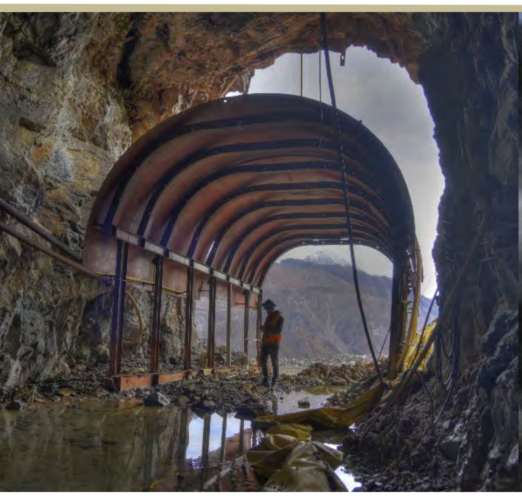
Cantung Mine Closure
Geotechnical Stability Assessment



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LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Alvarez & Marsal LLC, North American Tungsten Corp. Ltd., and their agents. Tetra Tech Canada Inc. (Tetra Tech) 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 Alvarez & Marsal LLC, North American Tungsten Corp. Ltd., 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 document is subject to the Limitations on the Use of this Document attached in the Appendix A or Contractual Terms and Conditions executed by both parties.

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was retained by Alvarez & Marsal LLC (A&M), acting as court appointed monitors for the closure process for North American Tungsten Corporation Ltd.'s (NATC) Cantung Mine, to conduct a geotechnical stability assessment of the open pit and portals of the mine. An initial site visit was undertaken in 2017.

The primary goal of the 2017 stability assessments was to identify any major safety concerns which may affect workers during the closure process, or the general public who may attempt to gain access to the site after it is abandoned. Other objectives of the assessment include:

- Providing recommendations for permanent stabilization works and remediation options;
- Providing recommendations for preventing public access; and
- Assessing any long-term subsidence concerns that may exist.

The stability assessments for both the pit and underground workings includes rock mass characterization using both the Rock Mass Rating (RMR) and Norwegian Geotechnical Institute's Q-system (NGI-Q). Additionally a visual rock fall assessment was completed for both the open pit and for the slopes above the portals to the underground works.

Preliminary remediation options have been developed for the underground portals and conveyor adit at the site, and this report presents conceptual designs for those options.

During the 2017 site visit it was noted that the access road to the open pit crosses several avalanche/debris chutes which, if left unmaintained, could pose a significant hazard. A brief inspection of each of these chutes was conducted in order to characterize the debris flow/avalanche potential and to recommend some preliminary considerations with respect to the long-term closure of the site.

The context of this main report relates to the findings of the 2017 inspection. In 2018, a second site visit was undertaken to inspect the entire length of the conveyor adit. As this inspection took place at a later date and is specific to a particular location, the 2018 findings are contained in a stand-alone report located in Appendix B of this report. As such, the refined conveyor adit observations and recommendations outlined in Appendix B take precedence to those set out in this 2017 main report.

Figure 1 shows a site plan of the mine including the open pit and underground portal locations.

2.0 OPEN PIT ASSESSMENT

The Cantung Open Pit is located at an elevation approximately 400 m above the mine process buildings, to the east, at the end of a 3.5 km access road. The pit is configured in a horseshoe shape with three excavated walls to the northwest, southwest, and southeast, which mimics the shape of the valley it is located in. Waste rock dumps from excavating the pit are present above the highest benches of the southwest and southeast walls, as well as having been end-dumped into the valley to the northeast. The base of the pit is approximately 120 m long, 30 m wide, and the first bench face is 5 m high. The total height of the excavated pit walls is approximately 30 to 60 m, with the northwest face being the highest.

The rock mass of the pit generally consists of a strong to very strong, grey and iron-stained, fresh to slightly weathered, fine-grained limestone. Bedding is typically sub-horizontal, and is most clearly visible on the northwest face. No major faulting was observed, and common joint structure throughout the pit includes one bedding-parallel joint set and at least one sub-vertical joint set.

An overview of the pit naming conventions and general layout is shown in Figure 2. Photos 1 through 13 show features discussed in the following sections.

2.1 Methodology

The open pit was assessed both from the ground level at the base of the pit, as well as by hiking up a decommissioned ramp/access road to the top of the Southeast and Southwest Walls. The Northwest Wall was inaccessible because the ramps and benches have either been completely eroded or filled with talus material from the slopes above. The following assessments were completed:

- Determining the presence of any major structures in the pit walls;
- Bench height, width, capacity, and catchment effectiveness;
- Looking at water inflow and drainage, and how that may affect pit wall stability;
- Assessing the rock mass conditions using the Rock Mass Rating (RMR) (Bieniawski, 1989) and by observing potential kinematic instabilities; and
- Determining where active rock fall is occurring, and delineating rock fall 'safe zones'.

The RMR is a system developed to classify rock masses geomechanically using a set of six parameters focusing on the strength of the intact rock material, discontinuity characteristics, the effects of groundwater, and a rating adjustment based on the orientation of the excavation with respect to discontinuities (Bieniawski, 1989). The ratings for individual parameters are summed in order to arrive at a final rating which is used to classify the rock mass in terms of friction angle, cohesion, and standup time.

2.2 Assessment Details

As shown in Figure 2, the pit walls are referred to by their position relative to the centre of the pit. The following subsections detail the results of our assessments.

2.2.1 Northwest Wall

The structure in the Northwest Wall is dominated by sub-horizontal bedding with two vertical joint sets. The wall is comprised of six sub-vertical faces separated by five benches. Many of the benches have been eroded or completely filled in with talus, and some of the faces tend to blend together. The faces were numbered 1 through 6 from the top of the pit, down. The approximate heights and a brief description of each face are summarized in Table 2.2.1-1 below. Figure 3 shows an image of the northwest wall with the faces and approximate bench heights labelled.

Table 2.2.1-1: Northwest wall bench face heights

Face Number	Approx. Height (m)	Comments
1	5	Only visible towards the northeast of the pit, most prominent at the north corner.
2	10	Relatively good bench performance between Faces 2 and 3.
3	15	Faces 3 and 4 combine towards the northeast.
4	15	The face forms a talus slope towards the northeast, substantial freeze-thaw fracturing.
5	5	The bench between Faces 4 and 5 has a rock fall berm some 2 - 4 m high which is providing good catchment.
6	5	Very little rock fall on bench between faces 5 and 6.

The bench between Faces 1 and 2 has essentially completely eroded, and is providing no catchment for rock fall originating from the slopes above the pit. There are four talus areas where the soil has eroded above the pit along the northwest wall, and these are a source for cobble-sized rock fall. Additionally there are a number of small gullies that channel rock fall from the natural rock faces on the mountain top, into the pit. The bench between Faces 2 and 3 is providing some catchment in places; however, it is mostly eroded on the east side. The bench between Faces 3 and 4 is providing no effective catchment and is almost completely eroded. The bench between Faces 4 and 5 is approximately 8 m wide, is in good condition, and has a rock fall berm that is 3 to 4 m high which is providing good catchment. The bench between Faces 5 and 6 is mostly clear of debris, is 6 to 8 m wide, and providing good catchment.

Water seepage was observed from Face 4 and the rock mass on this face is significantly more fractured than higher faces, most likely due to pronounced freeze-thaw action. This makes the bench between Faces 4 and 5 more susceptible to rock fall, although the large berm prevents this rock fall from reaching farther into the pit. This is an important observation as, with the berm and little evidence of rock fall on the bench between Faces 4 and 5, the base of the pit is considered to have a low rock fall risk.

There were no immediate kinematic stability concerns observed in the Northwest Wall, although some minor wedges were noted. In general, blocks formed by discontinuities were rectangular in shape, and did not have kinematic release planes. Block sizes in Faces 1 and 2 were generally on the order of 2 m while the other faces were more frost-shattered, reducing block sizes to 0.5-1 m. Rock fall in the catchment ditch was typically significantly smaller than this, indicating that kinematic instability has not been a major failure mechanism in the past. An RMR of 77 was obtained indicating Good Rock, the calculation for this is shown in Table 2.2.1-2.

Iron staining was noted in many locations on the face, particularly where groundwater seepage was occurring, or appeared to have occurred in the past.

Table 2.2.1-2: RMR for NW and SW walls of the Open Pit

Parameter	Category	Description	Rating
A1	Strength of intact rock material	Multiple hammer blows to chip, R2, UCS of 100 - 250 MPa	12
A2	RQD	90 - 100%	20
A3	Spacing of discontinuities	0.6 - 2 m	15
A4	Discontinuity length	3 - 10 m	2
	Joint separation	0.1 - 1 mm	4
	Joint roughness	Slightly rough	3
	Discontinuity infilling	None	6
	Joint weathering	Slightly weathered	5
A5	Groundwater	Damp (seepage from Face 4, moss covered face)	10
B	Rating adjustment for orientation	Strike parallel to slope axis, dip 45 - 90°	0
C	**Rock Mass Class**	**II, Good Rock**	**77**

2.2.2 Southwest Wall

The Southwest Wall consists of one large, upper face and two smaller, lower faces. Above the upper face, waste rock was dumped in order to continue the ramp that leads to the bench between Faces 2 and 3 of the Northwest Wall. Figure 4 shows an image of the Southwest Wall with bench-faces and heights labelled. The structure in the Southwest Wall consists of a bedding-parallel joint set that dips approximately 20° to the northwest, as well as two sub-vertical joint sets. The two lower faces are both approximately 5 m high while the upper face is approximately 20 m high.

The bench between the upper and middle faces is a continuation of the bench between Faces 4 and 5 of the northwest wall. This bench is 8 to 10 m wide and has a 3 to 4 m high rock fall berm constructed on it. This berm is providing good catchment for rock fall originating from the upper face. The bench between the middle and lower faces is approximately 10 m wide and is mostly clear of rock fall debris.

There is a small waterfall located in the west corner of the pit, and an approximately 25 m length of the southwest face is wet and moss-covered due to groundwater seepage. Ponding is occurring at the base of this waterfall and most of the wet rock is iron-stained. It appears that the rest of the Southwest Wall is typically exposed to some type of water flow due to significant iron staining, particularly near the south corner of the pit. These features are shown in Photos 5 and 6.

Rock fall in this area of the pit is likely to be sourced almost entirely from the excavated pit faces or the spoils above the excavated faces, rather than from the natural rock slopes of the surrounding mountain. There is a very large talus slope above the Southwest Wall of the pit; however, the toe of this slope has sufficient set-back from the pit such that rock fall will not likely make it far enough to fall into the pit. Tension cracks in the spoil pile above the Southwest Wall were noted up to 4 m back from the crest; they were up to 5 m long, 50 mm wide, and 250 mm deep. The consequence of failure for this spoil pile is fairly low since there is nothing at risk below; however, the road is not suitable for heavy machinery or vehicles to drive on.

Similar to the Northwest Wall, there were no significant kinematic stability concerns noted in the Southwest Wall. Block sizes are typically on the order of 0.5 to 1 m and signs of frost shattering are present. The RMR for this wall is the same as for the northwest wall, with a rating of 77 which indicates good rock. The calculation is presented in Table 2.2.1-2.

There is iron staining on virtually all the exposed rock surfaces, likely due to the amount of water inflow which occurs through the waterfall and groundwater seepage.

2.2.3 Southeast Wall

The Southeast Wall of the pit has been affected by significant erosion and waste rock dumping, therefore much of the faces have been obscured by large amounts of talus material. In general it appears that there was a large upper face, and two smaller, lower faces; with the upper face being approximately 10 m high, and the lower faces both being 5 m high. Figure 5 shows an image of the Southeast Wall with approximate bench-face heights labelled. The rock structure consists of one persistent, sub-horizontal joint set and at least two sub-vertical joint sets accompanied by other random joints.

The bench between the upper and middle faces is approximately 10 to 12 m wide, although it is largely full of talus material. The rock fall berm that is present at this bench level around the rest of the pit continues under this face, however; there is a 10 m break under a large talus slope near the south corner of the pit which presents a heightened rock fall hazard. The berm under the southwest wall is also slightly smaller than it is around the rest of the pit, being only 2 to 3 m high. The bench between the lower two faces is 8 m wide towards the south corner of the pit, and narrows to approximately 3 m wide at the east corner. This bench has some rock fall debris, particularly under the large talus slope near the break in the berm, but it appears to be providing good catchment.

There are no signs of seepage or water inflow on this face, and no ponding on any of the benches. Rock fall sourced from the natural rock slopes above the face does not appear to be a significant hazard in the base of the pit; and although much of the southeast wall is covered by talus slopes, they were likely mostly formed while waste rock dumping above the face was occurring.

The rock mass conditions on the Southeast Wall are slightly poorer than in other areas of the pit, and show more signs of weathering and erosion. The RMR is slightly lower at 66, but this still falls into the category of Good Rock. The calculation for this value is shown in Table 2.2.3-1.

Iron staining is prevalent on most rock surfaces.

Table 2.2.3-1: RMR for SE wall of Open Pit

Parameter	Category	Description	Rating
A1	Strength of intact rock material	Multiple hammer blows to chip, R2, UCS of 100 - 250 MPa	12
A2	RQD	75 - 90%	17
A3	Spacing of discontinuities	200 - 600 mm	10
A4	Discontinuity length	3 - 10 m	2
	Joint separation	1 - 5 mm	1
	Joint roughness	Slightly rough	3
	Discontinuity infilling	None	6
	Joint weathering	Slightly weathered	5
A5	Groundwater	Damp	10
B	Rating adjustment for orientation	Strike parallel to slope axis, dip 45 - 90°	0
C	**Rock Mass Class**	**II, Good Rock**	**66**

2.3 Open Pit Assessment Summary

The structure of the pit walls is generally dominated by a sub-horizontal joint set and two sub-vertical joint sets. Bench face heights, bench widths, and catchment effectiveness vary considerably across the pit, but in general the lower two benches are the widest and have the best performing catchment. There is a rock fall berm placed on the edge of the second-lowest bench that varies in height from 2 to 4 m. This berm is sufficient to stop most rock fall emanating from the pit faces from reaching the base of the pit; even in the area near the south corner where the berm is discontinuous, the two benches are wide enough to keep the base of the pit generally safe.

Water primarily flows into the pit within the waterfall located in the west corner of the pit, and through groundwater seepage in the northwest and southwest faces. Localized ponding occurs on the second lowest bench around these faces, and there is some minor ponding near the middle of the pit at the base. Drainage is achieved completely through seepage into the ground. One drainage concern at the site is caused by the fines content of the waste rock dumps. It is likely that the higher than usual fines content is hindering drainage and contributing to local instabilities which are manifested through tension cracks above the Southwest Wall.

Rock fall from above the pit walls is most concerning near the Northwest Wall due to the gullies that channel it into the pit from the natural rock slopes above. The berm below the Northwest Wall is high enough, and the catchment is wide enough to prevent most rock fall from reaching the base of the pit. Generally, the base of the pit can be delineated as a rock fall 'safe zone', while access to the upper benches should be restricted as much as practicable. Conversations with the mine staff revealed that rock fall is significantly more active during, and just after periods of precipitation. Therefore it is recommended that access to the pit is controlled during and after rainfall or snowfall events. Figure 6 shows a summary plan of the pit, with hazard areas delineated. Since periodic access control will not be practical after abandonment, it is recommended to completely restrict public access to the open pit after closure; one potential method for doing so is highlighted in Section 2.5.

The rock mass conditions in the pit were good, yielding an RMR of 66 to 77. Some faces of the pit walls exhibited signs of frost shattering, and locally there may be areas with an RMR slightly less than those values. Most of the rock faces exhibited iron staining.

2.4 Future Use of Open Pit

One potential use for the open pit during the remediation process, and after closure, is as a large landfill for inert waste if the current landfill were to reach capacity. The pit is potentially an ideal location for a landfill due to its proximity to the mine site, and desirable drainage conditions. The base of the pit mostly consists of coarse, level blast rock which allows for rapid drainage of surface water that flows into the pit. The base of the landfill cell could be designed with high permeability layer beneath an impermeable lining that would allow surface water and groundwater to flow around the landfill whilst draining underneath, without coming into contact with the waste.

It is recommended that only the area of the open pit that is below the rock fall berm be used for a landfill due to the rock fall hazard. This area would have a capacity of approximately 32,000 m^3, based on the assumption that it could be filled to double the height of the lowest bench-face.

A conceptual design of the landfill 'cell' is presented in Figure 6. The cell would be underlain by coarse gravel / cobbles to promote drainage beneath the waste, which would be lined with a geotextile-geomembrane-geotextile liner that would form an impermeable barrier between the landfill materials and the surrounding environment. On top of the waste would be low-permeability capping soils, separated from the cell by the same three-layer liner at the base.

Notwithstanding the above desirable features of the potential use of the Open Pit as a landfill, there will be long-term access and maintenance issues that could impede inspections and groundwater monitoring following the closure. As discussed in Section 2.5 below, the Open Pit Access Road is crossed by six channels that are associated with high geohazard risk, which would require significant mitigation and/or yearly maintenance to allow for sampling and monitoring. Additionally, the haul road, in its current shape, is not suitable for vehicles to pass each other, which would result in low efficiency for hauling materials to the landfill, or would require significant upgrades. As a result of the above deficiencies, use of the Open Pit as a potential landfill has not been considered further.

2.5 Open Pit Access Road

The uppermost extent of the Open Pit Access Road is crossed by six channels/gullies which may present an avalanche or debris flow hazard. The channels each have high relief and a small drainage area, with Melton Ratios of 1.5 to 2. The Melton Ratio is the relief of a watershed divided by the square root of its area, and comparing it to the length of that watershed can be used as an indication of the hydrogeomorphic processes that affect it. Watersheds with Melton Ratios greater than 0.6 and a length of less than 2.7 km are typically considered to have a high debris flow potential (Wilford, et al., 2004). This can be verified in the field by looking for damage such as levees along the channel, diamicton (a very poorly sorted collection of different sediments), or damage to trees/trim lines. Some of these features were noted, but the channels should be further classified by a geomorphologist.

The creeks are relatively evenly spaced along the road, and are labelled 1 through 6, starting from the last switch-back going towards the pit, shown in Figure 1. A brief description of each channel is presented below.

Channel 1

This channel is located just beyond the hairpin bend and does not directly cross the road—a berm has built up between the road and the channel. The gully is 5 m wide at the base, 10 m wide at the top, and is 4.5 m deep. The drainage area is fairly large compared to the other channels, and consists of tall, natural rock slopes. Minor levees and some diamicton were observed, further indicating debris flow potential.

Channel 2

This is the most significant channel that crosses the road, and will likely have the most impact after abandonment. The channel continues below the road, into the base of the valley below. It is 15 m wide and 5 m deep, and has been incised by high flow events. Many large boulders line the channel, and debris from past flow events lines the road near the crossing. Minor levees and some diamicton were observed, further indicating debris flow potential.

Channel 3

This channel splits approximately 200 m above the road, and crosses in two closely-spaced locations. The drainage area is large and consists of natural rock slopes. Boulders have built up near the split above the road, and the channel is inclined at approximately 32°.

Channel 4

This channel splits above the road, similar to Channel 3. The creek is approximately 6 m wide and 1 m deep with an inclination of approximately 30°. There are angular rock fragments and talus debris in the channel above the road, and the channel does not visibly continue below the road.

Channel 5

This channel shows the most debris flow potential of these channels, due to the silty nature of material visible in the fan. The debris fan is 20 m wide at the road, and spreads below. Above the road, the channel is 4 m wide and 2 m deep with a gradient of 35°; it follows a slightly sinuous path.

Channel 6

This channel discharges over an 8 m high rock slope that is adjacent to the road. The creek is 2 to 3 m wide and 1 m deep, filled with angular boulders. Above the road the channel is inclined at 42°, while below it is 30° to 35°. There is very little debris visible on the road, indicating that this channel may be less active than the others.

After the mine is abandoned, encouraging these channels to wash-out the road may be a practical way to limit access to the open pit. Conversely, if it is desired to maintain access to the open pit, some permanent mitigation measures for the effects of debris flows should be considered. During remediation, and if the open pit were to be used as a supplementary landfill location, further geohazard mapping/characterization of these channels should take place.

3.0 UNDERGROUND PORTAL AND STABILITY ASSESSMENT

There are four main portals/adits which access the underground workings at the mine:

- The Pit Underground (PUG) Adit is located adjacent to the Open Pit near the end of the pit access road, and is at the highest elevation;
- The Vent Adit consists of a manway and a vent portal that intersect in a V-shape approximately 10 m from the surface at the 950 level of the mine;
- The Main Haulage is at the 3950 level of the mine, is the largest portal opening, and it is located near the beginning of the Open Pit Access Road; and
- The Conveyor Adit as located below the Main Haulage, near the mill buildings and is the smallest portal opening, in the poorest quality rock.

A decommissioned adit exists approximately 200 m from the PUG portal along the Open Pit Access Road, known as the Alimak Raise. This adit is visible from the road as a wood and metal structure, shown in Photo 14. The adit is inaccessible and completely backfilled, but the slope around this area should be further backfilled with inert aggregate to remove the surface expression.

Each portal, with the exception of the Alimak Adit, was assessed using a similar methodology, detailed below.

3.1 Methodology

The outside areas of the portals were assessed in a similar manner to the open pit. This assessment included:

- Rock structure and kinematic stability observations;
- Rock mass characterization using the RMR system;
- Rock fall assessments around the portal slopes, and noting any rock fall on the portal structures;

- Noting the approximate dimensions of the area including slope heights, opening sizes, and bearing of the excavations; and
- Noting any construction work that should take place (machine scaling, structure removal, rock bolting, etc.).

Inside the portals, the first 30-40 m were observed and assessments included:

- Noting support types and performance along with rock deterioration or stress relief;
- Rock mass characterization using the RMR and NGI-Q systems, and comparing the results;
- Noting any major water inflows or ponding; and
- Describing any unusual rock structures or weakness zones.

The use of the RMR system is described in Section 2.1. The NGI-Q system is a quantitative rock mass classification system developed in Norway for use in hard rock tunneling (Norwegian Geotechnical Institute, 2015). The Q rating is defined as:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

Where:

RQD is the Rock Quality Designation (%)

J_n is the Joint Set Number (multiplied by 2 for portals)

J_r is the Joint Roughness Number

J_a is the Joint Alteration Rating

J_w is the Joint Water Rating

SRF is the Stress Reduction Factor

Each of the above parameters has a numerical value assigned to a qualitative rock mass condition. The Q-rating (obtained using the above formula) is then applied to a Rock Support Chart where it is compared with the span or height (whichever is greater) of the opening to recommend support classes.

3.2 Assessment Details

The locations of each of the portals is shown on Figure 1. Photos 15 and 16 refer to the PUG Adit, Photos 17 to 20 refer to the Vent Adit and manway, Photos 21 to 24 refer to the Main Haulage, and Photos 25 to 28 refer to the Conveyor Adit.

3.2.1 PUG Adit

The rock structure on the slope outside of the PUG Adit consists of two joint sets, plus other random jointing. The two main joint sets consist of one sub-horizontal, bedding parallel set, and one sub-vertical set that is parallel with the rock face. There is some potential for kinematic wedges to form, and many of the potentially unstable blocks have been supported with rock bolts and straps. The intact rock consists of very strong (100 - 250 MPa), grey and iron stained, fresh to slightly weathered, fine grained limestone. The RMR was found to be 72 outside the portal, and 62 inside the portal, indicating Good Rock; the calculation is shown in Table 3.2.1-1 below.

Rock fall from the slope above and around the portal is a concern here as there is an avalanche/debris channel that discharges directly above the portal entrance. The slope above the portal is approximately 20 m high and there is a large metal canopy structure that protects the opening. This appears to be performing adequately, with minor dents on the roof and some cobble-sized rock fragments present; however, in order to seal the portal it is recommended that this structure should be removed. To protect workers during the closure activities, an allowance for scaling of the face should be included in closure plans. The portal opening is 6.2 m wide and approximately 6 m high in a rough horseshoe shape. It enters the mountain at a bearing of approximately 270° and curves towards the southwest after approximately 20 m.

Inside the portal the crown is supported by pattern bolting with a spacing of approximately 1.5 m for the first 8 m of the tunnel, and intensifying to a spacing of approximately 1 m from a distance of 8 m, onwards. The sidewalls are largely unsupported. The Q-rating inside the portal is 4, indicating fair rock. This is a lower quality classification than what was given by the RMR and this is likely due to the Q-system's decreased rating for near-surface conditions at portals. The support recommended for this excavation is systematic bolting with 50-60 mm of shotcrete. The support appears to be performing adequately as-is and therefore we do not recommend additional measures be taken. The calculation of the Q-rating is shown in Table 3.2.1-2, below.

Table 3.2.1-1: RMR for PUG Adit

Category	Description (Outside)	Rating (Outside)	Description (Inside)	Rating (Inside)
Strength of intact rock material	Multiple hammer blows to chip, R2, UCS of 100 - 250 MPa	12	Multiple hammer blows to chip, R2, UCS of 100 - 250 MPa	12
RQD	75 - 90%	17	75 - 90%	17
Spacing of discontinuities	0.6 - 1 m	15	200 - 600 mm	10
Discontinuity length	3 - 10 m	2	3 - 10 m	2
Joint separation	0.1 - 1 mm	4	0.1 - 1 mm	4
Joint roughness	Smooth	1	Smooth	1
Discontinuity infilling	None	6	None	6
Joint weathering	Slightly weathered	5	Slightly weathered	5
Groundwater	Dry	15	Damp	10
Rating adjustment for orientation	Strike perpendicular to axis, drive with dip, dip 45 - 90°	-5	Strike perpendicular to axis, drive with dip, dip 45 - 90°	-5
Rock Mass Class	**II, Good Rock**	**72**	**II, Good Rock**	**62**

Table 3.2.1-2: Q-Rating for PUG Adit

Parameter	Description	Rating
RQD	Approximately 80%	80
J_n	Two joint sets, plus random joints, x2 for portal	12
J_r	Rough, irregular, planar	1.5
J_a	Unaltered joint walls, surface staining only	1
J_w	Dry or minor inflow	1
SRF	Low stress, near surface conditions	2.5
Q	**Fair Rock Mass Quality**	**4**

No unusual rock mass structures or weakness zones were encountered, and localized iron staining is present. There was some water ponding and multiple locations where water was dripping from joints or from rock bolts, but this is not a considered to be a major concern. A large ice plug was encountered 21 m into the tunnel which hindered passage any further. It is recommended that closure activities should encourage the formation of a year-round ice plug in order to seal the entrance.

3.2.2 Vent Adit

The structure of the rock mass around the Vent Adit consists of one joint set that dips steeply towards the east, and one bedding-parallel joint set that dips 10° to the north, as well as other random jointing. There is some potential for planar kinematic instabilities, although the potentially problematic blocks have been supported by rock bolts and metal straps. The intact rock consists of very strong (100 - 250 MPa), grey, fresh to slightly weathered, fine grained limestone. The RMR was found to be 63 outside the portal, indicating good rock, and 58 inside the portal, indicating fair rock. The calculation is shown in Table 3.2.2-1, below.

Table 3.2.2-1: RMR for Vent Adit

Category	Description (Outside)	Rating (Outside)	Description (Inside)	Rating (Inside)
Strength of intact rock material	Multiple hammer blows to chip, R2, UCS of 100 - 250 MPa	12	Multiple hammer blows to chip, R2, UCS of 100 - 250 MPa	12
RQD	50 - 75%	13	50 - 75%	13
Spacing of discontinuities	200 - 600 mm	10	200 - 600 mm	10
Discontinuity length	3 - 10 m	2	3 - 10 m	2
Joint separation	0.1 - 1 mm	4	0.1 - 1 mm	4
Joint roughness	Smooth	1	Smooth	1
Discontinuity infilling	None	6	None	6
Joint weathering	Slightly weathered	5	Slightly weathered	5
Groundwater	Dry	15	Damp	10
Rating adjustment for orientation	Dip 0 - 20° irrespective of strike	-5	Dip 0 - 20° irrespective of strike	-5
Rock Mass Class	**II, Good Rock**	**63**	**III, Fair Rock**	**58**

The slope above both the manway and vent portals is approximately 7 m high. There is a large concrete structure that provides rock mass support constructed around the manway entrance. The structure is 3.6 m wide, 2.8 m high, and extends 1.6 - 2.9 m deep. There is a set of metal doors forming a vent seal, located 4.2 m from the edge of the concrete structure that leads to the underground portion of the mine. The vent portal consists of the concrete vent building which is sealed against the rock mass with shotcrete; the seal appears to be in good condition. There are no immediate rock fall concerns near the manway entrance, although small cobble-sized rock fall from the overburden above the portal slope is possible. The vent portal structure had approximately 10 cobble-sized pieces of rock on the roof that had fallen from the slope above.

Between the concrete structure and the steel doors of the manway there is extensive pattern bolting in the crown of the excavation, with 0.5 - 1 m spacing. The sidewalls in this area are supported by two rows of rock bolts with 1 m spacing. Inside the steel doors there is some spot bolting, but the excavation is largely unsupported. Two stability concerns were noted: A large wedge has formed approximately 10 m from the vent portal structure which is exhibiting through-rock failure; and there is some stress release of the pillar at the intersection between the manway and vent portal. Neither of these issues present major stability concerns, as long as both entrances to this adit are permanently sealed.

The Q-rating inside the Vent Adit is 3.25, indicating poor rock. This is a lower quality designation than the RMR because of the lower ratings for near-surface conditions used by the Q-system. The support recommendations for this rating and excavation size is unsupported or spot bolting, which matches the conditions encountered. The calculation of the Q-rating is shown in Table 3.2.2-2, below.

There was some localized iron staining, but significantly less than what has been observed in other areas of the mine. There was no ponding water and only minor, localized drips or inflows from the crown.

Table 3.2.2-2: Q-Rating for Vent Adit

Parameter	Description	Rating
RQD	Approximately 65%	65
J_n	Two joint sets, plus random joints, x2 for portal	12
J_r	Rough, irregular, planar	1.5
J_a	Unaltered joint walls, surface staining only	1
J_w	Dry or minor inflow	1
SRF	Low stress, near surface conditions	2.5
Q	**Poor Rock Mass Quality**	**3.25**

3.2.3 Main Haulage

The Main Haulage portal is constructed into a 6 m high, near-vertical rock face with a large reinforced concrete structure that extends up to the crest of the slope. The structure of the slope consists of one sub-horizontal, bedding-parallel joint set, and one sub-vertical joint set, along with other random jointing. The slope on the north side of the portal has smaller block sizes than the slope on the south side and poses more of a risk for rock fall. A 4 m setback distance for personnel or vehicles from this slope is recommended unless some scaling or support work is completed. The portal structure provides significant protection from rock fall directly over the portal entrance, and its dimensions at the opening are 5.1 m wide, 4.3 m high, and 3 m deep.

The RMR for the slope surrounding the portal is 64 indicating good rock, while the RMR inside the portal is 57, indicating fair rock. The calculation is shown in Table 3.2.3-1, below.

Table 3.2.3-1: RMR for Main Haulage

Category	Description (Outside)	Rating (Outside)	Description (Inside)	Rating (Inside)
Strength of intact rock material	Multiple hammer blows to chip, R2, UCS of 100 - 250 MPa	12	Multiple hammer blows to chip, R2, UCS of 100 - 250 MPa	12
RQD	75 - 90%	17	75 - 90%	17
Spacing of discontinuities	200 - 600 mm	10	200 - 600 mm	10
Discontinuity length	3 - 10 m	2	3 - 10 m	2
Joint separation	1 - 5 mm	1	0.1 - 1 mm	4
Joint roughness	Smooth	1	Smooth	1
Discontinuity infilling	None	6	None	6
Joint weathering	Slightly weathered	5	Slightly weathered	5
Groundwater	Dry	15	Damp	10
Rating adjustment for orientation	Dip 0 - 20° irrespective of strike	-5	Strike perpendicular to tunnel axis, drive against dip, dip 20 - 45°	-10
Rock Mass Class	**II, Good Rock**	**64**	**III, Fair Rock**	**57**

The support in the crown of the tunnel includes split sets, rock bolts, metal strapping, and single-twist, galvanized chain link mesh. Rows of strapping alternate between being held in place by rock bolts and split sets, with the spacing between them at approximately 1 m. The mesh has bagged in some locations where minor rock fall has occurred, however; the overall performance of the support has not been compromised. The sidewalls are unsupported, and this has not caused any rock fall concerns.

The Q-value obtained is 2.67 which indicates poor rock, and the recommended support class based on the span of the excavation is unsupported or spot bolting, which is similar to the support in use. The lower rock quality indicated by the Q-system compared to the RMR is due to the near-surface conditions factor used by the Q-system. The calculation for the Q-value is shown in Table 3.2.3-2, below.

Table 3.2.3-2: Q-Rating for Main Haulage

Parameter	Description	Rating
RQD	Approximately 80%	80
J_n	Three joint sets, x2 for portal	18
J_r	Rough, irregular, planar	1.5
J_a	Unaltered joint walls, surface staining only	1
J_w	Dry or minor inflow	1
SRF	Low stress, near surface conditions	2.5
Q	**Poor Rock Mass Quality**	**2.67**

There was some iron staining present on the rock mass, and localized water pooling throughout the portal. More water inflow was present in the main haulage than in the Pit and Vent Adits, and in one location water was jetting out of a discontinuity. There was a large ice plug encountered in one of the offshoots from the main passageway approximately 100 m from the portal, and it is known that sealing the entrance doors without insulation can encourage an ice plug to form in the Main Haulage.

3.2.4 Conveyor Adit

The poorest rock conditions at the site were observed in the Conveyor Adit. At the surface, the portal consists of a concrete structure at the base of a slope that is mostly made up of talus and colluvium materials, including some boulders. The entrance is a small wooden door that is 1 m wide and 1.5 m tall, while the adit excavation dimensions are approximately 3 m wide and 2.5 m high. There is minor rock fall risk due to loose rocks on the slope above the portal, and no major stability issues are visible. An RMR assessment for the outside area could not be obtained because the rock mass is not visible.

During the 2017 inspection, the first 65 m of the conveyor adit were inspected. In 2018, the entire 566 m length of the tunnel was inspected and options for remediation were further developed. The observations and recommendations pertaining to the conveyor adit, as set out below, have been refined and superseded following the 2018 site inspection. The refined observations and recommendations are presented in the “2018 Conveyor Adit Inspection Report and Recommendations” found in Appendix B.

Inside the portal there is extensive timber and steel support. The crown is supported by up to 5 layers of timber 2x4’s arranged in a lattice pattern, supported by frame sets made of either 8 inch square timbers, or steel I-beams with a 3 inch flange. Where the frame sets are made from steel I-beams, the crown support lattices are seated within the flange of the I-beam. The wood and steel sets are spaced at 1.8 m intervals, and extend approximately 65 m into the portal. There are concerning signs of fatigue in the supports including cracking and sagging of some 2x4’s, sagging of the 8 inch roof cross-braces, buckling in some steel sets, and many cases where the 2x4’s are not seated properly in the webbing of the steel cross-beams. Where the crown support is not seated properly in the webbing of the steel cross-beams, there is often less than 10 mm of contact between the 2x4’s and the steel. This is a significant hazard, and the support system should be remediated before any workers enter the adit, or other closure work occurs within the adit.

In 2017, the RMR inside the portal was assessed to be 39, indicating poor rock mass conditions, and the Q-value was assessed as 0.83, indicating very poor rock mass. The calculations for each are shown in Tables 3.2.4-1 and 3.2.4-2 below.

Table 3.2.4-1: 2017 RMR for Conveyor Adit

Category	Description	Rating
Strength of intact rock material	Multiple hammer blows to chip, R2, UCS of 100 - 250 MPa	12
RQD	25 - 50%	8
Spacing of discontinuities	200 - 600 mm	10
Discontinuity length	3 - 10 m	2
Joint separation	1 - 5 mm	1
Joint roughness	Slightly rough	3
Discontinuity infilling	Soft clay infilling > 5 mm	0
Joint weathering	Moderately weathered	3
Groundwater	Damp	10
Rating adjustment for orientation	Strike perpendicular to tunnel axis, drive against dip, dip 20 - 45°	-10
Rock Mass Class	**IV, Poor Rock**	**39**

Table 3.2.4-2: 2017 Q-Rating for Conveyor Adit

Parameter	Description	Rating
RQD	Approximately 50%	50
J_n	Two joint sets plus random jointing, x2 for portal	12
J_r	Rough, irregular, planar	1.5
J_a	Silty, soft infilling	3
J_w	Dry or minor inflow	1
SRF	Low stress, near surface conditions	2.5
Q	**Very Poor Rock Mass Quality**	**0.83**

Most of the rock surfaces are iron stained, and there is significant water ponding throughout the adit. The water ponding has iron stained residue. Due to the exceptionally poor conditions encountered it is recommended that access be restricted during the mine closure and remediation works unless the tunnel support is remediated.

3.3 Subsidence Issues

Subsidence can occur at abandoned mine sites when a lack of care and maintenance leads to underground chambers collapsing which propagates to the surface. This is more prevalent in shallow mines, or in room and pillar mining where the overburden is softer than the ore that was removed.

Tetra Tech did not observe farther than approximately 100 m into any of the portals, with the exception of the Main Haulage where we were escorted to the workshop which is approximately 700 m from the portal. The workshop is a large excavation with very good quality rock, where Q-values greater than 40 were observed. We understand that such good quality rock also exists and was mined within the stopes. It is also known that a substantial portion of the stopes were backfilled while mining operations were continuing. Because of the good quality rock observed, and the backfilling operations that were completed, we believe that there is a low risk of collapse leading to surface subsidence at the mine.

Some of the stopes are large excavations, stacked on top of one another, which could lead to single or multiple sill pillar collapse. Notwithstanding this potential, given the backfilling operations and good quality rock observed, large scale subsidence is not considered to be a concern, based on the available information. It is also recognized that if large scale collapse or subsidence were to occur, the terrain above the mine is mountainous and does not have any critical infrastructure upon it that would be affected. Therefore, subsidence due to underground excavation collapse is not considered to be an issue for the majority of the underground workings.

The poor rock and support conditions in the Conveyor Adit are causes for concern with regards to eventual collapse and surface subsidence. In order to completely seal the adit, and to support the surface immediately around it, we recommend remediating the support within the adit and permanently sealing it. If the closure plan requires workers to enter the adit, support remediation should consist of installing a rock bolt pattern, and using fiber-reinforced shotcrete. If workers will not be entering the adit, preventing subsidence can be achieved by pumping a sand/bentonite slurry throughout, either from the current opening or via boreholes drilled from the surface. A further discussion of remediation options is presented in Section 4.

3.4 Underground Asbestos Storage

It is proposed that the main workshop, located approximately 700 m from the Main Haulage portal, could be a suitable location for long term asbestos storage / disposal. The workshop provides a large void space in excellent quality rock that is easily accessible during closure, and up to 13,500 m^3 of waste could be stored there.

The workshop consists of two large, parallel chambers that are connected by two slightly smaller, parallel chambers (one of which connects to the Main Haulage). The rock mass observed was of very good quality. The area is supported with significant pattern bolting and metal strapping, and the support was observed to be in good condition, showing little to no signs of fatigue or significant corrosion. No water inflow was noted within the workshop, and it could be sealed with a simple concrete plug at final closure.

The workshop was revisited during the 2018 conveyor adit inspection during which, NGI-Q ratings were undertaken, as well as an assessment of pillar stability. The findings are presented in in Appendix B.

4.0 REMEDIATION OPTIONS

Two potential remediation strategies for permanent closure of the underground portals are under consideration:

- Option 1 – Maintaining the current mine water conveyance where water flows through the Conveyor Adit, and any minor flow that normally drains through the Main Haulage is diverted to the Conveyor Adit.
- Option 2 – Developing a revised mine water conveyance such that all underground drainage flows through the Main Haulage at the 3950 level of the mine.

Conceptual designs for these two options at each of the portals are presented below. Items that are similar between the two options are the designs for dry plugs at the PUG and Ventilation Adits, as well as the slope support designs for each of the portals. Figures 7 to 10 show conceptual design drawings of the remediation options. Note that it is expected that the remediation option designs/the options themselves will evolve as they are studied further.

4.1 Option 1 – Maintain Existing Mine Water Conveyance

Currently, mine water flows out through the Main Haulage and Conveyor Adit portals. More significant flow passes through the Conveyor Adit, and there is a sump pump system to drain water at this portal. To maintain the existing flow through the Conveyor Adit, the support should be remediated such that future collapse is less likely, and a plug similar to the one described in Section 4.2.2 should be constructed. This type of plug allows for passive drainage of the mine and eliminates the need for long-term maintenance of the current pump system. The Main Haulage should then be sealed with a backfill plug, and a concrete pony wall should be constructed that would divert water to the Conveyor Adit.

Due to the poor rock mass conditions, and the critical nature of the drainage through the Conveyor Adit, the backfill plug would have to extend virtually through its entire length (or at least to a point where collapse would be unlikely in the next 50 to 100 years). The dry plugs for the PUG and Vent Adits, as well as the slope backfill designs should be similar to those of the remediation option described in Section 4.2.

The conceptual design elements of this remediation option are described in the following sections.

4.1.1 Remediate Conveyor Adit Support

During mine closure and remediation, to allow for safe work in the Conveyor Adit the existing support system should be carefully removed (in stages) and replaced with one that meets modern design standards. The current support consists of a timber lattice system along the crown, with a mixture of steel and timber sets. Both the timbers and steel are showing signs of fatigue, and long-term integrity is a major concern. If the adit collapses after closure it could block the majority of drainage from the mine leading to consequences such as a dramatic increase in pore pressures which would potentially destabilize slopes around the Conveyor Adit. Additionally, if the mine water is contaminated or acid-generating, a collapse could lead to significant ground water pollution without a feasible method to stop the flow.

The NGI Q-system provides tunnel support recommendations based on the span of the excavation, the excavation support ratio (ESR), and the Q-rating. The Q-rating system is described in section 3.1, and the calculation of the Q-value for the Conveyor Adit is shown in Table 3.2.4-2. The ESR is a correction factor for the tunnel span based on its intended use. The Conveyor Adit was given an ESR of 1.0, which is used for portals (Norwegian Geotechnical Institute, 2015). Using the Rock Mass Quality and Rock Support Chart (Figure 4.1.1-1 below) with the excavation dimension yields a recommendation for support class 3; however, due to the rock conditions and current support fatigue observed, support class 4 is recommended. This consists of 6 - 9 cm of fiber-reinforced sprayed concrete on the crown, walls, and invert, and pattern rock bolting, using 1.5 m long, 20 mm diameter bolts, at a spacing of 1.0 - 1.5 m. Detail D of Figure 10 shows a conceptual design of this support system.

Based on our observations, the current support system extends 65 m into the Adit, therefore it is recommended that it should be replaced with the above-described support for at least that distance. We did not observe any farther than 65 m, and it is considered very likely that enhanced support will be required beyond this point. We recommend installing this support system throughout the Conveyor Adit unless a Q-value greater than 10 is reached. At the point where consistently good rock is encountered, the entrance to the pipes, and the end of the backfill plug can be placed. This concept if further described in Section 4.1.2, below.

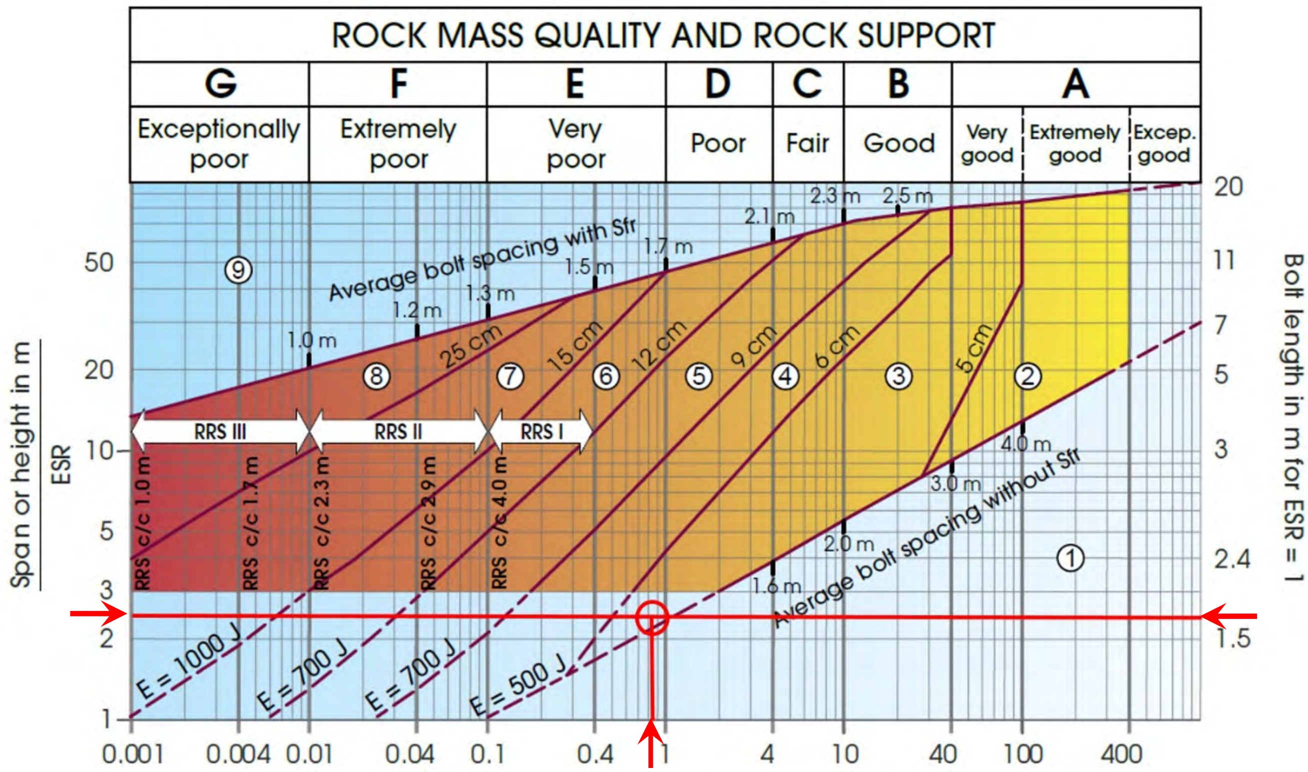

Figure 4.1.1-1: Q-system Rock Mass Quality and Rock Support Chart

4.1.2 Plug Conveyor Adit to Allow Drainage and Prevent Ingress

The Conveyor Adit plug should follow a similar design concept to the Main Haulage plug described in Section 4.2.2, in that pipes or culverts should be installed at the base of a backfill plug to drain water through to the surface. Currently, most of the water that flows through the mine is drained by pumps from the Conveyor Adit, therefore the pipes / culvert dimensions would have to be designed to passively maintain the same flow rate. The adit is a critical drainage path that should not be blocked; therefore preventing a collapse is a major design element.

The support system described in Section 4.1.1 cannot be guaranteed to prevent a collapse after 30 to 40 years without maintenance, and the best way to protect the mine water conveyance system is to backfill the entire length of the adit that is exposed to poor rock mass conditions. This means that at least 65 m of the tunnel will require backfill, although the entire backfill length could exceed 550 m if poor rock mass conditions persist from the portal to the raise that connects the adit to the Main Haulage. Three construction methods are proposed to backfill the tunnel, the first major step in each would be to place the pipes / culvert to convey water through the plug:

- Option 1: Build a series of check dams evenly spaced through the adit and pipe a sand and bentonite slurry material from the portal, retracting the pipe in stages as the adit fills.
- Option 2: Drill large-diameter boreholes from the surface into the adit at regular intervals and backfill with a sand slurry. The boreholes would be up to 175 m deep; however, most would be less than 70 m.
- Option 3: Pour a concrete pad around and over the pipes / culvert that allows small machinery to drive into the tunnel to place backfill material.

The total backfill volume would be up to 3500 m^3 if the entire length of the tunnel is filled. A conceptual design of the plug and water conveyance system is presented in Figure 9.

4.1.3 Plug Main Haulage to Divert Water and Prevent Ingress

This plug would follow a similar design to the one described in Section 4.2.2, without the pipe / culvert system at the base. Instead, a concrete wall 3 m in height should be constructed behind the backfill plug, which would prevent any water from flowing through the portal, diverting it to the Conveyor Adit. The shaft between the Main Haulage and the Conveyor adit is located at an elevation 2 m above the Main Haulage portal, therefore a 3 m high wall will carry a FS of 1.5 in terms of overtopping. A drawing of the conceptual design of the plug is shown in Figure 7.

4.1.4 Dry Plugs for PUG and Ventilation Adits

The dry plugs for the PUG and Ventilation Adits would follow the same design as those described in Section 4.2.4, with the conceptual design for both adits shown in Figure 8.

4.1.5 Backfill and Stabilize Slopes around the Portals

The slope backfill and stabilization designs should follow those described in Sections 4.2.3 and 4.2.5. The conceptual designs are shown in Figures 7 to 9.

4.2 Option 2 – Revised Mine Water Conveyance

The revised mine water conveyance remediation option would consist of sealing the Conveyor Adit with a bulkhead, thereby diverting the majority of water flowing out of the underground workings to the Main Haulage, where a plug that is designed to allow drainage, but prevent ingress, would be constructed. At each of the other portals, dry plugs that have the primary function of preventing access to the mine would be constructed. Additionally, a dry plug at the Conveyor Adit would be constructed that would prevent ingress to the section of the adit between the surface and the bulkhead.

The conceptual designs for each component of this option are discussed below, and drawings are appended in the Figures section.

4.2.1 Plug/Seal Conveyor Adit to Divert Water to Main Haulage

Currently, a large portion of the mine water drainage flows through the Conveyor Adit, and plugging this adit would likely fill it, diverting the flow to the Main Haulage. The Main Haulage is approximately 40 m in elevation above the Conveyor Adit, therefore the bulkhead must be designed to withstand this hydraulic pressure head. Section 4.2.1.1 describes where the bulkhead should be located within the adit, and Section 4.2.1.2 presents a preliminary design for the bulkhead, which should be reviewed by a qualified structural engineer.

4.2.1.1 Bulkhead Location

Because the Conveyor Adit is unlined, it is recommended that the bulkhead location be determined by considering the Norwegian Criteria for unlined hydropower tunnels and shafts, along with an appropriate factor of safety (FS). The Norwegian Criteria is an accepted 'rule of thumb' for determining the extent of unlined pressure tunnels in good, competent rock. The Criteria is based on maintaining suitable overburden thickness above the tunnel to resist the water pressure within the tunnel, preventing hydro-fracturing and potential leakage; its definition is as follows (Broch, 2014):

$$L > \frac{\gamma_w H}{\gamma_r \cos\beta}$$

Where:

- L is the recommended overburden thickness (shortest distance between the surface and the point studied)
- γ_w is the unit weight of water (taken to be 9.81 kN/m^3)
- H is the hydraulic head at the point studied (in this case approx. 40 m throughout the length of the adit)
- γ_r is the unit weight of the rock mass
- β is the slope of the average ground surface above the tunnel

The Norwegian Criteria is an empirical system, based on observations of failure or leakages in tunnels through massive, competent rock in Norway; therefore it is not directly applicable to all unlined tunnels. At the Cantung Mine, it is recommended that this Criteria be used with a FS of 1.5, and that the unit weight of the rock be considered as the buoyant unit weight. The final, major unknown with regards to the bulkhead design and use of the Norwegian Criteria is the appropriate ground surface profile to use. Ideally, an average bedrock profile would be used, but there is limited information in that regard.

Using a conservative estimate for the adjusted average ground surface yields a bulkhead location that is at least 182 m into the adit from the portal. Using the actual ground surface profile gives a bulkhead location that is 100 m from the portal. During Tetra Tech's inspection, we did not observe farther than 65 m into the adit, therefore the exact location for the bulkhead should only be determined after an inspection of the rock mass conditions at least between 100 m and 182 m into the adit. Figure 9 shows a cross-section of the ground surface above the Conveyor Adit, along with the proposed bulkhead location options.

Construction of the bulkhead would require the transportation of materials, equipment, and workers to its location from either the Conveyor Adit portal, or from the Main Haulage. Access through the Conveyor Adit portal could require a considerably shorter travel distance; however, the tunnel would need to be rehabilitated to at least this point because the current support system is inadequate and in disrepair (see Section 4.1.1 for the conceptual rehabilitation design of the Conveyor Adit). The tunnel conditions beyond 65 m from the Conveyor Adit portal are unknown, as are the access conditions between the Main Haulage and the Conveyor Adit. A more in-depth inspection should be completed prior to the detailed design stage.

Should it be practicable to construct a bulkhead near the raise that connects the Conveyor Adit to the Main Haulage, remediation of the support in the Conveyor Adit may not be necessary, or could be reduced in scale. If rock conditions permit, this would be the preferred option.

4.2.1.2 Preliminary Bulkhead Design

Three generally accepted methods for calculating the appropriate bulkhead length exist, and the chosen value should be the maximum of the three:

- Using a length to height ratio of 1.5 (1);
- Considering the hydraulic gradient of the rock mass to determine a length that prevents seepage around the plug (2); and
- Designing a length with appropriate shear resistance to withstand the water pressure on the upstream face (3).

Calculations for determining the length of the bulkhead are performed using the following formulas:

$$L = 1.5 \cdot h \ (1) \qquad L = \frac{H_w}{I} \ (2) \qquad L = \frac{FS \cdot \gamma_w \cdot H_w \cdot A}{c \cdot P_u} \ (3)$$

Where:

L is the length of the bulkhead

h is the height of the tunnel

H_w is the water head at the upstream face

I is the hydraulic gradient in the rock mass, estimated using Table 7 in Benson (1989)

FS is the factor of safety, commonly 1.5

γ_w is the unit weight of water, 9.81 kN/m^3

A is the cross-section area of the tunnel

c is the allowable shear stress at the concrete-rock interface, estimated using Table 7 in Benson (1989)

P_u is the perimeter length of the plug at the concrete-rock interface

Using Table 7 in Benson (1989) and the values for a 'moderate to weak, moderately jointed' rock mass and the maximum of Equations 1 to 3, the recommended minimum bulkhead length is 5 m, given using the seepage method. Since this is a permanent installation with no intended future maintenance, it is recommended that additional shear resistance should be added to the bulkhead by installing 2 m long rock bolts that protrude 1 m from the face at a spacing of 1.5 m. Additionally, a grout curtain should be installed on the upstream side of the bulkhead. The conceptual design for this bulkhead is shown in Figure 10. These conceptual designs should be reviewed by a qualified structural engineer before finalization.

4.2.2 Main Haulage Plug to Drain Mine Water and Prevent Ingress

The conceptual design for the Main Haulage plug consists of using inert aggregate material, potentially sourced from the waste rock dumps, to backfill the portal and slopes around the portal, with a number of small pipes / culverts at the base of the plug to convey mine water. A concrete pad should be constructed at the base of the plug to provide a level surface for the drainage pipes, as well as an impermeable surface below them to prevent seepage around the plug.

The size and number of drainage pipes / culverts should be determined based on the expected flow through the Main Haulage, which includes all mine water conveyance. The use of High Density Polyethylene (HDPE) pipes is recommended, however hot-dip galvanized steel culverts could also be used.

The plug should completely fill the portal (invert to crown) for a distance of at least 5 m, and will be sloped at the natural angle of repose for the material beyond that that distance. Assuming a 30° angle of repose, the plug would extend a total of approximately 15.5 m into the portal. The approximate total volume of material required for the plug is 360 m^3.

A drawing of the conceptual design is presented in Figure 7.

4.2.3 Backfill and Stabilize Slopes around Main Haulage

To remove any surface expression of the portal, and to stabilize the surrounding rock slopes, backfill material should be dumped to the natural height of the surrounding rock slopes. At a 30° angle of repose this will extend to approximately 15.5 m from the existing portal opening, meaning that the concrete pad and mine water conveyance pipes / culverts will need to be at least 31 m in length. To maintain the natural look of the slope, it is recommended that the backfill material be re-vegetated. The approximate total volume of the backfill material is 1800 m^3. The conceptual design for the slope backfilling is included in Figure 7.

4.2.4 Dry Plugs for the PUG, Ventilation, and Conveyor Adits

The dry plugs for the PUG, Ventilation, and Conveyor Adits should have a similar design to that of the Main Haulage plug, without the water conveyance system at the base. The plugs should consist of inert backfill material that completely fills the portal for a distance of at least 5 m, and be allowed to fall at the natural angle of repose beyond that.

In the PUG Adit, it is known that an ice plug naturally forms approximately 20 m from the entrance, and it is expected that this may encroach on the backfill plug over time, which would act to further seal the portal. In order to construct the backfill plug here, the metal canopy structure at the portal would need to be removed. Approximately 400 m^3 of backfill material will be required here. A conceptual drawing for this remediation design is presented in Figure 8.

The plug at the Vent Adit should extend farther into the underground than the other portals due to the observed kinematic instability and stress-related pillar failure described in Section 3.2.2. Some additional support installation, such as spot bolting, should be installed to make the area safe for work; the conceptual design for this is shown in Figure 8. It is recommended that the plug extend past the intersection between the manway and the vent portal, then be allowed to fall at the material's natural angle of repose. In order to get material into the intersection area, the air-lock door should be removed. Approximately 685 m^3 of backfill will be required here, and a conceptual design drawing is presented in Figure 8.

The dry plug at the Conveyor Adit would have an approximate volume of 50 m^3 and a conceptual design drawing is presented in Detail C of Figure 9.

4.2.5 Backfill and Stabilize Slopes around PUG, Ventilation and Conveyor Adits

The slope backfill for each of the PUG, Ventilation, and Conveyor Adits should consist of the same inert waste rock material for all of the dry plugs. The slopes around the portals of the Ventilation and Conveyor Adits are low enough such that the entire area can be practically backfilled, revegetated, and shaped to match the existing terrain. The rock slope at the PUG Adit portal is too high to be practically backfilled, therefore other slope stabilization methods should be used.

At the PUG Adit portal, prior to commencing work beneath the slope and inside the portal, scaling and rock bolting should take place. It is estimated that 50 hours of scaling, and an allowance for at least 12 m of rock bolts should be completed. After the slope stabilization and dry plug have been completed, the slope should be backfilled from 2 m above the top of the portal, extending out from the rock face at the natural angle of repose, as shown in Figure 8. In order to maintain the natural look of the rock face, large boulders could be placed over the fill material. The total estimated amount of backfill material at the PUG portal is 700 m^3.

The vent building, and concrete structure around the Vent Adit portal should be removed, and the rock slope can be backfilled with inert aggregate material. To maintain the natural look of the slope, the backfill should extend around the face from the manway to the vent portal, as shown in Figure 8. Approximately 400 m^3 of backfill material would be required here.

Some small concrete structures on the slope above the Conveyor Adit should be removed before backfill material is placed. The backfill material will easily match the natural slope, as there is mostly colluvium material in this area. Approximately 140 m^3 would be required here.

5.0 CONCLUSION

Tetra Tech's 2017 inspection of the Cantung Mine site included a visual inspection of the Open Pit from both the ground and middle bench levels, as well as inspections of the first 50 to 100 m into each of the underground portals. The inspections were completed with the goals of determining if there will be any major long-term stability concerns after the mine's closure, and to provide preliminary recommendations for conceptual remediation options.

The rock mass in the Open Pit does not show signs of major global stability concerns or large kinematic failures. Small-scale failures and rock fall from the surrounding mountains are common and there is a significant amount of talus material that fills most of the benches. A rock fall berm exists on the second lowest bench around the majority of the pit that provides good rock fall catchment. This means that the base of the pit can generally be considered a rock fall safe-zone; however, access to the pit should still be controlled during times of heavy precipitation. Drainage from the surrounding valleys flows into the pit via a small waterfall and through seepage in some of the bench faces. This water flows out of the pit through seepage in the base. These drainage conditions, and proximity to the mine site make the Open Pit a suitable location for a supplementary landfill if the current landfill reaches capacity; however, the access road conditions are poor, and would require significant maintenance/upgrades to make it suitable for hauling waste, as a consequence converting the open pit to a landfill has not been considered further. Once closure and remediation of the mine is complete, the access road to the pit can be decommissioned by removing culverts and encouraging the debris/drainage channels that cross it, to flow through.

The underground portals generally exhibit good rock mass conditions and ground support that is performing adequately, with the exception of the Conveyor Adit. At the PUG Adit, remediation should consist of slope stabilization through scaling and rock bolting above the portal, and construction of a dry plug at the portal entrance. The plug can be constructed using an inert aggregate backfill material, and this will likely encourage the formation of a year-round ice plug within the adit. Remediation of the Vent Adit should consist of removing the vent building and portal structures, as well as a dry plug similar to the PUG Adit. The slopes are low enough that backfilling them with the same inert aggregate material is feasible, and they could be shaped to visually match the surrounding terrain. A permanent mine water conveyance system and plug should be implemented at the Main Haulage, and potentially at the Conveyor Adit.

Poor rock mass and support conditions were observed in the Conveyor Adit, and further investigation is necessary to design an appropriate remediation strategy. Remediation options include plugging the adit with a bulkhead that will divert mine water to the Main Haulage at the 3950 level and implementing a dry plug at the portal; or developing a plug and water conveyance system that will prevent collapse after long-term closure. Construction of either option will likely require the support within the adit to be rehabilitated.

To further develop the remediation options a more in-depth inspection of the Conveyor Adit took place in 2018 and is detailed in Appendix B.

6.0 RECOMMENDATIONS

We recommend that the entire length of the Conveyor Adit should be inspected in order to best determine the appropriate remediation action for this area. This inspection was undertaken in 2018 and is reported in Appendix B. With regard to the other areas of the mine, we make the following recommendations:

Open Pit

1. Delineate the base of the pit as a rock fall safe zone for temporary access during closure and remediation activities, restrict or control access elsewhere in the pit, as delineated in Figure 6.
2. Control access to the pit during, and immediately after heavy precipitation events.
3. Decommission the open pit access road after closure and remediation activities are complete, and allow the creeks/debris channels that cross it to wash through. This will thwart the public from accessing the pit.

PUG Portal

1. Remove the metal canopy structure.
2. Support the slope above the portal through a small scaling program and rock bolting, as directed by a geotechnical engineer. Do not complete work in or around the portal until this is complete.
3. Backfill the portal to the crown with inert aggregate material sourced on-site for a distance of at least 5 m, as shown in Figure 8.
4. Partially backfill the slope above and around the portal with inert aggregate, as shown in Figure 8.

Vent Portal

1. Remove the vent fan building / portal structure, and air lock door in the manway; it is not necessary to remove the concrete structure around the manway.
2. Rehabilitate the underground support to make it safe for work.
3. Backfill the manway and vent portal to the crown at least as far as the intersection with inert aggregate material, as shown in Figure 8.
4. Backfill the slopes around the portals to the crest with inert aggregate material, and shape to match the existing topography. Consider re-vegetating the backfill slope to visually match the surrounding terrain.

Main Haulage (3950 Level)

1. Maintain a setback distance of 4 m from the slopes surrounding the portal during closure and remediation work, unless mechanical scaling takes place as directed by a geotechnical engineer.
2. Consider using the main workshop as a permanent storage location for asbestos-containing waste.
3. If Remediation Option 1 is chosen, construct a 3 m high concrete dam structure at least 12 m into the portal, and then backfill the portal using an inert aggregate material, filling it to the crown for a distance of at least 5 m.

4. If Remediation Option 2 is chosen, construct a level concrete pad on the invert of the portal to promote drainage through HDPE or galvanized steel culverts, and construct a plug on top of the pipes / culverts using inert aggregate material that fills the portal to the crown for a length of at least 5 m, as shown in Figure 7. Ensure that the plug does not block or constrict water flow through the pipes.
5. Backfill to the crest of the slopes surrounding the portal using inert aggregate material. Shape and re-vegetate the backfilled slope to match the surrounding terrain, as shown in Figure 7.

Conveyor Adit

1. Conduct an inspection of the entire length of the adit to determine rock conditions and support requirements, as well as to inspect potential bulkhead locations.
2. Remediate the ground support in areas where workers will be present and the Q-value is less than 10, to meet modern design standards as discussed in Section 4.2.1, and shown in Figure 9.
3. Consider the remediation options presented in Sections 4.1.1 and 4.2.2 in the context of the detailed inspection.

7.0 CLOSURE

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

Respectfully Submitted,
Tetra Tech Canada Inc.

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
B.W. HOWDEN
#44526

31 May 2019

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LT/BH/tak

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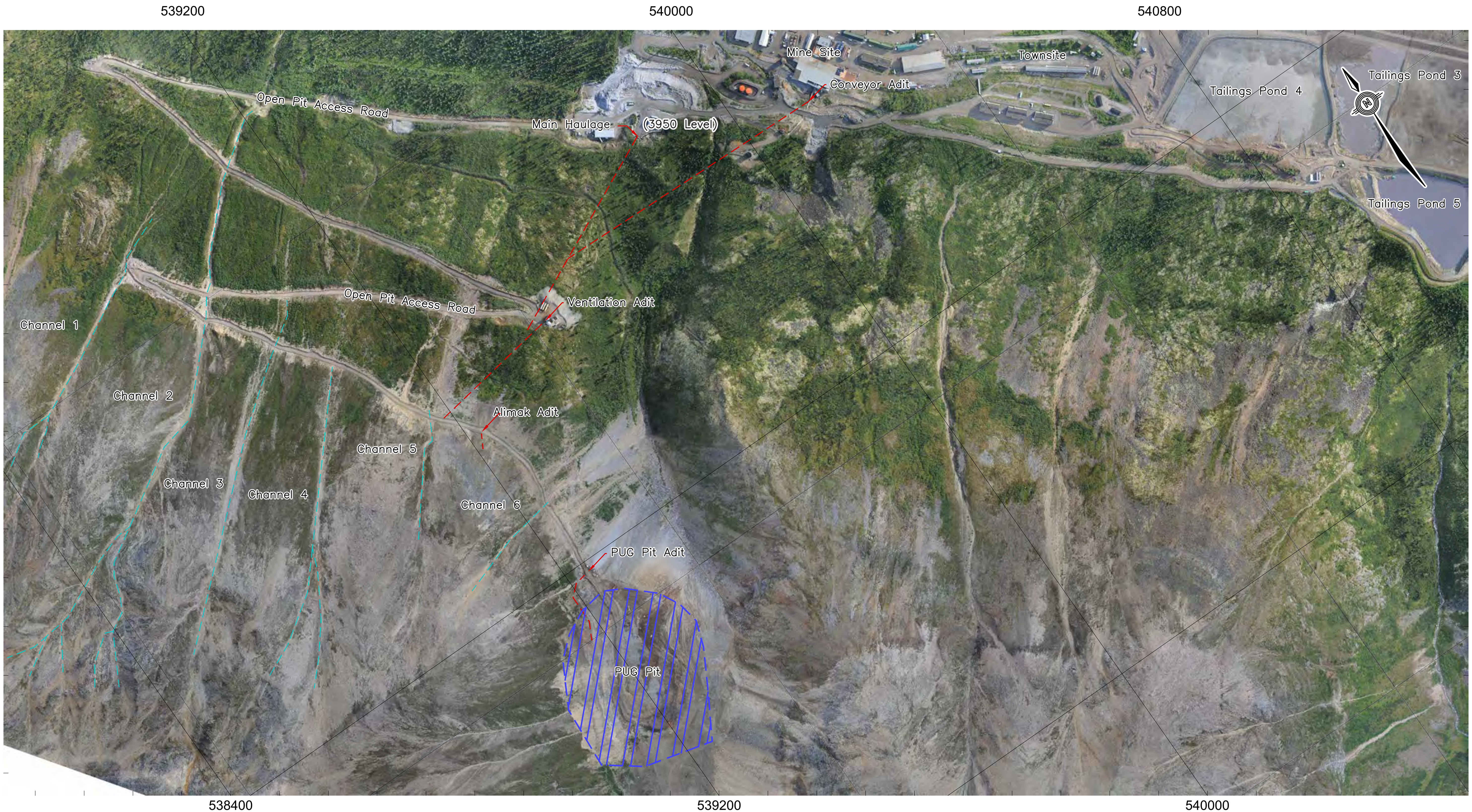
FIGURES

Figure 1	Site Overview
Figure 2	Pit Wall Naming Overview
Figure 3	Northwest Highwall
Figure 4	Southwest Wall
Figure 5	Southeast Wall
Figure 6	Open Pit Rock Fall Hazard Zones and Landfill Concept
Figure 7	Main Haulage (3950 Level) Remediation Options
Figure 8	Closure of the PUG and Ventilation Adits
Figure 9	Conveyor Adit Closure Option 1 – Bulkhead to Divert Water to the 3950 Level
Figure 10	Conveyor Adit Closure Option 2 – Backfill Drainage System and Support Remediation



E:\Cantung Civil 2017\Project\Production Drawings\WENW03039-02 Task 007.dwg [FIGURE 1] November 10, 2017 - 4:50:10 pm (BY: HALLEY, RICHARD)

0 250m

Scale: 1:7,500 @ 11"x17"

NOTES
BASED DATA SOURCE:
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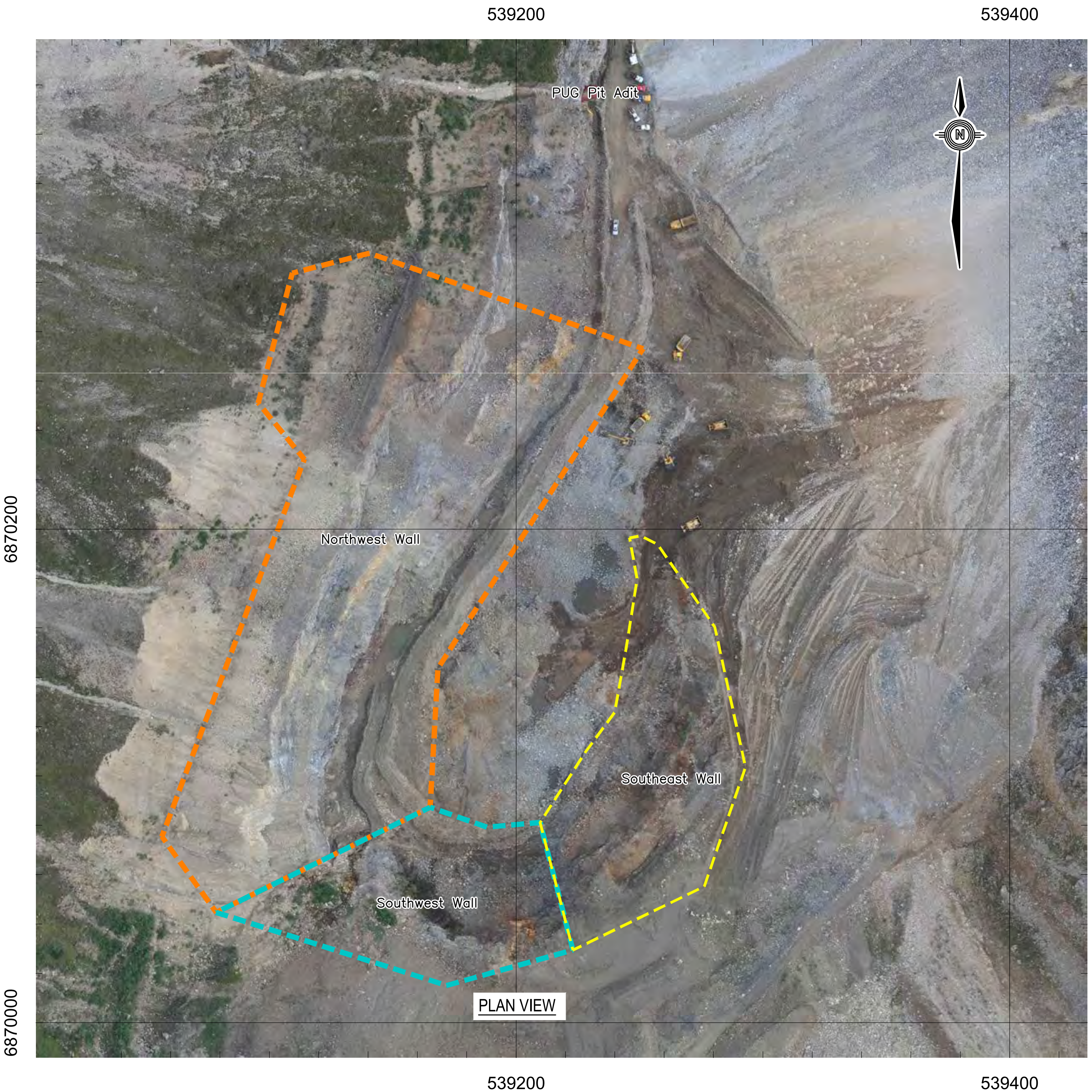
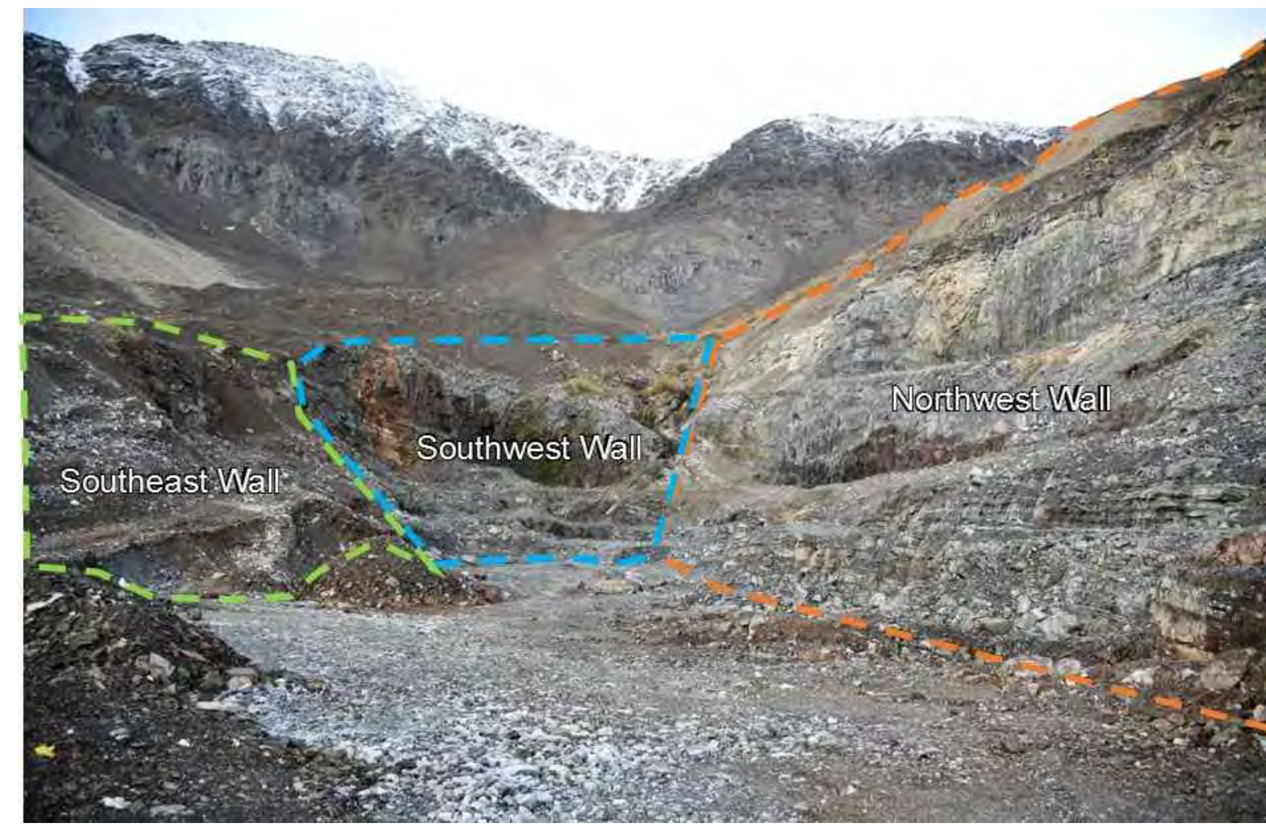
Cantung Mine Closure Geotechnical Stability Assessment

Site Overview

PROJECT NO.	DWN	CKD	REV	
WENW03039-007	RERH	XXX	0	Figure 1
OFFICE: TT- Kelowna	DATE: November 8, 2017			



PLAN VIEW



LOOKING SOUTHWEST
NOT TO SCALE

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Scale: 1:2,000 @ 11"x17"

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Pit Wall Naming Overview

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WENW03039-007	RERH	XXX	0	**Figure 2**
OFFICE	DATE			
TT- Kelowna	November 8, 2017			

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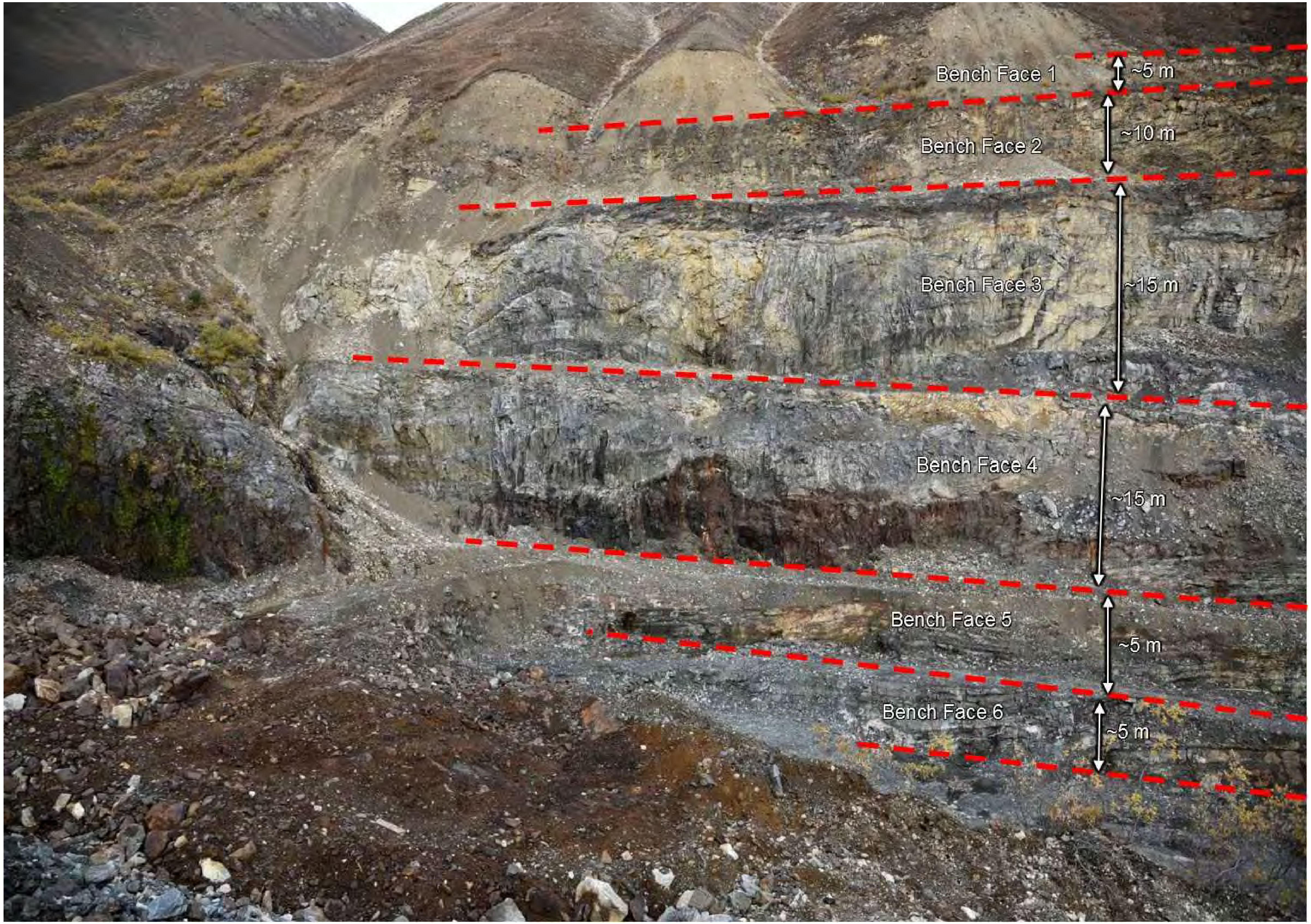

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Cantung Mine Closure Geotechnical Stability Assessment

Northwest Highwall

PROJECT NO.	DWN	CKD	REV	
WENW03039-007	RERH	XXX	0	**Figure 3**
OFFICE	DATE			
TT- Kelowna	November 8, 2017			

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Southwest Wall

PROJECT NO.	DWN	CKD	REV	
WENW03039-007	RERH	XXX	0	**Figure 4**
OFFICE	DATE			
TT- Kelowna	November 8, 2017			

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Southwest Wall

PROJECT NO.	DWN	CKD	REV
WENW03039-007	RERH	XXX	0

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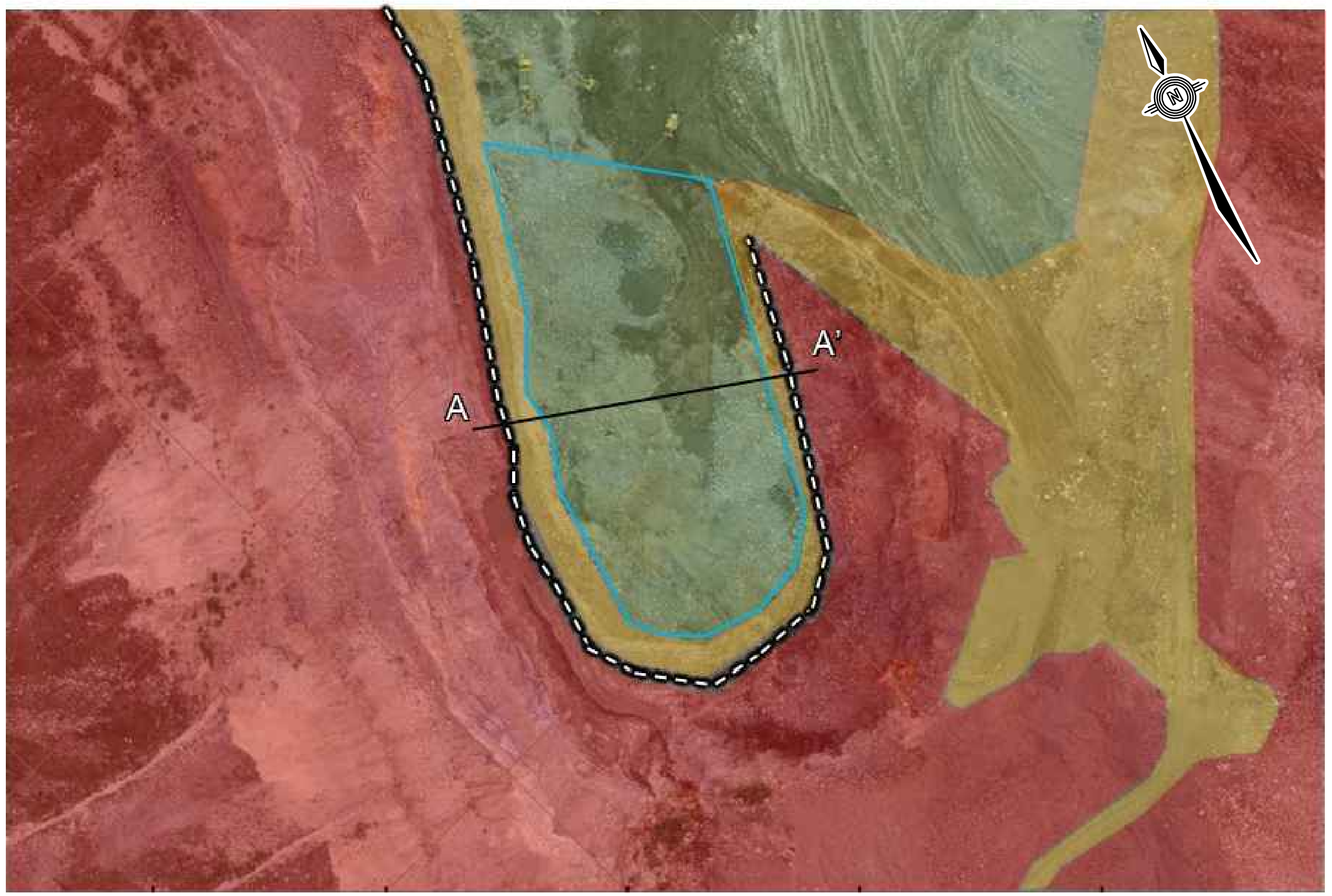
TT- Kelowna	November 8, 2017

Figure 5



PLAN VIEW

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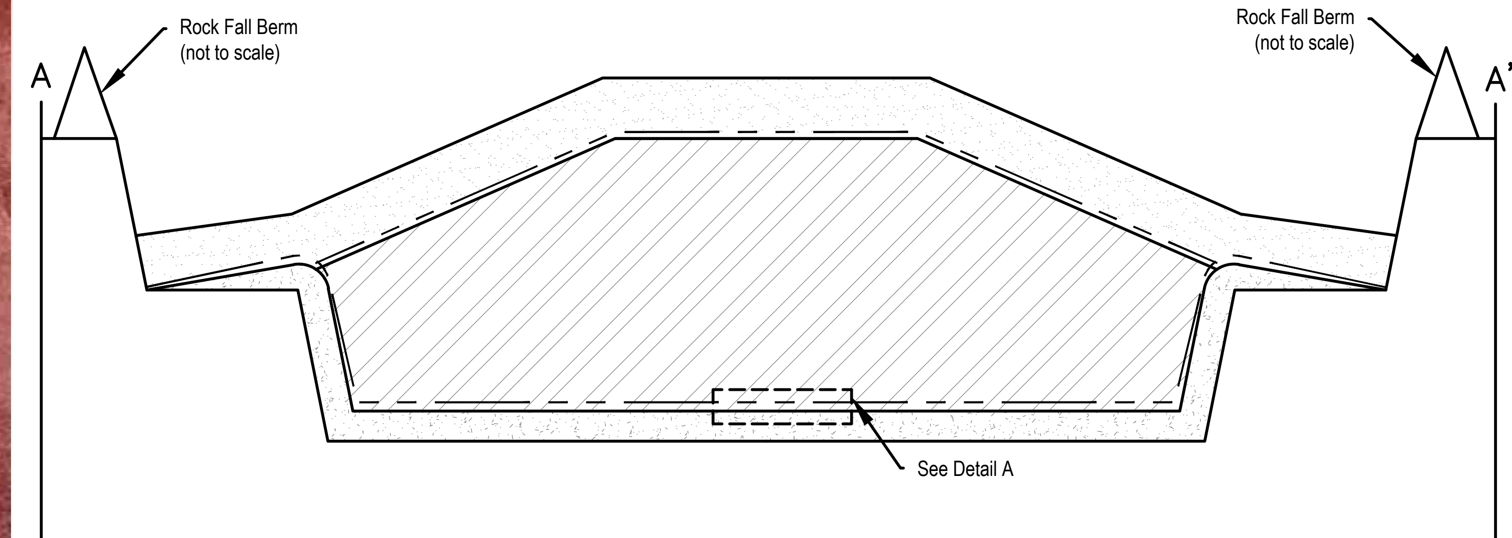

Section A-A'

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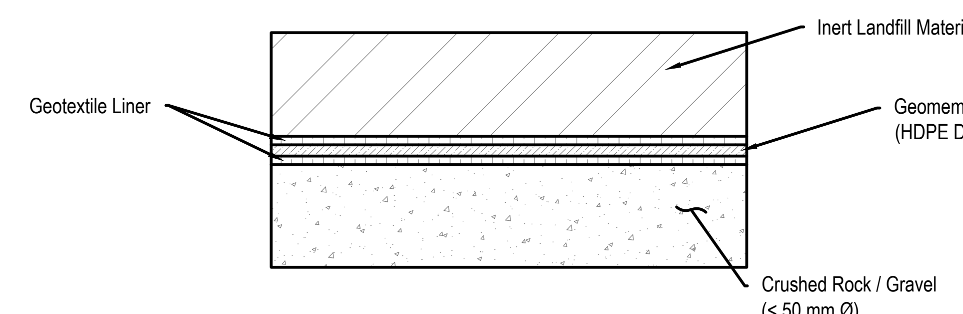

Detail A

Not to Scale

LEGEND

(red)	High Rock Fall Hazard Area - Restrict Access
(orange)	Moderate Rock Fall Hazard Area - Control Access
(green)	Low Rock Fall Hazard Area - Allow Construction Access
(cyan outline)	Suitable Landfill Area
(dashed black/white line)	Rock Fall Berm
(stippled box)	Crushed Rock / Gravel (< 50 mm Ø)
(long-dash line)	Liner System (See Detail A)
(hatched box)	Inert Waste
(stippled box)	Capping Soils (Low Permeability)

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Cantung Mine Closure
Geotechnical Stability Assessment

Open Pit Landfill Concept

PROJECT NO.	DWN	CKD	REV
WENW03039-007	RERH	XXX	0

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Figure 6

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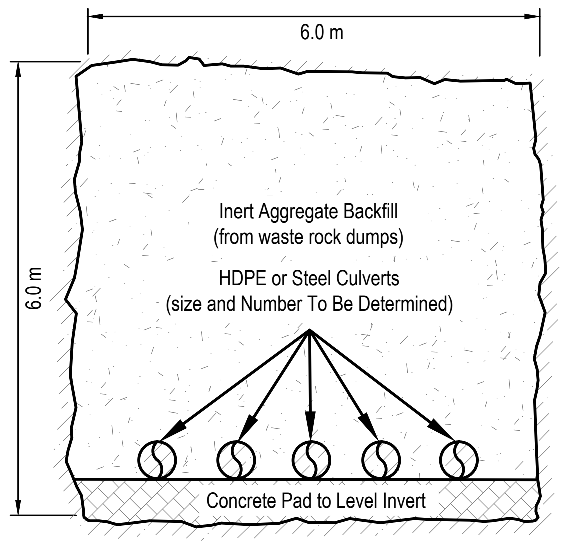
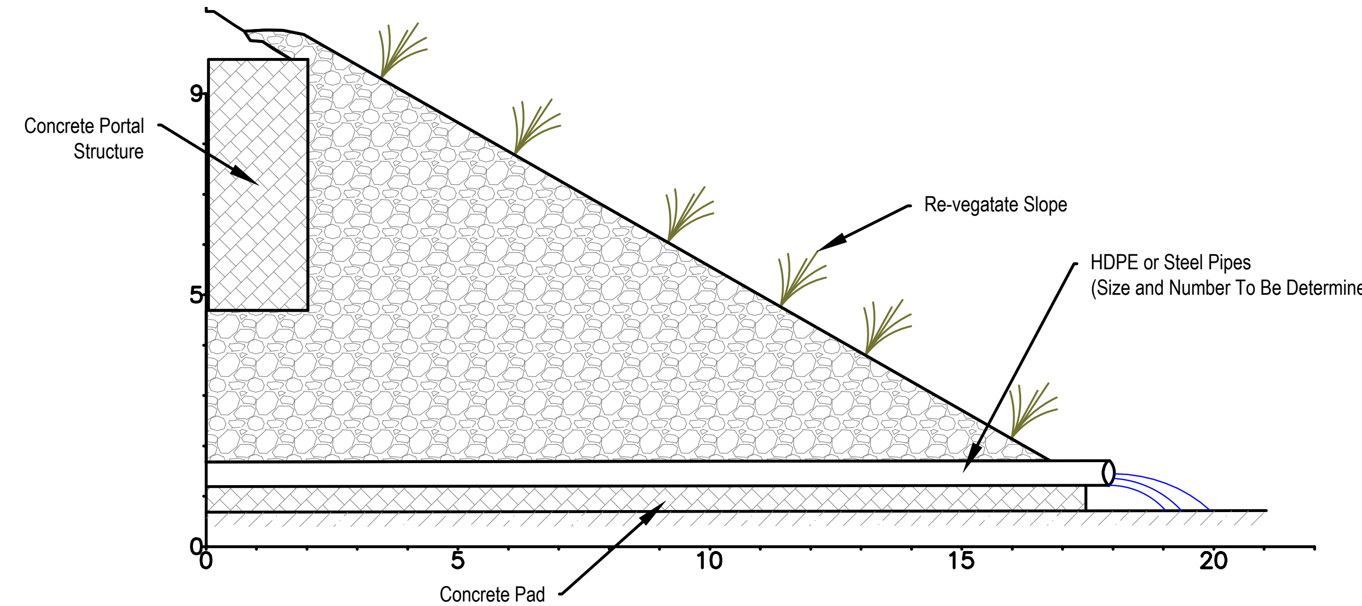


Option 1 - Plug To Drain Water and Prevent Ingress

Looking Down Portal

0 5m

Scale: 1:100 @ 11"x17"



Option 1 Section- Plug To Drain Water and Prevent Ingress

0 5m

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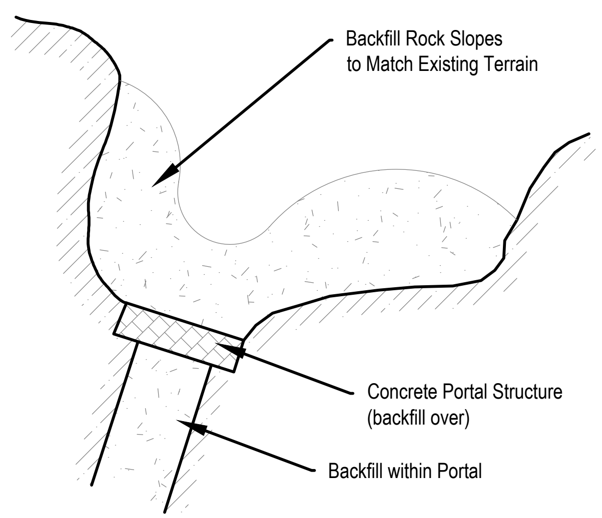
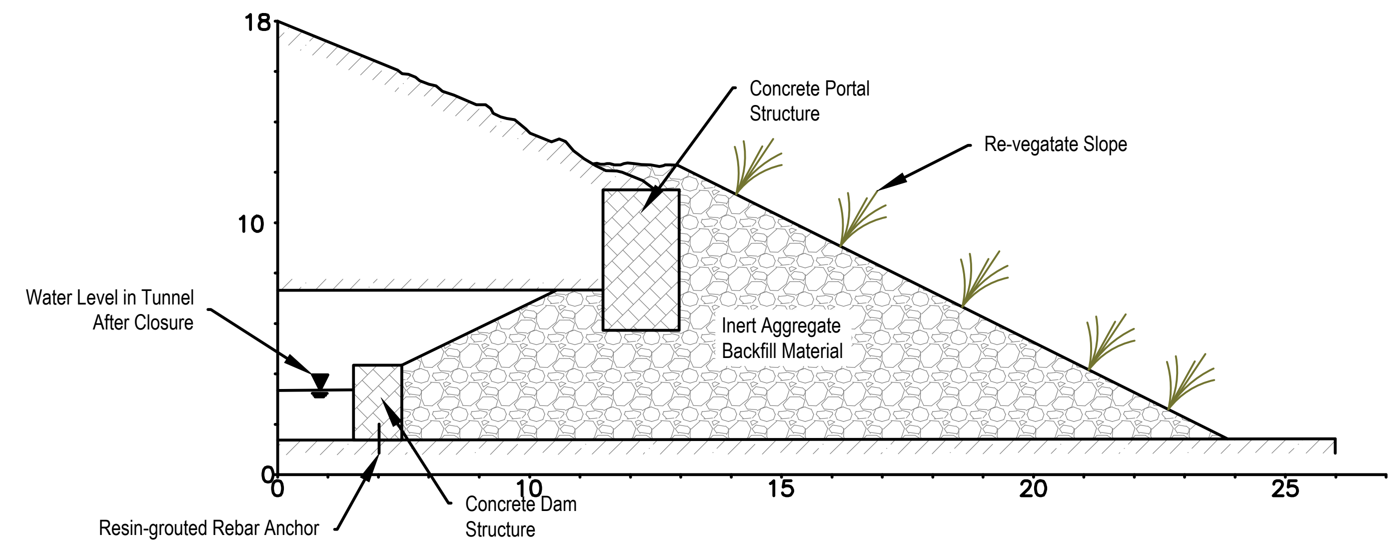


PLAN VIEW

not to scale



Option 2 Section - Seal Potal Divert Mine Water to Conveyor Adit

0 15m

Scale: 1:300 @ 11"x17"

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Cantung Mine Closure
Geotechnical Stability Assessment

Main Haulage (3950 Level)
Remediation Options

PROJECT NO.	DWN	CKD	REV
WENW03039-007	RERH	XXX	0

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Figure 7

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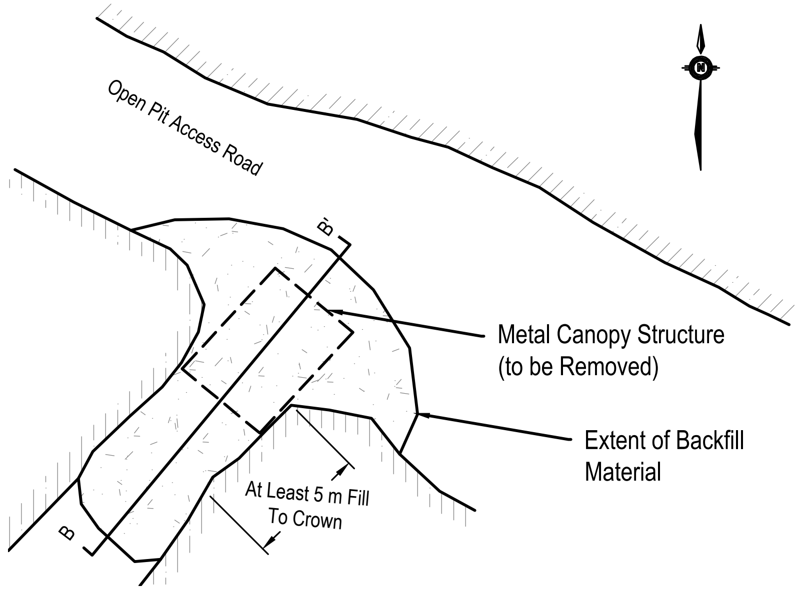
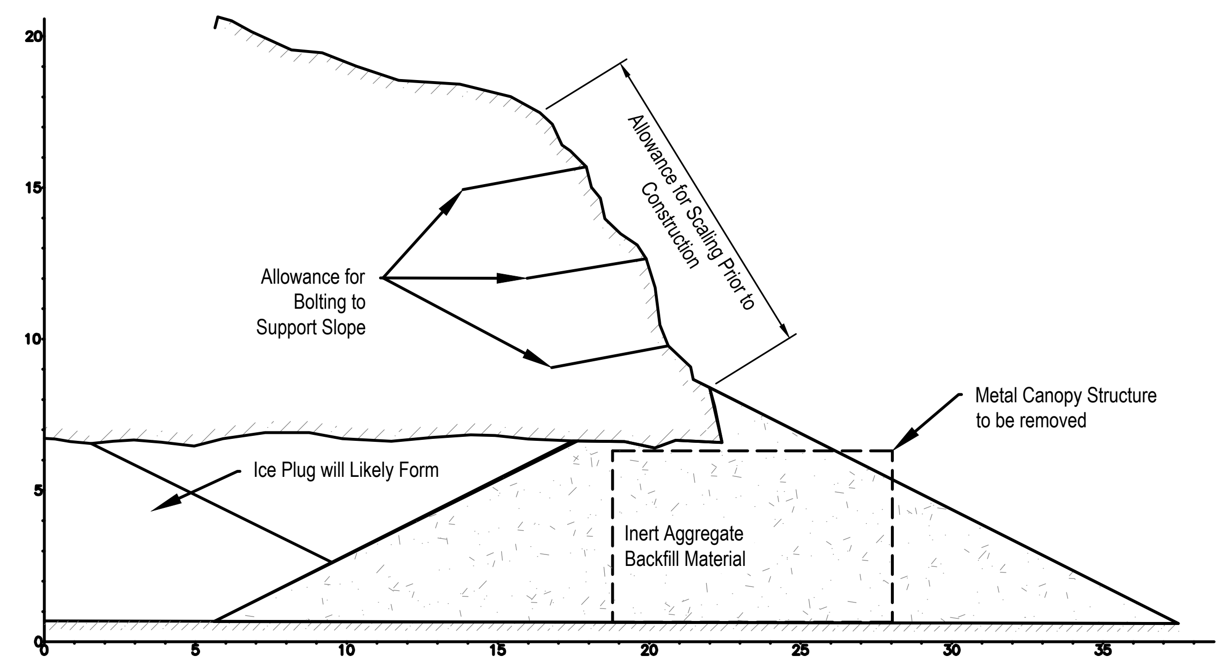


PUG ADIT DRY PLUG
PLAN VIEW
not to scale



Section B-B' - Plug Adit Dry Plug

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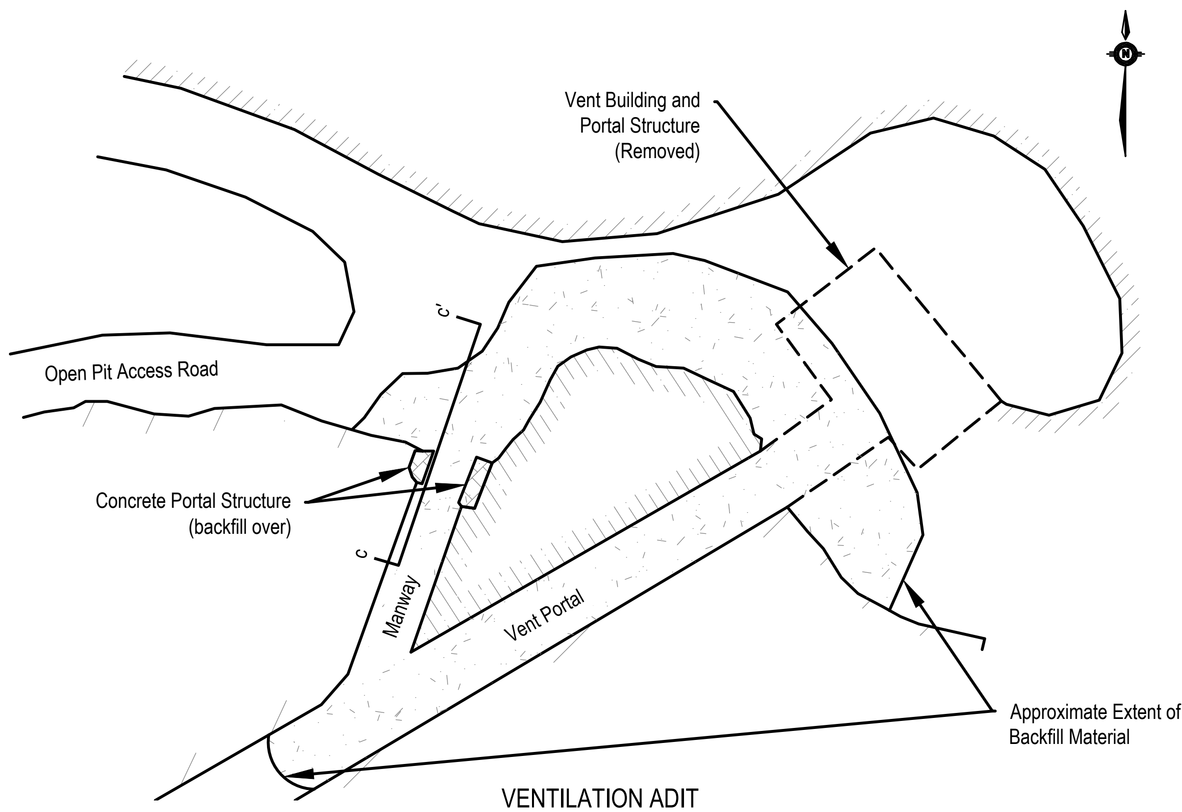
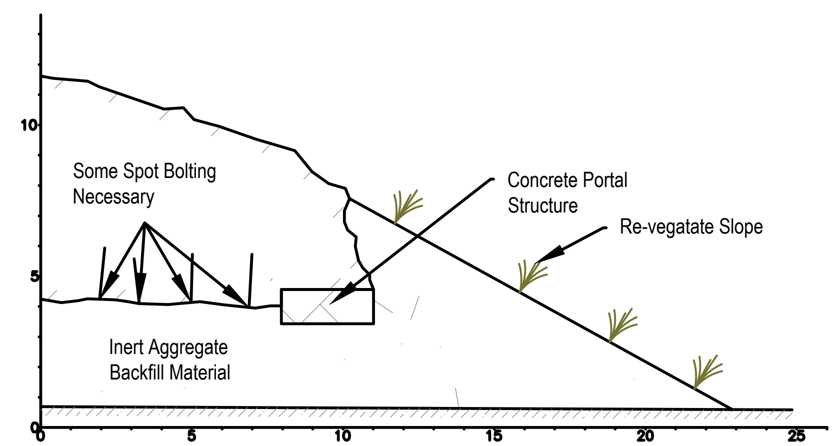


VENTILATION ADIT
PLAN VIEW
not to scale



Section C-C' - Ventilation Adit Dry Plug

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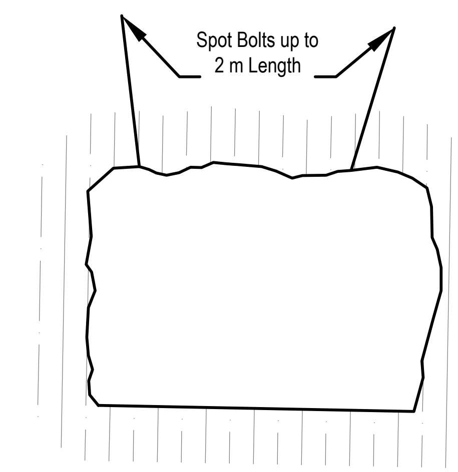

Ventilation Adit Remedial Work/ Safety Support

0 5m

Scale: 1:100 @ 11"x17"

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Cantung Mine Closure
Geotechnical Stability Assessment

Closure of the PUG and Ventilation Adits

PROJECT NO.	DWN	CKD	REV
WENW03039-007	RERH	XXX	0

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TT- Kelowna	November 8, 2017

Figure 8

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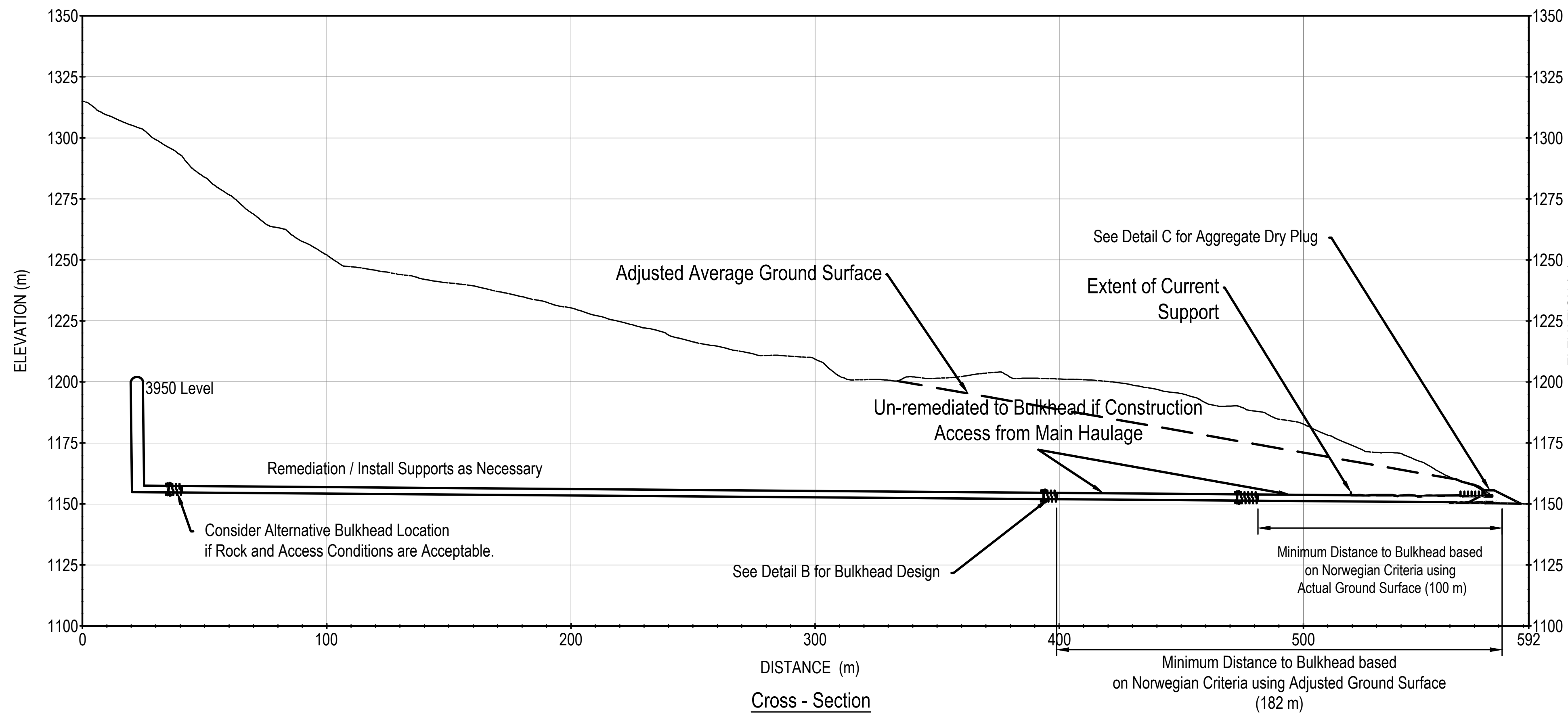

Cross - Section

0 100m

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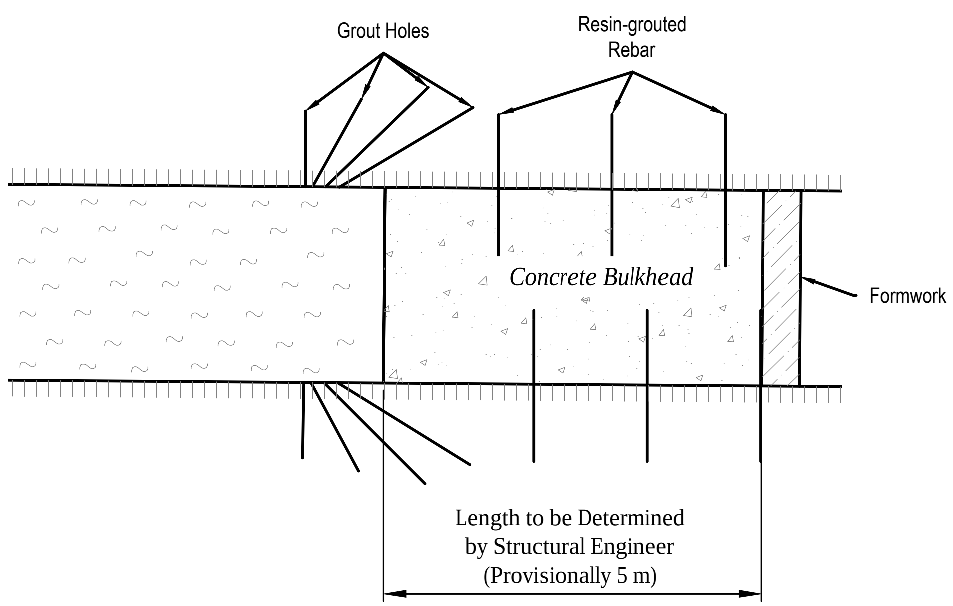

Detail B - Conceptual Bulkhead Design

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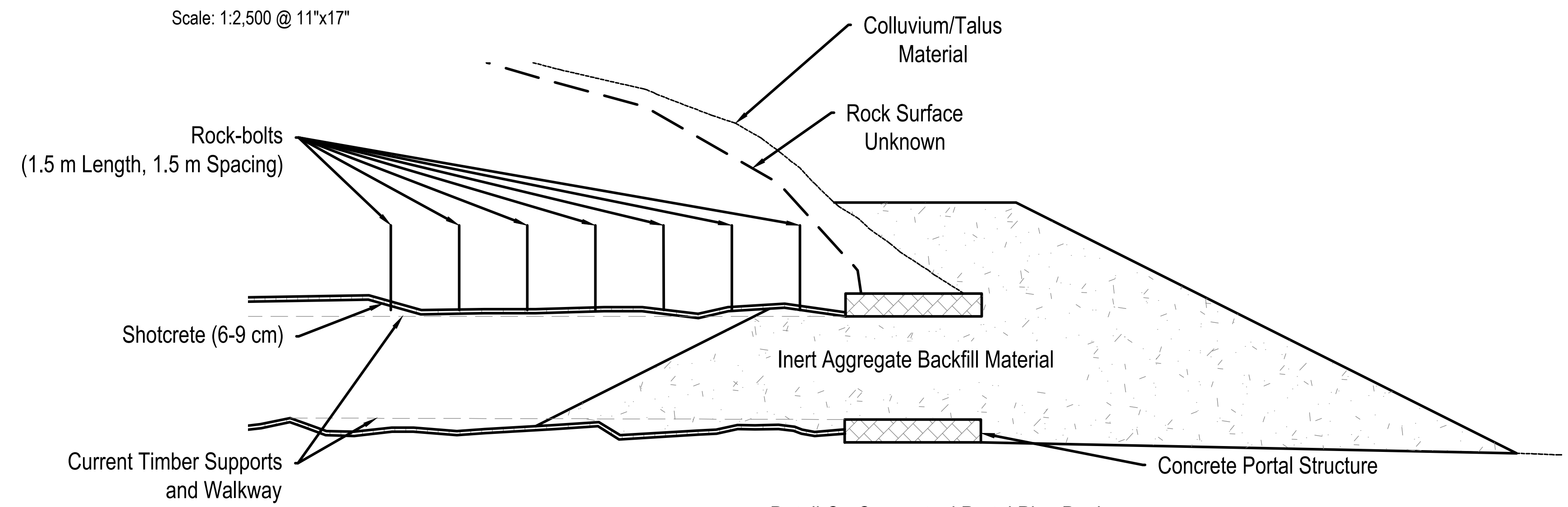

Detail C - Conceptual Portal Plug Design

0 5m

Scale: 1:150 @ 11"x17"

NOTES
BASED DATA SOURCE:
DATA PROVIDED BY INAC (2013)

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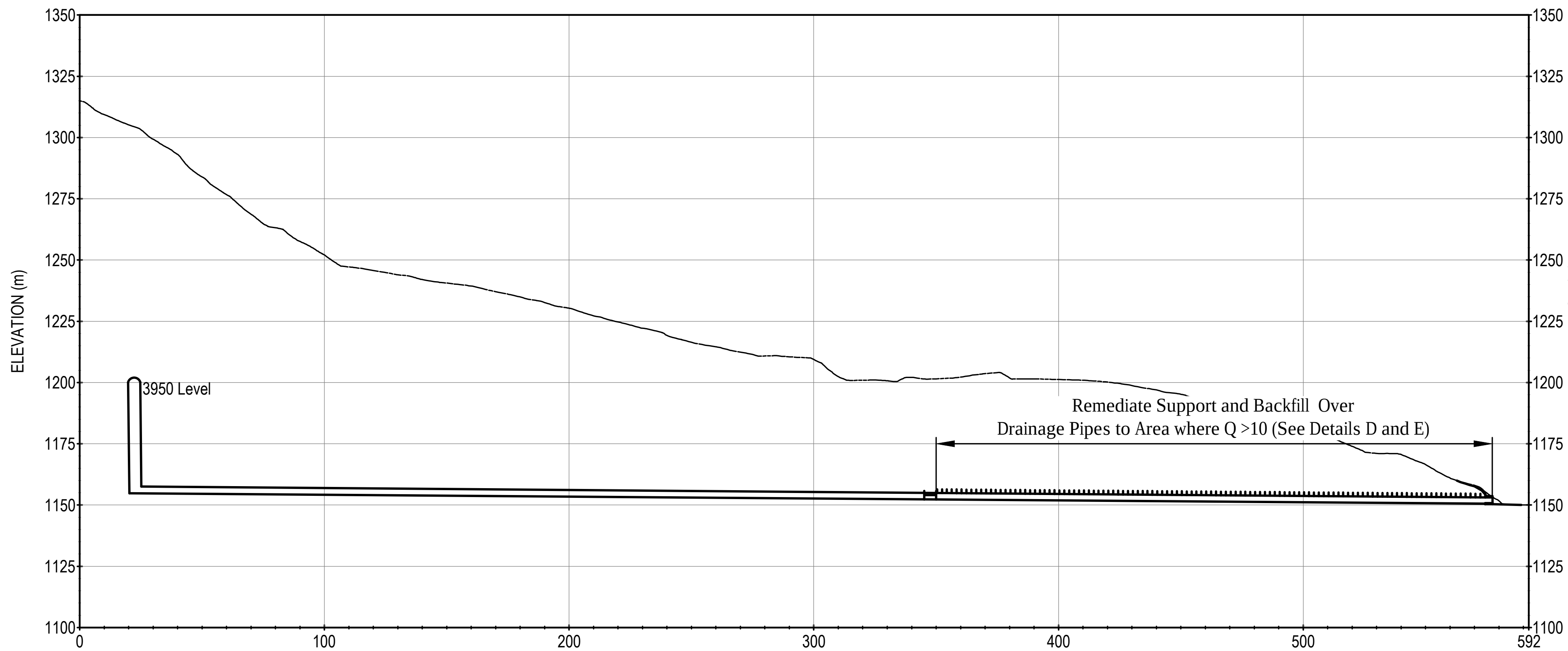
Cantung Mine Closure
Geotechnical Stability Assessment

Conveyor Adit Closure Option 1
- Bulkhead to Divert Water to 3950 Level

PROJECT NO.	DWN	CKD	REV
WENW03039-02	RERH	XXX	0

OFFICE	DATE
TT- Kelowna	November 8, 2017

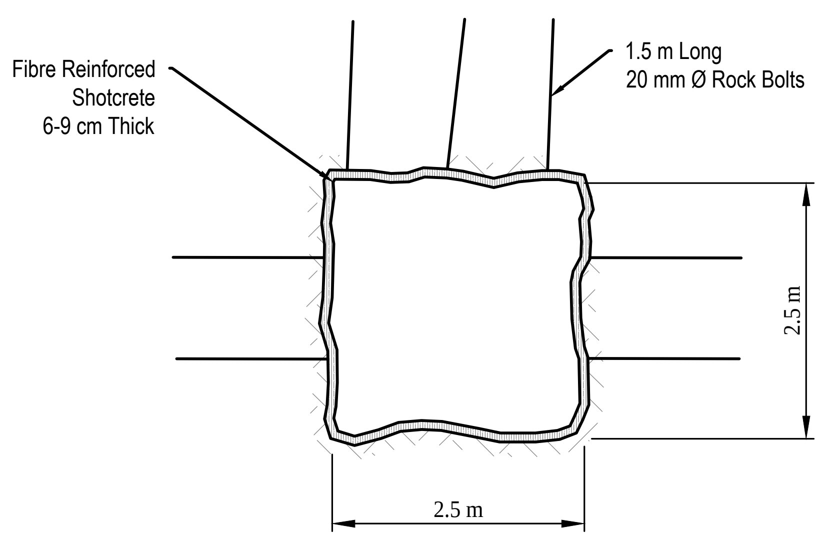
Figure 9



Cross - Section

0 100m

Scale: 1:2,500 @ 11"x17"



Detail D - Support and Remediation Conceptual Design

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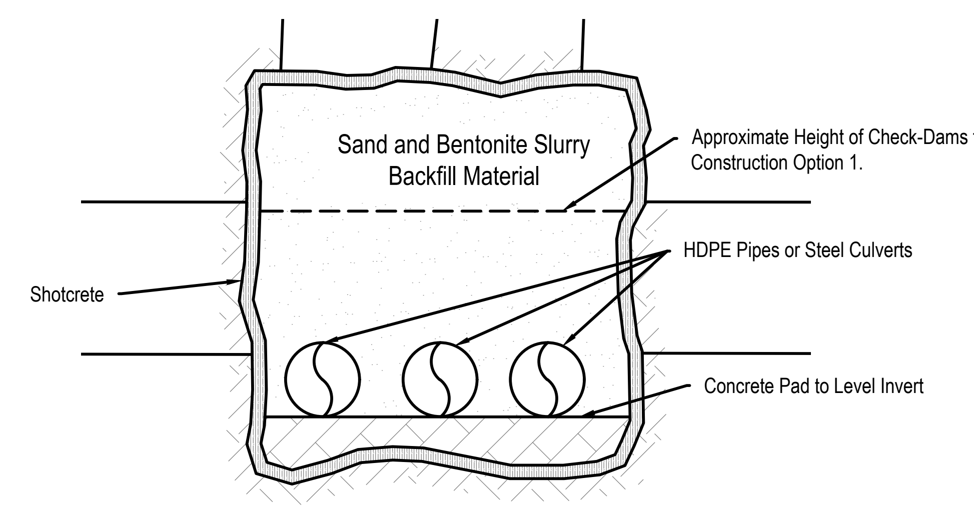

Detail E - Conceptual Backfill and Drainage Design

0 2.5m

Scale: 1:50 @ 11"x17"

NOTES
BASED DATA SOURCE:
DATA PROVIDED BY INAC (2013)

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Cantung Mine Closure
Geotechnical Stability Assessment

Conveyor Adit Closure Option 2
- Backfill Drainage System

PROJECT NO.	DWN	CKD	REV	
WENW03039-02	RERH	XXX	0	**Figure 10**
OFFICE	DATE			
TT- Kelowna	November 8, 2017			

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Photo 2: Upper benches of the NW wall of the Open Pit completely filled in with talus material

Photo 3: Middle benches of the NW wall of the Open Pit showing erosion and iron staining; note seepage from the face in the lower-right of the photo.

Photo 4: Lower benches of the NW wall of the Open Pit showing rock fall berm, providing effective catchment to benches below.

Photo 5: Southwest wall of the Open Pit showing seepage through the upper bench-face, ponding water on the upper-middle bench, and the rock fall berm to the right of the photo.

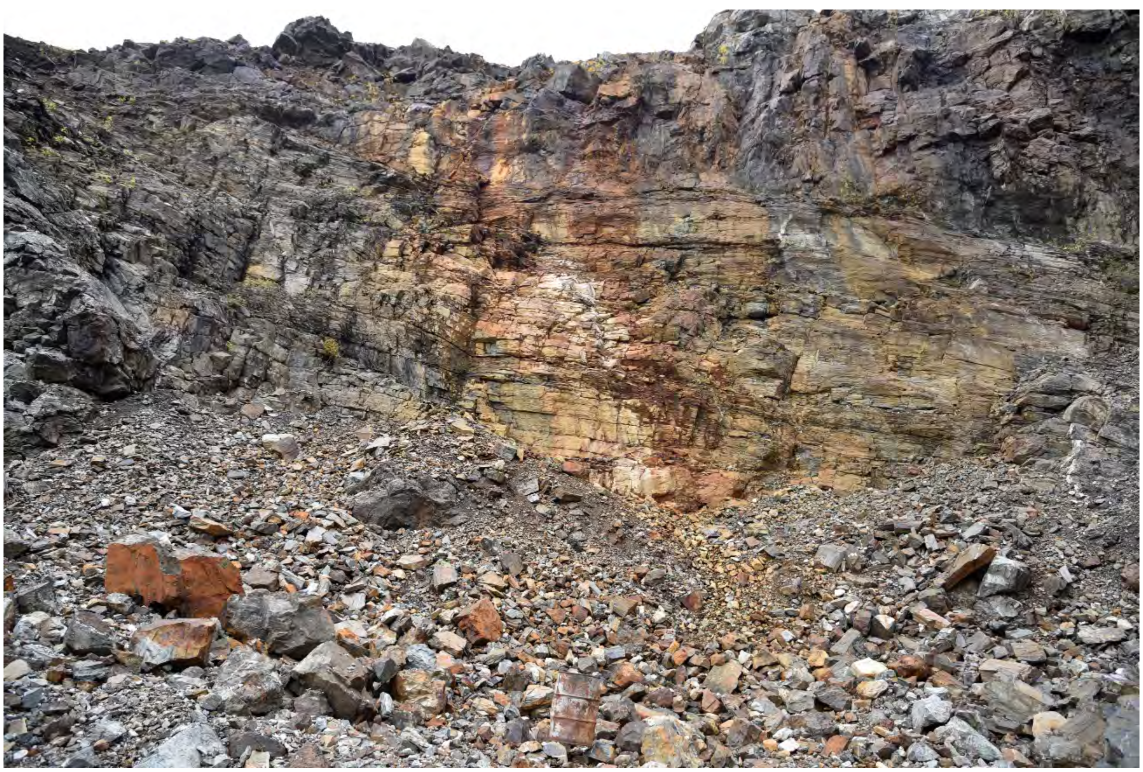

Photo 6: Significant iron staining from water inflow / seepage on the SW wall of the Open Pit.

Photo 7: Rock fall berm below the upper bench-face of the Southeast Wall of the Open Pit, iron staining and seepage on the SW Wall is visible in the background.

Photo 8: Drainage Channel 1 that crosses the Open Pit Access Road. Note levees potentially formed by debris flows

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Photo 10: Drainage Channel 3 crossing the Open Pit Access Road.

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Photo 14: Remnants of the Alimak Adit visible along the Open Pit Access Road; this area should be backfilled with inert aggregate material.

Photo 15: The PUG Portal and slope. The metal canopy structure should be removed, and slope stabilization should include an allowance for scaling and rock bolting.

Photo 16: Pattern bolting in the crown of the PUG Adit.

Photo 17: The Vent Adit, showing the vent portal (left) and manway (right, where the person is pictured). The vent buildings to the left should be removed.

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Photo 19: Vent Adit portal structure and Southeast Slope.

Photo 20: Stress release of the pillar at the intersection of the manway and vent portal of the Vent Adit.

Photo 21: Main Haulage (3950 Level) Portal.

Photo 22: Northwest Slope of the Main Haulage portal. It is recommended that a 4 m setback distance be maintained for workers and equipment during closure and remediation work.

Photo 23: Southeast Slope of the Main Haulage Portal.

Photo 24: Crown support in the Main Haulage.

Photo 25: Conveyor Adit portal and slope.

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Photo 27: Conveyor Adit timber sets support, poor rock mass conditions (left), and iron staining of the rock mass and water.

Photo 28: Cracked timber support in the crown of the Conveyor Adit.

APPENDIX A

TETRA TECH'S LIMITATIONS ON THE USE OF THIS DOCUMENT

LIMITATIONS ON USE OF THIS DOCUMENT

GEOTECHNICAL

1.1 USE OF DOCUMENT AND OWNERSHIP

This document pertains to a specific site, a specific development, and a specific scope of work. The document may include plans, drawings, profiles and other supporting documents that collectively constitute the document (the "Professional Document").

The Professional Document is intended for the sole use of TETRA TECH's Client (the "Client") as specifically identified in the TETRA TECH Services Agreement or other Contractual Agreement entered into with the Client (either of which is termed the "Contract" herein). TETRA TECH does not accept any responsibility for the accuracy of any of the data, analyses, recommendations or other contents of the Professional Document when it is used or relied upon by any party other than the Client, unless authorized in writing by TETRA TECH.

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Where TETRA TECH submits electronic file and/or hard copy versions of the Professional Document or any drawings or other project-related documents and deliverables (collectively termed TETRA TECH's "Instruments of Professional Service"), only the signed and/or sealed versions shall be considered final. The original signed and/or sealed electronic file and/or hard copy version archived by TETRA TECH shall be deemed to be the original. TETRA TECH will archive a protected digital copy of the original signed and/or sealed version for a period of 10 years.

Both electronic file and/or hard copy versions of TETRA TECH's Instruments of Professional Service shall not, under any circumstances, be altered by any party except TETRA TECH. TETRA TECH's Instruments of Professional Service will be used only and exactly as submitted by TETRA TECH.

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

1.3 STANDARD OF CARE

Services performed by TETRA TECH for the Professional Document have been conducted in accordance with the Contract, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Professional Document. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Professional Document.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of TETRA TECH.

1.4 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

1.5 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Professional Document, TETRA TECH may have relied on information provided by third parties other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

1.6 GENERAL LIMITATIONS OF DOCUMENT

This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this document, at or on the development proposed as of the date of the Professional Document requires a supplementary exploration, investigation, and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, TETRA TECH has not been retained to explore, address or consider and has not explored, addressed or considered any environmental or regulatory issues associated with development on the subject site.

1.8 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems, methods and standards 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 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.

1.9 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.

1.10 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 historical environment. TETRA TECH 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 exploration and review may be necessary.

1.11 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.

1.12 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.

1.13 INFLUENCE OF CONSTRUCTION ACTIVITY

Construction activity can impact 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, and construction sequence are known.

1.14 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, and 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.

1.15 DRAINAGE SYSTEMS

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. Where temporary or permanent drainage systems are installed within or around a structure, these systems must protect the structure from loss of ground due to mechanisms such as internal erosion and must be designed so as to assure continued satisfactory performance of the drains. Specific design details regarding the geotechnical aspects of such systems (e.g. bedding material, surrounding soil, soil cover, geotextile type) should be reviewed by the geotechnical engineer to confirm the performance of the system is consistent with the conditions used in the geotechnical design.

1.16 DESIGN PARAMETERS

Bearing capacities for Limit States or Allowable Stress Design, strength/stiffness properties and similar geotechnical design parameters 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 used in this report. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions considered in this report in fact exist at the site.

1.17 SAMPLES

TETRA TECH 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.

1.18 APPLICABLE CODES, STANDARDS, GUIDELINES & BEST PRACTICE

This document has been prepared based on the applicable codes, standards, guidelines or best practice as identified in the report. Some mandated codes, standards and guidelines (such as ASTM, AASHTO Bridge Design/Construction Codes, Canadian Highway Bridge Design Code, National/Provincial Building Codes) are routinely updated and corrections made. TETRA TECH cannot predict nor be held liable for any such future changes, amendments, errors or omissions in these documents that may have a bearing on the assessment, design or analyses included in this report.

APPENDIX B

2018 CONVEYOR ADIT INSPECTION AND RECOMMENDATIONS MEMO

TETRA TECH

TECHNICAL MEMO

ISSUED FOR USE

To:	Callum Beveridge (Alvarez & Marsal) Michael Westlake (Crown-Indigenous Relations and Northern Affairs Canada)	**Date:**	July 2019
		Memo No.:	001
From:	Lauren Taaffe, E.I.T. Ben Howden, P.Eng.	**File:**	704-ENW.WENW03039-03
Subject:	2018 Conveyor Adit Inspection Report and Recommendations		

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was retained by Alvarez & Marsal Canada Inc. (A&M), in its capacity as Court appointed Monitor for North American Tungsten Corporation Ltd. (NATC) and Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) to conduct an underground geotechnical stability assessment of the Conveyor Adit and underground workshop at the Cantung Mine in the Northwestern Territories (NWT), Canada. Tetra Tech previously conducted a site visit to the Cantung Mine in the fall of 2017 to assess the geotechnical stability of the open pit and portals of the mine. During this site visit, the first 65 m of the Conveyor Adit were inspected. Following the 2017 site visit, an inspection of the entire length of the Conveyor Adit was recommended. A follow up inspection therefore occurred on September 18, 2018. This report presents the results from this 2018 follow up inspection including recommendations to manage the water outflowing from the mine.

There are two potential options for underground water management under consideration:

- Option 1 – Maintain the existing flow through the Conveyor Adit by installing HDPE pipes/culverts at the base to allow passive drainage of mine water; and backfilling around the pipes with a sand slurry, or alternatively;
- Option 2 – Sealing the Conveyor Adit with a concrete bulkhead, thereby diverting the majority of water flowing to the Main Haulage at the 3950 level of the mine and then out of the underground workings.

In order to assess these issues, the 2018 inspection characterized the rock mass properties in the Conveyor Adit to identify a potential location for a bulkhead and assess tunnel support rehabilitation requirements. This assessment included the use of the Norwegian Geotechnical Institute's Q-system (NGI-Q after Barton et al. 1974).

The following sections outline the findings of the underground inspections, recommendations for bulkhead placement, and key considerations for detailed 30% level engineering design in 2019.

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Vancouver, BC V6C 1N5 CANADA
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2.0 SITE INSPECTION

The site inspection occurred on the afternoon of September 18, 2018 during overcast weather. Brian Delaney, P.Eng. accompanied Mr. Charles Hunt, P.Eng. and Ms. Lauren Taaffe, E.I.T. on the underground inspection. The inspection reviewed the main workshop at the 3950 level of the mine and the Conveyor Adit located beneath the Main Haulage. Each of these underground excavations were observed and assessed including:

- Rock mass characterization using the NGI-Q system;
- Noting support types and performance along with rock deterioration or stress relief;
- Noting any major water inflows or ponding of water; and
- Describing any unusual rock structures or weakness zones.

The NGI-Q system is a quantitative rock mass classification system developed in Norway for use in hard rock tunneling (Norwegian Geotechnical Institute, 2015). The Q rating is defined as:

$$(1)\quad Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}$$

Where:

RQD	is the Rock Quality Designation (%)	J_a	is the Joint Alteration Rating
J_n	is the Joint Set Number	J_w	is the Joint Water Rating
J_r	is the Joint Roughness Number	SRF	is the Stress Reduction Factor

Each of the above parameters has a numerical value assigned to a qualitative rock mass condition. The Q-rating (obtained using the above formula) is then applied to a Rock Mass Quality and Rock Support Chart where it can be compared with the span or height (whichever is greater) of the opening to recommend support classes.

The following sections describe observations and rock mass characteristics of the underground workshop and Conveyor Adit collected during the 2018 inspection.

2.1 Underground Workshop

The main underground workshop, located approximately 700 m from the Main Haulage portal, was assessed as a potential location for long term hazardous waste storage/disposal. The workshop provides approximately 13,500 m^3 of void space in excellent quality rock that is easily accessible.

The workshop consists of three large, parallel chambers connected by two slightly smaller, parallel chambers separated by two large rectangular pillars. Detailed measurements of the space were taken during the inspection. A scaled drawing presenting a plan view of the workshop is shown in Figure 1. During the inspection, it was noted that the pillars are in good condition and that there is little evidence of stress-related stability problems.

During the inspection, Q values for the workshop were assessed. Table 2.1-1 below presents the breakdown of the Q values assigned. In general, the rock mass observed was of good quality, and generally demonstrated Q values greater than 30 (in the range of ‘good’ quality rock which is from a value of 10 to 40). The walls and roof (back / crown) are supported with significant pattern bolting, wire mesh and metal strapping. The support systems were observed to be in good condition, showing little to no signs of fatigue or significant corrosion. Bagging within the mesh was not observed. No water inflows were noted within the workshop.

Access to the workshop is through two main vehicle entrances, or through a changing/locker room. Both of the vehicle entrances have shutter-style doors which could easily be reinforced and sealed off using welded-wire mesh and shotcrete. The changing room was observed to have a normal door.

Table 2.1-1: NGI-Q

Parameter	Description	Rating
RQD	Excellent, 0-7 joints per m^3	90
J_n	Two joint sets	4
J_r	Rough, irregular, planar	1.5
J_a	Unaltered joint walls, surface staining only.	1
J_w	Dry excavation	1
SRF	Medium stress, favourable stress condition	1
Q	**Good rock mass quality**	**33.75**

2.1.1 Pillar Stability

A preliminary stability analysis of the workshop pillars was undertaken using the Tributary Area method for rectangular pillars. This method calculates the pillar stress due to supporting the tributary area of overburden. It is equal to the overburden stress times the ratio of tributary area to pillar area. The formula to calculate this is presented in Equation (2) below. Using this equation, the average stress experienced by each pillar in the Main Haulage workshop was calculated to be approximately 2 MPa.

$$(2)\quad \sigma p = \gamma z * (1 + Wo/Wp) * (1 + Lo + Lp)$$

σ_p – Pillar stress
z – Height of overburden
γ – Unit weight of rock
Wo – Width of opening
Wp – Width of pillar

The strength of the pillars were also calculated using Equation (3) (Obert and Duval, 1967). The intact rock strength for limestone was used, which was found during rock strength testing on 43 samples from the Cantung mine (Delaney and Bakker, 2014). Using this equation, the strength of the pillars was found to be approximately 150 MPa, which is two orders of magnitude greater than the pillar stresses. This agrees with what was observed during the workshop inspection as no stress related deformation or failures, such as spalling, buckling or pillar hour-glass shapes were noted. Based on these calculations and observations taken during the inspection, the long term stability of the Main Haulage workshop is not of concern and would be a suitable location for long-term hazardous waste storage.

$$(3)\quad Sp = \sigma\left(0.778 + 0.222\frac{W}{H}\right)$$

Sp – Strength of pillar
W – Pillar width
σ – Intact rock strength (MPa)
H – Pillar height

2.2 Conveyor Adit

The Conveyor Adit span is approximately 3 m wide with a height of approximately 2.5 m. During the inspection, the entire 566 m length of the tunnel was inspected. Where different conditions in the rock mass were encountered, geotechnical boundaries were assigned and NGI-Q ratings were evaluated at each domain.

Figure 2 summarizes the minimum, mean, and maximum NGI-Q values assigned to the different geotechnical domains along the tunnel. On average, it was found that 38% of the tunnel length was in fair quality rock, 27% in very poor quality rock, 23% in good quality rock, and 12% in poor quality rock. The meter length of the tunnel in each specific rock mass quality for the minimum, mean, and maximum Q values is summarized in Tables 2.2-1 to 2.2-3 below. Recommendations for support presented in this report have been made based on mean NGI-Q values.

Table 2.2-1: Minimum NGI-Q Value Distribution

Class	F	E	D	C	B
Description	Extremely Poor	Very Poor	Poor	Fair	Good
Meterage	95	59	161	206	45
%	17%	10%	28%	36%	8%

Table 2.2-2: Mean NGI-Q Value Distribution

Class	F	E	D	C	B
Description	Extremely Poor	Very Poor	Poor	Fair	Good
Meterage	0	154	66	216	130
%	0%	27%	12%	38%	23%

Table 2.2-3: Maximum NGI-Q Value Distribution

Class	F	E	D	C	B
Description	Extremely Poor	Very Poor	Poor	Fair	Good
Meterage	0	95	110	231	130
%	0%	17%	19%	41%	23%

Three re-muck bays and three raises were also observed along the Conveyor Adit and are noted in Figure 2. The raise at the end of the Conveyor Adit is at an angle of approximately 53° and leads to the Main Haulage level. Water currently flows from the Main Haulage into the Conveyor Adit down this raise. The second raise is at approximately 558 m in the Conveyor Adit. This is believed to lead to the previous location of a crusher with a gantry crane on the Main Haulage level. A third raise at approximately 495 m in the Conveyor Adit was noted, however it is unknown which mine level this leads to, based on our review of the underground mine plan.

As shown in Figure 2, the current support system consists of a timber lattice system along the crown, with a mixture of steel and timber sets. Both the timbers and steel are showing signs of fatigue, and long-term integrity is a major concern. At some locations, the crown is additionally supported by wooden blocking or up to 5 layers of timber 2x4's arranged in a lattice pattern on top of the steel or timber sets. Steel and timber sets were noted to be at 1.8 m intervals. There are concerning signs of fatigue in the existing supports including significant corrosion of the steel sets, cracking and sagging of some 2x4's, sagging of the 8 inch roof cross-braces, buckling in some steel sets, and many cases where the 2x4's are not seated properly in the webbing of the steel cross-beams. This is considered to be a significant hazard, and the support system should be remediated if any workers are required to enter the adit on a routine basis.

Two water inflows from the rock mass were noted along the length of the adit. Temperature readings for these inflows were taken and found to range from 4°C to 6°C.

3.0 OPTIONS FOR UNDERGROUND WATER MANAGEMENT

3.1 Option 1: Maintain Existing Mine Water Conveyance

The majority of mine water flows out through the Conveyor Adit portal by draining down the raise at the end of the Conveyor Adit. The source of the water is from the Main Adit where there is a sump. All the inflows of groundwater throughout the mine flow to this point. The exception being at the Main Adit portal where some outflow of water was noted to be sourced from the first 600 m of the Main Adit. At around 250 m, the flow of water divides between the Conveyor and the Main Adit portal.

Maintaining the existing flow through the Conveyor Adit presents several challenges that need to be addressed. For example, the flow of water should not be impeded by partial or complete collapse of the adit, which might occur in the long-term (30, 50, or 100 years from now). Furthermore, the water flow should not freeze and form an ice plug. If this ice plug were to pressurize and 'blow out' in an uncontrolled manner, the release could damage other infrastructure. It is therefore considered that to maintain the existing flow through the Conveyor Adit, a High Density Polyethylene (HDPE) pipe (or culvert) should be installed along the invert to convey mine water to a ponded area outside of the adit.

Backfilling at least the first 240 m of the Conveyor Adit is recommended using a pumped sand slurry mix, both to protect the pipes in case of collapse, and to provide insulation and prevent freezing. This backfilling material could potentially be sourced from the waste rock dumps at the mine, or recently identified sand borrow pits.

At the upstream end of the pipe we suggest that a wall should be constructed to direct water into the pipe. Furthermore, should a partial ice blockage occur within the pipe, a wall will allow water to back up and build up pressure slowly as the Conveyor Adit fills. This bulkhead wall would be designed to withstand some nominal water pressure but would not be designed as a pressurized bulkhead.

There are potentially three levels of support rehabilitation that may be required for the Conveyor Adit. These are:

a) Permanent rehabilitation such that the support installed maintains the integrity of the opening in perpetuity.

b) Temporary rehabilitation, such that support installed maintains a safe opening during the course of construction works, but sand backfilling within the opening along the Conveyor Adit and around the drainage pipe occurs to maintain the integrity of the pipe from tunnel collapse.

   The backfilling material will fill the Conveyor Adit; if collapse were to occur the sand slurry backfill would support the opening and protect the pipes, minimizing the need to rehabilitate the support for pipe protection. Installation of the sand slurry backfill could either be completed through a tremie-style method by pumping through a pipe into the Conveyor Adit, or pumped through holes drilled down into the adit from the Main Haulage and / or the ground surface. Both of these installation methods also minimize the amount of time workers need to be within the Conveyor Adit during construction.

c) Partial rehabilitation down the inclined raise to the location of the bulkhead; no rehabilitation would occur from the bulkhead to the adit portal on the basis that access is carefully controlled and limited during the period of construction. This section of the adit would be backfilled with a sand similar to that outlined above for option b.

   An advantage to this option is the minimal requirements for remediation of the Conveyor Adit. This is due to construction access being possible at the "upstream" side of the bulkhead wall, through the raise from the Main Haulage at the end of the adit. As the proposed bulkhead location within the adit is approximately 85 m away from the raise in mostly fair and good quality rock, this is considered a feasible method of construction access.

3.2 Option 2: Plug Conveyor Adit and Re-direct Flow

This option would consist of sealing the Conveyor Adit with a concrete bulkhead, thereby diverting the majority of water flowing out of the underground workings to the Main Haulage, where a similar plug to that described in Option 1 would be constructed to convey water out of the tunnel. This would allow drainage out of the Main Haulage, but prevent ingress. Additionally, a dry plug at the Conveyor Adit would be constructed that would prevent ingress to the section of the adit between the surface and the bulkhead.

As the Main Haulage is approximately 40 m in elevation above the Conveyor Adit, the bulkhead in the Conveyor Adit must be designed to withstand this hydraulic pressure head. Using this criteria, a hypothetical bulkhead location has been calculated and presented in Section 3.2.1. A preliminary bulkhead design is presented in Section 3.2.2.

3.2.1 Potential Bulkhead Location

Because the Conveyor Adit is unlined, it is recommended that the bulkhead location be determined by considering the Norwegian Criteria for unlined hydropower tunnels and shafts, along with an appropriate factor of safety (FS). The Norwegian Criteria is an accepted 'rule of thumb' for determining the extent of unlined pressure tunnels in good, competent rock. The Criteria is based on maintaining suitable overburden thickness above the tunnel to resist the water pressure within the tunnel, preventing hydro-fracturing and potential leakage; its definition is as follows (Broch, 2014):

$$(4)\quad L > \frac{\gamma_w H}{\gamma_r \cos\beta}$$

Where:

- L is the recommended overburden thickness (shortest distance between the surface and the point studied)
- γ_w is the unit weight of water (taken to be 9.81 kN/m^3)
- H is the hydraulic head at the point studied (in this case approx. 40 m throughout the length of the adit)
- γ_r is the unit weight of the rock mass
- β is the slope of the average ground surface above the tunnel

The Norwegian Criteria is an empirical system, based on observations of failure or leakages in tunnels through massive, competent rock in Norway; therefore it is not directly applicable to all unlined tunnels. At the Cantung Mine, it is recommended that this Criteria be used with a FS of 1.5, and that the unit weight of the rock be considered as the buoyant unit weight. The factor of safety of 1.5 is typically applied for geotechnical applications to account for geotechnical uncertainty and is considered good practice. The final, major unknown with regards to the bulkhead design and use of the Norwegian Criteria is the appropriate ground surface profile to use. Ideally, an average bedrock profile would be used, but there is limited information available in that regard.

Using a conservative estimate for the adjusted average ground surface yields a bulkhead location that is at least 182 m into the adit from the portal. Using the actual ground surface profile gives a bulkhead location that is 100 m from the portal. Figure 2 shows a ground surface profile above the Conveyor Adit, along with the proposed bulkhead location.

During the 2018 site inspection, Tetra Tech identified a suitable location for a bulkhead within the Conveyor Adit at 470 to 480 m from the portal. At this location, NGI-Q values of 15 were observed, indicating good, competent rock. In particular, very little water was noted at this location. Due to this distance being greater than the minimum distances found with the Norwegian Criteria using the actual and adjusted ground surfaces, as well as the favourable rock mass conditions observed, this is considered to be an appropriate location for a bulkhead in the Conveyor Adit.

3.2.2 Bulkhead Design

Three generally accepted methods for calculating the appropriate bulkhead length exist, and the chosen value should be the maximum of the three (Benson, 1989):

- Using a length to height ratio of 1.5 (5);
- Considering the hydraulic gradient of the rock mass to determine a length that prevents seepage around the plug (6); and
- Designing a length with appropriate shear resistance to withstand the water pressure on the upstream face (7).

Calculations for determining the length of the bulkhead are performed using the following formulas:

$$(5)\ L = 1.5 \cdot h \qquad (6)\ L = \frac{H_w}{I} \qquad (7)\ L = \frac{FS \cdot \gamma_w \cdot H_w \cdot A}{c \cdot P_u}$$

Where:

L is the length of the bulkhead

h is the height of the tunnel

H_w is the water head at the upstream face

I is the hydraulic gradient in the rock mass, estimated using Table 7 in Benson (1989)

FS is the factor of safety, commonly 1.5

γ_w is the unit weight of water, 9.81 kN/m^3

A is the cross-section area of the tunnel

c is the allowable shear stress at the concrete-rock interface, estimated using Table 7 in Benson (1989)

P_u is the perimeter length of the plug at the concrete-rock interface

Using Table 7 in Benson (1989) and the values for a ‘moderate to weak, moderately jointed’ rock mass and the maximum of Equations 4 and 5 the recommended minimum bulkhead length is 5 m, given using the seepage method. Since this is a permanent installation with no intended future maintenance, it is recommended that additional shear resistance should be added to the bulkhead by installing 2 m long rock bolts that protrude 1 m from the face at a spacing of 1.5 m. Additionally, installing a grout curtain on the upstream side of the bulkhead is suggested. These preliminary designs should be reviewed by a qualified structural engineer before finalization.

3.3 Options Assessment

At this time we understand that Options 1a and 1b are preferred. With respect to Option 2, water management outside of the Main Haulage portal would be required to direct the increased volumes of water flowing out. Furthermore, the uncontrolled collapse or blow-out of a pressurized concrete plug in the Conveyor Adit might lead to serious consequences, and the release of sediment and water of unknown quality downstream of the Conveyor Adit.

With respect to Option 1c, we understand that to manage access to the Conveyor Adit through a risk assessment and management plan, and thereby only rehabilitate the adit partially, might put too much risk on the Contractor and jeopardize the health and safety of the workers.

This report therefore presents in more detail the work involved in pursuing Options 1a and 1b.

4.0 CONVEYOR ADIT REHABILITATION

The amount and extent of rehabilitation works required in the Conveyor Adit will depend on which of the options is chosen to proceed with to detailed design, Option 1a, or 1b. The following sub-sections describe the required rehabilitation work for the Conveyor Adit based on these two options.

4.1 Access Through Conveyor Adit

Construction of the bulkhead wall described in Option 1 would require the transportation of materials, equipment, and workers to its location from either the Conveyor Adit portal, or from the Main Haulage down the inclined raise. For both methods of access, rehabilitation of the Conveyor Adit portal would be required as the current support system is inadequate and in disrepair. Without rehabilitation of the tunnel, exposure of workers to poor rock conditions, rock fall, and other safety hazards would be unacceptable.

The NGI Q-system provides tunnel support recommendations based on the span of the excavation, the excavation support ratio (ESR), and the Q-rating. The Q-rating system is described in Section 3.0, and a summary of the Q-values for the Conveyor Adit is shown in Figure 2. The difference between Options 1a and 1b is the permanency of the support installed (temporary or long term support). The lifetime of the support installed can be assessed using the ESR function which is part of the Q-system analysis.

The ESR is a correction factor for the tunnel span based on its intended use. The recommended support category is determined using this correction factor. According to the NGI-Q Handbook (2015) an ESR value of 0.5 is for, "very important caverns and underground openings with a long lifetime, approximately 100 years or without access for maintenance"; while an ESR of 1.6 is for, "permanent mine openings, water tunnels for hydro power, water supply tunnels, pilot tunnels, drifts and headings for large openings". Depending on which ESR is used, support categories recommended along the Conveyor Adit will vary.

Within the Conveyor adit each of the sections having a different Q-value represents a different domain. The Rock Mass Quality and Rock Support Chart used to determine which support category the Conveyor Adit domains fall into is shown in Figure 4.

Tables 4.1-1 and 4.1-2 below summarize the meterage and percent distribution of the Conveyor Adit which fall into each support category for ESR values of both 0.5 (permanent support) and 1.6 (temporary support). Figure 3 contains diagrams presenting the support for each category in the tables below.

Table 4.1-1: Conveyor Adit Support Category Distribution for ESR=0.5 Permanent Support

ESR=0.5	Increasing level of support required →									
	Support Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Minimum Q	**Meterage**	45	0	367	0	59	0	95	0	0
	%	8%	0%	65%	0%	10%	0%	17%	0%	0%
Mean Q	**Meterage**	**45**	**0**	**367**	**0**	**154**	**0**	**0**	**0**	**0**
	%	**8%**	**0%**	**65%**	**0%**	**27%**	**0%**	**0%**	**0%**	**0%**
Maximum Q	**Meterage**	75	0	337	0	154	0	0	0	0
	%	13%	0%	60%	0%	27%	0%	0%	0%	0%

Table 4.1-2: Conveyor Adit Support Category Distribution for ESR=1.6 Temporary Support

ESR=1.6	Increasing level of support required →									
	Support Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Minimum Q	**Meterage**	412	0	59	0	95	0	0	0	0
	%	73%	0%	10%	0%	17%	0%	0%	0%	0%
Mean Q	**Meterage**	**412**	**0**	**59**	**95**	**0**	**0**	**0**	**0**	**0**
	%	**73%**	**0%**	**10%**	**17%**	**0%**	**0%**	**0%**	**0%**	**0%**
Maximum Q	**Meterage**	412	0	59	95	0	0	0	0	0
	%	73%	0%	10%	17%	0%	0%	0%	0%	0%

Mean Q values were used to determine quantities of support materials required for remediation. As summarized above, with an ESR of 0.5 for permanent support, 45 m of the Conveyor Adit requires Category 1 support, 367 m requires Category 3 support, and 154 m requires Category 5 support.

With an ESR of 1.6 for temporary support, this changes to 412 m requiring Category 1 support, 59 m requiring Category 3 support, and 95 m requiring Category 5 support.

Using the support categories found using the Mean Q values, support quantities to remediate the Conveyor Adit were assessed for both an ESR of 0.5 and 1.6. These quantities are summarized in Tables 4.1-3 and 4.1-4 below. It should be noted that the bolt type varies based on the assigned ESR; fully grouted 1.8 m long Expansion Shell Anchors are more appropriate for long term applications, compared to 1.5 m long Super Swellex Bolts for temporary applications.

Table 4.1-3: Conveyor Adit Rehabilitation Quantities for ESR=0.5 Permanent Support

Item	Quantity
Dry Mix Shotcrete (cu m)	290
Welded Wire Mesh (panels)	868
Steel Split Sets (pieces)	8683
Expansion Shell Anchors (m)	500

Table 4.1-4: Conveyor Adit Rehabilitation Quantities for ESR=1.6 Temporary Support

Item	Quantity
Dry Mix Shotcrete (cu m)	110
Welded Wire Mesh (panels)	257
Steel Split Sets (pieces)	2567
Super Swellex Bolts (m)	289

Assigned support categories and quantities for Conveyor Adit rehabilitation will be revised based on the appropriate ESR and option for underground water management selected in the detailed design stage.

4.2 Inclined Raise Rehabilitation

The integrity and stability of the inclined raise is considered important as it serves to drain the Main Adit and is equally important for long-term water management. The inclined raise could also be used as an access point to gain entry to the Conveyor Adit for rehabilitation and construction of the bulkhead wall.

With this method, materials would be brought in through the Main Haulage and down the raise to the Conveyor Adit. As the majority of the access would be through the Main Haulage, this option might require lesser amounts of rehabilitation of the Conveyor Adit. However, some work will be necessary at the raise.

Due to the orientation of the raise and anticipated high exposure time of workers during construction, using welded wire mesh and shotcrete along the raise's crown down to the invert is considered necessary. NGI-Q Category 5 support requirements for rock bolts were also assumed for the raise.

Support quantities for the raise using ESR values of 0.5 and 1.6 are presented in Tables 4.2-1 and 4.2-2 below.

Table 4.2-1: Raise Rehabilitation Quantities for ESR=0.5 Permanent Support

Item	Quantity
Sprayed Concrete cu m	54
Welded Wire Mesh (panels)	167
Steel Split Sets	2666
Rock Bolts (m)	103

Table 4.2-2: Raise Rehabilitation Quantities for ESR=1.6 Temporary Support

Item	Quantity
Sprayed Concrete cu m	54
Welded Wire Mesh (panels)	167
Steel Split Sets	2666
Rock Bolts (m)	86

5.0 KEY CONSTRUCTABILITY ISSUES AND RISKS

Some key constructability issues exist with the installation of a bulkhead in the Conveyor Adit. These risks include a collapse of the Conveyor Adit. Collapse would likely result in damage of the pipes and uncontrolled water flows. The proposed construction options minimize this risk by supporting the Conveyor Adit and protecting the pipes. With Option 1b, the backfill will be installed to completely fill the adit, so if collapse was to occur the backfill will support the excavation and protect the pipes. With Option 1a, the existing support system will be rehabilitated and additional support will be installed. This minimizes the likelihood of the existing support system failing in a collapse.

Another key design consideration is the potential for water to freeze in the pipes. When water freezes, an ice plug may potentially form in the pipes, resulting in an upstream pressure buildup and potential failure of the pipe. To minimize freezing occurring within the pipes in the Conveyor Adit, backfilling is recommended for insulating purposes, even if permanent support is installed. The pipe configuration in terms of elevation levels will also be altered such that all of the pipe is filled with water, the thermal mass and constant movement of the water should help to prevent freezing.

One other consideration is the deposition of fine sediment within the pipe. At the locations where the pipe is not filled with water this issue could be minimized by using oval-shaped pipes, which by virtue of their shape are self-cleaning (similar to those used in some sewer systems). This shape of pipe promotes flowing water, even in low-flow circumstances. To maintain continuous pipe flow conditions through the winter, a preliminary thermal analysis is recommended as part of detailed design to determine the level of insulation that would be required for the proposed pipes.

6.0 COST ESTIMATE

This section of the report presents cost estimates for the different stabilization options presented in the preceding sections. It should be appreciated that these estimates are solely to assist in the qualitative comparison of the options presented.

Based on the differing quantities and type of support, at this stage, the estimated cost to remediate the inclined raise at the end of the Conveyor Adit ranges from **$381,700 to $397,129** and the estimated cost to remediate the full length of the Conveyor Adit (Options 1a and 1b) ranges from **$664,594 to $1,829,010** (for temporary or permanent support respectively).

Tables 6.0-1 and 6.0-2 below present the cost estimates to rehabilitate the Conveyor Adit raise. Tables 6.0-3 and 6.0-4 present the cost estimates to rehabilitate the Conveyor Adit as part of Options 1a and 1b.

Table 6.0-1: Raise Remediation Cost Estimate for ESR=0.5 Permanent Support

Item	Quantity	Unit Rate	Cost
Sprayed Concrete cu m	54	$ 4,000.00	$ 216,000.00
Welded Wire Mesh (panels)	167	$ 40.00	$ 6,666.00
Steel Split Sets	2666	$ 50.00	$ 133,320.00
Rock Bolts (m)	103	$ 400.00	$ 41,143.00
		Total	**$ 397,129.00**

Table 6.0-2: Raise Remediation Cost Estimate for ESR=1.6 Temporary Support

Item	Quantity	Unit Rate	Cost
Sprayed Concrete cu m	54	$ 4,000.00	$ 216,000.00
Welded Wire Mesh (panels)	167	$ 40.00	$ 6,666.00
Steel Split Sets	2666	$ 50.00	$ 133,320.00
Rock Bolts (m)	86	$ 300.00	$ 25,714.00
		Total	**$ 381,700.00**

Table 6.0-3: Option 1a – Conveyor Adit Remediation Cost Estimate for ESR=0.5 Permanent Support

Item	Quantity	Unit Rate	Cost
Dry Mix Shotcrete (cu m)	290	$ 4,000.00	$ 1,159,950.00
Welded Wire Mesh (panels)	868	$ 40.00	$ 34,733.33
Steel Split Sets (pieces)	8683	$ 50.00	$ 434,166.67
Expansion Shell Anchors (m)	500	$ 400.00	$ 200,160.00
		Total	**$ 1,829,010.00**

Table 6.0-4: Option 1b – Conveyor Adit Remediation Cost Estimate for ESR=1.6 Temporary Support

Item	Quantity	Unit Rate	Cost
Dry Mix Shotcrete (cu m)	110	$ 4,000.00	$ 439,350.00
Welded Wire Mesh (panels)	257	$ 40.00	$ 10,266.67
Steel Split Sets (pieces)	2567	$ 50.00	$ 128,333.33
Super Swellex Bolts (m)	289	$ 300.00	$ 86,644.29
		Total	**$ 664,594**

*Note: Mobilization and demobilization costs are not included in unit prices. It should be noted that quantities and unit rate for welded wire mesh is based on a price per panel with 8 ft. by 4 ft. dimensions. In addition, quantities and unit prices for steel split sets were estimated assuming that split sets come in 0.5 m long pieces. Sprayed concrete rebound of 25% was also accounted for in the estimates.

7.0 CONCLUSIONS AND RECOMMENDATIONS

At this stage, Tetra Tech recommends Option 1b for underground water management at the Cantung Mine. This option would utilize the raise at the end of the Conveyor Adit for access during construction. Furthermore, due to the anticipated less complex construction of Option 1b, this also minimizes the extent of rehabilitation of the Conveyor Adit to temporary support levels, and ultimately reduces costs. However, installing a support system in the raise at the end of the Conveyor Adit is still recommended as part of Option 1b. The presented rehabilitation costs for construction will be further refined as part of detailed design once A&M and CIRNAC confirm and agree with the water management options outlined in this report.

As part of detailed design, quantities and associated costs for either the backfill or bulkhead water management options will be developed and refined. Tetra Tech will work with on-site personnel at the Cantung Mine to determine cost-saving opportunities, such as utilizing waste rock for backfill material and other construction materials which may already exist on site. However, at this stage, it is anticipated that Option 1b will be more cost effective than the other options outlined in this report.

As previously mentioned, the underground workshop on the Main Haulage level of the mine was determined to be a suitable location for hazardous waste storage during the inspection and no rehabilitation work is anticipated at this stage due to the good rock mass quality and pillar stability.

Specific next steps in the detailed design process are outlined below:

- Finalize design of temporary support in the Conveyor Adit, and support in the inclined raise.
- Design bulkhead wall (to withstand a nominal water pressure) within the Conveyor Adit and main haulage.
- Consider support around the location or other vertical raises (crusher and unidentified raise) within the Conveyor Adit, such that these locations remain stable.
- Finalize the design of water piping and a surface water spill pond to permanently submerge the pipe for the first several hundred metres from the portal.
- Carry out thermal assessment and analysis to verify whether water will or will not freeze.
- Consider sediment build up within the pipe system and methods of mitigating this issue. Pipes should be “self cleaning”.
- Design backfill locations and methods within the Conveyor Adit so that collapse does not affect the integrity of the pipe (and to assist with insulation).
- Develop closure plan for storage of hazardous material in the workshop.

8.0 LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Alvarez & Marsal (A&M) and Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) and their agents. Tetra Tech Canada Inc. (Tetra Tech) 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 (A&M) and CIRNAC, 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 document is subject to the Limitations on the Use of this Document attached in Appendix A or Contractual Terms and Conditions executed by both parties.

9.0 CLOSURE

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

Respectfully submitted,
Tetra Tech Canada Inc.

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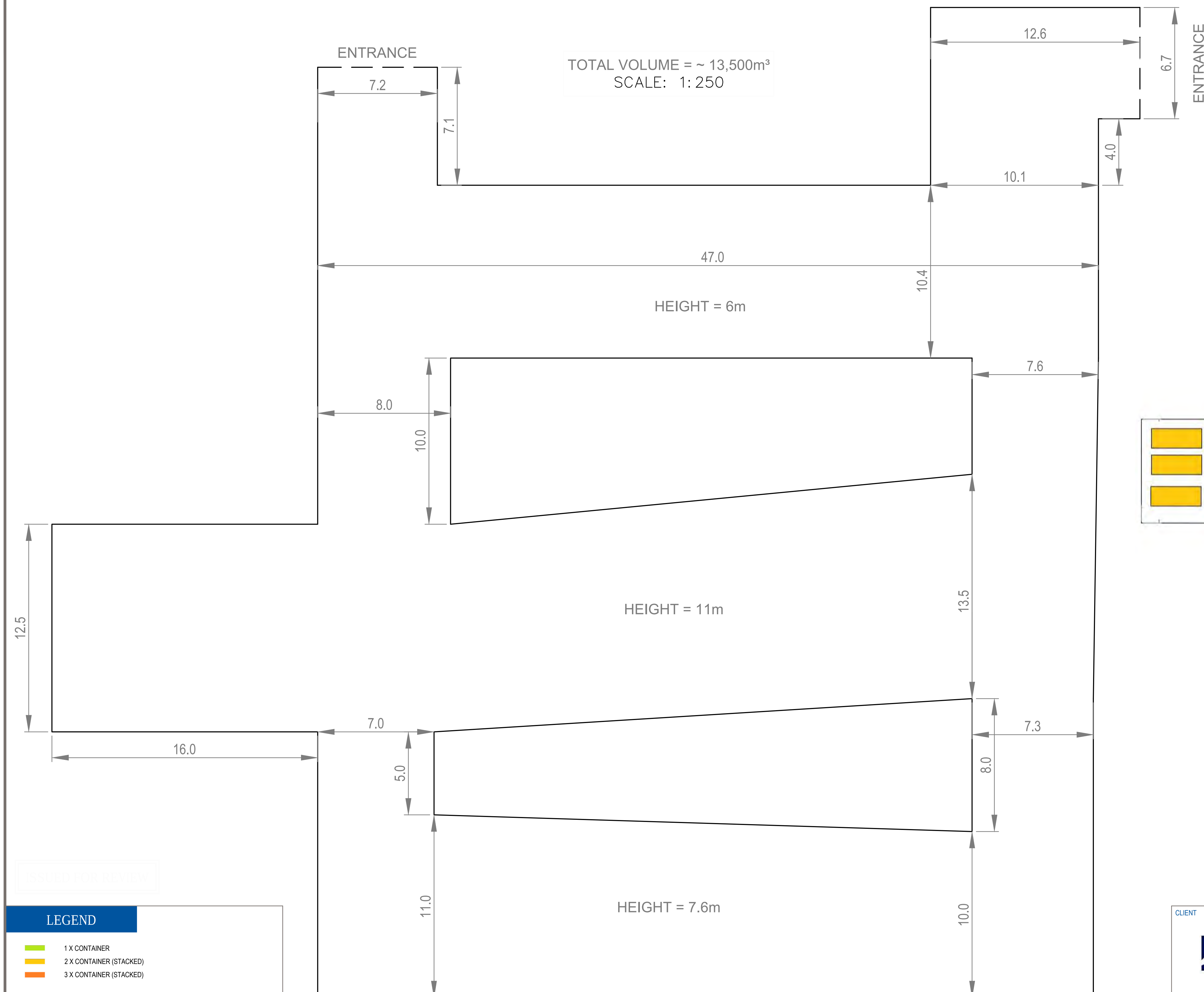
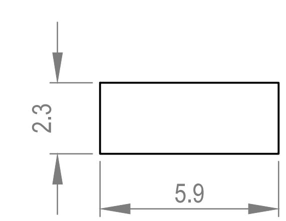
FIGURES



NOTE:

- 20ft CONTAINER = 6.1m X 2.44m X 2.59m
- IN SOME LOCATIONS CONTAINERS CAN BE STACKED 2 - 3 HIGH.
- INTERNAL VOID SPACE OF EACH CONTAINER = 5.9m X 2.35m X2.38m



212 CONTAINERS INTERNAL VOID SPACE = 6,995m³

LEGEND

- 1 X CONTAINER
- 2 X CONTAINER (STACKED)
- 3 X CONTAINER (STACKED)

NOTES
ALL UNITS IN METRES UNLESS OTHERWISE STATED

CLIENT

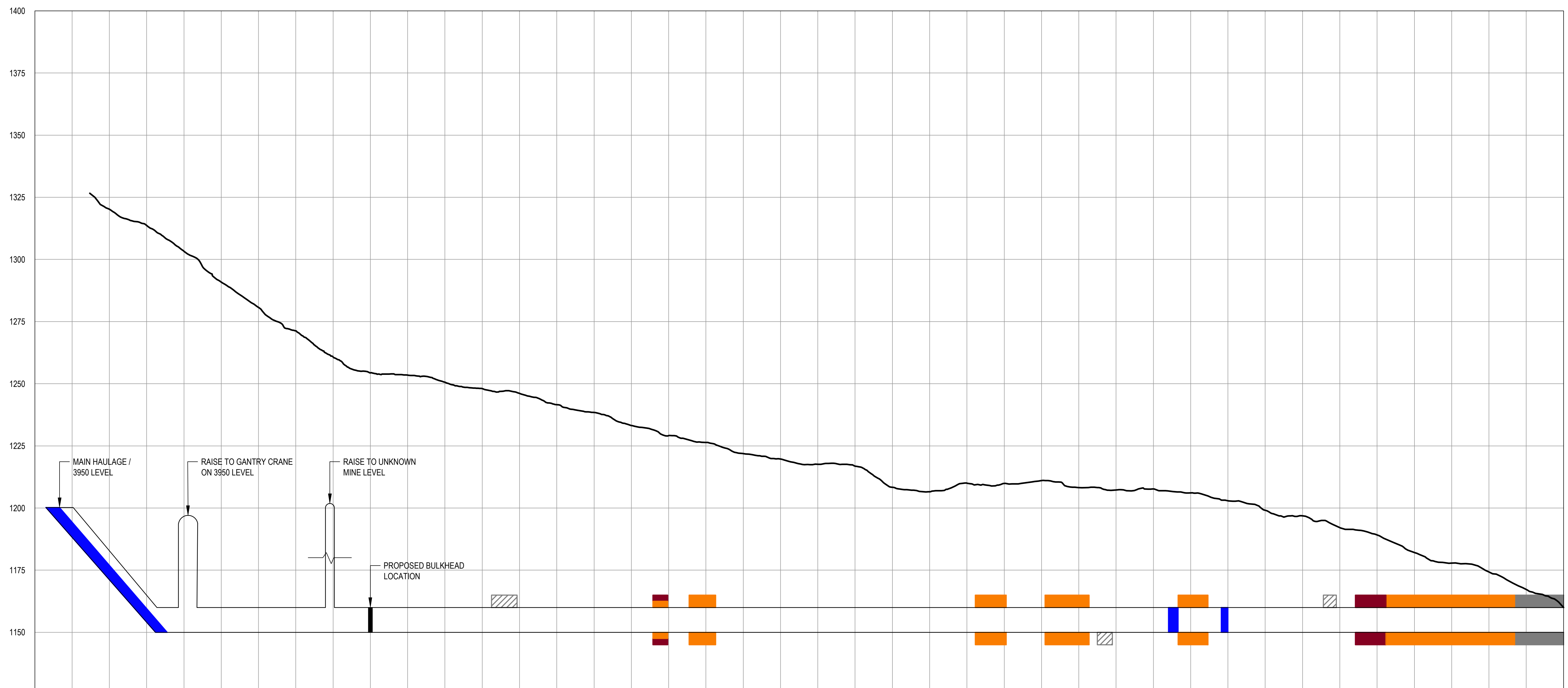
NORTH AMERICAN TUNGSTEN CORPORATION LTD

CANTUNG MINE

TETRA TECH

PROJECT NO.	DWN	CKD	REV
ENW.WENW03039-03	EW	LT	0
OFFICE	DATE		
VANC	NOVEMBER 2018		

FIGURE 1



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MIN Q		6.67	1.85	7.50	25.00	5.00	2.08	10.00	3.61	7.08	2.92	0.44	0.03
MAX Q		13.33	4.17	15.00	25.00	5.00	2.08	11.11	5.42	14.17	2.92	0.44	0.33
MEAN Q		10.00	3.01	11.25	25.00	5.00	2.08	10.56	4.51	10.633	2.92	0.44	0.18
CLASS DESCRIPTION		FAIR	POOR	GOOD	GOOD	FAIR	POOR	GOOD	FAIR	GOOD	POOR	VERY POOR	VERY POOR
ESR = 1.5 SUPPORT CATEGORY		1	1	1	1	1	1	1	1	1	1	3	4
ESR = 0.5 SUPPORT CATEGORY		3	3	3	1	3	3	3	3	3	3	5	5

LEGEND

- REMUCK BAY
- CONCRETE
- STEEL SETS
- TIMBER SETS
- WATER INFLOW

NOTES
ROCK MASS QUALITY & SUPPORT CLASSES ASSIGNED BASED ON MEAN Q VALUES.

SCALE: NTS

ISSUED FOR USE

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TETRA TECH

CANTUNG MINE

NGI-Q VALUES ALONG CONVEYOR ADIT ALIGNMENT

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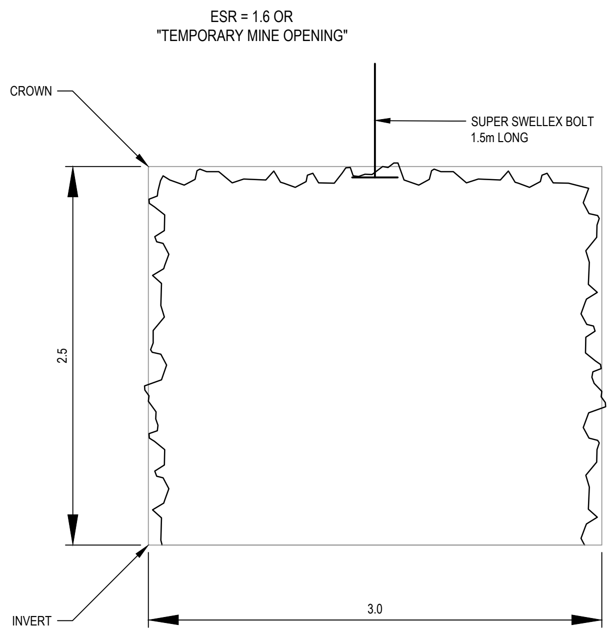
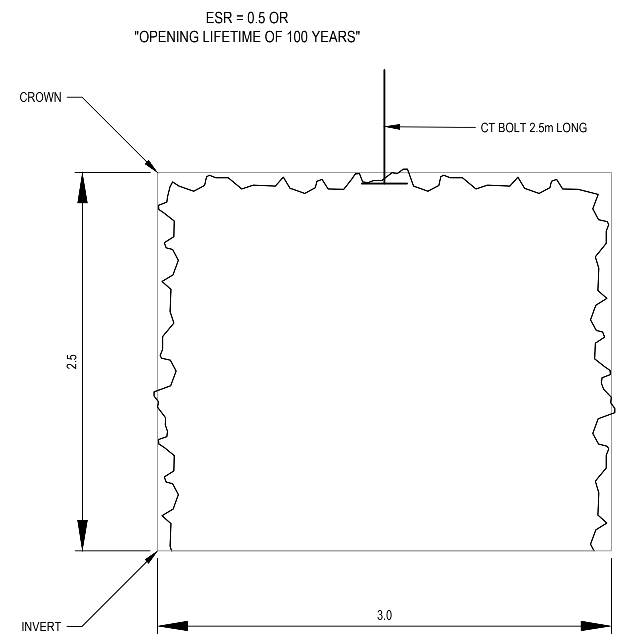
ENW.WENW03039-03	EW	LT	0

OFFICE	DATE
VANC	NOVEMBER 2018

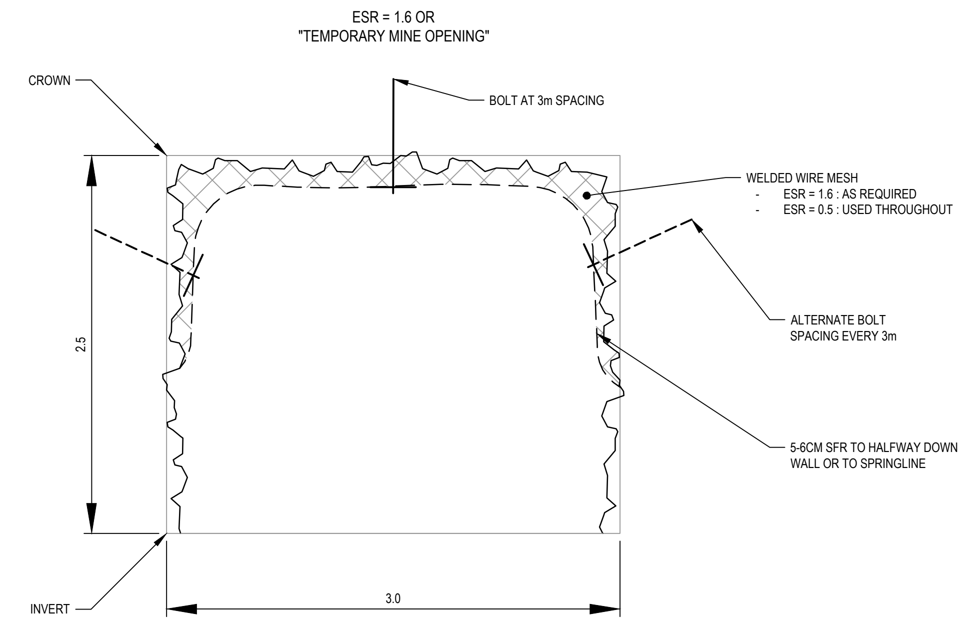
FIGURE 2





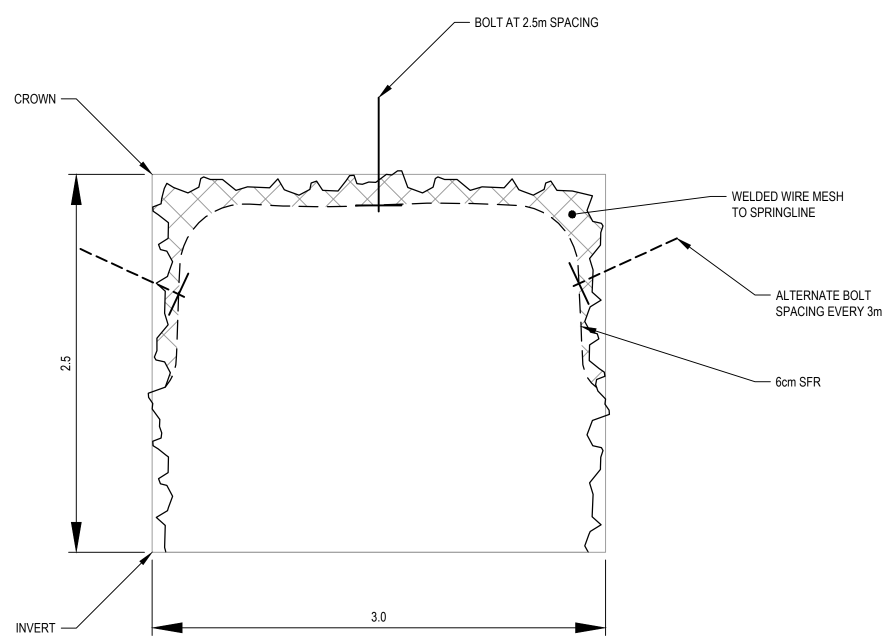
SUPPORT CATEGORY 1

- SPOT BOLT AND SCALING
- ASSUME 1 BOLT EVERY 5m

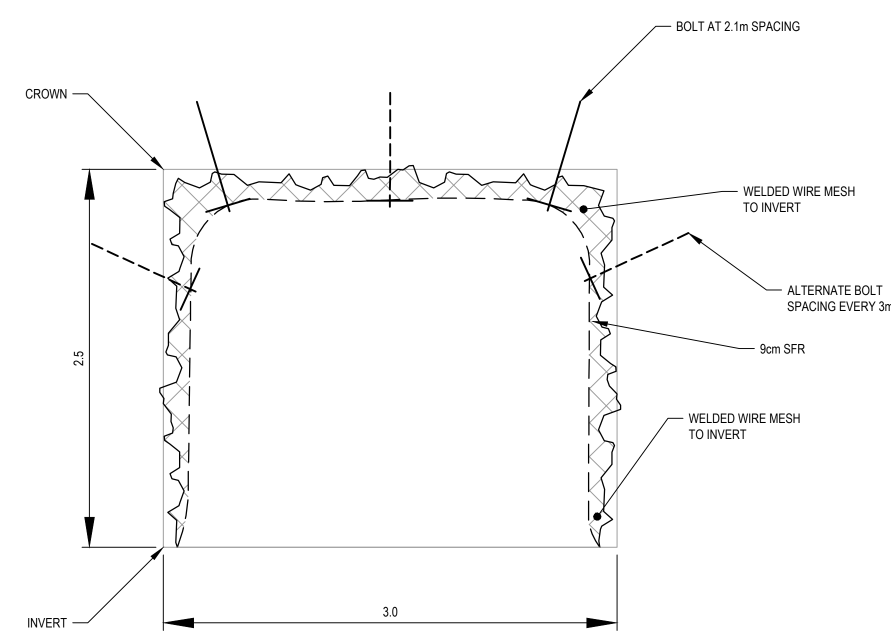


SUPPORT CATEGORY 3

- SFR = FIBRE REINFORCED SPRAYED CONCRETE



SUPPORT CATEGORY 4



SUPPORT CATEGORY 5

NOTE:
1. IN THE TEMPORARY CASE (ESR = 1.6) ROCK BOLTS ARE TO BE SUPER SWELLEX 1.5m LONG.
2. IN THE PERMANENT CASE (ESR = 0.5) ROCK BOLTS ARE TO BE CT-BOLTS OR SIMILAR EXPANSION STEEL, GALVANIZED AND FULLY GROUTED BOLTS.
3. WHERE WELDED WIRE MESH IS USED IT WILL BE 4ft X 8ft X _ SECTION PANELS OVERLAP WILL BE ONE SQUARE OR GRID ROW. 0.5m LONG SPLIT SETS WILL BE USED TO SECURE MESH.

Chainage (m)	Length (m)	Mean Q	ESR=1.6 Support Class	ESR=0.5 Support Class
0-18	18	0.18	5	7
18-70	52	0.18	5	7
70-82	12	0.18	5	7
82-95	13	0.18	5	7
95-140	45	0.44	3	5
140-154	14	0.44	3	5
154-180	26	2.92	1	3
180-190	10	10.63	1	3
190-207	17	4.51	1	3
207-223	16	4.51	1	3
223-235	12	4.51	1	3
235-285	50	4.51	1	3
285-340	55	10.56	1	3
340-365	25	2.08	1	3
365-435	70	5.00	1	3
435-470	35	25.00	1	1
470 - 480	10	25.00	1	1
480-500	20	11.25	1	3
500-515	15	3.01	1	3
515-566	51	6.60	1	3

LEGEND

NOTES
-

0 2.5
Scale: 1: 50 (metres)

ISSUED FOR USE

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CANTUNG MINE

NGI-Q SUPPORT CATEGORIES

PROJECT NO.	DWN	CKD	REV
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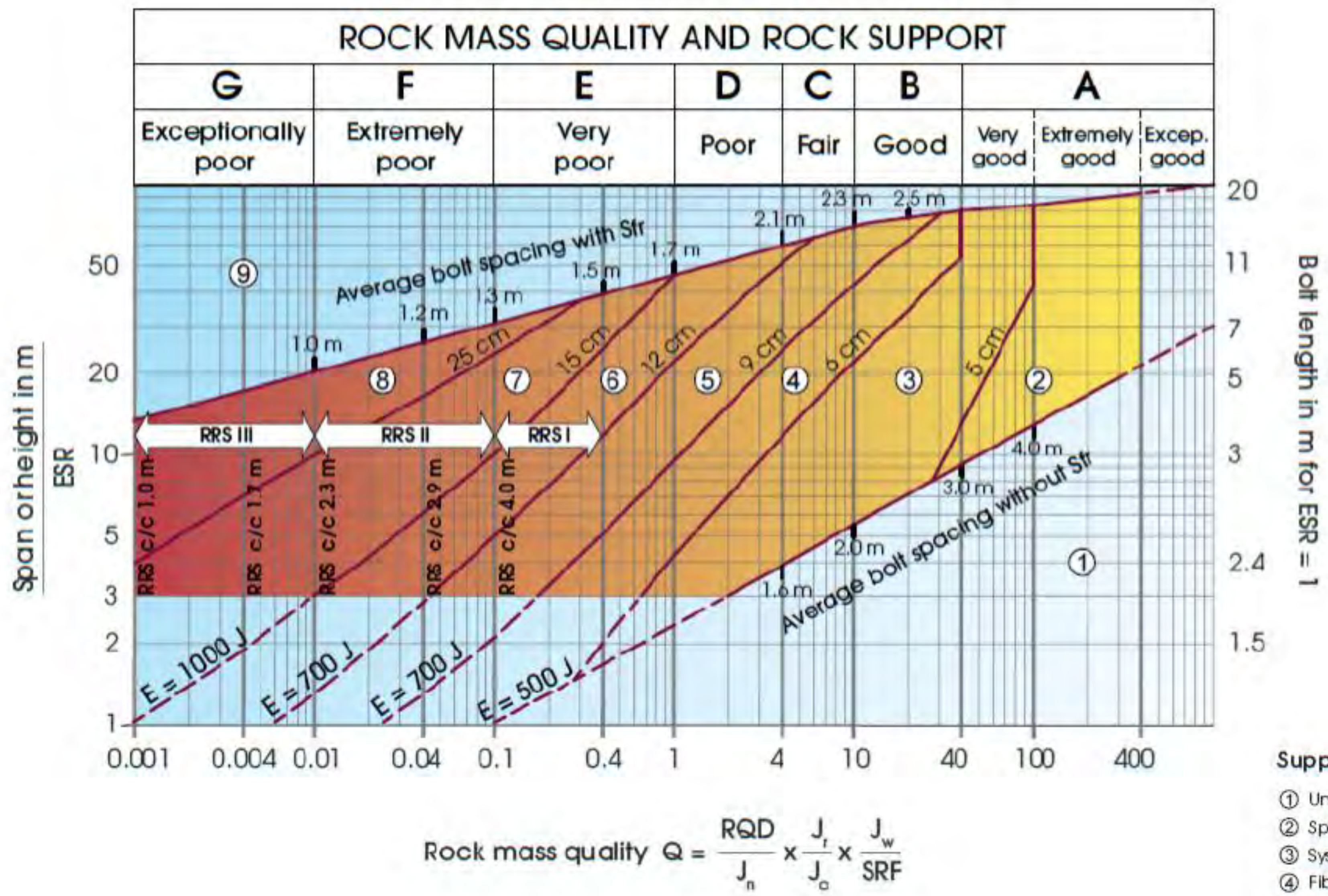
OFFICE: VANC
DATE: NOVEMBER 2018

FIGURE 3



Support categories

1. Unsupported or spot bolting
2. Spot bolting, **SB**
3. Systematic bolting, fibre reinforced sprayed concrete, 5-6 cm, **B+Sfr**
4. Fibre reinforced sprayed concrete and bolting, 6-9 cm, **Sfr (E500)+B**
5. Fibre reinforced sprayed concrete and bolting, 9-12 cm, **Sfr (E700)+B**
6. Fibre reinforced sprayed concrete and bolting, 12-15 cm + reinforced ribs of sprayed concrete and bolting, **Sfr (E700)+RRS I +B**
7. Fibre reinforced sprayed concrete >15 cm + reinforced ribs of sprayed concrete and bolting, **Sfr (E1000)+RRS II+B**
8. Cast concrete lining, **CCA** or **Sfr (E1000)+RRS III+B**
9. Special evaluation

Bolts spacing is mainly based on Ø20 mm

E = Energy absorbtion in fibre reinforced sprayed concrete

ESR = Excavation Support Ratio

Areas with dashed lines have no empirical data

RRS - spacing related to Q-value

I: **Si30/6 Ø16 - Ø20 (span 10m)**
D40/6+2 Ø16-20 (span 20m)

II: Si35/6 Ø16-20 (span 5m)
D45/6+2 Ø16-20 (span 10m)
D55/6+4 Ø20 (span 20m)

III: D40/6+4 Ø16-20 (span 5 m)
D55/6+4 Ø20 (span 10 m)
Special evaluation (span 20 m)

Si30/6 = Single layer of 6 rebars, 30 cm thickness of sprayed concrete

D = Double layer of rebars

Ø16 = Rebar diameter is 16 mm

c/c = RRS spacing, centre - centre

LEGEND

Reproduced from NGI, 2015

NOTES

STATUS

ISSUED FOR USE

CLIENT

NORTH AMERICAN TUNGSTEN CORPORATION LTD

TETRA TECH

CANTUNG MINE

ROCK MASS QUALITY AND ROCK SUPPORT CHART

PROJECT NO.	DWN	CKD	APVD	REV
ENW.WENW03039-03	LT	CH	CH	01

OFFICE	DATE
VANC	November, 2018

Figure 4

PHOTOGRAPHS

Photo 1: Workshop

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Photo 2: Workshop entrance shutter door 1.

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Photo 3: Workshop entrance shutter door 2

Photo 4: Jointing visible on workshop wall

Photo 5: Changing/locker room entrance to workshop

Photo 6: Looking down inclined raise from Main Haulage to Conveyor Adit

Photo 7: Overview of entrance to inclined raise down to Conveyor Adit

Photo 8: Inclined raise from Conveyor Adit to Main Haulage

Photo 9: Ladder leading to crusher point raise

Photo 10: Looking up crusher point raise

Photo 11: Raise to unknown mine level at 495 m

Photo 12: Recommended Bulkhead Location in Conveyor Adit (470 to 480 m)

Photo 13: Rock mass at Recommended Bulkhead Location in Conveyor Adit (470 to 480 m)

Photo 14: Rock mass at Recommended Bulkhead Location in Conveyor Adit (470 to 480 m)

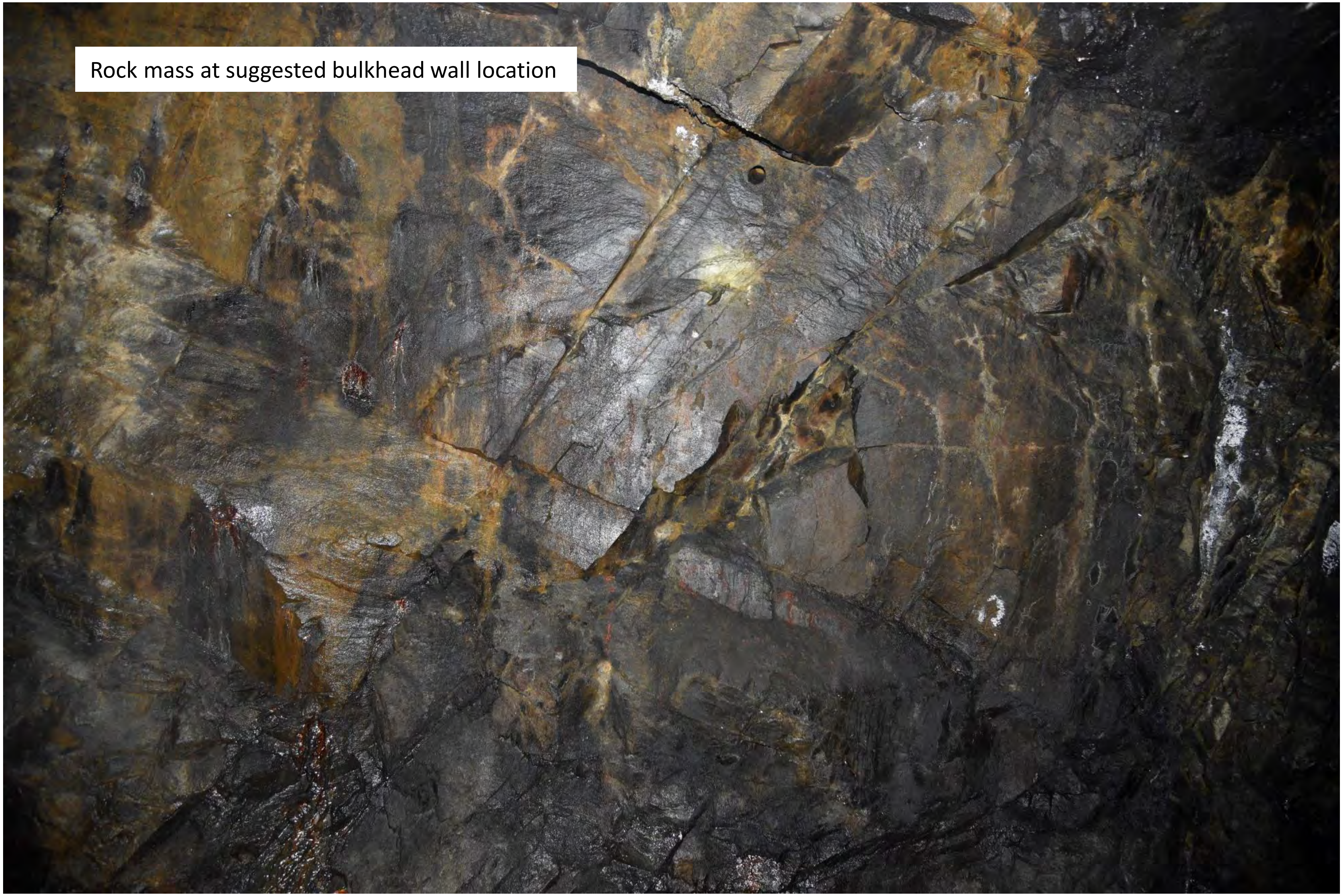

Photo 15: Rock mass at Recommended Bulkhead Location in Conveyor Adit (470 to 480 m)

Photo 16: Deteriorating timber and steel sets

Photo 17: Highly corroded steel sets

Photo 18: Station 340 m

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Photo 19: Steel sets from 223 to 235 m.

Photo 20: Steel sets from 196 to 207 m.

Photo 21: Water inflow temperature measurement at 157 m

Photo 22: Water inflow temperature measurement at 154 m

Photo 23: Timber lattice above timber sets.

Photo 24: Degrading timber set connection

Photo 25: Current condition of timber and steel sets

Photo 26: Steel sets with timber blocking at 70 m

Photo 27: Highly corroded and deteriorated steel sets.

Photo 28: Failure from adit crown at 35 m

Photo 29: Failure from adit wall in wooden catchment from 20 to 30 m

APPENDIX A

TETRA TECH'S LIMITATIONS ON THE USE OF THIS DOCUMENT

LIMITATIONS ON USE OF THIS DOCUMENT

GEOTECHNICAL

1.1 USE OF DOCUMENT AND OWNERSHIP

This document pertains to a specific site, a specific development, and a specific scope of work. The document may include plans, drawings, profiles and other supporting documents that collectively constitute the document (the "Professional Document").

The Professional Document is intended for the sole use of TETRA TECH's Client (the "Client") as specifically identified in the TETRA TECH Services Agreement or other Contractual Agreement entered into with the Client (either of which is termed the "Contract" herein). TETRA TECH does not accept any responsibility for the accuracy of any of the data, analyses, recommendations or other contents of the Professional Document when it is used or relied upon by any party other than the Client, unless authorized in writing by TETRA TECH.

Any unauthorized use of the Professional Document is at the sole risk of the user. TETRA TECH accepts no responsibility whatsoever for any loss or damage where such loss or damage is alleged to be or, is in fact, caused by the unauthorized use of the Professional Document.

Where TETRA TECH has expressly authorized the use of the Professional Document by a third party (an "Authorized Party"), consideration for such authorization is the Authorized Party's acceptance of these Limitations on Use of this Document as well as any limitations on liability contained in the Contract with the Client (all of which is collectively termed the "Limitations on Liability"). The Authorized Party should carefully review both these Limitations on Use of this Document and the Contract prior to making any use of the Professional Document. Any use made of the Professional Document by an Authorized Party constitutes the Authorized Party's express acceptance of, and agreement to, the Limitations on Liability.

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1.2 ALTERNATIVE DOCUMENT FORMAT

Where TETRA TECH submits electronic file and/or hard copy versions of the Professional Document or any drawings or other project-related documents and deliverables (collectively termed TETRA TECH's "Instruments of Professional Service"), only the signed and/or sealed versions shall be considered final. The original signed and/or sealed electronic file and/or hard copy version archived by TETRA TECH shall be deemed to be the original. TETRA TECH will archive a protected digital copy of the original signed and/or sealed version for a period of 10 years.

Both electronic file and/or hard copy versions of TETRA TECH's Instruments of Professional Service shall not, under any circumstances, be altered by any party except TETRA TECH. TETRA TECH's Instruments of Professional Service will be used only and exactly as submitted by TETRA TECH.

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

1.3 STANDARD OF CARE

Services performed by TETRA TECH for the Professional Document have been conducted in accordance with the Contract, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Professional Document. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Professional Document.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of TETRA TECH.

1.4 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

1.5 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Professional Document, TETRA TECH may have relied on information provided by third parties other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

1.6 GENERAL LIMITATIONS OF DOCUMENT

This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this document, at or on the development proposed as of the date of the Professional Document requires a supplementary exploration, investigation, and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, TETRA TECH has not been retained to explore, address or consider and has not explored, addressed or considered any environmental or regulatory issues associated with development on the subject site.

1.8 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems, methods and standards 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 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.

1.9 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.

1.10 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 historical environment. TETRA TECH 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 exploration and review may be necessary.

1.11 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.

1.12 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.

1.13 INFLUENCE OF CONSTRUCTION ACTIVITY

Construction activity can impact 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, and construction sequence are known.

1.14 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, and 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.

1.15 DRAINAGE SYSTEMS

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. Where temporary or permanent drainage systems are installed within or around a structure, these systems must protect the structure from loss of ground due to mechanisms such as internal erosion and must be designed so as to assure continued satisfactory performance of the drains. Specific design details regarding the geotechnical aspects of such systems (e.g. bedding material, surrounding soil, soil cover, geotextile type) should be reviewed by the geotechnical engineer to confirm the performance of the system is consistent with the conditions used in the geotechnical design.

1.16 DESIGN PARAMETERS

Bearing capacities for Limit States or Allowable Stress Design, strength/stiffness properties and similar geotechnical design parameters 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 used in this report. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions considered in this report in fact exist at the site.

1.17 SAMPLES

TETRA TECH 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.

1.18 APPLICABLE CODES, STANDARDS, GUIDELINES & BEST PRACTICE

This document has been prepared based on the applicable codes, standards, guidelines or best practice as identified in the report. Some mandated codes, standards and guidelines (such as ASTM, AASHTO Bridge Design/Construction Codes, Canadian Highway Bridge Design Code, National/Provincial Building Codes) are routinely updated and corrections made. TETRA TECH cannot predict nor be held liable for any such future changes, amendments, errors or omissions in these documents that may have a bearing on the assessment, design or analyses included in this report.