DAM SAFETY REVIEW OF HB MINE TAILINGS STORAGE FACILITY SALMO, BC

PRESENTED TO

Regional District of the Central Kootenay

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EXECUTIVE SUMMARY

The Regional District of Central Kootenay (RDCK) retained Tetra Tech EBA Inc., formerly known as EBA Engineering Consultants Ltd. to undertake a Dam Safety Review (DSR) for the Hudson Bay Mine tailings storage facility (HB dam) located near Salmo, BC.

Design, operation, closure, and reclamation of Mine Tailings Dams and Impoundments in British Columbia is regulated by the Health, Safety and Reclamation Code for Mines in British Columbia (2008) under the Mines Act (2003), which requires that all major impoundments, water management facilities and dams be designed in accordance with the criteria provided in the Canadian Dam Association (CDA), Dam Safety Guidelines (2007).

Based on the results of the investigation, analyses and assessment of the dam, a series of conclusions and recommendations were developed during the Dam Safety Review of this facility as summarized in the following Dam Safety Review Conclusions and Recommendations Table. Priorities (Low, Medium, High or Very High) are given in parentheses. Low, medium, high and very high priority recommendations should be addressed within 5, 3, 1 and 0.5 year(s) respectively.

Dam Safety Review of HB Mine Tailings Storage Facility – Observations, Conclusions and Recommendations

Task	Observations & Conclusions	Recommendations
Background Review	▪ The original dam design drawings were prepared using different assumed datums. ▪ Seepage at the toe of the dam has been noted throughout the life of the dam. ▪ The dam filter zone does not extended to above the maximum pond operating level. ▪ Burrowing from animal activity has been noted on the downstream slope of the dam has been noted throughout the life of the dam. ▪ No obvious signs of historical or current slope instability of the reservoir sides slopes were observed in the review of the available aerial photography.	▪ An updated drawing of the 2012 topographical survey of the dam should be prepared, utilizing mean sea level as the elevation datum, to avoid confusion with previous surveys and enable better correlation with historical data (High).
Site Reconnaissance	▪ Some brush vegetation is growing in the upstream slope of the dam. ▪ Minor rutting from vehicle traffic noted on the dam crest. ▪ Minor animal activity (tracks) was noted on the dam crest. ▪ The spillway channel inlet has no log boom. ▪ Noted rip-rap protection missing in spillway outlet channel.	▪ The brushy vegetation of the upstream slope of the dam should be removed (High). ▪ The rip-rap protection missing in spillway outlet channel should be replaced (Very High). ▪ A log boom should be installed across the spillway inlet channel entrance (Very High).
Consequence Classification	▪ The dam breach inundation mapping indicates that a total area of approximately 0.73 km^2 would be impacted in the event of a dam breach, including the Crowsnest Highway (BC 3) depositing approximately 714,000 m^3 of tailings. ▪ One permanent residence and the Crowsnest Highway where there is likely to be a temporary population are situated in the immediate downstream flood inundation zone where flood levels are expected to reach several metres, where an estimated potential loss of life of three people would occur in the event of a dam breach assuming a warning of less than 15 minutes. ▪ Economic consequences resulting from an failure of the embankment including, cleanup of deposited tailings, restoration of contaminated land and reconstruction of the HB Dam have estimated to be in the range of $45.7 M to $83.4 M.	▪ Based on the estimated economic loses that would occur due to a breach of the dam it is recommended that the consequence classification of the HB Dam is increased to "Very High". However any decision to modify the consequence classification rating must be confirmed by the Ministry of Energy and Mines (Very High).
Failure Mode Assessment	▪ The plausible failure modes of the dam are; overtopping, post seismic upstream and downstream slope instability and internal erosion through the embankment.	▪ There are no recommendations in this area of review.
Geotechnical Assessment	▪ Liquefaction induced vertical settlements of no greater than 225 mm would occur assuming that all of the 1955 embankment fill layer could liquefy. ▪ Results of the static stability analysis indicated that the embankment meets CDA criteria for normal static and seismic loading conditions. ▪ The dam is assumed to be Zoning Category 3 and therefore vulnerable to internal erosion based on zoning with the embankment materials likely to comprise silty sands and gravels with less than 30% fines that are extremely erodible. Based on the results of the internal erosion screening assessment potential failure modes could include; backward erosion and suffusion of the core; a crack or concentrated leak could form due to, desiccation by drying in the crest, due to freezing in the crest, and the presences of conduits through the embankment and poorly compacted fills.	▪ A feasibility engineering study should be undertaken to assess various modifications that could be made to the embankment to reduce its vulnerability to internal erosion. Depending on the outcome of this study it is possible that a geotechnical investigation would be required during detailed design to confirm the geotechnical properties of the existing dam filter and core materials (Medium).
Hydrotechnical Assessment	▪ Dam breach analysis results indicate that the HB Dam should have a "Very High" consequence classification. The CDA guidelines recommend an Inflow Design Flood (IDF) for a "Very High" consequence dam of ⅔ of the way between a 1,000-year flood and the Probable Maximum Flood (PMF). The peak inflow to the HB Dam during the IDF was determined to be 39.3 m^3/s, which would be safely passed by the spillway. ▪ The dam should have freeboard such that 95% of the waves do not overtop the dam crest during a 1,000-year wind event under maximum normal reservoir conditions or during a 2-year wind event under design flood conditions (IDF). These values were calculated at 1.09 m and 0.38 m, respectively. ▪ The HB Dam does have enough available freeboard to meet the minimum requirement for the design flood considered ("Very High") and would not be overtopped by waves from a 1,000-year wind event under normal reservoir conditions.	▪ There are no recommendations in this area of review.
Dam Safety Management	▪ The existing EPP and OMS Manual have not been updated since they were put together in 2011. Multiple changes have occurred since these documents were put together, including, changes of personnel, modification of the embankment and spillway, addition of extra instrumentation and changes to design criteria.	▪ The existing EPP and OMS Manual should be updated to reflect changes that have occurred since these documents were put together, incorporate additional information developed and any changes of personnel that may have occurred (Very High).

TABLE OF CONTENTS

APPENDIX SECTIONS

FIGURES

PHOTOGRAPHS

APPENDICES

ACRONYMS & ABBREVIATIONS

AEP	Annual Exceedance Probability
ALARP	As Low As Reasonably Practicable
AMSL	Above Mean Sea Level
APEGBC	Association of Professional Engineers and Geoscientists of British Columbia
BC MoE	British Columbia Ministry of Environment
CDA	Canadian Dam Association
CSR	Cyclic Stress Ratio
CSRS	Canadian Spatial Reference System
DBE	Dam Breach Elevation
DDSP	Directive for Dam Safety Program
DSG	Dam Safety Guidelines, Canadian Dam Association 2007
DSR	Dam Safety Review
DTM	Digital Terrain Model
EDGM	Earthquake Design Ground Motion
EPP	Emergency Preparedness Plan
ERP	Emergency Response Plan
FEMA	Federal Emergency Management Agency
GPS	Global Positioning System
GSC	Geological Survey of Canada
HEC-HMS	Hydrologic Modeling System
ICOLD	International Congress on Large Dams
IDF	Inflow Design Flood
IDF	Intensity-Duration-Frequency
LOL	Loss of Life
MEM	Ministry of Energy and Mines
MFLNRO	Ministry of Forests, Lands and Natural Resource Operations
MSC	Meteorological Service of Canada
NBCC	National Building Code of Canada
OMS	Operations, Maintenance and Surveillance
PAR	Population at Risk
PGA	Peak Ground Acceleration
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PPP	Precise Point Positioning
RDCK	Regional District of Kootenay Boundary
$S_a(T)$	Spectral Accelerations
SCS	US Soil Conservation Service
SMPDBK	Simplified Dam-Break
TSF	Tailings Storage Facility
US	United States
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey

LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Regional District of Central Kootenay and their agents. Tetra Tech EBA Inc. (Tetra Tech EBA) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than Regional District of Central Kootenay, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this report is subject to the terms and conditions stated in Tetra Tech EBA's Services Agreement. Tetra Tech EBA's General Conditions are provided in Appendix H of this report.

1.0 INTRODUCTION

1.1 General

The Regional District of Kootenay Boundary (RDKB) retained Tetra Tech EBA Inc., formerly known as EBA Engineering Consultants Ltd. (Tetra Tech EBA) to undertake a Dam Safety Review (DSR) of the Hudson Bay Mine tailings storage facility (HB Dam) near Salmo, BC.

A Dam Safety Review is considered to be a "snapshot in time" and the observations, conclusions, and recommendations provided in this report are deemed to be valid until the next scheduled Dam Safety Review, which should be conducted in 5 years (2018-19) for the HB Dam. However, if conditions (e.g., loading, reservoir level, etc.) change, results from this DSR may no longer be considered valid and/or current and a reassessment may be required.

Design, operation, closure, and reclamation of Mine Tailings Dams and Impoundments in British Columbia is regulated by the Health, Safety and Reclamation Code for Mines in British Columbia (2008) under the Mines Act (2003), while the BC Water Act (1996) regulates the licensing, diversion and use of water.

The Health, Safety and Reclamation Code for Mines in British Columbia (2008) requires that all major impoundments, water management facilities and dams be designed in accordance with the criteria provided in the Canadian Dam Association (CDA), Dam Safety Guidelines (2007), while the BC Water Act including all amendments up to BC Reg. 234/2013 (November 2013) requires all impoundments and dams be designed in accordance with the requirements of the BC Dam Safety Regulation including all amendments up to BC Reg. 163/2011 (November 30, 2011).

It is understood that activities at the site are conducted under Mine Permit Number M-218.

The dam is currently classified as a "Low" consequence dam based on application of the CDA 1999 Dam Safety Guidelines by BCG Engineering (BCG) during the last dam safety review in 2002, which equates to a "Significant" consequence dam in terms of the CDA 2007 Dam Safety Guidelines. A "Significant" classification (CDA 2007) suggests that in the event of a dam failure, no fatalities to the permanent population are anticipated and only limited socioeconomic, financial and environmental damages are expected.

The objective of the above Regulations and Guidelines is to mitigate loss of life, as well as damage to property and the environment from a dam breach, requiring dam owners to undertake the following, and other, activities:

- Operate the dam in a safe manner.
- Regularly inspect their dams.
- Develop and follow an up-to-date Operation, Maintenance and Surveillance (OMS) Manual, Emergency Preparedness Plan (EPP), and Emergency Response Plan (ERP).
- Undertake proper maintenance.
- Report incidents and take remedial action.
- Undertake periodic Dam Safety Reviews.

1.2 Site Description

Hudson Bay (HB) Dam is a zoned earthfill dam that is situated approximately 7 km to the south of the Township of Salmo, and 0.5 km east of the Crowsnest Highway (BC 3) at approximately Map Grid (NAD83), Zone 11 co-ordinates 481841E, 5442021N, as shown on the attached Figure 1.2. The dam is located in a natural valley, and the water from the impoundment discharges into a creek that is a tributary of the Salmo River.

The dam, which currently impounds water and tailings, has a crest length of approximately 240 m and a maximum height of 27 m from the toe to the crest at an elevation of approximately 713 m above mean sea level (Based on Shuttle Radar Topography Mission (SRTM)).

1.3 Operation, Maintenance and Surveillance

We understand that the day-to-day operation and maintenance of HB Dam is overseen by the RDCK Environmental Services department.

An Operation, Maintenance, and Surveillance (OMS) Manual and Emergency Preparedness Plans (EPP), which are followed by the RDCK Environmental Services Department, were developed for the dam in 2008 by Conestoga-Rovers & Associates (CRA).

From discussions with RDCK Environmental Services staff members, it is understood that documented inspections of the dam are undertaken on a weekly to semi-monthly basis including reading of the dam instrumentation using a customized inspection form contained within the OMS.

2.0 SCOPE OF WORK

Tetra Tech EBA's scope of work for this Dam Safety Review was developed in accordance with the requirements of the CDA Dam Safety Guidelines (2007). In summary, the study included the following tasks:

- Background review.
- Site reconnaissance.
- Review of consequence classification.
- Hydrotechnical analysis including hydrological analysis, dam break analysis, flood routing and hydraulics.
- Geotechnical assessment, including embankment stability and seepage.
- Review of any current Maintenance and Surveillance Manual.
- Review of any current Emergency Preparedness Plan.
- Review of any public safety management strategies.
- Assessment of compliance with CDA Principles.
- Development of conclusions and recommendations.

The results of each task are detailed in the following sections.

3.0 BACKGROUND REVIEW

3.1 Sources of Information

The following sources of background information were reviewed during the dam safety review:

- Historic aerial photographs.
- Readily available published sources of geological data.
- Available documentation associated with the dam including, drawings, reports and documented inspections of the dam.

A list of the available documentation associated with the dam at the time of this Dam Safety Review is summarized in the attached Appendix A, including that which was sourced from a search of BC Ministry of Energy and Mines (MEM) files.

3.2 Design, Construction and Modification

The Hudson Bay (HB) Dam was initially constructed in 1955 in order to retain and store lead and zinc tailings produced by the HB Mine, which was in operation from 1955 to 1966 and resumed again between 1974 and 1978. The dam was raised progressively during the mine life to accommodate the influx of tailings from the mine, via downstream construction methods, with fill added to the crest and downstream slope of the dam.

The dam is an earthfill embankment that was constructed utilizing materials borrowed from beyond its east and west abutments. The material from the east and west abutment vary slightly, with the materials from the east typically comprising silty fine to medium sand, while the materials from the west is typically a well graded till (silt, sand, gravel, cobbles, and boulders).

The initial dam crest was at 759 m (2492 ft.), and was constructed with an earthfilled timber crib wall at the base of the downstream toe. In 1964 the timber crib failed and deformed 3 to 4.6 m downstream. After this failure, concrete pipe drains were added to the downstream toe of the dam, and an earthfill berm was constructed to stabilize the crib structure. In 1967 the dam crest was at a height of 762 m (2500 ft.) from progressive raises during the mine life.

The flow of water from the upstream to the downstream was controlled via two timber decant towers and two 600 mm (24 inch) diameter steel pipes discharging into the outlet creek.

In 1973, prior to the resumption of mining activities Cominco retained Golder Associates Ltd. (Golder) to perform stability analyses on the tailings dam. The investigation comprised the drilling of three boreholes, which were drilled through the dam and into its foundation. One borehole was located on the dam’s crest and two were drilled on the downstream slope of the dam, with standpipe piezometers installed in these three boreholes. Standard penetration testing (SPT) was performed during the drilling program with an average SPT N value of 10 blows/ft. established for the dam material. The depth to bedrock below was established to be 20.72 m below the existing dam crest. The Golder borehole logs and associated laboratory testing data can be found in the attached Appendix B1, with the approximate borehole locations shown on Figure 3.6.

In 1974 report Golder recommended that a downstream filter blanket be constructed and that the dam should be raised by the downstream method. Based on this recommendation the dam was raised 3.05 m (10 ft.) and the downstream filter blanket was constructed between 1974 and 1975. In 1976 Cominco retained Golder to perform an assessment of the area surrounding the dam to assess potential borrow materials, as well as to assess the dam stability for future dam extensions. Based on this study the dam was raised 4.57 m (15 ft.) in 1977. In addition to the raising of the dam in 1977 the decant towers were filled with concrete and replaced with a new spillway and manhole, the manhole structure comprised a 915 mm (36 inch) diameter steel pipe designed to pass a maximum flow of 2.26 m^3/second.

In 1981 David Minerals retained Klohn Leonoff Consulting Engineers (KL) to investigate the feasibility of the using the HB Dam to deposit one million tonnes of tailings. This report concluded that the existing structure had an available storage capacity for 790,000 tonnes of tailings. Based on anecdotal evidence these additional tailings were placed in the HB Dam impoundment.

In 2000 RDCK commissioned BGC Engineering Consultants (BGC) to prepare a decommissioning plan for HB Dam. BGC undertook a geotechnical site investigation that comprised the drilling of two boreholes holes and eight testpits, which can be found in that attached Appendix B2 as well as a site survey. A pond sounding was conducted in the fall of 2000, which indicated that the maximum available storage to the dam crest was 200,000 m^3. The primary source of water recharge to the tailings pond is surface runoff. Based on the study BGC recommended:

- Construction of an open channel spillway and decommissioning of the 1977 spillway.
- Construction of a 10 m wide toe berm to meet the dam stability requirements.
- Construction of a 1.5 m thick rockfill blanket to provide adequate drainage.
- The addition of rip-rap to upstream slopes.

The ‘decommissioning’ of the dam was undertaken in 2005 in accordance with the recommendations provided by BGC in their 2000 report, in addition to this work the crest of the dam was re-graded with a camber. The dimensions of the dam post ‘decommissioning’ were:

- 240 m long
- 25 m high, with a crest elevation of approximately 713 m AMSL
- Crest width of between 6 and 7 m
- Overall upstream slope of 1.5H:1V and Downstream slope of 2H:1V

The toe berm dimensions were:

- 12 m wide
- 12 m high
- Downstream slope of 2.5H:1V

The new spillway consisted of a 90 m long side channel excavated into bedrock at the right abutment and a rip-rap lined outlet channel approximately 120 m long.

During the early summer of 2012, an embankment slough occurred sometime between routine inspections that were conducted on June 25, 2012 and July 2, 2012. On July 6, 2012 the presence of a sinkhole (SH-1) was identified at the toe of the upstream face of the embankment and on July 18, 2012 a second sinkhole (SH-2) was discovered approximately 12 m west of the first identified sinkhole. These sinkholes were only detected once the water level of the pond was sufficiently reduced to expose the features completely. A 50 mm diameter standpipe was found at the location of SH-1, which had not been recorded in previous reports and had also not been properly decommissioned. It was confirmed that a continuous seepage path existed between SH-1 and SH-2. The standpipe was removed to a depth of 4 m and core material was placed in 300 mm lifts to the crest and upstream slope elevations.

The embankment slough was repaired by reconstructing the core material to its original height and width using locally sourced glacial till. A shear key was built at the toe of the sloughed area and a coarse rock blanket was placed over on the downstream face of the reconstructed core material, a v-notch weir was also installed at the toe of the dam (Tetra Tech EBA 2012).

3.3 Historical Aerial Photography

A review of the historical aerial photographs of the HB Dam area held by the Geography Department of the University of British Columbia (UBC) was undertaken. Table 3.3 shows the aerial photos that were reviewed.

Table 3.3: Summary of Aerial Photographs Reviewed of the HB Dam Area

Year	Aerial Photo No.	Type
1951	BC 1313:7/8	Black and white – vertical
1969	BC5348–234/235	Black and white – vertical
1973	BC7461–112/113	Black and white – vertical
1978	BC78073–213/214	Black and white – vertical
1990	30BCB90033–174/175	Black and white – vertical
1998	30BCC98043–186/187	Colour – vertical
2005	30BCC05138–024	Colour – vertical

The review of the available historical aerial photographs examined the historical condition of the dam and impoundment side slopes. The review noted:

- The earliest available aerial photograph was prior to the initial construction of the dam indicating the nature of the original surface conditions.
- Several different stages of the dam construction are evident.
- No obvious signs of historical or current slope instability of the impoundment sides slopes were observed in the review.

The attached Figure 3.3 resents a sequence of aerial photographs taken from years 1951, 1969, 1978, 1990, 1998, and 2005.

3.4 Geological Setting

The HB Dam site is located in the Omenica Belt in south central British Columbia. Geological maps from the British Columbia Geological Society (BCGS, 2013) indicate that the bedrock underlying HB Dam is Cretaceous age Anstey Pluton, which is a granodiorite intrusive complex. The dam is however located proximal to a contact between the Anstey Pluton and Laid Formation sedimentary rocks – phyllite, argillite, schist, etc. The BGC, 2000 report, assumes that the bedrock underlying the site is composed of phyllite and cites the Canex Landfill (adjacent to the impoundment), study performed by Klohn-Crippenberger, 2000.

Borehole logs from Golder, 1973 and BGC, 2000 show that bedrock is typically 5.5 m below the natural ground surface and dips slightly to the south. The native soil underlying the dam is generally comprised of dense, glaciolacustrine, sandy silt, and silty clay.

3.5 Seismicity

The Geological Survey of Canada (GSC) has produced three probabilistic seismic hazard models and one deterministic seismic hazard model (Halchuk and Adams 2008) that form the basis of the seismic design provisions of the 2010 National Building Code of Canada (NBCC 2010). To capture epistemic uncertainty in source, two complete probabilistic seismic hazard models were created for Canada, with one model considering relatively small source zones drawn around historical clusters of seismicity and the other model considering larger regional zones reflecting seismotectonic units. The third probabilistic model was developed for the relatively aseismic central part of Canada and is based on global continental earthquake activity rates. The deterministic seismic hazard model considers a line source with a magnitude of 8.2 and depth of 25 km on the Cascadia subduction zone. The seismic design parameters provided in the NBCC 2010 are based on the highest value from the four models for each grid point assessed across Canada.

Based on the surficial geology of the area and the existing borehole logs, which indicate shallow bedrock, the site classification for seismic response for the HB Dam site is likely to be Site Class C. Peak Ground Accelerations (PGA) and Spectral Accelerations (S_a(T)) for a reference "Class C" site (very dense soil and soft rock) can be obtained from the Earthquakes Canada website (http://earthquakescanada.nrcan.gc.ca) for various return periods, with the reference values for the HB Dam summarized in Table 3.5a below.

Table 3.5a: Site Class C Design PGA and S_a for HB Dam, Salmo, BC

Annual Exceedance Probability (AEP)	PGA (g)	S_a(0.2)	S_a(0.5)	S_a(1.0)	S_a(2.0)
1/475 year	0.069	0.128	0.077	0.038	0.021
1/1,000 year	0.095	0.183	0.109	0.054	0.030
1/2,475 year	0.136	0.272	0.163	0.080	0.045

For seismic hazards with very low probabilities (i.e. greater than 2,475 years) the GSC recommends plotting the annual probability versus acceleration of the 1/475 year and 1/2475 year values on a log-log scale and extrapolating the line to the required return period. Extrapolated site "Class C" Peak Ground Accelerations (PGA) and Spectral Accelerations (S_a(T)) reference values for HB Dam are summarized in Table 3.5b below.

Table 3.5b: Extrapolated Site Class C Design PGA and S_a for HB Dam, Penticton, BC

Annual Exceedance Probability (AEP)	PGA (g)	Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)
1/5,000 year	0.182	0.378	0.226	0.109	0.060
1/10,000 year	0.242	0.517	0.308	0.149	0.082

With respect to selection of earthquake design magnitudes the CDA Technical Bulletin, Seismic Hazard Considerations for Dam Safety recommends utilising the greater of the mean magnitude, modal magnitude or the 84th percentile of the total magnitude contributions when considering multiple seismogenic probabilistic seismic hazards.

The relative contribution of the earthquake sources to the seismic hazard in terms of distance and magnitude can be obtained by deaggregation of the seismic hazard result. The deaggregation data for the NBCC 2010 design model has been obtained from Earthquakes Canada, which provides the mean and modal magnitude of the seismic hazard for the HB Dam as summarized in Table 3.5c below.

Table 3.5c: Design Earthquake Magnitudes for the HB Dam, Salmo, BC

Magnitude Contributions	PGA	Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)
Mean	5.70	5.89	6.01	6.14	6.20
Modal	5.125	5.875	6.375	6.875	6.875
84th Percentile	6.625	6.625	6.625	6.875	6.875

3.6 Existing Drawings

A review of existing documentation indicated that there are a number of as-built drawings for HB Dam, which can be found in the attached Appendix C. Starting with the most recent, below, are a summary of available as-built drawings:

- A survey conducted by Ward dated April 15, 2013 was undertaken after the reconstruction of the dam face after the slough failure and development of sinkholes. This survey includes dam crest elevations, new spillway invert, and settlement monuments. The survey was tied to a local datum.
- As-built figures of the facility after the ‘decommissioning’ plan was completed are included in the Operation, Maintenance and Surveillance Manual (CRA 2008). These drawings illustrate the as-built toe berm and spillway channel. Note that the spillway was lowered in 2012 and the datum does not match the survey undertaken by Ward.
- As-built figures of the facility prior to the ‘decommissioning’ plan are included in the HB Mine Tailings Pond and Dyke Decommissioning Plan (BGC 2002).

The original design drawings of the dam are presented on the attached Appendix B. Review of these drawings indicated that available as-builts are referenced to two different local datums and not to a geodetic elevation and it was also noted that the dam filter did not extend above the maximum pond operating level. Table 3.6 summarizes the surveyed dam crest elevation based on available as-built drawings.

Table 3.6: Dam Crest Elevation Comparison

Source of Drawings	Crest Elevation
Ward Engineering Survey (April 2013)	109.31 m
Operation, Maintenance and Surveillance Manual (2008)	85 m
Decommissioning Plan (2002)	2520 ft. (768.10 m)
Available Topographic Data* - Assumed Geodetic Elevation	713 m

Note: * Data based on Shuttle Radar Topography Mission (SRTM)

3.7 Instrumentation

A total of five piezometers are currently being monitored on the downstream slope of the dam to measure hydrostatic pressure within the dam (Piezometer P4 was decommissioned in 2005).

A new surface water staff gauge was installed on the east side of the facility to monitor pond water levels and an overflow v-notch weir is located downstream of the embankment to monitor dam seepage.

The locations of the piezometers are shown on the attached Figure 3.7a and the water level readings can be seen on the attached Figure 3.7b. Review of the data for the past 12 months indicates that there is an approximate correlation between the pond level and the hydrostatic pressures in the embankment.

3.8 Dam Inspection and Investigation Reports

A review was undertaken of available, more recent dam inspection reports undertaken by RDCK Environmental Services Staff as well as historic reports contained within the BC Ministry of Energy and Mines (MEM) files.

Key points from Tetra Tech EBA's review of existing inspection and investigation reports are as follows:

- Seepage at the toe of the dam has been noted throughout the life of the dam.
- The dam filter zone does not extended above the maximum pond operating level.
- Burrowing from animal activity has been noted on the downstream slope of the dam has been noted throughout the life of the dam.

4.0 SITE RECONNAISSANCE

A site reconnaissance of the HB Dam was conducted by Tetra Tech EBA on June 26, 2013. Tetra Tech EBA's site representatives were Mr. Brian Cutts, P.Eng., Dr. Adrian Chantler, P.Eng., and Ms. Sarah Portelance, E.I.T. They were accompanied by Ms. Amy Wilson of the RDCK.

Tetra Tech EBA inspected the crest, upstream slope, downstream slope, spillway, spillway chute, downstream toe, outlet (creek downstream) of the dam and the dam access road. Photographs 1 through 9 show the HB Dam at the time of the site reconnaissance. It was also observed that at the time of the inspection, the spillway was discharging and the reservoir was approximately 0.19 m above the spillway invert.

Key observations are as follows:

- The reservoir level was approximately 0.19 m above the spillway invert (Photo 6).
- Spillway width was measured as 1.7 m at the base (Photo 4).
- Some brush vegetation is growing in the upstream slope of the dam (Photo 2).
- Minor rutting from vehicle was traffic noted on the dam crest (Photo 1).
- Minor animal activity (tracks) was noted on the dam crest (Photo 1).
- Noted rip-rap protection missing in spillway outlet channel (Photo 5).
- Timber decant structure falling apart (Photo 7).

5.0 DAM BREAK ANALYSIS

The consequence classification of a dam depends on the incremental consequences of a dam failure, and this can be the result of overtopping, slope failure, a piping failure, or an earthquake. A dam break analysis, including characterization of a hypothetical dam breach, flood wave routing, and inundation mapping, was carried out as part of this review.

The characterization of the dam breach and initial flood hydrograph was conducted using the US National Weather Service Breach Erosion Model (BREACH). The BREACH model was used to evaluate breach opening, time of dam failure and the subsequent breach flow into the downstream creek. As the breach outflow will be composed of a mixture of water and sediment (tailings), flood wave routing was conducted using FLO-2D, a 2-dimensional model that has the ability to model non-Newtonian flows.

Pond soundings were carried out in 2000, which indicated that the lowest point in the pond was approximately at an elevation of 707.5 m AMSL (79.5 m BGC local datum). It was estimated that approximately 200,000 m³ of water storage is available within the pond up to the dam crest elevation of 713 m. Figure 5.0a shows the relationship between pond elevation and water storage volume of the reservoir.

Based on reports available at the time of the study, there is no information on the total volume of tailings deposited during mining operations. It is believed that the thickness of tailings ranges from 1.5 m at the northwest edge to greater than 20 m at the dam. The tailings have been described as fine grained and non-acid generating based on neutralization acid potential ratios of over 4.0 (Conestoga Rover 2008). To estimate the volume of tailings, available topographical data, aerial images and Civil 3D software were used to estimate the total volume of tailings. Figure 5.0b illustrates the volume curve from the toe of the dam (686 m AMSL) to a maximum elevation of 713 m (dam crest elevation). With the knowledge that approximately 200,000 m³ of water is impounded, it was estimated that 1,618,000 m³ of tailings are retained by the HB dam.

Based on historical tailings storage facility failures, it has been observed that only part of the tailings and stored water is released. The determination of the total outflow is difficult to evaluate accurately. As tailings are more viscous than water and not as free flowing, not all tailings are released from the impoundment (Dalpatram, 2011). Rico et al (2007) compiled available information on historical tailings dam failures and determined that in most failure cases, tailings ponds are not emptied and only a limited portion of tailings is released. Based on observed historical cases, Rico et al (2007) were able to correlate the total stored volume at the time of failure with the tailings outflow volume. Figure 5.0c illustrates an envelope curve indicating the potential maximum volume of tailings released downstream and an average curve where only a portion of tailings are released.

As historical observations suggest, it is not expected that 100% of tailings from the HB Dam would be released. Based on the illustrated average curve in Figure 5.0b for a total mixed volume of 1.8 million m³ stored in the HB reservoir, approximately 39% of the total volume (713,992 m³) is estimated to be released in the event of a dam failure. Figure 5.0d illustrates an assumed breach slope where approximately 1.1 million m³ of tailings remains impounded after the breach of HB Dam. This was estimated using Civil 3D and it was determined that the dam would breach to an elevation of 697.2 m (approximately 10.3 m lower than the bottom of the water pond. A summary of the overall dam breach parameters is provided in Table 5.0a.

Table 5.0a: Summary of Dam Breach Parameters

Dam Breach Parameter		Value (Note)
Type of Dam		Earth Embankment
Non-Breach Flow		3.2 m³/s (2-year flood)
Dam Breach Elevation (DBE)		713 m AMSL (at dam crest, overtopping failure)
Final Breach Elevation *		697 m AMSL (assumed toe of the breach profile)
Volume of Reservoir at Breach *		1,817,812 m³ (tailings plus water)
Reservoir Surface Area at Breach *		120,320 m²
Width of Crest		6.0 m
Length of Crest		240 m
Dam Face Slopes	(BGC 2002)	1:2
D_{50} Grain Size	(BGC 2002)	0.086 mm

Table 5.0a: Summary of Dam Breach Parameters

Dam Breach Parameter		Value (Note)
Porosity Ratio	(Bell 1992)	0.46
Unit Weight	(BREACH Guidelines)	100 lb/ft^3 (2373 kg m²)
Internal Friction³	(BGC 2002)	35.5°
Cohesive Strength	(BREACH Guidelines)	360 lb/ft^2 (8542 kg m²)
Volume of Tailings Remaining **		1,103,820 m³
Outflow Breach Volume (m³) **		713,992 m³
Final Breach Width (m) **		14.7 m
Breach Formation Time **		0.18 h
Peak Flow **		2115 m³/sec

Note: * Estimated using Civil3D
** Evaluated using BREACH

To account for non-Newtonian flows, flood modelling was conducted using FLO-2D, a 2-dimensional model that has the ability to simulate mudflows. One metre DTM point data was obtained based on Google Earth topography and used to generate a surface from the HB Dam site to the downstream Crowsnest Highway and Kettle River.

Water and tailings mixtures (mud flood) have fluid properties different from pure water (e.g. unit weight, dynamic viscosity, and initial shear stress) and will affect modelled hydraulic parameters such as flow depth, flow velocity, and time to peak. Commodities produced from 1912 to 1978 included lead, zinc, silver, cadmium, copper, gold and talc. Table 5.0b summarizes the water/tailings mixture properties in the HB Dam reservoir assuming fully mixed conditions and used in the FLO-2D model.

Table 5.0b: Summary of Water/Tailings Mixture Properties

Properties	Value
Tailings Specific Gravity [1]	2.9
Tailings Sediment Concentration [1]	0.56
Volume of Tailings	513,992 m³
Volume of Water	200,000 m³
Mud Flood Specific Gravity	2.4
Mud Flood Sediment Concentration	0.40
Viscosity of Mud Flood [2]	16.1 Pa-sec
Shear Stress of Mud Flood [2]	17.2 Pa

Note: [1] Literature value for a lead/zinc tailing composition (Vick 1976)
[2] Reference (FLO-2D Guidelines)

Figure 5.0e presents the results of the flood extents and final depth of flooding and Figure 5.0f shows the delay time between the initial dam breach and the time at which flooding reaches a flood depth of 0.60 m.

In the event of a failure, the mud flow will travel south within the outlet channel downstream of HB Dam towards Crowsnest Highway. Once the flood wave overtops the highway, the flow path spreads out as local gradients are relatively level.

6.0 CONSEQUENCE CLASSIFICATION

6.1 General

A consequence classification system has been developed by the Canadian Dam Association (CDA, 2007) to categorize the consequences of dam failure in terms of loss of life; environmental and cultural losses; and infrastructure and economic losses. The consequence classification of a dam should be selected using the highest rating based on these types of loss. Note that the consequences are incremental to those that would have occurred in the same event without failure of the dam. The CDA (2007) defines incremental consequence of failure as:

"The incremental consequences or damage that a dam failure might inflict on upstream areas, downstream areas or on the dam itself, over and above any losses or damage that may have occurred in the same event or conditions had the dam not failed".

These consequence categories are applied to establish guidelines for some of the design parameters for a dam, such as the Inflow Design Flood (IDF) and the Earthquake Design Ground Motion (EDGM), and the standard of care expected of owners. The CDA describes five consequence categories: "Low", "Significant", "High", "Very High" and "Extreme".

The BC Dam Safety Regulation, including all amendments up to BC Regulation 163/2011 (November 30, 2011), and the 2007 CDA Dam Safety Review Guidelines, provide consequence classification criteria as well as suggested design flood and earthquake levels as a function of dam consequence classification as reproduced as Table 6.1a below. It is noted that the BC Dam Safety Regulations were amended in 2011 so that consequence classifications are now in alignment with those provided in the 2007 CDA guidelines and care must be taken in the interpretation of engineering reports dated prior to November 2011.

Table 6.1a: CDA 2007 Consequence Classification Criteria and Design FQ and Flood

Dam Classification from CDA 2007	Loss of Life	Economic and Social Losses	Environmental and Cultural Losses	Annual Exceedance Probability Level	
				EQ Design Ground Motion	Inflow Design Flood
Extreme	>100	Extreme – Critical Infrastructure or Service	Major Loss of Critical Habitat – No Restoration Possible	1/10,000	PMF
Very High	10-100	Very High –Important Infrastructure or Services	Significant Loss of Critical Habitat – Restoration Possible	1/5,000	⅔ between 1/1000 year and PMF
High	1-10	High –Infrastructure, Public Transit and Commercial	Significant Loss of Important Habitat – Restoration Possible	1/2,500	⅓ between 1/1000 year and PMF
Significant	Unspecified	Temporary and Infrequent	No Significant Loss of Habitat – Restoration Possible	1/1,000	Between 1/100 and 1/1000 year
Low	0	Low	Minimal Short Term Loss	1/500	1/100 year

It is however noteworthy that the upcoming CDA Technical Bulletin "Mining Dams: Application of 2007 Dam Safety Guidelines to Mining Dams" (2013) which is currently in the draft stage is proposing more robust suggested design flood and earthquake levels for tailings dam in the closure 'passive care' phase as reproduced in Table 6.1b below in recognition that the design interval could extend hundreds of years and there is not regular monitoring. While the Salmo landfill is in operation the HB Dam would still be considered to be in the closure 'active care' phase and therefore the design criteria in Table 6.1a still applies, however it is anticipated that when the landfill closes the dam would have to transition to the design criteria reproduced in Table 6.1b.

Table 6.1b: CDA Suggested Design Criteria for Tailings Dams in Closure Passive Care Phase

Dam Classification from CDA 2007	Annual Exceedance Probability Level	
	EQ Design Ground Motion	Inflow Design Flood
Extreme	1/10,000	PMF
Very High	1/10,000	PMF
High	1/5,000	2/3 between 1/1000 year and PMF
Significant	1/2,500	1/3 between 1/1000 year and PMF
Low	1/1,000	1/1000 year

Based on the results of the dam break analysis flood inundation mapping a review of the consequence classification criteria for the HB Dam was conducted as per the CDA 2007 Dam Safety Guidelines considering each of the following loss criteria:

- loss of life
- environmental and cultural losses
- infrastructure and economics

6.2 Loss of Life

There are several factors that affect the severity of the loss of life consequence such as depth of flow, velocity and advance warning time within the inundated area.

However the most important factor in estimating the loss of life (LOL) that would result from dam failure is determining when dam failure warnings would be initiated. The United States Bureau of Reclamation (USBR) has compiled data of dam failure warning times from US dam failures that have occurred since 1960 as well as other notable global dam failures as summarised in Table 6.2a below.

Table 6.2a: Guidance for Estimating When Dam Failure Warning Would be Initiated (Earthfill Dam)

Dam Type	Cause of Failure	Special Considerations	Time of Failure	When Would Dam Failure Warning be Initiated	
				Many Observers at Dam	No Observers at Dam
Earthfill	Overtopping	Drainage area of dam less than 260 km²	Day	0.25 h before dam failure	0.25 h after floodwater reaches populated area
		Drainage area of dam less than 260 km²	Night	0.25 h after dam failure	1 h after floodwater reaches populated area
		Drainage area of dam more than 260 km²	Day	2 h before dam failure	1 h before dam failure
		Drainage area of dam more than 260 km²	Night	1 to 2 h before dam failure	0 to 1 h before dam failure
	Piping (full reservoir, normal weather)		Day	1 h before dam failure	0.25 h after floodwater reaches populated area
			Night	0.5 h after dam failure	1.0 h after floodwater reaches populated area

Table 6.2a: Guidance for Estimating When Dam Failure Warning Would be Initiated (Earthfill Dam)

Dam Type	**Cause of Failure**	**Special Considerations**	**Time of Failure**	**When Would Dam Failure Warning be Initiated**	
				Many Observers at Dam	**No Observers at Dam**
	Seismic	Immediate Failure	Day	0.25 h after dam failure	0.25 h after floodwater reaches populated area
			Night	0.5 h after dam failure	1.0 h after floodwater reaches populated area
		Delayed Failure	Day	2 h before dam failure	0.5 h before floodwater reaches populated area
			Night	2 h before dam failure	0.5 h before floodwater reaches populated area

Brown and Graham (1988) developed a series of empirical equations for estimating loss of life due to dam failure from analysis of major dam failures and flash floods. Their study concluded that loss of life is much greater in those areas that receive little warning time compared to those areas that receive 90 minutes or more of warning, and three empirical equations were developed as a function of warning time as summarised in Table 6.2b below.

Table 6.2b: Loss of Life Empirical Equations

Warning Time	**Estimated Loss of Life (LOL)**
Less than 15 minutes	LOL = 0.5 x PAR
When warning time is between 15 and 90 minutes	$LOL = PAR^{0.6}$
Greater than 90 minutes	LOL = 0.0002 x PAR

PAR = Population at Risk.

As no permanent observers are present at the HB Dam, warning times would be less than 15 minutes for all potential causes and times of dam failure and therefore the estimated loss of life would be expected to be equal to PAR x 0.5.

Only one residence was identified within the flood inundation extent with the 2011 census indicating that the average household size is Salmo 2.2 persons. Based on the flood routing analysis, it is expected that the flood wave would take more than one hour to reach the identified downstream residence however no advanced warning is anticipated based on the criteria in Table 6.2a.

During a daytime failure, there is also a higher possibility of vehicles travelling along the Crowsnest Highway and a temporary population of four persons was assumed.

Based on a permanent population at risk of two persons and a temporary population of four persons the estimated loss of life would be three assuming a warning of less than 15 minutes, which equates to a consequence classification rating of “High”.

6.3 Environmental and Cultural Loses

Reference to the BC Ministry of Environment, BC Species and Ecosystems Explorer indicates that there are no known populations of Red or Blue listed species situated within the inundation area. This suggests that no significant loss of habitat would occur in the event of dam failure and therefore this would equate to a consequence classification rating of “Significant”.

6.4 Infrastructure and Economic Losses

The Crowsnest Highway (BC 3) is the only notable infrastructure in the flood inundation zone which alone suggests a consequence classification category of “Very High” is appropriate for the HB Dam as there would be ‘very high economic losses affecting important infrastructure or services’ (Table 6.1a). The dam break analysis determined that approximately 1 km of highway would be covered by mud/tailings debris. Assuming a highway width of 12 m, a total volume of approximately 24,000 m³ of mud/tailings debris would need to be removed to re-open the highway. As this is a major highway with high economic importance, this category is considered appropriate, as it is estimated that the highway would be closed for three to four weeks for the cleanup, transportation and disposal of material in a secure landfill.

The most significant direct economic cost associated with a potential failure of the HB Dam is the cleanup of the deposited mud/tailings debris, restoration of impacted areas and re-construction of the dam. A preliminary estimate of the direct economic losses is provided in Table 6.4 below, which also suggest a “Very High” economic consequence as a result of dam failure.

Table 6.4: Estimate of Direct Economic Loses Due to Failure of HB Dam [1]

Item	Estimate
1 Removal of mud/tailings debris to secure landfill (714,000 m³ at $40 to $80 per m³)	$28,560,000 to $57,120,000
2 Restoration of impacted area (730,000 m² at $18 to $36 per m²)	$13,140,000 to $26,280,000
3 Replacement of HB Dam	$4,000,000 to $6,000,00
Total Estimated Direct Economic Loses	$45,700,000 to $83,400,000

[1] Cost are highly sensitive to haulage distances, levels of restoration and material availability and are presented for planning purposes only.

6.5 Conclusions

Based on the assessment of the three loss criteria summarised in the sections above, it is recommended that the consequence classification rating of the HB Dam be increased to “Very High”. This classification is above the current consequence classification of “Significant” as previously determined by BCG in the 2002 Dam safety review. For a dam with a “Very High” consequence classification, the CDA guidelines suggest that a dam safety review be conducted every 5 years.

7.0 FAILURE MODES ASSESSMENT

Foster et al. (2000a) reviewed a database on dam failures (up to 1986) worldwide prepared by the International Congress on Large Dams (ICOLD) and determined the most common modes of failure for an earthfill dam as presented below, with percentages of total failure in brackets:

a. Embankment overtopping (34%)

b. Piping through the embankment (33%)

c. Piping through the foundation (15%)

d. Downstream and upstream slope instability (4%)

e. Other causes e.g. earthquake (16% total)

The percentages presented above reflect the characteristics of that database, not the likelihood of those failures developing at HB Dam. It is important to note that the database presents cases where multiple modes of failure were believed to have occurred. As such, the percentage total is greater than 100%.

a. Embankment overtopping occurs when the spillway has insufficient capacity to discharge flood flows, either due to inadequate size or due to blockage with debris. Embankment overtopping is addressed in the hydrotechnical assessment presented in Section 9.0.

b. and c. Piping is the progressive internal erosion of dam fill or foundation materials along preferential seepage paths. The seepage starts to erode finer soil particles at the toe of a dam or at an interface between dissimilar materials that are not compatible from a filtering perspective (such as a silty clay core adjacent to a coarse rockfill shell). With time and continued seepage erosion, “pipes” or voids will be created within the dam that grow in an upstream direction towards the reservoir with acceleration of seepage and rate of erosion. Eventually, collapse of overlying fill, breach of the dam and subsequent uncontrolled discharge of the reservoir will occur. Piping is discussed further in Section 8.7.

d. Slope instability. Gravitational, seepage and seismic forces can cause instability in earthfill dams when they exceed the available shear strength of the soil. Slope stability of the dam is discussed further in Section 8.5.

e. Other causes of dam failure included slope instability due to earthquake forces, liquefaction and failure of the spillway/gate (appurtenant works).

For the HB Dam, the following failure modes are considered to be plausible:

- **Overtopping** – The spillway may be undersized for the design flood event or the spillway may become blocked with debris.
- **Post Seismic Upstream and Downstream slope instability** – The silty sand materials comprising the embankment may undergo liquefaction and a loss of strength when subjected to the design earthquake resulting in embankment instability and deformation.
- **Internal erosion through the embankment** – The 2012 sloughing of a section of the downstream slope and subsequent identification of several sinkholes suggest that it is vulnerable to internal erosion processes.

8.0 GEOTECHNICAL ASSESSMENT

8.1 General

The current assessment is based on the results of the geological assessment, observations made during the site reconnaissance, available data on the existing dam, published geological data, and Tetra Tech EBA’s engineering judgment, rather than a detailed intrusive geotechnical assessment (e.g. drilling, sampling, testing, etc.) and should therefore be considered preliminary in nature. The objective of this approach is to identify potential geotechnical issues so that any detailed geotechnical assessment can be tailored to that particular issue.

The geotechnical assessment of the dam was considered at the maximum height of the dam as well as the area that underwent reconstruction after the sloughing event. The geometry and soil conditions of the embankment are based upon the cross-sections, borehole logs and laboratory testing undertaken by BGC, 2000 and Golder, 1973.

The following subjects will be discussed in this Section:

- Embankment Seepage
- Liquefaction
- Embankment Stability
- Seismic Slope and Liquefaction Post-Seismic Deformation
- Internal Erosion (Piping)

8.2 Geotechnical Parameters Estimation

Soil parameters for the geotechnical analysis have been estimated using a combination of historical documentation, field observations and published data for similar material types.

Several publications provide typical values for a range of different soil types encountered, such as Craig (1992), which provides typical ranges of hydraulic conductivities in Table 2.1 (reproduced as Table 8.2a below) and Bowles (1988), which provides representative values of angle of internal friction in Table 2-6 (reproduced as Table 8.2b below). The hydraulic conductivity of sand and gravel mixtures is highly sensitive to the silt content as discussed in Bandini et. al. (2009) with the hydraulic conductivities as a function of silt content presented on the attached Figure 8.2.

Table 8.2a: Coefficient of Permeability (m/s) from Craig (1992)

<table>
<tr><th>1</th><th>10^{-1}</th><th>10^{-2}</th><th>10^{-3}</th><th>10^{-4}</th><th>10^{-5}</th><th>10^{-6}</th><th>10^{-7}</th><th>10^{-8}</th><th>10^{-9}</th><th>10^{-10}</th></tr>
<tr><td colspan="2" rowspan="2">Clean gravels</td><td colspan="3">Clean sands and sand gravel mixtures</td><td colspan="2">Very fine sands, silts and clay-silt laminate</td><td colspan="4" rowspan="2">Unfissured clays and clay-silts (>20% clay)</td></tr>
<tr><td colspan="5">Desiccated and fissured clays</td></tr>
</table>

Table 8.2b: Representative Values for Angle of Internal Friction Ø from Bowles (1988)

Soil Type	Angle of Internal Friction (ø)
Gravel	
Medium Size	40 – 50°
Sandy	35 – 50°
Sand	
Loose	27 – 35°
Dense	43 – 50°
Silt or silty sand	
Loose	27 – 30°
Dense	30 – 35°
Clay	20 – 42°

Based on review of the above references and available existing information on the dam the following geotechnical parameters as summarized in Table 8.2c below were utilized in the various analyses.

Table 8.2c: Summary of Parameters Utilized in Geotechnical Analysis

Unit	Material	Soil Parameters			
		c' (kPa)	φ' (°)	γ_{sat} (kN/m^3)	k_{sat} (m/s)
1	SILT, sandy/gravelly	0	34	20	10 10-7
2	SAND and SILT	0	32	20	10 x 10-7
3	Filter Blanket – SAND and GRAVEL	0	38	20	10 x 10-5
4	Original Dam Material (1955) – SAND, silty - loose	0	26	20	10 x 10-7
5	Original Dam Material (1955) – SAND and SILT	0	32	20	10 x 10-7
6	Native – SILT, clayey (GLACIOLACUSTRINE)	1	35	19	10 x 10-8
7	Native – SAND, gravelly/silty (TILL)	0	38	20	10 x 10-8
8	Bedrock	-	-	22	10 x 10^{-11}
9	Tailings	0	22	14	8.95 x 10^{-6}
10	Rock Drain (2005)	0	38	20	x 10^{-4}
11	Buttress (2005)	0	36	20	3 x 10^{-5}
12	Earthfill Berm (1966) – SAND, silty	0	36	20	10 x 10^{-9}

c' = Effective Cohesion Intercept.
φ' = Internal Angle of Friction.
γ_{sat} = Saturated Unit Weight of Soil.
k_{sat} = Saturated Hydraulic Conductivity.

8.3 Seepage

Initial pore water pressure conditions in the embankment suitable for input to for stability analyses were determined by undertaking a two-dimensional steady state seepage analysis utilising the built-in Finite Element module within RocScience Slide v 6.026. The soil hydraulic conductivity parameters used in the analysis are estimated from the background information and published correlations, and therefore may not be accurate; however the relative values are considered appropriate.

The seepage analysis was considered at both a pond elevation of 108.0 m (2012 Datum) to consider the pre-slough spillway elevation and a pond elevation of 105.5 m (2012 Datum) to consider current operating conditions.

The rates of toe seepage calculated for the dam are summarized in Table 8.3 below. It should be noted that the analyses were undertaken at the dam's maximum height and reduced seepage rates are anticipated where the embankment heights are less, and the analysis did not consider potential concentrated sources of seepage such as along conduits through the embankment.

Table 8.3: Estimated Rate of Toe Seepage for the HB Dam

Reservoir Level (Elevation m 2012 Datum)	Calculated Toe Seepage	Figure No.
108.0	21.02 m^3/day/m	8.3a
105.5	0.015 m^3/day/m	8.3b

8.4 Liquefaction Assessment

A simplified liquefaction triggering analyses was undertaken utilising the averaged Cyclic Stress Ratio (CSR) analysis adjusted to a 6.625 magnitude event and the strength profile from the SPT results conducted in the BGC Boreholes BH1 and BH2 utilising the methods of Idriss & Boulanger (2008) and Youd et al, 2001. The SPT profile was adjusted to account for the fines content of the encountered sand horizons.

The results of the analysis indicate that the looser, coarser grained layers within the 1955 embankment fill have a susceptibility to soil liquefaction during the design 1 in 5000-year earthquake.

Using the semi-empirical method presented in Figure 104 of Idriss and Boulanger (2008) of CSR versus, $(N_1)_{60cs}$ and volumetric strain, average volumetric strains of approximately 3% would occur during the design earthquake and therefore vertical settlements of no greater than 225 mm would occur assuming that all of the 1955 embankment fill layer could liquefy, which is well within the available freeboard of the dam.

Given the depositional nature (e.g. lacustrine clay) of the dam’s foundation there is considered to be very low risk of the dams’ foundation undergoing liquefaction during the design seismic event, which was confirmed by the simplified liquefaction triggering analyses.

Summary plots of both analyses methods undertaken on Borehole BH1 are presented on the attached Figure 8.4.

8.5 Embankment Stability Review

8.5.1 Criteria

The CDA Technical Bulletin, Geotechnical Consideration for Dam Safety provides accepted minimum slope stability factors of safety for various static and seismic loading conditions as reproduced in Table 8.5a and Table 8.5b below.

Table 8.5a: Acceptable Factors of Safety for Embankment Stability – Static Assessment

Loading Conditions	Minimum Factory of Safety	Slope
End of construction before reservoir filling.	1.3	Upstream and Downstream
Long-term (steady state seepage, normal reservoir level)	1.5	Downstream
Full or partial rapid drawdown	1.2 to 1.3	Upstream

Table 8.5b: Acceptable Factors of Safety for Embankment Stability – Seismic Assessment

Loading Conditions	Minimum Factory of Safety	Slope
Pseudo-Static	1	Upstream and Downstream
Post-Earthquake	1.2 to 1.3	Upstream and Downstream

8.5.2 Methodology

Static and pseudo-static seismic global stability factors of safety for the existing embankments were calculated using the two-dimensional Limit State Equilibrium analysis program RocScience Slide v 6.026.

Initial pore water pressure conditions in the embankment were determined by importing the results of the two-dimensional steady state Finite Element seepage analysis into the Limit State Equilibrium analysis.

With respect to assessing the seismic stability of earthfill dams, the CDA Technical Bulletin, Geotechnical Consideration for Dam Safety, recommends a staged approach, beginning with simplified methods using suitably conservative input assumptions to demonstrate that a dam is safe; progressing to more sophisticated analysis methods should the simplified approach lead to unfavourable results. The first recommended stage of analysis undertaken is the pseudo-static method, in which the effects of an earthquake are applied as constant horizontal load via the use of dimensionless coefficients (k_h) equal to the peak ground acceleration for the earthquake return period under consideration, which for HB Dam is 0.182 for the 1/5,000 year event. Should the embankment have a factor of safety in excess of 1.0 for this loading, it is considered not to undergo any significant deformation during the design earthquake and therefore no further analysis is required. Should a factor of safety of less than 1.0 be obtained from the pseudo-static analysis, then it is likely that the embankment will undergo deformation during the design earthquake event and a simplified deformation analysis (e.g., as per Newmark (1965), Bray (2007)) approach is recommend as the second stage of analysis to confirm that the embankment has adequate freeboard post the design earthquake event deformation. Should the second stage of analysis yield unfavourable results, then a series of more sophisticated analysis approaches (e.g., Finite Element Analysis) are recommended.

The liquefaction triggering analyses presented in Section 8.4 above indicated that the loose silty sands comprising the 1955 embankment fill, could undergo liquefaction when subjected to the design earthquake. Therefore for the post-earthquake residual shear strength soil cases, the undrained residual shear strength (S_r) of the 1955 embankment fill was estimated in accordance with Figure 88 of Idriss and Boulanger (2008) utilising the average SPT corrected blow count $(N_1)_{60cs}$ = 12 as encountered in the 2000 BGC borehole.

The stability review of the dam was considered at the maximum height of the dam as well as the area that underwent reconstruction after the sloughing event. The geometery of the maximum height cross section is based upon borehole logs and cross-sections from BGC, 2000 and Golder, 1973. The repaired slough area cross section was taken from the as-built report produced by Tetra Tech EBA, 2012. The results of the analysis are summarized in Table 8.5c below and are presented on the attached Figures 8.5a to 8.5f.

Table 8.5c: Factors of Safety – Slope Stability – HB Dam – Maximum Height of Dam

Loading Conditions	Minimum Calculated Factor of Safety	Slope	Figure No.
Static long-term (steady state seepage, highest seasonal reservoir level)	1.67	Downstream	8.5a
Static long-term (steady state seepage, highest seasonal reservoir level)	2.36	Upstream	8.5b
Full or partial rapid drawdown [1]	N/A	Upstream	N/A
Seismic pseudo-static (steady state seepage, highest seasonal reservoir level)[2]	1.04	Downstream	8.5c
Seismic pseudo-static (steady state seepage, highest seasonal reservoir level) [2]	1.20	Upstream	8.5d
Post seismic 1955 embankment fill at residual shear strength (steady state seepage, highest seasonal reservoir level)	1.20	Downstream	8.5e
Post seismic 1955 embankment fill at residual shear strength (steady state seepage, highest seasonal reservoir level)	2.28	Upstream	8.5f

[1] Not considered an applicable loading condition as the dam has limited capability to be drawn down rapidly.

[2] Lowest calculated FoS that would impact the dam freeboard.

Table 8.5d: Factors of Safety – Slope Stability – HB Dam – Repaired Section of Dam

Loading Conditions	Minimum Calculated Factor of Safety	Slope	Figure No.
Static long-term (steady state seepage, highest seasonal reservoir level)	2.25	Downstream	8.5g
Static long-term (steady state seepage, highest seasonal reservoir level)	12.64	Upstream	8.5h
Full or partial rapid drawdown [1]	N/A	Upstream	N/A
Seismic pseudo-static (steady state seepage, highest seasonal reservoir level)[2]	1.22	Downstream	8.5i
Seismic pseudo-static (steady state seepage, highest seasonal reservoir level) [2]	1.26	Upstream	8.5j
Post seismic 1955 embankment fill at residual shear strength (steady state seepage, highest seasonal reservoir level)	1.20	Downstream	8.5k

Table 8.5d: Factors of Safety – Slope Stability – HB Dam – Repaired Section of Dam

Loading Conditions	Minimum Calculated Factor of Safety	Slope	Figure No.
Post seismic 1955 embankment fill at residual shear strength (steady state seepage, highest seasonal reservoir level)	12.64	Upstream	8.5l

[1] Not considered an applicable loading condition as the dam has limited capability to be drawn down rapidly.

[2] Lowest calculated FoS that would impact the dam freeboard.

8.6 Seismic Slope and Liquefaction Post-Seismic Deformation

As the results of the pseudo-static stability analysis presented above did not result in calculated factors of safety less than 1 for neither the upstream nor the downstream slope, the embankment is considered not to undergo any significant deformation during the design earthquake and therefore no further analysis is required.

The results of the post seismic analyses resulted in calculated factors of safety greater than 1.2 for both the upstream and the downstream slope. This indicated that a flow slide condition would not develop and therefore the embankment is not considered to undergo any significant deformation after the design earthquake and therefore no further analysis is also required for this case.

8.7 Internal Erosion (Piping)

8.7.1 General

Internal erosion and piping occur when soil particles within an embankment dam or its foundation are transported downstream by seepage flows (ICOLD 2013).

Internal erosion is a major cause of dam incidents and failures that threaten the safety of dams, with 48% of historical embankment dam failures occurring due to internal erosion (Foster et al. 2000a). Internal erosion more frequently occurs within five years of first filling as weaknesses in the dam or its foundation are exploited by the rising water; however, there are many examples of dams where the effects of internal erosion were only observed many years after first filling as presented in Foster et al. (2000b) due to:

- They have not been subjected to, or designed to resist, extreme loads such as extreme water level and earthquakes, which can cause settlement and/or cracking. Cracking occurs as a result of seasonal variation in water levels, freezing and thawing, differential settlement and desiccation.
- Ageing causes deterioration, particularly of conduits, spillways and other structures through dams, at which locations internal erosion may be initiated.
- They may not be protected against internal erosion by filters, or if filters or transition zones are present, they may not have been designed to modern standards and may be ineffective.

8.7.2 Internal Erosion Mechanisms

Internal erosion mechanisms of embankment dams and their foundations are categorized into three general failure modes, namely:

- Internal erosion through the embankment, which includes internal erosion associated with penetrating structures, such as conduits associated with outlet works, spillway walls or adjoining a concrete gravity structure supporting the embankment.

- Internal erosion through the foundation.
- Internal erosion of the embankment into the foundation. Including (a) seepage through the embankment eroding material into the foundation, or (b) seepage in the foundation at the embankment contact eroding the embankment material.

The process of internal erosion may be broadly divided into four phases, namely:

- Initiation of erosion.
- Continuation of erosion.
- Progression to form a pipe or occasionally cause surface instability (sloughing).
- Initiation of a breach.

The models for the development of embankment failures due to internal erosion are shown on the attached Figure 8.7a.

- Concentrated leaks. Concentrated leaks occur where there is an opening in the soil through which preferential seepage occurs, with the sides of the opening enlarging through continual erosion by the leaking water. Such concentrated leaks may occur through a crack caused by differential settlement during construction of the dam or its operation, hydraulic fracturing due to low stresses around conduits or the upper parts of the dam due to differential settlement, or through desiccation at high levels of fill. Frost action also can create cracks in dam crests. Concentrated leaks can also occur due to collapse settlement of poorly compacted fill in the embankment, around conduits and adjacent to walls. They may also occur due to the action of animals burrowing into levees and small dams and tree roots rotting in dams and forming seepage conduits.
- Backward erosion. There are two types of backward erosion, namely:
  - Backward erosion piping. Backward erosion piping occurs where critically high hydraulic gradients at the toe of a dam erode particles upwards and internal erosion develops backwards below the dam through small erosion conduits and flow velocity can transport the eroded particles. The presence of backward piping erosion is often exhibited by the manifestation of sand boils at the downstream side of the dam. An example of backward erosion piping is shown on the attached Figure 8.7b.
  - Global backward erosion. Global backward erosion occurs in embankments with a narrow or downstream sloping core, which are inadequately protected by the filter or transition zone. The progression of the erosion process is assisted by gravity and there is no need for a cohesive soil layer to form the roof for a pipe and it is one of the causes of sinkholes in dams constructed of glacial tills. An example of global backward erosion is shown on the attached Figure 8.7b.
- Contact erosion. Contact erosion occurs when a coarse soil such as gravel is in contact with a fine soil and flow parallel to the contact in the coarse soil erodes the fine soil.
- Suffusion. Suffusion occurs when water flows through widely graded or gap graded (internally unstable) non-plastic soils, with the small particles of soil transported by the seepage flow through the pores of the coarse particles. Poorly graded soils such as non-plastic glacial tills are more vulnerable to suffusion. Suffusion results in an increase in permeability, greater seepage velocities, and potentially higher hydraulic gradients, potentially accelerating the rate of suffusion. A filter constructed of internally unstable materials will have a potential for erosion of the finer particles in the filter, rendering the filter coarser and less effective in

protecting the core materials from erosion. Segregation of broadly or gap graded non-plastic soils during dam construction may create layers which are internally unstable even though the average grading of the soil is internally stable.

8.7.3 Embankment Susceptibility

Once internal erosion is initiated, it will continue unless the eroding forces are reduced or the passage of the eroded particles is impeded in some way. Since the 1950s dam engineers have known that the most efficient way to stop the erosion process in embankments is to zone the dam and incorporate filters. Based on the statistics of embankment dam failures and incidents (Foster et al 2000a) these can be categorized in regards to their capability of providing control internal erosion in the embankment as shown in the attached Figure 8.7c and Table 8.7a below.

Table 8.7a: Susceptibility of Embankment Dams to Internal Erosion by Zoning

Likelihood of Internal Erosion	Control for Internal Erosion	Dam Zoning and Category Number [1]
A Very Vulnerable	Little or no control.	Homogeneous earthfill (0) Earthfill with rock toe (2)
B Vulnerable	Some control of internal erosion depending on detail of zoning and filter capability.	Zoned earthfill (3) Zoned earth and rockfill (4) Puddle core (8) Hydraulic fill (11)
C Low Vulnerability	Moderate control of internal erosion depending on the filter capacity and details of the core wall or face slab.	Concrete face earthfill (6) Concrete face rockfill (7) Concrete core earthfill (9) Concrete core rockfill (10)
D Very Low Vulnerability	Good control of internal erosion subject to good details of zoning and filter design.	Earthfill with filters (1) Central core earth and rockfill (5)

[1] See Figure 8.7c for Illustrations of Dam Zoning Categories.

Based on the available drawings for the HB Dam it is considered likely to be either a Zoning Category 1 or Category 3 embankment or a combination thereof and therefore a filter compatibility assessment was undertaken based on the results of the BCG 2000 investigation as discussed in Section 8.7.4 below. Existing drawings of the dam also indicate that the filter does not extend above the pond level and therefore the crest of the dam should be considered Zoning Category 0 and therefore this part of the embankment is very vulnerable to internal erosion.

8.7.4 Filter Compatibility Assessment

Filters in earth fill dams prevent erosion of soil particles from the soils that they interface with, and allow the drainage of seepage water. Filters are designed to be compatible with the other materials within the dam, and they must be sufficiently fine to prevent the erosion of their interface materials and coarse enough to allow drainage to occur. Filters are typically divided into two categories, critical and non-critical.

Critical filters are required to control internal erosion in the dam, and if they fail there is an increased likelihood of piping in the dam and potential breach. Critical filters are typically designed and constructed to very stringent criteria. Non-critical filters generally are located in areas that can be easily repaired, such as beneath rip-rap. The assessment of a filter's critical or non-critical status is predominantly linked to the flow conditions within the filter; critical filters typically have seepage flowing normal to the base soil – filter interface with potentially high gradient conditions between the two materials. Non-critical filters typically have either seepage flowing normal to base soil – filter interface with low gradients or flow parallel to the base – filter interface.

The filter material of the dam has been subject to assessment in accordance with procedures set out by the USBR, 1977; Sherard and Dunnigan, 1989; and Kenney et al, 1985. The results from these methods were compared and the results from the analysis can be seen in Table 8.7b.

Table 8.7b Critical and Non-Critical Filters Assessment

Material	**Fines Content (%)**	**D_{50}**	**D_{85}**	**USBR method (1977)**	**Design Criteria of Sherard and Dunnigan (1989)**	**Kenney et al (1985)**
2) SAND and SILT	65	0.02	0.5	No [1]	No[2]	No[3]
4) Original Dam Material (1955) - SAND and SILT	47	0.105	2.68	No [1]	No[2]	Yes[3]

[1] The filter contains great than 5% fines passing 0.075 mm; therefore fails the filter assessment criteria outlined in the USBR Method

[2] The filter material fails to meet the criteria that <40% of the material is finer than 4.76 mm;

[3] The filter material and base material 2, are not compatible with and fail the $D_{15F} < 5D_{50B}$; however, the filter material and underlying material 4 appear to be compatible according to this method.

The result of the filter compatibility assessment, suggests that the existing dam filter does not meet modern filter design criteria and therefore the dam should be considered a Zoning Category 3 embankment. It is noteworthy that the assessment was based on a limited number of SPT samples, which may not be representative due to spatial variation and the possibility that the large particles in the dam filter were greater than that of the diameter of the SPT sampler.

8.7.5 Screening Assessment

As only limited information was available on the materials used to construct the HB Dam or those that form its foundation to provide suitable inputs for an engineering analysis a potential internal erosion failure mode screening assessment has been undertaken as presented in the attached Appendix E. The screening assessment considered potential failure modes based on:

- Zoning of the embankment (as discussed in Sections 8.7.3 & 8.7.4) and the properties of the core.
- Foundation geology and properties.
- The details of the embankment, its conduits and retaining walls.

The screening assessment concluded that:

- The embankment is designed as a zoned earthfill embankment however the filter capability assessment of the embankment materials indicated that they have poor filter capability and therefore the embankment is considered Zoning Category 3 and therefore vulnerable to internal erosion based on zoning.
- Existing drawings of the dam also indicate that the filter does not extend above the pond level and therefore the crest of the dam should be considered Zoning Category 0 and therefore this part of the embankment is very vulnerable to internal erosion.
- Backward erosion and suffusion in the core could be potential failure modes.
- Backward erosion and suffusion in the foundation can be excluded as potential failure modes.

- Internal erosion of the embankment into or at the soil foundation can be excluded as a potential failure mode.
- A crack or concentrated leak could form due to, desiccation by drying in the crest, freezing in the crest, the design earthquake and the presences of poorly compacted fills.
- Based on the existing geotechnical data the embankment materials generally comprise silty sands (SM) and sandy silts (SM) with greater than 30% fines and therefore are highly erodible.
- Internal erosion along the decommissioned decant conduits could be a potential failure mode due to the presence of poorly compacted fill.

9.0 HYDROTECHNICAL ASSESSMENT

The following sections provide a brief description of the study watershed, a review of available climatic and hydrometric data, and a summary of the development of the Inflow Design Flood (IDF).

9.1 Watershed

HB Dam reservoir receives surface runoff from a 2 km² catchment area, of which 0.17 km² is occupied by the surface water pond. The boundary of the drainage basin is shown on Figure 9.1 and the median basin elevation of the watershed was determined to be approximately 940 m. The basin is generally characterized by steep slopes, medium brush and forest cover.

9.2 Climatic and Snow Course Data

A number of climate stations operated by the Meteorological Service of Canada (MSC) are located within the study region. In view of their close proximity to the project site, elevation, and relatively long period of record, the following stations were considered to have climatic data suitable to determine the climate conditions at the project site (Table 9.2a).

Table 9.2a: Regional Climate Stations

Station Name	Station No.	Elevation (m)	Period of Record	Data Type	Rainfall IDF Curve	Distance to Site (km)
Castlegar A	1141455	495	1954 - 2013	Hourly	Yes	38.4
Salmo BCFS	1146944	685	1972 - 1980	Daily	N/A	8.1
Kootenay Pass	1144413	1773	1974 - 1989	Daily	N/A	18.3

According to the 1971 to 2000 Climate Normals data provided by Environment Canada, the mean annual precipitation at the Castlegar Airport station is 752.2 mm (559.7 mm of rainfall and 211.0 mm of snowfall depth). Rainfall occurs throughout the year, whereas most snowfall occurs during October to May. Mean daily temperatures range from -2.7°C in January to 19.9°C in July.

Maximum daily rainfall for available corresponding years for the three selected stations were compared to evaluate orographic effects. Based on a total of 6 years, it was found that there was no significant correlation between rainfall and elevation. As the Castlegar Airport station has a longer period of record, a frequency analysis using a Gumbel Distribution was applied to evaluate the 24-hour rainfall total for a range of return periods (Environment Canada 2010). The rainfall amounts for various return periods at the HB site as shown in Table 9.2b.

Table 9.2b: Rainfall Intensity Frequency Data at HB Dam Site

Return Period (Years)	24-Hour Rainfall Total (mm)
2	28.4
5	35.2
10	39.7
50	49.6
100	53.8
1,000	67.6

BC Environment has a number of snow course and snow pillow sites in the Kettle and Kootenay region. Two stations were found to be within a 150 km radius, although both are at elevations greater than the studied watershed. The information for these automated snow pillow stations is presented in Table 9.2c.

Table 9.2c: Regional Snow Pillow Stations

Station Name	Station No.	Elevation (m)	Period of Record	Distance to Site (km)
Grano Creek	2E07P	1,874	1997 – Present	113
Moyie Mountain	2C10P	1,840	1971 – Present	110

Historical records demonstrate that on average snowmelt begins during the months of April and May. The average snow depth and water equivalent for the period of record of both selected snow-pillow stations are summarized in Table 9.2d.

Table 9.2d: Average Snowpack Data

Month	Snowpack Depth (cm)	Snow Water Equivalent (mm)
Jan	85	261
Feb	103	346
Mar	115	435
April	116	500
May	62	361

The data illustrates that the average maximum snowpack depth (116 cm) and the average maximum snow water equivalent (500 mm) in the region occur in April.

9.3 Determination of Inflow Design Flood

The CDA guideline for an Inflow Design Flood (IDF) for a Very High consequence dam is 2/3 of the way between a 1,000-year flood and the Probable Maximum Flood (PMF). In general, the PMF is defined as the most severe flood that may reasonably be expected to occur at a particular location. For the study watershed, which is governed either by major storms alone or rain-on-snow events, the representative IDF is 2/3 between the 1,000-year flood and the PMF generated by the Probable Maximum Precipitation (PMP) alone or on snow.

9.3.1 Determination of the 1,000-Year Flood

Considering that the watershed upstream of the HB Dam is less the 10 km², a rainfall-runoff approach was used to determine the 1000-year flood. A rainfall-runoff approach refers to the development of a hydrologic model to determine the runoff hydrograph at the site.

The rainfall frequency analysis from the Castlegar Airport climate station (Table 10.2-2) was used as the basis for determining the 1000-year 24-hour rainfall depth at site. The 1,000-year 24-hour rainfall total was determined to be 67.6 mm.

To account for the snowmelt occurring during a rain-on-snow event, the following equation was applied (Gray, 1973):

For heavily forested regions (60 – 100%),

$$M = (0.074 + 0.007*P)*(Ta - 32) + 0.05$$

Where:

M = snowmelt (in/day);

P = precipitation (in); and

Ta = temperature (°F).

For the 1000-year flood, the 1000-year 24-hour rainfall and the average daily temperature from April to May was used in estimating the daily snowmelt rate.

The average temperature during the months of April and May for the HB Dam watershed was evaluated using the temperatures recorded for the selected climate stations (Table 9.2a). The temperature at site was corrected based on elevations. Table 9.3 summarizes average historical temperatures and elevations for the three selected climate stations as well as the estimated temperature for the HB catchment.

Table 9.3: Average Temperature for the Months of April and May

Climate Station	Elevation (m)	Average Apr-May Temperature (°C)
Castlegar A	495	10.7
Salmo BCFS	685	8.4
Kootenay Pass	1774	1.8
HB Dam Catchment	940	6.2*

Note: * Estimated based on following equation: Temperature= -6.952 x ln(elevation) + 53.795

The average value of the mean daily temperature (6.2°C) was considered to be representative of the HB Dam watershed during the months of April and May. The average daily snowmelt during a 1000-year rainfall event was determined to be 8.5 mm/day. The combination of the 1,000-year 24-hour precipitation and snowmelt amounted to 76.1 mm.

The hydrologic model used in the runoff analysis was HEC-HMS version 3.3, developed by the U.S. Army Corps of Engineers. The US Soil Conservation Service (SCS) unit hydrograph method was applied to determine the runoff hydrograph from the 1000-year 24-hour rainfall combined with the average daily snowmelt rate. The SCS Type II distribution was selected to define the distribution of rainfall over 24 hours. The average daily snowmelt was evenly distributed and combined with the 1000-year hyetograph. In general, the catchment area upstream of HB Dam consists of dense brush and forest area. Soil Type B, representing soil with a moderate infiltration rate, was chosen for the study area and a Curve Number of 88 was estimated for the catchment area. Slopes, elevations and channel lengths were taken from topographic maps to estimate the time of concentration of the watershed.

The peak inflow to the HB reservoir during the 1,000-year return period flood was determined to be 15.2 m³/s.

9.3.2 Determination of the Probable Maximum Flood

The rainfall-runoff approach was used in determining the Probable Maximum Flood (PMF) into the HB Reservoir. The 24-hour Probable Maximum Precipitation (PMP) was estimated using the Hershfield method described in the Rainfall Frequency Atlas for Canada (Hogg and Carr, 1985).

$$K_{M24} = 19 \text{ x } 10^{-0.000965 \text{ X}}{}_{24}$$

$$X_{PMP} = X_{24} + K_{M24} \text{ x } S$$

where

K_{M24} = frequency factor for a 24-hour duration rainfall;

X_{24} = mean annual 24-hour extreme rainfall (mm);

X_{PMP} = PMP for a 24-hour duration (mm); and

S = standard deviation for a 24-hour duration rainfall (mm).

The 24-hour PMP determined by the Hershfield method is 172.2 mm.

The hydrologic model developed in determining the 1000-year peak flood estimate was used in deriving the Probable Maximum Flood. The 24-hour PMP was distributed using the SCS Type II rainfall distribution and the additional daily snowmelt rate was determined to be 16.8 mm/day. The daily snowmelt was evenly distributed and combined with the design hyetograph. The PMF for the HB Dam was determined to be 51.5 m³/s. This PMF is sufficiently conservative as it considers a PMP-on-snow event.

The PMF estimator for British Columbia (Abrahamson, 2010) was further used as a rough check for the results of the hydrologic model. The following equation for the Interior Region was applied:

$$Q_{PMF} = 19.933 \text{ x } A^{0.6351}$$

Where:

Q_{PMF} = probable maximum flood (m³/s); and

A = area of the watershed (km²).

The PMF determined using the PMF estimator for British Columbia is approximately 31 m³/s, which is 40% smaller than the PMF resulting from the rainfall runoff method. Given that the PMF estimator was developed for much larger catchments than the HB Dam drainage area, the difference in magnitude between both methods was considered acceptable, as smaller catchments do tend to have a faster response time to storms. As the PMF estimator is considered less accurate than the rainfall-runoff method, the PMF determined by the latter method is preferred. Therefore, the PMF to the HB Dam reservoir is determined to be 51.5 m³/s.

9.3.3 Inflow Design Flood

The rainfall-runoff method is considered appropriate for developing the IDF for HB Dam as it accounts for site specific conditions such as soil type and local climate data.

As indicated earlier, the 1,000-year flood and the PMF were determined to be 15.2 m³/s and 51.5 m³/s, respectively. The following equation was used in developing the combined IDF hydrograph at the project site:

$$Q_{IDF} = Q_{1,000} + C(Q_{PMF} - Q_{1,000})$$

where

Q_{IDF} = Inflow design flood (m³/s);

$Q_{1,000}$ = 1,000-year flood (m³/s)

C = Coefficient (2/3 for Very High Consequence Classification Dams).

The peak inflow to the HB Dam during the IDF was determined to 39.3 m³/s. The 1,000-year, PMF and IDF hydrographs are shown on Figure 9.3.

9.4 Spillway and Hydraulic Analysis

A spillway rating curve (Figure 9.4a) was developed based on the dimensions obtained from the site survey. The spillway is an excavated channel with a crest elevation of 709.39 m AMSL and the length of the spillway crest was measured to be 1.7 m. The rating curve shows that the theoretical capacity of the spillway is approximately 41.0 m³/s when the water level is at the dam crest (713 m AMSL).

9.4.1 Flood Routing

The flood routing was performed using the HEC-HMS model, which includes a routing component for flows through reservoirs. The reservoir storage capacity and elevation curve was obtained from the pond sounding in the Decommissioning Plan presented by BGC in 2002 as shown in Figure 5.0a. For the purpose of flood routing, the starting water surface elevation was assumed to be at the spillway crest (709.39 m AMSL). The results of the HEC-HMS flood routing during the IDF are summarized in Table 9.4, and Figure 9.4b presents the results of the flood routing graphically.

Table 9.4a: Results of Flood Routing

Spillway Crest	Initial Lake Level	Peak Lake Level	Peak Storage	Peak Inflow	Peak Outflow	Dam Crest Elevation	Still Water Freeboard
(m)	**(m)**	**(m)**	**(1,000 m³)**	**(m³/s)**	**(m³/s)**	**(m)**	**(m)**
709.39	709.39	711.61	98.6	39.3	16.6	713.0	1.39

9.4.2 Wind and Wave Analysis

Procedures defined by the CDA Dam Safety Guidelines were adopted in the freeboard assessment. In accordance with the 2007 CDA Guidelines, the freeboard at all dam structures should be evaluated for normal and extreme conditions. In general, the crest level of an embankment structure should be set so that the structure is protected against the most critical of the following cases (CDA 2007):

- No overtopping by 95% of the waves caused by the most critical wind with a frequency of 1/1,000 year when the reservoir is at its maximum normal elevation.
- No overtopping by 95% of the waves caused by the most critical wind when the reservoir is at its maximum extreme level during the passage of the IDF.

For a very high classification dam the freeboard should be such that 95% of the waves do not overtop the dam during a 1,000-year wind under normal freeboard conditions or during a 2-year wind under design flood conditions.

A wind and wave analysis was performed to determine the freeboard requirements. A frequency analysis of hourly wind data (1954-2013) at the Castlegar Airport Climate Station (1141455) was conducted. The winds blowing from the northwest, north and northeast were used, since these winds travel directly towards the upstream face of the dam. An extreme event analysis using the methods described by Goda (1988) was used to calculate the wind speed for various return periods from the 60-year time series data. Goda's extreme event analysis uses a partial duration or peak-over-threshold data series. The primary and secondary thresholds of 20 m/s and 30 m/s were selected, and the statistical distributions describing the extreme value analysis were produced. The best fit distributions where chosen to estimate the design event. Table 9.4b shows the Goda extreme event analysis results.

Table 9.4b: Goda Extreme Event Wind Speed Analysis Results

Return Period (y)	Wind Speed (m/s)	Wind Speed (km/h)
2	11.7	42.0
100	19.9	71.6
200	21.6	77.6
1,000	25.6	92.1

Setup and wave height were calculated using the 2-year and 1,000-year wind values. The wind tide or setup is a phenomenon in which the water level at the dam rises due to the effect of wind blowing over the water. The setup, wave height, wave period and wavelength were calculated using the following equations (CDA, 2007):

$$S = (F\ U^2)/(4850\ D)$$

$$H_s = 0.01616\ U_A\ F^{0.5}$$

$$U_A = 0.71\ U^{1.23}$$

$$T = 0.6238\ (U_A F)^{0.33}$$

$$L = 1.56\ T^2$$

where

S = Wind tide or setup in m

F = Fetch in km

U = Wind velocity in m/s

D = Average reservoir depth in m

H_s = Significant wave height in m

F = Fetch in km

U_A = Wind stress factor

U = Wind velocity in m/s

T = Wave period in seconds

L = Wavelength in m

The wave run-up is the height above the mean water surface at which a crest of a wave will interact with the barrier. The wave run-up is based on the design wave height. A factor of 1.37 was applied to the calculated significant wave height to obtain the design wave height, which is the average of the highest 5% waves, as recommended by the CDA for freeboard calculations.

To estimate irregular wave runoff on rough (rip-rap) impermeable slopes the following equation derived by the US Army Corps of Engineers (Hughes, 2005) was applied.

$$R/h = 4.4 (\tan \alpha)^{0.7} (M_f/pgh^2)^{0.5} (0.505) \qquad \text{for } 2.0 \leq \cot \alpha \leq 4.0$$

$$(M_f/pgh^2) = A_0 (h/gT^2)^{-A1}$$

$$A_0 = 0.639 (H_5/h)^{2.026}$$

$$A_1 = 0.180 (H_5/h)^{-0.391}$$

where

R = Vertical runup distance in m

H_5 = Design wave height in m

$\tan\alpha$ = Structure slope

M_f/pgh^2 = Momentum flux (dimensionless)

h = Water depth in m

Based on the embankment slope of 1:2, the vertical runup distance was determined to be 0.38 m and 1.06 m for the 2-year and 1000-year wind respectively. The results of the wind and wave analysis (Table 9.4c) illustrate that there is adequate freeboard during and the passage of the IDF and for an event where the water level is at the spillway crest (maximum elevation).

Table 9.4c: Summary of Wind and Wave Analysis

Scenario	Passing IDF	Maximum Elevation
Wind Frequency	2-year	1000-year
Wind Speed (m/s)	11.7	25.6
Significant Wave Height (m)	0.20	0.52
Wave Period (s)	1.1	1.5
Wavelength (m)	1.88	3.59
Wind Setup (m)	0.003	0.031
Wave Runup (m)	0.38	1.06
Required Freeboard (Setup + Runup) (m)	0.38	1.09
Available Freeboard from Still Water Level (m)	1.10	3.61*
Acceptable according to CDA Guidelines	YES	YES

Note: * maximum elevation set at spillway crest elevation (709.39 m amsl)

10.0 DAM SAFETY MANAGEMENT SYSTEM

10.1 General

Dam safety management can be generally described to have five components (CDA Guidelines 2007):

- Owner commitment to safety.
- Regular inspections and Dam Safety Reviews with proper documentation and follow up.
- Implementation of effective Operations, Maintenance and Surveillance (OMS) practices.
- Preparation of effective Emergency Preparedness Plan.
- Management of Public Safety.

A general schematic of a dam safety management system is presented in Figure 10.1. Tetra Tech EBA has assessed the dam safety management system in place for the HB Dam and the results of this assessment are presented in this section.

10.2 Operations, Maintenance, and Surveillance Manual

An Operations, Maintenance and Surveillance (OMS) Manual is a means to provide both experienced and new staff with the information they need to support the safe operation of a dam (CDA 2007).

As part of the scope of this DSR, Tetra Tech EBA reviewed the existing OMS Manual for this facility prepared by CRA (2011). Tetra Tech EBA has noted the following areas for potential improvement in the OMS:

- As the OMS is intended to be a “living” document that should be updated annually to reflect any changes that may have occurred in past year and as such the document control page should reflect this.
- The seismic hazard presented in Section 3.6 needs to be updated to comply with the current NBCC (2010) probabilistic seismic hazard.
- The site plan should be updated to the most current as-built drawings of the dam that include the 2012 reconstruction works.
- Section 4.3.1 should note that the dam access road is more suited for 4x4 vehicles.
- Section 4.3.4 should be updated to incorporate the revised spillway geometry and capacity following modification in 2012.
- The v-notch weir should be added to the facility instrumentation in Section 4.3.5.
- The consequence classification and dam safety review frequency should be updated in Sections 5.1 and 5.3.2 respectively in accordance with the recommendations of this dam safety review.
- Contact Information in Table 2.1 should be updated to reflect persons currently in identified roles.

The importance of regular monitoring of the seepage clarity and rate of seepage when the risk of piping exists is underlined by the following observations of the Foster et al. (2000b) study:

- An increase in leakage and observation of turbid water was commonly observed for all types of piping. However, in some cases, piping through the embankment did not display any warning signs before failure. Comparisons may need to be made between future conditions and past conditions. Old photographs are invaluable for this purpose.
- Sand boils, sinkholes, muddy leakage and increase in leakage were the most common observations in piping failures and incidents.
- For instances of piping through the foundation, the seepage was usually described as clear before a failure or dam incident occurred. In one case, gradual increases in seepage rate were observed for 24 years before the seepage accelerated and progressed to piping failure.

10.3 Emergency Response Plan

The objective of an Emergency Response Plan (ERP) is to establish a formal internal document that operators of a dam should follow in the event of an emergency at the dam. The ERP outline the key emergency response roles and responsibilities, in order of priority, as well as the required notifications and contact information (CDA 2007).

An ERP is incorporated into the existing EPP for this facility and it therefore discussed in the section below.

10.4 Emergency Preparedness Plan

The objective of an Emergency Preparedness Plan (EPP) is to provide the basic information that allows for the planning and coordination by municipalities, Royal Canadian Mounted Police, provincial agencies, utility owners and transportation companies and other parties that would be affected by a major flood (CDA 2007).

As part of the scope of this DSR, Tetra Tech EBA reviewed the existing EPP for this facility which also incorporated and ERP prepared by CRA (2011). Tetra Tech EBA has noted the followings area for potential improvement in the EPP:

- As the EPP is intended to be a “living” document that should be updated annually to reflect any changes that may have occurred in past year and as such the document control page should reflect this.
- Section 2.1 should note that the dam access road is more suited for 4x4 vehicles.
- The inundation maps that was prepared as part of the dam safety review should be incorporated into the EPP.
- Contact Information in Figure 4.1 and Table 4.2 should be updated to reflect person currently in identified roles.

10.5 Public Safety Management

The CDA released Guidelines for Public Safety and Around Dams in 2011. Public safety around dams is an emerging topic in the dam safety community in both Canada and around the world, which is here lead by the CDA.

Dam owners are responsible for managing the public safety risks caused by a dam, as far upstream and downstream as the owner has property rights. Beyond the property the dam owner may have additional responsibilities to assess specific locations where the hazards are known by the owner to result directly from the dam or its operation and to inform the public and other affected property owners of these hazards. In most jurisdictions in Canada, due diligence is the test that the dam owner has taken reasonable and prudent precautions to protect the public. The implementation of a Public Safety Plan (PSP), records of decisions made and activities performed to manage public safety at the dam, provide evidence of due diligence (CDA 2011).

Given that the HB Dam is situated within a secured facility, public interaction with the dam is not expected and therefore the need to prepare a PSP for this facility is not anticipated.

10.6 Dam Safety Expectations Assessment

The British Colombia Ministry of Environment (BC MoE) has developed a sample check sheet of Dam Safety Expectations, Deficiencies and Priorities (May 2010) which is based on the BC Hydro Hazards and Failures Modes Matrix and the 2007 CDA Guidelines. A dam safety expectations assessment has been undertaken of the Farleigh Lake Dam using the sample check sheet prepared by the BC MoE as presented in Appendix F.

The Dam Safety Expectations are divided into five categories:

- Dam Safety Analysis
- Operations, Maintenance and Surveillance
- Emergency Preparedness
- Dam Safety Review
- Dam Safety Management System

A brief summary of the results of the Dam Safety Expectations are discussed below.

10.6.1 Analysis and Assessment

There are two actual deficiencies, namely:

- The filter compatibility assessment indicates that the current dam filter probably does not modern filter design criteria.
- The filter does not extend above the maximum pond level and critical hydraulic gradients could develop in the crest of the dam.

and one potential deficiency, namely:

- The dam consequence classification rating should be increased to “Very High” based on the economic consequences of embankment failure.

10.6.2 Operations, Maintenance and Surveillance

There are three non-conformances in this category, which could be resolved by updating the existing OMS Manual prepared for the facility and undertaking an emergency exercise of RDCK staff involved in dam maintenance and surveillance.

10.6.3 Emergency Preparedness

There five non-conformances in this category, which all could be resolved by updating the existing EPP prepared for the facility.

10.6.4 Dam Safety Review

There are no deficiencies and non-conformances in this category. By commissioning this Dam Safety Review, the RDCK conforms to the dam safety expectations for this category.

10.6.5 Dam Safety Management System

There is one non-conformance in this category, which could be resolved by updating the existing OMS Manual, and EPP for the facility.

11.0 OBSERVATIONS & CONCLUSIONS

The conclusions reached during the Dam Safety Review of the HB Dam are presented as follows for each area of review.

11.1 Background Review

- The original dam design drawings were prepared using different assumed datums.
- Seepage at the toe of the dam has been noted throughout the life of the dam.
- The dam filter zone does not extended to above the maximum pond operating level.
- Burrowing from animal activity has been noted on the downstream slope of the dam has been noted throughout the life of the dam.
- No obvious signs of historical or current slope instability of the reservoir sides slopes were observed in the review of the available aerial photography.

11.2 Site Reconnaissance

- Some brush vegetation is growing in the upstream slope of the dam.
- Minor rutting from vehicle traffic noted on the dam crest.
- Minor animal activity (tracks) was noted on the dam crest.
- The spillway channel inlet has no log boom.
- Noted rip-rap protection missing in spillway outlet channel.

11.3 Consequence Classification Review

- The dam breach inundation mapping indicates that a total area of approximately 0.73 km² would be impacted in the event of a dam breach, including the Crowsnest Highway (BC 3) depositing approximately 714,000 m³ of tailings.
- One permanent residence and the Crowsnest Highway where there is likely to be a temporary population are situated in the immediate downstream flood inundation zone where flood levels are expected to reach several metres, where an estimated potential loss of life of three people would occur in the event of a dam breach assuming a warning of less than 15 minutes.

- Economic consequences resulting from a failure of the embankment including, cleanup of deposited tailings, restoration of contaminated land and reconstruction of the HB Dam have estimated to be in the range of $45.7 M to $83.4 M.

11.4 Failure Mode Assessment

- The plausible failure modes of the dam are; overtopping, slope instability, post seismic upstream and downstream slope instability and internal erosion through the embankment.

11.5 Geotechnical Assessment

- Liquefaction induced vertical settlements of no greater than 225 mm would occur assuming that all of the 1955 embankment fill layer could liquefy.

- Results of the static stability analysis indicated that the embankment meets CDA criteria for normal static and seismic loading conditions.

- The dam is assumed to be Zoning Category 3 and therefore vulnerable to internal erosion based on zoning with the embankment materials likely to comprise silty sands and gravels with less than 30% fines that are extremely erodible. Based on the results of the internal erosion screening assessment potential failure modes could include; backward erosion and suffusion of the core; a crack or concentrated leak could form due to, desiccation by drying in the crest, due to freezing in the crest, and the presences of conduits through the embankment and poorly compacted fills.

11.6 Hydrotechnical Assessment

- Dam breach analysis results indicate that the HB Dam should have a "Very High" consequence classification. The CDA guidelines recommend an Inflow Design Flood (IDF) for a "Very High" consequence dam of ⅔ of the way between a 1,000-year flood and the Probable Maximum Flood (PMF). The peak inflow to the HB Dam during the IDF was determined to be 39.3 m^3/s, which would be safely passed by the spillway.

- The dam should have freeboard such that 95% of the waves do not overtop the dam crest during a 1,000-year wind event under maximum normal reservoir conditions or during a 2-year wind event under design flood conditions (IDF). These values were calculated at 1.09 m and 0.38 m, respectively.

- The HB Dam does have enough available freeboard to meet the minimum requirement for the design flood considered (“Very High”) and would not be overtopped by waves from a 1,000-year wind event under normal reservoir conditions.

11.7 Dam Safety Management

- The existing EPP and OMS Manual have not been updated since they were put together in 2011. Multiple changes have occurred since these documents were put together, including, changes of personnel, modification of the embankment and spillway, addition of extra instrumentation and changes to design criteria.

12.0 RECOMMENDATIONS

The recommendations that have been reached during the Dam Safety Review of the HB Dam are presented as follows for each area of review. Priorities (Low, Medium, High or Very High) are given in parentheses. Low, medium, high and very high priority recommendations should be addressed within 5, 3, 1 and 0.5 year(s) respectively.

12.1 Background Review

- An updated drawing of the 2012 topographical survey of the dam should be prepared, utilizing mean sea level as the elevation datum, to avoid confusion with previous surveys and enable better correlation with historical data (High).

12.2 Site Reconnaissance

- The brushy vegetation of the upstream slope of the dam should be removed (High).
- The rip-rap protection missing in spillway outlet channel should be replaced (Very High).
- A log boom should be installed across the spillway inlet channel entrance (Very High).

12.3 Consequence Classification

- Based on the estimated economic loses that would occur due to a breach of the dam it is recommended that the consequence classification of the HB Dam is increased to “Very High”. However any decision to modify the consequence classification rating must be confirmed by the Ministry of Energy and Mines (Very High).

12.4 Failure Mode Assessment

- There are no recommendations in this area of review.

12.5 Geotechnical Assessment

- A feasibility engineering study should be undertaken to assess various modifications that could be made to the embankment to reduce its vulnerability to internal erosion. Depending on the outcome of this study it is possible that a geotechnical investigation would be required during detailed design to confirm the geotechnical properties of the existing dam filter and core materials (Medium).

12.6 Hydrotechnical Assessment

- There are no recommendations in this area of review.

12.7 Dam Safety Management

- The existing EPP and OMS Manual should be updated to reflect changes that have occurred since these documents were put together, incorporate additional information developed and any changes of personnel that may have occurred (Very High).

13.0 DAM SAFETY REVIEW INSURANCE STATEMENT

In accordance The Association of Professional Engineers and Geoscientists of BC (APEGBC) Professional Practice Guidelines – Legislated Dam Safety Reviews in BC (July 2013) we have completed a Dam Safety Review Assurance Statement, which is presented in the attached Appendix G.

14.0 CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech EBA Inc.

M.J. LAWS
#36691

May 28, 2014

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FIGURES

LEGEND

🟪 Regional District Boundary

NOTES
Base data source:
Imagery (date unknown) provided by Bing.
Regional District boundary downloaded from GeoBC.

STATUS
ISSUED FOR USE

HB DAM - 2013 DAM SAFETY REVIEW

Site Location

PROJECTION	DATUM	CLIENT
UTM Zone 11N	NAD83	Central Kootenay Regional District

Scale: 1:15,000

200 100 0 200 400
Meters

TETRA TECH EBA

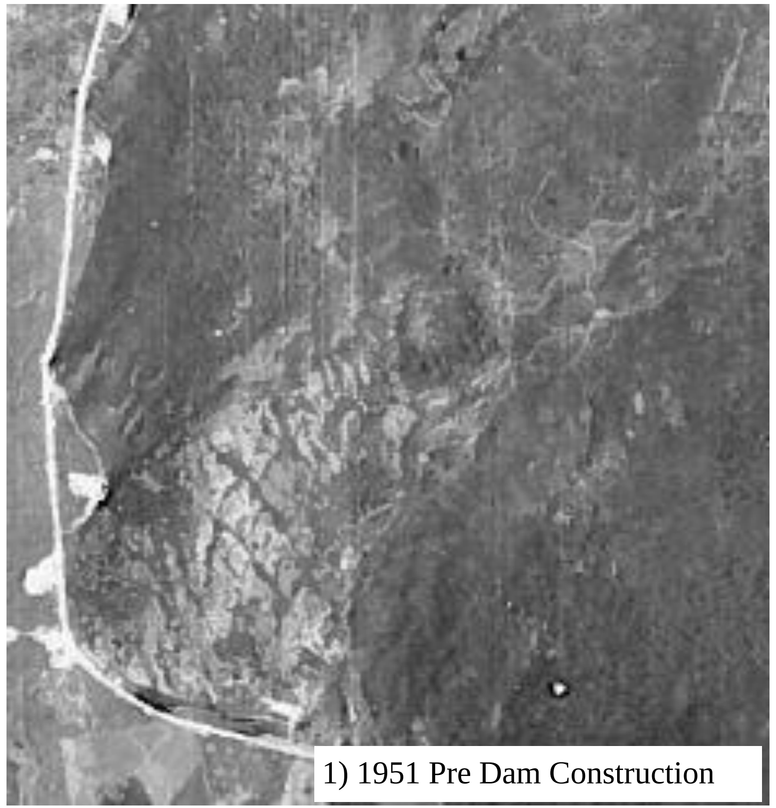
FILE NO.
Figure 1.2 - Site Location.mxd

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	SB	SP	MJL	0

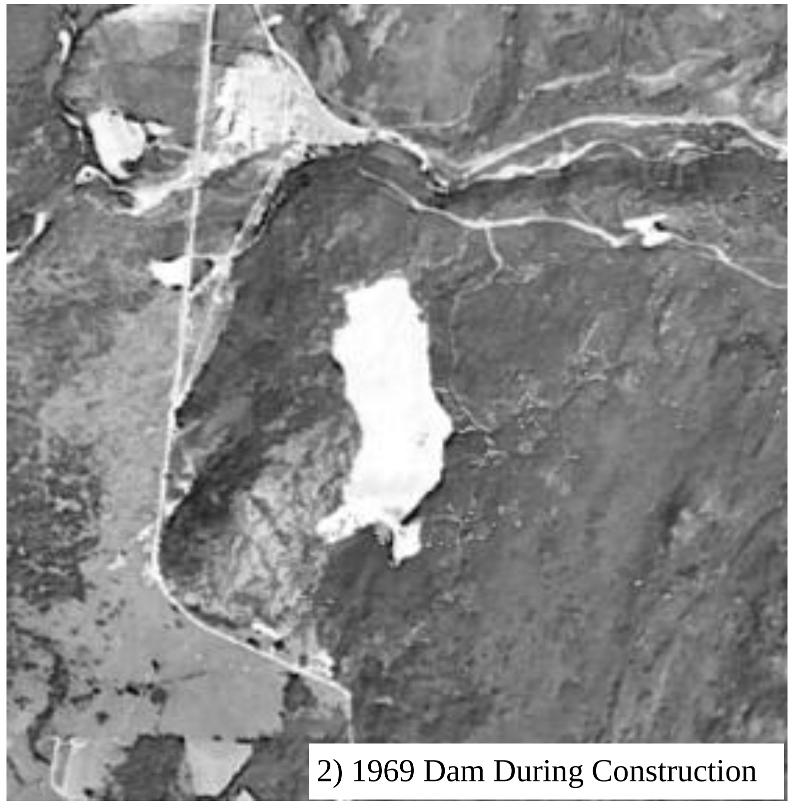
OFFICE	DATE
Tt EBA-KELOWNA	January 28, 2014

Figure 1.2

Q:\Kelowna\GIS\ENGINEERING\K131\K13103109_HB Dam\Maps\ISSUED FOR REVIEW\Figure 1.2-1 - Site Location.mxd modified 1/28/2014 by sarah.blair



1) 1951 Pre Dam Construction



2) 1969 Dam During Construction

3) 1978 Dam Post Operation

4) 1983 Dam Post-Operation

5) 1998 Dam Post-Operation

6) 2005 Dam During Decommission

LEGEND

NOTES

STATUS
ISSUED FOR USE

CLIENT

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Historical Aerial Photographs

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE
KELOWNA

DATE
March 31 2014

Figure 3.3

LEGEND

- ⊕ Borehole - Golder (1973)
- ⊕ Borehole - BGC (2000)
- ⊞ Testpit - BGC (2000)
- ⊙ Piezometer
- ✖ New Water Level Gauge

NOTES
Base data source:
Imagery (date unknown) provided by Bing.
Locations of Piezometers, and Water Level Gauge should be considered approximate as they have been digitized from a PDF of a site survey by Ward Engineering and Land Surveying Ltd. (file # 12-069, dated June 7, 2013).

Locations of the testpits and boreholes should be considered approximate as they have been digitized from a PDF of a site survey by Sproulers Enterprises Ltd., dated Oct. - Nov. 2000.

STATUS
ISSUED FOR USE

HB DAM - 2013 DAM SAFETY REVIEW

Instrumentation and Historical Geotechnical Investigation Testing Locations

PROJECTION UTM Zone 11N
DATUM NAD83
CLIENT Central Kootenay Regional District

Scale: 1:1,000
20 10 0 20
Meters

TETRA TECH EBA

FILE NO.
Figure 3.7a- Site Instrumentation.mxd

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	SB	LM	MJL	1

OFFICE KELOWNA
DATE March 28, 2014

Figure 3.7a

Q:\Kelowna\GIS\ENGINEERING\K131\K13103109_HB Dam\Maps\ISSUED FOR REVIEW\Figure 3.6-1 - Site Instrumentation.mxd modified 3/28/2014 by sarah.blair

LEGEND

NOTES

CLIENT

REGIONAL DISTRICT
CENTRAL KOOTENAY

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

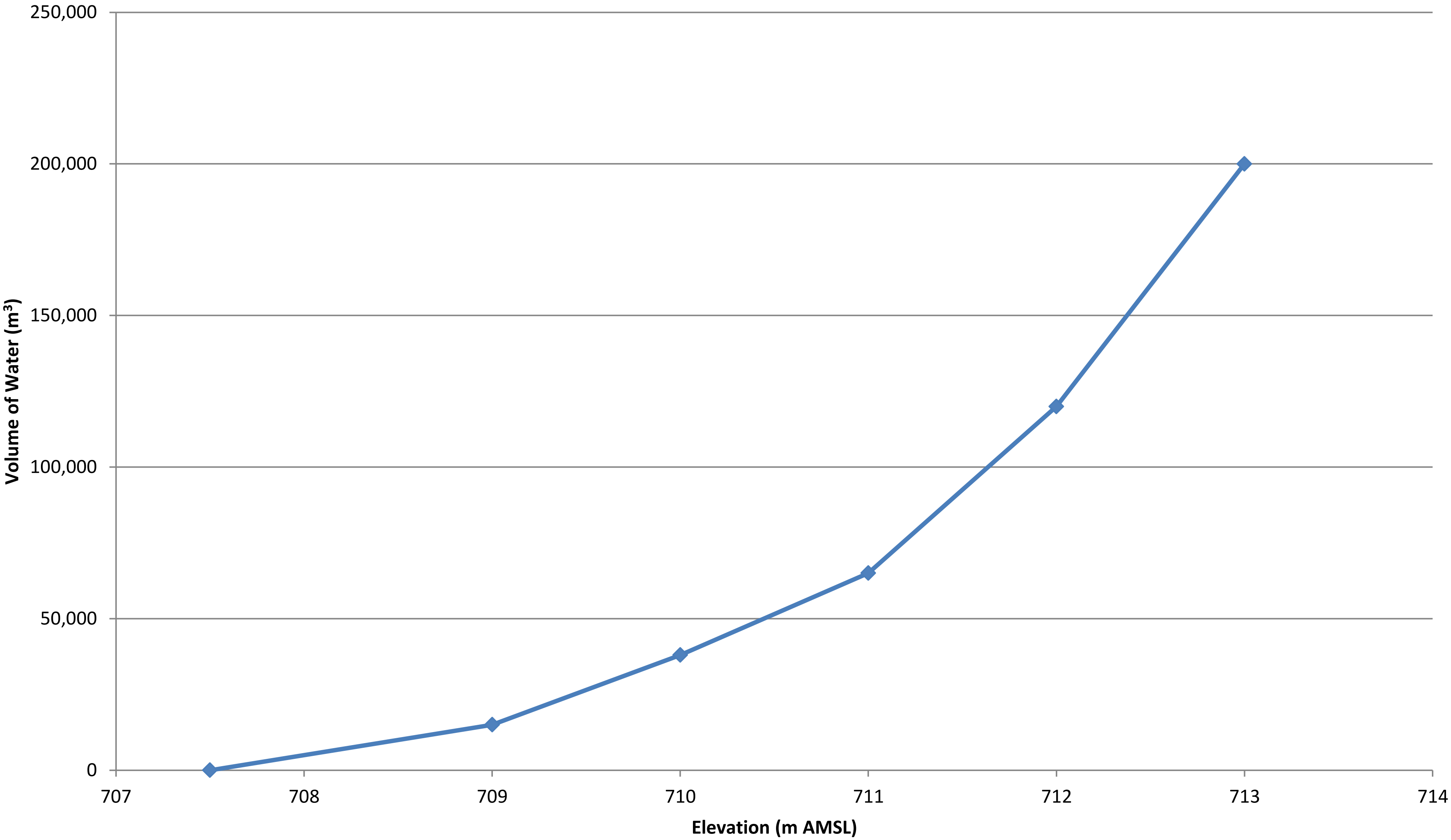
Piezometer readings fromP1, P2, P3, P5, and P6

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	RP	MJL	0

OFFICE	DATE
KELOWNA	March 7, 2014

Figure 3.7b

STATUS
ISSUED FOR USE



CLIENT

Central Kootenay Regional District

Volume of Water Impounded

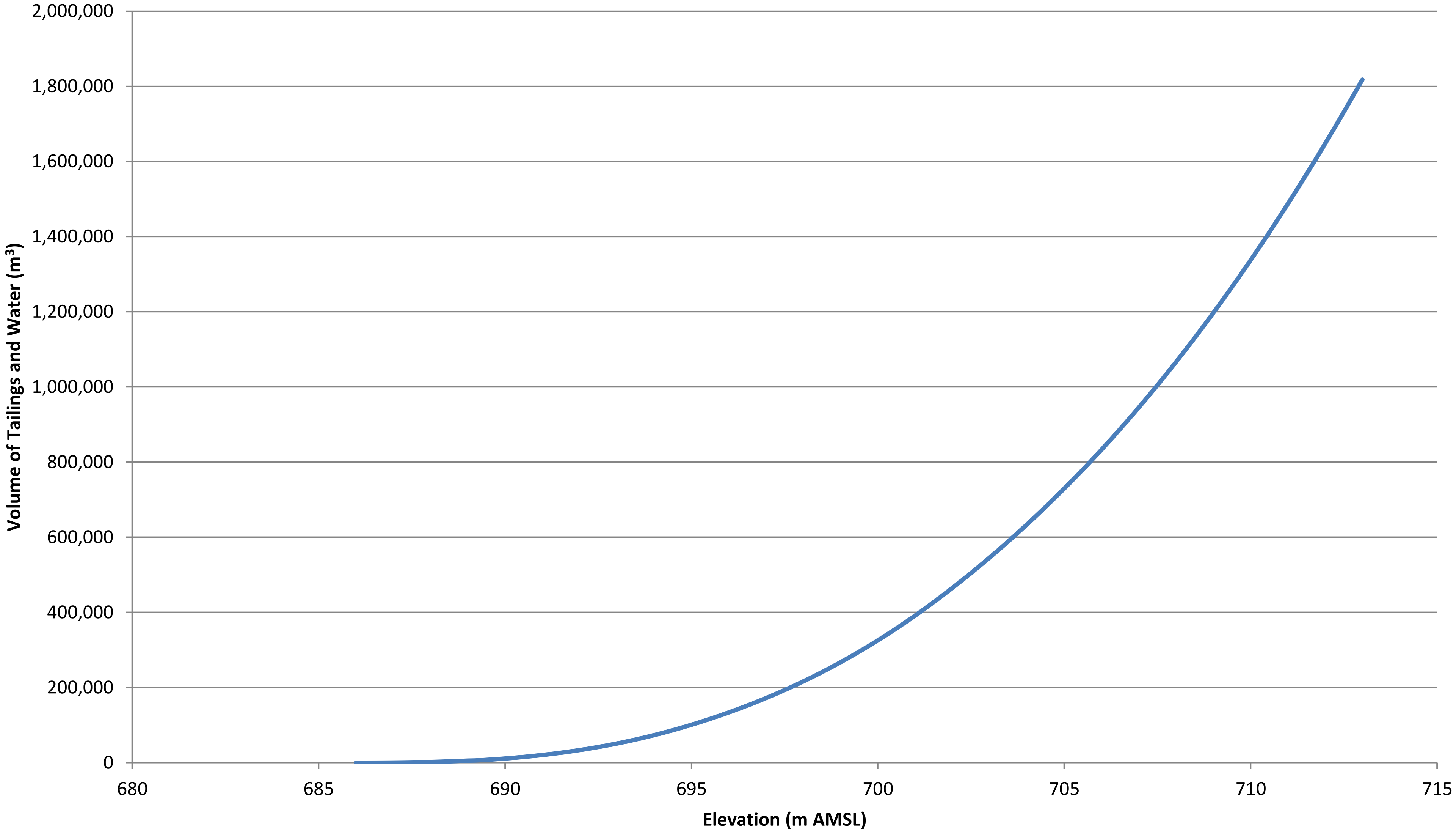
PROJECT NO.	DWN	CKD	APVD	REV
K131030109	SPB			0

OFFICE	DATE
EBA-VANC	September, 2013

STATUS
ISSUED FOR REVIEW

TETRA TECH EBA

Figure 5.0-1



CLIENT

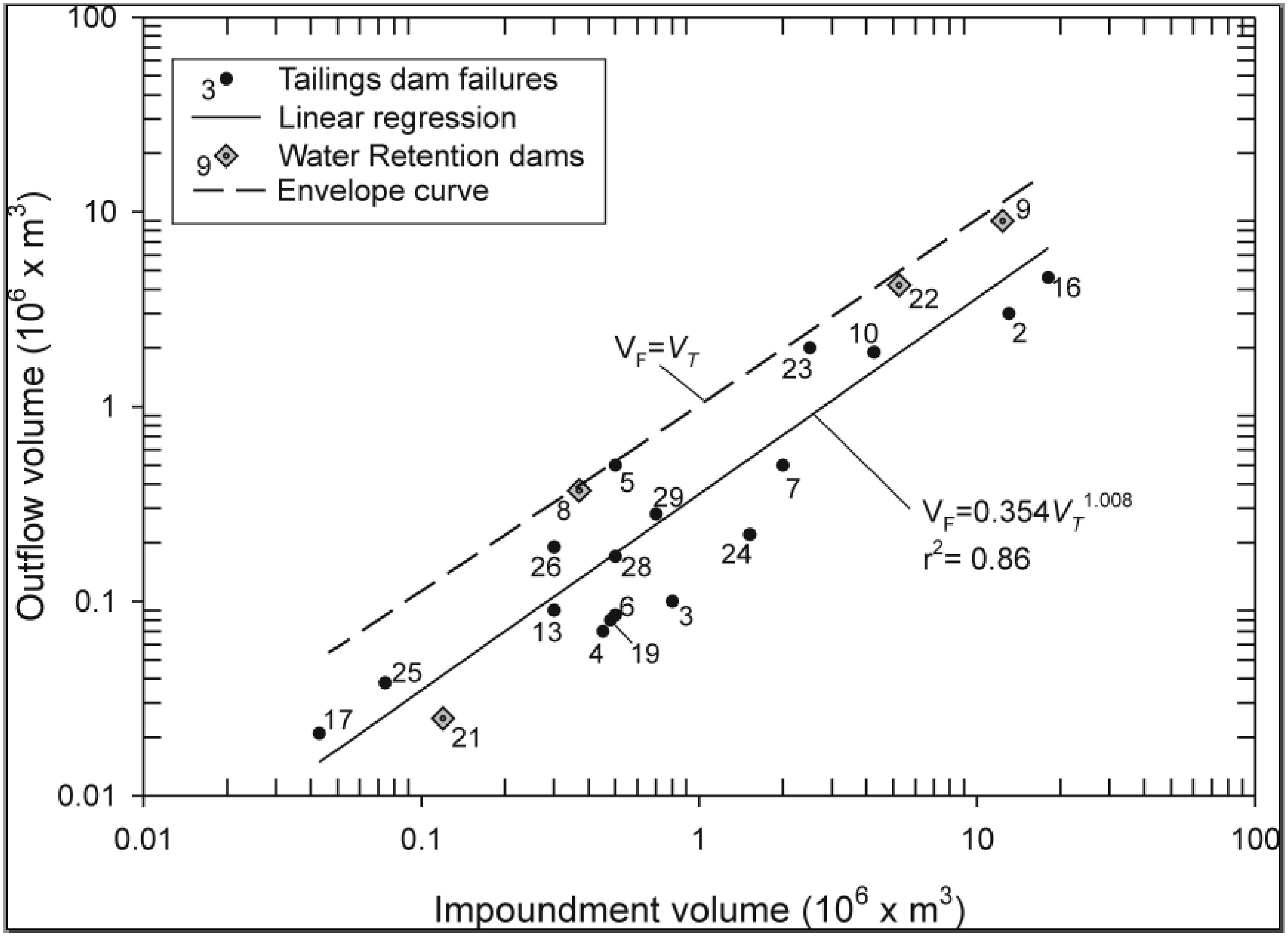
Volume of Tailings and Water Impounded

PROJECT NO.	DWN	CKD	APVD	REV
K131030109	SPB			0
OFFICE	DATE			
EBA-VANC	September, 2013			

Figure 5.0-2

STATUS
ISSUED FOR REVIEW

TETRA TECH EBA



LEGEND

NOTES

1. Adapted from Figure 4 of Rico et al. 2007, Floods from Tailings Dam Failures..

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

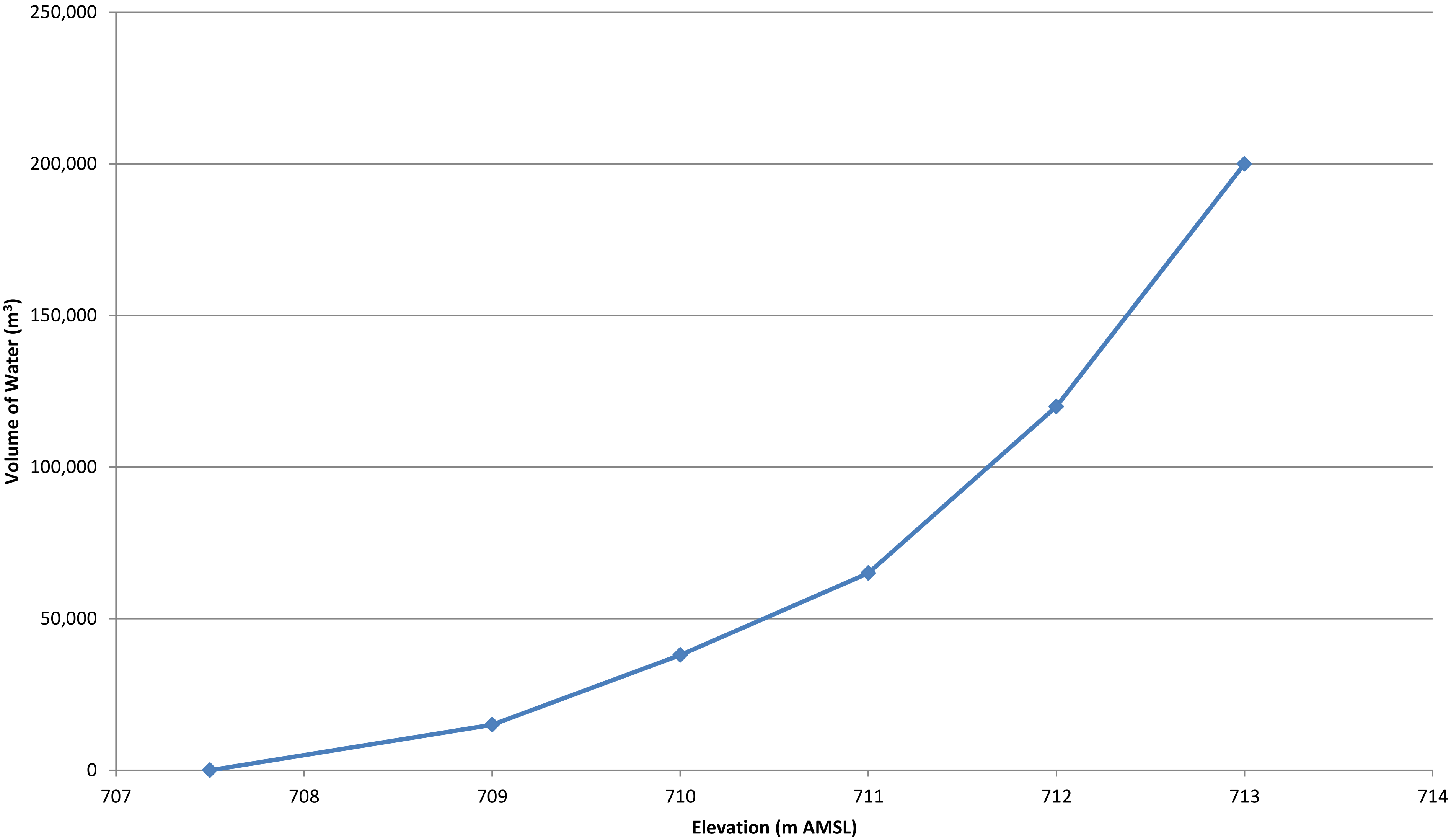
DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Volume of Tailings Released vs Impoundment Volume

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	SPB	RP	MJL	0

OFFICE	DATE
KELOWNA	February 24, 2014

Figure 5.0c



CLIENT

Central Kootenay Regional District

Volume of Water Impounded

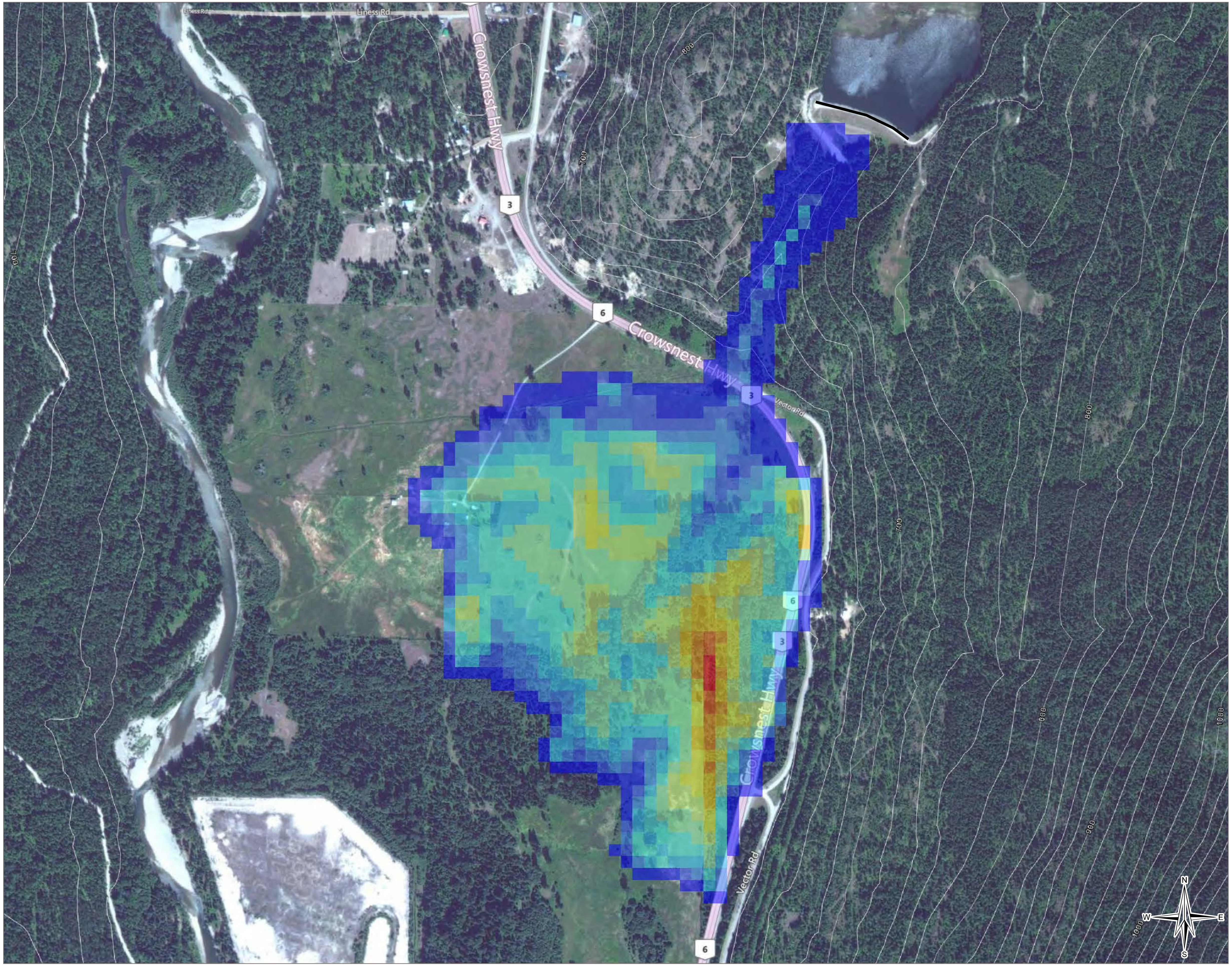
PROJECT NO.	DWN	CKD	APVD	REV
K131030109	SPB			0

OFFICE	DATE
EBA-VANC	September, 2013

STATUS
ISSUED FOR REVIEW

TETRA TECH EBA

Figure 5.0-1



LEGEND

Final Mud/Tailings Deposition Depth (m)

🟦	0.010 - 0.50
🟦	0.501 - 1.00
🟦	1.001 - 1.50
🟦	1.501 - 2.00
🟩	2.001 - 2.50
🟩	2.501 - 3.00
🟨	3.001 - 3.50
🟨	3.501 - 4.00
🟨	4.001 - 4.50
🟧	4.501 - 5.00
🟧	5.001 - 5.50
🟥	5.501 - 5.62

Total Impacted Area = 0.73 km^2

NOTES
Base data source:
Base imagery (date unknown) from Bing provided by ESRI.
Contours (20 m interval) are used throug the GeoBC web map service.

STATUS
ISSUED FOR USE

HB DAM - 2013 DAM SAFETY REVIEW

Final Mud/Tailings Deposition Depth (m)

PROJECTION UTM Zone 11N
DATUM NAD83
CLIENT Central Kootenay Regional District

Scale: 1:8,000
100 50 0 100 200
Meters

FILE NO.
Figure 5.0e - Final MudTailings Deposition Depth.mxd

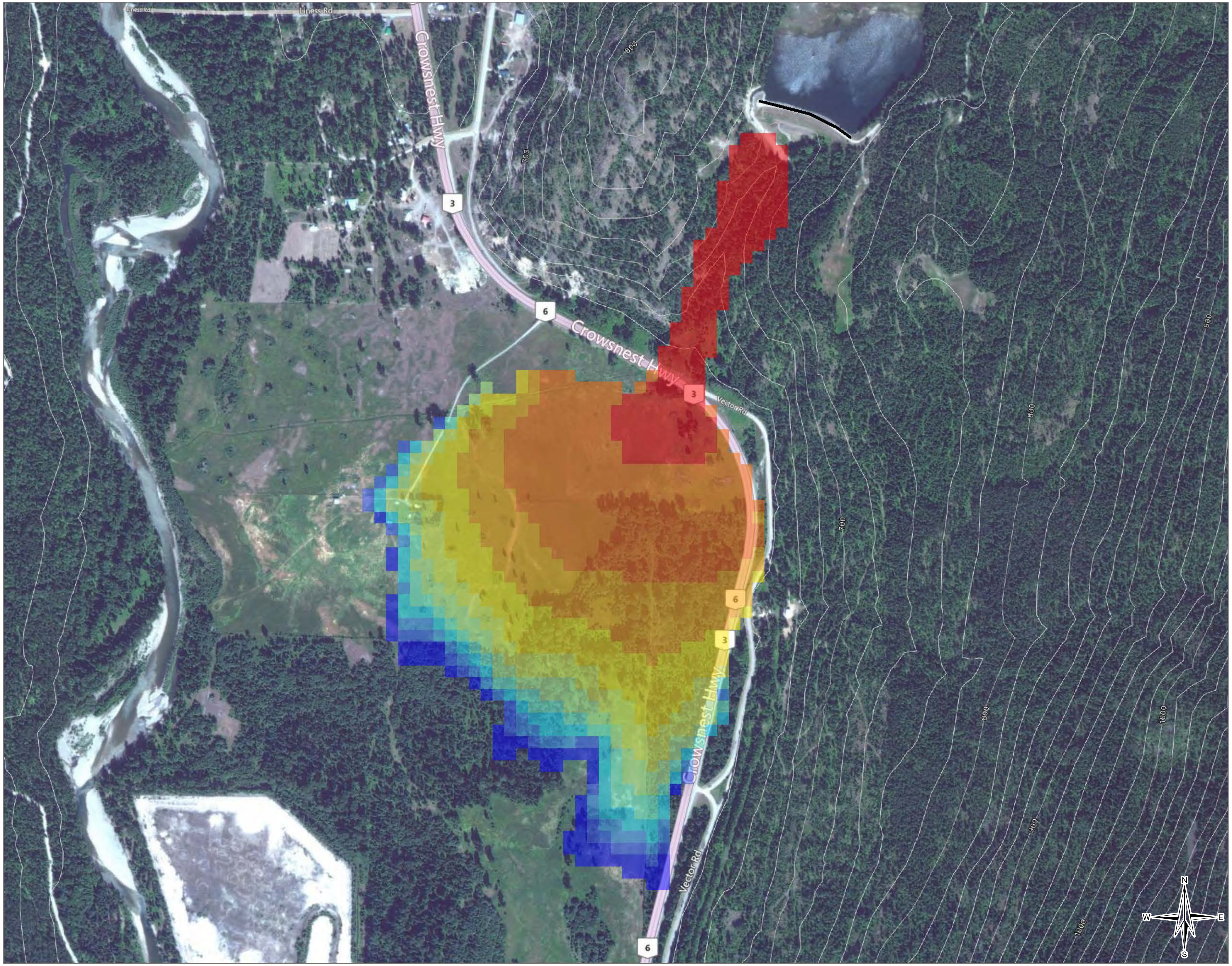
TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	SB	SP	MJL	0

OFFICE Tt EBA-KELOWNA
DATE January 28, 2014

Figure 5.0e

Q:\Kelowna\GIS\ENGINEERING\K131\K13103109_HB Dam\Maps\ISSUED FOR REVIEW\Figure 5.0-6 - Final MudTailings Deposition Depth.mxd modified 1/28/2014 by sarah.blair



LEGEND

Time (hrs) for 0.6 m (2 ft) Depth

- 🟥 0.030 - 0.250
- 🟧 0.251 - 0.500
- 🟧 0.501 - 1.000
- 🟨 1.001 - 2.000
- 🟨 2.001 - 3.000
- 🟩 3.001 - 4.000
- 🟩 4.001 - 5.000
- 🟦 5.001 - 6.000
- 🟦 6.001 - 7.000
- 🟪 7.001 - 8.000
- 🟪 > 8.00

NOTES
Base data source:
Base imagery (date unknown) from Bing provided by ESRI.
Contours (20 m interval) are used throug the GeoBC web map service.

STATUS
ISSUED FOR USE

HB DAM - 2013 DAM SAFETY REVIEW

Time (hrs) for 0.6 m (2 ft) Depth

PROJECTION UTM Zone 11N
DATUM NAD83
CLIENT Central Kootenay Regional District

Scale: 1:8,000
100 50 0 100 200
Meters

FILE NO.
Figure 5.0f - Time for 0.6m Depth.mxd

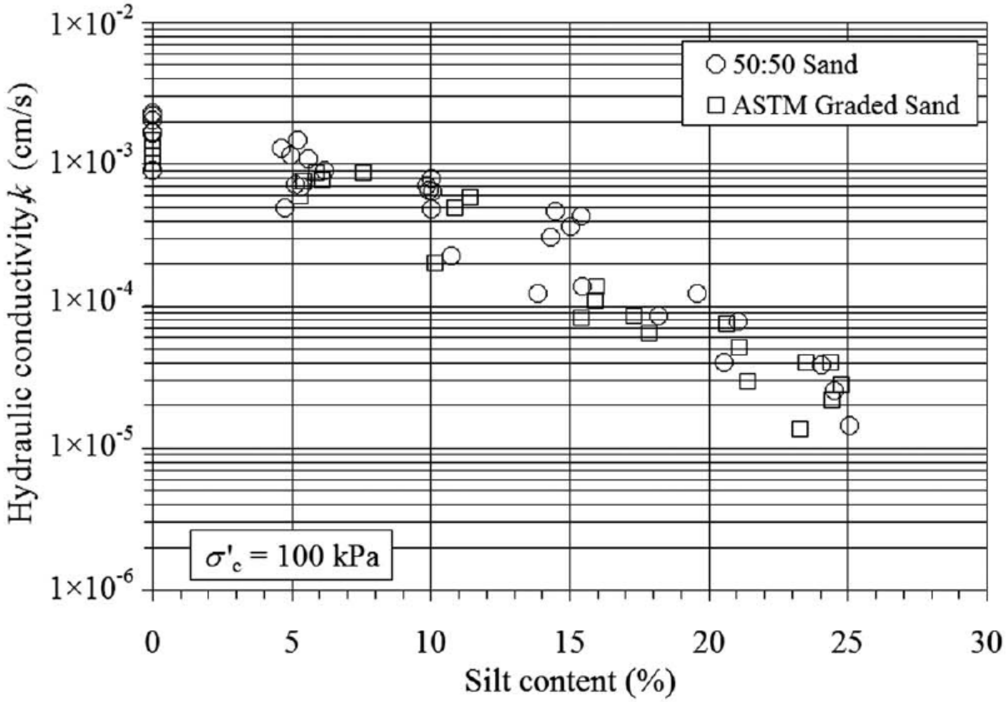
TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	SB	SP	MJL	0

OFFICE Tt EBA-KELOWNA
DATE January 28, 2014

Figure 5.0f

Q:\Kelowna\GIS\ENGINEERING\K131\K13103109_HB Dam\Maps\ISSUED FOR REVIEW\Figure 5.0-7 - Time for 0.6m Depth.mxd modified 1/28/2014 by sarah.blair



LEGEND

NOTES

1. Adapted from Figure 3 of Bandini et. al. (2009).

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

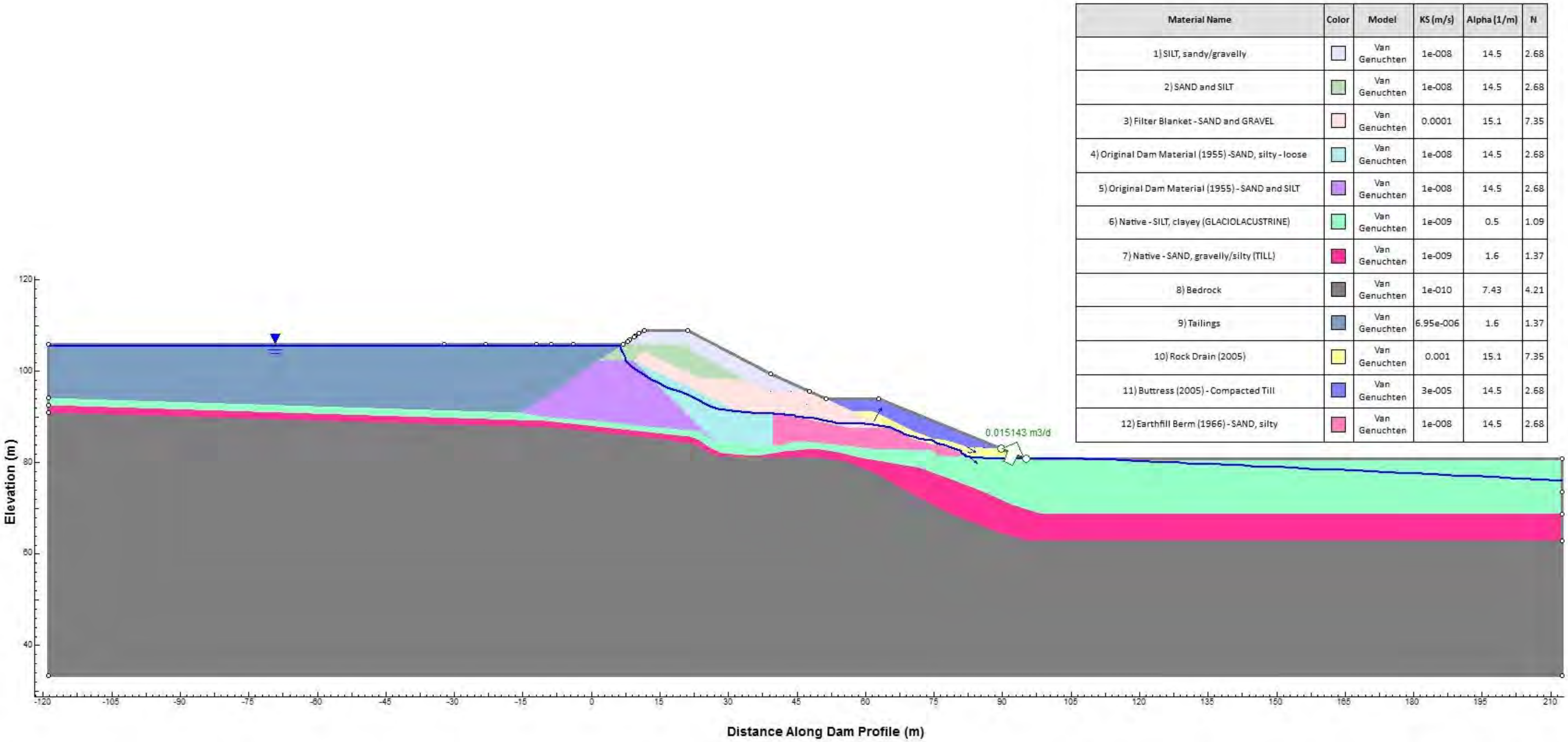
DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Saturated Hydraulic Conductivities for Sand-Silt Mixtures with Various Silt Contents

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	MJL	RP	MJL	0

OFFICE	DATE
KELOWNA	March 24, 2014

Figure 8.2



Material Name	Color	Model	KS (m/s)	Alpha (1/m)	N
1) SILT, sandy/gravelly	⬜	Van Genuchten	1e-008	14.5	2.68
2) SAND and SILT	🟩	Van Genuchten	1e-008	14.5	2.68
3) Filter Blanket - SAND and GRAVEL	⬜	Van Genuchten	0.0001	15.1	7.35
4) Original Dam Material (1955) -SAND, silty - loose	🟦	Van Genuchten	1e-008	14.5	2.68
5) Original Dam Material (1955) - SAND and SILT	🟪	Van Genuchten	1e-008	14.5	2.68
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	Van Genuchten	1e-009	0.5	1.09
7) Native - SAND, gravelly/silty (TILL)	🟥	Van Genuchten	1e-009	1.6	1.37
8) Bedrock	⬛	Van Genuchten	1e-010	7.43	4.21
9) Tailings	🟦	Van Genuchten	6.95e-006	1.6	1.37
10) Rock Drain (2005)	🟨	Van Genuchten	0.001	15.1	7.35
11) Buttress (2005) - Compacted Till	🟦	Van Genuchten	3e-005	14.5	2.68
12) Earthfill Berm (1966) - SAND, silty	🟥	Van Genuchten	1e-008	14.5	2.68

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

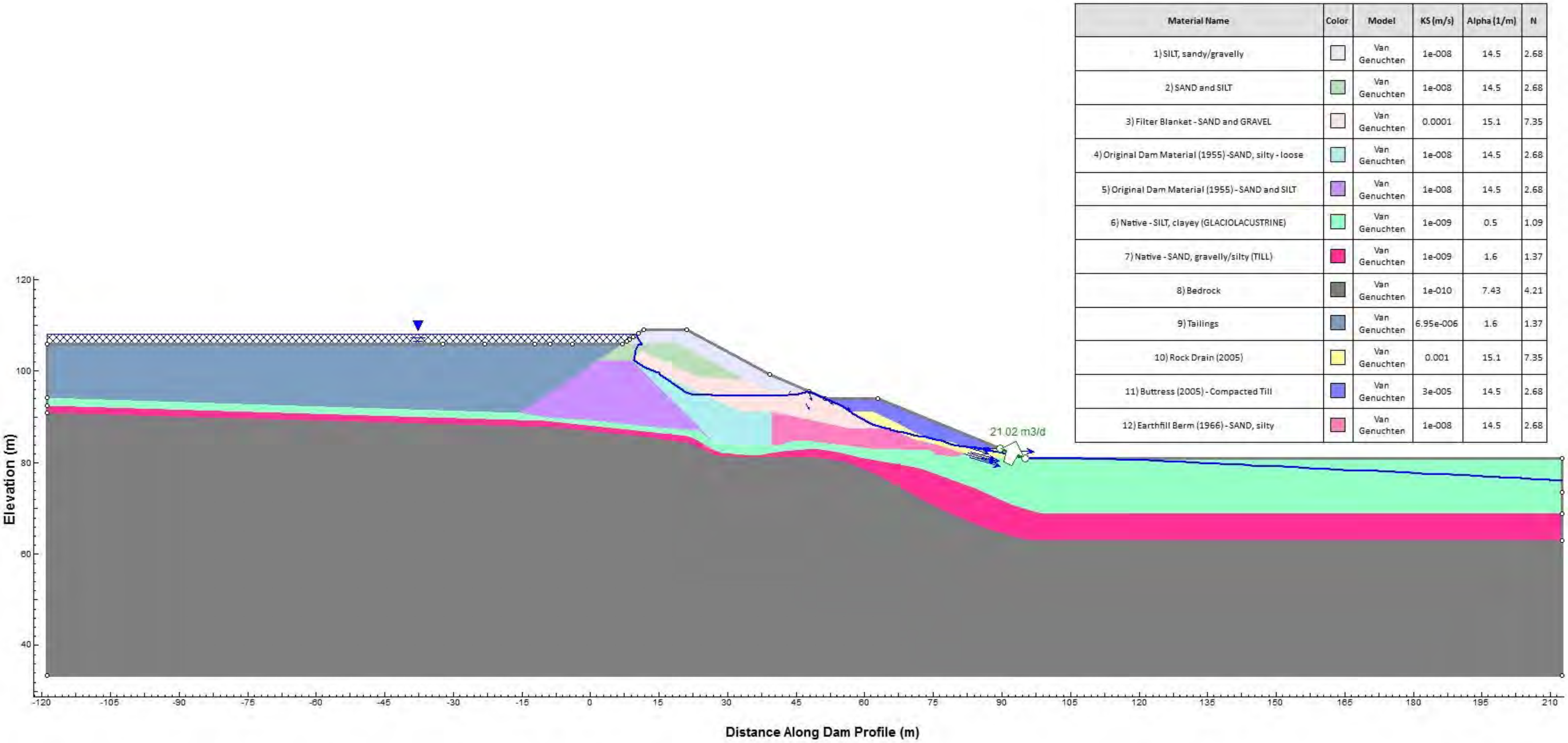
Steady State Seepage Analysis Reservoir Level at 105.50 m

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE
KELOWNA

DATE
February 24, 2014

Figure 8.3a



Material Name	Color	Model	KS (m/s)	Alpha (1/m)	N
1) SILT, sandy/gravelly	⬜	Van Genuchten	1e-008	14.5	2.68
2) SAND and SILT	🟩	Van Genuchten	1e-008	14.5	2.68
3) Filter Blanket - SAND and GRAVEL	⬜	Van Genuchten	0.0001	15.1	7.35
4) Original Dam Material (1955) -SAND, silty - loose	🟦	Van Genuchten	1e-008	14.5	2.68
5) Original Dam Material (1955) - SAND and SILT	🟪	Van Genuchten	1e-008	14.5	2.68
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	Van Genuchten	1e-009	0.5	1.09
7) Native - SAND, gravelly/silty (TILL)	🟥	Van Genuchten	1e-009	1.6	1.37
8) Bedrock	⬛	Van Genuchten	1e-010	7.43	4.21
9) Tailings	🟦	Van Genuchten	6.95e-006	1.6	1.37
10) Rock Drain (2005)	🟨	Van Genuchten	0.001	15.1	7.35
11) Buttress (2005) - Compacted Till	🟦	Van Genuchten	3e-005	14.5	2.68
12) Earthfill Berm (1966) - SAND, silty	🟥	Van Genuchten	1e-008	14.5	2.68

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Steady State Seepage Analysis Reservoir Level at 108 m

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

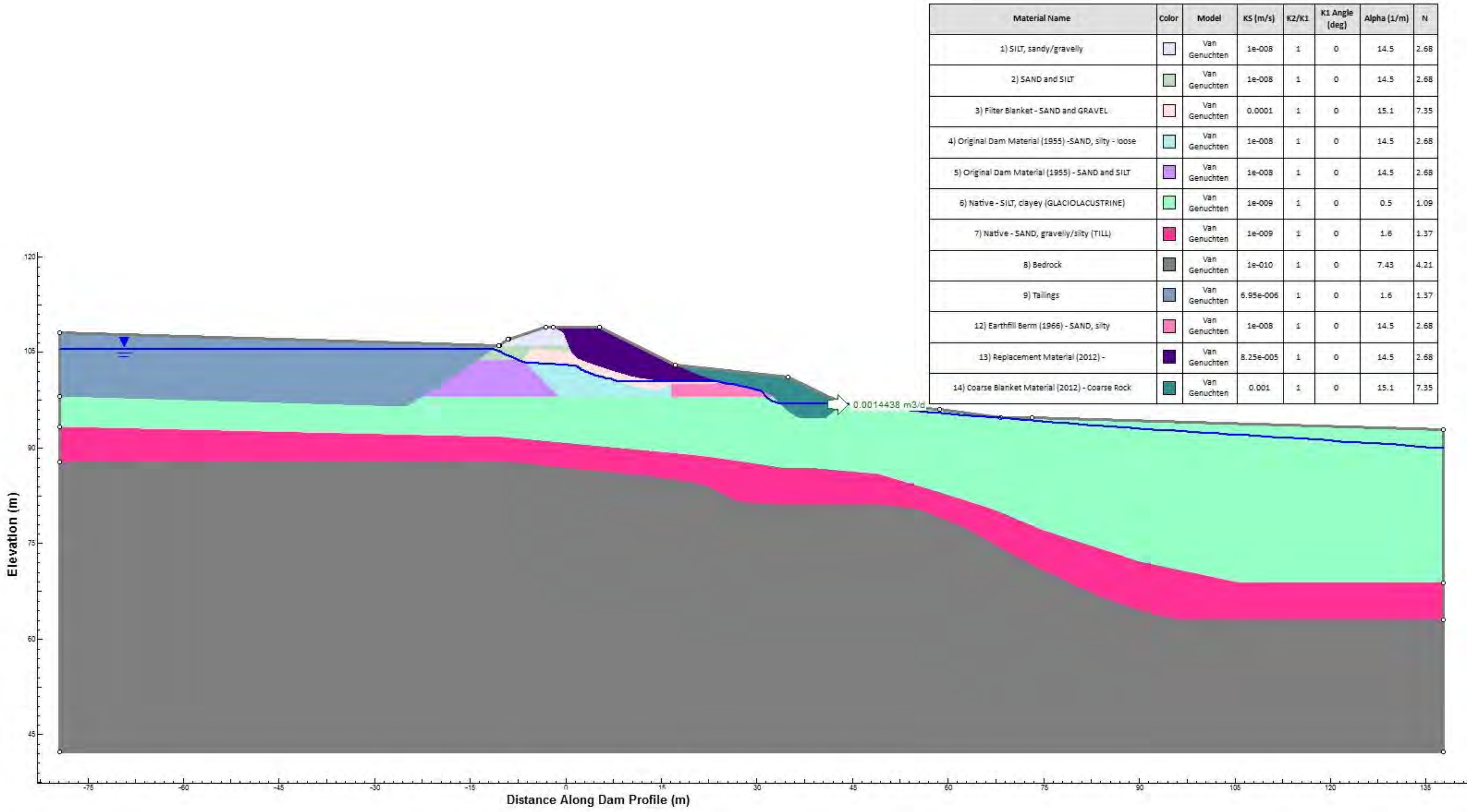
OFFICE

KELOWNA

DATE

February 24, 2014

Figure 8.3b



Material Name	Color	Model	KS (m/s)	K2/K1	K1 Angle (deg)	Alpha (1/m)	N
1) SILT, sandy/gravelly	⬜	Van Genuchten	1e-008	1	0	14.5	2.68
2) SAND and SILT	🟩	Van Genuchten	1e-008	1	0	14.5	2.68
3) Filter Blanket - SAND and GRAVEL	⬜	Van Genuchten	0.0001	1	0	15.1	7.35
4) Original Dam Material (1955) -SAND, silty - loose	🟦	Van Genuchten	1e-008	1	0	14.5	2.68
5) Original Dam Material (1955) - SAND and SILT	🟪	Van Genuchten	1e-008	1	0	14.5	2.68
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	Van Genuchten	1e-009	1	0	0.5	1.09
7) Native - SAND, gravelly/silty (TILL)	🟥	Van Genuchten	1e-009	1	0	1.6	1.37
8) Bedrock	⬛	Van Genuchten	1e-010	1	0	7.43	4.21
9) Tailings	🟦	Van Genuchten	6.95e-006	1	0	1.6	1.37
12) Earthfill Berm (1966) - SAND, silty	🟥	Van Genuchten	1e-008	1	0	14.5	2.68
13) Replacement Material (2012) -	🟪	Van Genuchten	8.25e-005	1	0	14.5	2.68
14) Coarse Blanket Material (2012) - Coarse Rock	🟩	Van Genuchten	0.001	1	0	15.1	7.35

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

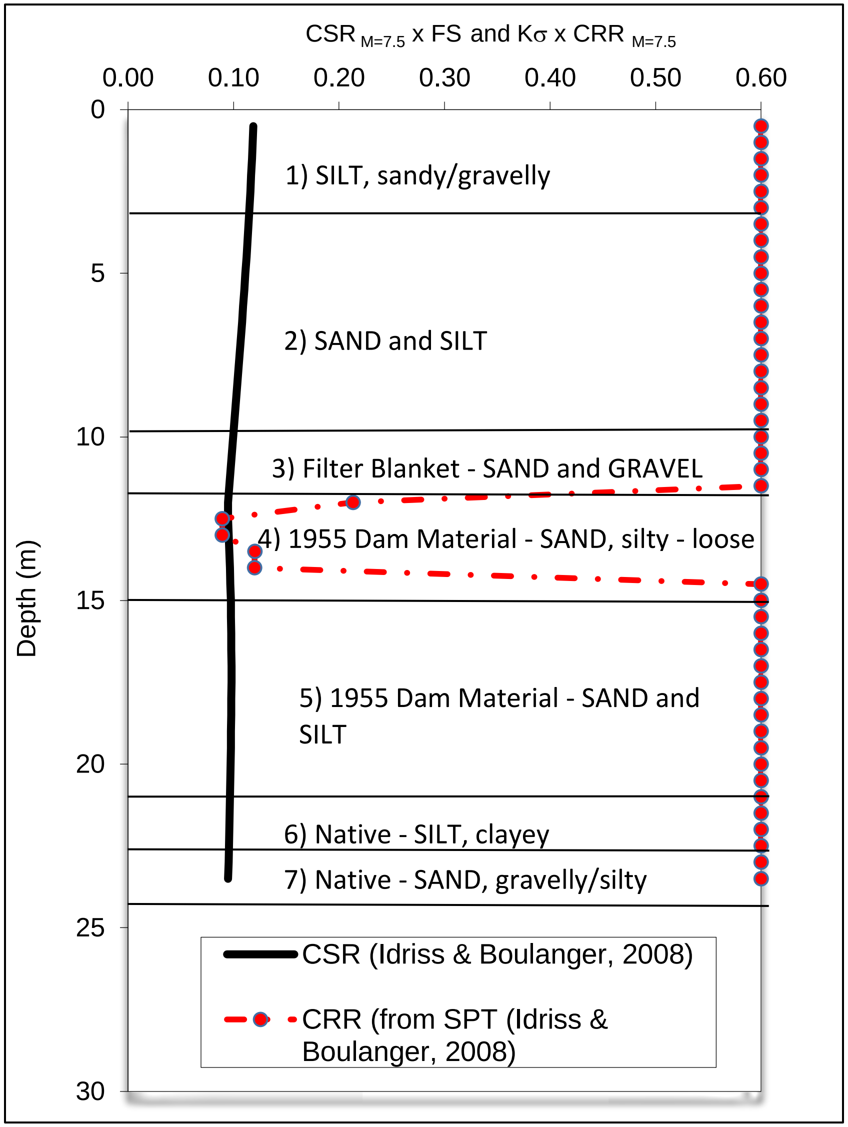
Steady State Seepage Analysis Reservoir Level at 105.50m Repaired Dam Section

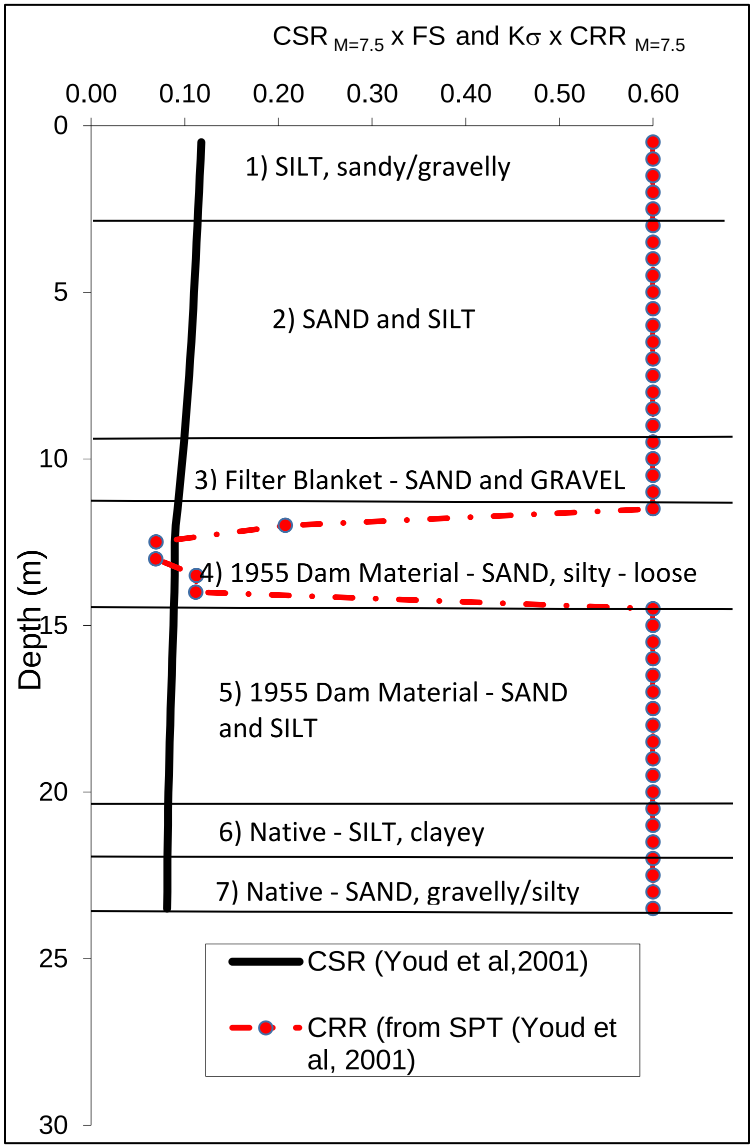
PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE
KELOWNA

DATE
February 24, 2014

Figure 8.3c





LEGEND

NOTES

STATUS
ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

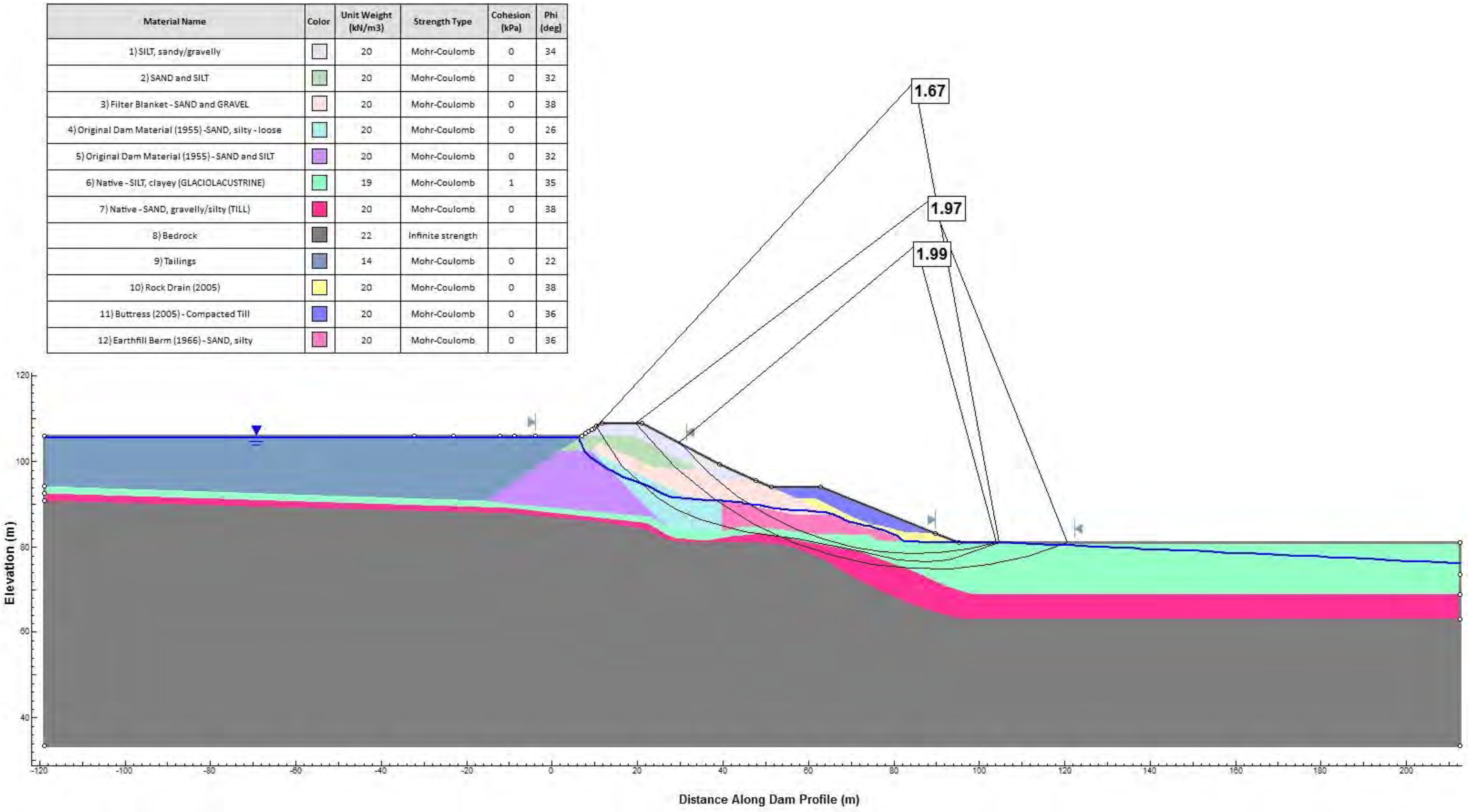
Liquefaction Analysis of Dam Materials

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE
KELOWNA

DATE
February 24, 2014

Figure 8.4



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
1) SILT, sandy/gravelly	⬜	20	Mohr-Coulomb	0	34
2) SAND and SILT	🟩	20	Mohr-Coulomb	0	32
3) Filter Blanket - SAND and GRAVEL	⬜	20	Mohr-Coulomb	0	38
4) Original Dam Material (1955) -SAND, silty - loose	🟦	20	Mohr-Coulomb	0	26
5) Original Dam Material (1955) - SAND and SILT	🟪	20	Mohr-Coulomb	0	32
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	19	Mohr-Coulomb	1	35
7) Native - SAND, gravelly/silty (TILL)	🟥	20	Mohr-Coulomb	0	38
8) Bedrock	⬛	22	Infinite strength		
9) Tailings	🟦	14	Mohr-Coulomb	0	22
10) Rock Drain (2005)	🟨	20	Mohr-Coulomb	0	38
11) Buttress (2005) - Compacted Till	🟦	20	Mohr-Coulomb	0	36
12) Earthfill Berm (1966) - SAND, silty	🟪	20	Mohr-Coulomb	0	36

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

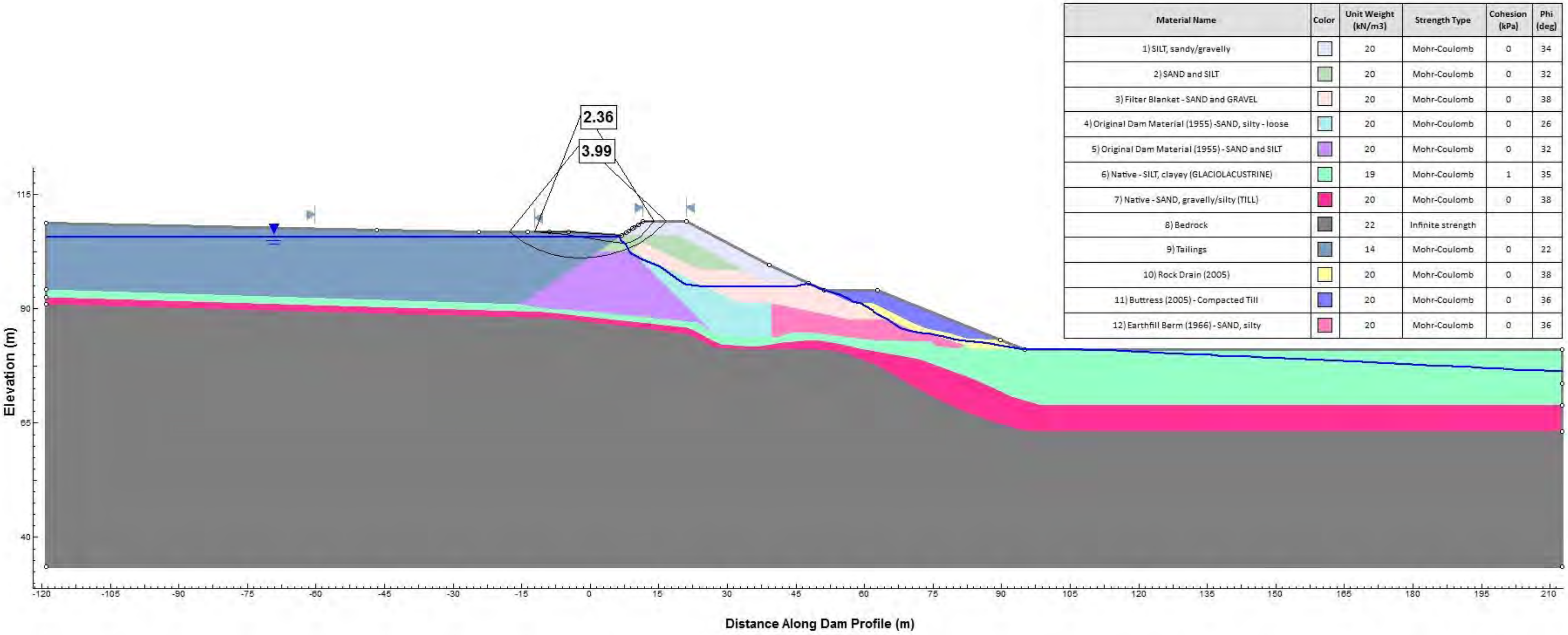
DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Static Long Term Stability Analysis Downstream Slope

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE	DATE
KELOWNA	February 24, 2014

Figure 8.5a



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
1) SILT, sandy/gravelly	⬜	20	Mohr-Coulomb	0	34
2) SAND and SILT	🟩	20	Mohr-Coulomb	0	32
3) Filter Blanket - SAND and GRAVEL	⬜	20	Mohr-Coulomb	0	38
4) Original Dam Material (1955) -SAND, silty - loose	🟦	20	Mohr-Coulomb	0	26
5) Original Dam Material (1955) - SAND and SILT	🟪	20	Mohr-Coulomb	0	32
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	19	Mohr-Coulomb	1	35
7) Native - SAND, gravelly/silty (TILL)	🟥	20	Mohr-Coulomb	0	38
8) Bedrock	⬛	22	Infinite strength		
9) Tailings	🟦	14	Mohr-Coulomb	0	22
10) Rock Drain (2005)	🟨	20	Mohr-Coulomb	0	38
11) Buttress (2005) - Compacted Till	🟦	20	Mohr-Coulomb	0	36
12) Earthfill Berm (1966) - SAND, silty	🟥	20	Mohr-Coulomb	0	36

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

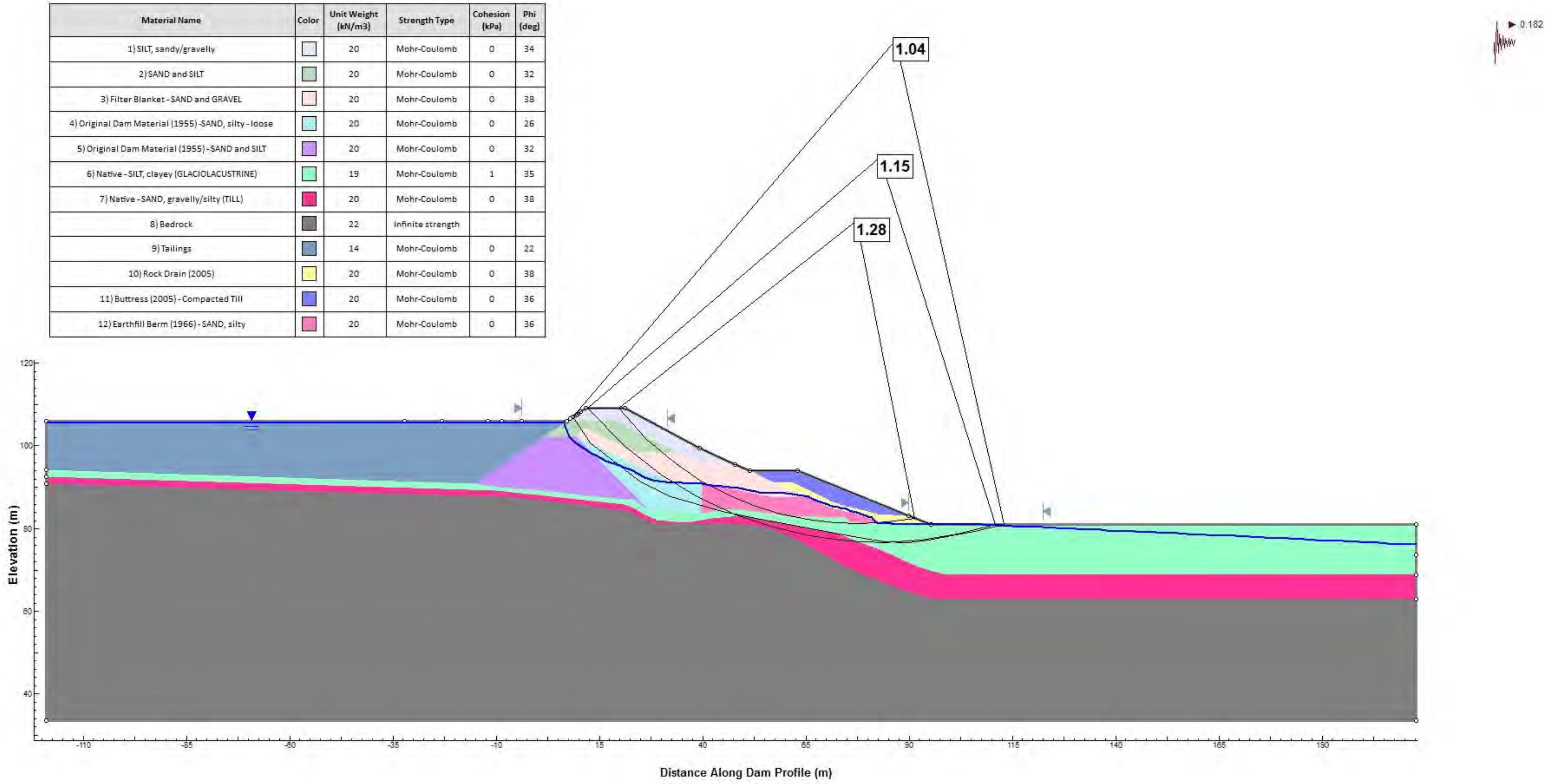
Static Long Term Stability Upstream Slope

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE
KELOWNA

DATE
February 24, 2014

Figure 8.5b



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
1) SILT, sandy/gravelly	⬜	20	Mohr-Coulomb	0	34
2) SAND and SILT	🟩	20	Mohr-Coulomb	0	32
3) Filter Blanket - SAND and GRAVEL	⬜	20	Mohr-Coulomb	0	38
4) Original Dam Material (1955) -SAND, silty - loose	🟦	20	Mohr-Coulomb	0	26
5) Original Dam Material (1955) - SAND and SILT	🟪	20	Mohr-Coulomb	0	32
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	19	Mohr-Coulomb	1	35
7) Native - SAND, gravelly/silty (TILL)	🟥	20	Mohr-Coulomb	0	38
8) Bedrock	⬛	22	Infinite strength		
9) Tailings	🟦	14	Mohr-Coulomb	0	22
10) Rock Drain (2005)	🟨	20	Mohr-Coulomb	0	38
11) Buttress (2005) - Compacted Till	🟦	20	Mohr-Coulomb	0	36
12) Earthfill Berm (1966) - SAND, silty	🟥	20	Mohr-Coulomb	0	36

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

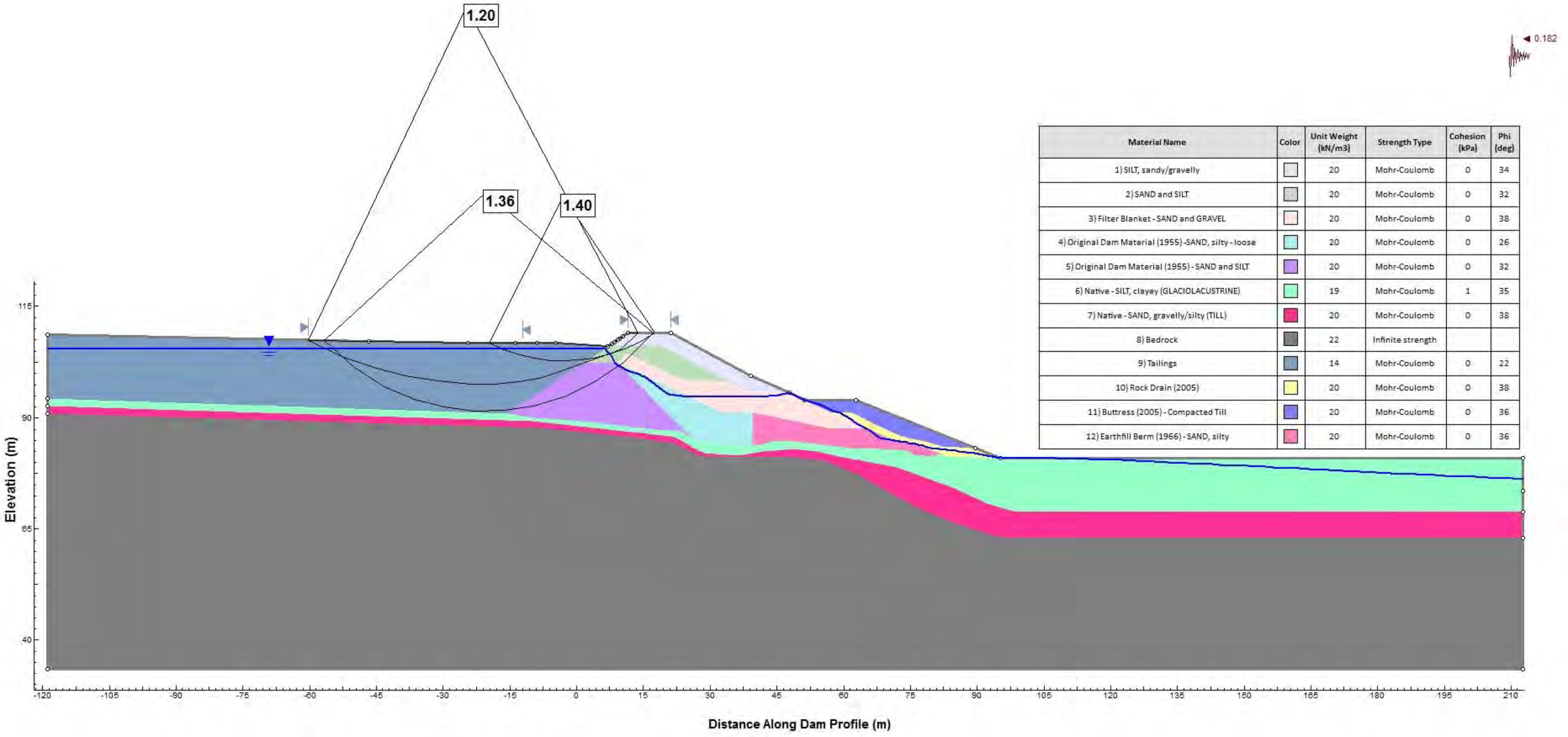
DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Pseudo-Static Stability Analysis Downstream Slope

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE	DATE
KELOWNA	February 24, 2014

Figure 8.5c



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
1) SILT, sandy/gravelly	⬜	20	Mohr-Coulomb	0	34
2) SAND and SILT	⬜	20	Mohr-Coulomb	0	32
3) Filter Blanket - SAND and GRAVEL	⬜	20	Mohr-Coulomb	0	38
4) Original Dam Material (1955) -SAND, silty - loose	🟦	20	Mohr-Coulomb	0	26
5) Original Dam Material (1955) - SAND and SILT	🟪	20	Mohr-Coulomb	0	32
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	19	Mohr-Coulomb	1	35
7) Native - SAND, gravelly/silty (TILL)	🟥	20	Mohr-Coulomb	0	38
8) Bedrock	⬛	22	Infinite strength		
9) Tailings	🟦	14	Mohr-Coulomb	0	22
10) Rock Drain (2005)	🟨	20	Mohr-Coulomb	0	38
11) Buttress (2005) - Compacted Till	🟦	20	Mohr-Coulomb	0	36
12) Earthfill Berm (1966) - SAND, silty	🟥	20	Mohr-Coulomb	0	36

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

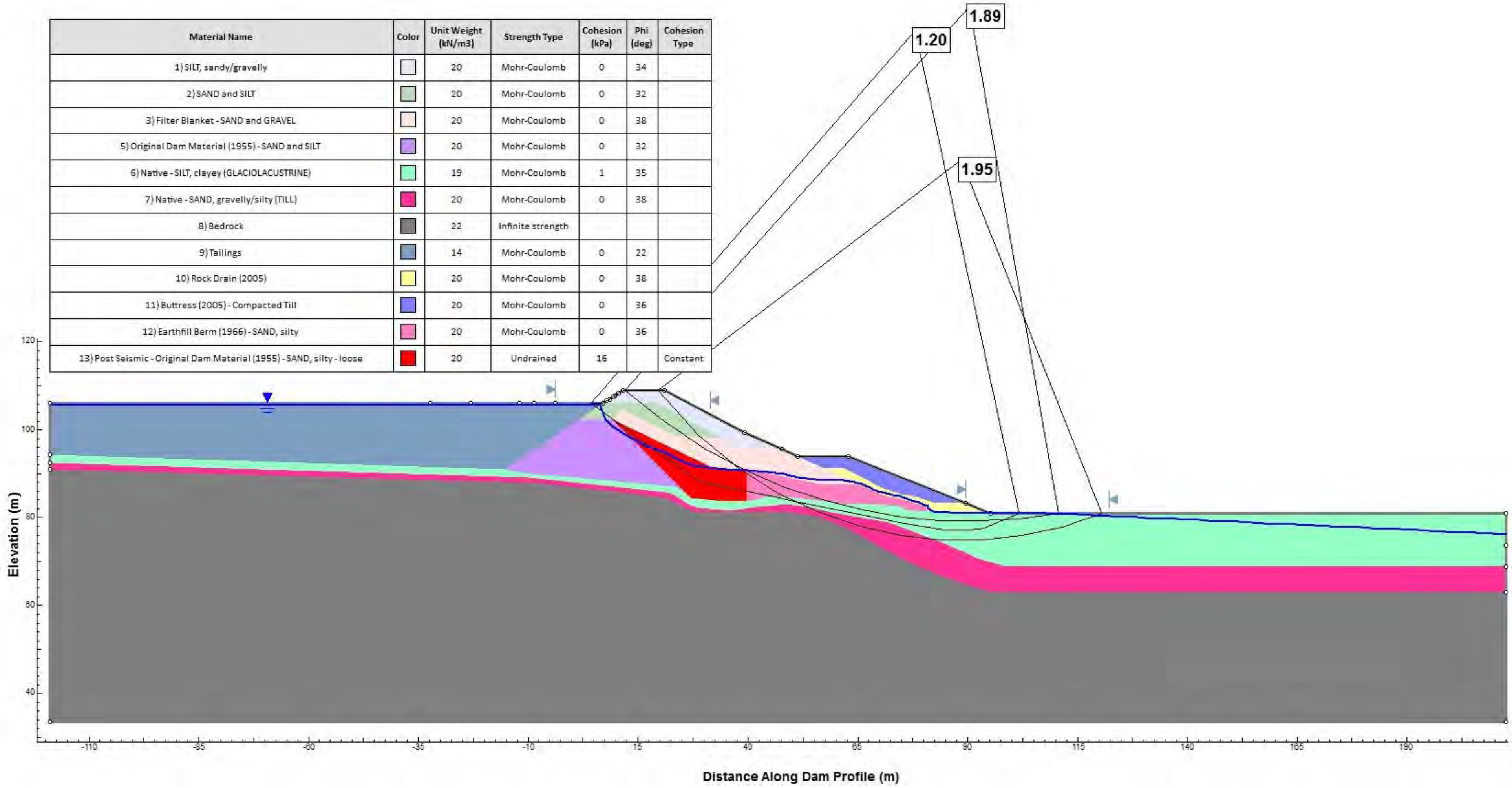
DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Pseudo Static Stability Analysis Upstream Slope

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE	DATE
KELOWNA	February 24, 2014

Figure 8.5d



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Cohesion Type
1) SILT, sandy/gravelly	⬜	20	Mohr-Coulomb	0	34	
2) SAND and SILT	🟩	20	Mohr-Coulomb	0	32	
3) Filter Blanket - SAND and GRAVEL	⬜	20	Mohr-Coulomb	0	38	
5) Original Dam Material (1955) - SAND and SILT	🟪	20	Mohr-Coulomb	0	32	
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	19	Mohr-Coulomb	1	35	
7) Native - SAND, gravelly/silty (TILL)	🟥	20	Mohr-Coulomb	0	38	
8) Bedrock	⬛	22	Infinite strength			
9) Tailings	🟦	14	Mohr-Coulomb	0	22	
10) Rock Drain (2005)	🟨	20	Mohr-Coulomb	0	38	
11) Buttress (2005) - Compacted Till	🟦	20	Mohr-Coulomb	0	36	
12) Earthfill Berm (1966) - SAND, silty	🟥	20	Mohr-Coulomb	0	36	
13) Post Seismic - Original Dam Material (1955) - SAND, silty - loose	🟥	20	Undrained	16		Constant

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

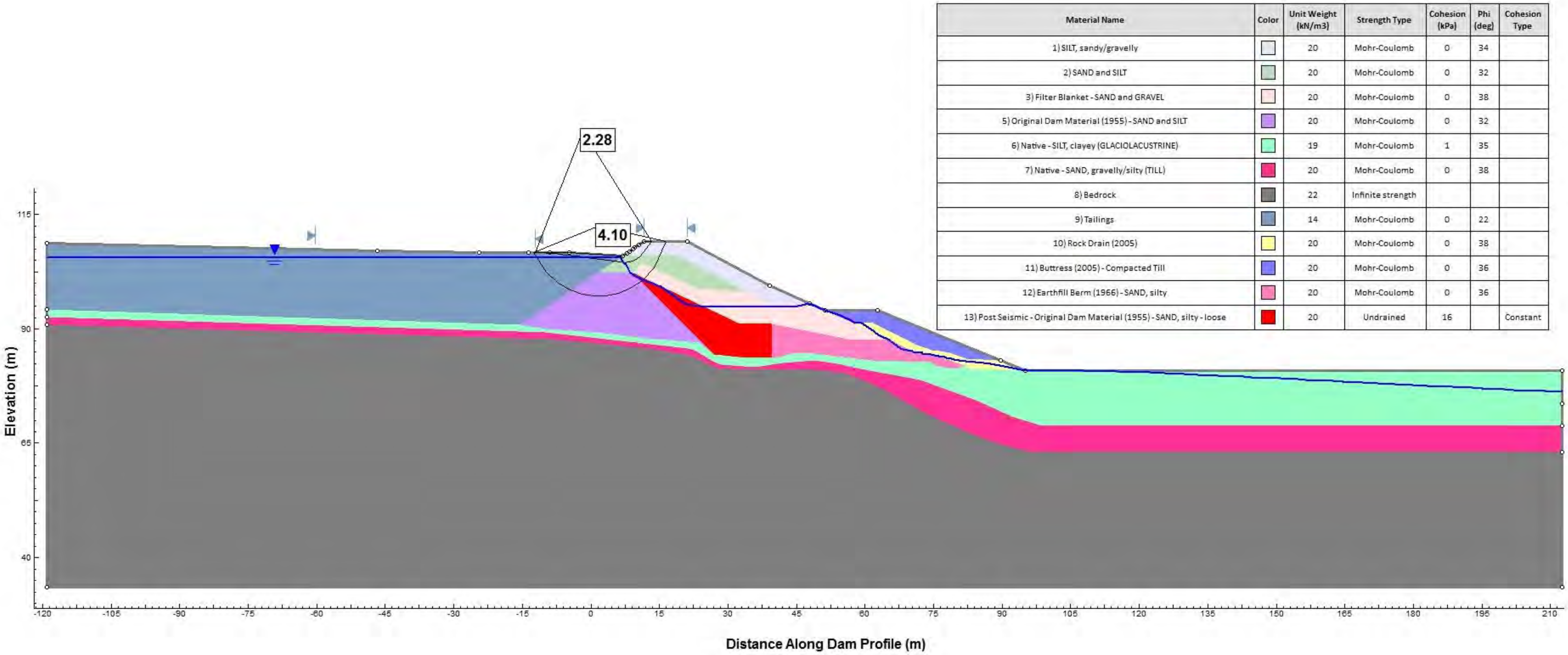
DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Residual Strength Stability Analysis Downstream Slope

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE	DATE
KELOWNA	February 24, 2014

Figure 8.5e



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Cohesion Type
1) SILT, sandy/gravelly	⬜	20	Mohr-Coulomb	0	34	
2) SAND and SILT	🟩	20	Mohr-Coulomb	0	32	
3) Filter Blanket - SAND and GRAVEL	⬜	20	Mohr-Coulomb	0	38	
5) Original Dam Material (1955) - SAND and SILT	🟪	20	Mohr-Coulomb	0	32	
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	19	Mohr-Coulomb	1	35	
7) Native - SAND, gravelly/silty (TILL)	🟥	20	Mohr-Coulomb	0	38	
8) Bedrock	⬛	22	Infinite strength			
9) Tailings	🟦	14	Mohr-Coulomb	0	22	
10) Rock Drain (2005)	🟨	20	Mohr-Coulomb	0	38	
11) Buttress (2005) - Compacted Till	🟦	20	Mohr-Coulomb	0	36	
12) Earthfill Berm (1966) - SAND, silty	🟥	20	Mohr-Coulomb	0	36	
13) Post Seismic - Original Dam Material (1955) - SAND, silty - loose	🟥	20	Undrained	16		Constant

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

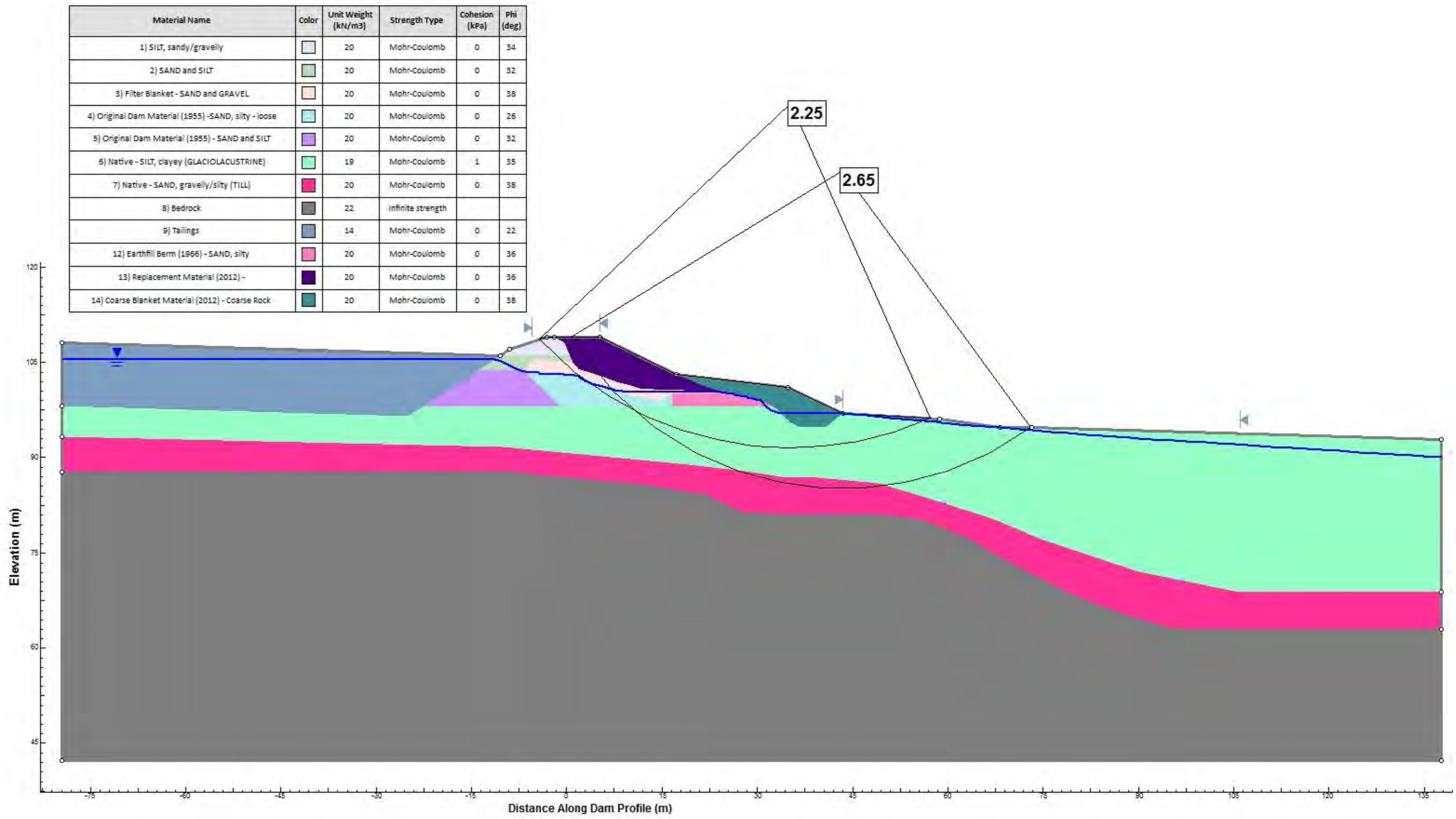
Residual Strength Stability Analysis Upstream Slope

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE KELOWNA

DATE March 28, 2014

Figure 8.5f



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
1) SILT, sandy/gravelly	■	20	Mohr-Coulomb	0	34
2) SAND and SILT	■	20	Mohr-Coulomb	0	32
3) Filter Blanket - SAND and GRAVEL	■	20	Mohr-Coulomb	0	38
4) Original Dam Material (1955) -SAND, silty - loose	■	20	Mohr-Coulomb	0	26
5) Original Dam Material (1955) - SAND and SILT	■	20	Mohr-Coulomb	0	32
6) Native - SILT, clayey (GLACIOLACUSTRINE)	■	19	Mohr-Coulomb	1	35
7) Native - SAND, gravelly/silty (TILL)	■	20	Mohr-Coulomb	0	38
8) Bedrock	■	22	Infinite strength		
9) Tailings	■	14	Mohr-Coulomb	0	22
12) Earthfill Berm (1966) - SAND, silty	■	20	Mohr-Coulomb	0	36
13) Replacement Material (2012) -	■	20	Mohr-Coulomb	0	36
14) Coarse Blanket Material (2012) - Coarse Rock	■	20	Mohr-Coulomb	0	38

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Static Long Term Stability Analysis Downstream Slope Repaired Dam Section

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

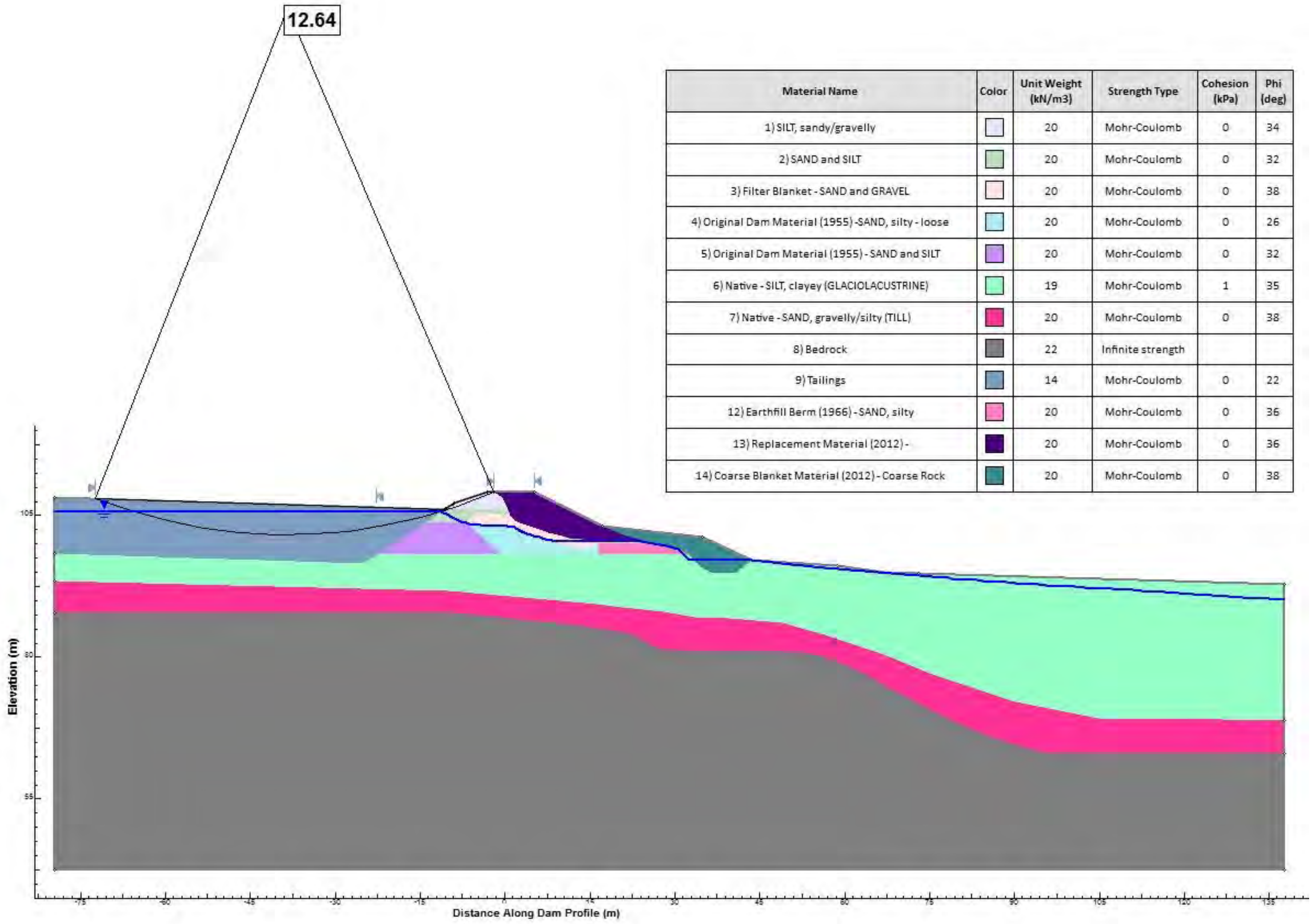
OFFICE

KELOWNA

DATE

February 24, 2014

Figure 8.5g



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
1) SILT, sandy/gravelly	■	20	Mohr-Coulomb	0	34
2) SAND and SILT	■	20	Mohr-Coulomb	0	32
3) Filter Blanket - SAND and GRAVEL	■	20	Mohr-Coulomb	0	38
4) Original Dam Material (1955) -SAND, silty - loose	■	20	Mohr-Coulomb	0	26
5) Original Dam Material (1955) - SAND and SILT	■	20	Mohr-Coulomb	0	32
6) Native - SILT, clayey (GLACIOLACUSTRINE)	■	19	Mohr-Coulomb	1	35
7) Native - SAND, gravelly/silty (TILL)	■	20	Mohr-Coulomb	0	38
8) Bedrock	■	22	Infinite strength		
9) Tailings	■	14	Mohr-Coulomb	0	22
12) Earthfill Berm (1966) - SAND, silty	■	20	Mohr-Coulomb	0	36
13) Replacement Material (2012) -	■	20	Mohr-Coulomb	0	36
14) Coarse Blanket Material (2012) - Coarse Rock	■	20	Mohr-Coulomb	0	38

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Static Long Term Stability Upstream Slope Repaired Dam Section

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

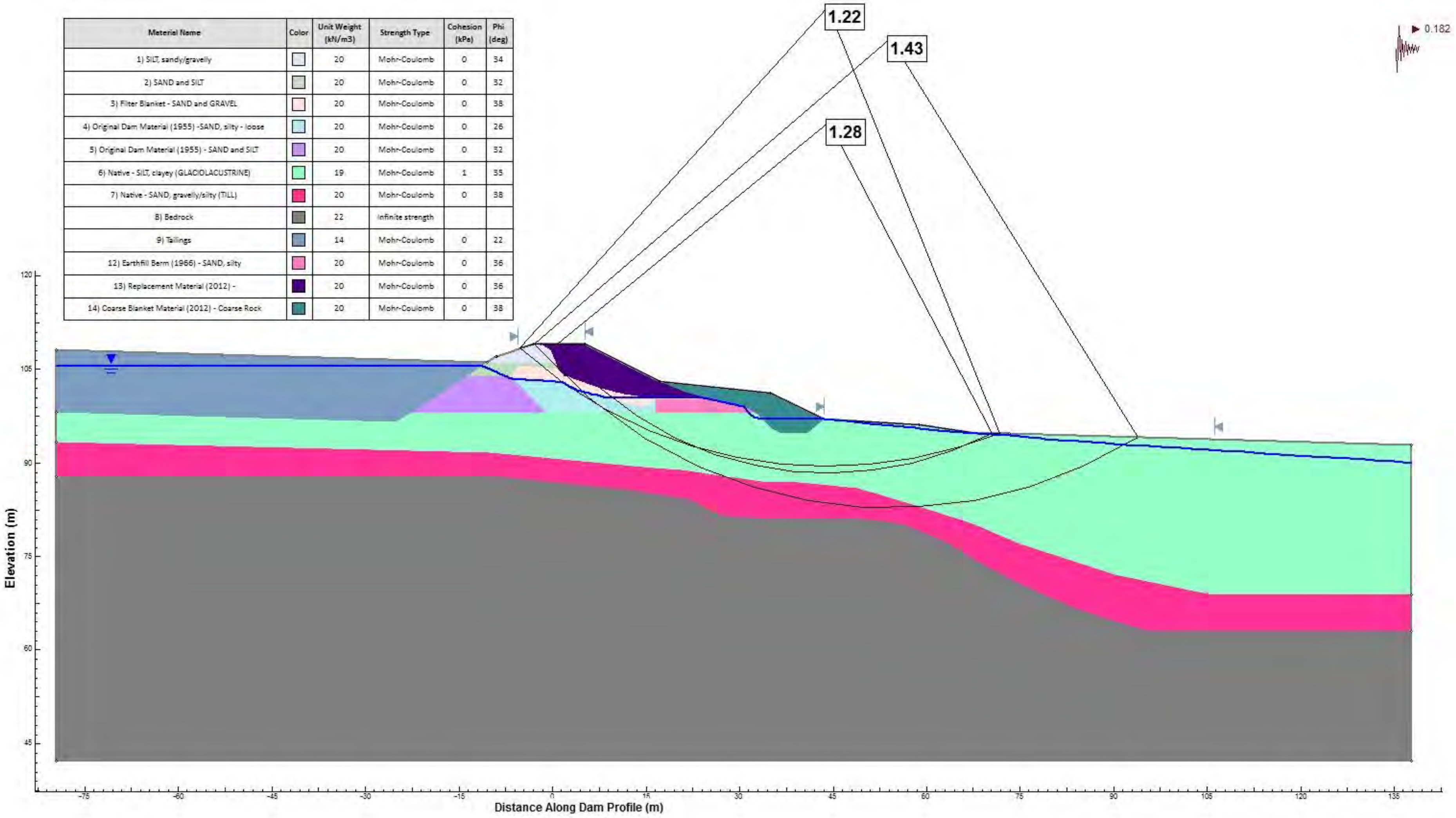
OFFICE

KELOWNA

DATE

February 24, 2014

Figure 8.5h



Meterial Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
1) SILT, sandy/gravelly	⬜	20	Mohr-Coulomb	0	34
2) SAND and SILT	⬜	20	Mohr-Coulomb	0	32
3) Filter Blanket - SAND and GRAVEL	⬜	20	Mohr-Coulomb	0	38
4) Original Dam Material (1955) -SAND, silty - loose	🟦	20	Mohr-Coulomb	0	26
5) Original Dam Material (1955) - SAND and SILT	🟪	20	Mohr-Coulomb	0	32
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	19	Mohr-Coulomb	1	35
7) Native - SAND, gravelly/silty (TILL)	🟥	20	Mohr-Coulomb	0	38
8) Bedrock	⬛	22	Infinite strength		
9) Tailings	🟦	14	Mohr-Coulomb	0	22
12) Earthfill Berm (1966) - SAND, silty	🟥	20	Mohr-Coulomb	0	36
13) Replacement Material (2012) -	🟪	20	Mohr-Coulomb	0	36
14) Coarse Blanket Material (2012) - Coarse Rock	🟦	20	Mohr-Coulomb	0	38

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Pseudo-Static Stability Analysis Downstream Slope Repaired Dam Section

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

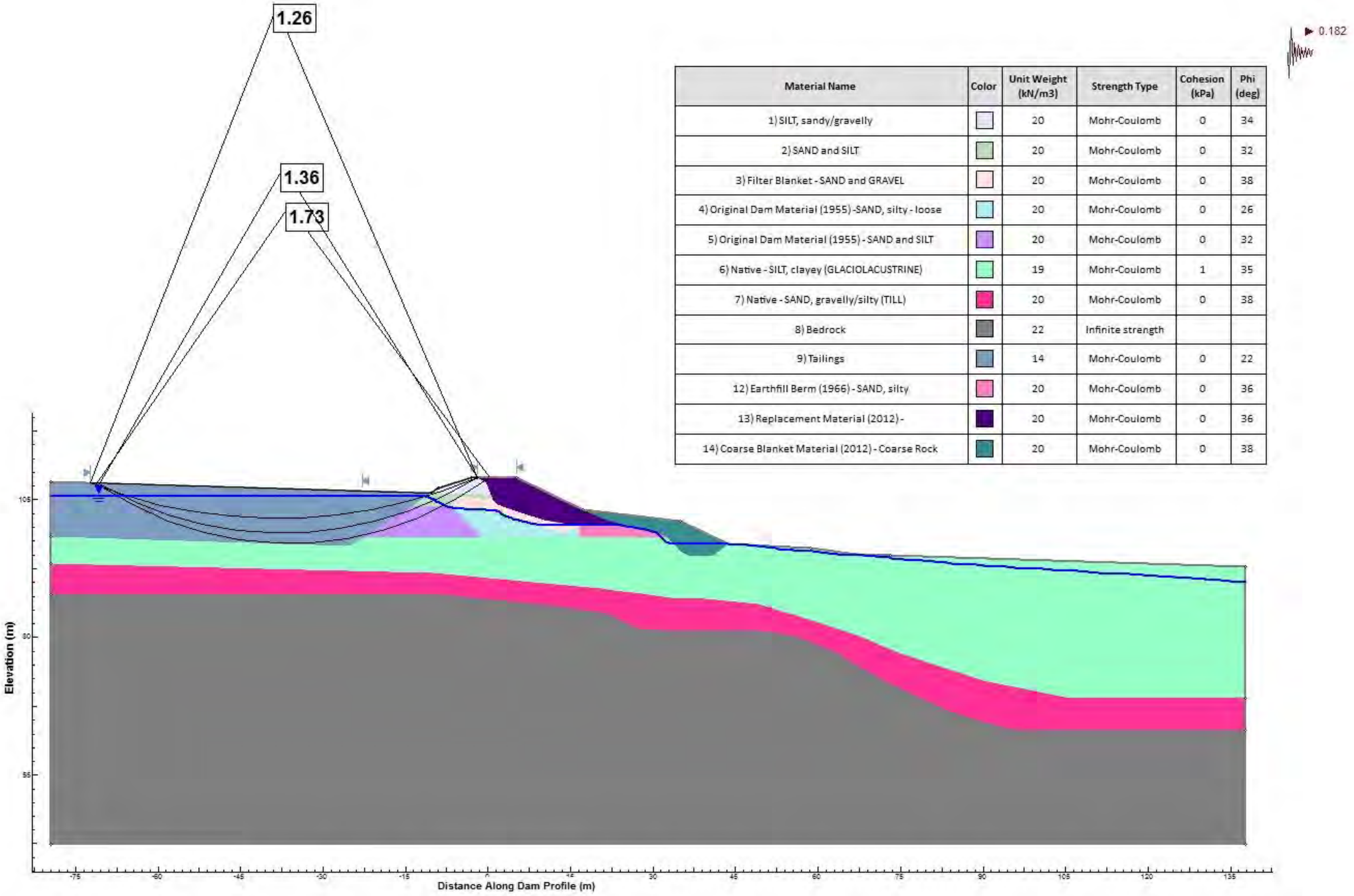
OFFICE

KELOWNA

DATE

February 24, 2014

Figure 8.5i



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
1) SILT, sandy/gravelly	⬜	20	Mohr-Coulomb	0	34
2) SAND and SILT	🟩	20	Mohr-Coulomb	0	32
3) Filter Blanket - SAND and GRAVEL	⬜	20	Mohr-Coulomb	0	38
4) Original Dam Material (1955) -SAND, silty - loose	🟦	20	Mohr-Coulomb	0	26
5) Original Dam Material (1955) - SAND and SILT	🟪	20	Mohr-Coulomb	0	32
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	19	Mohr-Coulomb	1	35
7) Native - SAND, gravelly/silty (TILL)	🟥	20	Mohr-Coulomb	0	38
8) Bedrock	⬛	22	Infinite strength		
9) Tailings	🟦	14	Mohr-Coulomb	0	22
12) Earthfill Berm (1966) - SAND, silty	🟥	20	Mohr-Coulomb	0	36
13) Replacement Material (2012) -	🟪	20	Mohr-Coulomb	0	36
14) Coarse Blanket Material (2012) - Coarse Rock	🟦	20	Mohr-Coulomb	0	38

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

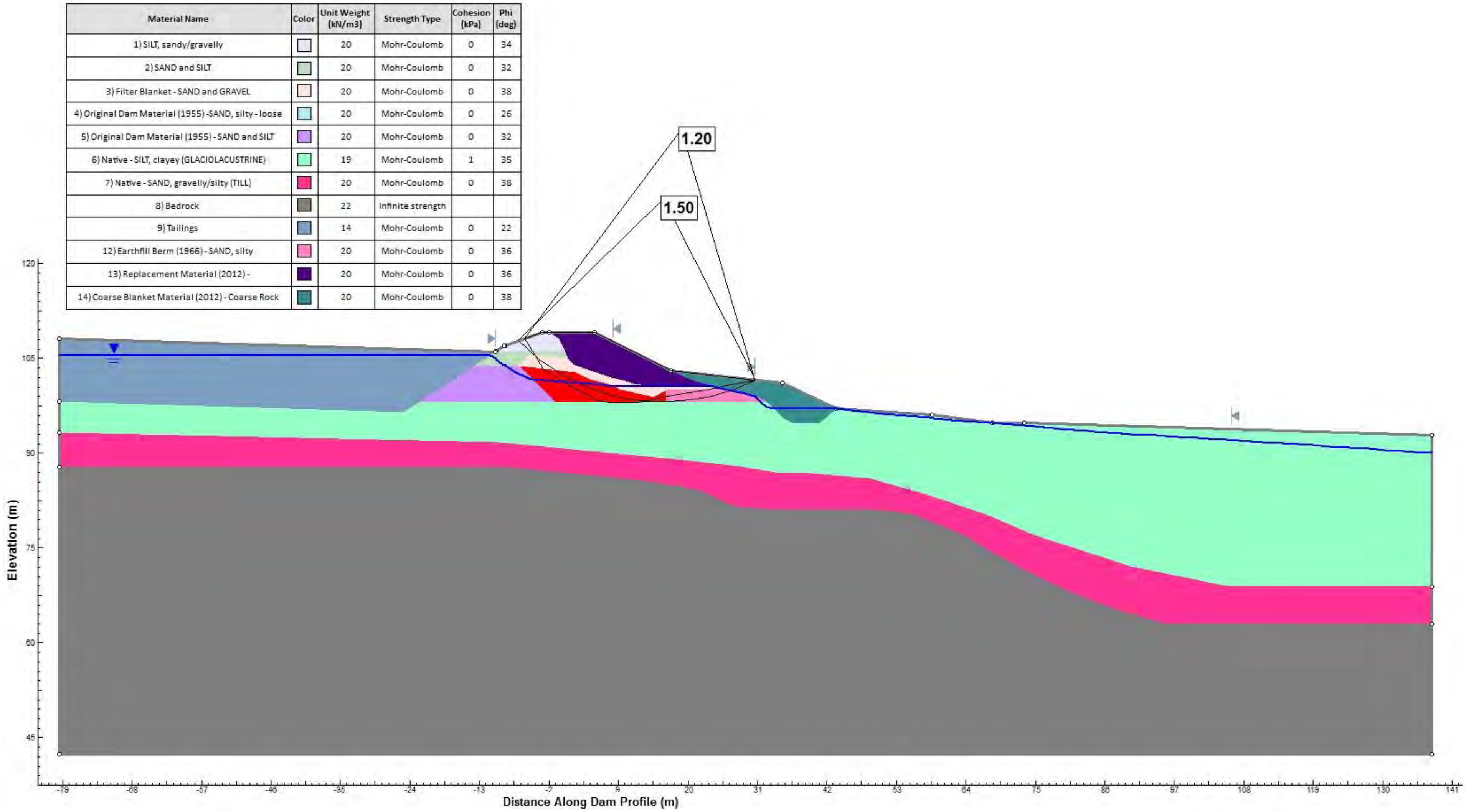
DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Pseudo Static Stability Analysis Upstream Slope Repaired Dam Section

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE	DATE
KELOWNA	February 24, 2014

Figure 8.5j



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
1) SILT, sandy/gravelly	⬜	20	Mohr-Coulomb	0	34
2) SAND and SILT	🟩	20	Mohr-Coulomb	0	32
3) Filter Blanket - SAND and GRAVEL	⬜	20	Mohr-Coulomb	0	38
4) Original Dam Material (1955) -SAND, silty - loose	🟦	20	Mohr-Coulomb	0	26
5) Original Dam Material (1955) - SAND and SILT	🟪	20	Mohr-Coulomb	0	32
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	19	Mohr-Coulomb	1	35
7) Native - SAND, gravelly/silty (TILL)	🟥	20	Mohr-Coulomb	0	38
8) Bedrock	⬛	22	Infinite strength		
9) Tailings	🟦	14	Mohr-Coulomb	0	22
12) Earthfill Berm (1966) - SAND, silty	🟥	20	Mohr-Coulomb	0	36
13) Replacement Material (2012) -	🟪	20	Mohr-Coulomb	0	36
14) Coarse Blanket Material (2012) - Coarse Rock	🟦	20	Mohr-Coulomb	0	38

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

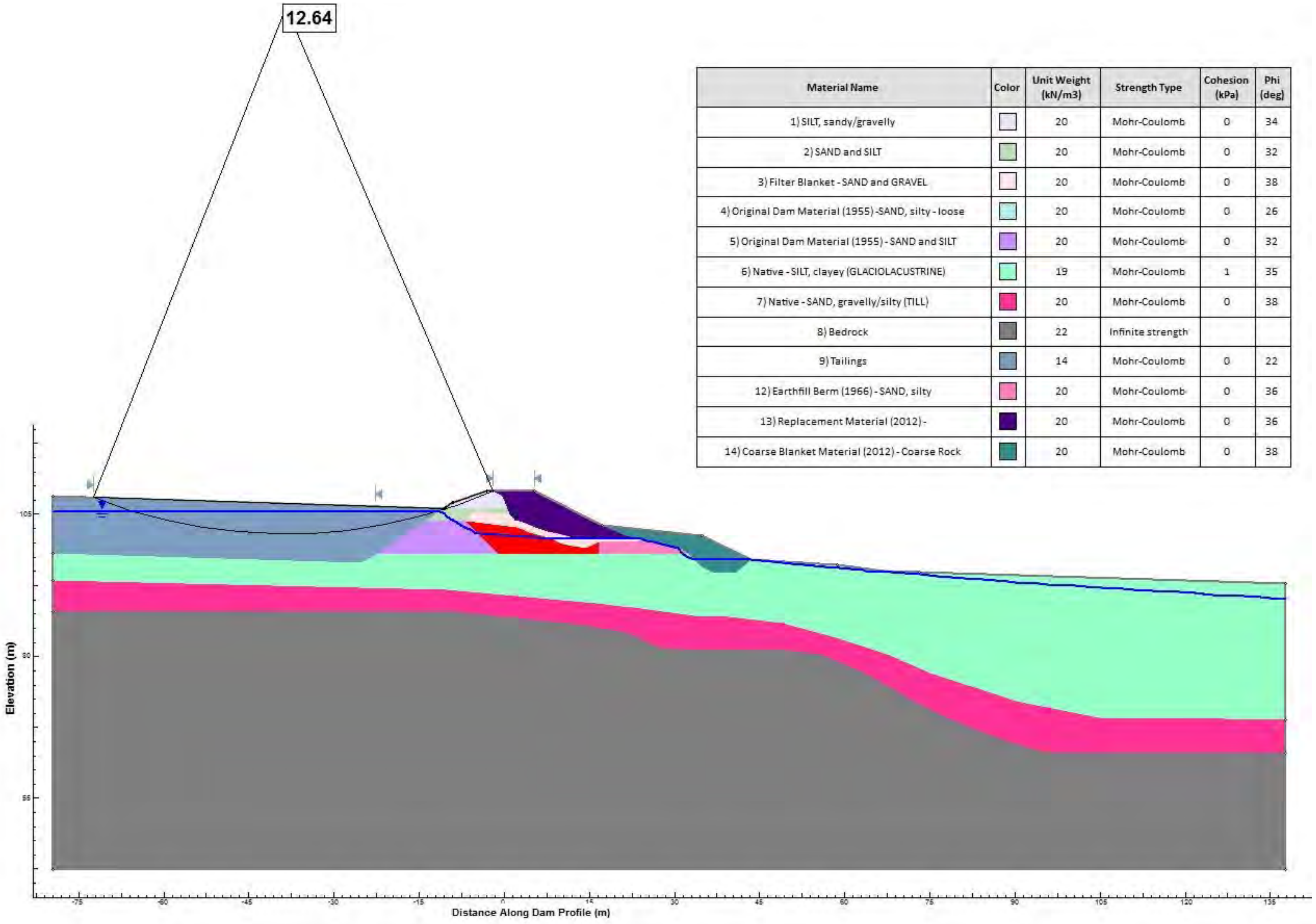
DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Residual Strength Stability Analysis Downstream Slope Repaired Dam Section

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE	DATE
KELOWNA	February 24, 2014

Figure 8.5k



Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)
1) SILT, sandy/gravelly	⬜	20	Mohr-Coulomb	0	34
2) SAND and SILT	🟩	20	Mohr-Coulomb	0	32
3) Filter Blanket - SAND and GRAVEL	⬜	20	Mohr-Coulomb	0	38
4) Original Dam Material (1955) -SAND, silty - loose	🟦	20	Mohr-Coulomb	0	26
5) Original Dam Material (1955) - SAND and SILT	🟪	20	Mohr-Coulomb	0	32
6) Native - SILT, clayey (GLACIOLACUSTRINE)	🟩	19	Mohr-Coulomb	1	35
7) Native - SAND, gravelly/silty (TILL)	🟥	20	Mohr-Coulomb	0	38
8) Bedrock	⬛	22	Infinite strength		
9) Tailings	🟦	14	Mohr-Coulomb	0	22
12) Earthfill Berm (1966) - SAND, silty	🟥	20	Mohr-Coulomb	0	36
13) Replacement Material (2012) -	🟪	20	Mohr-Coulomb	0	36
14) Coarse Blanket Material (2012) - Coarse Rock	🟩	20	Mohr-Coulomb	0	38

LEGEND

NOTES

Elevation based on 2012 survey datum

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Residual Strength Stability Analysis
Upstream Slope
Repaired Dam Section

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	LAM	MJL	MJL	0

OFFICE	DATE
KELOWNA	March 28, 2014

Figure 8.5l

INITIATION

Concentrated leak forms, erosion initiates along walls of crack

CONTINUATION

Continuation of erosion

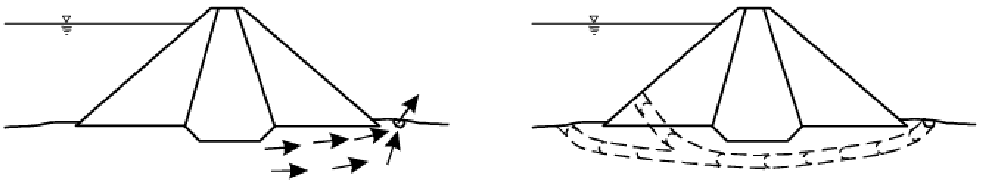
PROGRESSION

Enlargement of concentrated leak

BREACH

Breach mechanism forms

(A) INTERNAL EROSION IN THE EMBANKMENT INITIATED BY EROSION IN A CONCENTRATED LEAK



INITIATION → CONTINUATION → PROGRESSION → BREACH

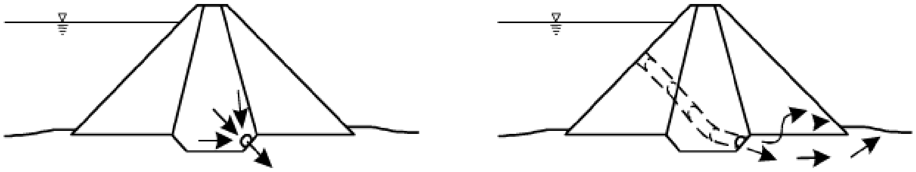
Leakage exits from the foundation and backward erosion initiates

Continuation of erosion

Backward erosion in progresses to form a pipe

Breach mechanism forms

(B) INTERNAL EROSION IN THE FOUNDATION INITIATED BY BACKWARD EROSION



INITIATION

Leakage exits the core into the foundation and backward erosion initiates as core erodes into the foundation

CONTINUATION

Continuation of erosion

PROGRESSION

Backward erosion progresses to form a pipe. Eroded soil is transported in the foundation

BREACH

Breach mechanism forms

(C) INTERNAL EROSION FROM THE EMBANKMENT TO FOUNDATION INITIATED BY BACKWARD EROSION

LEGEND

NOTES

1. Adapted from Figure 2.1 ICOLD Bulletin 164 Internal Erosion of Existing Dams, Leeves and Dikes, and Their Foundations.

STATUS
ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

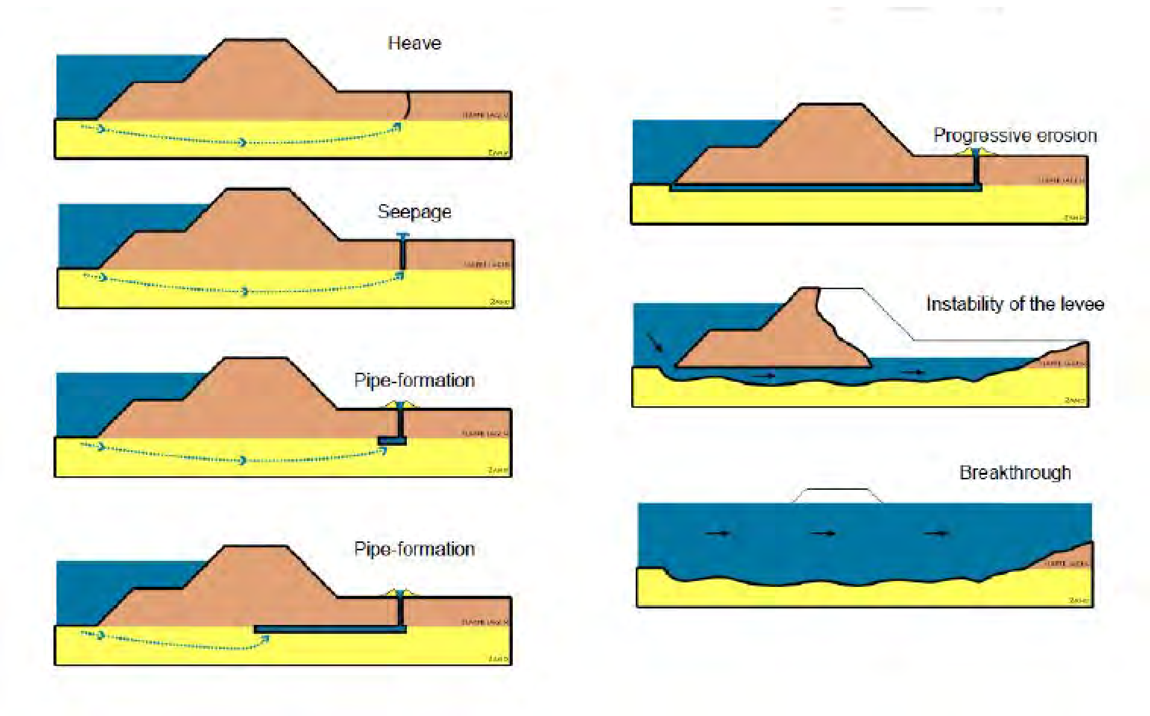
DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Models for the Development of Embankment Failures Due to Internal Erosion

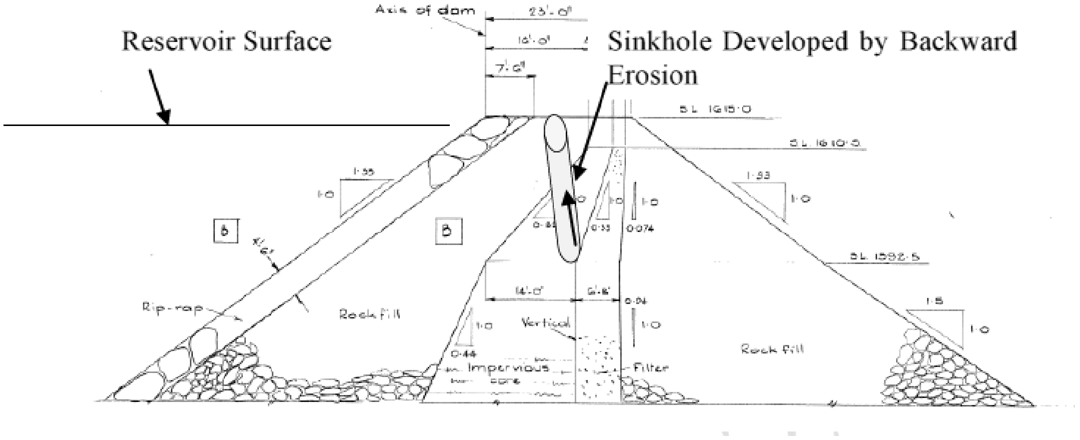
PROJECT NO.	**DWN**	**CKD**	**APVD**	**REV**
K13103109-01	MJL	BP	MJL	0
OFFICE	**DATE**			
KELOWNA	January 21, 2014			

Figure 8.7a

Example of Backward Erosion Piping



Example of Global Backward Erosion



LEGEND

NOTES

1. Adapted from Figures 2.7 and 4.1 of ICOLD Bulletin 164 Internal Erosion of Existing Dams, Leeves and Dikes, and Their Foundations.

STATUS
ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

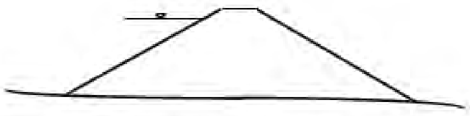
DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Examples of Backward Erosion

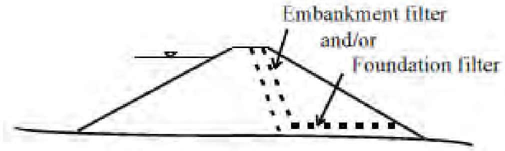
PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	MJL	BP	MJL	0

OFFICE	DATE
KELOWNA	January 21, 2014

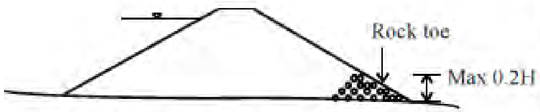
Figure 8.7b



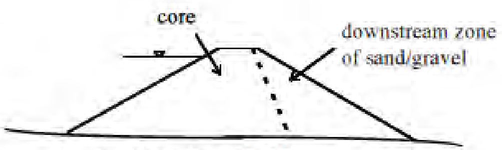
0. Homogeneous earthfill



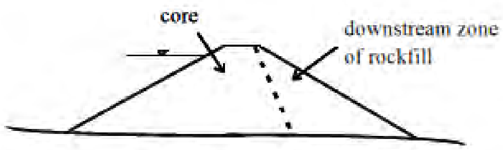
1. Earthfill with filter



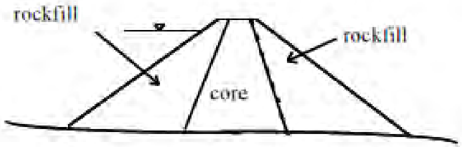
2. Earthfill with rock toe



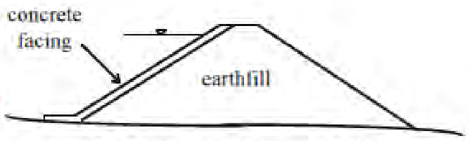
3. Zoned earthfill



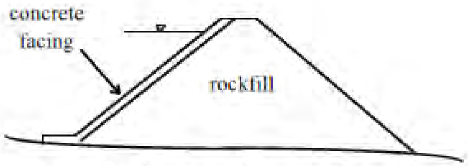
4. Zoned earth and rockfill



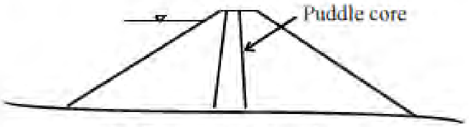
5. Central core earth and rockfill



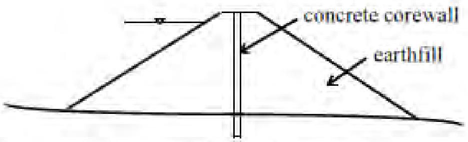
6. Concrete face earthfill



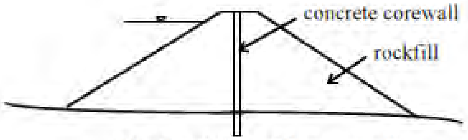
7. Concrete face rockfill



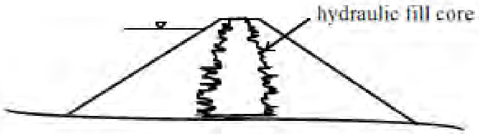
8. Puddle core earthfill



9. Earthfill with corewall



10. Rockfill with corewall



11. Hydraulic fill

LEGEND

NOTES

1. Adapted from Figure 2.9 ICOLD Bulletin 164 Internal Erosion of Existing Dams, Leeves and Dikes, and Their Foundations

STATUS
ISSUED FOR USE

CLIENT

TETRA TECH EBA

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

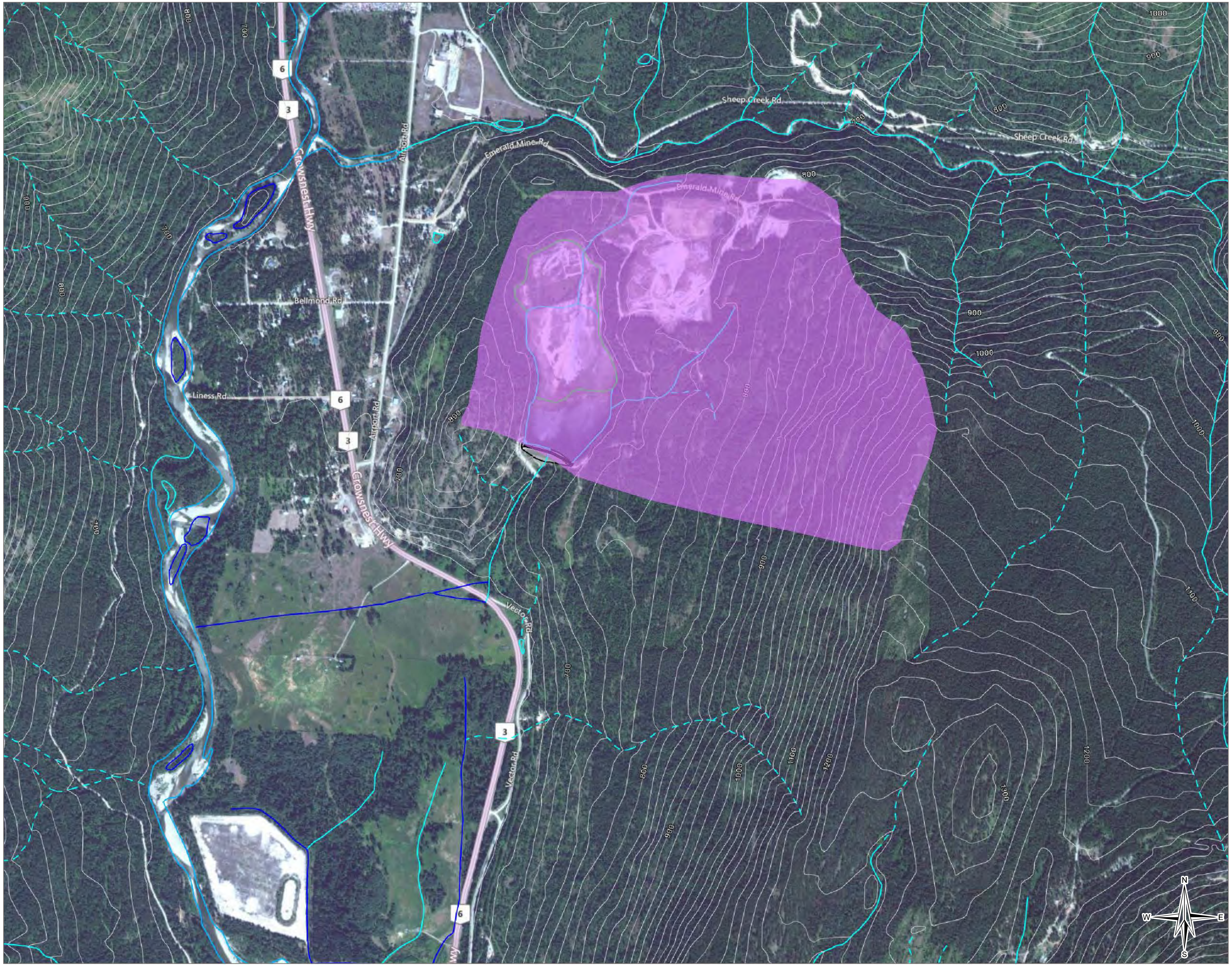
Dam Zoning Categories

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	MJL	RP	MJL	0

OFFICE
KELOWNA

DATE
February 24, 2014

Figure 8.7c



LEGEND

🟪 Catchment Area (2.19 km^2)

NOTES
Base data source:
Base imagery (date unknown) from Bing provided by ESRI.
Contours (20 m interval) and watercourses are used throug
the GeoBC web map service.

STATUS
ISSUED FOR USE

HB DAM - 2013 DAM SAFETY REVIEW

Upstream Drainage Basin

PROJECTION
UTM Zone 11N

DATUM
NAD83

CLIENT
Central Kootenay Regional District

Scale: 1:15,000
200 100 0 200 400
Meters

TETRA TECH EBA

FILE NO.
Figure 9.1 - Upstream Drainage Basin.mxd

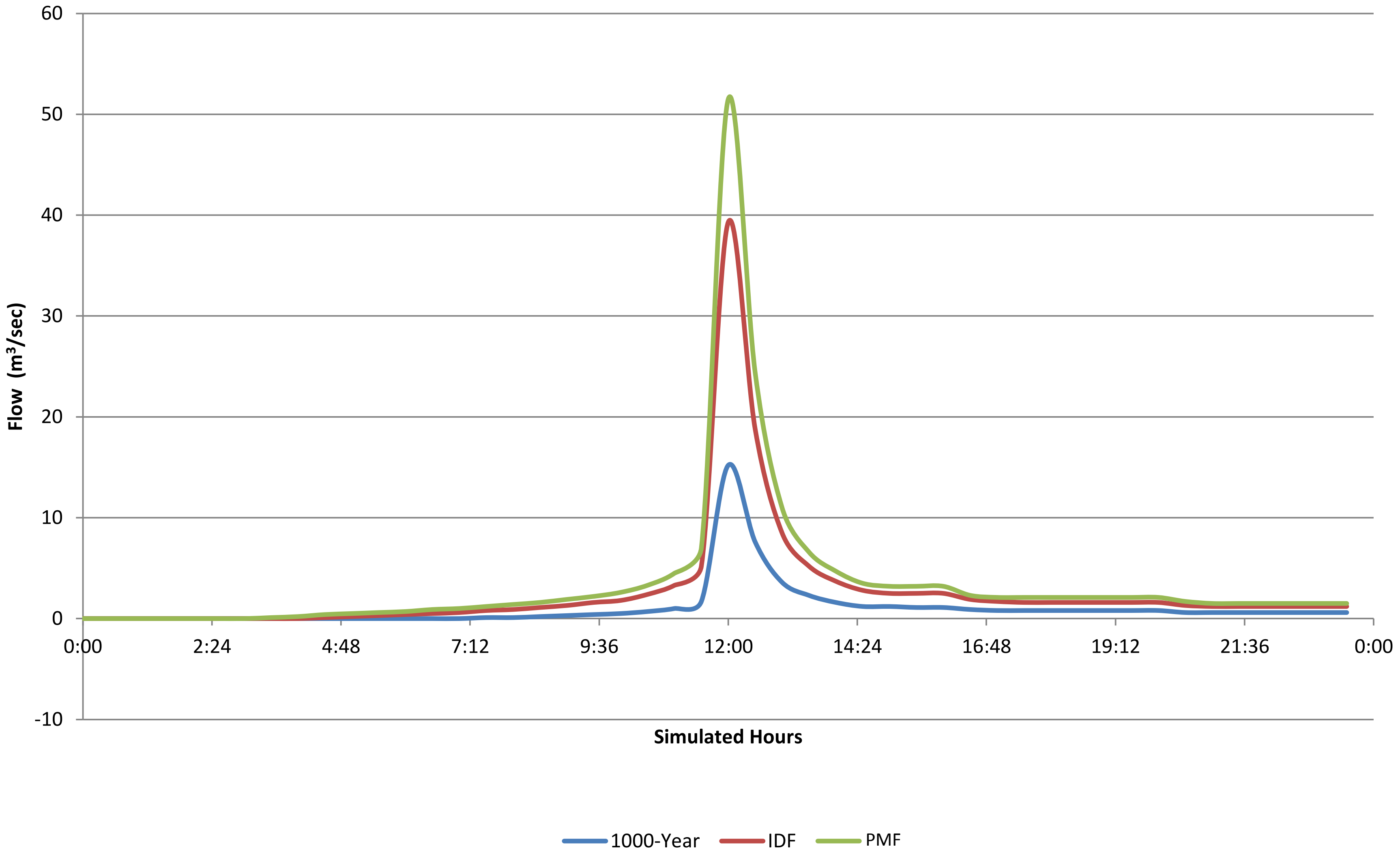
PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	SB	SP	MJL	0

OFFICE
Tt EBA-KELOWNA

DATE
January 28, 2014

Figure 9.1

Q:\Kelowna\GIS\ENGINEERING\K131\K13103109_HB Dam\Maps\ISSUED FOR REVIEW\Figure 10.1-1 - Upstream Drainage Basin.mxd modified 1/28/2014 by sarah.blair



CLIENT

Central Kootenay Regional District

Peak Inflows

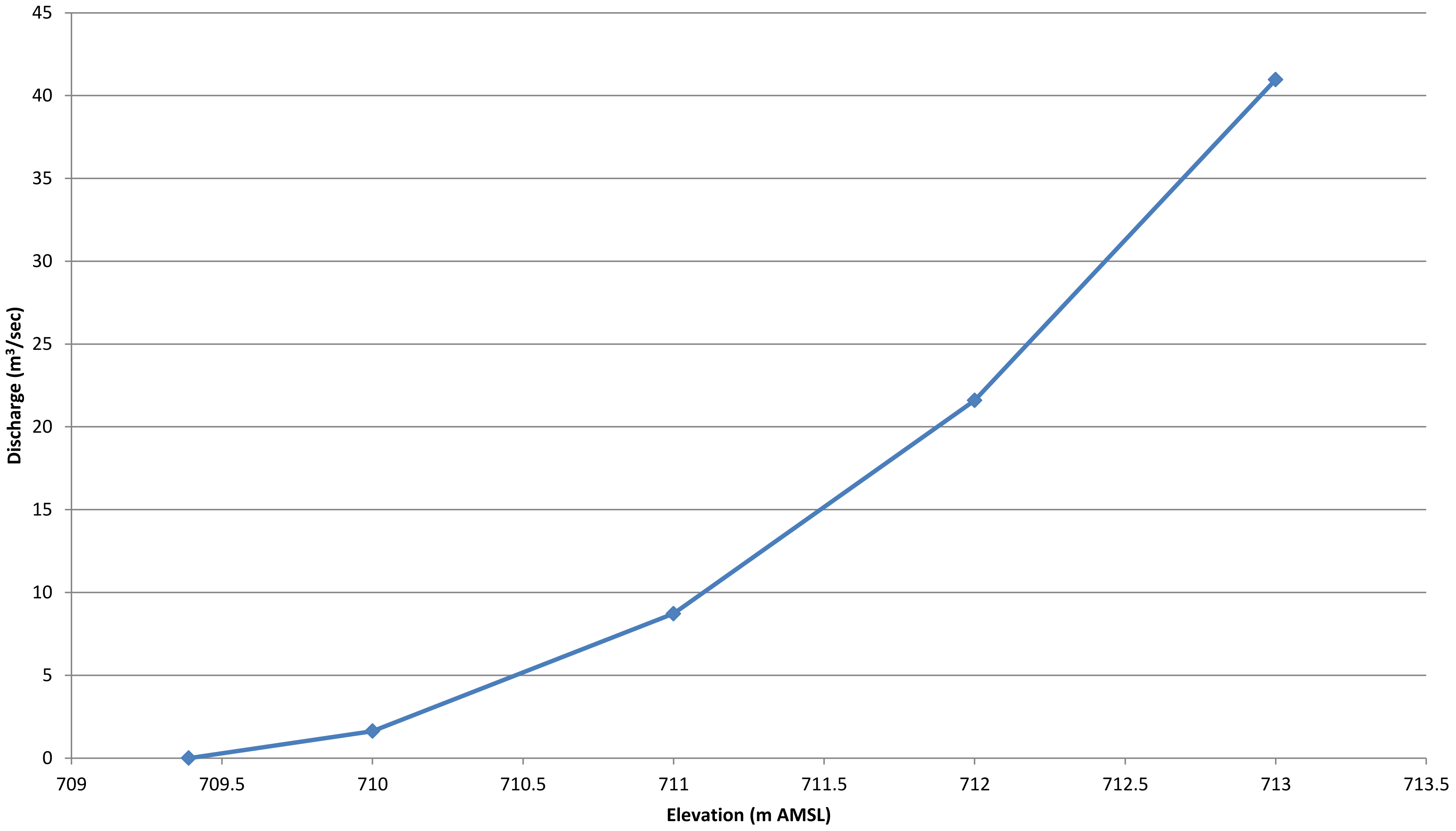
STATUS
ISSUED FOR REVIEW

TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
K131030109	SPB			0
OFFICE	**DATE**			
EBA-VANC	August, 2013			

Figure 10.3-1

ISSUED FOR USE
KELOWNA
February 24, 2014



Dam Crest Elevation - 713.00 m AMSL
Spillway Elevation - 709.39 m AMSL

CLIENT

Central Kootenay Regional District

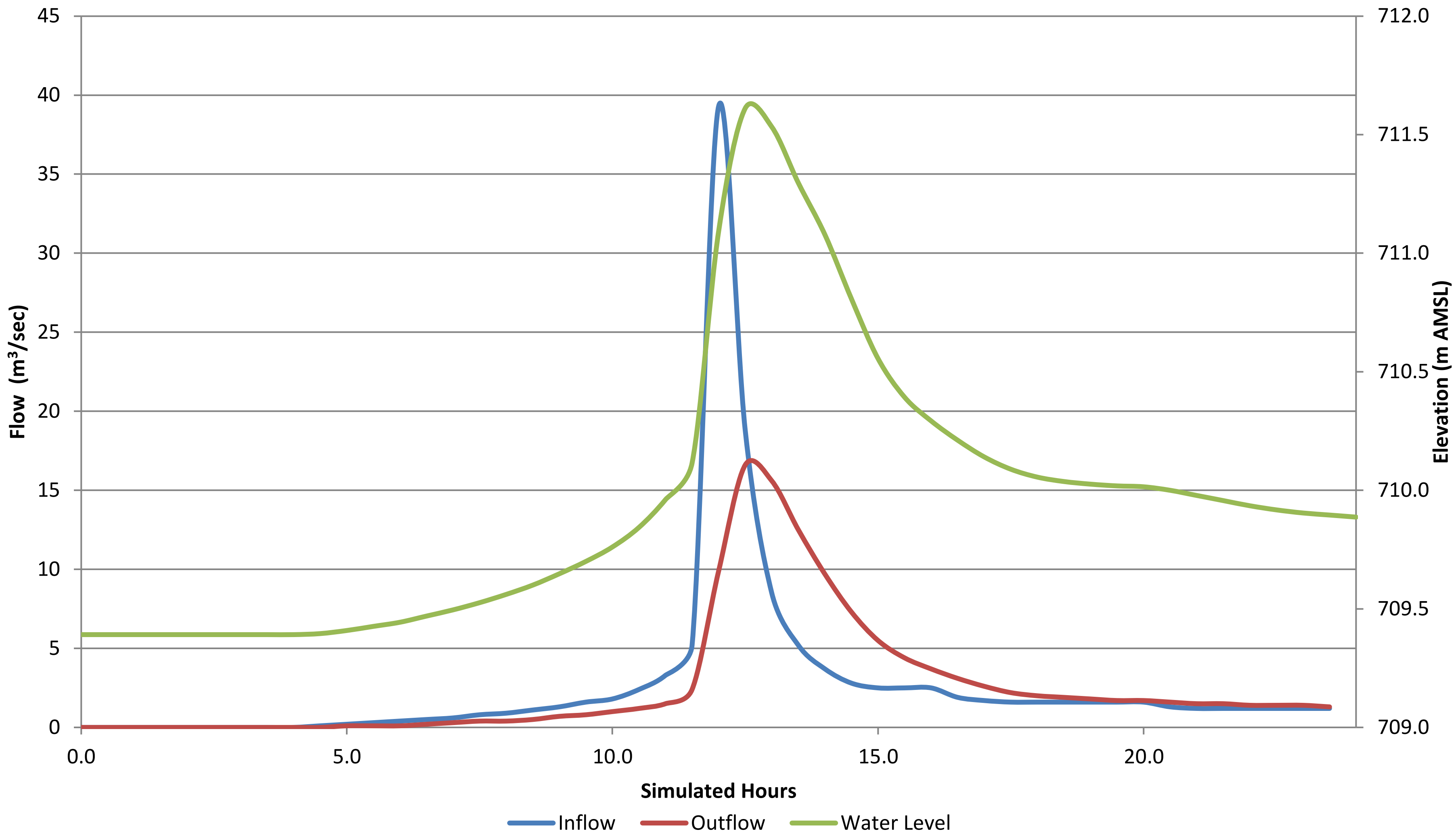
Spillway Rating Curve

PROJECT NO.	DWN	CKD	APVD	REV
K131030109	SPB			0
OFFICE	DATE			
EBA-VANC	August, 2013			

STATUS
ISSUED FOR REVIEW

TETRA TECH EBA

Figure 10.4-1



LEGEND

NOTES

Dam Crest Elevation - 713.00 m AMSL
Spillway Elevation - 709.39 m AMSL

STATUS

ISSUED FOR USE

CLIENT

REGIONAL DISTRICT CENTRAL KOOTENAY

TETRA TECH EBA

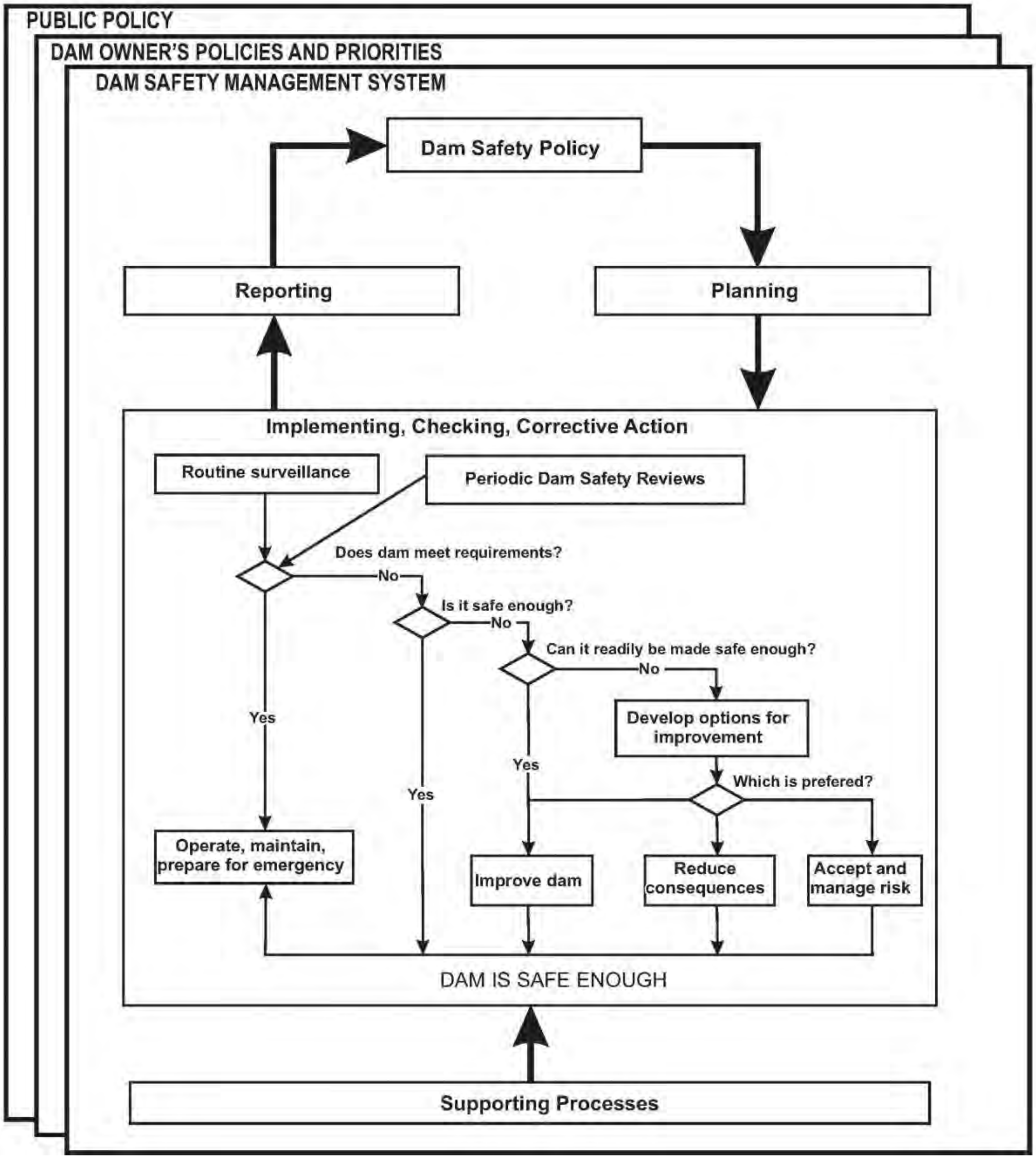
DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Flood Routing Results

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	SPB	RP	MJL	0

OFFICE	DATE
KELOWNA	February 24, 2014

Figure 9.4b



LEGEND

NOTES

CLIENT

DAM SAFETY REVIEW OF HB DAM, SALMO, BC

Dam Safety Management System

TETRA TECH EBA

PROJECT NO.	DWN	CKD	APVD	REV
K13103109-01	TMKP	RP	MJL	0

OFFICE	DATE
KELOWNA	March 7, 2014

Figure 10.1

STATUS
ISSUED FOR USE

PHOTOGRAPHS

Photo 1	Crest of dam – observed rutting from vehicle traffic and minor animal activity
Photo 2	Upstream Face – vegetation/Brush/Tree growing on the upstream face of the dam
Photo 3	Downstream Face – observed new rock blanket at slough
Photo 4	Spillway measured bottom width to be 1.7 m at the base
Photo 5	Spillway Channel – noted missing rip-rap protection on the right bank of channel (used for the slough repair)
Photo 6	Reservoir – staff gauge reading of water level was 1.85 ft. (approx. 709.58 m amsl)
Photo 7	Reservoir – remains of abandoned decant structure (severely damaged)
Photo 8	V-notch weir located downstream of the east embankment to measure seepage estimates
Photo 9	Dam outlet flows downstream under a culvert under Highway 3

Photo 1: Crest of dam – observed rutting from vehicle traffic and minor animal activity

Photo 2: Upstream Face – vegetation/brush/tree growing on the upstream face of the dam

Photo 3: Downstream Face – observed new rock blanket at slough

Photo 4: Spillway - bottom width measured to be 1.7 m

Photo 5: Spillway Channel – noted missing rip-rap protection on the right bank of channel (used for the slough repair)

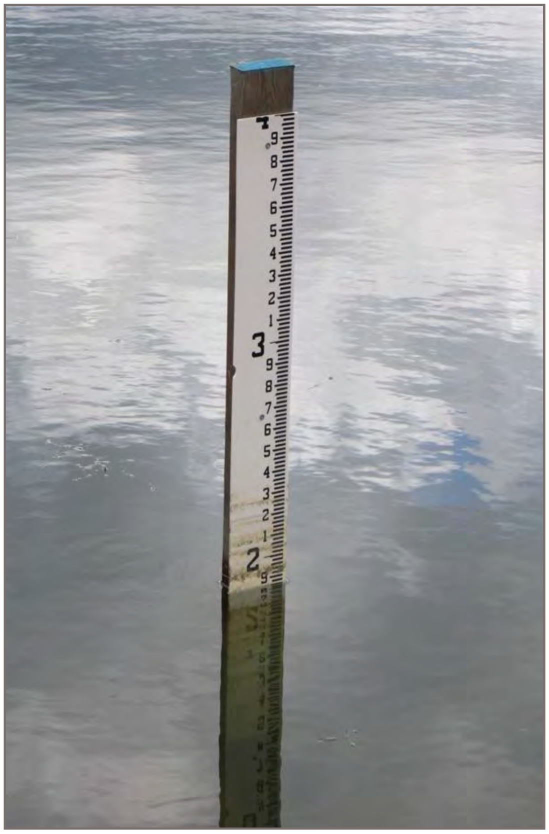


Photo 6: Reservoir – staff gauge reading of water level was 1.85 ft. (approx. 709.58 m amsl)

Photo 7: Reservoir – remains of abandoned decant structure (severely damaged)

Photo 8: V-notch weir located downstream of the east embankment to measure seepage estimates

Photo 9: Dam outlet flows downstream under a culvert under Highway 3

APPENDIX A

BACKGROUND INFORMATION REVIEW

BACKGROUND INFORMATION REVIEW

The following documentation contained within the Regional District of Central Kootenay file was reviewed to obtain relevant background information on the HB Mine Tailings Storage Facility.

- 1972 June 22 – Report to Cominco Ltd. Re: HB Tailing Dam near Salmo, BC – Golder Brawner Associates_1
- 1972 June 22 – Report to Cominco Ltd. Re: HB Tailing Dam near Salmo, BC – Golder Brawner Associates_2
- 1972 June 22 – Report to Cominco Ltd. Re: HB Tailing Dam near Salmo, BC – Golder Brawner Associates_3
- 1972 March 5 – Memo to Minister of Dept Mines and Petroleum Ref. Section 11 Mines Regulation Act Cominco Ltd, HB Mine
- 1973 to 1983 correspondence and memoranda related to mining
- 1974 January – Report to Cominco Ltd. on Site Investigation at Existing HB Mines Tailings Pond – Golder Brawner Associates
- 1974 January – Report to Cominco Ltd. on Site Investigation at Existing HB Mines Tailings Pond – Golder Brawner Associates (duplicate)
- 1974 June – HB Mine Tailing Dike Extension – Instructions to Tenders – Cominco Ltd.
- 1976 January 27– Letter and Progress report to Department of Mines and Petroleum Resources – Cominco Ltd.
- 1976 March 25 – PCB File No 0262100–PE–1853 Stability of Tailings Dam HB Mine – correspondence and reports
- 1976 December – Report to Cominco Ltd on Proposed dam Extension 1976 HB Mine – Golder Associates
- 1977 February – Cominco Ltd. – HB Tailing Dike Extension
- 1977 March 29 Letter to Cominco – re HB Tailing Dike Extension propsal and Specification
- 1977 May 5 – Dept. Mines and Petroleum Resources letter – HB Tailings Pond Extension 1977 Stability of Dam
- 1977 June 9 – Letter from Senior Reclamation Inspector to Cominco – HB Mine Taiing Dam Spillway
- 1977 July 22 – Letter to Cominco – Re HB Mine Tailings Dam Spillway
- 1978 April 20 – Letter to Cominco Ltd. ref. Effluent Quality Survey October 1977 – BC Environmental Protection
- 1981 November 27 – Tailings Disposal Scheme, HB Mill Salmo, BC – David Minerals Ltd.
- 1981 November 27 – Tailings Disposal Scheme, HB Mill Salmo, BC – David Minerals Ltd. (duplicate)
- 1982 February 8 – Cominco cover letter ref HY Mine Surface Work Permit M–85

- 1982 March – Stage 1 Submission for Reactivation of the HB Mill Located at Salmo_BC – International Environmental Consultants Ltd.
- 1982 March 15 – Letter from Reclamation Inspector to David Minerals
- 1982 May 11 – BCEMPR Memo – HB Gold Project
- 1982 June 21 – BCMEMPR – Memo _Re Safe storage level of tailings
- 1982 July 13 – David Minerals Letter Ref Reclamation Hy Tailings Pond
- 1982 November 12 – Letter from David Minerals to BCMEMPR Ref Reclamation Permit for the HB Mine
- 1982 November 18 – BCMEPR Letter HB Property
- 1982 November 23 Letter from BCEMPR to David Minerals Ltd – Ref Reclamation Permits M–85 HB Mine
- 1982 December 8 – File Not M–85 – David /Cominco HB Mine
- 1983 January 25 Letter from BCEMPR to David Minerals Ltd – Ref Reclamation Permits M–85 HB Mine
- 1983 August 31 – Cominco letter and Attachments to Registrar of Securities
- 1982 October 24 – BCEMPR – Letter to David Miners – procedure for making application for reclamation permit HB property
- 1986 October 23 – Report of Inspector of Mines – Crushing and Concentrating works – BC Ministry of Energy, Mines and Petroleum Resources
- 1987 – 1997 Inspection Reports – Historical pictures from 1951 to 1993
- 1987 October 16– Letter to Nor–Quest Resources Ltd and attached inspection report dated 28 Sep 1987 – BC Ministry of Energy, Mines and Petroleum Resources
- 1988 April 13 – Letter and Questionnaire to Ministry of Energy of Energy, Mines and Petroleum – Nor–Quest Resources
- 1989 January 11 – Annual Reclamation Report – Reclamation Permit M–85
- 1990 August 10 – Bank of Montreal letter to MEMPR
- 1993 February 25 – Memo Re HB Mill Reclamation and HB Tailings Pond
- 1993 February 26 – Memo Re HB Mill Reclamation and HB Tailings Pond
- 1993 March 3 – BCMEMPR Letter to Nor–Quest
- 1993 March 5 – Notice of work and Reclamation Program on a Mineral Property
- 1993 March 5 – Notice of work and Reclamation Program on a Mineral Property and fax cover
- 1993 March 4 File note from Dr. JC Errington re HB Mine

- 1993 March 17 – Memo from MEMPR to Inspector of Mines – Re Acid Generation Potential at the HB Mine site
- 1993 April 06 – BCMEMPR – Amendment to Reclamation Permit
- 1993 April 29 – BC Energy Mines and Petroleum Resources Inspection Report
- 1994 May 27 – Letter to Nu–Dawn Resources and Inspection Report – BC Ministry of Energy Mines and Petroleum Resources
- 1997 April 4 – Geological Survey Report and Production Report
- 1997 April 15 – Internal Memo re HB Mine M–85
- 1997 June 10 – BC MEI Inspection Report
- 1997 June 17 – Letter to RDCK ref HB Mine Tailings Impoundment – Ministry of Employment and Investment
- 1997 June 17 – Letter to RDCK ref HB Mine Tailing Impoundment and responses
- 1997 Aug 6 – Interoffice Memo to T Eaton Employment and Investment – Re HB Tailing Dam Discharge
- 1997 Aug 11 – Letter to C Evans MLA of Nelson
- 1997 October 30 – Letter to Nu–Dawn Resources and to Cominco Ltd. and inspection reports date June 1997 and April 1993
- 1997 October 30 – Letter to Cominco and attached inspection reports date June 1997 and April 1993 – BC Ministry of Employment and Investment
- 2002 – HB Mine Tailings Pond and Dyke Decommissioning Plan – BGC Engineering Inc.
- 2007 – Formal Inspection Report – Conestoga–Rovers Associates
- 2008 – Operation, Maintenance and Surveillance Manual – Conestoga–Rovers Associates
- 2008 – Final Draft Emergency Preparedness Plan – Conestoga–Rovers Associates
- 2009 – Annual Reclamation Report for 2008 – Conestoga–Rovers Associates
- 2011 – HB Dam Formal Annual Dam Inspection Report 2010 – EBA
- 2011 – HB Dam Formal Annual Dam Inspection Report – EBA
- 2012 – HB Mine Tailings Storage Facility Embankment Dam Slough Response – EBA
- 2012 – HB Mine Tailings Storage Facility Assessment of Embankment Dam Sloughing – EBA

APPENDIX B

PREVIOUS GEOTECHNICAL INVESTIGATION RESULTS

PROJECT No. K73218

RECORD OF BOREHOLE 1

LOCATION See Figure 1

BORING DATE OCTOBER 29.30, 1973 DATUM TAKEN FROM COMINCO DRAWING NO. HB-285-P

BOREHOLE TYPE ROTARY TRICONE

BOREHOLE DIAMETER 4 IN

SAMPLER HAMMER WEIGHT 140 LB. DROP 30 INCHES

PEN. TEST HAMMER WEIGHT — LB DROP — INCHES

SOIL PROFILE			SAMPLES			ELEVATION SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS/FT -------- SHEAR STRENGTH C_u, LB /SQ.FT	COEFFICIENT OF PERMEABILITY k, CM / SEC. WATER CONTENT, PERCENT W_P — W — W_L	ADDITIONAL LAB. TESTING	STANDPIPE INSTALLATION
ELEVN. / DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	BLOWS / FT.					
2505.0 / 0.0'	GR. SURFACE.									
	SOFT TO FIRM NON-PLASTIC BROWN SANDY SILT WITH SOME MED. & COARSE SAND & FINE GRAVEL.		1	2" D.O.	11	2500				
			2	2" D.O.	4					
			3	2" D.O.	14	2490				
			4	2" D.O.	5					W.L. 23.0' NOV. 23, 1973
			5	2" D.O.	15	2480				
			6	2" D.O.						
			7	2" D.O.	13	2470				
			8	2" D.O.	13					
			9	2" D.O.	23	2460				
2455.0 / 50.0'	STIFF STRATIFIED GREY & BROWN CLAYEY **SILT** WITH A TRACE OF MED. SAND.		10	2" D.O.	37					
2452.0 / 53.0'	FIRM BROWN & DARK BROWN **SILT** WITH SOME MED. & COARSE SAND, FINE GRAVEL & ORGANICS.		11	2" D.O.	24	2450				
			12	2" D.O.	>100					
2446.0 / 59.0'	VERY DENSE DARK GREY SILT, SAND & GRAVEL TO 1" DIA. (TILL).		13	2" D.O.	>100	2440				
2442.0 / 63.0'	VERY DENSE BLACK FRIABLE DESICCATED **SILT** WITH THIN PYRITE LENSES & ROUNDED GRAVEL TO 1½" DIA.		14	WS		2430				
			15	WS						
2437.0 / 68.0'	BEDROCK.		16	WS						
2420.0 / 35.0'	END OF HOLE.					2420				

15-◇-5 / 10 Percent axial strain at failure

VERTICAL SCALE 1 INCH TO 10 FEET

GOLDER, BRAWNER & ASSOCIATES

1

DRAWN RMO

CHECKED

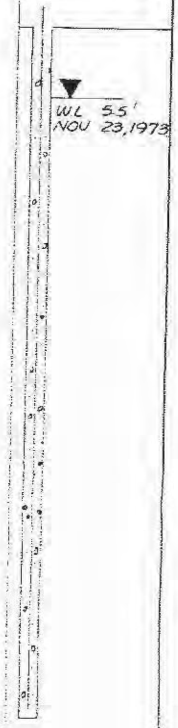
PROJECT No. V73218

RECORD OF BOREHOLE 2

LOCATION See Figure /
BORING DATE NOVEMBER 1, 1973
DATUM TAKEN FROM COMINCO DRAWING NO. HB 285 P
BOREHOLE TYPE ROTARY TRICONE
BOREHOLE DIAMETER 4 IN.
SAMPLER HAMMER WEIGHT 140 LB. DROP 30 INCHES
PEN. TEST HAMMER WEIGHT LB DROP INCHES

SOIL PROFILE			SAMPLES				DYNAMIC PENETRATION RESISTANCE BLOWS/FT / SHEAR STRENGTH C_u, LB./SQ.FT	COEFFICIENT OF PERMEABILITY k, CM./SEC. / WATER CONTENT, PERCENT W_P W W_L	ADDITIONAL LAB. TESTING
ELEVN. DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	BLOWS/FT.	ELEVATION SCALE			
2465.0 0.0'	GR. SURFACE.								
	SOFT BROWN SANDY SILT WITH MED. & COARSE SAND & GRAVEL TO 1½" DIA. OFTEN TILL LIKE.		1	2" D.O	10	2460			
			2	2" DO	8				
			3	2" DO	13	2450			
			4	2" DO	4				
2438.6'			5	2" D.O	20	2440			
26.4	WOOD								
27.0'	SOFT TO FIRM STRATIFIED BROWN & GREY SILT WITH OCC. GRAVEL TO 1½" DIA.		6	2" DO					
2431.0' 34.0 2429.0'	SAND & GRAVEL.					2430			
36.0'	BEDROCK.		7	WS					
			8	WS		2420			
			9	WS					
			10	WS					
2410.0' 55.0'	END OF HOLE.					2410			

STANDPIPE INSTALLATION



15-◇-5 Percent axial strain at failure (0 above, 10 below)

VERTICAL SCALE
1 INCH TO 10 FEET

GOLDER, BRAWNER & ASSOCIATES

2

DRAWN RMO
CHECKED

PROJECT No. V73218

RECORD OF BOREHOLE 3

LOCATION See Figure 1
BORING DATE NOVEMBER 1, 1973
DATUM TAKEN FROM COMINCO DRAWING NO. HB-285-P
BOREHOLE TYPE ROTARY-TRICONE
BOREHOLE DIAMETER 4 IN.
SAMPLER HAMMER WEIGHT 140 LB. DROP 30 INCHES
PEN. TEST HAMMER WEIGHT – LB DROP – INCHES

SOIL PROFILE			SAMPLES			ELEVATION SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS/FT SHEAR STRENGTH C_u, LB./SQ. FT	COEFFICIENT OF PERMEABILITY k, CM./SEC. WATER CONTENT, PERCENT W_P W W_L	ADDITIONAL LAB. TESTING	STANDPIPE INSTALLATION
ELEV'N / DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	BLOWS / FT.					
2455.0' / 0.0'	GR. SURFACE.									
	VARIABLE DENSITY BROWN & GREY SILT SAND & GRAVEL		1	2" D.O	>50	2450				
2448.0' / 7.0'	WOODEN CULVERT									W.L. 6.0' NOV 23 1973
8.0	VARIABLE DENSITY BROWN & GREY SILT WITH MED. & COARSE SAND & FINE GRAVEL.		2	2" D.O	>100					
			3	2" D.O	15	2440				
2435.0' / 20.0'	COMPACT BROWN & GREY SILT, SAND & GRAVEL (TILL)		4	2" D.O	37					
2432.0' / 23.0'										
2429.0' / 26.0'	VERY DENSE SAND & GRAVEL.		5	2" D.O	>100	2430				
			6	WS						
	BEDROCK.					2420				
			7	WS						
2410.0' / 45.0'	END OF HOLE.					2410				

15 0 5 10 Percent axial strain at failure

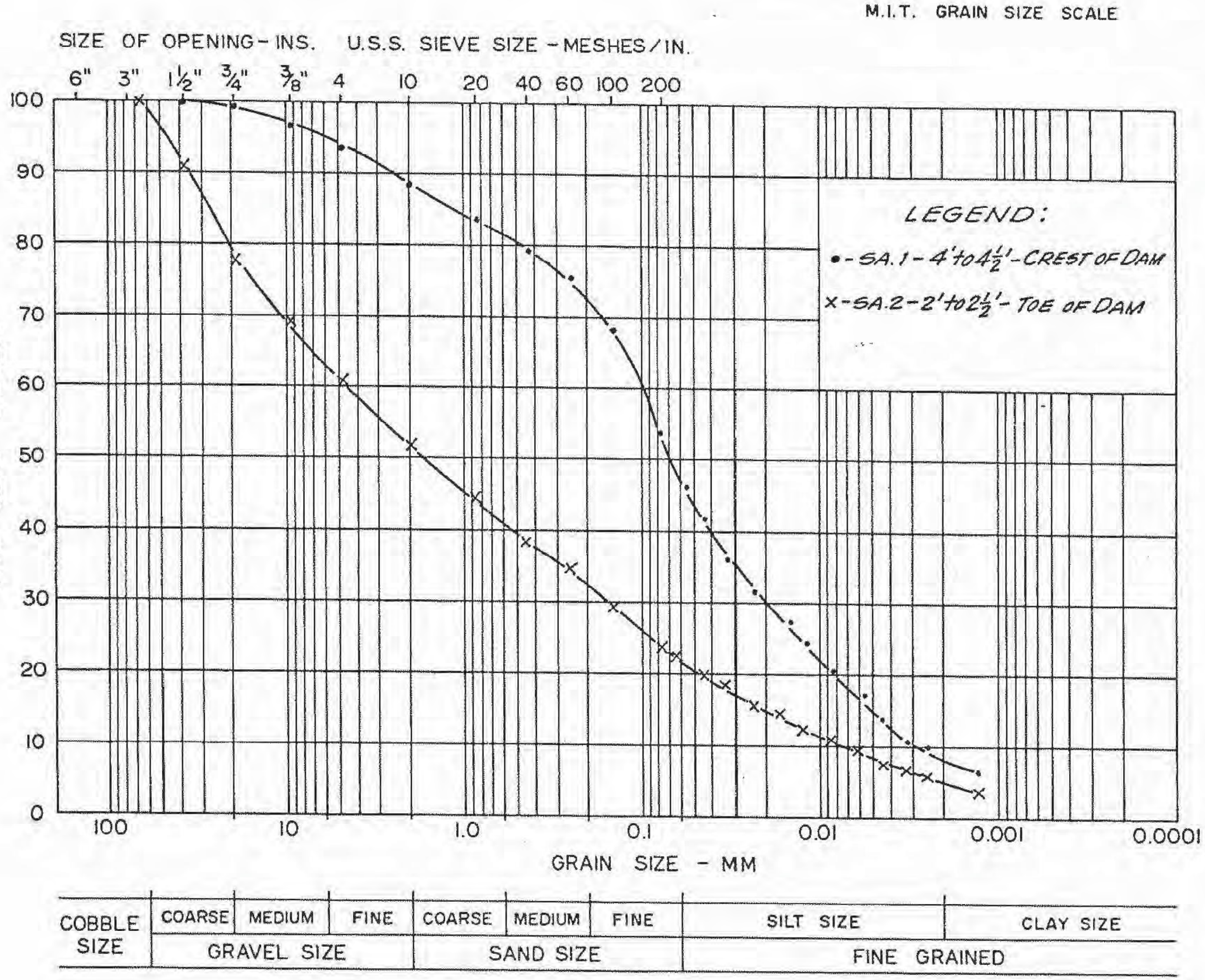
VERTICAL SCALE
1 INCH TO 10 FEET

GOLDER, BRAWNER & ASSOCIATES

3

DRAWN RMO
CHECKED

GOLDER, BRAWNER & ASSOCIATES

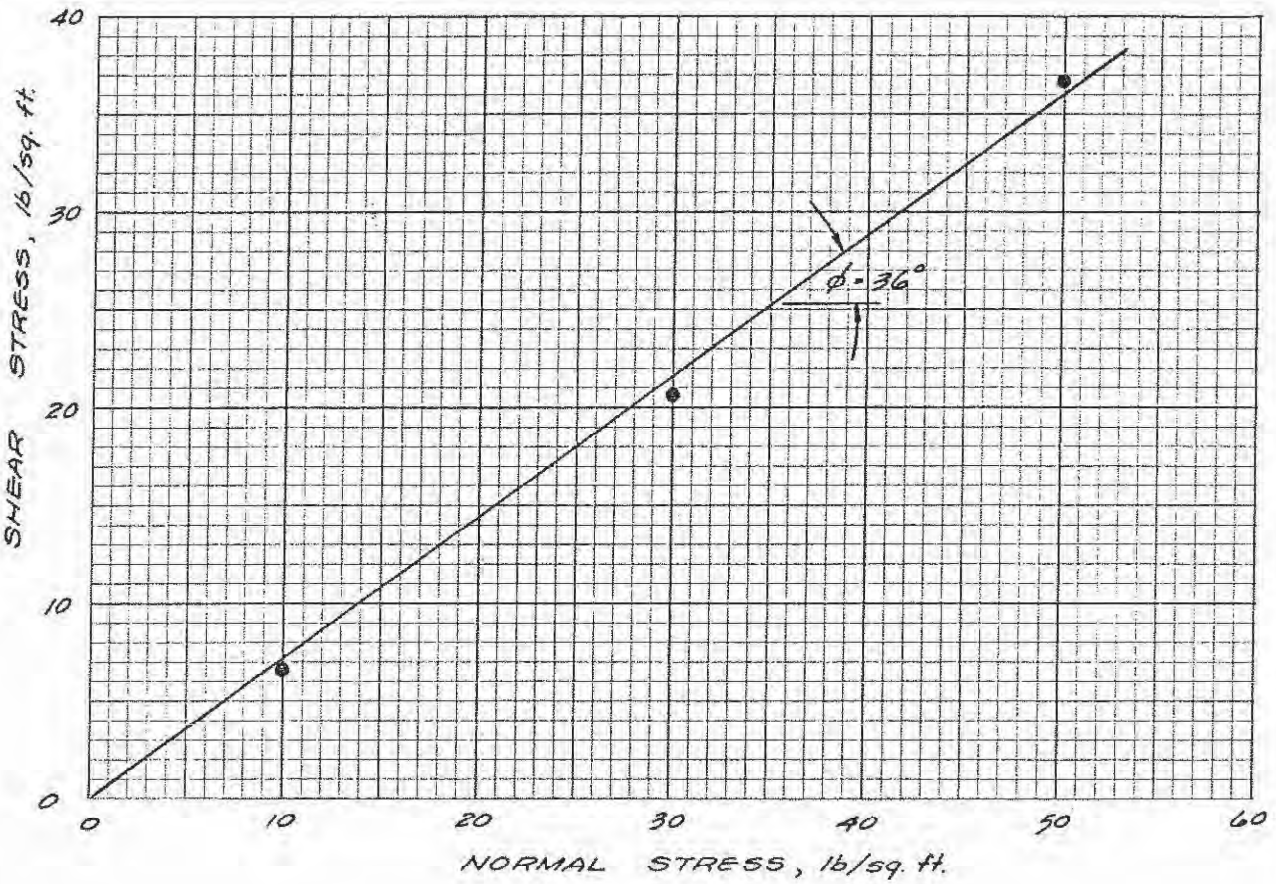


GRAIN SIZE DISTRIBUTION

FIGURE 5

DIRECT SHEAR TEST RESULT
H.B. TAILINGS DAM

FIGURE 6



RESULTS OF DIRECT SHEAR TEST ON
MINUS # 4 FRACTION OF MATERIAL FROM
TEST PIT #2. MATERIAL PLACED IN
SHEAR BOX AT DENSITY OF 106 lb/cu. ft.,
THEN SATURATED. RATE OF STRAIN 0.01 in/min.

Drawn H.F.
Approved
Date JUNE '72

GOLDER, BRAWNER & ASSOCIATES

Project No.

BORING NUMBER : BGC-BH-00-1

DRILLING METHOD : Hollow Stem Auger
DRILLING CONTRACTOR : Thorman
START : 12:15 am, Oct. 30/00
FINISH : 5:00 pm, Oct. 31/00
SAMPLE LEGEND : SPT ☒ GRAB G

LOCATION : Dam crest, 3m south of centerline

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6" (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
	Grab 1	N/A	N/A	G	SM		***Sandy SILT*** Trace gravel, compact, moist, olive grey, rootlets. [Fill]	P1 (24m) (3/4 " PVC) P2 (13.3m) (3/4" PVC)	
1									
	SPT 1	18/18	14/12/6	☒					
2					ML		***SILT*** Trace sand and clay, compact, moist, brown. [Fill]		
3	SPT 2	17.5/18	30/23/17	☒	SM To ML		***Sandy, gravelly SILT*** Some clay, compact to dense, moist, olive grey to medium brown. Contains limestone pebbles. Clay content increases with depth. Cobble at 5.2m. [Fill] Small cobble at 6.7m.	Bentonite Chips	
4									
	SPT 3	16.5/18	13/13/11	☒					
5									
6	SPT 4	18/18	4/7/10	☒					
7								Bentonite Grout	
	SPT 5	18/18	4/7/12	☒					
8									
9	SPT 6	15/18	25/55/65	☒	SW		***SAND and GRAVEL*** Some silt, dense to very dense, almost dry at top,		
10									

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Logged by:	MJP	Client: Regional District of Central Kootenay
Checked by:	BW	Project: HB Tailings Pond Decommissioning
Reviewed by:	IGB	Project No: 0268-001-02

BORING NUMBER : BGC-BH-00-1

DRILLING METHOD : Hollow Stem Auger
DRILLING CONTRACTOR : Thorman
START : 12:15 am, Oct. 30/00
FINISH : 5:00 pm, Oct. 31/00
SAMPLE LEGEND : SPT ☒ GRAB ▯

LOCATION : Dam crest, 3m south of centerline

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6"- (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
	SPT 7	17/18	16/23/25	☒			moisture content increases with depth, light grey. [Fill - Drain material]		
11									
12					SM		***Silty SAND*** Some gravel and trace clay, very loose, wet, medium grey to brown. [Fill] Drilling becomes very smooth at 11.6m. Tried SPT 8 but spoon sank under hammer weight.	Bentonite Chips Dec. 3/00 3:45 pm, Nov. 1/00 Sand	
	SPT 8	18/18	0/0/1	☒					
13									
	SPT 9	18/18	1/2/4	☒	SM		***SAND and SILT*** Some gravel and clay. Loose to compact, dark grey to olive grey, moist, contains decomposed wood fragments. [Fill]	Dec. 3/00	
14									
15									
	SPT 10	17/18	3/3/6	☒				Bentonite Chips	
16									
	SPT 11	18/18	2/5/5	☒					
17									
18									
	SPT 12	7/18	4/9/8	☒					
19					ML		***Clayey SILT*** Some sand, compact, light brown, mottled, moist. [Fill]		
	SPT 13	14/18	6/8/15	☒					
20								3:45 pm, Nov. 1/00	

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BORING NUMBER : BGC-BH-00-1

Page 3 of 3

DRILLING METHOD : Hollow Stem Auger
DRILLING CONTRACTOR : Thorman
START : 12:15 am, Oct. 30/00
FINISH : 5:00 pm, Oct. 31/00
SAMPLE LEGEND : SPT ☒ GRAB G

LOCATION : Dam crest, 3m south of centerline

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6"- (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
				☒					
21									
	SPT 14	18/18	6/7/7	☒					
22					ML		***Sandy SILT*** Trace clay, dark grey, wet, compact. [Glaciolacustrine]		
23	SPT 15	16/18	4/10/16	☒	SM		***Gravelly Silty SAND*** Some clay, moist, olive grey, compact. [Till] Increasing cobble content at 23.45m, based on rough drill action.	Sand Casagrande Tip	
24							End of Hole	(Auger Refusal) Suspect Bedrock	
25									
26									
27									
28									
29									
30									

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BORING NUMBER : BGC-BH-00-2

Page 1 of 2

DRILLING METHOD : Hollow Stem Auger
DRILLING CONTRACTOR : Thorman
START : 8:00 am, Nov. 1/00
FINISH : 3:30 pm, Nov. 1/00
SAMPLE LEGEND : SPT ⧗ GRAB G

LOCATION : 15m West of Dam Toe

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6"- (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
					OL		Organics, wet, soft.	Cement	
	Grab 1	N/A	N/A	G	GM		***Sandy GRAVEL*** Some silt and large boulders, wet. [Fill]	Bentonite Chips	
1									
	SPT 1	18/18	5/9/13	⧗	ML		***Sandy SILT*** Trace clay, moist, compact, grey, weakly stratified with light grey sand layers containing minor muscovite, and thin organic layers at a 5-30 cm spacing. [Glaciolacustrine]	P3 (17.5m) →	
2									
3	SPT 2	18/18	7/9/13	⧗					
4								Dec. 3/00	
	SPT 3	18/18	5/11/16	⧗			Silt content increases and organic content decreases with depth.	Drill Cuttings	
5									
6	SPT 4	18/18	8/13/15	⧗			1mm thick white volcanic ash layer at 6.40m depth.		
7									
	SPT 5	18/18	7/12/15	⧗					
8									
9	SPT 6	?	11/11/17	⧗			SPT blow counts for samples 6-11 logged by Thorman Drill Crew.		
10									

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BORING NUMBER : BGC-BH-00-2

Page 2 of 2

DRILLING METHOD : Hollow Stem Auger
DRILLING CONTRACTOR : Thorman
START : 8:00 am, Nov. 1/00
FINISH : 3:30 pm, Nov. 1/00
SAMPLE LEGEND : SPT ⧗ GRAB ☐

LOCATION : 15m West of Dam Toe

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6" - (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
	SPT 7	?	9/11/18	⧗					
11									
								Bentonite Chips	
12									
	SPT 8	?	7/12/18	⧗	ML				
13									
	SPT 9	?	8/12/18	⧗					
14									
15									
	SPT 10	?	7/10/16	⧗	CL		***CLAY and SILT*** Moist, compact, contains thin sand layers,olive grey. [Glaciolacustrine] Increasing content of small, subrounded pebbles at depth.		
16								4:00 pm, Nov. 1/00	
17								Sand	
18									
	SPT 11	?	11/13/37	⧗					
19							End of Hole		
20									

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BORING NUMBER : BGC-TP-00-1

Page 1 of 1

DRILLING METHOD : Shovel
DRILLING CONTRACTOR :
START : Oct. 31/01
FINISH : Oct. 31/01

LOCATION : Downslope slope face

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6" - (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
					GW		***SAND and GRAVEL*** With trace silt, moist, easy digging.	Limited vegetation. Piezometer P4 is approximately 5m upslope from test pit.	
							End of Pit		
1									
2									
3									
4									

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BORING NUMBER : BGC-TP-00-2

Page 1 of 1

DRILLING METHOD : Shovel
DRILLING CONTRACTOR :
START : Oct. 31/01
FINISH : Oct. 31/01

LOCATION : Downstream slope face

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6"- (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
					ML	⁙	***Sandy SILT*** With some clay and gravel, compact, moist, probably derived from local glacial till.	Grass-covered slope. Piezometer P4 is approximately 10m downslope from test pit.	
							End of Pit		
1									
2									
3									
4									

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Checked by:	BW	Project: HB Tailings Pond Decommissioning
Reviewed by:	IGB	Project No: 0268-001-02

BORING NUMBER : BGC-TP-00-3

Page 1 of 1

DRILLING METHOD : Shovel
DRILLING CONTRACTOR :
START : Nov. 1/01
FINISH : Nov. 1/01

LOCATION : 200m south of east dam abutment

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6"- (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
1					SM	▨	***SILT and SAND*** With some gravel and trace clay, moist, compact to dense. [Lodgement Till].	Located in ~250m long borrow pit.	
2 3 4							End of Pit		

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Reviewed by:	IGB	Project No: 0268-001-02

BORING NUMBER : BGC-TP-00-4

Page 1 of 1

DRILLING METHOD : John Deer 790D LC Excavator
DRILLING CONTRACTOR : Conkin
START : Nov. 1/00
FINISH :
SAMPLE LEGEND : SPT ☒ GRAB G

LOCATION : ~5m East and 5m North of Flume

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6" - (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
					SM		***Silty SAND*** Trace gravel, dry to moist, light grey.		
1									
	Grab 1	N/A		G					
2	Grab 2	N/A		G	ML		***Sandy SILT*** Moist, grey, compact. [Glaciolacustrine]		
3							End of Pit		
4									
5									
6									
7									
8									
9									
10									

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Reviewed by:	IGB	Project No: 0268-001-02

BORING NUMBER : BGC-TP-00-5

Page 1 of 1

DRILLING METHOD : John Deer 790D LC Excavator
DRILLING CONTRACTOR : Conkin
START : Nov. 1/00
FINISH :
SAMPLE LEGEND : SPT ⧓ GRAB G

LOCATION : ~30 m South of existing decant

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6"- (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
							Silty SAND Trace gravel, brown, moist.		
1					SM to ML				
2							***SAND and GRAVEL*** Moist.		
							Sandy SILT Dark grey, moist, weakly stratified.		
3							***SAND with some silt***		
4							***Sandy SILT*** Medium grey, moist, compact, contains horizontal oxidized orange layers, sand content increases with depth. Spoil pile angle of repose 40 degrees. Moisture content increases close to water table.		
5									
	Grab 1	N/A	N/A	G					
6							End of Pit		
7									
8									
9									
10									

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Reviewed by:	IGB	Project No: 0268-001-02

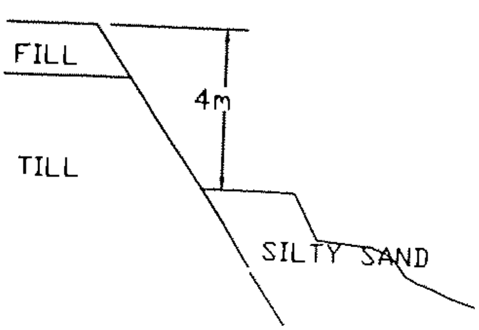
BORING NUMBER : BGC-TP-00-6

Page 1 of 1

DRILLING METHOD : John Deer 790D LC Excavator
DRILLING CONTRACTOR : Conkin
START : Nov. 1/00
FINISH :
SAMPLE LEGEND : SPT ☒ GRAB ▯

LOCATION : ~75 m S.E. of West Abutment Edge of old fill slope

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6"- (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
1					SM		***Silty SAND*** Woody debris, brown. [Road fill/weathered till]	5m north, a grey silty sand with oxidized orange sand and gravel layers, has been exposed at an approximate depth of 4-5.4 m. This deposit overlies (uncomformably) the dense lodgement till	
2 3 4 5					SM		***Silty Sand*** Some gravel, dense, moist, gravel is supported in silty sand matrix. [Lodgement Till]		
6 7 8 9 10							End of Pit		



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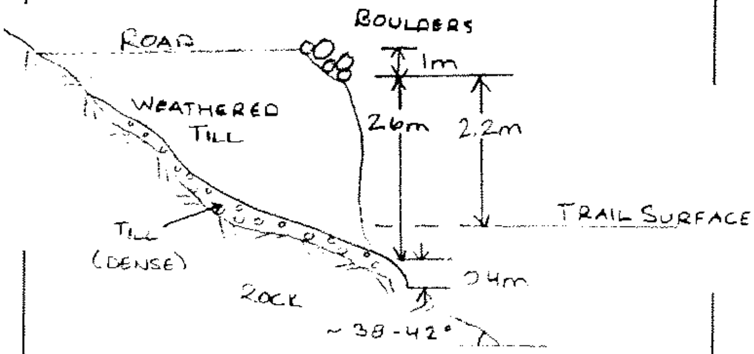
Reviewed by:	IGB	Project No: 0268-001-02

BORING NUMBER : BGC-TP-00-7

Page 1 of 1

DRILLING METHOD : John Deer 790D LC Excavator
DRILLING CONTRACTOR : Conkin
LOCATION : Drill access trail, ~15m S. of W. Abutment
START : Nov. 1/00
FINISH :
SAMPLE LEGEND : SPT ☒ GRAB G

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6"- (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
0–1						●	***Granitic Boulders***	Bedrock exposed in road cut, approximately 10m west of test pit.	
1–3.7 2 3					ML	▒	***Sandy SILT*** Some gravel, light brown, dry to moist. [Weathered Till]		
3.7–4	Grab 1	N/A	N/A	G	SM	▒	***Lodgement Till*** As encountered in BGC-TP-00-6.		
4							End of Pit		
5								Granitic Bedrock (Surface dips 38-42° towards 156°.)	
6									
7									
8									
9									
10									



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Reviewed by:	IGB	Project No: 0268-001-02

BORING NUMBER : BGC-TP-00-8

Page 1 of 1

DRILLING METHOD : John Deer 790D LC Excavator
DRILLING CONTRACTOR : Conkin
LOCATION : 15m S.E. of BGC-TP-00-7
START : Nov. 1/00
FINISH :
SAMPLE LEGEND : SPT ⧓ GRAB ☐

DEPTH BELOW SURFACE (m)	NUMBER	RECOVERY	STANDARD PENETRATION 6"-6"-6"- (N)	SAMPLE SYMBOL	USCS SYMBOL	SOIL SYMBOL	SOIL DESCRIPTION	COMMENTS	INSTRUMENT
					ML		***Sandy SILT*** Some gravel. [Weathered Till]		
1					SM		***Silty SAND*** Some gravel and trace clay, dense, moist, difficult to excavate. [Lodgement Till]	Excavator operator indicated that a cat with a ripper is often required to excavate this material, but that it weakens considerably when it gets wet. (Very difficult to excavate)	
2									
3							End of Pit		
4									
5									
6									
7									
8									
9									
10									

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Checked by:	BW	Project: HB Tailings Pond Decommissioning
Reviewed by:	IGB	Project No: 0268-001-02

Regional District of Central Kootenay
HB Mine Tailings Pond Closure

Tabulated Summary of Laboratory Testing Results

Project No. 0268-001-02

Sample	Grain Size Analysis								Nat. M.C.	Atterberg Limits			Activity	Permeability Estimate	Comments
	% Gravel (2-60mm)	% Sand (.06-2mm)	% Silt (2-60μm)	% Clay (<2μm)	D_{10} (mm)	D_{15} (mm)	D_{50} (mm)	D_{85} (mm)	(%)	LL	PL	PI	(PI / %Clay)	(m/sec)	
TP#1 (D/S Face of Dam)	47.6%	50.4%	2.0%	0.0%	0.014	0.200	1.500	26.000	-	-	-	-	-	1.960E-06	Filter blanket material.
TP#2 (D/S Face of Dam)	12.2%	22.8%	47.5%	17.5%	0.001	0.002	0.012	0.850	17.5%	30%	20%	10%	0.6	1.000E-08	Probably from till borrow.
TP#3 (Borrow Area - Till)	15.3%	37.7%	39.5%	7.5%	0.004	0.006	0.075	2.360	10.8%	16%	13%	3%	0.4	1.600E-07	Located ~200m S.E. of east abutment.
TP#7 (Till)	38.0%	42.0%	17.0%	3.0%	0.010	0.025	0.700	16.000	-	-	-	-	-	1.000E-06	Overlies granitic bedrock.
Tailings Sample	0.0%	10.0%	87.5%	2.5%	0.008	0.011	0.031	0.055	40.5%	-	-	-	-	5.625E-07	Tailings TP3 #1
Highways Gravel Pit	86.7%	12.3%	1.0%	0.0%	1.300	2.360	6.300	16.000	-	-	-	-	-	1.690E-02	Located just north of entrance to CANEX.
BH#1 - SPT#2	32.9%	31.1%	27.0%	9.0%	0.002	0.005	0.300	0.170	-	-	-	-	-	5.760E-08	Probably from till borrow.
BH#1 - SPT#5	11.0%	24.0%	48.0%	17.0%	0.001	0.002	0.020	0.500	19.8%	27%	19%	8%	-	1.000E-08	Probably from till borrow.
BH#1 - SPT#7	37.3%	51.7%	10.0%	1.0%	0.060	0.140	0.850	8.000	-	-	-	-	-	3.600E-05	Filter blanket material.
BH#1 - SPT#8	15.5%	43.5%	33.0%	8.0%	0.003	0.006	0.120	2.360	-	-	-	-	-	9.000E-08	Very loose, and wet.
BH#1 - SPT#10	7.8%	44.7%	35.5%	12.0%	0.002	0.003	0.070	0.610	-	-	-	-	-	2.250E-08	Loose to medium dense fill.
BH#1 - SPT#12	17.6%	41.4%	31.0%	10.0%	0.002	0.005	0.140	4.750	-	-	-	-	-	4.000E-08	Loose to medium dense fill.
BH#1 - SPT#13	1.0%	11.5%	60.5%	27.0%	0.001	0.001	0.005	0.045	25.6%	36%	24%	12%	0.4	6.400E-09	Select impermeable fill?
BH#1 - SPT#14	0.0%	31.0%	66.5%	2.5%	0.007	0.012	0.040	0.090	-	-	-	-	-	4.900E-07	Stratified glaciolacustrine silt.
BH#1 - SPT#15	26.4%	37.6%	25.0%	11.0%	0.002	0.004	0.220	7.500	-	-	-	-	-	3.610E-08	Till
BH#2 - SPT#2	0.0%	40.0%	55.0%	5.0%	0.005	0.007	0.045	0.090	-	-	-	-	-	2.025E-07	May contain trace organics.
BH#2 - SPT#8	0.0%	30.0%	66.0%	4.0%	0.005	0.008	0.030	0.070	-	-	-	-	-	2.500E-07	Stratified glaciolacustrine silt.
BH#2 - SPT#10	0.0%	6.0%	42.0%	52.0%	0.000	0.001	0.002	0.001	33.1%	47%	24%	23%	0.4	1.000E-10	Glaciolacustrine clay.

Notes:

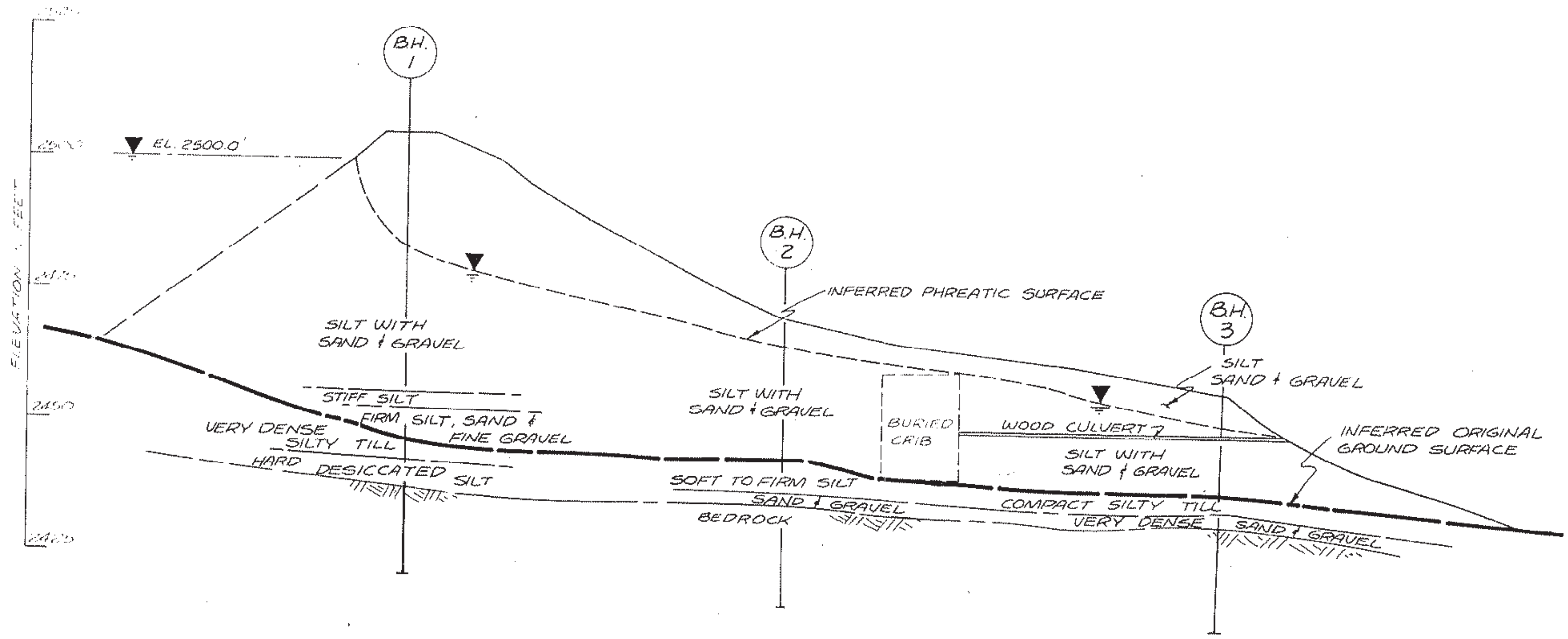
1. Laboratory testing conducted by C.N. Ryzuk & Associates Ltd.
2. All tests conducted according to ASTM Standards.
3. Permeability estimates based on k (m/sec) = $0.01*D_{10}^2$, where D_{10} is in mm (Craig 1987).

APPENDIX C

HISTORICAL DRAWINGS

CROSS SECTION A-A SHOWING
INFERRED SOIL STRATIGRAPHY
& PHREATIC SURFACE

FIGURE 2

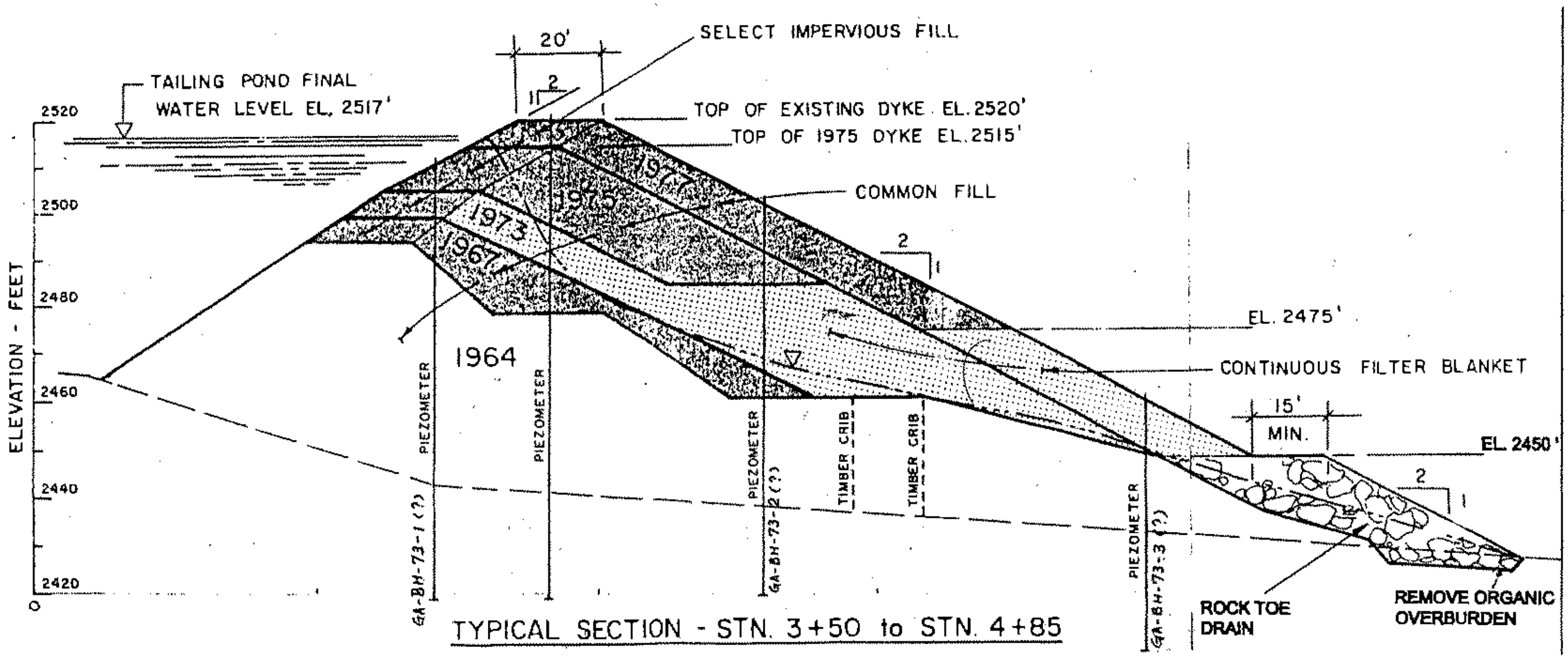


REFERENCE: COMINCO ENGINEERING
DWG. No. HB-285-P, TITLED
"HB MINE TAILINGS DISPOSAL"
DATED SEPTEMBER 7, 1973.

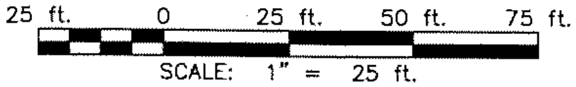
SECTION A-A
SCALES: HORIZ. & VERT. 1 IN. TO 20 FT.

GOLDER, BRAWNER & ASSOCIATES

DRAWN RMO
APP'D B.T.
DATE Dec. '73.



TYPICAL SECTION - STN. 3+50 to STN. 4+85



SCALE: 1" = 25 ft.

NOTE:

1. DRAWING SCANNED FROM DRAWING NO. D-2869-4 OF KLOHN-LEONOFF REPORT OF 1981.

REV.	DATE	REVISION	DRAWN	CHECKED	APPROVED

SCALE: AS SHOWN
DATE: FEB 2002
DRAWN: GEJ
DESIGNED: BW
CHECKED: MJP
APPROVED: IGB

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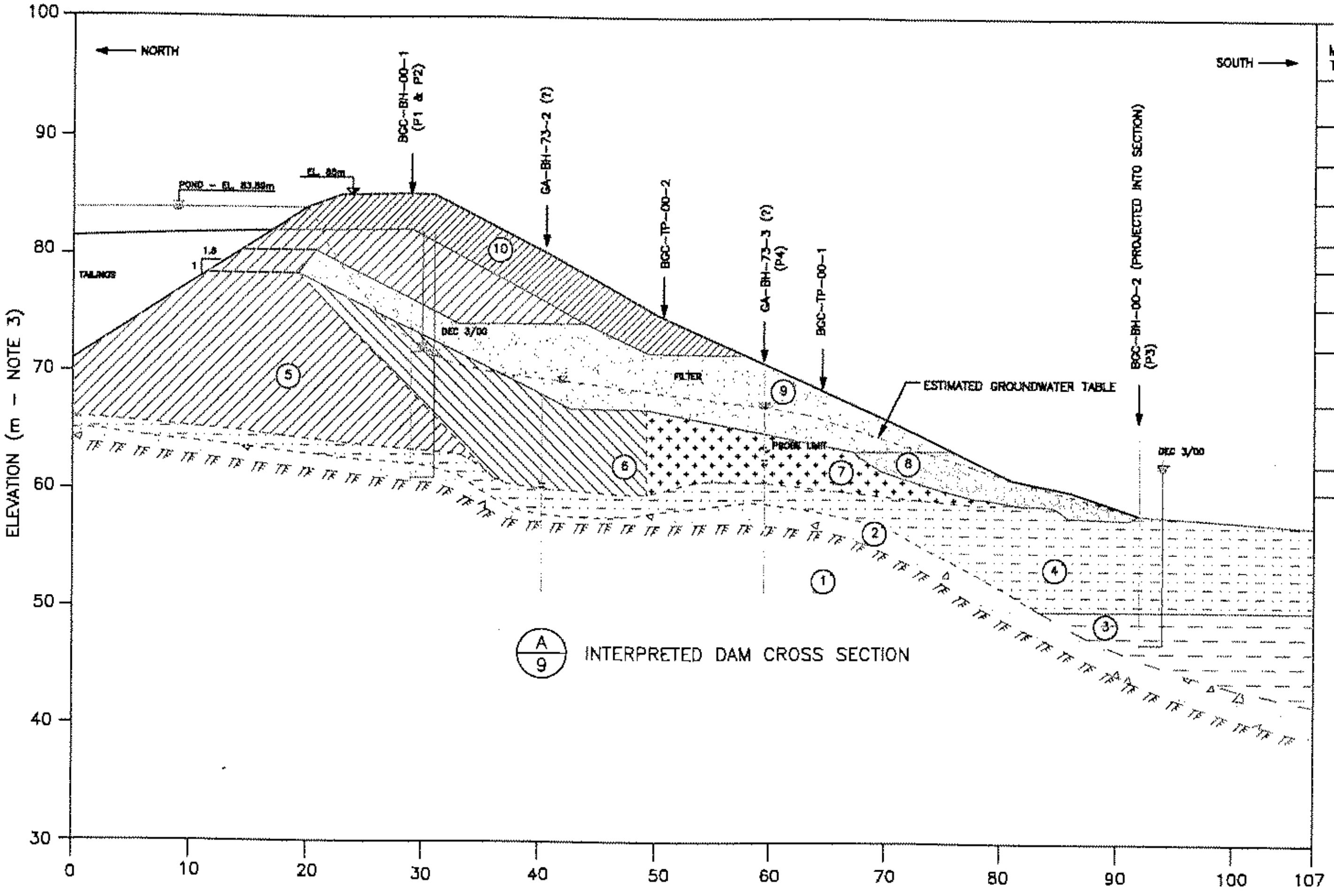
AN APPLIED EARTH SCIENCES COMPANY
Vancouver, B.C. Phone: (604) 684 5900

CLIENT: REGIONAL DISTRICT OF CENTRAL KOOTENAY

PROJECT HB MINE TAILINGS POND DECOMMISSIONING
TITLE EXISTING DAM SECTION AND CONSTRUCTION HISTORY (AFTER KLOHN-LEONOFF, 1981)
PROJECT No. 0268-001-05
DWG. No. DRAWING 4
REV. 0



A/9 INTERPRETED DAM CROSS SECTION

MATERIAL TYPE	SYMBOL	DESCRIPTION
10	▨	SANDY SILT WITH TRACE GRAVEL. COMPACT.
9	⁘	SAND WITH SOME GRAVEL. DENSE TO VERY DENSE. FILTER BLANKET.
8	⁘	SAND GRAVEL & COBBLES OBSERVED ON SURFACE. TOE DRAIN.
7	+ + +	SILT WITH SAND AND GRAVEL, COMPACT TO VERY DENSE.
6	▧	SILTY SAND, VERY LOOSE TO LOOSE. WET.
5	▨	SAND AND SILT. LOOSE TO COMPACT.
4	- - -	STRATIFIED GLACIOLACUSTRINE SANDY SILT. MOIST, COMPACT.
3	— —	STRATIFIED GLACIOLACUSTRINE SILTY CLAY. MOIST, VERY STIFF, CONTAINS THIN SAND LAYERS.
2	△	GRAVELLY SAND WITH SOME SILT AND TRACE CLAY. DENSE, MOIST, GREY/BROWN [LODGEMENT TILL].
1	TF TF TF	BEDROCK, GRANITIC AND META-SEDIMENTARY.

NOTES:

1) TOPOGRAPHIC SURVEY PROVIDED BY SPROULERS' ENTERPRISES LTD.
2) LOCATIONS OF ALL STRATIGRAPHIC BOUNDARIES ARE INTERPRETED BASED ON LIMITED SURFACE AND SUB-SURFACE OBSERVATIONS, AND ON PREVIOUS ENGINEERING REPORTS BY OTHERS THAT WERE PROVIDED BY THE CLIENT. THE LOCATION OF ALL STRATIGRAPHIC BOUNDARIES SHOULD BE CONSIDERED APPROXIMATE AND ACTUAL CONDITIONS MAY VARY.
3) ELEVATIONS REFERENCED TO A LOCAL DATUM. (85m ≈ EL 2520' ON DRAWINGS 3 TO 6).

6m 0 6m 12m 18m
SCALE: 1 : 400

REV.	DATE	REVISION	DRAWN	CHECKED	APPROVED

SCALE: AS SHOWN
DATE: FEB 2002
DRAWN: GEJ
DESIGNED: MJP
CHECKED: MJP
APPROVED: IGB

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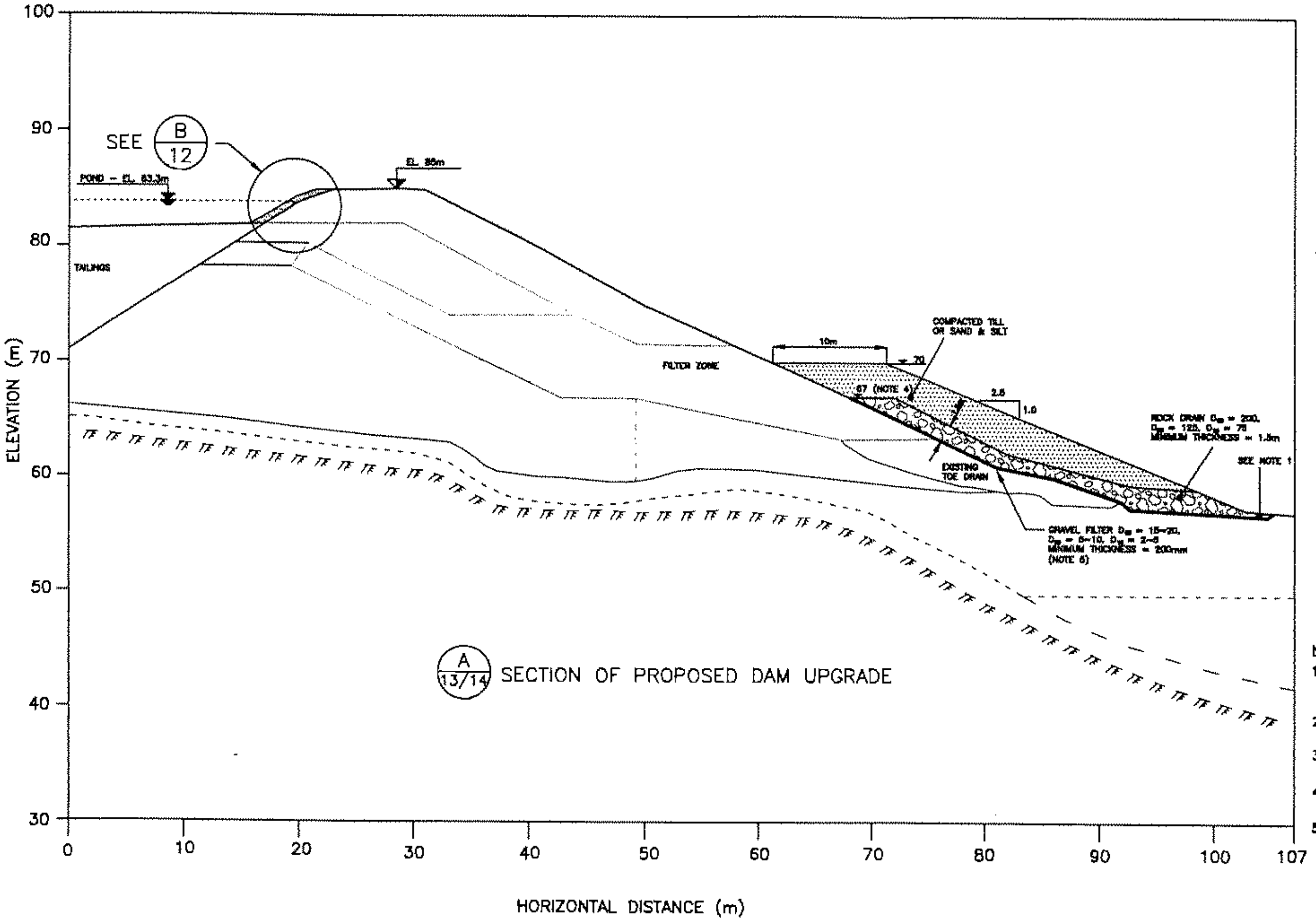
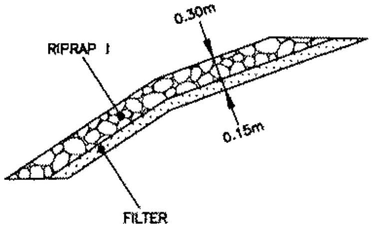
PROJECT: HB MINE TAILINGS POND DECOMMISSIONING
TITLE: INTERPRETED DAM CROSS SECTION
PROJECT No. 0268-001-05
DWG. No. DRAWING 10
REV. 0



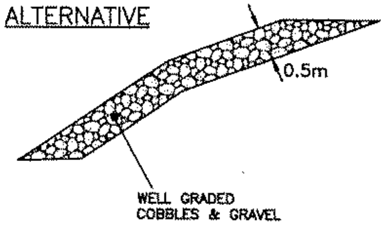
A/13/14 SECTION OF PROPOSED DAM UPGRADE

	D_{85}	D_{50}	D_{15}
RIPRAP	200	125	75
FILTER	15–20	5–10	2–5



B/12 TYPICAL EROSION PROTECTION DETAILS

ALTERNATIVE



NOTES:

1) TOE BERM FOUNDATION PREPARATION: CLEAN FOUNDATION BASE AND REMOVE SOFT ORGANIC OVERBURDEN BY EXCAVATING AT LEAST 1.0m OR UNTIL COMPETENT DENSE MATERIAL IS EXPOSED.
2) DAM ORGANIC SURFACE MUST BE REMOVED BEFORE PLACING ROCK DRAIN AND FILL MATERIALS.
3) TOE BERM ROCK DRAIN TO BE PLACED AT LEAST 1.5m THICK PERPENDICULAR TO SLOPE FACE.
4) UPPER LIMIT OF ROCK DRAIN TO BE PLACED AS SHOWN OR 1m ABOVE SEEPAGE WHICHEVER IS HIGHER.
5) CONDITIONS OF EXISTING TOE DRAIN ARE TO BE CONFIRMED DURING CONSTRUCTION. SOILS OVER THE ROCK DRAIN SHOULD BE REMOVED IF DEEMED APPROPRIATE. NO FILTER IS NECESSARY IF ROCKFILL IS EXPOSED.

6m 0 6m 12m 18m
SCALE: 1 : 400

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SCALE: AS SHOWN
DATE: FEB 2002
DRAWN: MJP
DESIGNED: BW
CHECKED: MJP
APPROVED: IGB

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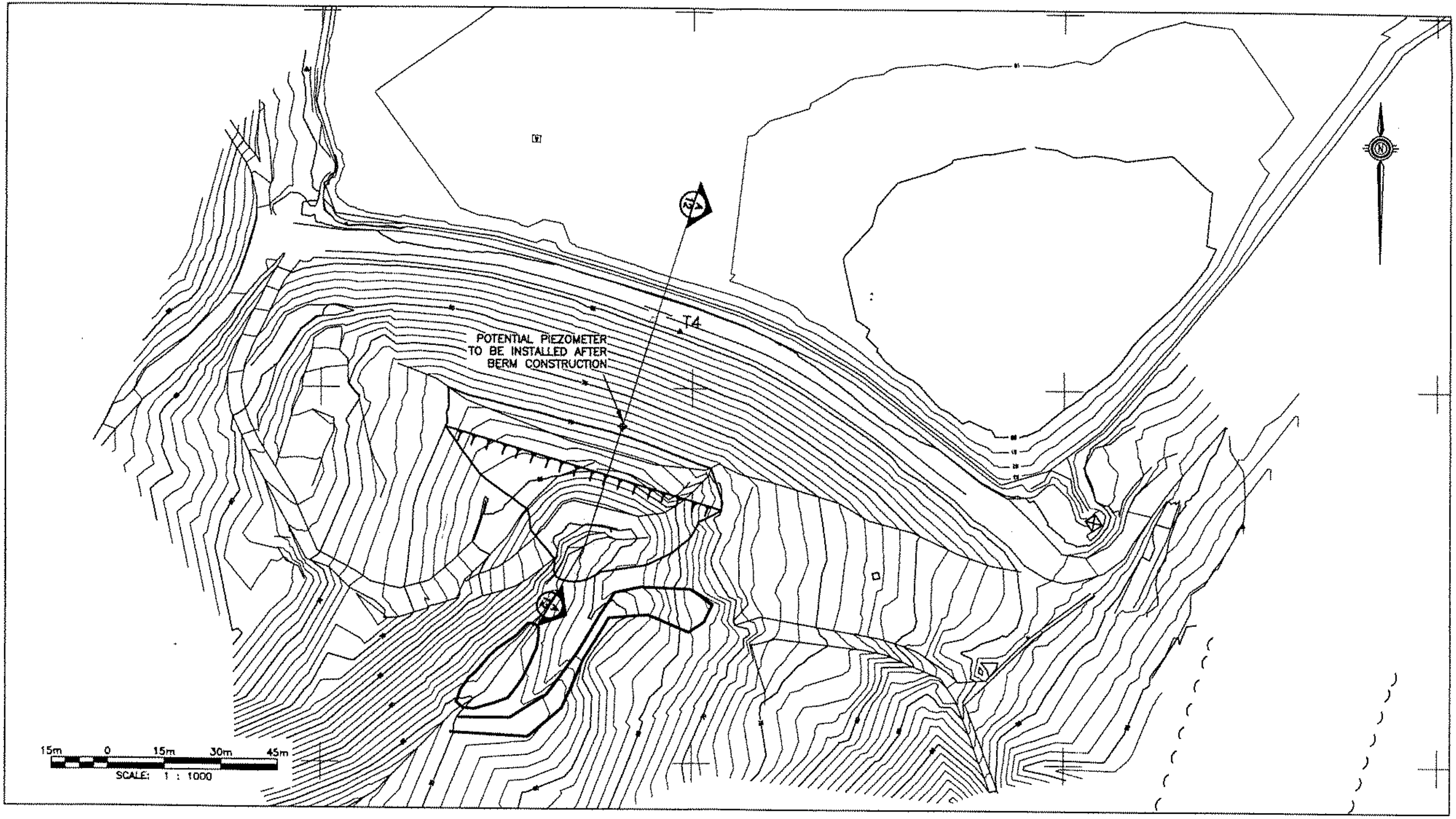
PROJECT: HB MINE TAILINGS POND DECOMMISSIONING
TITLE: SECTION OF PROPOSED DAM UPGRADE
PROJECT No. 0268–001–05
DWG. No. DRAWING 12
REV. 0



REV.	DATE	REVISION	DRAWN	CHECKED	APPROVED

SCALE: AS SHOWN
DATE: FEB 2002
DRAWN: GEJ
DESIGNED: BW
CHECKED: MJP
APPROVED: IGB

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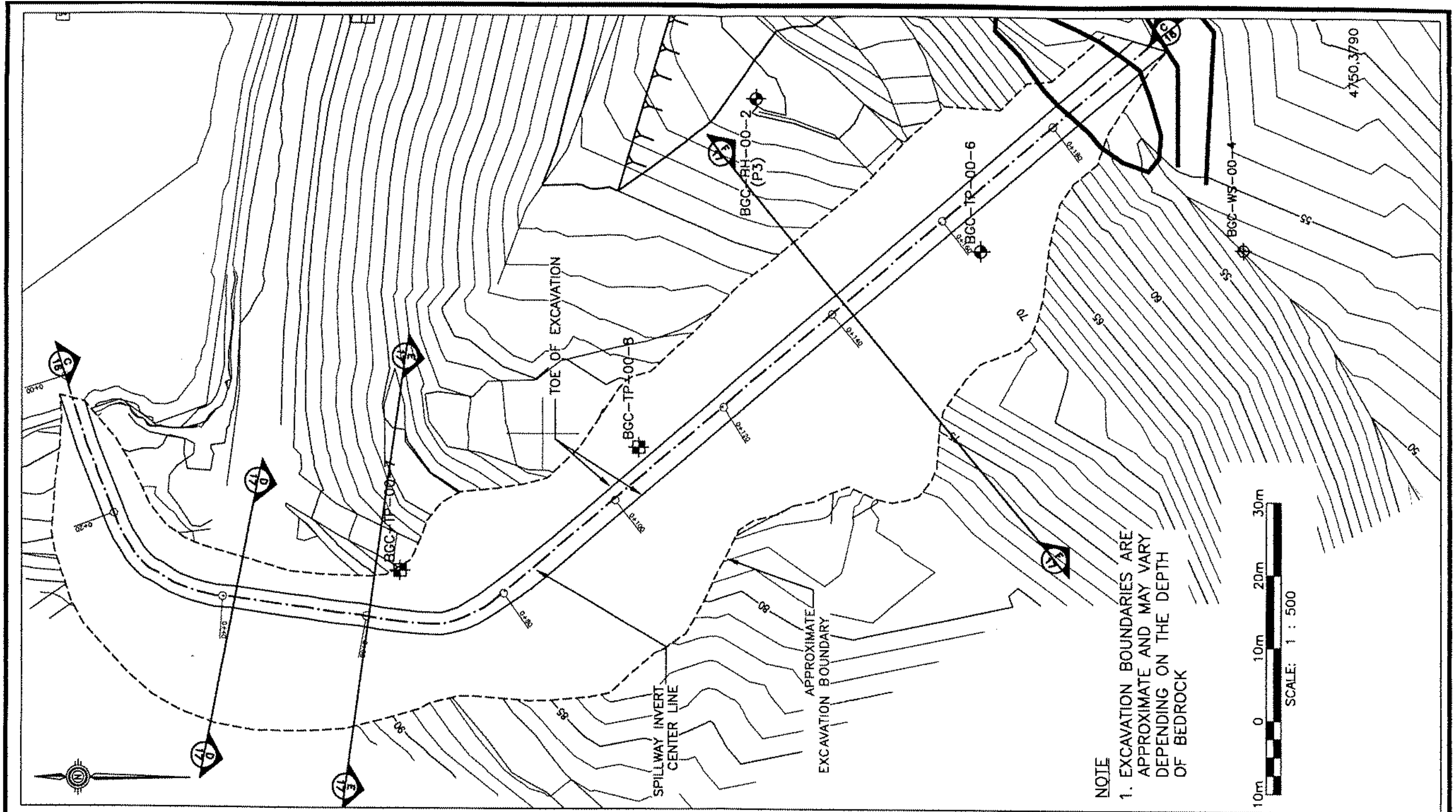
PROJECT: HB MINE TAILINGS POND DECOMMISSIONING

TITLE: PROPOSED TOE BERM PLAN

PROJECT No. 0268-001-05
DWG. No. DRAWING 14
REV. 0



NOTE

1. EXCAVATION BOUNDARIES ARE APPROXIMATE AND MAY VARY DEPENDING ON THE DEPTH OF BEDROCK

REV.	DATE	REVISION	DRAWN	CHECKED	APPROVED

SCALE:	AS SHOWN
DATE:	FEB 2002
DRAWN:	GEJ
DESIGNED:	BW
CHECKED:	MJP
APPROVED:	IGB

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CLIENT: REGIONAL DISTRICT OF CENTRAL KOOETNAY

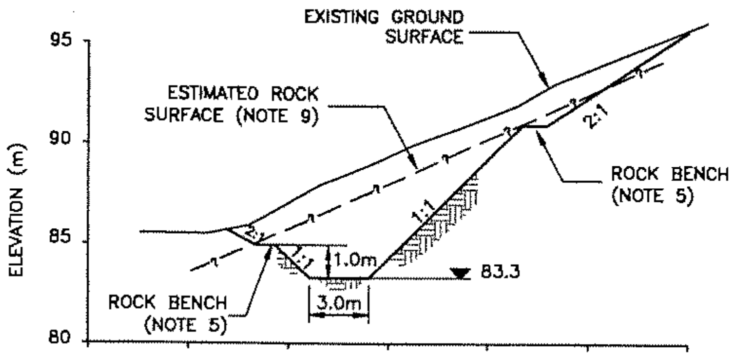
PROJECT
HB MINE TAILINGS POND DECOMMISSIONING

TITLE
PROPOSED SPILLWAY PLAN

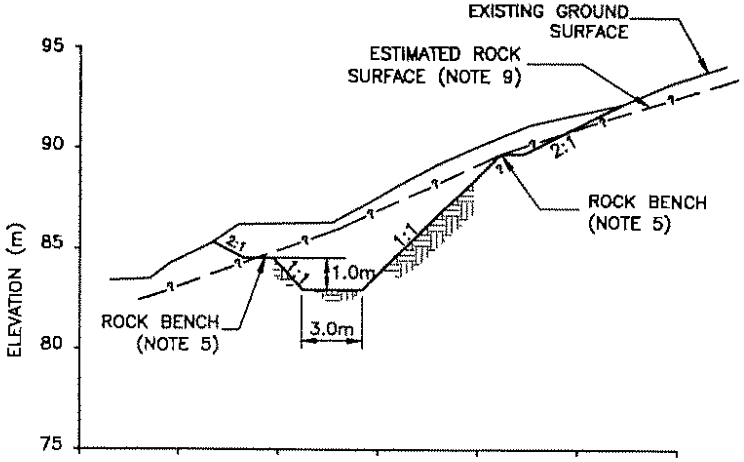
PROJECT No. 0268-001-05

DWG. No. DRAWING 15

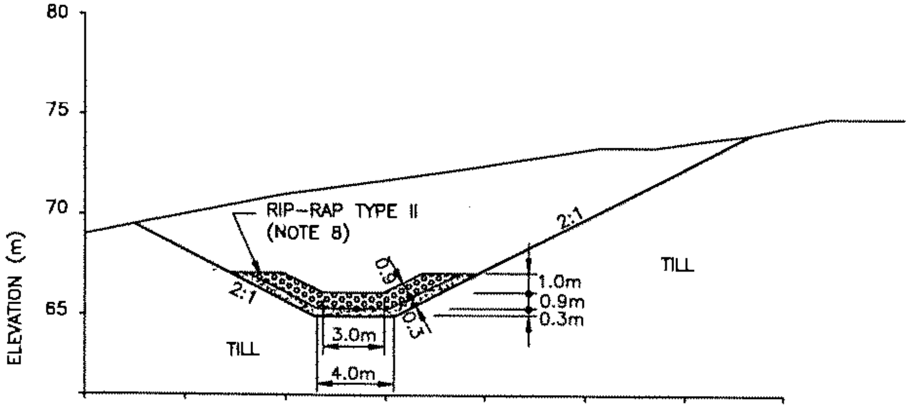
REV. 0



SECTION D 15/16 CHANNEL SECTION AT DAM CENTERLINE



SECTION E 15/16 TYPICAL CHANNEL SECTION IN ROCK



SECTION F 15/16 TYPICAL CHANNEL SECTION IN TILL

NOTE:
1. INVERT WIDTH: 3m
2. MINIMUM DEPTH OF CHANNEL IN ROCK: 1.0m
3. SIDE SLOPE IN ROCK: 1H:1V
4. SIDE SLOPE IN TILL: 2H:1V
5. ALLOW 1m 'BENCH' AT ROCK/TILL INTERFACE
6. MINIMUM LINED DEPTH: 1m
7. RIP-RAP AND FILTER THICKNESS MEASURED PERPINDICULAR TO SLOPE
8. RIP-RAP REQUIREMENT VARIES (SEE DWG. 16)
9. ROCK/TILL CONTACT TO BE CONFIRMED IN THE FIELD

REV.	DATE	REVISION	DRAWN	CHECKED	APPROVED

SCALE: 1:250
DATE: FEB 2002
DRAWN: KB
DESIGNED: BW
CHECKED: MJP
APPROVED: IGB

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CLIENT: REGIONAL DISTRICT OF CENTRAL KOOTENAY

PROJECT: HB MINE TAILINGS POND DECOMMISSIONING

TITLE: TYPICAL CROSS SECTIONS OF PROPOSED SPLILLWAY

PROJECT No.: 0268-001-05
DWG. No.: DRAWING 17
REV.: 0

APPENDIX D

DAM INSPECTION NOTES

Table D: Site Inspection Observations of the HB Dam

General Description Of Dam			
Date:	June 26, 2013	**Attendees:**	Adrian Chantler (TT EBA), Brian Cutts (TT EBA), Sarah Portelance (TT EBA), and Amy Wilson (RDCK)
Weather:	Fine and sunny	**Location:**	Emerald Mine Road, Salmo, BC
Length:	~240 m	**Outlet type:**	None
Max. Height:	~ 27 m	**Sluice gate:**	None
Crest Elevation:	~713 m	**Spillway:**	Free overflowing weir
Crest Width:	6 - 7 m	**Spillway Crest Elevation:**	709.39 m
Water Level:	~ 709.6 m	**Downstream Slope Angle:**	1V:2H
Appurtenances:	None	**Upstream Slope Angle:**	1V:1.5H

OBSERVATIONS	
Location	
Dam Access Road	The access road is in poor condition, vehicle access is more suited to 4 x 4 vehicles.
Right Abutment	Rock exposed in spillway channel cutting.
Crest	Minor rutting from vehicle traffic noted on the dam crest.
Crest	Minor animal activity (tracks) was noted on the dam crest.
Upstream Face	Some brush vegetation is growing in the upstream slope of the dam.
Downstream Face	New rock berm noted at toe of 2012 slough.
Downstream Face	V-notch weir located downstream of the east embankment to measure seepage estimates.
Reservoir	Remains of abandoned decant structure exposed (severely damaged).
Reservoir	Reservoir side slopes exhibit no obvious signs of instability in close proximity to the dam.
Spillway	Spillway flowing at time of inspection with the reservoir level approximately 0.19 m above the spillway invert.
Spillway	Spillway channel width 1.7 m at the base.
Spillway	RDCK inspector noted that during winter ice jams form in the spillway channel.
Spillway	No log boom in place.
Outlet Channel	Noted riprap protection missing in spillway outlet channel.
Outlet	Dam outlet flows downstream under a culvert under Highway 3.
Outlet	Observed one establishment across Highway 3 and Salmo River.

APPENDIX E

SCREENING ASSESSMENT OF POTENTIAL INTERNAL EROSION MODES

E1.0 SCREENING OF POTENTIAL INTERNAL EROSION FAILURE MODES ON THE ZONING OF THE DAM AND THE PROPERTIES OF THE CORE OF THE EMBANKMENT

The zoning of an embankment and in particular the presence or absence of filters which satisfy modern design criteria, and are constructed to a high standard, has a significant effect on the likelihood of failure by internal erosion. Figure 8.7c and Table E1.1 below show typical embankment zoning and their relative vulnerability related to the degree of filtering provided. These are generalisations but it can be said that any dam in the first Group A is very vulnerable because there is no filtering. Internal erosion in Group B dams may be limited by the hydraulic head losses through the upstream and downstream fill and filtering capacity of the fills. Group C dams are of low vulnerability because of the concrete upstream slab or core wall, subject to good detailing and no damage. Those in the fourth Group D have in principal a very low vulnerability because filters are provided, but the detail of zoning is critical. However in reality dams with formal and informal filters, the details of the filters are critical if internal erosion is to be controlled, and dams should not be regarded as safe from internal erosion just because their general zoning is favorable.

Table E1.1: Screening of HB Dam by Dam Zoning

Vulnerability to Internal Erosion	Potential for Control	Dam Zoning and Category Number
A Very Vulnerable	Little of no control.	Homogenous (unzoned) earthfill (0) Earthfill with rock toe (2)
B Vulnerable	Some control of internal erosion depending on detail of zoning and filter capability.	Zoned earthfill (3) Zoned earth and rock fill (4) Puddle core (8) Hydraulic fill (11)
C Low Vulnerability	Moderate control of internal erosion depending on the filter capability and details of core wall or slab face.	Concrete face earthfill (6) Concrete face rockfill (7) Concrete core earthfill (9) Concrete core rockfill (10)
D Very Low Vulnerability	Good control of internal erosion subject to good details of core wall or face slab.	Earthfill with filters (1) Central earth core and rock fill (5)
Conclusion	The embankment is designed as a zoned earthfill embankment however the filter capability assessment of the embankment materials indicated that they have poor filter capability and therefore the embankment is considered Zoning Category 3 and therefore vulnerable to internal erosion based on zoning. Existing drawings of the dam also indicate that the filter does not extend above the pond level and therefore the crest of the dam should be considered Zoning Category 0 and therefore this part of the embankment is very vulnerable to internal erosion.	

Table E1.2 shows the potential failure modes which can be screened out for internal erosion in the embankment. If these criteria are met the only potential failure modes which have to be considered are concentrated leak and contact erosion potential failure modes.

Table E1.2: Screening of HB Dam for Internal Erosion in the Core of the Embankment

Initiating Mechanism	Exclude the Failure Mode if the Following Conditions are Satisfied	Assessment
Backward Erosion in the Core.	Exclude if the soil has a Plasticity Index ≥ 7.	BCG Testpit TP 3 advanced in the borrow area to the east of the left abutment encountered a Till material with a PI=3 so cannot be excluded.
Suffusion in the Core.	Exclude if: The core has a Plasticity Index ≥ 7. OR Exclude if the core is not gap-graded. If the core is gap-graded or broadly graded, exclude if the proportion of the finer fraction of a non-plastic soil is more than 40% of the total mass of the soil.	BCG Testpit TP 3 advanced in the borrow area to the east of the left abutment encountered a Till material with a PI=3 so cannot be excluded.
Conclusion	Backward erosion and suffusion in the core could be potential failure modes.	

E2.0 SCREENING OF POTENTIAL INTERNAL EROSION FAILURE MODES ON FOUNDATION GEOLOGY AND PROPERTIES

Table E2.1 and E2.2 show the potential failure modes for internal erosion in the foundation, and from the embankment to the foundation can be screens based on the geology of foundation and the cut-off provide for the core of the embankment.

Table E2.1: Screening of HB Dam for Internal Erosion in the Foundation

Initiating Mechanism	Exclude the Failure Mode if the Following Conditions are Satisfied	Assessment
All modes of internal erosion of the foundation (backward erosion, suffusion, erosion in a crack).	Exclude if the soil layer beneath the dam is isolated by a cut-off trench in non-erodible rock.	Dam has no cut-off and is founded on soil therefore cannot be exclude.
Backward erosion in a soil in the foundation.	Exclude if: (1) The foundation soil has a Plasticity Index ≥ 7. OR	BCG Borehole BH1 & BH2 encountered a glaciolacustine clayey silt in the dam foundation with a PI=23 therefore can be excluded.

Table E2.1: Screening of HB Dam for Internal Erosion in the Foundation

Initiating Mechanism	Exclude the Failure Mode if the Following Conditions are Satisfied	Assessment
	(2) If the soil layer with PI ≤ 7 is not continuous below the embankment (i.e. terminated beneath the dam).	
Suffusion in a soil in the foundation.	Exclude if: (1) The foundation soil has a Plasticity Index ≥ 7. OR (2) The portion of the of the finer fraction of a non-plastic soil is more than 40% of the total mass of the soil. OR (3) If the soil layer with PI ≤ 7 is not continuous below the embankment (i.e. terminated beneath the dam).	BCG Borehole BH1 & BH2 encountered a glaciolacustine clayey silt in the dam foundation with a PI=23 therefore can be excluded.
Erosion in a crack in soil in the foundation.	Exclude if the foundation soil in non-plastic.	BCG Borehole BH1 & BH2 encountered a glaciolacustine clayey silt in the dam foundation with a PI=23 so can be excluded.
Conclusion	Backward erosion and suffusion in the foundation can be excluded as potential failure modes.	

Table E2.2: Screening of HB Dam for Internal Erosion from the Embankment to the Foundation and Contact Erosion

Initiating Mechanism	Exclude the Failure Mode if the Following Conditions are Satisfied	Assessment
Internal erosion of the embankment into or at a rock foundation.	Exclude if: (1) Rock foundation below the core is comprised of rock containing closed rock defects (<1mm wide) or defects open less than 3D_{95}, of the fine limit of the core. OR (2) Rock foundation below the core has been adequately treated (e.g. shotcrete, slush grouting, mortar or concrete treatment).	BCG Borehole BH1 & BH2 encountered a glaciolacustine clayey silt in the dam foundation with a PI=23 therefore can be excluded.
Internal erosion of the embankment into or at a soil foundation.	Exclude if: (1) Soil foundation below the core is comprised of fine grained soils with greater than 12% fines (fraction finer than No 200 sieve (0.075 mm)),	BCG Borehole BH1 & BH2 encountered a glaciolacustine clayey silt in the dam foundation with a fines contenet between 69% and 94%

Table E2.2: Screening of HB Dam for Internal Erosion from the Embankment to the Foundation and Contact Erosion

Initiating Mechanism	Exclude the Failure Mode if the Following Conditions are Satisfied	Assessment
	and the soil does not contain macrostrucutre such as root holes, relic joints or solution features. OR (2) Soil foundation below the core is comprised of sands (SP or SW) which are filter-compatible with the embankment materials (i.e. satisfy the No erosion criteria).	therefore can be excluded.
Conclusion	Internal erosion of the embankment into or at the soil foundation can be excluded as a potential failure mode.	

E3.0 SCREENING OF POTENTIAL INTERNAL EROSION FAILURE MODES ON DETAIL OF THE EMBANKMENT AND CONDUITS AND RETAINING WALLS

The likelihood of an embankment experiencing initiation of concentrated leak erosion will be low provided that the conditions described in Table E3.1 are ALL satisfied, AND the soil in the embankment is in Erosion Group 3 or 4, moderately erodible or erosion resistance, as determined from Table E3.2.

The likelihood of an embankment experiencing initiation of concentrated leak erosion at conduits and retaining walls will be low provided that the conditions described in Table E3.3 are ALL satisfied, AND the soil in the embankment is in Erosion Group 3 or 4, moderately erodible or erosion resistance, as determined from Table D3.2.

However these are not to say these potential failure modes cannot occur for high consequence of failure dams and hey should not be excluded without more detailed analysis.

Table E3.1: Screening of HB Dam for Conditions in which a Crack or Concentrated Leak could form in the Embankment

Initiating Mechanism	Exclude the Failure Path if the Following Conditions are Satisfied	Assessment
Transvers cracking due to cross valley settlement.	Exclude if the embankment abutments are flatter than 15°, and the embankment height is uniform across the valley.	Abutment slopes are greater than 15° however given the age of the dam could be excluded.
Transverse cracking due to cross valley arching.	Exclude if the width of valley to dam height ratio $W_v/H > 2$.	Can be excluded as the dam has a $W_v/H > 2$.
Transverse cracking due to differential settlements in the	Exclude if there is no compressible soil in the foundation below the core.	Can be excluded as no compressible soils are

Table E3.1: Screening of HB Dam for Conditions in which a Crack or Concentrated Leak could form in the Embankment

Initiating Mechanism	Exclude the Failure Path if the Following Conditions are Satisfied	Assessment
foundation beneath the core.		likely present in the foundation soils.
Cracking in the crest due to desiccation by drying.	Exclude if the reservoir level is below the likely depth of desiccation cracking under all conditions including during extreme floods.	Cannot exclude as the reservoir level is likely to be within the desiccation depth zone during an extreme flood.
Cracking due to earthquake.	Exclude if: (1) The MDE is below a peak ground acceleration of 0.2g; AND (2) The embankment abutments are flatter than 15 degrees, and the height is uniform across the valley; AND (3) The soils in the embankment and its foundation are not susceptible to liquefaction.	Cannot be exclude as the 1955 embankment fill material is potentially susceptible to liquefaction.
Transverse cracking at the foundation contact due to small scale irregularities in the foundation profile under the core.	Exclude if the persistence of the irregularity across the width of the core is less than 50% of the core base width.	Can exclude as no significant irregularities across the width of the dam.
Poorly compacted or high permeability layer in the embankment.	Exclude if: All soils are very well compacted with lift thicknesses less than 200mm, with good documentation and records; This means: (1) For plastic soils (Plasticity Index > 7), ≥98% standard dry density ratio, moisture content 2% dry to 1% wet of OWC; (2) For non-plastic soils and soils with PI ≤7, >75% relative density.	Cannot exclude as no rocords are available to confirm that original fill materials are well compacted.
Poorly compacted or high permeability layer on the core-foundation contact.	Exclude if: (1) Contact soils are well compacted on a regular foundation surface with good documentation and records; OR (2) Uniform or regular rock surface or surface treated with shotcrete or concrete to correct slope irregularities, and soils well compacted (contact soil compacted using special compaction methods (e.g. rubber	Cannot exclude as there are no records to indicate whether there was any foundation treatment. Based on the age of the dam foundation treatment unlikely.

Table E3.1: Screening of HB Dam for Conditions in which a Crack or Concentrated Leak could form in the Embankment

Initiating Mechanism	Exclude the Failure Path if the Following Conditions are Satisfied	Assessment
	tires, use more plastic material, compaction wet of OWC); OR (3) Uniform well compacted soil foundation, with good mixing, bonding and compaction of contact fill; OR (4) Compacted soil foundation.	
Poorly compacted or high permeability layers in the crest due to freezing.	Exclude if: (1) The climate is such that temperatures do not fall below freezing point except possibly overnight or for a day or two; OR (2) If the reservoir stage being considered is below the likely depth of freezing.	Cannot exclude as winter temperatures all below freezing.
Conclusion	A crack or concentrated leak could form due to, desiccation by drying in the crest, due to freezing in the crest, and the presence of poorly compacted fills.	

Table E3.2: Screening of HB Dam for Erosion of Soil Related to Classification and Dispersivity

Erosion Soil Group	Soil Classification
1. Extremely Erodible.	All dispersive soils; Sherard pinhole classes D1 and D2; or Emerson Crumb Class 1 and 2. AND SM with <30% fines
2. Highly Erodible.	SM with > 30% fines; SC with < 30% fines; ML; SC with >30% fines; CL-ML;
3. Moderately Erodible.	CL; CL-CH; MH; CH with Liquid Limit <65%.
4. Erosion Resistant	CH with Liquid Limit > 65%.
Conclusion	Based on the existing geotechnical data the embankment materials generally comprise silty sands (SM) and sandy silts (SM) with greater than 30% fines and therefore is highly erodible.

Table E3.3: Screening of HB Dam for Internal Erosion around and into Conduits through the Embankment or Adjacent a Wall Supporting the Embankment Core for which Internal Erosion is Unlikely

Initiating Mechanism	Exclude the Failure Mode if the Following Conditions are Satisfied	Assessment
Poorly compacted or high permeability zone around a conduit through the embankment.	Exclude if: (1) There is no conduit passing through the embankment; OR (2) The conduit is totally embedded in a trench excavated in non-erodible rock, backfilled to the surface with concrete.	Cannot exclude as there are decommissioned decant conduits passing through the embankment.
Erosion into a (non-pressurized) conduit.	Exclude if: (1) There is no conduit passing through the embankment; OR (2) Careful internal inspection of conduit showing no of open joints or cracks.	Can exclude as the decommissioned decant conduits have been backfilled with grout.
Poorly compacted zone associated with a spillway or abutment wall.	Exclude if there is no spillway or abutment wall in contact with the embankment.	Can be excluded as there is no spillway or abutment wall in contact with the embankment.
Crack/gap adjacent to a spillway or abutment wall.	Exclude if there is no spillway or abutment wall in contact with the embankment.	Can be excluded as there is no spillway or abutment wall in contact with the embankment.
Conclusion	Internal erosion along the decommissioned decant conduits could be a potential failure mode due to the presence of poorly compacted fill.	

APPENDIX F

DAM SAFETY EXPECTATIONS ASSESSMENT

CHECK SHEETS FOR DAM SAFETY EXPECTATIONS DEFICIENCIES AND PRIORITIES

Deficiencies and non-conformances identified during the Dam Safety Review have been evaluated in accordance with the sample check sheet for Dam Safety Expectations Deficiencies and Priorities developed by BC MoE (May 2010). Deficiencies are classified into Actual Deficiencies and Potential Deficiencies and there is a variety of non-conformances. These classifications are described as follows.

Definitions of Deficiencies and Non-Conformances

1. Deficiencies
    a. Actual – An unacceptable dam performance condition has been confirmed, based on the CDA Guidelines, or other specified safety standard. Identification of an actual deficiency generally leads to an appropriate corrective action or directly to a capital improvement project:
        i. (An) Normal Load – Load which is expected to occur during the life of a dam.
        ii. (Au) Unlikely Load – Load which could occur under unusual load (large earthquake or flood).
    b. Potential – There is a reason to expect that an unacceptable condition might exist, but has not been confirmed. Identification of a potential deficiency generally leads to a Deficiency Investigation:
        i. (Pn) Normal Load – Load which is expected to occur during the life of a dam.
        ii. (Pu) Unlikely Load – Load which could occur under unusual load (large earthquake or flood).
        iii. (Pq) Quick – Potential deficiency that cannot be confirmed but can be readily eliminated by a specific action.
        iv. (Pd) Difficult - Potential deficiency that is difficult or impossible to prove or disprove.
2. Non-Conformances

    Established procedures, systems and instructions are not being followed, or, they are inadequate or inappropriate and should be revised:

    a. Operational (NCo), Maintenance (NCm), Surveillance (NCs).
    b. Information (NCi) – information is insufficient to confirm adequacy of dam or physical infrastructure for dam safety.
    c. Other Procedures (NCp) – other procedures, to be specified.

Table F: Dam Safety Expectations for the HB Dam

	DAM SAFETY EXPECTATIONS	Yes	N/A	No	Deficiencies		Non-Conformances	Comments
					Actual	Potential		
1.0	**Dam Safety Analysis**							
1.1	Records relevant to dam safety are available including design documents, historical instrument readings, inspection and testing reports, operational records and investigation results.	X						
1.2	The Dam is classified appropriately in terms of the consequences of failure including life, environmental, cultural and third-party economic losses			X		Pu		Based on the economic consequences of embankment failure it is recommended to increase the dam consequence classification to “Very High”.
1.3	Inundation study adequate to determine consequence classification. Flood and “sunny day” scenarios assessed.	X						Undertaken as part of the DSR.
1.4	Hazards external and internal to the dam have been defined.	X						Undertaken as part of the DSR.
1.5	The potential failure modes for the dam and the initial conditions downstream from the dam have been identified.	X						Undertaken as part of the DSR.
1.6	All other components of the water barrier (retaining walls, saddle dams, spillways, road embankments) are included in the dam safety management process.	X						
1.7	The MDE selected reflects current seismic understanding.	X						
1.8	The IDF is based on appropriate hydrological analyses.	X						
1.9	The dam is safely capable of passing flows as required for all applicable loading conditions (normal, winter, earthquake, and flood).	X						
1.10	The dam has adequate freeboard for all applicable operating conditions (normal, winter, earthquake, and flood).	X						
1.11	The analyses are current.	X						
1.12	The approach and exit channels of discharge facilities are adequately protected against erosion and free of any obstructions that could adversely affect the discharge capacity of the facilities.	X						
1.13	The dams, abutments and foundations are not subject to unacceptable deformation or overstressing.	X						
1.14	Adequate filter and drainage facilities are provided to intercept and control the maximum anticipated seepage and to prevent internal erosion.			X	An			The filter compatibility assessment indicates that the current dam filter probably does not modern filter design criteria.
1.15	Hydraulic gradients in the dams, abutments, foundations and along embedded structures are sufficiently low to prevent piping and instability.			X	An			The filter does not extend above the maximum pond level and critical hydraulic gradients could develop in the crest of the dam.
1.16	Slopes of an embankment have adequate protection against erosion, seepage, traffic, frost and burrowing animals	X						
1.17	Stability of reservoir slopes are evaluated under all conditions and unacceptable risk to public safety, the dam or its appurtenant structures is identified.	X						
1.18	The need for reservoir evacuation or emergency drawdown capability as a dam safety risk control measure has been assessed.			X				The reservoir does not have the ability to be drawn down rapidly.
2.0	**Operation, Maintenance and Surveillance**							
2.1	Responsibilities and authorities are clearly delegated within the organization for all dam safety activities.			X			NCo	The OMS should be updated to reflect current persons in identified roles.
2.2	Requirements for the safe operation, maintenance and surveillance of the dam are documented with sufficient information in accordance with the impacts of operation and the consequences of dam failure.	X						

Table F: Dam Safety Expectations for the HB Dam

	DAM SAFETY EXPECTATIONS	Yes	N/A	No	Deficiencies		Non-Conformances	Comments
					Actual	Potential		
2.3	The OMS Manual is reviewed and updated periodically: when major changes to the structure, flow control equipment, operating conditions or company organizational structure and responsibilities have occurred.			X			NCo	The OMS Manual has not been updated since it was put together in 2011.
2.4	Documented operating procedures for the dam and flow control equipment under normal, unusual and emergency conditions exist, are consistent with the OMS Manual and are followed.	X						
	Operation							
2.5	Critical discharge facilities are able to operate under all expected conditions.							
a.	Flow control equipment is tested and is capable of operating as required.		X					No flow control equipment.
b.	Normal and standby power sources, as well as local and remote controls, are tested.		X					No flow control equipment.
c.	Testing is on a defined schedule and test results are documented and reviewed.		X					No flow control equipment.
d.	Management of debris and ice is carried out to ensure operability of discharge facilities.	X						
2.6	Operating procedures take into account:							
a.	Outflow from upstream dams		X					
b.	Reservoir levels and rates of drawdown	X						
c.	Reservoir control and discharge during an emergency	X						
d.	Reliable flood forecasting information	X						
e.	Operator safety	X						
	Maintenance							
2.7	The particular maintenance needs of critical components or subsystems, such as flow control systems, power supply, backup power, civil structures, drainage, public safety and security measures and communications and other infrastructure are identified.			X			NCm	The OMS Manual should be updated to include scheduled maintenance and testing of the emergency pump.
2.8	Maintenance procedures are documented and followed to ensure that the dam remains in a safe and operational condition.	X						
2.9	Maintenance activities are prioritized and carried out with due consideration to the consequences of failure, public safety and security.	X						
	Surveillance							
2.10	Documented surveillance procedures for the dam and reservoir are followed to provide early identification and to allow for timely mitigation of conditions that might affect dam safety.	X						
2.11	The surveillance program provides regular monitoring of dam performance, as follows:							
a.	Actual and expected performances are compared to identify deviations.	X						
b.	Analysis of changes in performance, deviation from expected performance or the development of hazardous conditions.	X						
c.	Reservoir operations are confirmed to be in compliance with dam safety requirements.	X						
d.	Confirmation that adequate maintenance is being carried out.	X						
2.12	The surveillance program has adequate quality assurance to maintain the integrity of data, inspection information, dam safety recommendations, training and response to unusual conditions.							

Table F: Dam Safety Expectations for the HB Dam

	DAM SAFETY EXPECTATIONS	Yes	N/A	No	Deficiencies		Non-Conformances	Comments
					Actual	Potential		
2.13	The frequency of inspection and monitoring activities reflects the consequences of failure, dam condition and past performance, rapidity of development of potential failure modes, access constraints due to weather or the season, regulatory requirements and security needs.	X						
2.14	Special inspections are undertaken following unusual events (if no unusual events then acknowledge that requirement to do so is documented in OMS).	X						
2.15	Training is provided so that inspectors understand the importance of their role, the value of good documentation, and the means to carry out their responsibilities effectively.	X						The primary RDCK Dam Inspector (Ms. Amy Wilson) and the RDCK Resource Recovery Operations Supervisor (Mr. David Bromley) have received formal dam safety training facilitate by the MFLNR Dam Safety Branch on October 18, 2012 in Nelson. Informal dam safety training activities have also been conducted on site by Mr. Brian Cutts, P.Eng. of EBA with other RDCK staff members.
2.16	Qualifications and training records of all individuals with responsibilities for dam safety activities are available and maintained.	X						
2.17	Procedures document how often instruments are read and by whom, where the instrument readings will be stored, how they will be processed, how they will be analyzed, what threshold values or limits are acceptable for triggering follow-up actions, what the follow-up actions should be and what instrument maintenance and calibration are necessary.	X						
3.0	**Emergency Preparedness**							
3.1	An emergency management process is in place for the dam including emergency response procedures and emergency preparedness plans with a level of detail that is commensurate with the consequences of failure.	X						
3.2	The emergency response procedures outline the steps that the operations staff is to follow in the event of an emergency at the dam.	X						
3.3	Documentation clearly states, in order of priority, the key roles and responsibilities, as well as the required notifications and contact information.	X						
3.4	The emergency response procedures cover the full range of flood management planning, normal operating procedures and surveillance procedures.	X						
3.5	The emergency management process ensures that effective emergency preparedness procedures are in place for use by external response agencies with responsibilities for public safety within the floodplain.	X						
3.6	Roles and responsibilities of the dam owner and response agencies are defined.			X			NCp	The EPP should be updated to reflect current persons in identified roles.
3.7	Inundation maps and critical flood information are appropriate and are available to downstream response agencies.			X			NCp	The EPP should be updated to include the inundation maps developed as part of this dam safety review..
3.8	Exercises are carried out regularly to test the emergency procedures.			X			NCp	Assumed to be a non-conformance as no supporting documentation was provided.
3.9	Staff are adequately trained in the emergency procedures.			X			NCp	Assumed to be a non-conformance as no supporting documentation was provided.
3.10	Emergency plans are updated regularly and updated pages are distributed to all plan holders in a controlled manner.			X			NCp	The OMS Manual has not been updated since it was put together in 2011.
4.0	**Dam Safety Review**							
4.1	A safety review of the dam ("Dam Safety Review") is carried out periodically based on the consequences of failure.	X						The RDCK commission this dam safety review. This is the first comprehensive dam safety review of this structure. Another dam safety review should be conducted in five year (2019). The RDCK should endeavor to implement the recommendations of this review before that time.
5.0	**Dam Safety Management System**							
5.1	The dam safety management system for the dam is in place incorporating:							

Table F: Dam Safety Expectations for the HB Dam

	DAM SAFETY EXPECTATIONS	Yes	N/A	No	Deficiencies		Non-Conformances	Comments
					Actual	Potential		
a.	Policies							
b.	Responsibilities			X			NCo	The OMS & EPP should be updated to reflect current persons in identified roles.
c.	Plans and procedures including OMS, public safety and security	X						
d.	Documentation	X						
e.	Training and review	X						
f.	Prioritization and correction of deficiencies and non-conformances	X						Prioritizations of deficiencies are provided in this dam safety review.
g.	Supporting infrastructure		X					
5.2	Deficiencies are: documented, reviewed, and resolved in a timely manner. Decisions are justified and documented.	X						Deficiencies are documented in this dam safety review.
5.3	Applicable regulations are met.	X						

APPENDIX G

DAM SAFETY REVIEW ASSURANCE STATEMENT – MINING DAMS

APPENDIX G: *DAM SAFETY REVIEW ASSURANCE STATEMENT – MINING DAMS*

Note: This Statement is to be read and completed in conjunction with the current "*APEGBC Guidelines for Legislated Dam Safety Reviews in British Columbia*, ("*APEGBC* Guidelines") and is to be provided for *dam safety review reports* in accordance with permit conditions and the *Health, Safety and Reclamation Code for Mines in British Columbia* or the *British Columbia Dam Safety Regulation*, B.C. Reg. 44/2000 as amended (refer to Table C-1 in Appendix C). Italicized words are defined in the *APEGBC* Guidelines. An assurance statement is required for each *dam* that is assessed.

To: The *Owner(s)*

Date: May 28, 2014

Regional District of Central Kootenay
Name
202 Lakeside Drive

Nelson, BC V1L 6B9
Address

With reference to the permit conditions and the *Health, Safety and Reclamation Code for Mines in British Columbia* or the *British Columbia Dam Safety Regulation*, B.C. Reg. 44/2000 as amended (refer to Table C-1 in Appendix C).

For the *Dam*:

UTM (Location): 481841E, 5442021N
Located at (Description): Emerald Mine Road, Salmo, BC
Name of *dam* or description: Hudson Bay Dam
Provincial *dam* number:
Dam function:
Owned by: Regional District of Central Kootenay

(the "*Dam*")

Current *Dam classification* is:

Check one

☐ Low
☑ Significant
☐ High
☐ Very High
☐ Extreme

The undersigned hereby gives assurance that he/she is a *Qualified Professional Engineer*.

I have signed, sealed and dated the attached *dam safety review report* for the *Dam* in accordance with the *APEGBC Guidelines*. That report must be read in conjunction with this Statement. In preparing that report I have:

Check to the left of applicable items (see Guideline Section 3.2):

✓ 1. Collected and reviewed available and relevant background information, documentation and data n/a 2. Reviewed the environmental objectives for the materials stored in the impoundment and related design requirements "Dam In Closure Phase"

✓ 3. Understood the current *classification* for the *Dam*, including performance expectations

✓ 4. Undertaken an initial facility review

✓ 5. Reviewed and assessed the *Dam* safety management obligations and procedures

✓ 6. Inspected the condition of the *Dam*, impoundment area and relevant areas upstream and downstream of the facility

✓ 7. Interviewed operations and maintenance personnel

n/a 8. Interviewed Engineer of Record "Dam In Closure Phase"

✓ 9. Reviewed available maintenance and operating records, the Operations, Maintenance and Surveillance (OMS) Manual and the Emergency Preparedness Plan

n/a 10. Confirmed proper functioning of mine waste and water management systems and environmental control systems "Dam in Closure Phase"

✓ 11. After the above, reassessed the consequence *classification*, including the identification of required *dam* safety criteria

✓ 12. Carried out a *dam safety analysis* based on the *classification* in Item 11

✓ 13. Evaluated facility performance and conformance with design basis and operating criteria

✓ 14. Identified, characterized and determined the magnitude of deficiencies in the safe operation of the *Dam* and non-conformances in the *dam* safety management system

✓ 15. Recommended and prioritized actions to be taken in relation to deficiencies and non-conformances

✓ 16. Prepared a *dam safety review report* for submittal to the *Regulatory Authority* by the *Owner* and reviewed the report with the *Owner*

✓ 17. The *dam safety review report* has been reviewed in meeting the intent of *APEGBC* Bylaw 14(b)(2).

Based on my *dam safety review*, the *Dam classification* is:

Check one

☐ Appropriate
☑ Should be reviewed or amended

I undertook the following type of *Dam Safety Review*:

Check one

☐ Audit
☑ Comprehensive
☐ Detailed design-based multi-disciplinary
☐ Comprehensive, detailed design and performance

I hereby give my assurance that, based on the attached *Dam Safety Review report,* at this point in time:

Check one

☐ The *Dam* is reasonably safe in that the *dam safety review* did not reveal any unsafe or unacceptable conditions in relation to the design, construction, maintenance and operation of the *Dam* as set out in the attached *dam safety review report.*

☐ The *Dam* is reasonably safe but the *dam safety review* did reveal non-conformances with the regulatory requirements as set out in section(s) ____ of the attached *dam safety review report.*

☑ The *Dam* is reasonably safe but the *dam safety review* did reveal deficiencies and non-conformances as set out in section(s) 10.6 of the attached *dam safety review report.*

☐ The *Dam* is not safe in that the *dam* safety review did reveal deficiencies and/or non-conformances which require urgent action as set out in section(s) ____ of the attached *dam safety review report.*

Michael J. Laws
Name

May 28, 2014
Date

Signature

M. J. LAWS
36691

(Affix Professional Seal here)

150, 1715 Dickson Avenue
Address

Kelowna, BC V1Y 9G6

250.862.4832
Telephone

If the *Qualified Professional Engineer* is a member of a firm, complete the following:

I am a member of the firm Tetra Tech EBA Inc. (Print name of firm)
and I sign this letter on behalf of the firm.

APPENDIX H

TETRA TECH EBA GENERAL CONDITIONS – GEOTECHNICAL REPORT

GENERAL CONDITIONS

GEOTECHNICAL REPORT

This report incorporates and is subject to these “General Conditions”.

1.0 USE OF REPORT AND OWNERSHIP

This geotechnical report pertains to a specific site, a specific development and a specific scope of work. It is not applicable to any other sites nor should it be relied upon for types of development other than that to which it refers. Any variation from the site or development would necessitate a supplementary geotechnical assessment.

This report and the recommendations contained in it are intended for the sole use of Tetra Tech EBA’s Client. Tetra Tech EBA does not accept any responsibility for the accuracy of any of the data, the analyses or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than Tetra Tech EBA’s Client unless otherwise authorized in writing by Tetra Tech EBA. Any unauthorized use of the report is at the sole risk of the user.

This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of Tetra Tech EBA. Additional copies of the report, if required, may be obtained upon request.

2.0 ALTERNATE REPORT FORMAT

Where Tetra Tech EBA submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed Tetra Tech EBA’s instruments of professional service), only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Tetra Tech EBA shall be deemed to be the original for the Project.

Both electronic file and hard copy versions of Tetra Tech EBA’s instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Tetra Tech EBA. Tetra Tech EBA’s instruments of professional service will be used only and exactly as submitted by Tetra Tech EBA.

Electronic files submitted by Tetra Tech EBA have been prepared and submitted using specific software and hardware systems. Tetra Tech EBA makes no representation about the compatibility of these files with the Client’s current or future software and hardware systems.

3.0 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, Tetra Tech EBA has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

4.0 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. Tetra Tech EBA does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

5.0 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

6.0 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. Tetra Tech EBA does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

7.0 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

8.0 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

9.0 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

10.0 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

11.0 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

12.0 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

13.0 SAMPLES

Tetra Tech EBA will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client’s expense upon written request, otherwise samples will be discarded.

14.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of the report, Tetra Tech EBA may rely on information provided by persons other than the Client. While Tetra Tech EBA endeavours to verify the accuracy of such information when instructed to do so by the Client, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.