# Deloitte & Touche Inc.

# Faro Mine Hydraulic Capacity Analysis

## Final Report
## June 2006

northwest hydraulic consultants
nhc

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# Faro Mine Hydraulic Capacity Analysis

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# Notification



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# Executive Summary

This report presents a study undertaken to estimate the current system capacity of the Rose Creek Diversion Canal (RCDC), Intermediate Dam spillway, and Cross Valley Dam spillway at the Faro Mine site, Yukon Territory. The study was initiated due to the results from earlier analysis of the Intermediate Dam spillway which suggested that the capacity was less than the design requirements outlined by the existing water licence.

Since 1998, Deloitte & Touche Inc. has been the interim receiver and responsible for the care and maintenance of the mine site. The Faro Mine Closure Project Office (FMCPO) is currently working to develop a mine closure plan. This closure plan may include a strategy to upgrade the RCDC for closure. Until a conveyance strategy is agreed upon and implemented, the existing conveyance structures are to be capable of safely conveying the 500-year instantaneous flood as required in the conditions of the existing water licence. The scope of this hydrotechnical analysis included the following tasks:

1. Assemble 500-year inflow design flood (IDF) estimates for each conveyance structure based on routing scenarios and area-based hydrologic estimates.
2. Compare the existing capacity with the IDF through hydraulic modelling and the development of rating curves for the structures.
3. Identify required modifications to address insufficient conveyance capacity and further investigations required to confirm stability assumptions made in preparation of this report.

Through hydrological analysis of the watersheds and hydraulic modelling of the RCDC the following minimum design requirements were determined for each of the conveyance components:

- RCDC = 130 $m^3/s$
- RCDC fuse-plug = 6.2 $m^3/s$
- Intermediate Dam Spillway = 11.2 $m^3/s$
- Cross Valley Dam Spillway = 15.5 $m^3/s$

These design values have been conservatively estimated ignoring the attenuation of North Fork flood flows resulting from the existing north haul road rockfill crossing.

Through one-dimensional numerical hydraulic modelling it was determined that the RCDC and the spillways around the north side of the Intermediate Dam and the Cross Valley Dam provide adequate capacity to convey the 500-year IDF. The riprap stability of the lower portion of the Intermediated Dam spillway and the entire Cross Valley Dam spillway during the IDF needs to be confirmed. Site inspections scheduled for June 2006, and test pit analysis scheduled for September 2006 will identify any stability shortcomings.

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# 1 Introduction

## 1.1 General

This report summarizes the hydrotechnical analysis of the current flow conveyance capacity of the hydraulic structures in the tailings area at the Faro Mine Site. These structures currently pass natural flows from Faro and Rose Creeks, and other small tributaries, around the tailings area downstream to the Pelly River. This study was undertaken to estimate the current system capacity of the Rose Creek Diversion Canal (RCDC), Intermediate Dam spillway and Cross Valley Dam spillway. This overall system study was initiated due to the results from earlier analysis of the Intermediate Dam spillway which suggested that the capacity was less than the design requirements specified by the current water licence. The calculated capacities in this report are based on the geometry of the structures only and this report highlights instances where stability of the structure is in question due to erosion or where further confirmation of hydraulic stability is required.

## 1.2 Project Background

Faro Mine is located 22 km north of the Town of Faro in the central Yukon, approximately 200 km northeast of Whitehorse. The mine was operated from 1969 until 1998. Deloitte & Touche Inc. (DT) has been the interim receiver and responsible for the operation of the mine site since 1998.

A series of impoundments were constructed across the Rose Creek valley with a diversion channel (RCDC) constructed along the south wall of the valley and a series of spillways along the north wall of the impoundment dams (Figure 1). As part of the operation at the mine site, an annual inspection of these structures is completed to ensure no major deterioration of the structures is occurring. Based on this ongoing visual inspection, important structures at the site are reviewed in detail on a continuing cycle. As part of this series of detailed studies a review of the Intermediate Dam spillway was performed in 2003 (**nhc**, 2003) which indicated that the capacity was less than the design value of 100 $m^3$/s. This lead to a study initiated in 2005 of the capacity of both the Intermediate and Cross Valley Dam spillway capacity. Preliminary results (**nhc**, 2005) which incorporated new survey information confirmed the capacity of the Intermediate Dam was less than the design value and that the capacity of the Cross Valley Dam was greater than designed. The focus of this study then changed to understanding the capacity of the entire hydraulic system around the tailings area.

The Faro Mine Closure Planning Office (FMCPO) is currently working to develop a closure plan for the Faro Mine site. Implementation of this plan is still a number of years away. During the ongoing development of the closure plan a number of scenarios are being investigated to safely convey incoming flow through this valley throughout closure. Until the closure conveyance strategy is agreed upon and implemented, the existing conveyance structures are to be capable of safely conveying the 500-year instantaneous flood as required in the conditions of the existing water licence, which states:

> Tailings Management System
>
> 41. The licensee shall channel the waters of Rose Creek around the tailings facility and shall ensure that the diversion canal has the hydraulic capacity to carry a 1:500 year flood flow.
>
> 42. The Licensee shall maintain the overflow structure on the Rose Creek diversion dam to ensure that flows that would cause overtopping of the diversion dykes are safely diverted through the tailings pond.
>
> 43. The License shall ensure that the spillways on the intermediate dam and the cross valley dam have the hydraulic capacity to carry a 1:500 year flood flow of Rose Creek.

In 2003 a review of the capacity of the RCDC was conducted following the original design philosophy (water licence Y2L3-2226) that the RCDC be capable of conveying the 500-year event (BGC, 2004). Low sections of the dike crest were encountered and subsequently raised by the required amount (BGC, 2005a). This letter report presents hydrotechnical analysis of the existing structures based on hydrology and survey data from previous studies (BGC, 2003; Hydrocon Eng., 1982; **nhc**, 2004).

## 1.3 Scope of Work

The scope of this hydrotechnical analysis included the following tasks:

1. Assemble 500-year inflow design flood (IDF) estimates for each conveyance structure based on routing scenarios and area-based hydrologic estimates.
2. Compare the existing capacity with the IDF through hydraulic modelling and the development of rating curves for the structures.
3. Identify required modifications to address insufficient conveyance capacity and further investigations required to confirm stability assumptions made in preparation of this report.

# 2 Inflow Design Flood Event

## 2.1 RCDC Design Flood

The conveyance structures analyzed in this report are the Rose Creek Diversion Channel (RCDC), the Intermediate Dam spillway, and the Cross Valley Dam spillway. Routing of the IDF was conducted using the previously estimated 500-year instantaneous peak flow of 130 $m^3/s$; as combined flow from the North Fork and South Fork of Rose Creek (**nhc**, 2004). This flow estimate was used as the IDF for analysis of the RCDC. The estimation of this flow assumes that the existing north haul road rockfill crossing does not attenuate the flow. As long as the haul road rockfill crossing exists, it is expected to attenuate flood flows reducing the peak flow and increase the lag time from the North Fork which reduces the likelihood of North Fork and South Fork peak flows coinciding with each other. Thus the IDF used for this analysis is significantly conservative. For this analysis it was assumed that the North Wall Interceptor Ditch (NWID) fails and any flow it generally intercepts would be conveyed by both the Intermediate Dam and Cross Valley Dam spillways.

## 2.2 Intermediate Dam Spillway Design Flood

Inflow to the Intermediate Impoundment includes overflow from the RCDC fuse-plug, and flow from the northeast slopes of the valley upstream of the Intermediate Dam. Hydraulic modelling of the 130 $m^3/s$ IDF through the RCDC used in analyzing its capacity resulted in an overflow of 6.2 $m^3/s$ through the fuse-plug.

The contributing watershed area for the Intermediate Dam spillway was delineated off the aerial photogrammetry generated contours to be 4.9 $km^2$ assuming failure of the north wall interceptor ditch (Figure 1). From the extreme flood curves (Figure 2) derived for the Faro mine site (**nhc**, 2004) the watershed based inflow to the Intermediate Dam is 5.0 $m^3/s$. Conservatively assuming these peak flood events occur with no lag time between them, the 500-year IDF for the Intermediate Dam spillway is 11.2 $m^3/s$.

## 2.3 Cross Valley Dam Spillway Design Flood

Inflow to the impoundment above the Cross Valley Dam includes flow from the northeast slopes draining above the Cross Valley Dam and the RCDC overflow discharge conveyed through the Intermediate Dam spillway, 6.2 $m^3/s$. The contributing watershed area above the Cross Valley Dam was delineated off the aerial photogrammetry generated contours to be 10.0 $km^2$ (Figure 1) including the area above the Intermediate Dam. From the extreme flood curves (Figure 2) derived for the Faro mine site (**nhc**, 2004) the watershed based inflow to the Cross Valley impoundment is 9.3 $m^3/s$. Conservatively assuming these peak flood events occur with no lag time between them, the 500-year IDF for the Cross Valley Dam spillway is 15.5 $m^3/s$.

# 3 Hydrotechnical Analysis

Based on recent ground surveys conducted by Yukon Engineering Services for BGC (2003 and 2004) of the RCDC and the dam spillways one-dimensional numerical hydraulic models were generated. HEC-RAS, a backwater hydraulic model developed by the United States Army Corps of Engineers was used to model the channels. The numerical model was developed following the assumption that the bed and banks of the various conveyance channels remain stable. Figures 3 through 5 show rating curves for the existing conveyance structures, Tables 1 and 2 provide hydraulic data for the Intermediate Dam and Cross Valley Dam spillways, and Appendix A provides profile plot and tabular results from the model analysis.

## 3.1 As-built Condition and Failure Assumptions

This report so far assumes that the current configuration of the RCDC and the Intermediate and Cross Valley dam spillways are stable and free of blockages during the IDF; such that no erosion, scour, or slumping occurs and the channels suffer no blockage by ice or debris while passing the IDF. In their current condition, both the Intermediate and Cross Valley dam spillways have pipelines, mixing chambers and other materials within the spillway channels that are assumed to not interfere with the hydraulic performance. The Dam Safety Guidelines (CDA, 1999) indicate that the capacity of spillways should be checked with extraneous conditions, as stated:

> 7.1 Flow Capacity of Hydraulic Structures
>
> Spillway
>
> 1. Adequate resistance to erosion and cavitation, as well as adequate wall height allowing for the effects of flow aeration ("bulking"), to safely pass the IDF.
>
> 7. Adequate safely from landslides, scour, and from debris build-up in the intake, chute, and exit channels that could restrict discharge capacity.

However, the original design document (Golder, 1980) indicates that the design capacity for the canal would be the 50-year Rose Creek flood with contingency capacity for a 500-year flood. The typical RCDC section was therefore designed such that 1 m of freeboard was available above the 50-year flood level and no freeboard was available at the 500-year flood level or extraneous flood scenarios.

This being said, hydraulic model runs simulating one third channel blockages along the left bank were conducted with the following results in order to estimate results from potential ice blockage, bank slump, or sedimentation:

- Blockage at fuse-plug resulted in 7.7 $m^3/s$ spilling over the fuse-plug.
- Blockage immediately downstream of the fuse-plug resulted in 16.7 $m^3/s$ spilling over the

fuse-plug.

- Blockage downstream of the fuse-plug where the freeboard is less than 0.5 m resulted in 6.0 $m^3$/s spilling over the fuse-plug and 0.9 $m^3$/s spilling over the right bank of the RCDC.

Simulation of these blockage scenarios suggest that flow at the Intermediate Dam and Cross Valley Dam spillways could increase by as much as 10.5 $m^3$/s from RCDC overtopping or additional fuse-plug flow. However, the simulations did not show a significant increase in velocity nor reduction of stability within the RCDC.

It has been assumed that the North Wall Interceptor Ditch (NWID) would fail during 500-year flood conditions and all flows would route through the Intermediate and Cross Valley dam spillways. The analysis did not investigate the potential for overtopping of the Intermediate Dam or Cross Valley Dam from wind or land-movement induced wave action.

## 3.2 RCDC Analysis

The results of the model testing show that at the IDF the RCDC spills 6.2 $m^3$/s over the fuse-plug with the existing geometry and up to 16.7 $m^3$/s with 1/3$^{rd}$ of the channel blocked. Upstream of the fuse-plug there is 3 to 5 m of freeboard from the IDF water level to the top of the north levee. From the fuse-plug downstream to the steep rock weir reach there is typically less than 0.5 m of freeboard. Along the steep rock weir reach the freeboard is greater or equal to 1 m.

The average-cross-sectional velocities modelled within the RCDC up to the steep rock weir reach remain relatively low, between 0.5 and 2.4 m/s. The hydraulic design report (Hydrocon, 1980) states that the channel is armoured with rock riprap with a median diameter of 200 mm. This size of rock should be stable for the majority of the RCDC. The modelled velocity increases up to 4 m/s through the steep rock weir reach where the design report states rock weirs be constructed of rock with a median diameter between 730 mm to 880 mm with a downstream slope of 2H:1V and 200 mm diameter riprap armouring between the weirs. Based on the original design report the weirs and bed are likely to be unstable during the IDF. In order to remain stable during the 500-year IDF the bed should be armoured with similarly sized rock as used to construct the weirs and the weirs should have a reduced downstream gradient (closer to 10H:1V). Placement and sizing should be confirmed during site inspections scheduled for June 2006 prior to finalizing these recommendations.

## 3.3 Intermediate Dam Spillway Analysis

The results of the model tests suggest that there is 1.5 to 2.0 m of freeboard along the Intermediate Dam spillway during the IDF. The average-cross-sectional velocities modelled remain relatively low less than 2.0 m/s for the upstream 280 m of channel. The downstream 70 m of channel experiences velocities as large as 2.9 m/s. According to design reports (Golder, 1991) the Intermediate Dam spillway was armoured using rock with a median diameter of

200 mm for the majority of the channel, with additional feature boulders (750 to 1250 mm diameter) placed on 4 m centre-to-centre spacing for the lower moderately sloped (4% gradient) portion of the channel, and with 1 m tall by 1 m wide boulder berms (750 to 1250 mm diameter) spaced with 5 m centre-to-centre spacing for the furthest downstream steep (16% gradient) portion of the channel.

Based on the design report, the Intermediate Dam spillway should remain stable during the 500-year IDF. However, the feature boulders sporadically placed along the mid slope may initiate local scour and plucking of the bed armouring. These boulders should be salvaged and used to extend the spillway outlet apron. The boulder weirs constructed across the steep lower slope is likely to cause plunging flows potentially destabilizing the slope. The weirs should be flattened to form a uniform bed surface of the 750 mm to 1250 mm diameter rock. Placement and sizing of existing riprap should be confirmed during site inspections scheduled for June 2006 prior to finalizing recommendations regarding the stability of the channel.

The resulting upstream water surface elevation from modelling the IDF is 1048.2 m El. which provides 0.7 m of freeboard above the lowest point along the Intermediate Dam (BGC 2003 Survey Data). If RCDC suffers from potential channel blockage the water surface elevation may increase to 1048.4 m El. providing 0.5 m of freeboard.

## 3.4 Cross Valley Dam Spillway Analysis

The results of the model tests suggest that there is 1.5 to 2.5 m of freeboard along the Cross Valley Dam spillway during the IDF. The average-cross-sectional velocities modelled along the spillway are relatively high between 3.0 and 5.0 m/s with shallow flow depths of less than 1.0 m. According to the hydraulic design report (Hydrocon, 1980) and as-built photographs (Golder, 1982) the Cross Valley Dam spillway armouring is limited to the crest of the spillway. The size or rock used in the armouring is specified by the design report to have a median diameter of 800 mm, while as-built photographs suggest the size to be closer to 300 mm. The original hydraulic design report expects erosion during a 50-year event, stating:

> "Erosion would occur in the unarmoured outlet channel downstream from the riprapped section but the length of riprapped apron downstream from the crest is sufficiently long to prevent undermining of the critical section – the crest."

Armouring of the majority of the channel with 300 mm diameter riprap and armouring of the downstream steeper (10% gradient) portion of the channel with larger 1000 mm diameter and larger riprap is likely required to ensure stability of the Cross Valley Dam spillway during the 500-year IDF. The exiting placement and sizing or riprap should be confirmed during site inspections scheduled for June 2006 prior to finalizing these recommendations.

The resulting upstream water surface elevation from modelling the IDF is 1031.07 m El. which provides 1.6 m of freeboard above the lowest point along the Cross Valley Dam (2003 Survey). If RCDC suffers from potential channel blockage the water surface elevation may increase to 1031.17 m El. providing 1.5 m of freeboard.

# 4 Recommendations

The recommendations of the study include structural upgrades and additional work to identify potential issues that would require future work. The upgrading of hydraulic capacity or stability of hydraulic structures is intended to be done as part of ongoing care and maintenance activities undertaken at the Faro mine site on an annual basis. Site investigations are scheduled for June 2006 to confirm the placement and size of riprap and confirm its adequacy for the design flows calculated in this study.

## 4.1 Proposed Hydraulic Structure Upgrades

The site investigation and analysis of these features may lead to additional works to improve stability or capacity. Priority and ranking of upgrades and investigations should be based on a primary-level risk assessment with preliminary scopes of work and costs developed as part of the overall plan.

### 4.1.1 RCDC Fuse-Plug

Flow over the fuse-plug is imminent during the IDF. The available as-built drawings (Hydrocon, 1982) show an as-built slope of 20% and a median riprap size of 800 mm immediately downstream of the crest of the fuse-plug weir and a coble transition zone at 6% slope between the structure and the impound tailings. Hydraulic analysis suggests that the structure should remain stable during the IDF. However, it would be prudent to investigate the entire spillway armouring material to ensure no changes have been made to the structure since the as-built drawings were completed, and hence the fuse-plug is capable of withstanding overtopping during flow events up to and exceeding the IDF.

### 4.1.2 RCDC

Hydraulic modelling of the RCDC suggests the freeboard is at some locations is less than 0.5 m (see Appendix A). Typically, we would recommend that these sites be inspected and any low spots along the RCDC north levee crest be raised to ensure adequate IDF freeboard in the event of channel blockage or bank settlement. However, due to the low risk of such an event this analysis could be postponed and incorporated with the ongoing Faro Mine site closure plan. The original RCDC design IDF was the 50-year Rose Creek flood with contingency capacity for a 500-year flood (Golder, 1980). The typical RCDC section was therefore designed such that 1 m of freeboard was provided above the 50-year flood level and no freeboard was provided above the 500-year flood level for any additional factor of safety or to account for extraneous flood scenarios.

The present state and condition of the RCDC is capable of meeting the original design specifications. However, we recommend monitoring is undertaken to ensure that this hydraulic capacity is maintained. Inspections of the RCDC should be undertaken prior to freshet after ice-off, during high water or peak freshet conditions, and monthly throughout spring runoff. Additional inspections should be carried out in early winter during prolonged periods of air temperatures less than 0ºC to identify any ice jamming or aufeis conditions in the channel. Furthermore, the riprap sizing and placement along the steep weir section at the downstream end of the RCDC should be inspected during the June 2006 site inspections to determine if further armouring is required to maintain stability during the 500-year IDF.

### 4.1.3 Intermediate Dam Spillway

The Intermediate Dam spillway has enough capacity to convey the IDF. The existing channel is expected to be constructed of 200 mm diameter cobble. High velocities are expected for the downstream 70 m of the channel which may cause instability and local scouring throughout the sporadic boulder placement and the boulder weir section. A site inspection is recommended to confirm existing channel conditions and further assess stability. It is likely that the sporadically placed boulders should be salvaged and the rock weirs be flattened to form a uniform bed in order to ensure stability during the 500-year IDF.

### 4.1.4 Cross Valley Dam Spillway

The Cross Valley Dam spillway has enough capacity to convey the IDF. The existing channel according to historic reports appears to generally be unarmoured. High velocities down the channel are expected to result in instability. A site inspection is recommended to confirm existing channel conditions and further assess stability. It is likely that the channel will require armouring with 300 mm to 1000 mm and larger riprap to ensure stability during the 500-year IDF.

## 4.2 Proposed Site Investigations and Analyses

Additional investigations and studies proposed as part of ongoing work at the Faro mine site should include:

1. Continue with annual inspection of the RCDC with special consideration for the hydraulic stability of the RCDC, the fuse-plug, the Intermediate Dam Spillway, the Cross Valley Dam Spillway, and the NWID. If unacceptable risk of erosion and scour is discovered, further recommendations for upgrading the structures stability and conveyance will be prepared at that time, including scope and estimated costs of the recommendations.

2. Materials used to construct the RCDC fuse-plug structure and the placement of such materials should be confirmed by site investigation and test pit programs.

3. The north levee of the RCDC downstream of the fuse-plug and upstream of the steep rock weir section was designed for no freeboard during the 500-year IDF. The mine site

closure plan should incorporate a freeboard above the design IDF to provide an additional factor of safety and allowance for extraneous flood scenarios such as slumping, debris, or ice blockage. Until such a plan is instigated inspections of the RCDC should be undertaken prior to freshet after ice-off, during high water or peak freshet conditions, and monthly throughout spring runoff. Additional inspections should be carried out in early winter during prolonged periods of air temperatures less than 0ºC to identify any ice jamming or aufeis conditions in the channel.

A site inspection is scheduled for June 2006 to assess existing riprap armouring size and placement along the RCDC, the fuse-plug, and the Intermediate and Cross Valley Dam Spillways. From this inspection test pit analysis will be prescribed for September 2006 to determine underlying material.

# 5 Summary

The report presents the 500-year IDF conveyance analysis. Through hydrological analysis of the watersheds and hydraulic modelling of the RCDC the following minimum design requirements were determined for each of the conveyance components;

- RCDC = 130 $m^3/s$
- RCDC fuse-plug = 6.2 $m^3/s$
- Intermediate Dam Spillway = 11.2 $m^3/s$
- Cross Valley Dam Spillway = 15.5 $m^3/s$.

Using, numerical one-dimensional hydraulic modelling, rating curves were developed for each component. Assuming no freeboard or extraneous design scenarios, the rating curves were used to estimate maximum conveyance capacity for each structure;

- RCDC prior to overtopping at fuse-plug = 113 $m^3/s$
- RCDC prior to overtopping other than fuse-plug = 140 $m^3/s$
- Intermediate Dam Spillway = 64 $m^3/s$
- Cross Valley Dam Spillway > 100 $m^3/s$.

Using the modelling results, it was determined that the RCDC and the spillways around the north side of the Intermediate Dam and the Cross Valley Dam provide adequate capacity to convey the 500-year IDF. However, stability of the surfacing material has not been checked in detail and should be confirmed through site inspection. Once the field work prescribed in this report is completed the riprap size and placement requirements should be checked and updated if necessary. Figure 6 schematically depicts the design flow paths along with estimated maximum capacity and locations of potential instability.

Although the current design is capable of conveying the IDF, under extraneous design scenarios such as partial channel blockage from ice or debris, further efforts should be made to ensure such scenarios are adequately thought-out and designed for under the closure plan conveyance strategy.

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# 7 Tables

## Table 1 Intermediate Dam Spillway Hydraulic Data

| | |
|---|---|
| Design Crest Elevation<br>Actual Crest Elevation | 1049.0 masl[1] (1081.5 m DVPD[2])<br>1048.83 masl low point (2003 Survey)<br>1048.9 masl average (2003 Survey) |
| Top of Core Elevation | 1048.5 masl |
| Design Full Supply Level (FSL)<br>Actual FSL | 1080.0 m DVPD<br>1047.7 m |
| Design Spillway Inlet Elevation<br>Actual Spillway Inlet Elevation | 1080.0 m DVPD<br>1047.7 m (2005 survey) |
| Design Freeboard<br>Actual Freeboard | 0.5 m<br>0.65 m |
| Design Seepage | unknown |
| Actual Reservoir Area | 220,000 $m^2$ at FSL |
| Actual Storage Capacity<br>Revised Storage Capacity | 1,200,000 $m^3$ at FSL<br>960,000 $m^3$ at FSL |
| Hydraulic Design Return Period | 1:500 year |
| Inflow Design Flood | 11.2 $m^3 \cdot s^{-1}$ |
| Spillway Rating Curve | preliminary available |
| Actual Spillway Capacity at Dam Crest<br>Actual Spillway Capacity at Dam Core | 63 $m^3 \cdot s^{-1}$<br>32 $m^3 \cdot s^{-1}$ |
| Design References | **nhc** ltd. 2005 |

[1] meters above seal level
[2] Down Valley Project Datum

## Table 2 Cross Valley Dam Spillway Data

| | |
|---|---|
| Design Crest Elevation<br>Actual Crest Elevation | 1033.5 masl<br>1033.1 masl average(2003 survey)<br>1032.7 masl lowest (2003 survey) |
| Top Of Core Elevation | 1032.5 masl |
| Full Supply Level (FSL) | 1030.78 masl |
| Spillway Inlet Elevation | 1030.58 masl (2005 survey) |
| Pilot Channel Inlet Elevation | 1030.71 masl (2005 survey) |
| Design Freeboard<br>Actual Freeboard | 0.5 m<br>1.6 m |
| Design Seepage | 0.03 $m^3 \cdot s^{-1}$ |
| Reservoir Area | 320,000 $m^2$ at FSL |
| Storage Capacity | 1,400,000 $m^3$ at FSL |
| Hydraulic Design Return Period | 1:500 year flood |
| Inflow Design Flood | 15.5 $m^3 \cdot s^{-1}$ |
| Spillway Rating Curve | Preliminary available |
| Spillway Capacity<br>WSE at Dam Crest<br>WSE at Dam Core | <br>375 $m^3 \cdot s^{-1}$<br>300 $m^3 \cdot s^{-1}$ |
| Design References | **nhc** ltd. 2005 |

# 8 Figures

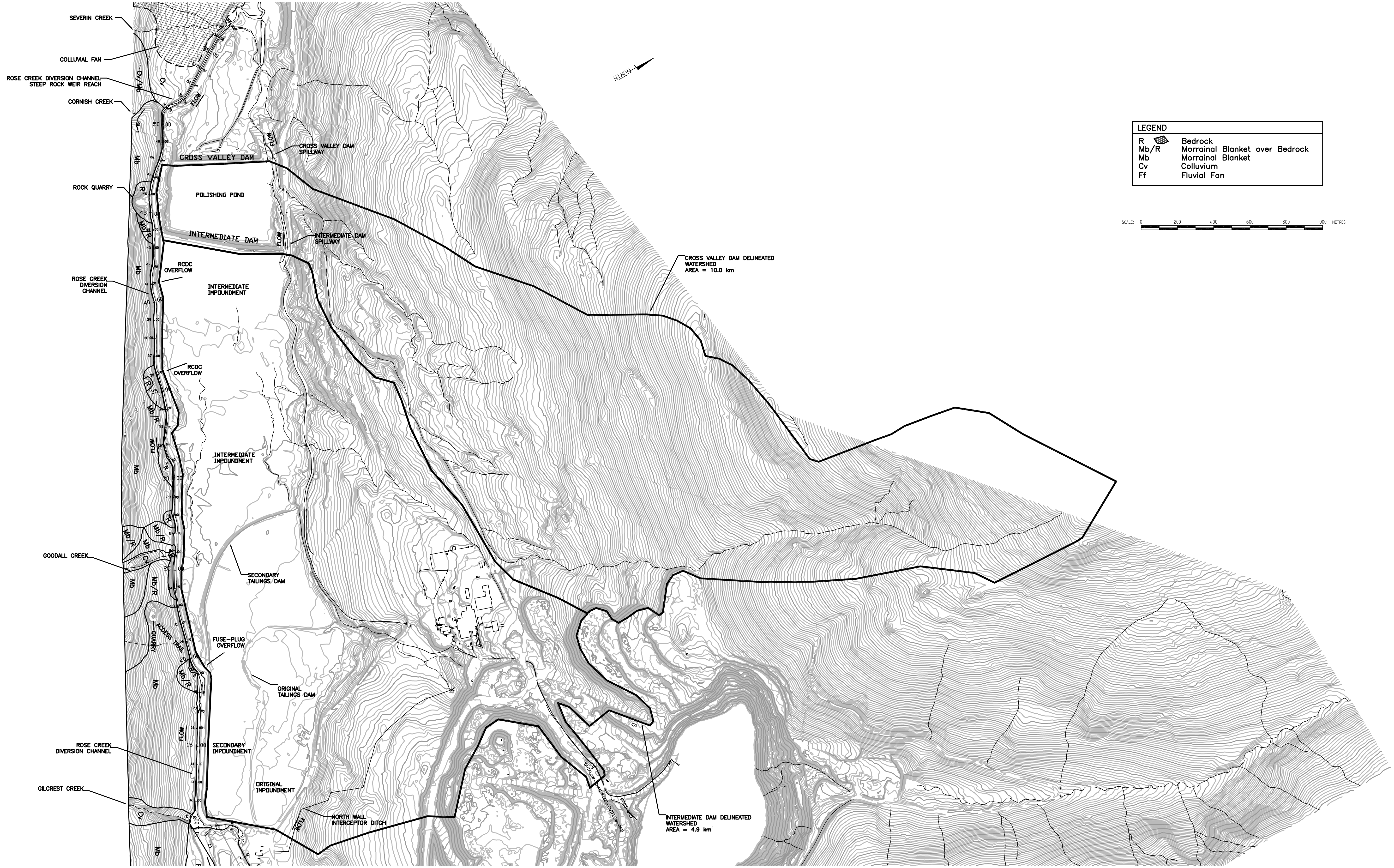



Figure 1: Watershed Delineation

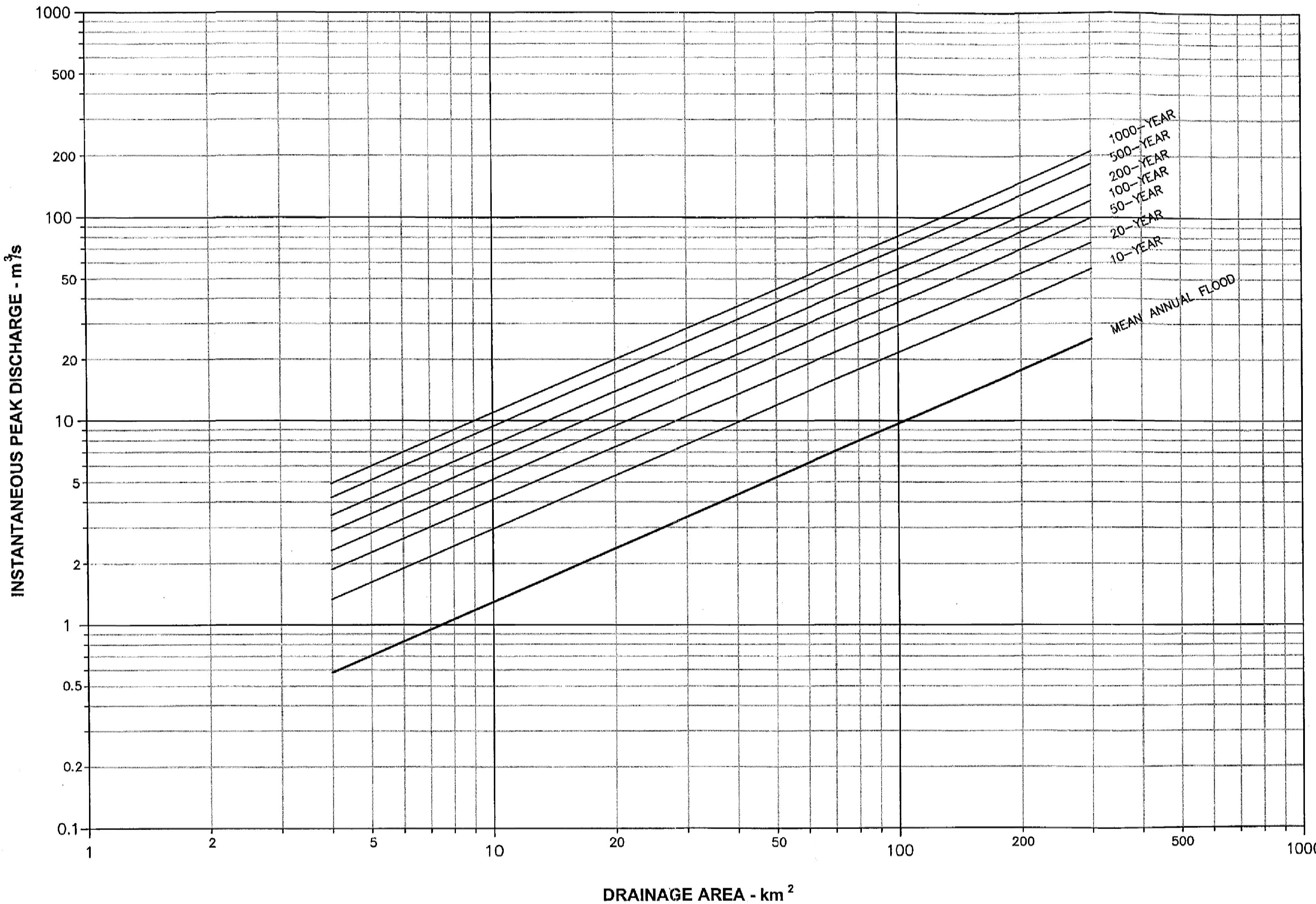
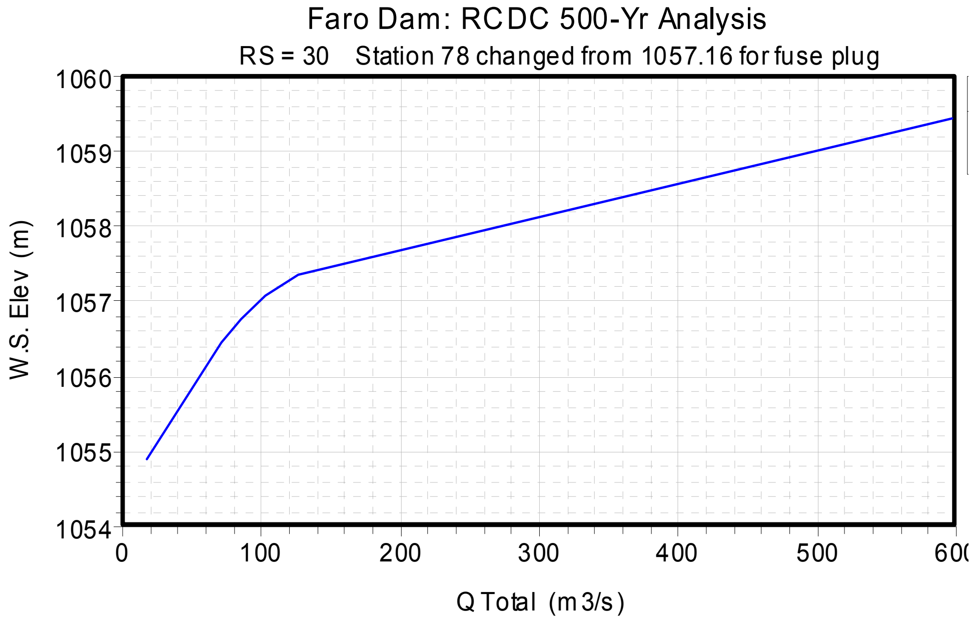


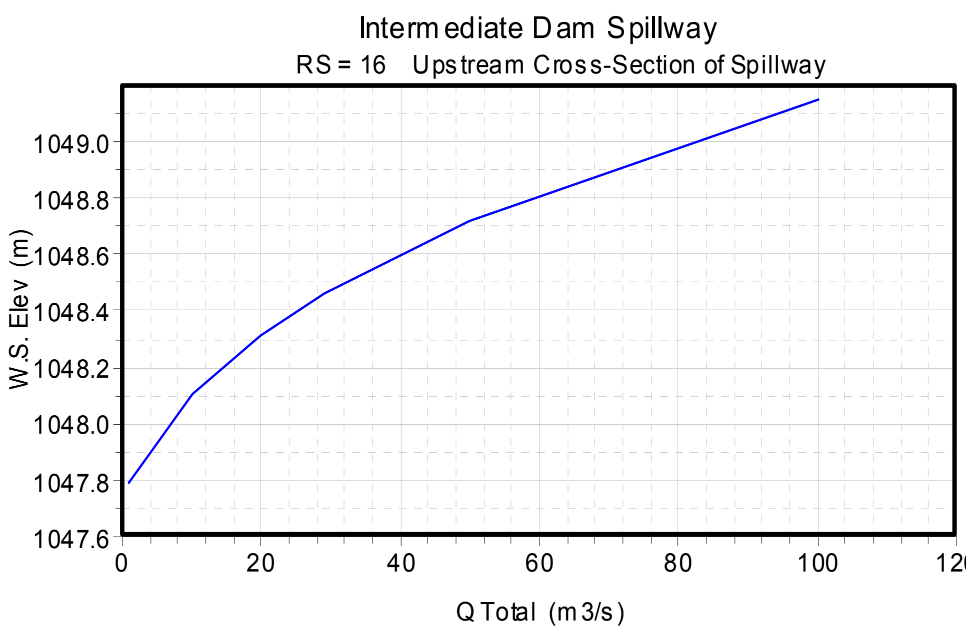

Figure 2: Extreme Flood Curves (nhc, 2004)

## Figure 3 RCDC Rating Curve at Fuse Plug




Note: The fuse-plug was modelled at 1057.2 m El. as estimated from as-built drawings and survey.

## Figure 4 Intermediate Dam Rating Curve




Note: Bank height is roughly 1050.0 m El. and Intermediate Dam Crest is 1048.8 m El.

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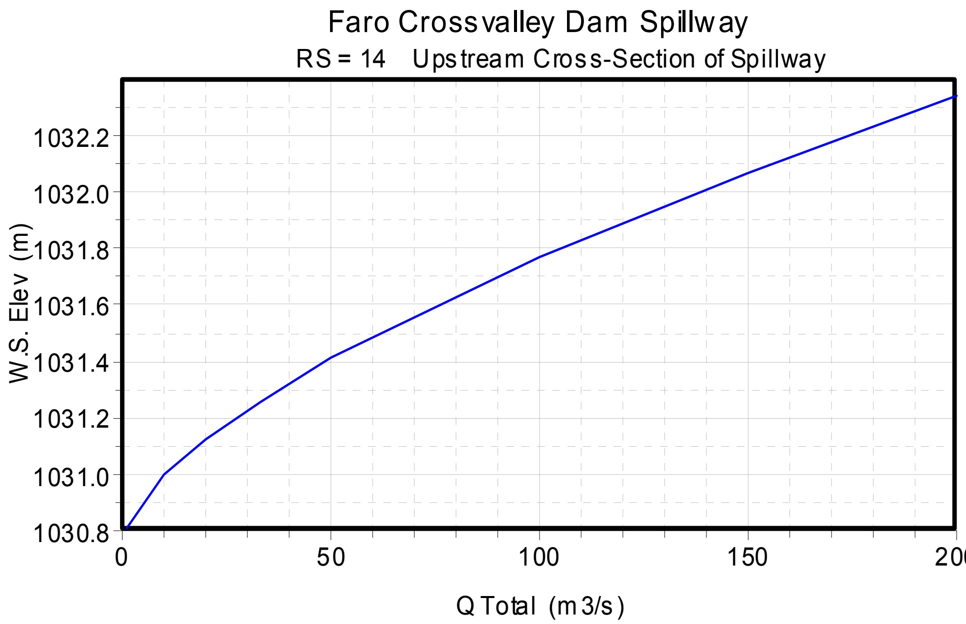
**Figure 5 Cross Valley Dam Rating Curve**




Note: Bank height is roughly 1033.2 m El. and Cross Valley Dam crest is 1032.7 m El.

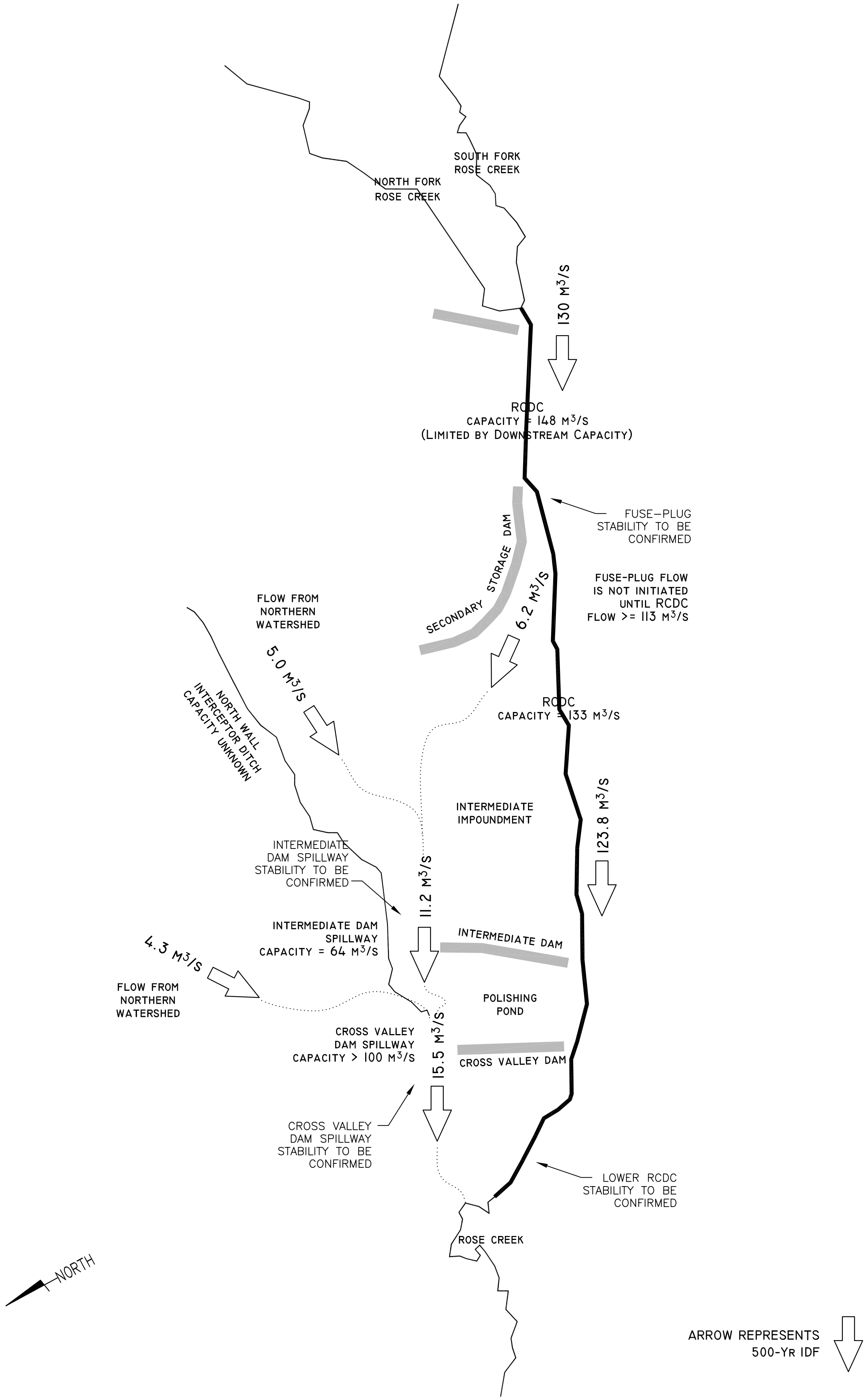
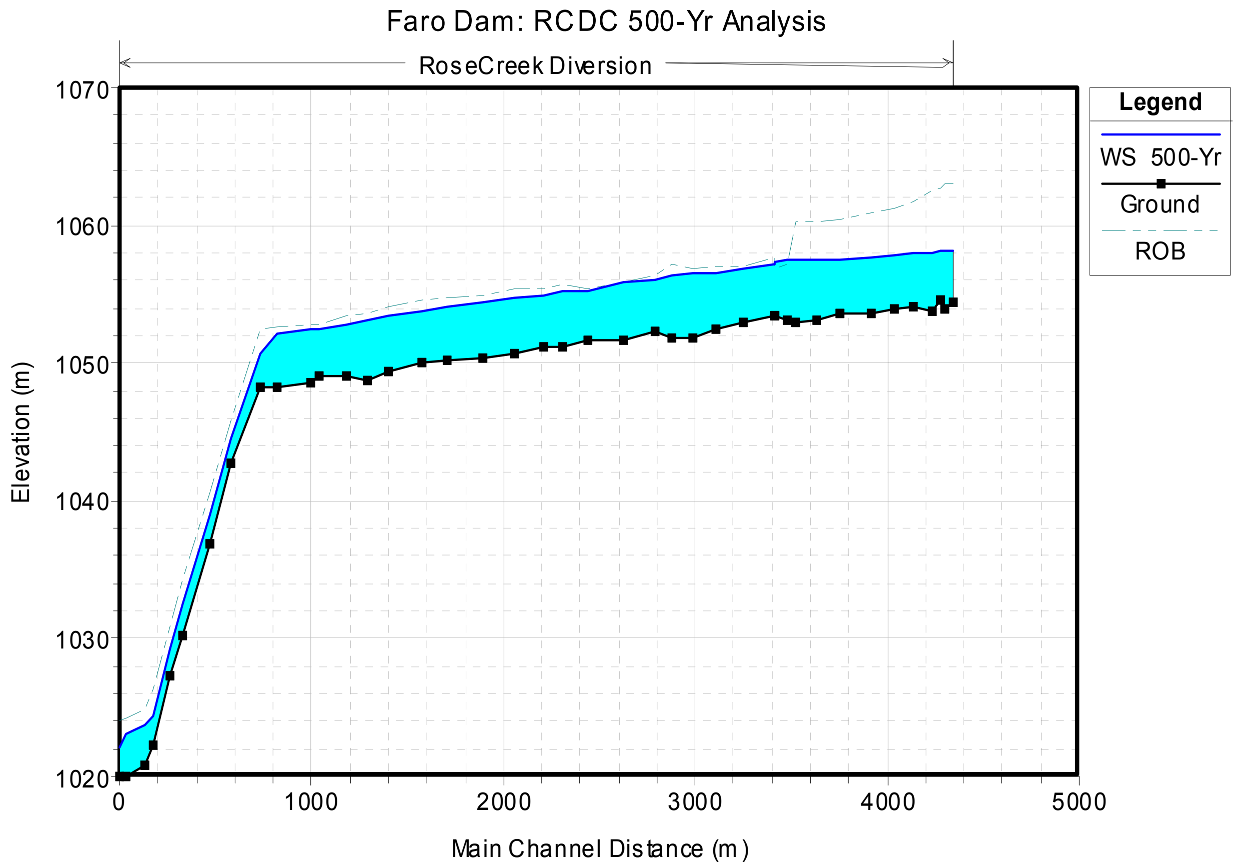



Figure 6: Faro Mine Tailings Area Conveyance Schematic

# 9 Appendix A: Hydraulic Model Results

## 9.1 RCDC Model Results



| River Station | Flow ($m^3/s$) | Length Chnl (m) | Min Ch Elev. (m) | W.S. Elev (m) | Max Ch Depth (m) | Right Freeboard (m) | Velocity Ave. (m/s) | Flow Area ($m^2$) | Top Width (m) | Froude No. |
|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 130.0 | 36 | 1054.5 | 1058.1 | 3.66 | 4.88 | 0.43 | 306 | 118.7 | 0.1 |
| 39 | 130.0 | 30 | 1053.9 | 1058.1 | 4.25 | 4.86 | 0.5 | 258 | 106.2 | 0.1 |
| 38 | 130.0 | 36 | 1054.5 | 1058.1 | 3.58 | 4.54 | 0.61 | 215 | 91.6 | 0.1 |
| 37 | 130.0 | 102.3 | 1053.7 | 1058.0 | 4.26 | 4.52 | 1.44 | 90 | 51.4 | 0.4 |
| 36 | 130.0 | 98.2 | 1054.1 | 1057.9 | 3.86 | 3.81 | 1.29 | 100 | 42.8 | 0.3 |
| 35 | 130.0 | 123.3 | 1053.9 | 1057.8 | 3.91 | 3.5 | 1.54 | 85 | 47.8 | 0.4 |
| 34 | 130.0 | 161.3 | 1053.6 | 1057.6 | 3.99 | 3.3 | 1.35 | 96 | 53.5 | 0.3 |
| 33 | 130.0 | 117.1 | 1053.6 | 1057.5 | 3.97 | 2.91 | 1.05 | 124 | 55.5 | 0.2 |
| 32 | 130.0 | 116.4 | 1053.0 | 1057.5 | 4.47 | 2.73 | 0.71 | 182 | 69.2 | 0.1 |
| 31 | 130.0 | 43.5 | 1053.0 | 1057.5 | 4.5 | 2.69 | 0.58 | 222 | 69.8 | 0.1 |
| | Fuse Plug | | | | | | | | | |
| 30 | 128.0 | 57.4 | 1053.1 | 1057.5 | 4.41 | -0.3 | 0.96 | 134 | 64.5 | 0.2 |
| 29 | 123.8 | 7.6 | 1053.5 | 1057.3 | 3.85 | -0.4 | 1.76 | 80 | 50.7 | 0.3 |
| | Fuse Plug | | | | | | | | | |
| 28.9 | 123.8 | 166.6 | 1053.4 | 1057.2 | 3.81 | 0.48 | 2 | 62 | 23.5 | 0.4 |
| 28 | 123.8 | 140.9 | 1052.9 | 1056.9 | 3.96 | 0.18 | 2.05 | 60 | 23.5 | 0.4 |
| 27 | 123.8 | 114.5 | 1052.4 | 1056.6 | 4.16 | 0.39 | 2.08 | 60 | 23.8 | 0.4 |
| 26 | 123.8 | 108.1 | 1051.8 | 1056.5 | 4.66 | 0.34 | 1.51 | 82 | 25.3 | 0.3 |
| 25 | 123.8 | 95.8 | 1051.9 | 1056.3 | 4.45 | 0.79 | 1.77 | 70 | 23.6 | 0.3 |
| 24 | 123.8 | 158.6 | 1052.3 | 1056.1 | 3.74 | 0.23 | 2.11 | 59 | 24.9 | 0.4 |
| 23 | 123.8 | 180.9 | 1051.6 | 1055.8 | 4.17 | 0.08 | 1.84 | 67 | 25.6 | 0.4 |
| 22 | 123.8 | 132.3 | 1051.7 | 1055.3 | 3.65 | 0.02 | 2.29 | 54 | 23.8 | 0.5 |
| 21 | 123.8 | 101.8 | 1051.2 | 1055.2 | 3.97 | 0.51 | 1.55 | 80 | 32.4 | 0.3 |
| 20 | 123.8 | 159.5 | 1051.1 | 1055.0 | 3.86 | 0.44 | 1.82 | 68 | 26.7 | 0.4 |
| 19 | 123.8 | 163.2 | 1050.7 | 1054.8 | 4.1 | 0.64 | 1.66 | 74 | 28.7 | 0.3 |
| 18 | 123.8 | 179.6 | 1050.4 | 1054.4 | 4 | 0.55 | 2.03 | 61 | 25.2 | 0.4 |
| 17 | 123.8 | 137.2 | 1050.2 | 1054.1 | 3.9 | 0.63 | 1.9 | 65 | 25.1 | 0.4 |
| 16 | 123.8 | 176.2 | 1050.0 | 1053.7 | 3.72 | 0.79 | 2.18 | 57 | 24.2 | 0.5 |
| 15 | 123.8 | 109.3 | 1049.4 | 1053.4 | 3.94 | 0.74 | 1.88 | 66 | 27.5 | 0.4 |
| 14 | 123.8 | 108.9 | 1048.8 | 1053.1 | 4.33 | 0.56 | 2.08 | 60 | 24.0 | 0.4 |
| 13 | 123.8 | 140.4 | 1049.0 | 1052.9 | 3.84 | 0.53 | 1.99 | 62 | 25.6 | 0.4 |
| 12 | 123.8 | 45.1 | 1049.0 | 1052.5 | 3.46 | 0.39 | 2.22 | 56 | 24.3 | 0.5 |
| 11 | 123.8 | 165.8 | 1048.6 | 1052.4 | 3.78 | 0.41 | 1.94 | 64 | 25.5 | 0.4 |
| 10 | 123.8 | 90.6 | 1048.3 | 1052.1 | 3.8 | 0.62 | 1.57 | 79 | 33.6 | 0.3 |
| 9 | 123.8 | 154.7 | 1048.2 | 1050.7 | 2.43 | 1.77 | 4.02 | 31 | 18.8 | 1.0 |
| 8 | 123.8 | 107.1 | 1042.7 | 1044.6 | 1.87 | 1.27 | 4.37 | 28 | 20.0 | 1.2 |
| 7 | 123.8 | 143.1 | 1036.9 | 1039.0 | 2.08 | 1.61 | 4.79 | 26 | 18.2 | 1.3 |
| 6 | 123.8 | 62.4 | 1030.2 | 1032.4 | 2.2 | 1.79 | 4.41 | 28 | 17.7 | 1.1 |
| 5 | 123.8 | 90 | 1027.4 | 1029.3 | 1.92 | 1.6 | 4.79 | 26 | 18.6 | 1.3 |
| 4 | 123.8 | 50 | 1022.3 | 1024.4 | 2.1 | 1.97 | 4.57 | 27 | 20.3 | 1.3 |
| 3 | 123.8 | 92.7 | 1020.8 | 1023.8 | 3.01 | 1 | 2.41 | 51 | 24.9 | 0.5 |
| 2 | 123.8 | 35.3 | 1020.0 | 1023.1 | 3.1 | 1.07 | 2.22 | 56 | 30.2 | 0.5 |
| 1 | 123.8 | | 1020.0 | 1022.1 | 2.08 | 1.98 | 3.89 | 32 | 20.9 | 1.0 |

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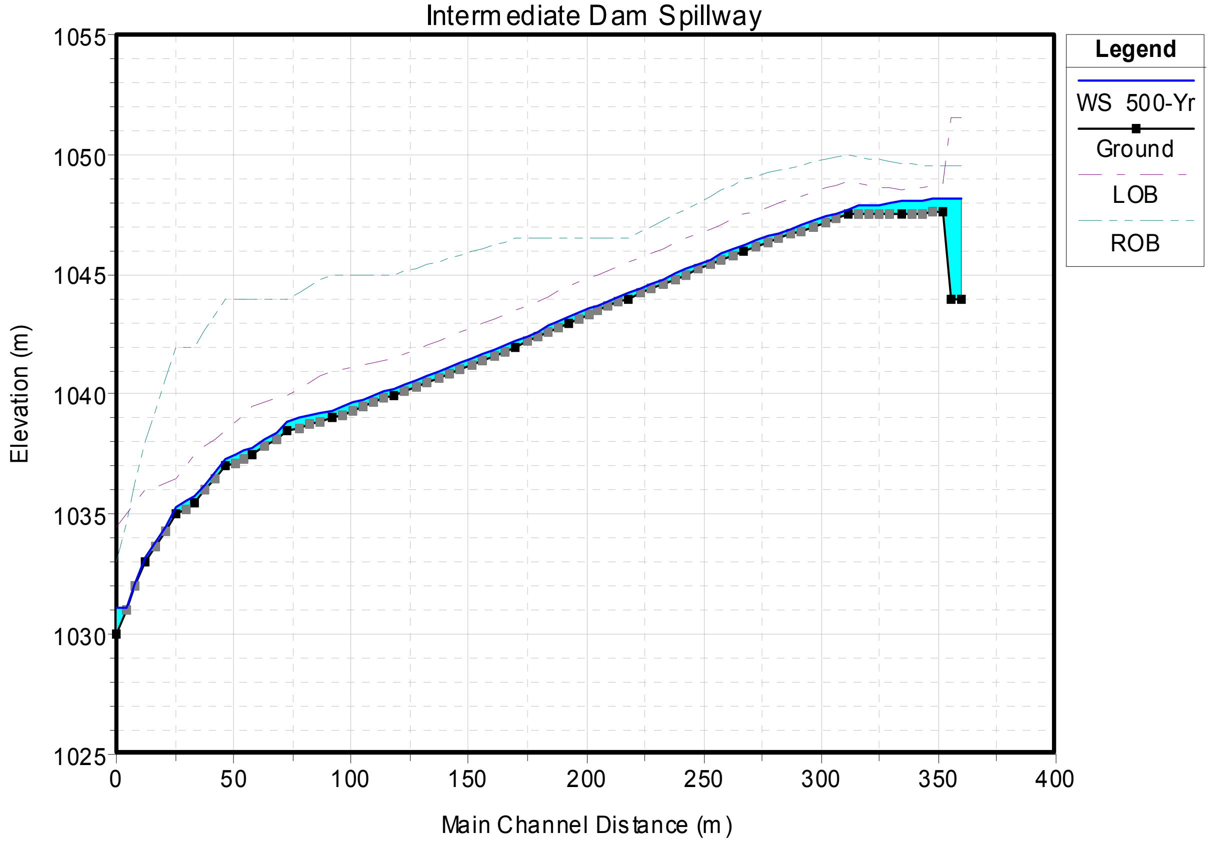
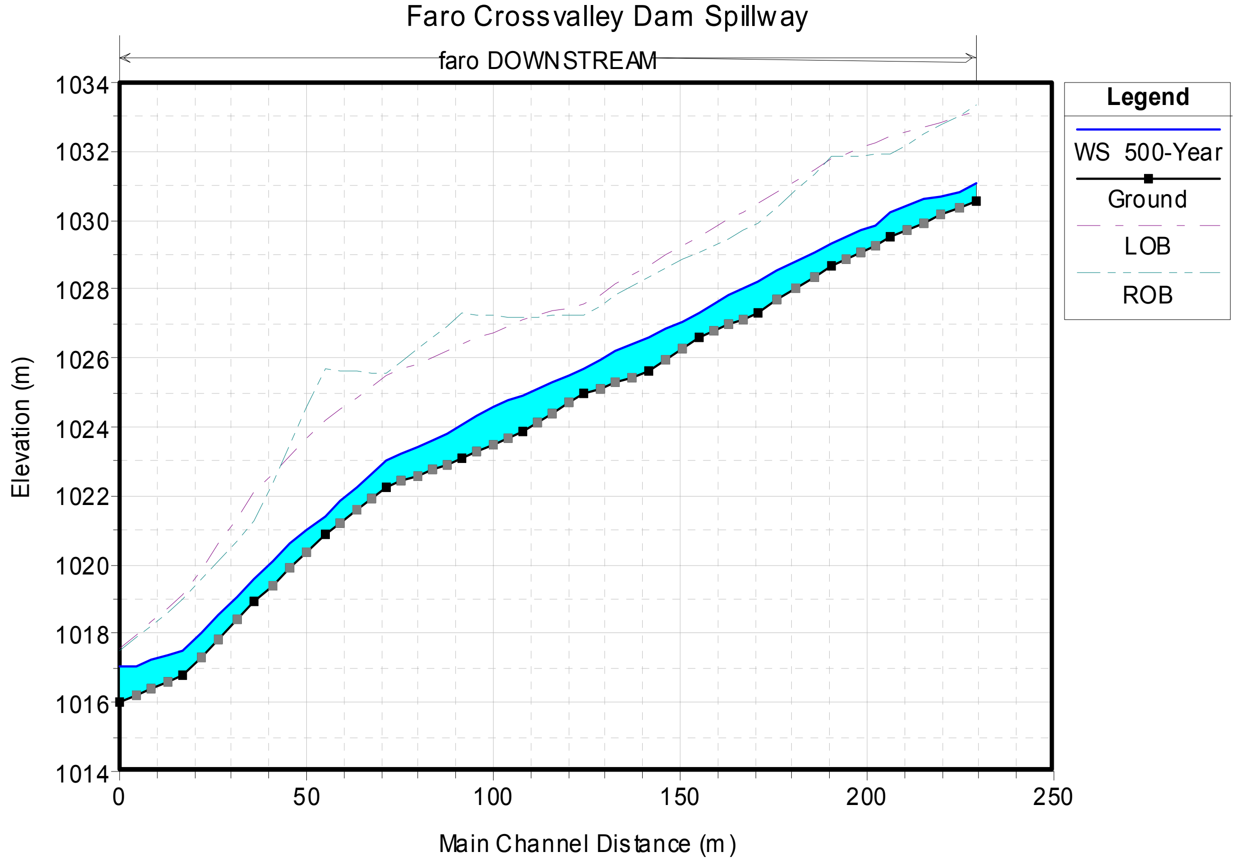
## 9.2 Intermediate Dam Model Results




| River Station | Flow (m³/s) | Length Chnl (m) | Min Ch Elev. (m) | W.S. Elev (m) | Max Ch Depth (m) | Freeboard (m) | Velocity Ave. (m/s) | Flow Area (m²) | Top Width (m) | Froude No. |
|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 11.2 | 3.9 | 1044.0 | 1048.2 | 4.2 | 1.3 | 0.0 | 283.9 | 95.1 | 0.0 |
| 17 | 11.2 | 4.1 | 1044.0 | 1048.2 | 4.2 | 1.3 | 0.1 | 178.4 | 72.2 | 0.0 |
| 16 | 11.2 | 4.4 | 1047.6 | 1048.1 | 0.5 | 0.7 | 0.9 | 13.0 | 30.6 | 0.4 |
| 15 | 11.2 | 4.5 | 1047.5 | 1048.1 | 0.6 | 1.5 | 0.8 | 13.6 | 31.8 | 0.4 |
| 14 | 11.2 | 4.9 | 1047.5 | 1047.7 | 0.2 | 1.2 | 1.5 | 7.5 | 33.4 | 1.0 |
| 13 | 11.2 | 5.0 | 1046.0 | 1046.3 | 0.3 | 1.2 | 1.6 | 7.1 | 28.0 | 1.0 |
| 12 | 11.2 | 4.3 | 1044.0 | 1044.2 | 0.2 | 1.3 | 1.6 | 6.9 | 31.1 | 1.1 |
| 11 | 11.2 | 4.4 | 1043.0 | 1043.3 | 0.3 | 1.3 | 1.7 | 6.7 | 27.8 | 1.1 |
| 10 | 11.2 | 4.7 | 1042.0 | 1042.2 | 0.2 | 1.3 | 1.8 | 6.3 | 27.1 | 1.2 |
| 9 | 11.2 | 4.4 | 1040.0 | 1040.3 | 0.3 | 1.2 | 1.8 | 6.3 | 24.1 | 1.1 |
| 8 | 11.2 | 4.8 | 1039.0 | 1039.4 | 0.4 | 1.7 | 1.9 | 5.8 | 17.4 | 1.1 |
| 7 | 11.2 | 4.9 | 1038.5 | 1038.9 | 0.4 | 1.1 | 1.9 | 6.0 | 17.2 | 1.0 |
| 6 | 11.2 | 3.9 | 1037.5 | 1037.8 | 0.3 | 1.7 | 2.5 | 4.5 | 15.5 | 1.5 |
| 5 | 11.2 | 4.3 | 1037.0 | 1037.3 | 0.3 | 1.2 | 2.1 | 5.3 | 17.5 | 1.2 |
| 4 | 11.2 | 3.9 | 1035.5 | 1035.8 | 0.3 | 1.8 | 2.9 | 3.9 | 16.4 | 1.9 |
| 3 | 11.2 | 4.5 | 1035.0 | 1035.3 | 0.3 | 1.2 | 2.4 | 4.7 | 18.1 | 1.5 |
| 2 | 11.2 | 4.1 | 1033.0 | 1033.2 | 0.2 | 2.8 | 2.8 | 4.0 | 22.7 | 2.1 |
| 1 | 11.2 | | 1030.0 | 1031.1 | 1.1 | 1.9 | 0.4 | 30.1 | 30.0 | 0.1 |

## 9.3 Cross Valley Dam Model Results




| River Station | Flow ($m^3/s$) | Length Chnl (m) | Min Ch Elev. (m) | W.S. Elev (m) | Max Ch Depth (m) | Freeboard (m) | Velocity Ave. (m/s) | Flow Area ($m^2$) | Top Width (m) | Froude No. |
|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 15.5 | 4.5 | 1030.6 | 1031.1 | 0.5 | 2.1 | 1.7 | 9.3 | 37.9 | 1.0 |
| 13 | 15.5 | 3.9 | 1029.5 | 1030.2 | 0.7 | 1.7 | 2.1 | 7.3 | 43.9 | 1.5 |
| 12 | 15.5 | 4.9 | 1028.7 | 1029.3 | 0.6 | 2.5 | 2.0 | 7.7 | 47.2 | 1.6 |
| 11 | 15.5 | 4.0 | 1027.3 | 1028.2 | 0.9 | 1.7 | 2.5 | 6.1 | 18.9 | 1.4 |
| 10 | 15.5 | 4.5 | 1026.6 | 1027.3 | 0.7 | 1.8 | 2.6 | 5.9 | 22.9 | 1.7 |
| 9 | 15.5 | 4.4 | 1025.6 | 1026.6 | 1.0 | 1.7 | 2.8 | 5.6 | 17.9 | 1.6 |
| 8 | 15.5 | 4.1 | 1025.0 | 1025.7 | 0.7 | 1.6 | 2.5 | 6.2 | 26.9 | 1.7 |
| 7 | 15.5 | 4.0 | 1023.9 | 1024.9 | 1.0 | 2.2 | 2.5 | 6.2 | 24.2 | 1.6 |
| 6 | 15.5 | 4.1 | 1023.1 | 1024.1 | 1.0 | 2.3 | 3.1 | 5.0 | 9.6 | 1.4 |
| 5 | 15.5 | 4.1 | 1022.3 | 1023.1 | 0.8 | 2.4 | 3.1 | 5.0 | 14.8 | 1.7 |
| 4 | 15.5 | 4.7 | 1020.9 | 1021.4 | 0.5 | 2.8 | 4.1 | 3.8 | 11.1 | 2.2 |
| 3 | 15.5 | 4.8 | 1018.9 | 1019.6 | 0.7 | 1.6 | 4.4 | 3.5 | 14.6 | 2.2 |
| 2 | 15.5 | 4.3 | 1016.8 | 1017.5 | 0.7 | 1.5 | 5.5 | 2.8 | 5.3 | 2.4 |
| 1 | 15.5 | | 1016.0 | 1017.0 | 1.0 | 0.5 | 3.7 | 4.1 | 15.7 | 1.6 |