HIGHLAND VALLEY COPPER
DAM BREAK AND FLOOD INUNDATION STUDY – BETHLEHEM TAILINGS STORAGE FACILITY NO. 1 TAILINGS POND DAMS

FINAL REPORT

Submitted to:

Teck Highland Valley Copper Partnership

P.O. Box 1500

Logan Lake, British Columbia

V0K 1W0

Submitted by:

AMEC Environment & Infrastructure,

A Division of AMEC Americas Limited

Fredericton, New Brunswick

February 2014

TE1330191.1000

28 February 2014

TE1330191

Mr. Chris Fleming
Teck Highland Valley Copper Partnership
P.O. Box 1500
Logan Lake, BC   V0K 1W0

Dear Mr. Fleming:

Re: Final Report - Dam Break and Inundation study for Bethlehem No. 1 Tailings Pond Dams

Please find enclosed the above-noted final report outlining the dam break and inundation study completed for the Bethlehem No. 1 Tailings Pond. The No. 1 Tailings Pond consists of two dams: the Bose Lake Dam and Dam No. 1. The analysis has considered dam failure and the release of both flood water and tailings. It is estimated that the incremental effect of flooding due to water alone downstream will be minimal. But the tailings migration could be substantial. Based on the 2007 Canadian Dam Association (CDA) Guidelines, the dam classification for the Bose Lake Dam was evaluated to be "Significant", and for Dam No. 1 "Very High".

Please contact the undersigned if you have any questions regarding our submission.

Sincerely,

AMEC Environment & Infrastructure,
a division of AMEC Americas Limited

Original hard copies signed and sealed
by C.A. (Andy) Small, M.Sc., P.Eng.

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HX/cjy

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1.0 INTRODUCTION

This report documents the dam break and inundation study conducted for the Bethlehem No. 1 Tailings Pond dams (Bose Lake Dam and Bethlehem Dam No. 1), located at the Highland Valley Copper (HVC) site in Logan Lake, British Columbia (BC). This report has been prepared by AMEC Environment & Infrastructure, a division of AMEC Americas Limited (AMEC). This study has been conducted as per our proposal submitted to HVC in August, 2013.

2.0 BACKGROUND

The HVC Mine is located near Logan Lake, approximately 50 kilometres (km) southwest of Kamloops, BC. A general site location is shown in Figure 2.1. Bethlehem No. 1 Tailings Pond is part of the larger Bethlehem Tailings Storage Facility (TSF), which contains two tailings ponds: Bethlehem Tailings Ponds No. 1 and No. 2. A site plan of the Bethlehem TSF is shown in Figure 2.2, and plan view drawing in Figure 2.3. The No. 1 Tailings Pond consists of two dams: Dam No.1 to the west, and the Bose Lake Dam to the east. The two dams impound both tailings and water, with water flowing in an easterly direction and ponding upstream of the Bose Lake Dam. Due to the topography of the No. 1 Pond, there is no water being impounded by Dam No. 1. The following sections provide a background of the Bose Lake and No. 1 dams.

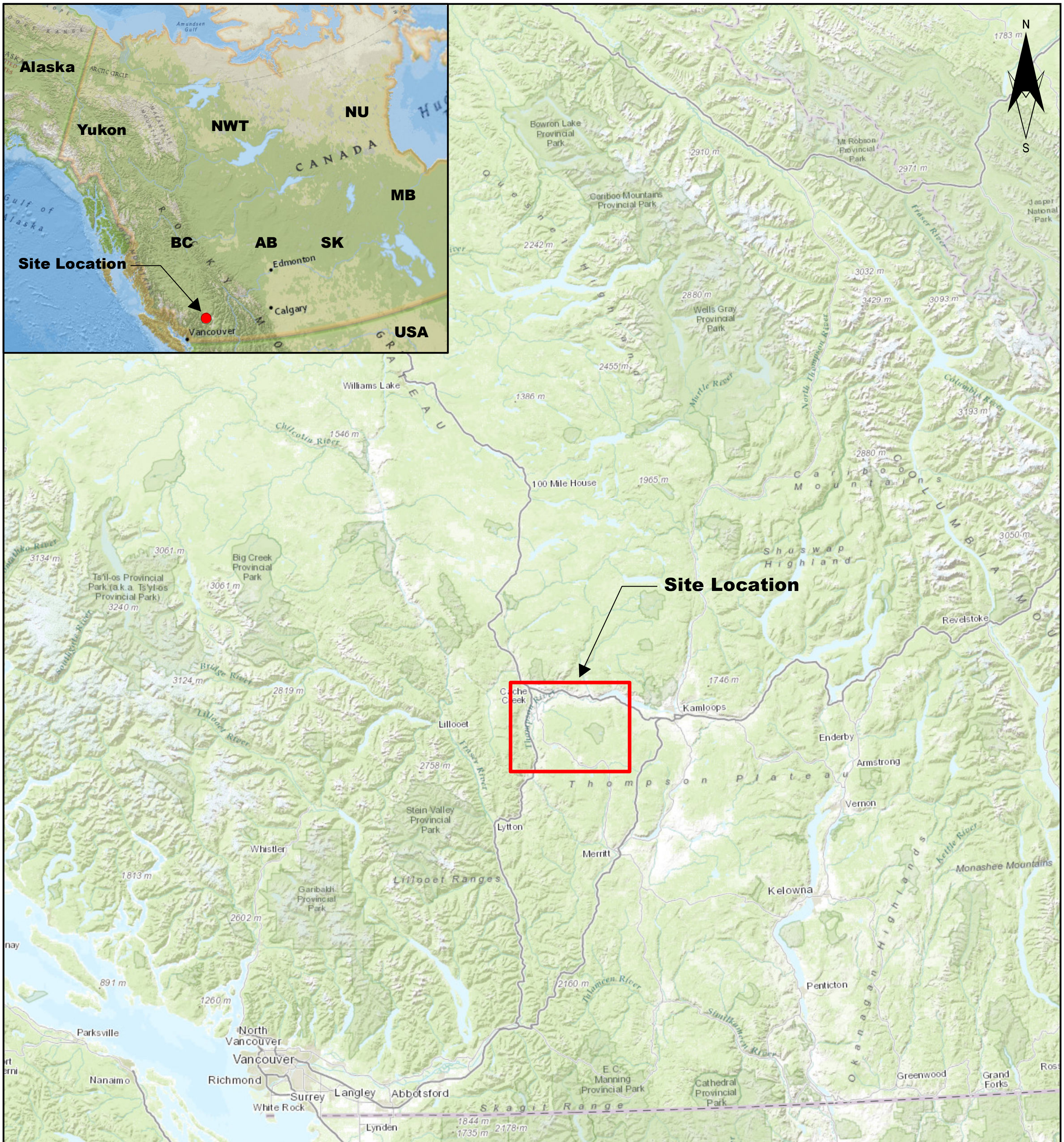
2.1 Bose Lake Dam

The Bose Lake Dam is a compacted earth and rockfill dam constructed in 1972 to 1974 and raised in 1981 as a water retention dam by the downstream method. Figure 2.4 shows a plan view and typical cross section of the Bose Lake Dam. The Bose Lake Dam has an impervious glacial till main zone and a filter zone and rockfill toe to control seepage. It is located in a saddle at the eastern end of the tailings impoundment.

Some of the key elevations and dimensions for the Bose Lake Dam are as follows:

- embankment crest elevation = 1475.1 metres above sea level (masl);
- embankment length = 650 metres (m);
- embankment toe elevation = 1441.6 masl;
- nominal height of embankment = 33.5 m;
- spillway crest elevation = 1469.3 masl;
- bottom of pond elevation = 1469.6 masl; and
- tailings beach elevation = 1472 masl.

A permanent spillway with a concrete sill founded on bedrock was constructed in 1995 at the north abutment of the dam. The orientation and geometry of the Bose Lake Spillway is shown in Figure 2.5. At the downstream end where the spillway channel intersects a public access road, two road culverts with 1380 millimetres (mm) and 600 mm diameters carry spillway flow under the public access road to Bose Lake (Klohn Crippen Berger (KCB) 2002).



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CLIENT: Highland Valley Copper Teck	SCALE: 0 25 50 100 Kilometres 1:40,000,000	PROJECT: DAM BREAK AND INUNDATION STUDY	DWN BY: TM CHK'D BY: JM DATE: Nov 26, 2013
AMEC Environment & Infrastructure, a Division of AMEC Americas Limited Suite 1 - 495 Prospect Street Fredericton, NB E3B 9M4 Tel. 506-458-1000 Fax 506-450-0829 www.amec.com	DATUM: NAD 83 PROJECTION: UTM Zone 10 PROJECT NO: TE1330191.2000	TITLE: BETHLEHEM TAILINGS STORAGE FACILITY SITE LOCATION MAP	REV. NO: FIGURE NO: 2.1

Path: G:\GIS\PROJECTS\TE133019_TECK_TrojanDam\MXD\20131220_BethlehemDams_Overview_Fig2_1.mxd User: dale.mccoy Date: 20/12/2013 SOURCE: ESRI Map Service, Topographic

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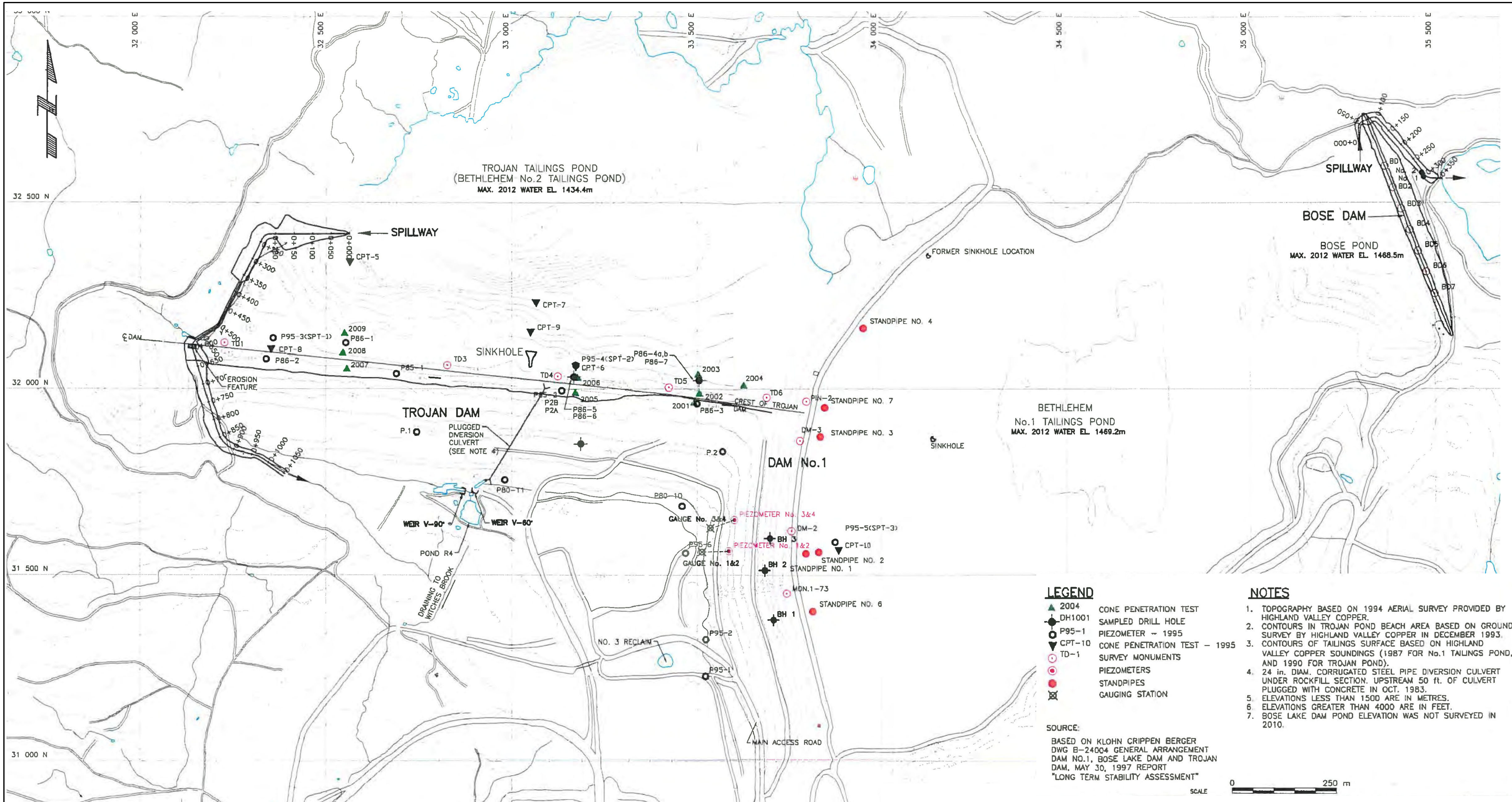
CLIENT: Highland Valley Copper — Teck	PROJECT No: TE1330191.2000	PROJECT: DAM BREAK AND INUNDATION STUDY	DWN BY: TM
	DATUM: NAD 83		CHK'D BY: JM
	PROJECTION: UTM Zone 10		DATE: Dec 3, 2013
AMEC Environment & Infrastructure, a Division of AMEC Americas Ltd. 495 Prospect St., Suite 1 Fredericton, NB E3B 9M4 Tel. 506-458-1000 Fax 506-450-0829 www.amec.com	SCALE: 500 250 0 500 Metres 1:25,000	TITLE: BETHLEHEM NO.1 TAILINGS POND	REV NO: 1
			FIGURE: 2.2

Path: G:\GIS\PROJECTS\TE133019_TECK_TrojanDam\MXD\20131220_JM_BethlehemBoseLakeDam_SitePlan_FIG2_2.mxd User: dale.mccoy, Date: 20/12/2013

SOURCE: Teck Aerial Imagery 2012,2011



LEGEND

- ▲ 2004 — CONE PENETRATION TEST
- DH1001 — SAMPLED DRILL HOLE
- P95-1 — PIEZOMETER – 1995
- CPT-10 — CONE PENETRATION TEST – 1995
- TD-1 — SURVEY MONUMENTS
- PIEZOMETERS
- STANDPIPES
- GAUGING STATION

SOURCE:
BASED ON KLOHN CRIPPEN BERGER DWG B-24004 GENERAL ARRANGEMENT DAM NO.1, BOSE LAKE DAM AND TROJAN DAM, MAY 30, 1997 REPORT "LONG TERM STABILITY ASSESSMENT"

NOTES

1. TOPOGRAPHY BASED ON 1994 AERIAL SURVEY PROVIDED BY HIGHLAND VALLEY COPPER.
2. CONTOURS IN TROJAN POND BEACH AREA BASED ON GROUND SURVEY BY HIGHLAND VALLEY COPPER IN DECEMBER 1993.
3. CONTOURS OF TAILINGS SURFACE BASED ON HIGHLAND VALLEY COPPER SOUNDINGS (1987 FOR No.1 TAILINGS POND, AND 1990 FOR TROJAN POND).
4. 24 in. DIAM. CORRUGATED STEEL PIPE DIVERSION CULVERT UNDER ROCKFILL SECTION. UPSTREAM 50 ft. OF CULVERT PLUGGED WITH CONCRETE IN OCT. 1983.
5. ELEVATIONS LESS THAN 1500 ARE IN METRES.
6. ELEVATIONS GREATER THAN 4000 ARE IN FEET.
7. BOSE LAKE DAM POND ELEVATION WAS NOT SURVEYED IN 2010.

SCALE 0 250 m

CLIENT: Highland Valley Copper Teck	PROJECT No: TE1330191.2000	PROJECT: DAM BREAK AND INUNDATION STUDY	DWN BY: TM
	SOURCE: BASED ON KLOHN CRIPPEN BERGER DWG NO. B-24004 GENERAL ARRANGEMENT DAM NO.1, BOSE LAKE DAM AND TROJAN DAM, MAY 30, 1997 REPORT - LONG TERM STABILITY ASSESSMENT		CHK'D BY: JM
			DATE: Dec 5, 2013
AMEC Environment & Infrastructure, a Division of AMEC Americas Ltd. 495 Prospect St., Suite 1 Fredericton, NB E3B 9M4 Tel, 506-458-1000 Fax 506-450-0829 www.amec.com		TITLE: GENERAL ARRANGEMENT DAM NO.1, BOSE LAKE DAM & TROJAN DAM	REV NO:
			FIGURE: 2.3

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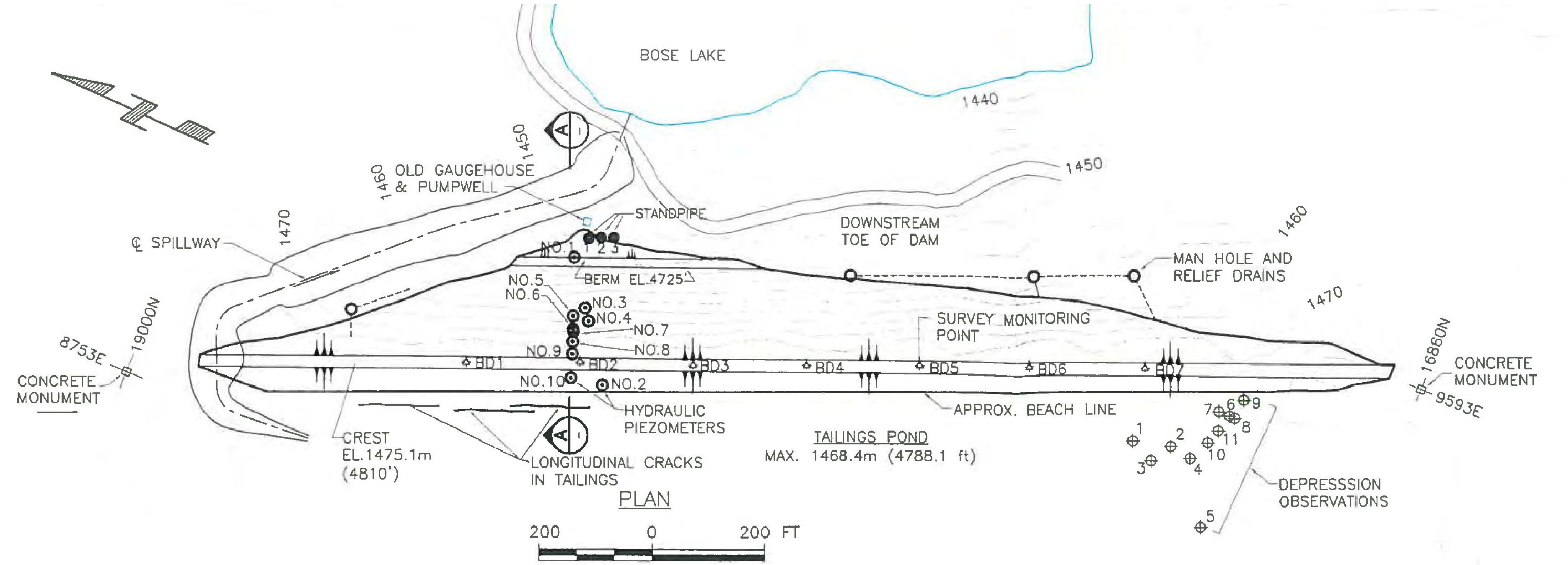
Path: G:\GIS\PROJECTS\TE133019_TECK_TrojanDam\MXD\20131220_JM_TrojanDam_BoseLake_Dam1_General_FIG_2_3.mxd User: dale.mccoy, Date: 20/12/2013

SOURCE: Teck Report - Bethlehem and Highmont Tailings Storage Facilities - 2012 Annual Review of Tailings Dam, August 2013



CONSTRUCTION MATERIAL SPECIFICATIONS (NOTE 3)

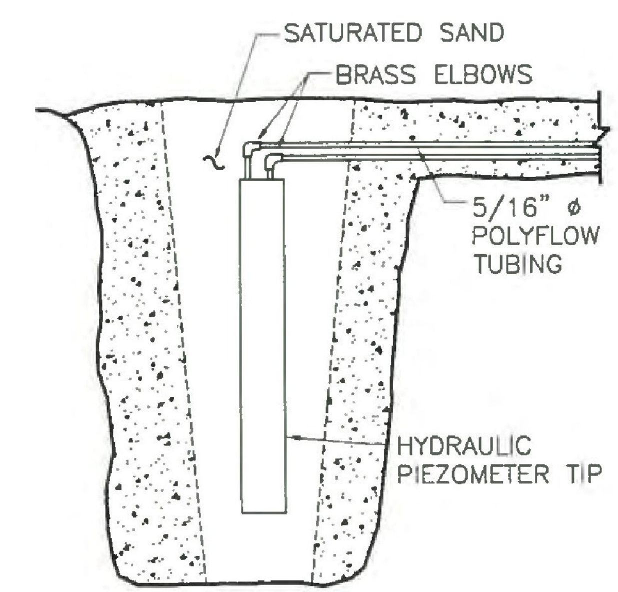
IMPERVIOUS FILL – WELL-GRADED SILTY SAND AND GRAVEL, MAX. SIZE 6", WITH >10% FINER THAN NO. 200 SIEVE.

ROCKFILL – ROCK AND SANDY GRAVEL, REASONABLY SOUND, MAX. SIZE 24", LESS THAN 30% FINER THAN NO. 4 SIEVE.

FILTER MATERIAL – MEDIUM TO COARSE SANDY GRAVEL, SOUND AND DURABLE, MAX. SIZE 3", LESS THAN 10% FINER THAN NO. 200 SIEVE.

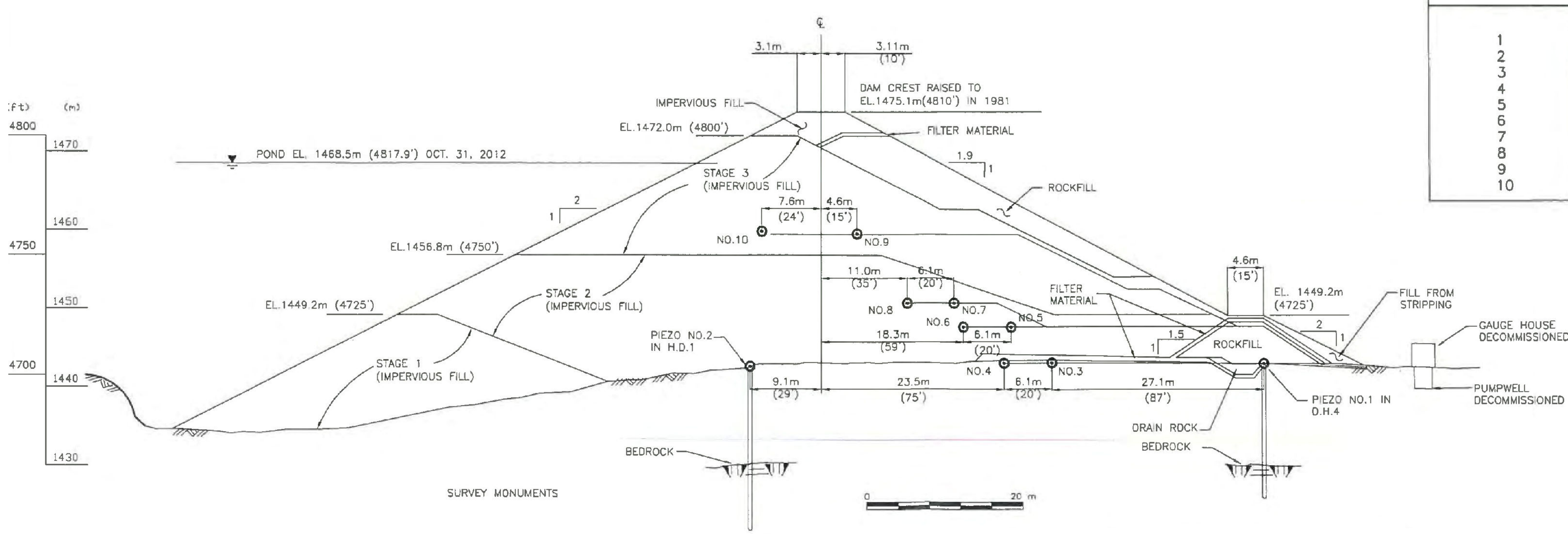
DRAIN ROCK – FREE-DRAINING GRAVEL, MAX. SIZE 3" LESS THAN 20% FINER THAN NO.4 SIEVE.

PIEZOMETER NO.	TIP ELEV. ft	TIP ELEV. m
1	4704.63	1443.0
2	4703.66	1442.7
3	4705.0	1443.1
4	4705.0	1443.1
5	4720.0	1447.7
6	4720.0	1447.7
7	4730.0	1450.7
8	4730.0	1450.7
9	4759.0	1459.5
10	4760.0	1459.8



PIEZOMETER DETAIL

NTS



SECTION A

NOTES:

1. BASED ON DWG.D-211-83-01 SUPPLIED BY COMINCO COPPER DIVISION
2. OUTLINES OF CONSTRUCTION STAGES ARE APPROXIMATE
3. CONSTRUCTION MATERIAL SPECIFICATIONS AS OUTLINED IN DECEMBER 31, 1980 DESIGN REPORT BY H. FELLHOUSER, P.ENG.
4. SURVEY MONITORING POINTS BD8, BD9 AND BD10 DESTROYED IN 1999 OR2000.
5. ELEVATIONS AND COORDINATES BASED ON BETHLEHEM DATUM
6. SOURCE DRAWING B-23012 LISTED PIEZO NO.4 ELEVATION @ 4720', BUT SECTION IS TAKEN TO BE CORRECT.

LEGEND

- BD1 SURVEY MONUMENTS
- NO.1 PIEZOMETERS
- STANDPIPES
- DEPRESSIONS AND HOLES
- CONCRETE MONUMENT
- RELIEF DRAINS

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CLIENT:	Highland Valley Copper / Teck
PROJECT No:	TE1330191.2000
SOURCE:	KLOHN LEONOFF PROJECT NO. PB2916 18, DWG NO. D-2026 REV C DATED NOV 13, 1992 UPDATE: KLOHN CRIPPEN DWG B-23012, DEC 9, 1996 PROJECT PM291323, REPORT - LONG-TERM STABILITY ASSESSMENT
PROJECT:	DAM BREAK AND INUNDATION STUDY
TITLE:	PLAN AND TYPICAL SECTION BOSE LAKE DAM
DWN BY:	TM
CHK'D BY:	JM
DATE:	Dec 5, 2013
REV NO:	
FIGURE:	2.4

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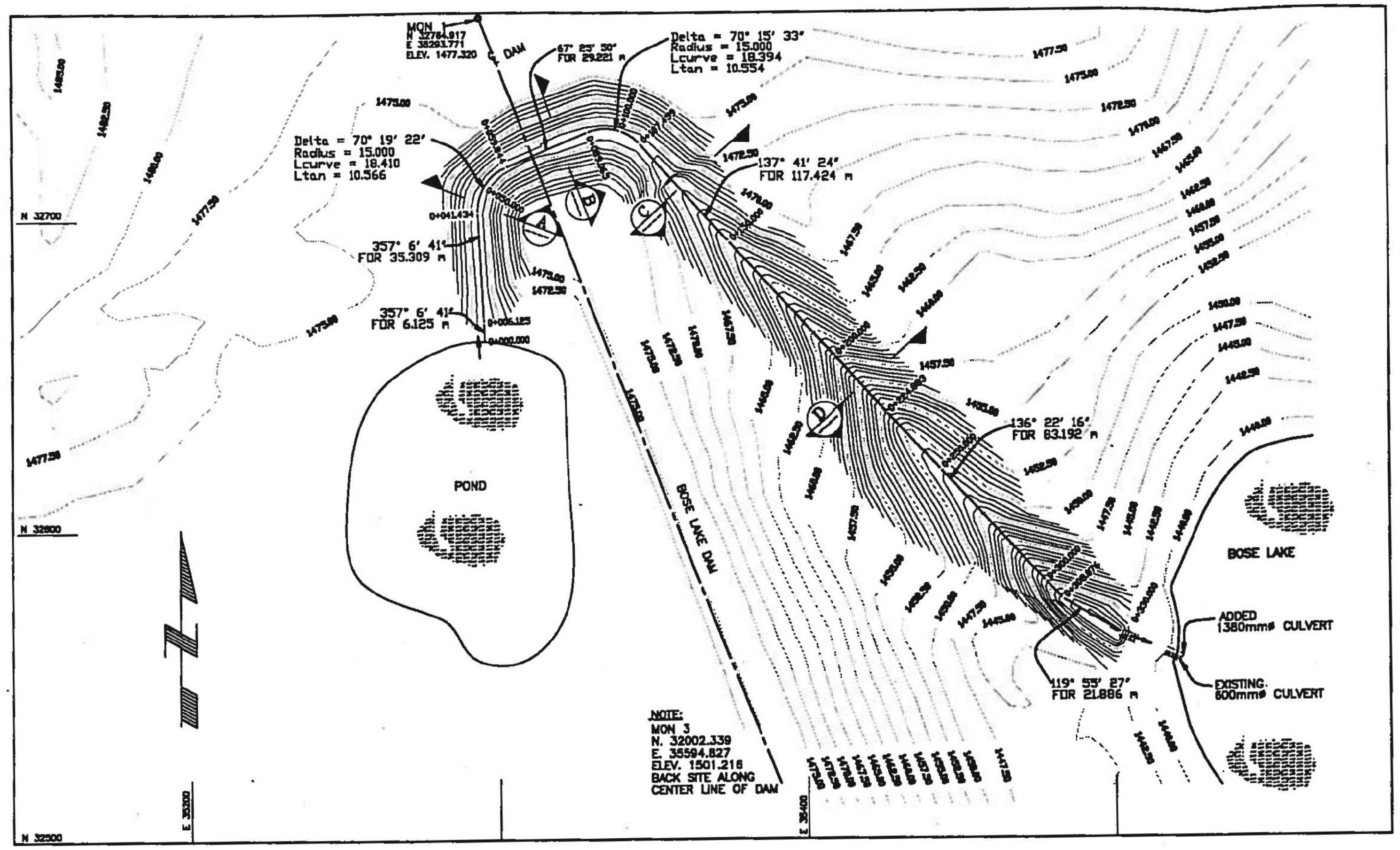
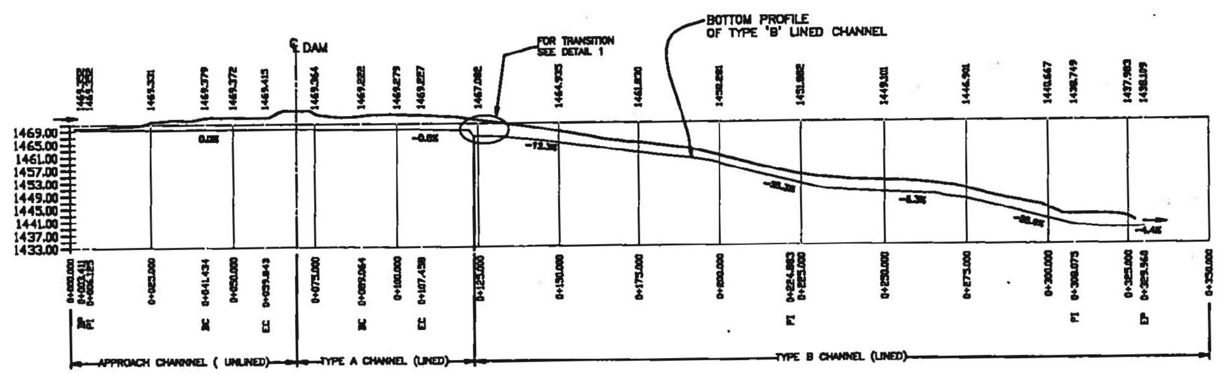
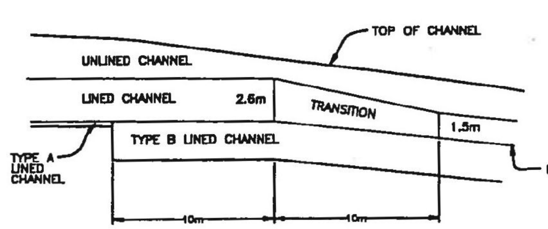
SOURCE: Teck Report - Bethlehem and Highmont Tailings Storage Facilities - 2012 Annual Review of Tailings Dam, August 2013



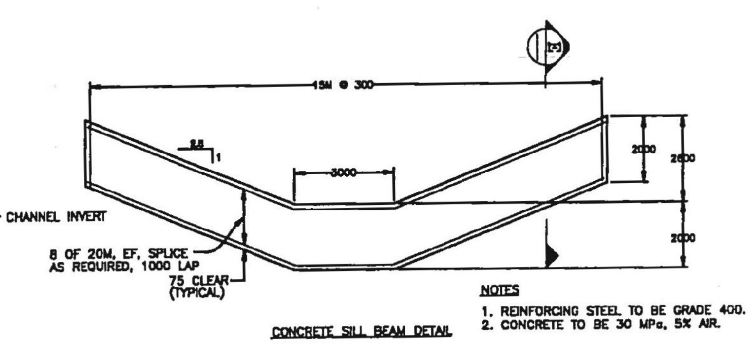
GENERAL ARRANGEMENT – PLAN



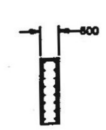
PROFILE ALONG SPILLWAY CHANNEL



DETAIL 1
1:200



DETAIL 2
1:100



SECTION E
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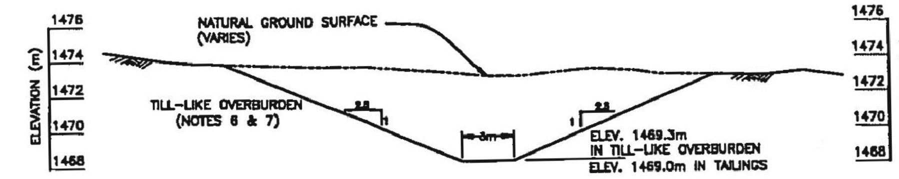
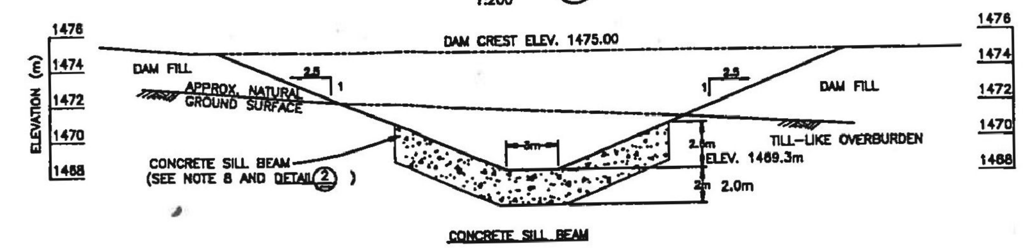


SECTION A
1:200



SECTION B
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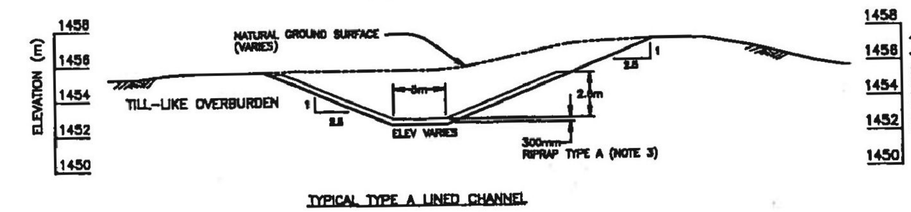
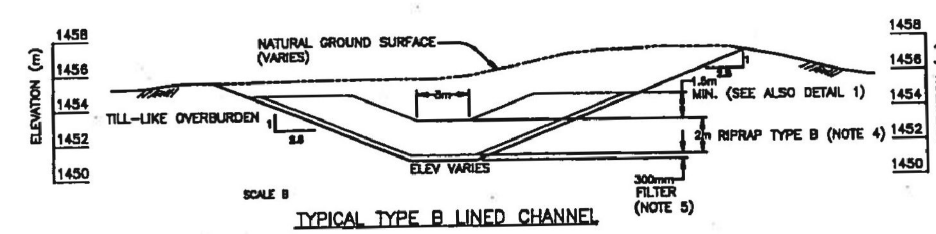


SECTION C
1:200



SECTION D
1:200

NOTES

1. BASE TOPOGRAPHY AND AS-BUILT SURVEY WERE SUPPLIED BY HIGHLAND VALLEY COPPER.
2. APPROACH CHANNEL IS HORIZONTAL FROM TAILINGS TO CONCRETE SILL AT DAM CENTRELINE WITH AN ELEV. OF 1469.3m IN TILL AND 1469.0m IN TAILINGS.
3. TYPE A RIPRAP TO CONSIST OF A 300mm THICK LAYER OF HARD DURABLE ROCK WEIGHING NOT LESS THAN 2400 kg/m^3. NO DIMENSION OF AN INDIVIDUAL ROCK SHOULD BE LESS THAN 1/3 OF LARGEST DIMENSION. THE RIPRAP SHOULD BE WELL GRADED AND CONFORM TO THE FOLLOWING:

% LESS THAN BY WEIGHT	WEIGHT (kg)	DIA. (mm)
100	2.5 TO 5.0	125 TO 160
50	1.3 TO 2.1	100 TO 120
15	0.3 TO 1.1	60 TO 95
5	0.3	60

NO FILTER LAYER WAS REQUIRED.

4. TYPE B RIPRAP TO CONSIST OF A 2000mm THICK LAYER OF HARD DURABLE ROCK WEIGHING NOT LESS THAN 2400 kg/m^3. NO DIMENSION OF AN INDIVIDUAL ROCK SHOULD BE LESS THAN 1/3 OF LARGEST DIMENSION. THE RIPRAP SHOULD BE WELL GRADED AND CONFORM TO THE FOLLOWING:

% LESS THAN BY WEIGHT	WEIGHT (kg)	DIA. (mm)
100	1500 TO 3000	1050 TO 1340
50	750 TO 1270	840 TO 1000
15	190 TO 630	530 TO 800
5	160	500

5. FILTER MATERIAL SHOULD BE WELL GRADED AND CONFORM TO THE FOLLOWING:
   MAXIMUM PARTICLE SIZE = 400mm
   D_{85} = 150mm TO 300mm
   D_{50} = 40mm TO 100mm
   D_{15} = 10mm TO 30mm
6. WHERE EXCAVATION WAS THROUGH TAILINGS, SIDE SLOPES WERE 10H:1V.
7. WHERE EXCAVATION WAS THROUGH TILL-LIKE OVERBURDEN, OR WEATHERED BEDROCK ENCOUNTERED BETWEEN STA. 0+050m AND STA. 0+062m AND BETWEEN STA. 0+076m AND STA. 0+101m, SIDE SLOPES WERE 2.5H:1V.
8. SEE DETAIL 2 FOR CONCRETE SILL BEAM CROSS SECTION AND STEEL REINFORCEMENT. FOUNDATION PREPARATION FOR AND BACKFILL AROUND THE SILL BEAM WERE INSPECTED BY THE FIELD ENGINEER. THE BACKFILL UPSTREAM OF THE SILL BEAM WAS COMPACTED TO A MINIMUM DENSITY OF 97% STANDARD PROCTOR OPTIMUM DENSITY, WHILE THE RIPRAP DOWNSTREAM OF THE SILL BEAM WAS PLACED TO MINIMIZE SEGREGATION BUT WITHOUT COMPACTION. BACKFILL ON BOTH SIDES OF THE CONCRETE SILL BEAM WERE PLACED CONCURRENTLY WITH MINIMUM DIFFERENTIAL IN ELEVATION TO PREVENT TILTING THE BEAM.
9. AT THE EXISTING PUBLIC ACCESS ROAD NEAR STA. 0+330 A 1380mm ø CULVERT WAS INSTALLED TO SUPPLEMENT THE EXISTING 600mm ø CULVERT.
10. ROAD WAS RIPRAP LINED ON UPSTREAM SIDE IN CHANNEL AREA.
11. ALL DIMENSIONS, AND ELEVATIONS IN METRES.
12. RIPRAP AND FILTER MATERIALS WERE PLACED IN A MANNER TO PREVENT SEGREGATION OF THE PLACED MATERIALS.
13. CONSTRUCTION ADJUSTMENTS AND MODIFICATIONS WERE BASED ON THE ACTUAL GROUND CONDITIONS ENCOUNTERED.
14. MODIFICATIONS TO THE SPILLWAY AND CONSTRUCTION MATERIALS FOR RIPRAP AND FILTERS REQUIRED FOR LINING THE SPILLWAY CHANNELS WERE CHECKED BY FIELD ENGINEER AND DESIGNERS FOR COMPLIANCE WITH THE DESIGN INTENT.

CLIENT: Highland Valley Copper / Teck	PROJECT No: TE1330191.2000	PROJECT: DAM BREAK AND INUNDATION STUDY	DWN BY: TM
	SOURCE: BASED ON KLOHN CRIPPEN BERGER DWG NO. 114-BQB-201-1, AS-BUILT BOSE LAKE DAM SPILLWAY PLAN, PROFILE & SECTIONS, JAN 12, 2002		CHK'D BY: JM
			DATE: Dec 3, 2013
AMEC Environment & Infrastructure, a Division of AMEC Americas Ltd. 495 Prospect St., Suite 1 Fredericton, NB E3B 9M4 Tel, 506-458-1000 Fax 506-450-0829 www.amec.com		TITLE: AS-BUILT BOSE LAKE DAM SPILLWAY PLAN, PROFILE & SECTIONS	REV NO:
			FIGURE: 2.5

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The Bose Lake Dam has previously been classified as ”Low” in accordance with the 1999 Canadian Dam Association (CDA) Guidelines (KCB 2003). The inflow design flood (IDF) for this classification would be the 1:100-year rainfall event, under the updated CDA 2007 Guidance. However, the spillway that was installed in 1995 was designed to convey the probable maximum flood (PMF) (KCB 1994).

Under flood conditions, it is possible that there will be an accumulation of flood water behind Bose Lake Dam. Breach of Bose Lake Dam under flood conditions would cause the release of flood water and tailings material. The flood water will cause the water level in Bose Lake to rise, potentially flooding downstream areas.

Bose Lake is a public fish and recreational lake frequented by seasonal visitors, and is annually stocked with rainbow trout. A public access road to Bose Lake is located downstream of the Bose Lake Dam. There appears to be no existing development immediately downstream of Bose Lake. Bose Lake drains into Axe Creek which flows in an easterly direction until its confluence with Guichon Creek.

2.2 Bethlehem Dam No. 1

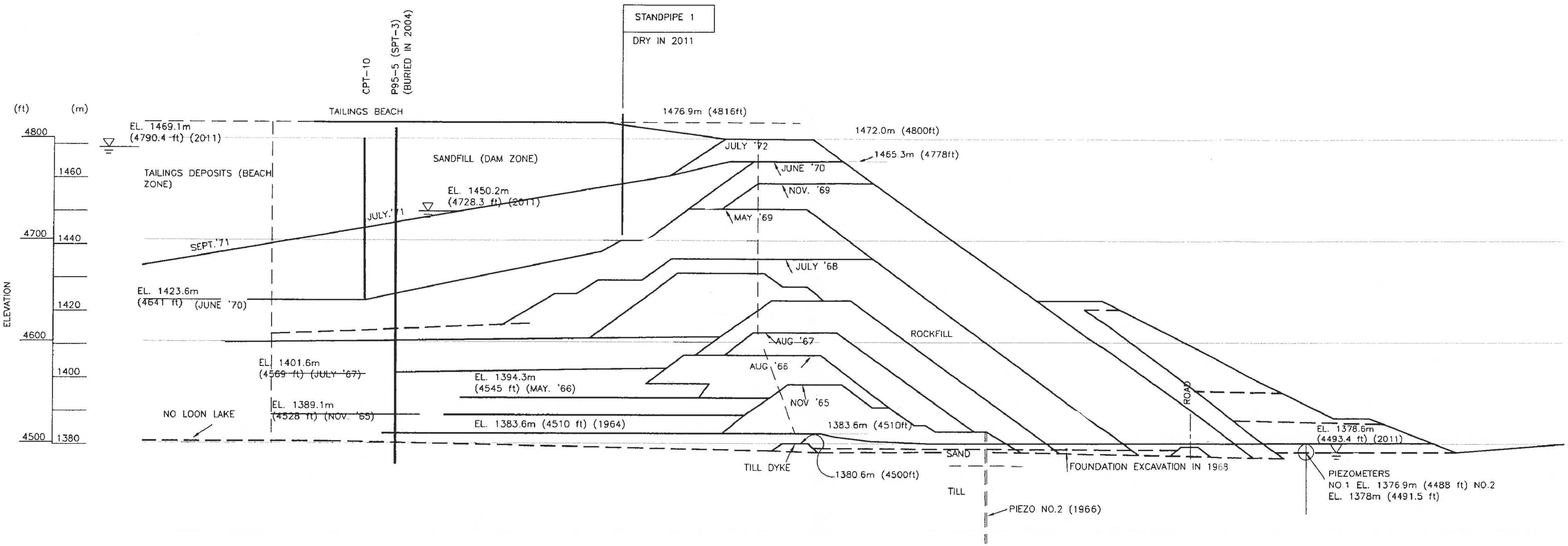
Bethlehem Dam No. 1 is a rockfill dam with a low starter dyke of glacial till founded, in general, on competent glacial overburden. Plan and cross sections of Dam No. 1 are showed in Figures 2.3 and 2.6, respectively. It was raised using spigotted and/or cyclone tailings upstream of the rockfill dam essentially by centerline method from 1962 to 1983. A downstream buttress rockfill berm, founded partially on stripped foundation, was added in the valley section in 1970 to 1971 to control dam deformation in the area due to the presence of swamp deposits in the main dam foundation. All construction related to downstream dam deformation ceased in the 1990s, although ongoing dam settlement due to rockfill adjustment continues at a much reduced nominal rate.

Some of the key elevations and dimension for Bethlehem Dam No. 1 are as follows:

- embankment crest elevation = 1472 masl;
- embankment length = 1.9 km;
- dam toe elevation = 1380.9 masl;
- nominal height of embankment = 96 m; and
- tailings beach elevation = 1476.9 masl (forms crest of dam).

There is no water against Dam No. 1 under normal and flood conditions. The beach tailings impounded immediately behind Dam No. 1 are at elevation 1476.9, which is higher than the Bose Lake Dam crest of 1475 masl.

There is a concern that a tailings release due to dam failure from Dam No. 1 could impact workers located downstream in the Valley Open Pit. A public highway (BC Highway 97C) also lies in the downstream environment and may also be affected by dam failure. Dam failure may also result in tailings being deposited into near-by Witches Brook, which may result in a loss of important aquatic habitat downstream.



SECTION A 13

SOURCE
1. BETHLEHEM AS-BUILT DAM SECTION
2. UPDATED KLOHN-CRIPPEN PROJECT PM291623, DWG.B-23007, DEC.9, 1996, REPORT "LONG-TERM STABILITY ASSESSMENT".

CLIENT: Highland Valley Copper Teck	PROJECT No: TE1330191	PROJECT: DAM BREAK AND INUNDATION STUDY	DWN BY: JT
	SOURCE: BASED ON KLOHN CRIPPEN DWG. B-23017 DEC 9, 1996, PROJECT M291623, REPORT - LONG TERM STABILITY ASSESSMENT		CHK'D BY: JM
			DATE: Dec 13, 2013
AMEC Environment & Infrastructure, a Division of AMEC Americas Ltd. 495 Prospect St., Suite 1 Fredericton, NB E3B 9M4 Tel, 506-458-1000 Fax 506-450-0829 www.amec.com		TITLE: TYPICAL SECTIONS DAM NO.1	REV NO:
			FIGURE: 2.6

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SOURCE: Teck Report - Bethlehem and Highmont Tailings Storage Facilities - 2012 Annual Review of Tailings Dam, August 2013

3.0 STUDY OBJECTIVES AND SCOPE

As part of HVC's commitment to responsible tailings management, HVC requested AMEC to conduct dam break analyses of these dams. In the proposal issued to HVC in August 2013, the objectives of the study were identified as the following:

- To complete an inundation study for Bethlehem No. 1 Pond dams.
- To estimate the deposited tailings in the event of dam breach.
- To classify the dam in accordance with the 2007 CDA Guidelines (CDA 2007).

The following tasks were outlined in the August 2013 scope of work:

- Hydrological modelling to estimate IDF hydrographs into the Pond No. 1 reservoir and at other locations of interests in the potentially affected area along the flood path.
- Dam break analysis and inundation modelling to delineate flood zones in the areas of interest. The incremental change in downstream water level due to dam failure will also be evaluated as part of this task.
- Delineation of potential areas of tailing deposit.
- Dam classification, including evaluation of population at risk and incremental loss.
- Reporting.
- Project management.

After a detailed review of background information and site characteristics, the following two changes to the original scope were made:

1. The deposited tailings upstream of Dam No.1 (1476.9 masl) are at a higher elevation than the crest of the Bose Lake Dam (1475 masl). During a flood event, if Pond No. 1 were to fill with water, Bose Lake Dam would be overtopped first and prevent overtopping of Dam No. 1. For this reason, a hydrological assessment of Dam No. 1 has not been completed as part of this study.
2. Downstream of the Bose Lake Dam, Axe Creek flows in an easterly direction until its confluence with Guichon Creek. There is presently no development along Axe Creek and therefore, detailed inundation mapping is not considered necessary for the area downstream of Bose Lake Dam.

4.0 FAILURE SCENARIOS

Dam breach analysis is used to determine the ultimate discharge from a hypothetical break of the facility as outlined in the 2007 CDA Guidelines. The outcome of the analysis is a flood peak or flood wave generated immediately downstream of the dam, which is routed through the topography downstream of the facility to a point where the effects are considered negligible. Two hypothetical failure scenarios have been considered for this study:

1. sunny-day failure, and
2. flood-induced failure. (as noted above, only the Bose Lake Dam has been considered for a flood-induced failure.)

4.1 Sunny-Day Failure

This failure mode simulates a sudden dam breach that occurs during normal operation caused by internal erosion, piping, earthquakes, improper operation, or another unanticipated event. It is assumed that no rainfall occurs in the surrounding catchments at the time of the breach. While the sunny-day failure may not result in the largest flood peak, or flood wave, this type of failure can occur suddenly and without warning. For this reason, a sunny-day failure may result in a higher incremental consequence than a flood-induced failure. A sunny-day failure has been considered for both the Bose Lake and Bethlehem No. 1 dams.

4.2 Flood-Induced Failure

This failure mode simulates a dam breach resulting from a natural flood. As noted above, the spillway is designed to pass a PMF, hence the potential for overtopping is very low. To simulate the flood induced event, it is assumed that the failure of the dam could be triggered at the peak of the flood event resulting in the subsequent release of a flood wave. It is assumed that flow conditions associated with the flood event that is being considered for the breach are occurring in all the catchments at the time of the breach. This failure scenario has been considered for the Bose Lake Dam only.

5.0 HYDROLOGY

A hydrological assessment has been completed for the Bose Lake Dam only since there is no possibility of Dam No. 1 being overtopped.

The objective of the hydrological modelling is to generate hydrographs for the predetermined modelling scenarios at the location of interest downstream of the Bose Lake Dam. These hydrographs were subsequently used as input in the inundation modelling/assessment.

The watersheds surrounding the Bethlehem No. 1 Pond are predominately comprised of undeveloped, mountainous terrain. A map of the drainage areas contributing to the No. 1 Pond and near-by watercourses is presented in Figure 5.1. During a storm event, inflow would be generated from watershed B1-U and accumulate in the No. 1 Pond. Once the water elevation in the pond exceeds the spillway invert elevation, water will flow downstream through the spillway into Bose Lake. Runoff generated by watersheds downstream of the Bose Lake Dam has also been considered up to the confluence of Axe Creek and Guichon Creek. A summary of the watersheds and respective drainage areas are presented in Table 5.1.

Table 5.1 Watershed Summary for Bethlehem No. 1 Pond and Downstream

Watershed Name	Drainage Area Square Kilometres (km^2)*
B1-U	3.03
B1-D	0.94
B2-D	1.70
B3-D	0.25
B4-D	31.40

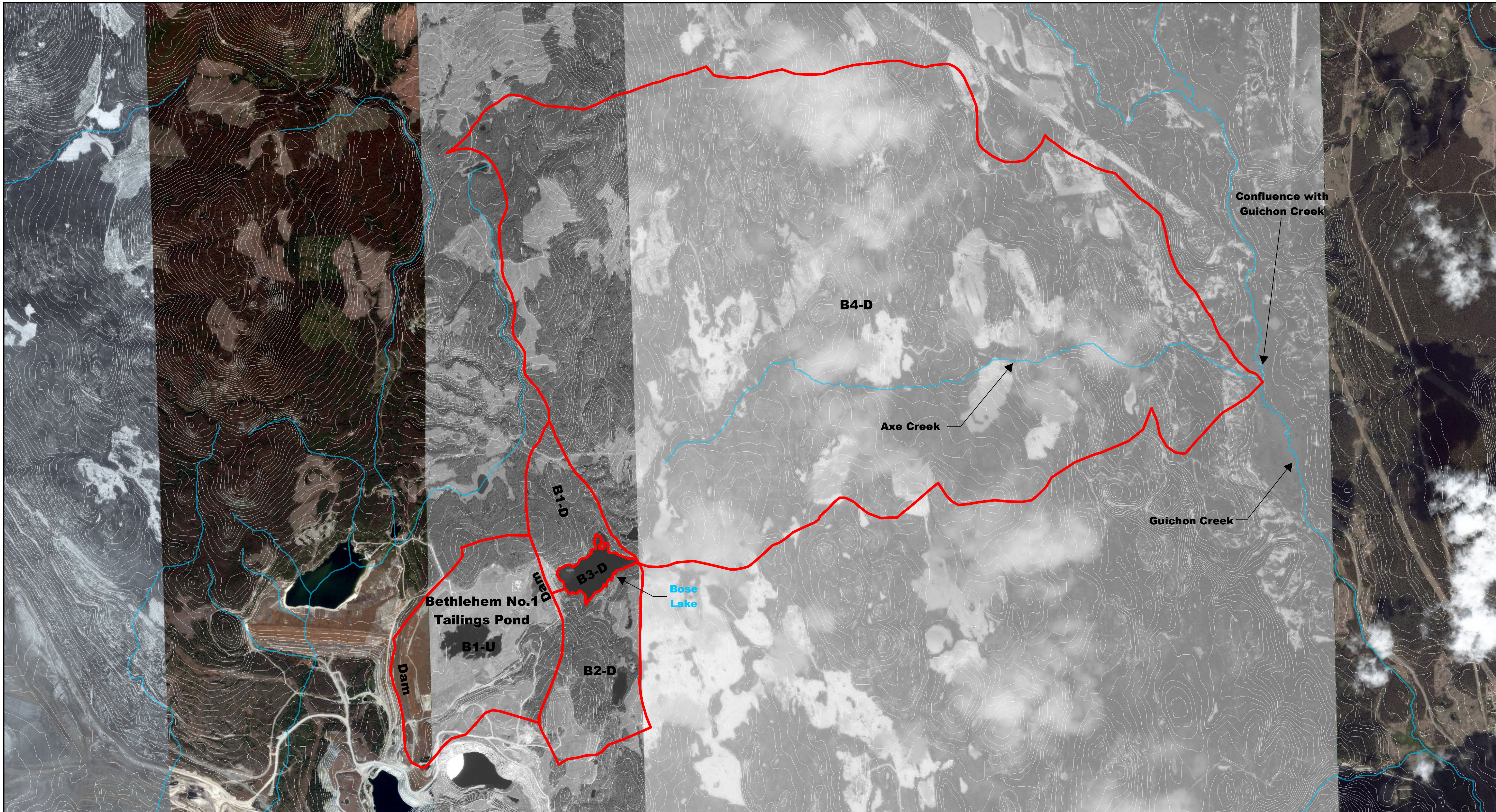
5.1 Design Rainfall Distribution

The following flood events were considered for the hydrological modelling:

- 1:100-year;
- 1:1000-year;
- 1/3 between 1:1000-year and the PMF;
- 2/3 between 1:1000-year and the PMF; and
- PMF.

Modelling for each scenario was completed using a 30-day duration.

The probable maximum precipitation (PMP) was estimated in the early 1990s to support the spillway design for the Bose Lake Dam (Klohn Crippen Berger (KCB) 2002). That estimate was generated using a Hershfield probabilistic method for estimating PMP (KCB 1994). According to that study, the 24-hour PMP rainfall depth was estimated to be 260 mm and was based on rainfall data for the Kamloops Airport and Mamit Lake weather stations; these stations are located approximately 20 and 50 km from the HVC site, respectively. The study notes that records from the Highland Valley Lornex station, which is closer to the site, was not used due to a relatively short record available at the time. The Highland Valley Lornex station is located approximately 5 km away from the Bose Lake Dam.



N
S

Legend

Watercourse

Contour

Catchment Area

The map shown here has been created with all due and reasonable care and is strictly for use with AMEC Project Number: TE1330191 This map has not been certified by a licensed land surveyor, and any third party use of this map comes without warranties of any kind. AMEC assumes no liability, direct or indirect, whatsoever for any such third party or unintended use.

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PROJECT No:	TE1330191.2000
DATUM:	NAD 83
PROJECTION:	UTM Zone 10
SCALE:	800 400 0 800 Metres 1:40,000
PROJECT:	DAM BREAK AND INUNDATION STUDY
TITLE:	BOSE LAKE CATCHMENT BOUNDARIES AND WATERCOURSES
DWN BY:	JT
CHK'D BY:	JM
DATE:	Dec 5, 2013
REV NO:	
FIGURE:	5.1

Path: G:\GIS\PROJECTS\TE133019_TECK_TrojanDam\MXD\20131220_JM_Bose_Lake_Catchment_Boundary_FIG5_1.mxd User: jonathan.thornton, Date: 28/02/2014

SOURCE: Bing Map- Aerial Photography, Data AMEC 2013

Precipitation records at the Highland Valley Lornex station (#1123469) are currently available from 1967 to 2007 (40 years). These data have been used by the Hydrometeorology Division of the Canadian Climate Centre to estimate PMP values for a range of storm durations (1-30 days). The Canadian Climate Centre has generated a 24-hour PMP total rainfall depth of 182.2 mm. Given the proximity of the Highland Valley Lornex Station to the HVC site (5 km), these PMP data are more representative of actual weather conditions at the HVC site. It is, therefore, recommended that the Canadian Climate Centre PMP estimates for the Highland Valley Lornex Station be adopted for the HVC site.

Intensity-duration-frequency data for the Environment Canada weather station in Kamloops, BC (Station # 1163780) were used to derive the incremental rainfall depth for the 1:100-year rainfall event. A 1:100-year design rainfall distribution was then created using the Alternating Block method (Chow 1988). This rainfall distribution was then applied to the other rainfall events listed above.

Given the size of the drainage areas contributing to the Bethlehem No. 1 Pond (Table 5.1), it was determined that a 30-day composite design storm would be most suitable. The 30-day incremental rainfall depths were also distributed using the Alternating Block method (Chow 1988). The 30-day, PMP rainfall distribution is shown in Figure 5.2, having a total rainfall depth of 556.5 mm (according to Canadian Climate Centre estimates). The 24-hour rainfall distribution was considered to be the wettest day, and was superimposed on the 16th day of the 30-day rainfall event. The 24-hour, PMP rainfall distribution is shown in Figure 5.3 having a total rainfall depth of 182.2 mm.

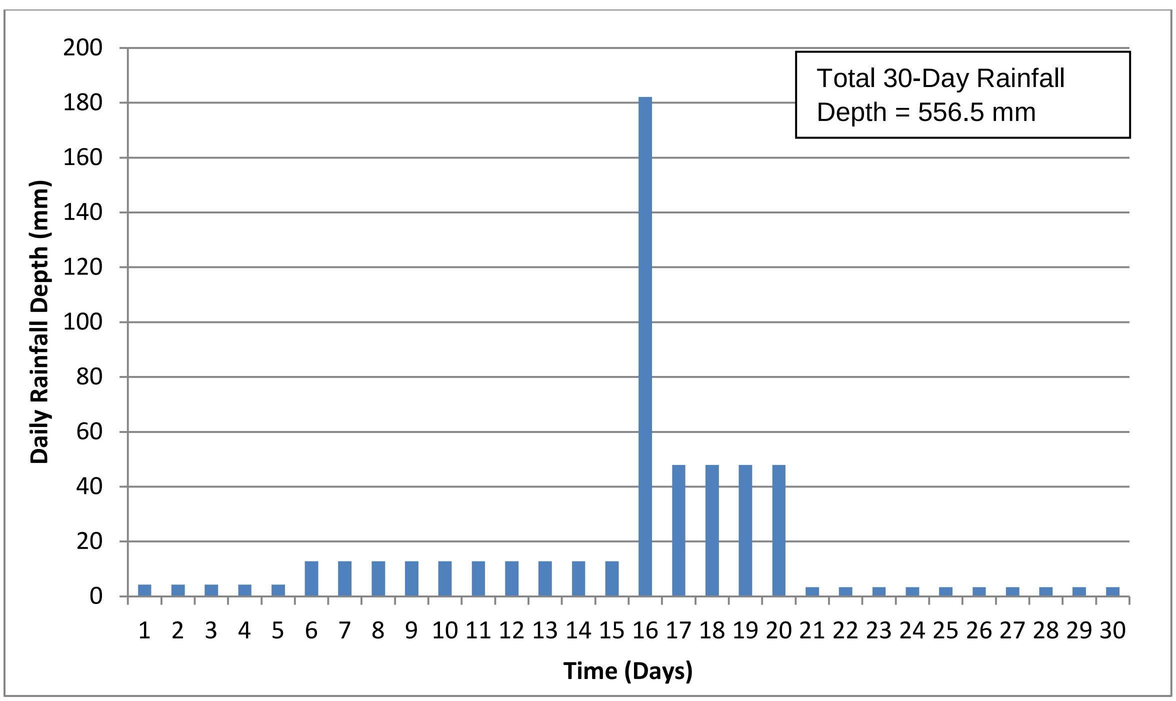


Figure 5.2 Rainfall Hyetograph for 30-day, PMP Rainfall Event for the HVC Site

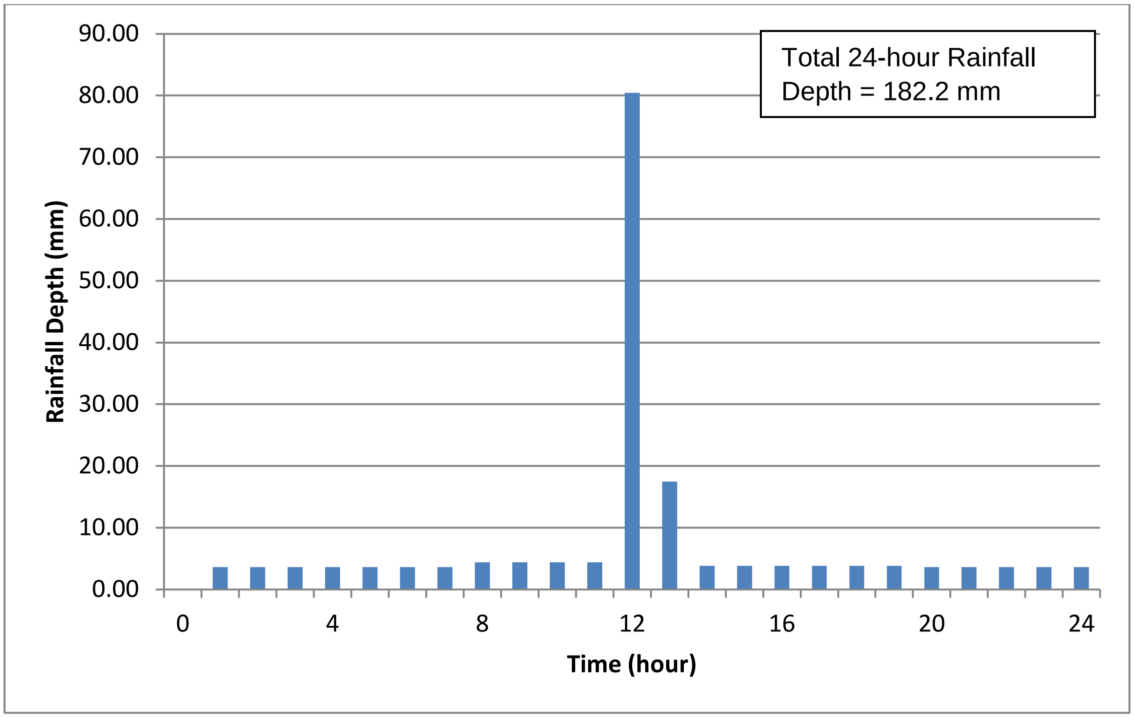


Figure 5.3 Rainfall Hyetograph for 24-hour, PMP Rainfall Event for the HVC Site

5.2 Hydrological Modelling

The hydrological modelling was completed using the US (United States) Army Corps of Engineers (ACE) software HEC-HMS (version 3.5) as the modelling platform. The model encompasses the watersheds draining into the Bethlehem No. 1 Pond, and watersheds from Bose Lake down to the confluence of Axe Creek and Guichon Creek. Initial modelling considered the pond under normal operating conditions (ie., no dam break) and accounted for discharge from the Bose Lake spillway only. This is considered to be the base case for the flood assessment.

The US Soil Conservation Service (SCS) unit hydrograph method was used to model the rainfall runoff response within each watershed. The SCS unit hydrograph method has been derived for a wide range of catchment sizes and types (Ponce 1989) and has been deemed appropriate for the drainage areas contributing to the Bethlehem No. 1 Pond.

The SCS runoff curve number method has been used to determine the amount of runoff generated for each watershed. According to Ponce (1989), a runoff curve number of 77 is suitable for a wooded drainage area for average antecedent rainfall conditions. This value represents the upper limit for undeveloped watersheds as there has been considerable logging activity (clear cutting) in the surrounding catchment area.

The design storms were modeled when the surrounding catchment is in a saturated state (high antecedent rainfall condition). Therefore, the runoff curve number has been adjusted to 90 to reflect a saturated catchment condition (Ponce 1989). The HEC-HMS model was run for the five rainfall events noted above. Specific parameters for each watershed have been summarized in Table 5.2 below. A percent impervious value of 100% has been used to simulate rainfall on Bose Lake (B3-D). A 50% impervious value has also been assigned to B1-U to account for the areas of exposed tailings with limited vegetative cover (interpreted from aerial photography).

Table 5.2 Watershed Parameter Summary for Bethlehem No. 1 Pond Modelling

Watershed Name	Runoff Curve Number	Percent Impervious
B1-U	95	50
B1-D	90	0
B2-D	90	0
B3-D	N/A[1]	100
B4-D	90	0

Notes:
N/A – not applicable

Stage-storage data for the Bethlehem No. 1 Pond was obtained from KCB (1994) and the stage-storage curve is shown in Figure 5.4. Geometry of the Bose Lake Spillway has also been obtained from KCB (2002) and is presented in Figure 2.5. It has been assumed that the water surface elevation in the No. 1 Pond is at the spillway invert elevation (1469.6 masl) prior to modelling each design rainfall event.

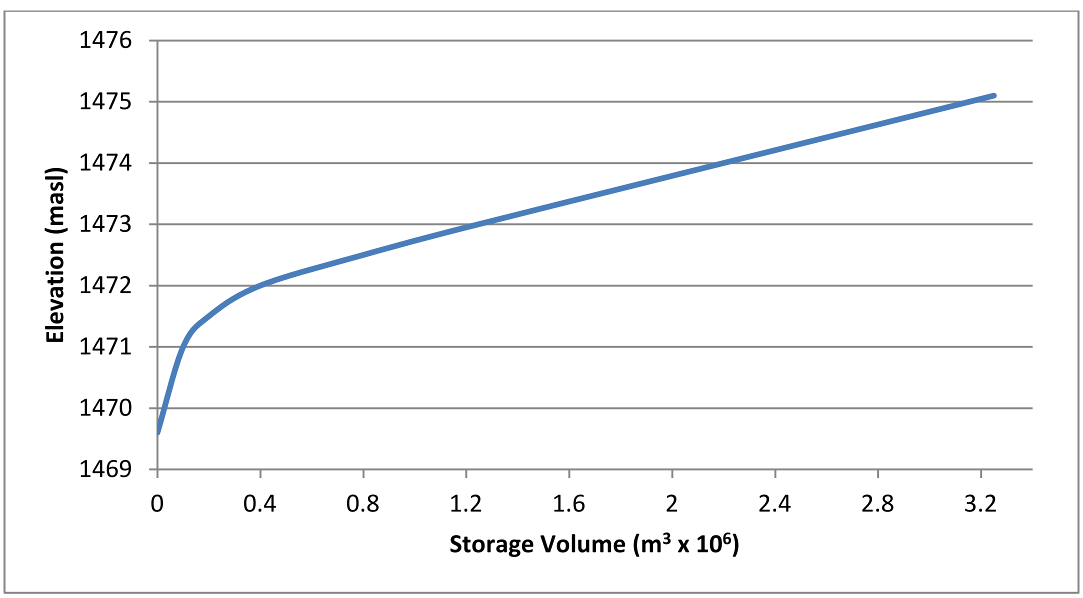


Figure 5.4 Stage-Storage Curve for Bethlehem No. 1 Pond

5.3 Base Case Modelling Results

The base case conditions were modelled for the five rainfall events noted above. The resulting inflow and outflow hydrographs for the Bethlehem No. 1 Pond during the 30-day, PMF design storm are presented in Figure 5.5. Figure 5.5 shows a peak inflow to the No. 1 Pond of 43.6 cubic metres per second (m^3/s) for the PMF. The corresponding spillway outflow has a peak value of 13.7 m^3/s. The difference between the peak inflow and outflow values is due to attenuation of inflow by the pond prior to discharging through the spillway. A summary table of the HEC-HMS results is also presented in Table 5.3.

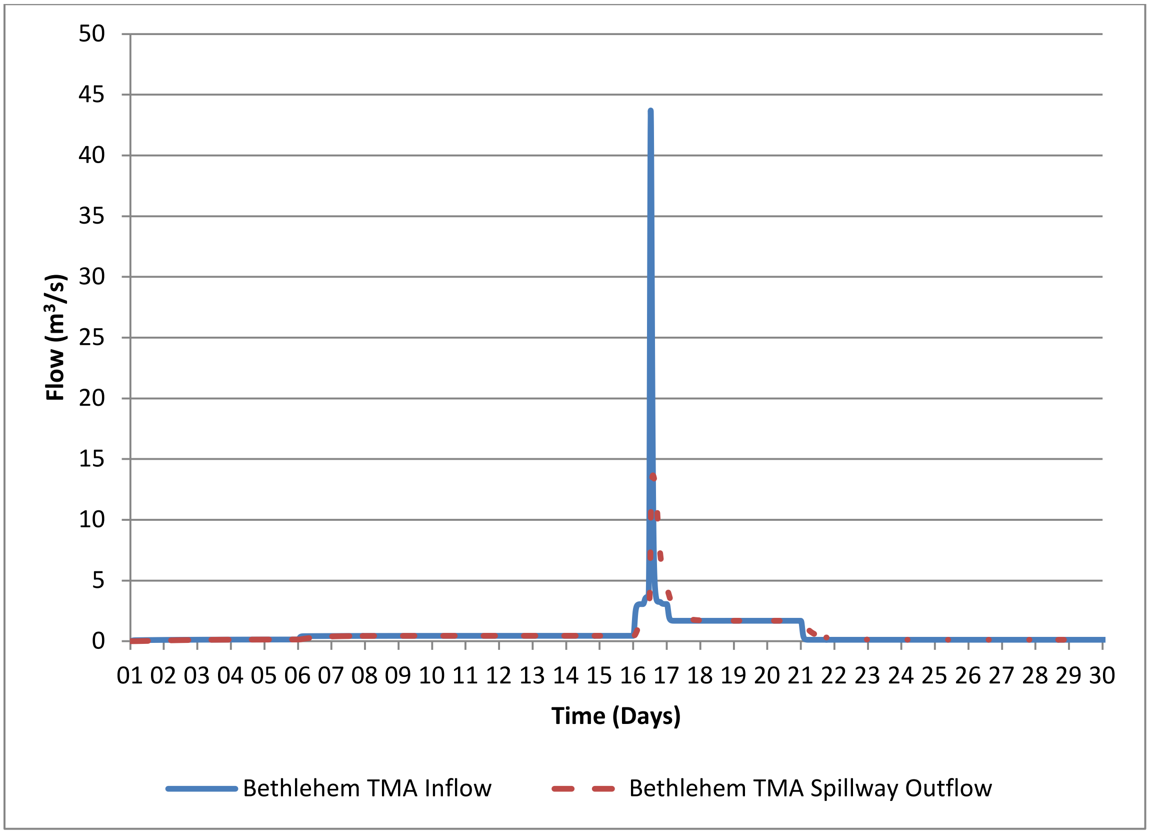


Figure 5.5 Hydrograph of Inflow to Bethlehem No. 1 Pond and Outflow (Spillway Only) during 30-day PMF Rainfall Event for the Base Case

Table 5.3 Summary of Hydrological Model Results for Base Case

Flood Event (Base Case - No Failure)	Peak Water Level in No. 1 Pond (masl)	Peak Inflow to No. 1 Pond (m^3/s)	Peak Outflow (Spillway) (m^3/s)
l00-year return period	1470.4	12.4	3.5
l000-year return period	1470.7	18.4	5.5
1/3 between 1:1000 and PMF	1471.1	28.6	9.7
2/3 between 1:1000 and PMF	1471.5	39.4	12.9
PMF	1471.5	43.6	13.7

The Bose Lake Spillway design described by KCB (1994) notes that the spillway was designed to safely pass the PMF. The PMF flow through the spillway was estimated by KCB (1994) to be in the order of 18 m^3/s. This is greater than the peak flow modelled as part of this assessment (13.7 m^3/s). The difference in peak flow can be attributed to the updated PMF rainfall depth used in this study, which is lower than that used for the KCB (1994) study.

As noted in Table 5.3, the peak water level in the No. 1 Pond during the PMF event is estimated to be 1471.5 masl, which compares to the peak water level of 1471.6 masl estimated by KCB (1994).

The peak flow values modelled for each watershed contributing to the Bethlehem No. 1 Pond were also compared to regional equations developed for Agriculture and Agri-Foods Canada (Abrahamson and Pentland 2010). It was found that the modelled peak flows were generally in agreement with the regional equations for the BC Interior. Some variation between modelled flows and the regional equations is expected due to the inclusion of site specific hydrological parameters in the model. Overall, however, it was found that the modelled flows were generally in agreement with the regional equations.

6.0 DAM BREAK ASSESSMENT

As noted above, a hydrological dam break assessment has been completed for Bose Lake Dam only. Failure of Dam No. 1 is not expected to generate a flood wave of water. However, tailings run out in the event of dam failure has been evaluated for both dams and is discussed in Section 8.0.

Two failure modes have been considered for the Bose Lake Dam: a flood-induced failure, and a sunny-day failure. A breach was not simulated for the sunny-day failure since the Bethlehem No. 1 Pond is typically dry, and the spillway invert corresponds to zero water storage in the No. 1 Pond (refer to Figure 5.4). However, the sunny-day failure would likely result in a release of tailings and is discussed in Section 8.0.

For a flood-induced failure, overtopping of Bose Lake Dam is not expected under any of the flood events that were modeled since the peak water levels do not exceed the dam crest elevation of 1475.1 masl (refer to Table 5.3). Therefore, dam failure due to overtopping is considered unlikely. Another possible failure mode is due to piping through the internal structure of the dam, but this is also very unlikely given that the pore pressures and seepage through the dam are low. While neither failure mode is considered likely, both have been considered for the Bose Lake Dam and are discussed below.

Dam overtopping failure occurs when water is able to flow over the dam crest, causing erosion of the dam crest material. This erosion results in the formation of a dam breach that expands progressively downward into the dam structure. It may be possible to force overtopping of the Bose Lake Dam by introducing a blockage in the spillway. A complete blockage of the spillway is considered unlikely, but is still conceivable. Such a blockage may occur due to accumulation of debris or ice in the spillway.

Failure due to piping could be caused by seepage through the dam core. Seepage through the core during a flood event may increase in velocity and quantity; eroding fine sediments from the dam core. When enough material erodes, a direct hydraulic connection could be made between the impoundment reservoir and the downstream dam face (USACE 2010). Once such a connection is made, dam failure is imminent and a full breach of the dam is likely. It should be noted that the probability of a piping failure coinciding with flooding conditions in the pond is considered extremely low.

The hydrological model discussed in Section 5.2 has been modified to include both a forced overtopping failure and piping failure of the Bose Lake Dam. The timing of both failure modes has been set to coincide with the peak flow due to flooding in downstream catchments. This timing of dam failure allows for the greatest possible flood wave downstream.

The anticipated flood inundation zone downstream of Bose Lake Dam consists largely of undeveloped, wooded terrain. As noted above, the primary concern with dam failure is environmental damage downstream and the potential loss of important aquatic habitat. There is also a danger to the transient population on the Bose Lake public access road and recreational areas.

6.1 Breach Parameters

The parameters defining the configuration of the dam breach were estimated from available literature and are discussed below. Froehlich (2008) provides methods to estimate breach parameters for both piping and overtopping failures. The peak water level for the PMF of 1471.5 masl, corresponding to an impoundment volume of 260,000 cubic metres (m^3) was used to develop the breach parameters for the piping failure. For the overtopping scenario (with a blocked spillway), the peak water level in the pond was modelled to be 1472.3, corresponding to an impoundment volume of approximately 800,000 m^3.

Breach Height and Elevation: The crest elevation of the Bose Lake Dam is approximately 1475.1 masl. According to stage-storage information for the Bethlehem No. 1 Pond, the elevation of the pond corresponding to zero storage is 1469.6 masl (refer to Figure 5.4). Therefore the breach would have a maximum possible height of 5.5 m, and a minimum elevation of 1469.6 masl (bottom of pond) for both overtopping and piping failure modes.

Breach Side Slope Ratio: The breach side slope ratio for an overtopping failure is estimated at 1H:1V (Froehlich 2008) based on down cutting of the flood wave through the compacted embankment fills. The side slope ratio for piping failure is assumed to be steeper and is estimated to be 0.7H:1V (Froehlich 2008).

Breach Width: The average dam breach width varies between 1 to 5 times the height of water against the dam at failure. According to methods outlined in Froehlich (2008), the dam breach width has been estimated to have a bottom width of 23.6 m for overtopping, and 11.8 m for piping failure.

Breach Development Time: Breach development time can range between 0.1 to 4 hours depending on the impoundment volume (Harrington 2012). The estimated breach time for overtopping has been estimated to be approximately 0.91 hours, and 0.52 hours for piping (Froehlich 2008).

6.2 Dam Break Modelling Results

The HEC-HMS model framework used to model the base case conditions (no dam failure) was modified to include both an overtopping and piping dam failure. The dam failures were set to coincide with the peak flood level in the downstream watershed; this allowed for the largest possible flood wave downstream. Modelling results for the dam failure are presented in Tables 6.1 and 6.2 for overtopping and piping failure, respectively. The No. 1 Pond inflow and outflow hydrographs for the PMF are also presented in Figure 6.1 for overtopping failure, and Figure 6.2 for piping failure.

It can be seen in Tables 6.1 and 6.2 that the overtopping failure results in a considerably larger flood wave. This is due to the increased volume of water impounded against the dam as a result of the (hypothetically) blocked spillway. Since the overtopping failure results in the largest flood wave, these results have been carried forward and used for the inundation assessment to follow.

It should be noted that despite efforts to force an overtopping failure, none of the modeled storm events actually resulted in a peak water level greater than the dam crest elevation, with a blocked spillway. This highlights the low probability of an overtopping failure occurring at the Bose Lake Dam. The following factors have been considered necessary to cause an overtopping failure:

1. bose Lake Spillway is blocked; and
2. breach is triggered without actual overtopping of the dam crest, or a volume of water in excess of the PMF is stored in the pond such that the crest is overtopped.

The probability of these two factors occurring during a flood event is extremely low. However, this scenario has been considered to investigate the maximum consequence associated with failure of the Bose Lake Dam.

The piping failure did not result in the largest flood wave and will not be considered further. However, it as noted above, the probability of a piping failure occurring during a flood event is also extremely low.

Table 6.1 Summary of Hydrological Model Results for Overtopping Dam Failure

Flood Event (Overtopping Failure)	Peak Water Level (masl)	Peak Inflow to No. 1 Pond (m^3/s)	Peak Outlfow (Breach) (m^3/s)
l00-year return period	1471.5	12.4	69.0
l000-year return period	1471.6	18.4	105.8
1/3 between 1:1000 and PMF	1471.7	28.6	113.6
2/3 between 1:1000 and PMF	1472.1	39.4	154.4
PMF	1472.3	43.6	179.9

Table 6.2 Summary of Hydrological Model Results for Piping Dam Failure

Flood Event (Piping Failure)	Peak Water Level (masl)	Peak Inflow to No. 1 Pond (m^3/s)	Peak Outflow (Spillway) (m^3/s)	Peak Outlfow (Breach) (m^3/s)
l00-year return period	1470.4	12.4	3.5	11.2
l000-year return period	1470.7	18.4	5.5	17.1
1/3 between 1:1000 and PMF	1471.1	28.6	9.7	28.9
2/3 between 1:1000 and PMF	1471.5	39.4	13.0	43.9
PMF	1471.5	43.6	13.7	51.7

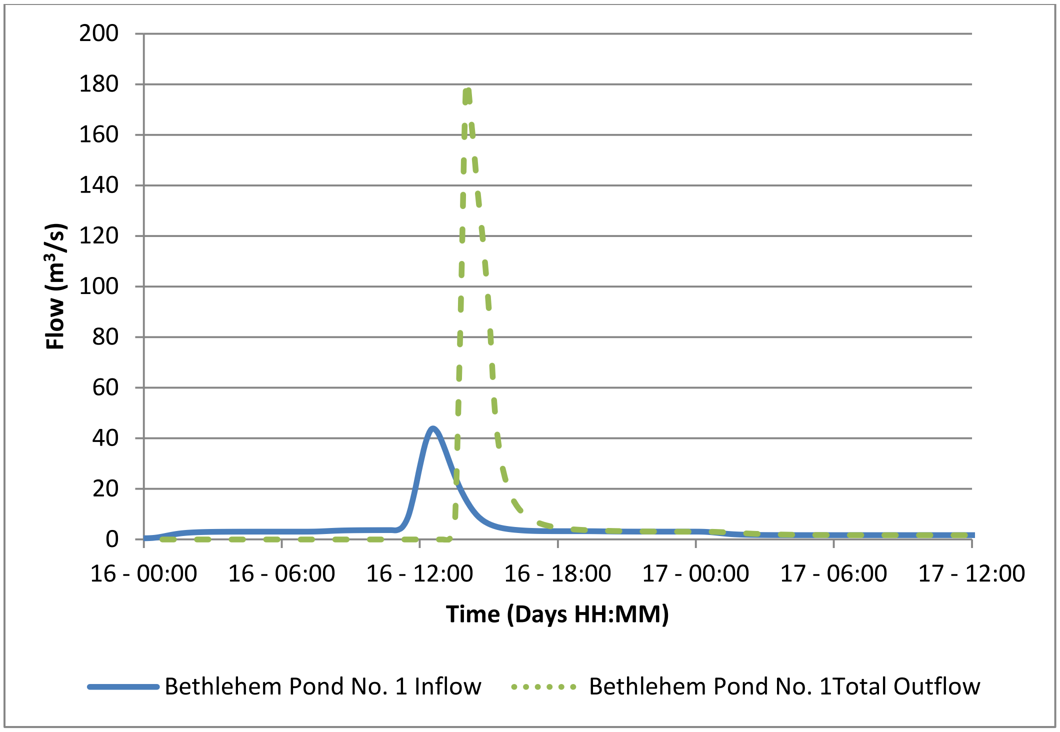


Figure 6.1 Hydrograph of Inflow to Bethlehem No. 1 Pond and Outflow (Breach Only) during 30-day PMF Rainfall Event with Overtopping Dam Failure

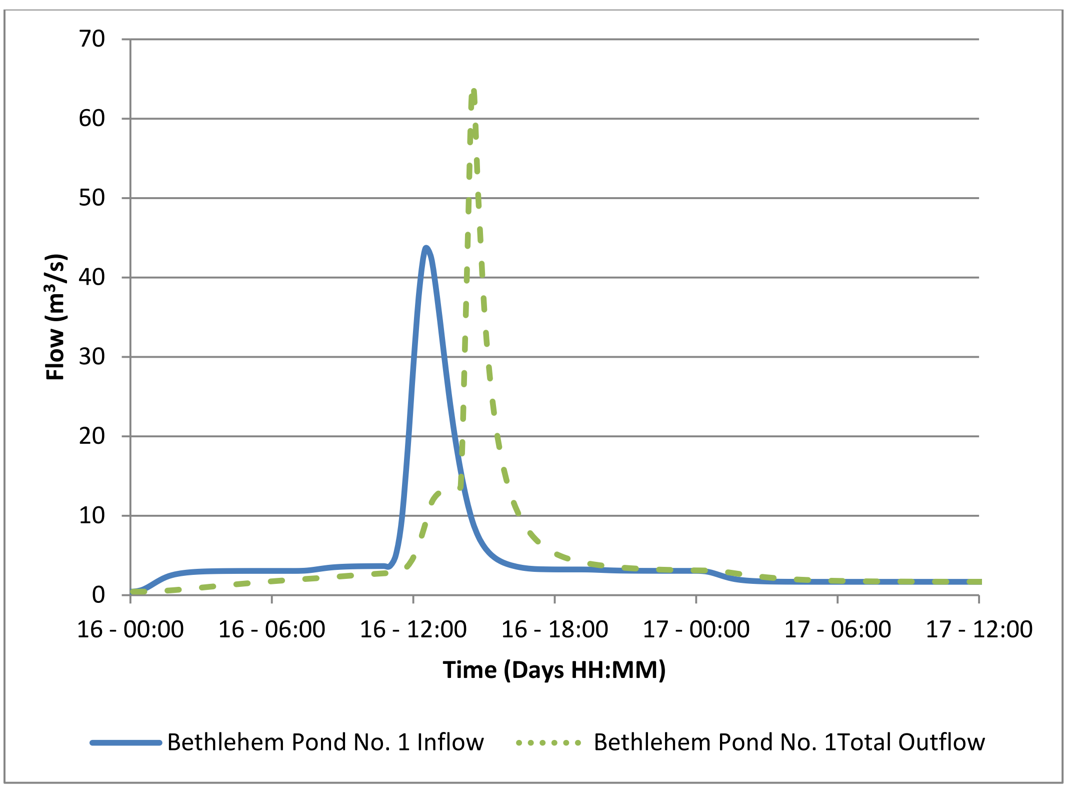


Figure 6.2 Hydrograph of Inflow to Bethlehem No. 1 Pond and Outflow (Spillway and Breach) during 30-day PMF Rainfall Event with Piping Dam Failure

7.0 INUNDATION MODELLING

This section describes the inundation modeling that was done for the area downstream of the Bose Lake Dam for the overtopping failure hydrographs generated as part of the hydrological modelling. Inundation mapping is typically conducted for watercourses with existing developments. As noted previously, there is no development downstream of Bose Lake and therefore inundation mapping has not been prepared as part of this study.

A steady-state model was developed using HEC-RAS for the reach of Axe Creek between Bose Lake and the confluence with Guichon Creek. The ArcGIS software with add-in Geo-RAS was used to prepare the input geometry data for the hydraulic analysis. Input into the HEC-RAS model included primarily channel geometry data for the modelling reaches in the form of cross sections. This information has been derived from topographical datasets available from Natural Resources Canada (NRC) (NRC 2013). These datasets have an accuracy ranging from $^{+}/_{-}$ 0.5 to 1.0 m.

Flows generated from the hydrological modelling for the downstream limit of Axe Creek (confluence with Guichon Creek) were input into the HEC-RAS model. Table 7.1 summarizes the HEC-RAS modelling results. The modelling results indicate that the incremental change in water level between the base case and the overtopping failure scenarios is minimal. The maximum incremental difference in water level occurs for the PMF and is in the order of 0.26 m. This suggests that the effects of incremental flooding will be minimal, and modelling further downstream is not considered necessary.

Table 7.1 HEC-RAS Model Summary for Downstream Limit of Axe Creek

Flood Event (Dam Failure)	No Failure		Failure (Overtopping)	
	Peak Flow (Axe Creek) (m^3/s)	Peak Water Level (m)	Peak Flow (Axe Creek) (m^3/s)	Peak Water Level (m)
l00-year return period	57.6	1070.67	72.4	1070.76
l000-year return period	87.9	1070.85	112.1	1070.97
1/3 between 1:1000 and PMF	138.5	1071.09	167.2	1071.21
2/3 between 1:1000 and PMF	197.0	1071.32	255.6	1071.51
PMF	221.2	1071.40	302.7	1071.66

The water level elevation in Bose Lake is also expected to increase during flood conditions. The peak water level in Bose Lake with and without dam failure is summarized in Table 7.2. The maximum incremental water level raise in Bose Lake is for the PMF and corresponds to rise of 0.87 m.

It is expected that public access roads immediately adjacent to Bose Lake will experience some temporary flooding during the passing of a flood event. However, incremental flooding due to dam failure is expected to have only a minor effect on these roads, since most of the roadways are above the 1450 masl contour.

Table 7.2 Peak Water Levels in Bose Lake

Flood Event	No Failure	Failure (Overtopping)
	Peak Water Level (masl)	**Peak Water Level (masl)**
l00-year return period	1440.75	1441.05
l000-year return period	1440.80	1441.26
1/3 between 1:1000 and PMF	1441.00	1441.43
2/3 between 1:1000 and PMF	1441.17	1441.87
PMF	1441.25	1442.12

Note that this inundation modeling assumed only water, and did not consider tailings run out. The tailings component of dam failure is discussed in the following section.

8.0 TAILINGS RUN OUT

Tailings run out analysis has been completed for Bose Lake and the Dam No. 1. Given that there is ponded water against Bose Lake Dam, and no ponding against the Dam No. 1, the approach for assessing tailings run out is different for each dam.

8.1 Bose Lake Dam

The analysis in the previous section describes the flood wave caused by failure of the Bose Lake Dam. It is also expected that tailings will be released as a result of dam failure. There are two mechanisms for tailings release at the Bose Lake Dam. First, the flood wave will entrain tailings solids during the breach and carry them in suspension as it travels downstream. It is assumed that the flood wave can carry a solids content of up to 35%, and as the flood wave continues and the velocities reduce, then the percentage of solids that can be retained in the flow will reduce and tailings solids will settle out. Secondly, following the initial release of the flood wave a bulk mass of tailings may mobilize due to the loss of confinement and shear strength; it is expected that this release will be in the form of debris flow (liquefied mass).

It is expected that much of the released tailings solids will be deposited in Bose Lake. There is currently no stage-storage data available for Bose Lake. Therefore, estimating the extent of tailings that could occupy Bose Lake and the extent of tailings run out downstream of Bose Lake is not possible. However, an estimated total tailings run out volume has been prepared and is discussed below. A literature review has also been completed to estimate historical tailings run out distances for similar dam failures.

The total volume of tailings impounded within the Bethlehem No. 1 Pond has been estimated from the geometry of the pond presented by KCB (1994), shown in Figure 2.4. Based on this information, the estimated total volume of impounded tailings is 111 million cubic metres (Mm^3). This estimate was calculated using an average top of tailings elevation of 1474.5 masl, and an estimated average tailings bottom elevation of 1411.3 masl (average values for Bose Lake and Dam No. 1), and a TMA surface area of 1.76 km^2.

Using the methods outlined in Froehlich (2008), the breach geometry for tailings release was estimated. It has been assumed that the breach will extend from the top of tailings (1472 masl) down to the bottom of the dam (1441.6 masl). It should be noted that this estimate is intended for water and is, therefore, a rough approximation of the actual breach size. The breach geometry was calculated to have a bottom width of 118 m, side slopes of 1:1, and a total depth of 33.5 m (bottom of dam). The development time for the breach was estimated to be 1.8 hours.

An acceptable angle of repose for deposited tailings has been judged to be roughly consistent with a slope of approximately 3%. Using the estimated breach geometry, and a 3% deposition angle, the total volume of spilled tailings has been estimated to be roughly 4.0 Mm^3. This estimate assumes that the zone of mobilized tailings expands in a radial shape upstream from the breach bottom, up to the top elevation of tailings. This total volume has been assumed to account for both entrained tailings released in the flood wave, and that released as a liquefied mass.

It is believed that all tailings released due to dam failure will flow into Bose Lake and likely continue, to some extent, downstream into Axe Creek. A literature review has been undertaken to estimate tailings run out distance for historical tailings dam failures. A summary of this research is presented in Appendix A. The literature suggests that tailings run out distance varies widely and distances between 0.1 and 40 km have been reported. However, run-out distances between 5 and 10 km appear to be more common for dams of similar height to Bose Lake Dam (30 m).

8.2 Bethlehem No. 1 Dam

As indicated previously, there is no standing water ponding against Bethlehem No. 1 Dam under normal and flood conditions, therefore, this dam is not susceptible to flood-induced failure. However this dam is potentially susceptible to earthquake induced failure or other unspecified failure mechanisms.

Only about 1.5% of historical embankment dam failures have been attributed to earthquakes (USBR 2012). The shaking motion during an earthquake could cause the earthfill material to liquefy and lose its shear strength. The reduction in shear strength may potentially cause the embankment slopes to deform, flatten, slide, and fail. The crest elevation of the dam may drop, with large longitudinal cracks developing along the dam alignment. There may also be differential settlement along the dam alignment. Earthquake will significantly reduce the ability of the earthfill dams to contain its contents. In the most severe condition, the embankment dam may fail, causing the contents (tailings, water) behind the dam to be released.

An embankment dam may fail during an earthquake and release its contents. Under this scenario, there will be very little advanced warning for emergency measures to be implemented to reduce potential losses, particularly when the loss of life may be expected. An embankment dam may also fail after the earthquake. Under this scenario, there will be time available to evacuate the potentially affected population or workers, as well as properties of significance.

An earthquake may potentially cause significant damage along the entire alignment of the dam. However, Dam No. 1 is a rockfill dam and is not believed to be susceptible to liquefaction and will retain a portion of its containment ability even through the most severe earthquake. There is a potential for settlement of the rockfill during an earthquake which may cause the dam crest to drop. The dam would still continue to provide containment to the tailings storage behind the dam, although the containment would be reduced from its former capacity.

For the purposes of a dam break analysis, the CDA (2007) Guidelines state that a hypothetical dam breach should be considered. The probability of such a dam breach is not an explicit consideration. Hence, for this analysis, we assumed that a breach could hypothetically develop during a seismic event, despite the probability of this being very low.

The volume of tailings run out is dependent on many complex factors, including the damaged condition of the dam and the liquefied state of the tailings after the earthquake. The tailings run out will form a beach downstream of the dam. The final slope of the beach will be such that the sliding force on the tailings mass resulting from the slope is balanced by the internal friction in the tailings mass. In the absence of water flow (other than the water that will flow with the tailings as a liquefied mass), the migration of tailings run out will be governed by this terminal slope and will be limited. For the purpose of this study, it is assumed that the breach will occur along the entire alignment of the Dam No. 1.

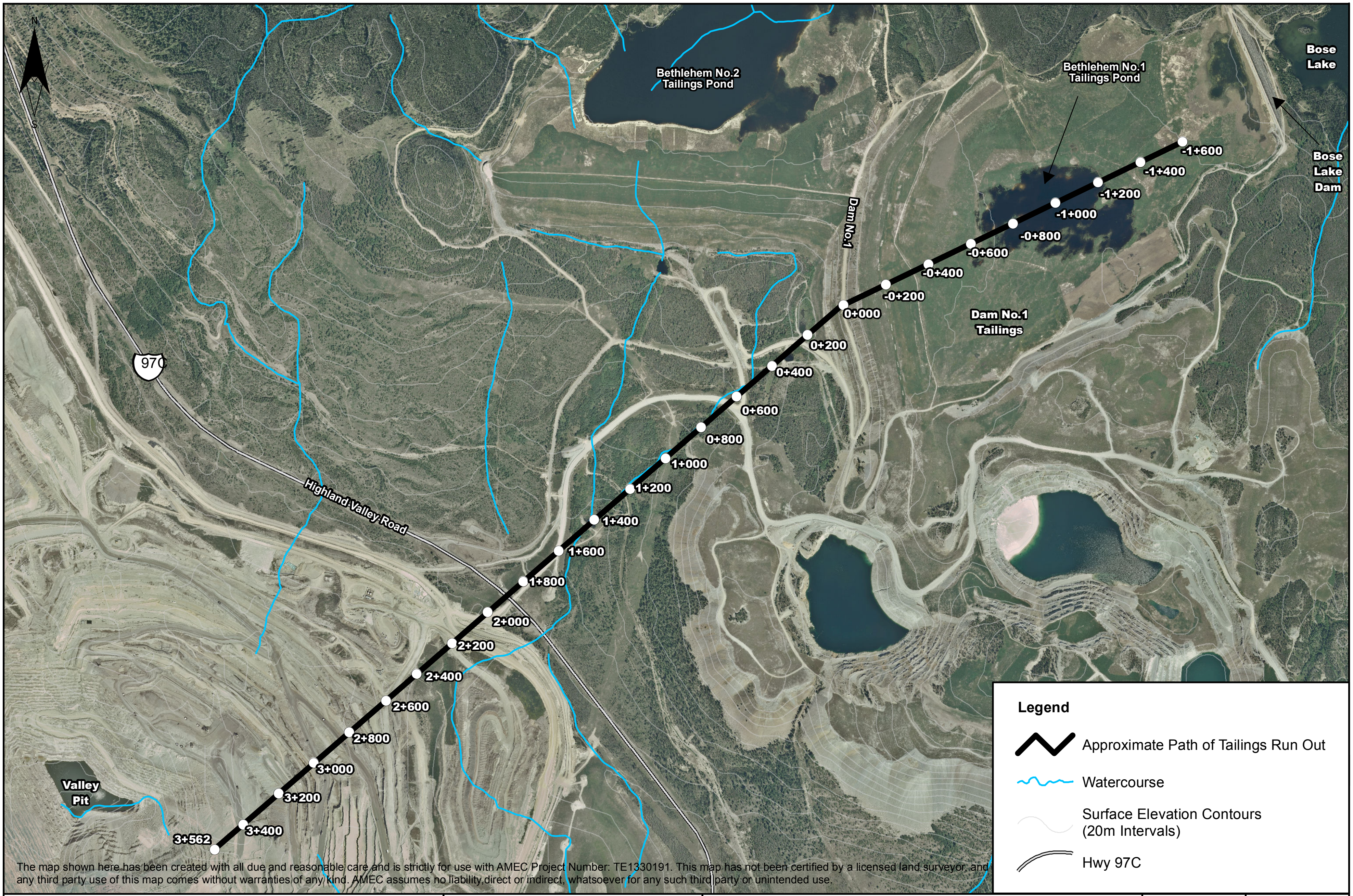
An estimated path of tailings run out is shown in Figure 8.1. In the event of a dam breach and associated tailings run out, the terminal point of the tailings run out will be the open pit.

There is uncertainty regarding the terminal slope of the tailings run out, and this slope is dependent on the liquid content of the tailings run out. Literature used in the course of this study (Blight 2003), documented the final slopes resulting from flow failure (liquefied failure) ranging from 2-4%. In a study for a similar facility (AMEC 2013), AMEC adopted a slope of 5 %. For the purpose of this study, tailings run out from the Dam No. 1 was estimated using a final slope of 3%, which was judged to be a conservative value.

Figure 8.2 shows the existing profile along the path of the tailings run out. It also shows the assumed final slope of 3% at the end of the tailings run out. Based on a comparison of the two profiles, the volume of tailings to be released has been estimated to be 55.7 Mm^3. It is apparent that the topography downstream of the dam has a slope steeper than 3%. This suggest that the topography downstream of the dam is too steep for the released tailings to deposit, and a dominant portion of the released tailings will continue to migrate until it reaches the Valley Open Pit.

The released tailings will be deposited on Highway 97C, causing damage to the highway and interruption to traffic. Cleanup and repair effect will be required in order to reopen the highway.

The released tailings will cause an infill of the Valley Open Pit. The water level in the pit is currently at approximately elevation 776 masl (from 2012 LiDAR data). It is expected that failure of Dam No. 1 would cause tailings deposition in the Valley Open Pit up to elevation 950 masl. HVC advised that the workers in the Valley Open Pit typically work above elevation 805 masl. Tailings deposition in the pit may potentially exceed this elevation. The inflow of tailings will also cut off the escape route otherwise used by the workers.



The map shown here has been created with all due and reasonable care and is strictly for use with AMEC Project Number: TE1330191. This map has not been certified by a licensed land surveyor, and any third party use of this map comes without warranties of any kind. AMEC assumes no liability, direct or indirect, whatsoever for any such third party or unintended use.

CLIENT: Highland Valley Copper
Teck

0 100 200 400 600 800 Meters

DATUM: NAD83

PROJECT: DAM BREAK AND INUNDATION STUDY BETHLEHEM DAM No.1

DWN BY: JT

DATE: Feb 26, 2014

CHK'D BY: HX

REV. NO:

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PROJECTION: UTM Zone 10 North

PROJECT NO: TE1330191

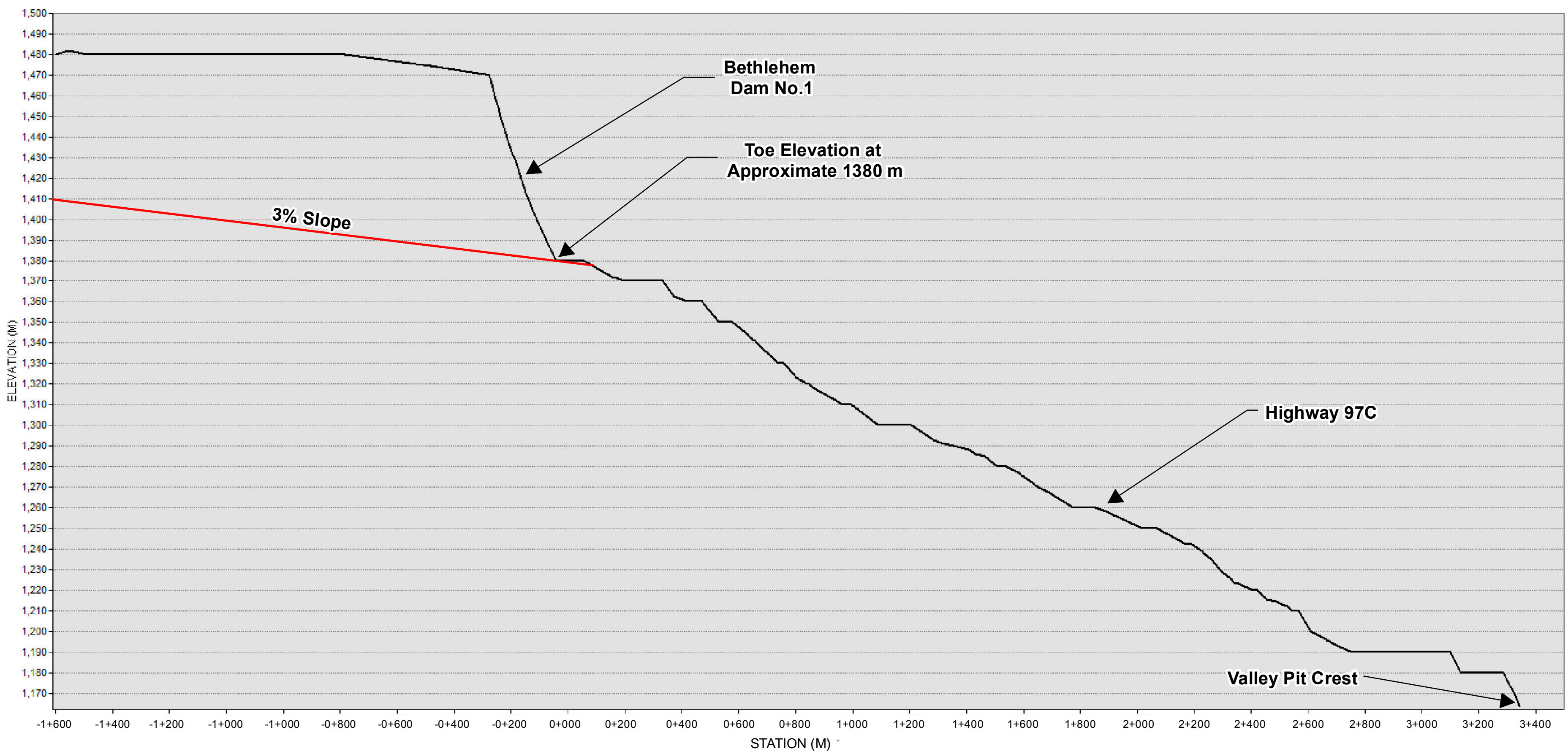
TITLE: APPROXIMATE PATH OF TAILINGS RUN OUT

SCALE: 1:22,000

FIGURE NO: 8.1

Path: G:\GIS\PROJECTS\TE133019_TECK_TrojanDam\MXD\20140226_Bethlehem_No_1_Section.mxd User: jonathan.thornton Date: 27/02/2014

SOURCE: TECK LiDAR Ortho Photograpy 2012/2011



CLIENT: Highland Valley Copper Teck		PROJECT: DAM BREAK AND INUNDATION STUDY BETHLEHEM DAM NO.1	DWN BY: JT	DATE: Feb 26, 2014
	DATUM: NAD83		CHK'D BY: HX	REV. NO.:
AMEC Environment & Infrastructure, a Division of AMEC Americas Limited Suite 1 - 495 Prospect Street Fredericton, NB E3B 9M4 Tel. 506-458-1000 Fax 506-450-0829 www.amec.com	PROJECTION: UTM Zone 10 North	TITLE: PROFILES ALONG THE APPROXIMATE PATH OF TAILINGS RUN OUT	SCALE:	FIGURE NO: 8.2
	PROJECT NO: TE1330191			

Path: G:\GIS\PROJECTS\TE133019_TECK_TrojanDam\MXD\20140226_Bethlehem_No_1_Profile.mxd User: jonathan.thornton Date: 27/02/2014

SOURCE: TECK LiDAR Ortho Photograpy 2012/2011

9.0 DAM CLASSIFICATION

9.1 2007 CDA Guidelines

For both Bethlehem Dam No. 1 and the Bose Lake Dam, a classification is required for determining the recommended IDF and freeboard requirements, seismic criteria, and surveillance program. A summary of the 2007 CDA Guidelines regarding dam classification is presented in Table 9.1. Based on the 2007 CDA Guidelines, a dam structure is classified by considering the following four consequence categories:

Table 9.1 2007 CDA Dam Classification Guidelines

Dam Class	PAR[1]	Incremental Losses		
		LOL[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 (eg., highway, industrial facility, storage facilities for dangerous substances)
Extreme	Permanent	More than 100	Major loss of critical fish or wildlife habitat	Extreme losses affecting critical infrastructure or services (eg., hospital, major industrial complex, major storage facilities for dangerous substances)

Notes:

1: Definition for PAR:

None – There is no identifiable PAR, so there is no possibility of LOL other than through unforeseeable misadventure.

Temporary – People are only temporarily in the dam-breach inundation zone (eg., seasonal cottage use, passing through on transportation routes, participating in recreational activities).

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

2: Implications for LOL:

Unspecified – The appropriate level of safety is required at a dam where people are temporality 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.

PAR: This considers if population exists in the potentially affected area resulting from the failure, and the permanent nature of the population. If permanent population is present in the potentially affected area, regardless of the size of the population, the dam must be classified as “High and Above”. It should be noted that, unlike the other consequence categories, PAR is determined based on the total population that may be affected, rather than the incremental population resulting from the failure of the dam.

Incremental LOL: This is the potential life that may be lost as a consequence of the failure of the dam structure. CDA provides bench mark values for the incremental LOL. A dam may be classified up to extreme based on this consequence category.

Incremental Loss of Environmental and Culture Values: This is the potential loss that may be incurred as a consequence of the failure of the dam structure. CDA provides qualitative descriptions for guiding the evaluation of this determinant factor. A dam may be classified up to extreme based on this consequence category.

Incremental Loss of Infrastructure and Economics: This is the potential loss that may be incurred as a consequence of the failure of the dam structure. CDA provides qualitative descriptions for guiding the evaluation of this determinant factor. A dam may be classified up to extreme based on this consequence category.

9.2 Classification for Bose Lake Dam

Classification of Bose Lake Dam according to the 2007 CDA Guidelines has been undertaken. With respect to a flooding failure event, based on the evaluation outlined below, a Dam Classification of “Significant” has been determined. This classification is higher than the previous dam classification based on the 1999 CDA Guidelines, which resulted in a classification of “Low” (KCB 2003). Comments for each consequence category are discussed below and summarized in Table 9.2.

Table 9.2 Dam Classification of Bose Lake Dam (CDA 2007)

Consequence Category	Matching Description of 2007 CDA Guidelines	Rational	Consequence Category
PAR	Temporary	Bose Lake is a recreational area and is used by the public.	Significant
Incremental LOL	Unspecified	Transient population on public access roads and temporary visitors to Bose Lake.	Significant
Incremental Loss of Environmental and Cultural Values	Loss of marginal fish habitat	Tailings deposition is likely in Bose Lake and will cause a temporary loss of marginal fish habitat	Significant
Incremental Loss of Infrastructure and Economics	Low economic losses	Area contains limited infrastructure.	Low
Dam Classification			**Significant**
Effect on HVC	Dam repair, habitat restoration/compensation downstream.		

PAR: Bose Lake is a recreational area with a public campground located on its southern shore. The campground offers 6 campsites and is likely frequented in the summer months. It is unlikely that campers would be present in the event of a flood-induced failure. However, for a sunny-day failure there may be campers present. For this reason, the population at risk has been judged to be temporary.

Incremental LOL: The incremental LOL is “unspecified” since the population downstream is considered temporary. This temporary population consists of seasonal campers present near the lake, and the transient population on the access roads around Bose Lake. During a flood event it is unlikely that this temporary population would be present downstream of the dam.

Incremental Loss of Environmental and Cultural Values: Bose Lake is annually stocked with rainbow trout to support a sport fishery in the lake. Failure of the Bose Lake Dam and deposit of tailings into the lake would limit the carrying capacity of the lake for rainbow trout. It would likely take years or decades for the carrying capacity to re-establish. Therefore, deposition of tailings into the lake is likely to cause the loss of marginal fish habitat. The magnitude of the effects would be proportional to the volume of tailings released. A review of historical tailings dam failures suggests that this run-out of tailings could extend to up to 10 km downstream.

Incremental Loss of Infrastructure and Economics: The area downstream of Bose Lake contains very little infrastructure. A campground and public access roads would be temporarily disrupted in the event of dam failure. This disruption is considered to be minor and temporary.

9.2.1 Potential Effects on HVC

The study demonstrates that there would be a loss of habitat in Bose Lake and Axe Creek. This loss of habitat would require some form of rehabilitation or compensation from HVC. HVC would also be required to repair the dam, and recover spilled tailings from the downstream environment. These cleanup and repair efforts would come at a significant cost to HVC.

9.2.2 Closure Implications

The dam classification outlined above has been prepared for the current operational condition of the dam and mine site. Closure of the mine may have implications on the classification of the Bose Lake Dam. However, given that the inundation zone consists of largely undeveloped natural terrain, the effect of mine closure on dam classification is expected to be minimal.

9.3 Classification for Bethlehem Dam No. 1

Classification of Dam No. 1 according to the 2007 CDA Guidelines has been undertaken. Based on the evaluation outlined below, a Dam Classification of “Very High” has been determined. This classification is higher than the previous dam classification based on the 1999 CDA Guidelines, which resulted in a classification of “Low” (KCB 2003). Comments for each consequence category are discussed below and summarized in Table 9.3.

Table 9.3 Dam Classification of Bethlehem No. 1 Dam (CDA 2007)

Consequence Category	Matching Description of 2007 CDA Guidelines	Rational	Consequence Category
PAR	Permanent	There are workers in the Valley Open Pit on a regular basis.	High and Above
Incremental LOL	100 or fewer, or More than 100	Inflow of tailings from Dam No. 1 will be deposited in the pit. It will also cut off the escape route otherwise used by the workers	Very High to Extreme
Incremental Loss of Environmental and Cultural Values	Minimum short term loss, no long term loss	Tailings run out is not expected to have any impact on Environmental or Cultural Values in the area.	Low
Incremental Loss of Infrastructure and Economics	Disruption of public transportation	Temporary disruption of traffic on BC Highway 97C	High to Very High
Dam Classification			**Very High**
Effect on HVC	Dam repair, habitat restoration/compensation downstream.		

PAR: The Valley Open Pit is located down gradient of Dam No. 1, and there are workers in the pit on a regular basis. These workers are, therefore, considered “permanent”, and the dam classification for this consequence category is assessed to be “High and Above”. There is also danger to the transient population present on BC Highway 97C.

Incremental LOL: There are often more than 100 workers in the Valley Open Pit. Deposition of tailings into the pit will cause infilling of the pit and cut-off the escape route used by the workers. This may result in a potentially high fatality rate, however, it is understood that many of the workers would be able to exit the pit, and/or seek refuge in the event of dam failure. Therefore, the LOL is believed to be “100 or fewer”, and the dam classification for this consequence category is assessed to be “Very High”.

Incremental Loss of Environmental and Cultural Values: The release of tailings is expected to migrate into the Valley Open Pit. Since there is no flood wave associated with dam failure, it is expected that the mobilized tailings will follow the dominate land slope toward the Valley Open Pit. Tailings are not expected to migrate into Witches Brook to the east of the pit, which is believed to support important fish habitat. Therefore, the dam classification for this consequence is assessed to be “Low”.

Incremental Loss of Infrastructure and Economics: A dam breach would result in an HVC operation shutdown for an extended period of time, with major economic impacts to the region (employment, spin-off and associated businesses, etc.). Therefore, the incremental loss of infrastructure and economic loss is assessed to be “High” to “Very High”.

9.3.1 Effects on Highland Valley Copper (HVC)

As noted above, failure of Bethlehem No. 1 Dam will cause significant disruption to the mining and milling operations at the site. Significant cost will be incurred for repairing the dam. Breach of the dam will also cause significant damage to facilities (mine roads) downstream of the dam. The tailings deposited in the Valley Open Pit will need to be removed prior to work resuming.

9.3.2 Closure Implications

The dam classification outlined above has been prepared for the current operational condition of the dam and mine site. Closure of the mine will have implications on the classification of Bethlehem No. 1 Dam. In particular, the fate of the Valley Open Pit and the absence of workers within the pit will likely reduce the dam classification. It should be noted, however, that classification of the dam should be re-assessed once closure conditions become better defined.

10.0 EMERGENCY PREPAREDNESS PLAN

The dam break and inundation analysis for Bose Lake and Bethlehem No. 1 Dams are intended to support the development of an Emergency Preparedness Plan (EPP). The EPP should be prepared in accordance with the specifications provided in the 2007 CDA Guidelines. This study suggests that particular emphasis should be placed on the Valley Open Pit and the recreational areas downstream of Bose Lake Dam.

11.0 CONCLUSION AND RECOMMENDATIONS

An evaluation of the Bose Lake Dam has indicated that the available freeboard and spillway are adequate for base case conditions (no failure) up to the PMF storm event. A dam break assessment was then completed to estimate the resulting flood wave and inundation downstream. The assessment suggests that the extent of incremental flooding as a result of dam failure will be minimal (0.26 m) at the downstream limit of Axe Creek. For this reason, no further modelling is recommended at this time.

Classification of Bose Lake Dam was also undertaken according to the 2007 CDA Guidelines. The dam classification was found to be “Significant” due to the risk posed to the downstream aquatic environment, and recreational areas downstream.

It is recommended that a bathymetry survey of Bose Lake be undertaken to better estimate the effect tailings deposition in the lake would have on the downstream aquatic environment. If it is expected that the lake would store most of the deposited tailings, migration of tailings downstream to Axe Creek would be limited.

Since Bethlehem No. 1 Dam impounds only tailings, a flood inundation assessment for the No. 1 Dam was not completed. An assessment of deposited tailings in the event of dam failure has been completed for the Bethlehem No. 1 Dam. It is estimated that most of the released tailings during dam failure would be deposited in the Valley Open Pit. The fill elevation in the pit after dam failure has been estimated to be approximately 950 masl. It is expected that failure of the Bethlehem No. 1 Dam may endanger workers in the pit.

Classification of the Bethlehem No. 1 Dam was undertaken according to the 2007 CDA Guidelines. The dam classification was found to be “Very High” due to the risk posed to workers in the Valley Open Pit downstream.

12.0 CLOSING

We trust that our submission meets your requirements. Please do not hesitate to contact us if you have any questions regarding this submission.

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APPENDIX A
Summary of Historical Tailings Dam Failures

Table A1 Summary of Historical Tailings Dam Failures

Year	Location	Dam Height	Type of Tailings	Cause of Failure	Total Volume of Tailings in Impoundment (m^3)	Volume of Spilled Tailings (m^3)	Distance of Spilling Flow	References
1928	Barahona, Chile	65 m	Copper tailings	8.2 Richter earthquake		3×10^6 of fine tailings	50 km	1, 2,5
1963	Louisville, Kentucky	31 m		Seepage	1×10^6	1×10^6	0.1 km	5
1965	El Cobre, Chile (2 impoundments)	64 m	Copper tailings	7.5 Richter earthquake	4.25×10^6	1) 1.9×10^6 2) 0.5×10^6 fine tailings	12 km	1,4
1965	Los Maquis, Chile	15 m	Copper	dam failure (liquefaction) during earthquake	6×10^4	21×10^3	5 km	4, 5
1965	La Patagua New Dam, Chile	15 m	copper	dam failure (liquefaction) during earthquake		35×10^3	5 km	4
1965	Cerro Negro No.3, Chile	20 m	copper	dam failure during earthquake	7.9×10^5	85×10^3	5 km	4, 5
1965	Bellavista, Chile	20 m	copper	dam failure during earthquake	7×10^5	7×10^4	800 m	4, 5
1966	Mir mine, Sgorigrad, Bulgaria		lead, zinc, copper, silver	dam failure from rising pond level after heavy rains and/or failure of diversion channel		45×10^4	8 km	4
1974	Bafokeng, South Africa	20 m	platinum	Overtopping	2×10^7	3×10^6	42 km	1, 5
1978	Mochikoshi, Japan	32 m		Seismic	8.1×10^3	1.4×10^3	30 km	5
1980	Tyrone, New Mexico, USA		copper	dam wall breach, due to rapid increase in dam wall height, causing high internal pore pressure		2×10^6	8 km	4
1981	Balka Chuficheva, Lebedinsky, Russia	25 ft	iron	dam failure	27×10^6	3.5×10^6	1.3 km	4
1985	Olinghouse, Wadsworth, Nevada, USA		gold	embankment collapse from saturation		25×10^3	1.5 km	4

Year	Location	Dam Height	Type of Tailings	Cause of Failure	Total Volume of Tailings in Impoundment (m^3)	Volume of Spilled Tailings (m^3)	Distance of Spilling Flow	References
1985	Cerro Negro No.4, Chile	40 ft	copper	dam wall failure, due to liquefaction during earthquake	2×10^6	5×10^5	8 km	4, 6
1985	Veta de Agua No.1, Chile	24 ft	copper	dam wall failure, due to liquefaction during earthquake	70×10^4	28×10^4	5 km	4, 6
1986	Itabirito, Minas Gerais, Brazil	30 ft		dam wall burst		1×10^5 tonnes	12 km	4, 6
1994	Harmony, Merriespruit, South Africa	31 m	gold	Dam wall breach following heavy rain		6×10^5	4 km	4
2003	Cerro Negro, Petorca prov., Quinta region, Chile		copper	tailings dam failure		5×10^4 tonnes	20 km	4
2012	Gullbridge Mine, NF, Canada	7 m	Copper tailings	Overtopping			Most of tailings lie within 100 m of the dam	3

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