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REPORT ON

DAM BREACH AND INUNDATION STUDY
TAILINGS STORAGE FACILITY
PREMIER GOLD
STEWART, BC

Submitted to:

Premier Gold Project
P. O. Box 476
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EXECUTIVE SUMMARY

A Dam Breach and Inundation Study was undertaken for the Premier Gold Tailings Storage Facility for Boliden Limited. A number of potential embankment failure mechanisms were identified and considered. The most likely failure mechanism was estimated to be the internal erosion of the embankment fill at the un-grouted 900 mm diameter corrugated steel pipe. However, a reverse gravel/rock filter has been constructed to mitigate the risk, and the likelihood of this failure mechanism has been reduced to a low likelihood of occurrence.

Overtopping of the tailings storage facility (TSF) embankment under probable maximum flood (PMF) conditions is estimated as having a low likelihood of occurrence based on the perpetual or long term maintenance of the closure spillway and Cascade Creek Diversion Channel (CCDC). Alternatively, the failure of the Long Lake water dam upstream of the Premier site is considered to be the most likely event that could result in an overtopping breach of the TSF embankment. The estimated likelihood of this event is low, as it is anticipated that the new dam operators would inspect, monitor and maintain the dam to minimize the likelihood of the event occurring. The modeling however shows that a flood wave resulting from the low likelihood dam breach at Long Lake would greatly exceed the capacities of the CCDC and closure spillway. This would result in overtopping of the TSF main dam embankment.

The study for the release of the tailings was completed to evaluate the possible run out of tailings and to determine the impact of the tailings downstream. This was estimated based on a method developed by Vick (1991) and incorporates case history data that was collected and analyzed by Lucia et. al. (1981) and Lucia (1981). The case histories used in the Vick method comprise a wide range of initial conditions that include embankment size, embankment breach mechanism, tailings volume and grain size distribution and ground slope(s) in the region where the run out occurred. Based on this approach, a flow-slide of liquefied, saturated tailings resulting from a breach in the main embankment at the Premier TSF is not expected to come to rest in the steep portion of the valley upstream of the confluence of Cascade and Lesley Creeks. In the absence of additional flow inputs from Lesley Creek, the estimated run-out distance for the tailings flow-slide is in the order of 500 m downstream from the confluence of Lesley Creek and Cascade Creek, or roughly 1,300 m downstream of the main embankment.

It is noted however, that the fine tailings deposited within the channel would be highly susceptible to erosion and it is expected that most of the tailings that are released as the result of a dam breach of the main embankment would in time be transported downstream to the Salmon River. Once re-suspended, the silt and clay-sized tailings particles could remain in suspension until they reach the Portland Canal (Pacific Ocean) approximately 19 km downstream of the main embankment.

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1.0 INTRODUCTION

A Dam Breach and Inundation Study was undertaken for the Premier Gold Tailings Storage Facility (TSF) for Boliden Limited (Boliden). The mine and the project area is located 18 km north of Stewart, British Columbia and approximately 2 km northeast of the British Columbia – Alaska border.

The purpose of the study is to:

- Identify potential main embankment failure modes;
- Estimate the likelihood of related breaching events and discuss the consequences of the events;
- Estimate the volume and limit or extent of tailings run out;
- Estimate inundation limits; and
- Evaluate downstream impacts on human safety and the environment.

2.0 BACKGROUND

The following section provides a brief description of the Tailings Storage Facility (TSF) and the downstream receiving environment in the event of a dam breach.

2.1 Tailings Storage Facility Description

The TSF at the Premier Gold is located within the historical Cascade Creek valley approximately 1 km upstream of its confluence with Lesley Creek (Figure 2-1). The TSF, which is oriented along a northwest axis, is approximately 1,000 m long and 200 m across and covers an area of approximately 25 ha. The main impoundment structure or main dam is 230 m long and 42 m high (Cascade Creek channel section) and was constructed with an internal "seal" zone and has a combined rock and earth fill shell. The facility operated between 1989 and 1996 and received a total of approximately 2.3 million cubic meters of tailings.

The TSF was built in 1988-89 and included the construction of a diversion channel for Cascade Creek at the north end of the facility. The Cascade Creek Diversion Channel (CCDC) was created by diverting the Cascade Creek water flows toward the east and into Lesley Creek to a point approximately 1.6 km upstream of the Cascade Creek and Lesley Creek confluence. The diversion channel has a rated maximum flow capacity, without freeboard, of approximately 360 m^3/sec (Knight Piesold, 1988).

As part of the TSF construction, Indian Creek, located to the southwest of the facility was diverted around the tailings storage facility by way of the Indian Creek diversion. Subsequent to the implementation of the diversion channel, the lower portion of Lesley Creek, carrying the diverted flows, has occasionally been referred to as Cascade Creek. Furthermore, the section of Cascade Creek below the tailings dam and upstream of the confluence with Lesley Creek has occasionally been referred to as Indian Creek. For clarity, we will use the pre-TSF nomenclature for the watercourses (Refer to Section 2.2).

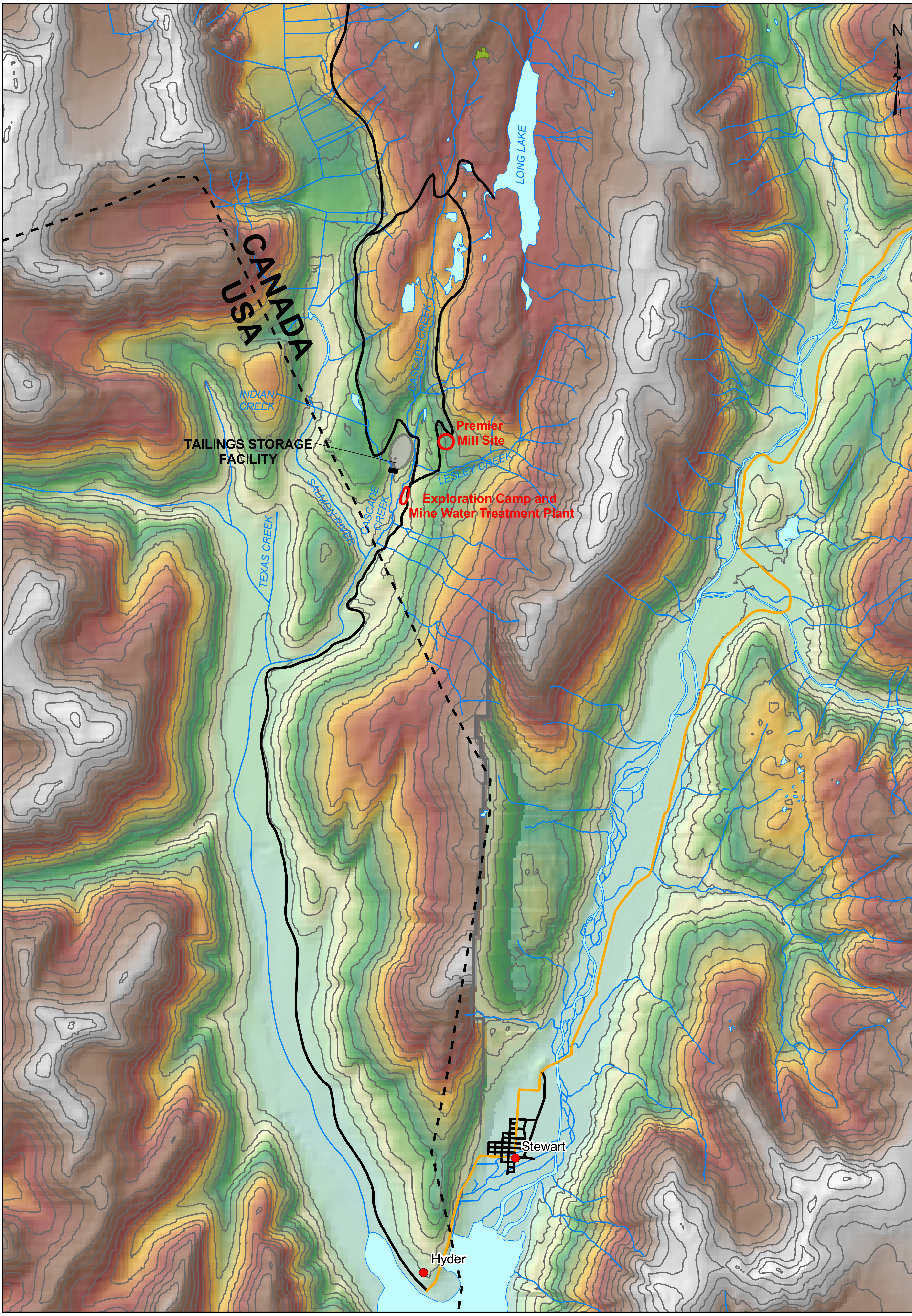
The closure plan for the tailings facility proposes the maintenance of a water cover and an engineered cover adjacent to the main dam over the stored tailings. This will be achieved by relocating all tailings above elevation 331.5 m to this level or to a lower elevation within the facility. A minimum 1 m deep water cover would then be maintained over the tailings. The Indian Creek diversion will be abandoned and the creek flows will be redirected to the TSF to provide an adequate supply of water and to maintain the desired water cover. The closure spillway, located in the northeast quadrant of the facility, will have an invert elevation of 332.5 m and will control the water level in the facility. Water would then pass over the spillway and join Lesley Creek to the northeast of the TSF.

The engineered cover over the tailings is proposed (Boliden, April 2002) for the area immediately adjacent to the dam. This cover would extend 50 m horizontally from the dam in an effort to keep the water cover a safe distance away from the dam and reduce the amount of precipitation infiltration in this zone near the dam face.

2.2 Description of Downstream Valley

A description of the downstream valley, which will be affected from a potential breach, is given in this section. Refer to Figure 2-1 for location of reaches.

1. **First Reach**: Cascade Creek, downstream of the TSF embankment, is located within a steep, incised valley and is confined between steep rock walls. The 800 m long reach between the dam and the Cascade Creek/Lesley Creek confluence has an average gradient of 17% with frequent waterfalls in the upper section. The width of Cascade Creek in this reach varies between 5 and 15 m.
2. **Second Reach**: Cascade Creek, between Lesley Creek and its confluence with the Salmon River has an average gradient of 5% (range of 20% to 1%) over its 950 m length. This reach of Cascade Creek is also located within an incised valley and is confined throughout most of its length between bedrock walls. The width of Cascade Creek in this reach varies between 10 and 20 m.
3. **Third Reach**: The Salmon River between the Cascade and Texas Creek confluences is significantly wider than Cascade Creek with widths ranging from 100 to 200 m. The valley walls bounding the river are also very steep and bedrock walls are common. The predominant river substrate is large cobles with some gravels. This river reach spans approximately 3,300 m and has an average gradient of 1%. Downstream of the Texas Creek confluence, the Salmon River is less confined and becomes heavily braided with bank full widths reaching 500 m. The Portland Canal is approximately 14 km downstream from the Texas Creek confluence.



LEGEND

- Camp
- Tailings Storage Facility
- Flood Peak Water Level
- Dam
- Border
- Road
- Contour - 100 m interval
- River/Stream
- Waterbody
- Wetland

2,000 1,000 0 2,000 Meters

Scale - 1:75:000

REFERENCE

USGS, MSRM, Geobase, DMTI, ESRI

Datum: NAD 83 Projection: UTM Zone 9

PROJECT

BOLIDEN WESTMIN (CANADA) LTD.
CASCADE CREEK
STEWART, B.C.

TITLE

SITE LOCATION

PROJECT No. 04-1413-024			SCALE AS SHOWN	REV. 0
DESIGN	SD	07 Jan. 2005		
GIS	CDB	07 Jan. 2005		
CHECK	SD	07 Jan. 2005		
REVIEW				

Golder Associates
Burnaby, B.C.

FIGURE 2-1

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3.0 EVALUATION OF DAM BREACH MECHANISMS

This section provides an evaluation of the dam breach event. A dam breach that would allow tailings to be deposited downstream of the TSF could occur at three locations: the closure spillway, the east dam and/or at the main dam. It is anticipated that the most likely location of a dam breach that would have the most impact is at the main dam or embankment of the tailings facility. A breach at the spillway would be mitigated through the design of the spillway with a rock base, and the east dam is a much lower embankment section and has a limited elevation of tailings above the ground downstream of the dam.

Thus, this section discusses the evaluation of the main dam section under the most likely anticipated failure modes which are either seismic induced or flood induced. The discussion presents the six principal potential failure mechanisms that were initially identified. While other failure mechanisms are present, they were estimated to have a very low likelihood of occurring and were not considered further. The principal mechanisms that were evaluated included:

- internal erosion of the dam due to a failure of the pipes under the dam;
- seismic deformation;
- movement (stability) of the downstream dam face or slope;
- foundation erosion;
- overtopping of the dam due to a spillway blockage or overtopping of the dam due to a probable maximum flood; and
- overtopping of the dam due to a dam breach at the proposed Long Lake power water dam upstream of the site.

From these, select mechanisms were considered for further analysis based on the relative likelihood of occurrence and the consequence of failure. The following provides for a discussion of the likelihood of occurrence and the consequence for each identified failure mechanism and the associated level of risk.

For this study, risk has been defined as “the chance of injury or loss defined as a measure of the probability and severity of an adverse effect to health, property, the environment or other things of value” (CSA 1997), in addition risk is defined as “ the chance of something happening that will have an impact on the objectives of the design” – *risk* is measured in terms of a combination of the consequences of an event and their likelihood; *consequence* is the outcome or impact of an event; *event* is the occurrence of a particular set of circumstances; and *likelihood* is used as the general description of the probability or frequency (i.e. the chance of something happening) (AS/NZS 2004).

3.1 Closure Design Criteria of Tailings Storage Facility

The key design criteria (applicable to breach analysis) that have been used in this study were taken from the initial design reports developed by Knight & Piesold (1989) (the Design Engineer). The key design parameters that impact the dam breach and inundation study for the tailings facility are:

- 1 in 1,000 year return period earthquake;
- 1 in 1,000 year return period flood from tributary areas (including diversion channel flows in the event of blockage);
- the Probable Maximum Flood (PMF) for the diversion channel capacity; and
- the anticipated long term or perpetual maintenance of the diversion channel and closure spillway.

As noted above, the tailings facility closure spillway is located in the northeast portion of the facility and will have an invert elevation of 332.5 m. Thus, the pond will operate at or above this level. The water discharged from the facility will pass over the spillway and flow into Lesley Creek.

In addition to the 1 meter deep water cover over the tailings, an engineered soil cover is to be placed over the tailings adjacent to the upstream side of the tailings dam (Boliden, April 2002). This cover would extend some 50 m upstream from the upstream face of the dam or embankment in order to define a minimum beach zone in front of the dam and to minimize the infiltration into this zone.

Additional references used in the study included:

- Ministry of Energy and Mines BC (MEM) Health, Safety and Reclamation Code and Guidelines for Acid Rock Drainage;

- The Canadian Dam Association (CDA) Embankment Safety Guidelines;

- the embankment stability analysis of the current dam and tailings facility configuration as completed by Klohn-Crippen (2002), (The results and conclusions from the Klohn-Crippen stability and hydrologic analysis are accepted as being correct);

- the “as-built” documentation for the tailings storage facility and embankment conditions; and

- the scheduled long-term maintenance and the proposed closure configuration as per the Closure Plan (Boliden 2002).

3.2 Potential Failure Modes

As noted above, the potential failure mechanisms considered were:

- 1A: internal erosion (piping) of embankment fill by way of the un-grouted 900 mm diameter Corrugated Steel Pipe (CSP);
- 1B: internal erosion of embankment fill through the grouted decant pipes;
- 2: deformation as a result of a seismic event;
- 3 downstream dam slope instability;
- 4: foundation erosion;
- 5A: overtopping due to blockage in spillway;
- 5B: overtopping due to a PMF; and
- 6 overtopping due a dam breach at the proposed Long Lake water dam.

In reviewing the failure mechanisms, an initial screening was completed in order to remove the "very low" risk issues. This screening considered several factors including the likelihood the event would occur during the next 10,000 years. The issues associated with internal erosion of the dam at, or as a result of, the internal pipes (Failures 1A and 1B) were separated because one of the pipes (the 900 mm CSP) was not totally grouted. The same was the case for overtopping the main dam due to a blocked spillway and/or the PMF (Failures 5A and 5B).

The "likelihood of an occurrence" was also estimated and is defined as noted above – as the probability or frequency or chance of the event happening. In order to rank the likelihood of an occurrence the following were considered. If an event has a likelihood of an occurrence in 1,000 to 10,000 years (10^{-3} to 10^{-4}), then it was considered to have a "very low" likelihood. Similarly, if an event has a likelihood of an occurrence in 100 to 1,000 years (10^{-2} to 10^{-3}), then it was considered to have a "low" likelihood. Further if the event has a likelihood of an occurrence in 10 to 100 years (10^{-1} to 10^{-2}), then it was considered to have a "moderate" likelihood. An event that would occur in the next 10 years was considered to have a "high" likelihood of occurrence.

Based on the above likelihood definitions and the sound engineering completed to date and the site conditions, the following estimates were made:

- Failure Mechanism 3 - Based on the dam design and the materials used to construct the dam and the reverse filter berm on the downstream side of the dam, the probability of a slope instability is “very low”;

- Failure Mechanism 4 - The rock foundation means that a failure due to foundation erosion is “very low”;

- Failure Mechanism 5A - The potential for overtopping the main dam due to a blockage in the closure spillway is “very low” due to the sizing of the spillway (significant extra capacity); and

- Failure Mechanism 5B - The diversion channel can manage a PMF, if the channel is clear as the capacity of the channel is large relative to the PMF; thus the likelihood for overtopping due to a PMF is “very low”.

These mechanisms were not considered further in the analysis. Alternatively, the failure of, or at, the 900 mm CSP pipe (estimated as a “low”); the deformation of the dam foundation during or as a result of a seismic event (estimated as “very low to low” as the dam is founded on rock); and the overtopping of the main dam due to a breach at new Long Lake Dam (estimated as “low”) were considered in more detail.

Table 3-1 summarizes potential failure modes and the factors considered.

Table 3-1: Potential Failure Mechanisms

Potential Failure Mechanisms	Summary of Factors	Likelihood of Occurrence
SEISMIC INDUCED		
1A Internal erosion of embankment fill by way of the un-grouted 900 mm CSP pipe	• Condition unknown at present • Reverse filter has been constructed at the outlet of the CSP pipe in order to retain migrating particles. • The loss of dam fill into voids of pipe could induce settlement and cracking in the dam which may lead to piping of embankment material. • Particle migration leading up to the potential failure has environmental consequences and may require cleanup.	Low
1B Internal erosion by way of decant pipes	• Decant pipes have been backfilled/grouted effectively.	Very Low
2 Seismic event and potential deformation	• Under dynamic loading existing embankment Factor of Safety (FoS) = 1.6[a]	Very Low to Low
3 Slope Instability	• Under static condition existing embankment FoS = 1.6[a]; under closure condition FoS = 1.8[a].	Very Low
4 Foundation Erosion	• Foundation comprised of competent, slush grouted bedrock; particle migration not associated with this type of material.	Very Low
FLOOD INDUCED		
5A Overtopping due to spillway blockage	• Spillway designed to be self maintaining and its capacity is not likely to be significantly affected by debris. • Fuse plug provides backup spillway. • Spillway sized to pass the 1:1,000 yr flow from diversion channel and tributary areas with 1.0 m freeboard at the dam.	Very Low
5B Overtopping due to PMF	• Diversion channel sized to divert the PMF with no allowance for freeboard. • Spillway capacity sufficient to handle PMF if diversion channel has about 50% of its operating capacity remaining.	Very Low
6 Overtopping due to dam breach at Long Lake	• Dam breach at Long Lake would lead to spill of CCDC floodwaters into tailings facility. • Depending on size of Long Lake dam breach, spillway capacity likely insufficient to handle the flow. • Fuse plug provides backup spillway. • Overtopping may occur from flood wave run-up.	Low

[a] Klohn Crippen (2002).

3.3 Selected Failure Mechanisms

Based on the initial evaluation above, three failure mechanisms with “low” or “very low to low” likelihoods of occurrence were considered further and are discussed in detail below. The three mechanisms are considered in this section on the basis of risk as defined in the Section 3.

3.3.1 Internal Erosion –Failure Mechanism 1

The embankment breach caused by internal erosion of the embankment fill has been estimated to have a “low” likelihood of occurrence.

Material may “erode” through the embankment as follows at the grouted pipes:

- Failure Mechanism 1A - The 900 mm diameter corrugated steel pipe (CSP) used as a surface water diversion during the original construction of the embankment. An unsuccessful attempt was made to backfill this pipe with grout. The pipe is still discharging, as per visual observation. Some suspended particles have been observed in seepage;

- Failure Mechanism 1B - The two 200 mm diameter HDPE pipes encased in concrete used as supernatant decants during mine operation. These pipes have been backfilled with concrete grout; and

- Failure Mechanism 1B - The one 150 mm HDPE perforated under-drain pipe (including laterals) set slightly upstream of the upstream toe of the embankment. The pipe is encased in concrete through the embankment and sleeved with a 300 mm diameter CSP section through the seal zone. This pipe has been backfilled with concrete grout as part of closure activities.

In order to assist in managing this failure mechanism, a reverse filter was constructed on the downstream face of the embankment. The reverse filter consists of four engineered fill zones (placed as a berm) at the outlet of the existing, un-grouted 900 mm diameter CSP pipe. The purpose of the filter is to reduce the potential for migration of material from the tailings facility; however it does not totally prevent embankment fill from eroding or piping into the 900 mm CSP culvert. As the 900 mm CSP pipe has not been effectively grouted there is a “low” likelihood of an occurrence of a loss of material downstream. The filter is designed to avoid build up of fines (caking) at the upstream face of the berm; hence some finer material may pass through. The finer materials that might pass would consist of tailings from the impoundment and/or fine material from the embankment fill. Migration of embankment fill could potentially lead to a breaching event especially if the breaching mechanism is accelerated by a seismic event. However, as the filter is designed to function during and after a seismic event, it is anticipated that the piping breach of the reverse filter has a "low" likelihood of occurring. There is a "very low" likelihood that during a major seismic event (assume the tailings are liquefied) that there would be a small volume of water and tailings to flow through the filter out of the tailings facility. The design of the reverse filter means this event would be considered to have a "low" consequence and it is estimated that it would have a "very low" risk.

As the two 200 mm and the one 150 mm diameter pipes have been effectively grouted, the likelihood of an occurrence of an escape of tailings from them due to internal erosion is ranked as "very low". Thus, as the failure mechanism is estimated to have a "very low" consequence and risk, it is not considered further.

3.3.2 Seismic Event and Potential Deformation – Failure Mechanism 2

Failure of the competent bedrock foundation has a "very low to low" likelihood. The location of any potential seismic induced failure would, if it occurred, be within the embankment. This failure mechanism in the main dam section would have a "very low" likelihood as this section of the dam is on sound bedrock.

It is noted that a small portion of the downstream shell of the East dam is founded on dense, medium-grained sand. Based on the limited contact area (approximately 30 m length, parallel to the valley) and the side effects or confining configuration from valley wall (i.e. wedging) and the limited depth of the dense sand, failure through the sand has a "low" likelihood of occurrence. However, given the low height of tailings at this section of the dam, the failure mechanism would have a "very low" consequence and it is estimated that there would be a "very low" risk. .

3.3.3 Overtopping Failure - Failure Mechanism 6

The flows in the Cascade Creek drainage are managed by the diversion channel and if needed, by the closure spillway, under the closure configuration of the TSF. The diversion channel is sized to convey the PMF event, and the closure spillway is sized to pass the 1 in 1,000 year storm discharge[1] from the diversion channel (161 m^3/sec, assumed diversion is 100% ineffective) and the runoff from the TSF tributary areas (16 m^3/sec). Once routed through the pond, the outflow discharge can be accommodated with 1.0 m of freeboard to the final closure dam crest. The current closure plan incorporates the long term or perpetual maintenance of the diversion channel.

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1) The 1000 year flood is recommended by the Canadian Dam Association Guidelines (1999) for the upper and lower limit of low and high-consequence tailings dams, respectively.

However, under a more extreme event with a “very low to low” likelihood of occurrence, the tailings dam could be overtopped. An example, is the event caused by a dam failure at Long Lake, the resultant flood wave would overwhelm the diversion channel and TSF spillway in about 1 hour. This event would result in overtopping flow conditions of the TSF main embankment. This failure mechanism would have a “high” consequence but as it has a “very low to low” likelihood the risk would be estimated as “low”.

Given the planned and current maintenance program for the diversion channel and spillway, and considering the anticipated magnitude of flooding from various scenarios, it is estimated that the only likely failure mechanism that would result in an overtopping dam failure would be triggered by the failure of the new or proposed Long Lake water dam. Hence, any evaluation of the potential downstream inundation following a tailings storage facility dam breach is contingent on the failure of the Long Lake dam.

Table 3-2 provides an estimate of the potential risk associated with the potential failure modes that were selected for further analysis.

Table 3-2: Risk Matrix for Embankment Breach for Selected Scenarios

Hazard	Likelihood of Occurrence	Years	Consequence	Risk
Failure Mechanism 1A Internal erosion failure [a]	Low	100 to 1,000	Very Low	Very Low
Failure Mechanism 2 Embankment failure under seismic load	Very Low To Low	100 to 1,000	Low	Very Low
Failure Mechanism 6 Overtopping failure [b]	Very Low [c]	1,000 to 10,000	High [d]	Low[e]

a Internal erosion through existing pipes and conduits is referenced in Klohn-Crippen (2001) and deals with the slow release of tailings via piping or internal erosion.

b Failure by over topping assuming the proposed Long Lake Dam, located upstream, fails and the associated discharge is the cause of overtopping and breach of the embankment.

c The likelihood of occurrence is estimated by review of design parameters and the proposed long term maintenance program of the Long Lake Facility. For this study, it is assumed the proposed Long Lake facility would be properly designed and constructed and will be maintained. Therefore, the likelihood of occurrence of any sort of failure at the Long Lake facility, and hence over topping the Premier embankment, is assumed to be very low to low.

d It is anticipated that a significant amount of tailings would be entrained by floodwaters given the large volume of the TSF inflow flood hydrograph (Section 5.0).

e It is assumed that the owner/operator of the Long Lake facility would bear full responsibility for any damages resulting from a failure of the Long Lake facility.

3.4 Dam Breach Parameter Predictions

Three methods are commonly applied in estimating dam breach dimensions:

1. Comparative analysis of case studies (i.e. literary search);
2. Statistical breach parameters; and
3. Embankment breach simulation models.

A literary search of over 100 documented embankment failures did not identify a basin configuration similar to the TSF, hence comparative analysis is not possible. Detailed breach simulation models are beyond the scope of this study.

The use of statistical parameters is the method applied in this study. A predictive equation presented by Fread (1998) was used to determine the average breach width:

$$b_{av} = 9.5 k_0 (V_r H)^{0.25} \tag{1}$$

Where: b_{av} is the average width of the breach (ft), k_0 = 0.7 for piping and 1.0 for overtopping failures, V_r is the volume of water in the reservoir (acre-feet) and H is the height of water over the breach bottom (ft) and is generally taken as the dam height.

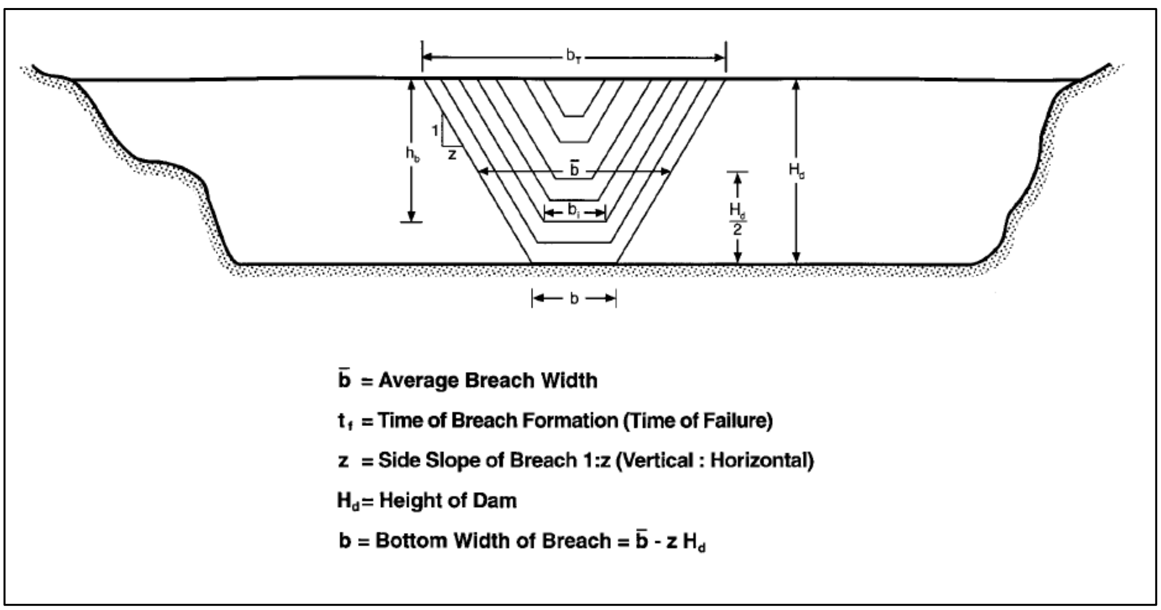


Figure 3-1: Breach Parameters

The volume of water was taken as:

1. The struck level volume for the piping failure to represent the liquefied tailings; or
2. The inflow hydrograph volume for the overtopping failure mode (see Section 5.0).

The breach geometry was then determined by adjusting the Z value to obtain the top and bottom widths while ensuring that these fall within the embankment dimensions. The resulting breach parameters are presented in Table 3-3 and compared to guidelines set out by the United States Federal Energy Regulatory Commission (U.S. FERC).

Table 3-3: Selected Breach Parameters

Breach Parameter	Piping	Overtopping
Dam Crest Elevation (m)	336.0	
Width of Breach – Top[a] (b_T) (m)	88	182
Width of Breach – Average (b_{av}) (m)	46	106
Width of Breach – Bottom[a] (b) (m)	4	30
Final Breach Invert Elevation (m)	294	
Height of Breach[b] (h_b) (m)	42	
Side Slope of Breach[c] (ZH:1V)	1.0	1.8
Time to Failure[d] (Tf) (hr)	N/A	0.5
B_{av}/H_d[e]	1.1	2.5
Water Surface Elevation – Initial[f] (m)	332.5	

a Maximum top and bottom widths are respectively 230 and 30 m i.e. limited by embankment size.
b Set equal to nominal height of dam (H_d)
c Recommended Range by U.S. FERC: $0.25 \leq Z \leq 1.0$
d Recommended Range by U.S. FERC: $0.1 \leq T_f \leq 1.0$
e Recommended Range by U.S. FERC: $1.0 \leq B_{av}/H_d \leq 5.0$.
f U.S. FERC recommends normal operating water level for fair weather failures.

4.0 EVALUATION OF TAILINGS RUN-OUT

This section presents the results of a first order estimate of tailings run-out distance from an overtopping event of the TSF main embankment.

4.1 Method

The method used to estimate volume of released tailings and run out was developed by Vick (1991) and is based in large part upon case history data that was collected and analyzed by Lucia et. al. (1981) and Lucia (1981).

The method is based on a simplified 2-dimensional force equilibrium analysis, which assumes that at the moment the tailings come to rest, the average shear strength of the tailings at the ground surface is equal to the shear stress required for static equilibrium.

The Vick method is based on a number of case histories, comprising a wide range of initial conditions that include embankment size, embankment breach mechanism, tailings volume and grain size distribution and ground slope(s) in the region where the run out would occur. It is an empirical method and does not represent a physical model. It provides an initial first order estimate of the potential run out distance.

4.2 Limitations

Channel Gradient

- The average Cascade Creek channel gradient from the dam the Leslie Creek confluence is approximately 9.7^{o}; and

- The average Cascade Creek channel gradient from Leslie Creek to the Salmon River is approximately 2.7^{o}.

Vick (1991) and Lucia et. al. (1981) concluded that tailings run outs do not come to a rest on ground slopes greater than 9^{o}. Hence, the method by Vick is only applicable downstream from the Lesley Creek confluence. Based on the foregoing, it is conservatively assumed that the entire volume of released tailings resulting from an overtopping breach of the main embankment report to the reach downstream of the Lesley Creek confluence.

Volume of Run Out

A review of case histories by Lucia et al. (1981) indicated that less than 100% of available tailings will run out. While Vick provides a statistical component to determine the probability of occurrence for various values of the run out volume, the study conservatively assumes 100% of the tailings above the invert of the breach are available for flow.

4.3 Input Parameters

The following section describes the selection of the input parameters used in the analysis of tailings run out resulting from an overtopping breach of the main embankment.

Embankment and Tailings Storage Facility

The embankment has the following characteristics:

- Elevation of the downstream toe of the embankment is 280 m;
- Elevation of the embankment crest is 336 m;
- Total height of embankment (H_t) is 42 m; and
- The slope of the downstream face of the embankment (θ) is 30.6^o.

It is understood that the tailings storage facility has a total volume of tailings of approximately 2.3×10^6 cubic meters (Drawing 1434.005 Rev.1, Knight & Piesold, 1988).

Embankment Breach

The dimensions of the estimated embankment breach associated with overtopping are summarized in Table 3-3.

Channel Gradient

The average Cascade Creek channel gradient from the Lesley Creek confluence to the Salmon River confluence is approximately 2.7^o.

Tailings Properties

Field and laboratory test results from a geotechnical investigation by Klohn-Crippen (2002) indicate the tailings have the following material properties:

- Unit weight (γ) of the saturated tailings is 2.1 tonnes/m^3;
- Standard Penetration Testing (SPT) blow count is 2;
- Percentage of fines (passing #200 mesh) in the tailings was approximately 50%; and
- Internal friction angle of the liquefied tailings of $\phi = 4.6^o$.

Volume of Tailings Available for Run-out

The calculation of run out distance requires that the volume of available tailings be normalized relative to the unit width of the embankment breach as follows:

- The volume of available tailings is 2.3×10^6 m^3;
- is divided by the estimate breach width W = 46 m (Section 3.8); and
- resulting in a volume of tailings per width of breach of $V_{f\,=}$ 50,000 m^3/m.

Estimate of Shear Strength of Tailings

The method requires an estimate of the Equivalent Clean Sand ECS $(N_1)_{60}$ value for the tailings. The SPT blow-count reported in Section 4.3 is corrected for fines by adding a correction factor provided by Vick (1991) as follows:

- The correction factor for a soil with a fines content of 50% is 4 blows/ft;
- When added to the recorded SPT = 2 yields a corrected ECS $(N_1)_{60} = 6$; and
- ECS $(N_1)_{60} = 6$ corresponds to an undrained shear strength of S_U = 90 psf, or 4.4.

4.4 Tailings Run Out

Calculation

Strength and volume curves were constructed to compare the height of the run out (H_T) to the slope of the surface of the tailings run out. The point of intersection between the strength and volume curves represents static equilibrium of run out (for the trial value of V_f.) This point corresponds to H_T = 140 m and $\alpha = 4.6^o$.

The run out distance (L) is the sum of:

- L_e, the distance from the headscarp to the base of the embankment; and
- L_T, the distance from the base of the embankment to the terminus of the run out.

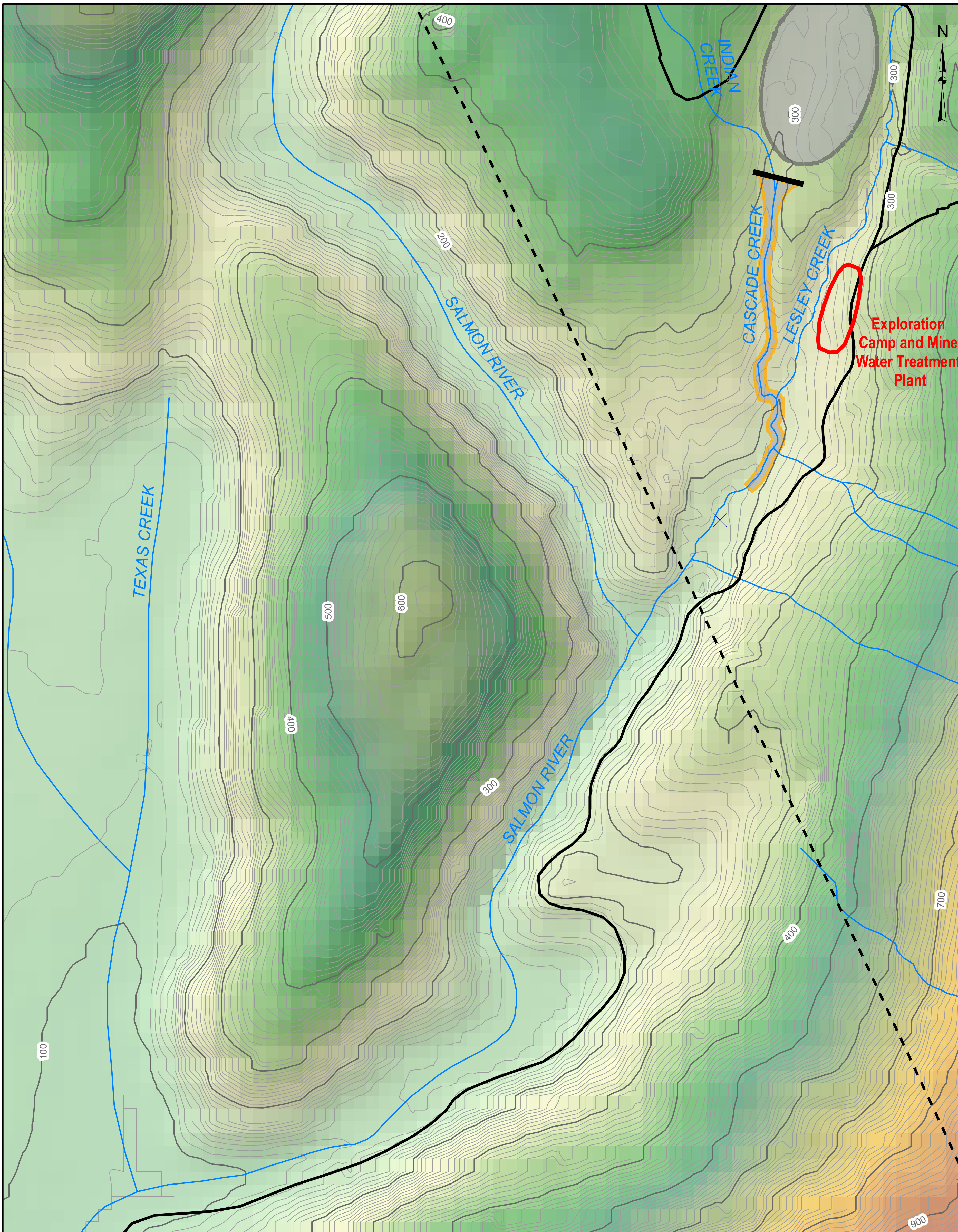
These distances are determined geometrically from the dimensions of the run out based on the strength/volume curves intersection.

Results

With the exception of minimal adhesion to the valley side walls, tailings released through the breach are assumed not to come to rest in the 800 m long steep channel located immediately downstream of the main embankment. Hence, the computed terminus distance of 500 m represents the distance downstream from the confluence of Lesley Creek and Cascade Creek, or approximately 1,300 m downstream of the main embankment (Figure 4-1).

It should also be noted that this analysis does not consider the effects of any additional flow inputs from Lesley Creek, or the CCDC by way of Lesley Creek. Any fine tailings deposited below the Lesley Creek confluence would be subject to erosion and it is expected that most of the tailings that are released would be transported downstream to the Salmon River by these additional flows.

Once re-suspended, the silt and clay-sized tailings particles could remain in suspension until they reach the Pacific Ocean approximately 19 km downstream from the main embankment.



LEGEND

	Camp		Border
	Tailings Storage Facility		Road
	Extent of Initial Tailing Run-out		Contour - 100 m interval
	Cross-section		Contour - 10 m interval
	Dam		River/Stream
			Waterbody
			Wetland

500 250 0 500 Meters

Scale - 1:15,000

REFERENCE

USGS, MSRM, Geobase, DMTI, ESRI

Datum: NAD 83 Projection: UTM Zone 9

PROJECT

BOLIDEN WESTMIN (CANADA) LTD.
CASCADE CREEK
STEWART, B.C.

TITLE

EXTENT OF INITIAL TAILINGS RUN-OUT

Golder Associates
Burnaby, B.C.

PROJECT No. 04-1413-024			SCALE AS SHOWN	REV. 0
DESIGN	SD	07 Jan. 2005	**FIGURE 4-1**	
GIS	CDB	07 Jan. 2005		
CHECK	SD	07 Jan. 2005		
REVIEW				

N:\Bur-Graphics\Projects\2004\1413\04-1413-024\GIS\aprs\Report\figure-04-1_tailings-runout.mxd

5.0 EVALUATION OF INUNDATION

The following section presents the evaluation of inundation resulting from the simulated dam breach of the Premier Gold tailings storage facility main embankment. The evaluation involved the simulation of potential overtopping failure scenarios, prediction of the resulting dam breach flood discharges immediately downstream of the main embankment and routing of the outflow hydrograph through the receiving creek/river valley. The simulation of the dam breach, resulting outflow hydrographs and routing of the resulting hydrographs downstream was conducted using the latest version (Version 2-0-0, June 1, 2000) of the FLDWAV model, a dam break flood prediction model developed by U.S. National Weather Service (NWS, 1998).

5.1 Dam Breach Scenarios

As described previously, the tailings storage facility dam breach scenario assumes an overtopping type failure caused as a result of an incoming flood wave, resulting from a dam breach of the Long Lake water dam located approximately 6 km upstream of the site.

As part of an independent study, Golder (November 2003) undertook a dam break modeling analysis for the proposed dam at Long Lake. As part of this evaluation, the resulting flood hydrograph was routed downstream to the CCDC and the Alaskan border. The modeling effort did not account for the limited capacity of the CCDC and the fact that the majority of the flood hydrograph would spill into the tailings storage facility.

In order to estimate the incoming flood waves into the TSF, the routed flood hydrographs from the Long Lake dam break evaluation were adjusted to account for the CCDC capacity (360 m^3/s) (Figure 5-1). Three flood hydrographs were derived representing the best estimate and the upper and lower bounds as represented by the sensitivity analysis undertaken for the Long Lake dam break evaluation (Golder, 2003).

The TSF spillway was not modeled as part of the dam break analysis. This approach is considered reasonable since:

- It represents an obstructed spillway;

- The magnitude of the incoming flood wave is 3.5 to 10 times the spillway capacity and the TSF flow attenuation capacity is essentially non-existent (flood wave volume 5 to 12 times the available storage volume); and

- The entire flood wave is accounted for below the Lesley Creek/Cascade Creek confluence where the discharges from the CCDC, the spillway and the overtopping/dam breach would join.

A single breach geometry, as opposed to a range of breach sizes, was modeled since the governing factor for the outflow hydrograph in this case is the magnitude of the inflow hydrograph. The three different inflow hydrograph volumes were input into Equation (1) (Section 3.5) with similar breach width results (b_{av} ranged between 89 to 109 m respectively for lower and upper bounds). Hence, the breach width (Table 3-3) was computed using the best estimate inflow hydrograph volume.

Three dam breach scenarios are evaluated in the current analysis. They are represented by the best estimate or base case and the lower and upper bound estimates.

5.2 Modeled Reaches

The TSF dam breach flood hydrographs were routed along a study reach of approximately 19 km which included:

- Cascade Creek, from just downstream of the dam to its confluence with Lesley Creek;
- Cascade Creek from its confluence with Lesley Creek to the Salmon River; and
- Salmon River, from the confluence with Cascade Creek to its outlet in the Portland Canal.

As described previously, Cascade Creek is characterized by deeply incised channel with a steep longitudinal gradient. Over most of its length, the channel is constrained within very steep bedrock walls with negligible water storage in the overbank areas. Due to the limited availability of detailed topographic information, main channel widths were typically estimated based on field observations.

A total of 13 cross-sections were provided in the model along the modeled reaches. The model automatically interpolates cross sections between input cross sections in order that the minimum distance between model cross sections is 30 m. Figure 5-2 illustrates the location of the input cross-sections.

Note that detailed information for the Salmon River was unavailable for the current evaluation. The lower reaches of the river were modeled primarily to lessen potential modeling effects of downstream uncertainties on flood conditions in the upstream reaches of the system. Therefore, the accuracy of the routing results in the downstream reaches of the Salmon River is expected to be limited. Furthermore, any potential tidal influences at the mouth of the Salmon River were ignored.

Manning's *n*, a roughness coefficient, is the key model input parameter affecting the resulting dam breach flood routing in the downstream channels and valleys. Table 5-1 presents best estimates of Manning's *n* values for the channels which have bedrock or boulder/cobble bed materials, and valley walls with generally dense vegetative cover. Also presented are the upper and lower bound estimates of the Manning's *n* values which were used in the model sensitivity analysis. These upper and lower bound roughness estimates were combined with the upper and lower bound breach geometries and inflow hydrographs to establish three modeling scenarios to define the potential inundation.

Table 5-1: Estimates of Manning's n Values

Description	Manning's n Estimates		
	Lower Bound	Base Case	Upper Bound
Channel	0.035	0.040	0.060
Valley Wall	0.060	0.100	0.150

5.3 Modeling Results

A summary of the simulated hydraulic conditions downstream of the TSF main dam following an overtopping breach initiated by a breach of the Long Lake dam is provided in Table 5-2 and Figure 5-2. Figures 5-3 to 5-5 illustrate the dam breach hydrographs at the dam, at the confluence with Lesley Creek, and at the mouth of the Salmon River, respectively. Figure 5-6 to 5-8 presents the flood wave profiles, peak flood depths and peak flood discharges along the modeled reaches.

The peak flood discharges from the dam breach, observed immediately downstream of the dam, range between 940 and 2,430 m^3/sec with the best estimate being approximately 1,430 m^3/sec. The Premier TSF dam breach only has a minor effect on the peak flood discharges from the inflow hydrographs (originating from the Long Lake dam breach, Figure 5-1) providing for a 5 to 14% increase respectively for the upper and lower bound cases. This is not surprising given the large inflow volumes and the limited attenuation storage offered within the TSF.

The flood wave is passed essentially un-attenuated from the TSF dam to the Lesley Creek confluence where it joins the waters diverted by the CCDC. At this point the CCDC discharge capacity (360 m^3/sec) is added to the flood hydrograph before continuing downstream. It is estimated that the peak discharge values from the flood hydrographs below the Lesley Creek confluence will be attenuated by up to 10% by the time it reaches the Portland Canal.

The peak flood wave flow depths attain maximum values ranging between 6.3 and 11.6 m (lower and upper bound) in the vicinity of the Lesley Creek confluence where the CCDC flows join the main flood wave (Figure 5-7). This range of flood depths can easily be accommodated within the Cascade Creek ravine which is in excess of 25 m in depth. Furthermore, any backwatering effects up Lesley Creek from the flood wave are not expected to pose any hazards since plenty of relief is present upstream of the confluence to any potential access points. The CCDC culvert crossing of the Granduc Road would likely be washed-out by the flows that would remain within the CCDC.

Modeling results indicate that the peak flood wave flow depths within the Salmon River are less than or equal to approximately 3.3 m under the base case (best estimate). These flood flow depths can easily be accommodated within the upstream reaches of the Salmon River which is confined between steep valley walls down to the Texas Creek confluence.

More detailed cross-sectional information for the lower reaches of the Salmon River would be needed to validate the modeling results in these reaches and provide the ability to comment on the inundation potential. This is considered outside the scope of the current evaluation considering that the event initiating the TSF dam breach is an upstream breach of the Long Lake dam and that the subsequent TFS dam breach does not significantly affect the flood hydrographs.

Under an overtopping breach scenario, a significant amount of tailings is expected to be entrained in the flood wave given the large volume of water that would pass through the TSF. The flood wave momentum and the steep valley/river gradients will generate high flood flow velocities (between 3 and 24 m/sec) which will carry a portion of the entrained tailings to the mouth of the Salmon River and into the Portland Canal.

Table 5-2: Summary of Modeling Results

Cross Section [a]	Station (m)	Invert El. (m)	Peak Water Level (m)			Peak Water Depth (m)			Peak Discharge (m^3/sec)			Time to Peak (hrs)		
			Lower	Base	Upper	Lower	Base	Upper	Lower	Base	Upper	Lower	Base	Upper
1 (Dam)*	0	305.1	336.7	337.0	337.4	n/a	n/a	n/a	946	1430	2482	1.51	1.71	1.49
2 *	19	304.1	307.0	307.1	307.1	3.0	3.0	3.0	946	1430	2482	1.51	1.71	1.49
3 *	77	300.1	303.3	304.8	306.3	3.2	4.7	6.2	945	1430	2479	1.52	1.71	1.49
4 *	137	295.1	298.3	298.3	298.3	3.2	3.2	3.2	945	1429	2477	1.52	1.72	1.49
15	173	282.8	285.1	285.6	286.0	2.3	2.8	3.2	945	1429	2476	1.52	1.72	1.49
30	222	266.0	268.8	269.9	270.9	2.7	3.8	4.9	945	1429	2475	1.52	1.72	1.49
40 *	255	254.9	259.0	260.6	264.6	4.1	5.8	9.7	945	1429	2474	1.52	1.72	1.49
51 *	629	200.0	203.6	205.0	208.5	3.6	5.0	8.5	944	1429	2469	1.52	1.72	1.49
55*	769	179.9	183.5	184.9	188.4	3.6	5.0	8.5	944	1428	2467	1.53	1.72	1.49
59 (Lesley Ck)*	900	170.1	174.1	175.6	179.6	4.0	5.5	9.4	944	1428	2465	1.53	1.72	1.49
66*	1,146	150.0	156.3	157.8	161.6	6.3	7.8	11.6	1303	1788	2822	1.53	1.73	1.49
72	1,341	143.1	145.9	146.8	149.1	2.8	3.6	5.9	1303	1788	2820	1.53	1.73	1.50
77	1,504	137.4	139.8	140.5	142.5	2.3	3.1	5.1	1303	1787	2820	1.53	1.73	1.50
83 (border)	1,699	130.6	132.6	133.3	135.1	2.1	2.7	4.5	1302	1787	2818	1.53	1.73	1.50
94 (Salmon R.)*	2,056	118.0	119.7	121.3	123.4	1.7	3.3	5.4	1302	1787	2813	1.55	1.74	1.50
123	2,994	108.6	110.8	111.6	113.5	2.3	3.0	4.9	1299	1784	2792	1.58	1.78	1.53
154	3,995	98.5	100.6	101.3	103.0	2.1	2.8	4.5	1297	1781	2777	1.62	1.82	1.56
186 *	5,030	88.1	90.6	91.4	93.4	2.4	3.2	5.3	1293	1778	2760	1.66	1.87	1.60
197 (Texas Ck Conf.)*	5,386	86.5	88.9	89.7	91.6	2.4	3.2	5.2	1290	1776	2750	1.68	1.88	1.62
216	6,001	83.6	85.9	86.7	88.7	2.4	3.1	5.1	1286	1774	2733	1.71	1.92	1.65
340	10,010	64.9	67.0	67.7	69.3	2.0	2.8	4.4	1253	1763	2655	1.92	2.14	1.93
352	10,399	63.1	65.0	65.7	67.3	1.9	2.6	4.2	1250	1763	2650	1.94	2.15	1.95
495	15,018	37.9	39.8	40.5	42.1	1.9	2.6	4.1	1223	1757	2596	2.22	2.39	2.29
629 (Mouth)*	19,346	14.3	16.2	16.9	18.4	1.9	2.6	4.1	1201	1752	2545	2.51	2.61	2.61

a Cross-sections identified by a star are user input.

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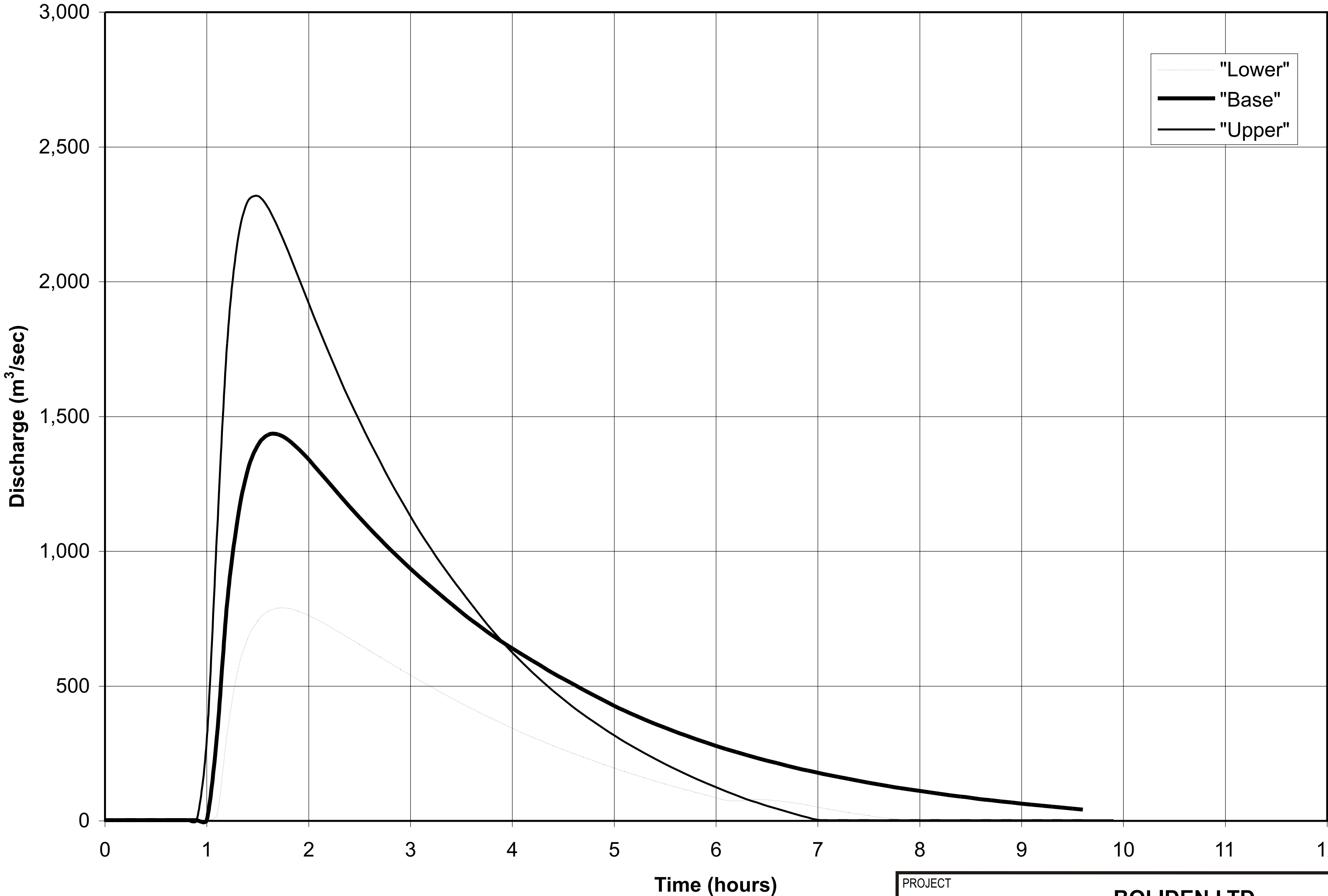
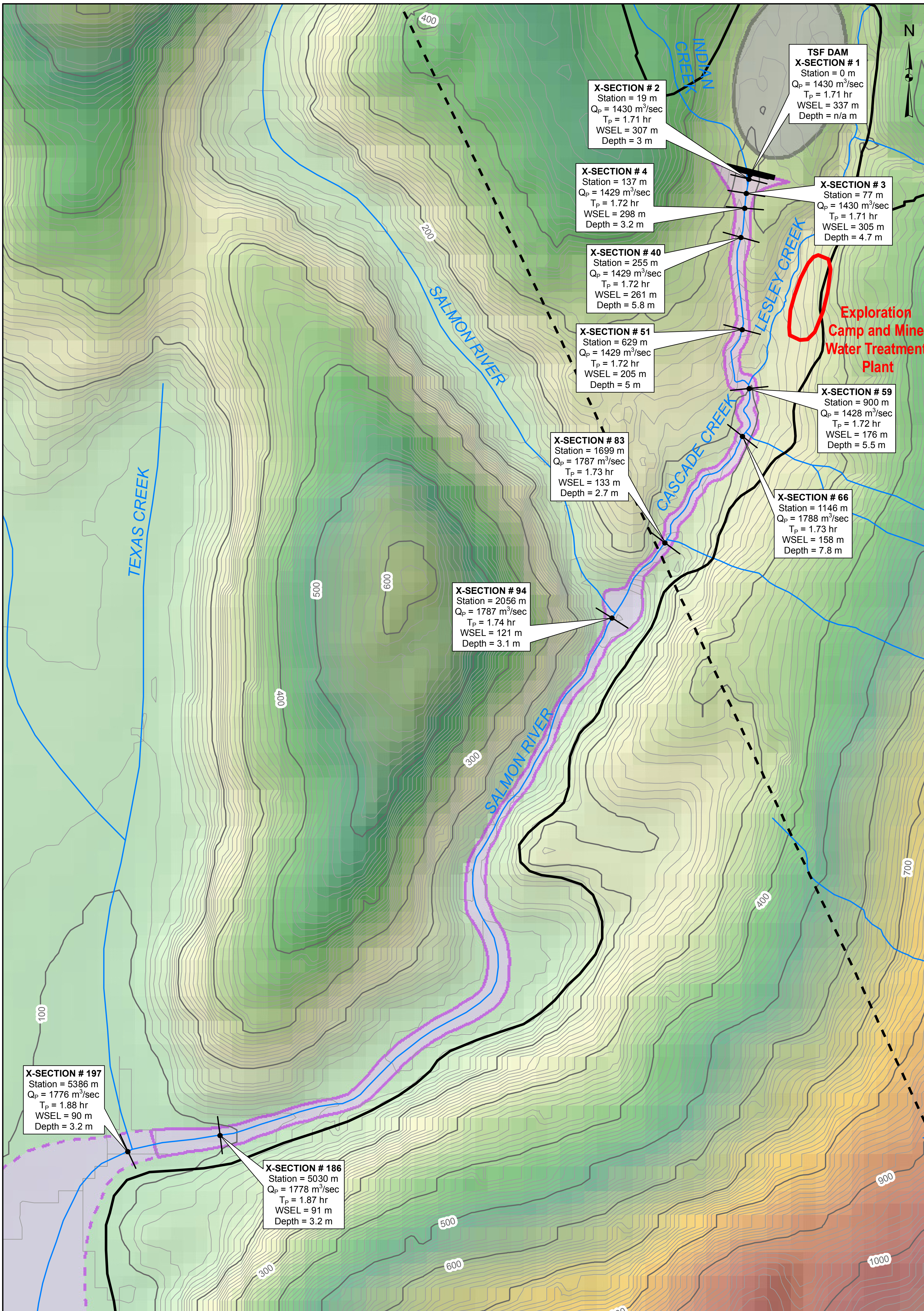


PROJECT	**BOLIDEN LTD.** **PREMIER GOLD MINE, STEWART, B.C.**
TITLE	**TAILINGS STORAGE FACILITY** **INFLOW HYDROGRAPHS**

Golder Associates					
PROJECT No.	04-1413-024		FILE No. FIGURES 2		
DESIGN	SGD	13JAN05	SCALE NTS	REV.	
CADD	SS	13JAN05	**FIGURE 5-1**		
CHECK	SGD	13JAN05			
REVIEW					



LEGEND

- Camp
- Tailings Storage Facility
- Flood Peak Water Level
- Cross-section
- Dam
- Border
- Road
- Contour - 100 m interval
- Contour - 10 m interval
- River/Stream
- Waterbody
- Wetland

500 250 0 500 Meters

Scale - 1:15,000

REFERENCE

USGS, MSRM, Geobase, DMTI, ESRI

Datum: NAD 83 Projection: UTM Zone 9

PROJECT

BOLIDEN WESTMIN (CANADA) LTD.
CASCADE CREEK
STEWART, B.C.

TITLE

FLOOD PEAK WATER LEVEL

PROJECT No. 04-1413-024			SCALE AS SHOWN	REV. 0
DESIGN	SD	07 Jan. 2005	**FIGURE 5-2**	
GIS	CDB	07 Jan. 2005		
CHECK	SD	07 Jan. 2005		
REVIEW				

Golder Associates
Burnaby, B.C.

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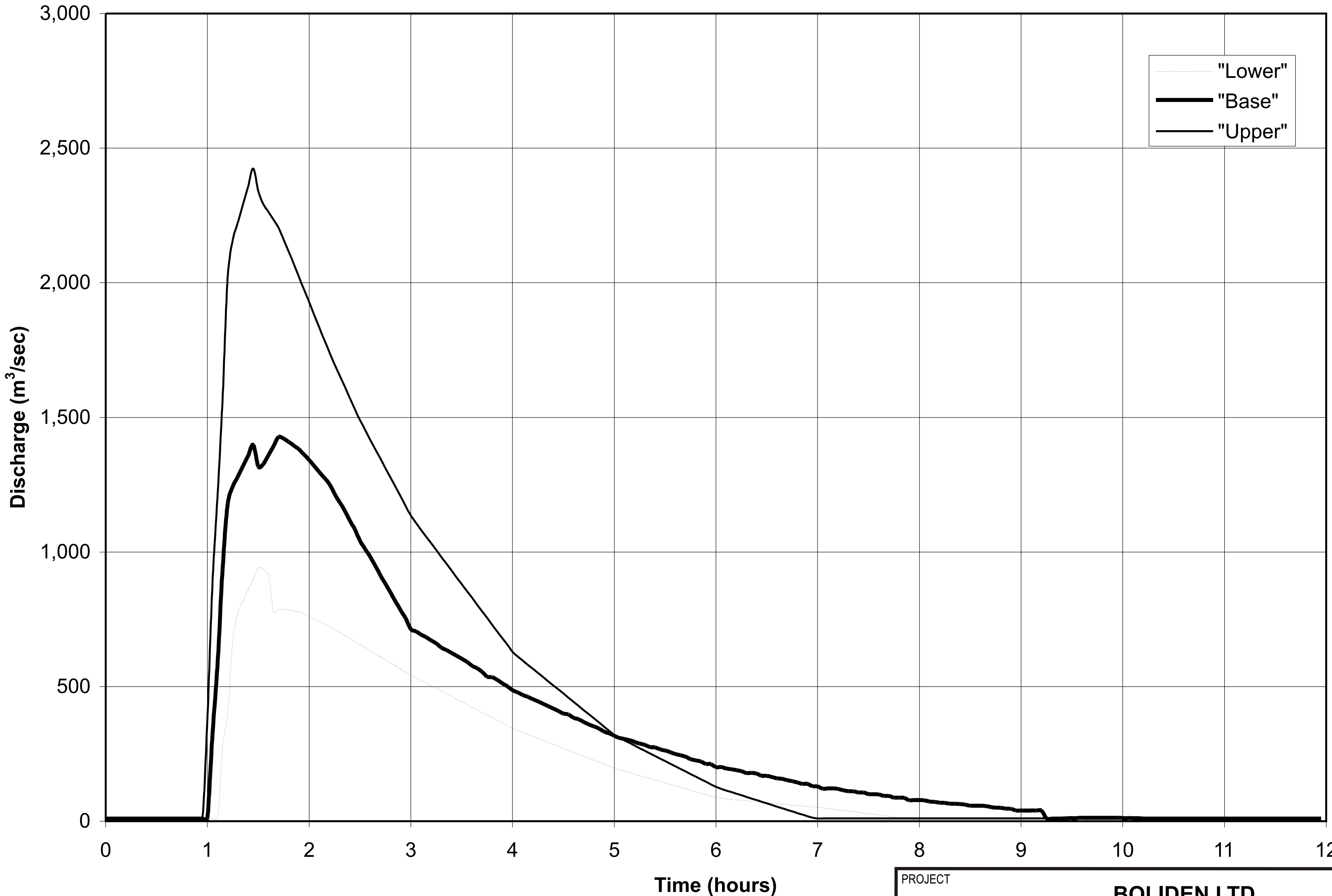


PROJECT

BOLIDEN LTD.
PREMIER GOLD MINE, STEWART, B.C.

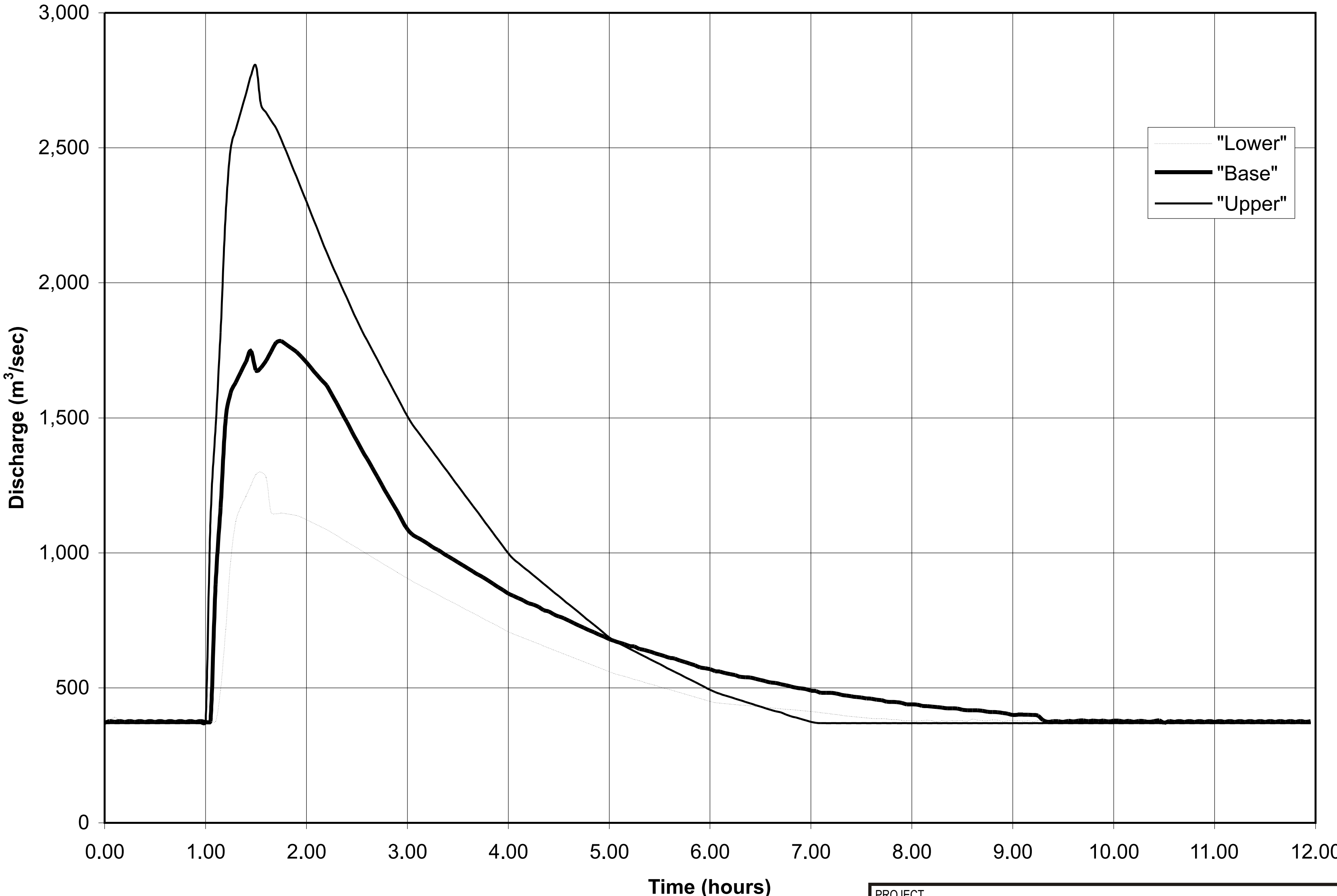
TITLE

DAM BREACH HYDROGRAPHS AT DAM

Golder Associates

PROJECT No.	04-1413-024		FILE No. FIGURES 2	
DESIGN	SGD	13JAN05	SCALE NTS	REV.
CADD	SS	13JAN05	**FIGURE 5-3**	
CHECK	SGD	13JAN05		
REVIEW				

DRAWING DATE: 13-Jan-05 COREL FILE: N:\Bur-Graphics\Projects\2004\1413\04-1413-024\Figures 2.cdr

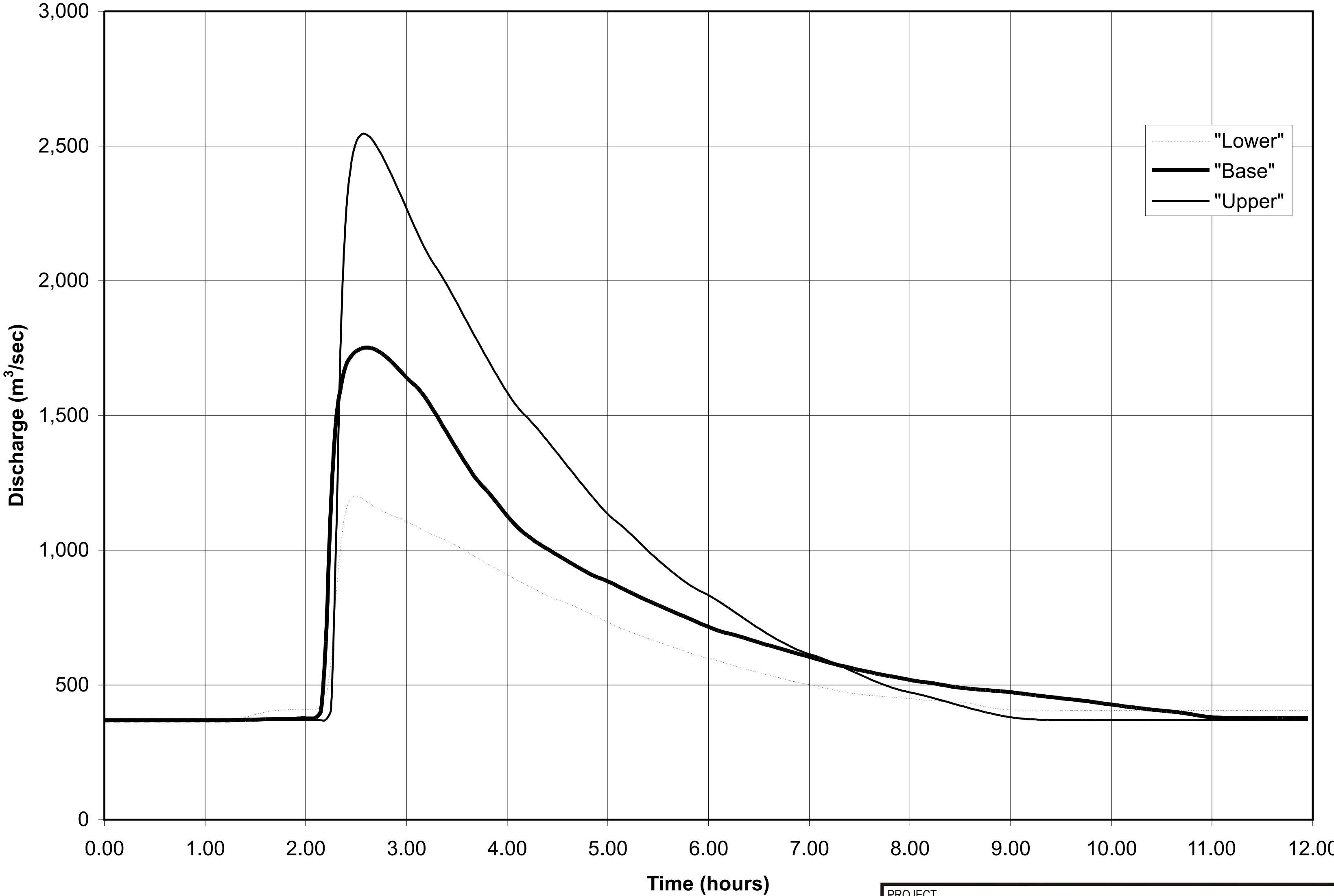


PROJECT	**BOLIDEN LTD.** **PREMIER GOLD MINE, STEWART, B.C.**
TITLE	**DAM BREACH HYDROGRAPHS AT** **LESLEY CREEK CONFLUENCE**

Golder Associates

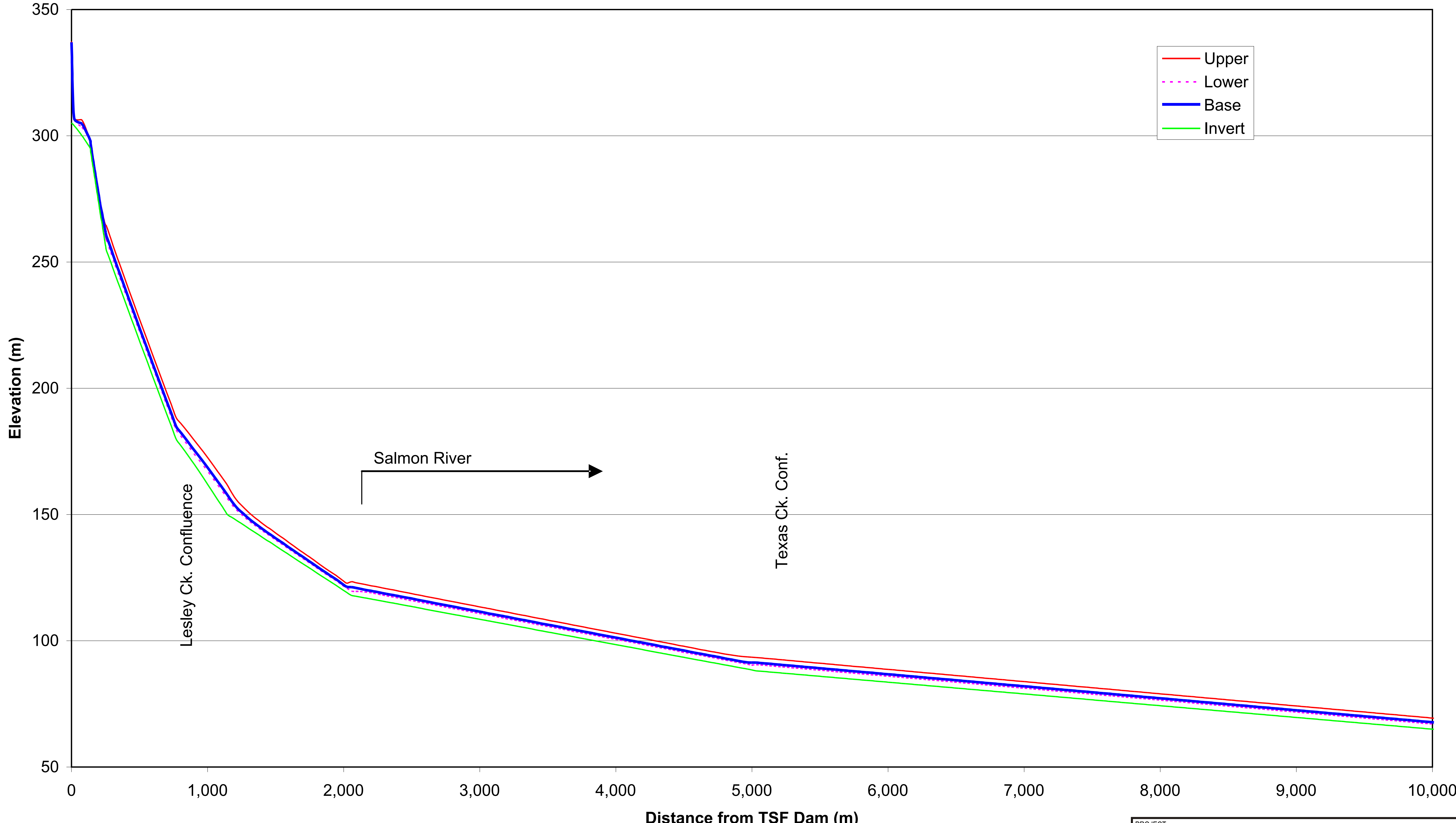
PROJECT No.	04-1413-024		FILE No. FIGURES 2	
DESIGN	SGD	13JAN05	SCALE NTS	REV.
CADD	SS	13JAN05	**FIGURE 5-4**	
CHECK	SGD	13JAN05		
REVIEW				

DRAWING DATE: 13-Jan-05 COREL FILE: N:\Bur-Graphics\Projects\2004\1413\04-1413-024\Figures 2.cdr



PROJECT	BOLIDEN LTD. PREMIER GOLD MINE, STEWART, B.C.			
TITLE	DAM BREACH HYDROGRAPHS AT SALMON RIVER MOUTH			
PROJECT No.	04-1413-024		FILE No.	FIGURES 2
DESIGN	SGD	13JAN05	SCALE NTS	REV.
CADD	SS	13JAN05		
CHECK	SGD	13JAN05	FIGURE 5-5	
REVIEW				

Golder Associates



PROJECT

BOLIDEN LTD.
PREMIER GOLD MINE, STEWART, B.C.

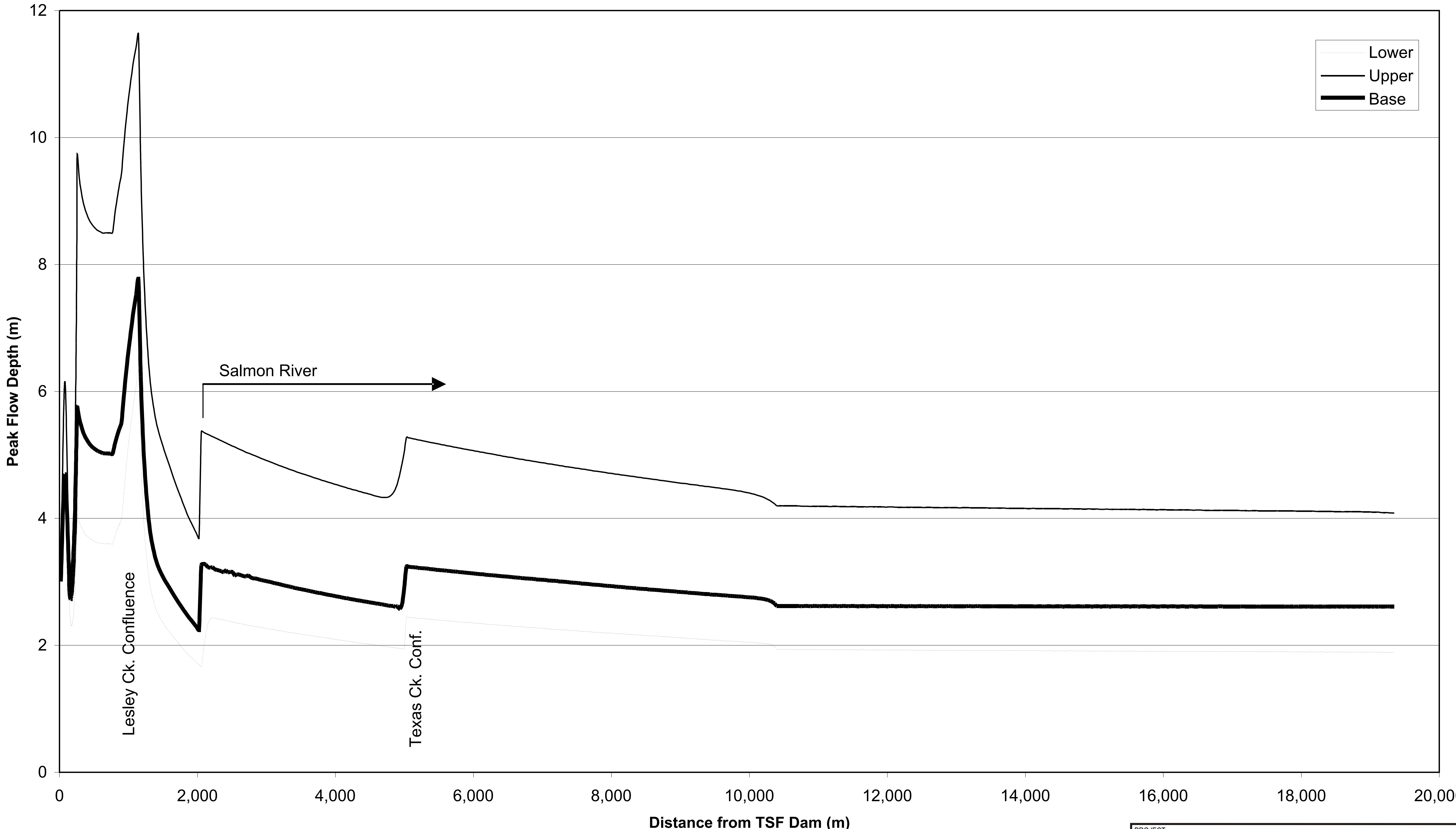
TITLE

PEAK WATER LEVEL PROFILES

PROJECT No.	04-1413-024		FILE No. FIGURES 3
DESIGN	SGD	13JAN05	SCALE NTS REV.
CADD	SS	13JAN05	**FIGURE 5-6**
CHECK	SGD	13JAN05	
REVIEW			

Golder Associates

DRAWING DATE: 13-Jan-05 COREL FILE: N:\Bur-Graphics\Projects\2004\1413\04-1413-024\Figures 3.cdr



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PROJECT

BOLIDEN LTD.
PREMIER GOLD MINE, STEWART, B.C.

TITLE

PEAK WATER DEPTH PROFILES

Golder Associates

PROJECT No.	04-1413-024		FILE No. FIGURES 3
DESIGN	SGD	13JAN05	SCALE NTS REV.
CADD	SS	13JAN05	**FIGURE 5-7**
CHECK	SGD	13JAN05	
REVIEW			

6.0 EVALUATION OF POTENTIAL DOWNSTREAM IMPACTS

6.1 Context of Model Conservatism

The foregoing modeled analyses are predicated on site data as well as various assumptions employed using professional judgement. Uncertainty is inherent in the site data due to natural variation (stochastic nature of the system) as well as imperfect data describing the site systems and processes that could cause the modeled failure modes (e.g. Long Lake dam failure). Additional uncertainty is inherent in the models themselves, which simulate the failure mode processes (e.g. inundation flow and dam breaching); this is typical of all models of natural and engineered systems.

To offset the uncertainty in the failure simulations, Golder has employed various conservative assumptions which have the effect of making the models over predict the likelihood of the failure mode. There are in fact two "layers" of conservative assumptions employed in the foregoing assessment. First, during failure mode scenario development, conservative assumptions effectively "force" a failure mode to occur (e.g., selection of seismic event required to force a dam breach at Long Lake and ultimately a dam breach at the TSF). Secondly, the subsequent hydrological models used conservative assumptions to simulate the extent or magnitude of the consequences of the event. Perhaps, the most significant uncertainty is that which relates to the failure of the Long Lake dam as a trigger for the TSF failure. Table 6.1 provides a brief summary of the more significant assumptions made in the analysis.

Discussion of the potential downstream impacts should be considered in the context of the above uncertainties and the associated conservative assumptions. Effectively, the failure mode analyses suggest the probability of the failure events are highly unlikely or have a very low to low likelihood of occurring. With this in mind, the following sections discuss the consequences that might exist, given that the failure event has occurred.

Table 6.1: Evaluation of Uncertainty and Conservative Assumptions

Assumption	Uncertainty	UNDER/OVER ESTIMATE OF RISK	Rationale
Failure Mode Scenario Assumptions			
Main embankment breach of the tailings facility. Breach of East embankment and/or spillway not considered.	Low	Over estimate	Spillway and East embankment design. Worst case scenario from a tailings run-out perspective.
Fair weather failure of the Long Lake Dam	Low	Neutral	The likelihood of a PMF failure of the Long Lake Dam is considered very low. The likelihood seismic failure coinciding with a PMF event is considered very low
Closure spillway, reverse filter berm and CCDC are in place and functional	Low	Neutral	Design parameters/capacities. Anticipated long-term maintenance and closure planning (see Table 3-1).
Tailings Run-Out Model Assumptions			
All tailings report to the confluence of Lesley Creek and Cascade Creek	High	Overestimate	Conservative assumption. Overly steep reach. Some tailings may be trapped in the steep reach; however, unable to quantify amount.
All tailings above the breach invert are available for run-out	High	Overestimate	Conservative assumption. Applicability of existing tailings volume prediction methods to TSF uncertain.

Dam Inundation Model Assumptions			
TSF spillway not modeled as part of the dam break analysis	High	Neutral - Overestimate	Conservative assumption. The magnitude of the incoming flood wave is 3.5 to 10 times the spillway capacity and the entire flood wave is accounted for below the Lesley Creek/Cascade Creek confluence.
Single breach geometry	High	Neutral	Governing factor for the outflow hydrograph is the magnitude of the inflow hydrograph and not the breach geometry
Main channel widths estimated based on field observations and limited mapping. 13 cross-sections input to model with model interpolation in between.	High	Neutral - Overestimate	Detailed topographic data unavailable for site, so approximations were required based on professional judgment.
Dam Inundation Consequence Model Assumptions			
	High	Overestimate	Comprehensive climatological and meteorological data unavailable for site, so approximations were required based on professional judgment.
	Low	Over estimate	Site-specific use patterns and weather data were unavailable, so exposure frequency was estimated
Dam Breach Consequence Model Assumptions			
	Low	Over estimate	

6.2 TSF Structure and Personnel Safety

A list of the potential impacts that would result as a consequence of the dam breach or failure are provided below. The list represents what are considered to be major site impacts. A flow of the tailings and associated flooding from a dam breach may result in the following:

1. ***Release of contaminated water from the TSF***: The water released from the TSF would result in transport of dissolved and adsorbed metals down the creek/river channel to the Salmon River. The metals concentration would in all likelihood result in adverse conditions for aquatic biota; however, the event would likely be more impacting to aquatic biota in the river channel due to physical impacts rather than chemical/contaminant actions. Eventual release of dissolved and adsorbed metals to the Salmon River would degrade the water column quality temporarily until the event attenuated. Although, deposition of dissolved metals would occur to the sediments of the Salmon River, it is likely that this effect would be smaller than the direct deposition of metals adsorbed to tailings solids that would be released from the TSF and conveyed by the flood.
2. ***Damage to the newly constructed filter berm resulting in increased groundwater seepage to the receiving environment:*** The resulting seepage and discharge of dissolved metals via groundwater to surface water would occur on a much more protracted time frame than the failure event. The scale and groundwater concentrations of contaminants in seepage has not been evaluated, but is it likely that the flow event would leave a groundwater contaminant source that would require remediation.
3. ***Exposure of the Decant Pipes and Underdrain Pipes:*** Increased groundwater seepage to the receiving environment would result. Similar to the previous item, groundwater seepage with elevated dissolved metals is likely to result. The scope of this outcome has not been predicted. It is noted that in the event of a dam breach, there will be no reverse filter and the CSP pipe would be exposed so the pipe could be easy dug out. The dam would be rebuilt to some level to re-contain the tailings and provide for a flooded environment for the tailings for the second closure.
4. ***Washout of the fuse plug spillway***: The fuse plug on the right dam abutment would in all likelihood have been washed out during the water wave from the Long Lake event. The bedrock invert of the plug is at elevation 329 m and as such the invert would be above the invert of the estimated dam breach of 294 m. The plug spillway would not erode below the rock invert and the plug spillway may or may not be rebuilt depending on the plan that is accepted to re-close the tailings facility.
5. ***Deposition of tailings solids and debris washed downstream***; The coarse debris would be redeposited in the Cascade and Lesley Creek channels, with finer sands and silts carried to Salmon River. Most of the debris would be flushed out to Salmon River during the next spring freshet.

6. ***Personal and Mine Safety:*** From a perspective of the safety on mine personnel, tailings run out will not affect the Premier Gold personnel as the tailings run out predictions indicate that tailings would not reach the exploration office where the site offices are situated. Mine staff could potentially be affected if they were working (example sampling) in the Cascade Creek spillway or lower down the system at or near Lesley Creek during the time of dam breach failure. However, we consider this to be highly unlikely because (i) sampling is only periodic and for a short time, and (ii) the failure event would likely not be "instantaneous" and the time frame for inundation of the TSF would likely provide adequate time to evacuate from a downstream position if staff were working in this area.

6.3 Ecological

Downstream of the TSF, Cascade/Lesley Creek flow into Salmon River which constitutes Alaskan waters; this waterway is considered more substantive as fish habitat, but the lower reaches of Cascade Creek are also potential habitat for small fish.

Most of the fine tailings would be carried out to Salmon River potentially reaching the Portland Canal, but some tailings may be deposited with coarser debris along the banks of the First Reach which includes the Cascade Creek. Tailings deposited in the creek channel may damage aquatic habitat both in terms of a smothering effect (e.g. benthic biota and fish spawning grounds) or in terms of metal contaminants such as copper, cadmium and zinc. Tailings left on the creek banks and the canyon will oxidize and release metals over the longer term. Water quality in Cascade Creek and the Salmon River would be compromised significantly during the event with potential toxicological consequences to aquatic biota. Although attenuation would follow the breach event, metals would continue to remain elevated above pre-event levels for some time, and episodic higher flows (e.g. from rain or prefreshet) are likely to release residual loadings stored in deposited material along the banks. It is plausible sport fish within the Salmon River may be compromised in tissue quality due to metals, however no quantitative analysis of this potential outcome has been conducted.

6.4 Stream Clean-up

Clean up of tailings deposited in Cascade Creek or exposed along the creek banks would be required. Clean up may require excavation and flushing of the creek channel to wash the debris into Salmon River which would have more assimilative capacity via dilution, however the effect on sediment quality would ideally need to be averted. An engineered depositional area within the Cascade Creek reach could potentially be needed to mitigate further solids deposition to Salmon River. Any remaining debris would likely be flushed out of the channel during subsequent spring freshets during which flows are more substantive.

6.5 Human Health

Human health effects due to contaminant release are unlikely, as knowledge of the failure would elicit communication with downstream affected parties. Besides site workers, other downstream parties that could experience consequence from the breach event are US residents at the confluence of the Salmon River and the Portland Canal (Hyder, AK), where water quality and tailings fines could reach. Risk communication and advisories are expected to be conveyed during emergency response to avert consumption of potentially affected water or fish.

7.0 CONCLUSIONS

A Dam Breach and Inundation Study was undertaken for the Premier Tailings Storage Facility for Boliden. A number of potential embankment failure mechanisms were identified. The failure mechanism that was considered with the highest potential has a low likelihood of occurring, and is the internal erosion of the embankment fill at or around the un-grouted 900 mm CSP pipe. The construction of the reverse filter has reduced the likelihood of the event, but there is still a low likelihood that this could occur. If the event (internal erosion) does occur, the possible related breaching event could only occur if there is an associated seismic event of sufficient magnitude to liquefy tailings. It is judged that this has a very low to low likelihood of occurring and if it does with the filter in place, there is a very low risk of the event causing a significant impact.

Overtopping of the TSF embankment under PMF conditions is estimated as having a very low likelihood of occurrence based on the planned perpetual maintenance of the closure spillway and Cascade Creek Diversion Channel. Failure of the Long Lake water dam is considered to be the most likely event that could potentially result in an overtopping or dam breach of the TSF embankment. This event is however assumed to have a low likelihood of occurring given the new dam will be designed to current standards and will be inspected and maintained by the new dam operators. If in the unlikely event that there is a significant dam breach at Long Lake, the flood wave resulting from a dam breach would greatly exceed the capacities of the CCDC and permanent closure TSF spillway. This would result in overtopping of the TSF embankment.

Based on case histories, a flow-slide of liquefied, saturated tailings resulting from a breach in the main embankment at Premier is not expected to come to rest in the steep portion of the valley upstream of the confluence of Cascade and Lesley Creeks. In the absence of additional flow inputs from Lesley Creek, the estimated run-out distance for the tailings flow-slide is in the order of 500 m downstream from the confluence of Lesley Creek and Cascade Creek, or roughly 1,300 m downstream of the main embankment.

The fine tailings deposited within the channel would be highly susceptible to erosion and it is expected that most of the tailings that are released as the result of a breach of the main embankment would be transported downstream to the Salmon River via Cascade Creek flows. Once re-suspended, silt and clay-sized tailings particles could remain in suspension until they reach the Portland Canal (Pacific Ocean) approximately 19 km downstream of the main embankment.

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