Myra Falls Tailings Disposal Facilities
Dam Breach Inundation Study

Submitted to:

Nyrstar Myra Falls
Campbell River, British Columbia

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Nanaimo, British Columbia

January 2015

NX14001.0803

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EXECUTIVE SUMMARY

This report describes the results of a dam breach inundation study for the tailings disposal facilities (TDFs) at Nyrstar Myra Falls (NMF) mine site. NMF has two tailings facilities on the site, the Old TDF and the Lynx TDF. The Myra Falls mine is located approximately 90 km west of Campbell River, Vancouver Island, British Columbia. The mine is currently owned by Nyrstar Myra Falls.

The Old TDF was constructed in the late 1980s after tailings disposal in Buttle Lake was discontinued. The facility was initially constructed as a modified-centerline (upstream) tailings retention dam with annual raises of a till and waste rock outer embankment berm. The dam has subsequently been buttressed by compacted rockfill along the base of the downstream embankment to improve its stability under seismic loading. In the early 2000s it was determined that the Old TDF had reached its practical elevation limit with regard to slope stability. A new berm was constructed on the tailings surface set back from the outer embankment berm. This berm raise is referred to as the Amalgamated Paste Area (APA). The paste berm reached its final elevation in 2006 and tailings storage within the APA reached capacity in 2011.

The Lynx TDF is located northwest of the Old TDF. The facility is located within a previous open-pit mine. The facility is currently active, being a paste-tailings deposition area retained by a centerline-raised earthfill dam with a final design height of approximately 80 m.

Both the Old and Lynx TDFs are currently classified as High consequence dams in accordance with the Canadian Dam Association (CDA) guidelines. As a result of having a High classification, NMF is required to have a current dam breach inundation study as per the 18 August 2014 order from the Chief Inspector of Mines, British Columbia Ministry of Energy and Mines.

Inundation maps have been prepared for two hypothetical breach scenarios:

1. A piping failure during non-flood conditions; and
2. An overtopping failure during the inflow design flood (IDF), assuming a preceding failure or blockage of the upslope diversion channels.

The IDF for High consequence dams is $1/3^{rd}$ between the 1,000-year average recurrence interval (ARI) and the probable maximum flood (PMF). These failure scenarios were assessed for the Old and Lynx TDFs. A failure of the Lynx TDF was considered under both the current (2014) and ultimate dam conditions.

Inundation extents were determined using a two-dimensional (2D) hydraulic model. Breach outflow hydrographs were calculated using breach parameters derived from published literature. The hydrographs were then used as the upstream boundary condition for the hydraulic model. The hydraulic model and inundation maps extend from 1.6 km upstream of the Lynx TDF to Buttle Lake, 2.1 km downstream of the Old TDF.

The volume of water and tailings that would be released during a dam breach was estimated using relationships published by Rico (2008). In this study approximately 35% of the total stored volume is released during the breach. It is assumed that the tailings are liquefiable and behave like water.

Incremental flooding and loss of life impacts resulting from a dam breach would be constrained to the mine site, with inundation on the north and south banks of Myra Creek. The water treatment facilities would be destroyed and the access roads inundated, but the mine buildings would not be affected. Tailings would likely be deposited in Myra Creek and Buttle Lake, but are unlikely to travel farther downstream.

Based on the predicted inundation extents and loss of life estimates (as well as associated infrastructure and environmental impacts) for the plausible worst-case dam breach scenarios considered, it is recommended that both the Old TDF and Lynx TDF dams be classified as “High” consequence dams in accordance with current CDA Guidelines.

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1.0 INTRODUCTION

AMEC Environment and Infrastructure, a division of AMEC Americas Limited (AMEC), was retained by Nyrstar Myra Falls (NMF) to undertake a dam break inundation study for the two tailings disposal facilities (TDFs) at the Myra Falls mine site. These facilities comprise the Old TDF and the Lynx TDF.

This dam break study has been prepared in accordance with the *Canadian Dam Association Dam Safety Guidelines* (CDA, 2013) and the British Columbia Dam Safety Regulations (2011).

1.1 Site Description

The Myra Falls mine is an underground copper and zinc mine located within Strathcona Provincial Park, approximately 90 km south of Campbell River, Vancouver Island, British Columbia. The mine site has two TDFs; the Old TDF, which was first opened in the late 1980s, and the Lynx TDF, which has been operational since 2006. The general layout of the Myra Falls mine site is shown on Drawing 080303 (**Appendix C**).

The Old TDF is a horseshoe shaped impoundment on the north floodplain of Myra Creek. The facility was constructed after tailings placement in Buttle Lake was discontinued in the late 1980s. The facility was initially constructed as a modified-centerline (upstream) tailings retention dam with annual raises of a till and waste rock outer embankment berm. The dam has subsequently been buttressed by compacted rockfill along the base of the downstream embankment to improve its stability under seismic loading. In the early 2000s it was determined that the TDF had reached its practical elevation limit with regard to slope stability. A new berm was constructed on the tailings surface set back from the outer embankment berm. This berm raise is referred to as the Amalgamated Paste Area (APA). The Paste Berm reached its final elevation in 2006 and tailings storage within the APA reached capacity in 2011.

The Lynx TDF is located northwest of the Old TDF. The facility is located within a previous open-pit mine. The facility is currently active, being a paste-tailings deposition area retained by a centerline-raised earthfill dam with a final design height of approximately 80 m.

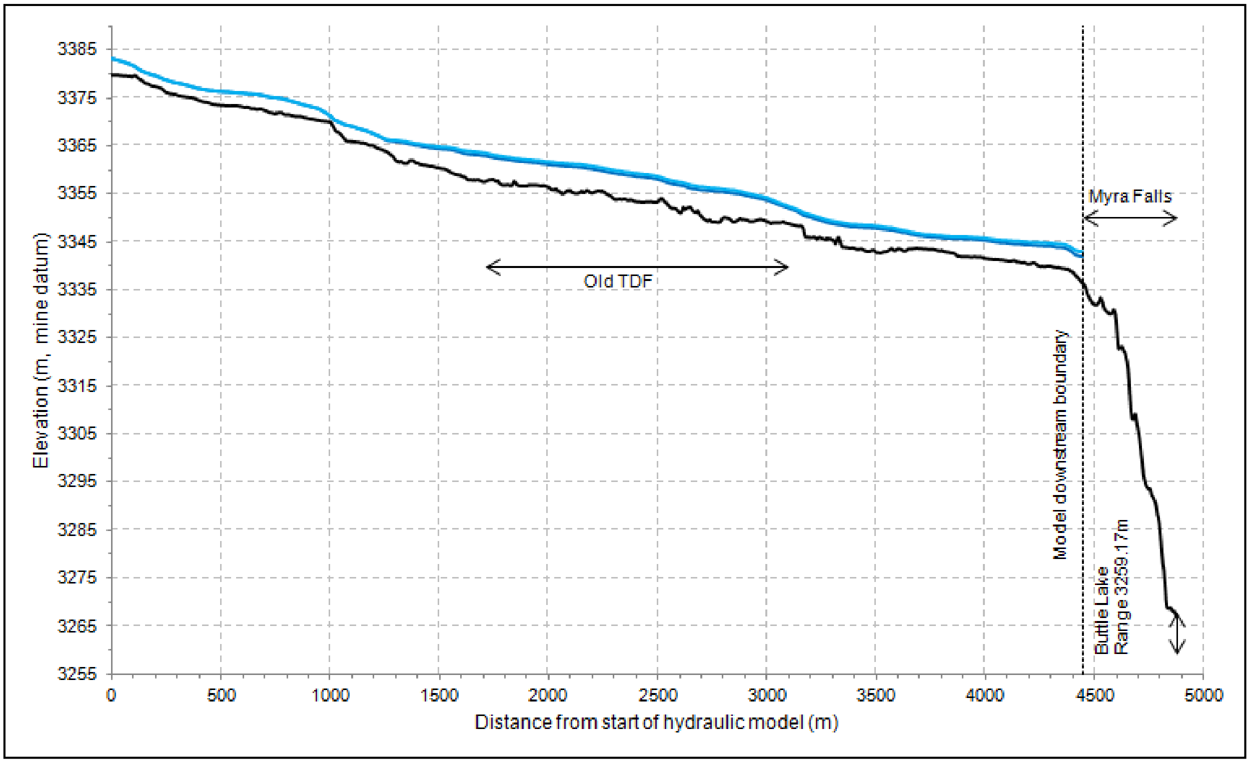
The topography around the mine site is mountainous with steep slopes immediately to the north of both the Old and Lynx TDFs. As part of the mine water management strategy, diversion channels were created to divert hill slope runoff away from the mine site. These channels collect runoff from 407 ha and discharge into Myra Creek downstream of the Old TDF.

Myra Creek runs through the mine site, flowing in an easterly direction towards Buttle Lake, which is located 1.7 km downstream of the mine site. Buttle Lake is 23 km long, has a surface area of 28 km^2 and is operated for hydroelectric generation. The operational range of Buttle Lake is between 212.0 and 220.98 m El. (3,259.17 to 3,268.15 m mine datum[1]).

[1] Mine datum is discussed in Section 2.2.1.

A longitudinal section of Myra Creek is shown on **Figure 1**. The stream maintains a mean gradient of approximately 1% through the mine site before reaching Myra Falls, approximately 400 m upstream of Buttle Lake. Myra Falls has a vertical drop of 68 m to Buttle Lake. During construction of the Old TDF Myra Creek was partially realigned and now follows the toe of the TDF for approximately 1.4 km. The realigned channel was armoured with riprap and designed to pass the 1000 year annual recurrence interval (ARI) flood event (the equivalent annual exceedance probability [AEP] is 0.1%) with a peak discharge of 560 m^3/s.

Figure 1 Myra Creek Long Section



1.2 Previous Studies

A number of previous studies and reports were reviewed.

In 2003, Klohn Crippen (KC) produced a dam break inundation study for the Old TDF. The report was written before the APA paste berm or seismic buttress were constructed, so it reflects the condition of the TDF as at December 2002. Because the Old TDF has limited water storage capacity, the report only considered a non-flood induced failure, reasoning that there would be little material difference between flood and non-flood induced failures. A mass balance approach was adopted to estimate potential movement of the TDF during a failure and the resulting blockage of Myra Creek. That report recommended a “High” consequence classification for Old TDF.

In 2008, AMEC produced a report on the mine water management strategy. The objectives were to define the environmental design flood (EDF) for the water management system and evaluate opportunities for improving mine water quality. The report outlines the site hydrology, including catchment areas, design standards for diversion ditches and design precipitation. The precipitation estimates in the study were revised in 2012 and a site hydrology review is currently in progress (expected completion early 2015).

The most recent dam safety reviews for the two tailings facilities were completed in February 2014 by Robertson Geoconsultants Inc. The reports recommended that both the Old and Lynx TDFs retain their High consequence classification.

2.0 AVAILABLE DATA

2.1 Site Visit

A site visit was conducted on 28 October 2014 by Dan Hughes-Games, P.Eng, and Pete Campbell of AMEC. Photos from the site visit are included in **Appendix A**. The weather had been wet for much of the week preceding the site visit and there was heavy rain during the visit. The visit covered both the mine site and the downstream reach of Myra Creek to Buttle Lake.

2.2 Site Survey

Site survey data were available in the form of contour data at 2 m vertical intervals. The survey covers the entire mine site and extends to the outlet of Myra Creek at Buttle Lake, 1.7 km downstream of the mine. The survey data were used to develop a terrain model of Myra Creek for the hydraulic modelling.

2.2.1 Elevation Data and Coordinate System

The mine uses a local grid coordinate system. The grid is translated and rotated relative to UTM Zone 10N and elevations are adjusted so that all values within the mine site (including underground) remain positive. The origin of the mine coordinate system is UTM 10 5494371.316N 308000.103E, -3047.170 m elevation and the coordinate grid is rotated 50.12^{o} relative to the UTM grid (48^{o} counter-clockwise relative to true north). As an example, the 2013 Lynx dam raise elevation reported as 3,398.8 m in local coordinates would be equivalent to 351.6 m geodetic.

All references to northing, easting and elevation in this report are referenced to the local mine system, unless otherwise noted. Azimuth directions given in the descriptions in the text are generally with respect to true north, that is, with Myra Creek running roughly west to east, whereas it runs diagonally from southwest to northeast across the mine grid.

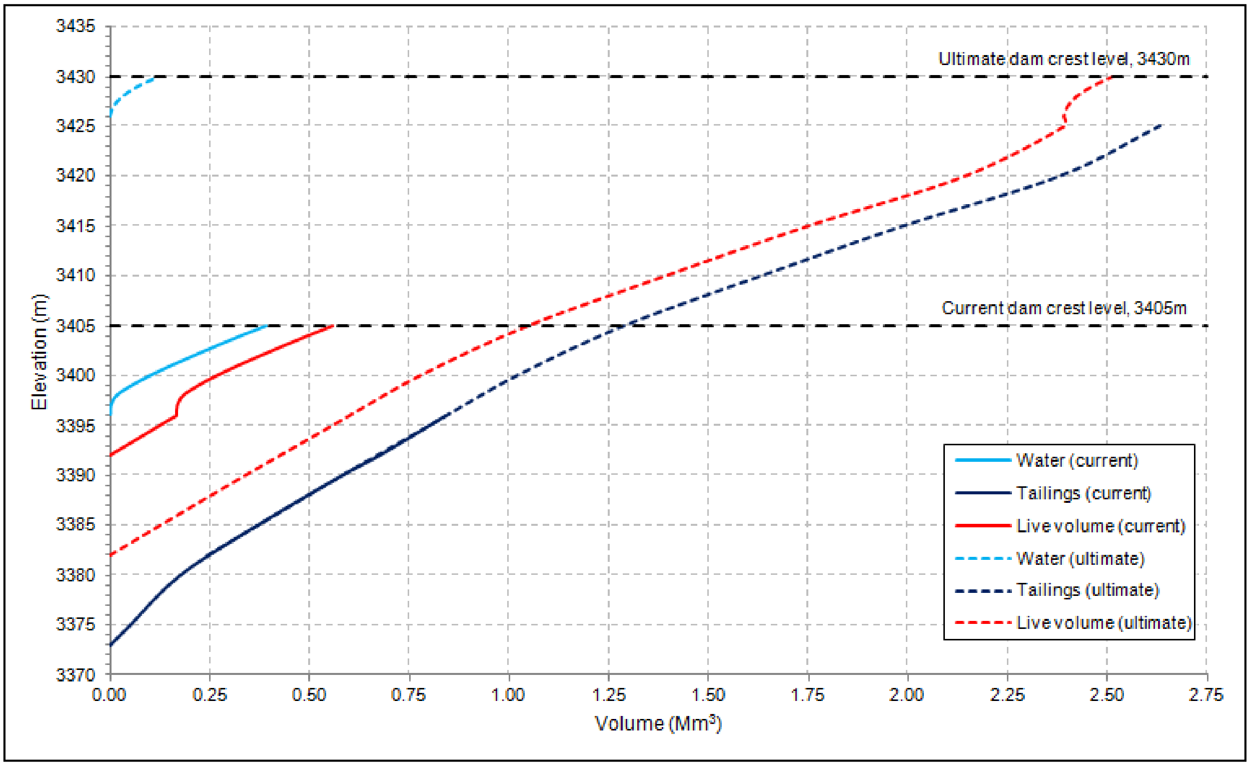
2.3 Tailings Material

The Old TDF contains a mix of conventional cyclone overflow tailings and paste tailings. The conventional cyclone tailings form the lower part of the structure and are retained by the outer embankment berm. The paste tailings are retained by the higher-elevation APA paste berm. The total water retention capacity above the APA paste berm is 0.12 Mm^3 between elevations 3389 m and 3392 m.

The Lynx TDF contains paste tailings. The estimated final tailings storage capacity will be 2.6 Mm^3. The expected elevation-storage curve is shown on **Figure 2** (AMEC, 2012).

For this study two scenarios have been considered: the dam in its current (2014) and ultimate configurations. The respective dam crest elevations are 3,405 and 3,430 m. The stage-storage curves used in the hydraulic models are based on the volume curve shown on **Figure 2**, scaled to the estimated breach release volume (see Section 5.2.1).

Figure 2 Lynx TDF Stage-Volume Curves



The Lynx TDF currently has a water retention capacity of 0.39 Mm^3 at elevation 3,405 m. The total tailings volume below elevation 3405 m is 0.84 Mm^3, of which 0.167 Mm^3 is above the assumed breach invert (toe of the embankment slope) of 3,392 m used in the modelling. The total live storage volume (combination of tailings and maximum water retention above the assumed breach invert) is 0.559 Mm^3. Water retention capacity makes up 70% of the live storage volume.

For the ultimate scenario, the Lynx TDF has a water retention capacity of 0.122 Mm^3 at elevation 3,426 and 3,430 m. The final tailings volume is estimated to be 2.63 Mm^3, of which 2.4 Mm^3 is above an assumed breach invert of 3,382 m representing the toe of the embankment once the dam has been raised to its ultimate height. The corresponding total live storage volume will be 2.51 Mm^3, of which 5% is water retention capacity.

3.0 CREDIBLE FAILURE MODE ANALYSIS

When assessing the potential consequences of a dam failure, it is standard practice to consider two hypothetical scenarios, a flood-induced and non flood-induced failure (sometimes also termed “wet” and “sunny day” failures, respectively).

Dam break modelling is standard practice for all dams and is undertaken for emergency planning purposes. Dam break modelling is an analysis of a hypothetical event and is not indicative of any actual concerns at either of the NMF TDFs. In British Columbia it is a requirement to determine potential inundation areas for dam classification, safety, and emergency planning purposes.

A flood-induced failure represents a dam breach resulting from a flood event, which would most likely occur due to overtopping of the structure, either as a result of spillway blockage or lack of discharge capacity. Flood events in excess of the inflow design flood (IDF), such as a probable maximum flood (PMF), may be considered and the dam failure is modelled at the maximum water storage level for the event being considered.

A non-flood induced failure represents a dam breach under normal flow and operating conditions, which may occur as a result of internal piping through the embankment, embankment instability or leakage from internal structures (e.g., conduits through the structure). These failure mechanisms could result from structural damage following a seismic event. Overtopping failures are typically not considered during a non-flood analysis but could occur as a result of a prolonged blockage of an outlet structure.

The following sections discuss hypothetical flood and non-flood induced failure mechanisms for the Myra Falls TDF dams.

3.1 Old Tailings Disposal Facility

The following failure mechanisms have been analysed for the Old TDF (see Section 4.0):

- Non-flood failure: Seismic shaking that liquefies the tailings, causing the outer berm to be displaced and move towards Myra Creek.
- Flood-induced failure: An overtopping failure of the APA Paste Berm caused by a preceding failure or blockage of the upslope diversion channel. Water released from the APA then overtops the outer embankment causing a failure and displacement of tailings into Myra Creek. The IDF is 1/3rd between the 1,000-year ARI and the PMF hydrographs.

The Old TDF has a limited water storage capacity, having been designed to retain the 200 year ARI flood event (0.5% AEP) from the local catchment between the TDF and the upslope diversion channel. An emergency spillway has been constructed that would enable the TDF to safely pass lower probability flood events. The spillway was designed for the 1,000-year ARI event (0.1% AEP) assuming a failure of the upslope diversion channel.

Although direct runoff to the Old TDF is limited by the upslope diversion, the diversion channel has limited conveyance capacity. A flood-induced failure of the Old TDF could occur following a failure or blockage of the diversion. Under this scenario, the IDF would exceed the storage capacity of the TDF with a subsequent spillway failure and overtopping of the APA paste berm. Such a failure of the APA Paste Berm is considered credible. The storage volume in the strip area (between the Outer Embankment Berm and the APA Paste Berm) is limited and could only retain a small volume of paste-tailings. In the event of an APA Paste Berm failure the strip area would likely be inundated beyond capacity, resulting in overtopping of the Outer Embankment Berm.

A non-flood induced failure could theoretically occur as a result of internal erosion, either through the APA paste berm or the outer embankment (for example, near the decanting structure). However, a more credible failure mode is considered to be seismic shaking that liquefies the tailings and causes deformations in either the APA berm or outer embankment (AMEC, 2013).

A worst-case non-flood scenario would be non-performance of the seismic upgrade berm during a seismic event, causing a complete failure of the Outer Embankment Berm and extensive deposition of tailings material and debris across Myra Creek. Blockage of the creek would result in relatively rapid rise in upstream water levels and flooding before the tailings begin to erode.

3.2 Lynx Tailings Disposal Facility

The selected failure mechanisms that were modelled for the Lynx TDF are:

- Non-flood failure: Internal erosion with the TDF water storage volume at normal level and no local inflow.
- Flood-induced failure: An overtopping failure caused by a preceding failure or blockage of the upslope watercourses or diversion channel. The IDF is 1/3rd between the 1,000-year ARI and the PMF hydrographs.

These failure mechanisms have been applied to both configurations of the Lynx TDF.

The Lynx TDF has been designed with a greater water retention capacity than the Old TDF. The design standard is for the Lynx TDF to maintain a minimum 78,000 m^3 storage volume with an additional 0.5 m of freeboard to the dam crest (this additional storage volume will vary depending on the level to which the dam has been raised at any time). As with the Old TDF, the Lynx TDF has a reduced direct catchment area due to the upslope diversion channels.
The design water storage volume is based on the 1,000-year ARI flood event (0.1% AEP) for the direct catchment only (i.e., between the TDF and the diversion channels).

Overtopping of the Lynx TDF in either its current (2014) and ultimate configurations may occur as a direct result of:

- Failure of an upslope watercourse or diversion channel to convey water away from the TDF, with the inflow then exceeding the available storage volume (and any spillway capacity), causing an overtopping breach; or
- A failure of a waste rock disposal site above the TDF depositing rock into the TDF, causing a landslide-driven wave which sends water over the crest of the dam.

Following final raising and completion, the TDF will likely have an emergency overflow spillway with sufficient capacity to pass the IDF either from the full or local catchment, depending on any future upgrade work to the diversion. On that basis, the second scenario could be considered more plausible for the final TDF configuration, but in practice the result would be the same - an overtopping failure of the dam near the southwest corner. Similar to the Old TDF, a non-flood induced failure could occur as a result of internal erosion, either following a seismic event or due to long-term leakage through the dam.

The dam breach model assumes a breach location in the southwest corner of the Lynx TDF. For the current configuration this is considered the worst case location due to the proximity of the mine buildings and the high potential breach depth. The breach location was selected to generate the worst case failure consequences.

4.0 OLD TAILINGS DISPOSAL FACILITY MODELLING

4.1 Approach and Methodology

Two different methodologies have been adopted for this study as the conditions in the two TDFs require different analysis methods. The Old TDF has limited water storage and even under flood-induced failure conditions is unlikely to release a large volume of water or have significant incremental flood and loss of life consequences outside the immediate mine site. The Lynx TDF, however, has a significant water storage volume and a failure can be approached in similar terms to a water retaining dam, as regards breach and inundation modelling.

The Old TDF has been considered using a mass-balance approach adopted from the previous inundation study by KC (2003), but assuming that a failure of the APA paste berm causes a subsequent failure of the lower embankment. With this approach, the volume of material removed from the TDF has been estimated along with the potential deposition in Myra Creek. The worst case scenario is considered to be the non-flood-induced failure as this would result in the largest scale blockage across Myra Creek and highest upstream backwater flood levels. Were the failure to occur on the western edge of the TDF (considered having the highest consequences), then any local inflow to the TDF would be discharged into Myra Creek downstream of the blockage in Myra Creek. The flood extents upstream of the blockage in Myra Creek have been calculated based on the tailings runout topography and compared incrementally against the 2-year ARI flood extents along Myra Creek.

4.2 Old Tailings Disposal Facility Inundation Modelling

The potential for a total failure of the Old TDF is discussed in Section 3.1. The outer embankment could hypothetically fail due to either overtopping from a flood-induced failure of the APA Paste Berm or due to seismic shaking. In either case the outer berm would be displaced towards Myra Creek and would partially or fully block the channel.

The Old TDF has a total length of 1,400 m and a failure could occur at any point along this length. A failure has been considered using a similar approach to the previous dam break study (KC, 2003). Cross-sections through the Old TDF and Myra Creek channel/valley were taken at 100 m intervals along the outer edge of the TDF. The potential mass movement was then calculated for each cross-section, assuming that the TDF failed and released material into the creek. The relative cut and fill volumes at each cross section were calculated assuming that released tailings would stabilise in the creek at an angle of 20H:1V (similar to the grade in the APA paste berm) bounded underneath by a 7H:1V backscarp extending upward into the TDF from the embankment toe near the creek. The final tailings runout geometry was calculated by balancing the cut and fill volumes within each cross section.

Following a failure, Myra Creek would back up behind the flow slide causing upstream inundation until the slide is overtopped. The inundation extents have been calculated using the topographic survey and the final stable height of the flow slide at each cross-section.
The mass-balance calculations and upstream inundation level are summarized in **Table 1**.
The cross-section locations are shown on Drawing 080303 (**Appendix C**).

Table 1
Old TDF Mass-Balance and Inundation Levels (AMEC computations)

Station (km)	Cut (m^2)	Fill (m^2)	Cut/Fill Error (%)	Inundation Level (m)
0+100	783	792	1.1	3359.9
0+200	672	708	5.3	3359.8
0+300	934	811	13.2	3359.9
0+400	963	969	0.6	3365.1
0+500	874	830	5.0	3365.5
0+600	1049	1044	0.5	3363.3
0+700	920	928	0.9	3364.5
0+800	1046	1034	1.1	3365.9
0+900	1119	1210	8.1	3365.9
1+000	1366	1367	0.1	3363.4
1+100	1326	1395	5.2	3363.1
1+200	1486	1465	1.4	3358.7

The Old TDF has very limited water storage capacity above the APA Paste Berm so a non-flood failure would not release a large volume of water into Myra Creek. If a failure occurred during a flood event there would be some water released into Myra Creek, but the incremental volume would be limited compared to a similar flood event without a dam failure. In terms of incremental flood discharge and volume, the worst case scenario would likely be a failure at the eastern end of the TDF (around station 1+200), where the TDF is at its highest and the runout distance would not be constrained by topography on the south bank of the creek.

The station locations and upstream inundation extent are shown on Drawing 080303 in **Appendix C**. A failure between stations 0+800 and 0+900 would cause the greatest upstream inundation, with water ponding to a level of 3,365.9 m (1.1 m below the mine shaft elevation at 3367 m cited by KC (2003)) before erosion of the tailings occurs. This would inundate all six water treatment ponds on the south bank of Myra Creek, low-lying parts of the mine head works and the main access road through the site. The overland conveyor would also be damaged. Anyone on the north bank near the mill or the site camp would be trapped but would not be at risk of flooding.

5.0 LYNX TAILINGS DISPOSAL FACILITY DAM BREACH INUNDATION MODELLING

5.1 Scenarios Considered

A range of flood-induced failure scenarios have been considered for the TDFs to assess the worst-case incremental consequences that could occur due to a dam breach. These scenarios are based on the CDA Guidelines and the required IDF for each consequence category.
A summary is given in **Table 2**, where the IDFs refer to the local mine runoff event. The table

excludes the low and extreme consequence categories; review of previous reports indicated that neither of these consequence categories would be applicable to the NMF TDFs. The non-flood failure scenarios used the mean annual flow in Myra Creek with no local mine site runoff. All flood-induced failure models used the 200-year ARI peak discharge in Myra Creek; given the relative difference in catchment areas, a storm of 1,000-year ARI or greater centered over the mine site would likely generate a lesser magnitude flood in the wider Myra Creek catchment. Selecting a lower “base flow” event in Myra Creek also allows for a more representative assessment of the incremental damages resulting from a dam failure.

These scenarios were repeated for the Lynx TDF in its current and ultimate configurations. The differences between these two conditions are the dam height and the tailings volume.

Table 2
Flood-Induced Failure Scenarios

Dam Consequence Category	IDF (local mine runoff)	Myra Creek Flood
Significant	1,000-year ARI	200-year ARI
High	1/3rd of the difference between 1,000-year ARI and Probable Maximum Precipitation	200-year ARI
Very High	2/3^{rds} of the difference between 1,000-year ARI and Probable Maximum Precipitation	200-year ARI

The methodology for the Lynx TDF is similar to that for conventional water retaining dam break analyses, using a combination of hydrological and hydraulic modelling to route a dam break flood wave through the mine site and downstream through Myra Creek. Because a worst consequence breach would likely be at the western arm of the Lynx Dam, the flow conditions would not be appropriately represented using a one-dimensional (1D) hydraulic model. A HEC-RAS (version 5) two-dimensional (2D) hydraulic model has been used in this study. The model was developed using available site survey information.

5.2 Hydrological Modelling

The US Army Corps of Engineers’ (USACE) HEC-HMS hydrological modelling software was used to develop runoff hydrographs upslope of and within the mine site and breach hydrographs for the Lynx TDF. At the time of writing this report, the mine site hydrology is being reviewed with expected completion in early 2015.

A hydrological model developed for the 2008 mine water management study (AMEC, 2008) was used in this study. The design precipitation depths were modified using the revised 2012 estimates. The HEC-HMS model was then used to model the dam breach and resulting outflow hydrographs using the parameters outlined below.

Peak discharges in Myra Creek have been calculated for previous studies (e.g., KC, 1999, 2003). No flood hydrographs were available for Myra Creek so the hydraulic models for this study use a steady-state inflow assumption. This ensures that the peak breach outflow coincides with the peak discharge in Myra Creek and the worst case inundation conditions are modelled. The peak discharge estimates for Myra Creek are given in **Table 3**.

Table 3
Peak Discharge in Myra Creek

ARI (years)	Maximum Instantaneous Discharge (m^3/s)
2	7
10	275
200	460
1000	560

5.2.1 Dam Breach Input Parameters

The parameters defining the configuration of the dam breach were estimated using published literature. Equations used for estimating the breach width and formation time are summarised by Wahl (2004) and include those by MacDonald and Langridge-Monopolis (1984), US Bureau of Reclaimation (1986), Von Thun and Gillette (1993), Froelich (1988, 1993), and the US National Weather Service (1992). These references include equations for both overtopping and piping failures. The dam breach parameters used for each of the model scenarios are summarised in Table B1 (**Appendix B**).

The failure mechanisms (either piping or overtopping) for each runoff event were determined by preliminary flow routing. Overtopping was used where the IDF volume was greater than the maximum TDF storage capacity. Piping failures were used for all other scenarios.

The potential volume that could be released during a breach was estimated using a relationship published by Rico (2008). This relationship estimates the total release volume, combining both water storage and tailings material. It assumes that all the tailings in the facility are potentially liquefiable and could be mobilised during a breach. The relationship developed by Rico is empirical and based on previous tailings dam failures. It typically estimates around 35% of the total stored volume will be released during a breach. The TDF elevation-storage curves used in the hydrological model were modified so that the total storage volume matched the estimated release volume. It should be noted that the tailings volume released during a breach would be highly dependent on extent to which the material would liquefy.

5.2.2 Dam Breach Outflow

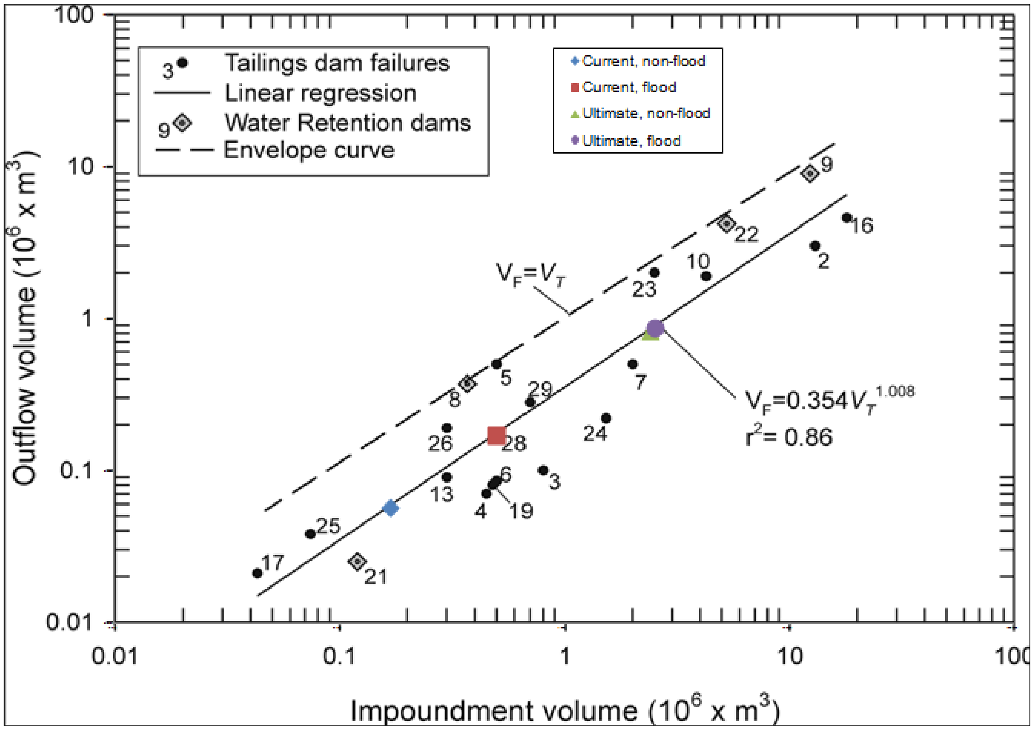
Breach outflow hydrographs are shown below. These are base case breach hydrographs for the non-flood and flood (1/3rd 1,000-year ARI and PMF) scenarios for current and ultimate configurations of the Lynx TDF. The breach hydrographs were generated in HEC-HMS using the breach parameters discussed in Section 5.2.1. The hydrographs have been used as the upstream boundary conditions for the HEC-RAS hydraulic models.

Because the reach between the Lynx TDF and Buttle Lake is short with limited floodplain storage, there is little attenuation of the hydrographs. The peak discharge, rather than total volume is therefore the key parameter in determining inundation extents. The highest peak discharge occurs for the non-flood, ultimate configuration breach. This has been modelled as a piping failure with a peak discharge of 1,446 m^3/s (**Figure 6**) – more than three times higher than the corresponding flood-induced peak discharge (446 m^3/s) shown on **Figure 7**. This is likely due to the breach mechanism: the non-flood failures have been modelled as piping events, whereas most flood-induced failures have been modelled as overtopping events. The non-flood peak discharge has been compared against published equations for estimating peak discharge and is within the expected envelope, which ranges from 1,000 to 5,000 m^3/s.

In both flood-induced failure cases, the breach occurs before the inflow hydrograph reaches its peak. This happens because the failure mechanism is overtopping and the model was set to initiate the dam breach when the water level reaches the dam crest. The available storage volume in the TDF is filled and the water level rises to the dam crest before the peak inflow occurs. This creates a double peaked breach hydrograph, where the first peak is due to the breach and the second is the un-attenuated inflow hydrograph discharging through the breach. Because the flood-induced failures occur before the peak inflow, the total volume of water and tailings released in these failures is higher than that estimated using Rico's (2008) equation. However, the total volume in the TDF at time of failure is correct. **Figure 3** shows the estimated release volumes for each of the four Lynx TDF scenarios plotted onto Rico's data and envelope equations. **Figures 4** through **7** show the breach hydrographs.

For the Lynx TDF in its current configuration, Rico's relationship underestimates the flood-induced release volume, so was not used. Of the total live storage, 70% is retained water. Using Rico's relationship, the estimated release volume is less than the water retention volume. To work around this issue, the Lynx TDF current configuration, flood-induced failure models assume that the release volume is equal to the entire water and tailings volume above the breach invert. The release volumes used in the current (non-flood) and all ultimate configuration (non-flood and flood-induced) models have been estimated using Rico's relationship as described above.

Figure 3 Estimated Breach Release Volumes



Source: Rico, 2008

Figure 4 Lynx TDF Breach Hydrograph, Current (2014) Configuration, Non-flood Failure

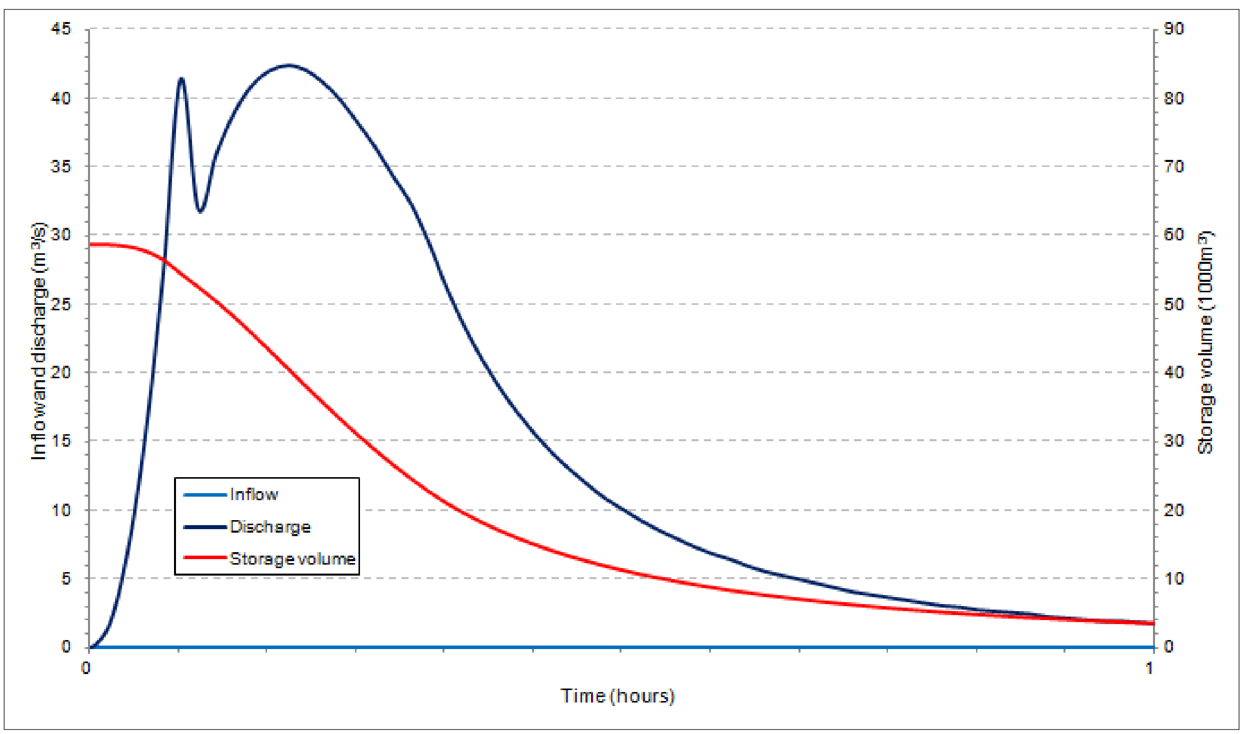


Figure 5 Lynx TDF Breach Hydrograph, Current (2014) Configuration, 1/3rd 1,000-year ARI and PMF Failure

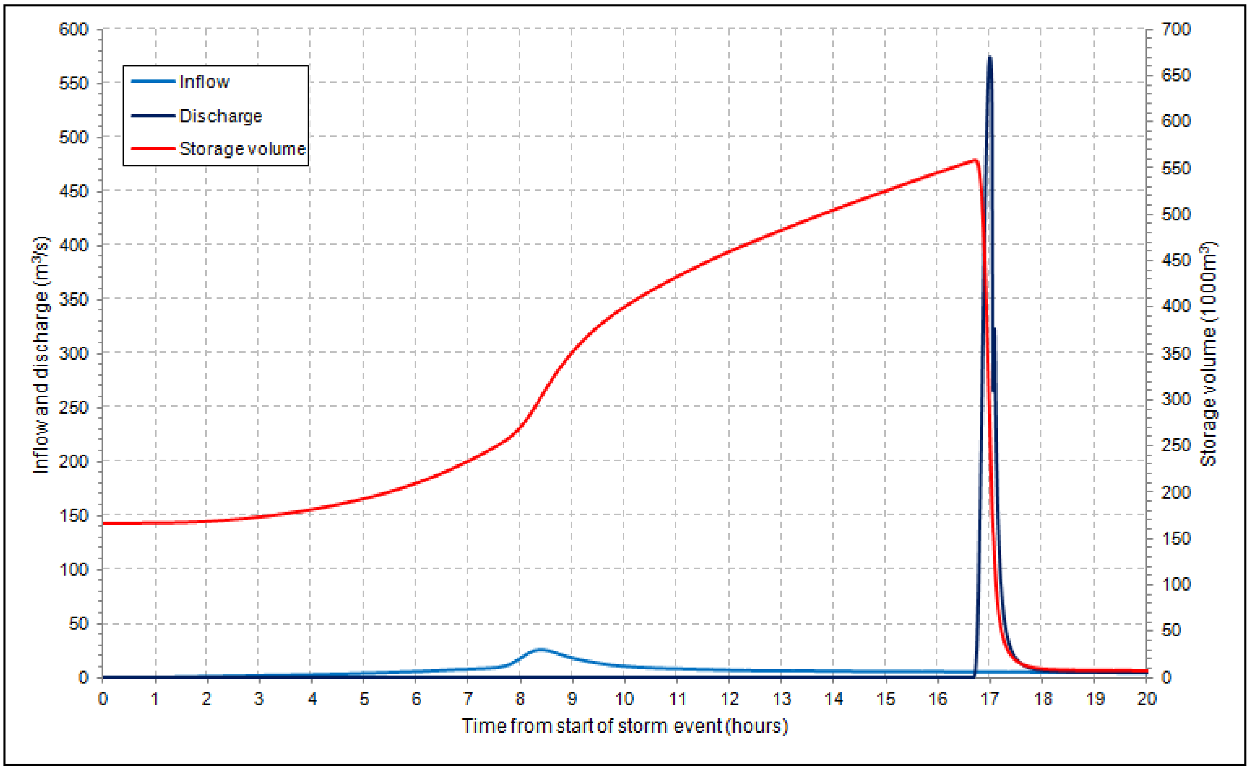


Figure 6 Lynx TDF Breach Hydrograph, Ultimate Configuration, Non-flood Failure

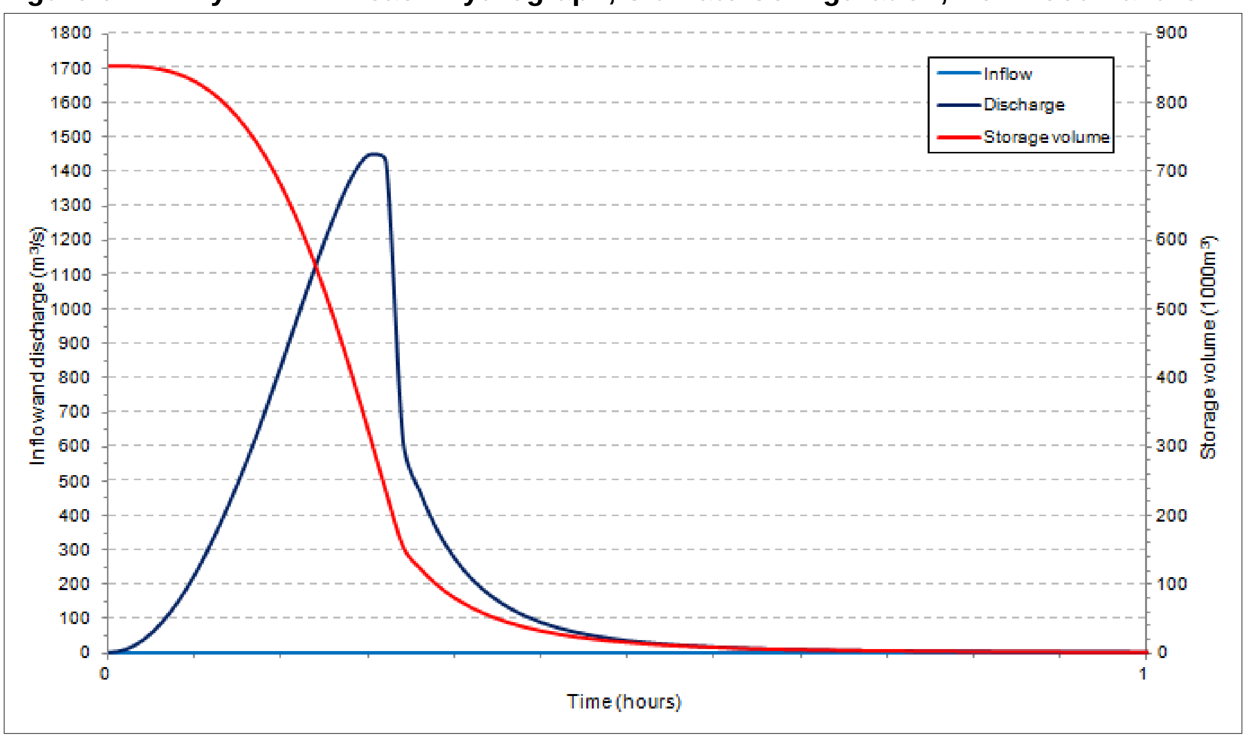
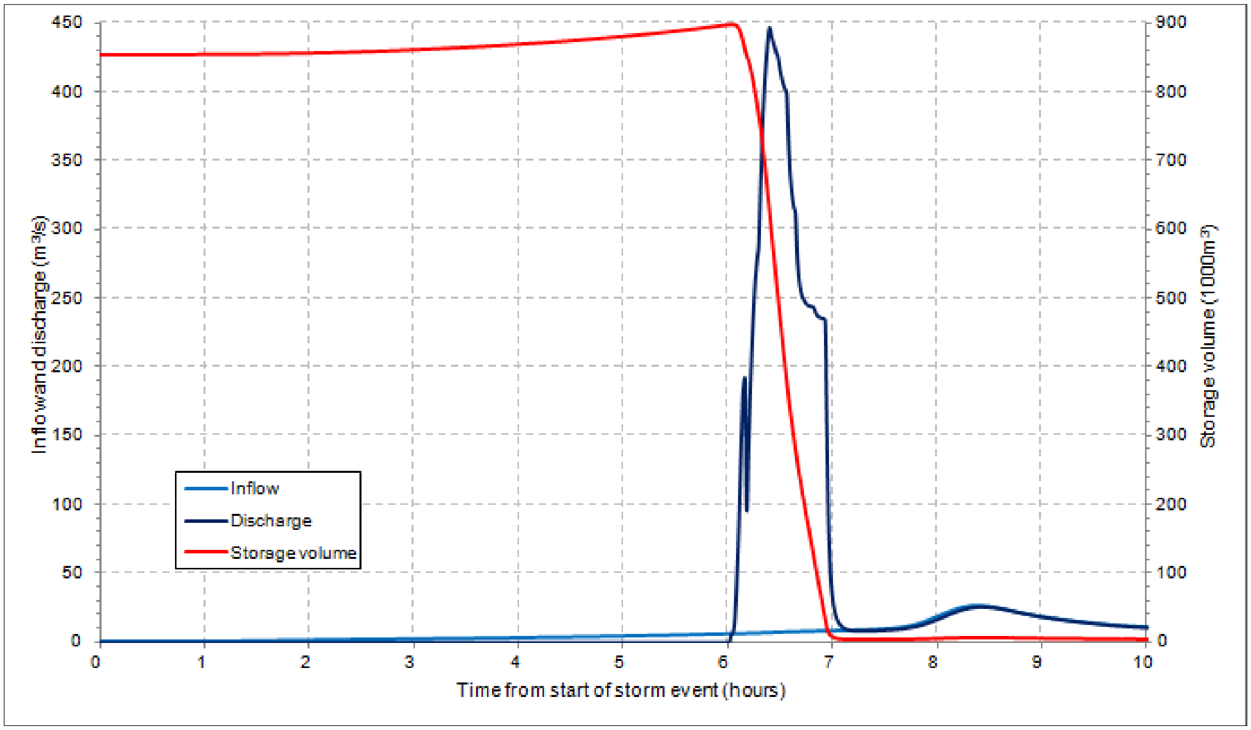


Figure 7 Lynx TDF Breach Hydrograph, Ultimate Configuration, 1/3rd 1,000-year ARI and PMF Failure



5.3 Hydraulic Modelling

The USACE HEC-RAS model was used to route the breach hydrographs through the mine site and downstream along Myra Creek. Although HEC-RAS has the capability to model a dam breach and outflow hydrograph, HEC-HMS was used to generate the breach hydrographs. This was considered acceptable as there are no downstream hydraulic conditions that could constrain the breach outflow. This simplified the modelling process and the breach hydrographs generated in HEC-HMS were used as the input to the HEC-RAS hydraulic models.

The Lynx TDF is located off-stream and uphill from Myra Creek. The geometry of the mine site and hypothetical breach location required a 2D modelling approach to fully consider the inundation effects at the mine site. The hydraulic model was developed using HEC-RAS version 5.0 (beta), which has 2D modelling capability. For ease of modelling and to avoid any numerical instability associated with 1D and 2D model interfaces, the model was built as a single 2D domain encompassing the full mine site and downstream valley.

The upstream extent of the 2D hydraulic model is a point 1.6 km upstream of the mine site. The downstream boundary is the upstream extent of Myra Falls, approximately 400 m upstream of Buttle Lake. The model was not extended downstream of Myra Falls because this section of river has supercritical flow conditions, dropping nearly 68 m over a distance of 400 m. This would create numerical instabilities in the unsteady-state hydraulic model. Instead, this furthest downstream reach of Myra Creek was modelled under steady-state conditions using a 1D

HEC-RAS model with discharge taken from the 2D model results. This is considered reasonable as there would be virtually no flood peak attenuation in this reach. The steady-state model results were then used to plot inundation extents along Myra Falls.

5.3.1 Input Data and Model Parameters

The 2 m survey contours were used to develop a digital terrain model (DTM) of the mine site at a 2.5 m grid resolution. This was then imported into the HEC-RAS model and used to develop a 2D domain containing rectangular cells at a 5 m grid resolution.

Spatially varied roughness coefficients (Manning's 'n') were entered in the 2D model using GIS files. The locations of trees, buildings, roads and areas of disturbed land were digitised based on the as-built survey and allocated appropriate roughness coefficients. A roughness coefficient of 0.04 was used for the Myra Creek channel, adopted from the Old TDF seismic upgrade report (KC, 1999).

Upstream boundary conditions were inflow hydrographs representing flow in Myra Creek (modelled as a steady-state time-series), discharge from the Lynx TDF breach, runoff from the mine site and discharge from the Lynx diversion channel (when it is assumed to be operating).

The downstream boundary condition was modelled using a rating curve. The rating curve was developed using a 1D HEC-RAS model and cross sections taken from the site survey DTM.

There are two road bridges and two pipe bridges crossing Myra Creek within the mine site. None of these structures were included in the hydraulic model. Survey information was not available for the pipe bridges or the downstream road crossing. The upstream road crossing (Myra Bridge) is a clear span structure with a deck elevation of 3,366.1 m. This is not affected by any of the modelled flood events (highest computed water level at the bridge is 3,364.87 m).

5.4 Lynx Tailings Disposal Facility Inundation Results

The results of the inundation modelling for both configurations of the Lynx TDF are shown in the drawings in **Appendix C**. A total of four drawings are presented, showing non-flood and flood-induced (1/3rd between the 1,000-year ARI and PMF) inundation effects.

For the flood-induced failures, the incremental consequences and flood impacts are similar for all flood magnitudes. Most of the incremental flood impacts are confined to the mine site, between the Lynx TDF and the mine head works. The following bullet points summarise the inundation consequences.

Mine structures include:

- Mill: The mill building is currently located southwest of the Lynx TDF. In its current location the building would not be inundated under any breach scenario; however, when the Lynx TDF reaches maximum height the mill will be very close to the toe of the dam.

- Site camp: The site camp is located south of the Lynx TDF, behind the mill building. The camp is used for temporary accommodation of mine staff and contractors. In its current location the site camp would not be inundated under any breach scenario.
- Water treatment ponds: There are six water treatment ponds on the south bank of Myra Creek and one (the Super Pond) on the north bank. The Super Pond is located directly in the flow path of a Lynx TDF breach and would be inundated with a water depth of up to 1.4 m. Flow velocities in this area are high (between 5 and 10 m/s). It is likely that the Super Pond would be destroyed. Water treatment ponds 3, 3A, and 4 are located on the south bank of Myra Creek and would be inundated in all Lynx TDF breach scenarios except a non-flood failure in the current configuration. Ponds 3 and 3A would be inundated by water spilling from Myra Creek, whereas pond 4 would be directly in the path of the initial flood wave from the Lynx TDF and would be destroyed. Damage to the water treatment ponds would release partially treated water and settled sediment into Myra Creek, both during the flood event and during any subsequent rain events until they are repaired.
- HW mine shaft: The HW mine shaft is located on elevated ground on the south bank of Myra Creek, opposite the Old TDF. The mine shaft building would not be inundated during any modelled breach events.
- Overland conveyor: The overland conveyor is elevated and a failure of the Lynx TDF would likely destroy the supports. Once the Lynx TDF reaches full height, the conveyor will be in close proximity to the downstream toe of the dam. Loss of the conveyor is an economic consequence of a dam breach and mine working would have to cease until the conveyor is repaired.

In addition to the structures listed above, there would be widespread inundation on the north bank of Myra Creek within the mine site. The breach formation times and time of travel for flood waves are short, so there would be limited warning time to evacuate the flood risk areas. There is a high probability that anyone working in the area would be impacted. The inundation extents in this area are similar for the current and ultimate scenarios because the topography is steep and breach flows are directed straight to the creek, rather than spreading laterally. This may change in the future if the topography around the dam toe changes, particularly if any overland flow paths are modified.

There would be minimal flood wave attenuation between the breach site and Myra Falls. The flood wave travel time between the breach site and the downstream boundary of the hydraulic model ranges between 10 and 18 minutes (for the ultimate non-flood and flood-induced failures, respectively).

6.0 SENSITIVITY ANALYSES

In accordance with the CDA guidelines and associated technical bulletins, a series of sensitivity analyses were conducted for the Lynx TDF. The base case for the sensitivity analyses is described above and shown on the inundation maps. Sensitivity analyses were only conducted for the non-flood and 1/3rd PMF scenarios.

The sensitivity analyses were limited to testing the effect on the breach hydrographs; none of the sensitivity hydrographs were routed downstream using the HEC-RAS hydraulic model. The following parameters were tested for sensitivity:

- Breach width;
- Breach formation time;
- Breach progression type (linear progression vs. sine wave); and
- Breach release volume.

The base case modelling used breach width and breach formation times that were the average values estimated by the five breach equations. For the sensitivity analyses, the maximum, and minimum estimates were used. Typically the Von Thun and Gillette (1993) equations give the highest width and formation time estimates. The NWS (1992) equations give the lowest estimates.

The sensitivity analysis considered the total release volume. The total volume is the sum of any stored water at the time of failure plus a certain volume of stored tailings. The release volume is estimated using an equation published by Rico (2008) and assumes that the tailings are liquefiable and will behave like water upon release. The base case analyses assumed that approximately 35% of the total volume would be released during a breach: the sensitivity analyses considered increasing and decreasing this amount by 50% (i.e., 17.5% of the total volume and 52.5% of the total volume). These sensitivity analyses have been applied to all Lynx TDF model scenarios except the current flood-induced scenario. For the current flood-induced scenario the sensitivity analysis assumes that only the water retention volume is released (0.33 Mm^3 rather than 0.495 Mm^3 in the base case). Because the base case current flood-failure assumes that the entire volume of water and tailings are released, it is not possible to do a sensitivity test for a higher release volume.

The sensitivity results for the Lynx TDF are shown in Tables B2 and B3 in **Appendix B**. The results show the breach hydrographs are most sensitive to a change in the formation time, particularly a reduction. When the failure time is reduced to the minimum estimate, the flood failure scenarios (1/3rd PMF) shows an increase in peak discharge of 17% and 94% for both the current and ultimate TDF configurations, respectively.

The results also show the peak discharge is sensitive to the total release volume. As expected, the peak discharges increase with higher release volumes and decrease with lower volumes. The change in discharge is between +24% and -50%, depending on the scenario. The change in peak discharge is not proportional to the change in release volume.

7.0 TAILINGS RUNOUT

Based on the information available, the estimated total volume of impounded tailings within the Lynx TDF is currently 1.2 Mm^3 with an expected ultimate volume of 2.63 Mm^3. The estimated release volumes during a breach have been calculated using relationships published by Rico (2008) and are summarised in **Table 4**. The total storage volume in **Table 4** is the live storage volume above the breach invert only – tailings below the modelled breach invert have not been included.

Table 4
Lynx TDF Estimated Release Volumes

Dam Configuration	Failure Condition	Total Storage Volume (Mm^3)	Release Volume (Mm^3)	Percent Release	Runout Distance (km)
Current (2014)	Non-flood	0.168	0.058	34.5%	1.7
	Flood-induced	0.497	0.495	99.6%	3.9
Ultimate	Non-flood	2.390	0.853	35.7%	12.8
	Flood-induced	2.512	0.898	35.7%	13.3

Rico (2008) also published an equation for estimating the runout distance, which is the distance the mobilized tailings could travel downstream of the breach. The equation estimates that in a non-flood failure with the current dam configuration, tailings could travel 1.7 km downstream of the breach. The lack of hydrograph attenuation and the constrained nature of Myra Creek mean tailings would likely travel to Buttle Lake under all scenarios. It is likely that coarse tailing material would deposit on the Myra Creek floodplain and the finer material (such as the amalgamated paste) would be transported to Buttle Lake. There may be some tailings dispersion within the lake. Bank erosion through Myra Creek could be expected, particularly in high energy locations near the breach site.

8.0 DAM CLASSIFICATIONS

8.1 Canadian Dam Association Guidelines (2007)

The 2007 CDA guidelines and their 2013 revision summarise the five consequence categories for dams based on the incremental consequences of a failure. The five consequence categories are Low, Significant, High, Very High, and Extreme. The CDA guidelines also present recommended IDFs for each of the five consequence categories.

The Lynx and Old TDFs are both considered to be High consequence structures per the CDA Guidelines and the B.C. Dam Safety Regulations. This consequence assessment was last reviewed in the 2013 Dam Safety Reviews (Robertson Geoconsultants Inc., 2014).

8.2 Dam Classification and Inflow Design Flood

The incremental failure consequences for the Old TDF and Lynx TDF are summarised in Tables D3 and D4, respectively in **Appendix D**.

It is recommended that the Old TDF and Lynx TDF be classified as “High” consequence dams in accordance with CDA Guidelines and local regulations. Because the mine operates on a shift basis, the population at risk is considered to be permanent; based on the approximate number of mine site workers expected to be located in the flood risk area, the estimated worst case loss of life is 10 or fewer people. In addition to the potential loss of life, infrastructure damage would be limited to facilities owned and operated by Nyrstar. Environmental and cultural damages would include potential for a large volume of tailings to be deposited in Myra Creek and Buttle Lake, which is also considered “High” consequence with respect to environmental and cultural consequences,

Other than the loss of the dam and mine buildings, other infrastructure losses would be limited to the two bridges that cross Myra Creek, considered to be a “Significant” consequence.

As the Lynx TDF is raised these consequences may change: buildings to the west of the Lynx dam will have to be relocated to accommodate the downstream toe of the dam and there may be some additional local earthworks, both of which could alter the breach flow paths and potential consequences.

Based on the recommended consequence classifications, the corresponding IDF for the Old TDF and Lynx TDF would be 1/3rd between the 1,000-year ARI and PMF hydrograph for the catchment area contributing to the TDFs (including the diversion channel(s) where blockage could result in flow into the TDF initiating overtopping).

8.3 Potential Effects on Nyrstar Myra Falls

Since both TDFs have a High consequence classification, NMF should maintain the current state of observation and monitoring. Closure of the facilities will require spillways with sufficient capacity to pass the IDF. If the upstream diversion ditches are to remain in place, they will either need to be upgraded to the same standard; otherwise the TDF spillways should be designed with additional discharge capacity.

It is recommended that this study be reviewed upon completion of the ongoing mine site hydrology and diversion channel upgrade projects. Results from both of these studies could affect the dam breach parameters and consequence classification.

It is also recommended that NMF review the Lynx TDF inundation extents closer to the Lynx TDF closure time. Any changes to the topography in the area could alter flood flow paths and inclusion of a high capacity spillway may change the potential failure mechanisms.

9.0 CLOSURE

This report has been prepared for the exclusive use of Nyrstar Myra Falls. This report is based on, and limited by, the interpretation of data, circumstances, and conditions available at the time of completion of the work as referenced throughout the report. It has been prepared in accordance with generally accepted engineering practices. No other warranty, express or implied, is made.

Yours truly,

AMEC Environment & Infrastructure

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United States Dam Safety Office. 1998. *Prediction of Embankment Dam Breach Parameters*, DSO-98-004.

Wahl. 2004. “Uncertainty of Predictions of Embankment Dam Breach Parameters.” *Journal of Hydraulic Engineering*, Vol.130 No.5.

Appendix A

Site Photos

Photo A1: Myra Creek realignment and old TDF, looking east

Photo A2: Lynx TDF (looking southeast)

Photo A3: Lynx TDF and downstream mine buildings (looking southwest)

Photo A4: Old TDF, amalgamated paste area (APA) (looking east)

Photo A5: Lynx diversion channel above the original TDF (looking northwest)

Photo A6: Old TDF strip area, APA paste berm on the right (looking west)

Photo A7: Extent of water retention, APA paste area, old TDF (looking west)

Photo A8: Old TDF spillway, looking upstream (north)

Photo A9: Old TDF decanting structure (looking east)

Photo A10: Myra Falls upper tier, looking upstream

Appendix B

Breach Parameters

Table B1 - Lynx TDF Breach Parameters

Breach Parameters used in the Lynx TDF hydrological modelling

Dam status	Failure condition	Failure type	Peak inflow (m^3/s)	Breach invert (m AD)	Crest level (m AD)	Runoff volume (Mm^3)	Water level (m AD)	Stored volume (Mm^3)	Release volume (Mm^3)	Runout distance (km)	Breach widths			Side slope (H:1V)	Formation time (hrs)
											Average (m)	Top (m)	Base (m)		
Current	Non-flood	piping	0	3392	3405	0.000	3396.07	0.168	0.058	1.7	13.0	17.4	8.6	0.34	0.31
	Flood (100yr ARI)	piping	13.2	3392	3405	0.270	3403.03	0.438	0.436	3.5	25.9	34.7	17.1	0.68	0.39
	Flood (200yr ARI)	piping	13.8	3392	3405	0.282	3403.23	0.450	0.448	3.6	26.3	35.2	17.4	0.69	0.39
	Flood (1000yr ARI)	piping	15.1	3392	3405	0.306	3403.63	0.474	0.473	3.7	27.0	36.2	17.8	0.71	0.40
	Flood (1/3rd 1000yr ARI and PMP)	overtop	25.9	3392	3405	0.515	3405.00	0.497	0.495	3.9	34.5	46.2	22.8	0.90	0.40
	Flood (2/3rd 1000yr ARI and PMP)	overtop	36.7	3392	3405	0.728	3405.00	0.497	0.495	3.9	34.5	46.2	22.8	0.90	0.40
Ultimate	Non-flood	piping	0	3382	3430	0.000	3425.92	2.390	0.853	12.8	77.2	103.4	51.0	0.55	1.30
	Flood (100yr ARI)	overtop	13.2	3382	3430	0.270	3430.00	2.512	0.898	13.3	96.7	129.6	63.8	0.68	0.91
	Flood (200yr ARI)	overtop	13.8	3382	3430	0.282	3430.00	2.512	0.898	13.3	96.7	129.6	63.8	0.68	0.91
	Flood (1000yr ARI)	overtop	15.1	3382	3430	0.306	3430.00	2.512	0.898	13.3	96.7	129.6	63.8	0.68	0.91
	Flood (1/3rd 1000yr ARI and PMP)	overtop	25.9	3382	3430	0.515	3430.00	2.512	0.898	13.3	96.7	129.6	63.8	0.68	0.91
	Flood (2/3rd 1000yr ARI and PMP)	overtop	36.7	3382	3430	0.728	3430.00	2.512	0.898	13.3	96.7	129.6	63.8	0.68	0.91

Notes:

1. Breach parameters such as average width and formation time are based on published literature for clear-water dam failures (e.g. water supply, hydroelectric etc.), not for tailings dams.
   The use of these parameters in modelling a tailings dam failure assumes that the tailings material is liquifiable and will act in a similar way to clear-water.
2. The stage-storage curves used in the model have been modified so the total storage volume matches the estimated release volume.
   The stored/release volume is the total volume of water and tailings that could be released following a dam failure.
   The release volume has been estimated using Rico's relationship (2008). For the current configuration, flood-induced failures this relationship gives results less than the water retention volume; in these cases the release volume has been assumed the same as the total live storage volume above the breach invert.
3. The runout distance is the estimated distance that tailings will travel downstream of the breach, also estimated with reference to Rico (2008).
   For all of these scenarios (except the current non-flood) the tailings are expected to travel the full length of Myra Creek and be deposited in Buttle Lake, approximately 3.5km downstream of the Lynx TDF.
4. Peak inflow has been estimated using precipitation-runoff modelling with allowance for snowmelt. The hydrological model was taken from the Mine Water Study (AMEC, 2008) with revised precipitation depths (AMEC, 2012).
5. An assessment of whether the dam would fail via overtopping or piping was based on the calculated inflow volume during the given flood event. The avilable water storage volumes are 0.39 Mm^3 for the current configuration and 0.12Mm^3 for the ultimate configuration.
6. The water level in the table is the level in the TDF at the time of failure. Failure occurs either at maximum water storage volume of the TDF (for overtopping) or when 100% of local runoff volume has entered the TDF (piping).

References:

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[2] Rico, Benito and Diez-Herero, 2008, *Floods from tailings dam failures* , Journal of Hazard Management

[3] US Dam Safety Office, 1998, *Prediction of Embankment Dam Breach Parameters* , DSO-98-004

[4] Wahl, 2004, *Uncertainty of Predictions of Embankment Dam Breach Parameters* , Journal of Hydraulic Engineering, Vol. 130, No. 5, May 2004

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[6] Wetmore & Fread, 1991, *The NWS Simplified Dam-break Flood Forecasting Model* , US National Weather Service

Tables B2 and B3 - Breach Parameter Sensitivity Analyses

Lynx TDF, all configurations and scenarios

Table B2: Current (2014) Configuration

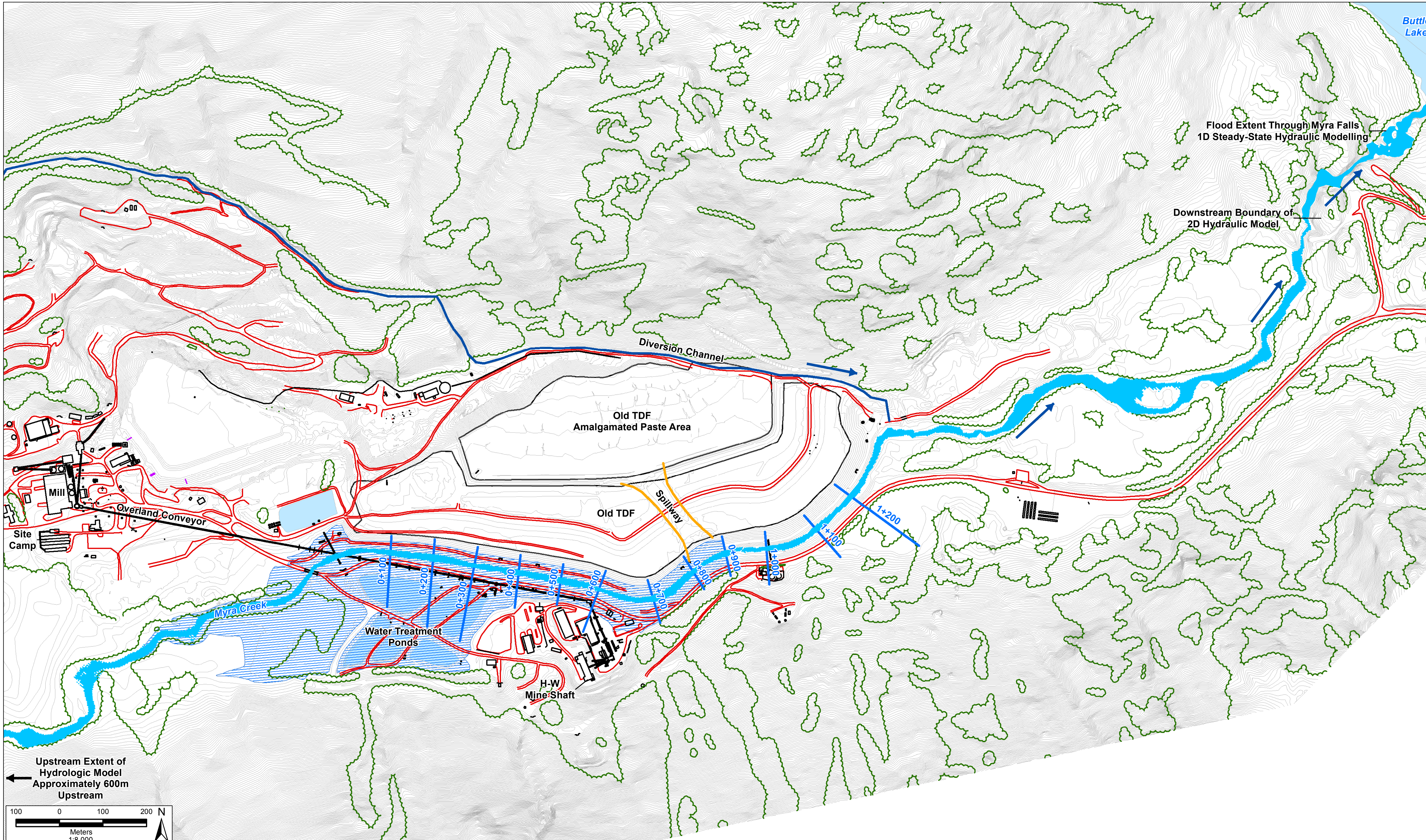
Case	Flood event	Breach Parameters					
		Base width (m)	Formation time (hrs)	Release volume (Mm^3)	Progression type	Peak discharge (m^3/s)	Change in peak (%)
Base case	Non-flood	8.6	0.31	0.058	linear	42	0.0
Maximum breach width		10.8	0.31	0.058	linear	51	22.4
Minimum breach width		7.5	0.31	0.058	linear	40	-5.0
Maximum formation time		8.6	0.56	0.058	linear	40	-5.0
Minimum formation time		8.6	0.13	0.058	linear	66	57.4
Sinusodial breach progression		8.6	0.31	0.058	sine wave	50	19.0
Increased release volume (+50%)		8.6	0.31	0.087	linear	52	24.3
Decreased release volume (-50%)		8.6	0.31	0.029	linear	30	-28.8
Base case	1/3rd 1000yr ARI and PMP	34.5	0.40	0.495	linear	573	0.0
Maximum breach width		38.6	0.40	0.495	linear	582	1.6
Minimum breach width		27.3	0.40	0.495	linear	561	-2.1
Maximum formation time		34.5	0.51	0.495	linear	461	-19.5
Minimum formation time		34.5	0.38	0.495	linear	672	17.3
Sinusodial breach progression		34.5	0.40	0.495	sine wave	603	5.2
Decreased release volume		34.5	0.40	0.330	linear	423	-26.2

Table B3: Ultimate Configuration

Case	Flood event	Breach Parameters					
		Base width (m)	Formation time (hrs)	Release volume (Mm^3)	Progression type	Peak discharge (m^3/s)	Change in peak (%)
Base case	Non-flood	51.0	1.30	0.853	linear	1446	0.0
Maximum breach width		87.2	1.30	0.853	linear	1577	9.0
Minimum breach width		20.4	1.30	0.853	linear	974	-32.7
Maximum formation time		51.0	1.45	0.853	linear	1226	-15.2
Minimum formation time		51.0	0.64	0.853	linear	2080	43.8
Sinusodial breach progression		51.0	1.30	0.853	sine wave	1739	20.2
Increased release volume (+50%)		51.0	1.30	1.280	linear	1724	19.2
Decreased release volume (-50%)		51.0	1.30	0.427	linear	825	-42.9
Base case	1/3rd 1000yr ARI and PMP	63.8	0.91	0.898	linear	446	0.0
Maximum breach width		95.0	0.91	0.898	linear	450	1.0
Minimum breach width		35.2	0.91	0.898	linear	434	-2.6
Maximum formation time		63.8	1.58	0.898	linear	263	-41.1
Minimum formation time		63.8	0.65	0.898	linear	867	94.4
Sinusodial breach progression		63.8	0.91	0.898	sine wave	446	0.0
Increased release volume (+50%)		63.8	0.91	1.346	linear	358	-19.7
Decreased release volume (-50%)		63.8	0.91	0.449	linear	225	-49.6

Appendix C

Drawings



Sources: AMEC, Nyrstar.

Legend

- Flood Extent (No Breach)
- Breach Flood Extent
- Water
- Cross Section
- Diversion Channel
- Road
- Spillway
- Tailings Facility or Structure
- Trees
- 2m Contour

*Note: Surface topography based on survey data supplied by Nyrstar Myra Falls. This survey was done (MASL + 3048 m). Survey contours are at 2m vertical intervals.

nyrstar

Myra Falls Dam Breach
Old TDF Tailings Runout
and Inundation Extent

DATE: January 2015	
ANALYST: NH	QA/QC: PC RA GB
PDF: Fig3 Myra Falls Old TDF Failure 15-01-12	

Drawing 080303

amec

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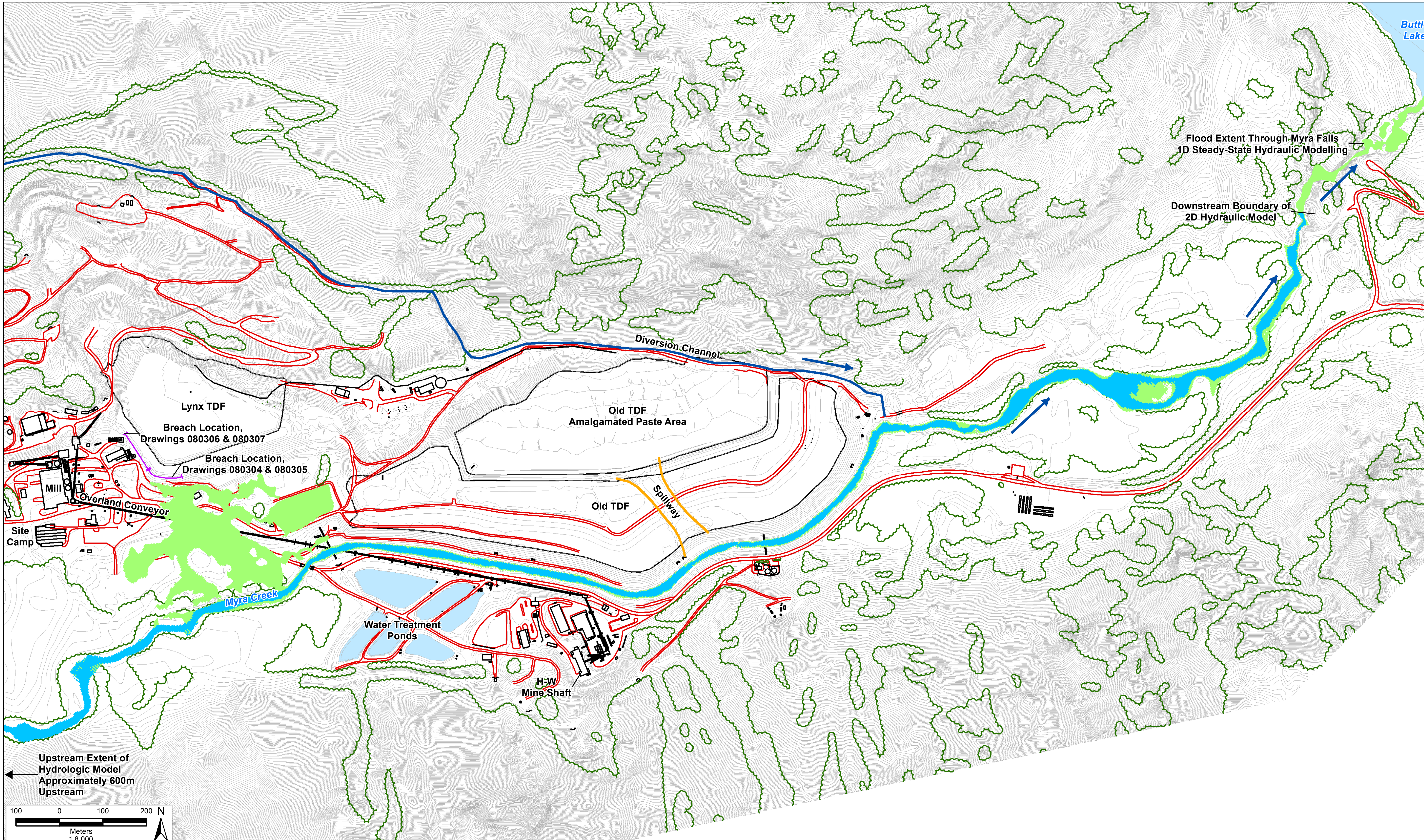


S:\Gis\Projects\NX14001\ArcGIS\Fig4 Myra Falls Flood Failure Current.mxd

Legend

- Flood Extent (No Breach)
- Modeled Flood Extent (With Breach)
- Water
- Breach Location
- Diversion Channel
- Access Road
- Spillway
- Tailings Facility or Structure
- Trees
- 2m Contour

Sources: AMEC, Nyrstar.

*Note: Surface topography based on survey data supplied by Nyrstar Myra Falls. This survey was done (MASL + 3048 m). Survey contours are at 2m vertical intervals.

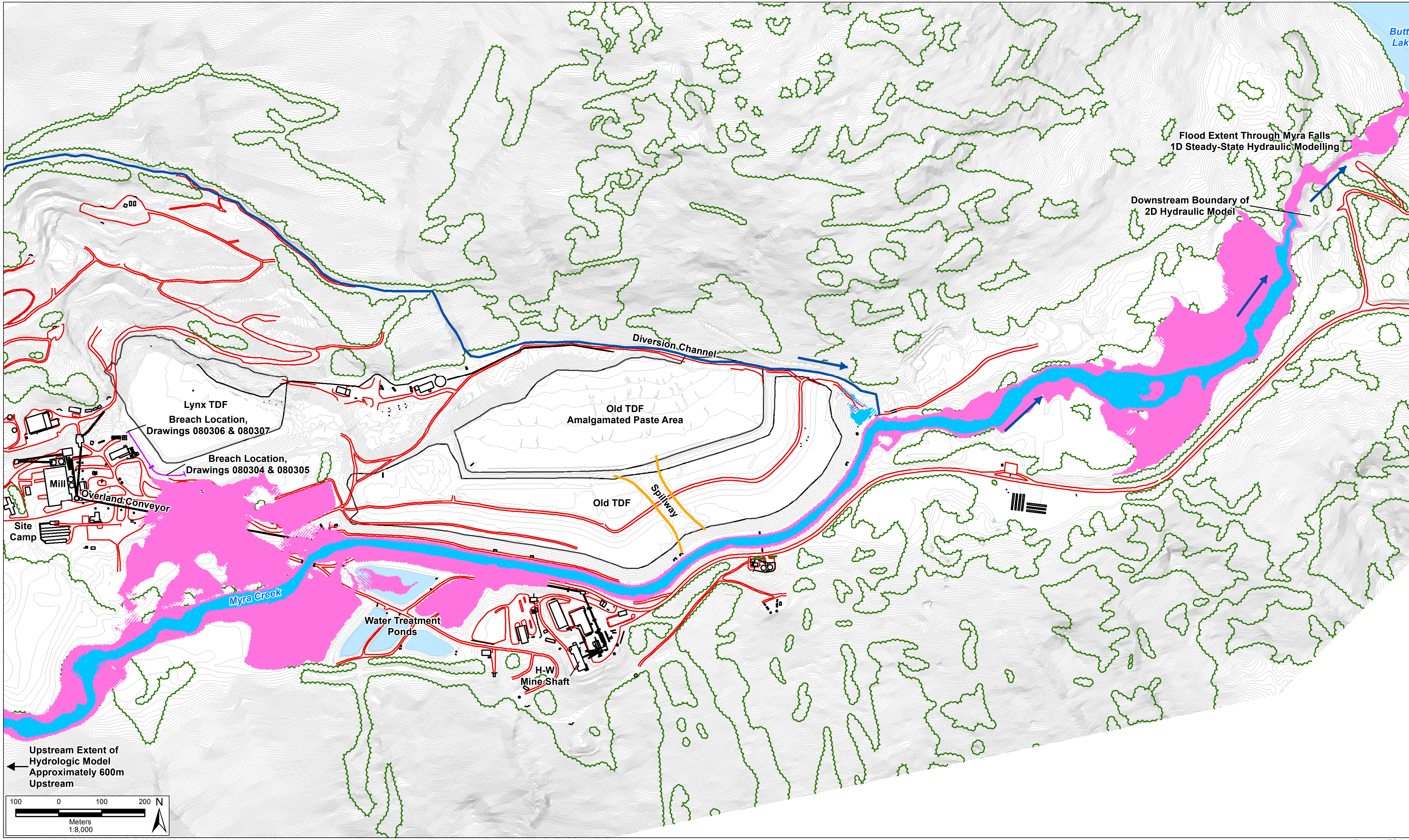
nyrstar

Myra Falls Mine Dam Breach
Lynx TDF Inundation Extents,
Non-Flood, Current Configuration

DATE: January 2015	
ANALYST: NH	QA/QC: PC RA GB
PDF: Fig4 Myra Falls Flood Failure Current 15-01-12	

Drawing 080304

amec



S:\Gis\Projects\NX14001\ArcGIS\Fig5 Myra Falls Flood Failure Current.mxd

Sources: AMEC, Nyrstar.

Legend

- Flood Extent (No Breach)
- Modeled Flood Extent (With Breach)
- Water
- Breach Location
- Diversion Channel
- Access Road
- Spillway
- Tailings Facility and Structure
- Trees
- 2m Contour

*Note: Surface topography based on survey data supplied by Nyrstar Myra Falls. This survey was done (MASL + 3048 m). Survey contours are at 2m vertical intervals.

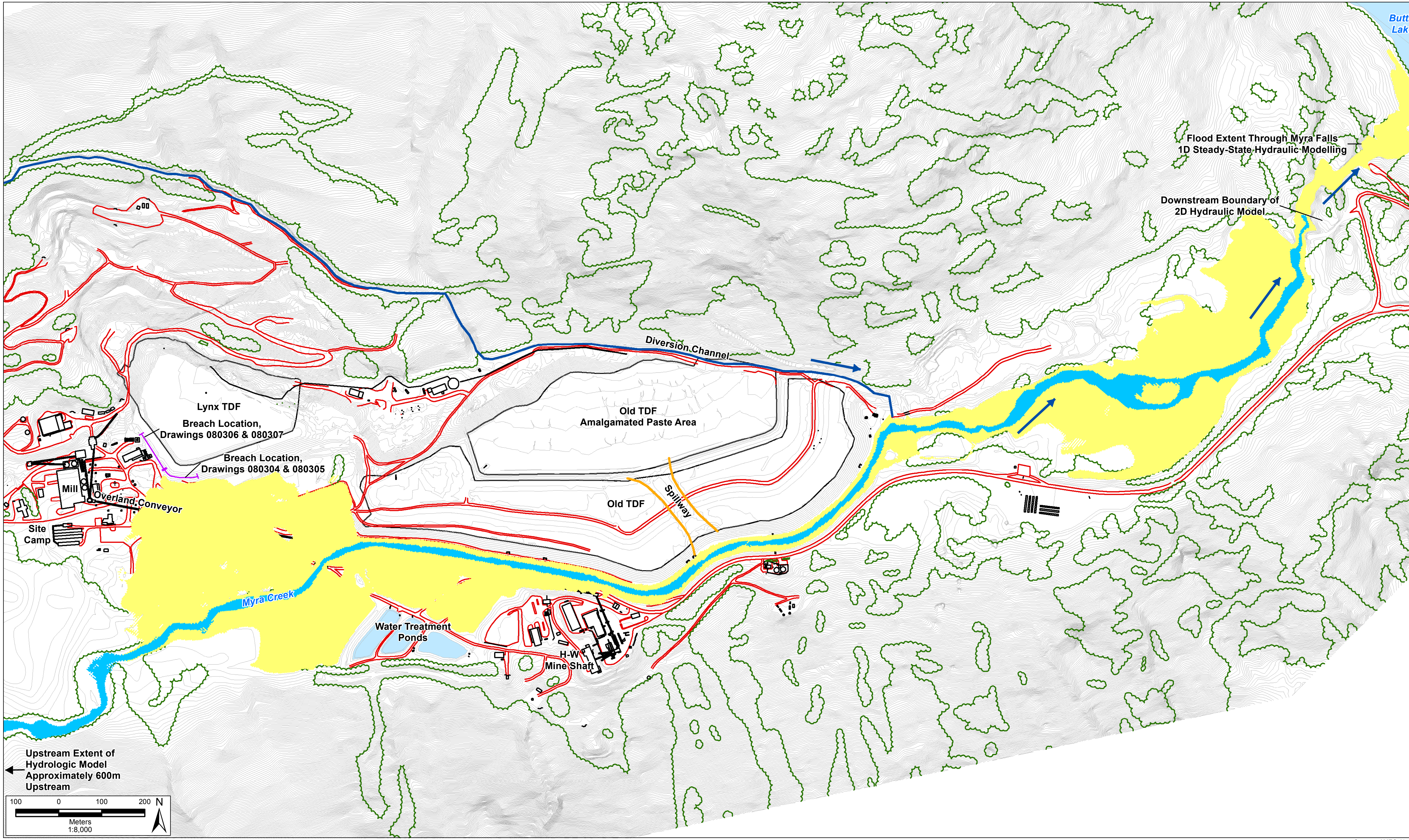
nyrstar

Myra Falls Mine Dam Breach
Lynx TDF Inundation Extents,
Flood Failure, Current Configuration

DATE: January 2015	
ANALYST: NH	QA/QC: PC RA GB
PDF: Fig5 Myra Falls Flood Failure Current 15-01-12	

Drawing 080305

amec



Legend

Flood Extent (No Breach)	Diversion Channel	Trees
Modeled Flood Extent (With Breach)	Access Road	2m Contour
Water	Spillway	
Breach Location	Tailings Facility or Structure	

Sources: AMEC, Nyrstar.

*Note: Surface topography based on survey data supplied by Nyrstar Myra Falls. This survey was done (MASL + 3048 m). Survey contours are at 2m vertical intervals.

nyrstar

Myra Falls Mine Dam Breach
Lynx TDF Inundation Extents,
Non-Flood, Ultimate Configuration

DATE: January 2015
ANALYST: NH
QA/QC: PC RA GB
PDF: Fig6 Myra Falls NF Ultimate 15-01-12

Drawing 080306

amec

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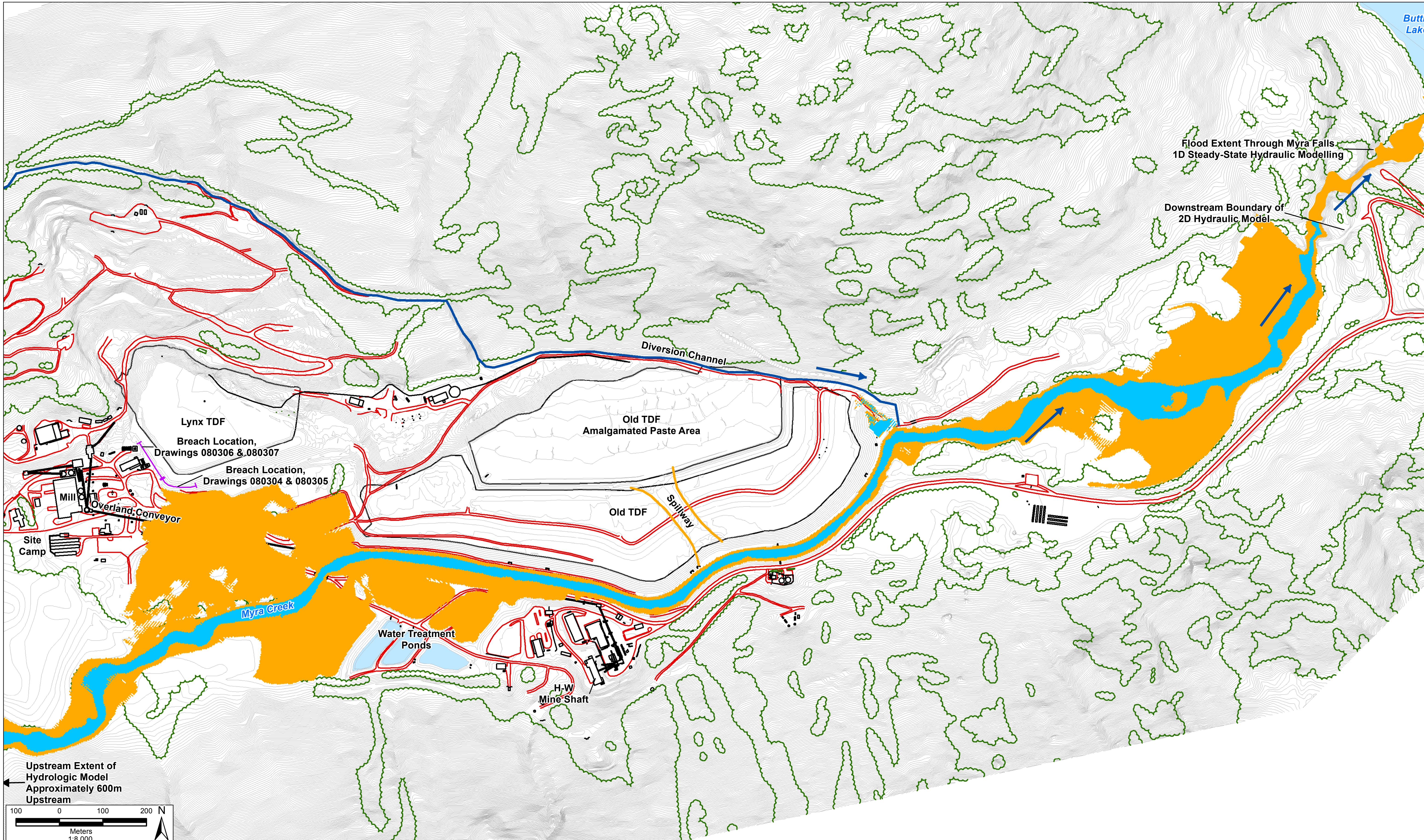

Sources: AMEC, Nyrstar.

Legend

Flood Extent (No Breach)	Diversion Channel
Modeled Flood Extent (With Breach)	Access Road
Water	Spillway
Breach Location	Tailings Facility or Structure
Trees	2m Contour

*Note: Surface topography based on survey data supplied by Nyrstar Myra Falls. This survey was done (MASL + 3048 m). Survey contours are at 2m vertical intervals.

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Myra Falls Mine Dam Breach
Lynx TDF Inundation Extents,
Flood Failure, Ultimate Configuration

DATE: January 2015

ANALYST: NH

QA/QC: PC RA GB

PDF: Fig7 Myra Falls FF Ultimate 15-01-12

Drawing 080307

amec

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Appendix D

CDA Dam Classification Tables

Table D1
Dam Consequence Classification

Consequence Classification	Population at Risk [1]	Incremental Losses		
		Loss of Life [2]	**Environmental and Cultural Values**	**Infrastructure and Economics**
Low	None	0	Minimal short-term loss. No long-term loss.	Low economic losses: area contains limited infrastructure or services.
Significant	Temporary Only	Unspecified	No significant loss or deterioration of fish or wildlife habitat. Loss of marginal habitat only. Restoration 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).

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).

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 requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.

*Adapted from CDA, 2007 revised 2013, Table 2-1

Table D2
Suggested Design Flood and Earthquake Levels

Consequence Classification [1]	AEP	
	IDF [2]	EDGM [3]
Low	1/100	1/100
Significant	Between 1/100 and 1/1000 [4]	Between 1/100 and 1/1000
High	1/3 between 1/1000 and PMF [5]	1/2,475[6]
Very High	2/3 between 1/1000 and PMF [5]	½ between 1/2,475[6] and 1/10,000 or MCE[5]
Extreme	PMF [5]	1/10,000 or MCE[5]

Acronyms: AEP, annual exceedance probability; EDGM, earthquake design ground motion; IDF; PMF; and MCE, maximum credible earthquake

2 Simple extrapolation of flood statistics beyond 10^{-3} AEP (1/1,000 year flood) is not acceptable.

3. Mean values of the estimated range in AEP levels for earthquakes should be used. The earthquake(s) with the AEP as defined in Table 1-2 is then input as the contributory earthquake(s) to develop the Earthquake Design Ground Motion (EDGM) parameters as described in Section 6.5 of the Dam Safety Guidelines(CDA, 2007 revised 2013).

4. Selected on the basis of incremental flood analysis, exposure, and consequences of failure.

5. PMF and MCE have no associated AEP.

6. This level has been selected for consistency with seismic design levels given in the National Building Code of Canada.

*Adapted from CDA, 2007 revised 2013, Table 6-1

Table D3
Summary of Incremental Consequences of Dam Breach – Old TDF

Failure Scenario	Population at Risk	Incremental Losses			Classification (Consequence Category – CDA 2007 revised 2013)	Effect on Nyrstar
		Loss of Life	Environmental and Cultural Values	Infrastructure and Economics		
Non-flood	Permanent	High, 10 or fewer	High, Significant loss or deterioration of important fish or wildlife habitat due to tailings entering Buttle Lake	Significant, Low economic losses	High	Clean-up, repair costs for dam and mine head works, damage to reputation
Flood-Induced	Permanent	High, 10 or fewer	High, Significant loss or deterioration of important fish or wildlife habitat due to tailings entering Buttle Lake	Low, Minimal economic losses when compared to initial flow	High	Clean-up, repair costs for dam and mine head works, damage to reputation

Table D4
Summary of Incremental Consequences of Dam Breach – Lynx TDF

Failure Scenario	Population at Risk	Incremental Losses			Classification (Consequence Category – CDA 2007 revised 2013)	Effect on Nyrstar
		Loss of Life	Environmental and Cultural Values	Infrastructure and Economics		
Non-flood	Permanent	High, 10 or fewer	High, Significant loss or deterioration of important fish or wildlife habitat due to tailings entering Buttle Lake	Significant, Low economic losses	High	Clean-up, dam and bridge repair costs, damage to reputation
Flood-Induced	Permanent	High, 10 or fewer	High, Significant loss or deterioration of important fish or wildlife habitat due to tailings entering Buttle Lake	Low, Minimal economic losses when compared to initial flow	High	Clean-up, dam and bridge repair costs, damage to reputation