Conclusions from Rose Creek Tailings Area Alternatives Evaluation

Prepared for

Government of Canada
as represented by Aboriginal Affairs and
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A Report on Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area, Faro Mine

B IPRP Technical Memorandum, Final Review Comments – Rose Creek Tailings Area Workshop, Faro Mine Remediation Project

C TRB Summary Report 3: Rose Creek Tailings Area, Faro Mine Remediation Project

Acronyms and Abbreviations

AANDC	Aboriginal Affairs and Northern Development Canada
BCG	BGC Engineering Inc.
C&R	closure and remediation
CH2M HILL	CH2M HILL Canada Limited
CVD	Cross Valley Dam
CVP	Cross Valley Pond
Draft report	*Draft Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area, Faro Mine*
El.	elevation
ID	Intermediate Dam
II	Intermediate Impoundment
IPRP	Independent Peer Review Panel
KCB	Klohn Crippen Berger
m	metre
masl	metres above sea level
mbgs	metres below ground surface
MCE	maximum credible earthquake
PDT	Project Design Team
PMF	probable maximum flood
RA	risk analysis
RCC	roller-compacted concrete
RCD	Rose Creek Diversion
RCTA	Rose Creek Tailings Area
SRK	SRK Consulting Engineers and Scientists
TRB	Technical Review Board
YG	Government of Yukon

SECTION 1

Introduction

This conclusions report provides a detailed description of concepts for the selected closure and flood routing alternative in the Rose Creek Tailings Area (RCTA). These concepts crystallized after a series of actions to evaluate alternatives for the RCTA, including:

- A 2-day workshop at the CH2M HILL Canada Limited (CH2M HILL) office in Burnaby, British Columbia on August 28 and 29, 2012. The workshop was attended by Government of Yukon (YG) and Federal Government representatives (including Aboriginal Affairs and Northern Development Canada [AANDC]), the YG Independent Peer Review Panel (IPRP), the CH2M HILL Technical Review Board (TRB), the Independent Engineer, and the Project Delivery Team (PDT).
- Pre-meeting activities and reports, including the report *Draft Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area, Faro Mine*, published August 2012 (provided as Attachment A; Final report, November 2012).
- Post-meeting reports prepared by YG's IPRP and CH2M HILL's TRB, provided as Attachment B and Attachment C, respectively.

The most important criterion for RCTA flood routing is the capacity to pass the probable maximum flood (PMF), compared to the existing condition that only accommodates routing of the 500-year flood event. The proposed concepts also address concerns such as the risk of breaching the Rose Creek Diversion (RCD) dike during normal operations, and interaction between the flood routing concepts and other elements of remediation, such as the collection of contaminated groundwater, management of surface water flowing over tailings covers, and the future role of the Cross Valley Dam (CVD) and Cross Valley Pond (CVP).

SECTION 2

Summary of Alternatives Evaluation

Over the last 10 years, different options for routing floods through the Rose Creek Valley were considered and studied. Initially, the options focused on modifying and enlarging the RCD so that its capacity would be increased from passing the 500-year flood to passing the PMF. By the end of this study period, the concepts evolved to include passing the PMF over the Intermediate Impoundment (II), entering the area through a fuseplug, and then exiting the II through a spillway on the right abutment of the Intermediate Dam (ID). The Closure and Remediation (C&R) Plan (SRK, 2010) detailed two versions of this concept.

The TRB expressed concerns with the ability of the multi-swale configuration used in the C&R Plan closure options to prevent channelization and serious erosion or scour of the cover system that are associated with the PMF flows (or flows from other large flood events). As a result, three more robust flood routing alternatives were developed. CH2M HILL's PDT performed risk analyses (RA) to evaluate the performance and reliability of each of these alternatives, and prepared a report (Attachment A) to document the RA. The report also included a comparative order-of-magnitude cost estimate.

The August 28 and 29 workshop in Burnaby was held to review the PDT's final recommendations regarding suitable alternatives and selection of a preferred alternative, and to receive feedback from YG, AANDC, the IPRP, and the TRB. The goal of the workshop was to obtain general consensus among the workshop participants for a selected alternative. The three alternatives presented include:

- Alternative 1 – Routing of the full PMF through a modified (widened and deepened) RCD with no flow entering the II.
- Alternative 2 – Channelling of flows greater than the 500-year flood over the top of an overflow weir and into a single, large, armoured channel (the side channel) designed to carry the difference between the PMF and the 500-year flood flow. The side channel would run parallel and immediately adjacent to the RCD, principally founded on soil and bedrock, with the north dike dividing the RCD and the proposed side channel. Construction of energy dissipation structures to control erosion and an improved spillway to route the flow across the tailings and around the ID are central elements of this alternative.
- Alternative 3 – Routing of flows that exceed the 500-year flood up to the PMF flood over an overflow weir structure into the RCTA and over a covered tailings surface via a single, wide, riprap-lined swale (about 120-metres [m] wide and 1.5-m deep) dedicated to containing the flood flow until a pool has formed that would be able to dissipate the energy during the flood peaks. Construction of an improved spillway around the ID is also a central element of this alternative.

The RA results indicate relatively low risk for Alternatives 1 and 2, with unacceptable annual probabilities of failure for the existing condition and for Alternative 3. The Draft report concluded that the three alternatives can be considered to have similar construction costs, and that it would not be possible to select any of the three alternatives purely based on the comparative Class 5 cost estimate.

Following the workshop in Burnaby, final feedback was provided by the IPRP and the TRB, as documented in their reports published in September and October 2012, respectively. These reports provided an excellent basis for selection of a preferred RCTA alternative; Section 3 provides details about the concepts.

2.1 Post-meeting IPRP Report

The findings and recommendations from the IPRP are documented in their report in Attachment B. The main and most significant findings and recommendations are as follows:

- Risks of failure for Alternative 1 may be underestimated due to the potential of landsliding and ice blockages. Alternative 1 should include a PMF spillway at the ID and comprehensive erosion protection measures in the RCD between the ID and the downstream discharge point.

- Risks of failure for Alternatives 2 and 3 may be overestimated with respect to the environmental impacts of tailings erosion (Type 1 and Type 2 tailings releases – see definitions in Attachment A). The IPRP noted that Type 1 releases should not be considered a failure mode under extreme runoff conditions, and Type 2 releases under similar conditions should be considered of low significance.
- The IPRP recommend that the CVD be retained to provide an emergency water storage facility to accommodate groundwater discharges to the surface during upsets and power outages to the main RCTA seepage collection system, as well as to provide for some sedimentation of tailings eroded during extreme runoff events.
- The IPRP recommended a number of Down Valley hydraulic mitigations to manage the risk in the short and intermediate terms, most importantly:
  - Build out the permanent PMF spillway structure as soon as reasonably possible.
  - Since it will take significant time to design and construct the new spillway structure, the IPRP suggested that the following short-term improvements should be considered to decrease the risk of overtopping and breaching the ID, including:
    - Increasing the hydraulic capacity by increasing the width and depth of the existing ID spillway channel
    - Increasing the height of the ID embankment crest by installing a geomembrane to extend the core to the ID crest and by adding a temporary crest berm
    - Protecting the ID spillway channel from erosion by installing reno/gabion mattress
    - Increasing the RCD capacity by removing vegetation and raising the north dike

2.2 Post-meeting TRB Report

The conclusions and recommendations from the TRB are documented in their report in Attachment C. The most significant conclusions and recommendations are as follows:

- Regardless of alternatives selected, the TRB agreed with the IPRP that a PMF spillway at the right abutment of the ID is prudent.
- The TRB is in favour of Alternative 2, based on the following considerations:
  - The difficulties of implementing Alternative 1 due to vulnerability to plugging from landslides
  - Potential erosion issues with the steep downslope section of the RCD during extreme flood events that could threaten the ID left abutment
  - A PMF spillway is recommended for all alternatives (i.e., Alternative 1 does not eliminate the need for a PMF spillway on the ID)
  - Alternative 2 has the advantage of the RCD providing a buffer from landslides and other blockage mechanisms
  - With appropriate design, Alternative 2 can capture the effects of a north dike failure within the scope of long-term maintenance
- The TRB noted that there is significant uncertainty in the reference documentation regarding the quality of the earthworks in the RCD dike, which reportedly transverses a wide variety of materials, ranging from bedrock to till and creek alluvium, and was built under winter conditions. They stated that this uncertainty needs to be resolved by appropriate design measures.

- The TRB recommends that a review of the available methods and means to provide a competent foundation for Alternative 2 should be carried out. The PDT must identify short-term priorities to reduce risks during the period prior to the start of closure implementation. The PDT should develop and implement a monitoring program for the interim periods aimed at managing risks and potential hazards identified by the group that met during the TRB meetings, including YG and their representatives and the IPRP.
- Precedence for natural landslide- and icing-related issues needs to be examined and evaluated at other Yukon project locations. Precedent for the use of potential construction elements, such as articulated concrete blocks, grouted riprap, and other erosion protection measures, should also be examined in a Northern Canadian setting.

SECTION 3

Selected RCTA Alternative

3.1 Preliminary Concepts

Alternative 2, as briefly described in the previous section, was selected as the preferred alternative for routing the inflow design flood through the RCTA. The alternative entails the use of a single, large, armoured channel (the side channel) located immediately adjacent (north) of the RCD into which flood flows greater than the 500-year flood will be channeled. The RCD dike will divide the RCD and the proposed side channel.

The following concepts will be integrated into this preferred alternative:

- Flows smaller than the 500-year flood will be routed through the existing RCD with some improvements. Larger floods up to the inflow design flood (the PMF) will be routed over an overflow weir structure located at the existing overflow (fuseplug). It is anticipated that the overflow weir will be significantly longer than the existing overflow, and the initial concept has it at a length of about 400 m. The downstream slope of the weir will be reinforced against erosion using elements such as articulating concrete blocks or grouted riprap.
- Although the use of a side channel provides a safeguard in case of RCD dike failure, the functionality of the RCD and the stability and integrity of the RCD dike will be an important design consideration. Specific improvements will be defined once a more complete evaluation of the dike adequacy has been completed. Some improvements that will be considered include:
  - Installation of a cutoff wall over sections where excessive seepage occurs from the RCD through the RCD dike or its foundation (such as the location of the existing fuseplug).
  - Installation of a downstream berm incorporating a filter/drain system at the downstream toe of the RCD dike; this measure will significantly decrease the likelihood of piping through the RCD dike.
- The side channel dike will be founded on natural ground or bedrock (i.e., the tailings under the footprint of the dike will be removed). The present concept includes excavation of tailings beneath the side channel bottom; however, in-place displacement methods will also be considered.
- Flood water channelled through the side channel will be routed over the tailings surface immediately upstream of the ID embankment to a spillway in rock cut on the right abutment of the ID. The existing ID Pond will be filled with tailings, and once the cover is placed over the entire intermediate tailings surface, erosion protection will be placed over this area upstream of the ID.
- The pool of water that will develop behind the ID during flooding will serve as an energy dissipater. To facilitate rapid pooling, it is proposed that the sill of the spillway entrance be at an elevation of (El.) 1,047 metres above sea level (masl), which will be about 1 m higher than the tailings surface at the II.
- The new spillway will roughly follow the same alignment as the existing spillway. The conceptual side channel spillway consists of three elements: (1) a control structure consisting of a mass concrete structure with an uncontrolled (ungated) 60-m-wide ogee crest, (2) a relatively steep discharge channel cut in rock and about 30-m wide, and (3) a terminal structure at the downstream end of the spillway consisting of a plunge basin or energy dissipater (60-m long, 40-m wide, and about 5-m deep) that will be lined with grouted riprap. A short exit channel will convey water from the plunge basin to the CVP. The design will provide flexibility to allow continuation of a spillway chute (channel) to completely bypass the CVP and the CVD in case this option is preferred to enlarging the CVD spillway. A small drainage channel is proposed in the top of the ogee crest, as well as in the bottom of the spillway channel, to allow for the continuous drainage of rainfall and snowmelt within the II area.

- The spillway concept requires about 4 m of excavation along the centreline of the spillway channel, but up to about 10 m in the basin immediately downstream of the control structure and up to 15 m in the plunge basin (energy dissipater). The existing geotechnical information indicates that the depth of bedrock at this location varies from about 0 to 11 m below ground surface (mbgs). The bedrock is a dark grey, very closely foliated, medium-strong schist with quartz veins. To prevent scour into the right abutment of the ID, the preliminary concept is to use a reinforced concrete wall on the south side of the channel that will separate the spillway channel from the ID embankment, with its bottom extending about 5 m below the bottom of the spillway discharge channel. In addition, it is anticipated that dental concrete, rock bolting, or equivalent measures will be necessary on the base and sides of the spillway to provide protection against scour.
- The ID will be raised to at least El. 1,052 masl. The existing ID does not have filter and drainage systems in the lower part below the downstream bench of the embankment. Because the water surface of the CVP was maintained at or just below the bench level, seepage and filtering at the downstream slope was a lesser concern. However, since the concept is that the CVP will be drained and maintained in a dry state, it is possible that the phreatic surface can develop and daylight on the lower downstream face. It is proposed that new filter and drains be installed on the downstream slope to properly drain the embankment and prevent an unwanted and potentially detrimental seepage force developing on the downstream face of the ID. The drains will be connected to a downstream toe drain or drainage trench from where the contaminated groundwater will be collected and pumped to the treatment plant.
- In the Intermediate mpoundment, the tailings will be covered with a protective soil and vegetative cover consisting of approximately 0.5 m of a stabilizing rock zone overlaid by an additional 1-m-thick layer of loosely compacted glacial till material that will promote vegetation growth. The stabilizing rock zone will also serve as a drainage blanket.
- Contaminated groundwater collection systems will be installed upstream and downstream of the ID. The upstream collection system will collect contaminated seepage flowing from the tailings and along the stabilizing rock drainage blanket.
- Following the IPRP recommendation, the recommended concept for the CVD is that the dam embankment be retained to provide an emergency water storage facility. The CVP will also provide a facility to allow sedimentation of tailings eroded during extreme runoff events. It is recommended that the normal operating condition be a low water level CVP: either drain the pond or only maintain a very low water level in the pond. Studies performed by Klohn Crippen Berger (KCB, 2006b) indicated that the CVD would not be stable for the design earthquake event (which is the maximum credible earthquake [MCE]), but that it would be stable for an earthquake event with a return period of 500 years (KCB, 2007). If the pond is normally empty or at a low level, seismic stability for a 500-year return period earthquake is considered to be an acceptable seismic design criterion. The CVD spillway will be upgraded to pass the PMF flood.
- Since the recommended concept is that CVP will be maintained in the drained condition, a low-level outlet will have to be installed at the CVD. An initial concept is to excavate a notch at the right abutment in which a 30-inch-diameter outlet pipe will be installed and backfilled with mass concrete or roller-compacted concrete (RCC). This concrete backfilling can be incorporated as part of a new PMF spillway for the CVD.

3.2 Recommended Additional Studies

The following additional studies are recommended:

- RCD Dike Integrity: Perform an evaluation of the integrity of the RCD dike, which will include a detailed study of as-built information and historical geotechnical foundation and dike information, review of the performance data for the dike, and evaluation of the slope stability and internal erosion/piping of the embankment. There is significant uncertainty regarding the quality and integrity of the RCD (north) dike, based on the following considerations:

  - BGC (2004) noted that the RCD traverses a wide variety of materials, ranging from bedrock to till and creek alluvium. 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 degradation during construction.
  - BGC (2005) noted that a significant portion of the fill for the north dike was placed during March and April, when average air temperatures were below freezing, and that frozen ground was reportedly placed as fill during dike construction. It is very difficult to achieve satisfactory placement and compaction of fill materials for the dike because the material is frozen and it cannot be adequately compacted. In addition, even if great care was taken by the inspectors and earthworks contractor, ice, snow, and large rocks (which appear to be frozen lumps of soil) will be incorporated into the fill.
  - Dike settlements have occurred historically that were either the result of inadequate compaction of the fill materials during the previous winter, or thaw settlement of ice-rich permafrost within the foundation soils. BGC noted that in the decade since construction, the crest of the north dike between stations 31+00 and 41+00 settled a total of about 1 m.
  - There are no chimney drains/filters in the dike.
- Overflow Weir: Since the overflow weir is along the length of the RCD, with flow in the channel parallel to the weir, the performance of the weir is difficult to predict by theoretical or even computational hydraulic models. It is, therefore, recommended that physical hydraulic modelling be performed to aid in the design of the structure.
- Side Channel Dike Foundation: A review of the available methods and means to provide a competent foundation for the side channel in Alternative 2 should be carried out. Initial concepts considered included ground improvement techniques, such as deep soil mixing, and structural systems, such as temporary sheetpiling in the areas of the deepest tailings. The IPRP noted that these ground support systems to allow tailings excavation and replacement is a major engineering effort, and questioned whether such an approach is necessary and cost-effective. They further noted that alternative approaches, such as incremental loading with/without wick drains and soil improvements using compacted sand/stone columns, may achieve the necessary ground strengths at lower costs. Displacement methods will also be considered.
- Tailings Cover: Perform studies to assess the performance of the tailings cover, especially in the areas where significant grading will be performed, such as in the ID Pond, where fill placement of between 7 and 9 m will take place. Design issues will include the performance of the tailings cover upon significant settlement, and construction issues include trafficability and dewatering.
- ID Spillway: Limited drilling has been completed in the ID spillway (KCB, 2007). An additional geotechnical investigation is required in support of the ID PMF spillway design. This work is anticipated to be carried out as part of the Down Valley Hydraulic Upgrades to be completed as medium-term improvements to reduce the risk of breaching the ID.
- CVD Spillway: Hydraulic and geotechnical studies will be necessary to support the design of the PMF spillway at the right abutment of the CVD.

SECTION 4
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Attachment A
Report on Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area, Faro Mine

Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area, Faro Mine

Prepared for

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Acronyms and Abbreviations

2D	two-dimensional
AEP	Annual Exceedance Probability
ALARP	as low as reasonably practicable
APF	annual piping probability of failure
C&R	closure and remediation
CH2M HILL	CH2M HILL Canada Limited
cm	centimetre
CVD	Cross Valley Dam
DAMRAE	Dam Safety Risk Analysis Engine
El.	Elevation
FMC	Faro Mine Complex
FMRP	Faro Mine Remediation Project
HSE	Health and Safety Executive
ID	Intermediate Dam
IPRP	INDEPENDENT PEER REVIEW PANEL
km	kilometre
m	metre
m/sec	metres per second
m^3/sec	cubic metre per second
mamsl	metres above mean sea level
mbgs	metres below ground surface
MCE	maximum credible earthquake
mm	millimetres
mm^3	million cubic metres
PFM	potential failure mode
PFMA	potential failure modes analysis
PMF	probable maximum flood
Q	flow rate
RAC	RAC Engineers & Economists
RCD	Rose Creek Diversion
RCTA	Rose Creek Tailings Area
ROM	Rough Order of Magnitude
SRK	SRK Consulting Engineers and Scientists

SRP	System response probability
T1	Type 1
T2	Type 2
T3	Type 3
TRB	Technical Review Board
UK	United Kingdom
UNSW	University of New South Wales
USACE	United States Army Corps of Engineers
USU	Utah State University

SECTION 1

Introduction

1.1 Purpose

During the course of numerous studies that have been conducted over the last 10 years, different options for routing floods and, specifically, the maximum design flood through the Rose Creek valley were considered and studied. Initially, the options focused on modifying and enlarging the Rose Creek Diversion (RCD) so that its capacity would be increased from passing the 500-year flood to passing the probable maximum flood (PMF). Towards the end of this study period, the concepts evolved to include passing the PMF over the tailings through a fuse plug and then through a spillway on the right abutment of the Intermediate Dam (ID).

The closure and remediation (C&R) Plan (SRK Consulting Engineers and Scientists [SRK], 2010) detailed two versions of this concept. In the one case, the spillway size and invert would be somewhat similar to that of the existing ID spillway, which would require a substantial raise of the ID (up to 9 metres [m]) and possibly also raising the RCD dyke. The second version of this concept was to use a larger spillway with a lower invert, which would be able to pass the flood with lower flood elevations, such that the ID raise could be minimize and that it would not be necessary to raise the RCD dyke. This version would require significant excavation and regrading of the tailings to provide a tailings surface that had a relatively steeper slope toward the lower spillway invert.

From the literature study performed by the CH2M HILL Canada Limited (CH2M HILL) team, it appears as if a conclusive/comprehensive alternatives analysis to select a preferred option to pass the design flood (i.e., the PMF) has never been conducted; if it was conducted, it was not documented.

This preliminary report described a preliminary alternatives evaluation that included the following work items:

- Review the concepts recommended in previous studies and the C&R Plan.
- Consider and evaluate three different conceptual alternatives to pass the design flood, including comparison of order-of-magnitude cost estimates and hydraulic analyses of flood routing for each of the alternatives.
- Preliminary risk analyses to evaluate the performance and reliability of each of the three considered alternatives. The risk analyses were led by a subconsultant, RAC Engineers & Economists (RAC), a company that specializes exclusively in risk assessments of dams.

NOTE: *The results of the risk analyses in this report are incomplete. The risk analysis was only advanced sufficiently to aid in selecting a preferred alternative*.

1.2 Review of Previous Concepts

The main alternatives that were studied in the past include:

- Conveying the PMF in a modified/enlarged RCDRCD
- Passing the PMF over the tailings with the requirement of major regrading of the tailings surface and a lesser dam raise
- Passing the PMF over the tailings without the requirement of major regrading of the tailings surface, but with a larger dam raise

The last two options were included in the C&R Plan.

The preceding three alternatives were presented to CH2M HILL's Technical Review Board (TRB) consisting of Rick Riker, Fred Matich, and Peter McCreath, on April 17 and 18, 2012, in a 2-day workshop conducted at the CH2M HILL Vancouver office. During the workshop, the TRB expressed concerns regarding the ability of the multi-swale configuration used in both the closure options to control the significant flows that are associated with the PMF (or other large storms) to prevent channelization and serious erosion or scour of the cover system in the manner desired. It was argued that channelization can develop outside the swales, resulting in concentrated flow seeking its own course, and resulting in erosion and potential erosion and down-cutting into the tailings cover. Should channelization occur, it is likely that the tailings cover would be compromised and tailings could be carried into the downstream watershed. If this were to occur, the project would be out of compliance. Because of these concerns, two alternative options were developed to convey flood flows in the tailings area; these alternatives are discussed in the following section of this report.

1.3 Rose Creek Tailings Area Closure Alternatives

Descriptions of each of the alternatives for safeguarding the tailings in Rose Creek Tailings Area (RCTA) are provided herein. The alternatives will be designed to withstand earthquake loadings up to a level of shaking associated with the maximum credible earthquake (MCE) and flood loadings up to the PMF. The following concept drawings of the three alternatives are provided in Appendix A:

- Alternative 1 – Figures 210 to 212
- Alternative 2 – Figures 220 to 229
- Alternative 3 – Figures 230 to 231

Figures 240 to 241 in Appendix A show the concepts for the ID raise and improvements, including concepts for collecting contaminated shallow seepage water downstream from the dam toe. The project will also include a deep cut-off wall and deep seepage collection trench that will be located downstream from the Cross Valley Dam (CVD).

1.3.1 Alternative 1

Alternative 1 would route the full PMF flow through a modified RCD, as shown on Figure 210, with no flow entering the tailings storage area except from the local catchment area. The modification concept is shown on Figures 210 (plan), 211 (profile), and 212 (sections). This alternative proposed that the RCD be both widened and deepened in areas. Along the upstream portions, the canal would be widened into the tailings area where the tailings are absent or relatively thin. This would be accomplished by removing any tailings that would be located below or within the influence of the toe of the RCD. Along the downstream portion near the ID, the widening would occur primarily on the south slope of the existing diversion channel requiring cutting into the existing hillside slope.

In the tailings storage areas, the tailings would be covered with a protective soil and vegetative cover consisting of approximately 0.5 m of a stabilizing rock zone overlaid by an additional 1-m-thick layer of loosely compacted glacial till material that will promote vegetation growth.

HEC-RAS and MIKE 21 analyses were used to approximately size the channel. Channel modifications proposed with Alternative 1 are adequate for conveyance of the PMF through the RCD. The analysis results indicate that the velocities stay fairly low (less than about 4 metres per second [m/sec]) until the lower reach of the channel is reached where the velocities increase to about 10 m/sec.

It is recommended that a cut-off wall structure be incorporated in the channel to prevent headward erosion up the channel and endangerment of the ID left abutment. Larger riprap will have to be used along the steep sections for erosion protection, but is anticipated that significant damage would be experienced along the lower sections of the channel during a major flood event, and in that case maintenance repairs will have to be performed.

Construction can likely be accomplished in the winter to avoid impacts on aquatic habitat that would be caused by conventional earth moving construction equipment. It appears feasible to expand into the right bank with rock cuts and to deepen the channel in some areas to safely and reliably achieve the channel size needed to convey the PFM. The most significant issues still under evaluation by the design team are blockage of the channel by either icings and or flood debris in combination with large floods (early spring flows). The issues of protecting aquatic habitat during construction seems to be manageable if construction is restricted to the winter season when flows are low and localized small diversions can be used.

1.3.2 Alternative 2

The modified concept shown on Figure 220 would channel flows greater than the 500-year flood over the top of an overflow weir and into a single, large, armoured channel (the side channel) designed to carry the difference between the PMF and the 500-year flood flow. This side channel would run parallel and immediately adjacent to the RCD, with the RCD dyke dividing the RCD and the newly proposed side channel.

The overflow weir is shown on Figures 220 (plan) and 225 (section). An initial concept is to harden the embankment at the overflow weir location with articulating concrete blocks, as shown on Figures 222 and 223, with a grouted riprap at the downstream toe of the overflow weir that would act in conjunction with the rest of the erosion dissipation structure (riprap apron) to dissipate energy.

Downstream from the erosion dissipation structure, the initial concept for the channel is to only harden the channel sideslopes with riprap. The results from the HEC-RAS analyses indicate that the velocities would approach about 3 to 4 metres per second, so that vegetation alone would not be sufficient to prevent erosion in the bottom of the channel. However, flood flows in this channel would be a very rare occurrence, and some sacrificial scour in the channel bottom would be acceptable provided the scour would not undercut the slopes and causes slope failure and breaching of the dykes.

Along this alignment, which is on the original valley wall, the tailings are presently either absent or relatively shallow. CH2M HILL's initial concept is to route flood flows over the tailings surface to a spillway in rock cut on the right abutment. We anticipate that the pool that would develop behind the ID would serve as an energy dissipater allowing use of a spillway at the right abutment. To facilitate rapid pooling, it is proposed that the sill of the spillway entrance be at an elevation of (El.) 1,047 metres above sea level (masl), which is about 1 m higher than the tailings surface at the intermediate impoundment. A relatively small drainage channel is proposed in the bottom of the spillway channel at El. 1,046 masl to allow for the continuous drainage of rainfall and snowmelt directly within the tailing storage facility. This would allow for a dry tailings surface under normal operating conditions.

The initial concept for the spillway is to have its footprint at the right abutment of the dam but cut into the bedrock farther into the north hill slope of the valley to create a much wider spillway and the capacity to pass the PMF. The existing information indicates that the depth of bedrock at this location varies from about 0 m to about 11 m below the ground surface (mbgs). The bedrock is a dark grey, very closely foliated, medium strong schist with quartz veins that range from 10 to 30 millimetres (mm) thick. The upper 2 m of the bedrock is broken down to gravel size particles. To prevent scour into the right abutment of the dam and into the dam, the preliminary concept is to use a reinforced concrete wall on the inside of the spillway channel, as shown on Figures 227 and 229 in Appendix A. In addition, it is anticipated that dental concrete, rock bolting, or equivalent measures might be necessary on the base and sides of the spillway.

Another option would be a spillway on the left abutment of the ID; in that case, a spillway structure will likely have to be constructed. One significant advantage of the side channel alternative is that it can be constructed without any significant impacts (including fish passage) to the RCD flows. Construction of a spillway that will tie back into the RCD may diminish this advantage. It is anticipated that some minor modifications may be necessary to the existing RCD to carry the 500-year flood flows, such as upgrading riprap along some sections or raising some portions of the crest.

The ID will have to be raised to about El. 1,052 masl as shown on Figure 241 in Appendix A. Note that the existing dam does not have filter and drainage systems installed in the lower part (below the downstream bench) of the embankment. This was appropriate because the water surface of the Cross Valley Pond was at the bench level, and seepage and filtering was a lesser concern. It is anticipated that the Cross Valley Pond will be drained and maintained in a dry state, and during severe floods when a pool build up behind the ID, it is possible that the phreatic surface would daylight on the lower surface; therefore, it is proposed that new filters and drains be installed as shown schematically on Figure 241. Note that these modifications (installation of filters and drains) will also have to be made for Alternative 1 to prevent seepage from daylighting on this slope, but the earthwork will be significantly less in that case.

MIKE 21 (two-dimensional [2D] hydraulic analysis) was used to size the side channel and the results are provided in Appendix B. Average velocities in the parallel channel are about 3 to 4m/sec and across the tailings it is less than 1m/sec. The overflow weir required for the approximate desired flow split would be 400 m in length, with sill elevations ranging from 1,056.5 m (downstream end) to 1,057.5 m (upstream end). The maximum flood water surface elevation predicted adjacent to the ID is about 1,051 m, and the existing crest elevation of the embankment is 1,049.1 m. A minimum dam raise to a crest elevation of 1,052 m is therefore needed; however, the crest elevation may have to be higher to include wave runup.

Due to the apparent thick tailing deposits near the downstream reach of the proposed channel alignment and potentially significant excavation of tailing material, the end of the channel was located upstream from these thicker tailings deposits, with an erosion dissipation apron constructed on the tailings cover downstream of the channel exit. The most significant issues are in areas where the tailing thickness is greater than about 3 to 5 metres, and difficulty in excavating, and the cost to remove.

1.3.3 Alternative 3

This alternative would route flows that exceed the 500-year flood up to the PMF over an overflow weir structure into the RCTA and over a covered tailings surface via a single wide riprap-lined swale (about 120 m wide and 1.5 m deep), dedicated to containing the flood flow until a pool has formed that would be able to dissipate the energy during the flood peaks. Flows up to the 500-year flood would be routed in the current RCD, with minor improvements to the existing channel. The flood flow would exit the tailing impoundment through an improved spillway at the right abutment of the dam. This concept is a modification to the “multiple swale” concept in the C&R Plan and appears to mitigate some of the concerns with the multiple swale, including the difficulty of equal distribution through all the swales and the tendency to erode and form a larger channel along one of the swales that could become preferential as a result of differential settlement and cracking of the tailings surface and in the tailings cover. The TRB endorses this alternative concept, provided that adequate cover protection is provided and the flow is adequately contained in this single dedicated “swale.”

A 120 m-wide dedicated channel will be somewhat incompatible with the environmental objectives of the project (the surface will not look like natural vegetation). Maintenance will also be an issue because long-term settlement and distortion of the dedicated swale must be maintained to prevent channelization.

1.4 Risk Study Objectives

The following are overall objectives for the risk study:

- To conduct a dam safety risk assessment for each of the three flood routing alternatives being considered for the RCTA. Risk analysis and assessment is considered the most logical and quantitative approach because it addresses reliability and safety of the dyke and dam structures that convey the flood flows and protect the tailings, and it considers the full range of flood and seismic loading as part of this evaluation.
- To systematically consider and evaluate potential failure modes associated with each of the alternatives, which should lead to an in-depth understanding of the most critical elements for design.

Because of the preliminary nature of the engineering analysis for the alternatives evaluation and the limited resources available for performing the assessment, various simplifications were made while performing the risk assessment. A number of supporting studies were completed over the last 10 to 15 years, but many of the studies were preliminary or conceptual in nature, so it was necessary to make some reasonable assumptions to develop inputs for the risk assessment. Also, the dam and dyke failure consequences are difficult to quantify for this project; hence, the evaluation of risks was limited to the estimation of probabilities of failure and qualitative assessment of the failure consequences. Despite these limitations, it is considered that the study was successful in accomplishing its objectives and that it served as a valuable tool in understanding and quantifying the advantages and disadvantages of each of the alternatives considered.

1.5 Steps in Conducting the Risk Analyses

The risk analyses were performed by team members from CH2M HILL, RAC, BGC Engineering, and Matrix Solutions. The risk analyses included five conference call sessions, which lasted about 4 to 5 hours, and during time a potential failure modes analysis (PFMA) was performed. The sessions were moderated by Dr. Loren Anderson and Dr David Bowles from RAC. Risk analyses were conducted by executing each of the following steps in the risk assessment process for the RCTA:

1. Define the purpose
2. Conduct a site visit, and develop the conceptual design of three alternatives
3. Perform a PFMA
4. Develop the risk model
5. Estimate loading probabilities
6. Estimate system response probabilities
7. Estimate consequences (discussed but not quantified due to limitations on availability of information needed for estimation of consequences)
8. Calculate the risk
9. Evaluate the risk – what risk is tolerable?
10. Recommend and make the case for a decision

Steps 1 and 2 were conducted at the Faro Mine Complex (FMC) by the design team and the CH2M HILL TRB during a site visit on June 26 and 27, 2012. Steps 3 through 6 were conducted during five teleconference sessions from July 23 to August 2, using the Microsoft LiveMeeting to remotely share a single computer screen. Steps 7 through 9 were largely conducted by RAC with coordination and consultation with the rest of the team, following the conclusion of the previous steps. Various activities were performed between the two working sessions and coordinated through conference calls to prepare information for use in the second working session.

The following CH2M HILL team members who participated in the working sessions:

- John Spitzley, Design Manager
- Rick Riker, Chair Person for the TRB
- Jaco Esterhuizen, RCTA Task Manager
- Howard Thomas, Team Member

The following RAC team members participated in the working sessions:

- David S. Bowles, Managing Principal – RAC Project Manager
- Loren Anderson, Principal – Risk Assessment Facilitator
- Sanjay S. Chauhan, Principal and Senior Risk Engineer – responsible for implementing its in-house Dam Safety Risk Analysis Engine (DAMRAE) risk analysis modelling (Srivastava et. al., 2009 and 2011)

The following BGC team member participated in the working sessions:

- Gerry Ferris, Geotechnical and Dam Engineer

The following Matrix Solutions team member participated in the working sessions:

- Wim Veldman, Hydrology and Hydraulics Engineer – Cold Regions Specialist

During the RA process, consultation with CH2M HILL's TRB team members (Fred Matich and Pete McCreath) was also conducted.

1.6 Rose Creek Tailings Area

1.6.1 Project Description

The Faro Mine Complex (FMC) is located in the central Yukon, approximately 200 kilometres (km) northeast of Whitehorse and 22 km north of the city of Faro. The mine operated between 1969 and 1998. Approximately 28.6 million cubic metres (Mm^3) of tailings were produced during that time and were deposited in the RCTA, which is located within the Rose Creek Valley. A series of impoundments were constructed across the Rose Creek Valley, to contain the tailings. Water is diverted around the RCTA via the RCD, which is located along the south side of the tailings area. The canal diverts clean water from the North and South Forks of Rose Creek, around the south side of the tailings storage facility.

The diversion canal was constructed in two separate stages. An upstream section of the canal was completed in 1974 to carry clean water past the second tailings impoundment. A longer downstream section was completed in 1981 in preparation for construction of the intermediate tailings impoundment downstream (west) of the second tailings impoundment. This second reach extended the canal by about 3,800 m, to the location where it discharges back into Rose Creek, downstream from the CVD. The existing canal is approximately 4,700 m in total length. Rock weirs were constructed to reduce stream velocities and compensate for the grade difference between the RCD (0.2%) and the original Rose Creek million cubic metres Valley (2%). The diversion canal was designed to carry a 1-in-50-year flood event, with 1 m of freeboard. The contingency design capacity, with no freeboard, will carry a 1–in-500-year flood event (BGC, 2005). The weirs were designed on the basis of a 1-in-50-year flood event.

1.6.2 Description of Dam Structures

Descriptions of each of the relevant dams in the RCTA are summarized in the following sections.

1.6.2.1 Secondary Dam

The Secondary Dam was designed by Golder Associates and its construction started in 1974. The West Limb of the Secondary Dam is defined as the curved portion of the dam that crosses the Rose Creek Valley in a roughly north to south direction. The East Limb is the portion of the Secondary Dam that is parallel to the south Rose Creek Valley wall. The West Limb of the Secondary Dam was raised using centerline construction and compacted fill to a maximum height of 27 m. The East Limb is a low retention dyke that was constructed of compacted fill. Tailings were deposited behind this dam from 1975 until 1982 and then for approximately 5 months in 1986. Rose Creek was diverted to a channel that ran parallel to the south Rose Creek Valley wall and emptied into its original channel downstream from the Secondary Dam. Cross-sections and photos of the Secondary Dam are shown on Figure 1-2.

1.6.2.2 Intermediate Dam

In 1981, the ID was constructed across the Rose Creek Valley to contain supernatant water and tailings solids. It was raised in 1988, 1989, and 1991 to a final crest elevation of 1,049.4 mamsl, a maximum height of 32 m above the old Rose Creek channel. A typical section through the dam is shown on Figure 1-2. There is an emergency spillway channel on the right abutment, constructed as a rock-lined channel in natural overburden material.

The ID is a zoned earthfill embankment with a sloping upstream low-permeability core and a downstream random fill shell. Granular filter zones were constructed on both sides of the core. The initial construction in 1981 made use of natural terrace material present across the valley. A drainage blanket was placed over this footprint downstream from the core and filter zone, extending to the toe of the planned final dam construction.

Upstream and downstream slopes are at 2Horizontal (H):1Vertical (V). A 20-m-wide berm was constructed on the downstream slope at about elevation 1034, approximately adjacent to the polishing pond; therefore, the overall downstream slope is at 2.1H:1V. There is a nominal cutoff for seepage reduction through the uppermost soils beneath the core of the dam. There is no deep foundation cutoff to reduce seepage through the permeable soils. Instead, the tailings on the upstream slope and foundation were relied on to reduce seepage to an acceptable level. The drains on the dam section are set to just above the design level of the polishing pond.

1.6.2.3 Cross Valley Dam

The CVD was constructed as part of the Down Valley Project in the early 1980s to expand the tailings disposal capacity in the Rose Creek Valley. The CVD retains a polishing pond downstream from the ID. The embankment is a zoned dam with core and filters constructed as a conventional water retaining dam with no retained tailings. Figure 1-3 shows the design section of the CVD without the seepage berm at the downstream toe. The seepage berm was constructed at a later date (after the original construction was completed) to control seepage that appeared near the toe of the dam.

The crest of the dam is at El. 1034 m and the downstream toe is at El. 1016 m (nominal). The height of the dam is about 18 m above original grade. The dam is approximately 500 m long. The dam section is a central impervious core, supported by upstream and downstream granular shells at slopes of 2H:1V. The core and downstream shell are separated by a chimney drain that connects to a blanket drain to the toe. There is also a chimney filter on the upstream side of the core, which would act as a crack stopper. The central impervious core connects to an impervious upstream blanket that extends beneath the upstream shell, to 60 m upstream from the toe. The core was extended a few metres into existing ground below the stripped grade. This nominal cut-off and upstream blanket were designed to reduce seepage through the foundation soils. There are no other cut-offs to the pervious Rose Creek sediments.

1.6.2.4 Emergency Spillways

The current spillways at the right abutments of the ID and the CVD are not sized to pass large floods. They have capacities of about 30 to 40 cubic metres per second (m^3/sec), and pass the snowmelt and stormwater generated from precipitation on the tailings area only.

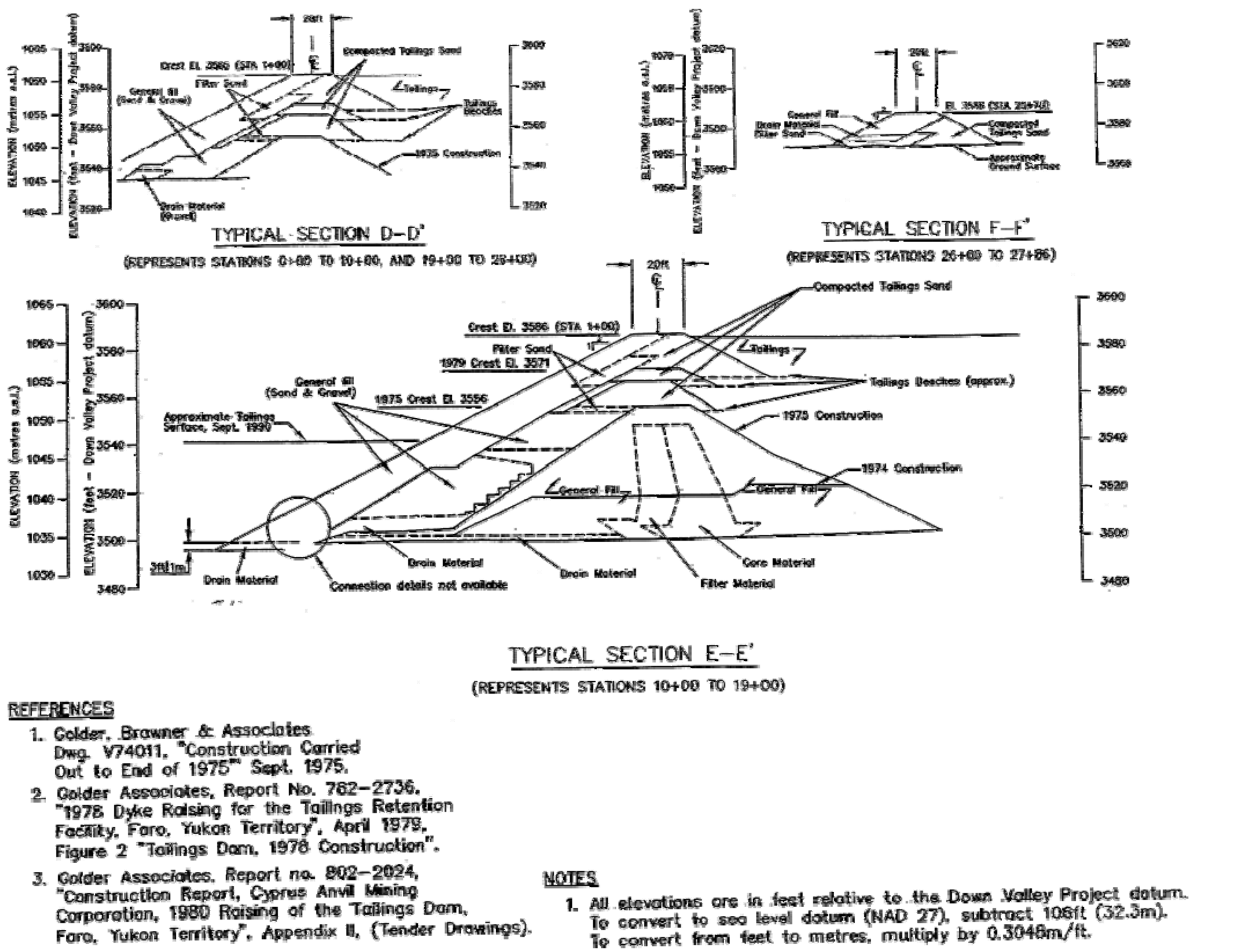
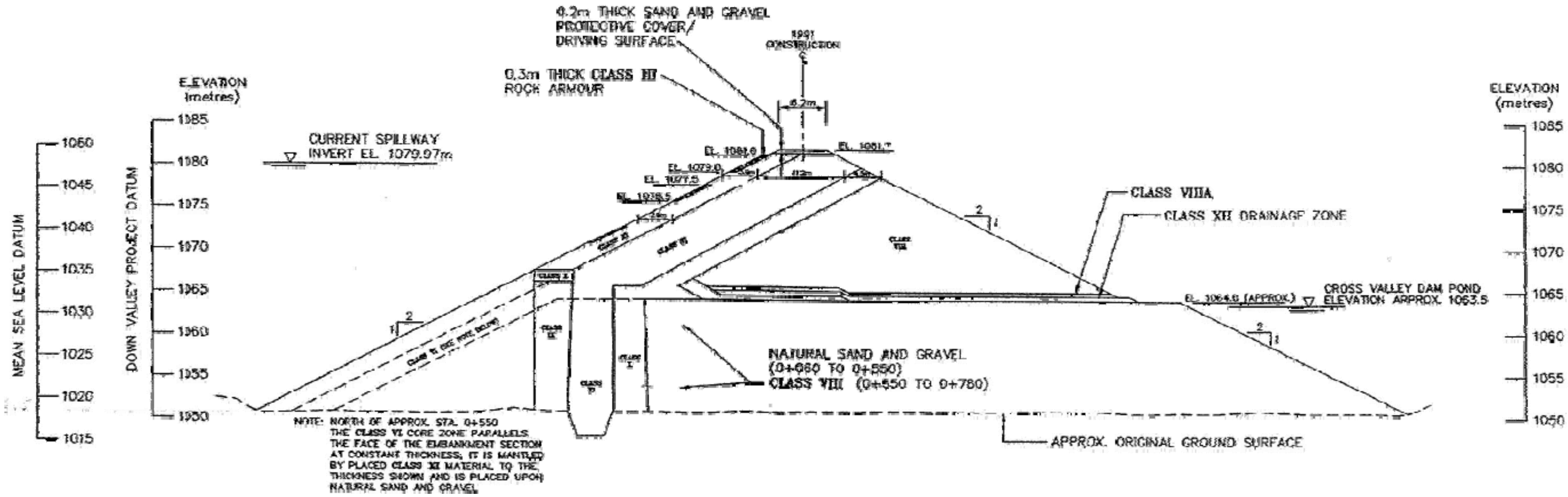


FIGURE 1-1
Rose Creek Tailings Area
Faro Mine Remediation Project



NOTES :

1. Embankment geometry and internal zoning as shown in Golder Associates Drawing 912-2402-3, Int. Dam Raising & C.V. Dam Toe Drain, Cross Section and Detailed Plan, Rev. 1, Aug. 8, 1991.
2. All elevations are referenced to Down Valley Project Datum. Subtract 32.3m from elevations shown to convert to mean sea level (NAD27) datum.
3. Refer to Golder Associates as built reports for detailed descriptions of material classes. General descriptions as follows :

CLASS VI	Dam Core (glacial till)
CLASS VII	Upstream Shell (silty sand and gravel)
CLASS VIII	Downstream Shell (sand and gravel)
CLASS VIIIA	Drainage Filter (sand and gravel)
CLASS IX	Upstream Filter (silty sand)
CLASS X	Downstream Filter (sand and gravel)
CLASS XI	Tailings Sand (fine to medium sand)
CLASS XII	Drainage Zone (gravel)

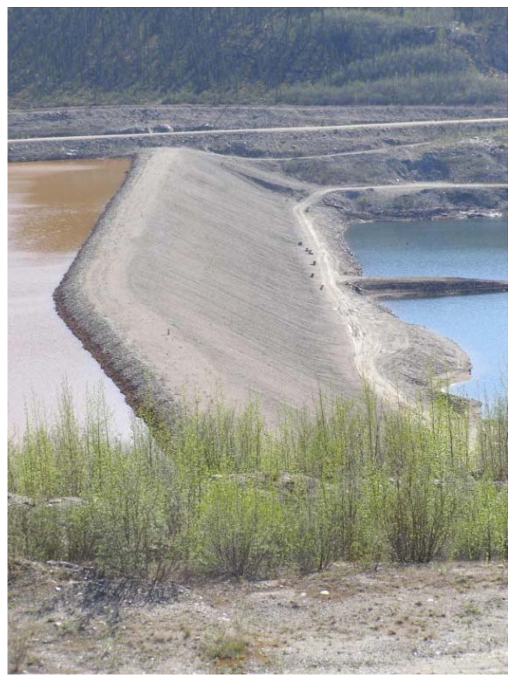


FIGURE 1-2

As-Built Cross-Sections and Photographs of the Secondary Dam

Faro Mine Remediation Project

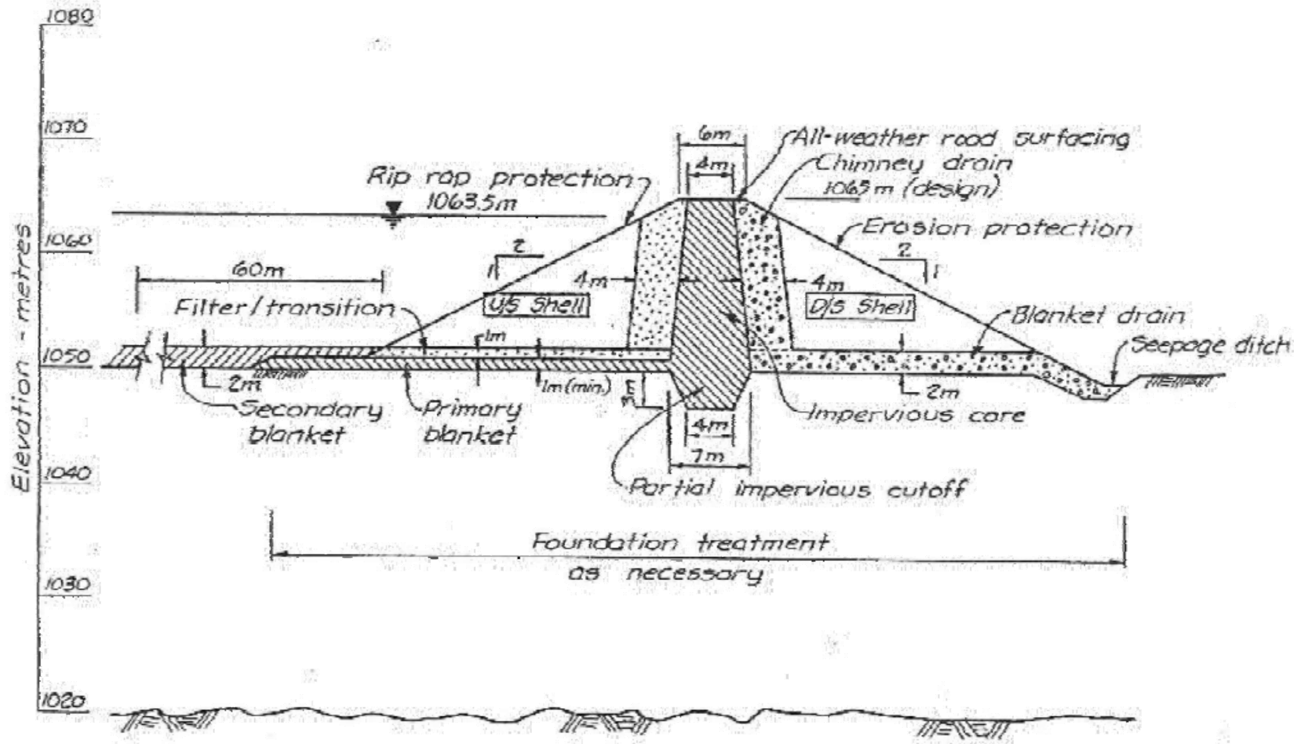


FIGURE 1-3
As-Built Cross-Sections and Photograph of the Intermediate Dam
Faro Mine Remediation Project

FIGURE 1-4
As-Built Cross-Section and Photograph of the Cross Valley Dam
Faro Mine Remediation Project

FIGURE 1-5
Photographs of the Intermediate Dam and Cross Valley Dam Spillways
Faro Mine Remediation Project

1.7 Comparison of Alternatives Using a Risk Assessment Process

1.7.1 Components

Comparisons of the alternatives are, to a large part, based on the concept of risk management. The process of risk management comprises the various component processes that are represented schematically on Figure 1-6. At the highest level, risk management combines risk assessment, risk control, and decision-making on all aspects of dam safety. Risk assessment comprises risk analysis, risk evaluation, and the formulation of decision recommendations. Risk analysis involves both risk identification and risk estimation.

1.7.2 Risk Assessment Purpose

A risk assessment should commence with a clear definition of its purpose. It should identify the factors affecting safety decision-making in the context of the specific risk assessment purpose. Examples of some of the purposes for risk assessments include the following:

- To systematically identify and better understand potential failure modes.
- To identify, justify, and prioritize investigations and analyses to reduce uncertainties in risk estimates for various facility components including the dams and dyke that convey the flows and contain the tailings.
- To strengthen the formulation, justification, and prioritization of risk-reduction measures.
- To identify ways to improve safety through changes in operation, monitoring and surveillance, safety management systems, staff training, emergency action planning, and business decision-making related to the long-term safety and reliability of the facility.
- To identify cost-effective options to more rapidly reduce safety risks.
- To justify expenditures on safety improvements to owners and economic regulators.
- To provide a framework for quantifying engineering judgment and communicating technical issues with the owner in a more open and transparent manner.
- To facilitate the evaluation of the facility’s safety risks to the public and the environment in a manner that allows comparison with other infrastructure and technological hazards.
- To provide a non-technical basis for communicating risks to the public.
- To provide a basis for development of a safety case or safety demonstration for owners and regulators.
- To assess the adequacy of insurance coverages.
- To strengthen the basis for corporate governance related to safety risks.
- To strengthen the exercise of the owner's duty of care, due diligence, and legal defensibility with respect to the reliability of the facility once closed.

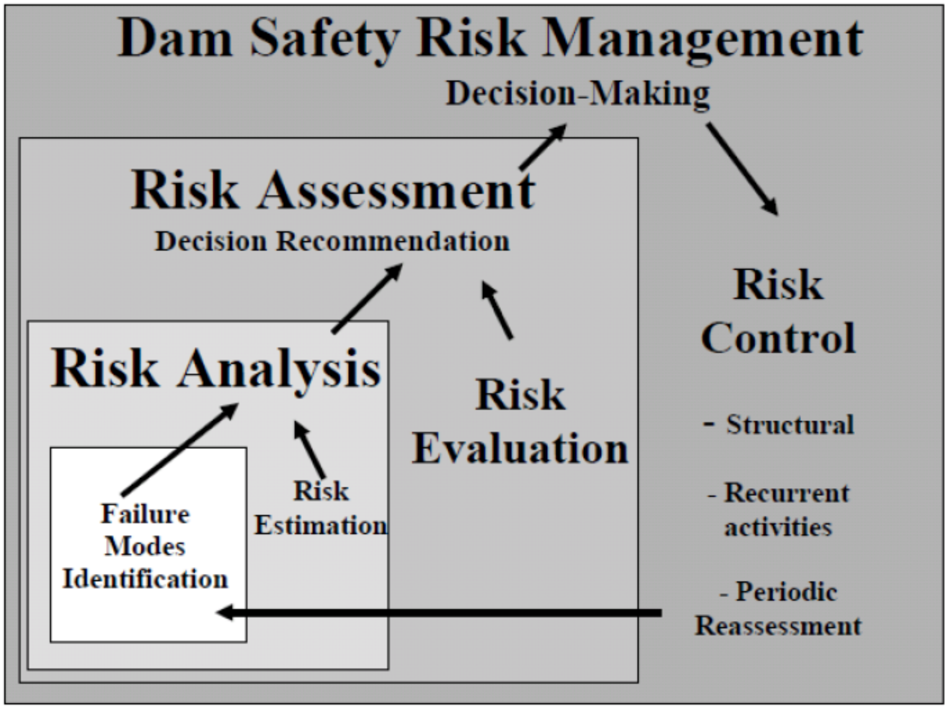


FIGURE 1-6
Interrelationships between the Components of Dam Safety Risk Management (USSD, 2003)
Faro Mine Remediation Project

1.7.3 Risk Assessment Scoping and Risk Identification

The process of scoping and selecting the extent and level of detail or complexity for a risk assessment should build on the statement of purpose and on a failure-mode identification process. In this process, all potential failure modes for the subject dam are enumerated and described, including the relationship between each failure mode and those types of consequences of failure that are relevant to satisfy the statement of purpose. Investigations and analyses may be identified to assess the physical plausibility of some failure modes. A structured and systematic process should be followed to adequately complete the potential failure modes identification. The scoping process continues by narrowing the list of physically plausible failure modes to a subset of those that can be justified to include in the risk assessment, to achieve the statement of purpose with the desired level of confidence. These can be referred to as “significant” failure modes. The list of failure modes that are considered to be significant and other aspects of the scoping of a specific risk assessment, such as the level of detail and types of consequences that are to be addressed, can vary for different risk assessments for the same dam, if those risk assessments are conducted for different purposes.

1.7.4 Risk Estimation

Risk estimation is the process of quantifying probabilities and consequences for all significant failure modes. System response or fragility relationships are developed for each failure mode with a level of detail and associated effort that can vary, depending on the scope that is justifiable for the risk assessment. Traditional engineering analysis, reliability analysis, and engineering experience and judgment are all important in estimating these relationships. Dam break modelling provides the basis for the estimation of dam failure consequences for each failure mode and for a range of exposure conditions affecting potential life loss. RAC has developed a dam safety risk analysis tool, DAMRAE (Srivastava et. al., 2009 and 2011), to perform these calculations and to present results so that they can be readily interpreted and used to support dam safety decision-making.

1.7.5 Risk Evaluation

Risk evaluation is the process of examining and judging the significance of the estimated risk. The United Kingdom (UK) Health and Safety Executive (HSE) (2001) have a well-established framework for risk evaluation. It is widely used for regulating the risk associated with hazardous industries in the UK. It has also significantly influenced the development of risk evaluation approaches for dams in Australia (ANCOLD, 2003) and the United States (Munger et. al., 2009). The HSE framework for the tolerability of the risk can be used to assess the estimated risk for an existing dam. Other factors, such as the dam owner's business or legal considerations can also be important in the overall risk evaluation process. In countries with common law legal systems, this process is not complete until the extent that the risk can be reduced "as low as reasonably practicable" (ALARP) has been evaluated. This requires the formulation of risk control (treatment) options that can include structural measures and strengthened recurrent dam safety management activities, such as monitoring and surveillance, emergency action planning, and staff training.

1.8 Organization of the Report

The remainder of this report is divided into four main chapters. Chapter 2 documents the steps that were followed while performing the risk assessment. Chapter 3 presents the results of the risk assessment for the three RCTA alternatives. Chapter 4 contains a summary of the risk study and conclusions for the RCTA, based on an interpretation of the risk assessment results.

SECTION 2

Steps in Risk Assessment for the Rose Creek Tailings Area

2.1 Step 1 – Define the Purpose

The purpose of the risk assessment for the alternatives evaluation for the RCTA was defined as follows:

- To systematically consider and evaluate potential failure modes associated with each of the alternatives, leading to an in-depth understanding of the most critical elements of its anticipated performance. Failure is defined as some form of loss of containment of the tailings by surface water transport pathways.
- To obtain preliminary estimate probabilities of failure and a qualitative characterisation of the consequences of failure for each of the RCTA alternatives, so that the reliability and safety of these alternatives can be compared and ranked. This information and the order-of-magnitude cost estimates for the project will form a basis for decision-making, and for selecting a preferred alternative.
- To identify specific elements of each design for design optimization to further reduce risk.

Because of the limited resources available for performing this risk assessment, the following reductions in scope (compared to most risk assessments) were necessary:

- The number of failure modes considered was limited to those judged to be significant in terms of the purpose of the risk assessment, as summarized previously
- No new supporting analyses or investigations were performed
- Consequences were not quantitatively estimated; therefore, it was not possible to evaluate the estimated risk against life safety tolerable risk guidelines
- Some sensitivity studies were executed to explore the effect of uncertainty in the effects of blockage of the RCD and diversion weir by woody debris (Alternative 2 only) and the annual exceedance probability assigned to the PMF

Despite these limitations, it is considered that the study was successful in accomplishing the stated objectives and that it served as an extremely valuable tool in understanding and quantifying the advantages and disadvantages of each of the alternatives considered.

2.2 Step 2 – Identify and Screen Potential Failure Modes

2.2.1 Potential Failure Modes Analysis

2.2.1.1 Approach

The following steps were followed for the PFMA during the first two working sessions:

1. Collect and review available information about the RCTA, with a special focus on the RCD, the Secondary Dam, and the ID.
2. Conduct a team site inspection to identify potential vulnerabilities across a range of reservoir levels and inflow flood magnitudes.
3. Perform a PFMA during the team meetings with the following agenda:
    a. Identify potential failure modes (PFM) as follows:
        i. Conduct a structured identification of failure modes, considering the major physical components or processes of the RCTA including the functional interdependencies over a complete range of

magnitudes of flood and earthquake types of loading to assess whether or not a credible failure mode exists that could lead to a loss of tailings.

ii. Identify additional failure modes from the USACE Internal Erosion Toolbox (USACE, 2009) list of potential failure modes and other lists provided by RAC.

b. Perform an initial screening and classification of PFMs identified in Step 3a as credible and significant – see Figure 2-1 on screening and classification of PFMs.

c. Prepare a detailed description of each credible and significant PFM from initiation to loss of tailings.

d. Summarize the evidence, including lists of more likely (adverse) and less likely (favorable) factors for each credible and significant PFM.

e. Revise and finalize the screening and classification of credible and significant PFMs in Step 3b, based on additional insights gained from Steps 3c and 3d – see Figure 2-1 on screening and classification of PFMs.

f. Identify surveillance and monitoring opportunities for credible and significant PFMs, with the goal of providing earlier detection of the onset of failure or an improved understanding of performance with respect to a failure mode (this step was not conducted during the PFMA).

g. Identify potential interim (if appropriate) and long-term, risk-reduction measures for credible and significant PFMs.

h. Estimate breach parameters for credible and significant PFMs (because no breach analyses were planned as part of this study, this step was not performed).

i. Develop preliminary event trees to include all credible and significant PFMs for use in the risk assessment.

2.2.1.2 Results

Various groupings of potential failure modes are listed below based on the outcome of the classification according to credibility and significance summarized on Figure 2-1.

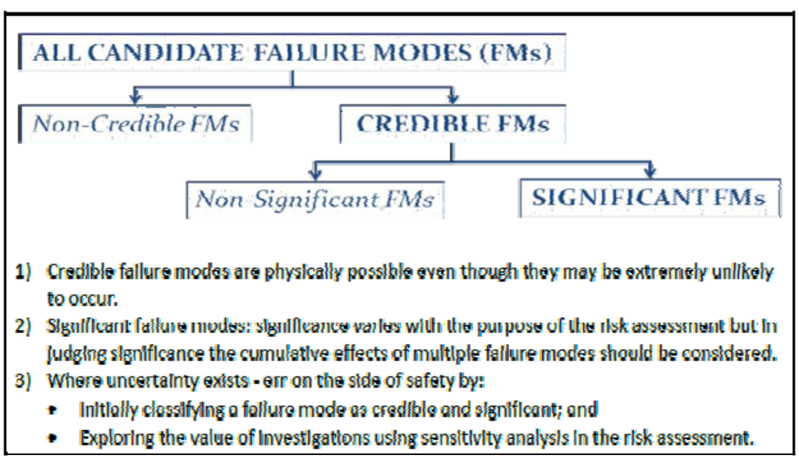


FIGURE 2-1
Screening and Classification of Potential Failure Modes
Faro Mine Remediation Project

The failure modes identified during the PFMA sessions are listed in Tables 2-1, 2-2, and 2-3 for Alternatives 1, 2, and 3, respectively.

Failure modes were identified for flood and earthquake loadings conditions. The failure modes for earthquake loading were deemed "not significant" for the following reasons:

- The dam structures contain tailings and not water; in some cases such as at the Secondary Dam, where liquefiable soil was identified in the foundation, a loss of crest would not necessarily imply a loss of tailings because the upper layers of the tailings would not be saturated.
- Ground improvement will be performed at the locations where liquefiable foundations soils were identified.
- There is a low likelihood of tailings loss after the design earthquake. However, significant damage may occur during such an event, which would require repair.

i) Credible and Significant Failure Modes – Flood

<u>Alternative 1:</u>

1. PFM1F-1 – Overtopping the RCD dyke, resulting in damage, and breaching of the tailings cover, which would release tailings, and more significantly, resulting in overtopping and breaching of the ID as a result of exceeding the ID spillway capacity.
2. PFM1F-2 – Piping or slope stability failure of the RCD dyke, resulting in damage and breaching of the tailings cover, which would release tailings, and more significantly, resulting in overtopping and breaching of the ID as a result of exceeding the ID spillway capacity.
3. PFM1F-4 – Channel blockage by icings in RCD that blocks the channel resulting in the overtopping of the RCD dyke, and causing damage, the breaching of the tailings cover, and the release of tailings; more significantly, resulting in overtopping and breaching of the ID as a result of exceeding the ID spillway capacity.
4. PFM1F-9 – Channel blockage by woody debris, resulting in overtopping of the RCD dyke, causing damage and breaching of the tailings cover, which would release tailings, and more significantly, resulting in overtopping and breaching of the ID as a result of exceeding the ID spillway capacity.

<u>Alternative 2:</u>

1. PFM2F-4 – Piping or slope stability failure of the RCD dyke, causing flow releases into the side channel or onto the riprap apron or tailings cover downstream from the channel exit, resulting in damage, the breaching of the tailings cover, and the release of tailings.
2. PFM2F-10 – Channel blockage by woody debris resulting in overtopping of the RCD dyke, causing damage, breaching the tailings cover, and releasing tailings.
3. PFM2F-6 – Channel blockage by icings in RCD that blocks the channel resulting in the overtopping of the RCD dyke, and causing damage, the breaching of the tailings cover, and the release of tailings; more significantly, resulting in overtopping and breaching of the ID as a result of exceeding the ID spillway capacity.
4. PFM2F-15 – Erosion and breaching of the tailings cover downstream from the side channel and riprap apron before a dissipating pool forms.

<u>Alternative 3:</u>

1. PFM3F-1 – Overtopping the RCD dyke causing release onto tailings cover, resulting in damage, the breaching of the tailings cover, and the release of tailings.
2. PFM3F-3 – Piping or slope stability failure of the RCD Dyke causing releases onto tailings cover, resulting in damage, the breaching of the tailings cover, and the release of tailings.
3. PFM3F-5 – Channel blockage by icings in RCD that blocks the channel resulting in the overtopping of the RCD dyke, and causing damage, the breaching of the tailings cover, and the release of tailings; more significantly, resulting in overtopping and breaching of the ID as a result of exceeding the ID spillway capacity.

4. PFM3F-9 – Channel blockage by woody debris resulting in overtopping of the RCD dyke, causing damage, breaching the tailings cover, and releasing tailings.
5. PFM3F-13 – Overbank flow occurs when exceeding the capacity of the dedicated 120 m-wide riprapped swale, and flow in preferred flow paths leading to channelization, erosion, and the eventual breaching of the tailings cover.

Detailed descriptions of the credible and significant failure modes are provided in Appendix C.

ii) Other Failure Modes – Not Credible or Credible and Not Significant

See Tables 2-1 through 2-3 for credible and not significant failure modes.

TABLE 2-1
Potential Failure Modes for Alternative 1 – Modified (Enlarged) RCD
Faro Mine Remediation Project

Designation	Description	Notes	Significant/Credible?	Category of FM/Loading	Component
PFM1F-1	**Overtopping the RCD dyke**	**Overtopping of the RCD dyke could be caused by exceeding the capacity of the channel. Settlement of the dyke can occur if there is still frozen soil that could thaw in future, when the permafrost has already melted for the most part. Because it was assume that there is at least 0.6 m freeboard and that settlement can be monitored for first 10 to 15 years, the likelihood of overtopping as a result of crest settlement is considered very low.**	**Credible and significant**	**Flood**	**RCD dyke**
PFM1F-2	**Piping and slope stability failure of the RCD dyke**	**Use the University of New South Wales (UNSW)** Method (Foster et al, 1998) **for assessing annual probability of piping failure. Use Silva's Method to relate factor of safety to annual probability of slope failure. Likelihood of piping and slope instability increases for larger flooding (higher water surface against RCD dyke); however, filter/drains will be incorporated in the dyke to mitigate concern. Piping through the foundation is the larger concern for this failure mode.**	**Credible and significant**	**Flood**	**RCD dyke**
PFM1F-3	Landslide into RCD, that blocks the channel	Need to evaluate the stability of the slopes above the left side of the channel. Geological evidence indicates that the slopes above the channel are stable. No evidence of slope instability on the valley wall since channel was constructed.	Credible but not significant	Flood	RCD dyke
PFM1F-4	**Icing in RCD that blocks the channel**	**Piping, stability or overtopping may occur as result of increased water surface in the channel when blocked. PMF and icing *(aufeis)* not likely to occur at same time. Historically, more incidences have occurred in the section downstream from the overflow weir. Significantly larger RCD for Alternative 1 will mitigate this concern to some extent.**	**Credible but not significant**	**Flood**	**RCD dyke**

TABLE 2-1
Potential Failure Modes for Alternative 1 – Modified (Enlarged) RCD
Faro Mine Remediation Project

Designation	Description	Notes	Significant/Credible?	Category of FM/Loading	Component
PFM1F-5	Ice damming that blocks the channel	Piping, stability, or overtopping may occur as result of reducing the capacity in the canal. For larger channel, ice damming would be less of an issue. Creek does not have large base flow.	Credible but not significant	Flood	RCD dyke
PFM1F-6	Channel erosion in downstream steep portion of channel	Headward erosion impacting the right bank of the channel causing breaching. Provide appropriate structures to limit headward erosion.	Credible but not significant	Flood	RCD dyke
PFM1F-7	Channel erosion in the upstream portions of channel	Adequate riprap protection at the right bank. Make sure that design covers adequate thickness and riprap sizes.	Credible but not significant	Flood	RCD dyke
PFM1F-8	Overtopping by surge wave from sudden release of upstream blockage (culvert blockage, woody debris or haul road embankment blockage)	Culverts and haul roads will be removed under the C&R Plan. If culverts and haul roads are not removed, then this can be credible and significant failure mode	Credible but not significant	Flood	RCD dyke
PFM1F-9	**Channel blockage by woody debris**	**Piping, slope failure, or overtopping may occur as result of increased water surface in the channel when blocked during significant floods. Because the haul road will be removed, the likelihood of woody debris accumulation will increase compared to the existing (baseline) condition. The larger RCD for Alternative 1 will mitigate this concern to some extent.**	**<u>Credible and significant</u>**	**Flood**	**RCD dyke**
PFM1F-10	North Valley Interceptor Ditch breaches and releases onto the tailings area	Erode and breach tailings cover and release tailings; possibly erode the spillway, as well. Proper design will take care of this problem.	Credible but not significant	Flood	North Valley Interceptor Ditch
PFM1EQ-1	*Earthquake-induced liquefaction leading to a failure of the East Limb of the Secondary Dam near the canal entrance*	*Failure of the dyke during normal flow event could cause release of tailings into the RCD. Liquefaction will be remediated in this area.*	*Credible but not significant (after mitigation is performed).*	*Earthquake*	*Secondary Dam*

TABLE 2-1
Potential Failure Modes for Alternative 1 – Modified (Enlarged) RCD
Faro Mine Remediation Project

Designation	Description	Notes	Significant/Credible?	Category of FM/Loading	Component
PFM1EQ-2	*Earthquake-induced liquefaction leading to a failure of the ID causing a release of tailings.*	*KCB field investigation (Becker Hammer) and report indicate that the foundation is not liquefiable. Dam is considered non-liquefiable because it was built in compacted (engineered) layers.*	*Credible but not significant*	*Earthquake*	*ID*
PFM1EQ-3	*Earthquake-induced liquefaction leading to a failure of the RCD dyke causing a release of water onto the tailings.*	*Foundations conditions silty till or gravel. New dyke will be built on natural materials; tailings will be removed from the foundation.*	*Credible but not significant*	*Earthquake*	*RCD dyke*
PFM1EQ-4	*Earthquake-induced liquefaction in the foundation leading to a failure of the West Limb of the Secondary Dam causing a release of secondary tailings onto the intermediate tailings.*	*KCB field investigation (Becker Hammer) and report indicate that a portion of the foundation is liquefiable. Dam is centreline construction with less compaction control. Liquefaction will be remediated in this area.*	*Credible but not significant (after mitigation is performed).*	*Earthquake*	*Secondary Dam*
PFM1EQ-5	*Earthquake-induced liquefaction leading to severe settlement/deformation, breaching of the tailings cover, and release of tailings during local surface runoff.*	*Assume inspection of cover after significant earthquake event and repair of the defects*	*Credible but not significant*	*Earthquake*	*Tailings cover*

TABLE 2-2
Potential Failure Modes for Alternative 2 – Side Channel
Faro Mine Remediation Project

Designation	Description	Notes	Significant/Credible?	Category of FM/Loading	Component
PFM2F-1	Overtopping the RCD dyke, resulting in releases into side channel and exceedance of side channel capacity	Given that the overflow weir is at a lower elevation than the dyke crest, the likelihood of overtopping and breaching the RCD dyke can be considered small. The exceedance of the side channel capacity after overtopping the RCD dyke may be an issue for PMF, but it is considered a small likelihood for smaller floods. Failures of the RCDC dyke will be into the side channel.	Credible but not significant	Flood	RCD dyke
PFM2F-2	Overtopping the side channel dyke	Overtopping of the side channel dyke could be caused by exceeding the capacity of the channel, settlement of the dyke crest, etc. Design allowance for these issues will reduce the effect of this.	Credible but not significant	Flood	RCD dyke
PMF2F-3	Breaching of the ID due to piping or slope instability	Drying out of core and impacts by freeze-thaw cycles will result in cracks (desiccation and freeze-thaw). Internal filters and drains in existing dam, concept is to add more drains on downstream slope. Checking through United States Army Corps of Engineers (USACE) Toolbox.	Credible but not significant (assuming filter/drain design is robust)	Flood	RCD dyke
PFM2F-4	**Piping and slope stability failure of the RCD dyke, causing releases into side channel, or onto the riprap apron and/or onto tailings cover downstream from the side channel exit, and resulting in damage and breaching of the tailings cover and release of tailings**	**Use the UNSW Method to assess annual probability of failure against piping. Use Silva's Method to relate factor of safety to annual probability of slope failure.**	**<u>Credible and significant</u>**	**Flood**	**RCD dyke**
PFM2F-5	Landslide into RCD that blocks the channel	Need to evaluate the stability of the slopes above the left side of the channel. Geological evidence indicates that the slopes above the channel are stable. No evidence of slope instability on the Valley wall since channel was constructed.	Credible but not significant	Flood	RCD dyke

TABLE 2-2
Potential Failure Modes for Alternative 2 – Side Channel
Faro Mine Remediation Project

Designation	Description	Notes	Significant/Credible?	Category of FM/Loading	Component
PFM2F-6	**Icing in RCD that blocks the channel**	**Piping, stability, or overtopping may occur as result of increased water surface in the channel when blocked. PMF and icing (aufeis) not likely to occur at same time. Historically, more incidences have occurred in the section downstream from the overflow weir.**	**Credible but not significant**	**Flood**	**RCD dyke**
PFM2F-7	Ice damming that blocks the channel	Piping, stability, or overtopping may occur as result of reducing the capacity in the canal. Creek does not have large base flow.	Credible but not significant	Flood	RCD dyke
PFM2F-8	Channel erosion in downstream steep portion of RCD channel	Headward erosion impacting on the right bank of the channel causing breaching. Existing design to be checked for adequacy and modified as necessary.	Credible but not significant (less significant than for Alternative1; less flow)	Flood	RCD dyke
PFM2F-9	Channel erosion in the upstream portions of RCD channel	Adequate riprap protection on the right bank. Make sure that design covers adequate thickness and riprap sizes.	Credible but not significant (less significant than for Alternative 1; less flow)	Flood	RCD dyke
PFM2F-10	**RCD channel blockage by woody debris**	**Piping, slope failure, or overtopping may occur as result of increased water surface in the channel when blocked during significant floods. Because the haul road will be removed, the likelihood of woody debris accumulation will increase compared to the existing (baseline) condition.**	**<u>Credible and significant</u>**	**Flood**	**RCD dyke**
PFM2F-11	North Valley Interceptor Ditch breaches and releases onto the RCTA	North Valley Interceptor Ditch erodes and breaches the tailings cover and release tailings with possible erosion of spillway as well. Proper design will take care of this problem.	Credible but not significant	Flood	North Valley Interceptor Ditch
PFM2F-12	Erosion of spillway channel resulting in dam breach	Design spillway channel in rock (including rock protection) and possibly include cut-off wall to protect dam abutment.	Credible but not significant	Flood	RCD dyke

TABLE 2-2
Potential Failure Modes for Alternative 2 – Side Channel
Faro Mine Remediation Project

Designation	Description	Notes	Significant/Credible?	Category of FM/Loading	Component
PFM2F-13	Failure of the overflow weir resulting in exceedance of side-channel capacity	Mainly an issue for PMF event.	Credible but not significant	Flood	RCD dyke
PFM2F-14	Erosion of the side-channel bottom or side slopes, resulting in breaching of the side channel dyke and release of water onto the tailings cover	Channel will be fully lined with riprap. If there is a loss of riprap, the assumption is that it may scour the channel bottom or side slopes, but it would not endanger the RCD or side channel dykes. Some repairs may be necessary after the very infrequent flood event.	Credible but not significant	Flood	Side channel
PFM2F-15	**Erosion and breaching of the tailings cover downstream from the side channel and riprap apron prior to having a dissipating pool formed**	**It is estimated/calculated that flows will not have enough velocity to cause erosion prior to having an energy-dissipating pond. Assume that erosion apron will extend far enough and wide enough to limit this concern.**	**Credible and significant**	**Flood**	**Tailings cover**
PFM2F-16	Rock slope failure in ID spillway resulting in debris that blocks or partially blocks the spillway, causing overtopping and breaching of the ID	It is assumed that adequately conservative design of the rock cut slopes will be incorporated. Smaller debris piles as a result of shallow sloughing will be washed away by the flows through the spillway.	Credible but not significant	Flood	ID spillway
PFM2EQ-1	*Earthquake-induced liquefaction, leading to a failure of the East Limb of the Secondary Dam near the canal entrance*	*Failure of the dyke during normal flow event could cause release of tailings into the RCD. Liquefaction will be remediated in this area.*	*Credible but not significant (after mitigation is performed)*	*Earthquake*	*Secondary Dam*
PFM2EQ-2	*Earthquake-induced liquefaction, leading to a failure of the ID and causing a release of tailings*	*KCB field investigation (Becker Hammer) and report indicate that the foundation is not liquefiable. Dam is considered non-liquefiable because it was built in compacted layers.*	*Credible but not significant*	*Earthquake*	*ID*
PFM2EQ-3	*Earthquake-induced liquefaction, leading to a failure of the RCD dyke causing a release of water into the side channel*	*Foundations conditions consist of silty till or gravel. New dyke will be built on natural materials; tailings will be removed.*	*Credible but not significant (even less significant than for Alternative 1*	*Earthquake*	*RCD dyke*

TABLE 2-2
Potential Failure Modes for Alternative 2 – Side Channel
Faro Mine Remediation Project

Designation	Description	Notes	Significant/Credible?	Category of FM/Loading	Component
PFM2EQ-4	*Earthquake-induced liquefaction, leading to a failure of the West Limb of the Secondary Dam and causing a release of secondary tailings onto the intermediate tailings*	*KCB field investigation (Becker Hammer) and report indicate that a portion of the foundation is liquefiable. Dam is centreline construction with less compaction control. Liquefaction will be remediated in this area.*	*Credible but not significant (after mitigation is performed)*	*Earthquake*	*Secondary Dam*
PFM2EQ-5	*Earthquake-induced liquefaction, leading to severe settlement/deformation, breaching of the tailings cover, and release of tailings during local surface runoff*	*Assume inspection of cover after significant earthquake event and repair of the defects. Likelihood of large flood event after large earthquake event is very low.*	*Credible but not significant*	*Earthquake*	*Tailings cover*

TABLE 2-3
Potential Failure Modes for Alternative 3 – Single, Dedicated, Large Swale (Channel)
Faro Mine Remediation Project

Designation	Description	Notes	Significant/Credible?	Category of FM/Loading	Component
PFM3F-1	**Overtopping of the RCD dyke, causing releases onto tailings cover, and resulting in damage, the breaching of the tailings cover, and the release of tailings**	**Given that the overflow weir is at a lower elevation than the dyke crest, the likelihood of overtopping the RCD dyke can be considered small. Spillage will be onto the swale, which is not as protected as Alternative 2.**	**<u>Credible and significant</u>**	**Flood**	**RCD dyke**
PMF3F-2	Breaching of the ID due to piping or slope instability	Drying out of core and impacts by freeze-thaw cycles will result in cracks (desiccation and freeze-thaw). Internal filters and drains in existing dam, concept is to add more drains on downstream slope. Checking through the USACE Toolbox for failure mechanisms.	Credible but not significant (assuming filter/drain design is robust)	Flood	ID
PFM3F-3	**Piping and slope stability failure of the RCD dyke, causing releases onto tailings cover, and resulting in damage, the breaching of the tailings cover, and the release of tailings**	**Use the UNSW Method to assess annual probability of piping failure. Use Silva's Method (Silva et al., 2008) to relate factor of safety to annual probability of slope failure.**	**<u>Credible and significant</u>**	**Flood**	**RCD dyke**
PFM3F-4	Landslide into RCD that blocks the channel	Need to evaluate the stability of the slopes above the left side of the channel. Geological evidence indicates that the slopes above the channel are stable. No evidence of slope instability on the valley wall since the channel was constructed. If blockage is downstream from the overflow weir, flow over the weir will prevent or limit the possibility of overtopping.	Credible but not significant	Flood	RCD dyke
PFM3F-5	**Icing in RCD that blocks the channel**	**Piping, stability, or overtopping may occur as result of capacity in the canal. PMF and icing (*aufeis*) not likely to occur at same time. Portions of RCD downstream from overflow weir historically experience more incidences in the canal. If the blockage is downstream from the overflow weir, the flow over the weir will prevent or limit the possibility of overtopping.**	**Credible but not significant**	**Flood**	**RCD dyke**

TABLE 2-3
Potential Failure Modes for Alternative 3 – Single, Dedicated, Large Swale (Channel)
Faro Mine Remediation Project

Designation	Description	Notes	Significant/Credible?	Category of FM/Loading	Component
PFM3F-6	Ice damming that blocks the channel	Piping, stability, or overtopping may occur as result of reducing the capacity in the canal. For a larger channel, ice damming would be less of an issue. The creek does not have a large base flow. If the blockage is downstream from the overflow weir, the flow over the weir will prevent or limit the possibility of overtopping.	Credible but not significant	Flood	RCD dyke
PFM3F-7	Channel erosion in downstream steep portion of RCD channel	Headward erosion, impacting the right bank of the channel and causing breaching. Existing design to be checked for adequacy and modified as necessary.	Credible but not significant	Flood	RCD dyke
PFM3F-8	Channel erosion in the upstream portions of RCD channel	Adequate riprap protection at the right bank. Make sure that design covers adequate thickness and riprap sizes.	Credible but not significant	Flood	RCD dyke
PFM3F-9	**RCD channel blockage by woody debris**	**Piping, slope failure, or overtopping may occur as a result of increased water surface in the channel when it is blocked during significant floods. Because the haul road will be removed, the likelihood of woody debris accumulation will increase compared to the existing (baseline) condition.**	**Credible and significant**	**Flood**	**RCD dyke**
PFM3F-10	North Valley Interceptor Ditch breaches and releases onto the tailings area	The North Valley Interceptor Ditch may erode and breach tailings cover and release tailings, with possible erosion of spillway as well. Proper design will take care of this problem.	Credible but not significant	Flood	North Valley Interceptor Ditch
PFM3F-11	Erosion of spillway channel resulting in dam breach	Design spillway channel in rock (including rock protection) and possibly include cutoff wall to protect dam abutment.	Credible but not significant	Flood	ID spillway
PFM3F-12	Failure of the overflow weir, resulting in exceedance of side channel capacity	Mainly an issue for PMF event.	Credible but not significant	Flood	Overflow weir (RCD)

TABLE 2-3
Potential Failure Modes for Alternative 3 – Single, Dedicated, Large Swale (Channel)
Faro Mine Remediation Project

Designation	Description	Notes	Significant/Credible?	Category of FM/Loading	Component
PFM3F-13	**Overbank flow occurs when exceeding the capacity of the dedicated 120-m-wide riprapped swale, and flow in preferred flow paths leading to channelization, erosion, and eventual breaching of the tailings cover**	**It is assumed that dedicated swale (120 m wide) will be sized to minimize flow depth and velocity over the tailings cover, outside the channel. Swale is constructed on soft tailings and differential settlement can disrupt dedicated swale.**	**<u>Credible and significant</u>**	**Flood**	**Overflow weir (RCD)**
PFM3F-14	Rock slope failure in ID spillway, resulting in debris that blocks or partially blocks the spillway, causing overtopping and breaching of the ID	It is assumed that adequately conservative design of the rock cut slopes will be incorporated. Smaller debris piles as a result of shallow sloughing will be washed away by the flows through the spillway.	Credible but not significant	Flood	ID spillway
PFM3EQ-1	*Earthquake-induced liquefaction, leading to a failure of the East Limb of the Secondary Dam near the canal entrance*	*Failure of the dyke during normal flow event could cause release of tailings into the RCD. Liquefaction will be remediated in this area.*	*Credible but not significant (after mitigation is performed)*	*Earthquake*	*Secondary Dam*
PFM3EQ-2	*Earthquake-induced liquefaction, leading to a failure of the ID causing a release of tailings.*	*KCB field investigation (Becker Hammer) and report indicate that the foundation is not liquefiable. Dam is considered non-liquefiable because it was built in compacted layers.*	*Credible but not significant*	*Earthquake*	*ID*
PFM3EQ-3	*Earthquake-induced liquefaction, leading to a failure of the RCD dyke and causing releases onto tailings cover, resulting in damage, the breaching of the tailings cover, and the release of tailings.*	*Foundations conditions will be silty till or gravel. New dyke will be built on natural materials; tailings will be removed.*	*Credible but not significant*	*Earthquake*	*RCD dyke*
PFM3EQ-4	*Earthquake-induced liquefaction, leading to a failure of the West Limb of the Secondary Dam and causing a release of secondary tailings onto the intermediate tailings.*	*KCB field investigation (Becker Hammer) and report indicate that a portion of the foundation is liquefiable. Dam is centreline construction with less compaction control. Liquefaction will be remediated in this area.*	*Credible but not significant (after mitigation is performed)*	*Earthquake*	*Secondary Dam*
PFM3EQ-5	*Earthquake-induced liquefaction, leading to severe settlement/deformation, the breaching of the tailings cover and/or armoured swale, and the release of tailings during flooding (larger than 500-year event) and local surface runoff.*	*Assume inspection of cover after significant earthquake event and repair of the defects. Likelihood of large flood event after large earthquake event is very low.*	*Credible but not significant*	*Earthquake*	*Tailings cover*

2.3 Step 3 – Develop Risk Model

2.3.1 Flood Event Tree

The flood event trees for Alternatives 1, 2, and 3 are shown in Figures 2-2, 2-3, and 2-4, respectively, in the format of the DAMRAE software (Srivastava et al 2009 and 2011) developed by RAC/Utah State University (USU) for the USACE. The arrows indicate that the state values associated with a branch at the origin of the arrow are used in a branch to its right, in the event tree to which the arrow points.

2.4 Step 4 – Estimate Flood-loading Probabilities

2.4.1 Flood Loading and Plugging with Debris

The peak stage vs. Annual Exceedance Probability (AEP) relationships for the RCDC (existing configuration, and Alternatives 2 and 3) were derived from stage-discharge curves shown in Figure 2-5 for the "no-blockage", "10 percent blockage", and "20 percent blockage" cases.

The stage-discharge curve for the "no-blockage" case was developed using the 2D hydraulic modelling (MIKE 21), and results are presented in Appendix B. The stage-discharge curves for the "10 percent blockage" and "20 percent blockage" cases were approximated by shifting the "no-blockage" curve to account for the reduced cross-sectional area.

Similarly, the peak reservoir stage vs. AEP relationship for the intermediate dam was derived from the stage-discharge curve shown in Figure 2-6.

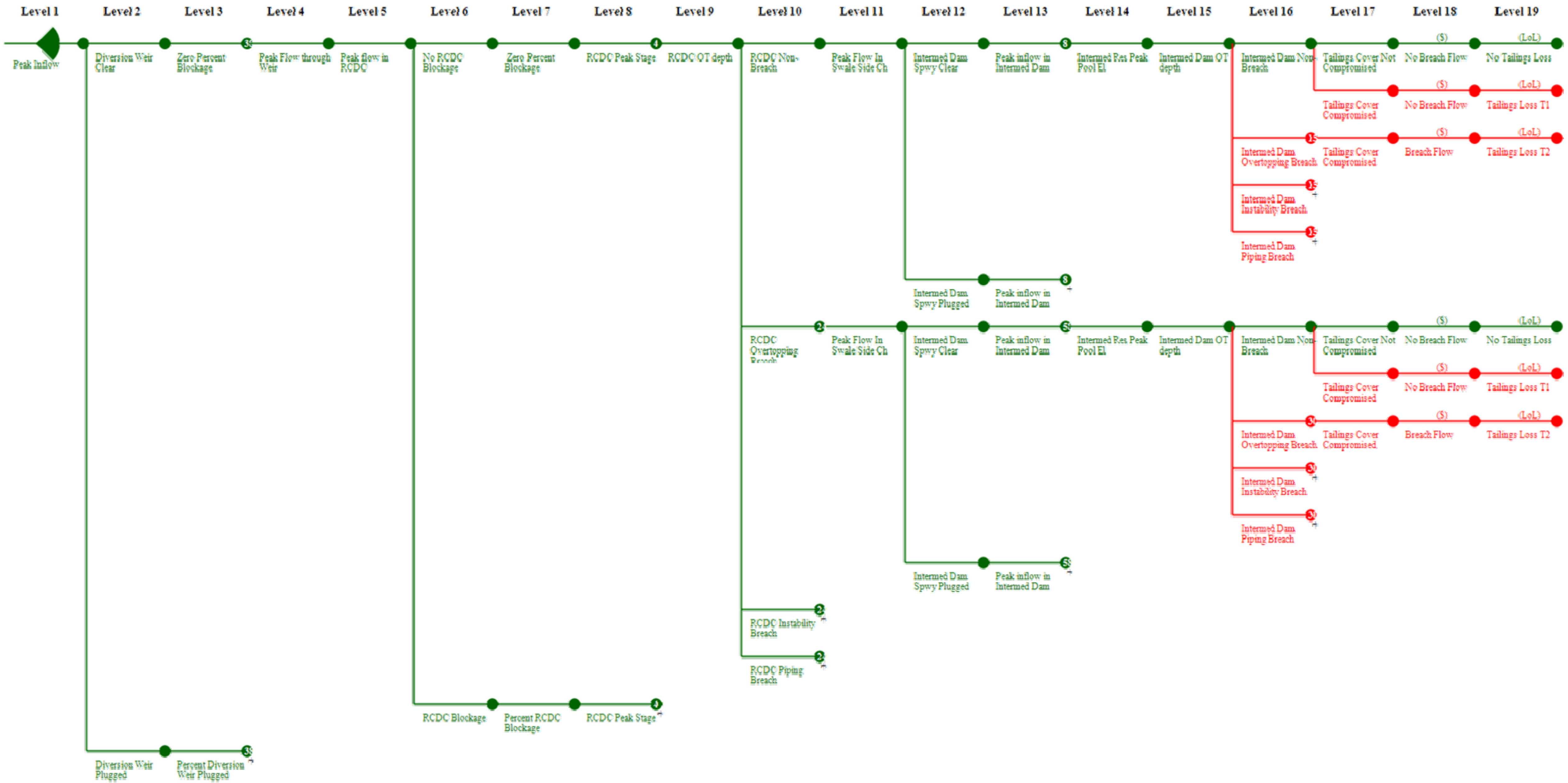


FIGURE 2-2
Flood Event Tree for Existing Condition and Alternative 1
Faro Mine Remediation Project

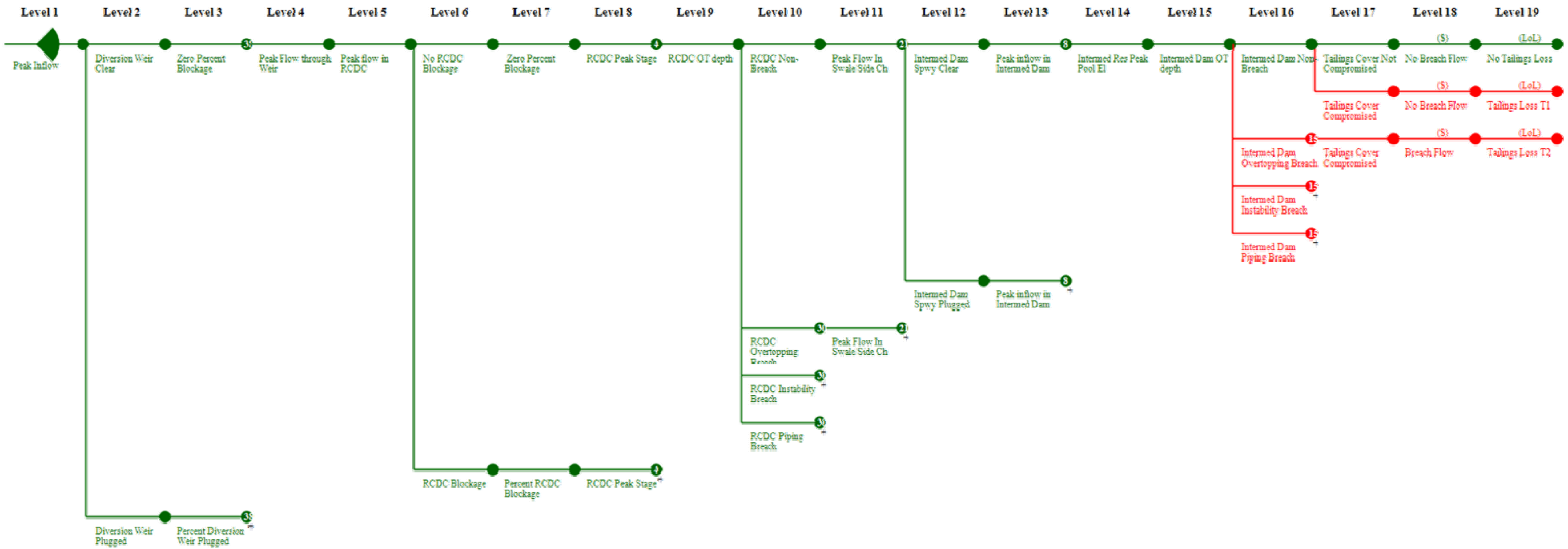


FIGURE 2-3
Flood Event Tree for Alternative 2
Faro Mine Remediation Project

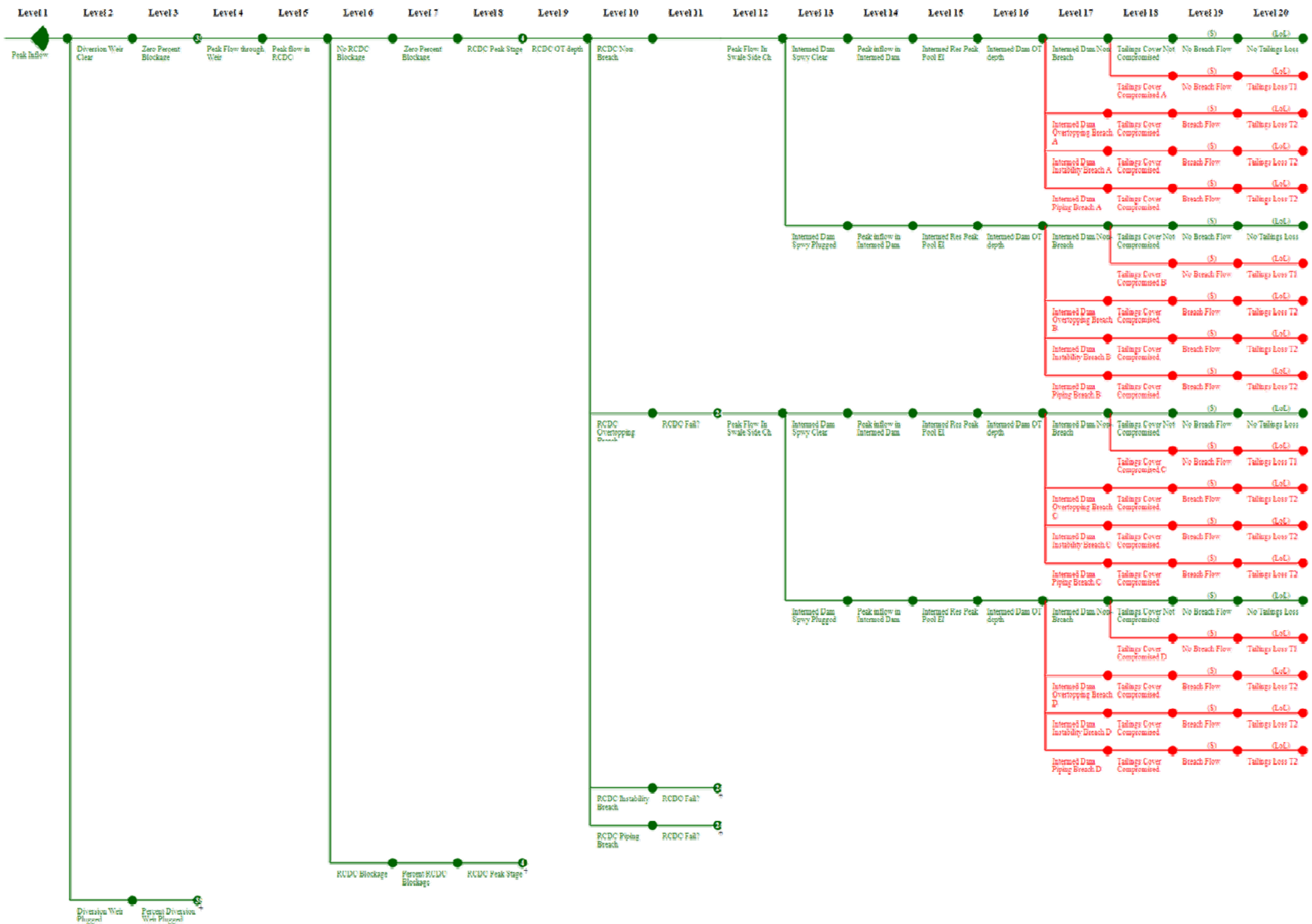


FIGURE 2-4
Flood Event Tree for Alternative 3
Faro Mine Remediation Project

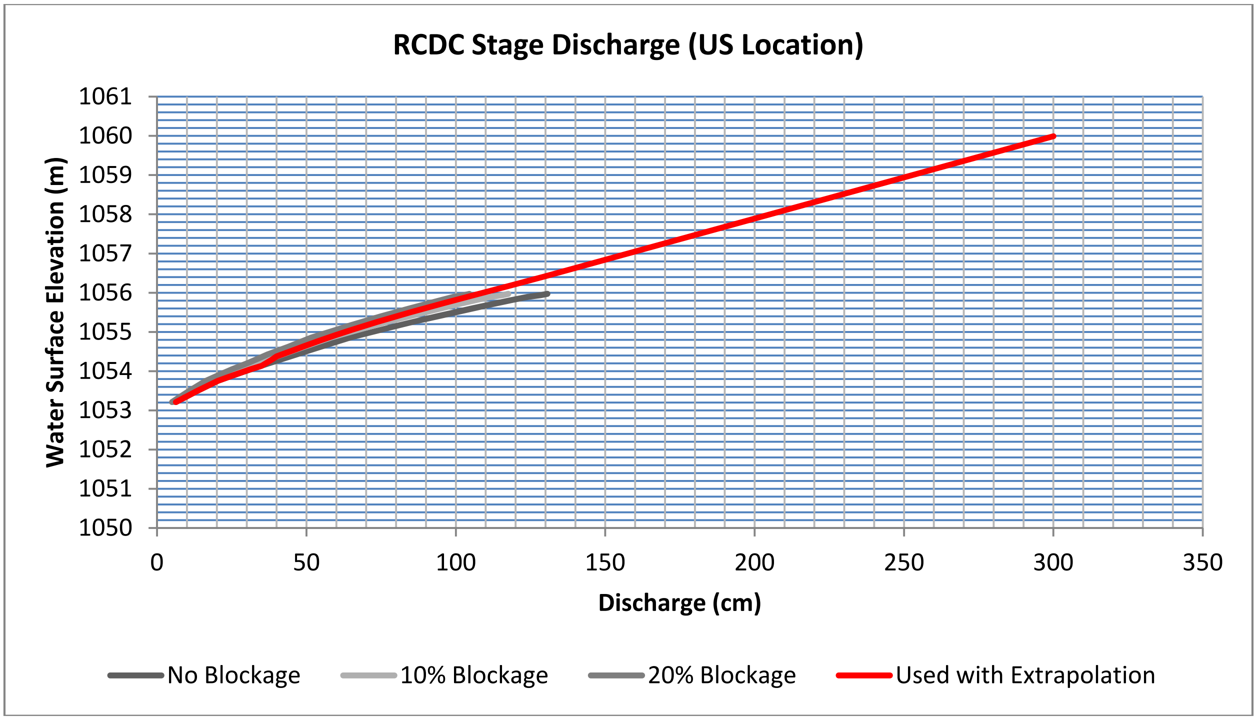


FIGURE 2-5
Peak Reservoir Stage versus AEP Relationships for the RCD for Existing Condition, Alternative 2, and Alternative 3
Faro Mine Remediation Project

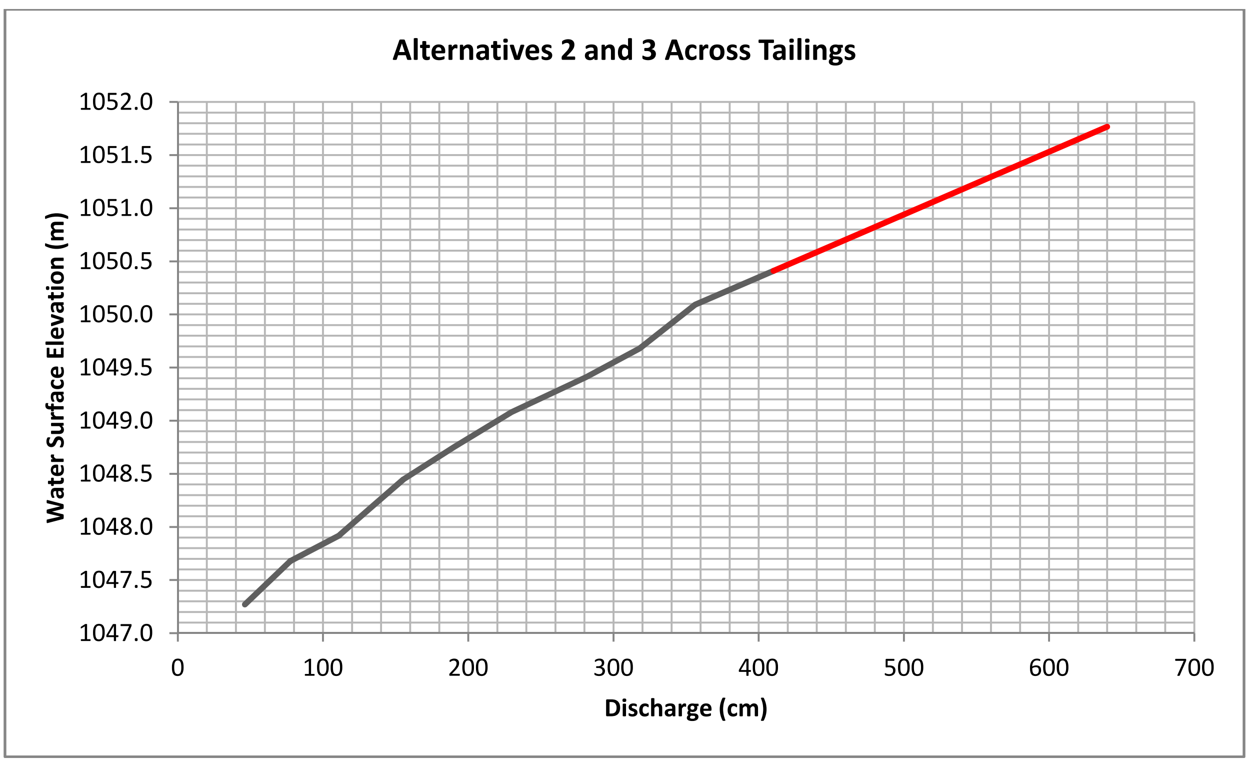


FIGURE 2-6
Peak Reservoir Stage versus AEP Relationships for ID for Alternative 2 and Alternative 3
Faro Mine Remediation Project

2.5 Step 5 – Estimate System Response Probabilities

The SRPs used in the risk analysis are conditional probabilities that represent the probability of an event associated with the dyke or dam performance, in response to the occurrence of the events represented by the branches to the left, along a pathway through the event tree. SRPs are estimated on the basis of information from many sources, including: laboratory testing, engineering analysis, experimental evidence, engineering judgment, and historical performance records for comparable dams. In some cases, SRPs can be calculated directly, and for other cases, the probability must be estimated based on deterministic analysis and judgment. When judgmental probabilities were assigned, Table 2-4 was used as a guide for estimating SRPs.

TABLE 2-4
Probability mapping scheme (Reclamation-USACE-URS-UNSW 2008)
Faro Mine Remediation Project

Verbal Descriptor	Probability
Virtually Certain	0.999
Very Likely	0.99
Likely	0.9
Neutral	0.5
Unlikely	0.1
Very Unlikely	0.01
Virtually Impossible	0.001

The general process used to estimate the SRPs for the RCTA Alternatives included the following steps for each credible and significant failure mode:

1. Review the failure mode and discuss the factors that would influence its SRPs, including any historical analyses.
2. Identify and conduct any agreed-upon analysis to characterize the failure mode and for use in estimating its SRPs. For this study, additional detailed analysis was not performed.
3. Discuss the results of previous analyses and other factors, such as generic relationships and case histories, which could be used to inform the estimation of the SRPs.
4. Estimate the SRPs, including a best estimate and in some cases the upper and lower bound estimates.
5. Set a threshold value for the SRP relationship below which the SRP value is zero (or very near to zero).
6. Review the results and adjust as necessary, based on engineering judgment.

SRPs were developed for the following general types of flood failure modes:

- Overtopping
- Piping
- Slope failure

2.5.1 Overtopping

Overtopping failure of the RCD, as well as overtopping failure of the ID, was included in the risk model. Since water would be fast-flowing and parallel to the crest in the RCD, it was assumed that there would be a fairly high conditional probability of 0.67 that overtopping failure would occur if the water stage was at the dyke crest. This is in contrast with the ID, where the conditional probability of overtopping failure was assumed to be zero if the water was at the dam crest, because the water would be pooling.

In developing the SRP relationships for an overtopping failure of the four embankments, a number of factors were taken into consideration, including the following:

- The erodibility of the material on the downstream face of each individual embankment
- The condition of the dam crest for each individual embankment
- The potential duration of overtopping
- The fetch and natural protection from wave action
- Comparisons with relationships developed for other dams.

The SRP relationships for the RCD and ID are shown in Figure 2-7.

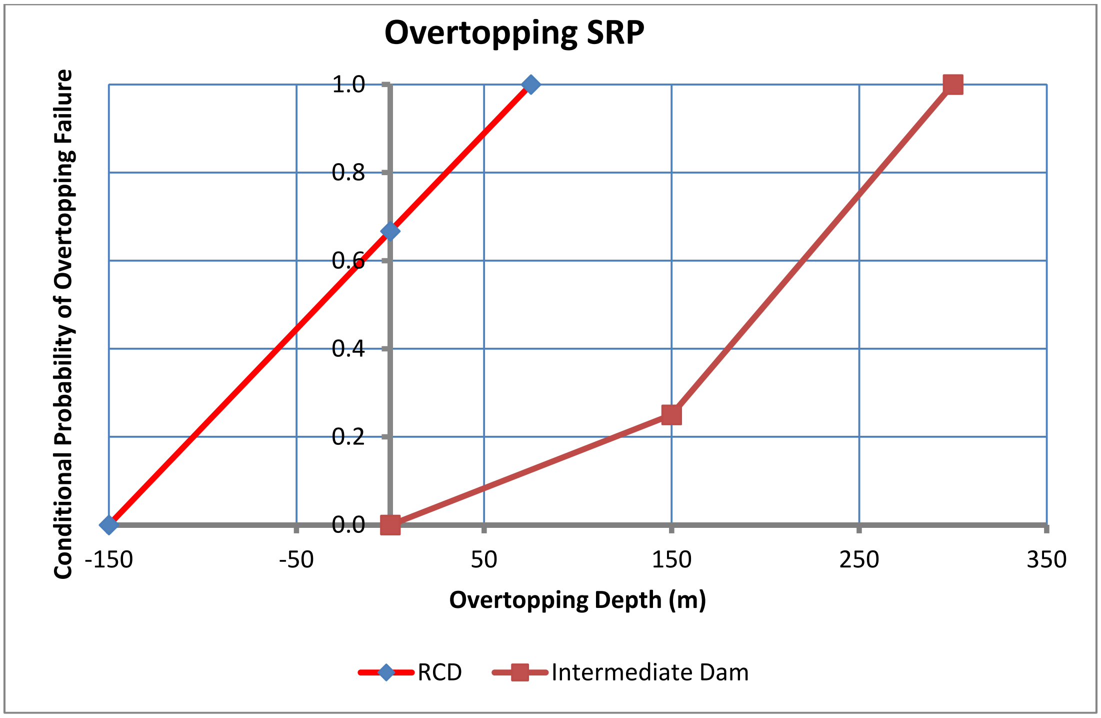


FIGURE 2-7
Overtopping SRP
Faro Mine Remediation Project

2.5.2 Piping

The annual piping probability of failure (APF) was estimated using the UNSW Method (Foster et al, 1998). The method is an empirical approach developed using data of historical piping incidents, for which the probability of piping is a function of the mode of piping (through the foundation versus through the embankment) as well as the dam zoning. Weight factors are then applied to these probabilities to account for factors such as the presence of filters, presence of cutoff trench, grouting of the foundation, soil type, monitoring and surveillance, and such.

Note that the probability values obtained using this method are annual probabilities of failure and should not be multiplied by the annual probability of reaching a particular water elevation.

The annual piping APFs for the RCD and ID are provided in Table 2-5 and Table 2-6, respectively.

TABLE 2-5
Annual Probability of Failure by Piping for the RCD Dyke
Faro Mine Remediation Project

	RCD Dyke			
Piping Failure Mode	**Existing**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Embankment Piping	1.84E-04	0.00E+00	0.00E+00	0.00E+00
Foundation Piping	7.60E-05	0.00E+00	0.00E+00	0.00E+00
Piping Embankment into Foundation	9.88E-06	0.00E+00	0.00E+00	0.00E+00
Total Piping APF	**2.70E-04**	**1.00E-06**	**2.70E-04**	**2.70E-04**

TABLE 2-6
Annual Probability of Slope Failure by Piping for the Intermediate Dam
Faro Mine Remediation Project

	Intermediate Dam			
Piping Failure Mode	**Existing**	**Alternative 1**	**Alternative 2**	**Alternative 3**
Embankment Piping	8.64E-08	0.00E+00	0.00E+00	0.00E+00
Foundation Piping	1.00E-06	0.00E+00	0.00E+00	0.00E+00
Piping Embankment into Foundation	7.49E-07	0.00E+00	0.00E+00	0.00E+00
Total Piping APF	**1.84E-06**	**1.00E-08**	**1.00E-06**	**1.00E-06**

2.5.3 Slope Instability

Slope stability issues are standard considerations that are always associated with the safety evaluation of earth embankment dams. Acceptable safety factor criteria have been established by the engineering profession for the evaluation of the normal operation conditions of steady state seepage and rapid drawdown. Silva et al.,(2008) have suggested relationships relating safety factors to annual probability of failure based on data from "real world projects", using the plot shown on Figure 2-8.

These relationships were used to estimate the annual probability of failure for the slope stability failure mode for the RCD and the ID. Appropriate safety factors for reservoir elevations representing normal and flood conditions, as shown in the table within Figure 2-20, were used as the bases for making these probability estimates. The estimated safety factors of 1.5 for the RCD and 1.6 for the ID yielded annual probabilities of failure of about 5×10^{-4} per year for the RCD and 2×10^{-5} per year for the ID, respectively. These values were obtained from Silva et al. (2008), assuming that the ID is a Category II project, and that the RCD is slightly poorer than a Category II project. Category II is described by Silva et. al.,(2008) as follows: "*facilities designed, built, and operated using standard engineering practice. Many ordinary facilities fall into this category.*" It must be emphasized that the probability values obtained using this method are annual probabilities of failure and should not be multiplied by the annual probability of reaching a particular water elevation.

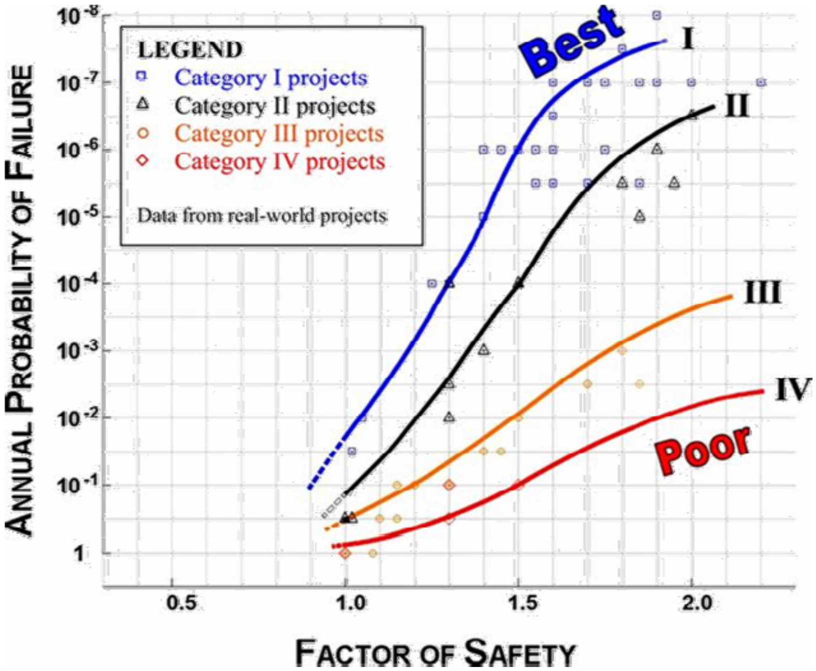


FIGURE 2-8
Factor of Safety versus Annual Probability of Failure from Silva et al. (2008)
Faro Mine Remediation Project

UNEDITED SUPPORTING NOTES FROM RISK ASSESSMENT SESSIONS

Definition of Failure

1) w/o X-Valley Dam

Significant Loss of Cover =Continuous loss of tailings = failure
Continuous Loss of Tailings can be caused by:

- Alt 1 – Flood Loading
  - Breach of the RCDC Dyke – high breach flows onto the tailings behind the intermediate Dam causing a loss of tailings and likely loss of the intermediate Dam
    - Use the UNSW historical method to determine the probability of failure for existing structures. For a new design assign a low probability of failure assigned by the team, say 1E-6.
    - For an overtopping failure of the RCDC Dyke only a few inches of overtopping will cause the embankment to fail because of the flow velocity component in the channel. At the PMF without blockage there will be adequate freeboard to prevent overtopping but with blockage the embankment will likely overtop.
      - OT SRP would have a threshold at 150 mm below the crest of the dyke and the probability would reach 1.0 at a depth of overtopping of 75 mm. Assume a linear distribution between 0 and 1.
    - Assume that the breach flow will be about 75% of the flow in the RCDC
    - SRP of Compromising the tailings – for this preliminary analysis the SRP = 1 for any breach flow from the RCDC. The RCDC is a structure design for the PMF and any breach flow would be very high.
  - Breach of the Intermediate Dam without a breach of the RCDC is not likely because there is no pool behind the dam

- Alt 2 – Flood Loading
  - Breach of the Side Channel Dyke – resulting in loss of cover. This will be a properly designed structure and we will assign a low probability of failure of 1E-6.
  - Breach of the Intermediate Dam – piping or slope stability failure – spillway capacity will prevent an Overtopping failure of the intermediate dam. BLOCKAGE OF THE SPILLWAY BE A SLIDE WILL BE CONSIDERED – SEE Alt 3 below.
    - Estimate the piping probability of the existing Intermediate Dam using the UNSW method
    - Estimate a slope stability failure using the method by Silva, et al.
  - Breach of Cover from Side Channel Exit Flows into the pool and flow to the spillway
  - **A breach of the RCDC would not cause a breach of the Side Channel because the Side Channel will have a stable bottom with a width of >40 metres.**
  - Channel plugging will be different for Alt 2 and 3 compared to Alt 1.
- Alt 3 – Flood Loading
  - Breach of the RCDC Dyke – high breach flows onto the tailings behind the intermediate Dam causing a loss of tailings
    - OT
    - Piping
    - **Same condition as for Alt 1 up to a flow of 135 cumecs (1in 500 flood event) or from an overflow condition caused by debris plugging. The tailings will be compromised. This is a no pool condition.**
    - For flows in excess of 135 cumecs flow over the diversion weir will form a pool in covered tailings area. The probability of compromising may be a bit less.
  - Breach of the intermediate Dam - piping or slope stability failure – spillway capacity will prevent an Overtopping failure of the intermediate dam. Use the same method as alternative 2. However, long term degradation of the rock material in the spillway may trigger a massive slide into the spillway blocking the capacity. Blocking the spillway would lead to overtopping the Intermediate Dam at high flows. NEED TO ADD THIS TO THE EVENT TREE. Consider this as a very unlikely probability (0.01) for 30% plugging.
  - Breach of the Cover – Flow across the cover has the potential to scour the cover and expose and scour tailings. Overland flow velocities over the tailings (flow has exceeded the capacity of the 120 metre wide swale) may be as high as 3 to 4 m/s. Considerations should be given to settlement, nick points, channelization, etc. Must consider the capacity of the swale.
  - Failure of the RCDC d/s of the location of the Intermediate Dam is considered as Credible but Not Significant because it will not involve tailings.

Icings Considerations

- Can 9 meters of Icing occur in the channel?
  - Variations along the channel
  - Will vary from year to year
- Combination of Icing and Woody Debris – Very unlikely that this would occur
- Icing process
  - Little of no velocity to flow

  - Freezes to the bottom
  - Results in flow over the ice
  - Cracks in the ice
  - Some flow will pop up
  - Local inflows can cause localized build up
- Breakup process
  - Flow over the top of the ice and then the ice will lift
  - 9 meters would not lift and would down-cut through the ice
  - Have runoff from snow melt as things begin to thaw
- Condition of the tailings during icing
  - Overtopping in the middle of winter freezes going down the dyke and onto the tailings
  - Thin sheet of water that freezes
  - Not a concentrated overflow
  - Snow on the tailings pond
- April PMF is about 60 cumecs
- No correlation between the amount of ice buildup and the occurrence of the April PMF
- Pilot Channel – good for icing preventions reasons
- PMF event would be **rain on snow**
- Questions of the effect of icing that need to be estimated
  - Depth of Icing
  - Is 9 meters possible?
- Probability of failure will be a function of
  - Probability of various depths of icing and the remaining depth to accommodate flow in the RCDC – suggest that we limit the estimate to the probability of 9 meters of icing because less than 9 meters can be accommodated by the Alternative 1 channel flows
  - Probability of the depth for flow – loading probability
  - Depth of overflow – (= depth channel – depth of ice – depth flow)
  - Overflow SRP as a function of the overflow depth (failure of the dyke)
  - SRP for loss of tailings from the flows associated with the RCDC dyke failure
  - SRP for loss of tailings from flows flowing over the frozen tailings
  - Effect of maintenance – removal of ice to maintain a certain freeboard
  - Location of the blockage –
- Low point of the overflow weir is 1056.5
- Downstream dyke has a low point less than 1056.5
- Probability of maximum icing is greater at the downstream end of the RCDC
- Icing is a function of temperature
  - Based on temperature the Annual Probability of getting 9 meters depth of ice is perhaps 0.01
  - Based on 30 years of weather data and have not had extreme icing to this point
- 9 meters of ice is for the Alternative 1 case only
- Alternative 2 and 3 the maximum channel depth is about 3 to 5 meters
- Considerations
  - Impact on the RCDC Flow
  - Impact on the RCDC Failure
  - Impact of the loss of tailings cover and tailings

2.6 Step 6 – Estimate consequences

Three levels of failure categories were initially considered:

- Type 1 (T1) – Represents a loss of tailings by flow over the overflow weir and into the covered tailings area causing a compromise of the cover which in turn causes a release of the tailings. Flow across the covered tailings area would only occur for Alternatives 2 and 3 where flow in the RCDC above a flow rate of 135 m^3/sec is diverted into the covered tailings area. A loss of tailings by this method would likely be serious, but would not be of the same magnitude as T2 or T3.
- Type 2 (T2) – Represents a loss of tailings by a failure of the RCDC dyke cascading into the covered tailings area, disrupting the cover, and causing a significant loss of tailings. Failure of the RCDC dyke would cause a significant loss of tailings.
- Type 3 (T3) – Represents a loss of tailings as a result of the failure of the Intermediate Dam (by Overtopping, Slope Instability, or Internal Erosion and Piping). Failure of the Intermediate Dam would cause the most serious loss of tailings.

Consequences such as environmental impact, cost, human health and safety, and legal and other obligations are then considered for the different impact categories according to the Government of Yukon's Risk Register, as shown in the next three tables.

"Potential Consequences of Event" Categories
Type 1 – Tailings cover compromised – no or minor release from Intermediate Tailings Area
Overall Category - Moderate

Consequences and Categories	Low	Minor	Moderate	Major	Critical
1. Environmental Impact	No Impact	Minor localized or short-term impacts	Significant impact on valued ecosystem component	Significant impact on valued ecosystem component and medium-term impairment of ecosystem function	Serious long-term impairment of ecosystem function
2. Special Considerations	Some disturbances but no impact to traditional land use	Minor or perceived impact to traditional land use	Some mitigable impact to traditional land use	Significant temporary impact on traditional land use	Significant permanent impact on traditional land use
3. Legal and Other Obligations	• No non Compliance but lack of conformance with departmental policy requirement • Informal advice from a regulatory agency • No land claim or other agreement	• Technical/Administrative non-compliance with permit, approval or regulatory requirement • Warning letter issued • Land claim or other agreement requires the Crown to satisfy administrative obligations (e.g. notification)	• Breach of regulations, permits, or approvals (e.g. one day violation of discharge limits) • Order or direction issued • Land claim or other agreement requires the Crown to respond, but no time frame is specified	• Substantive breach of regulations, permits or approvals (e.g. multi-day violation of discharge limits) • Prosecution • Land claim or other agreement requires the Crown to exercise its obligations within a specified time frame (i.e. two-five years)	• Major breach of regulation-wilfull violation • Court order issued • Land claim or other agreement requires the Crown to exercise its obligations within a specified time frame (i.e. one-two years)
4. Consequence Costs	< $100,000	$100,000 - $500,00	$500,000 - $2.5 Million	$2.5 - $10Million	> $10 Million
5. Community Media Reputation	Local concerns, but no local complaints or adverse press coverage	Public concern restricted to local complaints or local adverse press coverage	Heightened Concern by local community, criticism by NGO's or adverse local/regional media attention	Significant adverse national public NGO or media attention	Serious public outcry/ demonstrations or adverse international NGO attention or media coverage
6. Human Health and Safety	Low-level short-term subjective symptoms/ No measurable physical effect/ No medical treatment	Objective but reversible disability/impairment and/or medical treatment injuries requiring hospitalization	Moderate irreversible disability or impairment to one or more people	Single fatality and/or severe irreversible or impairment to one or more people	Multiple fatalities

"Potential Consequences of Event" Categories
Type 2 – Tailings cover compromised – release from Intermediate Tailings Area
Overall Category - Major

Consequences and Categories	Low	Minor	Moderate	Major	Critical
1. Environmental Impact	No Impact	Minor localized or short-term impacts	Significant impact on valued ecosystem component	Significant impact on valued ecosystem component and medium-term impairment of ecosystem function	Serious long-term impairment of ecosystem function
2. Special Considerations	Some disturbances but no impact to traditional land use	Minor or perceived impact to traditional land use	Some mitigable impact to traditional land use	Significant temporary impact on traditional land use	Significant permanent impact on traditional land use
3. Legal and Other Obligations	• No non Compliance but lack of conformance with departmental policy requirement • Informal advice from a regulatory agency • No land claim or other agreement	• Technical/Administrative non-compliance with permit, approval or regulatory requirement • Warning letter issued • Land claim or other agreement requires the Crown to satisfy administrative obligations (e.g. notification)	• Breach of regulations, permits, or approvals (e.g. one day violation of discharge limits) • Order or direction issued • Land claim or other agreement requires the Crown to respond, but no time frame is specified	• Substantive breach of regulations, permits or approvals (e.g. multi-day violation of discharge limits) • Prosecution • Land claim or other agreement requires the Crown to exercise its obligations within a specified time frame (i.e. two-five years)	• Major breach of regulation-wilfull violation • Court order issued • Land claim or other agreement requires the Crown to exercise its obligations within a specified time frame (i.e. one-two years)
4. Consequence Costs	< $100,000	$100,000 - $500,00	$500,000 - $2.5 Million	$2.5 - $10Million	> $10 Million
5. Community Media Reputation	Local concerns, but no local complaints or adverse press coverage	Public concern restricted to local complaints or local adverse press coverage	Heightened Concern by local community, criticism by NGO's or adverse local/regional media attention	Significant adverse national public NGO or media attention	Serious public outcry/ demonstrations or adverse international NGO attention or media coverage
6. Human Health and Safety	Low-level short-term subjective symptoms/ No measurable physical effect/ No medical treatment	Objective but reversible disability/impairment and/or medical treatment injuries requiring hospitalization	Moderate irreversible disability or impairment to one or more people	Single fatality and/or severe irreversible or impairment to one or more people	Multiple fatalities

"Potential Consequences of Event" Categories
Type 3 – Intermediate Dam Failure
Overall Category - Critical

Consequences and Categories	Low	Minor	Moderate	Major	Critical
1. Environmental Impact	No Impact	Minor localized or short-term impacts	Significant impact on valued ecosystem component	Significant impact on valued ecosystem component and medium-term impairment of ecosystem function	Serious long-term impairment of ecosystem function
2. Special Considerations	Some disturbances but no impact to traditional land use	Minor or perceived impact to traditional land use	Some mitigable impact to traditional land use	Significant temporary impact on traditional land use	Significant permanent impact on traditional land use
3. Legal and Other Obligations	• No non Compliance but lack of conformance with departmental policy requirement • Informal advice from a regulatory agency • No land claim or other agreement	• Technical/Administrative non-compliance with permit, approval or regulatory requirement • Warning letter issued • Land claim or other agreement requires the Crown to satisfy administrative obligations (e.g. notification)	• Breach of regulations, permits, or approvals (e.g. one day violation of discharge limits) • Order or direction issued • Land claim or other agreement requires the Crown to respond, but no time frame is specified	• Substantive breach of regulations, permits or approvals (e.g. multi-day violation of discharge limits) • Prosecution • Land claim or other agreement requires the Crown to exercise its obligations within a specified time frame (i.e. two-five years)	• Major breach of regulation-wilfull violation • Court order issued • Land claim or other agreement requires the Crown to exercise its obligations within a specified time frame (i.e. one-two years)
4. Consequence Costs	< $100,000	$100,000 - $500,00	$500,000 - $2.5 Million	$2.5 - $10Million	> $10 Million
5. Community Media Reputation	Local concerns, but no local complaints or adverse press coverage	Public concern restricted to local complaints or local adverse press coverage	Heightened Concern by local community, criticism by NGO's or adverse local/regional media attention	Significant adverse national public NGO or media attention	Serious public outcry/ demonstrations or adverse international NGO attention or media coverage
6. Human Health and Safety	Low-level short-term subjective symptoms/ No measurable physical effect/ No medical treatment	Objective but reversible disability/impairment and/or medical treatment injuries requiring hospitalization	Moderate irreversible disability or impairment to one or more people	Single fatality and/or severe irreversible or impairment to one or more people	Multiple fatalities

2.7 Step 7 – Calculate the Probabilities of Failure

The risk analysis calculations for this pilot study were performed using DAMRAE. DAMRAE was developed for, and is used by, the USACE. It is also used by the Tennessee Valley Authority and by RAC during many other risk assessment projects.

2.8 Results of Risk Model

2.8.1 Risk Analysis Results

The Credible Potential Failure modes that are summarized in Tables 2-1, 2-2, and 2-3 for Alternatives 1, 2, and 3, respectively, were evaluated for the RCTA; those that were judged to be Credible and Significant were identified, and are summarized, in Table 2-7. These credible and significant failure modes for each alternative were included in the Risk Models (Event Trees) shown in Figures 2-2, 2-3, and 2-4.

TABLE 2-7
Credible and Significant Failure Modes
Faro Mine Remediation Project

Alternative 1:

- PFM1F-1 – Overtopping the RCD dyke, resulting in damage, the breaching of the tailings cover, and the release of tailings; more significantly, resulting in overtopping and breaching of the ID as a result of exceeding the ID spillway capacity.
- PFM1F-2 – Piping or slope stability failure of the RCD dyke, resulting in damage, the breaching of the tailings cover, and the release of tailings; more significantly, resulting in overtopping and breaching of the ID as a result of exceeding the ID spillway capacity.
- PFM1F-4 – Channel blockage by icings in RCD that blocks the channel resulting in the overtopping of the RCD dyke, and causing damage, the breaching of the tailings cover, and the release of tailings; more significantly, resulting in overtopping and breaching of the ID as a result of exceeding the ID spillway capacity
- PFM1F-9 – Channel blockage by woody debris, resulting in the overtopping of the RCD dyke, and causing damage, the breaching of the tailings cover, and the release of tailings; more significantly, resulting in overtopping and breaching of the ID as a result of exceeding the ID spillway capacity.

Alternative 2:

- PFM2F-4 – Piping or slope stability failure of the RCD dyke, causing flow releases into the side channel or onto the riprap apron or tailings cover downstream from the channel exit, resulting in damage and breaching of the tailings cover and release of tailings.
- PFM2F-10 – Channel blockage by woody debris, resulting in the overtopping of the RCD dyke, and causing damage, the breaching of the tailings cover, and the release of tailings.
- PFM2F-6 – Channel blockage by icings in RCD that blocks the channel resulting in the overtopping of the RCD dyke, and causing damage, the breaching of the tailings cover, and the release of tailings; more significantly, resulting in overtopping and breaching of the ID as a result of exceeding the ID spillway capacity.
- PFM2F-15 – Erosion and breaching of the tailings cover downstream from the side channel and riprap apron, prior to having a dissipating pool formed.

Alternative 3:

- PFM3F-1 – Overtopping the RCD dyke, causing release onto tailings cover, and resulting in damage, the breaching of the tailings cover, and the release of tailings.
- PFM3F-3 – Piping or slope stability failure of the RCD Dyke, causing releases onto tailings cover, and resulting in damage, the breaching of the tailings cover, and the release of tailings.
- PFM3F-5 – Channel blockage by icings in RCD that blocks the channel resulting in the overtopping of the RCD dyke, and causing damage, the breaching of the tailings cover, and the release of tailings; more significantly, resulting in overtopping and breaching of the ID as a result of exceeding the ID spillway capacity.
- PFM3F-9 – Channel blockage by woody debris, resulting in the overtopping of the RCD dyke, and causing damage, the breaching of the tailings cover, and the release of tailings.
- PFM3F-13 – Overbank flow occurs when exceeding the capacity of the dedicated 120-m-wide riprapped swale, and flow in preferred flow paths leading to channelization, erosion, and the eventual breaching of the tailings cover.

System response probabilities (SRPs) and loading probabilities were developed, as discussed in Section 2.5. For overtopping modes of failure, the SRP for each of the failure modes is shown as a function of either the flow rate (Q), or the relevant water surface elevation. Comparing system response probabilities between the existing case and the three alternatives shows the difference in the responses for each of the failure modes.

Note that whereas channel blockage by icing was considered initially as a significant failure mode, analysis results indicated that it has a very low likelihood and can therefore be considered as “not significant”. Consequently, this failure mode was not included in the larger Risk Model, but it is discussed in detail below.

The results of the risk assessment are summarized in Table 2-8. Three levels of failure consequences are shown in Table 2-8, T1, T2, and T3, as defined in Section 2.6.

Note in Table 2-8 that the plugging of the RCD and the plugging of the overflow (diversion) weir are listed as failure modes. The Risk Models (Event Trees) shown in Figures 2-2, 2-3, and 2-4 clearly show the role of these plugging failure modes, as well as how they contribute to the three levels of consequences. As shown in the Risk Models, plugging does not directly lead to a loss of tailings; rather, plugging can cause an increase in the level of the water surface in the RCD or increase the diversion into the covered tailings area, which in turn can lead to one of the direct failure modes of flow across the tailings, failure of the RCD dyke, or failure of the Intermediate Dam.

2.8.1.1 Probability of a Loss of Tailings and Consequence resulting from Icing in the RCD

The probability of icing blockage in the RCD can be evaluated using the Risk Models shown in Figures 2-2, 2-3, and 2-4 for the Existing Condition and for Alternatives 1, 2 and 3. As described in Section 2.6, three levels of Failure Categories were considered in describing the consequences of failure. These three category levels included:

T1 – Loss of tailings from flows passing over the covered tailings area
T2 – Loss of tailings from a catastrophic failure of the RCD
T3 – Loss of tailings from a catastrophic failure of the Intermediate Dam

As shown in the Event Trees referenced above the sequence of events (Branches on the Event Tree) that would lead to failure include:

- Level 1 – Probability of various flood levels
- Level 6 – Blockage of the RCD; in this case from icing
- Level 10 – Overtopping failure of the RCD
- Level 16 – Breach of the Intermediate Dam and catastrophic loss of tailings (T3 failure)
- Level 17 – Tailings Cover compromised and Loss of Tailings (T1 or T2 failure)

Level 1 Flood Loading

Veldman (2012) – see Appendix D - shows that the “April PMF” is about 60 m^3/sec, which is only 9% of the project PMF of 674 m^3/sec. The AEP of the “April PMF” is likely less than 1.0E-04 and possible as low as 1.0E-05.

TABLE 2-8
Summary of Risk Model Results
Faro Mine Remediation Project

Failure Mode	Annual Probability of Failure (APF) (/yr)	Annual Probability of Failure (APF) Percent of Total (%)	Reduction in Annual Probability of Failure (APF) (%)
[Existing Condition]			
Non-Breach	0.00E+00	0	0
Tailings Cover Compromised	0.00E+00	0	0
Intermed Dam Overtopping Breach	4.55E-03	99.52	0
Intermed Dam Instability	2.00E-05	0.44	0
Intermed Dam Piping	1.84E-06	0.04	0
TOTAL	**4.57E-03**	**100**	**0**
[Closure Alt 1]			
Non-Breach	0.00E+00	0	0
Tailings Cover Compromised	0.00E+00	0	0
Intermed Dam Overtopping Breach	2.00E-06	16.65	99.96
Intermed Dam Instability	1.00E-05	83.26	50
Intermed Dam Piping	1.00E-08	0.08	99.46
TOTAL	**1.20E-05**	**100**	**99.74**
[Closure Alt 2]			
Non-Breach	0.00E+00	0	0
Tailings Cover Compromised	2.31E-06	17.26	0
Intermed Dam Overtopping Breach	5.85E-08	0.44	100
Intermed Dam Instability	1.00E-05	74.82	50
Intermed Dam Piping	1.00E-06	7.48	45.65
TOTAL	**1.34E-05**	**100**	**99.71**
[Closure Alt 3]			
Non-Breach	0.00E+00	0.00%	0
Tailings Cover Compromised	7.51E-06	0.89%	
Tailings Cover Compromised from RCDC Failure	8.23E-04	97.79%	0
Intermed Dam Overtopping Breach	5.85E-08	0.01%	100
Intermed Dam Instability	1.00E-05	1.19%	50
Intermed Dam Piping	1.00E-06	0.12%	45.65
TOTAL	**8.42E-04**	**100.00%**	**81.59**

Level 6 Probability of Icing Blockage

Veldman (2012) further shows that with 9 metres of icing induced blockage in the RCDC for Alternative 1, the channel will still have enough flow capacity to pass 60 m^3/sec with 0.6 metres of freeboard. The depth of icing-induced blockage will be a function of winter temperatures. Based on 30 years of temperature data and observations of the operation of the RCDC there has been no incidents of extreme icing. With guidance from Veldman the Engineering team estimated that the probability of 9 metres of blockage from icing would be less than 0.01 in any given year. A greater depth of icing would have a lower probability of occurring.

Level 10 Overtopping Failure of the RCDC

The potential for an overtopping failure of the RCDC during the period of icing in the channel was discussed in the risk analysis session and it was concluded that it is very unlikely that overtopping of the RCD dyke during frozen conditions would result in a catastrophic failure of the dyke. Thus, flow onto the tailing would only be a small fraction of the flow in the channel with an April PMF of 60 m^3/sec. Furthermore, in the unlikely event that top down erosion of the dyke did occur, it would only be down to the top of the ice which would limit the size of the breach. The Engineering Team estimates that the conditional probability of failure from overtopping the RCDC would be very unlikely or about 0.01.

Level 16 Breach of the Intermediate Dam

The overtopping flow from the RCDC under "April PMF" conditions would likely be less than the 32 m^3/sec existing spillway capacity of the intermediate Dam spillway for the Existing condition and for alternative 1 and much less than the 539 m^3/sec capacity for Alternatives 2 and 3. Thus, the probability of failure of the Intermediate Dam and a resulting T3 level of failure during "April PMF" flows in the RCDC would be less than 0.001 and likely near zero.

Level 17 Tailings Cover Compromised

The frozen condition of the tailings cover during small overtopping flow over the tailings cover during an "April PMF" event would have a low probability of compromising the cover and result in loss of tailings. The engineering team estimated that the threshold flow required to cause a loss of tailings would likely be in the 25 to 50 m^3/sec range, and that the probability of compromising the cover and causing a loss of tailings would be less than 0.01 at a flow rate of 60 m^3/sec. Furthermore, the team estimated that in the very unlikely event of a breach of the RCDC the rather low flows would not result in a T2 failure conditions.

Annual Probability of a T1 loss of Tailings for Alternative 1

Assuming the extreme conditions described above, the annual probability of a T1 failure level would have an upper bound probability of failure of 1.0E-08. The probability of T2 and T3 failures would be even less.

Probability of T1 loss of Tailings for Alternatives 2 and 3

The annual probability of an icing induced T1 loss of Tailings for Alternatives 2 and 3 would be somewhat greater than for Alternative 1 because the channel has a smaller cross section. However, a two order increase in the annual probability of a T1 loss of tailings would still be less than 1.0E-06.

Conclusion

The Icing induced failure modes are not significant.

2.8.2 Discussion of Results (Probabilities of Failure)

Important observations can be made, using the results of the Risk Model, as summarized in Table 2-8.

- The total annual probability of a loss of tailings for each case:
  - Existing Case – 0.00457 (1 in 219)
  - Alternative 1 – 0.000012 (1 in 83,333)
  - Alternative 2 – 0.0000134 (1in74,627)
  - Alternative 3 – 0.000842 (1 in 1,188)
- The existing case is dominated by an overtopping failure of the Intermediate Dam, caused primarily by an overtopping failure of the RCDC. **The existing annual probability of failure is unacceptable.**
- Alternative 1 is dominated by an instability failure of the Intermediate Dam, which is not related to a failure of the RCDC Dyke. **Alternative 1 has the lowest annual probability of failure**.
- Alternative 2 is dominated by an instability breach of the Intermediate dam, which is not related to either flow across the covered tailings, or to a failure of the RCDC dyke. **The annual probability of failure is only slightly greater than for Alternative 1.**
- Alternative 3 is dominated by a failure of the RCDC dyke disrupting the tailings cover and resulting in a significant loss of tailings. Unlike Alternative 2, where the Side Channel has been designed to accommodate a failure of the RCDC dyke, the swale area in Alternative 3 would not be designed to accommodate a failure of

the RCDC dyke. This would result in a significant loss of tailings and an **unacceptable annual probability of failure**.

- By observing the annual probabilities of failure for each alternative the largest contributors to failure can be identified and appropriate design changes can be made to reduce the probability of failure.
- Sensitivity studies have been run on the effect of RCDC and overflow weir plugging on the resulting annual probabilities of failure.
- A sensitivity study has been run on the effect of the assigned AEP of the PMF on the annual probability of failure.

2.8.3 Risk Assessment

The risk was assessed in a somewhat qualitative manner, using a heat map, which is a matrix that considers likelihood of failure versus consequence severity. This system is in accordance with the risk register used by the Government of Yukon and the Canadian Government. The map was extended to include an “extremely unlikely” category.

Risk Assessment Classification
- “Likelihood of Occurrence” Categories (Extended)

Likelihood	Consequence Severity				
	Low	Minor	Moderate	Major	Critical
Almost Certain	M	MH	H	VH	VH
Likely	M	M	MH	H	VH
Possible	L	M	MH	H	H
Unlikely	L	L	M	MH	MH
Very Unlikely	L	L	L	M	MH
Extremely Unlikely	L	L	L	L	M

The likelihood of failure categories were determined from the probabilities of failure obtained from the risk model by using the following table:

"Likelihood of Occurrence" Categories (Extended)

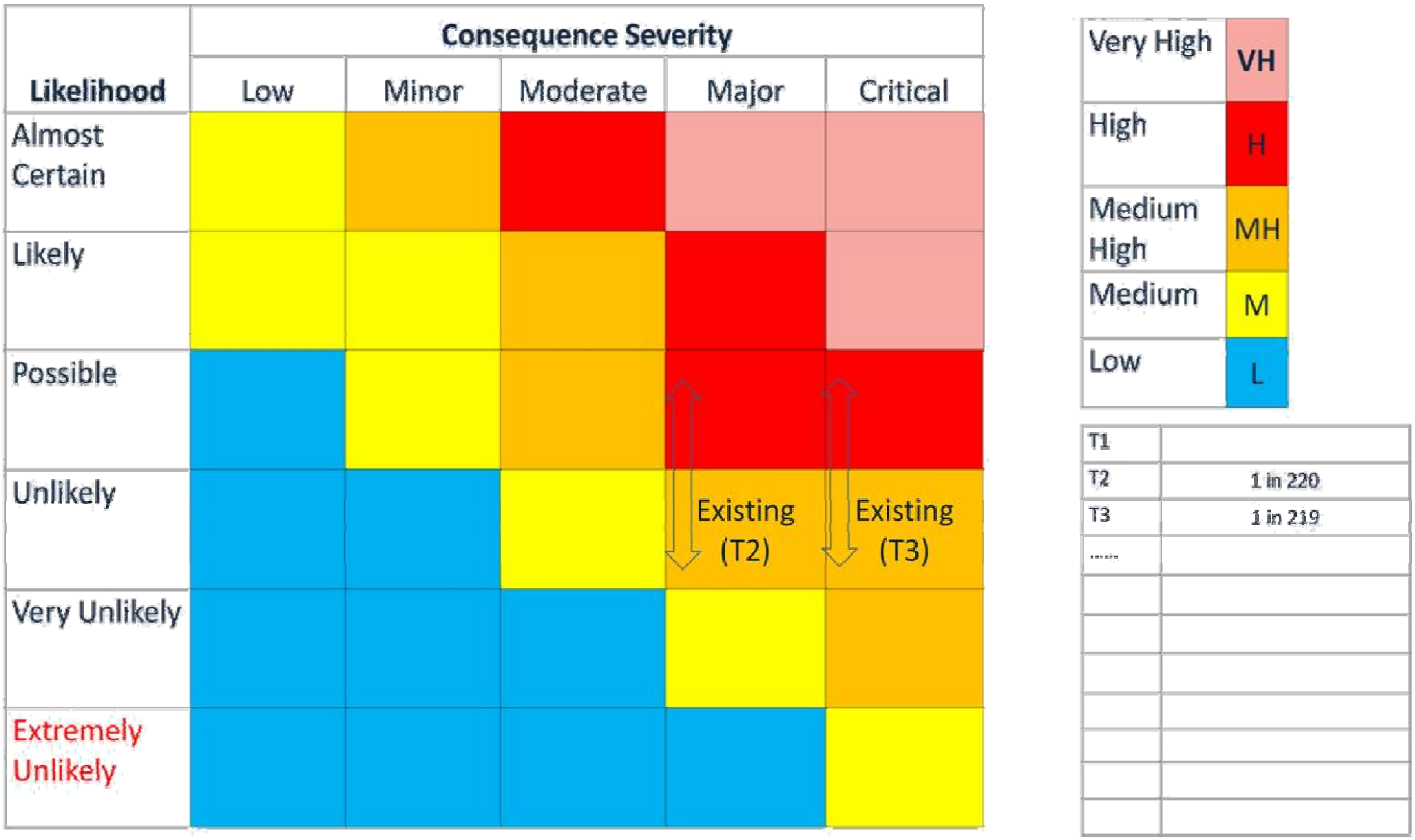
Assigned Likelihood	Descriptive	Health Events Only	Frequency
Almost Certain	Happens Often	1 case/100person-years	High frequency (more than once per year)
Likely	Could easily happen	1 case/1,000 person-years	Event does occur, has a history, once every 1-10 years
Possible	Could happen and has happened before	1 case/10,000 person-years	Occurs once every 10-100 yeas
Unlikely	Hasn't happened yet but could	1 case/ 100,000 person-years	Occurs once every 100-1,000 years
Very Unlikely	Conceivable, but only in extreme circumstances	1 case/1,000,000 person-years	Occurs once every 1,000-10,000 years
Extremely Unlikely			Occurs less than once every 10,000 years

The following pages of this report show the evaluation results for each for each of the four cases:

- Existing (baseline) Condition
- Alternative 1
- Alternative 2
- Alternative 3.

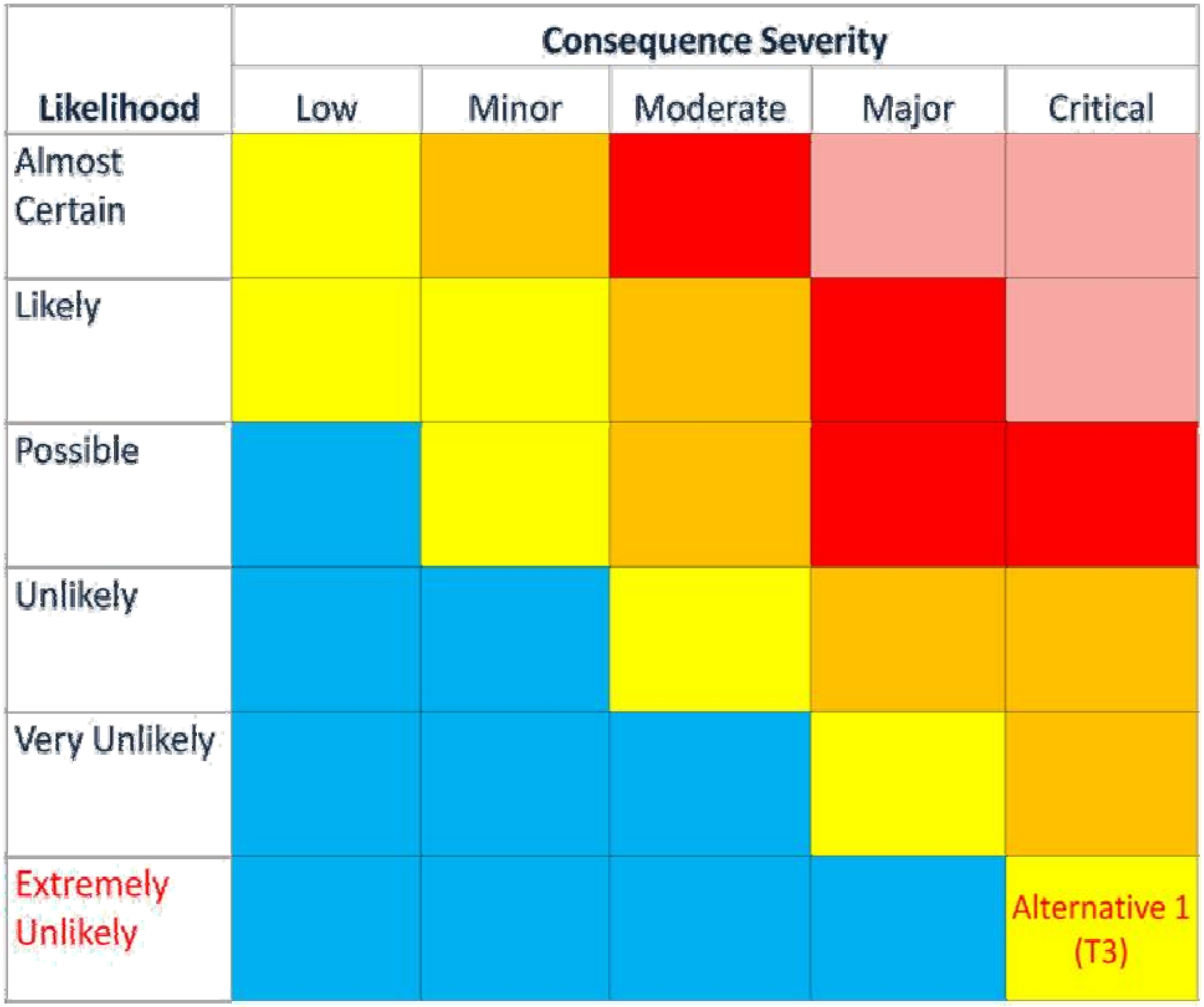
From the results, it is evident that the risk for the existing condition is unacceptable with medium-high to high risk. The risk for Alternatives 2 and 3 is medium, whereas the risk for Alternative 3 is medium to medium-high.

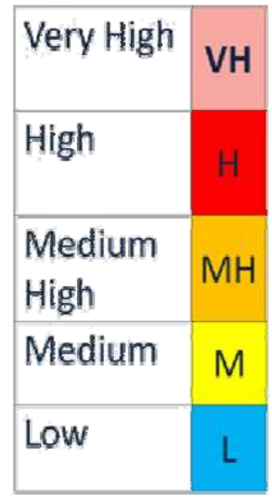
Risk Assessment Classification
Existing



Risk Assessment Classification

Alternative 1





T1	
T2	
T3	1 in 83,000
……	

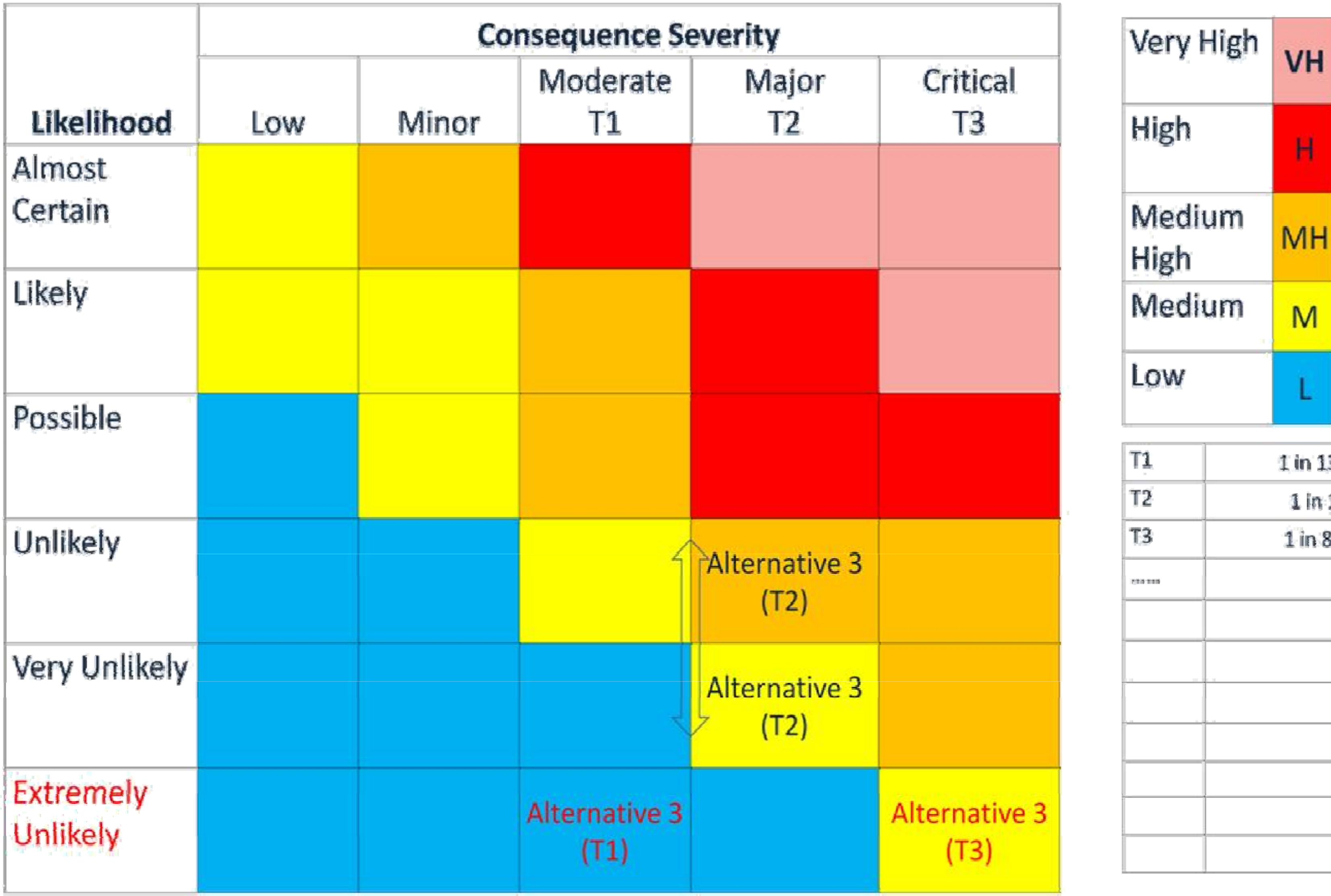
Risk Assessment Classification
Alternative #2

Likelihood	Consequence Severity				
	Low	Minor	Moderate	Major	Critical
Almost Certain					
Likely					
Possible					
Unlikely					
Very Unlikely					
Extremely Unlikely			Alternative 2 (T1)		Alternative 2 (T2)

Very High	VH
High	H
Medium High	MH
Medium	M
Low	L

T1	1 in 433,000
T2	
T3	1 in 90,000
......	

Risk Assessment Classification
Alternative #3



T1	1 in 133,000
T2	1 in 1,200
T3	1 in 87,000
......	

SECTION 3

Construction Cost Estimate

The costs opinions shown for the three alternatives for the RCTA are based on a Class 5 Estimate, a Rough Order of Magnitude (ROM). This type of estimate is primarily used as a concept screening tool. The expected accuracy is a low (– 50 %) to a high (+100 %). These estimates are based on very limited information and, consequently, have very wide accuracy ranges.

In this case, limited information is available about the tailings' thickness where the new channels will be constructed, so the foundations may require extensive work to provide the necessary support for the structures. In addition, we have not located a specific source for the riprap, bedding, dam filter, and till material. The assumption used in the estimate was that the material is available onsite, that it would require some development cost, and that the haul distance from the source to the process plant was no more than 10 km. It was also assumed that adequate construction water was available in sufficient quantities and that this could be obtained relatively close to the work.

There are no specifications at this time, and all drawings and elevations are preliminary. The quantities used in the cost calculations are also preliminary.

All costs are in 2012 Canadian dollars. No royalty costs, if any, permit costs, if any and no taxes, if any are included in this cost opinion.

The cost estimates do not include all elements of the work; Table 3-1 provides a listing of most of the RCTA project elements, and indication of whether a component was included in the estimate. The elements that were not included in the comparative cost estimate are considered to be the same for the three alternatives.

TABLE 3-1
RCTA Project Elements Included in the Construction Cost Estimate
Faro Mine Remediation Project

RCTA Project Elements	Included in Construction Cost Estimate?	Comments
Cross Valley Dam (removed)	No	
Cross Valley Pond (cleaned-up)	No	
Cross Valley Spillway (removed)	No	
Intermediate Dam (raised and incorporating filter/drains)	*Yes*	*Dam is raised for Alternatives 2 and 3.* *No raise for Alternative 1, but cost for filters/drains on lower downstream slope was included.* *Riprap on the upstream slope not included and assumed to be common to all three alternatives.*
Intermediate Dam Pond (modified)	*Yes*	*Pond will be filled in with tailings for all three alternatives and covered similar than for rest of intermediate tailings area. The cost estimate includes material quantities, but it does not include special construction cost for difficulty of working in pond area and dewatering costs.*
Intermediate Dam Spillway (upgraded for PMF flows)	*Yes*	
Intermediate Tailings (re-graded, covered and re-vegetated)	*Yes*	*Cost for re-grading and tailings cover is included for each of the alternatives but cost for re-vegetation is not included.*

TABLE 3-1
RCTA Project Elements Included in the Construction Cost Estimate
Faro Mine Remediation Project

RCTA Project Elements	Included in Construction Cost Estimate?	Comments
Intermediate Tailings Erosion Dissipation Measures	*Yes*	*Side Channel for Alternative 2 and Single, Dedicated Channel for Alternative 3. Not applicable for Alternative 1.*
Seepage collection structures upstream and downstream of Intermediate Dam	No	
Downstream Cut-off Wall	No	Downstream of Cross Valley Dam
Deep Seepage Interceptor System (Trench)	No	Downstream of Cross Valley Dam
Overflow (diversion) weir	*Yes*	*Included for Alternatives 2 and 3, but not applicable for Alternative 1*
Original Tailings (re-graded, covered and re-vegetated)	No	
Pumphouse Dam (not maintained)	No	
Rose Creek Diversion Channel (upgraded for PMF upstream of the Overflow Weir)	No	
Rose Creek Diversion Channel (upgraded for 500 year flood downstream of the Overflow Weir)	No	Alternatives 2 and 3
Rose Creek Diversion Channel Drop Structures (upgraded)	No	
Rose Creek Downstream of Tailings Area (ultimate receiving environment)	No	
Secondary Dam (liquefaction mitigation measures at East Limb)	No	
Secondary Dam (liquefaction mitigation measures at West Limb)	No	
Secondary Tailings (re-graded, covered and re-vegetated)	No	

A summary of the cost estimates is given in Table 3-2.

TABLE 3-2
Summary of Construction Cost Estimates
Faro Mine Remediation Project

Alternative	Estimated Construction Cost
1	$125.0 million
2	$145.7 million
3	$139.3 million

Given the accuracy ranges for Class 5 cost estimates (100%/-50%), or even if this estimate was optimistically considered a Class 4 estimate with an expected accuracy of a low (– 30 %) to a high (+50 %), it is evident that there is significant range in cost overlap for the three alternatives as depicted in Figure 3.3. For all practical considerations, the three alternatives can be considered to have similar construction cost. It would not be possible to select any of these alternatives purely based on the costs presented here; other considerations will determine the selection.

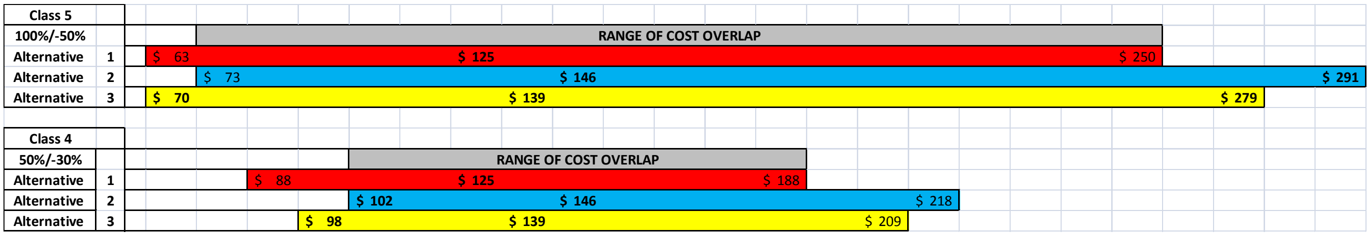


FIGURE 3-1
Range of Estimated Construction Cost Overlap
Faro Mine Remediation Project

SECTION 4

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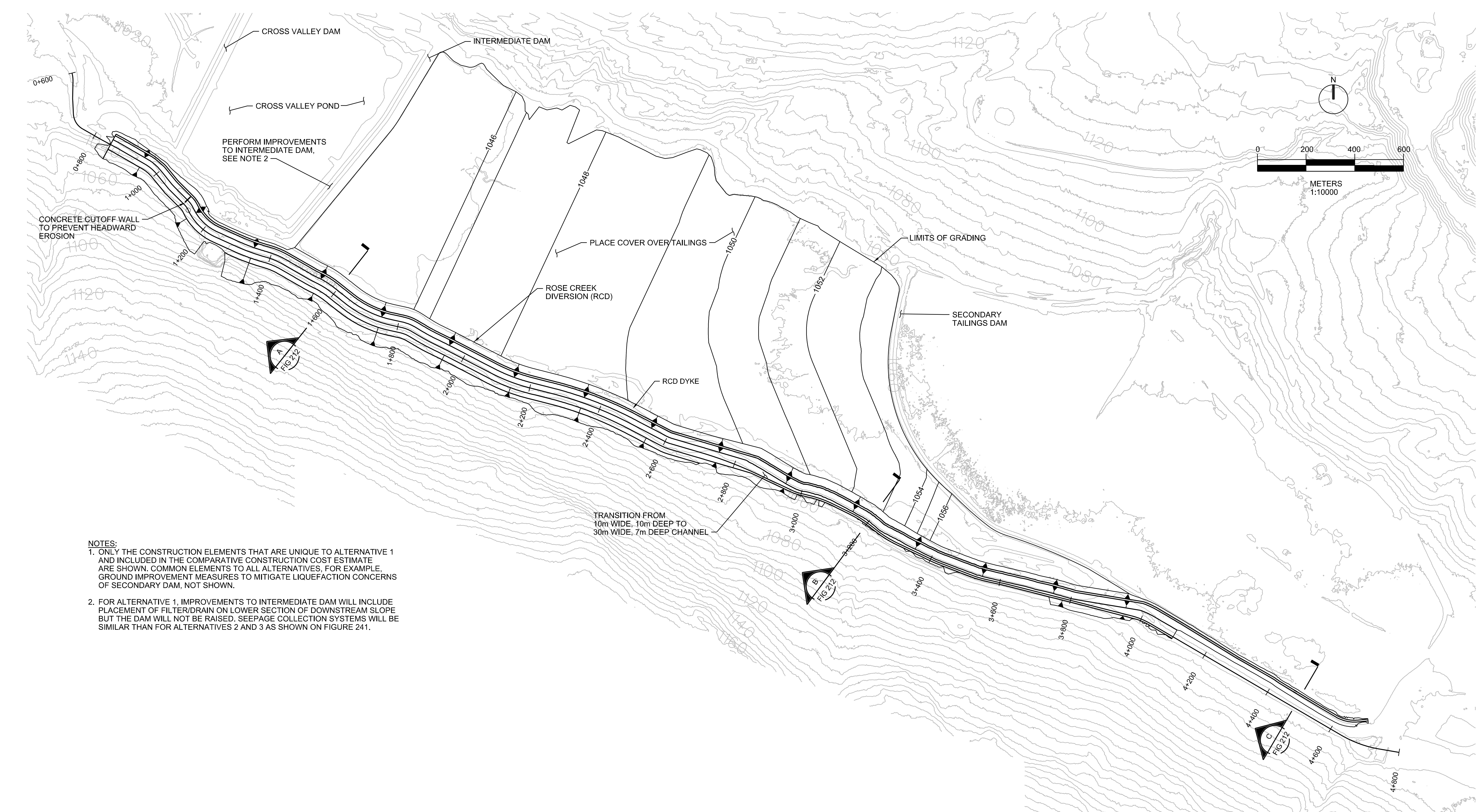
Appendix A
RCTA Alternatives Concept Drawings

PLOT TIME:

2012\08\23

200_FIGURE210.dgn



NOTES:

1. ONLY THE CONSTRUCTION ELEMENTS THAT ARE UNIQUE TO ALTERNATIVE 1 AND INCLUDED IN THE COMPARATIVE CONSTRUCTION COST ESTIMATE ARE SHOWN. COMMON ELEMENTS TO ALL ALTERNATIVES, FOR EXAMPLE, GROUND IMPROVEMENT MEASURES TO MITIGATE LIQUEFACTION CONCERNS OF SECONDARY DAM, NOT SHOWN.

2. FOR ALTERNATIVE 1, IMPROVEMENTS TO INTERMEDIATE DAM WILL INCLUDE PLACEMENT OF FILTER/DRAIN ON LOWER SECTION OF DOWNSTREAM SLOPE BUT THE DAM WILL NOT BE RAISED. SEEPAGE COLLECTION SYSTEMS WILL BE SIMILAR THAN FOR ALTERNATIVES 2 AND 3 AS SHOWN ON FIGURE 241.

FIGURE 210
ROSE CREEK TAILINGS AREA
ALTERNATIVE 1
CHANNEL GRADING PLAN

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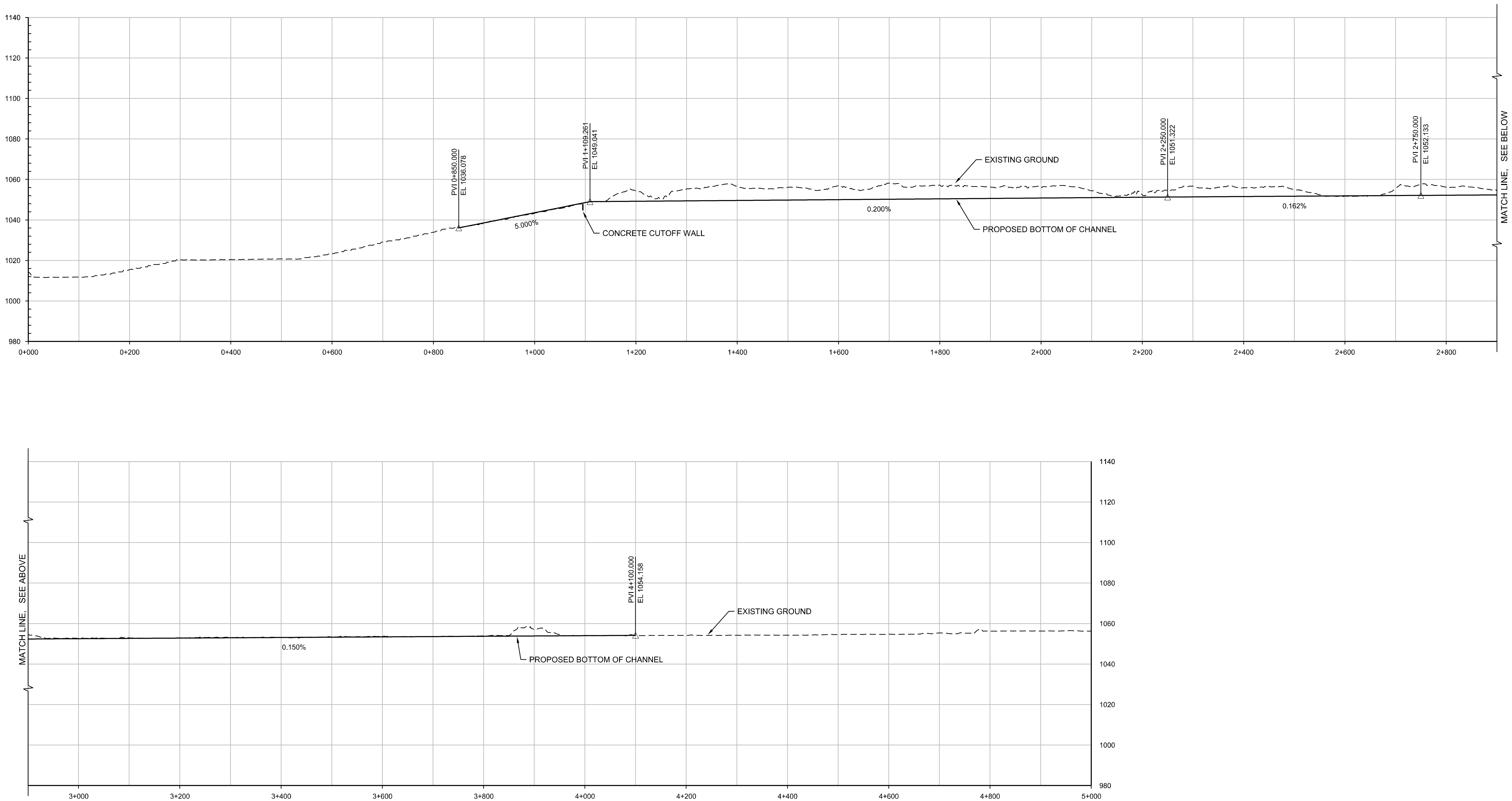


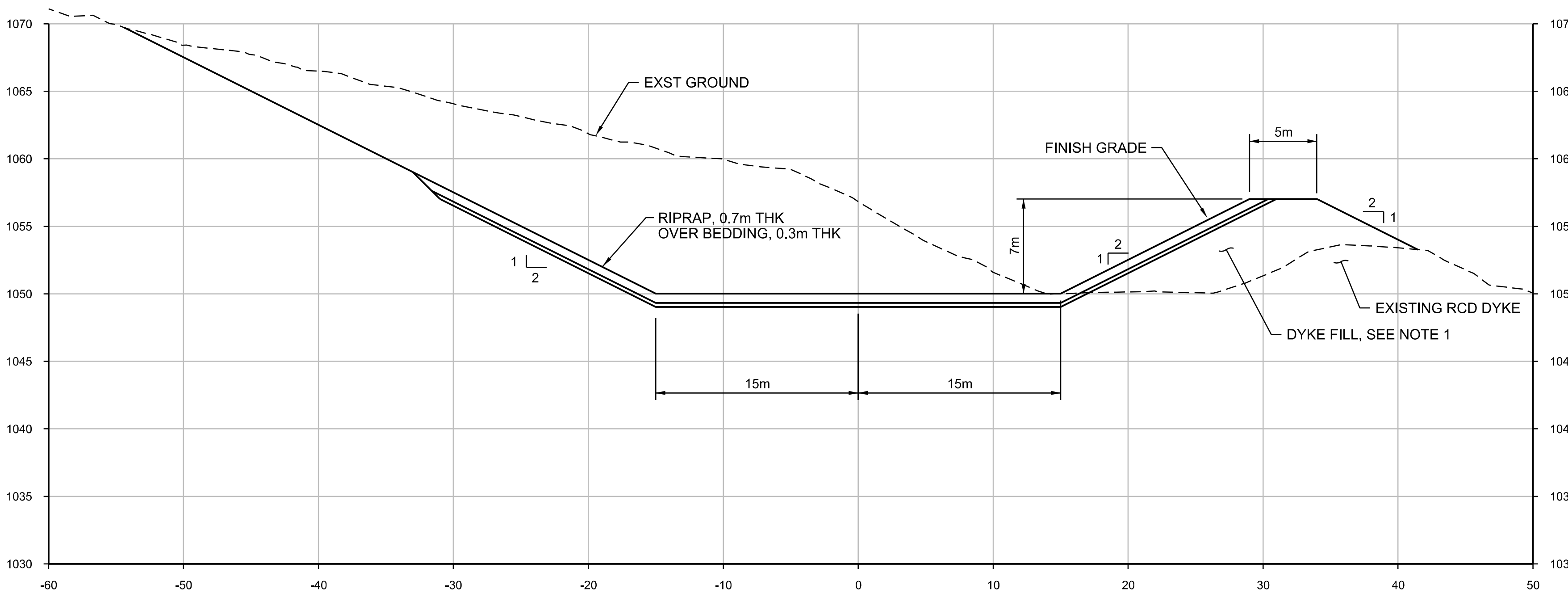
PROFILE ALONG CENTERLINE OF DIVERSION

HORIZ: 1:8000
VERT: 1:2000

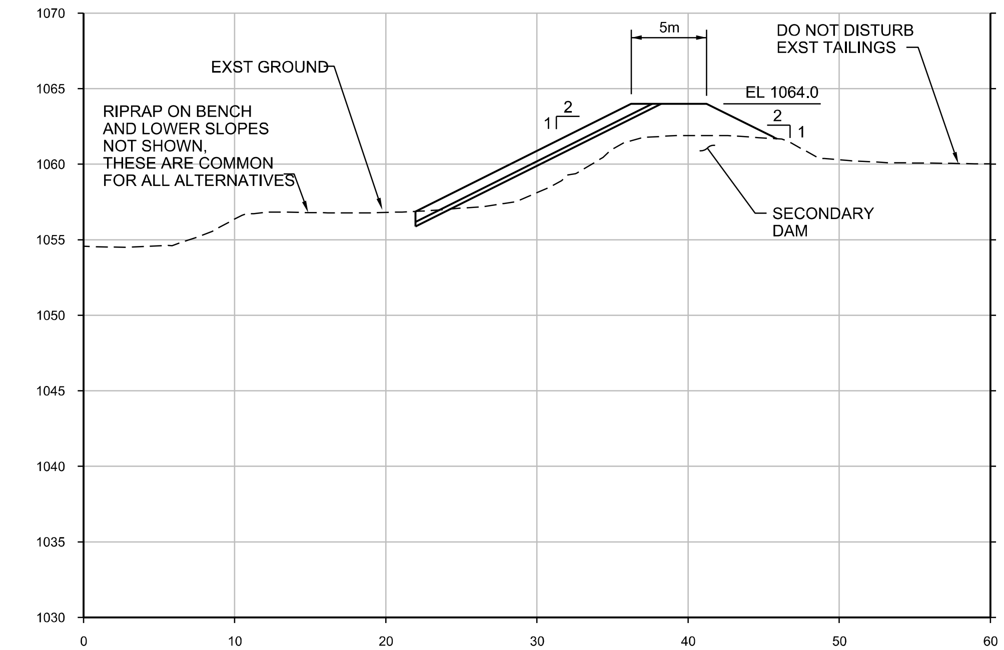
FIGURE 211
ROSE CREEK TAILINGS AREA
ALTERNATIVE 1
DIVERSION PROFILE

CH2MHILL®

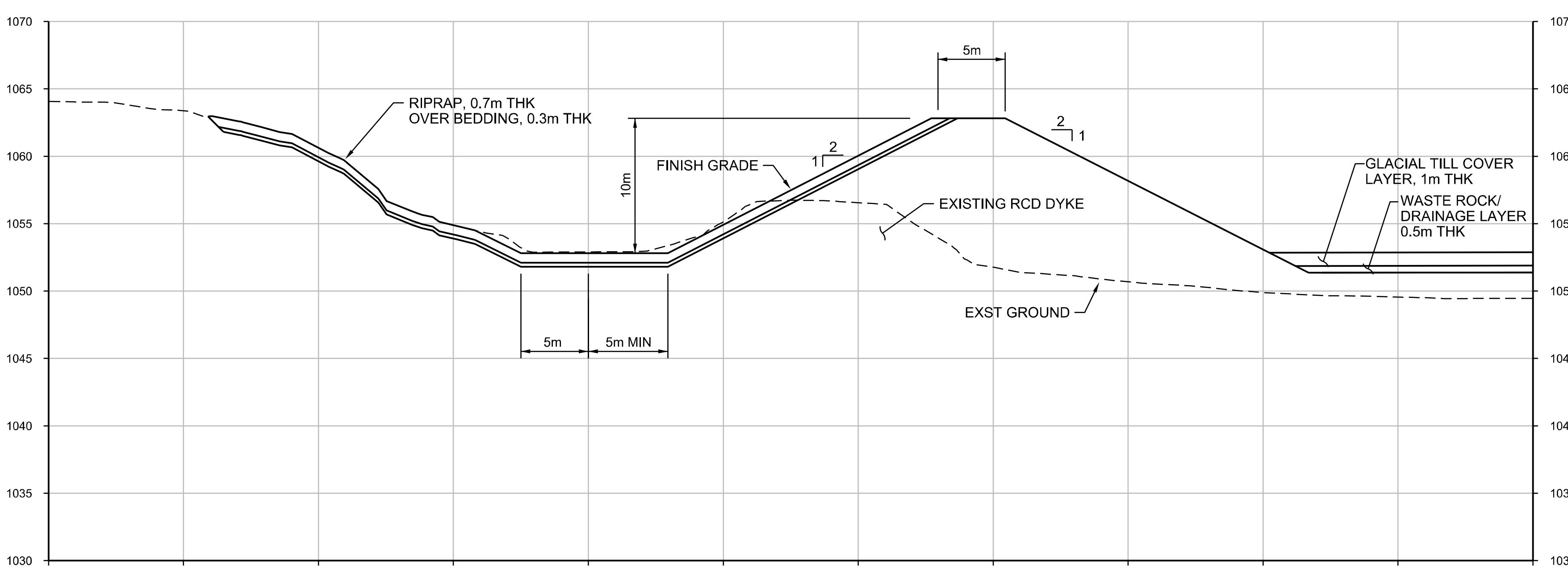
200_FIGURE211.dgn 2012\08\23 PLOT TIME: 8:37:57 AM



A SECTION
1:500
FIG 210



C SECTION
1:500
FIG 210



B SECTION
1:500
FIG 210

NOTES:

1. A CORE OR BLANKET CONSTRUCTED OF LOW PERMEABILITY MATERIAL IS NOT SHOWN, BUT WILL BE INCORPORATED IN THE DYKE. IN ADDITION, FILTERS/ DRAINS ARE NOT SHOWN BUT WILL BE INCORPORATED IN THE DYKE, AND ARE INCLUDED IN THE CONSTRUCTION COST ESTIMATE.

FIGURE 212
ROSE CREEK TAILINGS AREA
ALTERNATIVE 1
CHANNEL SECTIONS

CH2MHILL®

PLOT TIME: 10:13:14 AM 2012\08\23 200_FIGURE220.dgn

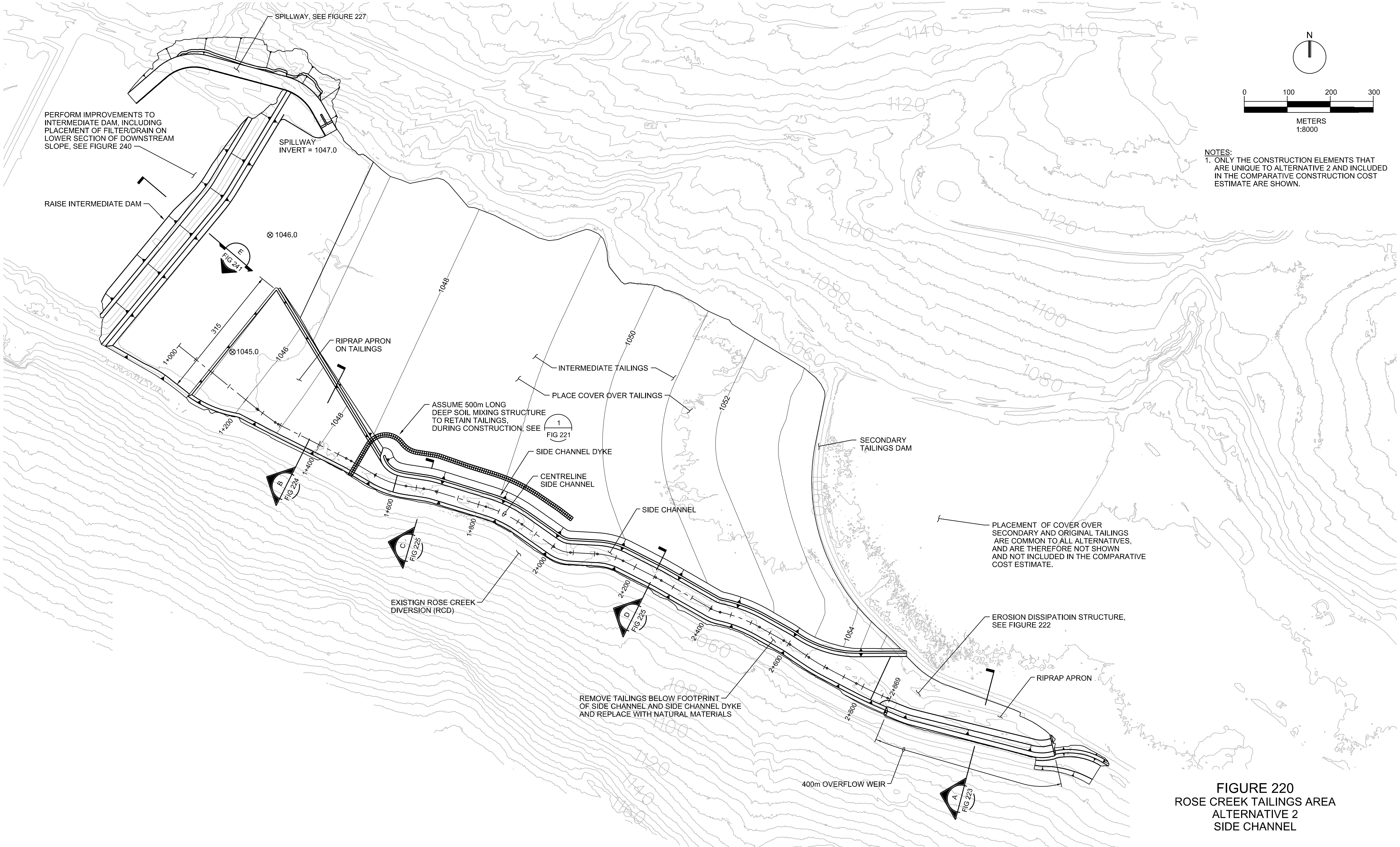
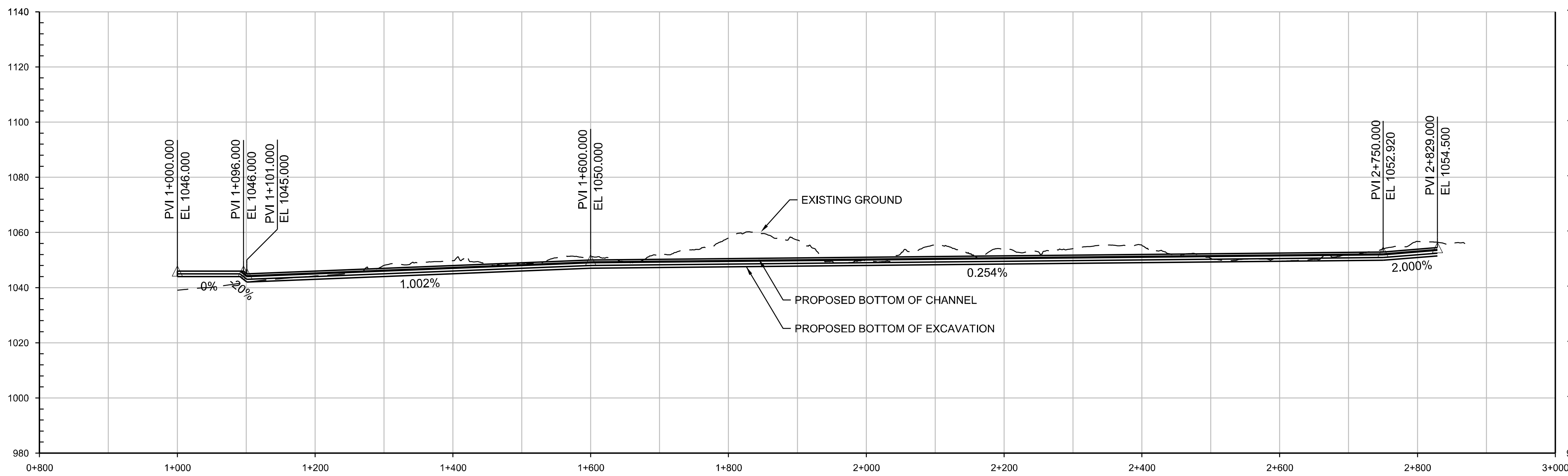


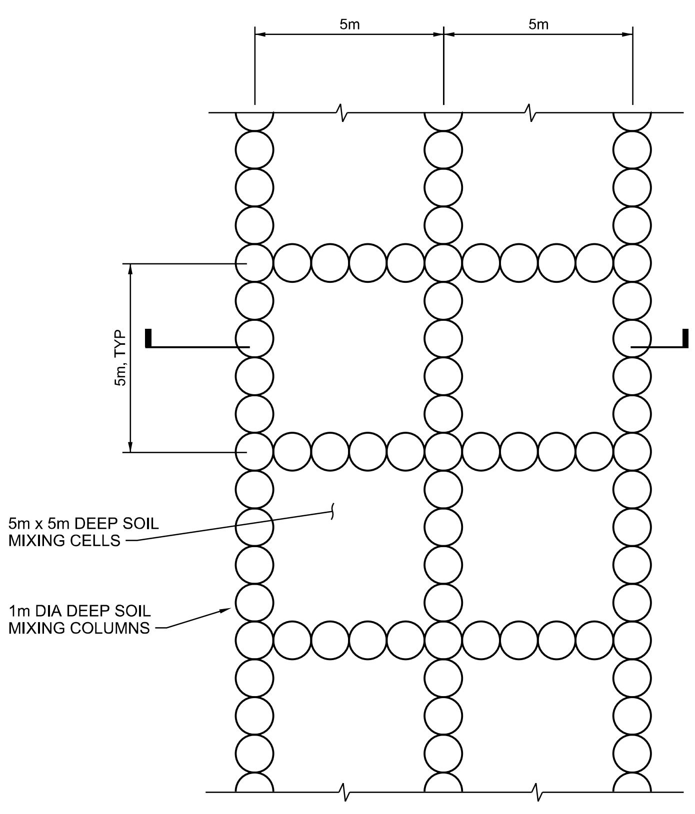
FIGURE 220
ROSE CREEK TAILINGS AREA
ALTERNATIVE 2
SIDE CHANNEL

CH2MHILL®

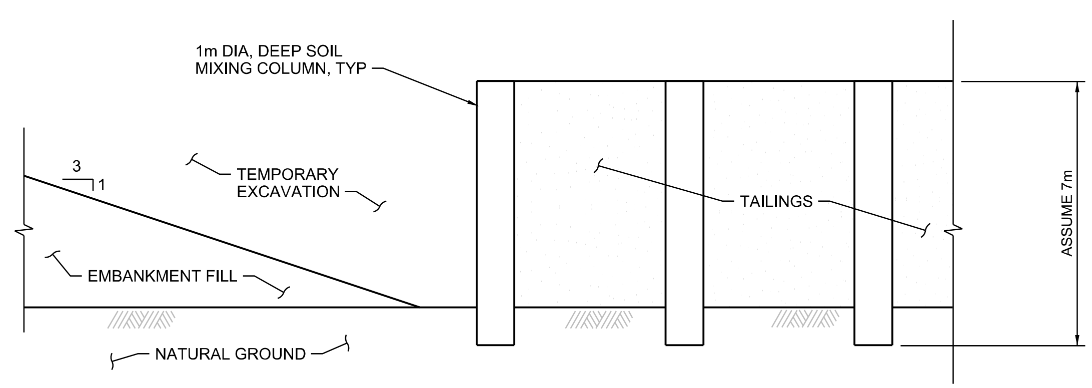


PROFILE ALONG CENTERLINE OF DIVERSION SIDE CHANNEL

HORIZ: 1:8000
VERT: 1:2000



PLAN



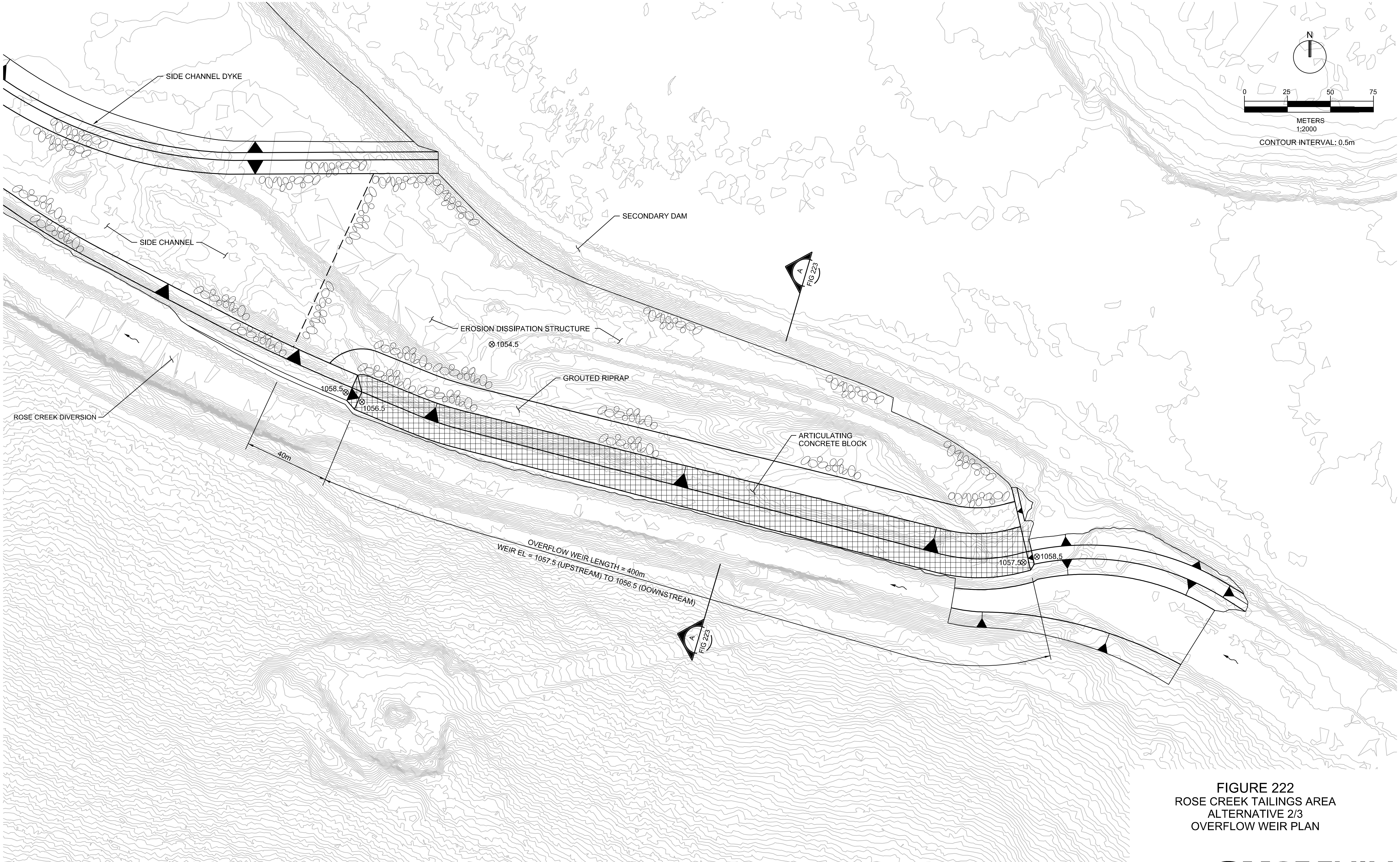
SECTION

1 DETAIL
NTS
FIG 220

FIGURE 221
ROSE CREEK TAILINGS AREA
ALTERNATIVE 2
CHANNEL PROFILE

CH2MHILL®

200_FIGURE221.dgn 2012\08\23 PLOT TIME:



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200_FIGURE222.dgn

FIGURE 222
ROSE CREEK TAILINGS AREA
ALTERNATIVE 2/3
OVERFLOW WEIR PLAN

CH2MHILL®

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2012\08\23

200_FIGURE223.dgn

NOTES:
1. THE CONCEPTS SHOWN ARE PRELIMINARY AND TO PROVIDE CONSERVATIVE COST ESTIMATES. TO REPLACE ARTICULATING CONCRETE BLOCKS WITH MORE NATURAL MATERIALS SUCH AS LARGE RIPRAP WILL BE CONSIDERED.

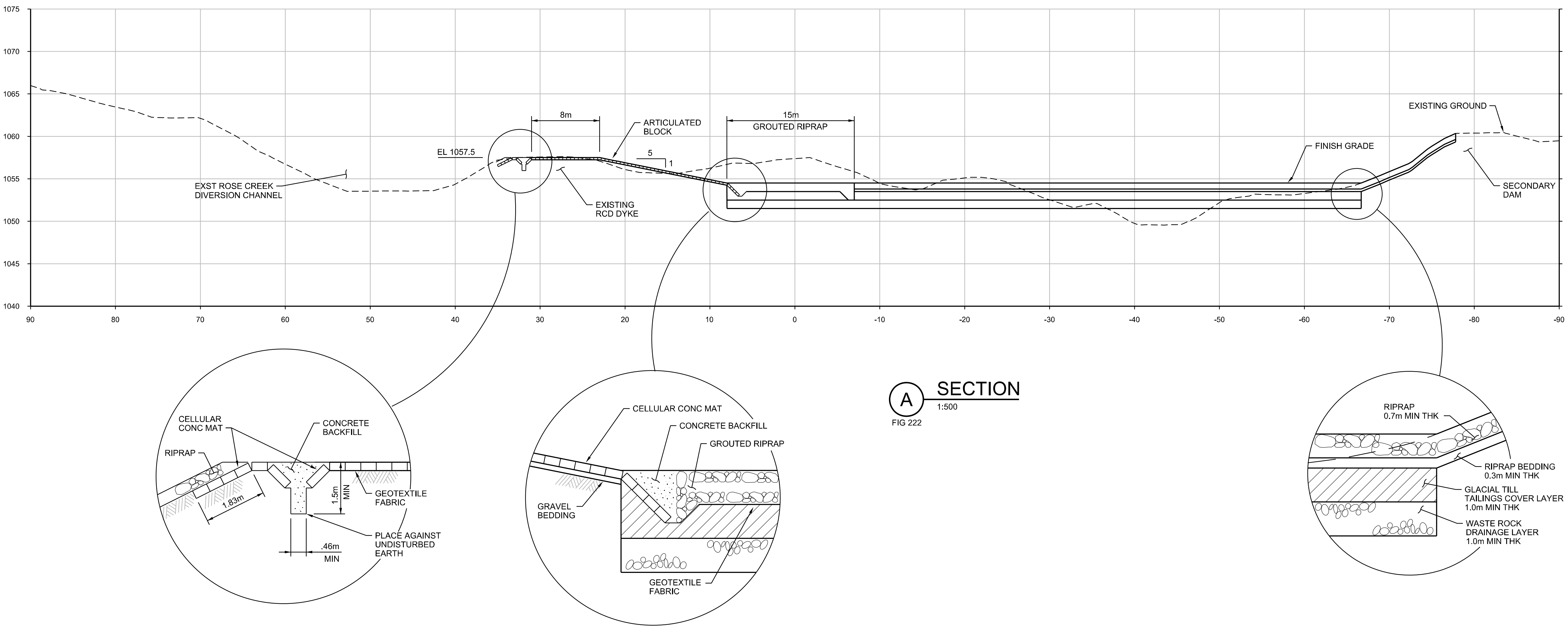

FIGURE 223
ROSE CREEK TAILINGS AREA
ALTERNATIVE 2/3
SECTION A

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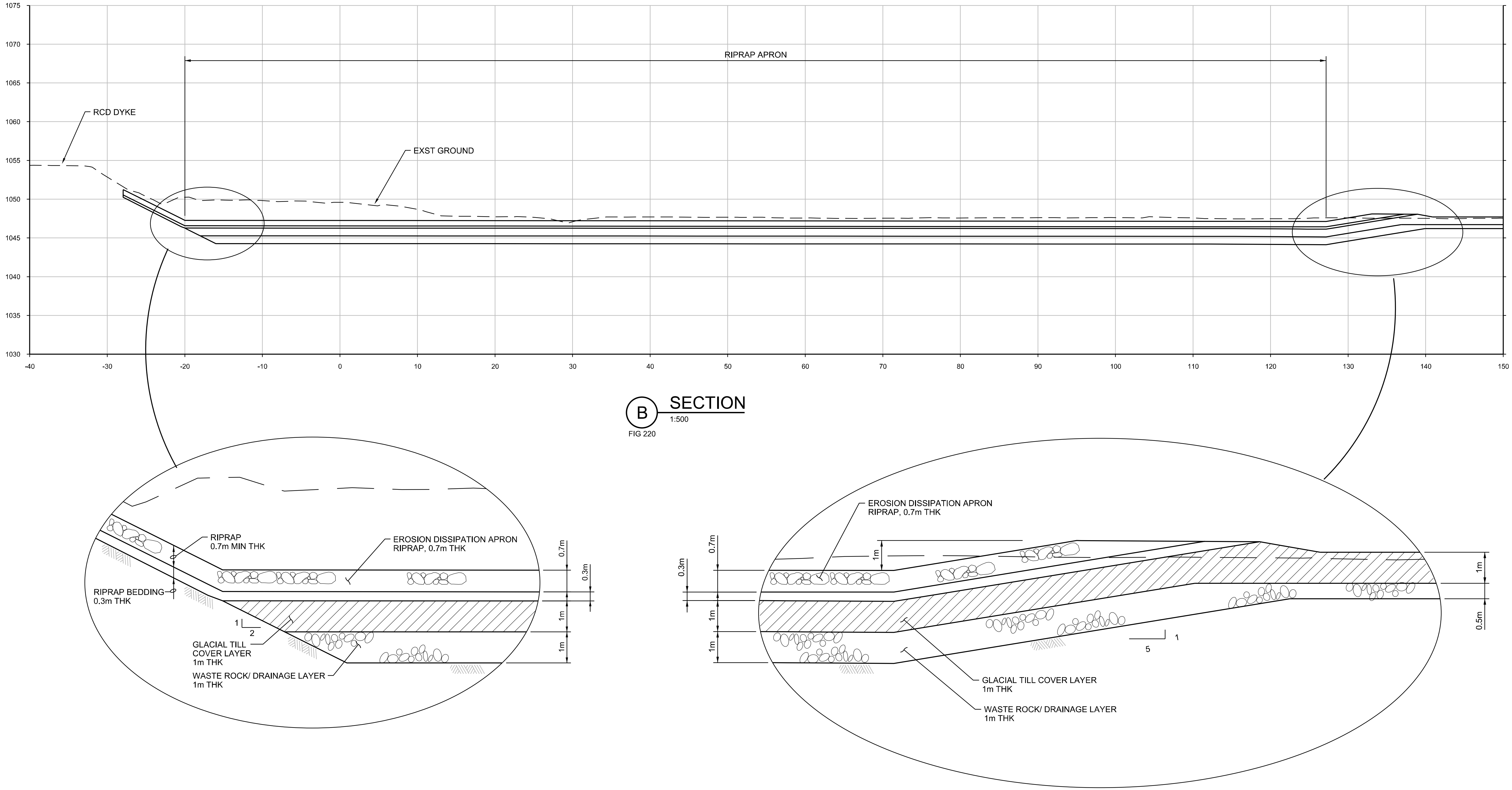

B SECTION
1:500
FIG 220

FIGURE 224
ROSE CREEK TAILINGS AREA
ALTERNATIVE 2
SECTION B

CH2MHILL®

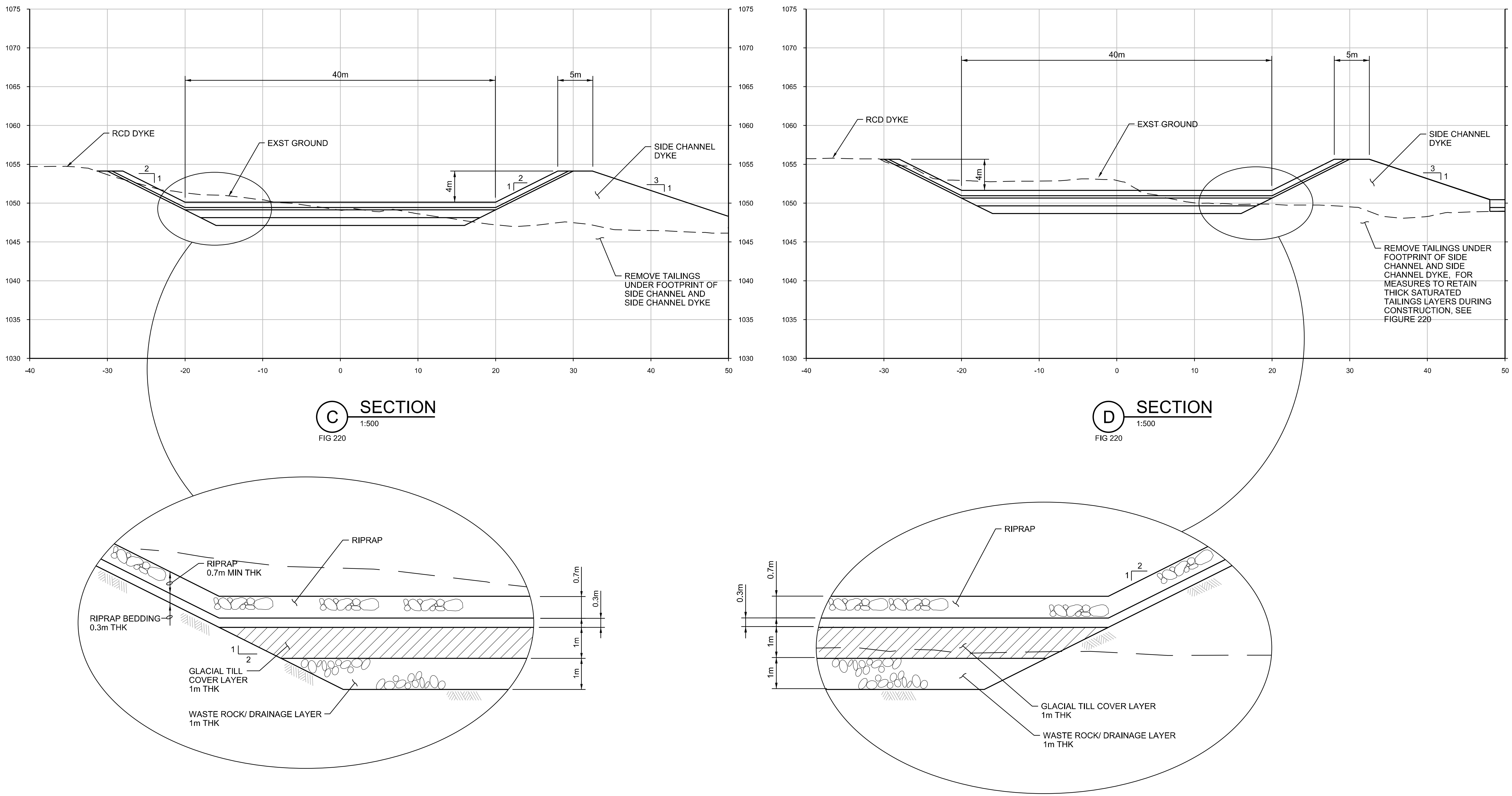

FIGURE 225
ROSE CREEK TAILINGS AREA
ALTERNATIVE 2
SECTIONS C & D

CH2MHILL®

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2012\08\23
200_FIGURE225.dgn

200_FIGURE227.dgn 2012\08\23 PLOT TIME: 11:49:30 AM

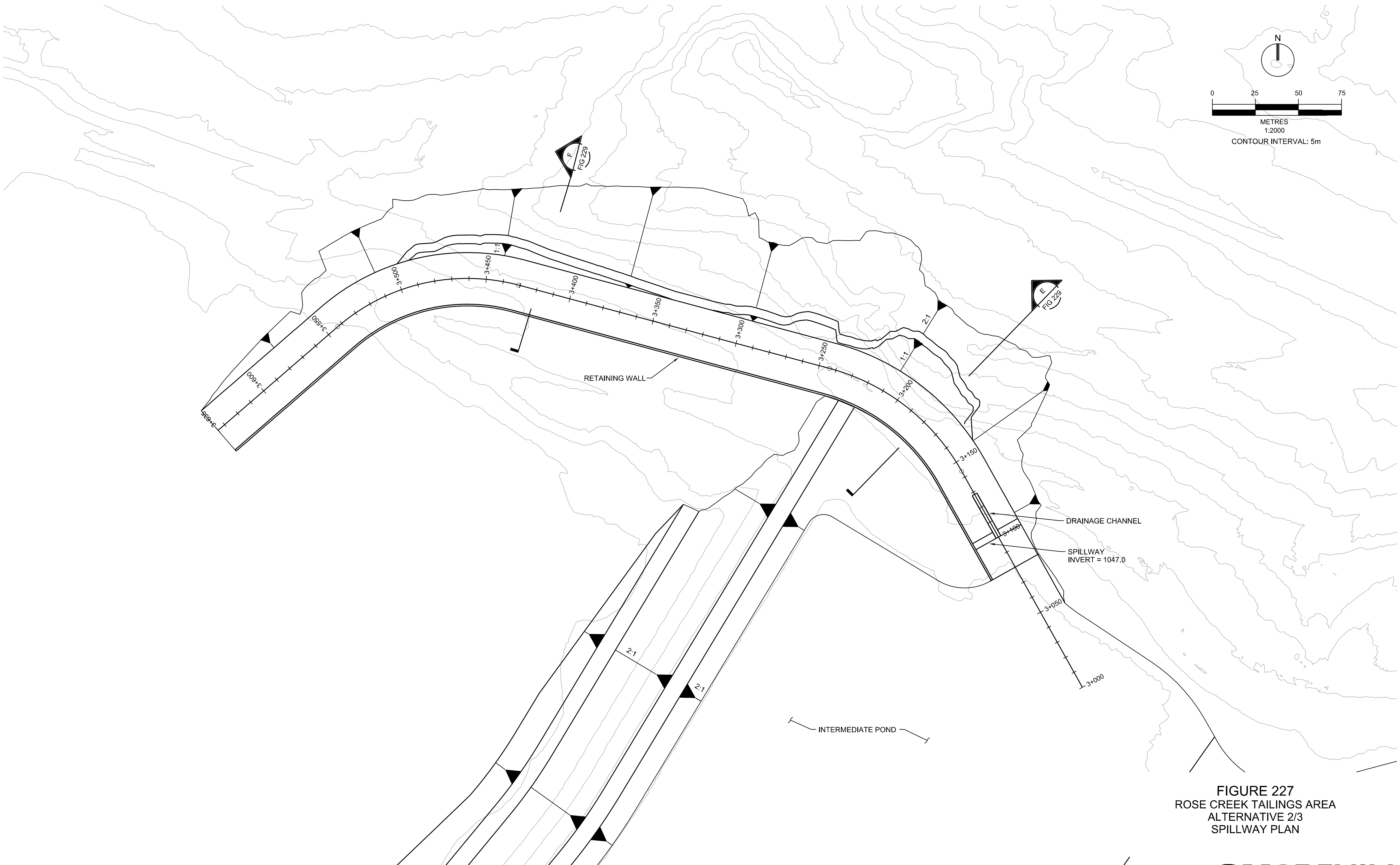
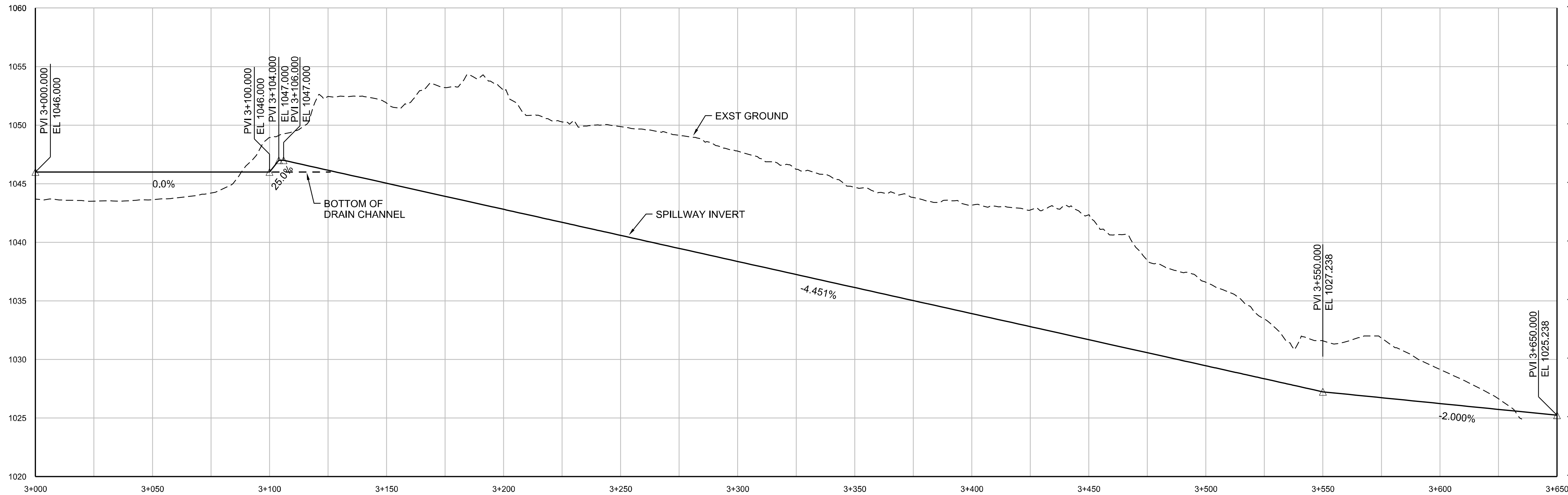


FIGURE 227
ROSE CREEK TAILINGS AREA
ALTERNATIVE 2/3
SPILLWAY PLAN

CH2MHILL

200_FIGURE228.dgn 2012\08\23 PLOT TIME: 11:53:40 AM



SPILLWAY PROFILE

HORIZ: 1:2000
VERT: 1:400

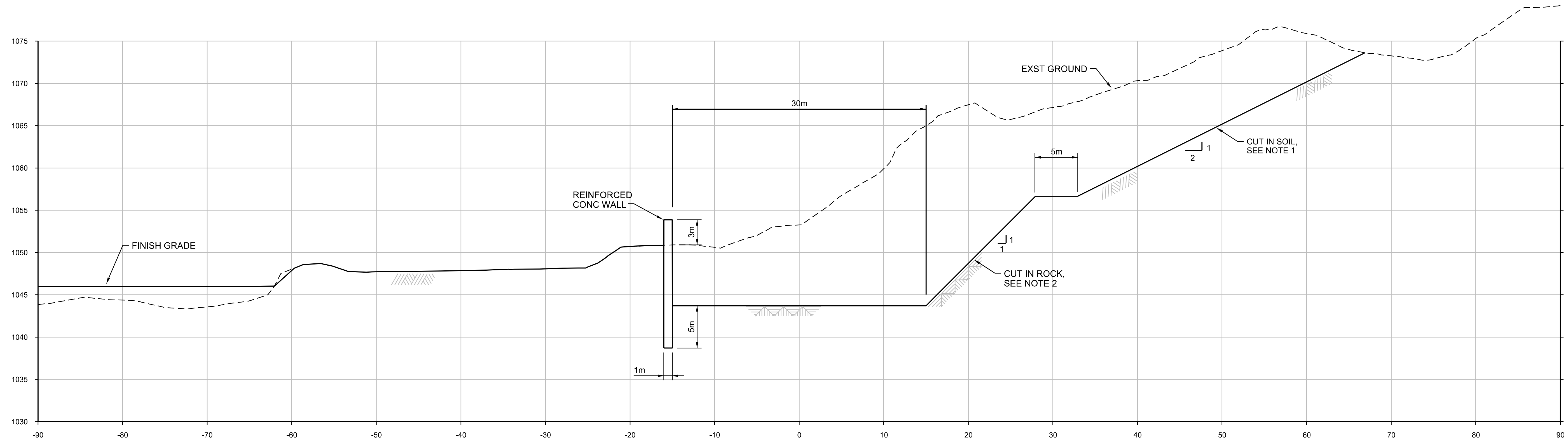
FIGURE 228
ROSE CREEK TAILINGS AREA
ALTERNATIVE 2/3
SPILLLWAY CENTERLINE PROFILE

CH2MHILL®

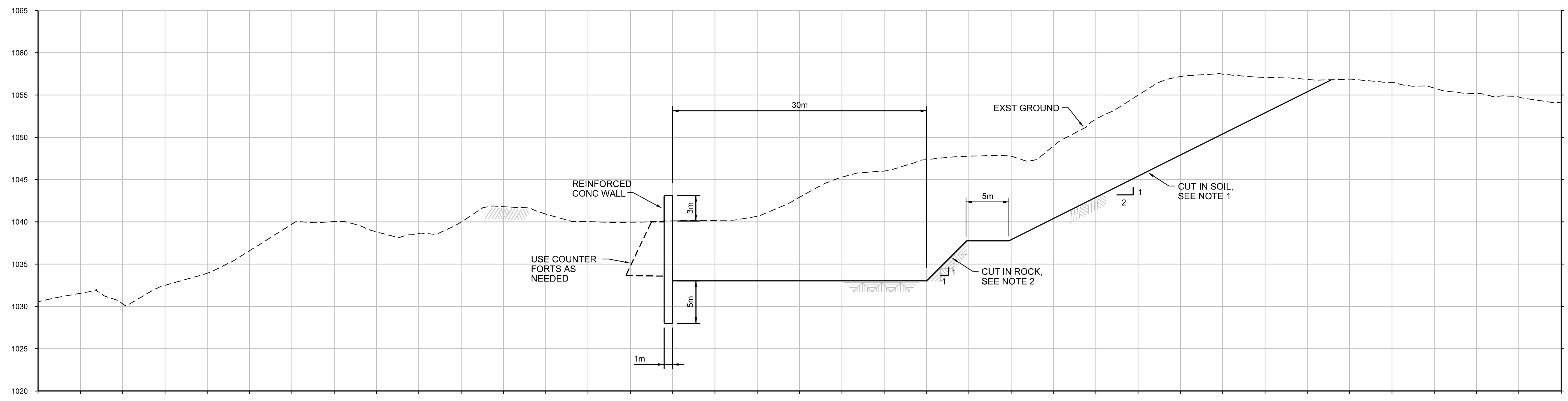
PLOT TIME: 11:58:19 AM

2012\08\23

200_FIGURE229.dgn



E SECTION
1:500
FIG 227



F SECTION
1:500
FIG 227

NOTES:

1. EXCAVATE SOIL AND WEATHERED ROCK AND REPLACE WITH DENTAL CONCRETE.
2. REINFORCE WITH SHOTCRETE, DENTAL CONCRETE AND ROCK BOLTS AS NEEDED.
3. THE CONCEPTS SHOWN ARE PRELIMINARY. AN ALTERNATIVE CONCEPT IS TO USE A LARGER AND DEEPER EXCAVATION INTO THE SIDE HILL INSTEAD OF THE REINFORCED CONCRETE WALL.

FIGURE 229
ROSE CREEK TAILINGS AREA
ALTERNATIVE 2/3
SPILLWAY SECTIONS E AND F

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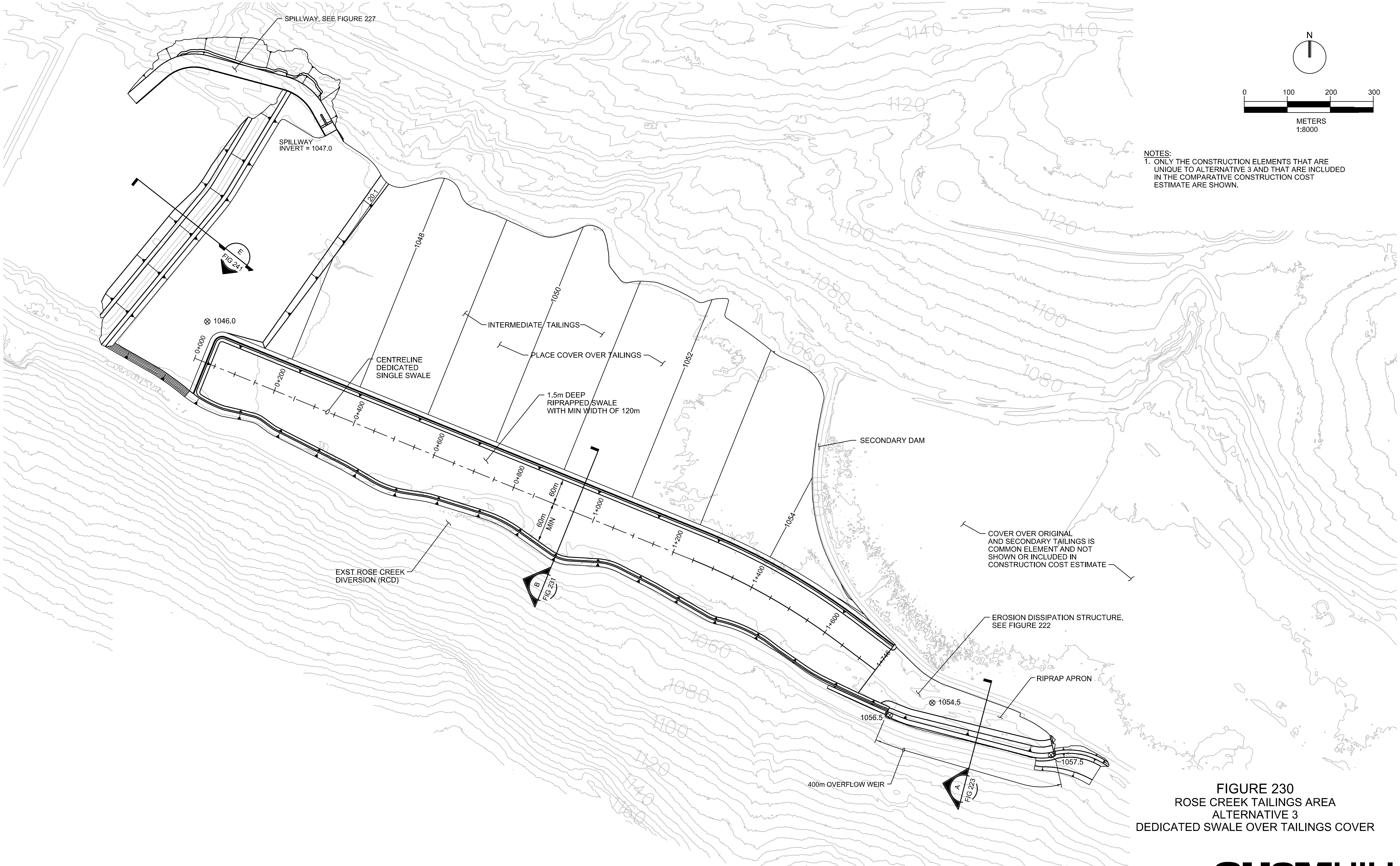
2012\08\23

200_FIGURE230.dgn



NOTES:
1. ONLY THE CONSTRUCTION ELEMENTS THAT ARE UNIQUE TO ALTERNATIVE 3 AND THAT ARE INCLUDED IN THE COMPARATIVE CONSTRUCTION COST ESTIMATE ARE SHOWN.

FIGURE 230
ROSE CREEK TAILINGS AREA
ALTERNATIVE 3
DEDICATED SWALE OVER TAILINGS COVER

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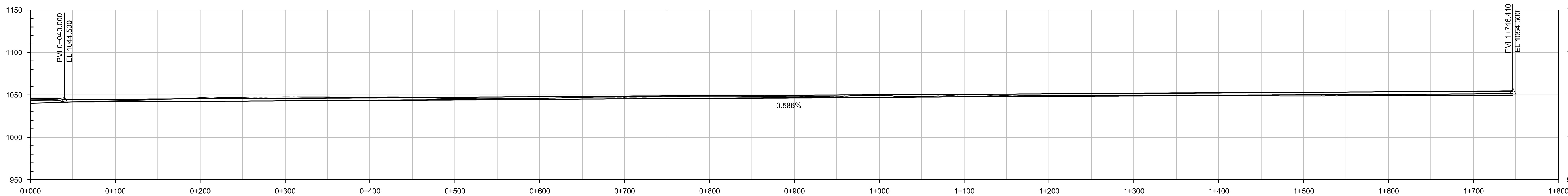
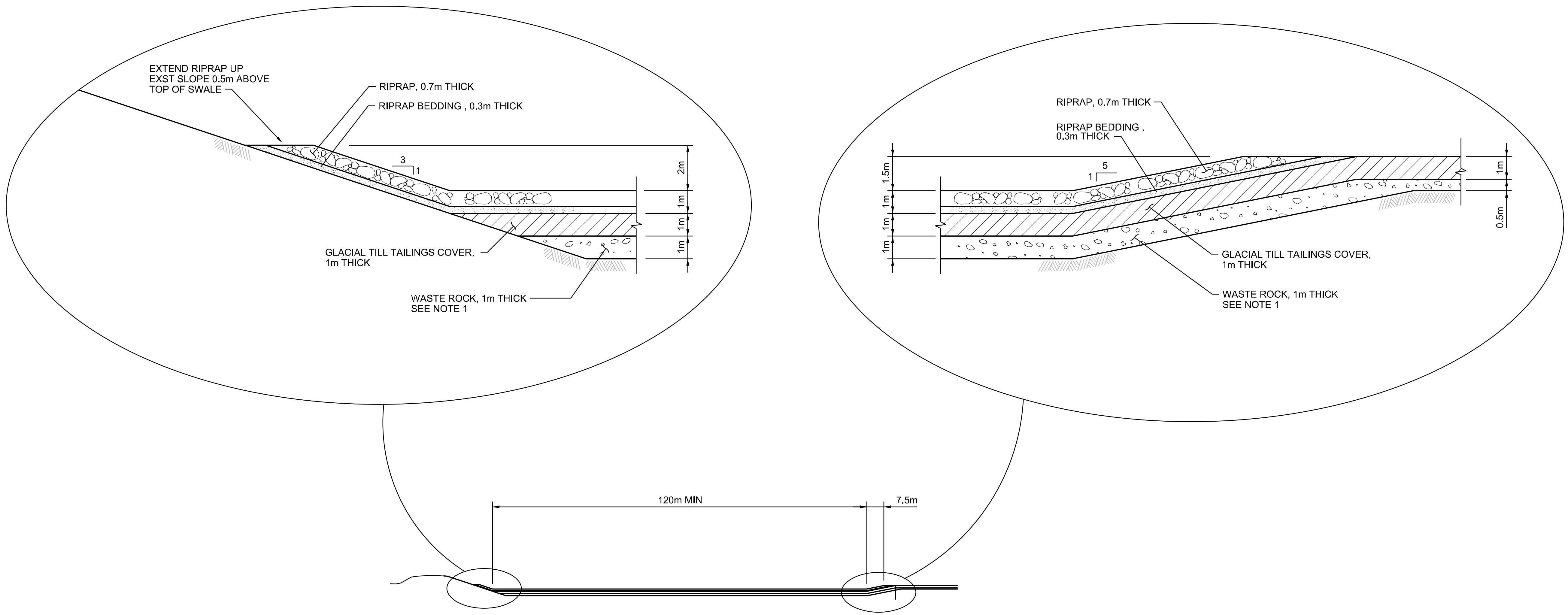


PROFILE ALONG CENTERLINE OF SINGLE DEDICATED SWALE
1:5000



NOTES:
1. THE 2-INCH MINUS PORTION OF WASTE ROCK TO BE SCREENED OUT AND USED AS FILTER LAYERS AT BOTTOM AGAINST TAILINGS AND AT TOP AGAINST GLACIAL TILL.

B SECTION
1:2000
FIG 230

FIGURE 231
ROSE CREEK TAILINGS AREA
ALTERNATIVE 3
PROFILE AND SECTION

CH2MHILL®

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200_FIGURE240.dgn

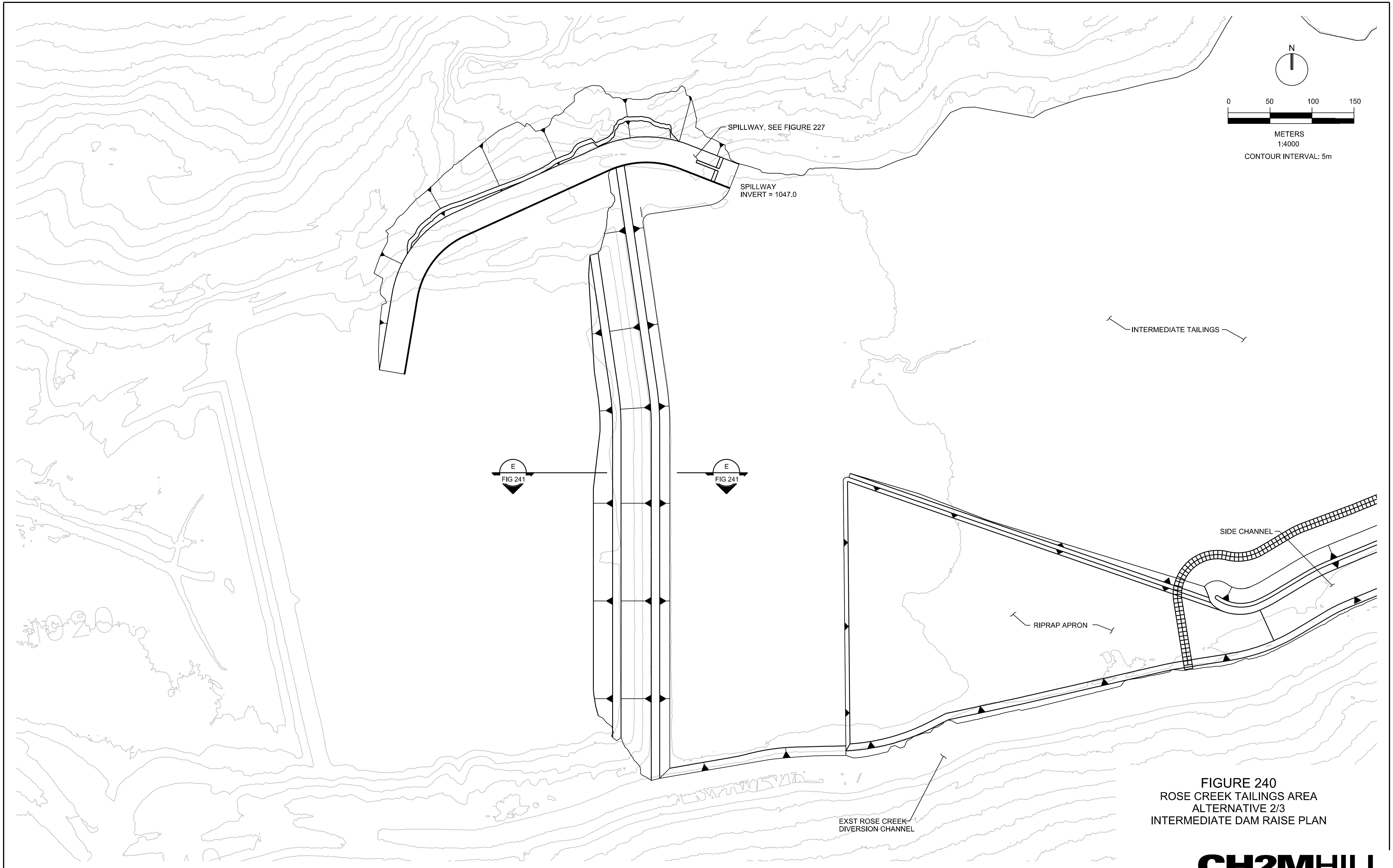
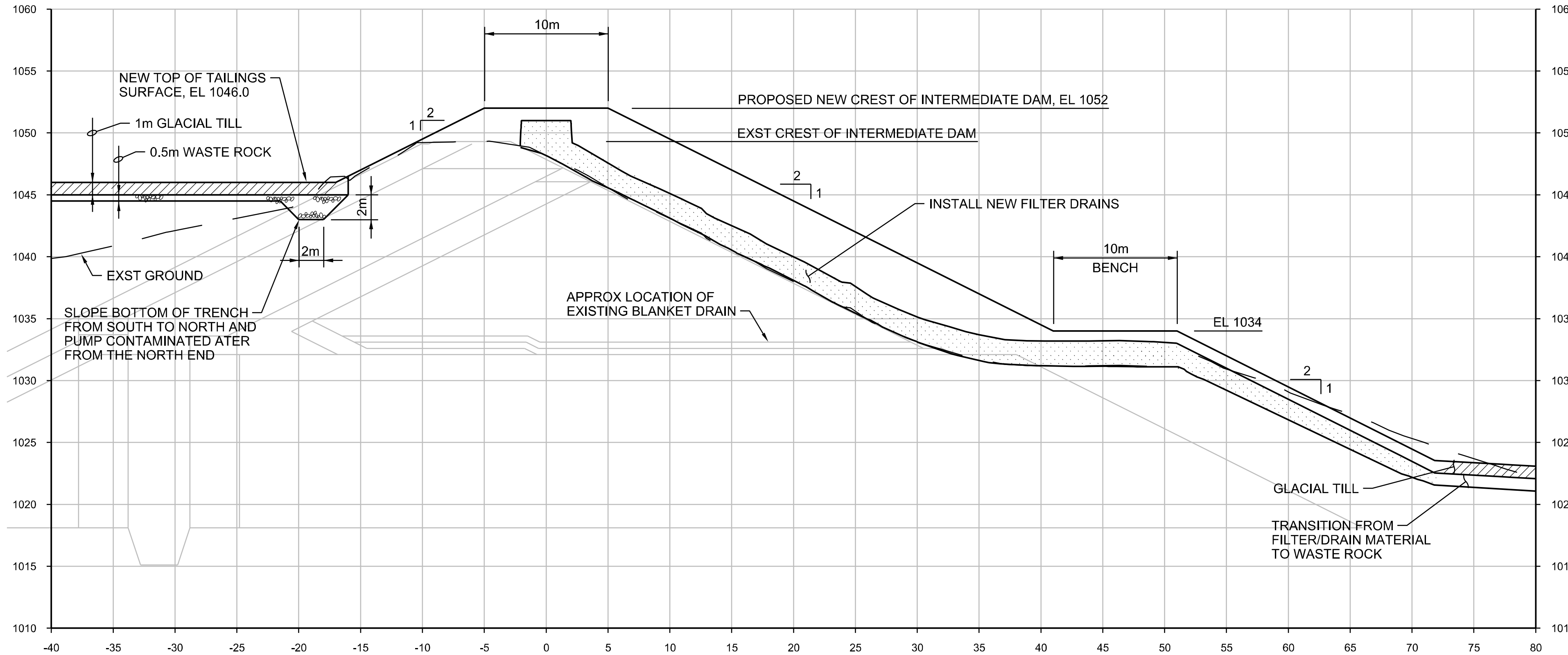


FIGURE 240
ROSE CREEK TAILINGS AREA
ALTERNATIVE 2/3
INTERMEDIATE DAM RAISE PLAN

CH2MHILL®



E
SECTION
1:250
FIG 240

PLOT TIME: 5:20:33 PM 2012\08\23 200_FIGURE241.dgn

FIGURE 241
ROSE CREEK TAILINGS AREA
ALTERNATIVE 2/3
INTERMEDIATE DAM RAISE SECTION

CH2MHILL®

Appendix B
2D Hydraulic Modelling Results

Faro Mine Rose Creek Diversion Alternatives: Two-Dimensional Hydraulic Modelling Approach and Results Faro Mine Remediation Project

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Introduction

This technical memorandum summarizes results of CH2M HILL's hydraulic analysis for three proposed alternatives to convey the probable maximum flood (PMF) through the Rose Creek Diversion (RCD) and adjacent tailings. The hydraulic analysis evaluates hydraulic impacts related to the proposed improvements.

Using topographic and bathymetric data available for the RCD and proposed improvements, CH2M HILL prepared two-dimensional (2D) hydraulic models to evaluate hydraulic conditions for the PMF. Consistent with values determined by Water Management Consultants located in Richmond, BC, the PMF flow rate used in all hydraulic modelling is 692 cubic metres per second (m^3/sec).

This technical memorandum describes the 2D modelling approach and is organized into the following sections:

- Background Information
- Model Approach and Results Applications
- Model Development
- Model Boundary Conditions
- Model Calibration
- Model Simulations
- Model Results

Background Information

The RCD is located in the Faro Mine Complex and is adjacent to a series of tailings ponds. To convey the PMF, modifications are required to the RCD, the tailings, or both to effectively convey the PMF without significant erosion of the channel and tailings area.

Model Approach and Results Applications

Previous hydraulic modelling used the U.S. Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS) software to evaluate hydraulic conditions. HEC-RAS is a one-dimensional (1D) hydraulic model that computes hydraulic properties (using 1D energy and momentum equations) based on cross section data.

For this analysis, to describe inundation continuously over the project reach, CH2M HILL used MIKE 21, a 2D hydraulic model developed by Danish Hydraulic Institute Water and Environment. Because hydraulics (depth and velocity) can be computed continuously throughout the model network, complex flow paths and overland flow characteristics are simulated more accurately with a 2D model. In contrast, a 1D hydraulic model computes average hydraulics at discrete locations (cross sections) and does not provide continuous data across a surface like the Rose Creek tailings.

Outputs from the 2D model include depth, depth-averaged velocity, and water surface elevation (WSEL). Model results are presented as colour-coded contours and velocity vectors overlaid on aerial photographs, facilitating the interpretation of depth and velocity at specific locations of interest. As this project proceeds to future phases, the model can continue to provide valuable information to designers and other interested parties.

Model Development

Spatial Extent

This project reach of the RCD is approximately 5,000 metres long with an average width of about 100 metres across the main channel surface. The total domain area used in the hydraulic model (including areas above the water surface) is 11 square kilometres (3,800 metres by 2,900 metres).

Units and Datum

The 2D model is based on light detection and ranging (LiDAR) data dated October 3, 2011. All computational data are reported in metric units, CGVD 28 vertical datum, and NAD83 CSRS horizontal datum.

Bathymetry

To represent the channel and pond bathymetry and tailings topography, a single digital terrain model (DTM) was prepared that covers the extent of the model domain for each alternative.

Computational Grid

The MIKE 21 hydraulic model uses a rectilinear grid system (equally spaced grid cells); model inputs, numeric computation, and model outputs; all are reported on the defined grid system referred to here as a computational grid. The computational grid for the MIKE 21 model was interpolated from the DTM describing the channel bed and tailings (bathymetry). The computational grid is composed of 2,755,000 points for analyses of the three alternatives. The MIKE 21 model works with metric units only. Therefore, the computation grid was defined in terms of metric units. Each grid cell is 2 metres by 2 metres (4 square metres).

Model Boundary Conditions

Upstream and Downstream Boundaries

The MIKE 21 hydraulic model solves the partial differential equations (St. Venant Equations), which require defined boundary conditions at all open boundaries (i.e., the upstream and downstream ends of the project reach).

The downstream boundary condition is defined by the WSEL from previous HEC-RAS model results for the PMF. The upstream boundary condition is the PMF flow rate in the RCD at the upstream boundary of the model grid.

Model Calibration

Ideally, model calibration would be accomplished by comparing measured and simulated WSEL values for a known discharge. Since no calibration data are available for the high flows analyzed, the model was calibrated by adjusting the channel roughness (Manning's *n*) within a range of reasonable values (0.030 to 0.040) to test the sensitivity to roughness and match the simulated results to previous modelling. A constant roughness value of 0.040 was selected for use in all three models.

Applying a constant roughness value of 0.040 is a conservative approach, based on professional engineering judgment. For a given reach, the roughness coefficient in a 2D model is lower than in a 1D model because the roughness coefficient only accounts for resistance associated with skin friction. In contrast, roughness in a 1D model must also include bed and planform resistance (which is accounted for by the spatial representation of the channel in a 2D model).

For all three models, the constant roughness value of 0.040 was applied to all grid cells. In reality, the roughness will be variable when comparing the channel, tailings, and ponds. However, because the intent of this modelling work is to compare differences in inundation patterns and the extent of flooding resulting from differences in topography, using a constant roughness value means that differences will be a result of changes in topography, not roughness.

Model Simulations

For the evaluation of alternatives, three models were prepared to simulate discharge through the project reach:

- Alternative 1 includes modifications to increase the capacity of the RCD along its full length. These modifications include excavation of the left bank to widen the channel and fill on the right bank (levee) to increase the effective depth of the channel.
- Alternative 2 includes a lateral weir structure designed to function as a board-crested weir to divert approximately 562 m^3/sec from the RCD into a flood conveyance channel that flows roughly parallel with the RCD. This channel diverts flows in excess of the 500-year event (130 m^3/sec) west to the Intermediate Dam (ID) and north across the tailings upstream from the ID. A spillway at the north end of the ID conveys flows into the Cross Valley Dam Impoundment. The bathymetric grid used in the model simulation was modified to provide a flood flow outlet at the northwest corner of the Cross Valley Pond.
- Alternative 3 includes the same lateral weir structure as Alternative 2. Flows diverted from the RCD are conveyed directly across the tailings to the ID in a single channel that is 120 metres wide. Downstream from the ID, Alternative 3 is the same as Alternative 2.

All model simulations use a computational grid interpolated from topography defined by a DTM that is a composite of proposed improvements and LiDAR data that define existing conditions.

Model Results

Channel and Tailings Inundation

Model results are presented in a series of exhibits illustrating the extent of channel and tailings inundation associated with the PMF event (692 m^3/sec). For each alternative, exhibits are provided that illustrate water depth and current speed over the full model extent. In addition to these, five enlarged views are included with velocity vectors to provide greater detail starting at Reach 1, upstream, and extending to Reach 5, downstream.

These model results identify discrete locations where channel capacity may need to be increased to adequately convey the PMF. Results also illustrate locations that may require additional stabilization measures.

Attachments include the following:

Attachment 1: Alternative 1 Results

- 1A – Water Depth at PMF
- 1B – Current Speed at PMF
- 1C – Enlarged View – Water Depth and Velocity Vectors for Reach 1
- 1D – Enlarged View – Water Depth and Velocity Vectors for Reach 2
- 1E – Enlarged View – Water Depth and Velocity Vectors for Reach 3
- 1F – Enlarged View – Water Depth and Velocity Vectors for Reach 4
- 1G – Enlarged View – Water Depth and Velocity Vectors for Reach 5

Attachment 2: Alternative 2 Results

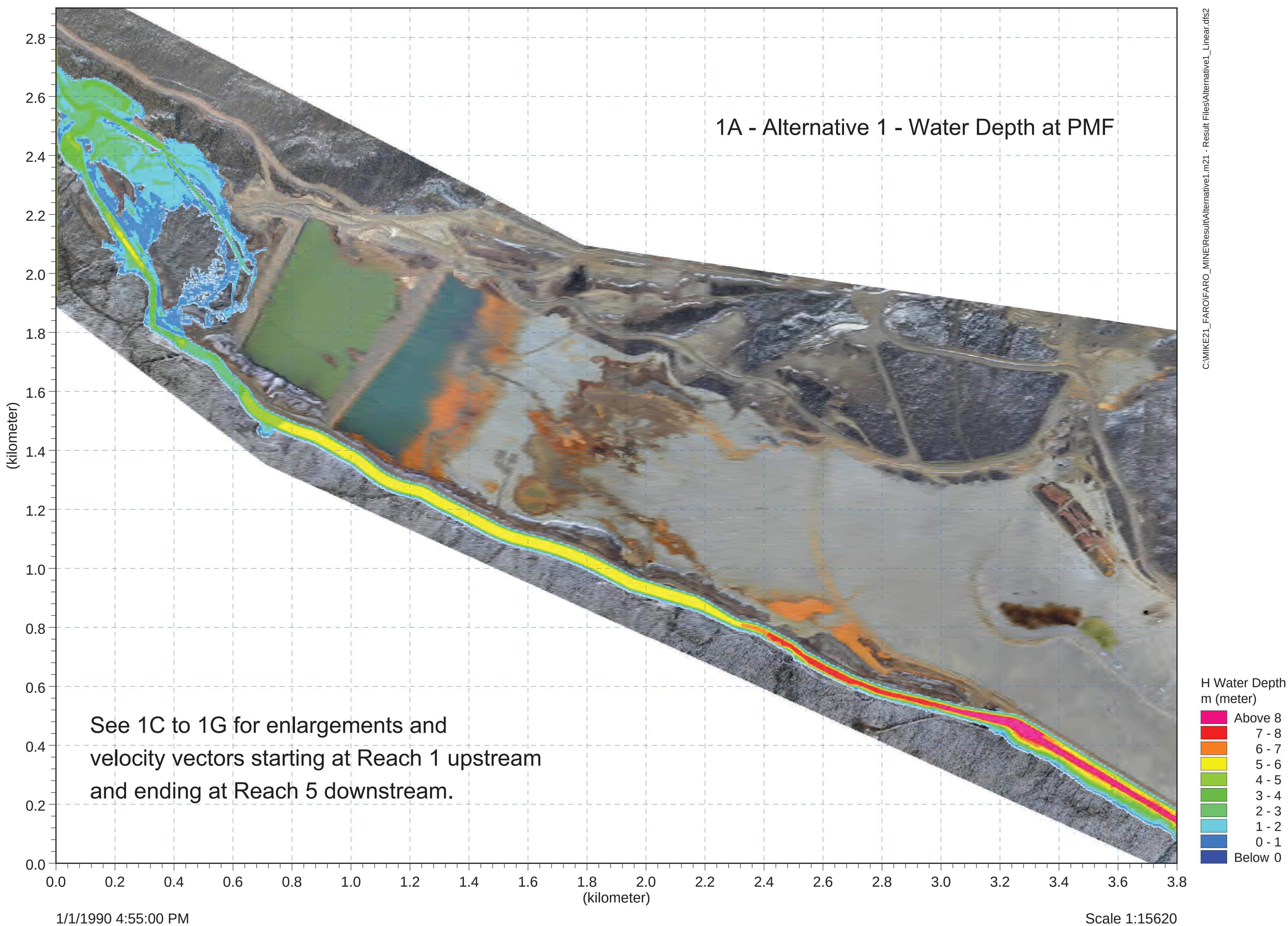
- 2A – Water Depth at PMF
- 2B – Current Speed at PMF
- 2C – Enlarged View – Water Depth and Velocity Vectors for Reach 1

- 2D – Enlarged View – Water Depth and Velocity Vectors for Reach 2
- 2E – Enlarged View – Water Depth and Velocity Vectors for Reach 3
- 2F – Enlarged View – Water Depth and Velocity Vectors for Reach 4
- 2G – Enlarged View – Water Depth and Velocity Vectors for Reach 5

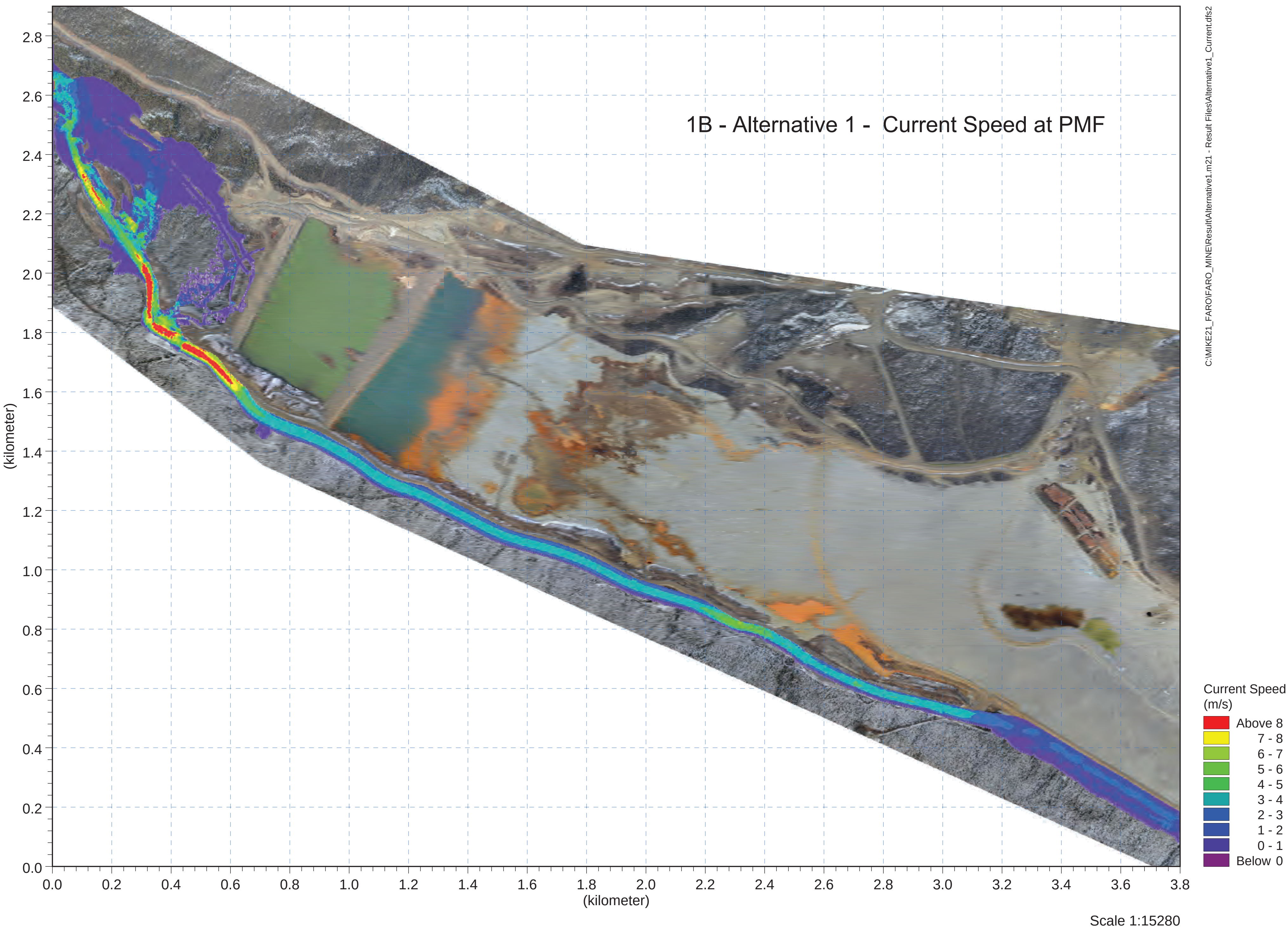
Attachment 3: Alternative 3 Results

- 3A – Water Depth at PMF
- 3B – Current Speed at PMF
- 3C – Enlarged View – Water Depth and Velocity Vectors for Reach 1
- 3D – Enlarged View – Water Depth and Velocity Vectors for Reach 2
- 3E – Enlarged View – Water Depth and Velocity Vectors for Reach 3
- 3F – Enlarged View – Water Depth and Velocity Vectors for Reach 4
- 3G – Enlarged View – Water Depth and Velocity Vectors for Reach 5

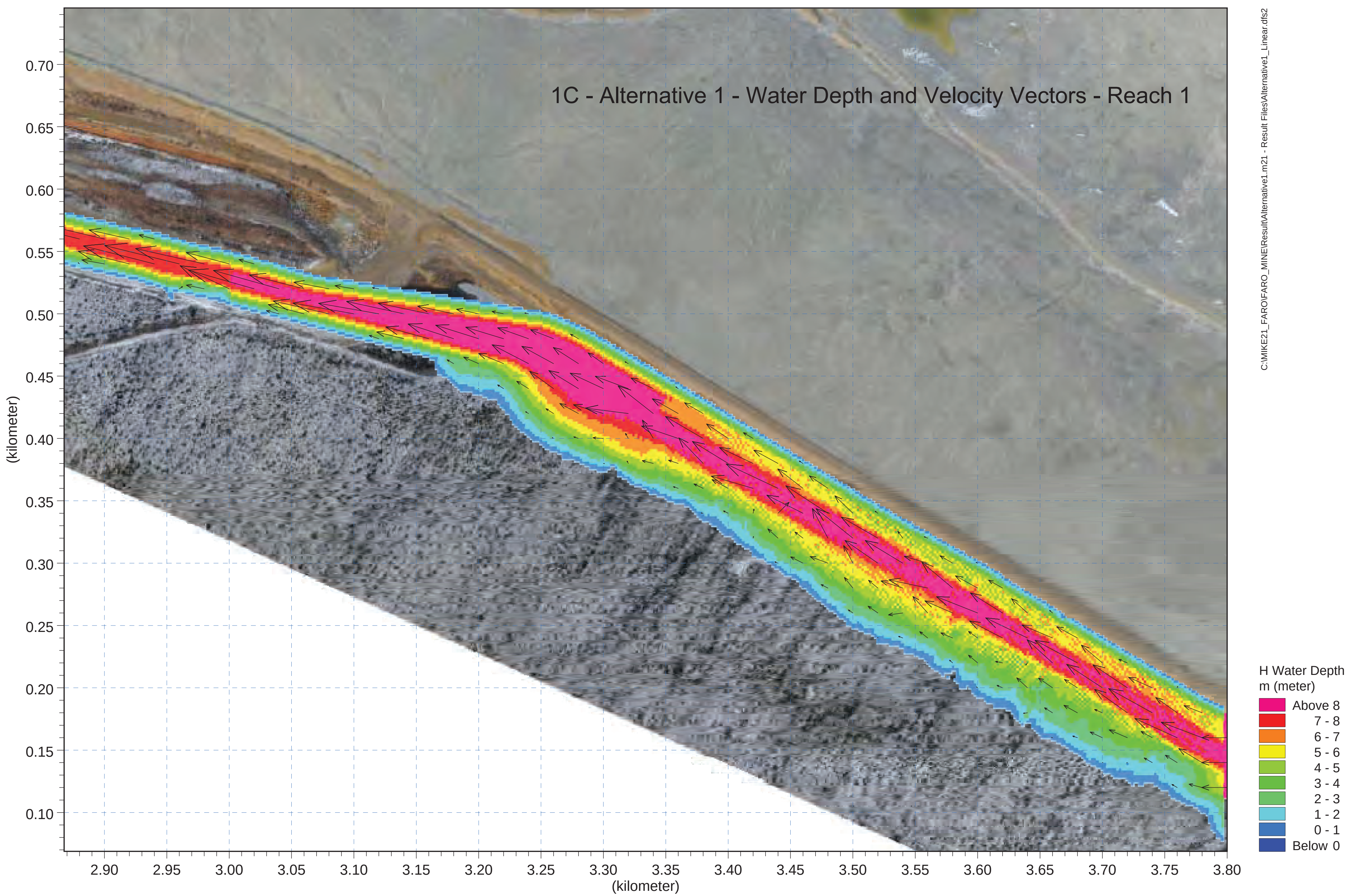
Attachment 1
Alternative 1 Results



1A - Alternative 1 - Water Depth at PMF
See 1C to 1G for enlargements and velocity vectors starting at Reach 1 upstream and ending at Reach 5 downstream.
(kilometer)
(kilometer)
C:\MIKE21_FARO\FARO_MINE\Result\Alternative1.m21 - Result Files\Alternative1_Linear.dfs2
H Water Depth
m (meter)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
1/1/1990 4:55:00 PM
Scale 1:15620



1B - Alternative 1 - Current Speed at PMF
(kilometer)
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
(kilometer)
C:\MIKE21_FARO\FARO_MINE\Result\Alternative1.m21 - Result Files\Alternative1_Current.dfs2
Current Speed (m/s)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
Scale 1:15280



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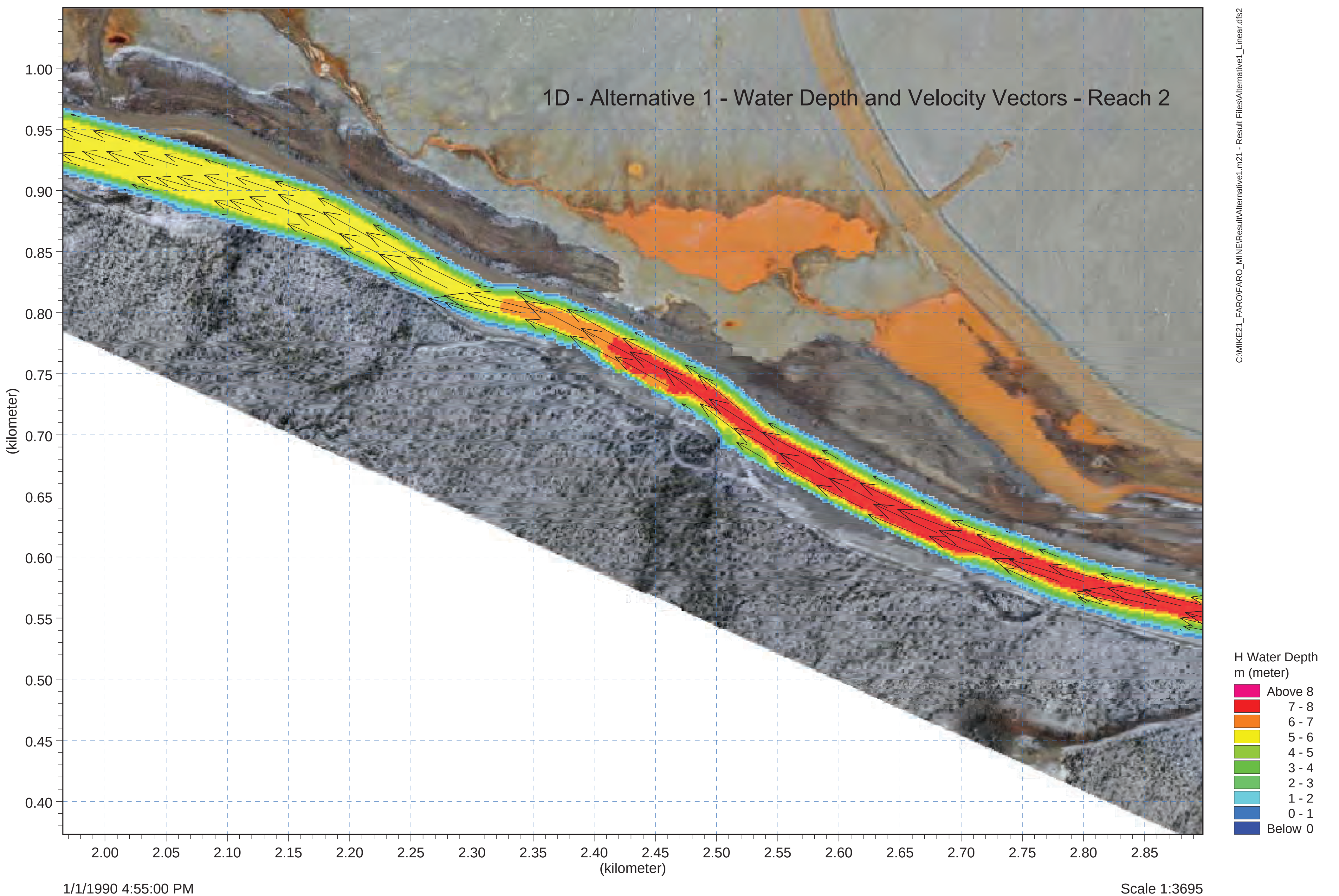
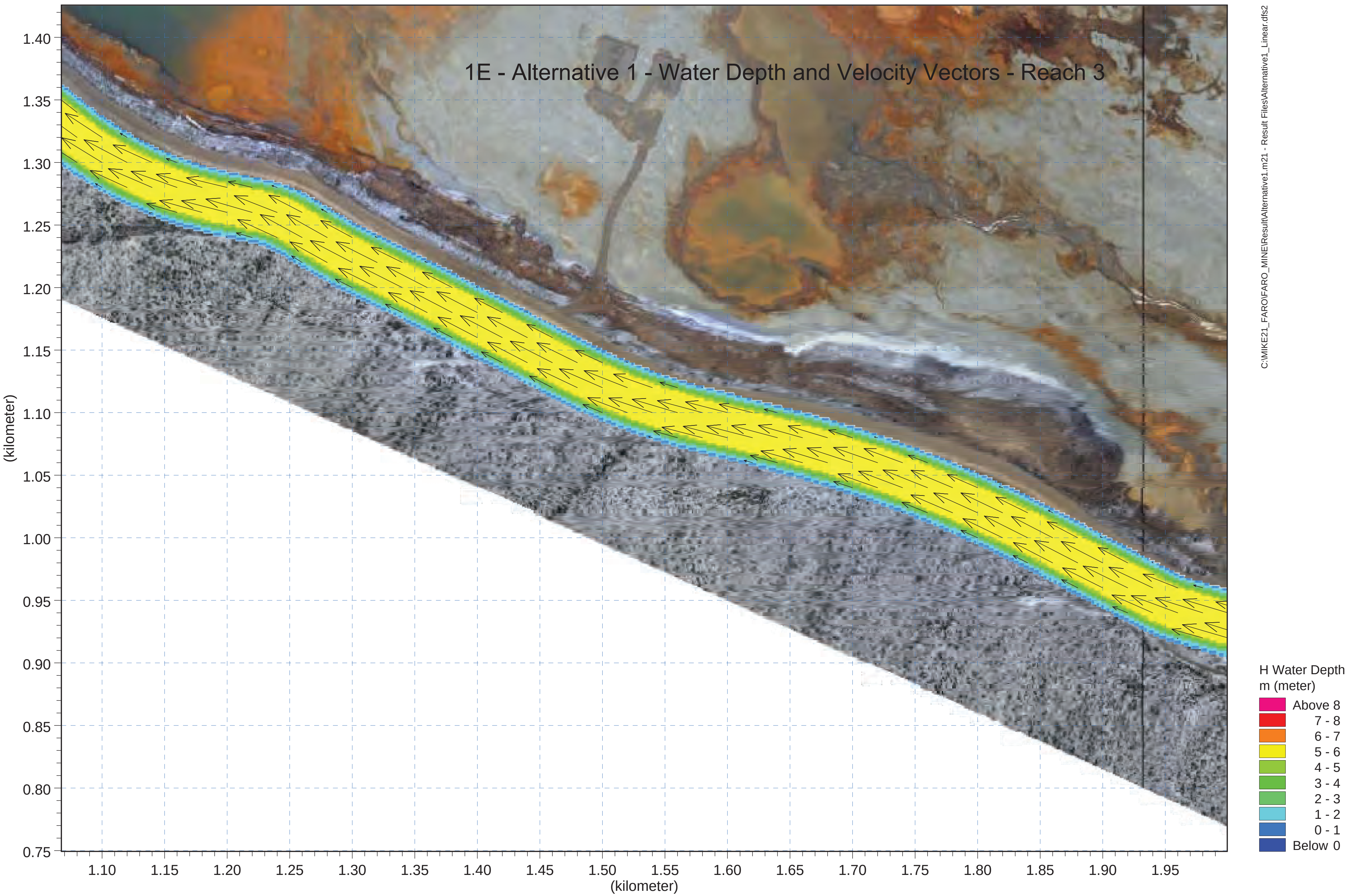
Scale 1:3695


1D - Alternative 1 - Water Depth and Velocity Vectors - Reach 2
(kilometer)
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
2.00
2.05
2.10
2.15
2.20
2.25
2.30
2.35
2.40
2.45
2.50
2.55
2.60
2.65
2.70
2.75
2.80
2.85
(kilometer)
C:\MIKE21_FARO\FARO_MINE\Result\Alternative1.m21 - Result Files\Alternative1_Linear.dfs2
H Water Depth
m (meter)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
1/1/1990 4:55:00 PM
Scale 1:3695



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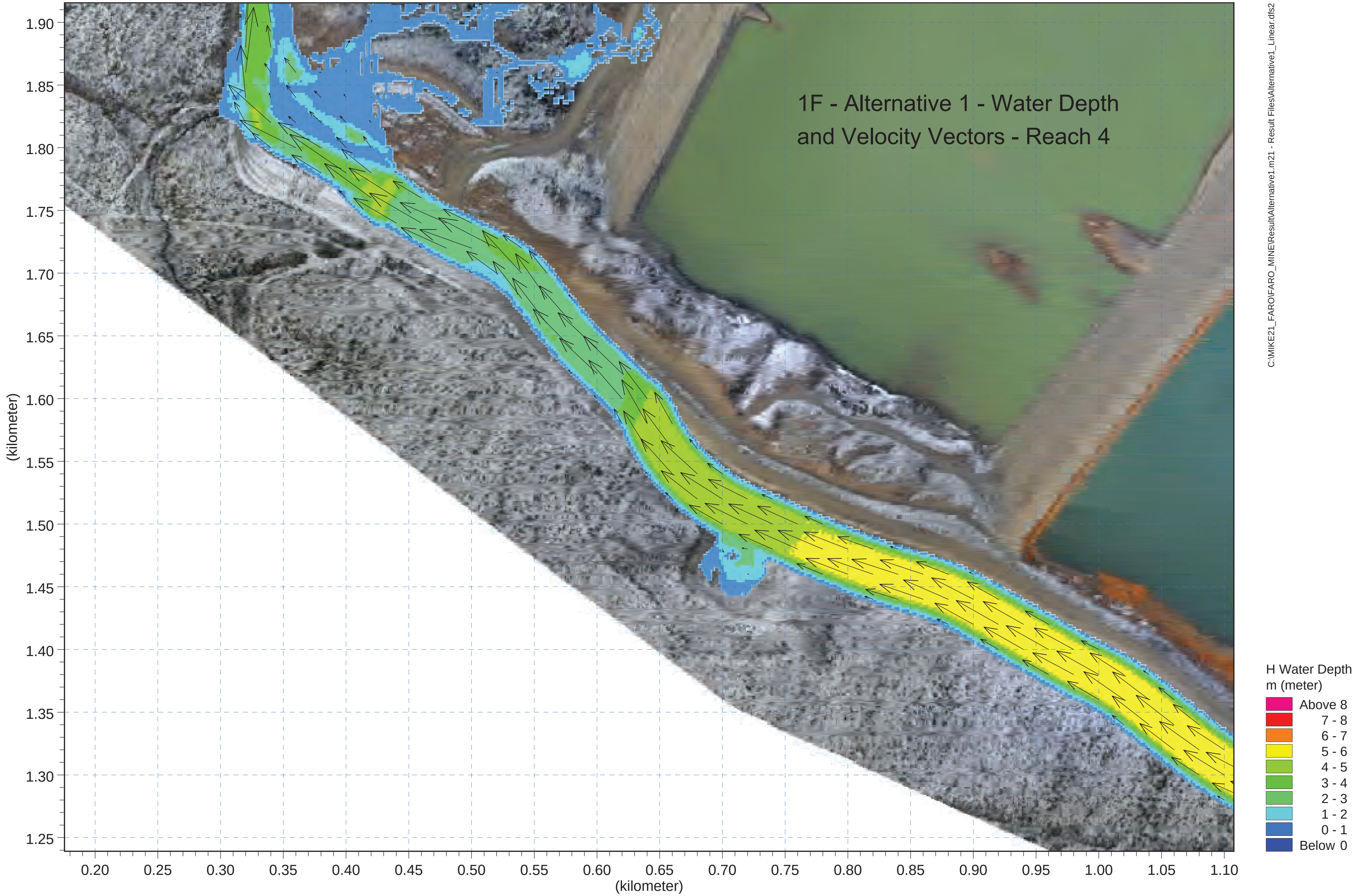

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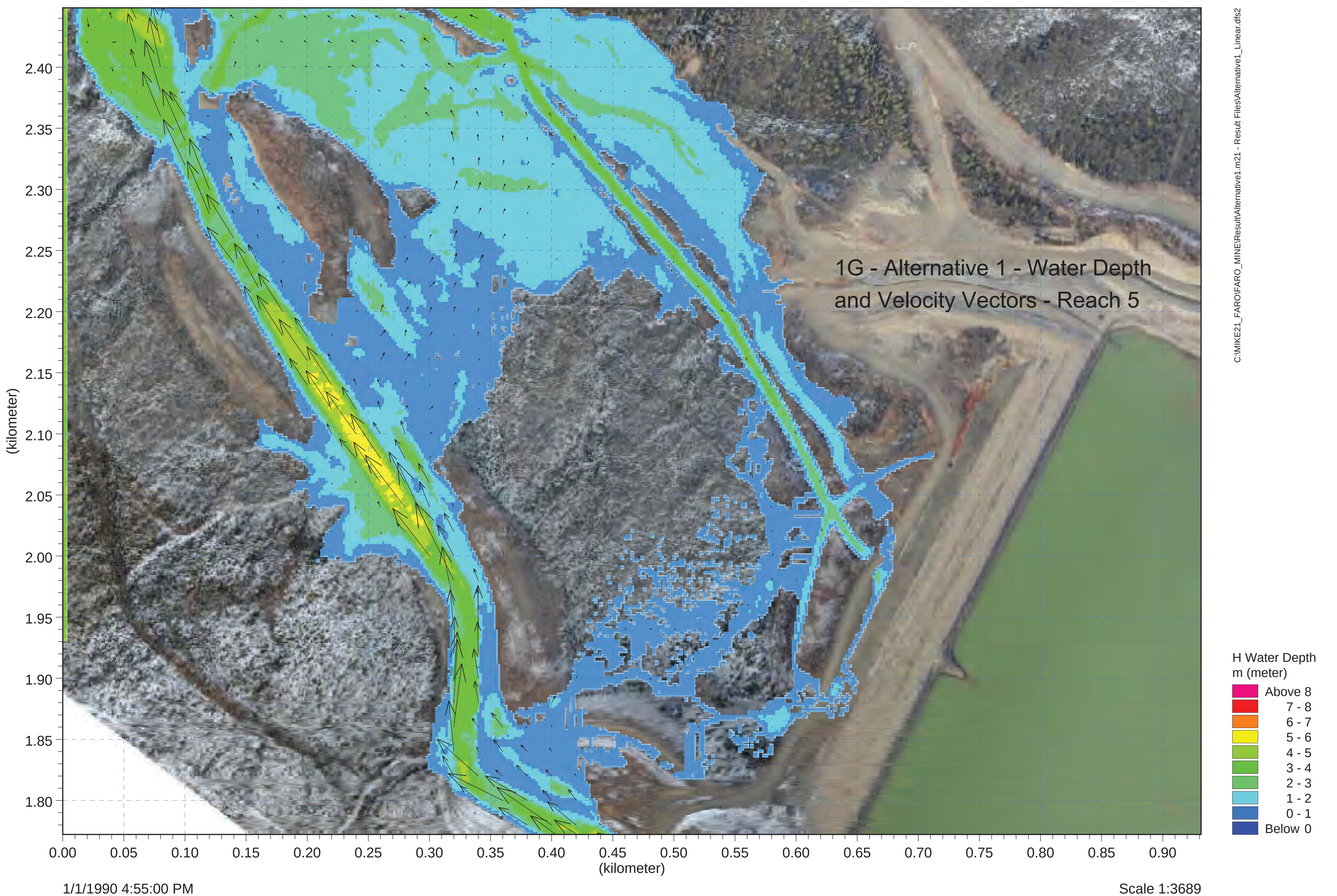
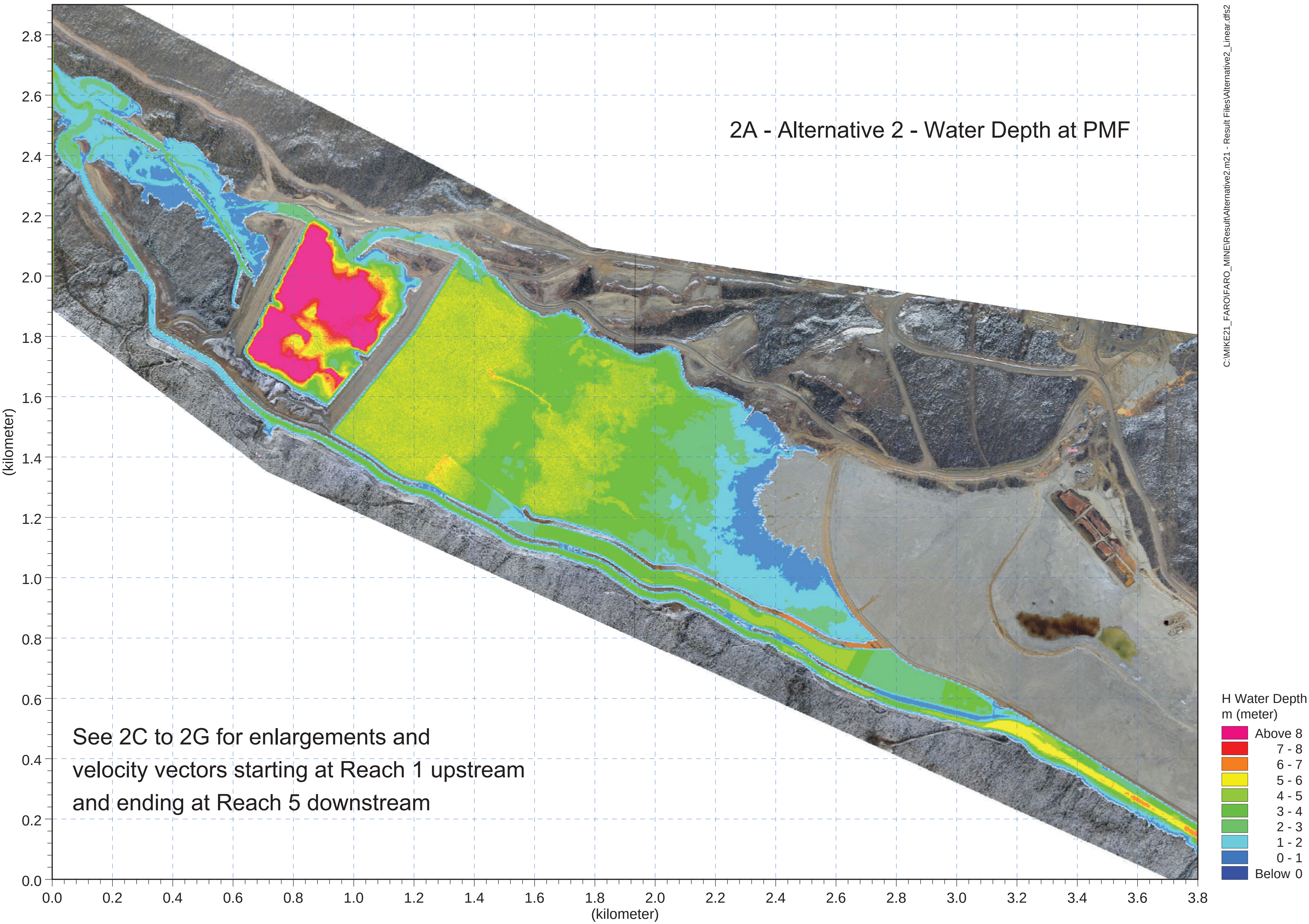

1G - Alternative 1 - Water Depth
and Velocity Vectors - Reach 5
(kilometer)
2.40
2.35
2.30
2.25
2.20
2.15
2.10
2.05
2.00
1.95
1.90
1.85
1.80
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
0.85
0.90
(kilometer)
C:\MIKE21_FARO\FARO_MINE\Result\Alternative1.m21 - Result Files\Alternative1_Linear.dfs2
H Water Depth
m (meter)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
1/1/1990 4:55:00 PM
Scale 1:3689

Attachment 2
Alternative 2 Results



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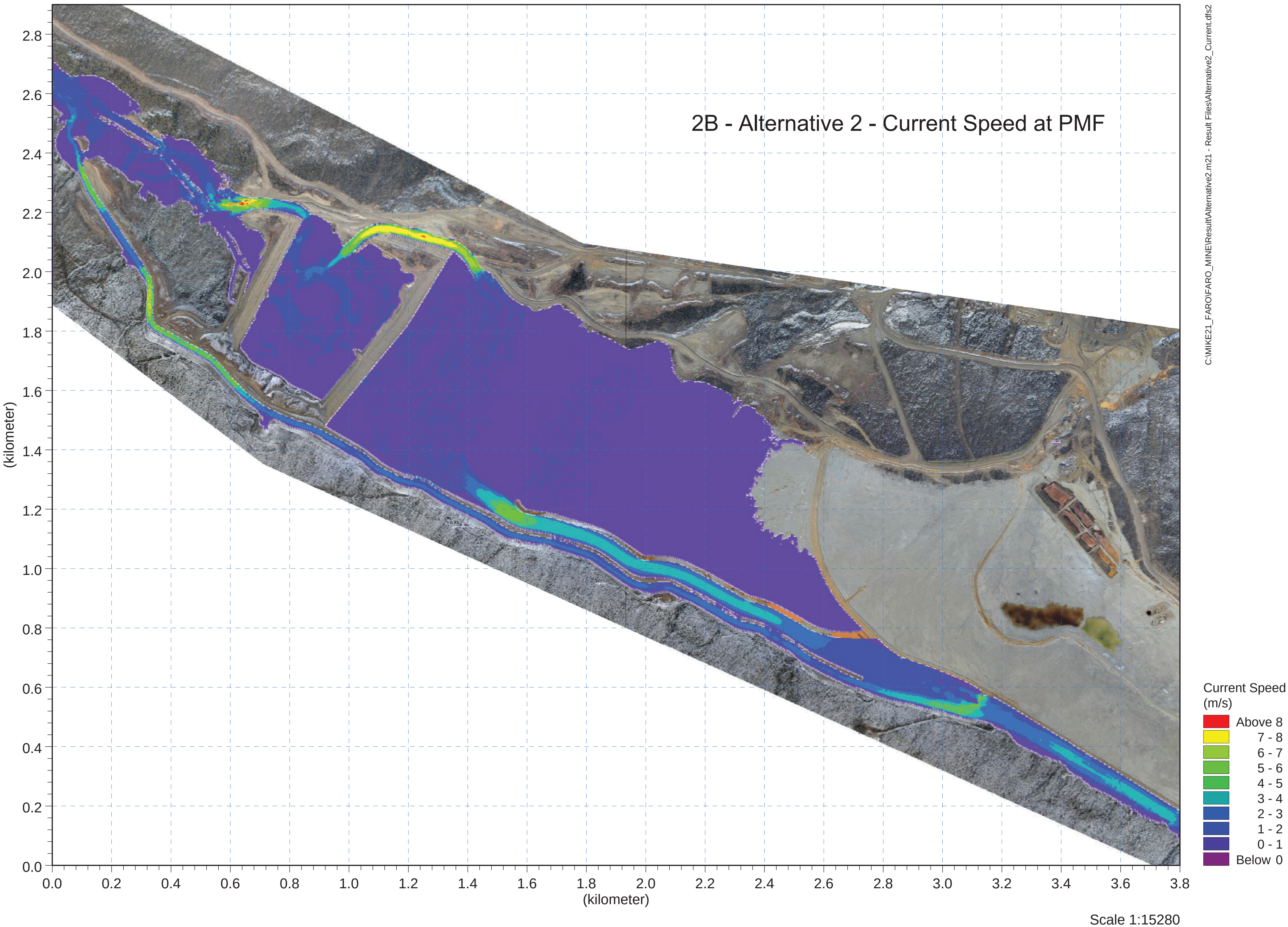
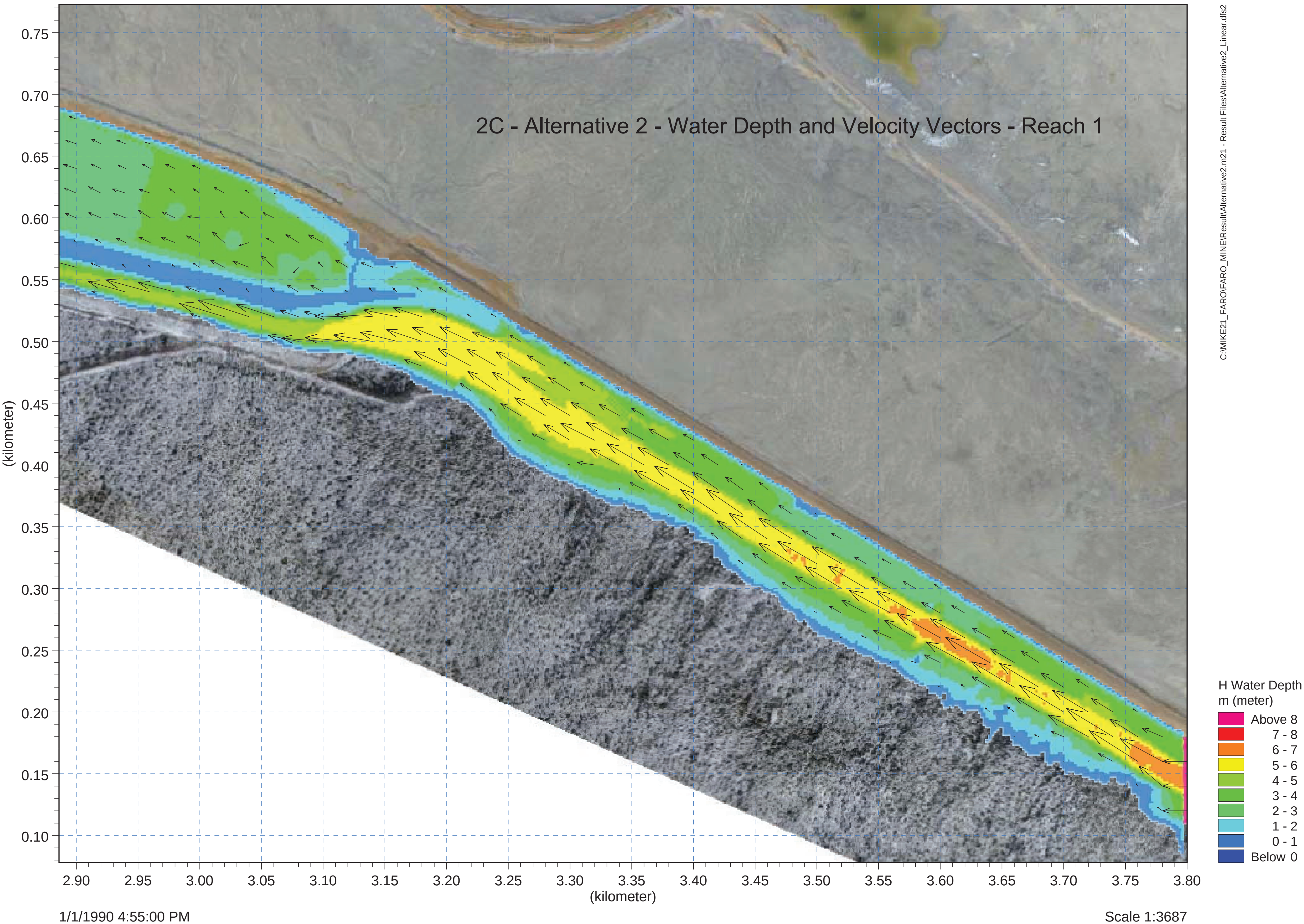

2B - Alternative 2 - Current Speed at PMF
C:\MIKE21_FARO\FARO_MINE\Result\Alternative2.m21 - Result Files\Alternative2_Current.dfs2
(kilometer)
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8
(kilometer)
Current Speed
(m/s)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
Scale 1:15280


2C - Alternative 2 - Water Depth and Velocity Vectors - Reach 1
C:\MIKE21_FARO\FARO_MINE\Result\Alternative2.m21 - Result Files\Alternative2_Linear.dfs2
(kilometer)
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
2.90
2.95
3.00
3.05
3.10
3.15
3.20
3.25
3.30
3.35
3.40
3.45
3.50
3.55
3.60
3.65
3.70
3.75
3.80
(kilometer)
H Water Depth
m (meter)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
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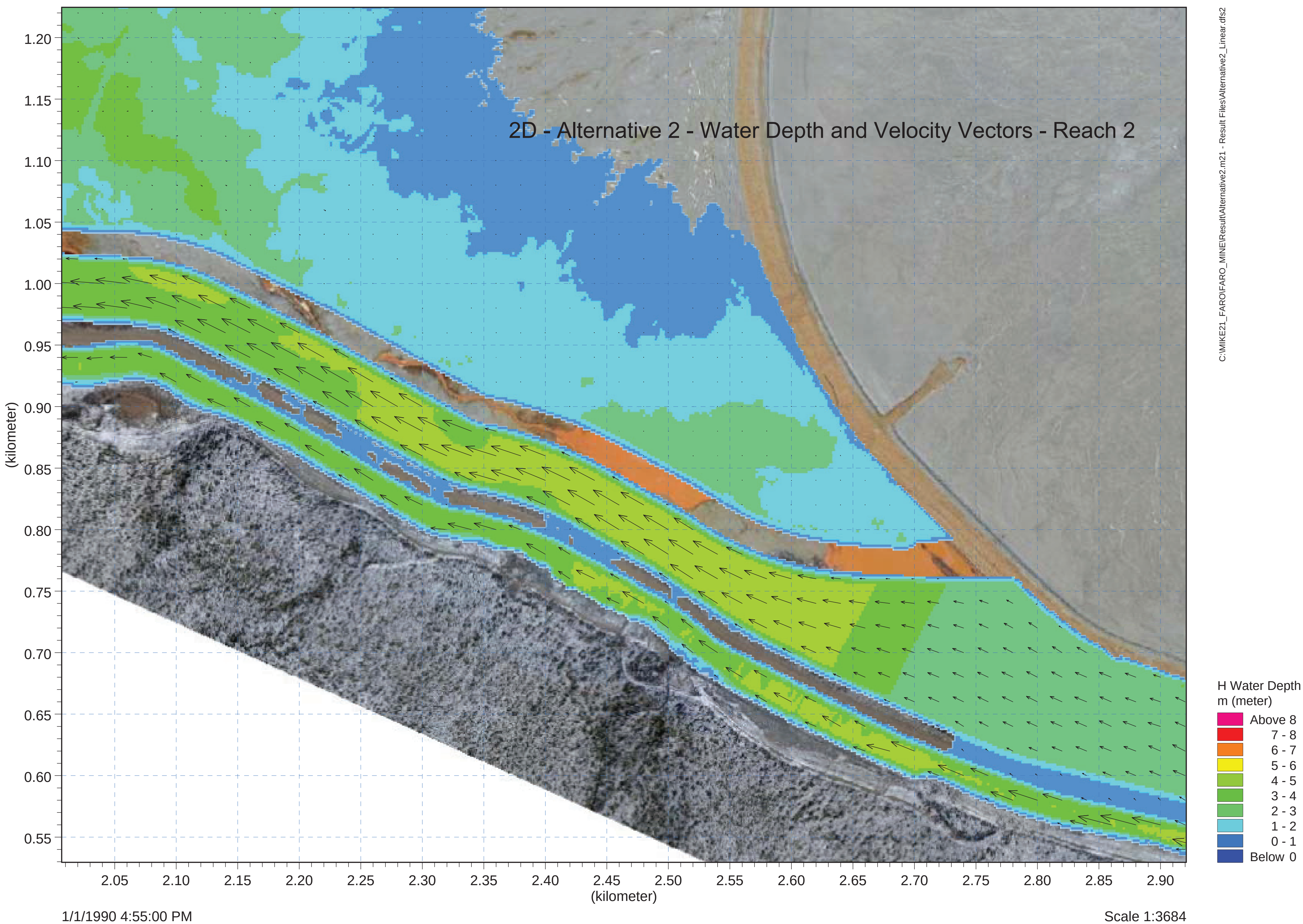
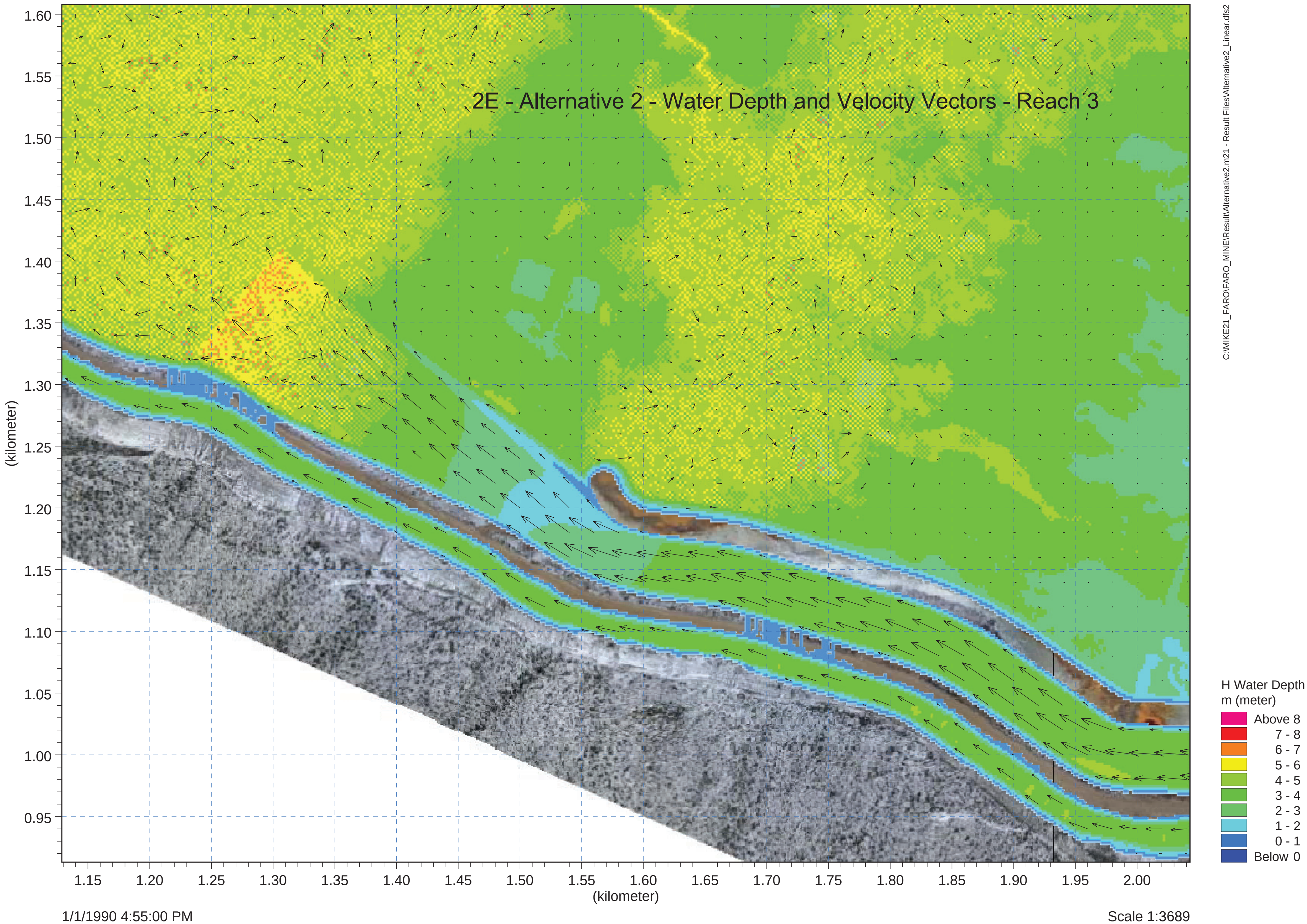
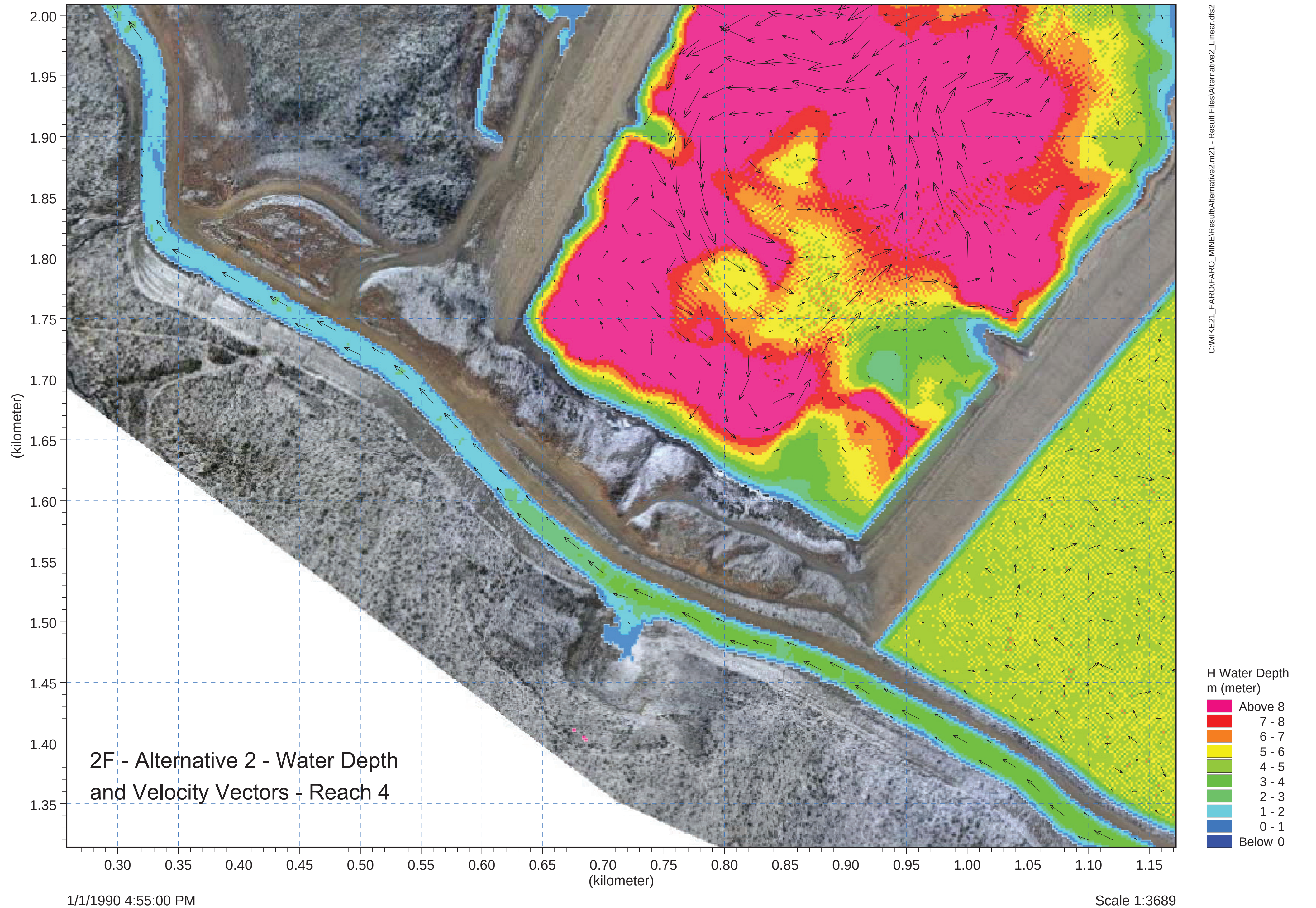
Scale 1:3687



2D - Alternative 2 - Water Depth and Velocity Vectors - Reach 2
C:\MIKE21_FARO\FARO_MINE\Result\Alternative2.m21 - Result Files\Alternative2_Linear.dfs2
(kilometer)
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
2.05
2.10
2.15
2.20
2.25
2.30
2.35
2.40
2.45
2.50
2.55
2.60
2.65
2.70
2.75
2.80
2.85
2.90
(kilometer)
H Water Depth
m (meter)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
1/1/1990 4:55:00 PM
Scale 1:3684


2E - Alternative 2 - Water Depth and Velocity Vectors - Reach 3
(kilometer)
(kilometer)
1.15
1.20
1.25
1.30
1.35
1.40
1.45
1.50
1.55
1.60
1.65
1.70
1.75
1.80
1.85
1.90
1.95
2.00
0.95
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
1.40
1.45
1.50
1.55
1.60
C:\MIKE21_FARO\FARO_MINE\Result\Alternative2.m21 - Result Files\Alternative2_Linear.dfs2
H Water Depth
m (meter)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
1/1/1990 4:55:00 PM
Scale 1:3689


2F - Alternative 2 - Water Depth
and Velocity Vectors - Reach 4
(kilometer)
(kilometer)
2.00
1.95
1.90
1.85
1.80
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
H Water Depth
m (meter)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
C:\MIKE21_FARO\FARO_MINE\Result\Alternative2.m21 - Result Files\Alternative2_Linear.dfs2
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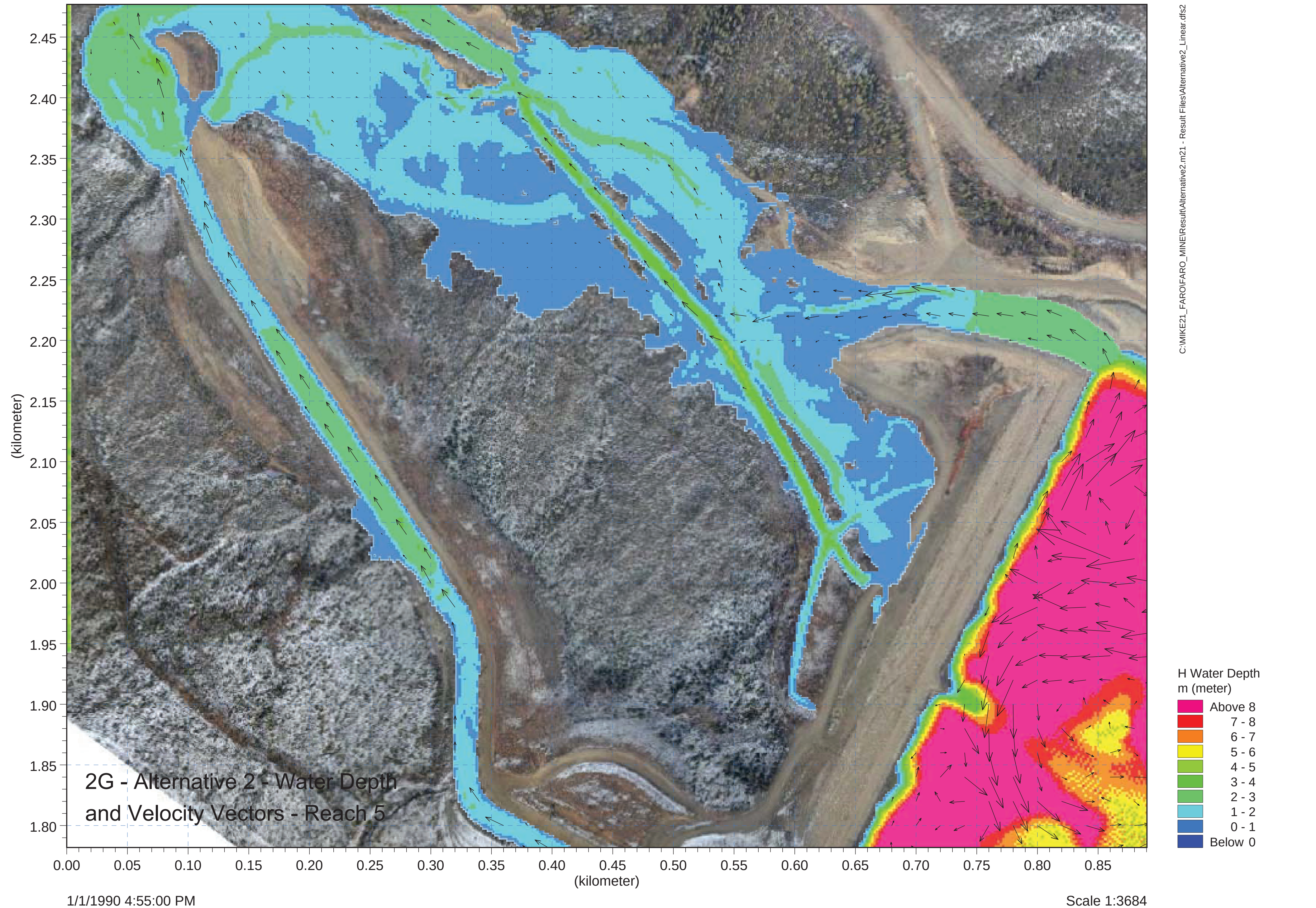
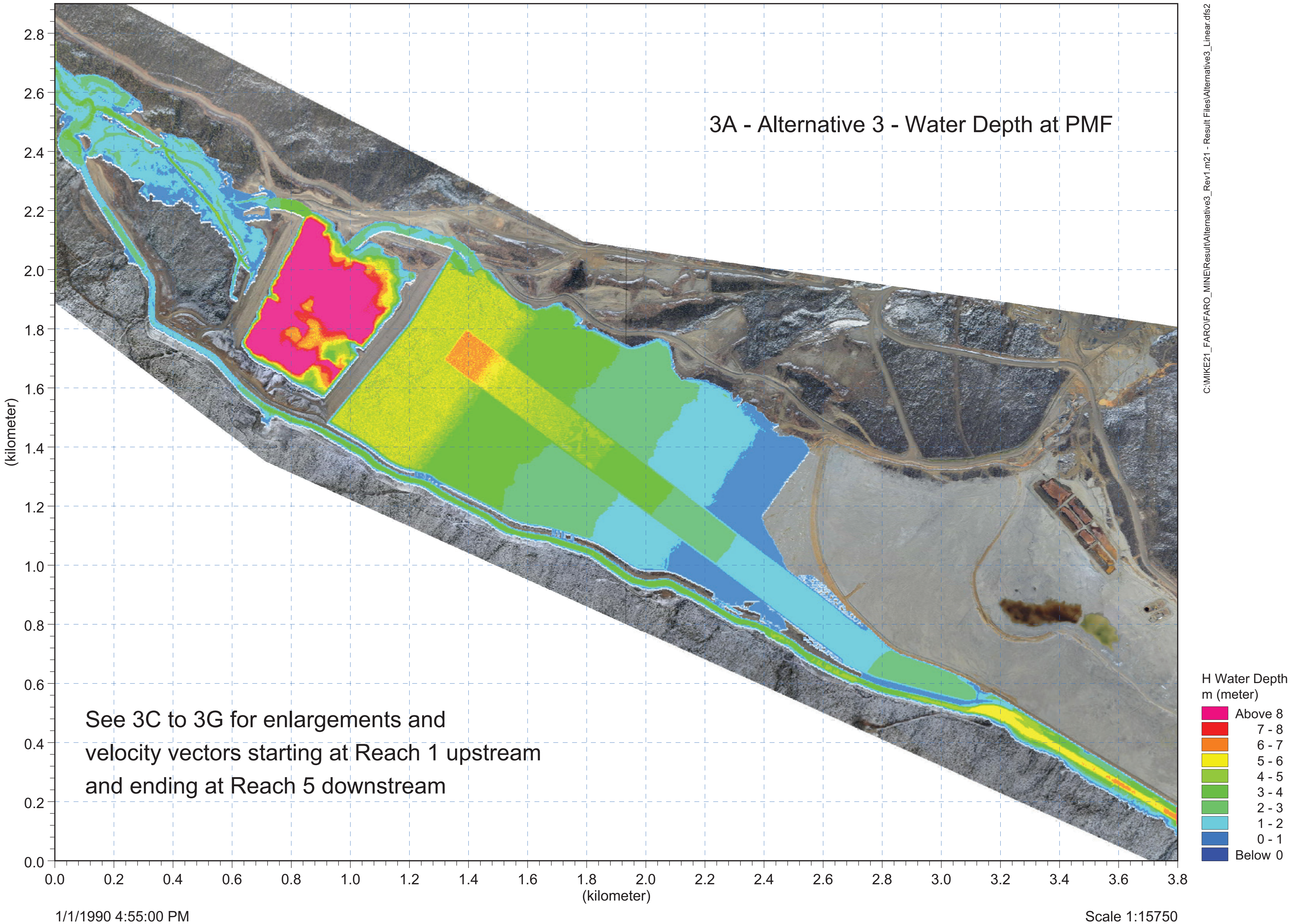


2G - Alternative 2 - Water Depth
and Velocity Vectors - Reach 5
(kilometer)
(kilometer)
2.45
2.40
2.35
2.30
2.25
2.20
2.15
2.10
2.05
2.00
1.95
1.90
1.85
1.80
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
0.85
H Water Depth
m (meter)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
1/1/1990 4:55:00 PM
Scale 1:3684
C:\MIKE21_FARO\FARO_MINE\Result\Alternative2.m21 - Result Files\Alternative2_Linear.dfs2

Attachment 3
Alternative 3 Results


3A - Alternative 3 - Water Depth at PMF
See 3C to 3G for enlargements and
velocity vectors starting at Reach 1 upstream
and ending at Reach 5 downstream
(kilometer)
(kilometer)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
H Water Depth
m (meter)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
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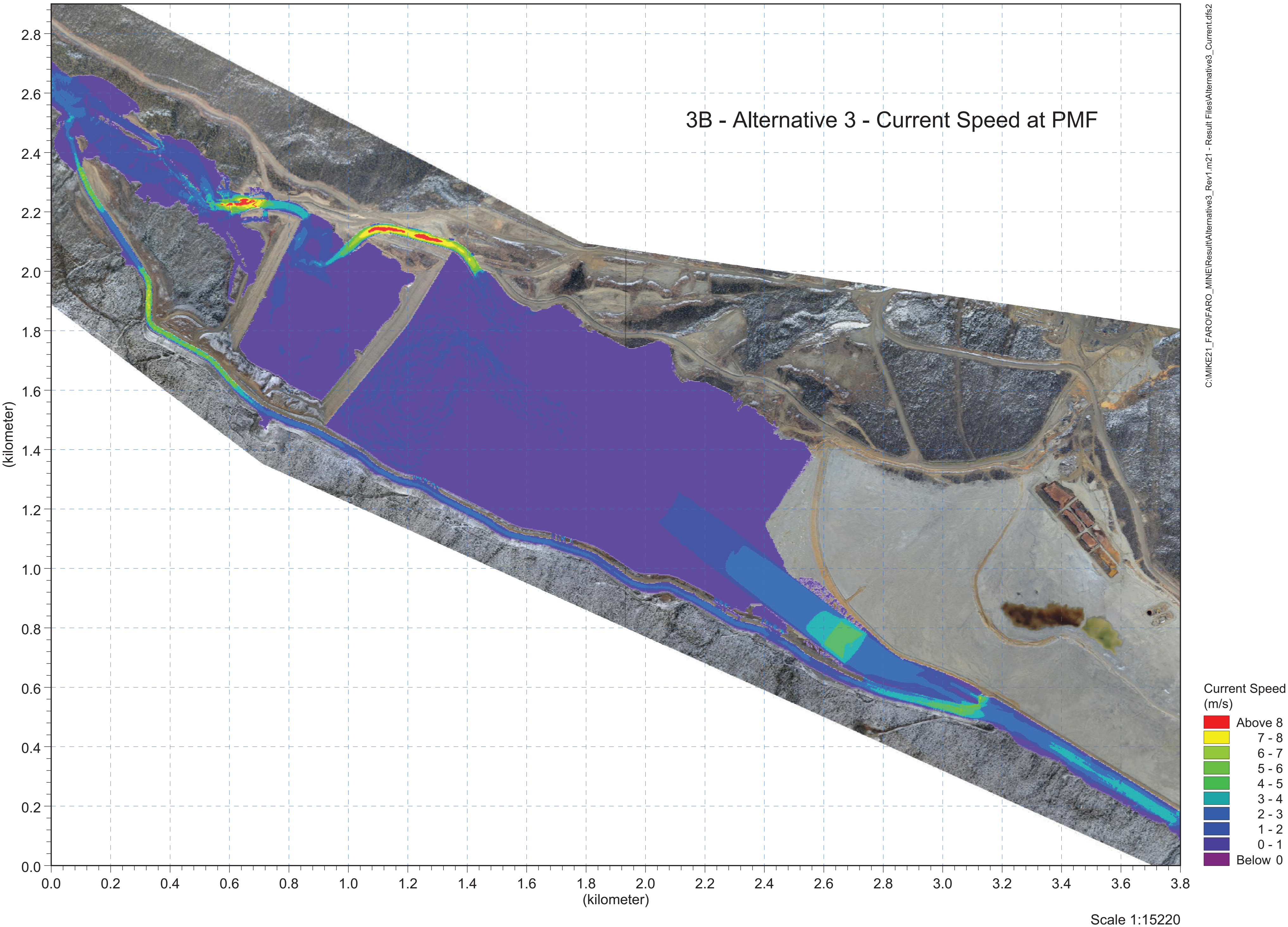
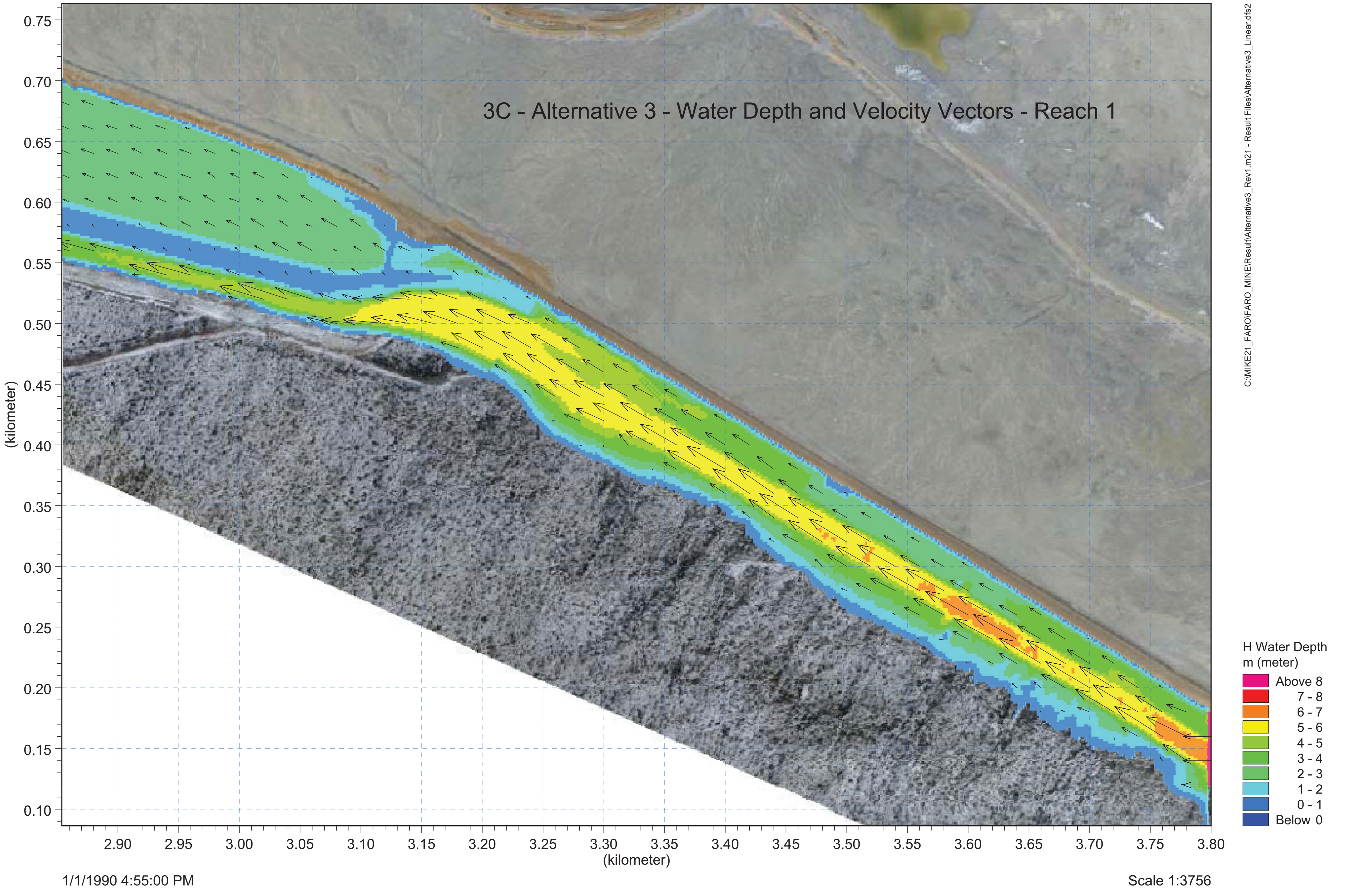
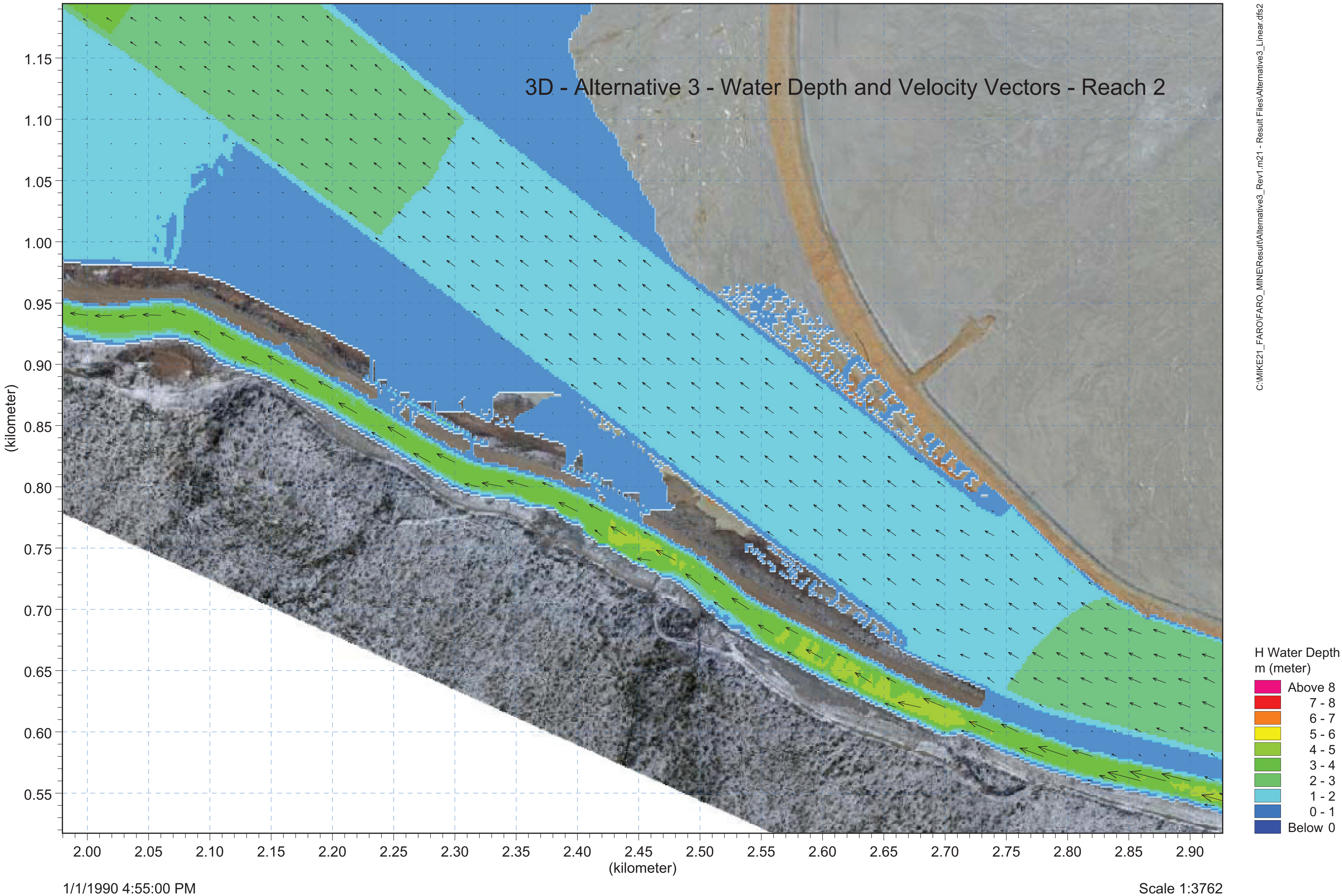
Scale 1:15750


3B - Alternative 3 - Current Speed at PMF
C:\MIKE21_FARO\FARO_MINE\Result\Alternative3_Rev1.m21 - Result Files\Alternative3_Current.dfs2
Current Speed (m/s)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
(kilometer)
(kilometer)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
Scale 1:15220


3C - Alternative 3 - Water Depth and Velocity Vectors - Reach 1
C:\MIKE21_FARO\FARO_MINE\Result\Alternative3_Rev1.m21 - Result Files\Alternative3_Linear.dfs2
(kilometer)
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
2.90
2.95
3.00
3.05
3.10
3.15
3.20
3.25
3.30
3.35
3.40
3.45
3.50
3.55
3.60
3.65
3.70
3.75
3.80
(kilometer)
H Water Depth
m (meter)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
1/1/1990 4:55:00 PM
Scale 1:3756


3D - Alternative 3 - Water Depth and Velocity Vectors - Reach 2
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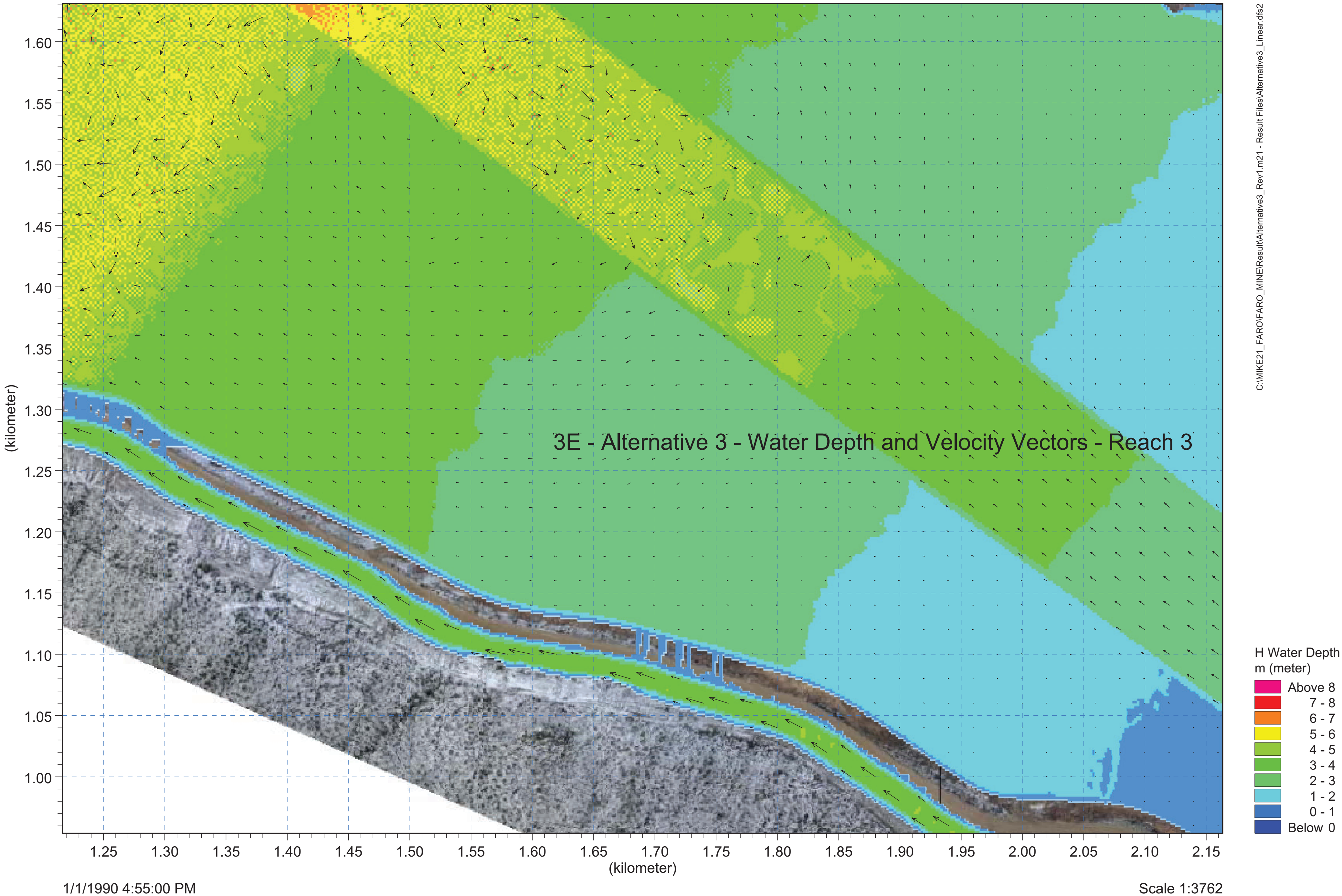
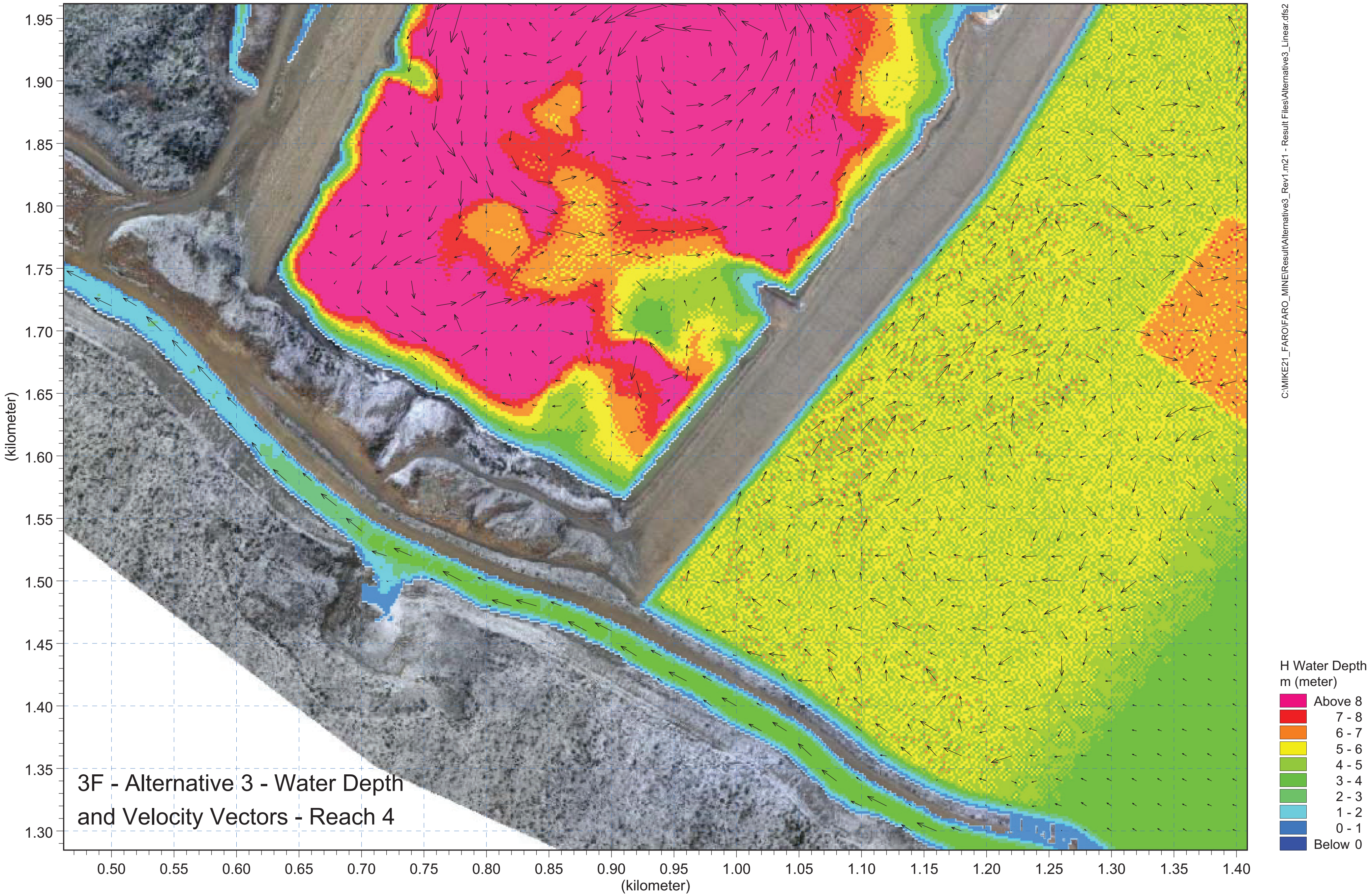
(kilometer)
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
2.00
2.05
2.10
2.15
2.20
2.25
2.30
2.35
2.40
2.45
2.50
2.55
2.60
2.65
2.70
2.75
2.80
2.85
2.90
(kilometer)
H Water Depth
m (meter)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
1/1/1990 4:55:00 PM
Scale 1:3762


C:\MIKE21_FARO\FARO_MINE\Result\Alternative3_Rev1.m21 - Result Files\Alternative3_Linear.dfs2
3E - Alternative 3 - Water Depth and Velocity Vectors - Reach 3
(kilometer)
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
1.25 1.30 1.35 1.40 1.45 1.50 1.55 1.60 1.65 1.70 1.75 1.80 1.85 1.90 1.95 2.00 2.05 2.10 2.15
(kilometer)
H Water Depth
m (meter)
Above 8
7 - 8
6 - 7
5 - 6
4 - 5
3 - 4
2 - 3
1 - 2
0 - 1
Below 0
1/1/1990 4:55:00 PM
Scale 1:3762



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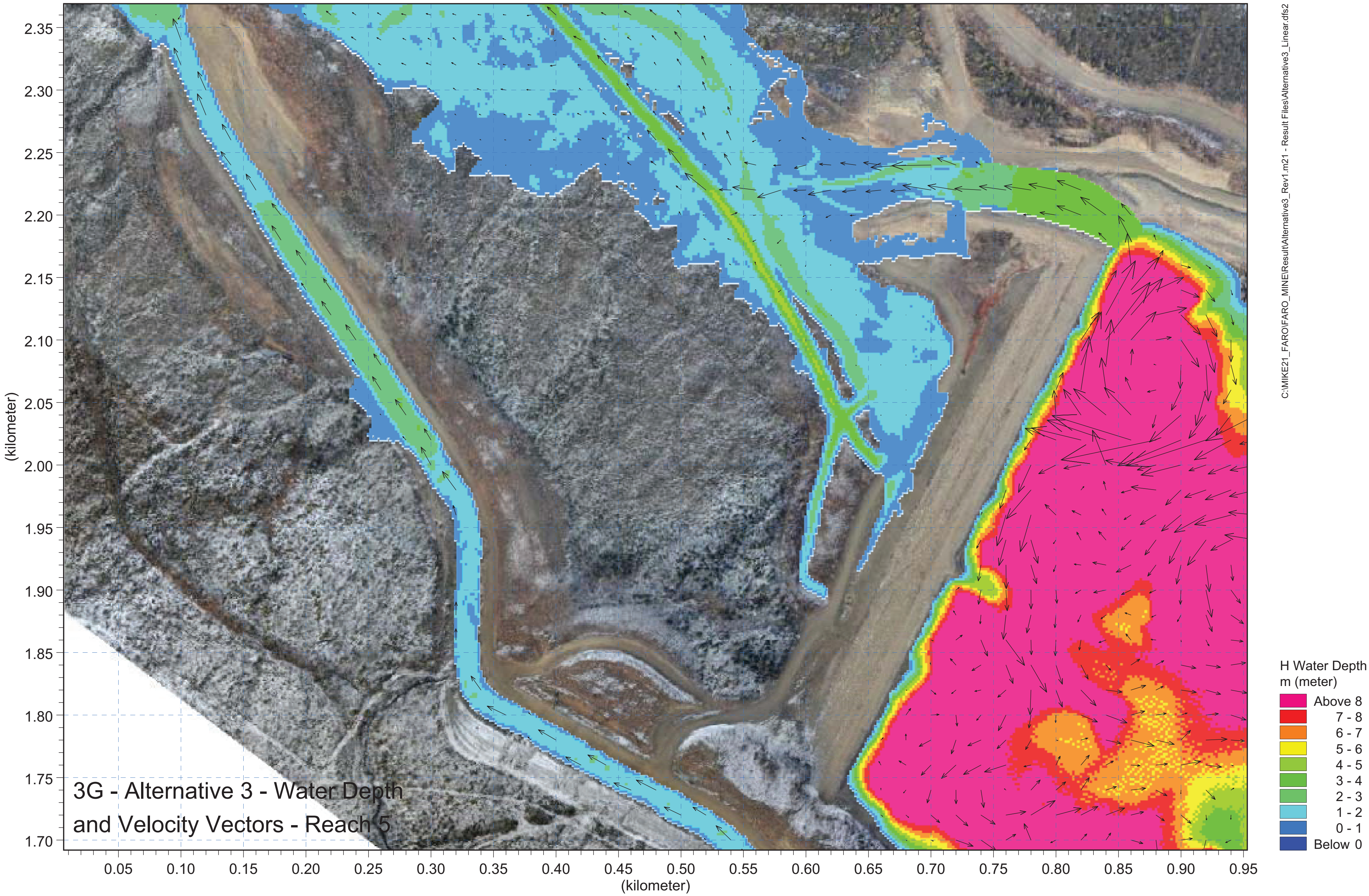
Scale 1:3762



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Scale 1:3762

Appendix C
Detailed Descriptions of Potential Failure Modes (Credible and Significant Only)

FARO MINE CLOSURE PROJECT – RCTA ALTERNATIVES EVALUATION

POTENTIAL FAILURE MODES ANALYSIS

PFM1F-1

Loading: Flood

Description: Overtopping the RCD dyke

The water level in the RCDC rises to a level near the crest of the dyke on the right side of the channel. Prior to initiation of overflow wave action impacts on the upstream face of the dyke and water begins to surge over the crest of the dyke. The high water level is caused by exceeding the design channel capacity, channel blockage from woody debris.

Steady overtopping of the dyke from a water level that exceeds the level of the dyke crest would result in a breach at some location along the alignment of the dyke as a result of the erosive action of the overtopping flow. The breach would progress laterally from the initiation nick point. The initiation of the breach may occur at or near the crest of the dyke and progress downward by surface erosion, or it may occur near the toe of the dyke and undercutting will progress upslope toward the crest until there is a lowering of the crest. Loss of crest will result in a breach of the embankment. The breach will be a function of the depth and duration of overtopping/overflow and the erosion characteristics of the embankment material.

Prior to steady overtopping of the dyke wave action can cause damage to the upstream slope of the embankment with the potential to lower the level of the crest. Furthermore, as the water surface rises the waves will eventually overwash the crest, and the surging overwash action can cause significant erosion of the crest and downstream slope of the dam causing the dam to breach.

Background and Evidence:

The existing dyke has performed well over the past 40 plus years but has never flowed full. On one occasion a one kilometer section of the dyke was raised up to 1 meter to mitigate the effects of dyke embankment settlement. The dyke raise was completed with granular material only, but the raised dyke will re-establish an impermeable zone and add filters. A typical section of the dyke shows a primarily granular embankment with a sloping core layer. It appears that the core was designed to extend to the crest of the dyke but along the length of the raised portion only granular material was used to make the raise.

Conditions making PFM Likely Or Unfavorable Factors	***Conditions making PFM Unlikely Or Favorable Factors***
• There is a somewhat unquantified potential source of woody debris. •	• The new dyke will be properly designed with appropriate zoning. • The new design will include a minimum of 0.6 meters of freeboard. • It appears that the greatest potential for icing would not occur during the times of the year associated with extreme flood events. • The plan form of the channel will be modified to reduce restrictions/corners to reduce water surface surging.

*** - Major Contributing Factors**

Knowledge Gaps and uncertainty: • The performance of the water surface with respect to surging is a source of uncertainty..
Potential Risk Reduction Actions
Ability to Detect Failure Mechanisms: •
Ability to Intervene: •
Interim Risk Reduction Measures: •
Permanent Risk Reduction Measures: •
Paste and number figures, photos, sketches and other key documents referred to above

FARO MINE CLOSURE PROJECT – RCTA ALTERNATIVES EVALUATION
POTENTIAL FAILURE MODE ANALYSIS
PFM1F-2/PFM2F-4/PFM3F-3

Loading: Flood

Description: Piping and slope stability failure of the RCD dyke causing releases into side channel, or onto the riprap apron and/or onto tailings cover downstream from the side channel exit, resulting in damage and breaching of the tailings cover and release of tailings

Seepage occurs through the embankment. Cracks or high permeability zones in the embankment cause a high phreatic surface such that seepage occurs at the downstream toe or slope. Since there are no chimney filter/drains in the embankment, the downstream slope and toe represent an unprotected exit face. exists or where permeable zones. Because of the concentration of flow lines at the exit face, a critical gradient develop that cause detachment of soil particles. Since there is an unprotected exit, i.e., backward erosion starts, resulting eventually in piping.

Cohesive layers layers in the foundation or embankment will hold a roof, there is no upstream zone to provide either crack filling action or to limit the flow and the piping process progresses. The "pipe" enlarges and a breach of the dam will occur by:

1) Gross enlargement of the pipe
2) Increase of pore pressure in the downstream slope of the dam
3) By sinkhole development along the upstream face of the dam including the dam crest.

All three breach mechanisms work to lower the crest and ultimately lead to release of reservoir pool as the crest is lowered.

Background and Evidence:
The embankment has performed satisfactorily for more than forty years.

Conditions making PFM Likely Or Unfavorable Factors	***Conditions making PFM Unlikely Or Favorable Factors***
• Presence of potentially permeable material in largest (downstream) portion of the embankment. • The channel may not have experienced large floods that really have tested the embankment yet. • There is no cutoff wall in the foundation but the seepage liner extended below the bottom of the channel (see Figure below) which will tend to lower the seepage gradient.	• High water levels will only be a transient/temporary loading condition • Cutoff wall and geomembrane barrier system creates a long seepage path, which will tend to lower the seepage gradient. • Acceptable performance to date.

*** - Major Contributing Factors**

Knowledge Gaps and uncertainty:
• The existence of erodible material.

• Distribution of seepage gradient along a potential seepage (piping) path.

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

None

Ability to Intervene:

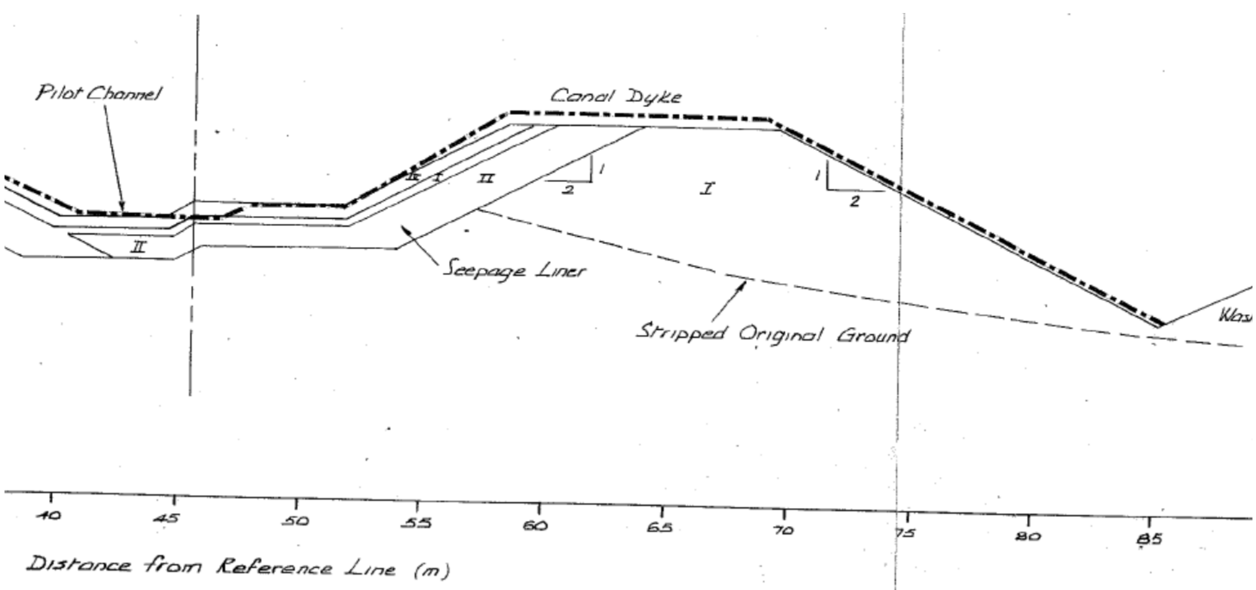
None

Risk Reduction Measures:

Anticipated Warning Time and Breach Width:

Pool Elevation		Warning Opportunity Time:	Breach Formation Time:	Breach Width:
Normal				
Spillway				
Unusual				
PMF				
Other				

Figures:



NAME OF DAM
POTENTIAL FAILURE MODES ANALYSIS
PFM1F-9

Loading: Flood

Description:

Channel blockage by woody debris during a large flood which results in a reduction in the capacity of the channel.

Large rainfall and larger floods results in local bank erosion and forces on the vegetation that will erode the soil at the base of the tree which becomes woody debris. A woody debris mat will form at a local constriction or snag points and reduce the flow capacity of the channel, this would have the effect of:

1) If the woody mat forms upstream of the diversion it could result in an outburst flood that would be larger than the design water flood and result in overtopping the RCDC.
2) If the woody debris forms a mat in the diversion this will raise the stage upstream of the woody mat which could then overtop the diversion bank depending on the flood size and the amount of blockage.

Overtopping of the RCDC dyke would divert water down the slope of the 1980 portion of the dyke leading to erosion through the tailings cover and carrying eroded tailings past the Intermediate Dam. If the overflow leads to failure of the RDCD dyke could result in overwhelming of the existing spillway and breaching of the ID.

Background and Evidence:

Typical occurrence during large floods in a treed basin. The scale of the problem has not been quantified.

Conditions making PFM Likely Or Unfavorable Factors	***Conditions making PFM Unlikely Or Favorable Factors***
• Removal of the north fork rock drain will expose additional source of woody debris.	• The larger Alternative 1 channel will be a much lesser constriction for catching and building up debris. • May not be enough large debris to block the larger channel. Larger floods have thecapacity to develop larger woody debris mats, but also have larger capacity to transmit downstream. • Smoothing the plan geometry in the RCDC will reduce the amount of points that debris will start to develop.

*** - Major Contributing Factors**

Knowledge Gaps and uncertainty:

- A detailed study of this type of hazard has not been completed for the specifics of this basin.
- Maintenance of the channel by removal of vegetation in the channel will be required to reduce the amount of debris mat locations.

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

- Not possible

Ability to Intervene: • Not possible
Interim Risk Reduction Measures: •
Permanent Risk Reduction Measures: • Install a basis to collect the debris upstream of the start of the diversion
Paste and number figures, photos, sketches and other key documents referred to above

RCD
POTENTIAL FAILURE MODES ANALYSIS
PFM1F-4, PFM2F-6, PFM3F-5 ICING IN THE RCD THAT BLOCKS THE CHANNEL

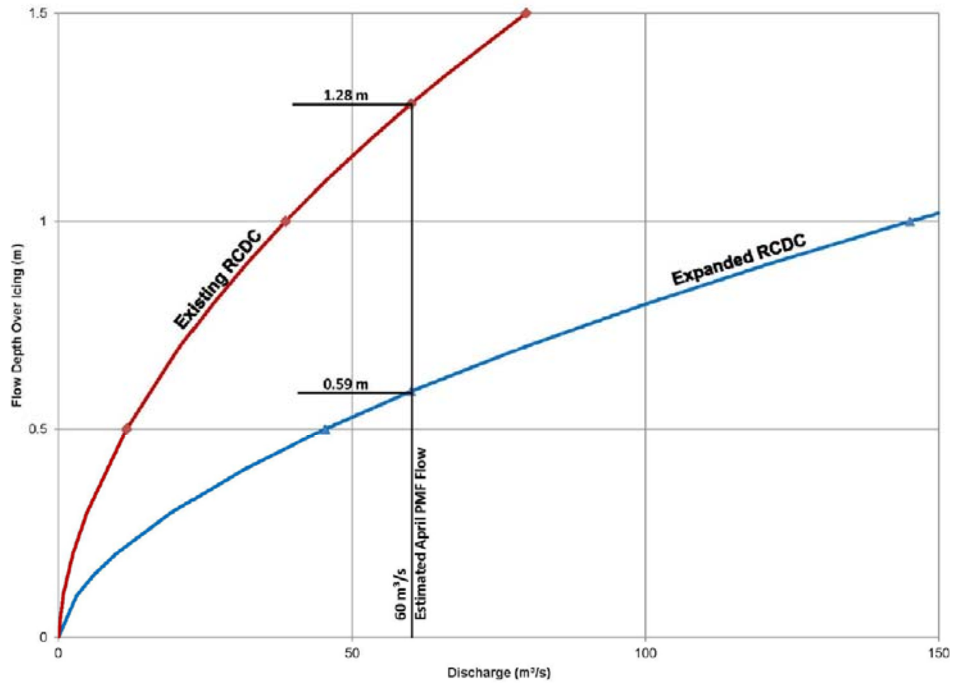
Loading: Flood

Description: Following a cold winter, icing occurs in the RCD which creates a block in the channel that significantly reduced that channel capacity. The icing occurs as a result of side hill inflows at selected locations along the channel, during winters with low temperature and low snowfall Veldman (2012). An April rain on snow flood causes high flows into the RCD which is blocked by the icing, causing the channel dyke to be overtopped. The overflow would cascade down the slope of the RCD and onto the covered tailings area scouring the cover and exposing tailings which would then be transported downstream. The potential for enough icing to block the channel to April flood flows would be higher for the existing case and Alternatives 2 and 3 than for Alternative 1.

Background and Evidence: Cases of icing have been well document in the Yukon and parts of Alaska but in the 30 year history of the RCDC icing has not caused a flooding problem. Historical temperature and flood flow data demonstrates that an RCD icing failure mode would occur during a high rain on snow flood event during the month of April. An April PMF event would have a flow of about 60 m^3/sec compared to the PMF flow of 674 m^3/sec. Low temperature events that could cause icing to occur are independent from April flooding events.

Conditions making PFM Likely Or Unfavorable Factors	***Conditions making PFM Unlikely Or Favorable Factors***
• A spill over the RCD would be an uncontrolled spill onto the tailings area	• A pilot channel will reduce the effects of icing. • Overflow of the RCD from blockage caused by icing would require the joint occurrence of rare icing and flooding events. These two events are independent, and therefore, would require the joint occurrence of two rare and independent events. • The "April PMF" event is only about 60 m^3/sec. • The covered tailings area would be frozen and the cover would be resistant to scour. There is a low probability of the loss of tailings from overflow of the RCD dyke during frozen conditions. • Overtopping the RCD dyke would not result in a catastrophic failure of the dyke. Thus, flow onto the tailing would only be a small fraction of the flow in the channel with an April PMF of 60 m^3/sec and likely much less than the threshold flow required to cause loss of the cover and tailings. • Overtopping the RCD dyke would not cause the sufficient flow to overtop the Intermediate Dam.

* - Major Contributing Factors
Knowledge Gaps and uncertainty: • Depth of icing.
Potential Risk Reduction Actions
Ability to Detect Failure Mechanisms: • The icing would be detectible and the personnel would be available to remove the blockage during routine maintenance. A rain on snow flood event would be predicable in a time frame of several days to a week.
Ability to Intervene: • Regular maintenance is part of the long term operational plan including keeping the access roads along the RCDC dyke cleared.
Interim Risk Reduction Measures: • Remove icing induced blockage through regular maintenance.
Permanent Risk Reduction Measures: • A pilot channel will be designed and constructed which reduces the effects of icing.
Paste and number figures, photos, sketches and other key documents referred to above



Matrix Solutions Inc. ENVIRONMENT & ENGINEERING	SITE VISIT DATE: June 26 – 27, 2012			CLIENT: CH2M HILL CANADA LIMITED
	JOB No.: 15706-522			FARO MINE - YUKON
	FIELD: WMV	DRAWN: RC	CHECK: WMV	ROSE CREEK DIVERSION CHANNEL SUMMARY OF RCDC FLOW CAPACITY WITH ICE
				Figure 7

FARO MINE CLOSURE PROJECT – RCTA ALTERNATIVES EVALUATION
POTENTIAL FAILURE MODES ANALYSIS
PFM2F-10 / PFM3-9

Loading: Flood

Description:

Channel blockage by woody debris during a large flood which results in a reduction in the capacity of the channel.

Large rainfall and larger floods results in local bank erosion and forces on the vegetation that will erode the soil at the base of the tree which becomes woody debris. A woody debris mat will form at a local constriction or snag points and reduce the flow capacity of the channel, this would have the effect of:

1) If the woody mat forms upstream of the diversion it could result in an outburst flood that would be larger than the design water flood and result in overtopping the RCDC.
2) If the woody debris forms a mat in the diversion this will raise the stage upstream of the woody mat which could then overtop the diversion bank depending on the flood size and the amount of blockage. This blockage can also occur in the side channel spillway which would increase the stage in the side channel and the existing RCDC.

Over topping of the RCDC dyke would divert water down the slope of the 1980 portion of the dyke leading to erosion through the tailings cover and carrying eroded tailings past the Intermediate Dam. If the overflow leads to failure of the RDCD dyke could result in overwhelming of the existing spillway and breaching of the ID.

Background and Evidence:

Typical occurrence during large floods in a treed basin. The scale of the problem has not been quantified.

Conditions making PFM Likely Or Unfavorable Factors	***Conditions making PFM Unlikely Or Favorable Factors***
• Removal of the north fork rock drain will expose additional source of woody debris. • The relatively small existing channel and curves in the planform geometry of the RCDC will cause potential snag points to start woody debris mat.	• May not be enough large debris to block the larger channel. Larger floods have the capacity to develop larger woody debris mats, but also have larger capacity to transmit downstream. • Debris can be diverted over the side channel spillway reducing the amount of debris in the lower RCDC channel.

*** - Major Contributing Factors**

Knowledge Gaps and uncertainty:

- A detailed study of this type of hazard has not been completed for the specifics of this basin.
- Maintenance of the channel by removal of vegetation in the channel will be required to reduce the amount of debris mat locations.

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

- Not possible

Ability to Intervene: • Not possible
Interim Risk Reduction Measures: •
Permanent Risk Reduction Measures: • Install a basis to collect the debris upstream of the start of the diversion
Paste and number figures, photos, sketches and other key documents referred to above

FARO MINE CLOSURE PROJECT – RCTA ALTERNATIVES EVALUATION
POTENTIAL FAILURE MODE ANALYSIS
PFM2F-15

Loading: Flood

Description: Erosion and breaching of the tailings cover downstream from the side channel and riprap apron prior to having a dissipating pool formed.

Due to differential settlements of the tailings cover and the riprap apron, flow depths and velocities over the apron may not be uniform. High localized flow velocities over the riprap start dislodging and transporting material from the riprap layer. Scour pockets are formed that cause higher local velocities that accelerate the erosion process. Progressive scour of the riprap layer and the tailings cover layer occurs eventually resulting in breaching of the cover and transport of tailings downstream.

Another mechanism is that flow is not contained within the riprap apron because of the differential settlement and spills onto the unprotected tailings cover north of the apron. The velocities and energy of this water is high enough for rapid erosion and channelization in the tailings cover. Once the tailings cover is breached there is high likelihood of progression/enlargement of the breach and high potential for erosion and transport of tailings. Loss of tailings results in detrimental environmental consequences.

Background and Evidence:

-

Conditions making PFM Likely Or Unfavorable Factors	***Conditions making PFM Unlikely Or Favorable Factors***
• There is much uncertainty regarding differential movements of the tailings cover and the riprap apron in this location, but it is anticipated that differential settlements may be as much as about 1m or more. • Relatively thin layers of riprap can be disturbed over the long design life by vegetation, climatic conditions, long-term settlement, etc. • Uncertainty about maintenance of the riprap materials over such a wide channel for a very long time	• Preliminary HEC-RAS analysis results indicate that the velocities in the channel will be about 3 to 4 m/s • A pool will form relatively rapidly and be able to dissipate energy of the floodwater at this location • Side channel will be founded on till or gravel foundation and will be constructed so that settlement can be controlled.

*** - Major Contributing Factors**

Knowledge Gaps and uncertainty:

- Final velocities and riprap design

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

- Visible and visual inspection for riprap loss after a large flow event.

Ability to Intervene:

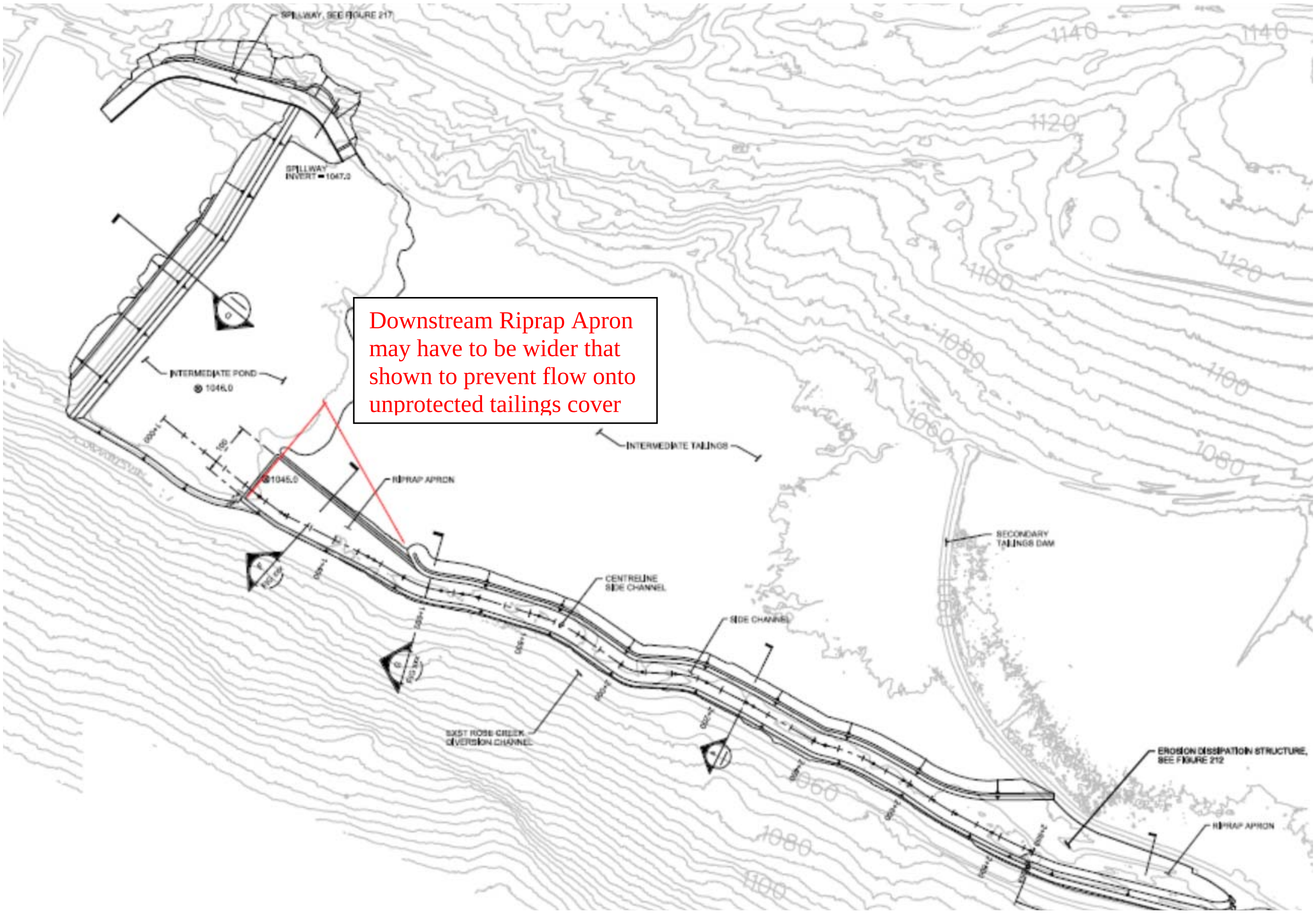
- Ability for intervention is low.

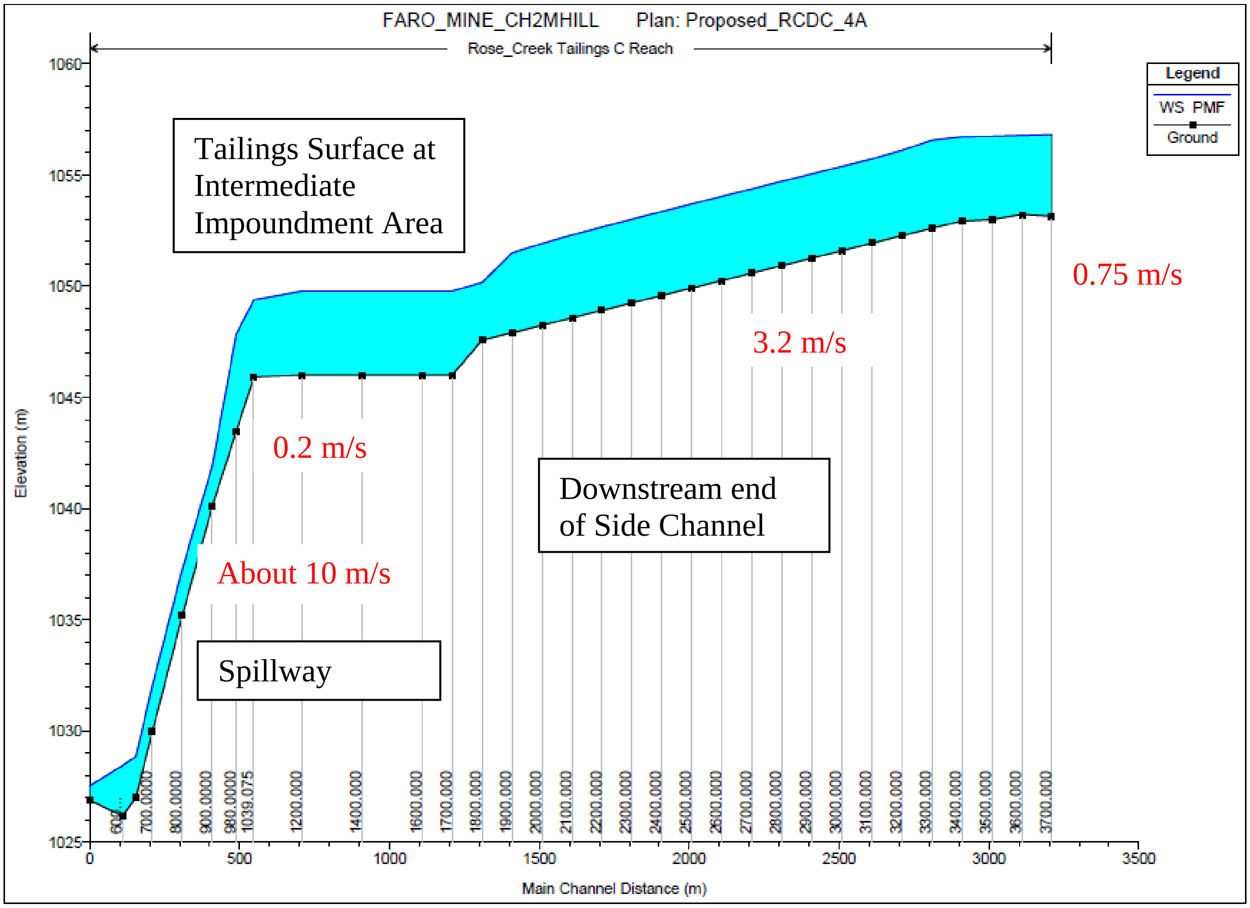
Risk Reduction Measures:

- Maintain riprap; fill in depressions and locations of localized riprap loss
-

Anticipated Warning Time and Breach Width:				
Pool Elevation		Warning Opportunity Time:	Breach Formation Time:	Breach Width:

Figures:


SPILLWAY, SEE FIGURE 217
SPILLWAY
INVERT = 1047.0
INTERMEDIATE POND
⊗ 1046.0
⊗1045.0
RIPRAP APRON
Downstream Riprap Apron may have to be wider that shown to prevent flow onto unprotected tailings cover
INTERMEDIATE TAILINGS
SECONDARY
TAILINGS DAM
CENTRELINE
SIDE CHANNEL
SIDE CHANNEL
EAST ROSE CREEK
DIVERSION CHANNEL
EROSION DISSIPATION STRUCTURE,
SEE FIGURE 212
RIPRAP APRON
1140
1140
1120
1120
1100
1100
1080
1080
1060
1060
1080
1100


FARO_MINE_CH2MHILL Plan: Proposed_RCDC_4A
Rose_Creek Tailings C Reach
Legend
WS PMF
Ground
Tailings Surface at Intermediate Impoundment Area
0.75 m/s
3.2 m/s
0.2 m/s
Downstream end of Side Channel
About 10 m/s
Spillway
Elevation (m)
Main Channel Distance (m)

FARO MINE CLOSURE PROJECT – RCTA ALTERNATIVES EVALUATION
POTENTIAL FAILURE MODE ANALYSIS
PFM3F-13

Loading: Flood

Description: Overbank flow occurs when exceeding the capacity of the dedicated 120m-wide riprapped swale, and flow in preferred flow paths leading to channelization, erosion and eventual breaching of the tailings cover.

Due to differential settlements of the tailings cover and the single dedicated riprapped swale (120m wide), flow depths and velocities over the swale are not uniform. High localized flow velocities over the riprap start dislodging and transporting material from the riprap layer. Scour pockets are formed that cause higher local velocities that accelerate the erosion process. Progressive scour of the riprap layer and the tailings cover layer occurs eventually resulting in breaching of the cover and transport of tailings downstream.

Another mechanism is that flow is not contained within the swale because of the differential settlement, and flows start to spill onto the unprotected tailings cover adjacent to the swale at certain locations. Where it flows onto the tailings cover, the velocities and energy of this water is high enough for rapid erosion and channelization in the tailings cover. Once the tailings cover is breached there is high likelihood of progression/enlargement of the breach and high potential for erosion and transport of tailings. Loss of tailings results in detrimental environmental consequences.

Background and Evidence:

- Precedence in nature and on other projects that single dedicated channel (or swale) should have highest chances to succeed.
- Two test pads (16m x 20m and 20m x 10m) were constructed over the tailings – one settled 150 mm and the other 50 mm. The pads were 5 m apart.

Conditions making PFM Likely Or Unfavorable Factors	***Conditions making PFM Unlikely Or Favorable Factors***
• There is much uncertainty regarding differential movements of the tailings cover and the single dedicated swale, but it can be high. The experience with the test pads gives concern with the potential for large differential settlements. • Relatively thin layers of riprap can be disturbed over the long design life by vegetation, climatic conditions, long-term settlement, etc.. • Uncertainty about maintenance of the riprap materials over such a wide swale for a very long time. • Settlement will cause swale depth to decrease over time so that the capacity may be reduced.	• It is anticipated that the velocities in the channel will be less than 3 m/s in the swale and less than 1 m/s for flows spilling over the swale onto the tailings cover. Velocities in channels formed may be significantly higher than for sheet flow? • A pool will form relatively rapidly and be able to dissipate energy of the floodwater at the downstream end.

*** - Major Contributing Factors**

Knowledge Gaps and uncertainty:

- Final velocities and riprap design

Potential Risk Reduction Actions

Ability to Detect Failure Mechanisms:

- Visible and visual inspection for riprap loss after a large flow event.

Ability to Intervene:

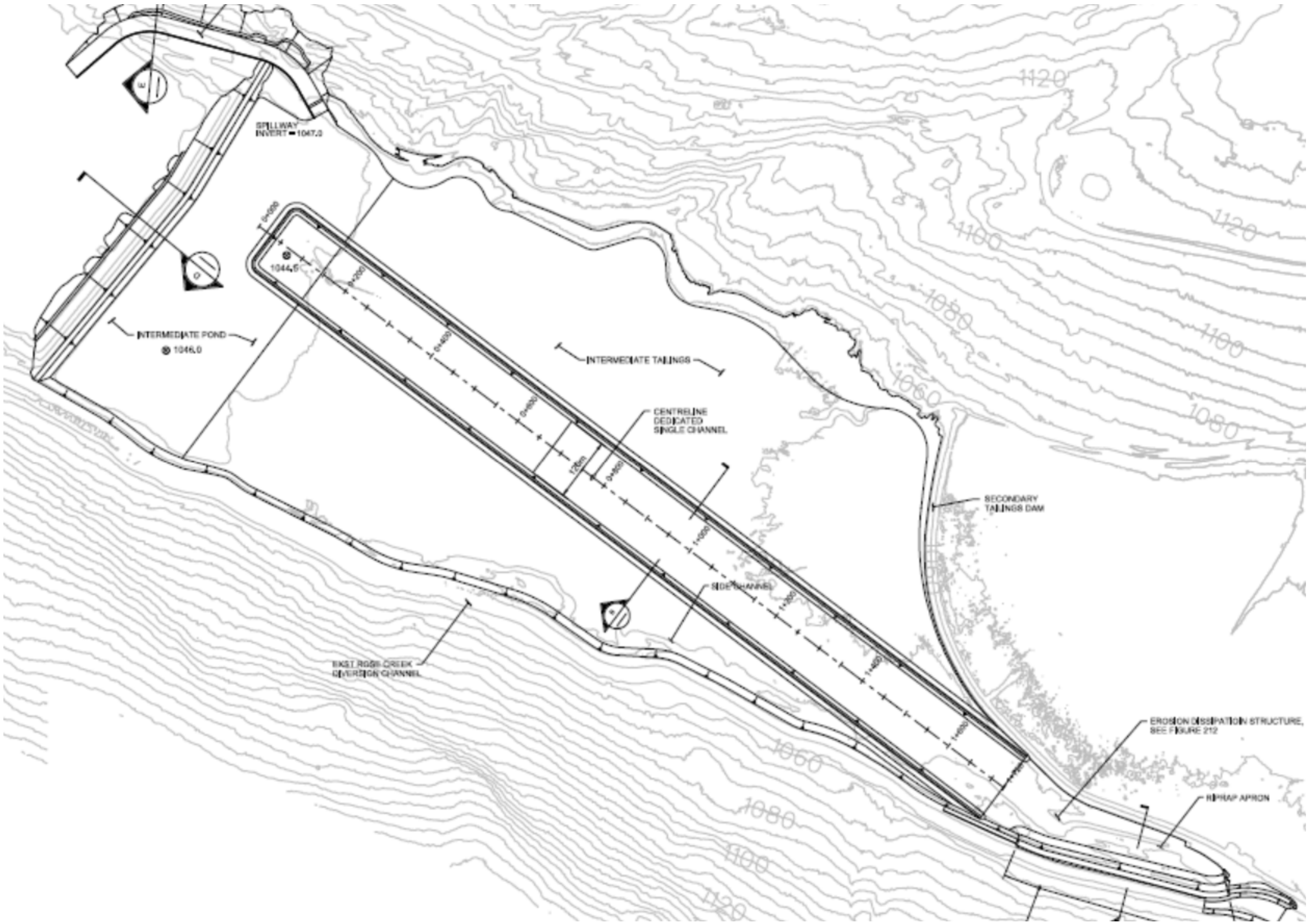
- Ability for intervention is low.

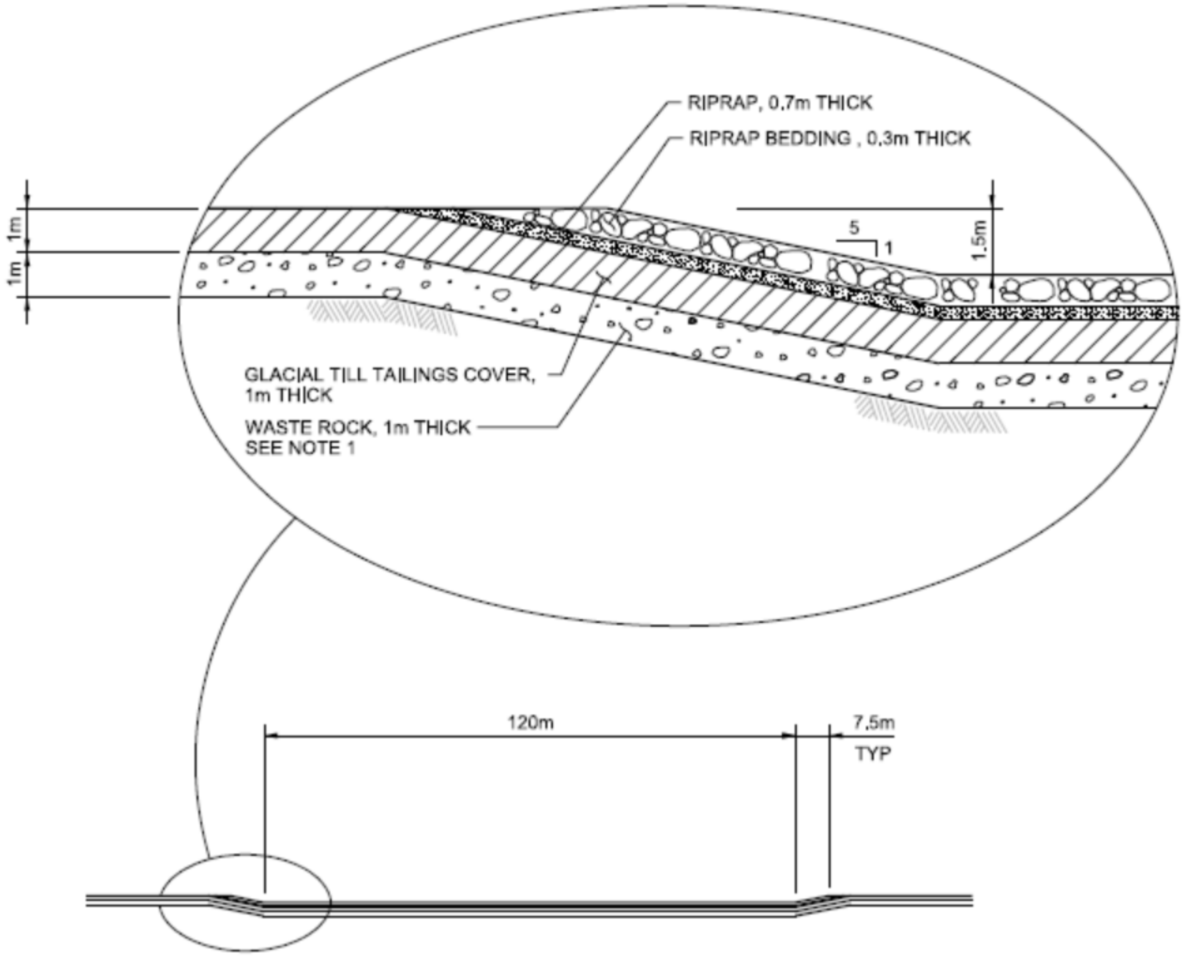
Risk Reduction Measures:

- Maintain riprap; fill in depressions and locations of localized riprap loss
-

Anticipated Warning Time and Breach Width:				
Pool Elevation		Warning Opportunity Time:	Breach Formation Time:	Breach Width:

Figures:


SPILLWAY
INVERT = 1047.0
1120
1100
1080
1060
1044.5
INTERMEDIATE POND
1046.0
INTERMEDIATE TAILINGS
CENTRELINE
DEDICATED
SINGLE CHANNEL
120m
SECONDARY
TAILINGS DAM
SIDE CHANNEL
EROSION DISSIPATION STRUCTURE,
SEE FIGURE 212
RIPRAP APRON



RIPRAP, 0,7m THICK
RIPRAP BEDDING , 0,3m THICK
1m
1m
5
1
1,5m
GLACIAL TILL TAILINGS COVER,
1m THICK
WASTE ROCK, 1m THICK
SEE NOTE 1
120m
7,5m
TYP

Appendix D
Icings White Paper

CH2MHILL

Rose Creek Diversion Channel
Icings White Paper
Final

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Job No: 15706-520

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APPENDICES

Appendix 1 Temperature Data
Appendix 2 Rose Creek Flow Data

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1.0 PURPOSE AND SCOPE OF WHITE PAPER

- Expanding the Rose Creek Diversion Channel (RCDC) from its current 1:500 year flood capacity to handle the Probable Maximum Flood (PMF) is one of the options being considered for the Rose Creek Tailings Area (RCTA).

- In a review of the RCTA options several years ago, concerns were expressed about the impact of the icings on the capacity of the RCDC during the PMF.

- The purposes of this White Paper are to determine:

  – the magnitude of a PMF-type flow in the RCDC when it has maximum icings,

  – whether the RCDC has sufficient capacity to convey that flow

- The scope of this White Paper is to:

  – describe causes of icings,

  – discuss variability of icings from year to year and from location to location in the RCDC,

  – discuss the lessons learned in the last 30 years from the existing RCDC,

  – analyze the change in icings from the existing to an expanded RCDC,

  – outline mitigative design measures and ice removal techniques that could be employed,

  – provide conclusions and recommendations that can be applied to the evaluation of options for the RCTA.

2.0 DESCRIPTION AND CAUSES OF ICINGS

- Icings* are well described in the papers by Carey (1), Kane (2) and Slaughter (3). Icings develop when:

  – winter surface flows, depths and velocities are low causing freezing to the bottom which causes overflows which, in turn, cause icings,

  – permafrost or rock or other impermeable streambed or channel sections force near-surface groundwater flow to the surface thus developing icings,

  – tributary inflow entering a wide river or channel overflows in a floodplain area or on to a river/channel icings generate additional icings.

* Also commonly referred to as Aufeis.

3.0 VARIABILITY OF ICINGS FROM YEAR TO YEAR AND FROM PLACE TO PLACE

- Commonly stated factors that promote significant icings are:
  - low snowfall and low temperatures particularly during the late fall freeze-up period,
  - high base flow prior to freeze-up
- From multi-year monitoring of icings and breakup on numerous river systems in the Arctic by Veldman (4), the following has been observed and concluded:
  - in general the above factors that promote icings are valid,
  - however, at site specific locations along a river system or along the RCDC, contrary weather and flow conditions can generate maximum icings in certain years at certain locations. For example in a cold winter, tributary inflow which overflows the RCDC (see Photos, Figures 1 and 2), will freeze quickly and generate maximum icings at or just downstream of the inflow point whereas in a warm winter, the tributary inflow will freeze at a location farther downstream along the RCDC.
- Ice removal from the existing RCDC has been required on several occasions in the last 30 years. The years and locations where this was required are not known and consequently a correlation between ice removal and temperature (Figure 3 and Appendix 1) is not feasible at this time. All other factors being equal, it is reasonable to assume that colder weather generates more icings at some location in the RCDC.
- Winter flows for Rose Creek are not measured and thus cannot be correlated to the severity of icings and the historic need for ice removal. (Note – if historic ice removal data becomes available, an attempt will be made to correlate it with regional winter flow data – see Section 5).

4.0 IMPACT OF RCTA PLAN AND EXPANDED RCDC ON WINTER FLOW AND POTENTIAL FOR ICINGS

- Winter flow in the RCDC will be decreased compared to historic conditions during mining as:
  - the present plan is to divert Faro Creek into the North Valley Wall Interceptor Ditch during mining. Until now, it has been diverted into the North Fork of Rose Creek. The diversion will result in an approximate 8% reduction in drainage area and thus winter base flow,
  - winter flow from the upper main stem of Rose Creek have been reduced since the 2006 removal of the Fresh Water Supply Dam which, when the mine was operating, released flow in the winter some of which bypassed the withdrawal point and flowed into the RCDC,
  - with the planned removal of the North Fork Rose Creek rock drain on the Haul Road, ponding upstream of the Haul Road will be eliminated and thus early winter flows into the RCDC will be decreased,
- The local tributary drainage area and thus local inflow into the RCDC (Figures 1 - 2) will not be affected by an expanded RCDC.

- An uphill side “pilot” channel in the RCDC, incorporated in the design of the existing channel for aquatic and ice control reasons, will be replicated in the expanded RCDC.

- The expanded RCDC cross section will be substantially larger than that of the existing channel (Figure 4).

- Considering a reduced winter flow in the future and a significantly larger channel, it follows that icing buildup in the expanded RCDC option will be less of a concern than in the present smaller RCDC.

5.0 MAGNITUDE OF A PMF TYPE FLOOD APRIL WITH ICE IN THE RCDC

- From an analysis of the temperature data (Appendix 1), few days of significant freezing occur in April.

- According to the Mayo studies (5) “… the typical seasonal pattern of a river in the Yukon’s Interior Hydrologic Region, is rapid increases in May and June…”

- From flow hydrographs of nearby watersheds in the Faro to Mayo area that have continuous flow data (Figures 5 and 6), it is very apparent that flows increase by mid to late April.

- Thus it is reasonable and sound to conclude from the regional flow data that the annual PMF, the design flood for an expanded RCDC, will not occur in April when winter icings are still present in the RCDC.

- A PMF-type flood in April was computed as follows:

  – the April 1-30 1:500 year flood for the RCDC was computed from the flow data from the Hess and Beaver rivers (for the April 1-30 perod, the Beaver River flows were significantly higher and thus used),

  – the April PMF for the RCDC was computed using the ratio of the annual PMF to theannual 1:500 year flood,

  – the resultant estimated April 1-30 PMF for the RCDC is approximately 60 m^3/s.

6.0 CAPACITY OF EXPANDED RCDC CHANNEL WITH ICE WITH AN APRIL PMF

- The closure plan for the Faro Mine will involve on-going operations, monitoring and maintenance. Equipment and personnel will be onsite continuously. Therefore the removal of ice from RCDC, if and when necessary, is a feasible and practical maintenance activity – equipment and operators involved in certain "summer only" activities such as road maintenance could be deployed to remove ice from the RCDC in March.

- Ice removal in late March, if necessary, can be achieved using conventional equipment such as a backhoe or a dozer or a grader fitted with teeth and a heavy duty snow blower. As the ice is ground-fast, equipment operation can be done safely on the icing.

- Assuming no downcutting of the ice due to flow in April or degradation due to melting temperatures, the over-ice capacity of the RCDC for various freeboard values (vertical distance between the top of the dyke on the tailings side versus top of ice) ranging from 0.5 m to 1.5 m is illustrated on Figure 7.

- From these relationships, it is apparent that, with the conservative assumptions as noted above, the capacity of the expanded RCDC with a freeboard of 1.0 m will exceed the estimated April PMF-type flood.

7.0 IMPACT ON EXPANDED RCDC CHANNEL ASSUMING NO ICE REMOVAL

- If the entire winter RCDC flow is converted to ice during the freezing period, it is expected that all or portions of the RCDC could ice over to the top of the dyke on the tailings side during some winters. In reality, especially at the beginning of the winter, a high percentage of the Rose Creek flow is expected to be conveyed downstream. As the winter season progresses, flows decrease (see Figures 5 and 6).

- Icings that overtop the tailings-side dyke and flow into the tailings area will, from experience with similar overflow conditions in the Arctic, not cause any erosion as the minimal overflow depth occurs over frozen ground and snow.

- In the maintenance of the RCTA, it is assumed that the RCDC dyke will be maintained for year-round access. Common icing control measures for roads in the Arctic such as a snow berm or a snow fence lined with a heavy-duty poly material can be used to prevent overflow of the dyke/maintenance road.

- If maximum ice buildup occurs in specific areas, from year to year, downstream of the local inflow locations for example, raising of the dyke/maintenance road may be required and prudent in those specific areas.

- Icings develop over time, unlike a major runoff event which can occur very rapidly in a small watershed. The impact of overflow in April re: downcutting of the RCDC icings, can be monitored over the years and mitigative measures if necessary implemented in a timely manner.

- Assuming no ice removal as an initial design basis, is expected to have no significant design or environmental consequences for the RCTA.

8.0 CAPACITY OF EXISTING RCDC WITH ICE

- The capacity of the existing RCDC to store icings and convey high April flows, with or without ice removal, is significantly less than that of the expanded RCDC as:
  - the width and depth and thus the storage capacity of the existing RCDC is significantly lower (Figure 4),
  - the flow into the existing RCDC will be the same as that into the expanded RCDC
- To convey the 1:500 year April flood in the existing RCDC computed to be about 12 m^3/s, a freeboard of about 0.5 m is required (Figure 7).
- As Options 2 and 3 are designed for the annual PMF minus the annual 1:500 year flood, overtopping of the existing RCDC in April due to icings and high flow would have no negative impact on the design and functionality of these two Options. From an environmental perspective however the impact of icings would be more frequent spillage into the tailings area.

9.0 CONCLUSIONS

- The existing RCDC provides a 30 year prototype model for icing conditions. Ice removal prior to breakup has been required at times (frequency and locations to be determined if the data is available).
- Future local and Rose Creek winter flows into RCDC, which generate the icings, will be equal to and less than historic flows respectively.
- The expanded RCDC (width and depth) will provide a significantly greater storage capacity for icings than the existing RCDC.
- Assuming a minimum freeboard of 0.6 m is ensured at the commencement of the spring freshet on April 1, the expanded RCDC has more than adequate capacity to convey a PMF type flood in the April timeframe even before hydraulic downcutting and melting of the ice occurs.
- More frequent flow overtopping in April, due to icings, could occur with the existing RCDC. From an environmental viewpoint, more frequent than intended spillage into the RCTA could be a concern.

10.0 RECOMMENDATIONS

- The evaluation of the Options should proceed on the following basis:
  - icings in an expanded RCDC will not, with ice removal if and when necessary to ensure a minimum freeboard of 0.6 m result in overtopping of the RCDC as a result of an April PMF-type flood,
  - icings in the existing RCDC will not affect the integrity of Options 2 and 3 however icings could result in more frequent-than-intended overtopping into the RCTA.

- Whatever option is selected, the need for and scope of an icing mitigation strategy (ice removal by April 1 and/or raising the dyke/access road) should be reviewed in Year 5 and Year 10 and in the additional measures implemented, if necessary. This is believed to be:
  - a cost effective approach
  - a sound design and environmental strategy

11.0 REFERERENCES

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   http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En
7. Various Faro Mine Reports, Flow and Weather.

____

Wim M. Veldman, M.Sc., FEIC, P.Eng.
November 14, 2012

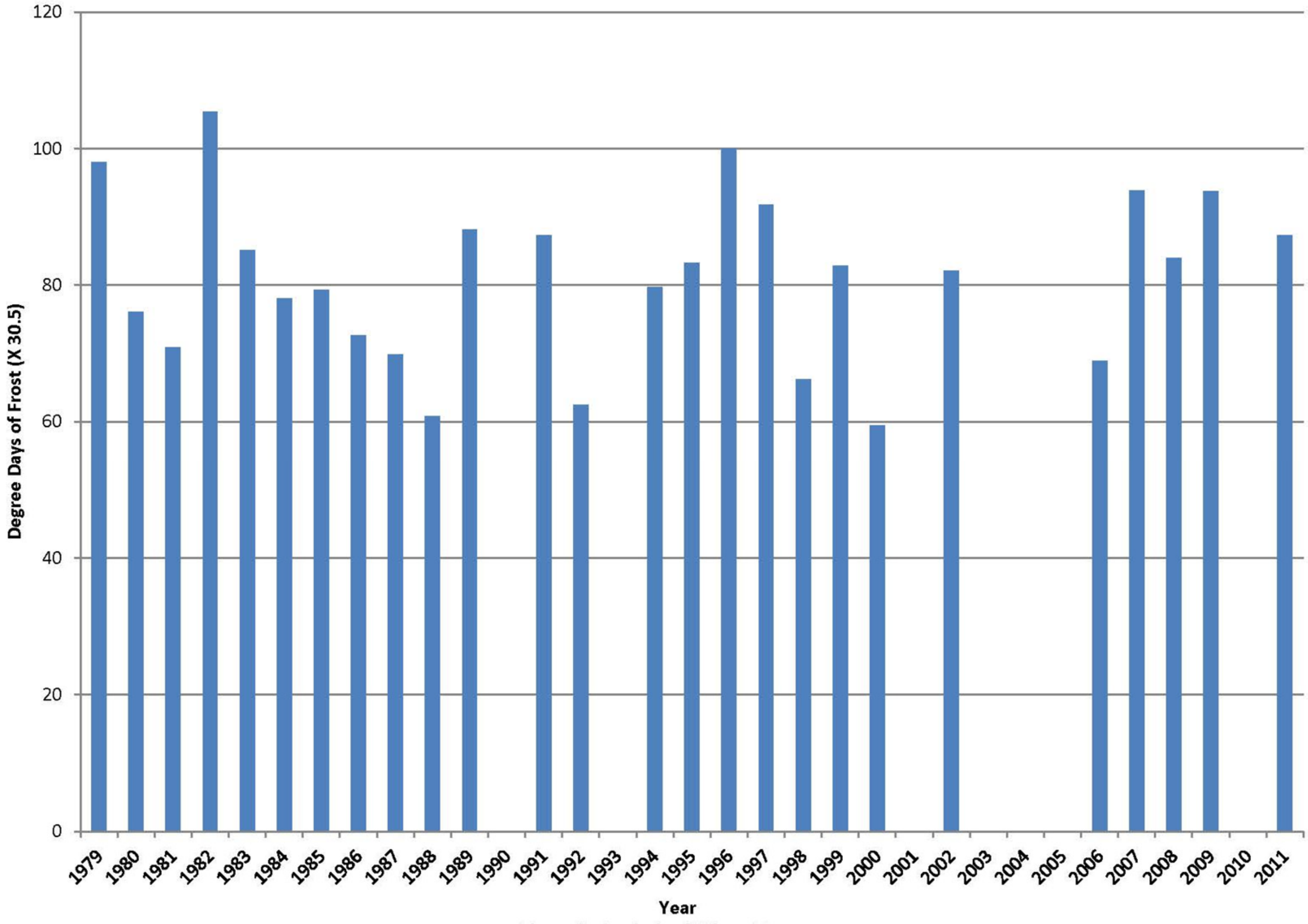
Photo 1: (0900, WMV, June 26-27, 2012)
Local inflow into RCDC opposite the Secondary Containment Dyke (approx. Station ___)

Photo 2: (0898, WMV, June 26-27, 2012)
Local inflow @ BCB 05-05 monitoring site (approx. Station ____)

Matrix Solutions Inc. ENVIRONMENT & ENGINEERING	SITE VISIT DATE: June 26 – 27, 2012			CLIENT: CH2M HILL CANADA LIMITED
	JOB No.: 15706-522			FARO MINE - YUKON
	FIELD: WMV	DRAWN: RC	CHECK: WMV	ROSE CREEK DIVERSION CHANNEL SITE PHOTOS OF LOCAL INFLOW — Figure 1

Photo 3: (0922, WMV, June 26-27, 2012)
Significant inflow into the steed drop section (approx. Station ___)

Matrix Solutions Inc. ENVIRONMENT & ENGINEERING	SITE VISIT DATE: June 26 – 27, 2012			CLIENT: CH2M HILL CANADA LIMITED
	JOB No.: 15706-522			FARO MINE - YUKON
	FIELD: WMV	DRAWN: RC	CHECK: WMV	ROSE CREEK DIVERSION CHANNEL SITE PHOTOS OF LOCAL INFLOW — Figure 2



Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

SITE VISIT DATE: June 26 – 27, 2012		
JOB No.: 15706-522		
FIELD: WMV	DRAWN: RC	CHECK: WMV

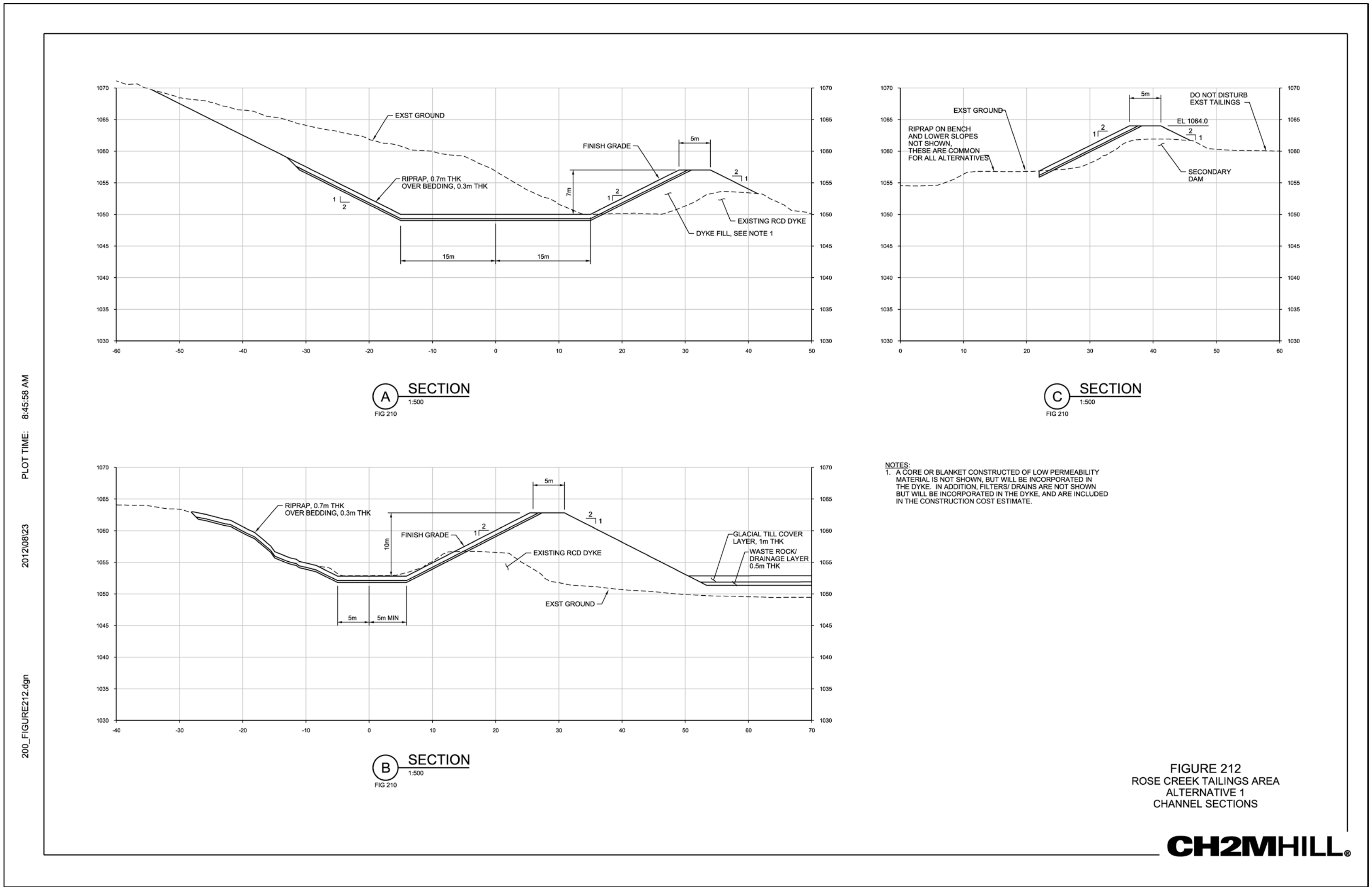
CLIENT:

CH2M HILL CANADA LIMITED

FARO MINE - YUKON

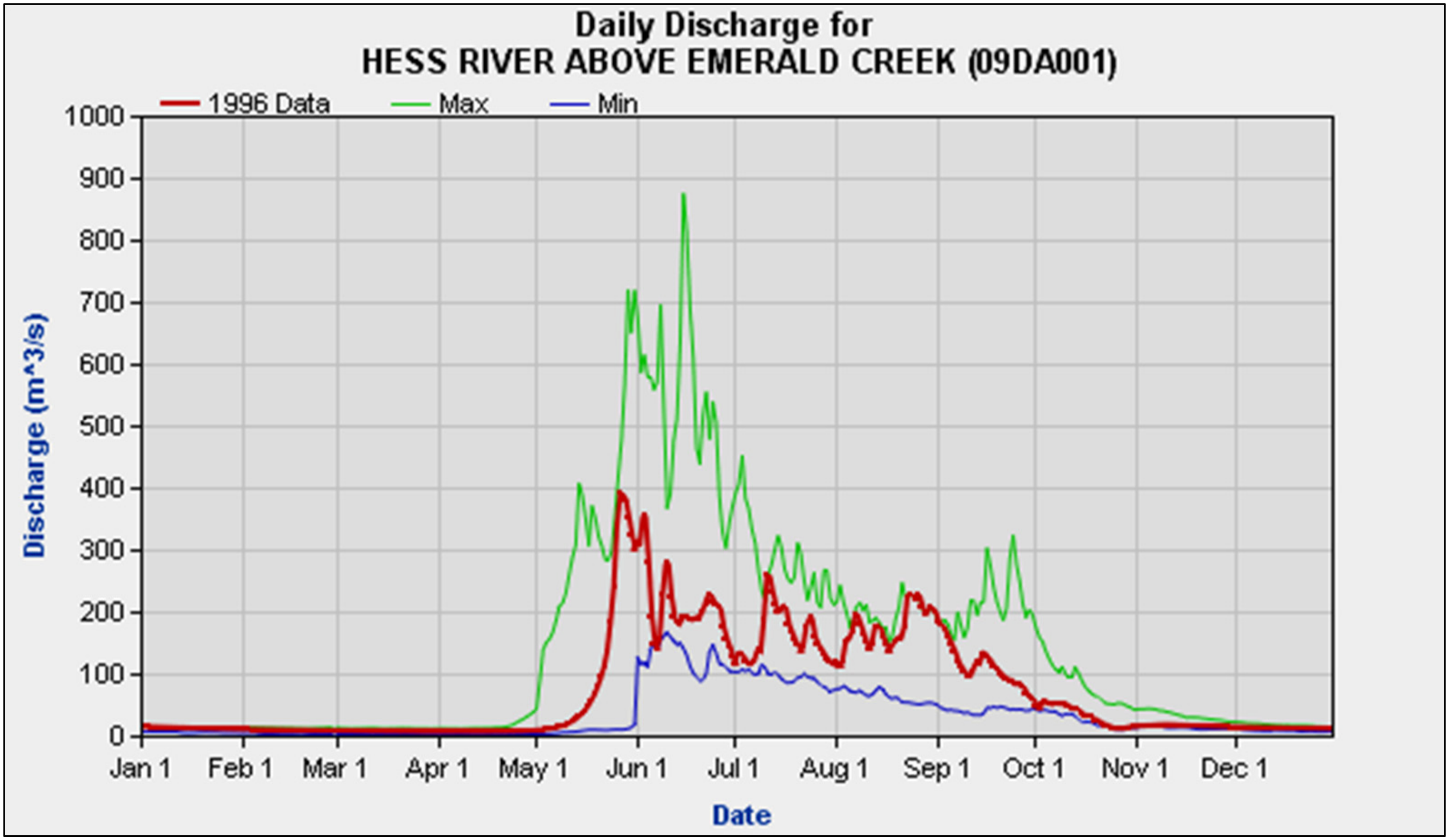
ROSE CREEK DIVERSION CHANNEL
ANALYSIS OF WINTER TEMPARATURE

Figure 3



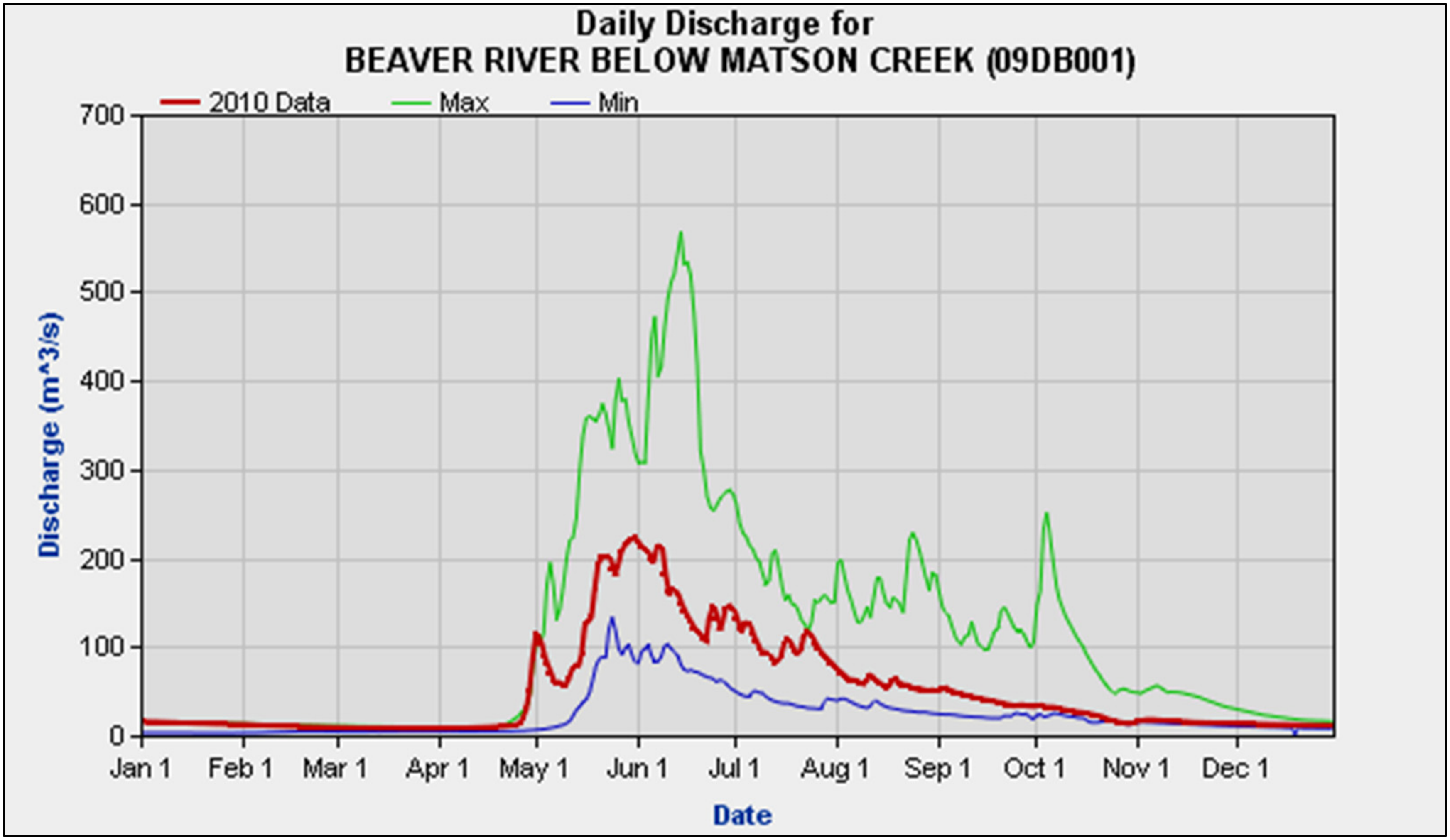
Channel Sections

Matrix Solutions Inc. ENVIRONMENT & ENGINEERING	SITE VISIT DATE: June 26 – 27, 2012			CLIENT:	CH2M HILL CANADA LIMITED
	JOB No.: 15706-522				FARO MINE - YUKON
	FIELD: WMV	DRAWN: RC	CHECK: WMV		ROSE CREEK DIVERSION CHANNEL COMPARATIVE RCDC CROSS SECTIONS
					Figure 4



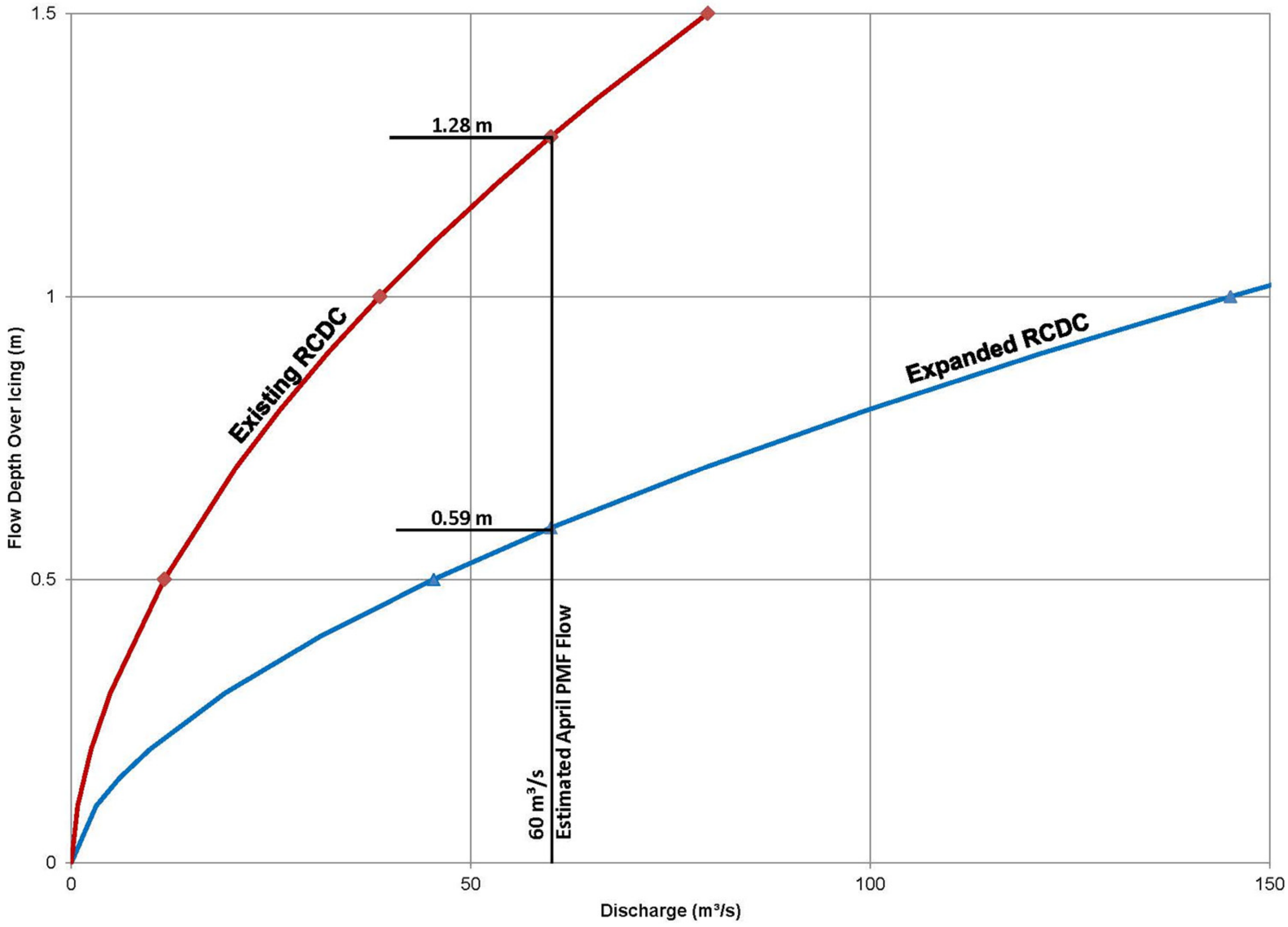
(Water Survey of Canada)

Matrix Solutions Inc. ENVIRONMENT & ENGINEERING	SITE VISIT DATE: June 26 – 27, 2012	CLIENT: CH2M HILL CANADA LIMITED
	JOB No.: 15706-522	FARO MINE - YUKON
	FIELD: WMV / DRAWN: RC / CHECK: WMV	ROSE CREEK DIVERSION CHANNEL HESS RIVER ABOVE EMERALD CREEK – DAILY DISCHARGE PERIOD OF RECORD 1976 TO 1996
		Figure 5



(Water Survey of Canada)

Matrix Solutions Inc. ENVIRONMENT & ENGINEERING	SITE VISIT DATE: June 26 – 27, 2012			CLIENT: CH2M HILL CANADA LIMITED
	JOB No.: 15706-522			FARO MINE - YUKON
	FIELD: WMV	DRAWN: RC	CHECK: WMV	ROSE CREEK DIVERSION CHANNEL BEAVER RIVER BELOW MATSON CREEK – DAILY DISCHARGE PERIOD OF RECORD 1995 TO 2010 Figure 6



Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

SITE VISIT DATE: June 26 – 27, 2012	CLIENT: CH2M HILL CANADA LIMITED
JOB No.: 15706-522	FARO MINE - YUKON
FIELD: WMV / DRAWN: RC / CHECK: WMV	ROSE CREEK DIVERSION CHANNEL SUMMARY OF RCDC FLOW CAPACITY WITH ICE
	Figure 7

APPENDIX 1

TEMPERATURE DATA

Monthly Average Temperature (°C) At Faro Airport, Yukon

Year	Jan	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVE
1977	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	-30.5	
1978	-21.9	-13.9	-7.3	0.3	7.4	12.8	15.3	13.2	8.6	1.6	-15.7	-19.9	**-1.6**
1979	-26.7	-30.6	-5.1	-0.7	6.5	11.7	15.1	14.1	8.7	1.3	-8.2	-21.6	**-3.0**
1980	-26.6	-11.1	-8.6	2.6	8.6	14.5	14.4	11.3	5.1	2.6	-7.6	-34.6	**-2.5**
1981	-8.9	-15.8	-4.0	-3.3	10.0	11.0	14.8	12.8	5.5	-1.2	-8.8	-24.7	**-1.1**
1982	-37.3	-21.2	-13.4	-2.0	5.6	13.9	15.9	11.7	7.6	-3.8	-17.6	-19.0	**-5.0**
1983	-22.7	-15.8	-10.0	1.4	7.7	13.3	14.6	11.0	3.7	-1.9	-14.7	-32.0	**-3.8**
1984	-18.6	-9.7	-3.1	2.4	6.8	11.7	13.7	11.5	5.9	-3.6	-16.6	-24.0	**-2.0**
1985	-9.0	-21.2	-8.5	-1.9	6.2	10.6	14.4	10.4	5.9	-3.9	-24.2	-12.5	**-2.8**
1986	-12.1	-15.6	-8.2	-4.9	5.7	12.3	15.5	10.8	6.4	0.6	-18.6	-12.9	**-1.8**
1987	-14.4	-11.5	-12.4	0.5	7.2	12.1	15.2	12.2	6.4	1.9	-8.4	-14.5	**-0.5**
1988	-21.5	-12.0	-4.4	1.8	8.3	13.3	14.0	12.2	6.0	-1.8	-11.7	-16.1	**-1.0**
1989	-26.4	-19.3	-14.6	1.5	8.9	13.7	16.4	15.0	7.2	-2.6	**miss.**	-13.1	
1990	-20.8	-24.0	-6.0	1.6	8.8	12.8	15.6	13.5	8.2	-3.1	-23.8	-23.1	**-3.4**
1991	-20.0	-11.2	-9.2	1.8	8.5	13.3	14.2	11.0	7.7	-4.6	-13.2	-16.5	**-1.5**
1992	-13.3	-13.8	-5.6	-0.7	5.0	13.0	15.3	12.1	1.4	-4.2	-9.0	**miss.**	
1993	-21.3	-16.1	-7.2	2.6	8.8	13.3	14.4	12.0	6.9	0.4	-11.6	-14.2	**-1.0**
1994	-23.9	-25.6	-4.4	2.9	7.2	13.1	16.2	16.1	5.5	0.1	-17.3	-20.0	**-2.5**
1995	-20.1	-14.8	-11.1	3.5	10.0	14.4	14.6	11.3	9.9	-0.9	-17.2	-21.2	**-1.8**
1996	-34.8	-15.0	-11.8	-1.2	5.7	12.2	14.7	10.5	5.7	-6.4	-18.9	-23.9	**-5.3**
1997	-25.6	-10.7	-12.7	1.2	7.5	13.5	16.0	13.0	8.3	-5.9	-10.4	-11.7	**-1.5**
1998	-25.2	-10.8	-8.1	2.6	9.5	14.1	15.7	11.9	6.3	-1.3	-14.3	-19.8	**-1.6**
1999	-23.3	-17.7	-7.7	1.1	5.7	14.2	14.0	14.1	7.4	0.1	-13.1	-12.6	**-1.5**
2000	-18.7	-10.2	-4.8	-1.1	5.7	13.6	14.1	10.6	5.1	-1.4	-10.3	**miss.**	
2001	-10.8	-16.4	-8.6	0.9	5.6	13.3	14.7	14.0	7.5	-2.0	-13.9	-21.2	**-1.4**
2002	-17.8	-14.8	-14.4	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	-14.9	
2003	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	**miss.**	
2004	-9.2	-8.7	1.6	8.4	17.1	15.9	13.7	4.5	-1.9	**miss.**	**miss.**	**miss.**	
2005	-22.4	-15.8	-3.3	2.0	11.1	14.8	14.5	13.7	7.4	-0.1	-9.3	-13.6	**-0.1**
2006	-20.1	-14.1	-11.8	0.5	7.7	15.0	16.4	12.5	7.8	-1.4	-26.4	-14.7	**-2.4**
2007	-16.2	-22.0	-14.6	0.3	7.6	14.0	15.8	14.4	6.0	-2.2	-11.4	-21.6	**-2.5**
2008	-24.1	-18.9	-8.0	0.4	9.2	12.8	13.3	11.7	6.4	-1.8	-10.9	-26.0	**-3.0**
2009	-23.4	-20.3	-13.2	0.1	9.0	15.1	17.3	13.0	7.8	-2.1	-12.9	-17.6	**-2.3**
2010	**miss.**	-10.8	-5.2	2.9	8.2	13.3	15.0	**miss.**	5.7	0.7	-11.0	-24.8	**-0.4**
2011	-20.8	-16.6	-14.1	0.3	8.1	13.5	14.4	11.3	7.3	-0.1	**miss.**	-11.3	**-1.4**

Monthly Average Temperature (°C) At Faro Airport, Yukon

Year	Jan	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVE
Max	-8.9	-8.7	1.6	8.4	17.1	15.9	17.3	16.1	9.9	2.6	-7.6	-11.3	
Year	1981	2004	2004	2004	2004	2004	2009	1994	1995	1980	1980	2011	
Mean	**-20.6**	**-15.9**	**-8.5**	**0.9**	**8.0**	**13.3**	**15.0**	**12.2**	**6.4**	**-1.5**	**-14.0**	**-19.5**	**-2.1**
Min	-37.3	-30.6	-14.6	-4.9	5.0	10.6	13.3	4.5	-1.9	-6.4	-26.4	-34.6	
Year	1982	1979	1989	1986	1992	1985	2008	2004	2004	1996	2006	1996	
St.Dev	6.6	5.0	4.0	2.3	2.2	1.2	0.9	2.0	2.2	2.2	4.9	6.1	

Faro Climate Normals

Monthly Climate Normals (1971-2000)	Daily Average Temperature	Standard Deviation	Daily Maximum	Daily Minimum	Extreme Maximum	Extreme Minimum
January	-21.5	7.0	-17.3	-26	7	-51
February	-16.0	5.5	-10.8	-21.3	12.1	-51
March	-8.2	3.3	-1.8	-14.5	12.5	-44
April	0.5	2.2	6.8	-5.7	21.5	-30.5
May	7.5	1.5	13.7	1.2	32	-8
June	13.0	1.0	19.3	6.6	31	-2.5
July	15.0	0.8	20.9	9	31	0
August	12.3	1.5	18.3	6.2	33.9	-4.5
September	6.5	1.8	11.6	1.3	24	-15.5
October	-1.7	2.5	2.1	-5.4	18.5	-34
November	-14.1	4.8	-10.4	-17.9	7	-46
December	-19.9	6.6	-15.8	-24.3	12.5	-52
Yearly	-2.2	6.0	3.1	-7.6		

APPENDIX 2

ROSE CREEK FLOW DATA

Staff gauge located near inlet of Rose Creek Diversion Canal, within the original diversion

The staff gauge was installed by Lebarge
Base of Staff gauge is at elevation (m amsl) **1054.317**

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
				2002		
17-Sep-02	8:15	9/17/2002 8:15	0.52	1054.837	3.464	Flow measurement by Lebarge
18-Sep-02	16:00	9/18/2002 16:00	0.508	1054.825	3.258	Flow measurement by Lebarge
				2003		
21-Jul-03		7/21/2003 0:00	0.46	1054.777	2.42847959	
				2004		
12-Apr-04	6:15 PM	4/12/2004 18:15	0.2	1054.517	0.302424497	
5-May-04	2:25 PM	5/5/2004 14:25	0.43	1054.747	2.05153438	
6-May-04	12:30 PM	5/6/2004 12:30	0.37	1054.687	1.408770267	
7-May-04	11:30 AM	5/7/2004 11:30	0.34	1054.657	1.140230791	
8-May-04	12:40 PM	5/8/2004 12:40	0.355	1054.672	1.270243493	
9-May-04	12:30 PM	5/9/2004 12:30	0.32	1054.637	0.979809071	
10-May-04	1:30 PM	5/10/2004 13:30	0.29	1054.607	0.765974792	
11-May-04	12:45 PM	5/11/2004 12:45	0.29	1054.607	0.765974792	
12-May-04	11:25 AM	5/12/2004 11:25	0.36	1054.677	1.315464189	
13-May-04	11:05 AM	5/13/2004 11:05	0.45	1054.767	2.298585502	
14-May-04	12:25 PM	5/14/2004 12:25	0.52	1054.837	3.299945807	
15-May-04	11:00 AM	5/15/2004 11:00	0.62	1054.937	5.123440531	
16-May-04	11:00 AM	5/16/2004 11:00	0.79	1055.107	9.392170395	
17-May-04	2:30 PM	5/17/2004 14:30	0.96	1055.277	15.29218087	
18-May-04	6:30 AM	5/18/2004 6:30	1.015	1055.332	17.57855059	Estimated, it was noted to be over the top of gauge
18-May-04	2:45 PM	5/18/2004 14:45	0.95	1055.267	14.89688119	
19-May-04	1:00 AM	5/19/2004 1:00	0.885	1055.202	12.47701391	
20-May-04	12:45 PM	5/20/2004 12:45	0.855	1055.172	11.44593551	
21-May-04	1:25 PM	5/21/2004 13:25	0.75	1055.067	8.247580647	
22-May-04	11:30 AM	5/22/2004 11:30	0.7	1055.017	6.940416808	
23-May-04	12:00 PM	5/23/2004 12:00	0.69	1055.007	6.695088248	
24-May-04	11:30 AM	5/24/2004 11:30	0.82	1055.137	10.30981023	
25-May-04	11:30 AM	5/25/2004 11:30	1.05	1055.367	19.13407187	Estimated, it was noted to be over the top of gauge
26-May-04	8:25 AM	5/26/2004 8:25	0.98	1055.297	16.10150173	
26-May-04	10:45 AM	5/26/2004 10:45	0.95	1055.267	14.89688119	
27-May-04	8:05 AM	5/27/2004 8:05	0.98	1055.297	16.10150173	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
27-May-04	11:15 AM	5/27/2004 11:15	0.965	1055.282	15.49216481	
27-May-04	10:30 PM	5/27/2004 22:30	0.995	1055.312	16.72500099	
28-May-04	12:30 PM	5/28/2004 12:30	0.97	1055.287	15.69371023	
29-May-04	2:40 PM	5/29/2004 14:40	0.88	1055.197	12.30145427	
30-May-04	12:25 PM	5/30/2004 12:25	0.82	1055.137	10.30981023	
31-May-04	12:15 PM	5/31/2004 12:15	0.875	1055.192	12.1273856	
1-Jun-04	1:10 PM	6/1/2004 13:10	0.83	1055.147	10.62715615	
2-Jun-04	12:15 PM	6/2/2004 12:15	0.84	1055.157	10.95029369	
3-Jun-04	11:30 AM	6/3/2004 11:30	0.72	1055.037	7.447065126	
4-Jun-04	11:30 AM	6/4/2004 11:30	0.67	1054.987	6.220231297	
6-Jun-04	8:30 AM	6/6/2004 8:30	0.8	1055.117	9.692352744	
7-Jun-04	11:15 AM	6/7/2004 11:15	0.835	1055.152	10.78799878	
8-Jun-04	2:20 PM	6/8/2004 14:20	1.2	1055.517	26.72089863	Estimated
9-Jun-04	10:35 AM	6/9/2004 10:35	1	1055.317	16.936	
10-Jun-04	2:00 PM	6/10/2004 14:00	0.78	1055.097	9.097638079	
11-Jun-04	1:00 PM	6/11/2004 13:00	0.72	1055.037	7.447065126	
12-Jun-04	1:45 PM	6/12/2004 13:45	0.65	1054.967	5.766183265	
13-Jun-04	11:40 AM	6/13/2004 11:40	0.64	1054.957	5.546864768	
14-Jun-04	1:20 PM	6/14/2004 13:20	0.63	1054.947	5.332630512	
15-Jun-04	3:15 PM	6/15/2004 15:15	0.63	1054.947	5.332630512	
16-Jun-04	2:15 PM	6/16/2004 14:15	0.62	1054.937	5.123440531	
17-Jun-04	1:00 PM	6/17/2004 13:00	0.6	1054.917	4.720031939	
18-Jun-04	3:30 PM	6/18/2004 15:30	0.57	1054.887	4.151733291	
19-Jun-04	6:20 AM	6/19/2004 6:20	0.57	1054.887	4.151733291	
20-Jun-04	6:40 AM	6/20/2004 6:40	0.57	1054.887	4.151733291	
21-Jun-04	6:15 AM	6/21/2004 6:15	0.54	1054.857	3.626610192	
22-Jun-04	6:10 AM	6/22/2004 6:10	0.52	1054.837	3.299945807	
23-Jun-04	6:15 AM	6/23/2004 6:15	0.5	1054.817	2.991608254	
24-Jun-04	6:15 AM	6/24/2004 6:15	0.485	1054.802	2.772167754	
25-Jun-04	6:10 AM	6/25/2004 6:10	0.47	1054.787	2.562682466	
26-Jun-04	7:50 AM	6/26/2004 7:50	0.46	1054.777	2.42847959	
28-Jun-04	6:10 AM	6/28/2004 6:10	0.44	1054.757	2.172953007	
30-Jun-04	6:10 AM	6/30/2004 6:10	0.43	1054.747	2.05153438	
5-Jul-04	6:15 AM	7/5/2004 6:15	0.37	1054.687	1.408770267	
6-Jul-04	6:15 AM	7/6/2004 6:15	0.36	1054.677	1.315464189	
7-Jul-04	6:10 AM	7/7/2004 6:10	0.36	1054.677	1.315464189	
8-Jul-04	6:10 AM	7/8/2004 6:10	0.36	1054.677	1.328	Flow measured by site staff
9-Jul-04		7/9/2004 0:00	0.36	1054.677	1.315464189	
10-Jul-04		7/10/2004 0:00	0.35	1054.667	1.225968836	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
11-Jul-04		7/11/2004 0:00	0.35	1054.667	1.225968836	
12-Jul-04		7/12/2004 0:00	0.35	1054.667	1.225968836	
13-Jul-04		7/13/2004 0:00	0.34	1054.657	1.140230791	
14-Jul-04		7/14/2004 0:00	0.34	1054.657	1.140230791	
15-Jul-04		7/15/2004 0:00	0.33	1054.647	1.058195865	
16-Jul-04		7/16/2004 0:00	0.32	1054.637	0.979809071	
17-Jul-04		7/17/2004 0:00	0.31	1054.627	0.905014583	
18-Jul-04		7/18/2004 0:00	0.35	1054.667	1.225968836	(bad hail and rain thunderstorm occurred previous afternoon)
19-Jul-04		7/19/2004 0:00	0.33	1054.647	1.058195865	
20-Jul-04		7/20/2004 0:00	0.33	1054.647	1.058195865	
21-Jul-04	7:15	7/21/2004 7:15	0.41	1054.727	1.821145097	
22-Jul-04	7:15	7/22/2004 7:15	0.355	1054.672	1.270243493	
23-Jul-04	6:35	7/23/2004 6:35	0.33	1054.647	1.058195865	
24-Jul-04	7:30	7/24/2004 7:30	0.34	1054.657	1.140230791	
25-Jul-04	6:20	7/25/2004 6:20	0.335	1054.652	1.098753855	
26-Jul-04	6:15	7/26/2004 6:15	0.33	1054.647	1.058195865	
27-Jul-04	6:10	7/27/2004 6:10	0.32	1054.637	0.979809071	
28-Jul-04	6:15	7/28/2004 6:15	0.32	1054.637	0.979809071	
29-Jul-04	6:10	7/29/2004 6:10	0.33	1054.647	1.058195865	
30-Jul-04	6:10	7/30/2004 6:10	0.33	1054.647	1.058195865	
31-Jul-04	6:10	7/31/2004 6:10	0.34	1054.657	1.140230791	
1-Aug-04	6:10	8/1/2004 6:10	0.355	1054.672	1.270243493	
2-Aug-04	6:10	8/2/2004 6:10	0.35	1054.667	1.225968836	
3-Aug-04	6:10	8/3/2004 6:10	0.355	1054.672	1.270243493	
4-Aug-04	6:10	8/4/2004 6:10	0.33	1054.647	1.058195865	
5-Aug-04	6:10	8/5/2004 6:10	0.325	1054.642	1.01854992	
6-Aug-04	6:10	8/6/2004 6:10	0.31	1054.627	0.905014583	
7-Aug-04	6:40	8/7/2004 6:40	0.305	1054.622	0.86894677	
8-Aug-04	5:50	8/8/2004 5:50	0.305	1054.622	0.86894677	
9-Aug-04	6:10	8/9/2004 6:10	0.295	1054.612	0.799434137	
10-Aug-04	6:10	8/10/2004 6:10	0.29	1054.607	0.765974792	
11-Aug-04	6:10	8/11/2004 6:10	0.29	1054.607	0.765974792	
12-Aug-04	6:10	8/12/2004 6:10	0.3	1054.617	0.833755698	
13-Aug-04	6:10	8/13/2004 6:10	0.295	1054.612	0.799434137	
14-Aug-04	6:10	8/14/2004 6:10	0.29	1054.607	0.765974792	
15-Aug-04	8:00	8/15/2004 8:00	0.295	1054.612	0.799434137	
16-Aug-04	6:45	8/16/2004 6:45	0.3	1054.617	0.833755698	
17-Aug-04	6:10	8/17/2004 6:10	0.29	1054.607	0.765974792	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
18-Aug-04	6:10	8/18/2004 6:10	0.29	1054.607	0.727	measured by site staff
19-Aug-04	6:10	8/19/2004 6:10	0.29	1054.607	0.765974792	
20-Aug-04	6:01	8/20/2004 6:01	0.29	1054.607	0.765974792	
21-Aug-04	6:15	8/21/2004 6:15	0.290	1054.607	0.765974792	
22-Aug-04	6:30	8/22/2004 6:30	0.280	1054.597	0.701613274	
23-Aug-04	6:10	8/23/2004 6:10	0.275	1054.592	0.6706962	
24-Aug-04	6:05	8/24/2004 6:05	0.280	1054.597	0.701613274	
25-Aug-04	6:05	8/25/2004 6:05	0.290	1054.607	0.765974792	
26-Aug-04	6:00	8/26/2004 6:00	0.290	1054.607	0.765974792	
27-Aug-04	6:05	8/27/2004 6:05	0.290	1054.607	0.765974792	
28-Aug-04	6:30	8/28/2004 6:30	0.3	1054.617	0.833755698	
29-Aug-04	6:30	8/29/2004 6:30	0.31	1054.627	0.905014583	
30-Aug-04	6:10	8/30/2004 6:10	0.310	1054.627	0.905014583	
31-Aug-04	6:10	8/31/2004 6:10	0.310	1054.627	0.905014583	
1-Sep-04	6:15	9/1/2004 6:15	0.290	1054.607	0.765974792	
2-Sep-04	6:10	9/2/2004 6:10	0.290	1054.607	0.765974792	
3-Sep-04	6:10	9/3/2004 6:10	0.305	1054.622	0.86894677	
4-Sep-04	6:30	9/4/2004 6:30	0.430	1054.747	2.05153438	
5-Sep-04	6:20	9/5/2004 6:20	0.405	1054.722	1.76610534	
6-Sep-04	6:10	9/6/2004 6:10	0.370	1054.687	1.408770267	
7-Sep-04	6:25	9/7/2004 6:25	0.345	1054.662	1.182633518	
8-Sep-04	6:20	9/8/2004 6:20	0.340	1054.657	1.140230791	
9-Sep-04	6.25	9/15/2004 6:00	0.330	1054.647	1.058195865	
10-Sep-04	6.2	9/16/2004 4:48	0.330	1054.647	1.058195865	
11-Sep-04	6:20	9/11/2004 6:20	0.320	1054.637	0.979809071	
12-Sep-04	6:05	9/12/2004 6:05	0.325	1054.642	1.01854992	
13-Sep-04	6:10	9/13/2004 6:10	0.330	1054.647	1.058195865	
14-Sep-04	6:20	9/14/2004 6:20	0.345	1054.662	1.182633518	
15-Sep-04	7:20	9/15/2004 7:20	0.345	1054.662	1.182633518	
16-Sep-04	7:15	9/16/2004 7:15	0.350	1054.667	1.225968836	
17-Sep-04	7:15	9/17/2004 7:15	0.340	1054.657	1.140230791	
18-Sep-04	7:15	9/18/2004 7:15	0.340	1054.657	1.140230791	
19-Sep-04	7:15	9/19/2004 7:15	0.330	1054.647	1.058195865	
20-Sep-04	7:05	9/20/2004 7:05	0.325	1054.642	1.01854992	
21-Sep-04	7:05	9/21/2004 7:05	0.330	1054.647	1.058195865	
22-Sep-04	7:20	9/22/2004 7:20	0.380	1054.697	1.505939756	
23-Sep-04	7:15	9/23/2004 7:15	0.370	1054.687	1.408770267	
24-Sep-04	7:10	9/24/2004 7:10	0.370	1054.687	1.408770267	
25-Sep-04	7:15	9/25/2004 7:15	0.360	1054.677	1.315464189	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
26-Sep-04	7:15	9/26/2004 7:15	0.340	1054.657	1.140230791	
27-Sep-04	7:10	9/27/2004 7:10	0.340	1054.657	1.140230791	
28-Sep-04	7:15	9/28/2004 7:15	0.330	1054.647	1.058195865	
29-Sep-04	7:15	9/29/2004 7:15	0.330	1054.647	1.058195865	
30-Sep-04	7:15	9/30/2004 7:15	0.330	1054.647	1.058195865	
1-Oct-04	7:15	10/1/2004 7:15	0.335	1054.652	1.098753855	
2-Oct-04	7:15	10/2/2004 7:15	0.330	1054.647	1.058195865	
3-Oct-04	7:15	10/3/2004 7:15	0.350	1054.667	1.225968836	
4-Oct-04	7:15	10/4/2004 7:15	0.345	1054.662	1.182633518	
5-Oct-04	7:15	10/5/2004 7:15	0.350	1054.667	1.225968836	
2005						
25-Apr-05	12:05	4/25/2005 12:05	0.440	1054.757	2.172953007	
26-Apr-05	6:45	4/26/2005 6:45	0.530	1054.847	3.46096512	
26-Apr-05	11:40	4/26/2005 11:40	0.470	1054.787	2.562682466	
27-Apr-05	6:30	4/27/2005 6:30	0.550	1054.867	3.796924554	
28-Apr-05	8:00	4/28/2005 8:00	0.675	1054.992	6.33698255	
29-Apr-05	6:25	4/29/2005 6:25	0.660	1054.977	5.990625657	
30-Apr-05	6:35	4/30/2005 6:35	0.675	1054.992	6.33698255	
1-May-05	6:30	5/1/2005 6:30	0.510	1054.827	3.143508308	ice affected
1-May-05	10:24	5/1/2005 10:24	0.445	1054.762	2.235239526	ice affected
1-May-05	13:52	5/1/2005 13:52	0.408	1054.725	1.799007521	ice affected
2-May-05	8:53	5/2/2005 8:53	0.478	1054.795	2.673178486	ice affected
2-May-05	5:20	5/2/2005 5:20	0.400	1054.717	1.712076197	
3-May-05	6:15	5/3/2005 6:15	0.390	1054.707	1.607024632	
3-May-05	10:07	5/3/2005 10:07	0.411	1054.728	1.832274872	
3-May-05	15:18	5/3/2005 15:18	0.410	1054.727	1.821145097	
4-May-05	9:58	5/4/2005 9:58	0.432	1054.749	2.075483304	
10-May-05					31.5	Estimated based on flow at rock drain of 21 m3/s
12-May-05	18:00	5/12/2005 18:00	0.861	1055.178	11.6478891	Flow measured by Laberge as 11.06 m3/s
20-May-05	8:00	5/20/2005 8:00	0.935	1055.252	14.31554099	
21-May-05	7:15	5/21/2005 7:15	0.920	1055.237	13.74803345	
22-May-05	6:35	5/22/2005 6:35	0.850	1055.167	11.27925772	
23-May-05	6:45	5/23/2005 6:45	0.780	1055.097	9.097638079	
24-May-05	6:00	5/24/2005 6:00	0.780	1055.097	9.097638079	
25-May-05	6:05	5/25/2005 6:05	0.810	1055.127	9.998220852	
25-May-05	13:55	5/25/2005 13:55	0.790	1055.107	9.392170395	
26-May-05	6:00	5/26/2005 6:00	0.810	1055.127	9.998220852	
26-May-05	18:55	5/26/2005 18:55	0.770	1055.087	8.808719844	
27-May-05	6:50	5/27/2005 6:50	0.830	1055.147	10.62715615	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
27-May-05	8:53	5/27/2005 8:53	0.848	1055.165	11.21299713	
28-May-05	6:40	5/28/2005 6:40	0.840	1055.157	10.95029369	
29-May-05	6:20	5/29/2005 6:20	0.750	1055.067	8.247580647	
30-May-05	6:00	5/30/2005 6:00	0.740	1055.057	7.975286608	
31-May-05	6:00	5/31/2005 6:00	0.740	1055.057	7.975286608	
1-Jul-05	5:25	7/1/2005 5:25	0.46	1054.777	2.42847959	
2-Jul-05	8:37	7/2/2005 8:37	0.49	1054.807	2.844200843	
3-Jul-05	5:30	7/3/2005 5:30	0.45	1054.767	2.298585502	
4-Jul-05	10:40	7/4/2005 10:40	0.44	1054.757	2.172953007	
5-Jul-05	5:50	7/5/2005 5:50	0.46	1054.777	2.42847959	
6-Jul-05	5:50	7/6/2005 5:50	0.435	1054.752	2.111719963	
7-Jul-05	5:50	7/7/2005 5:50	0.44	1054.757	2.172953007	
8-Jul-05	11:45	7/8/2005 11:45	0.55	1054.867	3.796924554	
9-Jul-05	5:10	7/9/2005 5:10	0.52	1054.837	3.299945807	
10-Jul-05	7:00	7/10/2005 7:00	0.45	1054.767	2.298585502	
11-Jul-05	6:00	7/11/2005 6:00	0.44	1054.757	2.172953007	
12-Jul-05	5:52	7/12/2005 5:52	0.42	1054.737	1.934281353	Flow measured by site staff as 2.213 m3/s
13-Jul-05	5:50	7/13/2005 5:50	0.43	1054.747	2.05153438	
14-Jul-05	5:52	7/14/2005 5:52	0.51	1054.827	3.143508308	
15-Jul-05	5:42	7/15/2005 5:42	0.49	1054.807	2.844200843	
16-Jul-05	5:30	7/16/2005 5:30	0.47	1054.787	2.562682466	
17-Jul-05	5:38	7/17/2005 5:38	0.445	1054.762	2.235239526	
18-Jul-05	6:05	7/18/2005 6:05	0.52	1054.832	3.221157094	
19-Jul-05	5:55	7/19/2005 5:55	0.565	1054.882	4.061245264	
20-Jul-05	7:10	7/20/2005 7:10	0.525	1054.842	3.379879981	
21-Jul-05	14:20	7/21/2005 14:20	0.51	1054.827	3.143508308	
22-Jul-05	6:50	7/22/2005 6:50	0.49	1054.807	2.844200843	
23-Jul-05	8:20	7/23/2005 8:20	0.47	1054.787	2.562682466	
24-Jul-05	6:54	7/24/2005 6:54	0.47	1054.787	2.562682466	
25-Jul-05	5:50	7/25/2005 5:50	0.49	1054.807	2.844200843	
26-Jul-05	5:48	7/26/2005 5:48	0.48	1054.797	2.701240819	
27-Jul-05	5:48	7/27/2005 5:48	0.48	1054.797	2.701240819	
28-Jul-05	5:50	7/28/2005 5:50	0.46	1054.777	2.42847959	
29-Jul-05	9:35	7/29/2005 9:35	0.52	1054.837	3.299945807	
30-Jul-05	12:43	7/30/2005 12:43	0.51	1054.827	3.143508308	
31-Jul-05	6:20	7/31/2005 6:20	0.525	1054.842	3.379879981	
1-Sep-05	12:50	9/1/2005 12:50	0.40	1054.717	1.712076197	
2-Sep-05	14:20	9/2/2005 14:20	0.39	1054.702	1.555989549	
3-Sep-05	11:45	9/3/2005 11:45	0.39	1054.702	1.555989549	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
4-Sep-05	16:15	9/4/2005 16:15	0.22	1054.537	0.383834681	
5-Sep-05	11:00	9/5/2005 11:00	0.37	1054.687	1.408770267	
6-Sep-05	12:30	9/6/2005 12:30	0.38	1054.697	1.505939756	
7-Sep-05	13:05	9/7/2005 13:05	0.39	1054.702	1.555989549	
8-Sep-05	11:05	9/8/2005 11:05	0.39	1054.707	1.607024632	
8-Sep-05	16:18	9/8/2005 16:18	0.398	1054.715	1.690746109	
9-Sep-05	7:00	9/9/2005 7:00	0.4	1054.717	1.712076197	
10-Sep-05	6:54	9/10/2005 6:54	0.39	1054.707	1.607024632	
11-Sep-05	11:50	9/11/2005 11:50	0.4	1054.717	1.712076197	
12-Sep-05	11:50	9/12/2005 11:50	0.39	1054.707	1.607024632	
13-Sep-05	10:40	9/13/2005 10:40	0.43	1054.747	2.05153438	
14-Sep-05	9:55	9/14/2005 9:55	0.46	1054.777	2.42847959	
15-Sep-05	9:50	9/15/2005 9:50	0.43	1054.747	2.05153438	
16-Sep-05	12:45	9/16/2005 12:45	0.42	1054.737	1.934281353	
17-Sep-05	14:45	9/17/2005 14:45	0.42	1054.737	1.934281353	
18-Sep-05	10:35	9/18/2005 10:35	0.42	1054.737	1.934281353	
19-Sep-05	13:10	9/19/2005 13:10	0.46	1054.777	2.42847959	
20-Sep-05	10:10	9/20/2005 10:10	0.42	1054.737	1.934281353	
21-Sep-05	12:20	9/21/2005 12:20	0.44	1054.757	2.172953007	
22-Sep-05	11:30	9/22/2005 11:30	0.44	1054.752	2.111719963	
24-Sep-05	10:00	9/24/2005 10:00	0.44	1054.752	2.111719963	
26-Sep-05	9:30	9/26/2005 9:30	0.43	1054.742	1.992390205	
28-Sep-05	16:20	9/28/2005 16:20	0.42	1054.737	1.934281353	
29-Sep-05	11:05	9/29/2005 11:05	0.42	1054.732	1.877201704	
1-Oct-05	12:20	10/1/2005 12:20	0.41	1054.727	1.821145097	
2-Oct-05	12:25	10/2/2005 12:25	0.40	1054.717	1.712076197	
3-Oct-05	12:25	10/3/2005 12:25	0.39	1054.707	1.607024632	
4-Oct-05	11:05	10/4/2005 11:05	0.38	1054.697	1.505939756	
5-Oct-05	11:25	10/5/2005 11:25	0.38	1054.697	1.505939756	
6-Oct-05	11:12	10/6/2005 11:12	0.38	1054.697	1.505939756	
11-Oct-05	12:30	10/11/2005 12:30	0.35	1054.667	1.225968836	
12-Oct-05	11:35	10/12/2005 11:35	0.37	1054.687	1.408770267	
13-Oct-05	11:10	10/13/2005 11:10	0.37	1054.682	1.361637578	
14-Oct-05	9:45	10/14/2005 9:45	0.35	1054.667	1.225968836	
17-Oct-05	9:55	10/17/2005 9:55	0.29	1054.607	0.765974792	
18-Oct-05	9:50	10/18/2005 9:50	0.29	1054.607	0.765974792	
19-Oct-05	11:05	10/19/2005 11:05	0.33	1054.647	1.058195865	
20-Oct-05	11:20	10/20/2005 11:20	0.29	1054.607	0.765974792	
24-Oct-05	12:45	10/24/2005 12:45	0.31	1054.627	0.905014583	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
25-Nov-05	2:30 PM	11/25/2005 14:30	0.27	1054.587	0.640611537	
2006						
7-May-06			0.71	1055.027	7.191063123	
8-May-06			0.68	1054.997	6.455039239	
20-May-06			0.58	1054.897	4.336312772	
21-May-06			0.57	1054.887	4.151733291	
22-May-06			0.61	1054.927	4.919254543	
23-May-06			0.68	1054.992	6.33698255	
24-May-06			0.66	1054.972	5.877761507	
25-May-06			0.67	1054.987	6.220231297	
26-May-06			0.71	1055.027	7.191063123	
27-May-06			0.69	1055.007	6.695088248	
28-May-06			0.84	1055.157	10.95029369	
29-May-06			0.59	1054.907	4.525731776	
30-May-06			0.50	1054.817	2.991608254	
31-May-06			0.53	1054.847	3.46096512	
1-Jun-06			0.61	1054.927	4.919254543	
2-Jun-06			0.69	1055.007	6.695088248	
3-Jun-06			0.69	1055.002	6.574406198	
4-Jun-06			0.80	1055.112	9.541553077	
5-Jun-06			0.83	1055.147	10.62715615	
6-Jun-06			0.65	1054.967	5.766183265	
7-Jun-06			0.58	1054.897	4.336312772	
8-Jun-06			0.55	1054.867	3.796924554	
9-Jun-06			0.58	1054.897	4.336312772	
10-Jun-06			0.65	1054.967	5.766183265	
11-Jun-06			0.79	1055.107	9.392170395	
12-Jun-06			0.76	1055.077	8.525379506	
13-Jun-06			0.69	1055.007	6.695088248	
14-Jun-06			0.63	1054.947	5.332630512	
15-Jun-06			0.59	1054.907	4.525731776	
16-Jun-06			0.75	1055.067	8.247580647	
17-Jun-06			0.73	1055.047	7.708460485	
18-Jun-06			0.72	1055.037	7.447065126	
19-Jun-06			0.60	1054.912	4.622269124	
20-Jun-06			0.54	1054.857	3.626610192	
21-Jun-06			0.51	1054.827	3.143508308	
22-Jun-06			0.51	1054.827	3.143508308	
23-Jun-06			0.49	1054.802	2.772167754	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
24-Jun-06			0.47	1054.782	2.4950395	
25-Jun-06			0.45	1054.762	2.235239526	
26-Jun-06			0.46	1054.772	2.362996885	
27-Jun-06			0.44	1054.752	2.111719963	
28-Jun-06			0.43	1054.742	1.992390205	
29-Jun-06			0.53	1054.847	3.46096512	
30-Jun-06			0.59	1054.907	4.525731776	
1-Jul-06			0.53	1054.842	3.379879981	
2-Jul-06			0.48	1054.797	2.701240819	
3-Jul-06			0.46	1054.777	2.42847959	
4-Jul-06			0.45	1054.767	2.298585502	
5-Jul-06			0.44	1054.757	2.172953007	
6-Jul-06			0.43	1054.747	2.05153438	
7-Jul-06			0.41	1054.727	1.821145097	
8-Jul-06			0.51	1054.827	3.143508308	
9-Jul-06			0.53	1054.847	3.46096512	
10-Jul-06			0.56	1054.877	3.97195134	
11-Jul-06			0.57	1054.887	4.151733291	
12-Jul-06			0.57	1054.887	4.151733291	
13-Jul-06			0.53	1054.847	3.46096512	
14-Jul-06			0.48	1054.797	2.701240819	
15-Jul-06			0.53	1054.847	3.46096512	
16-Jul-06			0.49	1054.802	2.772167754	
17-Jul-06			0.48	1054.797	2.701240819	
18-Jul-06			0.47	1054.782	2.4950395	
19-Jul-06			0.50	1054.817	2.991608254	
20-Jul-06			0.47	1054.787	2.562682466	
21-Jul-06			0.45	1054.767	2.298585502	
22-Jul-06			0.44	1054.757	2.172953007	
23-Jul-06			0.43	1054.742	1.992390205	
24-Jul-06			0.41	1054.727	1.821145097	
25-Jul-06			0.41	1054.722	1.76610534	
26-Jul-06			0.40	1054.717	1.712076197	
27-Jul-06			0.40	1054.717	1.712076197	
28-Jul-06			0.40	1054.712	1.659051398	
29-Jul-06			0.40	1054.712	1.659051398	
30-Jul-06			0.39	1054.702	1.555989549	
31-Jul-06			0.37	1054.687	1.408770267	
1-Aug-06			0.37	1054.682	1.361637578	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
2-Aug-06			0.37	1054.687	1.408770267	
3-Aug-06			0.42	1054.737	1.934281353	
4-Aug-06			0.41	1054.727	1.821145097	
5-Aug-06			0.39	1054.702	1.555989549	
6-Aug-06			0.39	1054.702	1.555989549	
7-Aug-06			0.39	1054.707	1.607024632	
8-Aug-06			0.41	1054.722	1.76610534	
9-Aug-06			0.43	1054.742	1.992390205	
10-Aug-06			0.40	1054.717	1.712076197	
11-Aug-06			0.38	1054.697	1.505939756	
12-Aug-06			0.36	1054.677	1.315464189	
13-Aug-06			0.43	1054.747	2.05153438	
14-Aug-06			0.47	1054.787	2.562682466	
15-Aug-06			0.51	1054.827	3.143508308	
16-Aug-06			0.46	1054.772	2.362996885	
17-Aug-06			0.44	1054.752	2.111719963	
18-Aug-06			0.44	1054.757	2.172953007	
19-Aug-06			0.43	1054.747	2.05153438	
20-Aug-06			0.42	1054.737	1.934281353	
21-Aug-06			0.41	1054.727	1.821145097	
22-Aug-06			0.41	1054.727	1.821145097	
23-Aug-06			0.39	1054.702	1.555989549	
24-Aug-06			0.39	1054.707	1.607024632	
25-Aug-06			0.40	1054.717	1.712076197	
26-Aug-06			0.43	1054.747	2.05153438	
27-Aug-06			0.43	1054.742	1.992390205	
28-Aug-06			0.41	1054.727	1.821145097	
29-Aug-06			0.42	1054.737	1.934281353	
30-Aug-06			0.41	1054.727	1.821145097	
31-Aug-06			0.40	1054.717	1.712076197	
1-Sep-06			0.41	1054.722	1.76610534	
2-Sep-06			0.41	1054.727	1.821145097	
3-Sep-06			0.40	1054.717	1.712076197	
4-Sep-06			0.40	1054.717	1.712076197	
5-Sep-06			0.41	1054.727	1.821145097	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
6-Sep-06			0.43	1054.747	2.05153438	
7-Sep-06			0.41	1054.727	1.821145097	
8-Sep-06			0.41	1054.722	1.76610534	
9-Sep-06			0.46	1054.777	2.42847959	
10-Sep-06			0.43	1054.747	2.05153438	
11-Sep-06			0.42	1054.732	1.877201704	
12-Sep-06			0.42	1054.732	1.877201704	
13-Sep-06			0.42	1054.737	1.934281353	
14-Sep-06			0.41	1054.722	1.76610534	
15-Sep-06						
16-Sep-06						
17-Sep-06						
18-Sep-06			0.39	1054.702	1.555989549	
19-Sep-06			0.39	1054.702	1.555989549	
20-Sep-06			0.39	1054.702	1.555989549	
21-Sep-06			0.39	1054.702	1.555989549	
22-Sep-06			0.39	1054.702	1.555989549	
23-Sep-06			0.39	1054.702	1.555989549	
24-Sep-06						
25-Sep-06			0.37	1054.687	1.408770267	
26-Sep-06			0.38	1054.692	1.45686882	
27-Sep-06			0.38	1054.692	1.45686882	
28-Sep-06			0.37	1054.687	1.408770267	
29-Sep-06						
30-Sep-06						
1-Oct-06						
2-Oct-06			0.36	1054.677	1.315464189	
3-Oct-06			0.34	1054.657	1.140230791	
4-Oct-06			0.35	1054.667	1.225968836	
5-Oct-06			0.34	1054.657	1.140230791	
6-Oct-06			0.34	1054.657	1.140230791	
7-Oct-06			**0.32**	1054.632	0.941966312	
8-Oct-06						
9-Oct-06						
10-Oct-06						
11-Oct-06			**0.35**	1054.667	1.225968836	
12-Oct-06			**0.33**	1054.647	1.058195865	
13-Oct-06						
14-Oct-06						

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
15-Oct-06		Frozen				
16-Oct-06						
17-Oct-06						
18-Oct-06						
19-Oct-06						
20-Oct-06						
21-Oct-06						
22-Oct-06						
23-Oct-06						
24-Oct-06						
25-Oct-06						
26-Oct-06						
27-Oct-06						
28-Oct-06						
29-Oct-06						
30-Oct-06						
31-Oct-06						
				2007		
	AM	**PM**	**GAUGE**	**Elev. (m)**	**Flow (m3/s)**	
15-May-07	**6.25**		**0.610**	1054.927	4.919254543	
16-May-07	**6.10**		**0.780**	1055.097	9.097638079	
17-May-07	**6.10**		**0.760**	1055.077	8.525379506	
18-May-07	**5.35**		**0.530**	1054.847	3.46096512	
19-May-07	**5.35**		**0.350**	1054.667	1.225968836	
20-May-07	**5.50**		**0.310**	1054.627	0.905014583	
21-May-07	**5.30**		**0.320**	1054.637	0.979809071	
22-May-07	**6.10**		**0.320**	1054.637	0.979809071	
23-May-07	**6.05**		**0.350**	1054.667	1.225968836	
24-May-07	**6.00**		**0.380**	1054.697	1.505939756	
25-May-07	**9.30**		**0.475**	1054.792	2.63141431	
26-May-07	**8.20**		**0.530**	1054.847	3.46096512	
27-May-07	**6.10**		**0.650**	1054.967	5.766183265	
28-May-07	**6.05**		**0.560**	1054.877	3.97195134	
29-May-07	**6.00**		**0.360**	1054.677	1.315464189	
30-May-07	**11.10**		**0.330**	1054.647	1.058195865	
31-May-07	**6.10**		**0.460**	1054.777	2.42847959	
1-Jun-07			**N/A**			
2-Jun-07			**N/A**			
3-Jun-07			**N/A**			

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
4-Jun-07	**6.10**		**0.450**	1054.767	2.298585502	
5-Jun-07	**6.00**		**0.550**	1054.867	3.796924554	
6-Jun-07	**6.10**		**0.790**	1055.107	9.392170395	
6-Jun-07	**11.00**		**0.850**	1055.167	11.27925772	
6-Jun-07		**3.05**	**0.800**	1055.117	9.692352744	
7-Jun-07	**6.05**		**0.660**	1054.977	5.990625657	
8-Jun-07	**6.15**		**0.410**	1054.727	1.821145097	
9-Jun-07	**6.25**		**0.280**	1054.597	0.701613274	
10-Jun-07	**6.35**		**0.235**	1054.552	0.452677257	
11-Jun-07	**6.05**		**0.350**	1054.667	1.225968836	
12-Jun-07	**6.30**		**0.480**	1054.797	2.701240819	
13-Jun-07	**6.10**		**0.470**	1054.787	2.562682466	
14-Jun-07	**6.35**		**0.460**	1054.777	2.42847959	
15-Jun-07			**N/A**			
16-Jun-07	**7.40**		**0.330**	1054.647	1.058195865	
17-Jun-07	**6.35**		**0.300**	1054.617	0.833755698	
18-Jun-07	**6.15**		**0.250**	1054.567	0.528443549	
19-Jun-07	**5.50**		**0.250**	1054.567	0.528443549	
20-Jun-07	**5.55**		**0.200**	1054.517	0.302424497	
21-Jun-07	**5.50**		**0.180**	1054.497	0.232366174	
22-Jun-07	**5.45**		**0.230**	1054.547	0.428971397	
23-Jun-07	**6.55**		**0.210**	1054.527	0.341675252	
24-Jun-07	**6.25**		**0.215**	1054.532	0.362387056	
25-Jun-07	**5.50**		**0.360**	1054.677	1.315464189	
26-Jun-07	**5.55**		**0.340**	1054.657	1.140230791	
27-Jun-07	**5.55**		**0.265**	1054.582	0.611351666	
28-Jun-07	**5.55**		**0.240**	1054.557	0.477152476	
29-Jun-07			**N/A**			
30-Jun-07			**N/A**			
1-Jul-07			**N/A**			
2-Jul-07			**N/A**			
3-Jul-07	**5.50**		**0.315**	1054.632	0.941966312	
4-Jul-07	**5.55**		**0.270**	1054.587	0.640611537	
5-Jul-07	**5.50**		**0.250**	1054.567	0.528443549	
6-Jul-07	**8.10**		**0.230**	1054.547	0.428971397	
7-Jul-07	**8.30**		**0.200**	1054.517	0.302424497	
8-Jul-07	**8.25**		**0.190**	1054.507	0.266012152	
9-Jul-07	**5.55**		**0.200**	1054.517	0.302424497	
10-Jul-07	**5.50**		**0.109**	1054.426	0.066270197	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
11-Jul-07	**5.55**		**0.170**	1054.487	0.201412603	
12-Jul-07	**5.50**		**0.160**	1054.477	0.173075396	
13-Jul-07	**5.40**		**0.150**	1054.467	0.147276242	
14-Jul-07	**5.50**		**0.160**	1054.477	0.173075396	
15-Jul-07	**5.50**		**0.245**	1054.562	0.502405215	
16-Jul-07	**5.55**		**0.285**	1054.602	0.733370311	
17-Jul-07	**5.55**		**0.295**	1054.612	0.799434137	
18-Jul-07	**5.50**		**0.250**	1054.567	0.528443549	
19-Jul-07	**5.50**		**0.220**	1054.537	0.383834681	
20-Jul-07	**8.25**		**0.195**	1054.512	0.283867983	
21-Jul-07	**8.45**		**0.185**	1054.502	0.248847943	
22-Jul-07	**8.25**		**0.170**	1054.487	0.201412603	
23-Jul-07	**5.55**		**0.170**	1054.487	0.201412603	
24-Jul-07	**5.55**		**0.170**	1054.487	0.201412603	
25-Jul-07	**5.45**		**0.155**	1054.472	0.159863551	
26-Jul-07	**11.40**		**0.150**	1054.467	0.147276242	
27-Jul-07	**8.30**		**0.150**	1054.467	0.147276242	
28-Jul-07	**8.35**		**0.165**	1054.482	0.186921793	
29-Jul-07	**8.30**		**0.170**	1054.487	0.201412603	
30-Jul-07	**5.55**		**0.185**	1054.502	0.248847943	
31-Jul-07	**5.55**		**0.160**	1054.477	0.173075396	
1-Aug-07	**5.55**		**0.160**	1054.477	0.173075396	
2-Aug-07	**5.55**		**0.140**	1054.457	0.123934345	
3-Aug-07	**8.55**		**0.140**	1054.457	0.123934345	
4-Aug-07	**8.40**		**0.170**	1054.487	0.201412603	
5-Aug-07	**8.40**		**0.140**	1054.457	0.123934345	
6-Aug-07	**5.45**		**0.145**	1054.462	0.13530329	
7-Aug-07	**5.45**		**0.175**	1054.492	0.21655754	
8-Aug-07	**6.20**		**0.165**	1054.482	0.186921793	
9-Aug-07	**5.50**		**0.145**	1054.462	0.13530329	
10-Aug-07			**N/R**			
11-Aug-07			**N/R**			
12-Aug-07			**N/R**			
13-Aug-07	**6.00**		**0.115**	1054.432	0.075774349	
14-Aug-07	**9.55**		**0.180**	1054.497	0.232366174	
15-Aug-07	**5.55**		**0.180**	1054.497	0.232366174	
16-Aug-07	**5.55**		**0.150**	1054.467	0.147276242	
17-Aug-07	**6.00**		**0.130**	1054.447	0.102966171	
18-Aug-07		**12.20**	**0.120**	1054.437	0.084285149	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
19-Aug-07	**7.30**		**0.125**	1054.442	0.093345305	
20-Aug-07	**7.00**		**0.120**	1054.437	0.084285149	
21-Aug-07	**5.50**		**0.120**	1054.437	0.084285149	
22-Aug-07	**9.30**		**0.120**	1054.437	0.084285149	
23-Aug-07	**8.50**		**0.140**	1054.457	0.123934345	
24-Aug-07	**6.45**		**0.130**	1054.447	0.102966171	
25-Aug-07	**7.00**		**0.130**	1054.447	0.102966171	
26-Aug-07	**6.20**		**0.130**	1054.447	0.102966171	
27-Aug-07	**8.00**		**0.150**	1054.467	0.147276242	
28-Aug-07	**8.05**		**0.135**	1054.452	0.113158878	
29-Aug-07	**10.25**		**0.130**	1054.447	0.102966171	
30-Aug-07	**8.30**		**0.120**	1054.437	0.084285149	
31-Aug-07	**8.45**		**0.115**	1054.432	0.075774349	
1-Sep-07	**7.40**		**0.130**	1054.447	0.102966171	
2-Sep-07	**7.25**		**0.130**	1054.447	0.102966171	
3-Sep-07	**7.20**		**0.125**	1054.442	0.093345305	
4-Sep-07	**9.20**		**0.130**	1054.447	0.102966171	
5-Sep-07	**10.10**		**0.125**	1054.442	0.093345305	
6-Sep-07	**9.30**		**0.150**	1054.467	0.147276242	
7-Sep-07			**N/R**			
8-Sep-07			**N/R**			
9-Sep-07			**N/R**			
10-Sep-07		**12.25**	**0.145**	1054.462	0.13530329	
11-Sep-07	**12.00**		**0.290**	1054.607	0.765974792	
12-Sep-07		**12.50**	**0.230**	1054.547	0.428971397	
13-Sep-07	**10.40**		**0.205**	1054.522	0.321690642	
14-Sep-07		**12.20**	**0.190**	1054.507	0.266012152	
15-Sep-07	**7.30**		**0.190**	1054.507	0.266012152	
16-Sep-07	**8.10**		**0.265**	1054.582	0.611351666	
17-Sep-07	**9.20**		**0.240**	1054.557	0.477152476	
18-Sep-07	**11.05**		**0.250**	1054.567	0.528443549	
19-Sep-07	**9.50**		**0.230**	1054.547	0.428971397	
20-Sep-07	**9.50**		**0.225**	1054.542	0.406026651	
21-Sep-07			**N/R**			
22-Sep-07	**8.05**		**0.230**	1054.547	0.428971397	
23-Sep-07			**N/R**			
Frozen						
2008						
18-May-08			**0.690**	1055.007	6.695088248	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
19-May-08			**0.790**	1055.107	9.392170395	
20-May-08			**0.890**	1055.207	12.65406878	
21-May-08			**0.790**	1055.107	9.392170395	
22-May-08			**0.810**	1055.127	9.998220852	
23-May-08			**0.810**	1055.127	9.998220852	
24-May-08			**0.825**	1055.142	10.46776142	
25-May-08			**0.935**	1055.252	14.31554099	
26-May-08			**1.045**	1055.362	18.9069989	
27-May-08			**1.050**	1055.367	19.13407187	
28-May-08			**1.050**	1055.367	19.13407187	
29-May-08			**0.955**	1055.272	15.09375435	
30-May-08			**0.770**	1055.087	8.808719844	
31-May-08			**0.700**	1055.017	6.940416808	
1-Jun-08			**0.645**	1054.962	5.655886001	
2-Jun-08			**0.695**	1055.012	6.81709019	
3-Jun-08			**0.730**	1055.047	7.708460485	
4-Jun-08			**0.680**	1054.997	6.455039239	
5-Jun-08			**0.615**	1054.932	5.020724568	
6-Jun-08			**0.560**	1054.877	3.97195134	
7-Jun-08			**0.550**	1054.867	3.796924554	
8-Jun-08			**0.625**	1054.942	5.227407497	
9-Jun-08			**0.665**	1054.982	6.104780623	
10-Jun-08			**0.670**	1054.987	6.220231297	
11-Jun-08			**0.660**	1054.977	5.990625657	
12-Jun-08			**0.640**	1054.957	5.546864768	
13-Jun-08			**0.625**	1054.942	5.227407497	
14-Jun-08			**0.615**	1054.932	5.020724568	
15-Jun-08			**0.580**	1054.897	4.336312772	
16-Jun-08			**0.615**	1054.932	5.020724568	
17-Jun-08			**0.600**	1054.917	4.720031939	
18-Jun-08			**0.610**	1054.927	4.919254543	
19-Jun-08			**0.650**	1054.967	5.766183265	
20-Jun-08			**0.670**	1054.987	6.220231297	
21-Jun-08			**0.740**	1055.057	7.975286608	
22-Jun-08			**0.695**	1055.012	6.81709019	
23-Jun-08			**0.730**	1055.047	7.708460485	
24-Jun-08			**1.110**	1055.427	21.9871099	
25-Jun-08			**0.840**	1055.157	10.95029369	
26-Jun-08			**0.705**	1055.022	7.065072869	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
27-Jun-08			**0.740**	1055.057	7.975286608	
28-Jun-08			**0.660**	1054.977	5.990625657	
29-Jun-08			**0.650**	1054.967	5.766183265	
30-Jun-08			**0.630**	1054.947	5.332630512	
1-Jul-08			**0.595**	1054.912	4.622269124	
2-Jul-08			**0.640**	1054.957	5.546864768	
3-Jul-08			**0.590**	1054.907	4.525731776	
4-Jul-08			**0.550**	1054.867	3.796924554	
5-Jul-08			**0.570**	1054.887	4.151733291	
6-Jul-08			**0.590**	1054.907	4.525731776	
7-Jul-08			**0.605**	1054.922	4.819025369	
8-Jul-08			**0.570**	1054.887	4.151733291	
9-Jul-08			**0.525**	1054.842	3.379879981	
10-Jul-08			**0.935**	1055.252	14.31554099	
11-Jul-08			**0.930**	1055.247	14.12484035	
12-Jul-08			**0.770**	1055.087	8.808719844	
13-Jul-08			**0.785**	1055.102	9.244200224	
14-Jul-08			**0.730**	1055.047	7.708460485	
15-Jul-08			**0.980**	1055.297	16.10150173	
16-Jul-08			**1.350**	1055.667	35.87472936	
17-Jul-08			**0.880**	1055.197	12.30145427	
18-Jul-08			**0.785**	1055.102	9.244200224	
19-Jul-08			**0.755**	1055.072	8.385789677	
20-Jul-08			**0.730**	1055.047	7.708460485	
21-Jul-08			**0.690**	1055.007	6.695088248	
22-Jul-08			**0.690**	1055.007	6.695088248	
23-Jul-08			**0.650**	1054.967	5.766183265	
24-Jul-08			**0.640**	1054.957	5.546864768	
25-Jul-08			**0.610**	1054.927	4.919254543	
26-Jul-08			**0.590**	1054.907	4.525731776	
27-Jul-08			**0.585**	1054.902	4.430414723	
28-Jul-08			**0.580**	1054.897	4.336312772	
29-Jul-08			**0.550**	1054.867	3.796924554	
30-Jul-08			**0.530**	1054.847	3.46096512	
31-Jul-08			**0.525**	1054.842	3.379879981	
1-Aug-08			**0.515**	1054.832	3.221157094	
2-Aug-08			**0.505**	1054.822	3.06699389	
3-Aug-08			**0.490**	1054.807	2.844200843	
4-Aug-08			**0.470**	1054.787	2.562682466	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
5-Aug-08			**0.460**	1054.777	2.42847959	
6-Aug-08			**0.450**	1054.767	2.298585502	
7-Aug-08			**0.470**	1054.787	2.562682466	
8-Aug-08			**0.485**	1054.802	2.772167754	
9-Aug-08			**0.540**	1054.857	3.626610192	
10-Aug-08			**0.520**	1054.837	3.299945807	
11-Aug-08			**0.485**	1054.802	2.772167754	
12-Aug-08			**0.465**	1054.782	2.4950395	
13-Aug-08			**0.460**	1054.777	2.42847959	
14-Aug-08			**0.450**	1054.767	2.298585502	
15-Aug-08			**0.460**	1054.777	2.42847959	
16-Aug-08			**0.460**	1054.777	2.42847959	
17-Aug-08			**0.460**	1054.777	2.42847959	
18-Aug-08			**0.480**	1054.797	2.701240819	
19-Aug-08			**0.490**	1054.807	2.844200843	
20-Aug-08			**0.460**	1054.777	2.42847959	
21-Aug-08			**0.450**	1054.767	2.298585502	
22-Aug-08			**0.455**	1054.772	2.362996885	
23-Aug-08			**0.490**	1054.807	2.844200843	
24-Aug-08			**0.480**	1054.797	2.701240819	
25-Aug-08			**0.755**	1055.072	8.385789677	
25-Aug-08			**0.985**	1055.302	16.30775586	
26-Aug-08			**0.940**	1055.257	14.50777861	
27-Aug-08			**0.860**	1055.177	11.61408289	
28-Aug-08			**0.820**	1055.137	10.30981023	
29-Aug-08			**0.825**	1055.142	10.46776142	
30-Aug-08			**0.770**	1055.087	8.808719844	
31-Aug-08			**0.720**	1055.037	7.447065126	
1-Sep-08			**0.700**	1055.017	6.940416808	
2-Sep-08			**0.680**	1054.997	6.455039239	
3-Sep-08			**0.650**	1054.967	5.766183265	
4-Sep-08			**0.640**	1054.957	5.546864768	
5-Sep-08			**0.630**	1054.947	5.332630512	
6-Sep-08			**0.625**	1054.942	5.227407497	
7-Sep-08			**0.610**	1054.927	4.919254543	
8-Sep-08			**0.670**	1054.987	6.220231297	
9-Sep-08			**0.785**	1055.102	9.244200224	
10-Sep-08			**0.710**	1055.027	7.191063123	
11-Sep-08			**0.710**	1055.027	7.191063123	

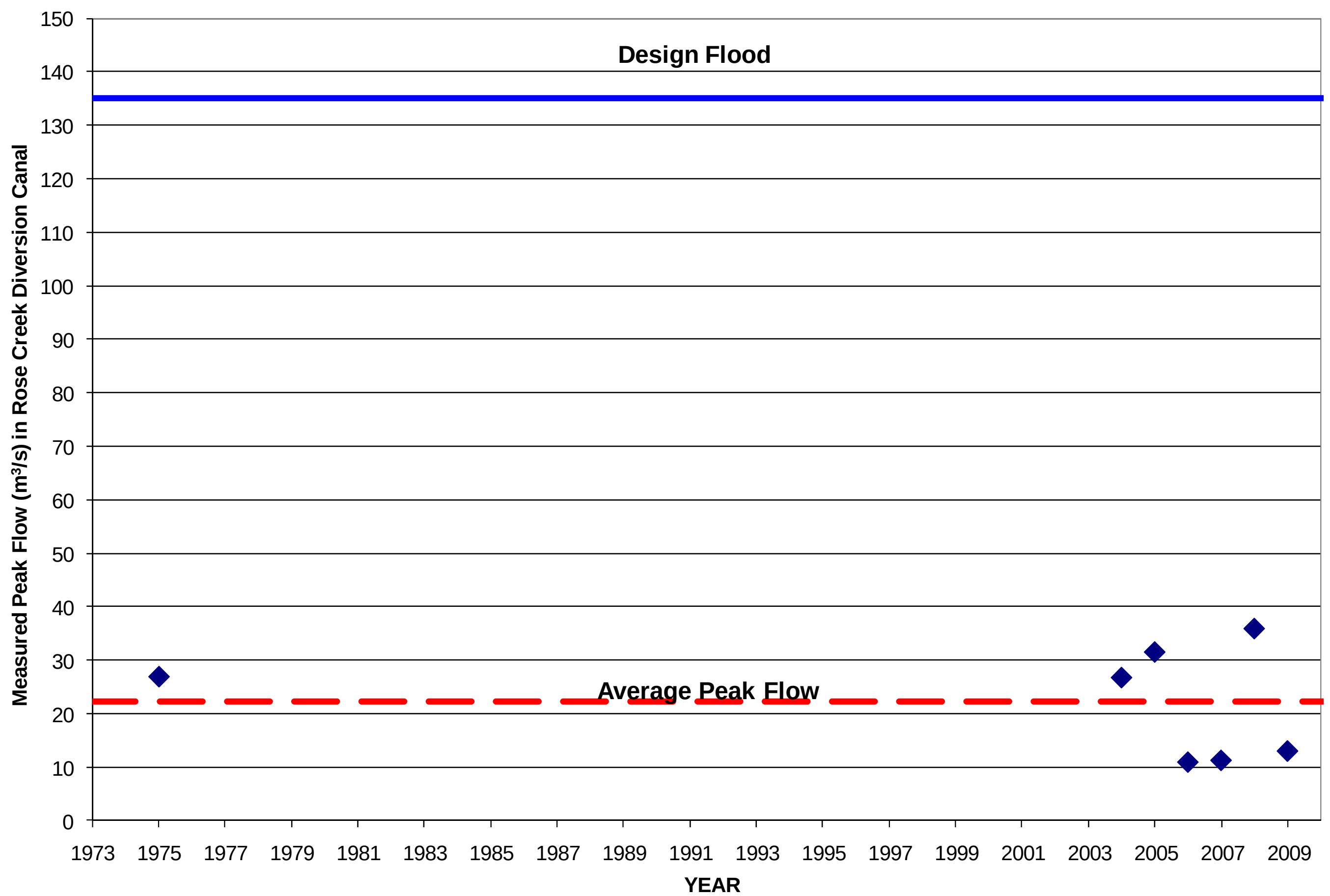
Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
12-Sep-08			**0.710**	1055.027	7.191063123	
13-Sep-08			**0.680**	1054.997	6.455039239	
14-Sep-08			**0.650**	1054.967	5.766183265	
15-Sep-08			**0.650**	1054.967	5.766183265	
16-Sep-08			**0.635**	1054.952	5.4391146	
17-Sep-08			**0.630**	1054.947	5.332630512	
18-Sep-08			**0.680**	1054.997	6.455039239	
19-Sep-08			**0.630**	1054.947	5.332630512	
20-Sep-08			**0.620**	1054.937	5.123440531	
21-Sep-08			**0.610**	1054.927	4.919254543	
22-Sep-08			**0.590**	1054.907	4.525731776	
23-Sep-08			**0.580**	1054.897	4.336312772	
24-Sep-08			**0.570**	1054.887	4.151733291	
25-Sep-08			**0.550**	1054.867	3.796924554	
26-Sep-08			**0.500**	1054.817	2.991608254	
27-Sep-08			**0.490**	1054.807	2.844200843	
28-Sep-08			**0.500**	1054.817	2.991608254	
29-Sep-08			**0.545**	1054.862	3.711181007	
30-Sep-08			**0.540**	1054.857	3.626610192	
1-Oct-08			**0.590**	1054.907	4.525731776	
2-Oct-08			**0.580**	1054.897	4.336312772	
3-Oct-08			**0.565**	1054.882	4.061245264	
4-Oct-08			**N/A**			
5-Oct-08			**0.490**	1054.807	2.844200843	
6-Oct-08			**0.530**	1054.847	3.46096512	
7-Oct-08			**0.485**	1054.802	2.772167754	
8-Oct-08			**0.430**	1054.747	2.05153438	
9-Oct-08			**0.500**	1054.817	2.991608254	
10-Oct-08			**0.450**	1054.767	2.298585502	
11-Oct-08			**0.485**	1054.802	2.772167754	
12-Oct-08			**0.470**	1054.787	2.562682466	
13-Oct-08			**0.480**	1054.797	2.701240819	
14-Oct-08			**0.450**	1054.767	2.298585502	
15-Oct-08			**0.460**	1054.777	2.42847959	
16-Oct-08			**0.455**	1054.772	2.362996885	
17-Oct-08			**0.420**	1054.737	1.934281353	
18-Oct-08			**N/A**			
Frozen						
				MAX	35.87472936	0

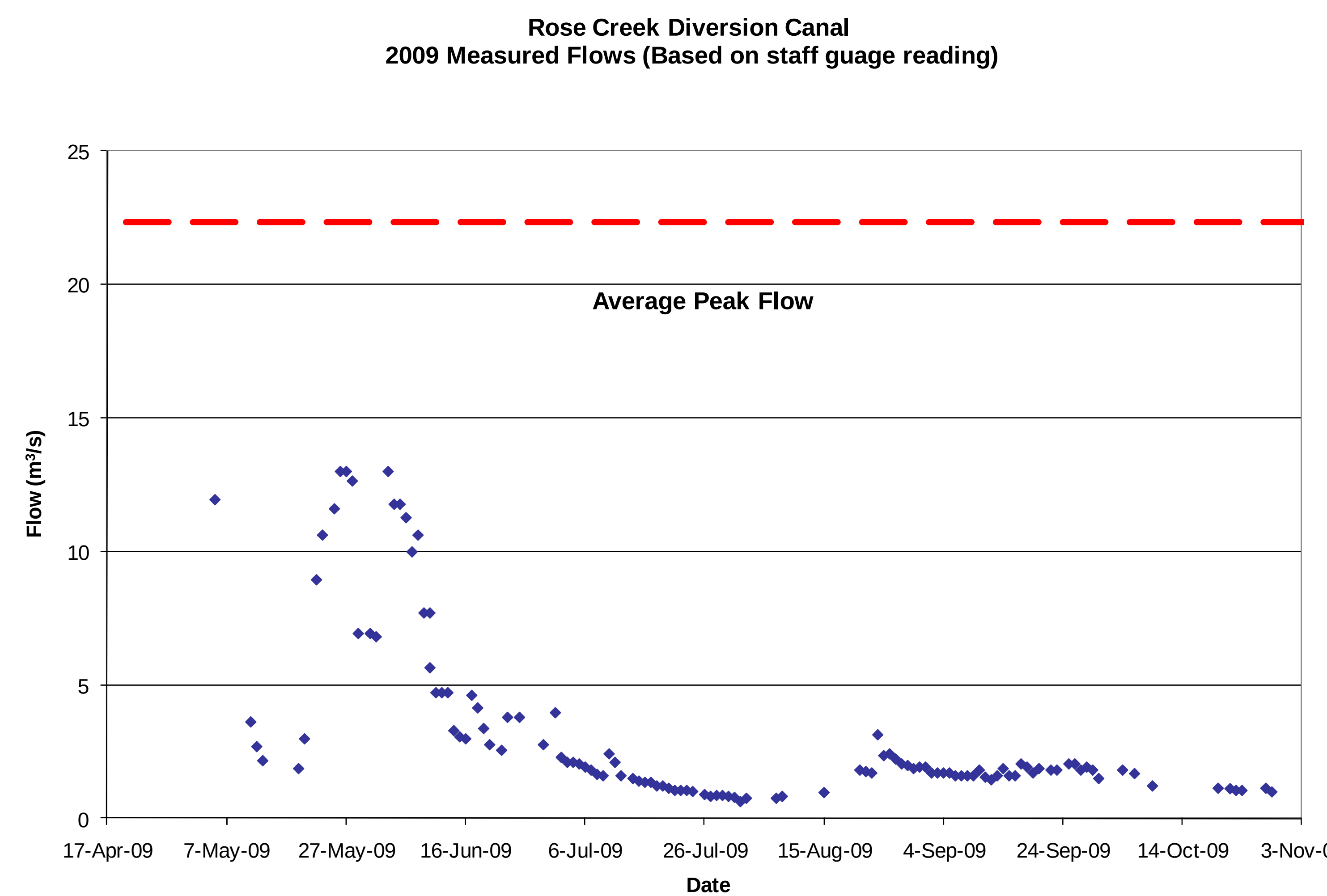
Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
	2009					
5-May-09			0.870	1055.187	11.95480366	
11-May-09			0.540	1054.857	3.626610192	
12-May-09			0.480	1054.797	2.701240819	
13-May-09			0.440	1054.757	2.172953007	
19-May-09			0.415	1054.732	1.877201704	
20-May-09			0.500	1054.817	2.991608254	
22-May-09			0.775	1055.092	8.952479458	
23-May-09			0.830	1055.147	10.62715615	
24-May-09				1054.317		*Read as 1.23, but is not consistent with sping melt or weather records
25-May-09			0.860	1055.177	11.61408289	
26-May-09			0.900	1055.217	13.01268106	
27-May-09			0.900	1055.217	13.01268106	
28-May-09			0.890	1055.207	12.65406878	
29-May-09			0.700	1055.017	6.940416808	
31-May-09			0.700	1055.017	6.940416808	
1-Jun-09			0.695	1055.012	6.81709019	
3-Jun-09			0.900	1055.217	13.01268106	
4-Jun-09			0.865	1055.182	11.78370418	
5-Jun-09			0.865	1055.182	11.78370418	
6-Jun-09			0.850	1055.167	11.27925772	
7-Jun-09			0.810	1055.127	9.998220852	
8-Jun-09			0.830	1055.147	10.62715615	
9-Jun-09			0.730	1055.047	7.708460485	
10-Jun-09			0.730	1055.047	7.708460485	
10-Jun-09			0.645	1054.962	5.655886001	
11-Jun-09			0.600	1054.917	4.720031939	
12-Jun-09			0.600	1054.917	4.720031939	
13-Jun-09			0.600	1054.917	4.720031939	
14-Jun-09			0.520	1054.837	3.299945807	
15-Jun-09			0.505	1054.822	3.06699389	
16-Jun-09			0.500	1054.817	2.991608254	
17-Jun-09			0.595	1054.912	4.622269124	
18-Jun-09			0.570	1054.887	4.151733291	
19-Jun-09			0.525	1054.842	3.379879981	
20-Jun-09			0.485	1054.802	2.772167754	
22-Jun-09			0.470	1054.787	2.562682466	
23-Jun-09			0.550	1054.867	3.796924554	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
25-Jun-09			0.550	1054.867	3.796924554	
29-Jun-09			0.485	1054.802	2.772167754	
1-Jul-09			0.560	1054.877	3.97195134	
2-Jul-09			0.450	1054.767	2.298585502	
3-Jul-09			0.435	1054.752	2.111719963	
4-Jul-09			0.435	1054.752	2.111719963	
5-Jul-09			0.430	1054.747	2.05153438	
6-Jul-09			0.420	1054.737	1.934281353	
7-Jul-09			0.410	1054.727	1.821145097	
8-Jul-09			0.395	1054.712	1.659051398	
9-Jul-09			0.390	1054.707	1.607024632	
10-Jul-09			0.460	1054.777	2.42847959	
11-Jul-09			0.435	1054.752	2.111719963	
12-Jul-09			0.390	1054.707	1.607024632	
14-Jul-09			0.380	1054.697	1.505939756	
15-Jul-09			0.370	1054.687	1.408770267	
16-Jul-09			0.365	1054.682	1.361637578	
17-Jul-09			0.365	1054.682	1.361637578	
18-Jul-09			0.350	1054.667	1.225968836	
19-Jul-09			0.350	1054.667	1.225968836	
20-Jul-09			0.340	1054.657	1.140230791	
21-Jul-09			0.330	1054.647	1.058195865	
22-Jul-09			0.330	1054.647	1.058195865	
23-Jul-09			0.330	1054.647	1.058195865	
24-Jul-09			0.325	1054.642	1.01854992	
26-Jul-09			0.310	1054.627	0.905014583	
27-Jul-09			0.300	1054.617	0.833755698	
28-Jul-09			0.305	1054.622	0.86894677	
29-Jul-09			0.305	1054.622	0.86894677	
30-Jul-09			0.300	1054.617	0.833755698	
31-Jul-09			0.295	1054.612	0.799434137	
1-Aug-09			0.270	1054.587	0.640611537	
2-Aug-09			0.290	1054.607	0.765974792	
7-Aug-09			0.290	1054.607	0.765974792	
8-Aug-09			0.300	1054.617	0.833755698	
15-Aug-09			0.320	1054.637	0.979809071	
21-Aug-09			0.410	1054.727	1.821145097	
22-Aug-09			0.405	1054.722	1.76610534	
23-Aug-09			0.400	1054.717	1.712076197	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
24-Aug-09			0.510	1054.827	3.143508308	
25-Aug-09			0.455	1054.772	2.362996885	
26-Aug-09			0.460	1054.777	2.42847959	
27-Aug-09			0.445	1054.762	2.235239526	
28-Aug-09			0.430	1054.747	2.05153438	
29-Aug-09			0.425	1054.742	1.992390205	
30-Aug-09			0.415	1054.732	1.877201704	
31-Aug-09			0.420	1054.737	1.934281353	
1-Sep-09			0.420	1054.737	1.934281353	
2-Sep-09			0.400	1054.717	1.712076197	
3-Sep-09			0.400	1054.717	1.712076197	
4-Sep-09			0.400	1054.717	1.712076197	
5-Sep-09			0.400	1054.717	1.712076197	
6-Sep-09			0.390	1054.707	1.607024632	
7-Sep-09			0.390	1054.707	1.607024632	
8-Sep-09			0.390	1054.707	1.607024632	
9-Sep-09			0.390	1054.707	1.607024632	
10-Sep-09			0.410	1054.727	1.821145097	
11-Sep-09			0.385	1054.702	1.555989549	
12-Sep-09			0.375	1054.692	1.45686882	
13-Sep-09			0.390	1054.707	1.607024632	
14-Sep-09			0.415	1054.732	1.877201704	
15-Sep-09			0.390	1054.707	1.607024632	
16-Sep-09			0.390	1054.707	1.607024632	
17-Sep-09			0.430	1054.747	2.05153438	
18-Sep-09			0.420	1054.737	1.934281353	
19-Sep-09			0.400	1054.717	1.712076197	
20-Sep-09			0.415	1054.732	1.877201704	
22-Sep-09			0.410	1054.727	1.821145097	
23-Sep-09			0.410	1054.727	1.821145097	
25-Sep-09			0.430	1054.747	2.05153438	
26-Sep-09			0.430	1054.747	2.05153438	
27-Sep-09			0.410	1054.727	1.821145097	
28-Sep-09			0.420	1054.737	1.934281353	
29-Sep-09			0.410	1054.727	1.821145097	
30-Sep-09			0.380	1054.697	1.505939756	
4-Oct-09			0.410	1054.727	1.821145097	
6-Oct-09			0.398	1054.715	1.690746109	
9-Oct-09			0.350	1054.667	1.225968836	

Date	Time		Reading	elevation (m)	Flow (m3/s)	Comments
20-Oct-09			0.340	1054.657	1.140230791	
22-Oct-09			0.338	1054.655	1.123529304	
23-Oct-09			0.330	1054.647	1.058195865	
24-Oct-09			0.330	1054.647	1.058195865	
28-Oct-09			0.340	1054.657	1.140230791	
29-Oct-09			0.323	1054.640	1.00294536	
30-Oct-09			Frozen			
				MAX	13.0127	





REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	N/A
DATE:	FEB 2010
DRAWN:	TMW
DESIGNED:	TMW
CHECKED:	HHH
APPROVED:	GWF

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: Denison Environmental Services

PROJECT: 2009 ANNUAL GEOTECHNICAL EVALUATION AND INSTRUMENTATION REVIEW

TITLE: ROSE CREEK DIVERSION FLOW

PROJECT No.:	FIGURE No.:	REV.:
0762-002-05	6	0

Appendix E
Construction Cost Estimates

BID TOTALS

Biditem	Description	Status - Rnd	Quantity	Units	Unit Price	Bid Total
10	SUBMITTALS & PERMITS		1.000	LS	50,000.00	50,000.00
20	MOB GRADING EQUIPMENT		1.000	LS	1,300,000.00	1,300,000.00
30	MOB ROCK & AGGREGATE EQUIPMENT		1.000	LS	800,000.00	800,000.00
35	MOB OFFICE&YARD		1.000	LS	180,000.00	180,000.00
40	SURVEY		1.000	LS	50,000.00	50,000.00
50	SWPPP		1.000	LS	90,000.00	90,000.00
60	CLEAR & GRUB CHANNEL		356,234.000	M2	0.31	110,432.54
70	PIONEER & ACCESS		1.000	LS	45,000.00	45,000.00
80	ESTABLISH CONSTRUCTION WATER		1.000	LS	200,000.00	200,000.00
90	EXCAVATE CHANNEL		818,970.000	M3	18.00	14,741,460.00
92	DRILL & SHOOT ROCK OUT CROP		200,000.000	M3	16.00	3,200,000.00
94	PLACE TILL EMBANKMENT		117,826.000	M3	17.00	2,003,042.00
96	PLACE EMBANKMENT FILTER DRAIN		75,000.000	M3	40.00	3,000,000.00
100	CONTROL STREAM		1.000	LS	350,000.00	350,000.00
110	FISH CONTROL		1.000	LS	35,000.00	35,000.00
120	FINISH GRADE CHANNEL		296,862.000	M2	2.50	742,155.00
130	FINISH U/S DYKE		15,020.000	M2	2.00	30,040.00
140	PLACE CHANNEL&US/DYKE BEDDING		148,712.000	TN	14.00	2,081,968.00
150	PLACE CHANNEL&US/DYKE RIP RAP		385,548.000	TN	15.00	5,783,220.00
160	PIONEER & ACCESS TAILINGS AREA		1.000	LS	100,000.00	100,000.00
170	EXCAV ,HAUL & PLACE TAILINGS		412,609.000	M3	7.00	2,888,263.00
180	IMPORT & PLACE FILL IN TAILINGS AREA		499,343.000	M3	15.06	7,520,105.58
190	FINISH TAILINGS AREA		1,093,208.000	M2	1.50	1,639,812.00
200	PLACE TAILING WASTE ROCK		917,038.000	TN	10.00	9,170,380.00
210	PLACE TAILING TILL		1,093,208.000	M3	10.00	10,932,080.00
220	SET UP RIR RAP PLANT		1.000	LS	100,000.00	100,000.00
230	SET UP AGGREGATE PLANT		1.000	LS	125,000.00	125,000.00
240	DEVELOP QUARRY		1.000	LS	300,000.00	300,000.00
250	DRILL & SHOOT ROCK		218,317.000	M3	16.00	3,493,072.00
260	LOAD & HAUL TO PLANT		424,103.000	TN	2.50	1,060,257.50
270	PROCESS RIP RAP		424,103.000	TN	3.00	1,272,309.00
280	LOAD & HAUL RIPRAP		385,548.000	TN	3.50	1,349,418.00
290	PROCESS WASTE ROCK		917,038.000	TN	5.00	4,585,190.00
295	LOAD&HAUL WASTE ROCK		917,038.000	TN	3.50	3,209,633.00
300	DEVELOP BEDDING SOURCE		1.000	LS	25,000.00	25,000.00
310	LOAD & HAUL BEDDING TO PLANT		93,565.000	M3	2.50	233,912.50
320	PROCESS BEDDING		148,712.000	TN	6.00	892,272.00
330	LOAD & HAUL BEDDING		148,712.000	TN	3.00	446,136.00
340	REMEDIATE DISTURBED AREAS		1.000	LS	100,000.00	100,000.00

BID TOTALS

Biditem	Description	Status - Rnd	Quantity	Units	Unit Price	Bid Total
375	CONCRETE CUTOFF WALL		54.000	M3	700.00	37,800.00
400	EXCAV DAM FOR FILTER DRAIN		87,094.000	M3	18.00	1,567,692.00
410	SHAPE EXCAV INTERMEDIATE DAM		60,000.000	M3	18.00	1,080,000.00
420	EMB FILL D/S GLACIAL TILL		10,084.000	M3	14.00	141,176.00
430	FILTER DRAIN MATERIAL		33,612.000	M3	40.00	1,344,480.00
800	DEMOB ROCK PLANTS		1.000	LS	300,000.00	300,000.00
810	DEMOB GRADING EQUIPMENT		1.000	LS	600,000.00	600,000.00
905	CONTINGENCY/ALLOWANCES		1.000	LS	22,326,753.00	22,326,753.00
910	PROJECT G&A		1.000	LS	4,465,350.00	4,465,350.00
920	MARK UP		1.000	LS	8,930,701.00	8,930,701.00
			Bid Total	========>		$125,029,110.12

08/24/2012 14:30
2012-742 FARO RCDC - ALT#2 SIDE CHANNEL-REV# 3
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BID TOTALS

Biditem	Description	Status - Rnd	Quantity	Units	Unit Price	Bid Total
10	SUBMITTALS & PERMITS		1.000	LS	75,000.00	75,000.00
20	MOB GRADING EQUIPMENT		1.000	LS	1,150,000.00	1,150,000.00
30	MOB ROCK & AGGREGATE EQUIPMENT		1.000	LS	500,000.00	500,000.00
35	MOB OFFICE&YARD		1.000	LS	180,000.00	180,000.00
40	SURVEY		1.000	LS	150,000.00	150,000.00
50	SWPPP		1.000	LS	75,000.00	75,000.00
70	PIONEER & ACCESS		1.000	LS	45,000.00	45,000.00
80	ESTABLISH CONSTRUCTION WATER		1.000	LS	200,000.00	200,000.00
90	EXCAVATE CHANNEL		504,208.000	M3	11.87	5,984,948.96
92	RET WALL - CDH COLUMNS		2,695.000	EA	2,157.70	5,815,001.50
93	CHANNEL FOUNDATION EXCAV		349,125.000	M3	15.93	5,561,561.25
95	IMPORT FOUNDATION MTRL		349,125.000	M3	15.00	5,236,875.00
100	CHANNEL EMBANKMENT(IMPORT)		213,125.000	M3	10.00	2,131,250.00
120	FINISH GRADE CHANNEL		256,336.000	M2	1.90	487,038.40
140	PLACE CHANNEL BEDDING		97,216.000	TN	12.00	1,166,592.00
150	PLACE CHANNEL RIP RAP		235,632.000	TN	15.00	3,534,480.00
152	PLACE CHANNEL TILL		160,564.000	M3	14.00	2,247,896.00
154	PLACE CHANNEL WASTE ROCK		260,452.000	TN	11.00	2,864,972.00
156	PLACE ARTICULATED BLOCK		9,400.000	M2	220.00	2,068,000.00
158	PLACE GROUTED RIP RAP		10,628.000	TN	27.00	286,956.00
160	PIONEER & ACCESS TAILINGS AREA		1.000	LS	125,000.00	125,000.00
170	GRADE TAILINGS&POND AREA		729,300.000	M3	11.13	8,117,109.00
175	SURPLUS FNDN EXCAV TO TAILINGS		303,238.000	M3	4.50	1,364,571.00
190	FINISH TAILINGS AREA		888,774.000	M2	1.30	1,155,406.20
200	PLACE TAILING TILL		888,774.000	M3	12.00	10,665,288.00
210	PLACE TAILING WASTE ROCK		745,548.000	TN	10.00	7,455,480.00
220	SET UP RIR RAP PLANT		1.000	LS	90,000.00	90,000.00
230	SET UP AGGREGATE PLANT		1.000	LS	150,000.00	150,000.00
240	DEVELOP QUARRY		1.000	LS	300,000.00	300,000.00
250	DRILL & SHOOT ROCK		133,427.000	M3	16.00	2,134,832.00
260	LOAD & HAUL TO PLANT		235,632.000	TN	2.50	589,080.00
270	PROCESS RIP RAP		235,632.000	TN	4.00	942,528.00
280	LOAD & HAUL RIPRAP		235,632.000	TN	3.50	824,712.00
300	DEVELOP BEDDING SOURCE		1.000	LS	50,000.00	50,000.00
310	LOAD & HAUL BEDDING TO PLANT		57,944.000	M3	25.67	1,487,422.48
320	PROCESS BEDDING		97,216.000	TN	5.00	486,080.00
330	LOAD & HAUL BEDDING		97,216.000	TN	3.00	291,648.00
340	REMEDIATE DISTURBED AREAS		1.000	LS	200,000.00	200,000.00
400	EXCAVATE DAM FOR FILTER DRAIN		17,601.000	M3	18.00	316,818.00

08/24/2012 14:30
2012-742 FARO RCDC - ALT#2 SIDE CHANNEL-REV# 3
***

BID TOTALS

Biditem	Description	Status - Rnd	Quantity	Units	Unit Price	Bid Total
410	SHAPE EXCAV INTERMEDIATE DAM		109,548.000	M3	21.00	2,300,508.00
420	EMB FILL D/S GLACIAL TILL		33,612.000	M3	16.00	537,792.00
430	FILTER DRAIN MATERIAL		87,390.000	M3	40.00	3,495,600.00
450	SPILLWAY EXCAVATION		291,000.000	M3	21.96	6,390,360.00
460	CONCRETE WALL -SPILLWAY		8,600.000	M3	1,566.28	13,470,008.00
470	ROCK REINFORCEMENT		5,000.000	M2	143.00	715,000.00
800	DEMOB ROCK PLANTS		1.000	LS	175,000.00	175,000.00
810	DEMOB GRADING EQUIPMENT		1.000	LS	450,000.00	450,000.00
905	CONTINGENCY/ALLOWANCES(25%)		1.000	LS	26,010,902.00	26,010,902.00
910	FIELD G&A(5%)		1.000	LS	5,202,180.00	5,202,180.00
920	MARK UP(10%)		1.000	LS	10,404,360.00	10,404,360.00
			Bid Total	========>		$145,658,255.79

08/24/2012 12:48
2012-744 FARO RCDC-ALT #3-SWALE RVSN #2
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BID TOTALS

Biditem	Description	Status - Rnd	Quantity	Units	Unit Price	Bid Total
10	SUBMITTALS & PERMITS		1.000	LS	50,000.00	50,000.00
20	MOB GRADING EQUIPMENT		1.000	LS	1,150,000.00	1,150,000.00
30	MOB ROCK & AGGREGATE EQUIPMENT		1.000	LS	750,000.00	750,000.00
35	MOB OFFICE&YARD		1.000	LS	180,000.00	180,000.00
40	SURVEY		1.000	LS	100,000.00	100,000.00
50	SWPPP		1.000	LS	75,000.00	75,000.00
70	PIONEER & ACCESS		1.000	LS	45,000.00	45,000.00
80	ESTABLISH CONSTRUCTION WATER		1.000	LS	200,000.00	200,000.00
90	EXCAVATE CHANNEL		648,803.000	M3	7.70	4,995,783.10
100	CHANNEL EMBANKMENT		176,433.000	M3	10.00	1,764,330.00
110	DEWATER SWALE EXCAVATION		1.000	LS	286,200.00	286,200.00
120	FINISH GRADE CHANNEL		379,745.000	M2	2.50	949,362.50
140	PLACE CHANNEL BEDDING		174,045.000	TN	12.00	2,088,540.00
150	PLACE CHANNEL RIP RAP		413,461.000	TN	15.00	6,201,915.00
152	PLACE CHANNEL TILL		325,965.000	M3	14.00	4,563,510.00
154	PLACE CHANNEL WASTE ROCK		588,923.000	TN	11.00	6,478,153.00
156	PLACE ARTICULATED BLOCK		9,400.000	M2	220.00	2,068,000.00
158	PLACE GROUTED RIP RAP		10,628.000	TN	27.00	286,956.00
160	PIONEER & ACCESS TAILINGS AREA		1.000	LS	150,000.00	150,000.00
170	GRADE TAILINGS AREA INCLD IM POND		1,080,392.000	M3	9.08	9,809,959.36
190	FINISH TAILINGS AREA		769,153.000	M2	1.30	999,898.90
200	PLACE TAILING TILL		769,153.000	M3	14.00	10,768,142.00
210	PLACE TAILING WASTE ROCK		645,205.000	TN	10.00	6,452,050.00
220	SET UP RIP RAP PLANT		1.000	LS	90,000.00	90,000.00
230	SET UP AGGREGATE PLANT		1.000	LS	150,000.00	150,000.00
240	DEVELOP QUARRY		1.000	LS	300,000.00	300,000.00
250	DRILL & SHOOT ROCK		264,157.000	M3	16.00	4,226,512.00
260	LOAD & HAUL TO PLANT		465,180.000	TN	2.50	1,162,950.00
270	PROCESS RIP RAP		465,180.000	TN	4.00	1,860,720.00
280	LOAD & HAUL RIPRAP		422,892.000	TN	3.50	1,480,122.00
300	DEVELOP BEDDING SOURCE		1.000	LS	50,000.00	50,000.00
310	LOAD & HAUL BEDDING TO PLANT		108,927.000	M3	3.00	326,781.00
320	PROCESS BEDDING		176,029.000	TN	5.00	880,145.00
330	LOAD & HAUL BEDDING		174,045.000	TN	3.00	522,135.00
340	REMEDIATE DISTURBED AREAS		1.000	LS	200,000.00	200,000.00
400	EXCAVATE DAM FOR FILTER DRAIN		17,601.000	M3	18.00	316,818.00
410	SHAPE EXCAV INTERMEDIATE DAM		109,548.000	M3	21.00	2,300,508.00
420	EMB FILL D/S GLACIAL TILL		33,612.000	M3	16.00	537,792.00
430	FILTER DRAIN MATERIAL		87,390.000	M3	40.00	3,495,600.00

BID TOTALS

Biditem	Description	Status - Rnd	Quantity	Units	Unit Price	Bid Total
450	SPILLWAY EXCAVATION		291,000.000	M3	21.96	6,390,360.00
460	CONCRETE WALL -SPILLWAY		8,600.000	M3	1,566.28	13,470,008.00
470	ROCK REINFORCEMENT		5,000.000	M2	143.00	715,000.00
800	DEMOB ROCK PLANTS		1.000	LS	175,000.00	175,000.00
810	DEMOB GRADING EQUIPMENT		1.000	LS	450,000.00	450,000.00
905	CONTINGENCY/ALLOWANCES(25%)		1.000	LS	24,879,887.00	24,879,887.00
910	FIELD G&A(5%)		1.000	LS	4,975,978.00	4,975,978.00
920	MARK UP(10%)		1.000	LS	9,951,955.00	9,951,955.00
			Bid Total	========>		$139,321,070.86

Attachment B
IPRP Technical Memorandum, Final Review Comments – Rose Creek Tailings Area Workshop, Faro Mine Remediation Project

TECHNICAL MEMORANDUM

TO: **Mr. Peter Mackenzie, P.Eng., Aboriginal Affairs and Northern Development Canada (AANDC)**

FROM: **Independent Peer Review Panel (IPRP)**
Review Team Participants – Andy Robertson, Randy Knapp, Ian Hutchison, Kenneth Raven.

DATE: **September 18, 2012**

RE: **Final Review Comments – Rose Creek Tailings Area Workshop, Faro Mine Remediation Project**

INTRODUCTION

On August 29 and 30, 2012 the Independent Peer Review Panel for the Faro Mine Remediation Project met with CH2MHill Project staff, CH2MHill Technical Review Board, Yukon government representatives and federal government as represented by Aboriginal Affairs and Northern Development Canada in the offices of CH2MHill offices in Burnaby, British Columbia.

The purpose of the 2-day workshop was to:

- present the alternatives under review by CH2MHill for the Rose Creek Tailings Area;
- present the results of the potential failure modes and effects analysis, risk assessment, and cost estimates;
- receive feedback from the Yukon government, AANDC and the IPRP regarding the risk assessment; and
- attempt to obtain general consensus for a selected alternative.

The IPRP was represented by Andy Robertson, Randy Knapp, Ian Hutchison and Kenneth Raven. Electronic copies of relevant CH2MHill reports including the *Draft Report on Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area, Faro Mine*, and *the Final Gap Assessment Report, Faro Mine Remediation Project* were provided to the IPRP in advance of the 2-day workshop.

The three alternatives presented by CH2MHill for the Rose Creek Tailings Area that were the main subject of the workshop, include:

- Alternative 1 – Routing of the full Probable Maximum Flood (PMF) through a modified (widened and deepened) Rose Creek Diversion (RCD) with no flow entering the tailings storage area.

- Alternative 2 – Channelling of flows greater than the 500-year flood over the top of an overflow weir and into a single, large, armoured channel (the side channel) designed to carry the difference between the PMF and the 500-year flood flow. The side channel would run parallel and immediately adjacent to the RCD, principally founded on soil and bedrock, with the north dyke dividing the RCD and the proposed side channel. Construction of energy dissipation structures to control erosion and an improved spillway to route the flow across the tailings and around the intermediate dam (ID) are central elements of this Alternative.

- Alternative 3 – Routing of flows that exceed the 500-year flood up to the PMF flood over an overflow weir structure into the Rose Creek tailings Area (RCTA) and over a covered tailings surface via a single wide riprap-lined swale (about 120 m wide and 1.5 m deep) dedicated to containing the flood flow until a pool has formed that would be able to dissipate the energy during the flood peaks. Construction of an improved spillway around the ID is also a central element of this Alternative.

The IPRP recognizes that it is currently a pivotal time for decision making concerning remediation alternatives and appreciates the opportunity of assisting Faro Remediation Project staff and territorial and federal governments in refining and selecting remediation alternatives for the Faro Mine site.

In addition, the IPRP was asked at the workshop to comment on down valley hydraulic mitigations presented by CH2MHill at the workshop.

FINDINGS AND RECOMMENDATIONS

The following statements comprise the findings and recommendations of the IPRP concerning the alternatives evaluation as given in the CH2MHill reports and the presentations made by CH2MHill at the workshop.

1. Based on the information available the three alternatives for addressing the PMF at the RCTA would appear to represent the plausible and feasible range of alternatives for routing of the PMF around/through the Rose Creek Valley.

2. The risk analyses and assessment process for the three Alternatives for RCTA was a useful platform for understanding the relative risks and potential failure modes, where failure is understood to be defined as release of tailings from the RCTA.

3. The inclusion of the side channel into Alternatives 2 and 3 is a major engineering improvement to the earlier alternatives developed in the Draft Closure and Remediation Plan developed by SRK Consulting Engineers and Scientists in 2010.

4. The IPRP considers that Alternatives 2 and 3 are variants on one remediation alternative and that a preferred Alternative for the site could be developed based on

engineering optimization of Alternatives 2 and 3 with the intent of maximizing cost effectiveness and selecting the parts of both Alternatives that best accommodate RCTA site conditions.

5. Recognizing the need to select a preferred Alternative for passing PMF flows through Rose Creek Valley, we recommend that such decisions need to consider all of the potential interactions such decisions may have with other elements of remediation of the Faro Mine site. Such potentially interactive remediation elements include surface water management, groundwater collection systems, tailings covers, spillway designs and role of the Cross Valley Dam (CVD). In order to address this concern, the design of these other remediation elements should be taken to a level that demonstrates feasibility and definitive layouts.

6. The IPRP considers that the risks of failure for Alternative 1 may be underestimated (i.e., landslides and ice blockages). Based on historical community concerns and risk mitigation requirements, Alternative 1 should include a PMF spillway at the ID, comprehensive erosion protection measures in the RCD channel between the ID and downstream discharge point, and consideration of a fish ladder. Otherwise, Alternative 1 may be perceived as potentially posing a threat of catastrophic failure to the ID.

7. The IPRP considers that the risks of failure for Alternatives 2 and 3 may be overestimated with respect to the environmental impacts of tailings erosion (Type 1 and Type 2 tailings releases). The IPRP is of the opinion that Type 1 releases should not be considered a failure mode under extreme runoff conditions, and Type 2 releases under similar conditions should be considered of low significance. Under PMF conditions, these losses may well be indistinguishable from background and only a small fraction of losses from other waste management facilities at the site (e.g., erosional losses from the waste rock dumps).

8. The CH2MHill analyses of the alternatives for routing the PMF through Rose Creek Valley assume that the Cross Valley Dam is removed. The IPRP continues to recommend that the Cross Valley Dam be retained, if for no other reason than to provide an emergency water storage facility to accommodate groundwater discharges to surface during upsets and power outages to the main RCTA seepage collection system. In addition, the Cross Valley Dam could provide for some sedimentation of tailings eroded during extreme runoff events.

9. The proposed ground support systems to allow tailings excavation and replacement described as part of Alternative 2 for supporting the side channel is a major engineering improvement. However, the IPRP questions whether this approach is necessary and cost-effective. Alternative approaches such as incremental loading with/without wick drains and soil improvements using compacted sand/stone columns may achieve the necessary ground strengths at lower costs.

10. Information needed to refine Alternatives for passing the PMF through Rose Creek Valley includes:

    - Tailings depths and properties in the area of the proposed side channel section to determine deformation properties/strengths and to optimize the cut and fill design.

    - Thermal regime and stability of the up-slope materials (soil and bedrock) on the north-facing slope of the RCD and underlying the RCD to further assess potential for landslide plugging of the RCD and potentially the proposed side channel.

    - Ground conditions in the areas of proposed spillways around the ID and the CVD to optimize design.

REVIEW COMMENTS – DOWN VALLEY HYDRAULIC MITIGATIONS

1. The current spillway system at the Intermediate Dam does not meet the Canadian Dam Association (CDA)- Dam Safety Guidelines for "Very High Hazard" classification for which the consequences of a failure would be a "significant/major loss or deterioration of important/critical fish or wildlife habitat for which restoration or compensation in kind is possible but impractical". The current spillway system is reported to have a capacity of approximately 30-40 m^3/s, which is less than the maximum flow that has been measured in RCD and would have to be passed in the event of RCD blockage. It is also far less than the 674 m^3/s PMF protection that is required (this assumes the haul road rock drain is removed).

2. We have been told that it may take from 10 to 15 years to install the final long-term spillway capacity. This period is consistent with an operating period rather than a temporary construction period and the IPRP considers the CDA Guidelines are applicable. The IPRP notes that the annual potential for flood exceedance for the RCD channel is about 1 in 300 (this is a rough estimate). For a 15 year service life the probability of failure could be as high as 1 in 20 or 5% which is unacceptable for a structure of this classification.

3. We therefore recommend that immediate attention be given to upgrading the spillway capacity of the ID as soon as possible. Our preferred approach is to build out the final spillway that is capable of handling the PMF. Initially this should be at least for the catchment area that currently drains to the RCD including the attenuation provided by the haul road rock drain (provided this is retained). The IPRP notes that the hazard classification for CVD is "significant" resulting in a flood design criteria of 1 in 100 to 1 in 1000, which the IPRP understands is closer to the current capacity – which should be verified and addressed appropriately.

4. Since it takes time for design and contractor mobilization and obtaining budget approvals, other short-term improvements should be considered that lead to a significant reduction in the current risk. A range of cost-effective measures selected from the modified list of those presented by CH2MHill in the workshop (see Attachment A) should be further evaluated and a list of feasible options that together achieve an acceptable risk reduction should be implemented expeditiously.

Attachment A – Potential ID Flood Capacity Improvement Options (CH2MHill 3/30/20120 modified by IPRP)

- Increase hydraulic capacity of spillway
    - Install trench fitted with erodible fuse plug
    - Increase width and depth of current spillway cut
    - Provide more regular bottom surface of channel (concrete slab, etc.)

- Increase height of embankment crest
    - Engineer as necessary (e.g. geosynthetic core extension), thermal cover to prevent piping and allow higher flood level
    - Add temporary crest berm

- Protect spillway channel from erosion (Reno/gabion mattress, etc.)

- Increase capacity of RCD
    - Remove vegetation
    - Raise north dyke (fill hollows, add temporary berm for protection at design flow; i.e. freeboard)
    - Identify and remove constrictions?

- Continue routine inspections and repairs as necessary (RCD, Spillway)

Attachment C
TRB Summary Report 3: Rose Creek Tailings Area, Faro Mine Remediation Project

Technical Review Board Summary Report 3: Rose Creek Tailings Area, Faro Mine Remediation Project

Prepared for

CH2MHILL®

November 2012

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A Agenda for the Meeting

B TRB Recommendations – Tracking and Status

Acronyms and Abbreviations

AANDC	Aboriginal Affairs and Northern Development Canada
BC	British Columbia
BGC	BGC Engineering
CDA	Canadian Dam Association
CH2M HILL	CH2M HILL Canada Limited
CVD	Cross Valley Dam
ID	Intermediate Dam
IPRP	Independent Peer Review Panel
PDT	Project Design Team
PMF	Probable Maximum Flood
RCD	Rose Creek Diversion
RCTA	Rose Creek Tailings Area
TRB	Technical Review Board
YG	Government of Yukon
YT	Yukon

SECTION 1

Introduction Purpose and Scope

The function of the Technical Review Board (TRB) is to provide an independent, internal, technical review of work being performed by the Project Design Team (PDT) to develop a closure plan for the Rose Creek Tailings Area (RCTA). The closure plan includes flood routing through the Rose Creek Diversion (RCD), over the RCTA, or a combination of the two. The RCTA comprises a series of tailings impoundments constructed in the Rose Creek Valley.

The TRB has been engaged on the project for three meetings. The initial (first) TRB meeting was held on April 17 and 18, 2012, and was a 2-day workshop hosted at the CH2M HILL Canada Limited (CH2M HILL) office in Burnaby, British Columbia (BC). At this initial meeting, the TRB was presented with background information, and the PDT presented alternatives under consideration for the closure of the RCD and RCTA.

Since the initial TRB meeting, 2 additional TRB meetings have occurred.

The second TRB meeting with PDT was held during the week of June 29, 2012 when the TRB met in Whitehorse and Faro, Yukon (YT) for the purpose of observing physical conditions at the project site, and to further evaluate the alternatives under consideration in the field. This site trip was the first opportunity for TRB to see the Faro Mine Complex (FMC) and its facilities. The observations and discussions arising from this site trip are presented in the TRB Summary Report 2, dated July 2012.

A third TRB meeting was conducted on August 28, 29, and 30, 2012. The purpose of the meeting was to review the PDT's final recommendations regarding alternative selection and to assist the PDT in preparation for their followup meeting with the Independent Peer Review Panel (IPRP).

At the time that the TRB meeting was held, the alternatives still under consideration included the following three alternatives:

Alternative 1 includes routing the full probable maximum flood (PMF) through a modified RCD, with no flow entering the RCTA, except from the local catchment area (as suggested in TRB Report 1). Some refinements or optimizations were identified for this alternative, including straightening of the channel in some locations and widening the channel to limit its depth along the lower reach of the channel, immediately upstream from the Intermediate Dam (ID). Construction can likely be accomplished in the low-flow winter season to minimize impacts on aquatic habitat, with simple, localized, pumped diversions and conventional earth-moving construction equipment. It appears feasible to expand into the left bank with rock cuts and deepen the channel in some areas.

The most significant issue still under evaluation by the PDT is potential blockage of the channel by either ice buildup, ice damming, or flood debris, in combination with large floods (e.g., early spring flows).

Alternative 2 involves constructing a side channel in the RCTA immediately adjacent to the RCD to handle flows exceeding the 500-year flood event (as suggested in TRB Report 1). Flows up to the 500-year event would be routed in the current RCD, with minor improvements to the existing channel. Because of the apparent thick tailings deposits near the downstream reach of the proposed channel alignment and associated significant potential excavation of tailings material, it appears prudent to terminate the end of the channel farther upstream and add erosion protection (e.g., a riprap apron) at the channel exit to prevent damage to the tailings cover. The PDT is still evaluating this option, with the details still to be developed.

The most significant issue for this alternative is the tailings thickness and the difficulty in maintaining a stable excavation slope when excavating below the groundwater table. Construction elements to accomplish this work may include dewatering, winter construction, and a retaining system. Design issues include erosion of the channel side slopes and bottom, which will likely require that it be riprap lined, with associated filter layers to prevent loss of underlying tailings material. Maintenance requirements on an ongoing basis also need to be addressed, including remediating the effects of differential settlement of the tailings and possible damage in the event of tailings liquefaction due to an earthquake. The TRB suggest the PDT consider inclusion of narrow channels on both sides of the main channel to handle routine runoff flow that will enter the side channel. These narrow channels will flow on a routine basis and can be maintained with minimal effort with respect to infiltration criteria requirements.

Alternative 3 would route flows that exceed the 500-year flood up to the PMF over an overflow weir structure, into the RCTA, and over a covered tailings surface via a wide riprapped channel or swale (tentatively about 120-metres [m] wide and 1.5-m deep) dedicated to containing the flood flow until a downstream pool has formed that would be able to dissipate the energy from the flood peaks. Flows up to the 500-year flood would be routed in the current RCD, with minor improvements to the existing channel. The flood flow would exit the tailing impoundment through an improved spillway at the right abutment of the ID. This concept is a modification to the proposed multiple-swale concept in *the Faro Mine Complex, Closure and Remediation Plan, Project Description – DRAFT 4A* (SRK Consulting [SRK], 2010) and appears to mitigate some of the concerns with the multiple-swale concept. Concerns include the difficulty of equal distribution of flow into each of the swales and the likely tendency for flows to preferentially erode and form a single, larger channel along one of the swales because of differential settlement of the tailings and the tailings cover. Infiltration into the tailings must be kept within design criteria, which could be handled by including narrow channels within the main channel, as recommended for Alternative 2. Maintenance requirements in the long-term also need to be considered, also as noted for Alternative 2. The TRB recommends that the PDT should further evaluate this alternative concept, provided that adequate cover protection is installed and the flow is adequately contained in this single, dedicated “swale.”

This Summary Report 3 presents the results of the third TRB meeting, during which presentations were made by the PDT, and confirms TRB review comments on the PDT presentations that were made in summary at the conclusion of the meeting.

1.1 Attendees

The following members of the TRB and PDT attended the third TRB meeting:

John Spitzley/CH2M HILL, PDT
Jaco Esterhuizen/CH2M HILL, PDT
Gerry Ferris/BGC Engineering (BGC), PDT
Loren Anderson/Utah State University, Professor Emeritus, PDT
Wim Veldman/Matrix Solutions, PDT
Peter McCreath/Clearwater Consultants, TRB
Fred Matich/MAJM Corporation Ltd., TRB
Rick Ricker/CH2M HILL, TRB

The attendees at this meeting included representatives from Aboriginal Affairs and Northern Development Canada (AANDC) and Government of Yukon (YG), as well as members of the IPRP, PDT, and TRB.

1.2 Format of Meeting

The format of the meeting, as presented in greater detail in the agenda in Attachment A, was structured as follows:

1. Design Team Presentations
2. Breakout Sessions by IPRP and TRB
3. Feedback Session
4. Discussion of IPRP and TRB Feedback

SECTION 2

Meeting Results

2.1 Pre-meeting Activities and Reports

Following the second TRB meeting and associated site trip, optimizations and refinements to the three proposed closure alternatives were discussed by teleconference and in preliminary terms by the TRB and the PDT. A report titled *Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area, Faro Mine*, dated August 2012, was issued in draft form by the PDT in advance of the third TRB meeting and provided valuable background for reference during the followup presentations.

2.2 PDT Presentations

PDT presentations included background information, alternatives under consideration, evaluation of icing potential, and risk assessment, and were made to the TRB on August 28, 2012, the first day of the sessions. The risk assessment presentation provided an excellent platform for comparative evaluations. There were a number of issues raised during the presentations, and the main issues are presented and discussed in the following sections. The TRB appreciates the diligence of the ongoing evaluations.

2.3 Main Issues Identified

There have been a number of issues identified by the TRB as a result of previous discussions and as an outcome of the third TRB meeting. These issues will ultimately need to be addressed as the project moves forward into design. The main issues are presented in the following list as feedback to the PDT. Many of these issues were also identified by the IPRP during the feedback session.

1. Fish Passage: This must be assured not only over the long-term but also during the period of remedial measures construction.
2. Blockage: The potential detrimental effects of RCD flow blockage (and any other project elements in its closure configuration) need to be adequately addressed, including blockage by:
   - Icing
   - Woody debris
   - Landslides
3. Quality of the North Dike: There is significant uncertainty in the reference documentation regarding the quality of the earthworks in the RCD North Dike, which reportedly traverses a wide variety of materials, ranging from bedrock to till and creek alluvium, and was built under winter conditions. This uncertainty needs to be resolved by appropriate design measures.
4. Fate of the Cross Valley Dam (CVD): In light of overall site surface water and groundwater management planning, carefully consider all aspects of maintaining the CVD before making a decision to remove it. Rationale must be developed to justify keeping or removing the CVD.
5. Improvement to the ID, including:
   - Measures to prevent possible impairment of filters due to long-term chemical precipitate accumulation
   - Buttressing downstream, as required by closure design
6. Long-Term Monitoring and Surveillance: Consistent with closure design of the RCTA and other elements of the overall project, as well as closure policy.
7. Maintenance and Perpetual Care

8. Scheduling future Improvements of the RCTA and the RCD: Further consideration and optimization of measures in the following broad categories:
    - Interim
    - Transition
    - Closure
9. Evaluation of Haul Road Benefits: Such as downstream attenuation effects during severe flooding.
10. Check precedent for use of articulated concrete block measures in overflow weirs in a Northern Canadian setting.

2.4 Interim Improvements

During the interactive sessions with the IPRP, there was considerable discussion and interest in interim improvements (i.e., improvements that might be appropriate in the near-term to reduce risk until the final closure plan is implemented which may not be complete for up to 10 years). This discussion was driven primarily by the IPRP, and the issues discussed included the following interim design criteria and considerations:

1. Dam Design:
    - Canadian Dam Association (CDA) criteria (High to Very High consequence category)
    - Consensus of group is that current risk exposure is unacceptable
    - Spillway Improvements are considered a high priority:
        – Significant spillway improvements would be required to meet CDA guidelines
        – Merits of full PMF versus some lesser flood were discussed with respect to safe dam requirements, risks over the interim exposure period (up to 15 years), and funding
        – A number of means of increasing spillway capacity were discussed, such as raising the dam (requires raising the core), deepening or widening the spillway, and providing an interim service spillway
        – Magnitude of the PMF given the presence of the Haul Road and other features was discussed (i.e., Haul Road will attenuate peak flows)
2. RCD:
    - Consider investigations to better define potential landslide risk on the south bank
    - Channel may not have 500-year capacity due to low points in the dike crest
    - For completeness, examine merits of providing a cutoff (such as cement bentonite) in the North Dike to offset uncertainty regarding piping potential
3. Side Channel, Alternative 2: Further evaluation and optimization of approaches to provide temporary support to excavations in tailings, during replacement with engineered earth fill. These are tentatively presented as achievable by deep soil mixing, or perhaps by temporary sheet piling support in the area of deepest tailings. Potential use of soft ground displacement techniques should be considered for this area, which will also provide an erosion protection cover to the tailings between the end of the presently proposed channel and the spillway at the ID.

The PDT needs to address these concerns and ideas expressed for interim improvements.

SECTION 3

Status of Previous Recommendations

The status of the recommendations made by the TRB in its Reports 1 and 2, as well as the recommendations made in the next section, is presented in summary in Attachment B to this report.

SECTION 4

Conclusions and Recommendations

The following main conclusions resulted from the TRB review activities associated with this meeting and discussions leading up to it. Based on the discussions and decisions to date, the choice is between Alternatives 1 and 2. Given that the PDT considers cost for the alternatives to be equivalent, the TRB favours Alternative 2. This decision is further based on the evaluations carried out to date.

Regardless of the alternative selected, the TRB agrees with the IPRP that a spillway at the right abutment of the ID is prudent. The key driving factors that lead the TRB to favour Alternative 2 are:

1. The difficulties of implementing Alternative 1 due to vulnerability to plugging from landslides
2. Potential erosion issues with the steep outlet (downslope section) portion of the RCD that could threaten the ID left abutment
3. A PMF spillway is recommended for all alternatives (i.e., Alternative 1 does not eliminate the need for a PMF spillway on the ID)
4. Alternative 2 has the advantage of the RCD providing a buffer from landslides and other blockage mechanisms
5. With appropriate design, Alternative 2 can capture the effects of a North Dike failure within the scope of long-term maintenance

TRB makes the following specific recommendations:

1. A review of the available methods and means to provide a competent foundation for the Alternative 2 channel and its outlet works should be carried out to supplement the concept already presented.
2. The current monitoring program does not necessarily address some of the issues identified in Section 2.0 of this report. The PDT should develop and implement a monitoring program for the interim periods aimed at managing risks and potential hazards identified by the group that met during the TRB meetings, including YG and their representatives and the IPRP.
3. Precedence for natural landslide- and icing-related issues needs to be examined and evaluated at other YT projects. Precedent for the use of expedients, such as articulated concrete block measures in a Northern Canadian setting, should also be examined.
4. The PDT must identify short-term priorities to reduce risks during the period prior to the start of closure implementation.

SECTION 5

General

The TRB appreciates the informative and constructive input to the discussions at this meeting by all of the participants. It would be pleased to expand on any aspect of this report, as required.

Respectfully submitted,

TECHNICAL REVIEW BOARD

Richard E. Riker, P.E., G.E.

Peter S. McCreath, P.Eng.

M.A.J. (Fred) Matich, P.Eng.

SECTION 6

Work Cited

SRK Consulting (SRK). 2010. *Faro Mine Complex, Closure and Remediation Plan, Project Description – DRAFT 4A*. Prepared for Yukon Government. March 29.

Attachment A
Agenda for the Meeting

Rose Creek Tailings Area
Vangorda and Faro Creek Diversions

ATTENDEES:

Stephen Mead/YG
Deborah Pitt/YG
Lionel Etheridge/CH2M HILL
Fred Matich/ Technical Review Board (TRB)
Peter McCreath/TRB
Rick Riker/TRB
Loren Anderson/RAC Engineers
Wim Veldmen/ Matrix Solutions
John Spitzley/CH2M HILL
Jim Stefanoff/CH2M HILL
Jaco Esterhuizen/CH2M HILL
Gerry Ferris/BGC
Howard Thomas/CH2M HILL
AANDC Representatives
IPRP Members

PREPARED BY: John Spitzley/ CH2M HILL

MEETING DATE: 08/29/2012 – 08/30/2012

VENUE: CH2M HILL,
Suite 2100, Metrotower II
Burnaby, BC

The purpose of this meeting is to present the alternatives under review by CH2M HILL for the Rose Creek Tailings Area; present the results of the potential failure modes and effects analysis, risk assessment, and cost estimates developed for the alternatives; receive feedback from YG, AANDC and the IPRP regarding the risk assessment; and attempt to obtain general consensus for a selected alternative.

A secondary purpose of the meeting is to review the proposed plans for the Faro and Vangorda Creek Diversions and CH2M HILL's recommendations for the selected routing.

Wednesday, August 29;

8:30 a.m. – 9:00 a.m.	Introductions
9:00 a.m. – 9:30 a.m.	Goals for Meeting
9:30 a.m. – 12:00 p.m.	Description of RCTA alternatives presented by CH2M HILL
12:00 p.m. – 1:00 p.m.	Lunch at CH2M HILL/ General Discussion
1:00 p.m. – 5:00 p.m.	Results of risk assessment of RCTA Alternatives presented by CH2M HILL Recommendation of a preferred alternative by CH2M HILL; feedback from YG/AANDC/IPRP

Thursday, August 30;

8:00 a.m. – 9:30 a.m.	Complete discussion of RCTA alternatives evaluation wiith the objective of reaching consensus on selection of a preferred alternative and path forward.
10:00 a.m. – 12:00 a.m.	Vangorda Creek Diversion – recommendation from CH2M HILL
12:00 p.m. – 1:00 p.m.	Lunch at CH2M HILL/ General Discussion
1:00 p.m. – 2:00 p.m.	Complete Discussion Vangorda Creek Diversion
2:00 p.m. – 5:00 p.m.	Faro Creek Diversion – recommendation from CH2M HILL

Attachment B
TRB Recommendations – Tracking and Status

Faro Mine Remediation Project - Rose Creek Tailings Area - Technical Review Board Recommendations - Tracking and Status

Number	Date	Recommendation	Status	Comments
TRB 1-1	May-14-12	**Alternative 1:** Modify the RCD to carry the entire PMF flow without any excess flow entering the RTCA	Completed	Discussed during June 2012 site visit, addressed by Design Team with modified RCD channel concept presented in Draft Report "Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area" dated August 24, 2012.
TRB 1-2	May-14-12	**Modified Concepts for Alternatives 2 and 3:** Eliminate the swales and carry the flow in a single armoured channel. The channel may be located on the south side of the RCTA, adjacent to the RCDC.	Completed	Discussed during June 2012 site visit, addressed by Design Team with 40 m wide armoured channel concept adjacent to RCDC presented in Draft Report "Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area" dated August 24, 2012.
TRB 2-1	July-26-12	The potential flood-attenuating benefits of retaining the haul road flow-through rock drain should be further evaluated by the Design Team	In Progress	To be addressed by Design Team as part of on-going design optimization and development of overall site water management plan for interim, transition and closure periods.
TRB 2-2	July-26-12	Alternative 1 should be further evaluated to quantify the probability of occurrence and the likely consequences of ice build-up and blockages occurring in conjunction with significant flood flows	Completed	Icing blockage potential and consequences addressed by Design Team in Appendix D of Draft Report "Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area" dated August 24, 2012, discussed during August 29/30, 2012 meeting with IPRP.
TRB 2-3	July-26-12	Reconfiguration of the side-channel Alternative 2 should be considered to minimize tailings excavation requirements	In Progress	Addressed by Design Team based on observations made during June 2012 site visit. Reconfigured 40 m wide channel concept presented in Draft Report "Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area" dated August 24, 2012. Alternative means of preventing unacceptable erosion of tailings, such as replacing tailings safety and/or stabilizing tailings to be addressed in on-going design evaluations. Special attention to be paid to the potential for piping of the North Dike due to reported defects arising from winter construction.
TRB 2-4	July-26-12	Alternative 3 should be further defined to ensure adequate erosion protection across the RCTA area	Completed	Addressed by Design Team, discussed during June 2012 site visit, reconfigured 120 m wide armoured channel/swale concept presented in Draft Report "Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area" dated August 24, 2012.

Faro Mine Remediation Project - Rose Creek Tailings Area - Technical Review Board Recommendations - Tracking and Status

Number	Date	Recommendation	Status	Comments
TRB 2-5	July-26-12	All three alternatives should be subjected to a potential failure mode analysis and risk analysis	Completed	Potential Failure Modes identified (Appendix C) and Risk Analyses results presented in Draft Report "Alternatives Evaluation and Risk Analyses for the Rose Creek Tailings Area" dated August 24, 2012. Results presented and discussed at August 29/30 2012 meetings
TRB 3-1	Sep-12	A review of the available ways and means to provide a competent foundation for the alternative 2 channel and outlet works should be carried out to supplement the concept already presented	In Progress	See comments under TRB 2-3 above. Consider also a protective surface armouring between the end of the Alternative 2 Channel and the Spillway at the north abutment of the ID.
TRB 3-2	Sep-12	The Design Team should develop and implement a monitoring program for the interim periods aimed at managing risks and potential hazards identified by the group.	In Progress	
TRB 3-3	Sep-12	Precedence for natural landslide and icing related issues need to be examined and evaluated at other projects in Yukon. Precedent for the use of expedients such as articulated concrete block measures in a Northern Canadian setting should also be examined.	In Progress	
TRB 3-4	Sep-12	The Design Team must identify short term priorities to reduce risks during the period prior to the start of construction of closure facilities.	In Progress	