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Faro Mine Closure Project Office

Rose Creek Diversion Canal Hydrotechnical Closure Design

Draft Report

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northwest hydraulic consultants nhc

Rose Creek Diversion Channel Hydrotechnical Closure Design

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Executive Summary

northwest hydraulic consultants (nhc) was retained by the Faro Mine Closure Project Office (FMPCO) to provide integrated hydrotechnical closure options for the Rose Creek Diversion Channel (RCDC) at the Faro Mine site. The RCDC diverts the North and South forks of Rose Creek around the primary and secondary tailings impoundments and the Intermediate and Cross Valley dams – which store tailings within the Rose Creek valley.

The current RCDC has an insufficient capacity to carry the most recent estimate of probable maximum flood (PMF) without overtopping. Comprehensive mine closure planning dictates that design options are required that would carry the revised PMF without overtopping or failure, which otherwise could result in loss of tailings into the environment into Rose Creek and Pelly River. The scenarios developed in this study accommodate several mine tailings management plans under current consideration and address concerns arising from past studies.

Two scenarios were developed: Scenario A where tailings are retained within the Rose Creek Valley, and Scenario B where both the Cross Valley and Intermediate Dam are removed. In Scenario A, the RCDC is upgraded to a PMF design along its entire length and remains in it's present location. In Scenario B, the RCDC is upgraded to PMF criteria for approximately 1.7 km where a spillway and control structure are located. Flows in excess of approximately 100-130 m^3/s would be routed down the spillway.

In both cases, the RCDC continues to pass most of the flow and provide fish passage around the site. Both scenarios incorporate large reinforced concrete grade and hydraulic control structures providing a fail-safe against catastrophic loss of the RCDC and loss of the tailings impoundment structures.

The costs associated with Scenario A are approximately $51 M dollars and the costs for Scenario B are $57 M, both including a 20% contingency. Prior to proceeding to detailed design and construction, additional geotechnical, civil and hydrotechnical design is required – including hydraulic modelling of the proposed ramp spillway and additional subsurface investigations.

1 Introduction

1.1 Scope of Work

The Faro Mine Closure Project Office (FMPCO) is developing and coordinating a closure plan for the Faro Mine near Faro, Yukon. As part of the closure planning process, they require a hydrotechnical design to bring the existing Rose Creek Diversion Channel (RCDC) into a condition suitable for closure. The design must be technically feasible, within an acceptable range of costs, and require minimum and infrequent ongoing maintenance.

The RCDC currently diverts the combined flows of the North and South forks of Rose Creek around the Primary and Secondary tailings impoundments and the Intermediate and Cross Valley dams – which also store tailings and provide mine water treatment. Runoff from adjacent areas to the north (Guardhouse Creek and North Wall Interceptor Ditch) and treated mine effluent from the Faro Pit are currently discharged along the north side of the valley through the tailings dams spillways, and would continue to be routed to Rose Creek separate from the RCDC in closure.

Importantly, the current channel has an insufficient capacity to carry the most recent estimate of the probable maximum flood (PMF) without overtopping. Final mine closure requires the hydrotechnical channel capacity be adequate to convey the PMF without failure due to overtopping, erosion, or sedimentation. Failure could ultimately result in loss of tailings into the environment through Rose Creek and Pelly River. The primary hydrotechnical design objective is to provide safe PMF conveyance. Long-term issues such as channel stability, slope stability, and potential permafrost degradation need to be addressed on the areas and slopes adjoining and adjacent to the RCDC. Fisheries and environmental issues are incorporated into the final closure planning process for the RCDC, and the closure plan must provide fish access and a no net loss of habitat along the future RCDC or other associated works.

1.2 Concept Development

The FMCPO set out a series of specific items and issues to be addressed with respect to the RCDC. They also established a process to develop the closure plan involving the consultants, FMCPO staff, and members of the technical workgroup. A phased approach was used in the development of the work plan and execution of the studies and work as detailed in Table 1.

Table 1 Project Objectives and Timelines

Task	Description	Milestone
1	Working Group Meeting	November 15, 2005
2	Options Assessment Study	November 2005 – March 2006
3	Options Assessment Completion	May 2006
4	Detailed Design	March 2006 – September 2006
5	Final Reporting	October 2006

An initial workgroup meeting was held on November 15th 2005 which was the first opportunity for the FMPCO and the technical working group to discuss previous study results, new information, and issues arising from additional work conducted in the intervening period. Many of these issues were developed into design criteria used in the evaluation of concept options.

The approach was to coalesce the issues to identify one or more viable concepts that would allow **nhc** to go forward and determine a final concept. These recommendations were based on the review of present data including the report, Hydrotechnical Study for Closure Planning, Faro Mine Site, Yukon (**nhc**/BGC 2004). Issues with some of the concepts developed in the 2004 report included:

- Concerns regarding stability of the spillway structures and long-term maintenance issues.
- Stability and long-term water management issues related to an engineered channel across the tailings.
- The use of additional rock drains to attenuate flows and reduce conveyance structure size.
- Elevated dike designs with loadings applied to existing tailings and areas of known prior instability.

Design objectives for the RCDC in closure were discussed, and a recommended course-of-action was proposed. These items include:

- Conveyance for the design PMF – with and without routing through the NFRD – to be determined with ongoing work.
- Accommodate tailings management options including:

  1. complete removal of all dams and tailings,
  2. removal of the Cross Valley Dam only (stabilize in place option), or

3. removal of the Cross Valley and Intermediate dams and removal of the tailings between the Intermediate Dam and the Secondary Dam.

The direction provided to **nhc** was specifically:

- Use geotechnical and hydrotechnical parameters to be consistent with current and proposed Canadian Dam Association (CDA) standards,
- Provide complete geotechnical solutions for poor foundation conditions in the south slope, under the dike and potentially under the channel,
- A single spillway option at or near the Cross Valley Dam left abutment, as determined by geotechnical and hydraulic considerations,
- Provide fish use and passage for species and lifestages – as required – through the RCDC, and provide opportunities for appropriate aquatic habitat restoration in the overall design,
- Identify and acquire additional data, as required, and
- Identify options to reduce the potential effects of glaciation or aufeis in the channel.

An initial draft of an options summary was provided in early January 2006 to the FMPCO and circulated to the technical working group. The options review was iterative and required redrafting of the outline to the satisfaction of the FMPCO and technical work group, and was finalized in May 2006.

2 Overview

2.1 Project Setting

The Rose Creek Diversion Channel (RCDC) diverts Upper Rose Creek along the south valley wall and provides separation and bypass of stream flows from the residual stored tailings from the Faro Mine. An earth dike varying 4 to 13 m wide and surfaced with a gravel access road separates the RCDC from the tailings. The RCDC was initially designed for the 50-year hydrologic event with provisions to convey the 500-year event at bankfull.

The RCDC was constructed in several phases as tailings stored within the Rose Creek valley increased down valley behind the Intermediate and Cross Valley dams. As a result the RCDC comprises a relatively flat channel section along most of its length followed by a steepened section that conveys flows back to the valley floor. The channel begins at the confluence of the North Fork and South Fork of Rose Creek immediately upstream of the Primary Impoundment with a relatively wide section along the primary tailings impoundment above the current fuse-plug structure, and a narrower channel section along side most of the Intermediate and Cross Valley Dam impoundments. Near the Cross Valley Dam, the RCDC becomes a relatively steep channel that discharges into the low gradient natural channel of Rose Creek, which is ultimately a tributary to the Pelly River. The existing channel sections and profiles are illustrated on the existing conditions drawings.

As-built reports indicate sand and gravel fill was used to construct the RCDC dike. The dike and fill slopes of the RCDC are protected with rock. The bed of the RCDC varies in materials: portions are engineered fills overlying existing moraines, coluvium and bedrock, other sections consist of bedrock tied closely to exposures and outcrops of bedrock along the left bank. The left bank cut slopes intersect these materials along the valley wall. The slopes are stable and do not show signs of translational or rotational mass failures, slips or ravel. Geotechnical assessments undertaken by BGC in assessments of the existing RCDC found no potential upslope hazards. The small tributary watershed to the south of the RCDC have low probability of debris flow or debris flood events.

North Fork Rose Creek has developed a post glacial fan on the South Fork floodplain up valley of the current tailings ponds, but currently appears to transport only a small amount of bedload. The bar features immediately upstream of the RCDC inlet appear to be formed from bank erosion of the North Fork below the mine access road culvert from the diversion of the creek along the Primary Impoundment. Recent removal of the Freshwater Supply Dam on South Fork Rose Creek, upstream of the RCDC, provided an opportunity to examine historical sediments stored in the reservoir. Very little accrued bed material was found in the historical reservoir and only a minor amount of bed material was apparent at the mouths of tributary streams. Overall, relatively small amounts of bedload are transported by Rose Creek from upslope processes. There are no elevated or exposed bar features within the RCDC which suggests that bedload transport into the channel is very low, and finer sediments are transported out of the channel during sustained high flows.

2.2 Hydrologic Data

Independent work was undertaken to generate Probable Maximum Precipitation (PMP) and Probable Maximum Flood values for the Faro Mine site (Taylor, 2005 and Water Management Consultants, 2006). The PMF data was delayed, as was the subsequent analysis required at the North Fork Rock Drain (NFRD) regarding the potential routing of flood flows. The routing work was ceased and a summary memo was produced when the decision was made to remove the NFRD and haul road in March 2006. This decision also reduces the hydrological options to one – a non-routed PMF from the North Fork Rose Creek and South Fork PMF values.

Data provided by Water Management Consultants (WMC) and presented in Table 2 identifies the PMF values at various locations along the RCDC. Note that the PMF routing assumes that all North tributaries are conveyed through the tailings areas and over dam spillway structures.

Table 2 RCDC Design PMF Values (WMC, 2006)

Watershed/Location	Area (km^2)	PMF Value (m^3/s)
North Fork Rose Creek	122.5	384
South Fork Rose Creek	83.5	290
Entrance - RCDC	206.0	674
RCDC tributary areas[1]	11.3	18
Exit - RCDC	217.3	692

The PMF estimate selected for hydraulic design of the RCDC closure concepts is 692 m^3/s, which represents the maximum expected inflow flood for the entire channel

In addition to the PMF, estimates of higher frequency flood flows and flow events of significance are required in the assessment of the concept designs. Instantaneous design flows for the RCDC are also presented in Table 3 as derived in **nhc** (2004).

[1] Areas south and directly tributary to the RCDC identified in WMC (2006)

Table 3 RCDC Significant Flood Flows (nhc, 2004)

Recurrence Interval	Flood Flow (m^3/s)
Mean Annual	20
10-year	45
20-year	60
50-year	79
100-year	96
200-year	115
500-year	145

nhc (2004) also provides a record and analysis of gauged streamflows at locations above and below the RCDC that provide an account of the seasonality and range of monthly flows to peak flows. While historical flows may not always accurately represent future flows, they do provide a context in terms of relative flows to physical and biological processes such as ice formation, break-up, and periods of fish migration.

2.3 Geotechnical and Physical Data

BGC Engineering Inc. (BGC) – as a project partner – has provided geotechnical information on potential options, as well as clarification of previous design issues with the RCDC. Considerable work has been done to better define the underlying geophysical conditions and geotechnical implications to proposed changes to the RCDC. These issues included:

- estimates of depth to bedrock along the proposed RCDC;
- mapping of geological and surficial materials; and
- review of as-built reporting.

In addition, Gerry Ferris P.Eng. of BGC provided interpretation of bedrock conditions and quantities in the vicinity of the existing quarry for purposes of riprap rock production, foundation and densification requirements in areas where dike changes might extend over tailings, rock strength, and conceptual pinning and foundation requirements.

Drilling log data and surficial material data was plotted, and foundation conditions identified along the length of the RCDC. These data were transferred to overlay plans and additional topography was also prepared for areas where an expanded channel section could ultimately daylight beyond existing data. More recent ground survey information was also included that provide better detail along most of the RCDC than the existing air photogrammetry. Original contour data was limited to approximately ± 2 m accuracy as determined from air photogrammetry interpretation to representative contour data. This data was added to existing topographical models and used as a base layer for derivation of all drawings, sections, and plans.

2.4 Site Inspection Data

An inspection of the RCDC and relevant features was undertaken by B. Chilibeck and D. Muir (**nhc**) on June 6th and 7th 2006, accompanied by Gerry Ferris (BGC) with the findings detailed in a memo dated July 5th 2006. Inspections were undertaken on the entire RCDC, South Fork Rose Creek, North Fork Rose Creek, and the Intermediate and Cross Valley dam spillways.

The lower portions of each branch of Rose Creek was walked, and visual estimations were made of channel stability and potential volumes of coarse sediment deposited in the lower reaches at the RCDC inlet. Relocation options for the North Fork of Rose Creek were field-truthed, as well as potential bank protection for the east wall of the Primary Impoundment.

Areas right adjacent to the shallow RCDC section were reviewed as to whether bearing and foundation would be possible with an extended dike, and what foundation material types would be expected (e.g. tailings, existing dike or overburden). The presence of nearby exposure to bedrock or surficial materials adjacent left and into the adjoining slope was estimated along the channel, as was the current materials in the bed of the RCDC. These data were recorded for review against as-built reports, and more recent data collected by BGC.

Along the steep sections of the RCDC, weir stability was reviewed and modifications were discussed in light of the current stability of the weirs. Areas for potential dike or channel expansion left or right of the current channel were assessed. Material gradations were developed for the as-built rock protection along the steep and shallow sections of the RCDC, and the weir sections along the lower RCDC that currently provide fish passage under a natural flow regime.

Slope stability, gullying and surface erosion along the cut slopes of the RCDC and the tributary connections from South aspect catchments were inspected. The existing quarry access and availability of additional rock was reviewed with BGC with the potential to expand the quarry to develop and supply rock for the design concepts.

3 Design Constraints and Criteria

In developing a conveyance strategy for Rose Creek through the Faro Mine site, design criteria were identified as targets that are to addressed. The criteria were developed with the goal of providing a conveyance strategy that would remain stable and functional with limited infrequent maintenance under all foreseeable conditions. The design criteria and issues are described below.

3.1 Hydrotechnical

Key to the design of closure at Faro mine is stability of hydrotechnical structures and facilities. Safety and stability of the tailings and remediation facilities must be ensured. In the conceptual design of the RCDC, we propose to ensure adequate capacity for the PMF, that the bed and side slopes are hydraulically stable, and geotechnical requirements are integrated into the upgrade plans.

The Rose Creek conveyance strategy is to have the capability to convey all foreseeable floods expected at the Faro Mine site. Flow entering Rose Creek at the site includes the North Fork of Rose Creek, the South Fork of Rose Creek, and flow from the south slope along the existing RCDC. Standard procedures for developing hydraulic conveyance criteria, is to select a recurrence interval or annual exceedance probability (AEP) for the instantaneous inflow design flood; such as 100-year flood (1% AEP) or a 200-year flood (0.5% AEP).

For extremely long life-span structures or structures with potentially high consequences from failure, the probable maximum flood (PMF) is often used as the design event. Theoretically the PMF has an infinite recurrence interval and 0% AEP. Due to the longevity desired for the conveyance strategy and the potential environmental consequences of failure the PMF was selected as the design event.

The inflow design flood (IDF) for the conveyance strategy is taken as the highest flow potentially to occur, hence the PMF at the lower end of the RCDC, 692 m3/s. The hydraulic design criteria is that any conveyance strategy must be capable of conveying the IDF without suffering unacceptable damages or jeopardizing any remaining tailings stored in the valley. Unacceptable damages would include loss of safe conveyance for subsequent flood events or damages that could not be repaired within the following season prior to a likely subsequent event.

3.1.1 Hydraulic Capacity

Additionally, the RCDC design must account for potential co-occurring events that could affect conveyance capability or channel stability. Such events include, partial or complete blockage of conveyance channels with wood debris, ice debris, sand, gravel, or rock deposits from upstream or upslope; superelevation of water surface along the outside bank of corners, and hydraulics such as hydraulic jumps, standing waves, flow concentrations, and localized high velocity currents.

3.1.2 Channel erosion and scour

Critical conveyance channels such as the RCDC must be designed to withstand frequent flood events without suffering damage through erosion or scour, and capable of withstanding infrequent flood events – such as 100-year and larger – without suffering significant damage or jeopardizing any remaining dams and tailings.

At the PMF, some movement and loss of material in the spillway is expected (as was identified in previous RCDC designs), and lower sections of the spillway may be damaged with any eroded material relocated into the spilling basin. In the unlikely event that significant erosion occurred on the spillway or steep section of the RCDC, its propagation upstream would be prevented due to buried key concrete sections, and the RCDC, dams, and tailings integrity would remain. Inspection and potential reconstruction of the spillway after a PMF would be required, and therefore incorporated as part of a monitoring and maintenance program associated with the overall closure plan.

3.1.3 Debris flows and floods

The IDF discussed previously under hydraulic criteria was developed solely on geo-climatic conditions. Geological and geotechnical conditions within a watershed can influence the magnitude of a design flood through the initiation of significant transport of debris previously stored within the channel or sudden collapse of dams created across upper channels by landslides resulting in saturated landslides (debris flow) or sediment laden floods (debris floods).

Generally, channels less than 10 km^2 with average gradients above 20% are considered to have debris flow potential (Jakob and Jordan, 2001). Since there is no sign of past debris flows or debris floods and the North Fork and South Fork have catchment areas of 122.5 km^2 and 83.5 km^2 respectively with average channel gradient less than 5%, significant changes in the IDF through debris flow or debris floods is considered highly unlikely.

3.1.4 Ice and Sediment

The widened RCDC will incorporate a pilot channel to reduce the effects of glaciation or aufeis. Even with a pilot channel, winter conditions may still result in glaciation of the RCDC in some winters, and mechanical excavation of accumulated ice may be required. Some regular maintenance and clearing of debris will be required to ensure that the pilot channel remains open. However, velocities should be sufficient to ensure fine sediments do not aggrade in the channel and are mobilized over the expected range of flows.

3.2 Geotechnical

The RCDC design concepts must account for potential geotechnical hazards that could threaten the conveyance or stability of the channel prior to and during PMF conditions (e.g. significant precipitation and melting). If left unmitigated, potential geotechnical hazards could result in impacting the performance or increasing the probability of failure of the RCDC.

Any conveyance strategy will account for these potential hazards. **nhc** in conjunction with BGC have considered these hazards through the design process and will continue to do so by expanding investigation, analysis, and design modification as the selected conveyance strategy progresses through to implementation. The discussion section at the end of this report identifies further studies required to address all of the geotechnical criteria. Criteria or methods assumed in development of the concepts are:

3.2.1 Soil liquefaction

Use of compacted granular materials for all dike construction with method compaction ensuring 95% proctor achieved in-situ, and the installation of seepage control to ensure un-saturated conditions in dike foundation or section materials is done to reduce the risk of seismically-induced liquefaction. Material types and gradations were specified on annotated drawings representative of the various conditions expected along the RCDC.

3.2.2 Landslides or Rock falls

Upslope assessments have identified all likely slide, mass movement, and areas of potential soil or earth creep. These issues can be mitigated by channel re-location, protective benching on slopes and regular maintenance activities associated with operation of the RCDC. RCDC hydraulic design criteria includes providing additional conveyance during the PMF through increased freeboard to account for blockages of up to 30% of the channel to account for potential landslides or rock falls.

3.2.3 Dike settlement

Investigations have not identified ice-rich ground or extensive permafrost along the proposed RCDC channel that would lead to potential thawing and shrinkage of underlying soils If ice or permafrost were encountered, permafrost and geotechnical engineering practices would be used during construction to ensure potential melting and settlement were minimized.

3.2.4 Seepage

Seepage in the current RCDC was mitigated by installation of a compacted silt layer along the dike face. In replacing the dike, a new impermeable barrier composed of a 500 mm thick layer of compacted clay ($k < 0.0001$) would be installed on the inside face of the channel. This barrier would be protected by a geotextile filter and overlying granular layers.

3.2.5 Surface erosion and mass failure

Surface erosion would be limited by minimizing slope-length factors where possible and applying erosion control through reseeding, mulching and revegetation. Mass failures, slips or mass wasting along cut slopes will be mitigated by proper drainage and conservative cut and fill slope grades according to materials encountered or used during construction.

3.3 Environmental

The primary environmental legislation impacting the closure conceptual design of the RCDC is the federal *Fisheries Act*. While overall review of the mine closure plan will encompass other environmental attributes and issues, design of the RCDC channel will impact fish and fish habitat which are managed by Fisheries and Oceans Canada (DFO). Preliminary recommendations from the DFO representative suggest that fish passage and to a less extend, fish habitat within or affected by the RCDC designs are the critical issues. To a large extent, the knowledge of fish species, habitat utilization and movement of fish within Rose Creek and the current RCDC is improving. Rose Creek is currently habitat for Arctic Grayling, which inhabit the creek above and below the mine site, and Chinook Salmon, which utilized habitats immediately below the mine site in Rose and Anvil Creeks and are expected to eventually utilize the RCDC and Rose Creek above the mine site. While other species of fish reside in these creeks, migration and access to habitats for these two species are a priority.

3.3.1 Fish passage

While no specific direction has been given by DFO, we have assumed hydraulic and habitat criteria complementary to both juvenile and adult fish in the design. These criteria will influence the RCDC designs, specifically the design of the steep section weirs and the thalweg channel. Ecohydraulic criteria used in the design process included maintaining upstream and downstream passage by ensuring adequate flow depth, velocities and hydraulics over a range of hydrologic conditions up to the mean annual flood. This would ensure a very high percentage of time that the RCDC would provide passage opportunities for migrating fish.

3.3.2 Fish habitat

Fish utilize the hydraulic habitats within the RCDC, and the design should ensure that there is no net loss of the habitats productive capacity represented by the metric of suitable habitat. Furthermore the designs should not impact downstream water quality by increasing contaminant concentration, turbidity, or temperature.

3.4 Structural

The PMF design should be simple and robust, therefore no mechanical systems, metal work or operator controls have been used. The overall designs rely predominantly on open water, free surface hydraulics and hydrotechnical design elements. At transitions between the hydraulic structures – spillways and flow control structures – the stability of the RCDC channel will be ensured with large keyed sections of mass steel-reinforced concrete. The primary design criteria will be to ensure the channel can not degrade or back cut and destabilize the remaining RCDC and tailings. The keyed sections would be located above the spillway sections, at the flow control structures, and at the transition to the steep channel. Structural reinforced concrete within the hydraulic structures such as the spillway also provides fail-safe operation during the PMF.

Notional sizing has been provided in the conceptual design, but final sizing will be determined by detailed structural analyses and physical model testing. Complete stress, shear, and bearing analysis will be conducted on these structures to account for hydraulic forces, earth pressures, dynamic forces, rock bearing capacity, and potential rock scour and erosion. Shape and size of these structures will be modified to meet all structural geotechnical, hydraulic, and seismic requirements.

3.4.1 Foundation and bearing

The keyed sections would entail excavation to bedrock and re-building with thick-walled mass concrete structure. Rock strength and bearing would be assessed during construction and anchoring requirements engineered at that time. Notional design and costing includes a provision for anchor bolting of all walls and block features.

3.4.2 Hydraulic and seismic loading

Keying and footing to bedrock also provides bearing and lateral resistance for the expected hydraulic forces on these structures during the PMF. Reinforcing and structural design would comply with seismic requirements during time of construction.

3.4.3 Ice loading

Ice-related loading is expected to be negligible during a PMF event. Ice would be lifted and broken-up during a flood event. If significant sheet ice formed over the channel, rock protection provides expansion room and would not transfer loads to adjacent slopes or structures. The channel-in-channel design provides additional area for aufies or glaciering within the MAF channel without compromising channel capacity. The floor of the PMF channel also provides area for machine access – if ice is to be mechanically removed, or for ice to push up and expand into if minor jams occur.

3.4.4 Impact loading and durability

Impact loading is expected to be small relative to self-weight and hydraulic loading during a PMF event. Reinforced concrete will be high-strength (30 MPa) and structures will be set below finished grade which will provide protection from environmental degradation of freeze-thaw and spalling.

4 Closure Design

For mine closure a conveyance strategy must be in place to safely convey the PMF. The existing RCDC structure does not have the conveyance capacity or stability to safely convey the PMF. The scale and cost of the proposed conveyance strategies and the location of a spillway structure to convey flows from the RCDC down to the valley floor depend on the tailings management scenario. The three tailings management scenarios being considered are listed below. Hydrotechnical concept designs have at this time only been prepared for scenario A and scenario B.

A. Stabilize in Place:
Tailings management through removal or breach of the Cross Valley Dam while maintaining the Intermediate Dam and the tailings impounded behind it. The conveyance strategy is to upgrade the current RCDC through widening, deepening, and further armouring of the channel to safely convey the PMF. The existing steep portion of the channel is used as a spillway to return flow from the channel along the south slope down to the existing native channel along the valley floor. Fish passage within this steep section will be upgraded and maintained within the modified version of the existing RCDC.

B. Partial Tailings Removal:
The Intermediate and Cross Valley dams are to be removed or breached and all tailings impounded behind the Intermediate Dam removed. This allows for a new spillway to be located below the Secondary Impoundment dam limiting the required PMF upgrading of the RCDC to the reach from its Primary Impoundment inlet to the new spillway 500 m downstream of the Secondary Impoundment. Minor fish passage and frequent flood flow conveyance upgrades would be required along the remainder of the existing RCDC. A channel along the valley floor would need to be re-established to reconnect with the existing native Rose Creek channel. This re-establishment of this channel is not part of the current **nhc** scope of work.

C. Complete Tailings Removal:
Complete tailings relocation will require removal or breach of the Cross Valley Dam, the Intermediate Dams, Secondary Impoundment dam, and the Primary Impoundment dam. Short-term actions would include maintaining the RCDC in its current configuration until groundwater remediation was complete, then Rose Creek would be returned to the valley floor in some stable channel configuration. At which point the RCDC could be sealed off and decommissioned. This option is not part of the current **nhc** scope of work.

Depending on tailings removal scenarios the hydraulic investigations of the RCDC upgrade can be broken into four components: the RCDC inlet, the PMF channel, the channel spillway – if required – and the steep section of the RCDC. Following is a summary of issues that were identified in the review.

4.1 RCDC Inlet

The inlet zone extends from the entrance of the RCDC upstream in both the South and North forks of Rose Creeks as required to address hydraulic, geotechnical, fisheries, and channel process issues. Significant issues identified in the scoping were:

- concentration of flow from North and South Forks of Rose Creek immediately upstream of the RCDC inlet resulting in potential hydraulic effects
- deposition of small to moderate volumes of coarse and fine sediments during the PMF or significant flood events, and
- effects of this on potential hydraulics of the RCDC

To ensure adverse hydraulic effects are not caused by the confluence of North and South Fork Rose Creeks, the North Fork Creek will be re-routed through the current exfiltration ponds into the South Fork above the pump house pond. The existing area of North Fork channel downstream of the mine road culvert to the RCDC inlet will be filled to the surrounding grade, and the channel diversion will be armoured to prevent bank erosion and stabilize the channel. The outlet of the pump house pond – currently a large weir structure – will be upgraded. By ensuring a large conveyance area and moving the confluence away from the RCDC inlet, potentially adverse hydraulics can be avoided.

1-D numerical modelling using HEC-RAS© was used to estimate the hydraulics of the proposed North Fork Diversion and establish channel configurations, bank heights and conveyance areas required for PMF design.

[insert]

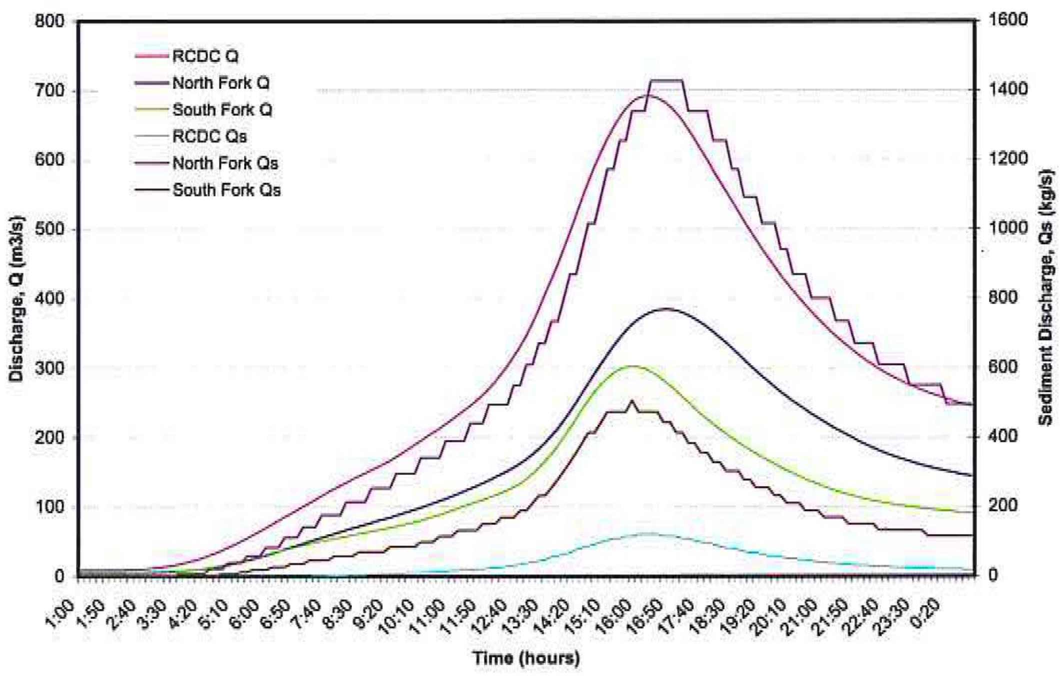
Erosion and channel process in the stream reaches upstream of the RCDC inlet could result in un-assessed quantities of coarse and fine sediments transported into the inlet area and RCDC itself. Using the channel characteristics of the immediate reaches upstream of the RCDC inlet and the RCDC itself, the potential sediment transport capacity can be estimated for the PMF event. The difference in the two values gives an approximation of the potential amount of sediment deposited at the RCDC inlet and the scale of potential mitigation required – if possible.

From a sediment transport perspective, channels can be divided into three distinctive reaches: sediment source, transport and depositional. On the Rose Creek system the source reaches are the upper parts of the watersheds where slopes and channels are coupled (e.g. sediment is delivered from slopes directly to the channel). Stream slopes in this reach are greater than 10%.

Below these reaches, sediments are transported by, but not recruited to the channel. In North Fork, this reach is immediate upstream of the confluence area upstream above the NFRD. In the South Fork, this reach extends upstream from the inlet to approximately the FWSD site. The depositional reach is the RCDC inlet area where the RCDC confines flows and bed slopes decrease to approximately 0.2 %.

During the PMF, we assume that these creek systems are not supply limited, that hillslope and channel processes provide unlimited quantities of sediment for transport, and the sediments available for deposition at the RCDC inlet is limited by the sediment transport capacity of the upstream transport reach on the South and North Forks. Using basic channel data and the PMF hydrology, the potential quantities of sediment transported during a PMF event were estimated using a variety of applicable bedload functions. Given the channel conditions and fully mobilized bed conditions during the PMF, the Ackers-White transport function provides a good representative function to estimate the total load transported[2].

Figure 1 Faro PMF Sediment Discharge



[2] Based on estimate of channel and sediment properties evaluated under **nhc** Bedload program.

The equation requires key inputs including the channel properties – estimated from the HEC RAS modelling - and an estimated sediment gradation. The Ackers-White relationship estimated a total sediment transport of 62,000 tonnes for this reach during the PMF event from both the North and South Forks of Rose Creek and 3,000 tonnes transported by the RCDC channel. This would suggest a net deposition of approximately 60,000 tones or 108,000 m^3.

Table 4 Characteristics and Potential PMF Sediment Budget for RCDC Inlet

Location	PMF (m^3/s)	Channel Width (m)	Channel Slope	Estimated Qs (tonnes)	Volume of Sediment (m^3)[3]
North Fork Rose Creek	384	15	0.02	49,000	88,200
South Fork Rose Creek	290	15	0.01	14,000	25,200
RCDC Channel	674	32	0.002	3,000	5,400
Net Deposition (RCDC Inlet)	-	-	-	60,000	108,000

To mitigate the potential effects of sediment deposition for flood events, including the PMF, the volume of the pump house pond should be evaluated and sufficient area and volume established to accommodate approximately 100,000 m^3 of sediment deposition in the vicinity of the RCDC inlet. Further detail of the proposed works is provided by the accompanying drawings.

4.2 RCDC Channel

1-D numerical modelling using USACE HEC-RAS© version 3.2.2 was used to estimate hydraulics reflecting design modifications throughout the design progression. This included hydraulic structures and channel section modifications required to ensure conveyance with correct freeboard requirements were met. The model was used to estimate average velocity at each cross-section and a water surface profile along the RCDC.

Using the model results stability was analyzed and rock riprap armouring requirements were developed. Design bank elevation accounting for expected PMF flow depth and a 1.0 m freeboard was determined also based on the model results. Table 5 presents hydraulic design parameters for the low gradient RCDC PMF design channel.

[3] Volumetric conversion for deposition of bed sediments is 1.8 m^3 per tonne.

Table 5 RCDC Design Parameters for Cross Section 0+000 to 3+600

Parameter	Design Value	nhc 2004[4]
Flow depth	6.1 to 7.0 m	8 m
Velocity average (maximum)	3.4 m/s	3.6 m/s
Low flow bottom width	10 m	
Channel width (bottom)	32 m	5-8 m
PMF wetted top width	48 m (approx.)	40 m (approx.)
Bank slopes	2:1 H:V	2:1 H:V
Longitudinal grade	0.0020 to 0.0022	0.0020 - 0.0022
Riprap size	D_{20} = 0.25 m D_{50} = 0.48 m D_{100} = 1.00 m	D_{50} = 0.30 m D_{100} = 0.45 m
Riprap liner thickness	1.0 m	0.6 m
Filter size	D_{20} = 0.01 m D_{50} = 0.03 m D_{100} = 0.05 m	?
Filter thickness	0.30m	0.15m
Clay-/ Till liner (K<0.0001)	0.50 m	1.0 m
Till Liner Elev.	MAF	PMF+1m
Freeboard	1m	1m + 1m

Model scenarios were run to account for a variety of "worst case" conditions that would influence hydraulic performance in order to test the adequacy and risk of failure of the design armouring and bank elevation. These test scenarios included a series of channel blockages at various locations potentially caused by sediment aggradation, side slope failures and slumps, or ice blockages.

A 30% channel blockage between Station 0+000 and 3+800 (0.2% gradient channel) results in upstream flow depth increased by 0.75 m; which is within the 1.0 freeboard allowance. Typical channel transport rates are in the order of 120 m^3/hour, but can increase by up to 3 times as velocity increases around a channel blockage. A 30% channel blockage with an assumed average width of 30 m would significantly increase flow velocity and result in half of the blockage washing out typically within 6 to 12 hours – significantly reducing its hydraulic effects – assuming the blockage was erodible such as sand and gravel. If the blockage filled an extensive length of channel, was un-erodible or unmovable, or blocked more than 30% of the channel, failure of the riprap bank armouring or overtopping of the bank could occur.

Using a physical model, the stability of the RCDC design section and proposed countermeasures can be further tested. Potential scour, erosion, and breach scenarios can

[4] 2004 **nhc** cross sections from Yukon Engineering Services (YES) Survey data (2003).

be modeled and effectiveness of the reinforced concrete channel invert control sections can be examined under various conditions, including PMF.

4.3 Spillway

The side channel spillway is proposed for the partial tailings removal scenario. It is intended that the side spillway convey roughly 90% of the PMF with the remaining flow or volumes from higher frequency floods be conveyed by the existing downstream portion of the RCDC.

An erodible fuse-plug would cover the spillway crest to maintain frequent flood flows through the existing RCDC. When a significant flood erodes the fuse-plug, the spillway would reduce the flows through remainder of the RCDC. It is intended that the fuse-plug be reconstructed after such an event to provide cover for the mass concrete component of the spillway crest, however if the fuse-plug is not replaced no additional risk would be posed against the hydraulic structures or the dams and tailings.

The spillway and its associated stilling basin was designed through use of empirical design methods and verified with a 1-D numerical model (USACE HEC-RAS© version 3.2.2). Key design parameters including width, slope, depth, velocity, stability requirements, and inlet sill elevation were estimated and verified with the model.

Due to the high velocities and steep channel (10% grade) general design equations and accepted modelling practices are near their applicable range. Experience from similar projects including detailed physical modelling conducted by **nhc** was used to develop armouring requirements for the spillway and the stilling basin.
provides a list of key design parameters. Further detail is provided by the accompanying drawings.

Table 6 Channel Spillway Design Parameters

Parameter	Value
Flow depth	1.7 m supercritical 3.7 m subcritical (jump)
Maximum Velocity	8.5 m/s
Channel width (bottom)	40 m
Bank slopes	2:1 (H:V)
Longitudinal grade	0.10
Riprap size	D_{20} = 1.20 m D_{50} = 1.70 m D_{100} = 3.00 m
Riprap liner thickness	3.5 m
Filter size	D_{20} = 0.040 m D_{50} = 0.160 m D_{100} = 0.280 m
Filter thickness	0.50 m

Steel reinforced mass concrete is proposed for the spillway crest as well as to construct a downstream hydraulic control and an upstream grade control. All three components are to be pinned down to the underlying bedrock with rock-bolts and surfaced with rock riprap to limit deterioration from erosion and freeze-thaw cycling. The three structures will be connected to each other to prevent flows from outflanking around any of the structures.

If this design scenario is to progress through to construction, scaled physical hydraulic model testing is recommended. The physical model will accurately represent the hydraulic performance of the spillway control section, the ramp section and the downstream flow control section. Scaled riprap used to construct the spillway will be used to ensure the stability of the structure. Physical modelling provides an opportunity to examine anomalous and temporary local hydraulics and potential concentrations of flows which otherwise can not be accurately predicted by any other means. Previous physically modeling on other projects has identified these features which could have initiated the loss of armouring riprap.

4.4 RCDC Steep Section

The design scenario that includes partial removal of the tailings and removal or breeching of the Cross Valley and Intermediate dams requires minor improvements to the RCDC to ensure its capability to safely convey flows in the order of the 200-year event - approximately 20% of the PMF. The downstream portion of the RCDC will be upgraded to safely convey the PMF in the design scenario that stabilizes tailings in place. This section concentrates on the scenario, in which the entire RCDC must be capable of conveying the PMF.

1-D numerical modelling using USACE HEC-RAS© version 3.2.2 was used to estimate channel hydraulics such as average velocity at each cross-section and a water surface profile along the RCDC. During extreme flood flows the flow down the steep sections can become supercritical – fast shallow flow – but only marginally, and therefore can hydraulically jump back to subcritical prematurely – deep slow flow. Because of the instability in flow regime, the channel was designed with the model results to account for the potential maximum depth (subcritical flow) with a 1.0 m freeboard and maximum velocity and erosive potential (supercritical flow). Table 7 presents hydraulic design parameters for the steep portion of the RCDC under PMF design conditions.

Model scenarios were also run to account for a variety of "worst case" conditions that would influence hydraulic performance in order to test the adequacy and risk of failure of the design armouring and bank elevation. These test scenarios included a series of channel blockages at various locations potentially caused by sediment aggradation, side slope failures and slumps, or ice blockages.

A 30% channel blockage at subcritical flow results in upstream flow depth increased by as much as 1.0 m to a total depth of 7.5 m; this is within the 1.0 freeboard allowance. Typical channel transport rates in this reach are in the order of 400 to 900 m^3/hour. A 30% channel blockage with an assumed average width of 30 m would significantly increase flow velocity and result in half of the blockage washing out typically within a few hours. If the blockage filled an extensive length of channel, was un-erodible or unmovable, or blocked more than 30% of the channel, failure of the riprap bank armouring or overtopping of the bank could occur.

Table 7 RCDC Design Parameters for Cross Section 3+600 to 4+700

Parameter	Design Value	nhc 2004
Flow depth	2.5 m supercritical 6.5 m subcritical	
Maximum Velocity	9.5 m/s	10 m/s
Low flow bottom width	10 m	
Channel width (bottom)	22 m	30 m
PMF wetted top width	30 m (approx.)	
Bank slopes	2:1 (H:V)	2:1 (H:V)
Longitudinal grade	0.047	0.049
Riprap size	D_{20} = 0.80 m D_{50} = 1.30 m D_{100} = 2.20 m	>2.0 m
Riprap liner thickness	2.6 m	
Filter size	D_{20} = 0.04 m D_{50} = 0.08 m D_{100} = 0.20 m	
Filter thickness	0.30m	
Clay-/ Till liner (K<0.0001)	0.50 m	

Rock riffles will be constructed within the low flow channel of the steep sections to maintain fish passage up the RCDC. The current rock weir structures constructed with 1.0 to 1.5 m diameter rock have been successful in maintaining fish migration and have remained relatively stable and intact. The riffles will be designed similar to the rock weirs except they will have a shallow slope on their downstream face allowing fish to swim up the face while providing increased stability and support. Details on riffle design and location is provided by the accompanying drawings.

nhc has undertaken physical modelling of similar ramp structures utilizing rock surfacing and riffles for stability and fish passage assessments. The work undertaken showed that the riffle structures provide improved depth of flow and a wider range of suitable hydraulic conditions over a range of inflows. The inter-rock spacing developed from the large materials used provides multiple passage opportunities in comparison to a fishway that may have a limiting condition for smaller fish sizes or weaker-swimming species.

Using a physical model, the stability of the RCDC design section and proposed countermeasures can be further tested. Potential scour, erosion, and breach scenarios can be modeled under various conditions – including the PMF – and stability and potential damage assessment of the riffle sections can be tested.

5 Summary

5.1 Scenario A – Stabilize Tailings in the Rose Creek Valley

The retention and stabilization of the tailings would require upgrading of the RCDC along its entire existing length to convey the PMF. The proposed scenario would involve increasing the conveyance of the channel by widening of the channel and raising the banks. Both modifications require moving outward or adding onto the right bank towards the impoundments north of the RCDC, blasting and/or excavating south into the south slope, or a combination of both. The evaluation on whether to cut into the south slope or build to the north is based on site inspection, available contour and air photo data, and past reports (BGC, 2005):

1. Between station 0+100 and 0+800, no channel widening or increasing of the bank height is required to convey the PMF.

2. From station 0+800 to 2+800 and station 3+800 onwards, channel straightening, widening, and increasing of the right bank height would be accomplished through reconstructing the channel and the right dike (facing downstream) towards the north. This work will require reconstructing the right dike (facing downstream) on solid ground and may require some sub-excavation and refill in shallow lifts and compacted.

3. Between station 2+800 and 3+800 soft unsupportive tailings up to 20 m in depth are located north of the existing north dike. In order to widen the channel blasting and/or excavation of the south slope is required. The majority of material addition required to increase the north dike height will be placed along the south side of the north dike to avoid placement of material over the tailings.

4. From station 3+800 to the end of the RCDC at station 4+700 there are two steeper sections at 4.7% grade separated by a 100 m long flatter section at 0.7% grade. The channel through this entire reach will be widened to 22 m and the banks raised to 7.5 m depth to accommodate for a potential subcritical flow depth of 6.5 m and 1.0 m of freeboard. Armouring of the channel is designed to remain stable under supercritical flow. Hydraulic modelling of this reach suggests that during the PMF flow is just supercritical (**F** > 1) in the steep portions and subcritical in the flatter portion. Hence the hydraulic jumps may be present at the tail end of the steep portions are likely to move up and downstream, and therefore the entire reach should be designed to be remain stable and not overtop no matter what the flow regime is in the channel.

Throughout the entire length of the RCDC a channel roughly 10 m wide and 1 m deep will provide conveyance for normal up to the estimated mean annual flood. The reduced sectional area of the MAF channel will maintain a reasonable velocity and flow depth allowing fish migration while maintaining a level of sediment transport capacity reducing the likelihood of channel aggradation.

Through the two steep portions of the channel downstream of station 3+800, the MAF channel will have rock riffles constructed across the channel similar to the existing rock weirs. The riffles will be designed and spaced accordingly to improve upstream fish migration and maintain stability in frequent flood events. Extreme flood events in excess of the 100-year flood may damage the rock riffles and thus require some post event maintenance to ensure fish migration effectiveness is maintained.

At the upstream end of the steep section a secured imbedded key of concrete is to be installed as grade control. The concrete will be anchored with rock bolts to the underlying bedrock, steal reinforced, and designed to withstand expected hydraulic and impact loading. The structure will be surfaced with granular channel lining to prevent freeze-thaw cycling and weathering of the concrete. The concrete grade control is included as a safeguard against downstream erosion. If the steep section of the channel downstream fails and erosion begins to propagate upstream, it will be prevented from continuing past the concrete grade control and prevented from jeopardizing the tailings and their impoundments structures. This key is to be installed as secondary line of defence, unnecessary except in the event of a catastrophic downstream failure.

During the PMF and more frequent floods (100-year and greater) there is potential to have some movement of the riprap channel lining and fish passage riffles, as well as the receding flood may result in deposition of debris and gravel within the channel. We recommend that the channel be inspected and maintained after extreme flood events. It is expected that any repairs or maintenance work would be minor and infrequent, and accomplished at minimal cost as part of overall closure monitoring and maintenance. Expected inspection and maintenance issue are discussed further in the summary.

5.1.1 Costs

Material quantities were estimated from the Autocad© Civil Design rendering model of the existing surface to the proposed design surface generated by the alignment and the proposed sections. Application of the typical design section unit quantities along the specific stationing generated volumes of materials for excavation and fill. Unit rates for manufacture, construction and placement were provided by the FMPCO.

The total project costs for upgrading of the entire RCDC assuming retention of the tailings is estimated at $51.5 M that includes a 20% cost contingency.

Table 8 Scenario A Project Costs

	Item	Unit	Rate	Quantity	Cost
1	Upgrade RCDC Inlet, NF and SF Rose Creek confluence	1	ea.	$6,375,000	$6,375,000
2	Upgrade RCDC to PMF design				
2.1	0+000 to 0+900	900	m	$8,767	$7,890,000
2.2	0+900 to 3+700	2,600	m	$4,852	$12,615,000
2.3	3+700 to 4+700	1,000	m	$13,115	$13,115,000
3	Construct 2 grade/hydraulic control structures	2	ea.	$1,450,000	$2,900,000
Subtotal					$42,895,000
Project Contingency (20%)					$8,579,000
Total Project Estimate					**$51,474,000**

5.2 Scenario B – Partially remove Tailings from Rose Creek Valley

Partial tailing removal will require removal of the Cross Valley and Intermediate Dams and the tailings stored behind. The RCDC requires upgrading to convey the PMF from its inlet the proposed spillway to be located at the exposed bedrock 550 m downstream from the existing fuse-plug. At that location a spillway is to be constructed to safely convey extreme flood flows down to the historic valley floor.

1. Between station 0+100 and 0+800, no channel widening or increasing of the bank height is required to convey the PMF.

2. From station 0+800 to 1+500, channel straightening, widening, and increasing of the right bank height would be accomplished through reconstructing the channel and the right dike (facing downstream) towards the north. This work will require reconstructing the right dike (facing downstream) on solid ground and may require some sub-excavation and refill in shallow lifts and compacted.

3. At station 1+500, a side channel spillway is proposed. The spillway is designed to convey the extreme flood events limiting the requirements placed on the RCDC from this point onwards downstream. The spillway is at a relatively gradual slope of 10% and wide enough to encourage shallow flow, both these design features allow a stable structure to be constructed of rock riprap. This location was selected for the spillway because there is extensive shallow and exposed bedrock allowing the spillway structure to be securely tied in to stable ground.

4. From station 1+500 onwards to the end at station 4+700, the channel capacity will not be increased, but the stability of the channel and the fish passage rock weirs will be confirmed and potentially improved upon to ensure longevity under

frequent floods and its portion of the PMF; i.e. approximately 100-year flood flow.

The spillway will incorporate three steal reinforced mass concrete features; a constriction or hydraulic control structure downstream of the spillway, the spillway crest, and a channel grade control upstream of the spillway. All three are to be pinned down to the underlying bedrock with rock-bolts and surfaced with rock riprap to limit deterioration from erosion and freeze-thaw cycling. The three structures will be connected to each other to prevent outflanking flows.

The hydraulic control structure is used to ensure the downstream channel has a narrow unreadable section. The narrow section ensures the water level upstream of the control is high enough during extreme events to encourage flow over the side spillway. The hydraulic control structure is simply concrete walls and base constructed within the banks and bed of the downstream channel to supporting the bed and banks and therefore limiting potential erosion.

The spillway crest is concrete weir along the crest of the spillway to ensure the crest elevation of the spillway is maintained even under the unlikely event of erosion of the spillway. The spillway crest is also to be constructed below grade with an erodible fuse-plug cover. The cover is to prevent deterioration from erosion and freeze-thaw cycles and to ensure moderate flood flows continue down the RCDC with only the most extreme floods overtopping and eroding the fuse-plug.

The upstream concrete grade control acts as a further safeguard to prevent erosion from propagating upstream from the spillway or the RCDC and jeopardizing the remaining impoundments and tailings. It too is to be covered with rock riprap to prevent deterioration. The grade control will ensure that in the unlikely event of erosion or failure of the spillway or the downstream portion of the RCDC, any erosion and head-cutting would not be able to propagate up the RCDC.

The side channel spillway is a relatively gentle slope of 10% in comparison with typical spillways. Because of the spillways low gradient, the flow velocity and subsequent Froude number is maintained relatively low and therefore a stilling basin of less than 20 m is required to ensure the flow returns from the supercritical spilling flow to a subcritical state in a controlled and appropriately rock armoured location.

During the PMF and other more frequent floods (100-year and greater) there is potential to have some movement of the riprap channel lining and fish passage riffles, as well as the receding flood may result in deposition of debris and gravel within the channel. It is therefore recommended that the channel be inspected and maintained after extreme flood events. It is expected that any repairs or maintenance work would be minor and infrequent, and accomplished at minimal cost as part of overall closure monitoring and maintenance.

5.2.1 Costs

Table 9 Scenario B Project Costs

	Item	Unit	Rate	Quantity	Cost
1	Upgrade RCDC Inlet, NF and SF Rose Creek confluence	1	ea.	$6,375,000	$6,375,000
2	Upgrade RCDC to PMF design				
2.1	0+000 to 0+900	900	m	$8,767	$7,890,000
2.2	0+900 to 1+700	800	m	$4,852	$3,881,538
3	Construct Spillway Structure	1	ea.	$23,135,00 0	$23,135,000
4	Construct grade/hydraulic control structures	2	ea.	$1,450,000	$2,900,000
Subtotal					$47,181,538
Project Contingency (20%)					$9,436,308
Total Project Estimate					**$56,617,846**

5.3 Project Risks, Operation and Maintenance

The design constraints pose a difficult problem for the PMF design, as previous work has shown that a rip-rap lined channel would be subject to erosion and loss of stability in an extreme flood event. Unprotected, channel erosion and head-cutting could progress upstream and compromise dam and tailings stability. A concrete spillway could be designed to pass the flood without erosion, but it would require continuous maintenance and repair work, and a spillway founded entirely on competent bedrock is not possible. Consequently, a relatively typical, low maintenance solution cannot be achieved.

In recognition that a maintenance-free solution cannot be readily and cost-effectively achieved, our focus has been applied to how to best minimize maintenance frequency and costs over the long term while ensuring stability and integrity of the structures. This notions is based on the expected frequency of the PMF occurring – an estimated 100,000 year event (Dr. M. Leytham, **nhc**, *pers. comm.*) – and damage expected to occur during that event give the concept design provided.

In Scenario A, the steep section is redesigned to discharge the flows approaching the PMF in a controlled manner with minor movement of riprap. In Scenario B, the steep section of the existing RCDC will function up to 500-year events with limited maintenance (e.g. replacement of fish passage roughness and weirs), and the spillway would pass the reaming flows up to 600 m^3/s. Resulting in a requirement for some repairs, managed in the same manner as the spillway.

The design scenario in either A or B provide steep sections of the channel and spillway constructed or armoured with large diameter (1.5-2 m.) riprap installed and founded to bedrock where possible, and of sufficient mass and quantity to resist scour and erosion, uplift and plucking. In the spillway design, grouting in between the large rock is recommended to increase the resistance to hydraulic forces. It is anticipated that this riprap will be sourced and produced from the nearby existing quarry source near the Intermediate Dam, therefore access is close and sufficient supplies are there for stockpiling for future use.

Annual Maintenance and Inspection

- CDA guidelines.
- Inspection of dike, hydraulic structures, steep section weirs and RCDC channel
- Removal of loose debris, drainage and ditching
- Inspection of slopes, drainage
- Survey of dike crest
- Channel assessment

Channel-filling Flow (1-5 to 1-50 year flow

- Erosion and scour assessment
- Hydraulic assessment and re-survey of RCDC weirs
- Resurvey of RCDC invert and inlet area
- Recording of stage

Structural Half-life (50 years)

- Inspection and testing of r/c
- Rock testing
- Re-grouting

Spillway Activation Flows (50 to 100-yar flows)

- Inspection of spillway structures
- Face inspection and re-grouting of spillway face
- Reconstruction of fuse-plug

PMF Flow

- All above, including reconstruction to as-built condition

5.4 Future Design Concept Issues

Project costs are based on assessment of existing conditions, current estimates of unit costs and assumptions regarding the constructability and geotechnical conditions that have not been adequately assessed. As such, they should be used with caution in relation to absolute project values, but provide comparable valuations for scoping and comparison to other closure activities. The following work items are suggested to optimize the design of the structures, reduce the field engineering requirements during the construction phase, and provide a better estimate of project scope and costs.

5.4.1 Hydrotechnical

In order to provide detail design information for the hydraulic structure – spillway and grade control features – scaled physical modelling is required. This information would provide the information required to design and assess the hydraulics of the control weir section, side spillway ogee and rock armoured spillway face, RCDC bank rock protection and weir design.

5.4.2 Geotechnical

Depth to bedrock will be located at the proposed locations of the concrete control structures once their position is finalized, or as part of an optional study. In addition to determining the depth to bedrock, the study would determine the depth to unweathered bedrock and strength of the rock (bulk strength and effects of joints). Foundation of the fill structures will be checked to determine the performance during normal loading due to the increased fill thickness. This will include investigating bearing strength and the stability of the diversion dike. The south slope forming the left upslope will be checked to determine local performance of the cut slope during normal operation. This being most relevant for new cut slopes. These items would be undertaken as a field investigation and drilling program.

Seepage cut-off will require further design for the raised dike sections both on the left and right side of the RCDC. For extreme loading circumstances the following additional investigation will be needed:

- slope stability under high water conditions;
- potential occurrence and results from landslide debris from upslope of the left bank;
- potential earthquake induced instability (liquefaction) particularly upslope of the left bank and along the dike; and
- stability changes resulting from selected option for the tailings and polishing pond.

Test excavation will need to be conducted dependent on the extent of new cut slopes, in order to determine the need for and thickness of thermal protection blanket. We suggest this issue is best dealt with as an investigation undertaken during actual construction.

Bedrock soundness must be inspected during construction with cut-off trenches installed where bedrock has fissures and cracks allowing extensive seepage. Bedrock slopes should be inspected to determine where slope stabilization techniques need to be applied; such as, slope flattening, scaling, rock bolts, and/or shotcrete. Furthermore, anchor strength is to be tested where concrete structures are anchored to bedrock. Pockets of ice rich soil or overlying ice rich colluvial exposed during construction will have to cut back and covered or removed to control sloughing. Thermal liners will be added as deemed necessary during construction.

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