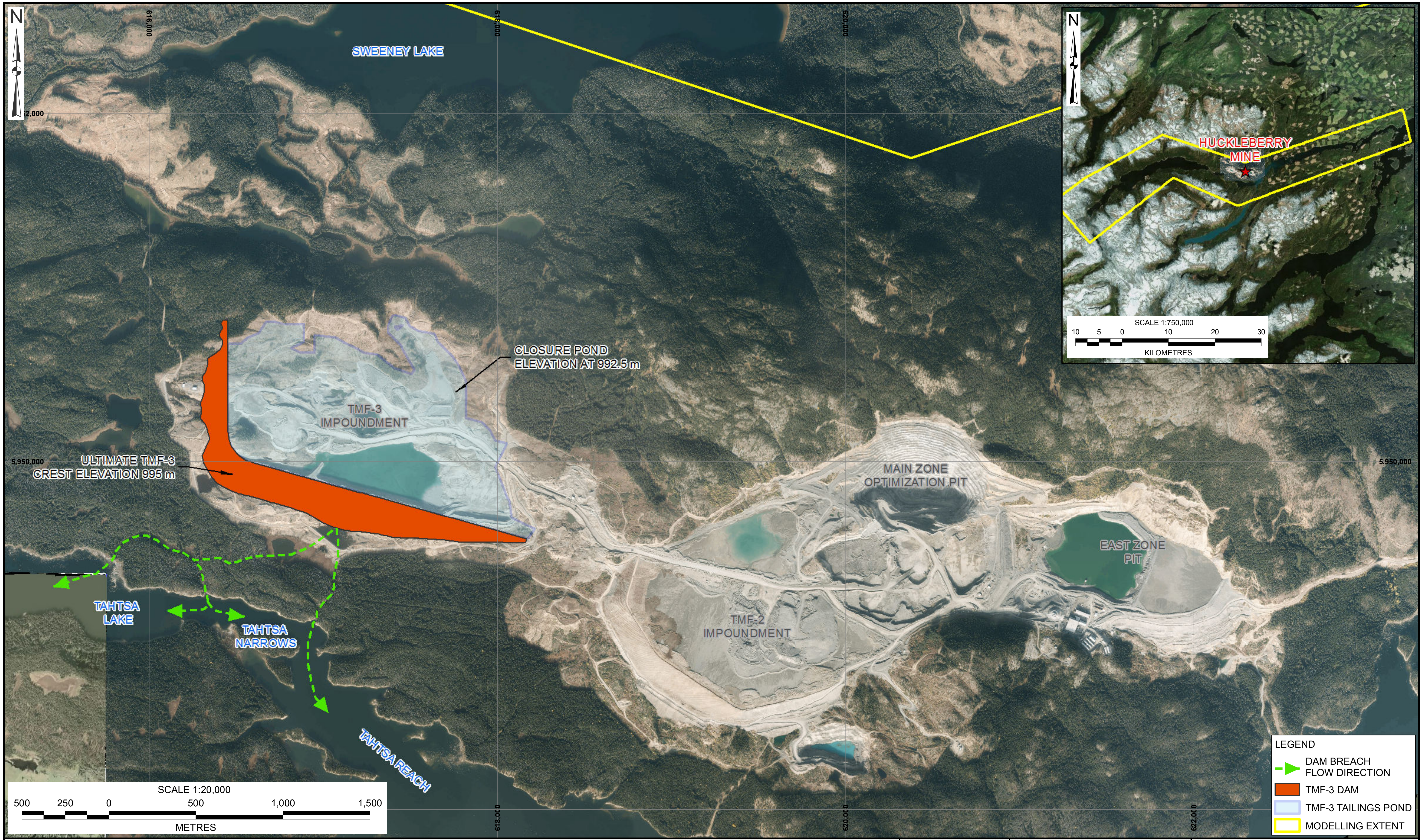
PROJECT: DAM BREACH AND INUNDATION STUDY

TITLE: LOCATION MAP

PROJECT No.: 1193004-M

01



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PROJECT No.: 1193004-M | 02

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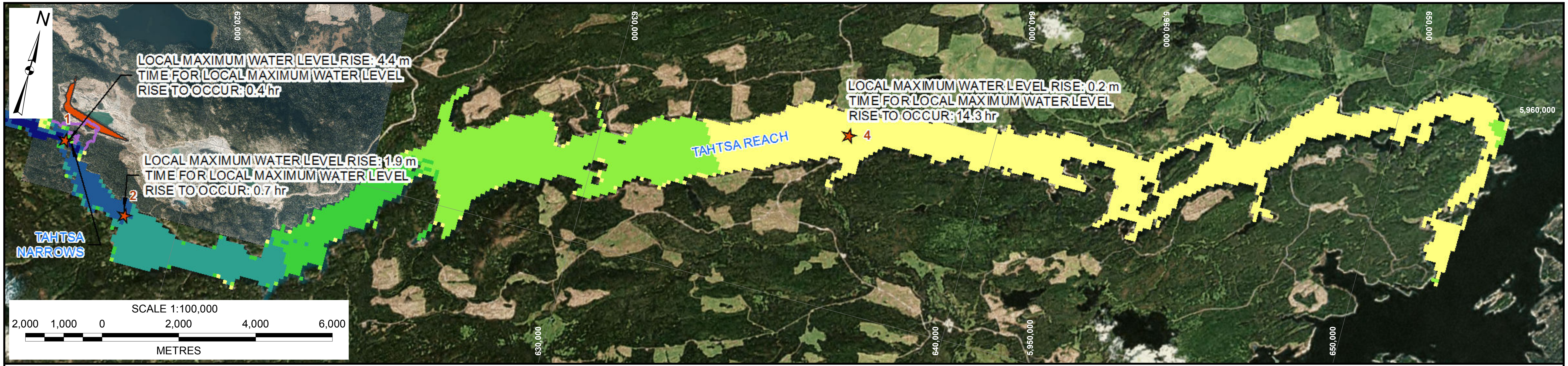

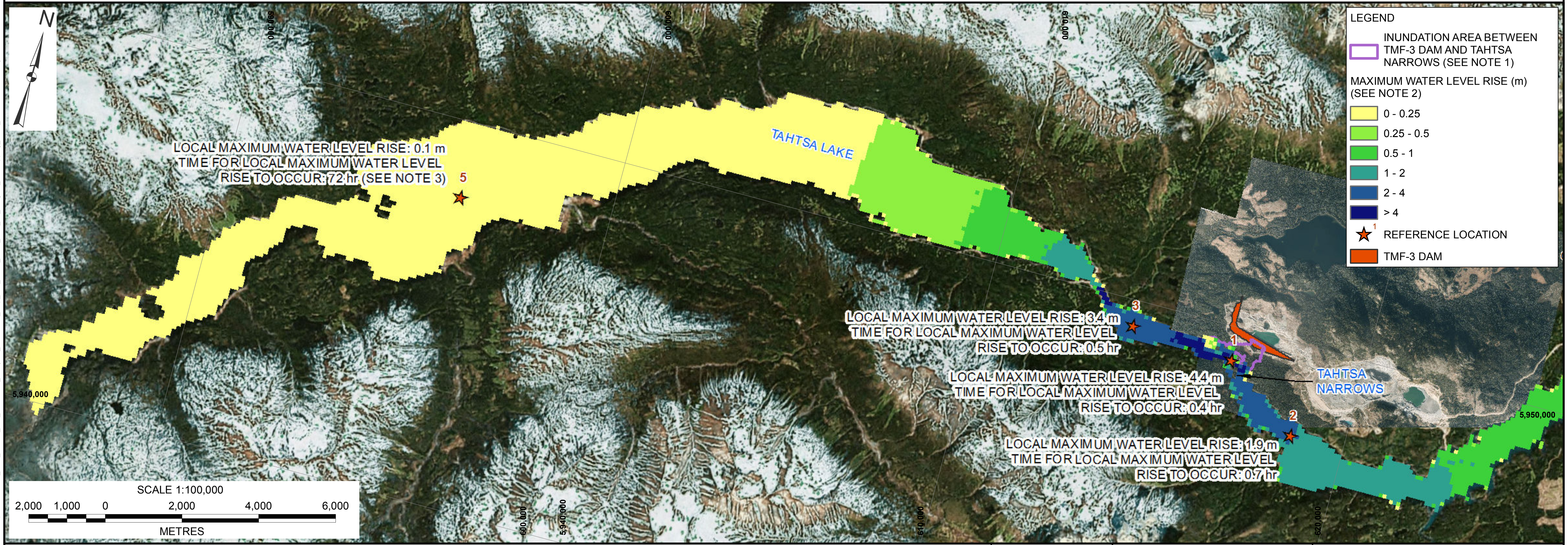

NOTES:
1. SEE APPENDIX A FOR FIGURES SHOWING DAM BREACH INUNDATION EXTENTS AND FLOW DEPTHS.
2. WATER LEVEL RISE REFERS TO THE MODEL ESTIMATED INCREASE IN WATER LEVEL ABOVE A RESERVOIR ELEVATION OF 854 masl, WHICH WAS ASSUMED FOR PMF CONDITIONS CORRESPONDING TO A RAINY-DAY (OVERTOPPING) SCENARIO.
3. THE TIME FOR THE MAXIMUM WATER LEVEL RISE TO OCCUR FOR THIS LOCATION REFLECTS A 72-HOUR MODEL DURATION AND IS NOT THE TRUE TIME FOR THE MAXIMUM WATER LEVEL RISE TO OCCUR (SEE SECTION 4.5.12).
4. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
5. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "DAM BREACH AND INUNDATION STUDY," AND DATED NOVEMBER 2014.
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PROJECT: DAM BREACH AND INUNDATION STUDY

TITLE: INUNDATION MAP AND MAXIMUM WATER LEVEL RISE FOR 2 DEGREE RAINY-DAY (OVERTOPPING) CASE

PROJECT No.: 1193004-M

DWG No.: 03

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APPENDIX A
FLO-2D INUNDATION FIGURES FOR BASE CASE BREACH LOCATIONS

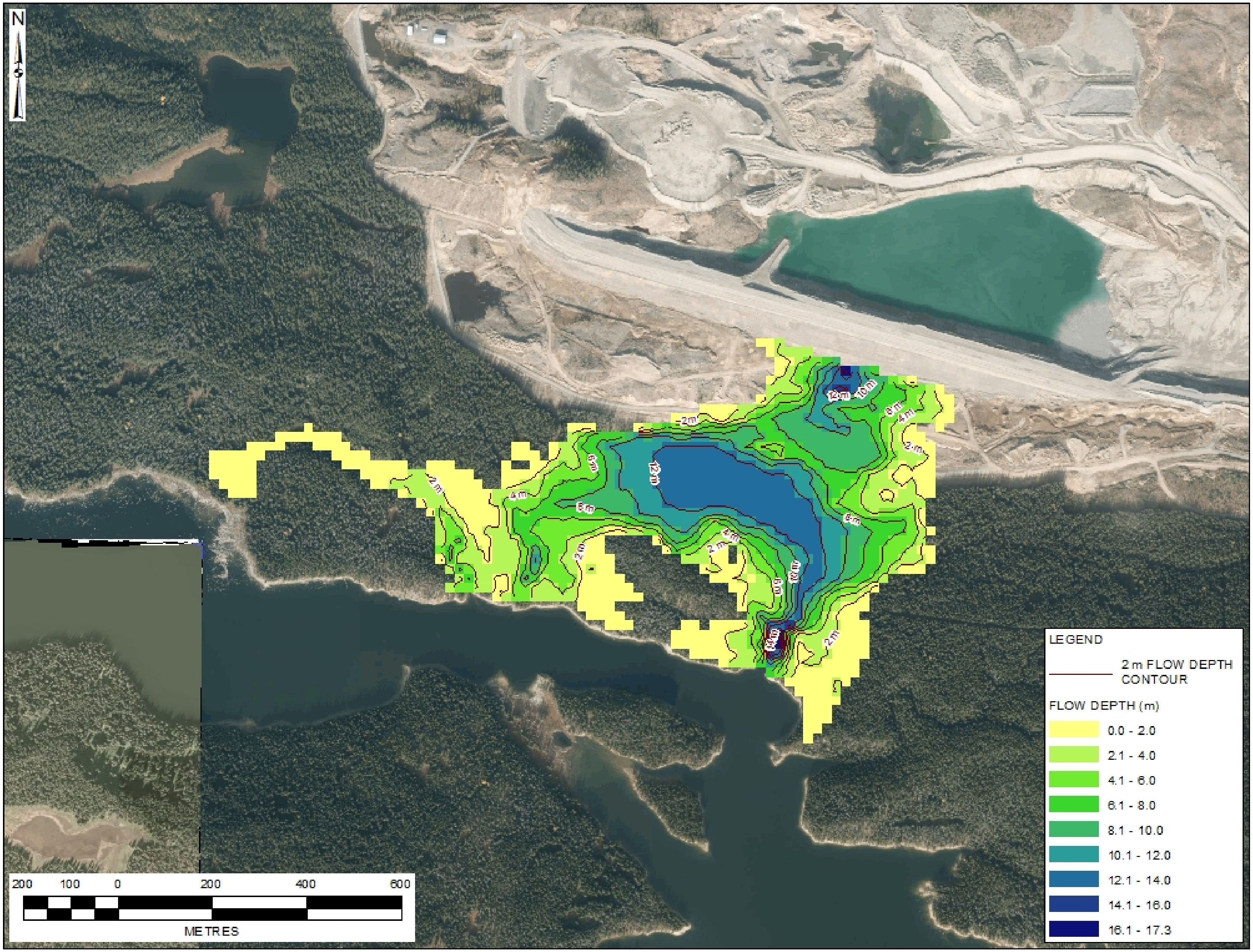

Figure A1 – Inundation map for the 2° back-scarp rainy-day (overtopping) case

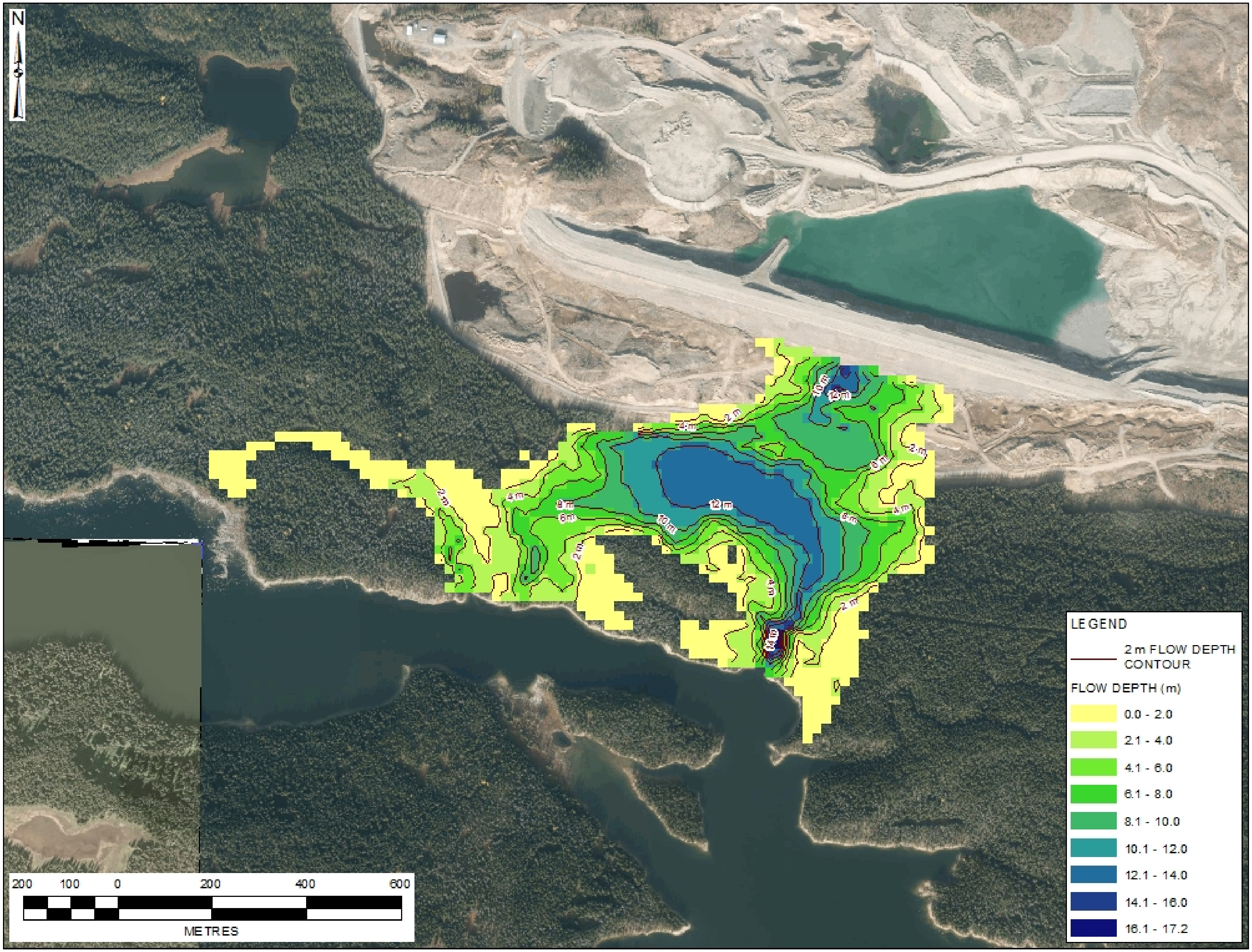

Figure A2 – Inundation map for the 5.7° back-scarp rainy-day (overtopping) case

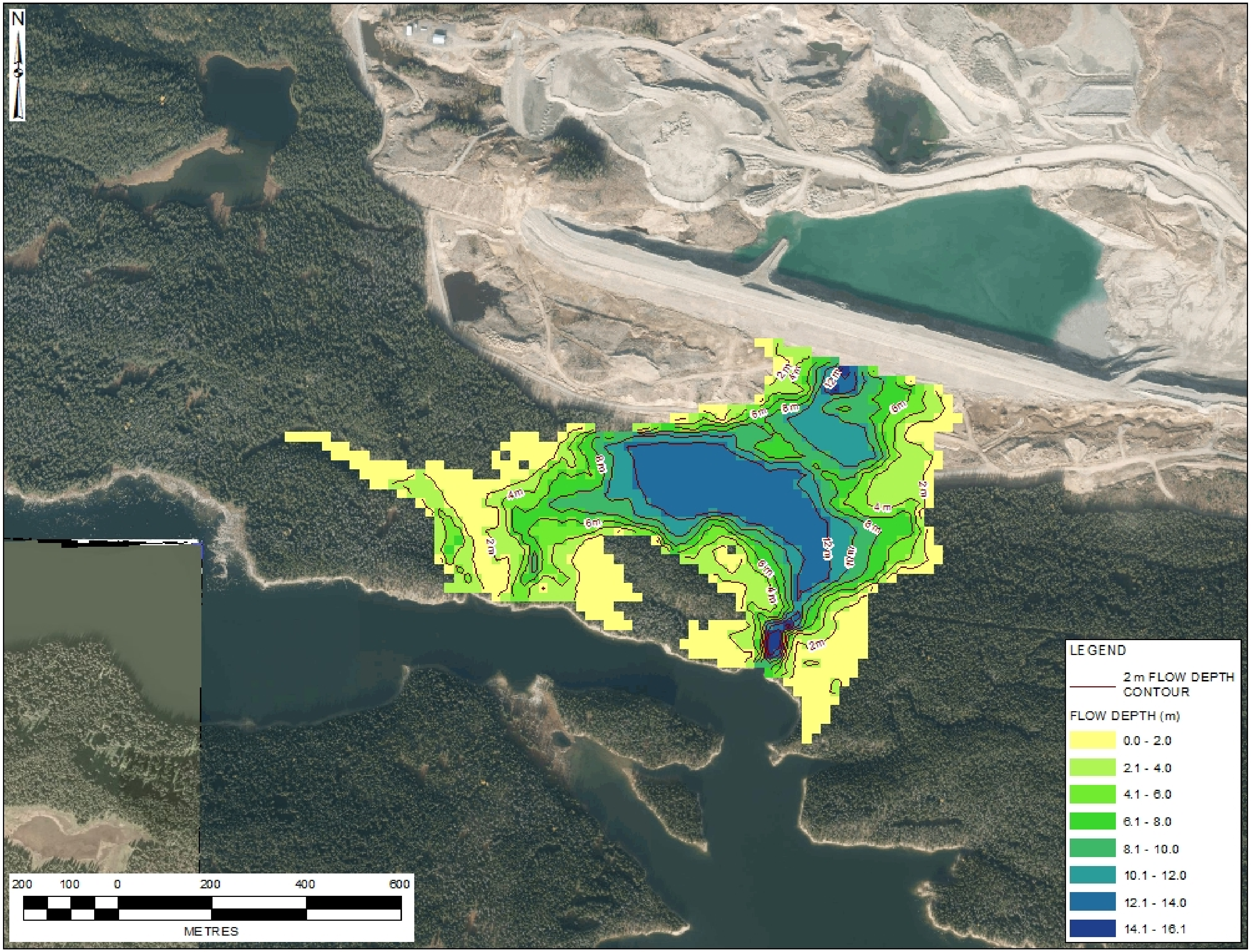

Figure A3 – Inundation map for the 2° back-scarp sunny-day (piping) case

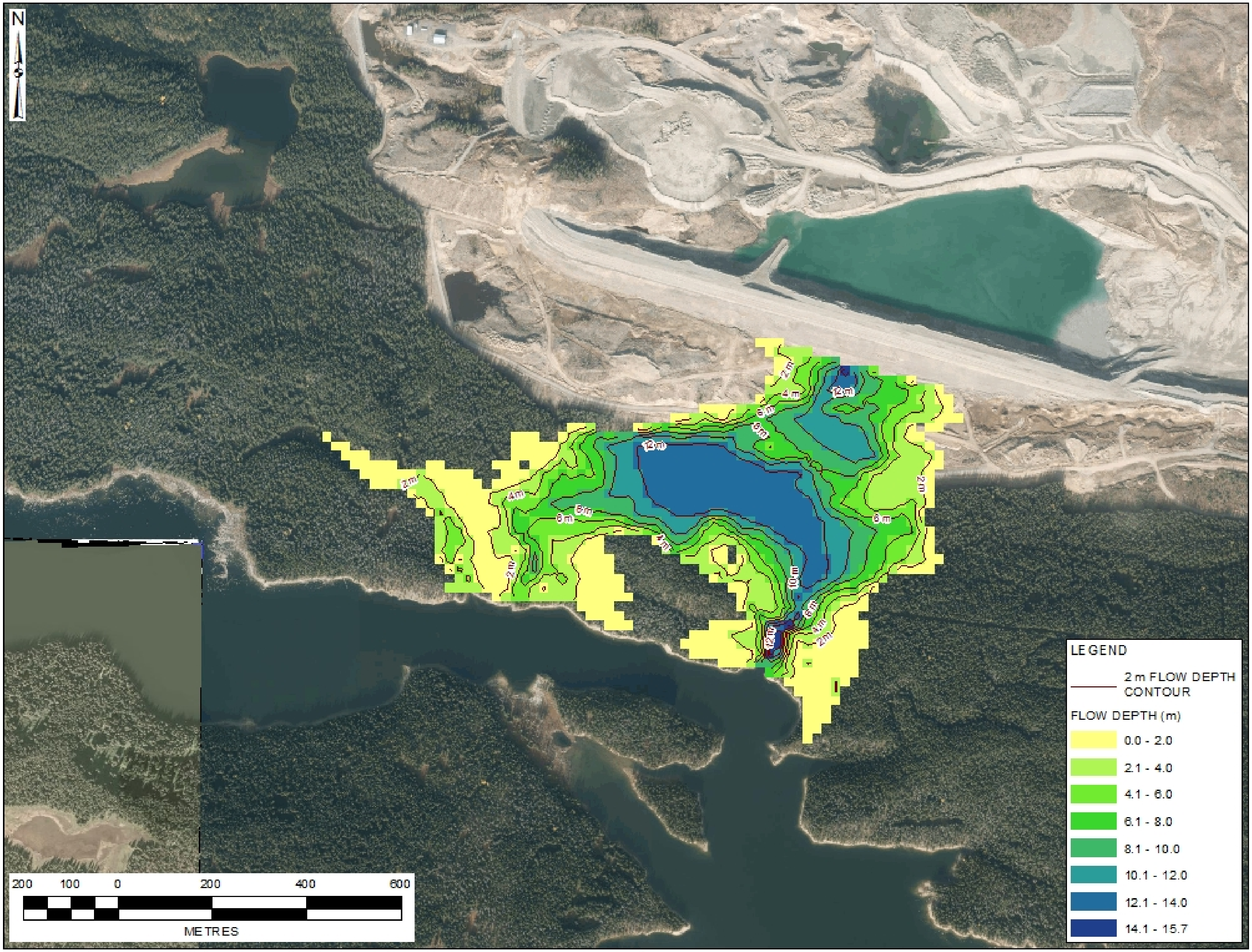

Figure A4 – Inundation map for the 5.7° back-scarp sunny-day (piping) case

APPENDIX B
FLO-2D INUNDATION FIGURES FOR OTHER BREACH LOCATIONS

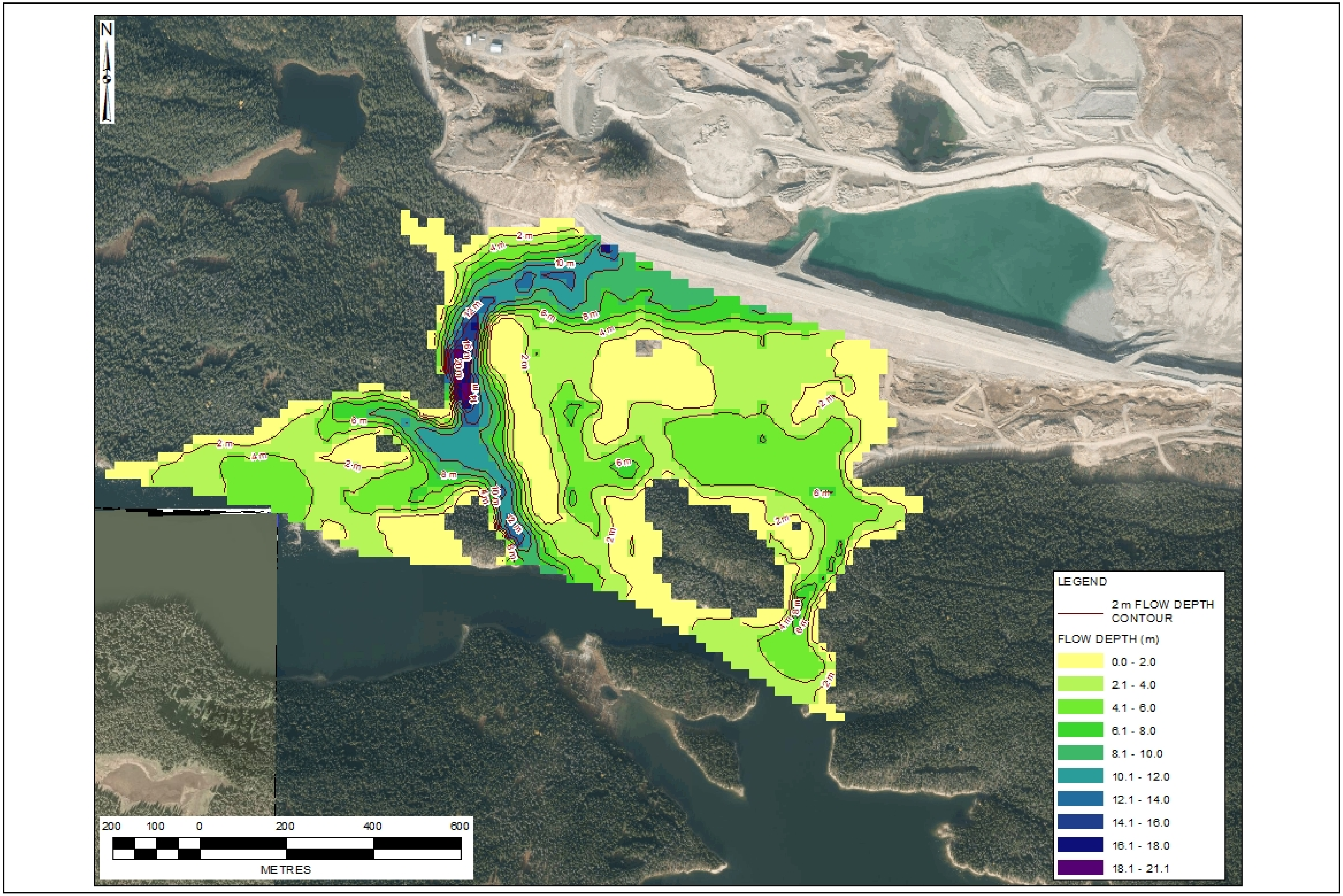

Figure B1 – Inundation map for breach at southwest corner (assuming base case 2° back-scarp release volume)

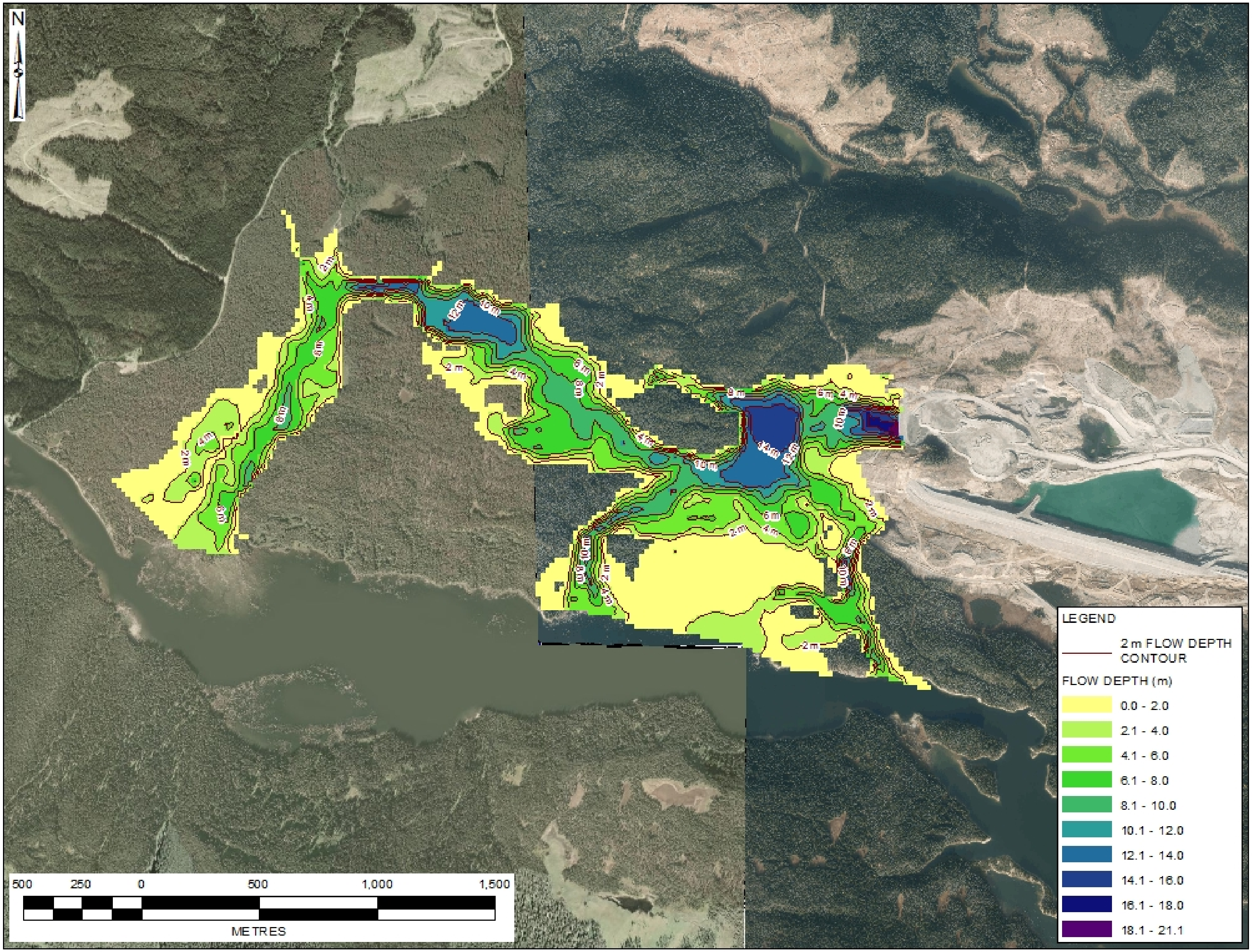

Figure B2 – Inundation map for breach at west side of dam (assuming base case 2° back-scarp release volume)