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PROJECT MEMORANDUM

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From:	**Holger Hartmaier (Ext. 113)**	**Date:**	**June 30,2004**
Subject:	**Rose Creek Diversion Channel- Closure Scenarios- Geotechnical Considerations**		
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This memorandum summarizes geotechnical considerations and assumptions made with respect to various closure scenarios for the Rose Creek Diversion Channel, located at the Faro Mine site, near Faro, Yukon.

1.0 BACKGROUND

As part of the long-term closure planning for the Anvil Range property, consideration was given to assessing the capacity of the Rose Creek Diversion Channel (RCDC) to handle extreme flood flows. The RCDC was originally designed to have a hydraulic capacity equivalent to a 50-year return period flood and contingency capacity for a 500-year return period flood, the latter assuming no freeboard. In 2001, Northwest Hydraulic Consultants Ltd. (**nhc**) completed a hydrotechnical assessment of the hydraulic capacity of the RCDC (**nhc**, December 2001) that included an estimate of the Probable Maximum Flood (PMF) at four locations along Rose Creek, and the Diversion Channel. One of the recommendations made in that report was to assess the existing conditions of the RCDC, specifically the channel geometry and condition and size of riprap protecting the channel bed and banks. In 2003 channel surveys were conducted (**nhc**, October 2003) and identified a segment of the existing RCDC channel dike that had insufficient freeboard to contain the 1:500 year design flood. Subsequently, as part of the current study, **nhc** re-interpreted the site hydrology and re-estimated the magnitude of the Probable Maximum Flood (PMF). A PMF flood peak of 730 m^3/s was adopted for the RCDC.

Upgrading the RCDC to convey the PMF flows requires consideration of the existing Down Valley Tailings facility, the condition of the existing channel and dike and the geotechnical foundation conditions. Within the context of this memorandum, only RCDC considerations (in concept) are provided.

Three scenarios were discussed in a teleconference call on October 31, 2003 between NHC, SRK and BGC:

- Scenario 1: Increase the size of the Rose Creek Diversion channel along the south side of the tailings facility to convey the PMF.
- Scenario 2: Abandon the RCDC downstream of the plug dam. From the plug dam, convey the PMF over the tailings (assume tailings are covered with a soil cover) in a swale lined with rip rap to the Intermediate dam pond, then over a new spillway by-passing the Intermediate and Cross Valley Dams.
- Scenario 3: Involves removal of tailings from the Original, Second and Intermediate Impoundment to El. 1042 m amsl. The Rose Creek PMF is directed into the tailings area immediately downstream of the Pumphouse Pond. The attenuated PMF passes over the spillway located at the Intermediate Dam.

For each scenario, passage of fish should be addressed.

2.0 EXISTING CONDITIONS

2.1 Rose Creek Diversion Channel

A contour plan generated by Yukon Engineering Services (YES) using survey data collected by YES during the summer of 2003 was used by NHC to create 39 cross-sections (**nhc**, 2003).

The RCDC can be subdivided into the following reaches, based on its hydraulic aspects:

- The furthest downstream reach from cross-section 0.5 to 3 (for section numbering and location, see Figure 2 in NHC, 2003) is a mildly sloped section below the rock drop weir section where the diversion flow returns into the natural Rose Creek channel.
- The rock drop weir section from cross-sections 3 to 9 is a steeply sloped section consisting of numerous rock weirs. This section compensates for the difference in grades between the RCDC (0.2%) and the original Rose Creek valley (2%).
- A mildly sloped section above the rock drop weir section from cross-sections 9 to 30, which was constructed in 1980 to divert Rose Creek around the expansion of the tailings facilities. A fuse plug dam (also known as the Diversion Dam) is located within the original Rose Creek channel between cross-sections 29-31.
- The upper end of the RCDC is a mildly sloped section that was in place prior to 1980 and is called the original diversion. This reach is located upstream of the fuse plug dam from cross-sections 30 to 39.

The RCDC extends for a total length of 3.6 km along the south valley wall of Rose Creek.

Assessment of the hydraulic capacity of the existing channel indicated the potential for overtopping of the right bank of the channel under the 500-year flood event. Additional sites where overtopping could occur were identified for the 500-year flood with 1.5 m of ice frozen to the channel. NHC (2003) estimated that raising of these low points would require 3200 m^3 of material.

Assessment of bed stability indicated that the rock drop weir section would be subject to full bed movement under 500-year flow conditions. The mildly sloped reaches upstream and downstream of the rock drop weir section would not be subject to bed movement. In the original diversion section, NHC recommended that field samples be obtained to confirm if the minimum bed D_{50} (median particle size) requirements are met.

Upgrading of rip rap was recommended in the rock drop weir section and in the mildly sloped section downstream to maintain bank stability under 500-year flow conditions. The mildly sloped section upstream of the rock drop weir was considered to have adequate bank protection for 500-year flow conditions, except for the original diversion, which likely needs upgrading (NHC, 2003).

No design information was available for the original diversion, upstream of the fuse plug dam. Design drawings and reports (Golder, 1980) are available for the reach downstream of the plug dam. Canal cross-sections shown on these drawings indicate that the following types of canal lining were utilized:

- Unlined channel in rock.
- Impervious lined channel to prevent seepage out of the RCDC.
- Thermal liner for protection of permafrost affected foundations.
- Canal outfall erosion protection downstream of the rock drop weir section.

In general, the channel profiles have a bottom width of 12.2 m, with side slopes of 2 Horizontal to 1 Vertical (2:1). According to the drawings, the canal dike on the right bank is constructed of rockfill, with a crest width that varies from 7.8 m to 11 m. The drawings show the presence of a waste pile along the outer toe of the dike of unspecified dimensions. Site staff have reported that the dikes are constructed of sand and gravel, however no information was available as to the “as-built” extent of each of these sections. In 2003, BGC conducted a photo documentation of the entire RCDC. Based on a review of these photos, bedrock was noted in the channel in the following locations:

- Between cross-sections (CS) 11 and 12
- Between CS 17 and 18
- Between CS 23 and 25
- Between CS 27 and 28

Further investigations are required to delineate the "as-built" details of the RCDC.

2.2 Tailings Disposal Facility

From upstream to downstream, the tailings facility consists of the following components:

- Original tailings impoundment.
- Second impoundment.
- Intermediate impoundment.
- Intermediate Dam
- Cross Valley Polishing Pond
- Cross Valley Dam

The RCDC was constructed to divert the flow of Rose Creek around the tailings facility. The original thalweg of Rose Creek lies under the tailings disposal area. The RCDC was constructed along the south valley slope of Rose Creek. Adjacent to the original channel upstream of the fuse plug dam (CS 31-39), the tailings level in the second impoundment is at about Elevation 1061-1062 m amsl and covers the original valley floor to a depth of about 13 m. Further to the right, the tailings level in the original impoundment is at about Elevation 1068.

The 2003 survey did not distinguish where the edge of the tailings disposal area was with respect to the outer toe of the RCDC dike. It was assumed that the tailings surface was located against the outer slope of the dike in the reach between CS 31-39.

Between CS 11 and CS 31, the dike lies adjacent to the Intermediate impoundment. The Intermediate pond is impounded against the Intermediate dam and lies adjacent to the RCDC dike in the reach between CS 11 and CS 14. Between CS 14 and CS 31, a narrow strip of ground separates the outer toe of the RCDC dike from the Intermediate tailings impoundment. Remnants of the former (pre-1980) Rose Creek channel are visible between CS 21 and CS 31.

The surface of the tailings in the Intermediate impoundment is at about Elevation 1050 m amsl. The maximum depth of tailings is about 15 m. The tailings surface slopes down towards the Intermediate dam impoundment. Water levels in the Intermediate impoundment may fluctuate between Elevation 1044 m amsl and 1048.8 m amsl. Surveys done in the fall of 2003 indicated a water level at 1047.26 m amsl. No information is available on the depth of water in the Intermediate pond. Water is siphoned from the Intermediate pond to the Cross Valley pond.

The Intermediate Dam is a zoned earthfill embankment with a low permeability core excavated into the foundation. The dam has a crest width of 6-7 m and an overall length of 650 m (BGC, 2003). The lowest point on the crest, based on 2003 surveys, is 1048.68 m amsl. A spillway is located on the north abutment, with a sill elevation of 1047.7 m amsl.

The Intermediate Dam was constructed in stages. The first stage was built in 1981 to Elevation 1035.7 m amsl. At that time, the spillway was located on the south abutment. In 1988, the dam was raised to Elevation 1040.7 m amsl and the spillway moved to the north abutment. In 1989, the dam was raised again, to Elevation 1045.7 m amsl. The final raise took place in 1991 to a design elevation of 1049.4 m.

The reach between CS 8 and CS 11 lies adjacent to the Cross Valley pond. CS 11 is close to the axis of the Intermediate dam. CS 8 is close to the axis of the Cross Valley dam. The Cross Valley pond, or polishing pond, extends from the downstream toe of the Intermediate Dam to the Cross Valley Dam. In the fall of 2003, the water level was at Elevation 1030.84 m. The outlet of the Intermediate Dam spillway enters the polishing pond on the north side. The Cross Valley Dam spillway inlet is also located on the north abutment. In this reach of the RCDC, the top of the diversion channel dike is about 22 m above the polishing pond.

Pond levels are now lower than the originally designed operating levels. Normal pond levels are maintained between 1029.4 m amsl and 1031.7 m amsl (BGC, 2003). Water from the Intermediate Dam is discharged into the polishing pond by siphons and then siphoned in the summer months directly into Rose Creek. Currently, water from the Faro pit is being treated through the mill water treatment system and is discharged indirectly to Rose Creek through the polishing pond.

The Cross Valley Dam retains the polishing pond for the tailings containment system. The dam was constructed to its final elevation of 1033.5 m amsl in 1981. It is a zoned earthfill embankment with a low permeability core and upstream blanket. The dam has a crest width of 6-7 m and an overall crest length of 500 m. The spillway, located on the north abutment, has an inlet at elevation 1031.2 m amsl.

2.3 Geotechnical Considerations

2.3.1 Existing Canal Route

The RCDC traverses a wide variety of materials, ranging from bedrock to till and creek alluvium (Golder, 1980). The channel is located on a north-facing slope, and much of the ground is permafrost affected, with sometimes ice-rich materials. The design of the channel included provisions for placement of insulating and filtering layers to prevent degradation of the permafrost areas. Winter construction was carried out to avoid thaw degradation during construction. The permafrost is considered “warm”, with temperatures of 0^{o} to -1^{o} C.

The following geotechnical information was obtained from the design report for the “new” diversion below the plug dam (Golder, 1980). No information was available for the original diversion, but generally conditions are expected to be similar to those observed elsewhere along the RCDC.

- About 0.3 m of moss and organic debris generally blanketed the ground along the canal route. This organic cover is instrumental in maintaining permafrost conditions, and freezes annually.
- Beneath the organic cover are black or brown organic silts and/or colluvium to a depth of about 1.2 m. This organic silt is often permafrost affected and may have water contents as high as 120%. In the vicinity of creeks and groundwater flows, this material can remain unfrozen on an annual basis and may present trafficability problems.
- Beneath the organic silt is till. The upper surface of the till is often pebble rich, indicating that some erosion of the till surface may have occurred at one time. There is evidence of colluvial action in the upper till based on the presence of organic layers and/or white volcanic ash being interlayered with till.
- The till varies in condition and composition along the canal route. Frozen till may occur throughout the route, although continuously frozen, ice-rich, fine-grained till was found downstream of Station 0+900 on the canal baseline (approximately CS 25).
- Thermistors installed along the canal route confirmed that most of the ground was frozen except for localized areas that were affected by subsurface water flow.
- Till water contents ranged from about 7% to 39%, with average water contents of 18% found in test pit samples. Water content increased with proximity to the ground surface.
- Till composition is highly variable. In general, the material is extremely broadly graded, with at least 9% by weight of silt and clay size particles. Most of the samples contained between 10% to 30% silt and clay sized particles. In general, the tills are non-plastic with occasional low plastic zones associated with higher fines contents.
- Coarse-grained materials were found in the Diversion Dam area. The expected hydraulic conductivities ranged from 1×10^{-5} cm/s to 1×10^{-6} cm/s.
- Hydraulic conductivity measured on a sample of till compacted to 100% of Standard Proctor density was 3×10^{-7} cm/s. The hydraulic conductivity increased by 15 times after the sample was subjected to several freeze-thaw cycles.
- Shear strength parameters for the non-plastic till were estimated to be about 36^o, with higher plasticity tills as low as 32.5^o.
- In situ densities of till ranged from 1780 to 2260 kg/m^3, with an average of 1989 kg/m^3.
- In the outfall portion of the canal (downstream of CS 9), alluvial deposits underlie the surficial organic silts. Some of these sand and gravel deposits were marginally frozen and required ripping during excavation. The alluvial deposits become sandier at depth.

- Bedrock was anticipated within the proposed canal depth in the following reaches (going downstream):
  - At the inlet
  - Sta. 0+50 to 0+230 (approximately CS 29 to CS 27)
  - Sta. 0+330 to 0+350 (CS 26)
  - Sta. 0+500 to 0+820 (approximately CS 25 to CS 23)
  - Sta. 1+490 to 1+600 (approximately CS 18 to CS 16)
  - Sta. 1+940 to 1+980 (approximately CS 14 to CS 13)
  - Sta. 2+200 to 2+410 (approximately CS 12 to CS 11)
- Bedrock consists of metamorphic units (phyllite and schists), dipping about 20 to 30 degrees to the south-southwest, into the hillside. A quarry was developed at Station 2+500 (near CS 10), south of the channel alignment.
- The specific gravity of the rock was found to be 2.80. The upper bedrock is disturbed and fractured. Hydraulic conductivities were not measured, but some till lining was anticipated to minimize seepage losses.
- In the south abutment of the Intermediate Dam, frozen till was expected, with the possibility of some colluvium and organic deposits. Shallow bedrock was also a possibility, with an irregular and possibly disturbed bedrock surface.
- Granular alluvium exists at the Cross Valley Dam, which has infilled the valley to a depth of 50 m. At the south abutment of the dam, frozen tills, and possibly some fine grained colluvium were expected. The upper 1.5 m was expected to be ice rich.
- Downstream of the Cross Valley Dam, the RCDC crosses an alluvial fan from a tributary of Rose Creek that flows down the south valley slope.

2.3.2 Tailings Impoundment Areas.

Mining commenced in 1969 at a production rate of 9200 tonnes per day. Tailings were initially placed in the Original Tailings pond and contained by a low dike constructed from valley alluvial materials (SRK, 1986). The dike was subsequently raised using both tailings and alluvial materials by upstream construction methods. Tailings were discharged into this impoundment by spigotting from the north slope of the impoundment The Original Impoundment extends from the north valley wall to the mid-point of Rose Creek valley. It has a surface area of about 27 ha and contains approximately 6 million m^3 of tailings (SRK, 1986).

The Second Tailings Impoundment was constructed in 1974 and extends across the original Rose Creek drainage. The dike is constructed from alluvial sands and gravels and was raised by the centreline construction method. Construction of this impoundment caused Rose Creek to be diverted onto a terrace along the south valley wall. Tailings were spigotted into this impoundment mainly from the north and south of the impoundment. The Second Impoundment has a surface area of about 40 ha and contains approximately 5 million m^3 of tailings to an average elevation of 1060 m amsl.

The Intermediate Dam was constructed in 1981 and has the capacity to retain 42 million m^3 of tailings. The Cross Valley Dam and polishing pond were constructed to achieve the required 60-day retention time for dam seepage and required water treatment.

The oxidized and sulphide ores were milled and treated in the mill facilities to recover zinc and lead/silver concentrates, which were shipped off site. Major reagents added in the mill included soda ash, lime, copper sulphate, sodium sulphite, xanthate, sodium cyanide and iron from millrods and balls (SRK, 1986). During the period of mine shutdown, pit dewatering continued. Mine water was treated with lime and discharged to the Second Tailings Impoundment, from where it decanted into the Intermediate Dam Impoundment, then to the Cross Valley Impoundment, from where it discharged into Rose Creek (SRK, 1986). The tailings are acid generating when exposed to oxygen and water.

In the upstream reach of the RCDC (CS 31 to CS 39), tailings have been assumed to reach the outer toe of the existing canal dike. From CS 31 to CS 14, the edge of the tailings is up to 90 m away from the toe of the dike. Between CS 14 and the Intermediate Dam (CS 11), the Intermediate pond covers the tailings to an undetermined depth along the south shoreline of the pond. The edge of the pond is close to the outer toe of the canal dike slope.

Information concerning the properties of the tailings was obtained from SRK (1991). This report provided an assessment of the decommissioning of the Down Valley tailings area and provided a good summary of tailings characteristics based on site investigations and laboratory tests, as noted in the following sections. Physical characteristics of the tailings considered in the SRK report include particle size distribution, solids specific gravities, in situ void ratio and density.

2.3.2.1 Particle Size Distribution

In general, the tailings consist of uniformly graded silt or fine sand, with considerable variation in the grain size distributions. Grain size variations occur as a result of pipeline discharge or sand/slime separation techniques, proximity to discharge point and milling process.

In 1981 and 1982, the milling process was changed producing tailings with finer particle size than those produced previously. The tailings in the Intermediate Dam Impoundment and the upper part of the Second Impoundment are, on average, finer than those in the Original Impoundment. Within in each impoundment, lateral sorting occurs as the tailings move away from the discharge points. The following spatial variations were noted (SRK, 1991) in the Original and Second Tailings Impoundments:

In the Original Impoundment:

- Coarse fractions are predominant in the northern and western part of the impoundment.
- The slimes fraction predominates in the southern and eastern part of the impoundment.
- Coarse fractions are also found along the edges of the impoundment, largely where it was used as a construction material in the Second Impoundment:
- Pre- 1986 tailings were deposited by spigotting along the impoundment perimeter. The 1986 tailings were discharged only in the north-western part of the impoundment. These cover the older tailings in the western part of the impoundment, but pinch out towards the east.
- Coarser fractions are found where overflow from the Original Impoundment occurred and where there was direct discharge- along the northwest part of the impoundment, along the Original Tailings Embankment and along the Second Tailings embankment.
- Slimes were found in the southern and central parts of the impoundment.

The above observations indicate the potential lateral and vertical variability in tailings properties. Detailed site-specific data would be required for any work involving construction within the tailings impoundments.

2.3.2.2 Specific Gravity

During the course of mining, various ore types were processed in the milling, resulting in variations in the specific gravity of the tailings. The tailings in the Original Impoundment have a higher solids specific gravity than those in the Second and Intermediate impoundments. This is due to the presence of barite with the massive sulphides in the early stages of mining of the Faro orebody. In the latter stages, the ore consisted of sulphide rich quartzites, with little or no barite. The range in specific gravity is also a reflection of varying sulphide content in the tailings samples.

Tailings samples taken during production in the Original Impoundment showed specific gravities ranging from 4.19 to 4.53, with a mean value of 4.5. Surface samples from the Original Impoundment appear to have lower specific gravity ranging from 3.26 to 3.83, with a mean value of 3.6.

Tailings from the Second Impoundment range in specific gravity from 3.66 to 4.04, with a mean value of 3.8. No data was available regarding the changes in specific gravity with depth in the Second Impoundment.

Specific gravity of tailings from the Intermediate Impoundment ranged from 3.66 to 4.04, with a mean value of 3.86.

2.3.2.3 Void Ratio/Density/Porosity

Maximum and minimum tailings void ratios were determined to be 1.06 and 0.58 respectively. In situ densities were reported as relative densities, based on downhole geophysical techniques and investigations carried out by Golder Associates in 1977 (SRK, 1991). The corresponding in situ void ratios calculated from the relative density data ranged from 0.73 to 0.92. Void ratios tended to be higher in areas of predominantly fine-grained tailings than in areas of coarse-grained tailings. In the sands, void ratios were generally less than 0.85, whereas in the slimes, they were greater than 0.89.

Frozen tailings, with ice lenses up to 1.2 m thick were reported, which also reduces the overall average void ratio. Since these investigations were done, the tailings have undergone some degree of consolidation, and if there has been any melting, the overall in situ void ratio would be decreased.

Dry solids densities of tailings depends on the method of deposition (spigotting), mill grind and ore source. Densities obtained in the laboratory ranged from 2.4 tonnes/m^3 for above water deposition to 0.9 tonnes/m^3 for below water deposition. Within the Down Valley tailings area, in situ densities ranged from 1.7 to 1.9 tonnes/m^3 and the specific gravity of the solids is 3.8 (SRK, personal communication). This would correspond to an average void ratio of 1.18. Note that the high specific gravity of the solids can result in misleading interpretations of the in situ relative density based on unit weight determinations alone. Variations in specific gravity data may also yield somewhat different void ratios.

Porosities were determined for tailings and till samples. For tailings, the majority of values ranged from 32.4 to 49.1 %, with no apparent correlation between porosity and grain size fraction. Till porosities ranged from 28.4 to 42 % for materials placed during construction.

Golder recently (fall, 2003) completed a program of cone penetrometer testing of the tailings in the Down Valley to assess the potential for liquefaction. The results of this investigation were not available at the time of writing of this memorandum, however the information would provide further details on the variation of in-situ density within the tailings deposits.

2.3.2.4 Hydraulic Properties

Hydraulic conductivity of the tailings is variable due to several factors:

- The degree of grinding in the mill at any given time.
- Segregation of the tailings discharge into coarse and fine fractions with distance from the discharge point.
- Zones of frozen tailings within the deposit.

In the Original and Second Impoundments, various winter and summer discharge points were used, creating a complex, strongly anisotropic deposit of coarse and fine layers. Coarser grained material was used to raise the dike.

Tailings in the Intermediate Impoundment were deposited from a single winter and summer discharge point, likely resulting in a more uniformly graded deposit, as discussed in Section 2.3.2.1.

The hydraulic conductivity of un-segregated (saturated) tailings ranged from $1x10^{-5}$ cm/s to $5x10^{-5}$ cm/s, increasing to $1x10^{-3}$ cm/s at the surface, where coarse tailings have been leached and subjected to frost action. Tailings slimes have an average hydraulic conductivity of about $1x10^{-6}$ cm/s, which may be an order of magnitude less at higher levels of consolidation.

Frozen zones within the tailings have effectively zero hydraulic conductivity. The distribution of frozen zones within the tailings is not clear, but the recent grid of cone penetrometer holes (Golder, 2003) failed to encounter any frozen zones (SRK, personal communication). Previously (SRK, 1991) reported frozen zones at depths up to 18 m from the surface that may be associated with ice incorporated during winter tailings deposition. It is possible that some ice lenses may have disappeared over time. The presence of frozen tailings at depth that may melt-out over time has significant impacts on the long-term predictions of tailings behaviour and on any potential structures to be built over the tailings.

2.3.2.5 Hydrogeology

In 2002, Gartner Lee Limited assessed the hydrogeology of the Down Valley tailings disposal area (GLL, 2002). The investigation program included drilling, installation of groundwater monitoring wells, test pitting and geophysics.

The tailings are largely exposed (beached), with a small portion flooded upstream of the Intermediate Dam. The saturated zone within the tailings extends to within 10 to 12 m of the surface. The water table within the tailings is largely controlled by the water level in the Intermediate Pond. A sand and gravel aquifer underlies the tailings, in the former Rose Creek valley, and ultimately discharges into Rose Creek. The aquifer overlies a denser basal till that rests on the valley bedrock. Seepage flow is predicted to be downward through the tailings into the aquifer. Regionally, the Rose Creek valley is a groundwater discharge area, with an upward flow gradient in the bedrock below the valley (SRK, 1986). This upward flow gradient prevents contaminated groundwater from entering the bedrock and confines the flow under the tailings within the valley alluvial aquifer.

In the Second Impoundment, water levels are close to the channel invert level (El. 1054 to 1055 m amsl) of the RCDC indicating that the water level in the channel may be controlling the water level in the tailings. Further downstream, water levels in the tailings drop below the level of the channel invert (El. 1049 ±), indicating a net potential seepage gradient from the channel towards the tailings. This gradient tends to increase as the relative elevation difference between the channel invert and the tailings surface increases in a downstream direction.

2.3.2.6 Thermal Conditions

The site is located within the discontinuous permafrost zone. In the north-facing slope along the alignment of the RCDC, almost continuous frozen ground was observed (Golder, 1980). Thermistor installations indicated ground temperatures in the range of 0 to –1 ^{o}C. No temperature measurements are available in the tailings. Based on the penetration resistances measured in the recent cone penetrometer testing by Golder Associates, there appears to be no evidence for frozen tailings.

3.0 CLOSURE SCENARIOS

In the course of assessing the various closure scenarios outlined in Section 1, several modifications were evolved based on the geotechnical and hydraulic considerations of the site. Details concerning the geotechnical aspects and considerations for each of these scenarios are summarized in this section.

The following scenarios were considered:

- Scenario 1- Increase the flood handling capacity of the existing channel by raising the height of the canal dike on the right bank.
  - Scenario 1a- Increase the capacity of the existing channel by widening the channel by 5 m on the left bank side.
  - Scenario 1b- Same as Scenario 1, except replace the drop weir section with a concrete stepped spillway and fish ladder to handle PMF flows.
- Scenario 2- Raise existing dike between CS 31 and CS 39 as in Scenario 1, but divert PMF flow across the tailings at the plug dam, using a dike constructed on tailings to direct the flow to a spillway at the Intermediate Dam.
- Scenario 3- Removal of tailings from Original, Second and Intermediate Impoundment to el. 1042 and divert Rose Creek PMF to enter impoundments immediately downstream of the Pumphouse Pond.

It should be noted that for each of these scenarios there are various levels of unknowns and assumptions, which have implications on cost. Therefore, the cost estimates presented should not be compared as if they were based on equal levels of uncertainty. A common cost element for all scenarios considered is the need to undertake a program of seismic upgrading of the entire Down Valley tailings disposal area, which would be in addition to the earthworks costs presented here. This would involve upgrading the Intermediate and Cross Valley Dams to withstand a Maximum Credible Earthquake (MCE) event. The level of upgrading required under each of the above scenarios may vary, depending on design details. For the purposes of this study, the seismic upgrading costs were assumed to be equal for each scenario, and therefore could be ignored in preparing the relative costs for each scenario.

Each of the proposed closure scenarios may contain risks that may not be acceptable to various stakeholders. For example, the required raising of the downstream canal dike may require the extension of the dike toe onto the tailings. Within this assessment, this option has been assumed feasible, however technical feasibility must still be confirmed, and detailed investigations would be required to address that option. Alternatively, routing of a PMF flood over the covered tailings appears to have conflicting design criteria and has never been done before. Therefore, the risks and technical feasibility of each option would need to be considered within future options assessment or design work.

3.1 Scenario 1

In this scenario, the canal dike on the right bank is raised to provide sufficient freeboard for the PMF flow. All the PMF flow will be handled in the channel. The following assumptions were made with respect to this Scenario:

- The existing vegetation on the left bank would be left in place between CS39 and CS 31 to preserve the permafrost and provide some measure of erosion protection.
- Clearing and grubbing will be required over the entire footprint of the new dike on the right bank. Stripping of the ground surface, including the surface of the existing dike to a minimum depth of 0.5 m will be required.
- New construction on the right bank associated with the dike raising would not encroach or constrict the existing hydraulic channel.
- Nominal dike section is based on a crest width of 6 m and side slopes of 2 horizontal :1 vertical.
- In general, the entire existing channel required an upgrade of the rip rap to ensure channel stability under PMF flow conditions. Since the size of rip rap required will vary depending on local flow conditions and the thickness of the rip rap layer is a function of the maximum particle size, a nominal thickness of 0.5 m rip rap lining was initially assumed for preliminary layout purposes. The quantities of rip rap included in the estimate however are based on the actual thicknesses assessed from hydraulic criteria by NHC. The rip rap zone extends from the crest of the new dike down to the toe of the

existing channel. Rip rap is also required on the left (south) side slope of the RCDC between CS 10 and CS 31 up the hydraulic level (1 m above the water level).

- The dike toe can be constructed over tailings in the downstream reach.

The 39 channel cross-sections generated from the 2003 survey were the basis for the design of the conceptual dike sections. There is no "as-built" information regarding the construction details of the existing channel, so there was no opportunity to detail the interface between the new construction and the existing structure.

The dike raise was assumed to be made as a continuous extension of the existing dike slope in order to place the new dike within the existing dike footprint as much as possible. NHC provided water levels for PMF flow of 730 m^3/s at each of the 39 cross-sections. The top of the impervious core or water retention element of the new dike was set a nominal 1.0 m above the 730 m^3/s water level. The physical crest of the dike was set 1.0 m above the top of the impervious water retention element.

The dike section will utilize natural materials similar to those used to construct the existing structure. This includes compacted till for impervious liner, compacted sand and gravel or rockfill for dike shell, processed sand and gravel for filter and transition and crushed rock as rip rap base. The existing quarry located near the Intermediate Dam was assumed to be the source of the rip rap. This quarry was used to construct the existing diversion and the recent breach of the Fresh Water supply dam. Further investigations would be required to determine if the quarry has sufficient volumes of rock to satisfy the requirements of the PMF channel. If not, other quarry locations need to be identified.

Various reaches of the RCDC required specific design modifications in order to accommodate local site conditions. These are described in the following sections, from upstream to downstream.

3.1.1 Original Diversion Section (CS 39 to CS 30)

In the upstream section between CS 31 and CS 39, the proximity of the Second Impoundment tailings presents a concern regarding seepage flow between the channel and the tailings. The tailings surface is about 6 m above channel invert at CS 39. As discussed in Section 2.3.2.4, there is an overall seepage gradient from the diversion channel into the tailings. There is also a potential seepage gradient from the tailings impoundment towards the diversion channel during periods of runoff and infiltration from the tailings surface. Since the existing conditions have performed satisfactorily to date, it was assumed that no impervious liner should be placed on the existing dike slope, since it could prevent seepage from the tailings from draining during periods of infiltration, leading to a decrease in the overall stability of the slope.

The new dike extension incorporates an impervious liner on the canal side to prevent seepage loss through the dike during periods of flood flow. The base of the liner coincides with the elevation of the tailings in the Second Impoundment. The outer toe of the new dike extension is founded on the tailings, which have been assumed to be stable. To account for varying tailings properties and potential for settlement, the outer dike slope was flattened to 3.5 H to 1 V. The dike shell is constructed of compacted sand and gravel. Maximum dike height above the tailings surface is about 5 m.

3.1.2 Fuse Plug Dam to Intermediate Pond (CS 30 to CS 14)

In this reach, the invert of the diversion channel begins to rise above the elevation of the adjacent tailings in the Intermediate Impoundment. There appears to be sufficient distance between the outer toe of the existing dike and the edge of the beached tailings to allow construction of the dike extension. The foundation conditions were inferred from previous investigation data and were assumed to comprise bedrock covered by sand and gravel alluvium associated with the former (pre-1981) Rose Creek diversion channel.

A fine compacted rockfill shell (200 mm minus) can be used in this section. The outer slope was shown at a conservative 2H:1V slope, however this could be steepened to 1.5H:1V when foundation conditions are confirmed in subsequent design phases.

The use of a rockfill shell requires the addition of a zone of compacted sand and gravel to act as a transition between the impervious liner and the rockfill. The fine rockfill was selected to maintain compatibility with the transition material. Detailed design of the dike zoning will be carried out during subsequent design phases when particle size gradations of actual construction materials are obtained.

On the canal side, the existing dike slope will be excavated to remove the existing rip rap and sub-excavated to place the impervious liner. To avoid encroachment of the new dike section into the hydraulic section of the PMF channel, a minor amount of additional material must be excavated. The crest of the new dike will be about 10 m above the existing ground surface at the upstream end and about 15 m high at the Intermediate Pond.

3.1.3 Intermediate Pond to Intermediate Dam (CS 14 to CS 11)

In this reach, there is limited space between the outer toe of the existing dike and the edge of the Intermediate Pond. The invert of the diversion channel is about 3 m above the pond level of 1047.3 m amsl. Construction of the new dike will require dewatering a portion of the Intermediate Pond, as the outer toe will encroach on to the tailings. A rockfill cofferdam with a dumped till cofferdam seal on the outer slope will be constructed first to at least 1 m above the Intermediate Pond water level. Pumping can then dewater the enclosed portion of the Intermediate Pond.

There is no information available concerning the bathymetry in the Intermediate Pond, so the layout and volumes of materials are subject to change depending on site conditions. The shell of the dike will be constructed of compacted sand and gravel in order to be compatible with the tailings foundation. In subsequent design phases, further refinements could be made by incorporating rockfill and sand and gravel zones to accommodate actual site conditions and material characteristics. The potential liquefaction hazard of the tailings foundation in the dike toe area must also be assessed.

On the canal side, a new liner and rip rap erosion protection layer will be placed from the channel invert to the top of the dike. New rip rap will be placed on the left bank and channel of the RCDC as well.

3.1.4 Intermediate Dam to End of Existing Dike (CS 11 to CS 7)

This reach lies adjacent to the Cross Valley Pond, the Cross Valley Dam and the start of the drop weir section of the existing diversion channel. The drop weir section begins at CS 9. Beyond the outer toe of the existing dike, the original ground surface slopes down to the Cross Valley Pond. The elevation difference between the channel bottom of the existing dike and the surface of the Cross Valley Pond is about 18 m.

Foundation conditions vary from sandy gravely till in the upstream portion to alluvial sand and gravel downstream of the Cross Valley Dam. Due to the potentially pervious nature of these materials and seepage gradients into the slope above the Cross Valley dam, an impervious liner was included extending over the entire right bank channel slope. Further design work is required in this reach to confirm the design assumptions and properly assess the seepage conditions and the final design of the required liners. For the purposes of this study, it was assumed that the water in the channel was hydraulically confined by the groundwater table on the left bank, and that the impervious liner would only be required to prevent seepage through the right bank slope and dike.

The outer shell of the new dike can be constructed using compacted rockfill. The depth of stripping required may be up to 1 m deep to remove thicker accumulations of organic debris in this area. The overall height of dike raising required in this reach is about 5-6m to provide the required freeboard for PMF flows.

Rip rap will be required on both banks and the channel invert down to CS 10. Downstream of CS 10, the mean channel velocity increases to 10 m/s and 2 m sized (D_{100}) stone size will be required for bank protection. This stone size may be impractical to obtain or place along the RCDC.

3.1.5 Downstream Section (CS 7 to CS 1)

This reach includes the downstream portion of the drop weir section and the outflow area where the diversion channel re-enters the natural Rose Creek channel. The drop weir section ends at CS 3. There is no existing dike along this section and a new dike must be constructed to provide the freeboard requirements for the PMF flows.

The existing channel is excavated into predominantly sand and gravel deposits associated with an alluvial fan of a tributary creek flowing down the south valley wall.

The proposed dike section is similar to that in the previous reach, consisting of a compacted rockfill shell and a full impervious liner on the right bank. There is no information available to determine if the existing channel is lined. The height of the new dike will be about 6-7 m above the surface of the existing channel bank.

Due to the high channel velocities in this reach, use of rock rip rap for channel bed and bank protection becomes impractical. The required rock sizes may be unobtainable within a reasonable haul distance of the site. As described in Section 3.3, Scenario 1b was developed to further address the need for a concrete spillway to handle the PMF flow downstream of CS 9.

3.1.6 Quantities and Cost Estimate

Table 1 summarizes the earthworks quantities and costs associated with Scenario 1 and does not include the additional costs for a spillway, outlet channel and fish by-pass, which are presented by NHC. The estimated cost for the earthworks portion associated with raising the dike along the entire channel was about $16.1 million. Note that this estimate does not include costs related to mitigating the effects of potentially liquefiable tailings within the dike foundation. Scenario 1b, which includes the costs associated with a concrete spillway downstream of CS 9 was subsequently developed as a preferred option over Scenario 1 and is discussed in more detail in Section 3.3.

Table 1 - Preliminary Cost Estimate

Rose Creek Diversion Channel Closure Options						
Scenario 1- Raise Existing Diversion Dike for PMF 800 m^3/s flow:						
ITEM	**DESCRIPTION**	**ESTIMATED QUANTITY**	**UNIT**	**UNIT PRICE**	**EXTENSION**	**COMMENTS**
1	Clearing and grubbing	272,961	m^2	$8.00	$2,183,688.00	Assumes right bank dike footprint only.
2	Excavate and stockpile existing rip rap	17,742	m^3	$8.00	$141,936.00	Assumes existing rip rap will not be re-used.
3	Excavate and stockpile existing liner	35,483	m^3	$8.00	$283,864.00	Assumes existing liner will not be re-used.
4	Common excavation and stripping	187,361	m^3	$8.00	$1,498,888.00	Material will be hauled to stockpile or waste area within 6 km. (includes removal of cofferdam seal).
5	Place Zone 1 impervious liner	94,885	m^3	$19.00	$1,802,815.00	Assumes new material to be obtained from Vangorda Plateau- 26 km one-way haul distance.
6	Place Zone 3 Crushed rock transition/underlay	7,503	m^3	$12.00	$90,036.00	Blasted rock used for crushing obtained from quarry within 6 km haul distance.
7	Place Zone 3a Pit run gravel transition/underlay	11,560	m^3	$14.00	$161,840.00	Assumes borrow area within 6 km, includes washing and screening and double handling.
8	Place Zone 4 sand and gravel shell	207,668	m^3	$7.00	$1,453,676.00	Assumes processing and hauling from borrow area within 6 km.
9	Place Zone 7 rockfill shell	408,099	m^3	$7.00	$2,856,693.00	Assumes suitable rockfill from waste dumps within 6 km. Note- must be non-PAG.
10	Place Zone 9 rip rap	146,730	m^3	$37.00	$5,429,010.00	Based on FWS bid- rip rap quarry site adjacent to RCDC.
11	Place Zone 1A cofferdam seal	5,475	m^3	$18.00	$98,550.00	Based on new Zone 1 from Vangorda Plateau borrow sources. Dumped only.
	TOTAL (Excluding mob/demob., escalation and extra work allowances)				**$16,000,996.00**	Excludes cost of stepped concrete spillway in drop weir section

3.2 Scenario 1A Widen Existing Channel by 5 m

This scenario involves expanding the existing channel invert by 5 m into the left (south) bank. The side slopes are assumed to be inclined at 2H :1V. This scenario was briefly considered to assess the relative merits of raising the dike versus increasing the width of the channel to increase existing channel capacity under Scenario 1. Based on 12 cross sections, the volume of excavation required to widen the channel is about 124,000 m^3. Assuming a unit cost for common excavation of $8.00/$m^3$ the estimated cost for removing the material is about $992,200. An additional $2 million would be required to clear and grub this area as the channel expansion will involve cutting into the forested hillside pf the Rose Creek valley. Hydraulically, the 5 m expansion would reduce water levels in the channel, but still require construction of a new dike extension on the north bank of the channel, although not quite as high as in Scenario 1. A spillway, spillway channel and fish by-pass channel would also be required downstream of CS 9.

The estimated cost of the reduced dike raise on the right was estimated to be about $12.1 million based on the cost estimate for a full dike raise provided in Scenario 1. The total estimated cost, including the additional clearing/grubbing and channel invert excavation is about $15 million.

Since this option offers marginal savings over scenario 1, it is appropriate to weigh the potential advantages and disadvantages of each scenario:

- Environmentally, scenario 1A increases the overall footprint of mine disturbance. The main concern is the potential for long term degradation of permafrost-affected slopes in the left bank of the channel. The above cost assessment does not include the cost of thermal protection measures for the excavated slopes, which would require over-excavating beyond the nominal 5 m width and covering the slope with thaw-stable thermal protection materials. These costs would definitely drive the cost above the cost estimated for scenarios 1 and 1b.
- In Scenario 1, the technical feasibility of constructing the dikes on top of tailings is not known and the potential costs associated with this aspect have not been determined.
- Widening the existing channel into the left bank may encounter more bedrock, which would improve the overall geotechnical feasibility of scenario 1A.

This scenario may offer advantages over other options that involve construction on the tailings, due to the unknown costs associated with mitigating potential liquefaction effects.

3.3 Scenario 1B

This scenario evolved from Scenarios 1 and 1a after it was determined that the channel bed in the rock drop weir section could not be made stable under PMF flow conditions with rip rap alone. Stabilizing scenarios included obtaining larger size armour stone or embedding the riprap in concrete. Both of these scenarios were not considered to be viable at the site for the following reasons:

- The required armour stone size (2-m, or larger) cannot be obtained from local sources and would be impractical to place along the RCDC.
- The concrete used to embed the rip rap would not stand up to the severe freeze-thaw action at the site over a long term period.

The only viable alternative is to replace the existing rock drop weir section with a concrete structure. In this scenario, downstream of CS 10, the existing channel would be replaced by a concrete approach wall and floor leading to a concrete spillway and chute on the south abutment of the Cross Valley Dam. Between CS 10 and CS 11, the right side of the existing channel will be excavated to create the flow expansion leading into the approach channel at elevation 1048 m amsl. At this point, the existing channel will continue below CS 10 as a fish by-pass channel The spillway chute discharges into a depressed stilling basin and an energy dissipating channel, containing scattered large boulders on top the channel rip rap. This leads to a rock lined channel, which returns the PMF flow into Rose Creek downstream of the Cross Valley Dam.

3.3.1 Quantities and Cost Estimate

Table 2 presents a summary of the quantities and capital cost estimate for the earthworks portion of Scenario 1b. The total capital cost of $13.4 million, excludes mobilization, demobilization, escalation and extra work allowances. The unit rates assumed for the cost estimate were in part derived from previous cost estimates used by BGC for construction work in the mine site area, but are nevertheless subject to revision depending on prevailing conditions at the time of construction. The associated cost estimates for the spillway, outlet channel and fish by-pass channel are presented by NHC.

The following points summarize the assumptions and comments regarding each of the major work items:

- Item 1, Clearing and grubbing includes the clearing and removal of all vegetation along the right bank footprint of the dike, the left bank between CS 10 and CS31 and the footprint of the spillway. Most of this work will be within the existing zone of clearing along the RCDC channel and is expected to involve removal of secondary shrub growth along the existing dike slopes and adjacent natural ground areas. No logging is expected to be required.

- Item 2, excavate and stockpile existing rip rap assumes that the rip rap being removed will not be re-used as the size of the rip rap must in general be increased to meet PMF flow requirements. The cost is based on the removal of the rip rap from the existing channel and hauling it to a stockpile area within 6 km of the site. The stockpile will be used for other mine site reclamation activities. The estimate of the volumes assumes rip rap will be removed along the entire length of the existing dike slope, from the crest down to the channel invert. This volume is expected to be conservative as some sections of the channel are known to have no rip rap coverage.
- Item 3, excavate and stockpile existing liner assumes that the excavated liner will not be re-used. Although there is no information to indicate how much of the channel is lined, the volume estimate is based on removing a 1 m thick slice of soil from the existing dike slopes. This was assumed to be required in conjunction with the rip rap upgrading, which involves placing thicker layers of rip rap than currently exist. Due to the potential for contamination of this material by other materials, it will not be re-used as liner material. It is anticipated that a stockpile area will be used within 6 km of the site so that this material can be re-used for other mine site reclamation activities.
- Item 4, common excavation and stripping includes the removal of 0.5 to 1.0 m of material from within the footprint of the new dike and the left bank and channel sections where new rip rap is required and hauling it to a stockpile or waste disposal area within 6 km of the site. The volume includes removal of the impervious cofferdam seal for the portion of the dike constructed in the Intermediate Pond.
- Item 5, placing Zone 1 impervious liner assumes a minimum 1 m thick liner along the entire length of the channel, except as noted above for the upstream section adjacent to the Second Impoundment. This volume may be reduced when more information is available concerning the as-built conditions along the dike. The borrow source is assumed to be on the Vangorda Plateau, a one-way haul distance of 26 km. The price includes the cost for excavating, hauling, placing, spreading and compacting the liner.
- Item 6, placing Zone 3 Crushed rock transition/underlay assumes a borrow source within 6 km of the site. This item is used as rip rap bedding consisting of coarse crushed rock with a maximum particle size of 130 mm. The cost includes drilling and blasting, hauling to a stockpile, crushing and screening, loading and haul to site; placing, spreading and compacting.
- Item 7, placing Zone 3a Pit Run gravel transition/underlay assumes a borrow source within 6 km of the site. The cost includes excavating and loading the material from a granular borrow area, processing including screening and washing, loading and hauling to site, dumping spreading and compacting.
- Item 8, Zone 4 sand and gravel shell is pit run sand and gravel from a borrow source within 6 km of the site. The cost includes excavating, hauling, placing, spreading and compacting.

- Item 9, Zone 7 rockfill shell assumes rockfill will be obtained from a quarry located within 6 km of the site. The unit cost includes drilling, blasting, loading, hauling, spreading and compacting. Note that the rockfill may be required to meet a gradation specification (say 200 mm minus) and the rock must be proven to be non-acid generating. This excludes using waste rock from the mine dumps, unless a source of non-acid generating rock is identified. Rock from the existing quarry near the Intermediate Dam has been proven to meet these requirements. Other quarries may be required in order to meet the project requirements.
- Item 10, Zone 9, rip rap, this quantity is based on the actual thicknesses of rip rap liner required to ensure stability of the channel slopes during PMF flow conditions. For estimating purposes, the source was assumed to be in the existing quarry at the Intermediate dam, although there is no confirmation that this source will be able to satisfy all the size requirements.
- Item 11, Zone 1A, cofferdam seal assumes using till from the Vangorda Plateau, as for the Zone 1. The cost for this material assumes excavate, load, haul and dump, with no compaction. Removal of this material after completion of dike construction is included in the volumes for common excavation (Item 4). During construction, it may be possible to utilize some of the material removed from the existing channel excavation for cofferdam seal, but this will depend on material quality and scheduling.

Table 2 - Preliminary Cost Estimate

ITEM	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	EXTENSION	COMMENTS
Rose Creek Diversion Channel Closure Options						
Scenario 1b: Same as Option 1 with Spillway at CS 9						
1	Clearing and grubbing	265,310	m^2	$8.00	$2,122,480.00	Assumes right bank dike footprint only. Includes spillway area.
2	Excavate and stockpile existing rip rap	14,691	m^3	$8.00	$117,528.00	Assumes existing rip rap will not be re-used.
3	Excavate and stockpile existing liner	29,382	m^3	$8.00	$235,056.00	Assumes existing liner will not be re-used.
4	Common excavation and stripping	161,836	m^3	$8.00	$1,294,684.00	Material will be hauled to stockpile or waste area within 6 km. (includes removal of cofferdam seal and spillway excavation).
5	Place Zone 1 impervious liner	88,345	m^3	$19.00	$1,678,555.00	Assumes new material to be obtained from Vangorda Plateau- 26 km one-way haul distance.
6	Place Zone 3 Crushed rock Transition Underlay	5,984	m^3	$32.00	$191,488.00	Assumes processing and hauling from borrow area within 6 km. Crushing will be of blasted rock.
7	Place Zone 3a Pit run gravel	3,091	m^3	$14.00	$43,267.00	Assumes processing and hauling from borrow area within 6 km.
8	Place Zone 4 sand and gravel shell	200,958	m^3	$7.00	$1,406,706.00	Assumes processing and hauling from borrow area within 6 km.
9	Place Zone 7 rockfill shell	344,604	m^3	$7.00	$2,412,228.00	Assumes suitable rockfill from waste dumps within 6 km. Note- must be non-PAG.
10	Place Zone 9 rip rap	103,074	m^3	$37.00	$3,813,738.00	Based on FWS bid- rip rap quarry site adjacent to RCDC.
11	Place Zone 1A cofferdam seal	5,475	m^3	$18.00	$98,550.00	Based on new Zone 1 from Vangorda Plateau borrow sources. Dumped only.
	TOTAL (Excluding mob/demob., escalation and extra work allowances)				**$13,414,280.00**	

3.4 Scenario 2

This scenario assumes that an engineered cover material 2 m thick has capped the entire Intermediate Impoundment. It must be noted that the overall philosophy of this scenario is at odds with the idea of placing a cap on the tailings and likely without precedent. The objectives of the tailings cap are to minimize infiltration and to prevent oxidation of the tailings. Routing the PMF flood on top of the engineered cap will increase the potential for infiltration of oxygen rich water into the underlying tailings, thereby diminishing its effectiveness as a cover. Also, the portion of the PMF channel constructed on the tailings will require a liner over the entire channel width to replace the cap, as well as erosion protection.

The existing canal dike between CS 31 and CS 39, would be raised as in Scenario 1. At the plug dam, the existing dike would be removed and the PMF flow would be diverted over the Intermediate Impoundment via a channel contained by a dike constructed on the tailings cap along the right bank. The expanded channel would extend from CS 31 to CS 25. The existing Diversion Dam would be removed in this reach. The invert of the PMF channel at CS 28 would be 1054 m amsl, similar to the existing diversion channel at that point. Most of the channel would be excavated into native ground down to CS 25. The PMF channel dike and portions of the right channel bottom will be constructed on the tailings cap.

At CS 25, a headwall would be constructed across the existing diversion channel, with a 20-m long conduit sized to allow a maximum flow of 30 m^3/s down the existing diversion for fish passage. A second 450-m long fish passage conduit will be placed from just upstream of CS 11 to the right wingwall of the spillway at CS 8, where it will re-enter the existing diversion channel The existing dike on the right bank will act as a splitter wall to separate the fish channel from the PMF channel between CS 25 and CS 11. The invert of the expanded channel at CS 25 is 1052.75 m amsl.

Downstream of CS 25, the PMF channel has a bed width of 80 m with side slopes at 2H:1V. The left bank of the PMF channel will be a slope excavated into the existing diversion channel dike, maintaining a minimum crest width of about 7 m. Between CS 25 and CS 17, most of the channel section will be excavated in the natural ground between the existing channel and the edge of the tailings. Portions of the right side of the channel will require excavation through tailings. The right bank slope of the PMF channel will be excavated through the tailings cap and protected with rip rap. The dike running along the north side of the PMF channel will be constructed on top of the cap.

Assuming that this technically challenging component is feasible, construction of the dike must consider potential settlements and deformation associated with the behaviour of the underlying tailings. To minimize potential displacements of the cap due to the embankment surcharge, the interface between the cap and the base of the PMF channel dike will be covered by a layer of geogrid. The dike itself should be constructed of compacted sand and gravel to accommodate any long-term deformations or settlement that may occur due to consolidation of the underlying tailings and to be compatible with the gradation of the cap material.

From CS 17 to just upstream of CS 14, the proportion of the PMF channel on the tailings cap increases significantly. By section CS 15 and all the way to the Intermediate Dam, the channel will be entirely on the tailings cap, except for the left bank area. Since the channel invert is set by hydraulic requirements, portions of the channel will be excavated through the cap and into the underlying tailings. The current water level in the tailings in this area is controlled by the Intermediate Pond, at Elevation 1047± m amsl. Channel invert level at CS 13 is 1045.4 m amsl, which would require excavating in tailings below the water table, another technically challenging component that could potentially affect the technical feasibility of this scenario. In order to construct this excavation, water levels in the tailings must be substantially reduced in advance of construction.

It has been assumed that the Intermediate Pond will disappear when the tailings cap is constructed. As a minimum, the depression will be filled in at least to Elevation 1047.3, the current water level, so that no water would accumulate on the surface of the cap. In that case, construction of the PMF channel in the vicinity of the Intermediate Pond area may require about 2.5 to 3.0 m of excavation through the cap material between CS 12 and CS 11.

At the right abutment of the Intermediate Dam (CS 11), the PMF channel becomes confined by a concrete wing wall on the right bank and a concrete lined bed across to the left bank toe. The invert elevation of the concrete lined bed at CS 11 is 1044 m amsl. The PMF channel merges with the existing diversion channel downstream of CS 11 to a concrete spillway headworks at the Cross Valley Dam. In the reach between the Intermediate Dam and the Cross Valley Dam, the PMF channel consists of a right bank concrete wing wall to contain the flow along the side hill above the Cross Valley pond. The concrete lined channel bed has a width of 30 m and extends to the toe of the left bank slope. The left bank slope comprises a 5H:1V cut and fill section originating from the existing left bank of the diversion channel. This slope will be heavily armoured with rip rap all the way to the spillway. The fish conduit is located along the alignment of the present RCDC, which will be affected by the cut and fill sections.

At CS 8, at the left abutment of the Cross Valley dam, the PMF channel enters the spillway headworks. A concrete wing wall must be constructed along the left side of the channel to cut off flow down the existing diversion channel. The fish conduit will pass through the wing wall and discharge into the existing RCDC. The spillway has an overall length of 172 m and a width of 30 m.

3.4.1 Quantities and Cost Estimates

Table 3 summarizes the preliminary estimates of quantities and capital costs for the earthworks portion of Scenario 2. The estimated capital cost is about $29.5 million excluding mobilization and demobilization, escalation and extra work allowances. The estimated capital cost of the spillway, outlet channel and fish by-pass channel is presented separately by NHC.

No costs have been included for dewatering tailings in the Intermediate Impoundment during construction, although this has been assumed to be feasible. Further information would be required regarding the long-term water table situation in the tailings if a tailings cap is in place. The preliminary quantities were estimated from cross-sections provided by NHC along the channel showing the required hydraulic profile of the channel.

The following sections describe the assumptions made for each of the major work items listed in Table 3:

- Item 1, Clearing and grubbing includes the clearing and removal of all vegetation along the new PMF channel and spillway footprint. Under Scenario 2 it was assumed that the tailings area has been capped by 2 m of cover material by others and that no clearing or grubbing would be required. Most of the work is expected to involve removal of secondary shrub growth along the existing RCDC and the area between the RCDC and the tailings impoundments. No logging is expected to be required.
- Item 2,Excavate and stockpile existing rip rap includes removing the existing rip rap from the RCDC channels that will be modified (downstream of CS 31) and replacing the existing rip rap between CS 31 to CS 39. It was assumed that the rip rap could not be re-used as the new channel will require a larger size. The existing rip rap will be removed and hauled to a stockpile within 6 km of the site, for re-use in other mine site reclamation work.
- Item 3 Excavate and stockpile tailings cap, includes removal of portions of the tailings cap along the PMF channel in order to establish the required channel grades. Since this material was specifically selected as a cover material based on its properties, it requires segregation from the other materials so it can be re-used for other mine reclamation applications. A stockpile area for this material was assumed to be located within 6 km of the site.
- Item 4, Common excavation and stripping includes the removal of 0.5 to 1m of material from within the footprint of the dike where it is constructed on natural ground or on top of the existing dike (CS 31-39). It also includes stripping of the ground surface under the areas where new rip rap will be placed in the channel bed and left bank area between CS 10 to CS 31 and under the footprint of the spillway. Common excavation does not include tailings, which are covered under Item 5. The cost assumes that the material will be hauled to a stockpile or disposal area within 6 km of the site.

- Item 5, Excavate and dispose of tailings includes the excavation, hauling and disposal of tailings in a designated disposal area. Tailings excavation will be required in some sections along the PMF channel in the Intermediate Impoundment (CS12-15). Since the tailings contain sulphides and metals and are potentially acid generating, they must be disposed of in an environmentally secure area. It was assumed that the excavated tailings would be disposed of in the flooded Faro Pit, which already contains tailings.
- Item 6, Place geogrid under dike foundation. This includes the section of dike constructed on the tailings cap between CS 28 to CS 11. The geogrid will be placed on the surface of the tailings cap. Depending on the type of cap material used, some surface preparation or stripping or both may be required to install the geogrid. A 1 m zone of stripping was included in the cost estimate under Item 3 for this purpose.
- Item 7 Zone 1, Impervious liner, assumes a 1 m thick liner along the entire length of the channel between CS 31 to CS11.1 (start of concrete lined section). The extent of the liner needs to be verified based on as-built conditions in the reach between CS 31-39 adjacent to the Secondary Impoundment. Additional liner may be required in this reach to prevent infiltration of water into the tailings area, which have been capped at great expense to keep water out. Nevertheless the capping will not prevent groundwater seepage entering the tailings from the valley sides. No liner was allowed for on the left bank along the concrete lined section downstream of CS 11.1. Final details of seepage control requirements must be based on details to be obtained in future investigations.
- Item 8, Zone 3 Crushed rock transition/underlay. This material is required as underlay for all rip rap areas between CS 9-31. The crushed material is specified as having a maximum particle size of 130 mm and a D_{50} of 40 mm. It was assumed that this material would be produced from quarry rock by drilling and blasting. The rock would be hauled to a stockpile for crushing, screening and washing. The cost also includes loading from the processed rock stockpile and hauling, spreading and compacting the material on the dike and channel.
- Item 9, Zone 3a Pit run gravel transition/underlay. includes the cost of excavating, hauling, processing (screening and washing), loading from the processed stockpile, hauling, spreading and compacting this material, which is used as rip rap underlay between CS 31-CS 39. The borrow source is assumed to be within 6 km of the site.
- Item 10, Zone 4 sand and gravel shell for the dike assumes suitable pit run sand and gravel can be obtained from a borrow source located within 6 km of the site. The cost includes excavating, hauling, spreading and compacting.
- Item 11, Zone 9, rip rap includes all the size classes specified by NHC on the basis of channel and bank velocities along the PMF channel. The D_{50} stone size for bank and channel bed protection ranges from 25 mm to 600 mm, with layer thicknesses ranging from 300 mm to 1.0 m.

Table 3 - Preliminary Cost Estimate

Rose Creek Diversion Channel Closure Options						
Scenario 2: PMF Channel on tailings:						
ITEM	**DESCRIPTION**	**ESTIMATED QUANTITY**	**UNIT**	**UNIT PRICE**	**EXTENSION**	**COMMENTS**
1	Clearing and grubbing	322,917	m^2	$8.00	$2,583,336.00	Assumes requirements do not pertain to tailings cap area.
2	Excavate and stockpile existing rip rap	15,191	m^3	$8.00	$121,528.00	Assumes existing rip rap will not be re-used.
3	Excavate and stockpile tailings cap	271,845	m^3	$8.00	$2,174,760.00	Assumes minimum 1 m stripping under dike, material hauled to stockpile within 6 km for re-use by others
4	Common excavation and stripping	817,950	m^3	$8.00	$6,543,600.00	Material will be hauled to stockpile or waste area within 6 km.
5	Excavate and dispose of tailings	100,865	m^3	$8.00	$806,920.00	Assumes material hauled into Faro Pit for disposal. Say 6 km haul distance.
6	Place geogrid under dike foundation	54,725	m^2	$15.00	$820,875.00	Upstream of CS 11
7	Place Zone 1 impervious liner	230,683	m^3	$19.00	$4,382,967.50	Assumes new material to be obtained from Vangorda Plateau- 26 km one-way haul distance.
8	Place Zone 3 Crushed rock Transition/underlay	126,443	m^3	$32.00	$4,046,160.00	Assumes processing and hauling from borrow area within 6 km using blasted rock for crushing.
9	Place Zone 3a Pit run transition/underlay	11,560	m^3	$12.00	$138,720.00	Assumes processing and hauling from borrow area within 6 km.
10	Place Zone 4 sand and gravel shell	176,533	m^3	$7.00	$1,235,727.50	Assumes processing and hauling from borrow area within 6 km.
11	Place Zone 9 rip rap	178,640	m^3	$37.00	$6,609,680.00	Unit rate based on FWS bid- rip rap quarry site adjacent to RCDC.
TOTAL (Excluding mob/demob., escalation and extra work allowances)					**$29,464,274.00**	

3.5 SCENARIO 3- PASS PMF FLOWS OVER TAILINGS IMPOUNDMENTS

The final scenario involves removal of all the tailings (to be done by others) in the Original, Second and Intermediate Impoundments down to Elevation 1042 m amsl. The Rose Creek PMF will enter the impoundments immediately downstream of the Pumphouse Pond. The attenuated PMF will pass over a new spillway located in the north abutment of the Intermediate Dam.

Under this scenario, the existing Rose Creek Diversion channel will remain as is. A new headwall will be constructed across the existing channel in the vicinity of CS 39. A conduit through the headwall will allow a maximum flow of 30 m^3/s for fish passage in the RCDC.

The excavated tailings will be relocated into the abandoned Faro pit. The remaining tailings will be flooded to Elevation 1045 m amsl with a water cover. The existing spillway on the north side of the Intermediate Dam has a sill Elevation at 1045 m amsl and discharges into the Cross Valley Pond. The lowest point on the Intermediate Dam, as surveyed in 2003, was 1048.68 m amsl. The top of the impervious core is assumed to be at Elevation 1049.2 m amsl. Assuming an initial water cover at Elevation 1045 m amsl, the PMF water level behind the Intermediate Dam is predicted to be at 1048.1 m amsl, leaving 1.1 m of freeboard on the impervious core.

A new concrete spillway will be constructed on the north bank, replacing the present unlined emergency spillway channel that discharges into the polishing pond. The new spillway will have a 55 m wide sill at elevation at 1045.0 m amsl and pass the PMF flood over the Intermediate Dam and around the Cross Valley Dam and Polishing Pond. The upstream portion, between the Intermediate Dam and the Cross Valley Dam will be stepped, leading to a chute and stilling basin downstream of the Cross Valley Dam.

The north bank location for the spillway was chosen over the south bank because of the width of spillway required. Topographically, there is more room along the north side to construct this spillway. Foundation conditions are expected to comprise a mixture of till, sand and gravel and colluvium. Bedrock in the north abutment of the Intermediate Dam, under the existing spillway, is at about Elevation 1040 m amsl. At the Cross Valley Dam, the bedrock under the spillway channel is at about Elevation 1015 m amsl.

There are no additional earthwork costs associated with this scenario as all associated removal of tailings will be done by others. The estimated capital cost of the new spillway, outlet channel and fish by-pass channel are presented separately by NHC. The additional earthworks required for this scenario are associated with the seismic upgrading program of the Down Valley tailings impoundment. Estimating these requirements is beyond the scope of the present study, but these are described in an introductory fashion in the next section.

3.5.1 Seismic Design Considerations

In 2002, Klohn Crippen Consultants Ltd undertook an independent dam safety review of the dams on the Anvil Range property, including the Intermediate and Cross Valley dams (Klohn Crippen, 2002). A "Very High" consequence category was assigned to both the Intermediate and Cross Valley dams based on the environmental consequences of a major uncontrolled release of tailings from the Down Valley tailings area.

This classification then requires the following:

- The safety of these structures must be ensured against extreme events such as the Probable Maximum Flood (PMF) and Probable Maximum Earthquake (MCE).
- Independent safety reviews should be conducted every five years, and
- The dam owner is required to prepare an Emergency Preparedness Plan (EPP).

Under Scenario 3, the tailings area will be designed to accommodate the PMF. BGC (2003) has recently completed an EPP as well as an Operation, Maintenance and Surveillance (OMS) Manual for dams on the Anvil Range property, including the Intermediate and Cross Valley dams, in their current configuration. The major outstanding requirement is an overall assessment of the seismic stability of the Down Valley tailings area, including the Intermediate and Cross Valley dams. Elements of this assessment are understood to be underway, which includes the cone penetrometer field program recently completed by Golder (Golder, 2003). As part of the 2002 dam safety review, Klohn Crippen undertook a preliminary seismic stability assessment of the Intermediate Dam. The analysis used peak ground accelerations of 0.15 g for the 1:10,000 year return period earthquake and the assumption that the tailings did not liquefy. The analysis indicated potential for serious damage to the dam, but would not likely result in the release of water or tailings. The assessment noted that the potential for fluid release would be further reduced if the Intermediate Pond was lowered. The stability of the Intermediate Dam is also dependent on the water level in the polishing pond. Rapid drawdown of the water level in the Polishing Pond could lead to instability of the downstream shell of the Intermediate Dam.

With the proposed water cap set at Elevation 1045 in Scenario 3, the overall stability of the Intermediate Dam must be assessed under both static and MCE seismic loading conditions. The seismic assessment should include the overall assessment of liquefaction potential in the Down Valley area and effects on the stability of the Intermediate and Cross Valley dam. No cost allowance has been included for the structural upgrades required for the two dams to meet MCE requirements. Note that some type of seismic upgrade will be required for all scenarios considered. Therefore, the embedded cost for this aspect should be considered to be common to all of the options, although the details may vary depending on the actual water levels to be retained behind the Intermediate Dam.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The fundamental premise of the need to upgrade the RCDC and other structures in the Down Valley to withstand the PMF is the long-term existence of tailings in the Rose Creek valley.

This study assessed the three scenarios that were discussed in a teleconference call on October 31, 2003 between NHC, SRK and BGC:

- Scenario 1: Increase the size of the Rose Creek Diversion channel along the south side of the tailings facility to convey the PMF.
- Scenario 2: Abandon the RCDC downstream of the plug dam. From the plug dam, convey the PMF over the tailings (assume tailings are covered with a soil cover) in a swale lined with rip rap to the Intermediate dam pond, then over a new spillway by-passing the Intermediate and Cross Valley Dams.
- Scenario 3: Involves removal of tailings from the Original, Second and Intermediate Impoundment to El. 1042 m amsl. The Rose Creek PMF is directed into the tailings area immediately downstream of the Pumphouse Pond. The attenuated PMF passes over the spillway located at the Intermediate Dam.

In the course of this assessment, it has become apparent that other viable options exist and that there are technical challenges associated with the above options. In addition, more information will be required regarding the overall long-term closure objectives before decisions can be made regarding which, if any, of these options should be pursued. Closure objectives will need to be determined for, among others, chemical stability, physical stability and the level of long-term active management.

To utilize the existing RCDC requires construction of a spillway in order to handle the flow velocities associated with returning the diverted channel flow back into Rose Creek, downstream of the Down Valley tailings facilities. Concrete spillways comprise a significant proportion of the costs, but are not considered to be permanent structures. Costing for these scenarios needs to consider long-term maintenance as well as reconstruction costs for these facilities.

Construction on the tailings deposits will be technically challenging and may in fact not be feasible. Costs for mitigating the potential liquefaction and geotechnical foundation issues have not been assessed in these cost estimates. The work completed by Golder in 2003 to evaluate the tailings characteristics should be considered to assess the potential for construction of the PMF structures founded on tailings.

Table 4 is a summary of the preliminary capital cost estimates for the earthworks components for each of the scenarios considered.

Table 4 - Preliminary Cost Estimate Summary

Scenario	Earthworks	Comments
1	$16,100,000	Concrete spillway required in drop weir section has not been included. Costs for mitigating potential tailings liquefaction have not been assessed.
1A	$15,000,000	Does not include costs for permafrost protection.
1B	$13,404,527	Same as Option 1 to CS 9, new spillway adjacent to Cross Valley Dam.
2	$29,460,297	Spillway on south abutment of Intermediate and Cross Valley Dams. Construction of dike and excavation of channel on tailings may not be technically feasible.
3	See comments*.	New concrete spillway on north abutment of Intermediate and Cross Valley Dams. Cost for seismic upgrading of Intermediate and Cross Valley Dams not included. No construction required on tailings.

Increasing the capacity of the RCDC can be done by raising the level of the existing dike, increasing the width of the channel or some combination of both. From a technical perspective, raising of the dike will involve construction on top of the tailings in the lower reaches of the RCDC, adjacent to the Intermediate Impoundment. Both methods will have to address the need to pass the PMF flows over the drop in channel grade from the Down Valley into the natural channel of Rose Creek. Under Scenario 1, the existing drop weir section was found to be unstable under the predicted PMF flows. As a result, a concrete spillway was considered necessary.

Scenarios 1A and 1B explore the dike raising versus the channel widening options respectively. As discussed in Section 3.2, there are advantages and disadvantages for each option. Further evaluation of scenario 1A is recommended, since it will avoid the need to construct the dike on tailings. This option also opens the possibility of extending the RCDC further downstream and reducing the overall grade of the channel before discharging the flow back into the natural Rose Creek channel.

The most expensive scenario is No. 2, which involves raising the existing dike upstream of CS 31 and constructing a new dike on tailings between CS 31 and CS 11.1. The widened PMF channel will be partially constructed across the tailings impoundment. The approach channel and spillway from the Intermediate Dam to the Cross Valley Dam involves construction of a concrete wall and floor. The technical challenges of constructing on the tailings may make this option unfeasible.

Scenario 3 requires only a new spillway to be constructed around the north abutments of the Intermediate and Cross Valley Dams. The additional hidden cost associated with this option is the cost for removal and relocation of the tailings down to Elevation 1042 m amsl. The seismic upgrading costs, common to all the other scenarios considered, represents the only significant civil earthworks cost component.

Assuming the embedded costs for seismic upgrading of the Down Valley tailings are approximately equal for each scenario and the costs associated with the tailings relocation are justified, then scenario 3 may be considered a feasible option for handling the PMF flows in the RCDC during closure. This Scenario also offers several environmental advantages with respect to closure of the tailings impoundments:

- A significant volume of tailings will be removed from the tailings impoundments and placed into more secure storage in the Faro Pit.
- No new construction or exploitation of natural resources would be necessary to construct a tailings cap, assuming the lowered tailings would be flooded with a water cap.
- Seismic upgrading of the Down Valley tailings impoundment would ensure that the existing facility is stable in the post closure period at a cost equivalent to the other options.
- There would be no significant increase of the current mine disturbed footprint, as the new spillway and seismic upgrading would take place within the existing footprint.
- There is more information available to proceed with the design of Scenario 3 compared with the information gaps leading to design and construction of the other options.

With this scenario, it should be noted that the tailings will be left in the valley, leading to a potential need for long-term treatment of groundwater from the Rose Creek aquifer.

5.0 CLOSURE

This memorandum summarizes the geotechnical considerations and associated cost estimates for earthworks for various closure options designed to increase the capacity of the RCDC to pass PMF flows. These options are only conceptual in nature and their technical feasibility has yet to be fully assessed. The conceptual design provided herein was undertaken as a scoping level study of potential options, costs and issues to be used as a basis for closure planning. The study has highlighted the need for stakeholders to establish an understanding of what needs to be achieved for the closure plan. Final decisions cannot be made unless the closure objectives and goals are identified. It is likely that some of these options will be removed from consideration because they fail to meet the basic objectives.

We trust that this information meets with your requirements at this time. Should you require any additional information, or have any questions, please do not hesitate to contact the undersigned at your convenience.

Yours truly,
Per BGC Engineering Inc.

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HHH/sf

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