RUBY DAM REHABILITATION FEASIBILITY STUDY

Volume I

Prepared for:

Montana Department of Natural Resources and Conservation
State Water Projects Bureau
Helena, MT

Prepared by:

HKM Engineering Inc.
P.O. Box 31318
Billings, MT 59107

January 2008

10

TABLE OF CONTENTS

Volume I

Executive Summary

Preferred Rehabilitation Option

Design Options Summary

Low-Level Outlet Works Rehabilitation Summary

Volume II

Downstream Tailwater Hydraulics

Water Availability Analysis

Economic Evaluation

Seepage and Slope Stability Analyses

Incremental Hazard Screening Study

Cultural Resources Inventory (Included Separately)

RUBY DAM REHABILITATION FEASIBILITY STUDY

EXECUTIVE SUMMARY

Prepared for:

Montana Department of Natural Resources and Conservation
State Water Projects Bureau
Helena, MT

Prepared by:

HKM Engineering Inc.
P.O. Box 31318
Billings, MT 59107

January 2008

H:\08\M087175\Ruby Reports\Final\ExecSummary_0108.doc

Ruby Dam Feasibility Study
Executive Summary

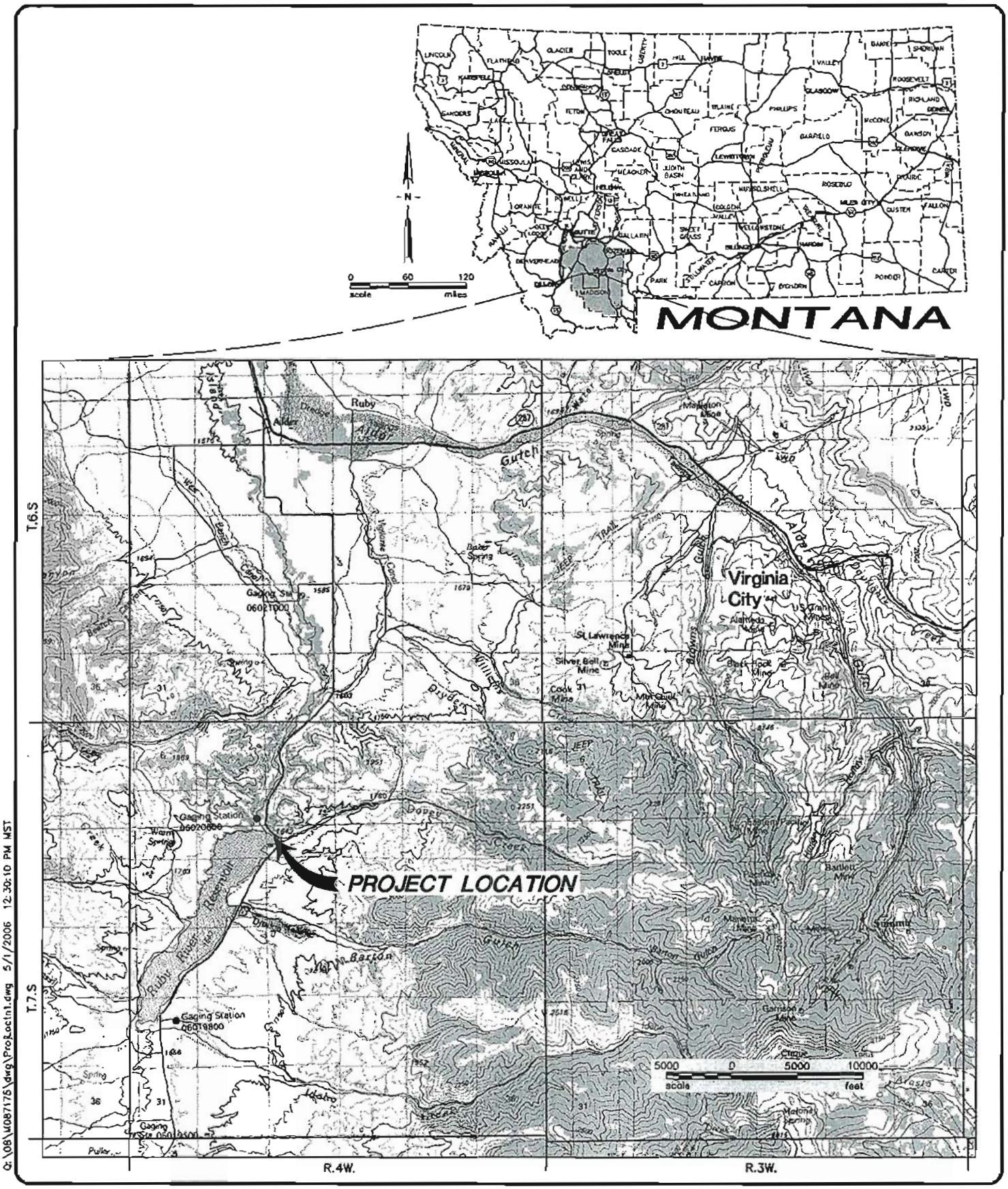
BACKGROUND

Ruby Dam is located in Madison County, Montana approximately six miles south of the town of Alder. The dam is located on the Ruby River, a tributary of the Jefferson River (Figure 1). Construction of the 111-foot high, 846-foot long dam started in 1936 and was completed in 1938. The dam is owned by the Montana Department of Natural Resources and Conservation (DNRC) and is operated by the Ruby River Water Users Association (WUA). Ruby dam is classified as a high hazard dam under the Montana Dam Safety Act guidelines.

The DNRC contracted with HKM Engineering Inc. (HKM) in October 2005 to perform a Feasibility Study for Ruby Dam that would evaluate the existing condition of the dam and develop rehabilitation alternatives that would bring the dam into compliance with the State of Montana Dam Safety Act.

PURPOSE

The DNRC identified several deficiencies and issues that were to be addressed in the Ruby Dam Rehabilitation Feasibility Study. The concrete spillway is in poor structural condition and needs to be replaced. The condition of the spillway foundation is unknown, and the spillway walls would likely overtop during the design flood required by current standards. The outlet works is not capable of passing the required flow for current standards without extensive damage. The desired outlet capacity is 1,100 cubic feet per second (cfs) but the current system experiences damage when discharging 500 to 600 cfs. The water delivered to the WUA has been reduced by 3,800 acre-feet due to sedimentation and a minimum conservation pool that protects the downstream fishery by limiting the reservoir drawdown. Increasing the reservoir's storage to gain back the reduction and to gain additional storage, if feasible, needs to be evaluated.



RUBY DAM REHABILITATION FEASIBILITY STUDY

PROJECT LOCATION MAP

FIGURE 1

HKM ENGINEERING

8M087.175 | AUGUST 2007

Q:\08\M087175\dwg\ProLocIn1.dwg 5/1/2006 12:30:10 PM MST

SELECTED ALTERNATIVE

A site plan of the project showing the features of the selected rehabilitation alternative is provided in Figure 2. The selected alternative includes the following features:

- Removal and replacement of the concrete spillway with a new concrete structure.
- Rehabilitating the outlet works with new steel penstock liner, control valve and terminal structure.
- Raising the spillway crest seven feet to elevation 5400 feet to increase reservoir storage to its practical maximum.
- Raising the embankment crest three feet to elevation 5413 feet, replacing the control house and modifying the drain.
- Providing new trails and bridges to allow access when the spillway is operating.
- Stabilizing highway slopes and mitigating other impacts of increased reservoir storage.

The spillway replacement will consist of removing most of the existing structure to construct a new spillway crest, chute and stilling basin in the same location. The new structure will maintain a constant chute width of 100 ft throughout its length (no taper as the existing). The spillway crest will consist of a labyrinth wall configuration in which a total crest length of 250 feet will fit into the 100-ft chute width. This configuration passes large flows at relatively shallow depths which reduces the required dam raise and reservoir impacts. The spillway chute will be very similar to the existing chute, except there will be no taper and the walls will be taller to prevent overtopping of the walls during extreme floods. The stilling basin is designed to provide complete energy dissipation up to the 500-yr flood (4,000 cfs). The basin will act as a flip bucket for larger flows including the spillway design flood (SDF) maximum flow of 20,050 cfs. The spillway approach channel will be excavated to provide better hydraulic performance and the excavation will include an improved vehicle access road in front of the spillway crest. This vehicle access will be submerged when the reservoir is full or spilling, which is similar to the existing access.

The outlet works modifications will consist of removing the existing butterfly control valve located in the center tower, installing a new steel penstock from the outlet piping in the center control tower to the downstream end of the outlet tunnel and installing new control valves and energy dissipater at the downstream toe of the dam. This configuration replaces the existing control valve that has current operation restrictions and provides a modern control valve that is readily accessible at the toe of the dam. It is proposed that the new valve will be a 60-inch jet flow gate and an additional 18-inch bypass gate valve will serve winter low flows. The steel penstock will be 72-inch diameter and will be grouted inside the existing concrete tunnel. The

Q:\08\M087175\dwg\NewConFeatures.dwg 9/18/2007 11:22:32 AM MDT

RUBY DAM REHABILITATION FEASIBILITY STUDY

SITE PLAN OF NEW CONSTRUCTION FEATURES

FIGURE 2

HKM ENGINEERING

8M087.175 | SEPT. 2007

steel penstock will convey reservoir pressure to the toe of the dam, which could accommodate future hydropower development. The outlet will be extended beyond the existing terminal structure (tunnel portal) and a new energy dissipation structure will be provided at the outlet. Moving the discharge point further from the dam eliminates the potential undermining of the dam during large releases. The existing guard gate will remain in the center tower and serve as a backup system to allow maintenance of the penstock and control valves.

The preferred alternative raises the normal pool seven feet from elevation 5393 to elevation 5400. Elevation 5400 is the maximum practical storage level. Impacts around the reservoir periphery and costs associated with raising the dam crest elevation make higher storage levels impractical. The total storage at the existing spillway crest elevation is 37,642 acre-feet, which is 1,203 acre-feet less than the 38,845 acre-feet of marketed water contracts. The loss of storage is the result of sedimentation that has occurred since the reservoir was constructed. The storage at elevation 5400 will be 45,115 acre-feet which is an increase of 7,473 acre-feet from the existing spillway crest. The additional storage will allow full delivery of the water contracts and provide a conservation pool of 2,600 acre-feet. The conservation pool is desired to avoid low storage levels that may result in adverse fisheries impacts. An additional 3,670 acre-feet of storage will be available for marketing to new uses. Evaluation of historic flows at the dam indicates that 7,000 acre-feet of additional water may be stored 8 out of 10 years. Marginal project costs associated with raising the pool to elevation 5400 are well below the economic benefits of the additional storage.

Raising the spillway crest 7 feet results in a corresponding 3-ft raise of the dam crest to elevation 5413 feet. The proposed plan will raise the crest, and replace the gate house on the center tower. In addition to this work the plan will also modify the existing drain by installing a new manhole and drain outlet to provide improved monitoring of the drain's performance. Currently the drain's outlet is buried below the spillway channel and not accessible.

Current access to the dam is limited when the reservoir pool is higher than elevation 5385 feet. The primary vehicle routes to the dam are: 1) through the spillway approach channel which is submerged when the reservoir pool is higher than 5385 feet; and, 2) through the spillway channel downstream of the dam which is submerged when the reservoir is spilling. There is a footbridge across the river downstream of the dam that would probably fail at a 50- to 100-year flood level. It is important to have adequate access to the dam during potential emergency conditions. The proposed plan includes a new pedestrian bridge over the spillway crest to maintain access across the spillway at all times – even during the design flood. The bridge could also accommodate lightweight equipment such as an ATV. A new vehicle access road and bridge downstream of the dam will also be constructed. The road and bridge will provide ready access for heavy maintenance equipment to the new control valves at the toe of the dam. The vehicle bridge and

road would be designed to accommodate the 100-yr flood; it would be impractical to design this bridge for the spillway design flood.

The reservoir raise will cause new impacts to areas around the raised reservoir perimeter. In particular, the raised pool may cause erosion of portions of the State Secondary Highway 357 along the east side of the reservoir. The proposed plan includes an allowance for riprap slope protection along the highway. There may be other impacts to property that requires mitigation. The extent and characteristics of the reservoir impacts will be determined in conjunction with evaluation of right-of-way and easements and are not part of this study. Reservoir and dam raise elevations were established to raise the reservoir pool to its practical maximum; however, a lower crest elevation could be selected for final design based on funding and additional discussions with water users, land owners, and State agencies.

The existing DNRC claims and easements records do not encompass all the area that is inundated within the current pool level. Raising the reservoir will increase the inundated areas outside the DNRC claims. It is estimated that there are about 25 non-DNRC acres inundated at the present level (El 5393), 73 acres at the raised pool level (El 5400), 217 acres below the existing dam crest (El 5410) and 250 acres below the proposed dam crest (El 5413). Much of the flood pool between the spillway crest and the top of dam would rarely be flooded. For example, if the reservoir was at full pool (5400 feet) and the 100-yr flood discharge of 2,500 cfs occurred the reservoir pool would increase by two feet. Additional study of the land rights and settlement of property issues will need to be completed prior to construction of the rehabilitation. An allowance for right-of-way and easement issues was included in the cost estimate.

The potential to incorporate hydropower development into the rehabilitation project was considered. Turbines and generators could be incorporated into the outlet works to generate electricity from reservoir releases. Adding hydropower generation features to Ruby Dam would likely bring the dam under the jurisdiction of the Federal Energy Regulatory Commission (FERC). There is some potential that the dam may not be under full FERC regulation if the hydropower is not a central purpose of the project. DNRC is investigating the potential for including a minor hydropower component. If the project were fully regulated by FERC, the dam and spillway would need to meet criteria which are much more stringent than current Montana Dam Safety Standards. The spillway design flood would increase from 20,000 cfs to a Probable Maximum Flood (PMF) that would require a spillway capacity over 70,000 cfs. Meeting the FERC spillway standards would increase project costs by nearly $5 million without costs for hydropower equipment or transmission lines. Therefore, adding hydropower generation with full FERC regulation is not economically feasible at this time. However, the steel penstock configuration of the outlet will accommodate future hydropower development if regulatory requirements change.

PROJECT COSTS

Preliminary cost information for the rehabilitation of Ruby Dam is shown below along with water storage information and the annual cost per acre-foot based on a 75 year project life and 4.5% discount rate. Funding for the rehabilitation will utilize various Montana State government sources of funding. It is anticipated that the DNRC Renewable Resources Grant and Loan (RRGL) program will be utilized for a portion of the funding with water users assessments repaying the loan. Additional state funding will be needed beyond that available from the RRGL program.

RUBY DAM REHABILITATION
PRELIMINARY COST INFORMATION
(2007 dollars)

PARAMETER	PREFERRED REHAB OPTION (L2-100-00)
Spillway Crest Elev.	5,400
Total Storage (AF)	45,115
Total Marketable Storage (AF)	42,515
Estimated Project Cost	$11,930,000
Cost per AF	$264
Annual Cost per AF*	**$12.35**

* Based on 75 yr project life, 4.5% discount rate

IMPLEMENTATION

Funding requests for the rehabilitation will be prepared for the 2009 State Legislature which would provide design and construction funding for the 2009-10 biennium. Final design would begin in the fall of 2009 with anticipated construction beginning in the fall of 2010. Access roads, bridges and the outlet modifications would be completed during the fall and spring prior to irrigation deliveries. The spillway replacement would begin during the summer of 2011 and extend into the winter. It will be necessary to complete the spillway construction prior to spring runoff to safely accommodate potential floods.

RUBY DAM REHABILITATION FEASIBILITY STUDY

Preferred Rehabilitation Option

Prepared for:

Montana Department of Natural Resources and Conservation
State Water Projects Bureau
Helena, MT

Prepared by:

HKM Engineering Inc.
P.O. Box 31318
Billings, MT 59107

January 2008

H:\08\M087175\Ruby Reports\Final\PrefOption_0108.doc

TABLE OF CONTENTS

Page

1.0 INTRODUCTION **1**
2.0 PREFERRED SPILLWAY OPTION **1**
2.1.1 Labyrinth Crest 2
2.1.2 Spillway Chute 2
2.1.3 Spillway Stilling Basin 3
2.2 Dam Raise 5
2.3 Land Acquisition 5
2.4 Reservoir Impacts 6
2.5 Drain Modifications 6
3.0 PREFERRED OUTLET WORKS OPTION **7**
4.0 COST ESTIMATE **7**
5.0 CONSTRUCTION SCHEDULE & SEQUENCE **8**

LIST OF TABLES

Table 1 - Claims and Easements Summary 5
Table 2 – Preferred Rehabilitation Option Cost Estimate 8

LIST OF FIGURES

Figure 1 – 100-ft Labyrinth Rating Curve 4
Figure 2 – Rehabilitation Schedule 10

LIST OF APPENDICES

Appendix A Preferred Rehabilitation Option Drawings
Appendix B Hydraulic Computations
Appendix B1 Labyrinth Crest
Appendix B2 Spillway Chute
Appendix C Reservoir Impacts
Appendix D Cost Estimate

Ruby Dam Preferred Rehabilitation Option

1.0 INTRODUCTION

The preferred options for rehabilitation of the Ruby Dam spillway and outlet works are discussed in this report as part of the Ruby Dam Rehabilitation Feasibility Study conducted by HKM Engineering Inc. (HKM) for the Montana Department of Natural Resources and Conservation (DNRC). Preliminary design of the preferred spillway crest, spillway chute, stilling basin, raised dam crest, outlet works, and drains are covered in this report.

The preferred rehabilitation option includes raising the spillway crest to elevation 5400, which is seven feet above the existing spillway flashboards. The decision to raise the spillway crest and increase the reservoir storage level was based on the Water Availability Analysis and Economic Evaluation which were performed as part of the Feasibility Study. These analyses showed that raising the storage level of Ruby Reservoir is feasible based on the amount of additional water available on an annual basis which is currently lost through spillway flows and the economic benefit of having additional water available to replenish storage lost to reservoir sedimentation, to provide a conservation pool to protect downstream fisheries, and to market other future uses.

Preliminary structural design of concrete structures is not included in this report section but is included in the Design Options Summary. The dam raise, drain modifications, and outlet works rehabilitation for the preferred option are also included in this report. Preliminary drawings for the preferred rehabilitation option are included in Appendix A. Hydraulic computations for the spillway crest and chute are included in Appendix B. Appendix C contains selected maps used to determine impacts to land and roads around the reservoir. A detailed cost estimate for the Ruby Dam preferred rehabilitation option is included in Appendix D.

2.0 PREFERRED SPILLWAY OPTION

The preferred Ruby Dam spillway rehabilitation option (Option *L2-100-00)* consists of a 100-ft wide two-cycle labyrinth weir crest at elevation 5400.0 ft with a 100-ft wide chute and stilling basin. Design parameters for this option include:

- Spillway Crest Type/Elevation: Two-Cycle Labyrinth/5400.0 ft
- Spillway Crest and Chute Width: 100 ft
- Rehabilitated Dam Crest Elevation: 5413.0 ft
- Spillway Design Flow: 20,000 cfs (50 LOL outflow)
- Spillway Stilling Basin Design Flow: 4,000 cfs (500-yr outflow)

Details of each component of the preferred spillway option are discussed in the following sections of this report. Drawings are included in Appendix A and additional information can be found in the Design Options Summary and Downstream Tailwater Hydraulics Report.

2.1.1 Labyrinth Crest

The spillway crest for the preferred option consists of a 100-ft wide two-cycle labyrinth weir at elevation 5400.0 ft. The labyrinth weir design has a total crest length of 250 ft based on a magnification factor of 2.5, which results in a maximum reservoir elevation of 5409.9 ft at the routed design flood (20,050 cfs). The labyrinth floor elevation was initially set at 5389.0 ft based on the crest elevation and minimum required wall height; due to the existing ground level the floor elevation was lowered to 5385.0 ft which slightly increases the hydraulic capacity of the labyrinth crest. The labyrinth weir spillway crest was designed with the weir projecting into the reservoir to improve approach flow conditions. The preferred spillway crest was set at 5400 ft to maximize the reservoir pool. A lower spillway crest elevation could be selected during final design based on funding and additional discussions with water users, land owners, and state agencies. Plan and profile drawings are included with the drawings in Appendix A. The rating curve for the labyrinth crest is shown in Figure 1. A printout of the spreadsheet used in the hydraulic design of this labyrinth crest is included in Appendix B1.

2.1.2 Spillway Chute

The spillway chute for the preferred option has a rectangular cross section with bed slopes that closely match those of the existing chute. The new right and left chute walls were designed to be constructed inside of the existing tapered section with the resulting void between the new and existing walls filled with gravel. Downstream of where the existing chute is less than 100 ft, the chute will be widened by excavating to the left of the existing chute wall and with the new wall constructed approximately 25 ft left of the existing wall. The right chute wall in the widened area will be constructed adjacent and inside of the existing wall.

The top of the chute walls were set at elevation 5413.5 ft in the area of the dam crest so the walls would be 6 inches higher than the dam crest. The walls were then sloped down to a minimum height of 10 ft; the 10-ft wall height is continued until the intersection with the stilling basin walls at elevation 5310 ft. The minimum wall height was based on the existing ground surface rather than on spillway hydraulics because the freeboard recommended above chute flows required lower wall heights than site topography allowed. Flow depths and velocities at the 20,000 cfs design flow in the 100-ft chute vary from approximately 10.8 ft at 19 ft/s just downstream of the crest to approximately 2.5 ft at 79.5 ft/s at the stilling basin.

Flow through the spillway chute was modeled using a spreadsheet that uses standard step calculations to compute flow depth and velocity at spillway stations. Spreadsheet printouts used to model the preferred chute configuration are included with the hydraulic computations in Appendix B2.

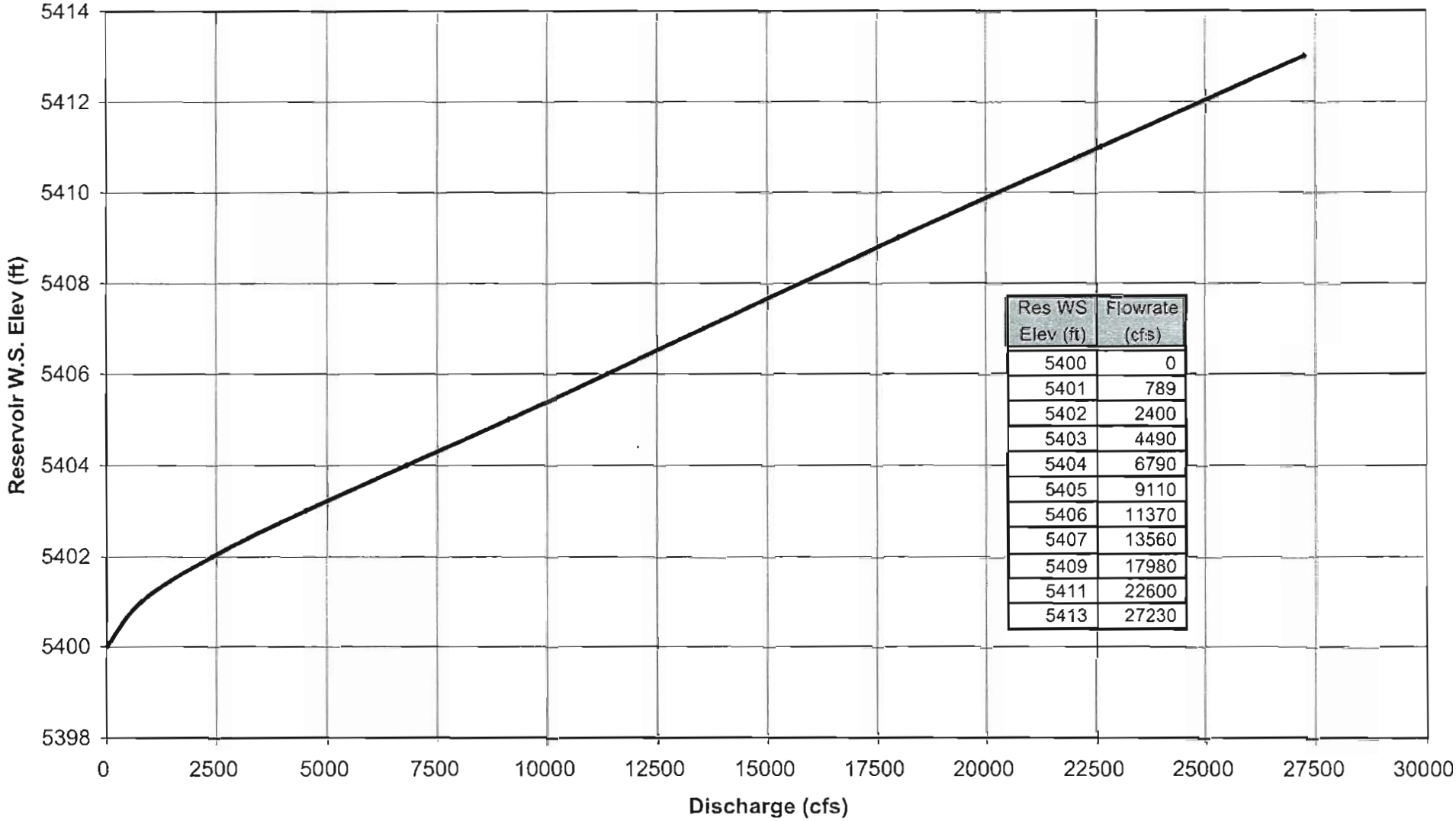
2.1.3 Spillway Stilling Basin

The spillway stilling basin for the preferred option consists of a modified US Bureau of Reclamation Type II basin or combination stilling basin-flip bucket with a width of 100 ft and a length of 50 ft. These dimensions were based on the chute width and the estimated length needed to contain the hydraulic jump for the stilling basin design flow of 4,000 cfs (500-yr flood). Hydraulic jumps for flows greater than the design flow are not contained within the stilling basin and the jump is swept downstream of the basin. When flow through the stilling basin becomes great enough, the basin end sill begins to act as a flip bucket and will project a water jet out of the basin and into the downstream river channel.

The combination stilling basin was modified from the standard Type II basin by lowering the end sill to an elevation one foot above the existing channel floor elevation, removing the dentates from the end sill, and not including chute blocks at the entrance to the basin. To minimize the potential for scour at the dam toe from flows in excess of 4,000 cfs, a 60-ft long 45° wingwall was designed on the left side of the basin outlet. The stilling basin design also includes riprap placement along the left bank of the river channel below elevation 5310 ft.

Figure 1

Ruby Dam Feasibility Study
Preferred Spillway Alternative
100' Labyrinth Rating Curve



Res WS Elev (ft)	Flowrate (cfs)
5400	0
5401	789
5402	2400
5403	4490
5404	6790
5405	9110
5406	11370
5407	13560
5409	17980
5411	22600
5413	27230

2.2 DAM RAISE

Due to the increased elevation of the spillway crest, raising the dam crest will be necessary to meet the minimum freeboard requirement of 3 ft. The preferred rehabilitation option includes raising the dam crest from the existing elevation of 5410 ft to 5413 ft to meet the required freeboard above the design flood maximum reservoir elevation of 5409.9 ft. The dam raise design consists of removing the top five feet of the downstream portion of the existing crest to 5405 ft. The upstream portion of the dam will be excavated for placement of a Terramesh® or wire-faced Mechanically Stabilized Earth (MSE) wall. Compacted impervious/semipervious material will be used to fill the excavated areas on the dam crest downstream of the MSE wall. Riprap will also be placed over the lower upstream half of the Terramesh®/MSE wall to key the wall into the embankment. The upstream wall allows the dam crest to have a 30-ft width which is adequate for vehicle travel and keeps the up and downstream faces at existing slopes.

2.3 LAND ACQUISITION

A map of land ownership at Ruby Reservoir is presented in Figure RI-1 in Appendix C. Based on available mapping DNRC currently has claims or easements on 1,134 acres of land (DNRC land) at Ruby Reservoir. This area nearly encompasses the surface area of the existing normal full pool at El. 5393. Due to the preferred spillway crest elevation increase to El. 5400, the surface area of the reservoir at full pool is also increased. Figure RI-1 in Appendix C shows the reservoir and lines delineating the 5393 and 5400 foot elevations. Figure RI-2 shows the reservoir's south end where most of the inundation associated with the reservoir raise will occur. Inundation areas around the reservoir that are outside of DNRC land are presented in Table 1 for several different elevations.

TABLE 1 - CLAIMS AND EASEMENTS SUMMARY

Existing DNRC Land Description		**Existing DNRC Land Area**	
DNRC Claim Areas & Easements			1,134 acres
Elevation	**Elevation/Description**	**Area Outside DNRC Land Boundary**	
		ft^2	**acres**
5413	Preferred Option - Top of Dam	10,898,515	250
5410	Existing Top of Dam	9,465,446	217
5400	Preferred Option - Spillway Crest	3,176,732	73
5393	Existing Spillway Crest	1,102,538	25

For the purpose of this Feasibility Study it was assumed that easements outside of existing DNRC claims and easement areas would need to be acquired for the preferred rehabilitation option. The DNRC will make a decision before final design on the elevation at which easements will need to be acquired (e.g. spillway crest, pool elevation at 100 year flood, top of dam). Because the exact area and value for easements is beyond the scope of this study, a "placeholder" value of $1,000,000 was used in the cost estimate for the Preferred Alternative which is presented in Appendix C. Further evaluation of DNRC land claims, the chosen easement elevation along with property appraisals will likely change the amount and cost of easements from the value used in this report.

2.4 RESERVOIR IMPACTS

The preferred option spillway crest (El. 5400) is seven feet higher than the existing normal full pool elevation at the existing spillway flashboards at 5393 ft. Due to this increase in the normal water surface elevation, several areas of roadway embankment along Highway 357 on the east side of the reservoir may be impacted by undercutting and erosion. Figure RI-2 presents locations along the highway that were identified as areas most likely to be impacted by raising the reservoir water surface elevation. To protect the road embankment in these areas, slope protection will be added to the existing roadway embankment from the toe of the embankment up to 3 ft above the spillway crest elevation. The proposed design includes rock riprap slope protection in select areas along the highway embankment with a minimum thickness of two feet. The approximate volume of slope protection required along the highway on the east side of Ruby Reservoir was calculated at 16,200 cy. Other modifications to the highway along the east side of Ruby Reservoir should not be necessary as the road surface has a minimum elevation of approximately 5420 ft. Detailed identification of slope protection requirements is beyond the scope of this study and more detailed evaluation will be necessary during final design.

One small area of potential impact is located along the road embankment near the southwest corner of the reservoir. At this location, the terrain is relatively flat and slope protection may not be required. Although this area may warrant further consideration during final design, slope protection for this area was not included in the quantities used in the cost estimate. The cost associated with reservoir impacts is included in the cost estimate for the preferred option presented in Appendix D.

2.5 DRAIN MODIFICATIONS

Modifications to the existing drain are proposed to obtain information on the original drain system. The original drain system consists of a toe drain and a foundation drain constructed with clay tile. Near the toe of the dam the clay tile drains are manifolded together into a 12-inch CMP

drain which has an outlet located beneath the spillway channel, downstream of the stilling basin; the drain's outlet is not accessible. The CMP conduit has likely deteriorated over the 70 years since its original installation. In order to gather additional information on the drain and seepage flows the outlet for the CMP should be located and a manhole installed. The manhole would serve as a sediment trap and the outfall should be raised above the stream channel, if feasible, to allow observation of the discharge. Installation of a monitoring well near the center of the dam could also provide useful information on the foundation drain's performance. Investigation of the CMP conduit and monitoring well installation should be completed prior to final design so any data on the condition of the toe drains and seepage can be incorporated into the final rehabilitation design. Additional discussion of the drainage system can be found in the Seepage and Slope Stability Analyses.

3.0 PREFERRED OUTLET WORKS OPTION

The preferred rehabilitation option for the Ruby Dam outlet works (Option OW4) consists of continued use of the existing guard gate and removing the butterfly control valve located in the valve tower, installation of a new 72-in diameter steel penstock into the existing outlet tunnel downstream of the valve tower, and installation of one 60-in jet flow gate and one 18-in gate valve near the toe of the dam. A new vehicle bridge in the area of the existing downstream foot bridge provides access to the new control valves at the dam's toe.

Option OW4 was the lowest cost of the outlet works options evaluated in the Low Level Outlet Works Rehabilitation Summary that satisfied DNRC discharge criteria. Discharge criteria required the outlet works to perform over a wide range of flows from a maximum of 1,100 cfs at reservoir elevation 5400 ft (preferred spillway crest) to minimum stream flows of 20 cfs. The configuration of the preferred rehabilitated outlet works option is included on the drawings in Appendix A. Additional discussion on outlet works rehabilitation alternatives including drawings, hydraulic calculations, and cost estimates can be found in the Low Level Outlet Works Rehabilitation Summary.

4.0 COST ESTIMATE

The estimated total cost for the preferred rehabilitation option is approximately $11,930,000. The preferred rehabilitation option cost estimate includes construction costs for rehabilitation of the spillway, outlet works, dam raise, access improvements, and road embankment slope protection. The program costs portion of the cost estimate includes geotechnical and

environmental studies, water rights, engineering, construction administration, easement acquisition, and contingencies. A summary of the cost estimate for the preferred rehabilitation option is presented in Table 2 with a detailed cost estimate included in Appendix D.

TABLE 2 – PREFERRED REHABILITATION OPTION COST ESTIMATE

Item	Cost
Direct Construction Costs	
Spillway Replacement	$ 4,300,000
Outlet Works Modifications	$ 1,149,000
Embankment Raise & Drains	$ 436,000
Access Roads & Bridges	$ 270,000
Reservoir Impacts	$ 650,000
Mobilization/Preparation (15%)	$ 1,021,000
Unlisted Items (10%)	$ 718,000
Total Direct Construction Cost	**$ 8,544,000**
Program Costs	
Geotechnical Investigations	$ 20,000
Cultural/Environmental	$ 15,000
Water Rights	$ 50,000
ROW/Easements	$ 1,000,000
Design (10%)	$ 854,000
Construction Administration (7%)	$ 598,000
Contingencies (10%)	$ 854,000
Total Project Cost	**$ 3,391,000**
TOTAL PROJECT COST	**$11,935,000**

5.0 CONSTRUCTION SCHEDULE & SEQUENCE

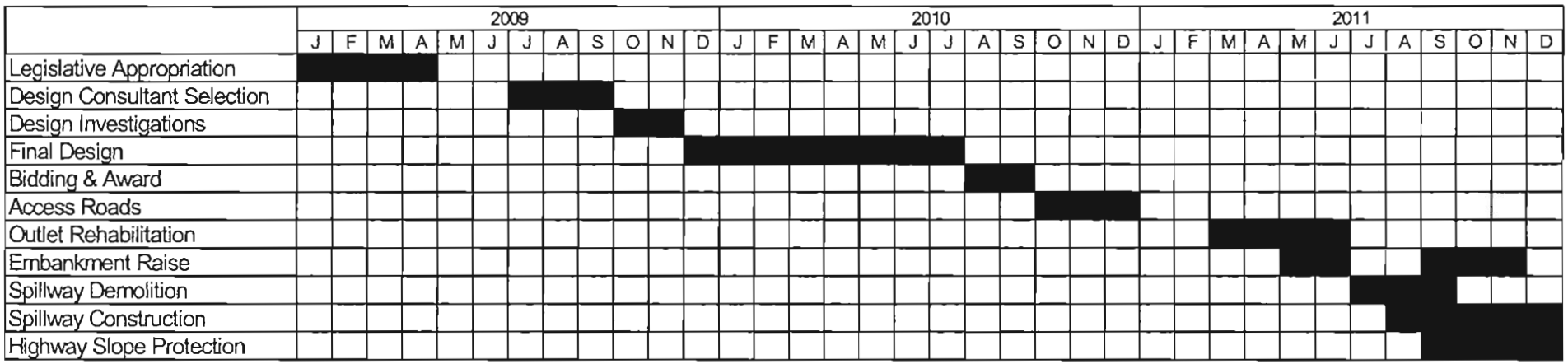
Rehabilitation construction of the spillway and outlet works at Ruby Dam will require careful scheduling and planning to maintain in-stream flows, water deliveries and protect the work from flooding. Rehabilitation of the outlet must be scheduled to occur outside of the season for water deliveries. It will also be advantageous to restrict the time that the outlet is out of service to coincide with spillway operation to maintain streamflow without pumping water over the dam.

If the outlet rehabilitation is constructed in advance of the spillway, the rehabilitated outlet will have a larger safe capacity to assist in routing floods during spillway construction.

Runoff into Ruby Reservoir fills the reservoir and flows through the spillway for six to eight weeks each year. The potential for large springtime runoff causing flows through the spillway is high, even if the reservoir outlet were operated to maintain restricted storage. Restricting storage would reduce deliveries and cause hardship for the water users. Therefore, the spillway needs to be operational April through June each year. Demolition of the spillway will need to be delayed until the risk of large runoff events is sufficiently reduced. This will result in a short season for the amount of construction activities required. It is likely that the spillway construction will extend into the winter.

The funding for this project will require appropriations from the Montana Legislature in 2009 for funding in the 2009-10 biennium. The engineering consultant would be selected in the summer/fall of 2009. Upon selection, the consultant would perform the field investigations and final design for bidding in the summer/fall of 2010. Construction of the access roads, particularly the downstream access could be completed in the fall with the remaining construction completed in 2011. The anticipated schedule is shown in Figure 2.

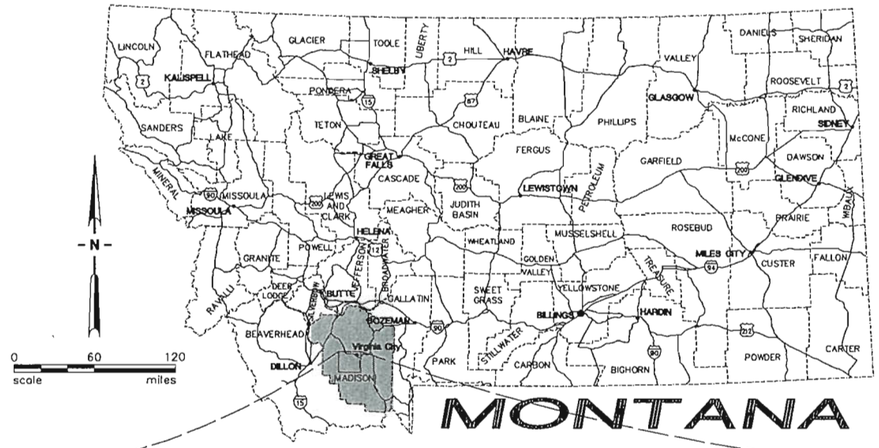
Figure 2 – Rehabilitation Schedule

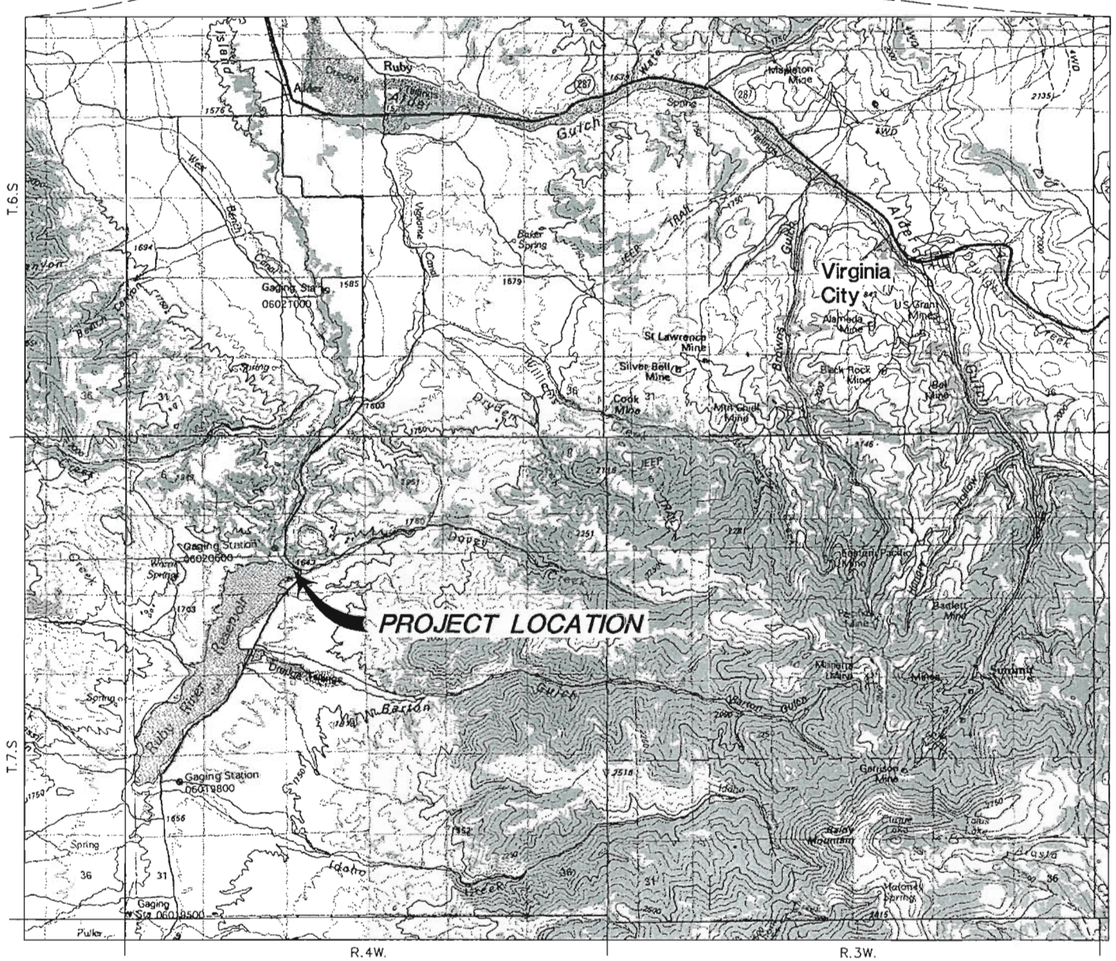


APPENDIX A

PREFERRED REHABILITATION OPTION DRAWINGS

RUBY DAM
REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA
PREFERRED OPTION DRAWINGS





PROJECT LOCATION MAP

5000 0 5000 10000
scale feet

Prepared for :

The Montana Department of Natural Resources and Conservation

WATER Resources Division

State Water Projects Bureau
P.O. Box 201601
Helena, MT 59620-1601
(406) 444-6646

Prepared by :

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

PRELIMINARY
NOT FOR CONSTRUCTION

SHEET INDEX

SHT. NO.	DESCRIPTION
G1	COVER SHEET, PROJECT LOCATION, SHEET INDEX
G2	GENERAL SITE PLAN OF EXISTING TOPOGRAPHY
G3	SITE PLAN OF NEW CONSTRUCTION FEATURES
PS-1	SPILLWAY PLAN AND PROFILE
PS-2	TYPICAL SPILLWAY SECTIONS AND DETAILS
PS-3	EMBANKMENT CREST RAISE PLAN AND SECTION
PS-4	SPILLWAY APPROACH PLAN
PS-5	PEDESTRIAN TRAIL PLAN
OW-1	OUTLET WORKS PLAN AND PROFILE
OW-2	OUTLET WORKS EXTENSION AND CONTROL BUILDING
OW-3	OUTLET CONTROL BUILDING, CONDUIT & IMPACT BASIN
OW-4	OUTLET WORKS IMPACT BASIN
OW-5	LOWER ACCESS ROAD

Proj. No. 8M087.175 SEPTEMBER 2007

G:\08\M087175\dwg\PreOp\PO_Cover.dwg 9/12/2007 11:16:11 AM MDT

SURVEYORS NOTE:

1. THE VERTICAL DATUM FOR THIS PROJECT IS THE CENTERLINE AT THE TOP OF THE SPILLWAY BEING 5392.00.

2. THE HORIZONTAL COORDINATE SYSTEM FOR THIS JOB IS BASED ON 4 ORIGINAL AERIAL TARGET POINTS AROUND THE RUBY RESERVOIR (POINTS 9, 15, 18, AND 20).

3. FIELD SURVEYS WERE PERFORMED IN OCTOBER AND NOVEMBER OF 2005 USING GPS.

4. THE LAT/LONG FOR CONTROL POINT NUMBER 1 IS:
LATITUDE: 45.141856443
W LONGITUDE: 112.062577079
ELLIPSOID HEIGHT: 5397.8642'
NAVD ELEVATION: 5431.28' (LOCAL ELEVATION IS 5427.31')
ROTATION FROM GPS NORTH AT CP 1: -0 deg 05'45.484311"
(OPUS SOLUTION ON 10-25-05)

5. NO NGS BM'S WERE SURVEYED.

6. THE OUTLET CHANNEL WAS SURVEYED ON NOVEMBER 30, 2005 AFTER THE WATER WAS SHUT OFF. CONTOURS WERE GENERATED FROM THE OUTLET TO THE CONFLUENCE OF THE RIVER CHANNEL BELOW THE DAM. THE DEEPEST AREA DIRECTLY DOWNSTREAM FROM THE OUTLET STILL COULD NOT BE MEASURED, AND IS LIKELY DEEPER THAN SHOWN. THE NORMAL WATER LINE (10-05) WAS SURVEYED, ALONG WITH THE LOWERED WATER LEVEL (11-05). BOTH WATER LEVELS ARE SHOWN.

AERIAL MAPPERS NOTE:

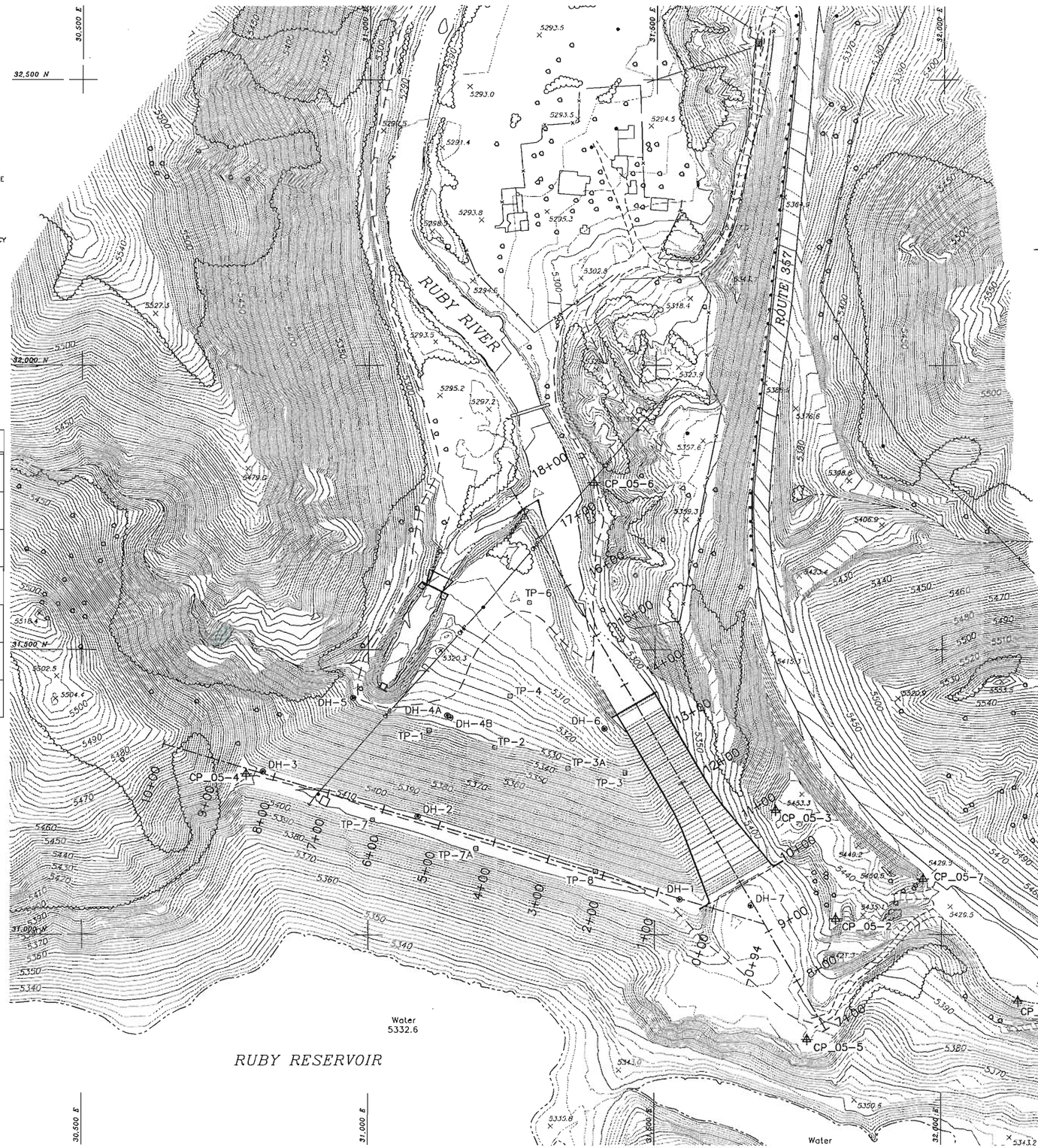
1. SPOT ELEVATIONS IN OBSCURED AREAS ARE APPROXIMATE AND MAY NOT MEET NATIONAL MAP ACCURACY STANDARDS.

SURVEY CONTROL TABLE

CONTROL POINT	COORDINATES	ELEVATION	DESCRIPTION
CP_05-1	N 30883.984 E 32134.611	5427.31	EXIST. PK NAIL IN ROCK
CP_05-2	N 31028.295 E 31815.810	5432.60	1/2" REBAR
CP_05-3	N 31218.664 E 31710.055	5450.24	1/2" REBAR
CP_05-4	N 31281.772 E 30786.302	5410.32	5/8" REBAR WITH YELLOW PLASTIC CAP
CP_05-5	N 30816.824 E 31766.593	5388.22	5/8" REBAR WITH YELLOW PLASTIC CAP
CP_05-6	N 31793.268 E 31391.484	5302.89	1/2" REBAR
CP_05-7	N 31097.391 E 31968.139	5435.68	MONT. DEPT. OF TRANSPORTATION BRASS CAP BENCHMARK

GEOTECHNICAL EXPLORATION HOLE LOCATIONS

DRILL HOLE	COORDINATES		TEST PIT	COORDINATES
DH-1	N 31061.55 E 31543.28		TP-1	N 31358 E 31105
DH-2	N 31206.95 E 31085.37		TP-2	N 31327 E 31218
DH-3	N 31286.10 E 30816.00		TP-3	N 31283 E 31448
DH-4A	N 31384.28 E 31135.98		TP-3A	N 31291 E 31347
DH-4B	N 31380.64 E 31141.64		TP-4	N 31419 E 31246
DH-5	N 31415.62 E 30973.69		TP-6	N 31583 E 31279
DH-6	N 31361.07 E 31411.22		TP-7	N 31201 E 31008
DH-7	N 31051.19 E 31666.48		TP-7A	N 31150 E 31186
			TP-8	N 31111 E 31396



LEGEND

- CP — SURVEY CONTROL POINT (1/2" REBAR OR 5/8" REBAR AND CAP)
- TP — TEST PIT LOCATION
- DH — MONITORING WELL LOCATION (WITH STEEL T POST)
- POWER POLE
- LIGHT POLE
- SIGN
- OHP — OVERHEAD POWER
- FENCE
- GUARD RAIL
- 5363.5 — SPOT ELEVATION
- TREE OR SHRUB
- TREE LINE

-N-

100 0 100 200
scale feet

CONTOUR INTERVAL = 2 FEET

PRELIMINARY
NOT FOR CONSTRUCTION

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

GENERAL SITE PLAN OF EXISTING TOPOGRAPHY PREFERRED OPTION

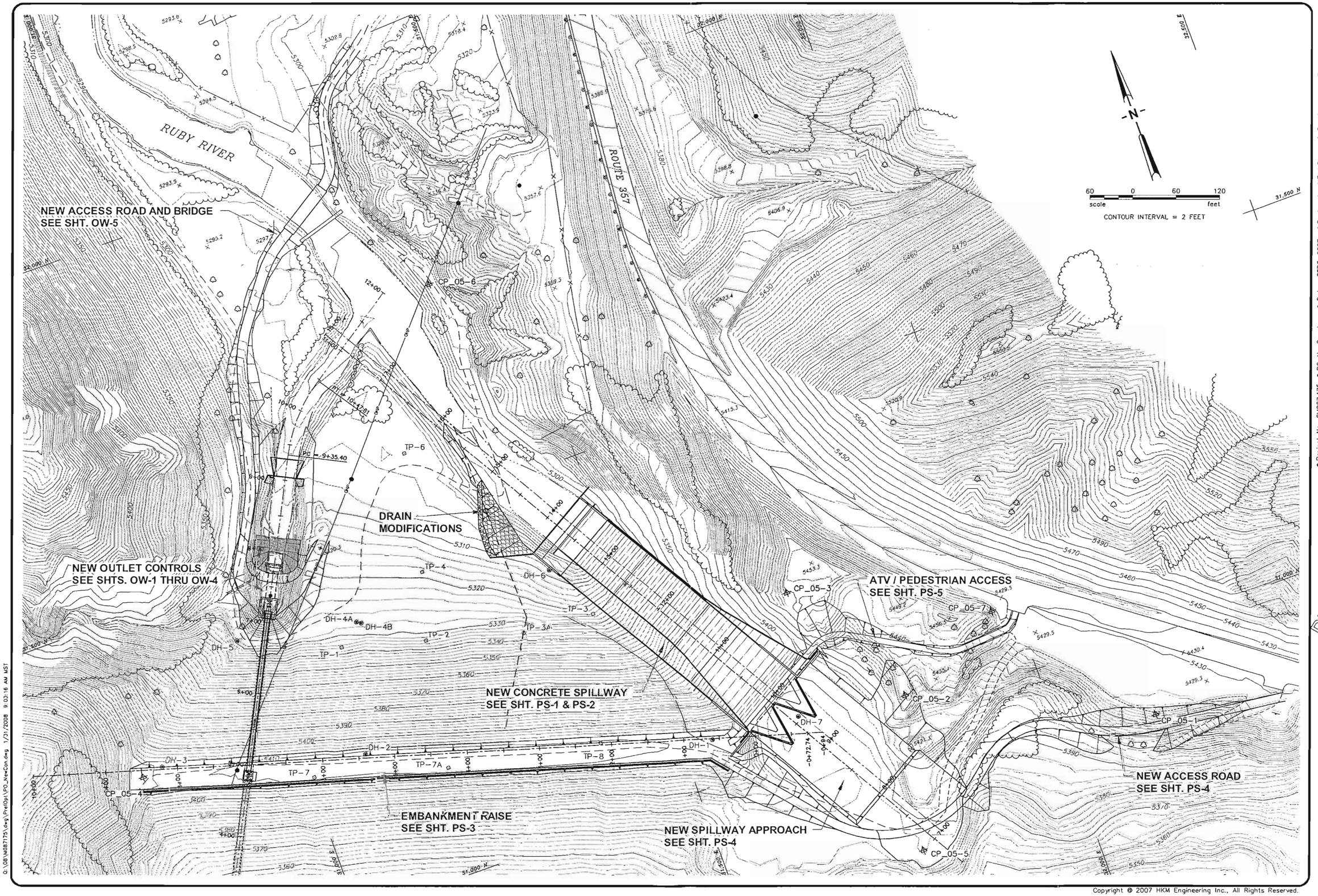
● Project No. 8M087.175 ● PO_GenSite.dwg ● Date SEPT. 2007 ● Designed JHT ● Drawn GAE ● Checked JHT ● Approved ??

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
G2
of 13

Q:\DB\M087175\dwg\PreFOpt\PO_GenSite.dwg 9/12/2007 11:15:15 AM MDT

Copyright © 2007 HKM Engineering Inc., All Rights Reserved.



No.	Revision	By	Date

WARNING
0 ½
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

Project No. 8M087.175 ● PO_NewCon.dwg ● Date SEPT. 2007 ● Designed JHT ● Drawn GAE ● Checked JHT ● Approved ??

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

SITE PLAN OF NEW CONSTRUCTION FEATURES
PREFERRED OPTION

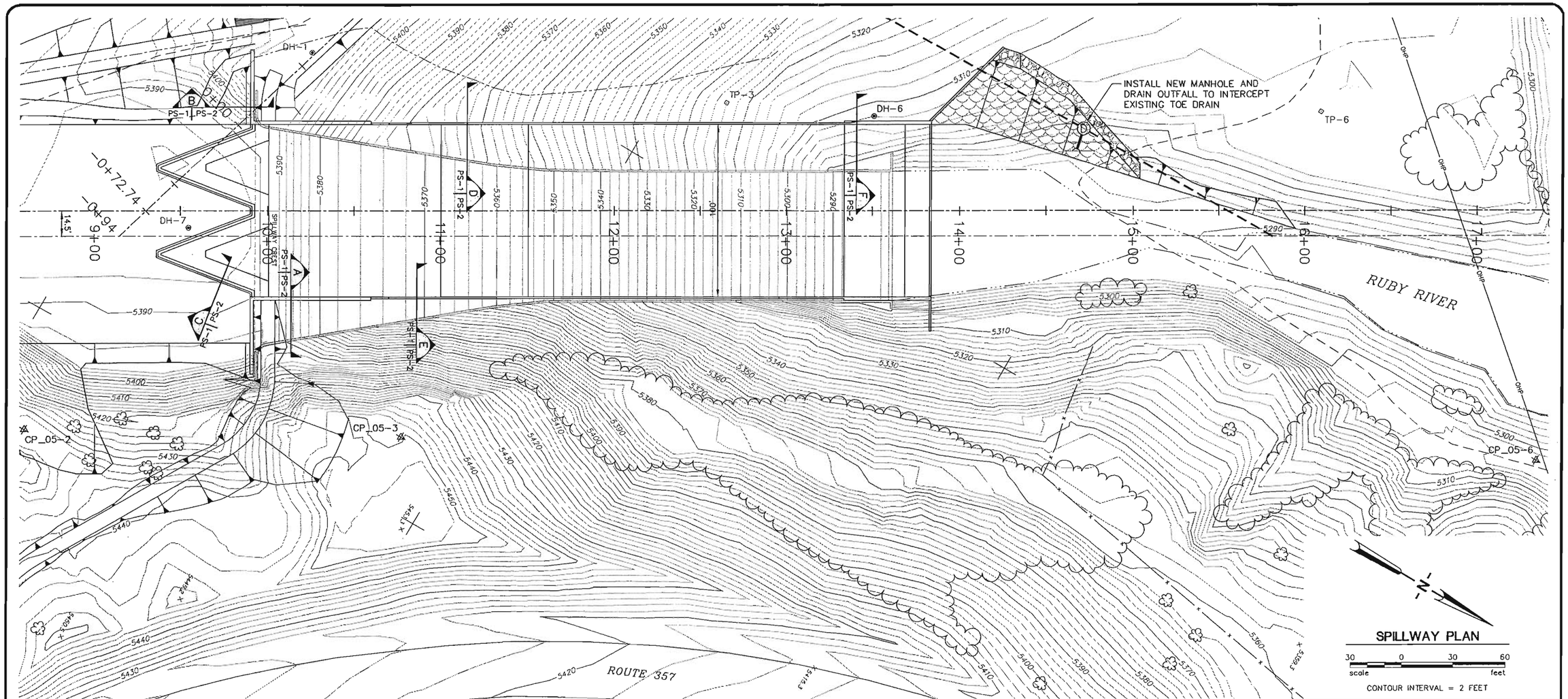
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6388

Sheet No.
G3
of 13

Copyright © 2007 HKM Engineering Inc., All Rights Reserved.

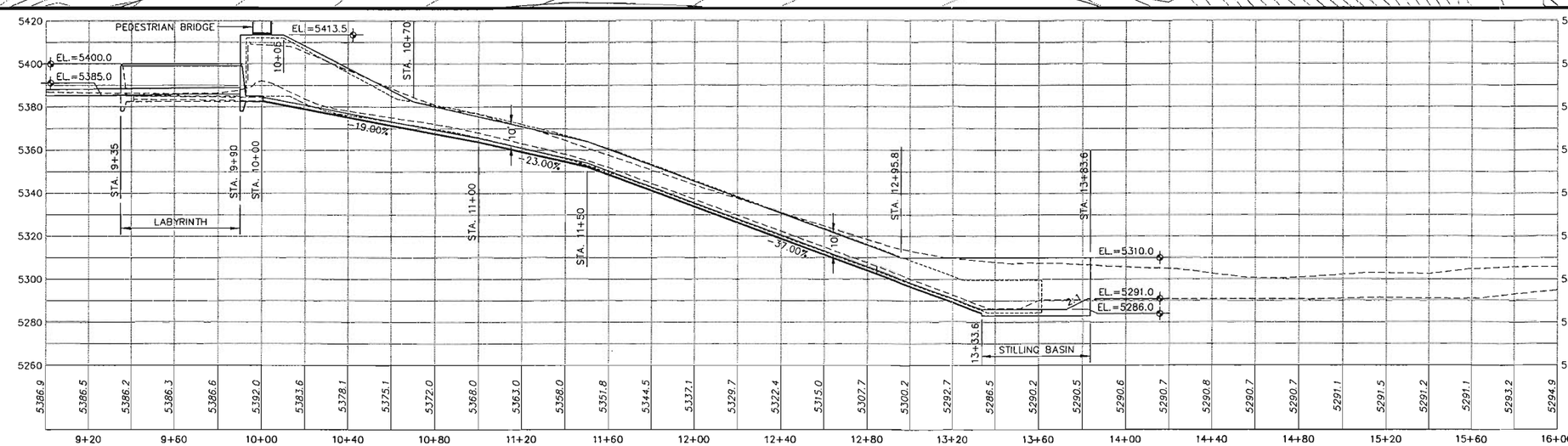
Q:\08\M087175\dwg\Prelfig\PO_NewCon.dwg 1/31/2008 9:03:16 AM MST



SPILLWAY PLAN

30 0 30 60
scale feet

CONTOUR INTERVAL = 2 FEET



SPILLWAY PROFILE

30 0 30 60
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1 INCH, DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

SPILLWAY PLAN AND PROFILE
PREFERRED OPTION

PRELIMINARY
NOT FOR CONSTRUCTION

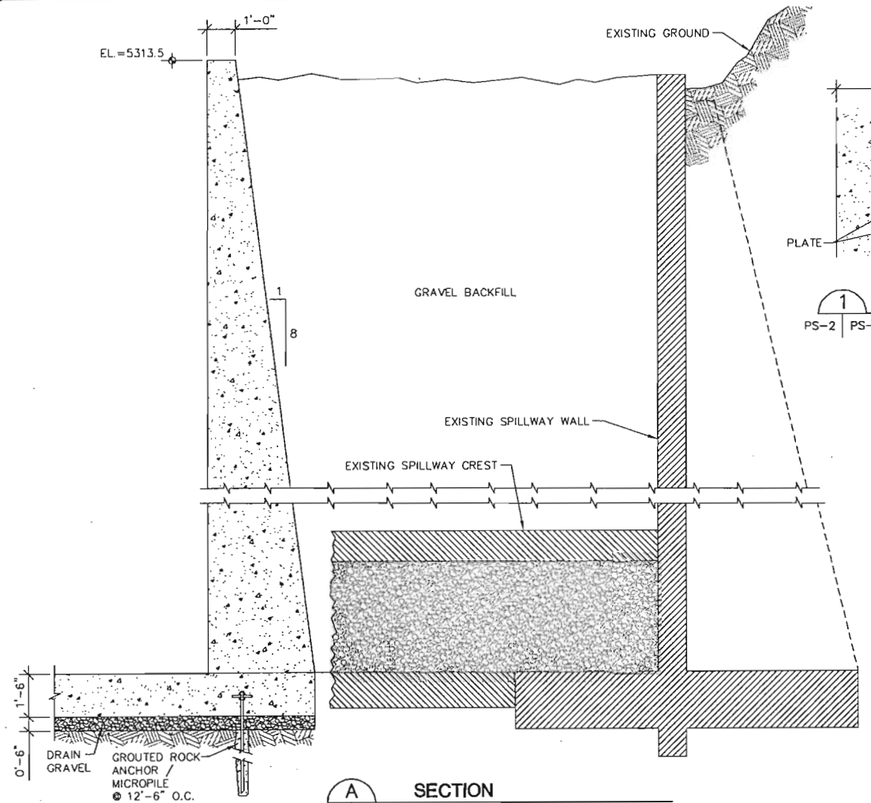
HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6388

Sheet No.
PS-1
of 13

Project No. 8M087.175 • PO_SW-PP.dwg • Date SEPT. 2007 • Designed JC • Drawn CAE • Checked JHT • Approved JHT

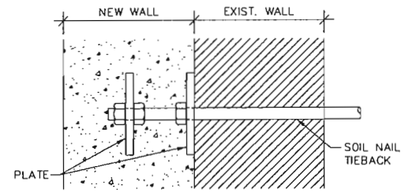
Q:\08\M087175\dwg\Prelopt\PO_SW-PP.dwg 1/31/2008 8:49:32 AM MST

Copyright © 2007 HKM Engineering Inc., All Rights Reserved.



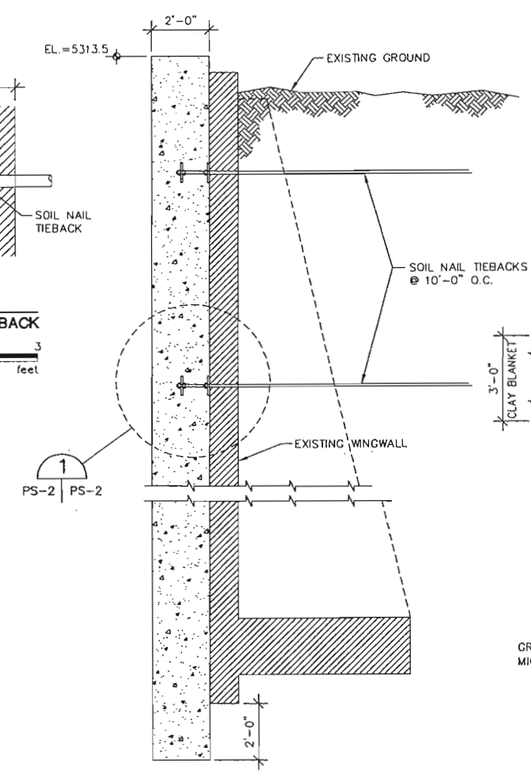
A PS-1 | PS-2 SECTION
TYPICAL SPILLWAY CREST WALL
STA. 9+90 TO 10+70

scale 1 0 1 2 3 4 5 6 7 feet



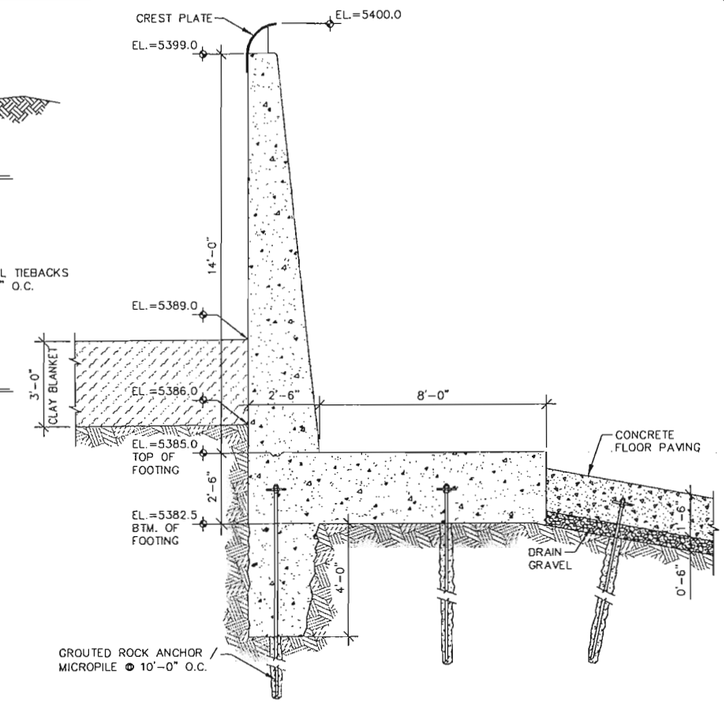
1 PS-2 | PS-2 DETAIL
TYPICAL SOIL NAIL TIEBACK

scale 1 0 1 2 3 feet



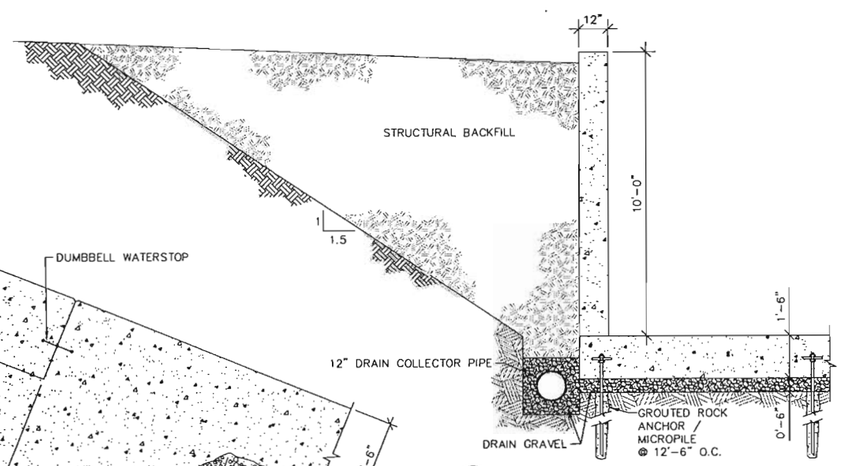
B PS-1 | PS-2 SECTION
TYPICAL WINGWALL

scale 1 0 1 2 3 4 5 6 7 feet



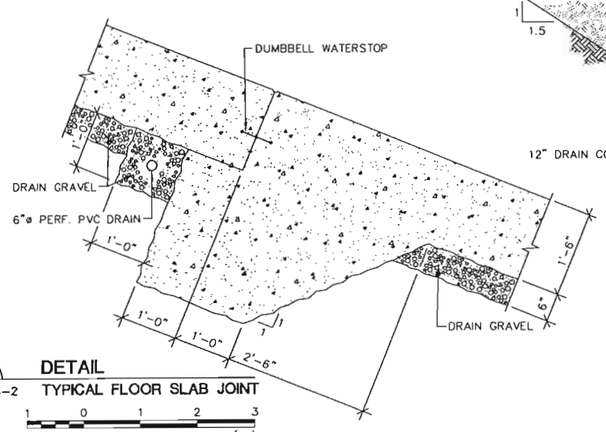
C PS-1 | PS-2 SECTION
TYPICAL LABYRINTH WALL

scale 1 0 1 2 3 4 5 6 7 feet



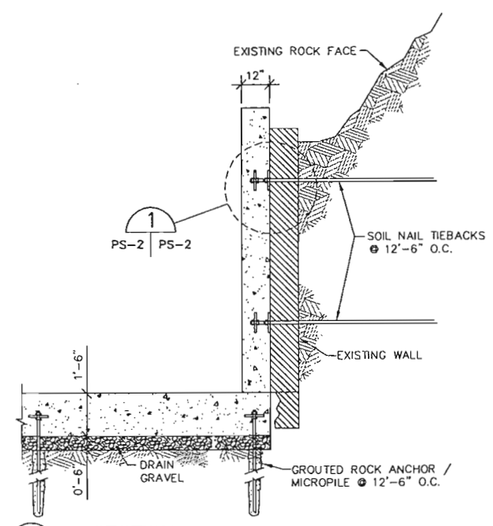
D PS-1 | PS-2 SECTION
TYPICAL SPILLWAY WALL
STA. 10+70 TO 12+85.8 LEFT
STA. 10+70 TO 11+50 RIGHT

scale 1 0 1 2 3 4 5 6 7 feet



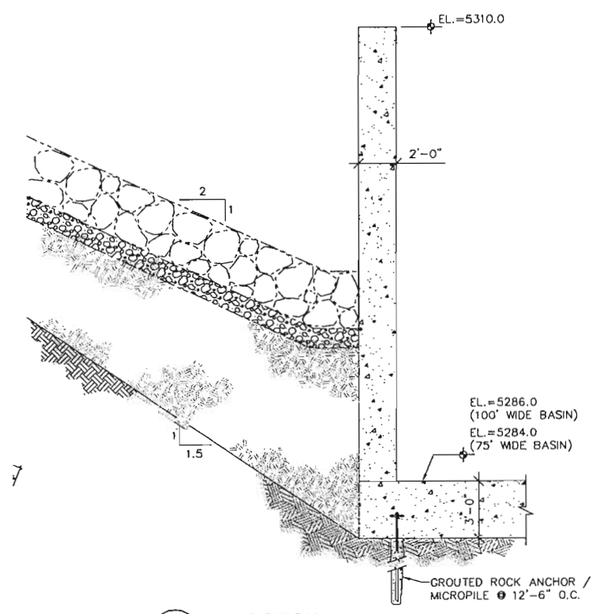
2 PS-2 | PS-2 DETAIL
TYPICAL FLOOR SLAB JOINT

scale 1 0 1 2 3 feet



E PS-1 | PS-2 SECTION
TYPICAL SPILLWAY WALL
STA. 11+50 TO 12+95.8 RIGHT

scale 1 0 1 2 3 4 5 6 7 feet



F PS-1 | PS-2 SECTION
TYPICAL STILLING BASIN WALL

scale 2 0 2 4 6 8 10 feet

PRELIMINARY
NOT FOR CONSTRUCTION

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

TYPICAL SPILLWAY SECTIONS AND DETAILS
PREFERRED OPTION

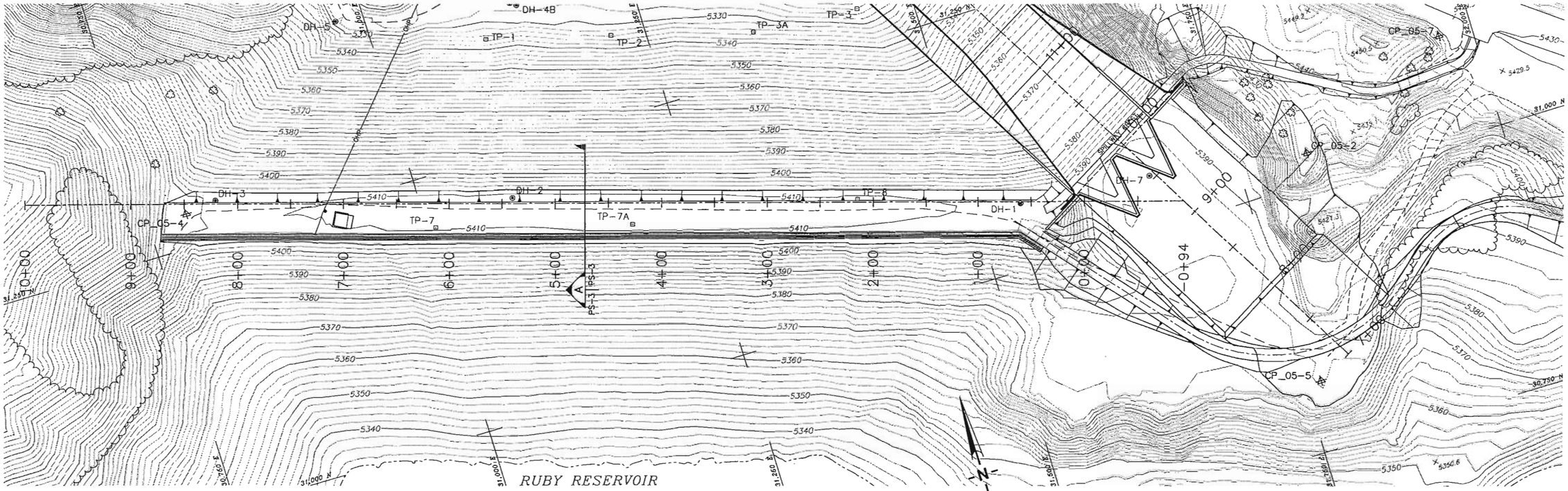
● Project No. 8M087.175 ● PO_SW-Dtls.dwg ● Date SEPT. 2007 ● Designed KJF ● Drawn GAE ● Checked KJF ● Approved JHT

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6398, Fax (406) 656-6398

Sheet No.
PS-2
of 13

Copyright © 2007 HKM Engineering Inc., All Rights Reserved.

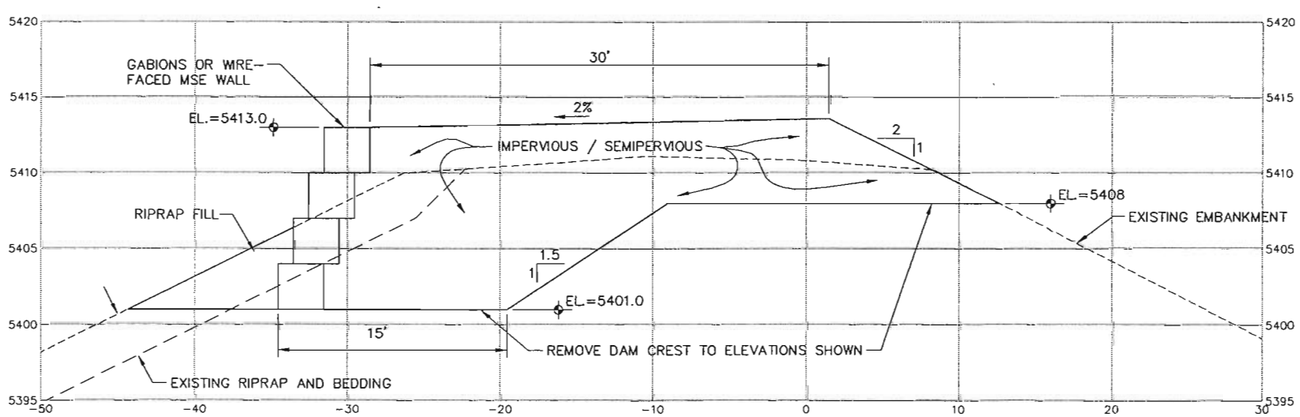
O:\08\M087175\dwg\PrelOpt\PO_SW-Dtls.dwg 9/12/2007 11:21:14 AM MDT



EMBANKMENT CREST PLAN

50 0 50 100
scale feet

CONTOUR INTERVAL = 2 FEET



A
PS-3 | PS-3

SECTION
CREST RAISE TYPICAL

5 0 5 10
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

EMBANKMENT CREST RAISE PLAN AND SECTION
PREFERRED OPTION

PRELIMINARY
NOT FOR CONSTRUCTION

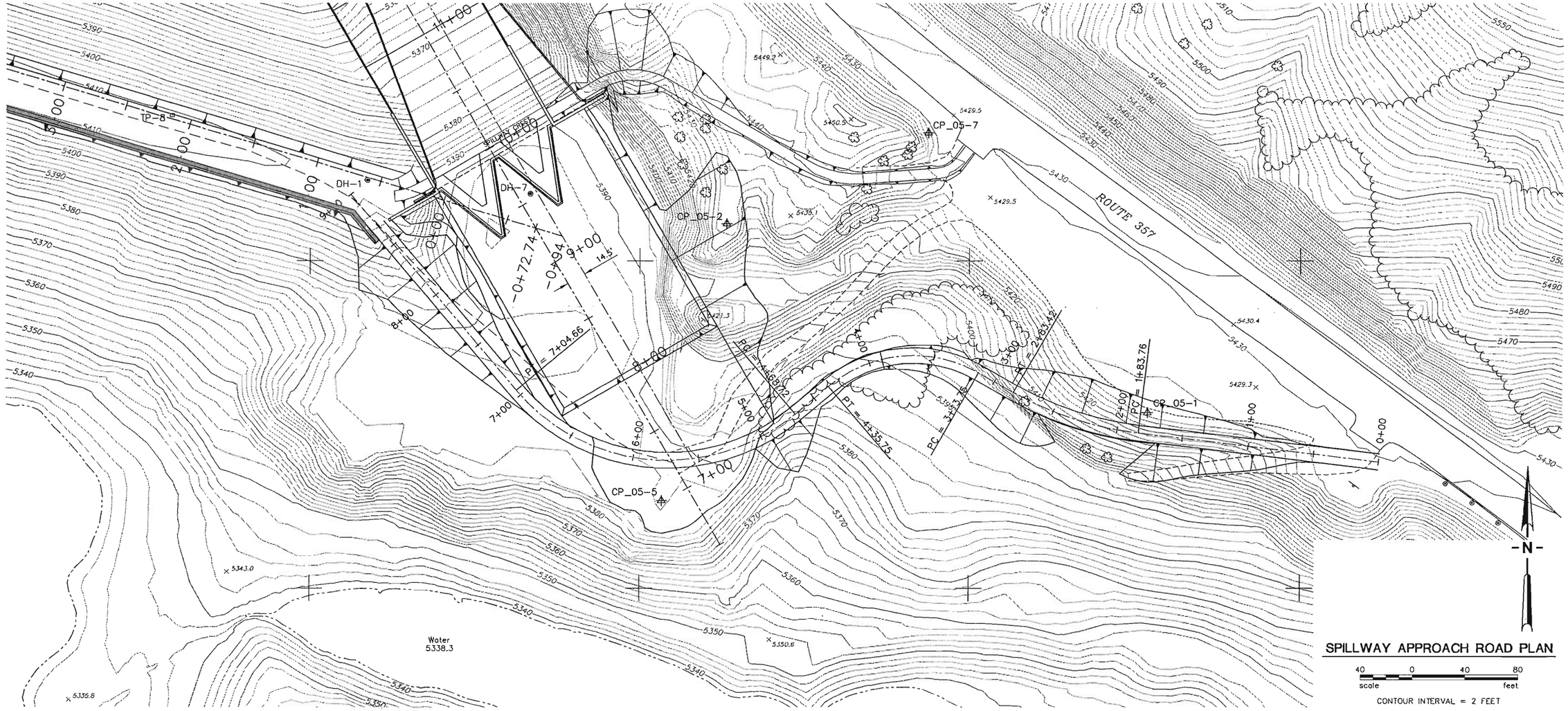
HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
PS-3
of 13

• Project No. 8M087.175 • PO_CrestPlan.dwg • Date SEPT. 2007 • Designed JHT • Drawn GAE • Checked JHT • Approved JHT

Q:\08\M087175\dwg\PreFOpt\PO_CrestPlan.dwg 9/14/2007 10:49:30 AM MDT

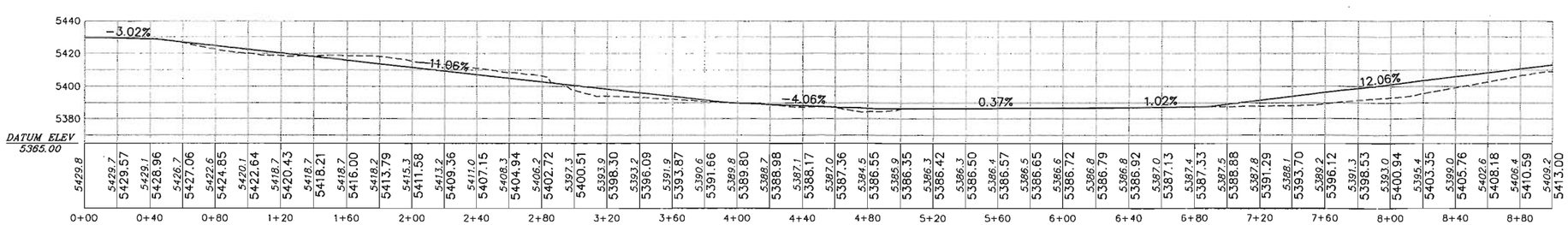
Copyright © 2007 HKM Engineering Inc., All Rights Reserved.



SPILLWAY APPROACH ROAD PLAN

40 0 40 80
scale feet

CONTOUR INTERVAL = 2 FEET



SPILLWAY APPROACH ROAD PROFILE

40 0 40 80
scale feet

PRELIMINARY
NOT FOR CONSTRUCTION

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

SPILLWAY APPROACH PLAN
PREFERRED OPTION

● Project No. 8M087.175 ● PO_Apprch.dwg ● Date SEPT. 2007 ● Designed JHT ● Drawn GAE ● Checked JHT ● Approved JHT

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1316
(406) 656-6399, Fax (406) 656-6398

Sheet No.
PS-4
of 13

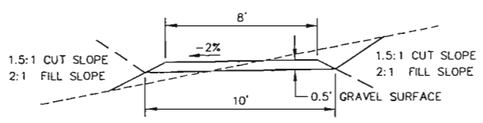
Copyright © 2007 HKM Engineering Inc., All Rights Reserved.

Q:\08\M087175\dwg\Prelfpt\PO_Apprch.dwg 9/14/2007 10:38:47 AM MDT

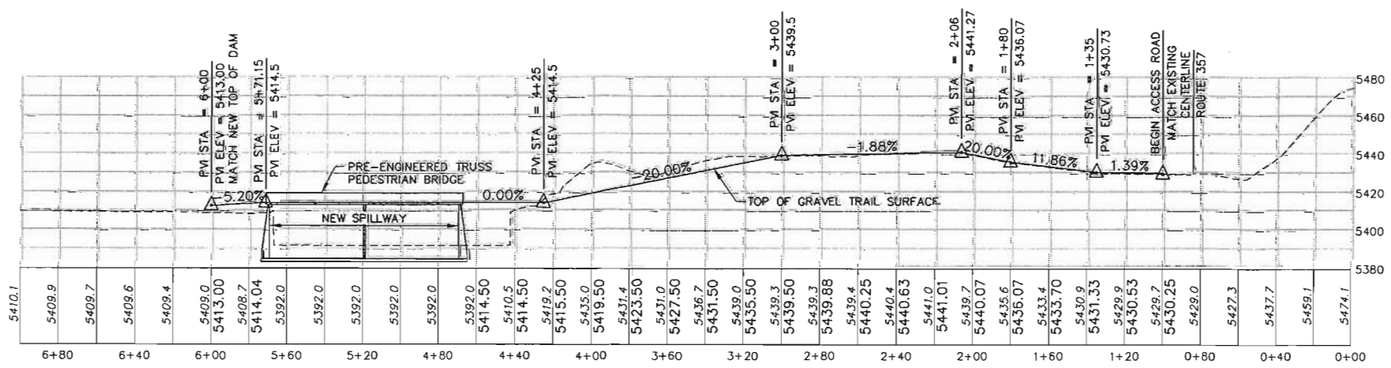
PEDESTRIAN TRAIL PLAN

40 0 40 80
scale feet

CONTOUR INTERVAL = 2 FEET



PEDESTRIAN TRAIL SECTION



PEDESTRIAN TRAIL PROFILE

40 0 40 80
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

PEDESTRIAN TRAIL PLAN
PREFERRED OPTION

PRELIMINARY
NOT FOR CONSTRUCTION

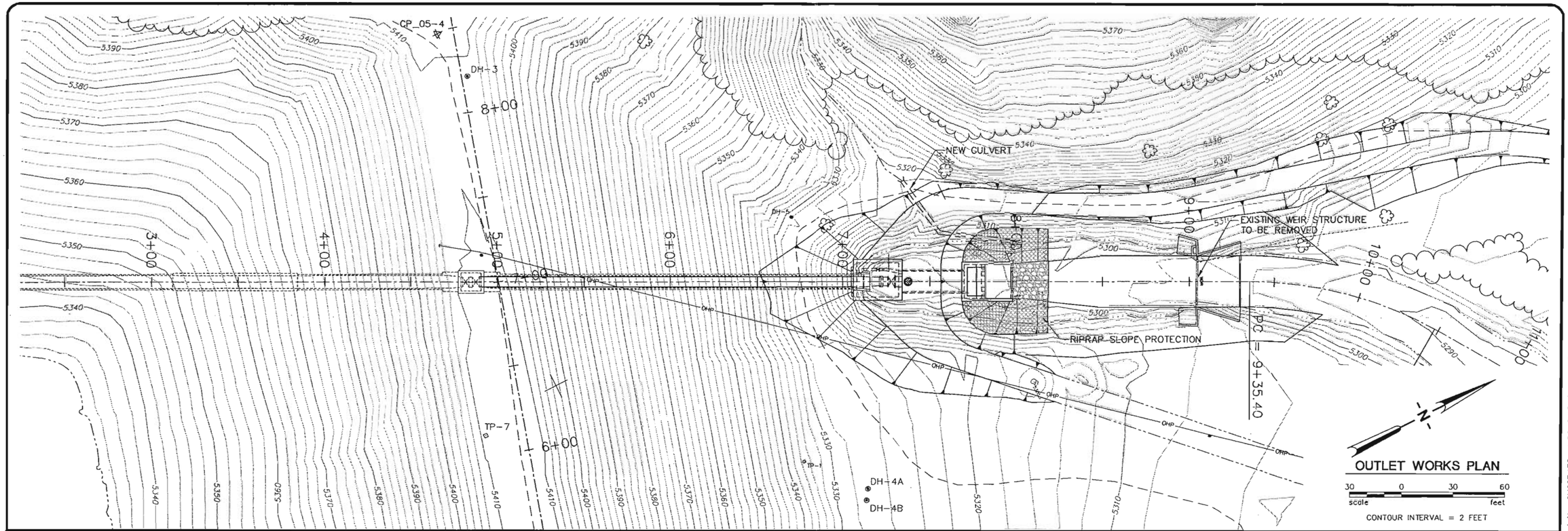
HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
PS-5
of 13

● Project No. 8M087.175 ● PO_PedTrail.dwg ● Date SEPT. 2007 ● Designed JHT ● Drawn GAE ● Checked JHT ● Approved JHT

G:\08\M087175\dwg\Prelim\PO_PedTrail.dwg 9/14/2007 10:21:33 AM MDT

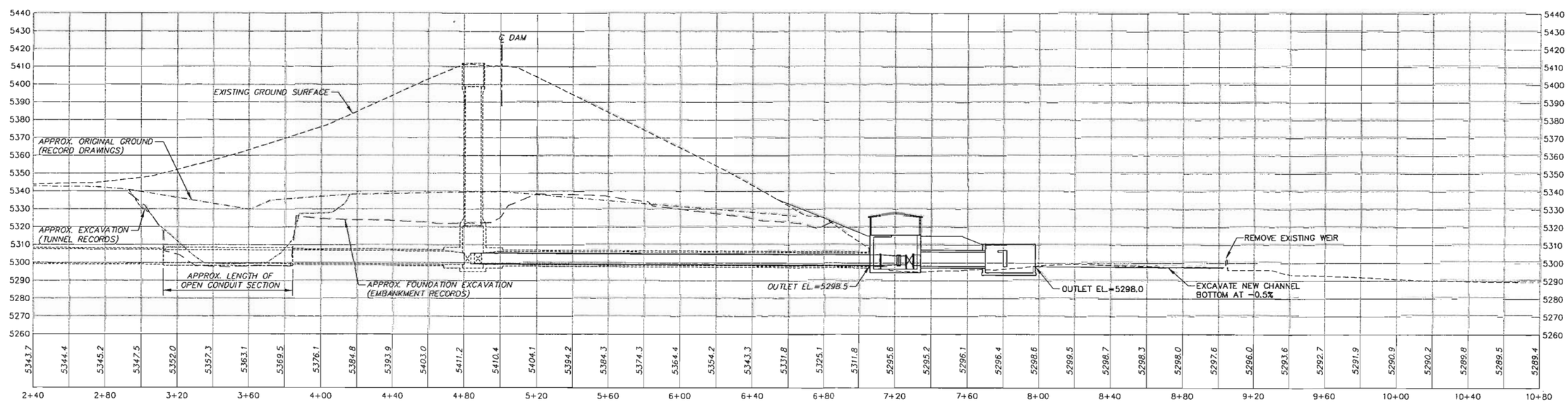
Copyright © 2007 HKM Engineering Inc., All Rights Reserved.



OUTLET WORKS PLAN

30 0 30 60
scale feet

CONTOUR INTERVAL = 2 FEET



OUTLET WORKS PROFILE

30 0 30 60
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

• Project No. BM087.175 • PO_OW.DWG • Date SEPT. 2007 • Designed JHT • Drawn GAE • Checked JHT • Approved JHT

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS PLAN AND PROFILE
PREFERRED OPTION

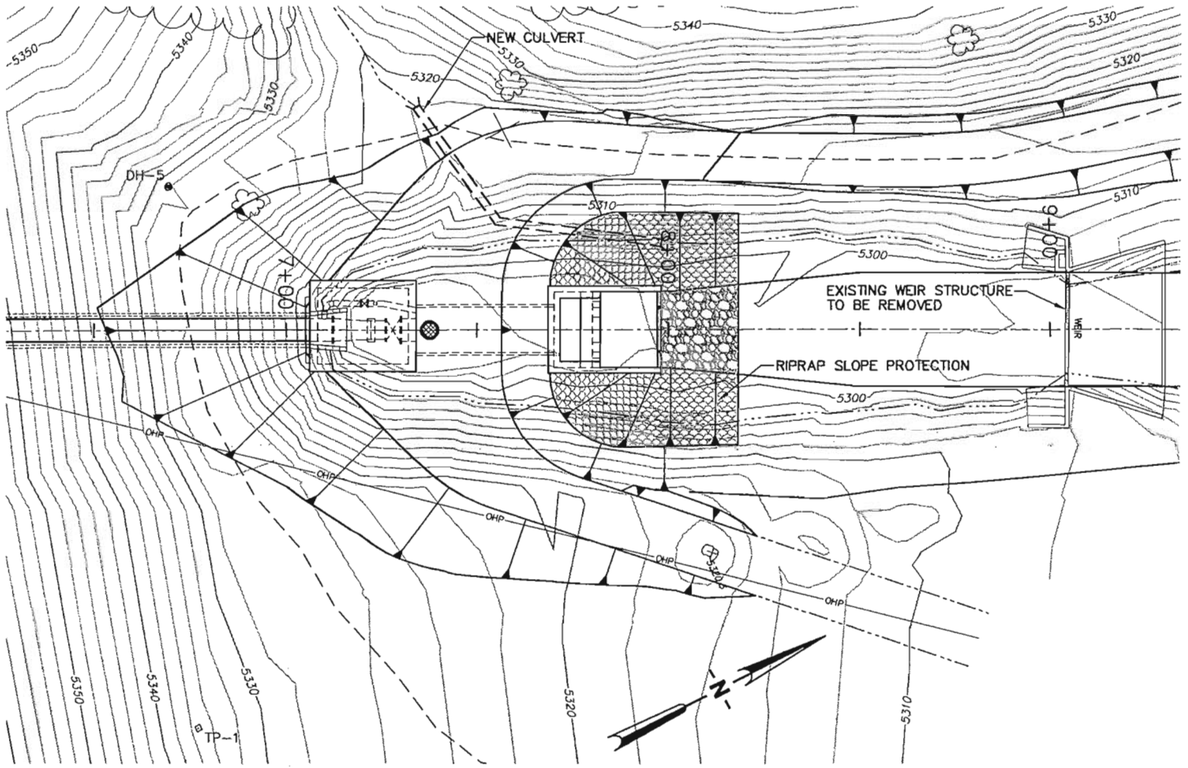
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW-1
of 13

Q:\DR\M087175\dwg\Prelim\PO_OW.DWG 9/12/2007 3:37:48 PM MDT

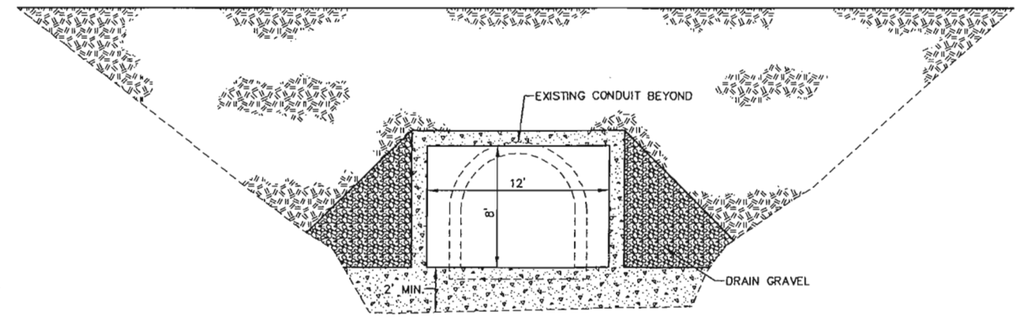
Copyright © 2007 HKM Engineering Inc., All Rights Reserved.



OUTLET WORKS EXTENSION AND STILLING BASIN PLAN

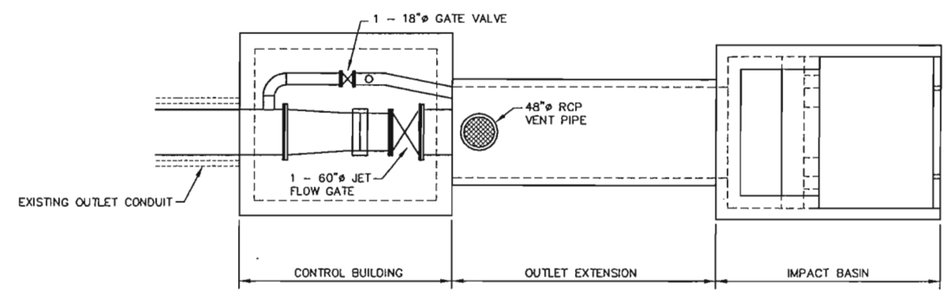
20 0 20 40
scale feet

CONTOUR INTERVAL = 2 FEET



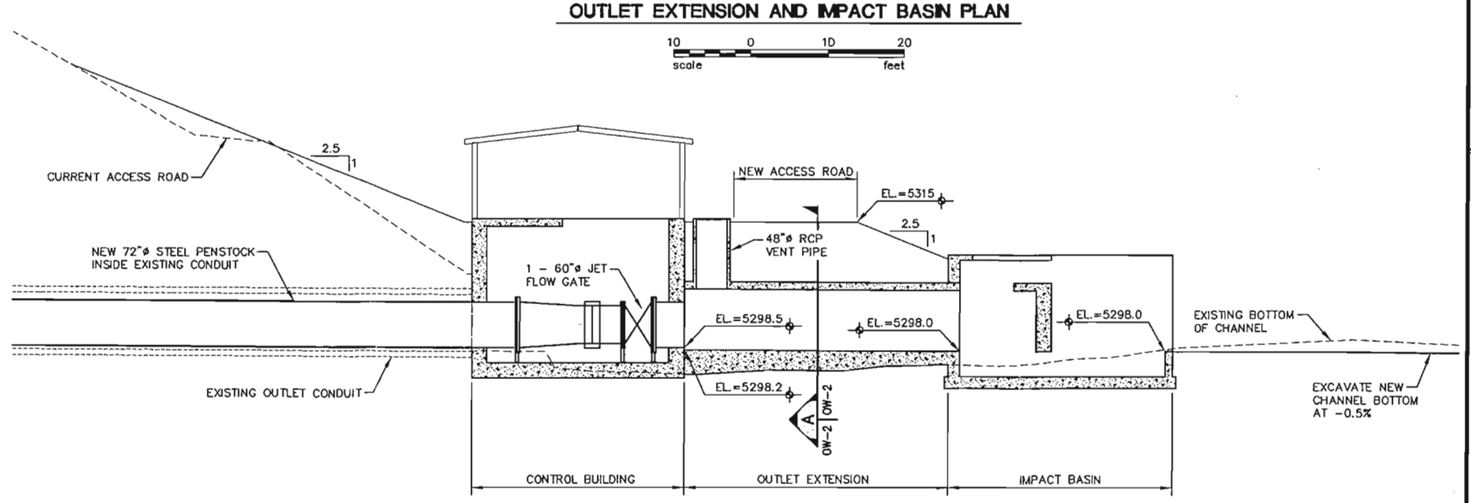
A SECTION
OW-2 | OW-2 OUTLET EXTENSION

5 0 5 10
scale feet



OUTLET EXTENSION AND IMPACT BASIN PLAN

10 0 10 20
scale feet



OUTLET EXTENSION AND IMPACT BASIN PROFILE

10 0 10 20
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS EXTENSION & CONTROL BUILDING
PREFERED OPTION

PRELIMINARY
NOT FOR CONSTRUCTION

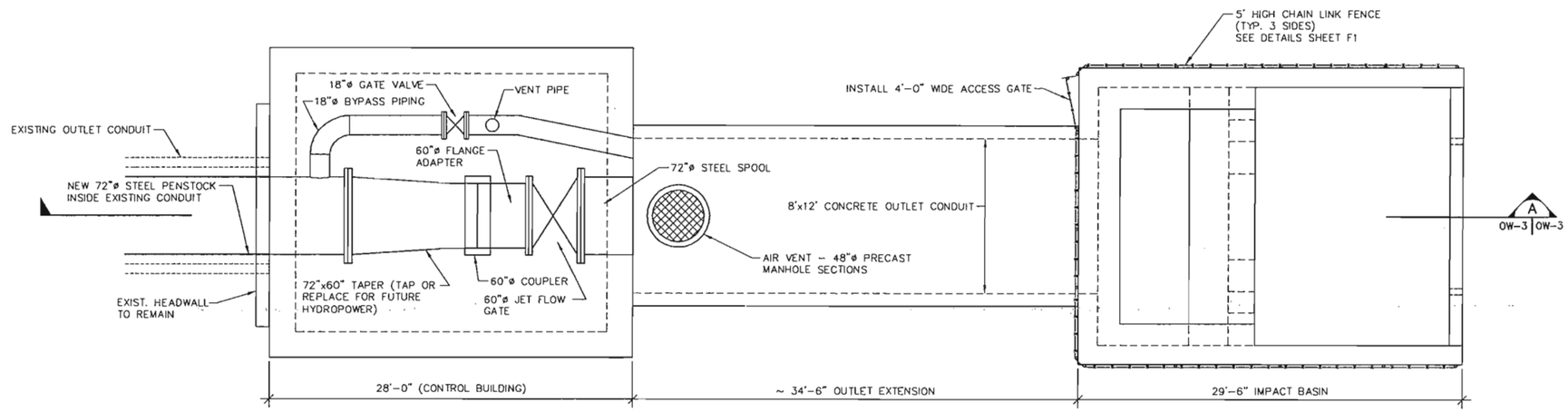
HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6388

Sheet No.
OW-2
of 13

• Project No. 8M087.175 • PO_OW.DWG • Date SEPT. 2007 • Designed JHT • Drawn GAE • Checked JHT • Approved JHT

G:\08\M087175\dwg\PrefOpt\PO_OW.DWG 9/12/2007 3:37:48 PM MDT

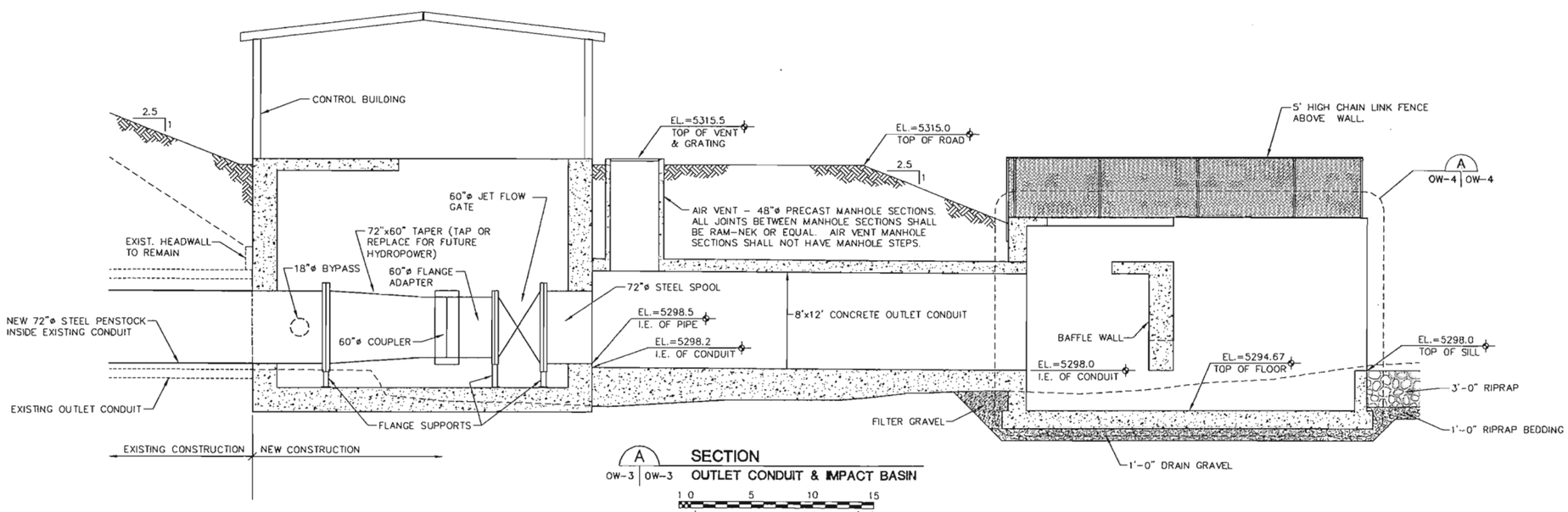
Copyright © 2007 HKM Engineering Inc., All Rights Reserved.



PLAN VIEW
OUTLET CONDUIT & IMPACT BASIN

1 0 5 10 15
scale feet

N



A SECTION
OW-3 OW-3 **OUTLET CONDUIT & IMPACT BASIN**

1 0 5 10 15
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET CONTROL BUILDING, CONDUIT & IMPACT BASIN
PREFERRED OPTION

PRELIMINARY
NOT FOR CONSTRUCTION

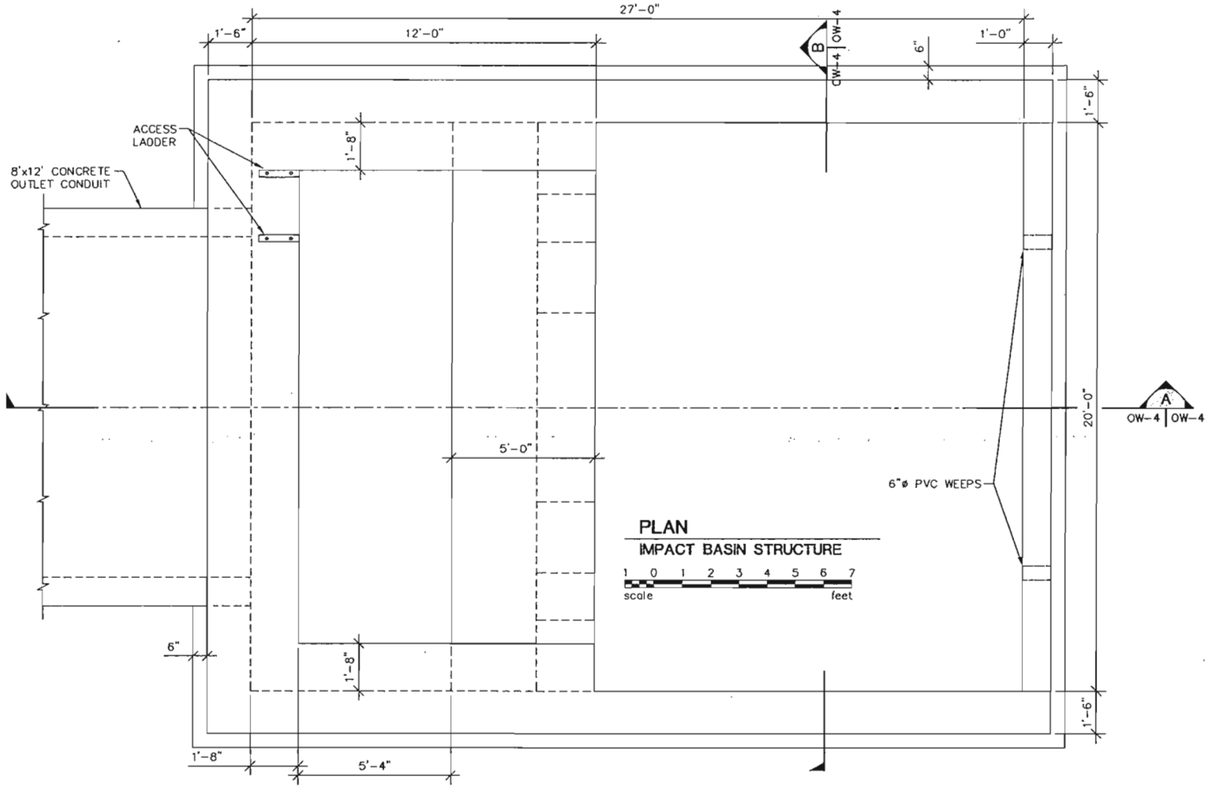
HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW-3
of 13

● Project No. 8M087.175 ● PO_OW-basin.dwg ● Date SEPT. 2007 ● Designed JHT ● Drawn GAE ● Checked JHT ● Approved JHT

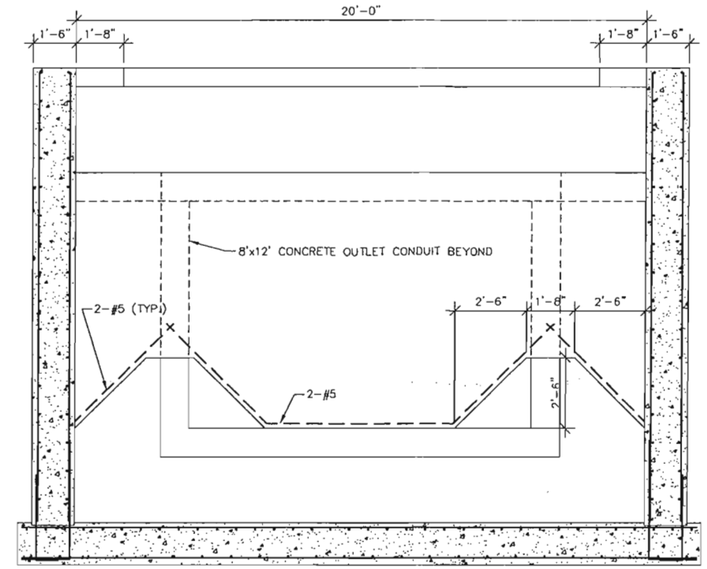
Q:\08\M087175\dwg\Prefopt\PO_OW-basin.DWG 9/12/2007 2:15:59 PM MDT

Copyright © 2007 HKM Engineering Inc., All Rights Reserved.



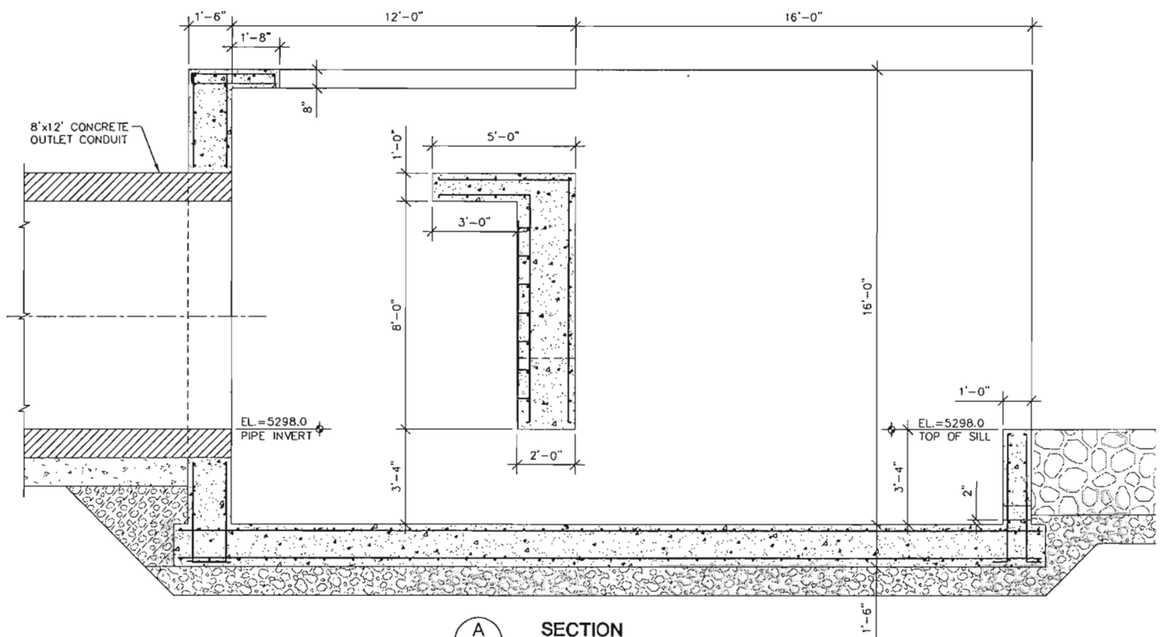
PLAN
IMPACT BASIN STRUCTURE

1 0 1 2 3 4 5 6 7
scale feet



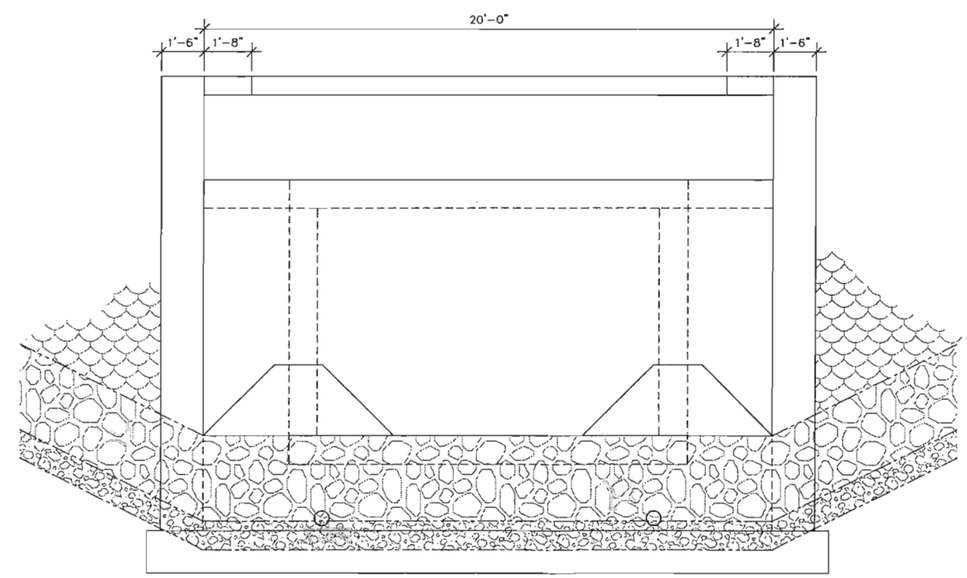
B SECTION
OW-4 | OW-4 IMPACT BASIN BAFFLE WALL

1 0 1 2 3 4 5 6 7
scale feet



A SECTION
OW-4 | OW-4 IMPACT BASIN STRUCTURE

1 0 1 2 3 4 5 6 7
scale feet



ELEVATION
IMPACT BASIN STRUCTURE

1 0 1 2 3 4 5 6 7
scale feet

PRELIMINARY
NOT FOR CONSTRUCTION

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS IMPACT BASIN
PREFERRED OPTION

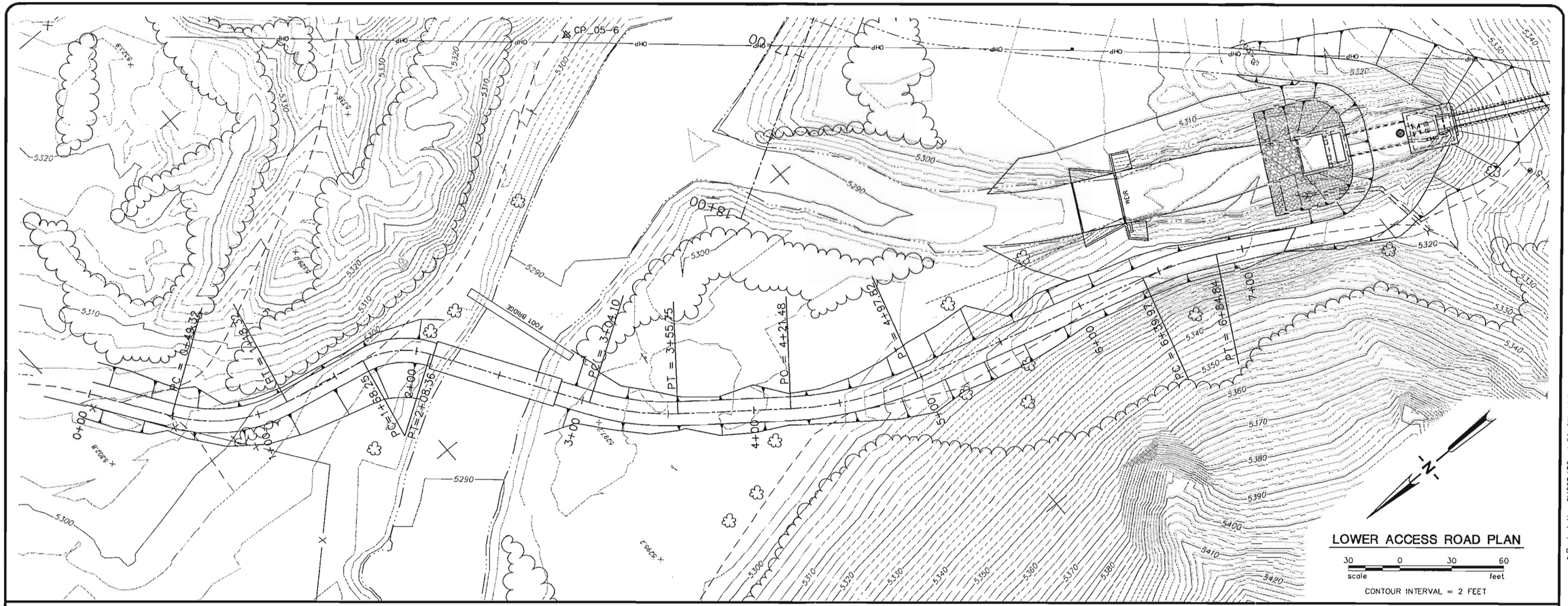
HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

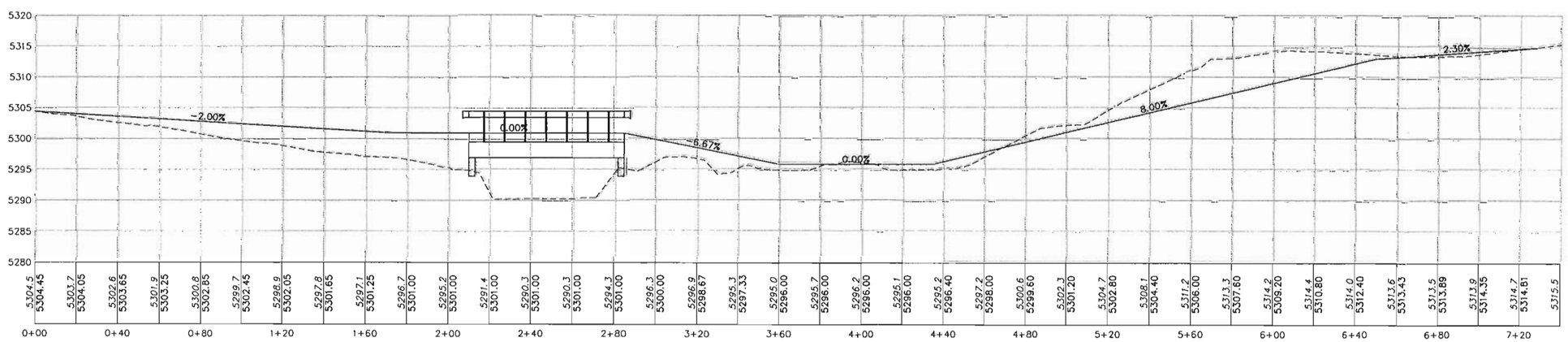
Sheet No.
OW-4
of 13

● Project No. 8M087.175 ● PO_OW-basin.dwg● Date SEPT. 2007 ● Designed JHT ● Drawn GAE ● Checked JHT ● Approved JHT

Q:\08\M087175\dwg\Prefopt\PO_OW-basin.DWG 9/12/2007 2:15:59 PM MDT

Copyright © 2007 HKM Engineering Inc., All Rights Reserved.





No.	Revision	By	Date

WARNING
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

Project No. 8M087.175 • PO_OWroad.dwg • Date SEPT. 2007 • Designed KJF • Drawn GAE • Checked JHT • Approved JHT

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

LOWER ACCESS ROAD PREFERRED OPTION

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW-5
of 13

Q:\08\W08775\dwg\PrelOpt\OW5a-4.dwg 9/29/2008 11:02:47 AM MST

Copyright © 2007 HKM Engineering Inc., All Rights Reserved.

APPENDIX B

HYDRAULIC COMPUTATIONS

APPENDIX B1
LABYRINTH CREST

LABYRINTH WEIR DESIGN
No Approach Velocity

PROJECT:	Ruby Dam	TIME:	17:26:17
PROJECT NO.	08M087.175	DATE:	15-Aug-07
FLOOD CRITERIA:	20,000 cfs	BY:	BSJ

USER INPUT

Max. Res	Zr	5409.9 ft	Thickness			
Crest el.	Zc	5400.0 ft	Wall	Tw	1.33	ft
Floor el.	Zf	5389.0 ft	Slab	Ts	1.33	ft
Spillway width	Ws	100.0 ft	Cutoff Depth			
Apex Width	2a	4 ft	Sheet Pile	Ds	0	ft
No. of cycles	n	2	Conc Wall	Dc	3	ft
Magnification	L/W	2.5				

CHECK ON RATIOS

Ldc/B =	0.35	Ld/B RATIO IS OK
H_o/P =	0.90	Ho/P RATIO IS OK
α =	21.04	Angle IS OK

Note: L_{dc}/B must be <= 0.35
Ho/P must be <= 0.9
α must be >= 6 deg

LABYRINTH DIMENSIONS (Per Cycle)

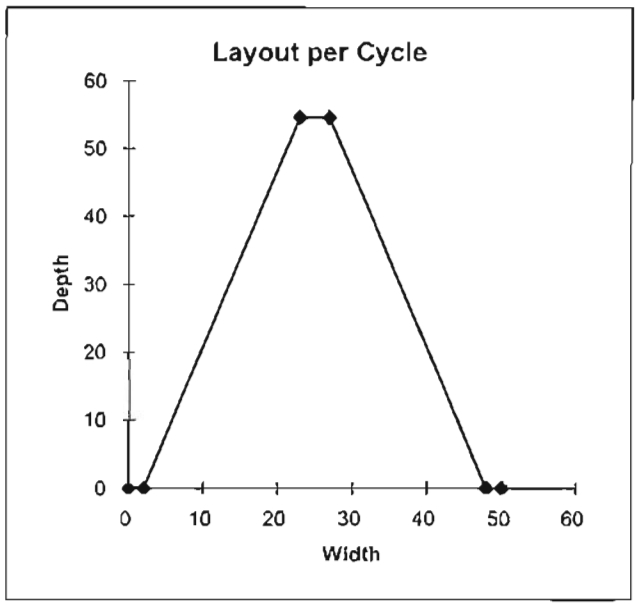
Wall Height	P	11	ft
Width	W	50.00	ft
Length	L	125.00	ft
Wall Length	B	58.50	ft
Depth	D	54.60	ft
Head max	H	9.90	ft
Wall Angle	α	21.04	deg
Length of Interference	L_{dc}	20.29	

CREST LAYOUT
(One Cycle)

X	Y
0	0
2.00	0
23.00	54.60
27.00	54.60
48.00	0
50.00	0

COST CALCULATION

	Unit price $/unit	Units	Cost $
Weir wall, cy	350	135	47,412
Abutment walls, cy	350	139	48,707
Slab, cy	225	366	82,461
Concrete cutoff, cy	200	108	21,570
Sheet pile, sf	20	0	0
Reinforcement, lb	0.65	104,856	68,156



ESTIMATED COST
$268,307

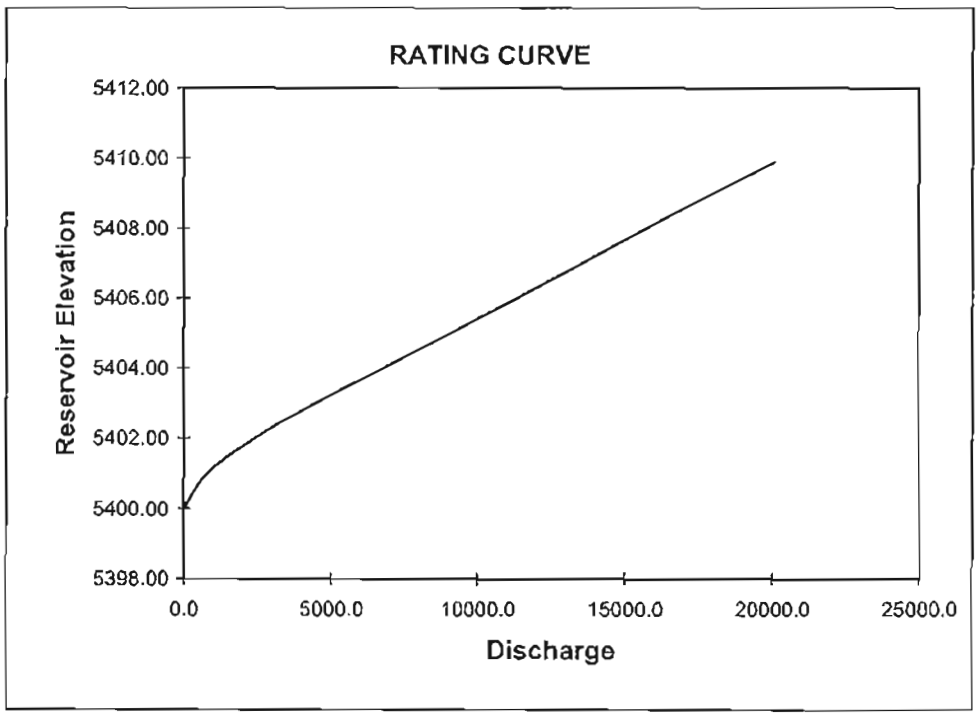
DISCHARGE
Qmax 20,062 cfs

COEFFICIENTS

Column	5.00
Cd lower	0.44
Cd Upper	0.54
Cd	0.48
Efficacy	1.54

RATING CURVE

HEAD	H_o/P	C_{lower}	C_{upper}	C_d	Q	RES
9.90	0.90	0.44	0.54	0.48	20062	5409.90
8.91	0.81	0.46	0.56	0.50	17774	5408.91
7.92	0.72	0.48	0.58	0.52	15566	5407.92
6.93	0.63	0.51	0.61	0.55	13409	5406.93
5.94	0.54	0.54	0.63	0.58	11236	5405.94
4.95	0.45	0.57	0.66	0.61	8997	5404.95
3.96	0.36	0.60	0.68	0.64	6697	5403.96
2.97	0.27	0.62	0.68	0.65	4425	5402.97
1.98	0.18	0.62	0.66	0.63	2363	5401.98
0.99	0.09	0.58	0.60	0.59	773	5400.99
0.00	0.00	0.49	0.49	0.49	0	5400.00

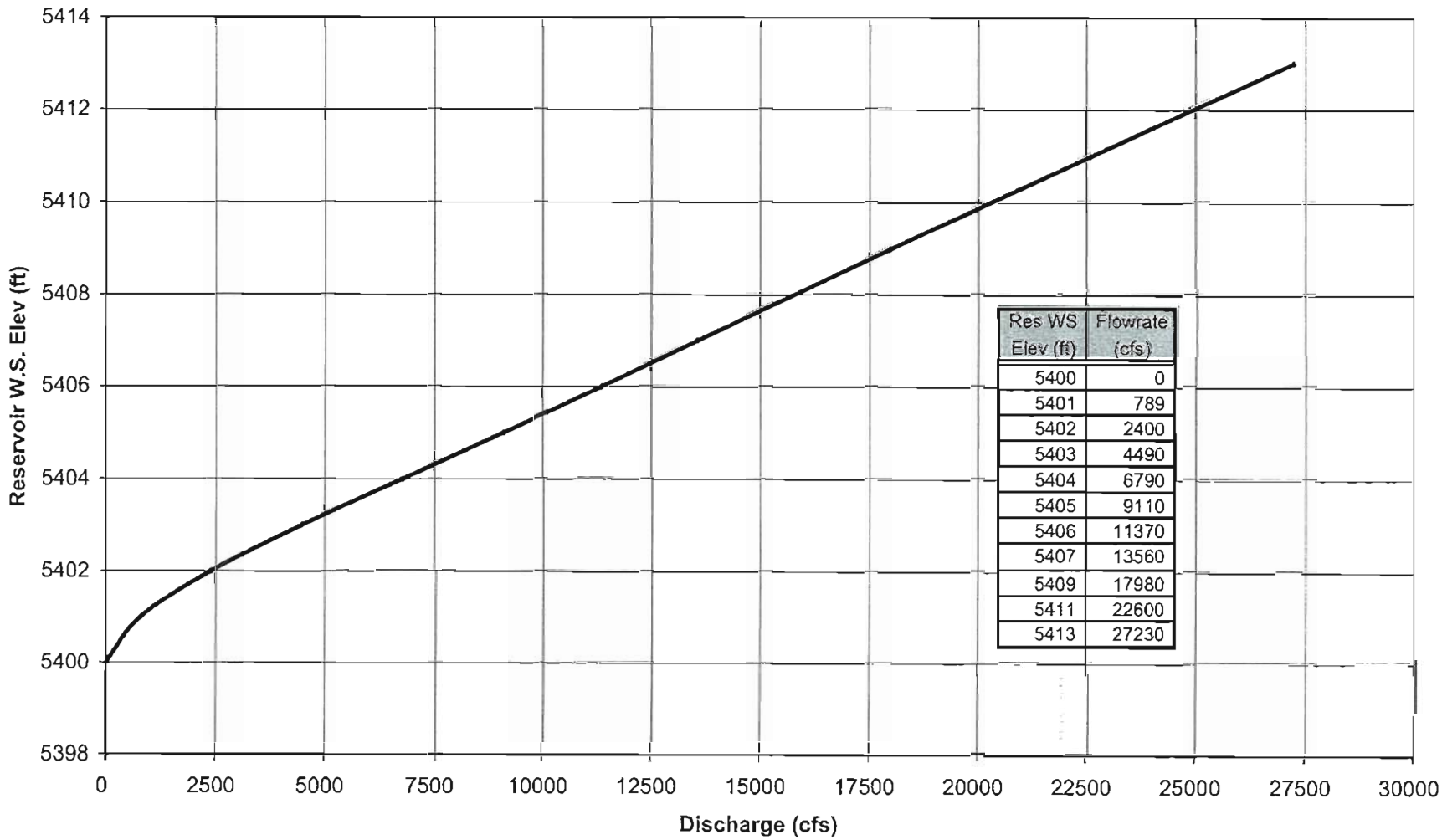


Discharge Coefficient Table Tullis et al. (1995)

Angle wall makes with centerline α

	6	8	12	15	18	25	35	90
A0	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
A1	-0.24	1.08	1.06	1.00	1.32	1.51	1.69	1.46
A2	-1.20	-5.27	-4.43	-3.57	-4.13	-3.83	-4.05	-2.56
A3	2.17	6.79	5.18	3.82	4.24	3.40	3.62	1.44
A4	-1.03	-2.83	-1.97	-1.38	-1.50	-1.05	-1.10	

Ruby Dam Feasibility Study
Preferred Spillway Alternative
100' Labyrinth Rating Curve



Res WS Elev (ft)	Flowrate (cfs)
5400	0
5401	789
5402	2400
5403	4490
5404	6790
5405	9110
5406	11370
5407	13560
5409	17980
5411	22600
5413	27230

APPENDIX B2

SPILLWAY CHUTE

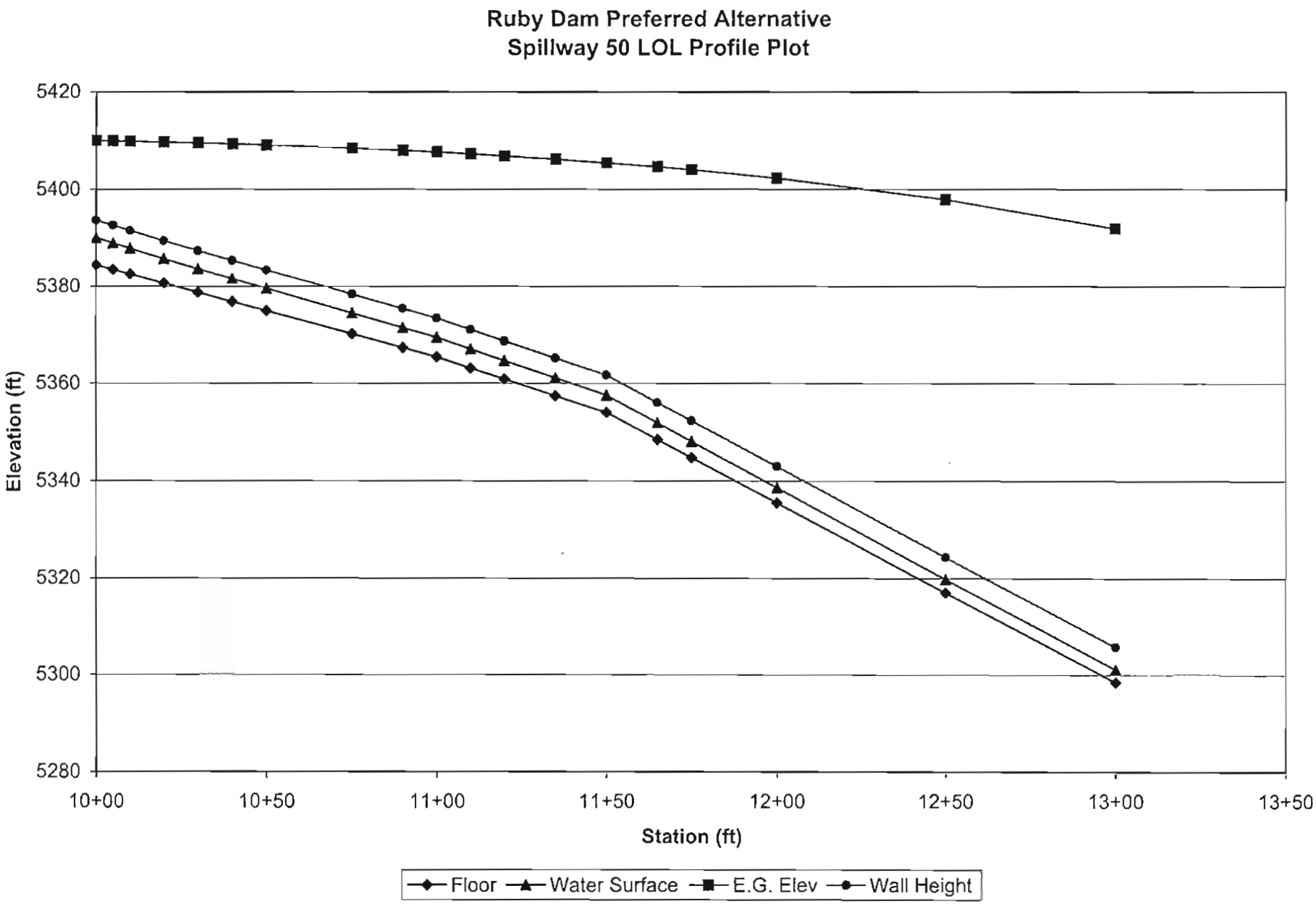
Ruby Dam Labyrinth Crest Spillway Hydraulics at Q = 20,000 cfs (50 LOL)

Design Discharge

Discharge	20000	cfs
Res Elev	5410.00	ft
Spwy Crest	5400.00	ft
Crest Width	100.0	ft
n	0.014	
P	11.0	ft
P/H	1.10	
Initial Slope	0.19000	ft/ft

5344.75

Sta	Elev	Slope	Width	Y	WS Elev	Wall Frbrd	Wall Height	V	H_v	R_h	S_f	EGL	EGL-Z-Y-Hv	Froude#	Y_c	β	L_1
9+90.00	5384.50		100.00	10.75	5395.25	3.03	13.78	18.60	5.37	8.85		5410.00	9.37526	1.00	10.75	1.570796	0.00
		0.00									0.00168						
10+00.00	5384.50		100.00	5.59	5390.09	3.59	9.18	35.80	19.90	5.03		5409.98	0.00000	2.67	10.75	0.384094	123.71
		-0.19									0.01321						
10+05.00	5383.55		100.00	5.45	5389.00	3.61	9.06	36.70	20.92	4.91		5409.92	0.00000	2.77	10.75	0.369234	129.21
		-0.19									0.01431						
10+10.00	5382.60		100.00	5.32	5387.92	3.64	8.96	37.57	21.92	4.81		5409.85	0.00000	2.87	10.75	0.355888	134.51
		-0.19									0.01543						
10+20.00	5380.70		100.00	5.10	5385.80	3.69	8.79	39.23	23.89	4.63		5409.69	0.00000	3.06	10.75	0.332755	144.67
		-0.19									0.01771						
10+30.00	5378.80		100.00	4.91	5383.71	3.73	8.64	40.77	25.81	4.47		5409.51	0.00000	3.24	10.75	0.313394	154.29
		-0.19									0.02005						
10+40.00	5376.90		100.00	4.74	5381.64	3.77	8.51	42.22	27.68	4.33		5409.31	0.00000	3.42	10.75	0.296891	163.43
		-0.19									0.02243						
10+50.00	5375.00		100.00	4.59	5379.59	3.81	8.40	43.59	29.50	4.20		5409.09	0.00000	3.59	10.75	0.282618	172.18
		-0.19									0.02486						
10+75.00	5370.25		100.00	4.28	5374.53	3.90	8.18	46.75	33.94	3.94		5408.47	0.00000	3.98	10.75	0.253757	192.79
		-0.19									0.03117						
10+90.00	5367.40		100.00	4.13	5371.53	3.94	8.07	48.47	36.47	3.81		5408.00	0.00000	4.20	10.75	0.240147	204.19
		-0.19									0.03501						
11+00.00	5365.50		100.00	4.04	5369.54	3.97	8.01	49.54	38.11	3.74		5407.65	0.00000	4.35	10.75	0.232211	211.44
		-0.23									0.03759						
11+10.00	5363.20		100.00	3.93	5367.13	4.01	7.94	50.84	40.14	3.65		5407.27	0.00000	4.52	10.75	0.223205	220.28
		-0.23									0.04088						
11+20.00	5360.90		100.00	3.84	5364.74	4.04	7.88	52.09	42.13	3.57		5406.87	0.00000	4.68	10.75	0.215142	228.81
		-0.23									0.04420						
11+35.00	5357.45		100.00	3.71	5361.16	4.09	7.80	53.86	45.04	3.46		5406.20	0.00000	4.93	10.75	0.204465	241.12
		-0.23									0.04926						
11+50.00	5354.00		100.00	3.60	5357.60	4.13	7.73	55.52	47.86	3.36		5405.46	0.00000	5.15	10.75	0.195233	252.84
		-0.37									0.05436						
11+65.00	5348.45		100.00	3.43	5351.88	4.20	7.63	58.29	52.77	3.21		5404.65	0.00000	5.55	10.75	0.181295	272.77
		-0.37									0.06368						
11+75.00	5344.75		100.00	3.33	5348.08	4.24	7.57	60.02	55.93	3.12		5404.01	0.00000	5.79	10.75	0.173473	285.33
		-0.37									0.07000						
12+00.00	5335.50		100.00	3.12	5338.62	4.34	7.46	64.02	63.64	2.94		5402.26	0.00000	6.38	10.75	0.157321	315.19
		-0.37									0.08535						
12+50.00	5317.00		100.00	2.82	5319.82	4.51	7.32	70.93	78.12	2.67		5397.94	0.00000	7.44	10.75	0.134742	368.83
		-0.37									0.12061						
13+00.00	5298.50		100.00	2.62	5301.12	4.63	7.25	76.47	90.80	2.49		5391.91	0.00000	8.33	10.75	0.120301	413.62
		-0.37									0.15416						
13+25.00	5289.25		100.00	2.54	5291.79	4.69	7.23	78.74	96.27	2.42		5388.06	0.00000	8.71	10.75	0.115113	432.44
		-0.37									0.16953						
13+33.70	5286.00		100.00	2.52	5288.52	4.70	7.22	79.47	98.07	2.40		5386.58	0.00000	8.83	10.75	0.113519	438.56


Ruby Dam Preferred Alternative
Spillway 50 LOL Profile Plot
5420
5400
5380
5360
5340
5320
5300
5280
Elevation (ft)
10+00
10+50
11+00
11+50
12+00
12+50
13+00
13+50
Station (ft)
Floor
Water Surface
E.G. Elev
Wall Height

Ruby Dam Labyrinth Crest Spillway Hydraulics at Q = 4,000 cfs (Routed 500-yr)

Design Discharge		
Discharge	4000	cfs
Res Elev	5402.80	ft
Spwy Crest	5400.00	ft
Crest Width	100.0	ft
n	0.014	
P	11.0	ft
P/H	3.93	
Initial Slope	0.19000	ft/ft

Sta	Elev	Slope	Width	Y	WS Elev	Wall Frbrd	Wall Height	V	H_v	R_h	S_f	EGL	EGL-Z-Y-Hv	Froude#	Y_c	β	L_1
9+90.00	5384.50		100.00	3.68	5388.18	2.42	6.10	10.87	1.83	3.43		5402.80	12.78541	1.00	3.68	1.570795	0.00
		0.000									0.00203						
10+00.00	5384.50		100.00	1.21	5385.71	2.88	4.09	33.16	17.07	1.18		5402.78	0.00000	5.32	3.68	0.189079	261.28
		-0.190									0.07845						
10+05.00	5383.55		100.00	1.19	5384.74	2.89	4.08	33.72	17.65	1.16		5402.39	0.00000	5.45	3.68	0.184355	268.12
		-0.190									0.08289						
10+10.00	5382.60		100.00	1.17	5383.77	2.90	4.07	34.24	18.20	1.14		5401.97	0.00000	5.58	3.68	0.180096	274.62
		-0.190									0.08722						
10+20.00	5380.70		100.00	1.14	5381.84	2.92	4.05	35.22	19.27	1.11		5401.10	0.00000	5.82	3.68	0.172532	285.92
		-0.190									0.09577						
10+30.00	5378.80		100.00	1.11	5379.91	2.93	4.04	36.10	20.23	1.08		5400.14	0.00000	6.04	3.68	0.166233	293.01
		-0.190									0.10387						
10+40.00	5376.90		100.00	1.08	5377.98	2.95	4.03	36.88	21.12	1.06		5399.10	0.00000	6.24	3.68	0.160936	308.00
		-0.190									0.11148						
10+50.00	5375.00		100.00	1.06	5376.06	2.96	4.02	37.58	21.93	1.04		5397.99	0.00000	6.42	3.68	0.156445	316.99
		-0.190									0.11859						
10+75.00	5370.25		100.00	1.02	5371.27	2.99	4.01	39.11	23.75	1.00		5395.02	0.00000	6.82	3.68	0.147261	337.08
		-0.190									0.13537						
10+90.00	5367.40		100.00	1.01	5368.41	3.00	4.00	39.79	24.59	0.99		5392.99	0.00000	6.99	3.68	0.143459	346.14
		-0.19									0.14334						
11+00.00	5365.50		100.00	1.00	5366.50	3.00	4.00	40.18	25.07	0.98		5391.56	0.00000	7.10	3.68	0.141396	351.26
		-0.23									0.14796						
11+10.00	5363.20		100.00	0.98	5364.18	3.01	3.99	40.84	25.90	0.96		5390.08	0.00000	7.27	3.68	0.137935	360.19
		-0.23									0.15622						
11+20.00	5360.90		100.00	0.97	5361.87	3.02	3.99	41.43	26.65	0.95		5388.52	0.00000	7.43	3.68	0.134986	368.15
		-0.23									0.16379						
11+35.00	5357.45		100.00	0.95	5358.40	3.04	3.98	42.21	27.66	0.93		5386.06	0.00000	7.64	3.68	0.13125	378.76
		-0.23									0.17419						
11+50.00	5354.00		100.00	0.93	5354.93	3.05	3.98	42.85	28.52	0.92		5383.45	0.00000	7.82	3.68	0.128283	387.62
		-0.37									0.18315						
11+65.00	5348.45		100.00	0.89	5349.34	3.08	3.97	44.94	31.36	0.87		5380.70	0.00000	8.39	3.68	0.119405	416.75
		-0.37									0.21437						
11+75.00	5344.75		100.00	0.87	5345.62	3.10	3.97	46.06	32.94	0.85		5378.56	0.00000	8.71	3.68	0.11507	432.60
		-0.37									0.23252						
12+00.00	5335.50		100.00	0.83	5336.33	3.14	3.96	48.43	36.42	0.81		5372.75	0.00000	9.39	3.68	0.106688	466.87
		-0.37									0.27457						
12+50.00	5317.00		100.00	0.78	5317.78	3.18	3.96	51.54	41.24	0.76		5359.02	0.00000	10.31	3.68	0.097159	513.00
		-0.37									0.33735						
13+00.00	5298.50		100.00	0.76	5299.26	3.20	3.96	52.55	42.89	0.75		5342.15	0.00000	10.62	3.68	0.094337	528.44
		-0.37									0.35997						
13+25.00	5289.25		100.00	0.76	5290.01	3.20	3.96	52.71	43.14	0.75		5333.15	0.00000	10.66	3.68	0.093921	530.80
		-0.37									0.36349						
13+33.70	5286.00		100.00	0.76	5286.76	3.20	3.96	52.76	43.23	0.75		5329.99	0.00000	10.68	3.68	0.093776	531.62

APPENDIX C

RESERVOIR IMPACTS

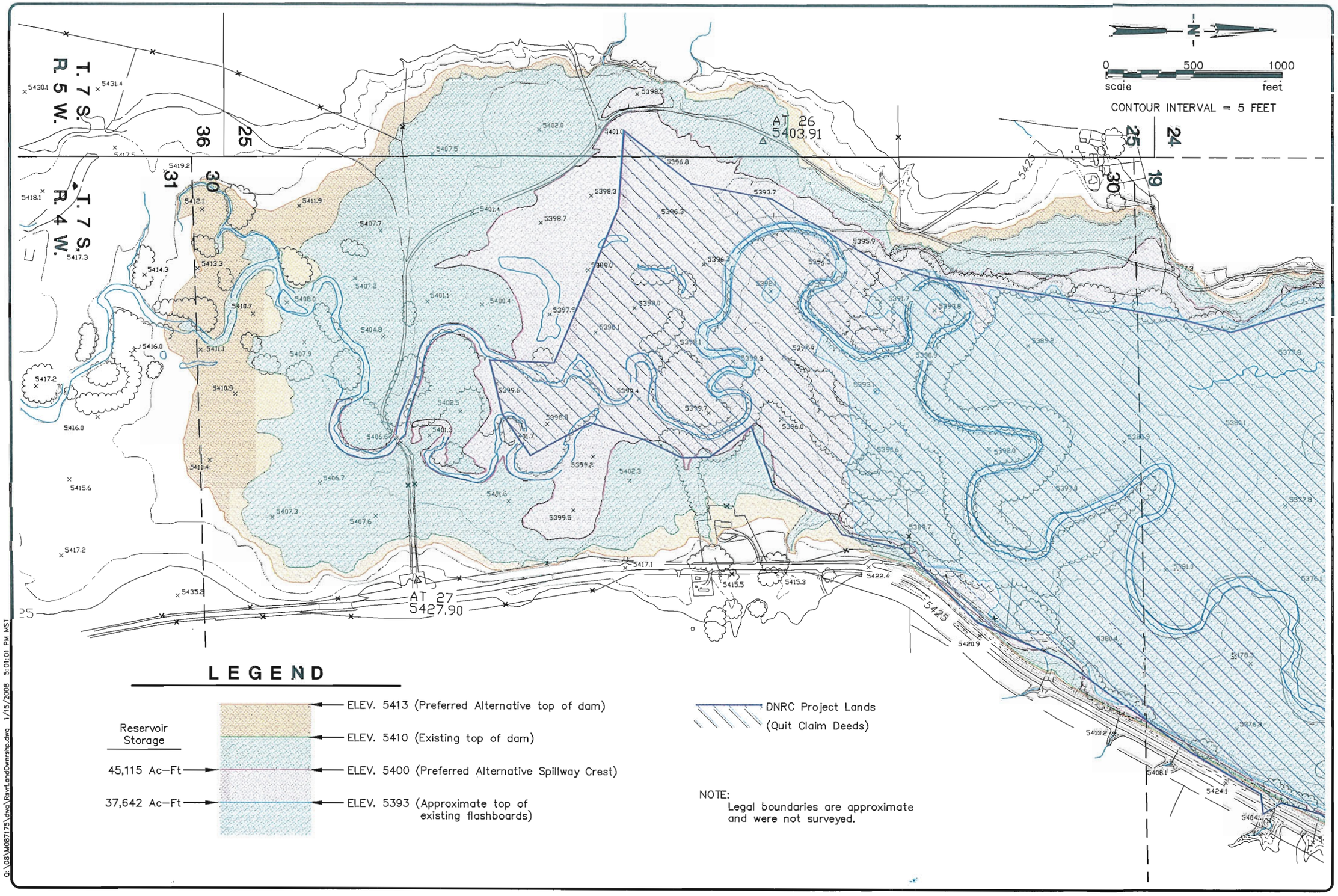


FIGURE RI-2

HKM ENGINEERING

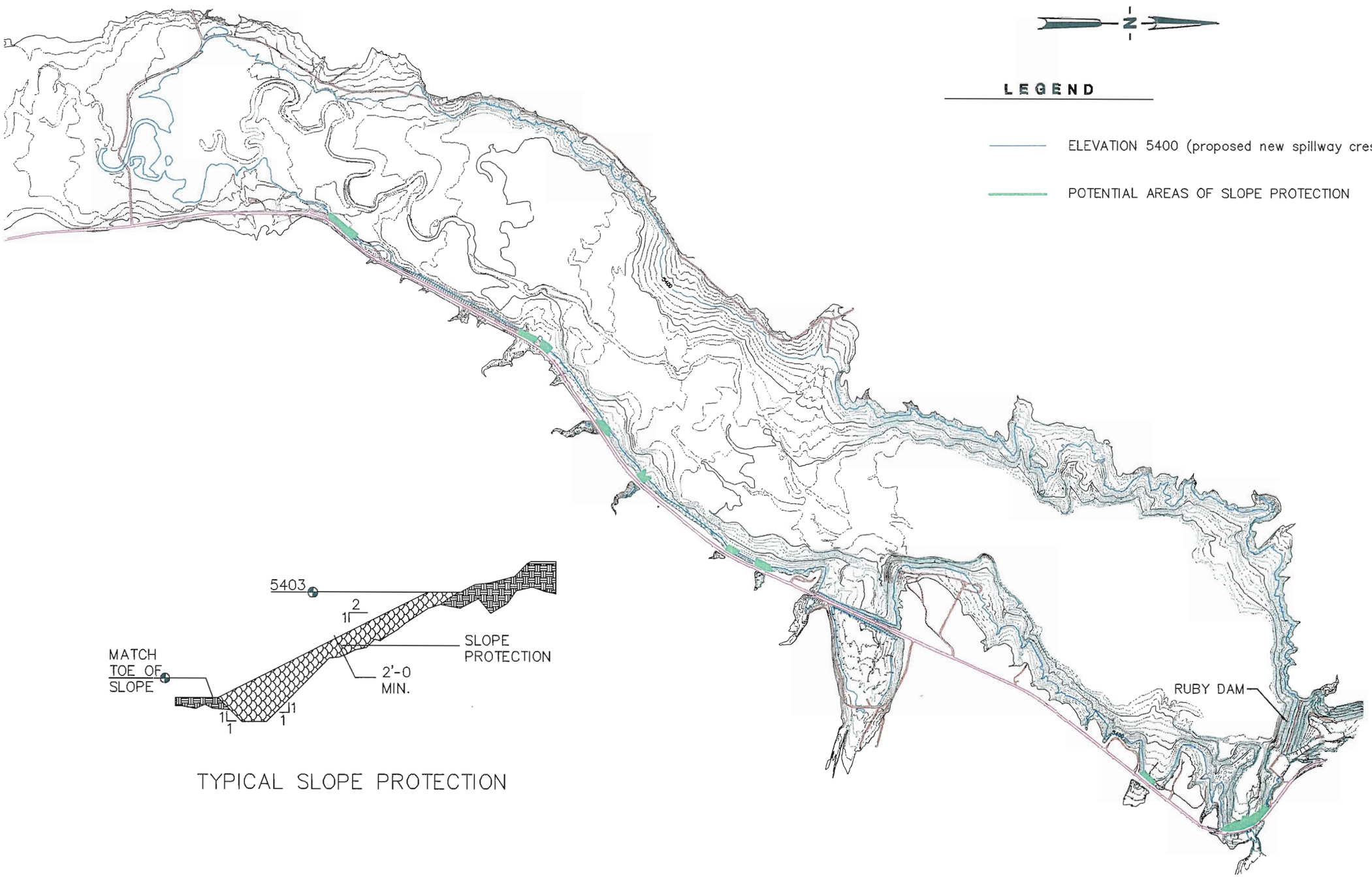
8M087.175

JAN. 2008

RUBY DAM REHABILITATION FEASIBILITY STUDY

UPPER RESERVOIR AREA - LAND OWNERSHIP

Q:\08\M087175\dwg\RsvrLandOwnership.dwg 1/15/2008 5:01:01 PM MST



TYPICAL SLOPE PROTECTION

FIGURE RI-3

HKM ENGINEERING

8M087.175 JAN. 2008

RUBY DAM REHABILITATION FEASIBILITY STUDY

AREAS OF RESERVOIR IMPACT TO ROADS

Q:\08\M087175\dwg\Rsvr_Impacts.dwg 1/15/2008 4:35:46 PM MST

APPENDIX D

COST ESTIMATE

RUBY DAM REHABILITATION FEASIBILITY
HKM - 8M087.175
Preferred Rehabilitation Alternative
Cost Estimate

Preferred Alternative - 100' Labyrinth Crest at elev 5400.0 ft; Dam Crest at elev 5413.0 ft; 100' Straight Chute; 100'x50' Combination Stilling Basin-Flip Bucket, new Jet Flow Gate outlet works

Spillway Crest Width =	100	
Spillway Crest Elevation =	5400.0	
Reservoir Storage =	45,115	
Chute Width =	100	
Max Res. W.S. =	5409.9	
Dam Crest Elevation =	5413.0	
Design Capacity =	20,000	
Dam Overtopping Flow =	27,230	
Stilling Basin Length =	50	
Stilling Basin Width =	100	
Stilling Basin Design Flow =	4,000	(500-yr Outflow)

Material Costs			
Floor Concrete	$	800.00	/CY
Wall Concrete	$	1,000.00	/CY
Clay Blanket	$	15.00	/CY
Labyrinth Wall Concrete	$	1,000.00	/CY
Labyrinth Crest Plate	$	105.00	/LF
Rock Anchors	$	575.00	/EA
Excavation	$	12.00	/CY
Rock Fill/Riprap	$	55.00	/CY
Drain/Filter Gravel/Beddi	$	60.00	/CY
Structural Backfill	$	10.00	/CY
Concrete Demo	$	35.00	/CY
6" Drain Pipe	$	15.00	/LF
12" Drain Pipe	$	35.00	/LF
Gabion Fill	$	160.00	/CY
General Fill	$	10.00	/CY
Impervious/Semipervious	$	10.00	/CY

Dam Crest Raise			Unit Cost	Total Material Cost
Riprap Excavation	1742	CY	$ 12.00	$ 20,904.00
Embankment Excavation	5000	CY	$ 12.00	$ 60,000.00
Gabion Fill	840	CY	$ 160.00	$ 134,400.00
Impervious / Semi pervious Fill	8300	CY	$ 10.00	$ 83,000.00
Riprap Fill	809	CY	$ 55.00	$ 44,495.00
Gate House / Extension	1	LS	$ 43,000.00	$ 43,000.00
		Total Cost		$ 385,799

Dam Crest Access			Unit Cost	Total Material Cost
Excavation	4448	CY	$ 12.00	$ 53,376.00
General Fill	350	CY	$ 10.00	$ 3,500.00
Pedestrian Bridge	1	LS	$ 79,560.00	$ 79,560.00
		Total Cost		$ 136,436

Spillway Approach			Unit Cost	Total Material Cost
Approach Excavation	9600	CY	$ 12.00	$ 115,200.00
Clay Blanket	803	CY	$ 15.00	$ 12,045.00
Access Road Excavation	700	CY	$ 12.00	$ 8,400.00
Access Road Backfill	1900	CY	$ 10.00	$ 19,000.00
		Total Cost		$ 154,645

Preferred Alternative - 100' Labyrinth Crest at elev 5400.0 ft; Dam Crest at elev 5413.0 ft; 100' Straight Chute; 100'x50' Combination Stilling Basin-Flip Bucket, new Jet Flow Gate outlet works

Spillway Crest STA 9+35 TO 9+90			Unit Cost	Total Material Cost
Concrete Demo	463	CY	$ 35.00	$ 16,205.00
Excavation	1966	CY	$ 12.00	$ 23,592.00
Rock Anchors	85	EA	$ 575.00	$ 48,875.00
Drain Gravel	108	CY	$ 60.00	$ 6,480.00
Floor Concrete	418	CY	$ 800.00	$ 334,400.00
Wall Concrete	365	CY	$ 1,000.00	$ 365,000.00
Labyrinth Wall Concrete	225	CY	$ 1,000.00	$ 225,000.00
Labyrinth Crest Plate	250	FT	$ 105.00	$ 26,250.00
Structural Backfill	2386	CY	$ 10.00	$ 23,860.00
		Total Cost		$ 1,069,662

Spillway Chute STA 9+90 TO 13+34			Unit Cost	Total Material Cost
Concrete Demo	1035	CY	$ 35.00	$ 36,225.00
Excavation	8377	CY	$ 12.00	$ 100,524.00
Rock Anchors	256	EA	$ 575.00	$ 147,200.00
Drain Gravel	621	CY	$ 60.00	$ 37,260.00
6" Drain Pipe	1200	LF	$ 15.00	$ 18,000.00
12" Drain Pipe	330	LF	$ 35.00	$ 11,550.00
Floor Concrete	1777	CY	$ 800.00	$ 1,421,600.00
Wall Concrete	466	CY	$ 1,000.00	$ 466,000.00
Structural Backfill	989	CY	$ 10.00	$ 9,890.00
		Total Cost		$ 2,248,249

Stilling Basin STA 13+34 TO 13+84			Unit Cost	Total Material Cost
Concrete Demo	136	CY	$ 35.00	$ 4,760.00
Excavation	2470	CY	$ 12.00	$ 29,640.00
Rock Anchors	36	EA	$ 575.00	$ 20,700.00
Drain Gravel	95	CY	$ 60.00	$ 5,700.00
Floor Concrete	676	CY	$ 800.00	$ 540,800.00
Wall Concrete	194	CY	$ 1,000.00	$ 194,000.00
Structural Backfill	1760	CY	$ 10.00	$ 17,600.00
Downstream Channel Riprap	260	CY	$ 55.00	$ 14,300.00
		Total Cost		$ 827,500

Preferred Alternative - 100' Labyrinth Crest at elev 5400.0 ft; Dam Crest at elev 5413.0 ft; 100' Straight Chute; 100'x50' Combination Stilling Basin-Flip Bucket, new Jet Flow Gate outlet works

Outlet Works Modifications Option OW4		Unit Cost	Total Material Cost
Demo for Penstock	1 LS	$ 36,750.00	$ 36,750.00
Excavation	350 CY	$ 12.00	$ 4,200.00
Drain/Filter Gravel/Bedding	215 CY	$ 60.00	$ 12,900.00
72" Penstock and Installation	1 LS	$ 282,150.00	$ 282,150.00
18" Bypass Piping	1 LS	$ 3,600.00	$ 3,600.00
60" Jet Flow Gate	1 LS	$ 265,000.00	$ 265,000.00
18" Gate Valve	1 LS	$ 6,000.00	$ 6,000.00
Gate Install (10% Gate Costs)	1 LS	$ 27,100.00	$ 27,100.00
Floor Concrete	152 CY	$ 800.00	$ 121,600.00
Wall Concrete	279 CY	$ 1,000.00	$ 279,000.00
Gate House	672 SF	$ 100.00	$ 67,200.00
Electrical Service	1 LS	$ 10,000.00	$ 10,000.00
Structural Backfill	850 CY	$ 10.00	$ 8,500.00
Riprap	307 CY	$ 55.00	$ 16,885.00
Channel Excavation	680 CY	$ 12.00	$ 8,160.00
Downstream Access Road			
Excavation	797 CY	$ 12.00	$ 9,564.00
Fill	679 CY	$ 10.00	$ 6,790.00
Road Gravel Surfacing	460 CY	$ 60.00	$ 27,600.00
Vehicle Bridge	1 LS	$ 89,270.00	$ 89,270.00
	Total Cost		$ 1,282,269

Miscellaneous			Unit Cost	Total Material Cost
Embankment Drain Mods	1	LS	$ 50,000.00	$ 50,000.00
Reservoir Impacts	1	LS	$ 650,000.00	$ 650,000.00
Mobilization/Preparation (15%)	1	LS	$ 1,021,000.00	$ 1,021,000.00
Unlisted Items (10%)	1	LS	$ 718,000.00	$ 718,000.00
		Total Cost		$ 2,439,000

Total Direct Construction Costs $ 8,543,560

Program			Unit Cost	Total Material Cost
Geotechnical Investigation	1	LS	$ 20,000.00	$ 20,000.00
Cultural / E. A.	1	LS	$ 15,000.00	$ 15,000.00
Water Rights	1	LS	$ 50,000.00	$ 50,000.00
ROW / Easements	1	LS	$ 1,000,000.00	$ 1,000,000.00
Design (10%)	1	LS	$ 854,000.00	$ 854,000.00
Construction Admin. (7%)	1	LS	$ 598,000.00	$ 598,000.00
Contingencies (10%)	1	LS	$ 854,000.00	$ 854,000.00
		Total Program Costs		$ 3,391,000

TOTAL PREFERRED OPTION COST $ 11,934,560

RUBY DAM REHABILITATION FEASIBILITY STUDY

Design Options Summary

Prepared for:

Montana Department of Natural Resources and Conservation
State Water Projects Bureau
Helena, MT

Prepared by:

HKM Engineering Inc.
P.O. Box 31318
Billings, MT 59107

January 2008

H:\08\M087175\Ruby Reports\Final\Design Opts_0108.doc

TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1
1.1 Flood Hydrology 1
1.2 Hydraulic Design 2
1.2.1 Spillway Crest Design 2
1.2.1.1 Ogee Crest 3
1.2.1.2 Labyrinth Crest 3
1.2.1.3 Fusegate Crest 4
1.2.2 Spillway Chute Design 4
1.2.3 Spillway Wall Heights 4
1.2.4 Spillway Stilling Basin Design 5
1.2.5 Minimum Dam Crest Elevation 6
1.3 Structural Design 7
1.3.1 Ogee Crest 7
1.3.2 Labyrinth Crest Wall 7
1.3.3 Abutment/Spillway Walls 8
1.3.4 Stilling Basin Floor 10
1.3.5 Stilling Basin Walls 10
1.4 Dam Raise 10
1.5 Outlet Works Modifications 11
1.6 Drains 12
2.0 REHABILITATION DESIGN OPTIONS 12
2.1 Option O1-120-96.7 13
2.1.1 Ogee Crest 13
2.1.2 Spillway Chute 13
2.1.3 Stilling Basin 15
2.1.4 Wall Dimensions 15
2.1.5 Dam Raise 15
2.2 Option O1-120-93.0 16
2.3 Option L1-75-96.7 16
2.3.1 Labyrinth Crest 18
2.3.2 Spillway Chute 18
2.3.3 Stilling Basin 19
2.3.4 Wall Dimensions 19
2.3.5 Dam Raise 19
2.4 Option L2-100-96.7 21
2.4.1 Labyrinth Crest 21
2.4.2 Spillway Chute 21
2.4.3 Stilling Basin 22
2.4.4 Wall Dimensions 22
2.4.5 Dam Raise 22
2.5 Option LB1-100-96.7 24
2.6 Option P1-100-96.7 25

2.6.1 Fusegate Crest 25
2.6.2 Spillway Chute 26
2.6.3 Stilling Basin 26
2.6.4 Chute Wall Dimensions 26
2.6.5 Dam Raise 27
3.0 COST ESTIMATE SUMMARY 27
3.1 Parametric Cost Analysis 27
4.0 PREFERRED REHABILITATION OPTION 29
5.0 REFERENCES 31

LIST OF FIGURES

Figure 1 120' Ogee Crest at 5396.7 14
Figure 2 120' Ogee at 5393.0 ft 17
Figure 3 75' Labyrinth Rating Curve 20
Figure 4 100' Labyrinth Rating Curve 23

LIST OF TABLES

Table 1 Hydrology Summary 2
Table 2 Flood Routing Summary 7
Table 3 Tieback Wall Average Wall Thicknesses 8
Table 4 Cantilevered Wall Average Wall Thicknesses 9
Table 5 Spillway Slab Thickness 9
Table 6 Structural Quantity/Cost Adjustment Factors 10
Table 7 Parametric Cost Analysis Summary 28

LIST OF APPENDICES

Appendix A Drawings
Appendix A1 Option O1-120-96.7
Appendix A2 Option L1-75-96.7
Appendix A3 Option L2-100-96.7
Appendix A4 Option LB1-100-96.7
Appendix A5 Option P1-100-96.7
Appendix B Foundation Excavation & Drains Drawing
Appendix C Cost Estimates
Appendix C1 Ogee Crest Options
Appendix C2 Labyrinth Crest Options
Appendix C3 Option LB1-100-96.7
Appendix C4 Fusegate Crest Options
Appendix D Spillway Hydraulic Computations
Appendix D1 Option O1-120-96.7
Appendix D2 Option L1-75-96.7
Appendix D3 Option L2-100-96.7
Appendix D4 Option L2-100-00
Appendix E Hydroplus Fusegate Technical Proposal
Appendix F McPhee Dam Model Study

Ruby Dam Rehabilitation Feasibility Study
Design Options Summary

1.0 INTRODUCTION

The purpose of this report is to document the design options for the Ruby Dam Rehabilitation Feasibility Study conducted by HKM Engineering Inc. (HKM) for the Montana Department of Natural Resources and Conservation (DNRC). This report discusses the preliminary design of the spillway crest, chute, stilling basin, raised dam crest, and a brief discussion for rehabilitation of the outlet works. Outlet works rehabilitation options are discussed in detail in the "Low Level Outlet Works Rehabilitation Summary Report" and additional discussion on raising the dam crest is included in the "Seepage and Slope Stability Analyses."

The Hydraulic Design section of this report describes the procedure used to size spillway components for each option to satisfy design criteria. Structural design of the concrete spillway crest, walls, floor, and the stilling basin are discussed in Section 0. Design of the dam raise, outlet works modifications, and toe drains are discussed in Sections 1.4, 1.5, and 1.6, respectively. A summary for each of the six feasibility design options is included in Section 2.0 with screening level cost estimates for each option included in Section 3.0.

Preliminary drawings for each option are included in Appendices A and B. Cost estimates for each option are included in Appendix C. Hydraulic computations for the spillway crest, chute, and stilling basin for each option are included in Appendix D.

1.1 FLOOD HYDROLOGY

The DNRC performed a hydrologic analysis for the Ruby Dam drainage in 2005; the initial results from this analysis are contained in the draft report titled "Ruby Dam Hydrologic Analysis." Montana has risked based spillway design flood standards which set the design precipitation (P_s) as a function of the estimated loss of life (LOL), 5,000 year precipitation ($P_{5,000}$), and probable maximum precipitation (PMP). The DNRC estimated the LOL downstream of Ruby Dam to currently be 30 with a future LOL of 50. The design precipitation depths were then used with the Army Corps of Engineers software program HEC-HMS v2.2.2 to model floods from the Ruby Dam basin. After the DNRC analysis and modeling were complete the 50 LOL flood event was chosen as the spillway design flood.

HKM performed a review of the draft DNRC hydrologic analysis as part of this Feasibility Study. HKM's primary comments regarded the application of depth-area-duration (DAD) factors when converting a "point" precipitation to a basin wide average precipitation. HKM's recommendations were to apply the DAD factors from WRIR-97-4004 (Regional Analysis of Annual Precipitation Maxima in Montana) to the $P_{5,000}$ and the DAD factors from HMR-55 (Hydrometeorological Report No. 55A – Probable Maximum Precipitation Estimates – U.S. Between the Continental Divide and the 103rd Meridian) to the PMP. The DNRC then finalized the Ruby Dam hydrology taking HKM's comments into account when performing the final analysis which resulted in a significant reduction in the total precipitation depths.

The final DNRC HEC-HMS model used a dimensionless hydrograph with a time to peak (q_p) of 13.7 hours and a Snyder standard lag (t_c) of 15.98 hours. A constant loss rate of 0.22 in/hr was chosen based on the weighted average of NRCS soil hydrologic groups in the basin; 10% of the basin was modeled as impervious due to surface water and the possibility that storms would occur in early summer when some of the ground may still be frozen. A summary of the results from the final DNRC hydrologic analysis including total precipitation, peak flowrate, and runoff volume for recurrence intervals of interest are summarized in Table 1.

TABLE 1 HYDROLOGY SUMMARY

Flood	Total Precipitation (in)	Peak Inflow Flowrate (cfs)	Runoff Volume (Acre-ft)
100-year	3.3	3,036	8,963
500-year	4.1	4,970	13,760
30 LOL	8.0	18,048	45,426
50 LOL	9.0	23,881	60,276
PMF	17.6	83,727	229,761

1.2 HYDRAULIC DESIGN

1.2.1 Spillway Crest Design

Three types of spillway crests were evaluated for the Ruby Dam Feasibility Study. The evaluated crests included ogee, labyrinth, and fusegate. Three primary spillway crest elevations were considered for this report; the existing top of flashboards elevation of 5393.0 ft, 5396.7 ft, and 5400.0 ft. The 5396.7 ft crest elevation will restore capacity which has been lost to sediment accumulation and provides 2,600 acre-ft of conservation storage for total storage of 41,450 acre-

ft. A crest elevation of 5400.0 ft provides 45,155 acre-ft of storage or approximately 7,500 acre-ft more storage than the existing flashboard crest elevation. In addition to the spillway crest elevations evaluated in this report, an intermediate crest elevation between the existing flashboards and the practical maximum of 5400 ft could be chosen during final design.

Ogee crest design was based on U.S. Bureau of Reclamation (USBR) Design of Small Dams, 3rd Edition. Labyrinth crest design was based on criteria contained in the ASCE text Hydraulic Design of Labyrinth Weirs by Henry T. Falvey.

1.2.1.1 Ogee Crest

For the ogee crest a conservative design discharge coefficient (C_o) of 3.65 was used in computation of the rating curve. For the ogee crest shape, a design head (H_o) of 12.8' and a crest (P) height of approximately 10' were used. The profile shape of the ogee crest was designed using guidelines from Design of Small Dams which uses the design head as the primary variable in defining the crest shape. The plan shape of the ogee was designed with converging sidewalls beginning just downstream of the crest. The chute sidewalls converge at an angle of approximately 8.5° between stations 10+00 and 11+50. The maximum allowable convergence was computed to be 18.4° based on the flow velocity and depth at the beginning of the transition as outlined in Section 9.19 of Design of Small Dams.

1.2.1.2 Labyrinth Crest

The labyrinth weir spillway crests were designed with the weir projecting into the reservoir to improve approach flow conditions. While studies by the USBR show this to provide improved performance, the standard performance curves were utilized in this design. These standard performance curves are based on labyrinths with the weir contained inside a rectangular flume. Quantitative design data for the improved performance is not available; however utilizing standard data provides a conservative solution. That is, the actual spillway flow will be slightly larger than the computed flow for a given reservoir elevation.

1.2.1.3 Fusegate Crest

The third type of crest evaluated was a labyrinth fusegate. The ogee and labyrinth spillway crests were designed for the 50 LOL flood, however a different spillway crest design was necessary to accommodate a spillway option for the probable maximum flood (PMF). A fusegate crest was considered for the PMF design option because other crests could not fit the existing site conditions and still have capacity for the PMF without a substantial and impractical dam raise. The purpose of including a spillway crest alternative capable of handling the PMF was to evaluate Ruby Dam's hydropower potential. Hydropower dams are regulated by the Federal Energy Regulatory Commission (FERC) which due to their more stringent flood standards requires hydropower dams to safely pass the PMF. The fusegate design and details are discussed in the Section 2.6 of this report.

1.2.2 Spillway Chute Design

The spillway chute for all feasibility options has a rectangular cross section; the profile of the spillway chute for the ogee crest options was determined by two set points (the station and elevation of the ogee crest and the beginning station and elevation of the stilling basin) in addition to the existing spillway profile. Slopes of the spillway chute closely match the existing spillway chute.

Flow through the spillway chute was modeled using a Microsoft Excel spreadsheet that uses standard step calculations to compute flow depth and velocity at given spillway stations. Printouts of the standard step spreadsheets used to model the chute for each option are included with the hydraulic computations in Appendix D.

1.2.3 Spillway Wall Heights

The height of chute and stilling basin sidewalls were based on the flow depths and velocities computed in the standard step chute spreadsheet, and on freeboard recommendations from Design of Small Dams for the spillway design flow of 20,000 cfs. The minimum chute wall heights were determined by using the USBR freeboard criteria for open channel spillways (Freeboard=$2.0+0.025vd^{1/3}$) and adding the freeboard height to the flow depth. The chute wall heights were then set to a uniform height above the minimum computed wall height to provide an added safety factor. The depth of flow was also evaluated at imminent failure (dam overtopping) flow to ensure sidewalls would not be overtopped at the ultimate flow entering the

spillway. The dam overtopping flow for the ogee and labyrinth crest varies from approximately 25,000 cfs to 30,700 cfs depending on the spillway crest type and elevation. The overtopping flow for the fusegate crest was estimated at approximately 137,600 cfs.

In addition to the flow and freeboard requirements, the spillway wall heights also need to conform to the geometric constraints of the existing site. As a result, the minimum spillway wall height based on the spillway profile and the existing ground surface was approximately 10 ft.

1.2.4 Spillway Stilling Basin Design

To dissipate flows at the bottom of the spillway chute, new stilling basins were designed. USBR Engineering Monograph No. 25 (EM-25) contains design parameters for stilling basin terminal structures. The stilling basin selected for use on most of the rehabilitation options was a modified Type II combination jump basin (combination stilling basin-flip bucket). This modified basin design uses an end sill to assist with the establishment of a hydraulic jump. The dimensions of the stilling basin are determined by the depth and velocity of the water (at design flow) at the basin entrance. While the overall design flow for the spillway was set at 20,000 cfs, the design flow for the stilling basin was set at 4,000 cfs as designing the basin for larger floods becomes cost prohibitive. The stilling basin design flow was chosen based on the 500-yr flood flow of 4,970 cfs reducing to approximately 4,000 cfs after reservoir routing.

If the flow through the stilling basin exceeds the design flow of 4,000 cfs, the hydraulic jump will begin sweeping out of the basin and eventually the stilling basin end sill will begin to act as a flip bucket projecting the flow downstream of the basin. To minimize scour at the toe of the dam from flows in excess of 4,000 cfs, large riprap will be placed on the left bank of the main channel up to elevation 5310 ft between stations 13+00 and 16+00. The trajectory of the water jet once the basin begins to 'flip' is based on the height and angle of the end sill. The height and angle of the end sill also has an effect on when the hydraulic jump begins to sweep out of the basin.

Additional details and discussion regarding this type of basin can be found in the report titled "Hydraulic Model Studies of McPhee Dam Spillway"; this report is included in Appendix F. A model study can be performed as part of the final design to make sure this type of stilling basin operates as desired. If a model study for the Ruby Dam spillway stilling basin is performed during final design, approximately $50,000 should be added to the cost estimates presented in this report.

A key consideration in the design of the stilling basin was the tailwater or downstream water depth. In order for a Type II stilling basin to function properly, there must be adequate tailwater to "hold back" the hydraulic jump. With insufficient tailwater, the hydraulic jump can be swept downstream of the stilling basin resulting in damage to the downstream channel. HKM also prepared a "Downstream Tailwater Hydraulics Report" as part of the Ruby Dam Feasibility Study. The Tailwater Report includes hydraulic analysis of the two channels downstream of Ruby Dam for various flow conditions to establish tailwater elevations at the stilling basin outlet. As indicated in that report, the 4,000 cfs tailwater elevation was determined to be 5299.5 ft; which is approximately equal to the sum of the conjugate (subcritical) depth of the hydraulic jump (approximately 15.8') and stilling basin floor elevation (5284 ft; 5284 + 15.8 = 5299.8 ft).

The combination jump basin was modified from the standard Type II basin by lowering the end sill to an elevation one foot above the existing channel floor elevation, removing the dentates from the end sill, and not including chute blocks at the entrance to the basin. All other dimensions of the stilling basin were computed according to recommendations in EM-25.

1.2.5 Minimum Dam Crest Elevation

Raising the dam crest was determined to be necessary for the raised spillway crest and to meet freeboard recommendations from the DNRC Hydrologic Analysis Report. The minimum freeboard during a flood event was recommended in the DNRC Hydrologic Analysis as 3.0 ft. Dam crest elevations were determined using HEC-HMS software to model the 50 LOL spillway design flood from the drainage basin through the reservoir and each of the spillway options. With the maximum reservoir water surface elevation known for a given spillway option, the minimum dam crest elevation was set based on the DNRC freeboard recommendation.

Routing of the design flood was modeled by revising the DNRC HEC-HMS model from the DNRC Hydrologic Analysis to include the reservoir storage-capacity along with the rating curve for five spillway options. The results of the selected HEC-HMS flood modeling are summarized in Table 2.

The peak water surface elevations for alternatives L2-100-96.7 and L2-100-00 were 5408.8 and 5410.0, respectively. Raising the spillway crest 3.3 feet resulted in a difference in peak water surface of only 1.2 feet because of differing crest hydraulics. The 100' labyrinth crest at elevation 5400 included a magnification ratio of 2.5 (resulting in an effective width of 100*2.5 =

250 feet), while the crest at elevation 5396.7 has a magnification ratio of 1.3 (130 feet effective width). As a result, L2-100-00 has nearly twice the hydraulic capacity of L2-100-96.7 (2.5 / 1.3 = 1.9). Hydraulic calculations and HEC-HMS run summaries are presented in Appendix D.

TABLE 2 FLOOD ROUTING SUMMARY

Spillway Design/Crest Elev. (Option)	Peak Inflow (cfs)	Peak Outflow (cfs)	Max W.S. Elev. (ft)	Minimum Dam Crest Elevation (ft)	Dam Overtopping Flow (cfs)
120' Ogee/5393.0 (O1-120-93.0)	23,881	19,891	5405.7	5410.0	30,700
120' Ogee/5396.7 (O1-120-96.7)	23,881	19,599	5409.3	5412.5	27,500
75' 2-Cycle Labyrinth/5396.7 (L1-75-96.7)	23,881	18,629	5410.2	5413.5	25,100
100' 2-Cycle Labyrinth/5396.7 (L2-100-96.7)	23,881	19,789	5408.8	5412.0	27,500
100' 2-Cycle Labyrinth/5400.0 (L2-100-00)	23,881	20,053	5410.0	5413.0	27,300
100' Fusegate/5396.7 (P1-100-96.7)	83,750	82,200	5412.0	5415.0	137,600

1.3 STRUCTURAL DESIGN

1.3.1 Ogee Crest

The ogee crest was designed using the two dimensional finite element analysis software Visual Analysis 5.5. This model was based on the geometry of the design section using the hydraulic model and assumed no structural support from the existing ogee crest which is to be encased. As part of this analysis, micropiles/grouted anchors were designed to support the new ogee crest on both the upstream and downstream edges of the existing ogee crest. Load conditions considered in this analysis included both uplift and downward load cases. The uplift analysis included an uplift pressure equal to water pressure at a depth of half of the abutment wall height with no flow depth over the ogee. Downward forces considered the dead weight of the ogee and the pressure acting on the ogee from the 20,000 cfs flow depth.

1.3.2 Labyrinth Crest Wall

The labyrinth crest walls were designed as a cantilevered retaining wall using the floor slab as the footing under the 20,000 cfs design flow hydraulic loading. In this analysis the maximum

reservoir surface was used to calculate pressures acting on the upstream face of the wall while the flow depth at station 10+02 was used to determine water pressures acting on the downstream face of the labyrinth. Similar to the design of the ogee crest, Visual Analysis software was also used to model the labyrinth crest wall under these hydraulic load conditions.

1.3.3 Abutment/Spillway Walls

The analysis of the upstream wingwalls, abutment sidewalls, and spillway chute walls for the ogee crest option was based on the concept that new wall construction would be conducted directly in front of the existing walls. In this way, horizontal tiebacks were designed to be placed through the existing wall and later tied into the new wall. These horizontal tiebacks will provide temporary structural stability for the existing retaining walls during construction when the existing spillway floor is removed. In addition, these anchors will provide structural stability for the new walls. This structural analysis was based primarily on the direct design method for column supported slabs which accounts for the two-way action of the slab spanning between tiebacks (columns). Load conditions considered in this analysis are based on at rest earth pressures and reflect differing backfill types and saturation levels. For this preliminary analysis at rest soil pressures were assumed based on International Building Code (IBC) 2003 values. Using equivalent fluid pressures, an at rest earth pressure of 60 pcf was assumed for gravel backfill (GP) and 100 pcf was assumed for clay backfill (CL). See Table 3 and Table 4 for average wall thickness comparisons for different wall heights and backfill materials.

TABLE 3
TIEBACK WALL AVERAGE WALL THICKNESSES

Wall Height (ft)	Backfill Type	Saturation Level	Average Wall Thickness (in)
25	Gravel	Half Wall Ht	20
	Clay	Full Wall Ht	28
	Clay	Half Wall Ht	26
12	Gravel	Half Wall Ht	12
	Clay	Full Wall Ht	14
	Clay	Half Wall Ht	12

Upstream wingwalls, abutment side walls, and spillway chute walls not constructed directly in front of the existing walls were designed as a cantilevered retaining wall using the floor slab as the footing. Similar load conditions as indicated above were also considered in this analysis.

TABLE 4
CANTILEVERED WALL AVERAGE WALL THICKNESSES

Wall Height (ft)	Backfill Type	Saturation Level	Average Wall Thickness (in)
25	Gravel	Half Wall Ht	30
	Clay	Full Wall Ht	38
	Clay	Half Wall Ht	34
12	Gravel	Half Wall Ht	12
	Clay	Full Wall Ht	18
	Clay	Half Wall Ht	14

The new spillway floor was designed to have a 6-inch gravel drain underneath a structural slab supported by a micropile/grouted rock anchor foundation. The spillway floor analysis was performed using the direct design method for column supported slabs based on either uplift or downward loading conditions. Downward loads analyzed included dead weight of the spillway chute floor and the pressure acting on the spillway floor from the 20,000 cfs flow depth without support from the underlying drain gravel. Uplift pressures considered in this analysis included an uplift pressure equal to water pressure at a depth of full and half of the spillway chute wall height with no account for flows through the spillway. In this analysis, the micropiles/grouted rock anchors were spaced at 12.5 ft on center. Spillway floor thicknesses based on this analysis and anchor spacing are shown in Table 5.

TABLE 5
SPILLWAY SLAB THICKNESS

Wall Height (ft)	Load Condition	Slab Thickness (in)
25	Full Wall Ht Up	30
	Half Wall Ht Up	24
	Flow Depth Dn	24
12	Full Wall Ht Up	16
	Half Wall Ht Up	16
	Flow Depth Dn	16

The estimated quantities used in the cost estimates given in this report for each rehabilitation option are based on concrete walls and floor slabs with gravel backfill and a hydrostatic pressure of one half of the wall height. As shown in previous sections of this report structural design may vary significantly based on consideration of differing backfill and hydrostatic conditions. If clay backfill is assumed instead of gravel; the wall concrete, floor concrete, and rock anchor quantities/costs will increase approximately by the factors shown in the Table 6.

TABLE 6
STRUCTURAL QUANTITY/COST ADJUSTMENT FACTORS

Item	Load Condition	Quantity/Cost Adjustment Factor
Floor Concrete	Gravel-Half	1.00
	Clay-Half	1.00
	Clay-Full	1.15
Rock Anchors	Gravel-Half	1.00
	Clay-Half	1.00
	Clay-Full	1.15
Wall Concrete	Gravel-Half	1.00
	Clay-Half	1.20
	Clay-Full	1.50

1.3.4 Stilling Basin Floor

The spillway stilling basin concrete floor thickness and reinforcing was assumed to have a thickness of 4 ft based on previous basin designs for projects with similar design flowrates and velocities. Detailed structural analysis was not performed for this Study but will need to be done during final design of the spillway stilling basin.

1.3.5 Stilling Basin Walls

The walls of the stilling basin were designed as a tieback wall or cantilevered retaining wall similar to the upstream wingwalls, abutment side walls, and spillway chute walls. Loading on the basin walls was based on lateral earth pressures from a gravel loading on the lower 12 ft of wall and flow conditions at the 4,000 cfs design flow. At the spillway design flow of 20,000 cfs, the hydraulic jump in the stilling basin will be swept downstream with the tailwater at an approximate elevation of 5310 ft. As a result, structural analysis of the stilling basin walls also included pressures due to maximum tailwater and neglected lateral pressures from flows in the stilling basin.

1.4 DAM RAISE

The existing dam crest is at approximate elevation 5410 ft, the design to increase the crest height up to 4 feet is generally the same with some slight variations depending on the height of the crest raise. The design consists of using Terramesh® or a wired-faced Mechanically Stabilized Earth

(MSE) type wall with impervious/semipervious backfill to raise the dam crest. A 15-foot wide level area will be excavated on the upstream side of the dam crest for placement of the Terramesh®/MSE stepped wall; the excavated area and vertical wall will allow the dam crest to remain 30 feet wide while keeping the downstream face at 2H:1V. The dam crest design for a raise greater than 4 feet is similar to the shorter raise except the Terramesh®/MSE crest wall is vertical instead of stepped.

Raising the dam crest will require an extension to the gate tower and a new concrete gatehouse. Preliminary analysis of the existing vertical shaft of the gatehouse indicates that the shaft is not structurally adequate to resist at-rest lateral earth pressures based on IBC 2003 soil loadings and using American Concrete Institute – Building Code and Commentary ACI 318-02. As a result, any dam raise options will also include modifications to the existing vertical shaft. Cost estimates for the dam raise include excavation, Terramesh®/MSE wall, backfill, gate tower extension, and a new gate house.

1.5 OUTLET WORKS MODIFICATIONS

Rehabilitation of the Ruby Dam existing outlet works is necessary because the outlet works does not meet DNRC maximum discharge requirements based on historical performance and hydraulic calculations which indicate cavitation damage occurs at the butterfly valve during higher flowrates. Outlet control valve and conduit hydraulic analyses were provided in the "Ruby Dam Hydraulic Analysis Report" prepared by Henry T. Falvey & Associates. MWH also prepared two reports regarding the outlet works, one discussing the outlet works inspection performed in December 2005 and the second report includes outlet works rehabilitation options. A summary report was prepared by HKM as part of this Feasibility Study that includes a summary of these three reports and additional hydraulic analysis for the preferred outlet configurations. Details of the preferred outlet rehabilitation options, including drawings and cost estimates, can be found in the Ruby Dam Feasibility Study section titled "Low Level Outlet Works Rehabilitation Summary Report."

The outlet works rehabilitation option included in the cost estimates for all rehabilitation design options is the preferred outlet works option (Alternative OW4) from the Low Level Outlet Works Rehabilitation Summary Report. This outlet works option includes removal of the existing butterfly valve from the valve tower, installation of a steel penstock through the existing conduit downstream of the valve tower, and new control valves and stilling basin downstream of the existing outlet terminal structure. This outlet alternative includes a flange upstream of the

control valve that provides the ability to add turbines in the future to generate hydropower. The outlet modification cost included in the cost estimate for each Design Option does not include hydropower development. Control valves considered in the evaluation of the outlet options focused on the use of fixed cone valves (FCV), jet flow gates (JFG), and sleeve valves (SV). More detailed discussion of the outlet options is included in the Outlet Works Rehabilitation Summary Report.

1.6 DRAINS

The condition of the tile and CMP drains installed to collect seepage during original construction of the dam is unknown. To address concerns with the unknown condition of the drains, primarily the 12-inch CMP drain located in the east portion of the dam toe, a new drain was designed to be installed approximately 130' downstream of the junction of three tile drains. The tile drain junction drains into the CMP which probably has deteriorated over the 70 years since original installation. A trench will be excavated approximately 90' downstream of the spillway basin into the dam toe until the CMP drain is found. A new manhole and outlet drain to the river channel will then be installed at this location to provide a shorter flow path for any seepage collected in the drain system. Estimated locations of the original drains and the proposed drain modifications are included on the drawings in Appendix B.

2.0 REHABILITATION DESIGN OPTIONS

Six rehabilitation options are discussed in this section of the report. The discussion of each option includes a brief description for each component of the design including the spillway crest, chute floor, chute walls, stilling basin, and the required dam crest raise. For the rehabilitation design options discussed in this section that have only one spillway crest elevation, additional crest elevations will be included in cost estimates for comparison. During final design of the Ruby Dam rehabilitation, spillway crest elevations not included in this report could be considered. The cost estimates for each rehabilitation option are summarized in Section 3.0; detailed estimates for each option including quantities and unit costs are included in Appendix C.

2.1 OPTION O1-120-96.7

Overall design parameters for Rehabilitation Option *O1-120-96.7* are discussed in detail in the following section. Design parameters for this option include:

Spillway Crest Type/Elevation: Ogee/5396.7 ft
Rehabilitated Dam Crest Elevation: 5412.5 ft
Spillway Crest and Chute Width: 120' Tapered to 75'
Spillway Chute Design Flow: 20,000 cfs
Stilling Basin Design Flow: 4,000 cfs (500-yr outflow)

Preliminary drawings for this option are included in Appendix A1 and a detailed cost estimate is included in Appendix C1.

2.1.1 Ogee Crest

The spillway crest for Ruby Dam Feasibility Option *O1-120-96.7* was designed as an uncontrolled ogee crest at an elevation of 5396.7 ft as discussed previously in Section 1.2.1. The reservoir head versus discharge rating curve developed for this crest configuration is included as Figure 1.

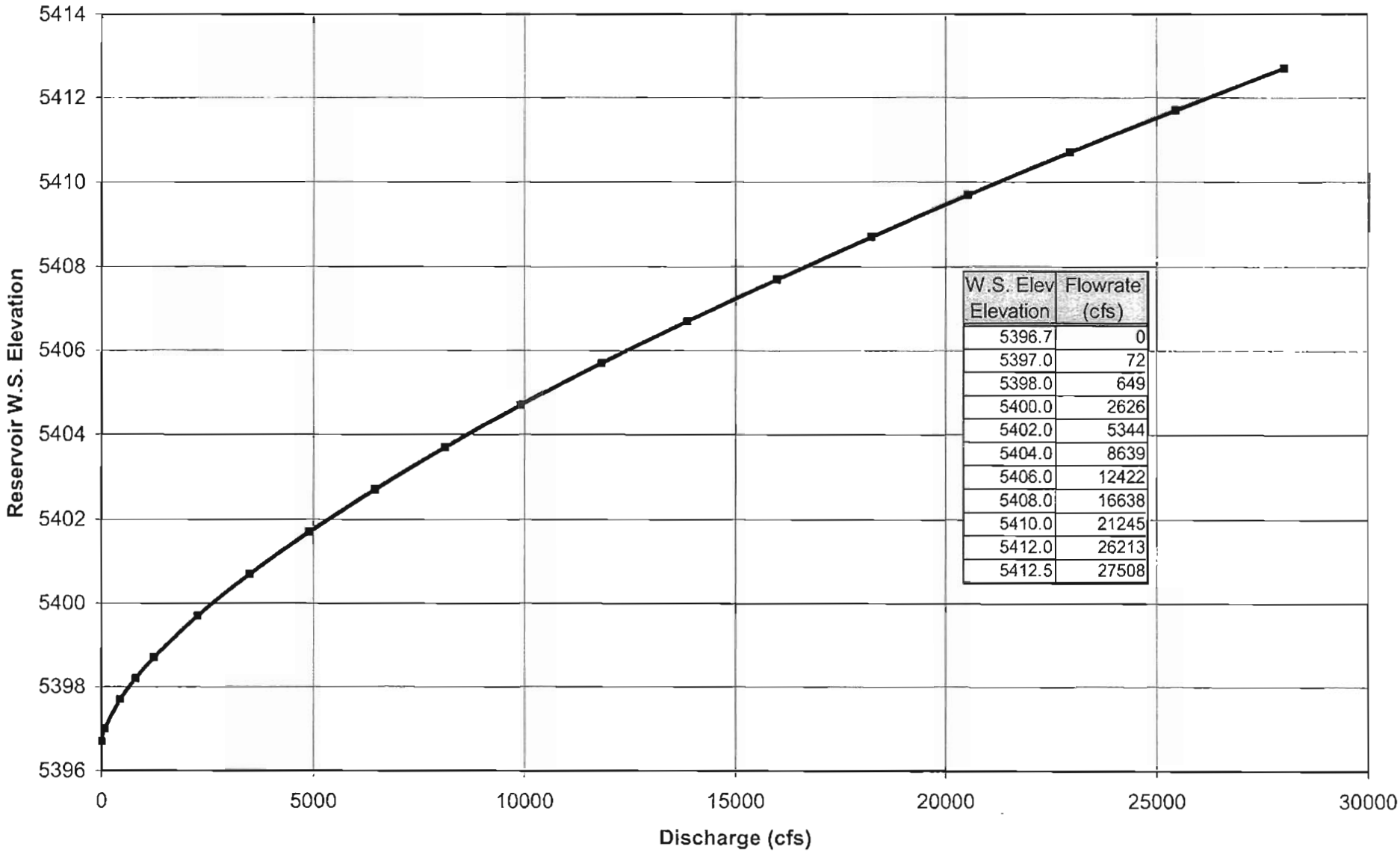
2.1.2 Spillway Chute

In order to match the existing chute dimensions and reduce excavation and concrete quantities as cost savings measures, the proposed chute design for Option *O1-120-96.7* includes a contraction. The chute begins converging at approximately station 10+00, just downstream of the crest, the channel tapers from a width of 120' to a 75' width at station 11+50.

The chute will be constructed by anchoring the existing walls on the right side of the chute into the near vertical hill side and casting the new walls on that side directly adjoining the existing walls. Walls on the left side of the chute will be constructed in a similar manner from upstream of the spillway crest downstream to approximately station 10+60. Downstream of station 10+60 the existing left wall will be demolished and a new wall constructed in its place so that the chute width is not reduced to less than 75'. The portion of left wall downstream of 10+60 will require excavation for construction of the new wall and structural backfill once the wall is complete.

Figure 1

Ruby Dam Feasibility Study
Option O1-120-96.7 - 120' Ogee Rating



W.S. Elev Elevation	Flowrate (cfs)
5396.7	0
5397.0	72
5398.0	649
5400.0	2626
5402.0	5344
5404.0	8639
5406.0	12422
5408.0	16638
5410.0	21245
5412.0	26213
5412.5	27508

2.1.3 Stilling Basin

The spillway stilling basin for this option was designed as a combination stilling basin-flip bucket (Section 1.2.4). In order to contain the hydraulic jump at the design flow of 4,000 cfs in a 75' wide stilling basin, the basin length was computed to be a minimum of 70'.

Based on freeboard requirements for the design flow of 4,000 cfs, the minimum top of wall elevation was computed to be 5307.3 ft. However, the tailwater elevation for the 20,000 cfs spillway design flow was estimated at approximately 5310 ft. The stilling basin walls were set at elevation 5310 ft so the basin walls would not be overtopped during the 20,000 cfs design flow. To minimize scour at the toe of the dam along the left side of the main channel, riprap will be placed on the left bank of the main channel up to elevation 5310 ft between stations 13+00 and 16+00.

2.1.4 Wall Dimensions

Flow depths at the 20,000 cfs design flow in the tapered chute vary from approximately 9.5' just downstream of the crest to approximately 3.5' just before the stilling basin entrance. The chute wall height was set to be 6 inches higher than the dam crest elevation from upstream of the crest to Station 10+20. At 10+20 the walls begin sloping to a 12' height at approximately 10+60; downstream of 10+60 the wall height remains at 12' until the intersection with the stilling basin wall. The 12' height was used due to the possibility of wave run-up on the walls from cross waves resulting from the chute contraction. Preliminary structural design of the chute sidewalls was discussed in the structural design section of this report.

2.1.5 Dam Raise

The flood routing modeling resulted in a maximum water surface of 5409.3 ft for the 50 LOL flood and a 120' ogee crest with an elevation of 5396.7 ft. The existing dam crest at Ruby Dam is approximately 5410.0 ft. In order to meet the 3' freeboard requirement, the dam crest for Option *O1-120-96.7* should be raised to 5412.5 ft. The raised dam crest design was discussed in Section 1.4.

2.2 OPTION O1-120-93.0

Another option for an ogee crest would be to construct a new spillway with a crest at the existing top of flashboards elevation of 5393.0 ft (*O1-120-93.0*). All components of this option besides the ogee crest were made similar to Option *O1-120-96.7;* except the dam crest will not need to be raised to meet minimum freeboard requirements. The rating curve for a new ogee crest with an elevation of 5393.0 ft is included in Figure 2.

A cost estimate for this option is included in Appendix C1. The hydraulics for an ogee crest at elevation 5393.0 ft are very similar to a crest at elevation 5396.7 ft (*O1-120-96.7*); so additional hydraulic computations for this option were not included in the Appendices.

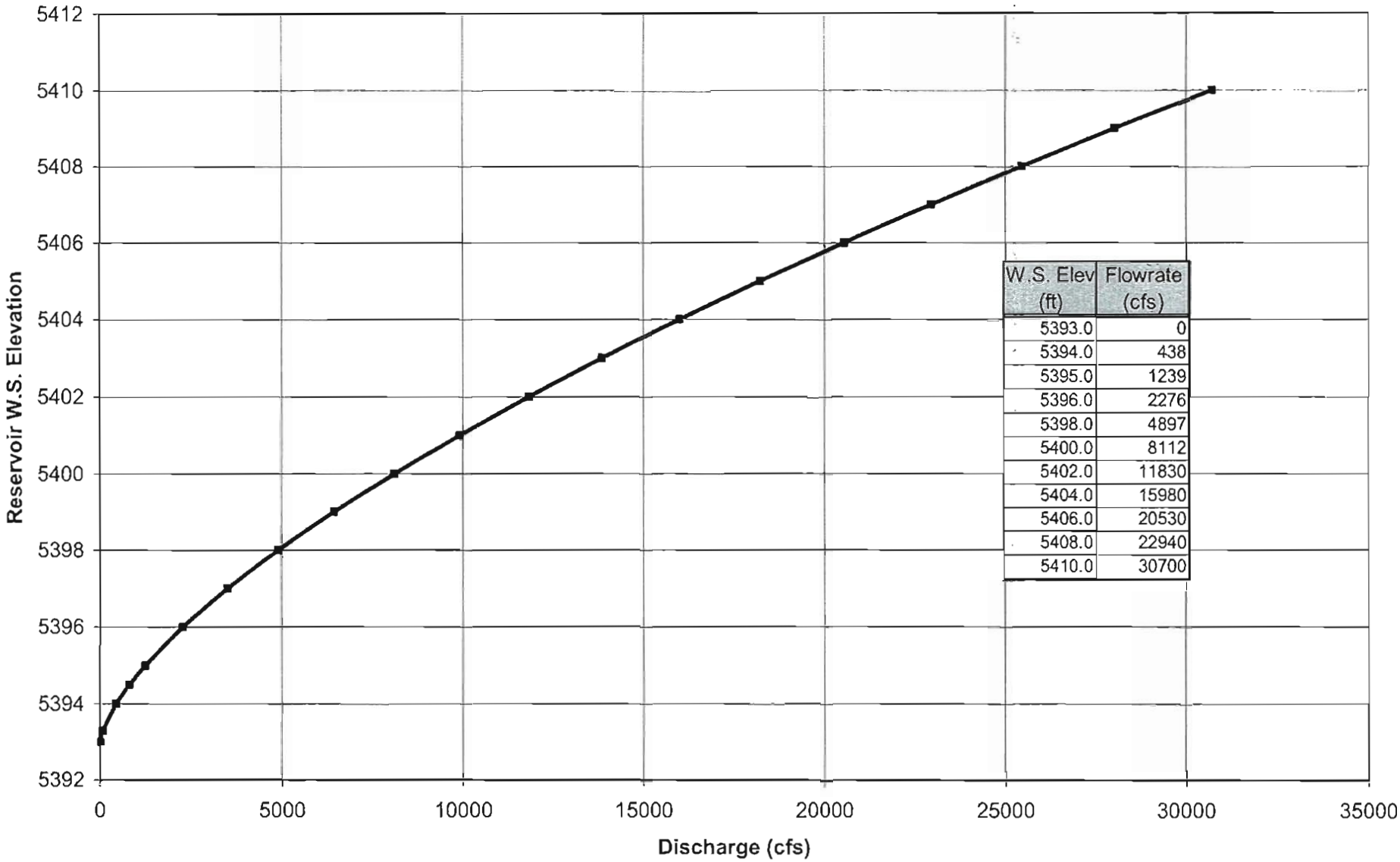
2.3 OPTION L1-75-96.7

Overall design parameters for Rehabilitation Option *L1-75-96.7* are discussed in detail in the following paragraphs of Section 2.3. A detailed cost estimate for this option is included in Appendix C2. Design parameters for this option include:

Rehabilitated Dam Crest Elevation: 5413.5 ft
Spillway Crest Type/Elevation: Two-Cycle Labyrinth/5396.7 ft
Spillway Crest and Chute Width: 75' Straight
Spillway Chute Design Flow: 20,000 cfs
Stilling Basin Design Flow: 4,000 cfs (500-yr outflow)

Figure 2

Ruby Dam Feasibility Study
Option O1-120-93.0 - 120' Ogee Rating



W.S. Elev (ft)	Flowrate (cfs)
5393.0	0
5394.0	438
5395.0	1239
5396.0	2276
5398.0	4897
5400.0	8112
5402.0	11830
5404.0	15980
5406.0	20530
5408.0	22940
5410.0	30700

2.3.1 Labyrinth Crest

A two-cycle labyrinth weir configuration was selected for the spillway crest in this option. The hydraulic analysis and design of the labyrinth weir was completed using criteria and a spreadsheet developed by Dr. Falvey.

For this option, the labyrinth crest was set at elevation 5396.7 and the spillway crest and chute widths (W) were set at 75 ft. The weir wall height (P), crest length (L), and maximum reservoir elevation were then each varied to determine the most cost effective crest configuration based on the estimated cost of the labyrinth weir alone. However, this crest configuration may not represent the most cost effective labyrinth choice on the basis of overall project cost due to the cost of excavation of the approach channel and/or dam raise costs. The selected configuration for this option has a chute width of 75', a labyrinth magnification factor (L/W) of 1.4, an approximate total crest length of 105 ft, and a maximum reservoir elevation (at ~20,000 cfs) of 5410.3 ft. The design hydraulic head divided by wall height (H_o/P) must be less than or equal to 0.9 for the labyrinth design to meet published design curves.

To satisfy the design curves, a minimum wall height of 15.7 ft is required for the selected configuration. The labyrinth floor was set at elevation 5381.0 ft based on the crest elevation and the required wall height.

Preliminary plan and profile drawings for this option are shown in Appendix A2. The rating curve for the designed labyrinth weir is presented as Figure 3. A printout of HKM's version of Dr. Falvey's spreadsheet is presented in Appendix D2 which shows computed performance of the labyrinth weir for the 50 LOL design.

2.3.2 Spillway Chute

The chute profile for Ruby Dam Feasibility Option *L1-75-96.7* was designed similar to the profile for Option *O1-120-96.7*. However the chute was not tapered in plan; instead the chute has a uniform 75' width from the spillway crest to the stilling basin. From the labyrinth weir at station 10+00 to station 10+20 the chute was sloped at 0.00375 ft/ft with the profile downstream of 10+20 similar for all options.

2.3.3 Stilling Basin

The stilling basin design for Option *L1-75-96.7* is identical to the combination stilling basin-flip bucket discussed in Section 2.1.3 for Option *O1-120-96.7*. The floor, sill, and wall elevations are all the same as the previously discussed stilling basins for the ogee crest options where the spillway chute tapers to 75-ft wide upstream of the stilling basin. A profile of the spillway stilling basin for this option is included on the drawings in Appendix A2.

2.3.4 Wall Dimensions

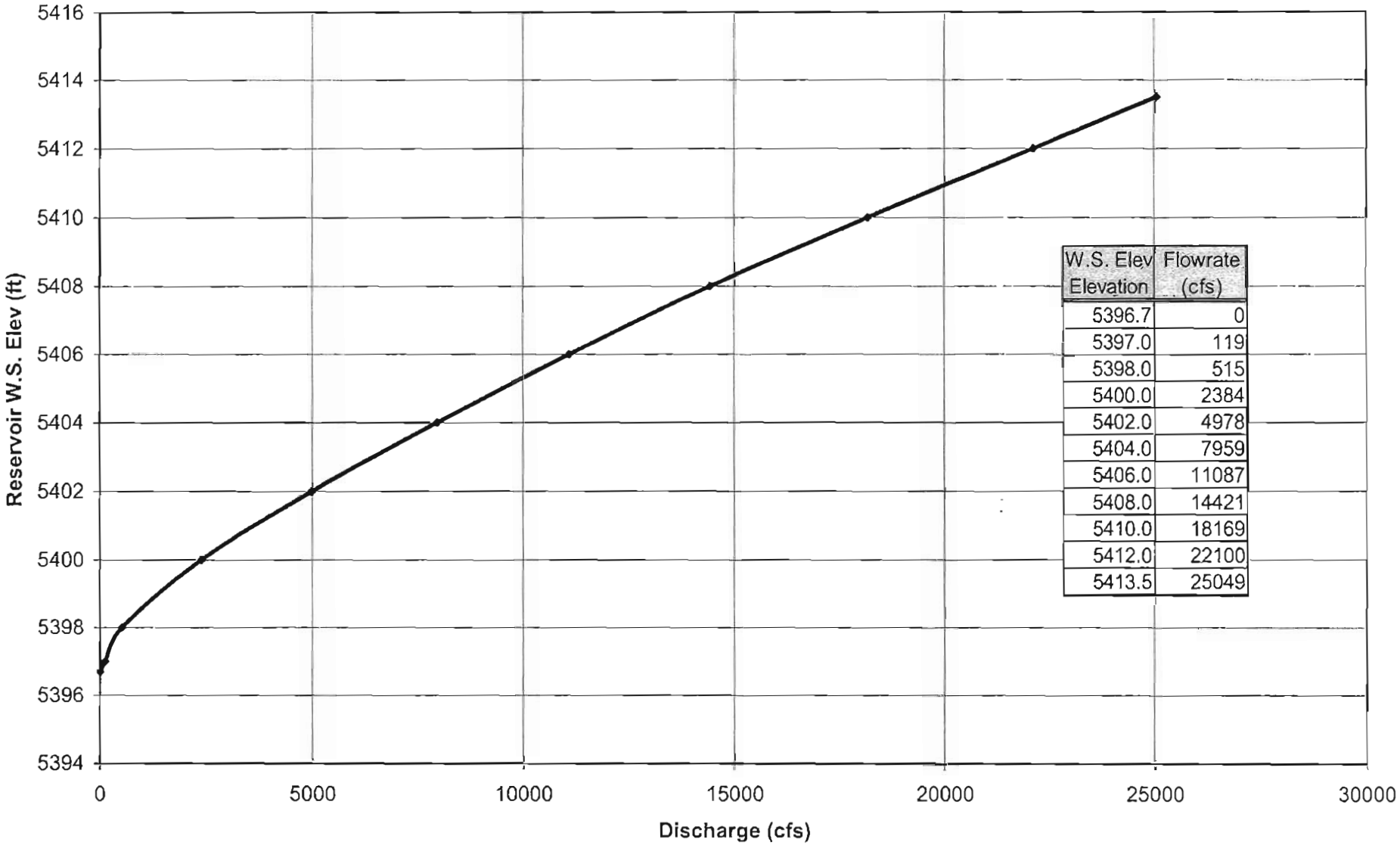
The initial height of the chute sidewalls was determined as discussed for Option *O1-120-96.7* in Section 1.2.3. The chute walls were set at elevation 5414.0 ft from upstream of the spillway to station 10+20 so the walls would be 6 inches higher than the top of dam. The walls were then sloped down to a height of 10' at approximately station 10+60; the 10' height was continued to the intersection with the stilling basin walls at elevation 5310 ft. Flow depths at 20,000 cfs in the 75' straight chute varied from approximately 13' just downstream of the crest to approximately 3.3' at the beginning of the stilling basin.

2.3.5 Dam Raise

In order to meet the 3' freeboard requirement above the 50 LOL flood maximum reservoir elevation of 5410.3 ft, the dam crest for Option L*1-75-96.7* was set at 5413.5 ft. The design for a 3.5' dam raise is similar to a 2.5' dam raise discussed for Option *O1-120-96.7* with a Terramesh®/MSE wall and compacted impervious backfill.

Figure 3

Ruby Dam Feasibility Study
Option L1-75-96.7 - 75' Labyrinth Rating Curve



W.S. Elev Elevation	Flowrate (cfs)
5396.7	0
5397.0	119
5398.0	515
5400.0	2384
5402.0	4978
5404.0	7959
5406.0	11087
5408.0	14421
5410.0	18169
5412.0	22100
5413.5	25049

2.4 OPTION L2-100-96.7

Overall design parameters for Rehabilitation Option *L2-100-96.7* are discussed in further detail in the following paragraphs of this section. Detailed cost estimates for this option as well as options with different crest elevations are included in Appendix C2. Design parameters for this option include:

Rehabilitated Dam Crest Elevation: 5412.0 ft
Spillway Crest Type/Elevation: 2-Cycle Labyrinth/5396.7 ft
Spillway Crest and Chute Width: 100' Straight
Spillway Chute Design Flow: 20,000 cfs
Stilling Basin Design Flow: 4,000 cfs (500-yr outflow)

2.4.1 Labyrinth Crest

The spillway crest for Option *L2-100-96.7* consists of a 2-cycle labyrinth weir similar to Option *L1-75-96.7* with a crest at elevation 5396.7 ft; except this option has a crest and chute width of 100'. The labyrinth weir design consisted of a magnification factor (L/W) of 1.3, a total crest length of 130 ft, and a maximum reservoir elevation (at ~19,800 cfs) of 5408.8 ft. The minimum wall height for a H_o/P of 0.9 is 13.7 ft for this configuration. The labyrinth floor elevation was set at 5383.0 ft based on the crest elevation and the minimum required wall height. A plan and profile drawing of this option is included on the drawings in Appendix A3.

The rating curve for the 100' labyrinth crest is shown in Figure 4. A printout of the spreadsheet used in the hydraulic design of this labyrinth crest is included in Appendix D3.

2.4.2 Spillway Chute

The spillway chute for this option was designed similar to the chute for Option *L1-75-96.7* but with a width of 100'. From the labyrinth weir at station 10+00 to station 10+20 the chute was sloped at 0.00375 ft/ft; downstream of 10+20 the chute profile was similar to other rehabilitation options. The new right and left chute walls were designed to be constructed inside of the tapered section between 10+00 and 10+75 with the area between the new and existing walls filled with gravel. Downstream of 10+75 where the existing chute is less than 100', the chute would be widened by excavating to the left of the existing wall and constructing the new wall approximately 25' left of the existing wall.

2.4.3 Stilling Basin

The stilling basin design for Option *L2-100-96.7* is similar to the combination stilling basin-flip bucket discussed for previous rehabilitation options, except the basin length and wall heights are slightly smaller due to the decreased unit discharge in the wider spillway. With a width of 100', the basin length was computed to be 50' to contain the 4,000 cfs hydraulic jump. The floor basin was set at elevation 5286 ft, the end sill at 5291 ft, and the top of side and wingwalls at 5310 ft.

2.4.4 Wall Dimensions

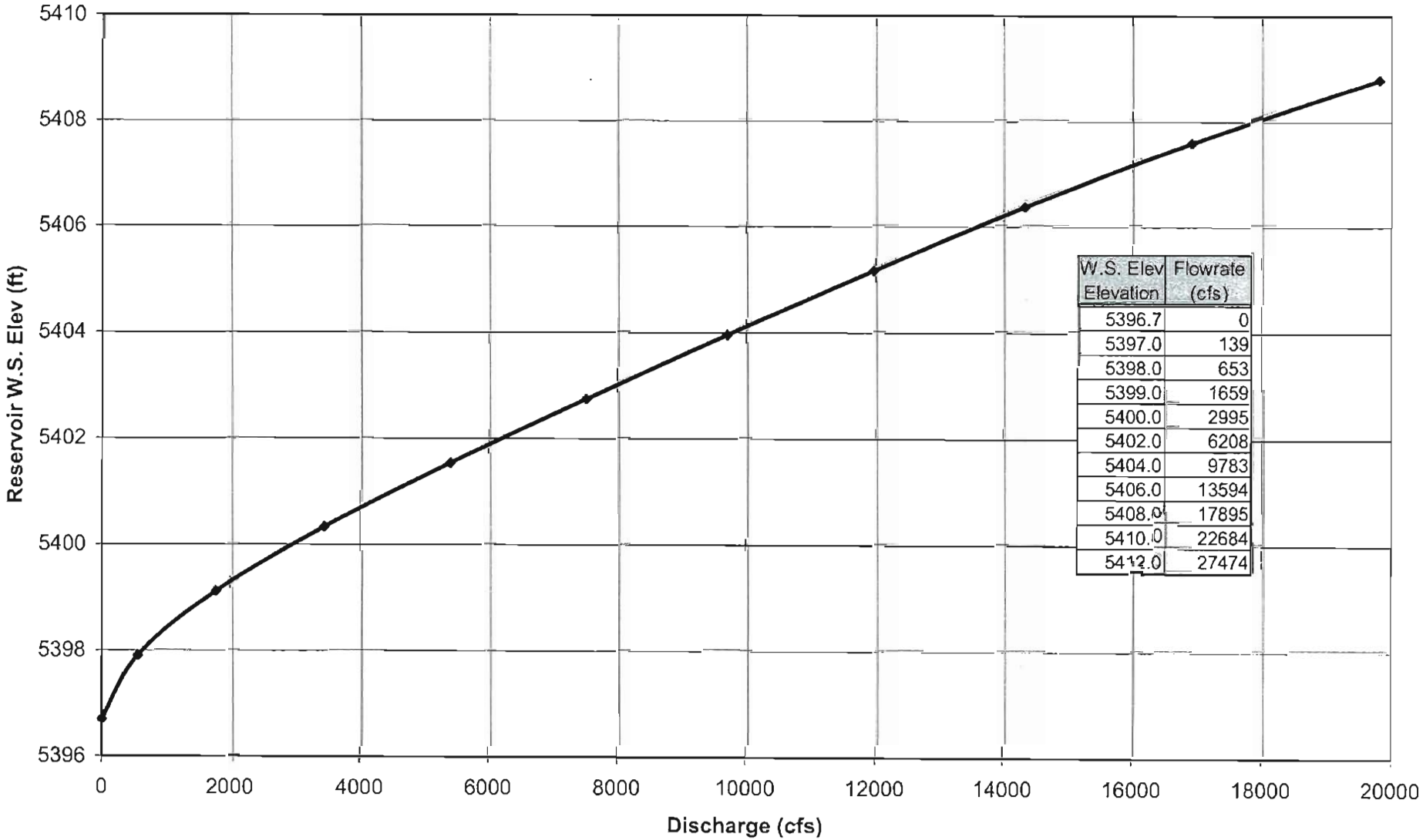
The height of the chute sidewalls was determined as discussed for previous options. The chute walls were set at elevation 5412.5 ft from upstream of the spillway downstream to station 10+20 so the walls would be 6 inches higher than the top of dam. The walls are then sloped down to a minimum height of 10' at approximately station 10+60; the minimum 10' wall height is continued until the intersection with the stilling basin walls at elevation 5310 ft. This minimum wall height is based on the existing ground surface rather than on spillway hydraulics because the site topography requires greater wall heights than the chute flows. Flow depths at 20,000 cfs in the 100' straight chute vary from approximately 11' just downstream of the crest to approximately 2.5' at the beginning of the stilling basin.

2.4.5 Dam Raise

The dam crest for this Option *L2-100-96.7* was raised above the existing elevation of 5410 ft to 5412.0 ft in order to meet the minimum 3' freeboard requirement above the 50 LOL flood maximum reservoir elevation of 5408.8 ft. The design for a 2.0' dam raise consists of removing the top 2 feet of the existing crest to 5408 ft and replacing with compacted backfill material up to 5412 ft. New rock riprap will also be placed on the upstream dam face over the new fill material. This dam raise will decrease the crest width to approximately 22 feet, which is still adequate for vehicle travel.

Figure 4

Ruby Dam Feasibility Study
Option L2-100-96.7 - 100' Labyrinth Rating Curve



W.S. Elev Elevation	Flowrate (cfs)
5396.7	0
5397.0	139
5398.0	653
5399.0	1659
5400.0	2995
5402.0	6208
5404.0	9783
5406.0	13594
5408.0	17895
5410.0	22684
5412.0	27474

2.5 OPTION LB1-100-96.7

Option *LB1-100-96.7* is similar to Option L2-100-96.7 with a 100' wide labyrinth crest except the spillway chute has baffle blocks located at regularly spaced intervals to dissipate energy in flow through the spillway chute. As a result of this energy dissipation throughout the spillway chute, the baffled chute eliminates the need for a stilling basin at the end of the chute as included in other rehabilitation options.

The baffled chute was designed for a unit discharge of 200 cfs; which corresponds to the 100 ft wide spillway chute with a design flowrate of 20,000 cfs. According to USBR Engineering Monograph No. 25 (EM-25) the maximum allowable design unit discharge should be approximately 60 cfs for a baffled chute. However according to EM-25 actual baffled aprons designed for a 60 cfs unit discharge have operated at 120 cfs for short periods without severe damage or overtopping of the chute walls. Typical flows through the spillway at Ruby Dam will result in a unit discharge less than 40 cfs, which provide favorable conditions in the chute and downstream channel. Larger flows in excess of 6,000 cfs (>60 cfs unit discharge) may cause minor damage to the chute concrete baffles, however minor damage should be considered acceptable due to the infrequent occurrence of these large floods; larger than design discharges would also likely cause some overtopping of the sidewalls. Overtopping of the chute side walls would vary from minor splashing to a measurable flow amount near the dam overtopping flow (~27,000 cfs). As a result of the turbulence created by the baffle blocks in this spillway, several design modifications were made from the spillway chute presented in option L2-100-96.7. Besides the concrete baffle blocks, two additional grouted rock anchors were added under each baffle block to account for the force exerted on the blocks. The chute wall heights were also increased from 10' to 15' to decrease the chances of overtopping of the sidewalls because flow depths in the baffled chute are greater than in a chute where the flow remains supercritical.

Drawings for Option LB1-100-96.7 are included in Appendix A4 with a detailed cost estimate included in Appendix C3.

2.6 OPTION P1-100-96.7

Three separate design options to accommodate the Probable Maximum Flood (PMF) were initially considered for this Feasibility Study. The design options consisted of 80', 100', and 120' spillway crests and chutes. Preliminary drawings and a detailed cost estimate were only developed for the 100' spillway because the costs were much higher for the 80' option due to the larger wall heights and the 120' chute did not fit the site. Design parameters for PMF Rehabilitation Option *P1-100-96.7* include:

Spillway Crest Type/Elevation: Fusegate/5396.7 ft
Rehabilitated Dam Crest Elevation: 5415.0 ft
Spillway Crest and Chute Width: 100' Straight
Spillway Chute Design Flow: 75,000 cfs (Approximate Routed PMF)
Stilling Basin Design Flow: 4,000 cfs (500-yr outflow)

Preliminary drawings for Option *P1-100-96.7* are included in Appendix A5. Detailed cost estimates for fusegate options are included in Appendix C4.

2.6.1 Fusegate Crest

The spillway crest for Ruby Dam Feasibility Option P1-*100-96.7* was designed as a reinforced concrete semi-labyrinth fusegate crest at an elevation of 5396.7 ft. The design of this fusegate crest system was designed based on Hydraulics and Design of Fusegates by Henry T. Falvey with assistance from Hydroplus, Inc. of Falls Church, VA. HKM performed preliminary spillway design and then provided Hydroplus with the project data necessary to prepare a technical proposal and cost estimate for fusegate alternatives. The preliminary Hydroplus cost estimate included two scenarios for spillway widths of 80, 100, and 120 ft. The scenarios considered were for semi-labyrinth and narrow labyrinth fusegate systems. In both scenarios the fusegate system was designed to pass the 50 LOL flood event without tipping out. In comparing these options, the narrow labyrinth fusegates have the ability to pass larger flows prior to tipping however they also have higher construction costs. Semi-labyrinth fusegates were selected as the preferred alternative because this option is the most cost effective fusegate alternative that has the ability to pass the 50 LOL flood without tipping.

The selected PMF crest includes five semi-labyrinth fusegates which are 23.7' high (sill elevation 5373.0 ft) and 20' wide. The Hydroplus design has the first gate tipping at reservoir elevation 5409.0 ft and then each of the four remaining gates tip at successively higher reservoir levels until the last gate tips and the PMF can be passed with a reservoir elevation of 5412.0 ft. This design allows the 50 LOL flood to be passed without any of the gates tipping and saves money because the gates will not have to be replaced due to tipping on a frequent basis. Hydroplus's Ruby Dam Technical Proposal which includes detailed information on the fusegate design is included in Appendix E.

2.6.2 Spillway Chute

The chute profile for Ruby Dam Feasibility Option *P1-100-96.7* was designed similar to the chutes for the other rehabilitation design options with a constant 100' width from the spillway crest to the stilling basin. From the fusegate spillway floor at elevation 5373 ft at station 10+00 the chute was sloped to match the elevation at station 10+20 that had been set in the other options so the profile downstream of 10+20 could be similar to the other rehabilitation options.

2.6.3 Stilling Basin

The stilling basin for the PMF Option was designed similar to that of the other options with a design flow of 4,000 cfs due to the higher costs associated with designing for a larger flow. In order to contain the hydraulic jump from a flow of 4,000 cfs in a 100' wide stilling basin, the basin length was computed to be 50'. The floor basin was set at elevation 5286 ft, the sill at 5291 ft, and the top of the side and wingwalls at 5310 ft. To minimize scour at the toe of the dam from flows in excess of 4,000 cfs, riprap will be placed on the main channel left bank up to elevation 5310 ft between stations 13+00 and 16+00.

2.6.4 Chute Wall Dimensions

Flow depths at 75,000 cfs in the 100' straight chute vary from approximately 38' at the spillway crest to approximately 9' at the stilling basin. Wall height through the dam embankment was set at the dam crest elevation from upstream of the crest to Station 10+30. At Station 10+30 the walls are lowered to a 20' height; downstream of 10+30 the wall height remains at 20' to the intersection with the stilling basin wall at elevation 5310 ft at Station 13+22.8.

2.6.5 Dam Raise

The PMF routing resulted in a maximum water surface of 5412.0 ft with the 100' fusegate crest. In order to meet the 3' freeboard requirement, the dam crest for Option *P1-100-96.7* was set at 5415.0 ft. The design for a 5' dam raise is similar to the other previously discussed new crest designs with a Terramesh®/MSE wall and compacted backfill.

3.0 COST ESTIMATE SUMMARY

Detailed cost estimates were prepared for each rehabilitation option discussed in this report. Additional cost estimates for rehabilitation alternatives with spillway crest elevations different than those discussed in this report were prepared to compare costs for different storage alternatives.

3.1 PARAMETRIC COST ANALYSIS

Cost estimates were prepared for each rehabilitation option discussed in Section 2.0 of this report as well as for other spillway crest elevations so a parametric cost analysis could be performed. The purpose of the cost analysis was to compare costs associated with different spillway crest elevations for the same crest type as well as the costs for different spillway crest types at the same elevation. Results of the parametric cost analysis are summarized in Table 7. Detailed cost estimates for each feasibility rehabilitation option including quantities and unit costs are included in Appendix C.

A cost estimate for an ogee crest at elevation 5400.0 ft was not prepared because the large amount of concrete for the ogee and the required dam crest raise would make this option much more expensive in comparison to a labyrinth crest at the same elevation. Review of the cost estimates in Table 7 shows that the estimated construction and total costs do not differ substantially between each spillway crest/chute type and crest elevation except for the PMF or fusegate option which has a construction cost approximately 60% greater than the other options. It can also be concluded from this cost analysis that the cost to raise the storage level above the existing flashboards elevation of 5393.0 ft is relatively small when considered on a cost per acre-ft basis. Discussion and conclusions regarding the economics of rehabilitating Ruby Dam are included in the Economic Evaluation Report.

TABLE 7 PARAMETRIC COST ANALYSIS SUMMARY

	Ogee Crest		Labyrinth Crest				Baffled Chute	Fusegate Crest		
Option Name	O1-120-93.0	O1-120-96.7	L1-75-96.7	L2-100-93.0	L2-100-96.7	L2-100-00	LB1-100-96.7	P1-100-93.0	P1-100-96.7	P1-100-00
Top of Dam Elevation (ft)	5410	5412.5	5413.5	5410	5410	5413	5410	5415	5415	5415
Spillway Crest Elevation (ft)	5393.0	5396.7	5396.7	5393.0	5396.7	5400.0	5396.7	5393.0	5396.7	5400.0
Storage (acre-ft)	37,642	41,450	41,450	37,642	41,450	45,115	41,450	37,642	41,450	45,115
Construction Costs										
Spillway	$3,553,966	$3,741,790	$3,634,148	$3,805,036	$3,948,838	$4,300,056	$3,748,378	$6,764,524	$6,648,464	$6,544,584
Dam Crest	$54,400	$342,500	$427,500	$54,400	$54,400	$385,800	$54,400	$578,800	$578,800	$578,800
Outlet	$1,280,000	$1,280,000	$1,280,000	$1,280,000	$1,280,000	$1,280,000	$1,280,000	$1,280,000	$1,280,000	$1,280,000
Upstream Bridge Access	$136,500	$136,500	$136,500	$136,500	$136,500	$136,500	$136,500	$136,500	$136,500	$136,500
Reservoir Impacts	$0	$200,000	$200,000	$0	$200,000	$650,000	$200,000	$0	$200,000	$650,000
Drains	$20,000	$50,000	$50,000	$20,000	$20,000	$50,000	$20,000	$20,000	$100,000	$100,000
Mobilization (15%)	$757,000	$863,000	$859,000	$794,000	$846,000	$1,020,000	$816,000	$1,317,000	$1,342,000	$1,393,000
Unlisted Items (10%)	$580,000	$641,000	$639,000	$609,000	$629,000	$717,000	$606,000	$1,010,000	$1,009,000	$1,003,000
Total Construction Cost	**$6,380,000**	**$7,250,000**	**$7,230,000**	**$6,700,000**	**$7,110,000**	**$8,540,000**	**$6,860,000**	**$11,110,000**	**$11,290,000**	**$11,690,000**
Program Costs										
Geotech Studies	$10,000	$20,000	$20,000	$10,000	$10,000	$20,000	$10,000	$30,000	$30,000	$30,000
Cultural/Environmental Studies	$0	$10,000	$10,000	$0	$10,000	$15,000	$10,000	$10,000	$15,000	$20,000
ROW/Easements	$500,000	$750,000	$750,000	$500,000	$750,000	$1,000,000	$750,000	$500,000	$750,000	$1,000,000
Engineering/Management (10%)	$638,000	$725,000	$723,000	$670,000	$711,000	$854,000	$686,000	$1,110,000	$1,130,000	$1,170,000
Construction Admin (7%)	$447,000	$508,000	$506,000	$469,000	$498,000	$598,000	$460,000	$780,000	$790,000	$820,000
Contingencies (10%)	$638,000	$725,000	$723,000	$670,000	$711,000	$854,000	$686,000	$1,111,000	$1,129,000	$1,169,000
Hydropower Studies	$0	$0	$0	$0	$0	$0	$0	$100,000	$100,000	$100,000
Water Rights	$0	$20,000	$20,000	$0	$20,000	$50,000	$20,000	$0	$20,000	$50,000
FERC License	$0	$0	$0	$0	$0	$0	$0	$50,000	$50,000	$50,000
Total Program Cost	**$2,230,000**	**$2,760,000**	**$2,750,000**	**$2,320,000**	**$2,710,000**	**$3,390,000**	**$2,640,000**	**$3,690,000**	**$4,010,000**	**$4,410,000**
Total Project Cost	**$8,610,000**	**$10,010,000**	**$9,980,000**	**$9,020,000**	**$9,820,000**	**$11,930,000**	**$9,500,000**	**$14,800,000**	**$15,300,000**	**$16,100,000**

4.0 PREFERRED REHABILITATION OPTION

Based on the analysis of design options and parametric cost analysis presented in this report, a preferred alternative was reached for rehabilitating Ruby Dam. HKM recommends *Option L2-100-00* as the preferred rehabilitation alternative. This Option consists of a new labyrinth spillway crest, new concrete spillway chute and stilling basin, raising the dam crest 3 feet, and rehabilitation of the outlet works. Outlet works rehabilitation options along with the preferred option are discussed in the Low Level Outlet Works Rehabilitation Summary Report.

The basic details of the preferred rehabilitation option (*Option L2-100-00*) are:

- 100-ft Two-cycle labyrinth crest at elevation 5400.0 ft
- 100-ft straight spillway chute and stilling basin
- 3-ft Dam crest raise with new gatehouse

Option L2-100-00 was chosen as the preferred rehabilitation option for several reasons. Although the labyrinth and ogee crests had similar costs at the two lower evaluated elevations (5393 and 5396.7 ft) the labyrinth was chosen as the preferred. crest because the ogee at higher crest elevations becomes more expensive and requires a higher dam crest raise than a labyrinth crest at the same elevation. The labyrinth crest is also more desirable because the crest design includes all new concrete as where the cost estimate for the raised ogee crest assumes new concrete would be cast above the existing crest. If the ogee crest is constructed of entirely new concrete rather than over the existing crest, the spillway construction cost will be higher than shown in Table 7.

A baffled chute has a slightly lower cost than a smooth chute with a stilling basin, however the chute and stilling basin was chosen for the preferred rehabilitation option because the smooth chute provides better operation at higher discharges. In addition the stilling basin-flip bucket moves energy dissipation downstream of the dam toe where the baffled chute dissipates energy through the chute and at the base of the chute. Moving energy dissipation of spillway flows further downstream of the dam toe lowers the possibility of causing erosion and damage to the dam embankment at high flows.

The preferred spillway crest elevation was set at 5400.0 ft for a number of reasons. Due to topography of the reservoir area this was the highest spillway crest and reservoir water surface elevation that did not have a substantial impact on Highway 357 along the east side of the reservoir or on surrounding properties. In addition, the 3-ft dam crest raise required with the preferred spillway crest elevation is near the maximum extent of a reasonable dam raise due to cost and constructability associated with raising an existing earth embankment. This spillway crest elevation also provides a conservative cost estimate when budgeting for the rehabilitation project as the final crest elevation could be set lower to decrease construction and easement costs. The preferred spillway and outlet works rehabilitation alternatives are also discussed in the Preferred Rehabilitation Option Report.

5.0 REFERENCES

Falvey, Henry T. Hydraulic Design of Labyrinth Weirs. ASCE Press, Reston Virginia, 2003.

Montana Department of Natural Resources and Conservation. Draft Ruby Dam Hydrologic Analysis. Helena, MT, July 2005.

U.S. Army Corps of Engineers, Hydrologic Engineering Center. HEC-HMS, Hydrologic Modeling System Version 2.2.2. Davis, CA, 2003.

U.S. Bureau of Reclamation. Design of Small Dams, 3rd Ed. U.S. Government Printing Office, Washington, D.C, 1987.

U.S. Bureau of Reclamation. Hydraulic Design of Stilling Basins and Energy Dissipators, Engineering Monograph No. 25. Washington, D.C., 1978.

APPENDIX A

DRAWINGS

APPENDIX A1

OPTION O1-120-96.7

SURVEYORS NOTE:

1. THE VERTICAL DATUM FOR THIS PROJECT IS THE CENTERLINE AT THE TOP OF THE SPILLWAY BEING 5372.00.

2. THE HORIZONTAL COORDINATE SYSTEM FOR THIS JOB IS BASED ON 4 ORIGINAL NORAD TARGET POINTS AROUND THE RIVER RESERVOIR (POINTS 5, 13, 16, AND 20).

3. FIELD SURVEYS WERE PERFORMED IN OCTOBER AND NOVEMBER OF 2005 USING GPS.

4. THE CALIBRATION FOR CONTROL POINT NUMBER 1 IS:
LATITUDE: 45°14'06.5"N
W LONGITUDE: 112°08'37.70"
ELLIPSOID HEIGHT: 5391.842'
NAVD ELEVATION: 5431.28' (LOCAL ELEVATION IS 5427.31')
ROTATION FROM GPS NORTH AT CP 1: +0 deg 08'46.4(0.31")
(TOPVS SOLUTION ON 10-25-05)

5. NO HCS BM'S WERE SURVEYED.

6. THE OUTLET CHANNEL WAS SURVEYED ON NOVEMBER 30, 2005 AFTER THE WATER WAS SHUT OFF FOR FOURTEEN HOURS. GENERALLY FROM THE OUTLET TO THE CONFLUENCE OF THE RIVER CHANNEL BELOW THE DAM. THE DEEPEST AREA IMMEDIATELY DOWNSTREAM FROM THE OUTLET STILL COULD NOT BE MEASURED, AND IS LIKELY DEEPER THAN SHOWN. THE NORMAL WATER LINE (10-05) WAS SURVEYED ALONG WITH THE LOWERED WATER LEVEL (11-05). BOTH WATER LEVELS ARE SHOWN.

NORM HARPER'S NOTE:

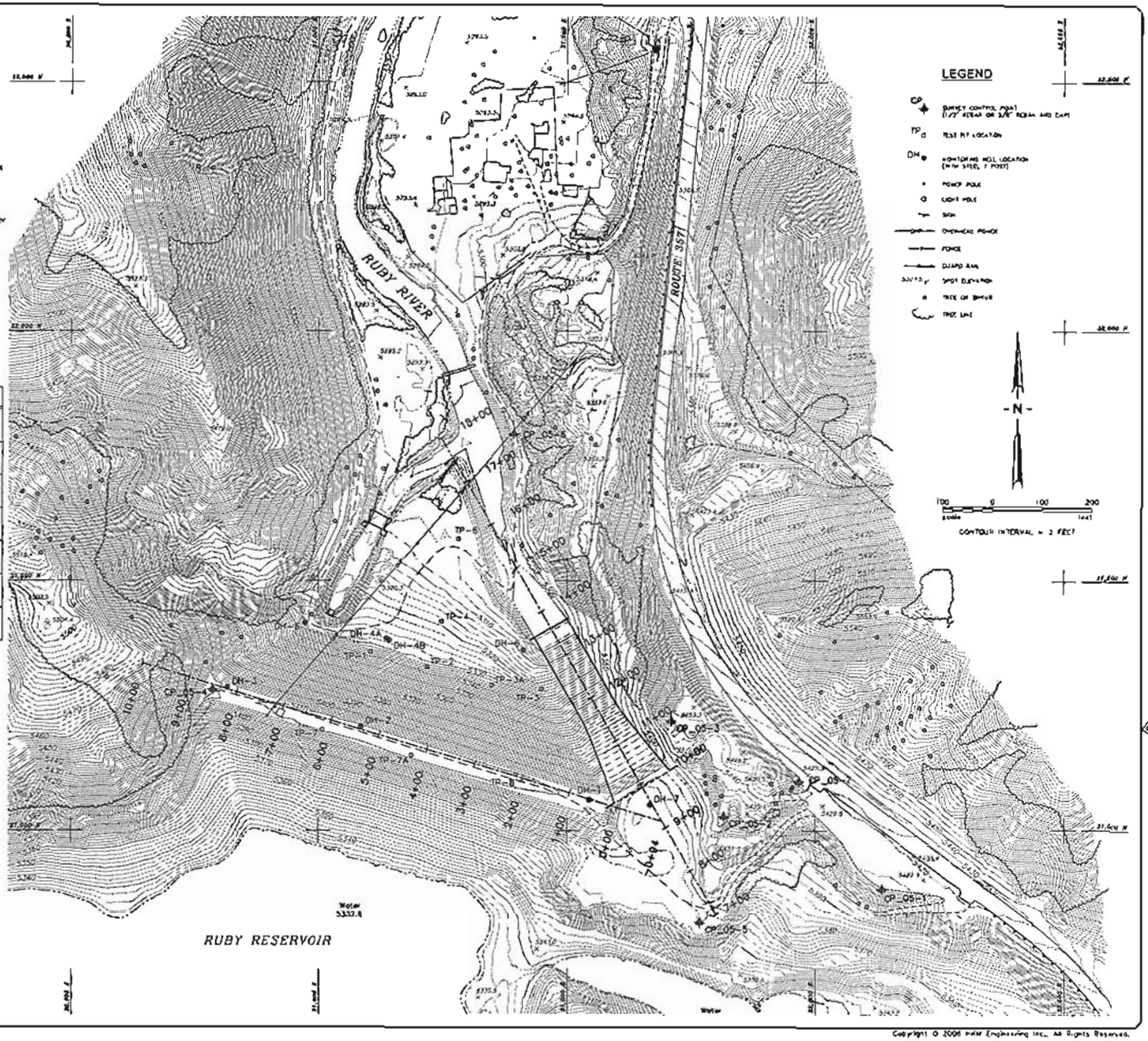
1. SPOT ELEVATIONS IN DENSE WEEDS ARE APPROXIMATE AND MAY NOT MEET NATIONAL MAP ACCURACY STANDARDS.

SURVEY CONTROL TABLE

CONTROL POINT	COORDINATES	ELEVATION	DESCRIPTION
CP_05-1	N 30883.984 E 32134.631	5477.31	EXIST. PK NAIL IN ROCK
CP_05-2	N 31025.295 E 31815.810	5432.40	1/2" REBAR
CP_05-3	N 31218.664 E 31740.050	5450.24	1/2" REBAR
CP_05-4	N 31281.772 E 30786.302	5410.32	5/8" REBAR WITH YELLOW PLASTIC CAP
CP_05-5	N 30618.824 E 31766.593	5388.22	5/8" REBAR WITH YELLOW PLASTIC CAP
CP_05-6	N 31793.203 E 31391.484	5302.89	1/2" REBAR
CP_05-7	N 31097.591 E 31968.139	5435.98	MONT DEPT OF TRANSPORTATION BRASS CAP BENCHMARK

GEOTECHNICAL EXPLORATION HOLE LOCATIONS

DRILL HOLE	COORDINATES		TEST PIT	COORDINATES
DH-1	N 31061.53 E 31543.28		TP-1	N 31358 E 31103
DH-2	N 31206.95 E 31063.37		TP-2	N 31327 E 31218
DH-3	N 31206.10 E 30816.00		TP-3	N 31363 E 31448
DH-4A	N 31384.76 E 31130.96		TP-3A	N 31391 E 31347
DH-4B	N 31380.84 E 31141.64		TP-4	N 31419 E 31246
DH-5	N 31415.67 E 30973.89		TP-6	N 31383 E 31279
DH-6	N 31381.07 E 31411.22		TP-7	N 31301 E 31006
DH-7	N 31031.16 E 31686.40		TP-7A	N 31150 E 31180
			TP-8	N 31111 E 31356



Copyright © 2006 HKM Engineering Inc. All Rights Reserved.

No.	Revision	By	Date

WARNING
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWINGS ARE NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

GENERAL SITE PLAN OF EXISTING TOPOGRAPHY
OPTION 01-120-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING INC.
Consulting Engineers
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6038

Sheet No
01-1
of 6

Copyright © 2006 HKM Engineering Inc. All Rights Reserved

Sheet No. 01-2 of 6

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6359, Fax (406) 656-6398

PRELIMINARY
NOT FOR CONSTRUCTION

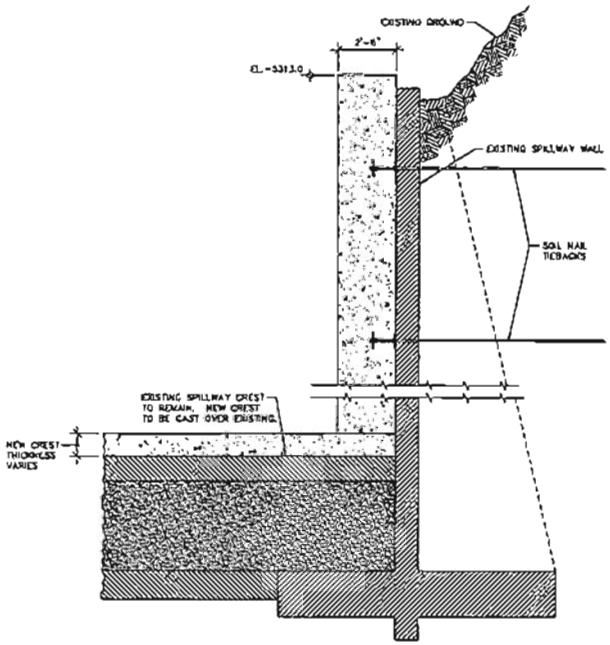
• Project No. BU067.115 • 01_SW-PP.dwg • Date JAN. 2006 • Designed JC • Drawn GAE • Checked JHF • Approved JHF

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

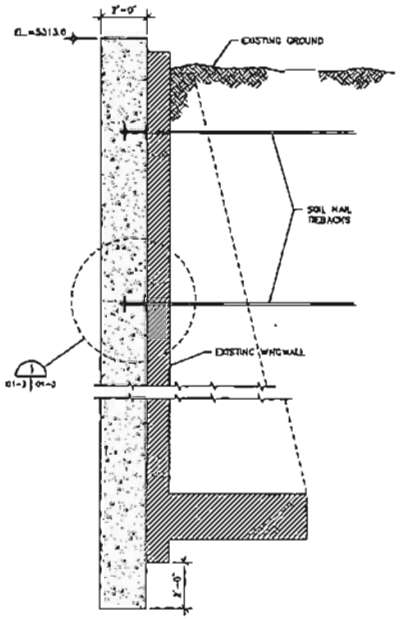
SPILLWAY PLAN AND PROFILE
OPTION 01-120-96.7

WARNING
0 ½
IF THIS BAR DOES NOT MEASURE ½" THEN DRAWING IS NOT TO SCALE

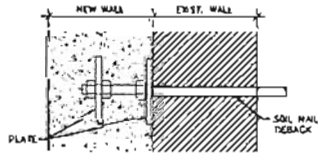
No.	Revision	By	Date



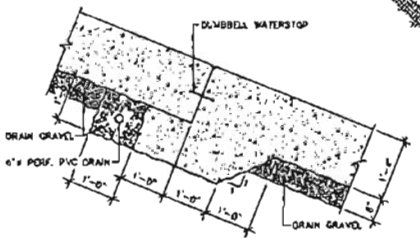
A SECTION
01-3 | 01-3 TYPICAL SPILLWAY CREST WALL



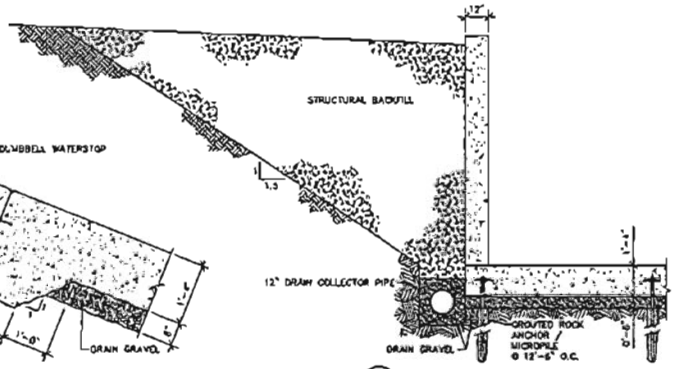
B SECTION
01-3 | 01-3 TYPICAL WINGWALL



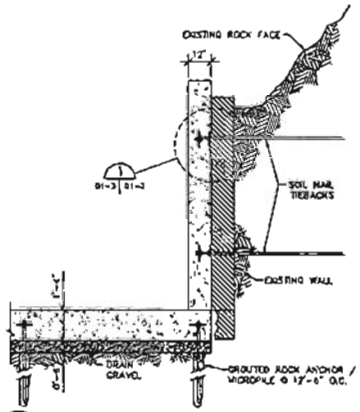
1 DETAIL
01-3 | 01-3 TYPICAL SOIL NAIL TIEBACK



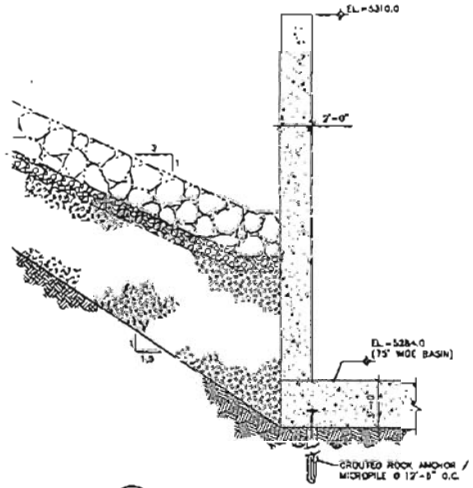
2 DETAIL
01-3 | 01-3 TYPICAL FLOOR SLAB JOINT



D SECTION
01-2 | 01-3 TYPICAL SPILLWAY WALL



E SECTION
01-2 | 01-3 TYPICAL SPILLWAY WALL



F SECTION
01-3 | 01-3 TYPICAL STILLING BASIN WALL

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

No.	Revision	By	Date

WARNING
1" ON THIS SHEET IS NOT 1" ON ANY OTHER SHEET

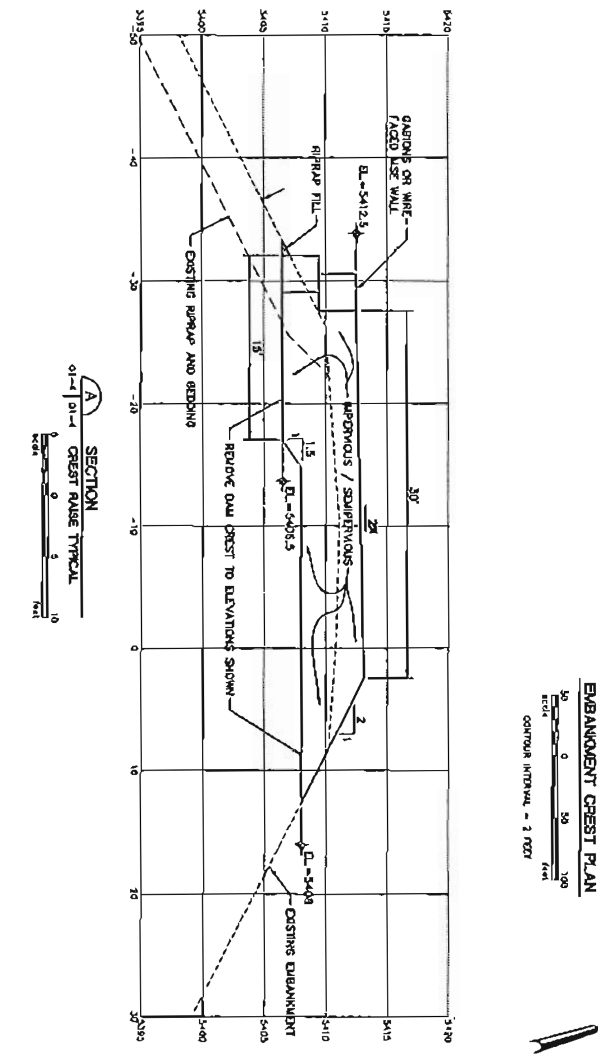
RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

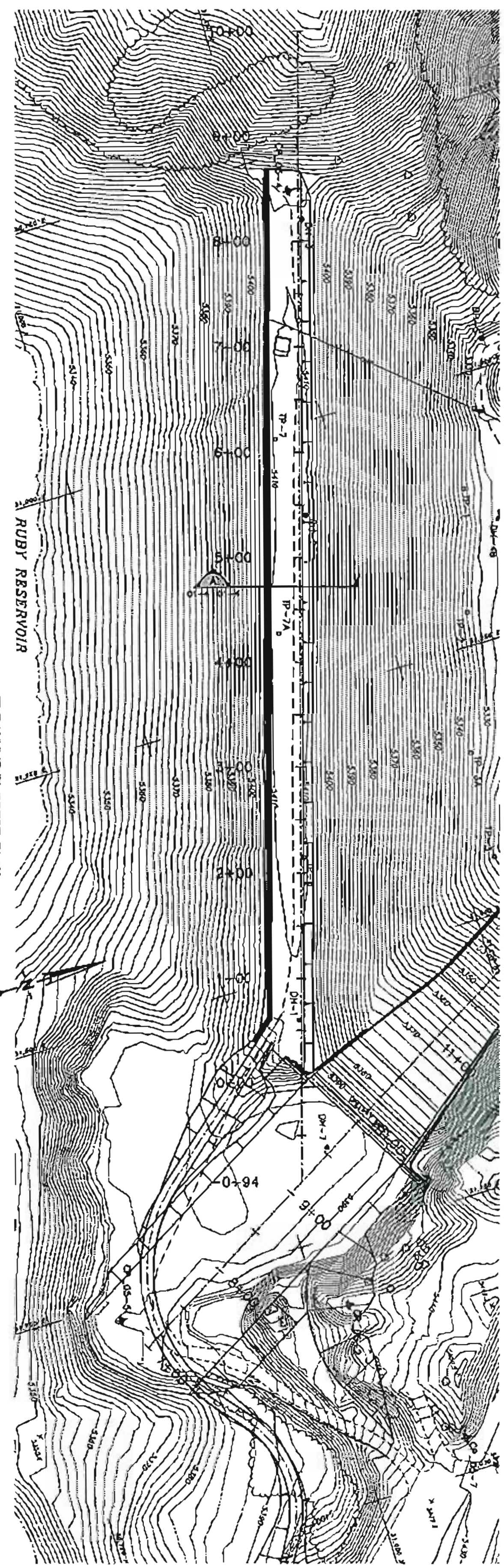
TYPICAL SPILLWAY SECTIONS AND DETAILS
OPTION 01-120-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 3115
Billings, MT 59107-3115
(406) 656-6325, Fax (406) 656-0294

Sheet No.
01-3
of 6





● Project No. 8N067.175 ● 01_CrestPlan.dwg ● Date JAN, 2008 ● Designed JHT ● Drawn CAE ● Checked JHT ● Approved JHT

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

EMBANKMENT CREST RAISE PLAN AND SECTION
OPTION O1-120-96.7

WARNING
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

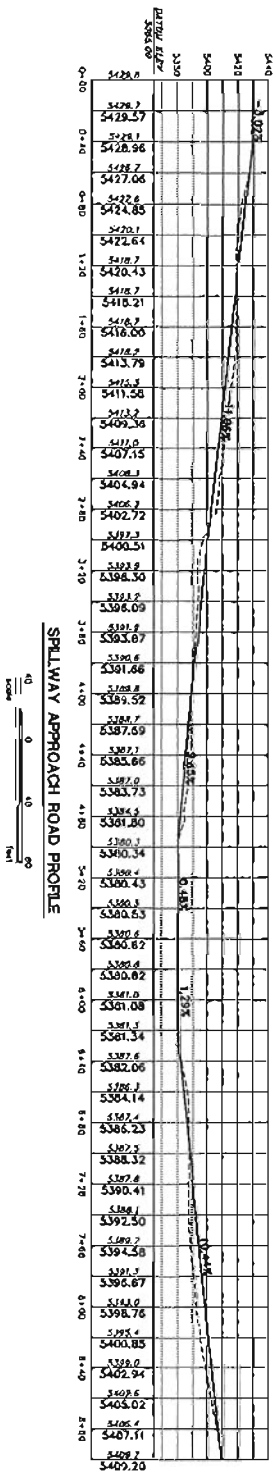
No.	Revision	By	Date

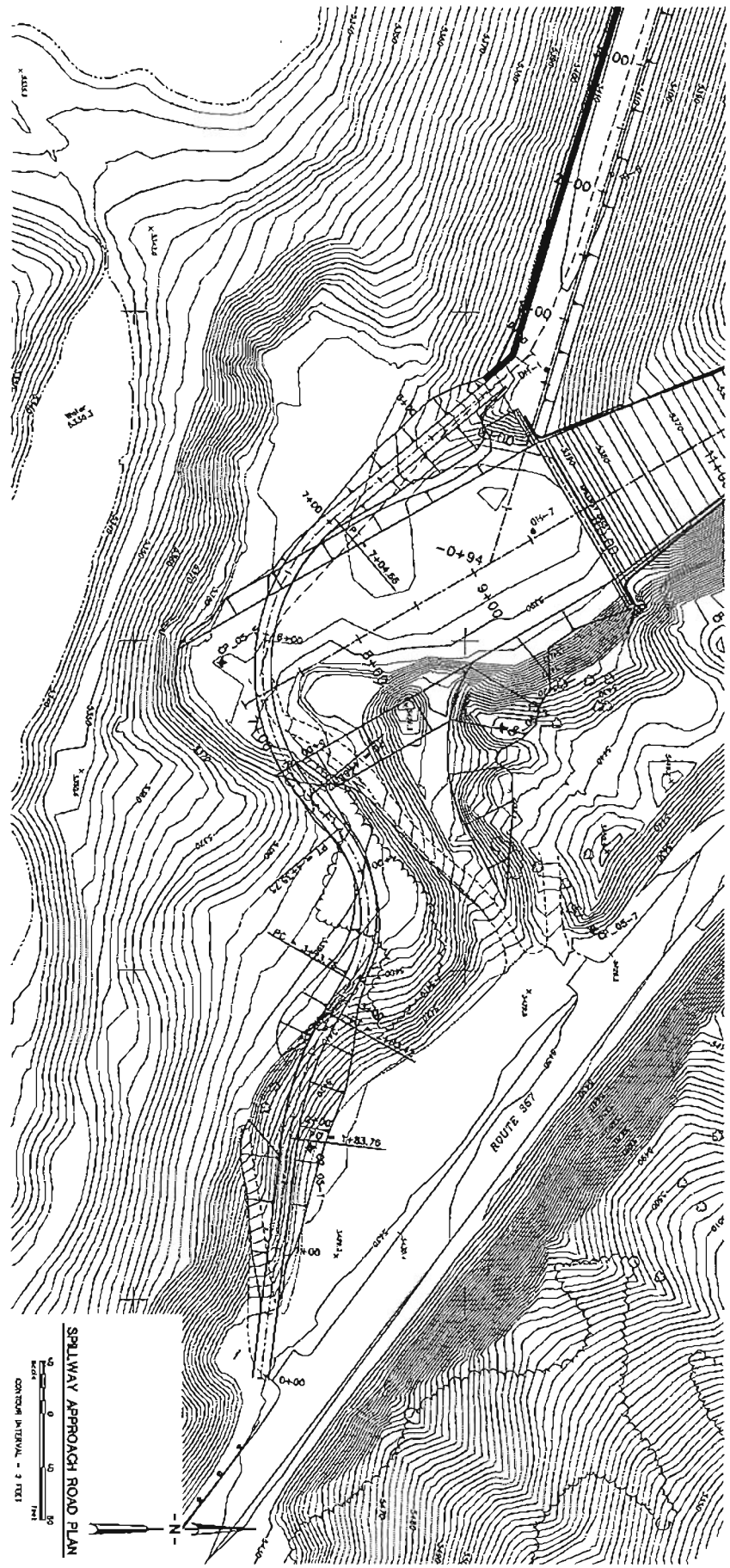
PRELIMINARY
NOT FOR CONSTRUCTION

HKM
ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No. 01-4 of 6

Copyright © 2008 HKM Engineering Inc. All Rights Reserved.





Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

• Project No. 6M087.175 • 01_Approch.dwg • Date JAN. 2006 • Designed JHT • Drawn CAE • Checked JHT • Approved JHT

Sheet No. 01-5

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

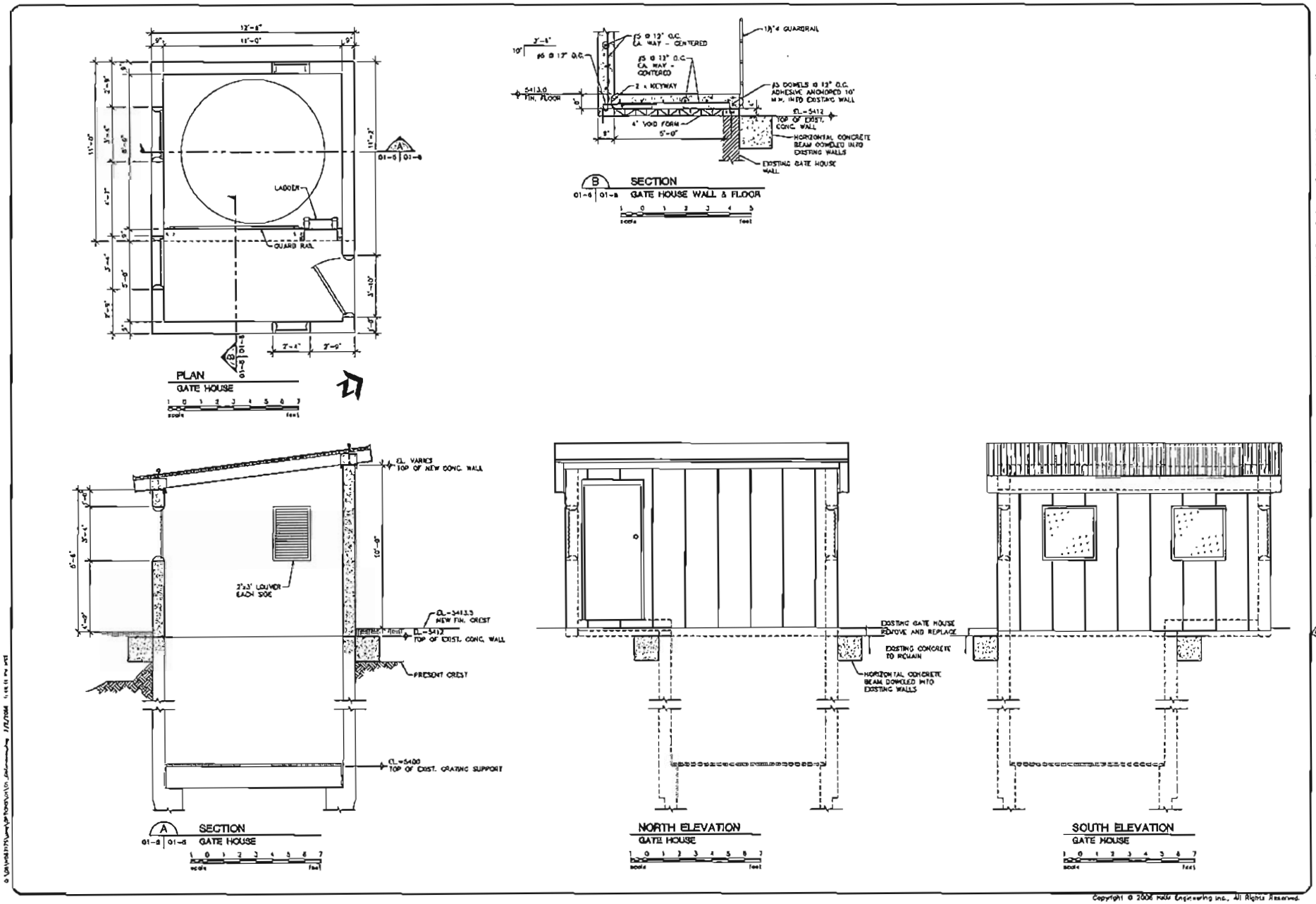
PRELIMINARY
NOT FOR CONSTRUCTION

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

SPILLWAY APPROACH PLAN
OPTION 01-120-96.7

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

No.	Revision	By	Date



RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS GATE HOUSE REPLACEMENT
OPTION 01-120-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No
01-6
of 6

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

APPENDIX A2

OPTION L1-75-96.7

SURVEYORS NOTE

1. THE VERTICAL DATUM FOR THIS PROJECT IS THE CONTROLINE AT THE TOP OF THE SPILLWAY BEING 5317.00.

2. THE HORIZONTAL COORDINATE SYSTEM FOR THIS JOB IS BASED ON A PRECISE NORM. TARGET POINTS AROUND THE RUBY RESERVOIR (POINTS 1, 13, 18, AND 20).

3. FIELD SURVEYS WERE PERFORMED IN OCTOBER AND NOVEMBER OF 2006 USING GPS.

4. THE LAT/LONG FOR CONTROL POINT NUMBER 1 IS:
LATITUDE: 45.4118543
W LONGITUDE: 112.0637075
ELLIPSOID HEIGHT: 5337.8147
MSL ELEVATION: 5431.38 (LOCAL ELEVATION IS 5427.31)
ROTATION FROM GRID NORTH AT CP 1: -0 deg 00'43 (DMS)11"
(GPS2 SOLUTION ON 10-25-05)

5. NO NGS BM'S WERE SURVEYED.

6. THE OUTLET CHANNEL WAS SURVEYED ON NOVEMBER 30, 2005 AFTER THE WATER WAS SHUT OFF. CONTOURS WERE GENERATED FROM THE OUTLET TO THE CONFLUENCE OF THE MAIN CHANNEL BELOW THE DAM. THE DEEPEST AREA DIRECTLY DOWNSTREAM FROM THE OUTLET STILL COULD NOT BE WADEABLE, AND IS LIKELY DEEPER THAN SHOWN. THE NORMAL WATER LINE (10-05) WAS SURVEYED. ALONG WITH THE LOWERED WATER LEVEL (11-05). BOTH WATER LEVELS ARE SHOWN.

NORMAL WARNERS NOTE

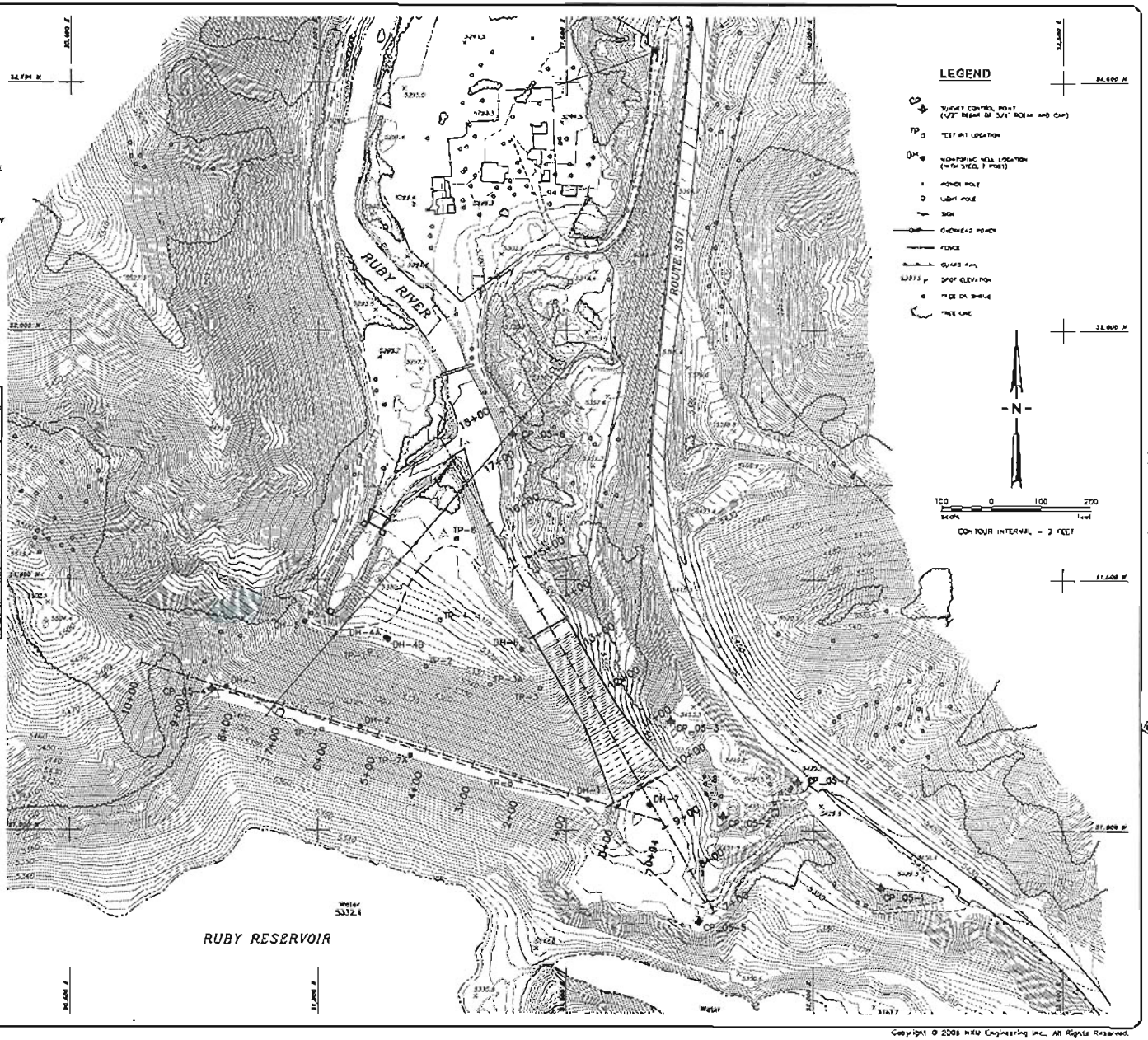
1. SPOT ELEVATIONS IN VEGETATED AREAS ARE APPROXIMATE AND MAY NOT MEET NATIONAL MAP ACCURACY STANDARDS.

SURVEY CONTROL TABLE

CONTROL POINT	COORDINATES	ELEVATION	DESCRIPTION
CP_05-1	N 30883.584 E 32134.481	5427.31	EXIST PK NAIL IN ROCK
CP_05-2	N 31028.295 E 31815.810	5432.80	1/2" REBAR
CP_05-3	N 31218.564 E 31710.055	5450.24	1/2" REBAR
CP_05-4	N 31293.772 E 30786.302	5410.32	5/8" REBAR WITH YELLOW PLASTIC CAP
CP_05-5	N 30816.824 E 31786.593	5386.22	5/8" REBAR WITH YELLOW PLASTIC CAP
CP_05-6	N 31793.298 E 31391.484	5302.83	1/2" REBAR
CP_05-7	N 31097.391 E 31466.135	5436.48	MONT. DEPT. OF TRANSPORTATION BRASS CAP BENCHMARK

GEOTECHNICAL EXPLORATION HOLE LOCATIONS

DRILL HOLE	COORDINATES		TEST PIT	COORDINATES
DH-1	N 31061.33 E 31343.28		TP-1	N 31308 E 31105
DH-2	N 31206.93 E 31083.37		TP-2	N 31327 E 31218
DH-3	N 31266.10 E 30816.00		TP-3	N 31283 E 31442
DH-4A	N 31384.28 E 31135.98		TP-3A	N 31291 E 31347
DH-4B	N 31380.84 E 31141.64		TP-4	N 31419 E 31248
DH-5	N 31415.67 E 30973.69		TP-5	N 31503 E 31279
DH-6	N 31341.07 E 31411.22		TP-7	N 31291 E 31006
DH-7	N 31051.19 E 31666.48		TP-7A	N 31150 E 31108
			TP-8	N 31111 E 31396



RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

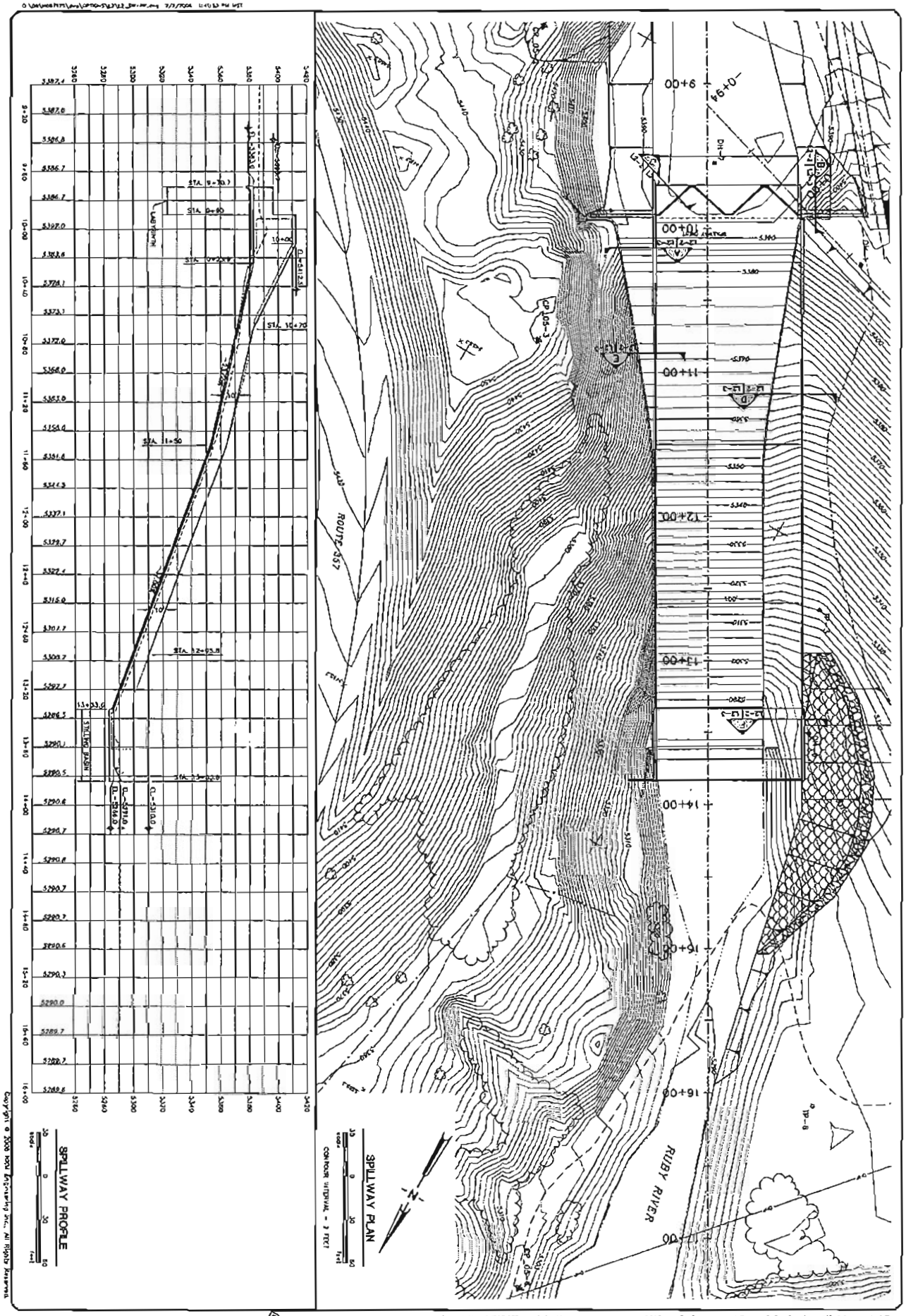
GENERAL SITE PLAN OF EXISTING TOPOGRAPHY
OPTION L2-100-86.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Orchard Tower Building
2821 Orchard Ridge Road
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-8399, Fax (406) 656-8399

Sheet No.
L2-1

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.



Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

Sheet No. L2-2 of 6

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6396

PRELIMINARY
NOT FOR CONSTRUCTION

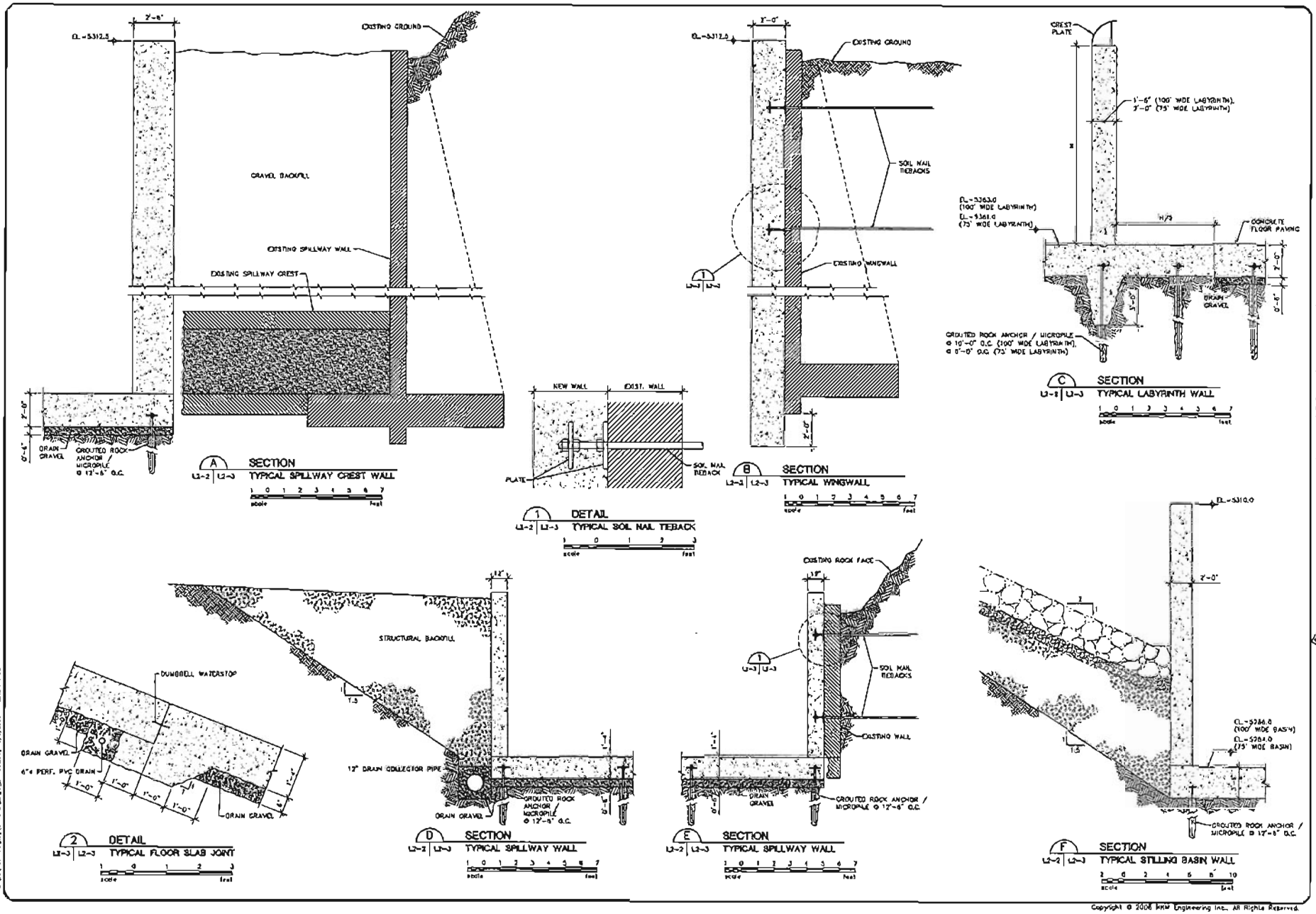
• Project No. 64067.175 • L2_SW-PP.dwg • Date JAN 2006 • Designed JC • Drawn CAE • Checked JMT • Approved JMT

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

SPILLWAY PLAN AND PROFILE
OPTION L2-100-96.7

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

No.	Revision	By	Date



RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

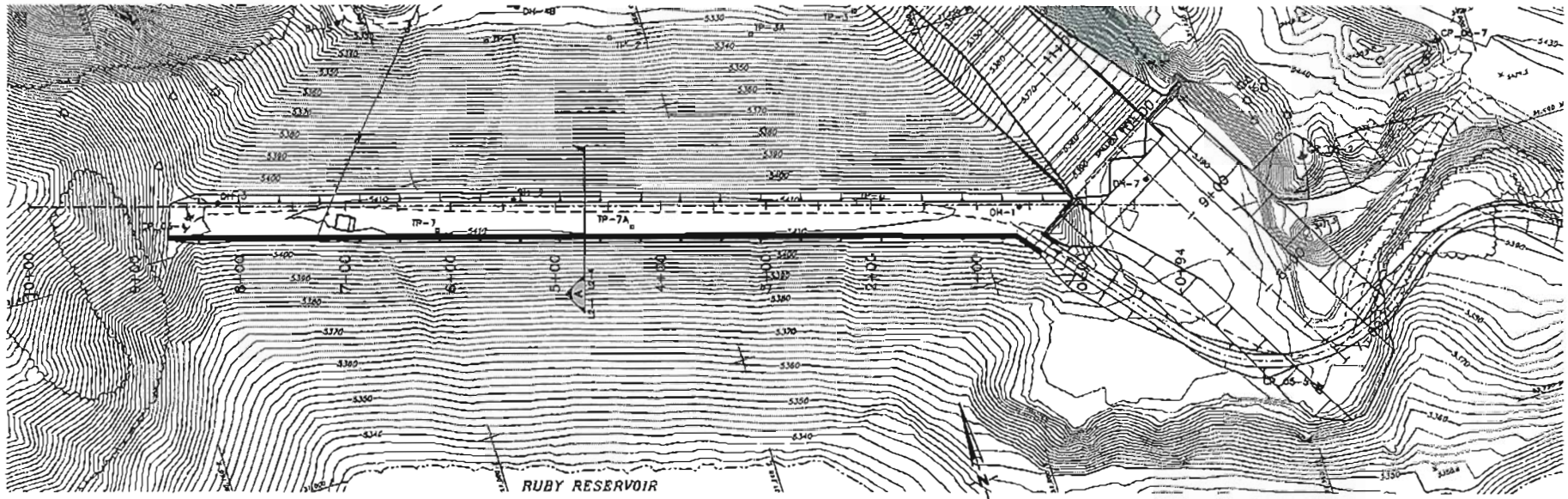
TYPICAL SPILLWAY SECTIONS AND DETAILS
OPTION L2-100-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
L2-3
of 6

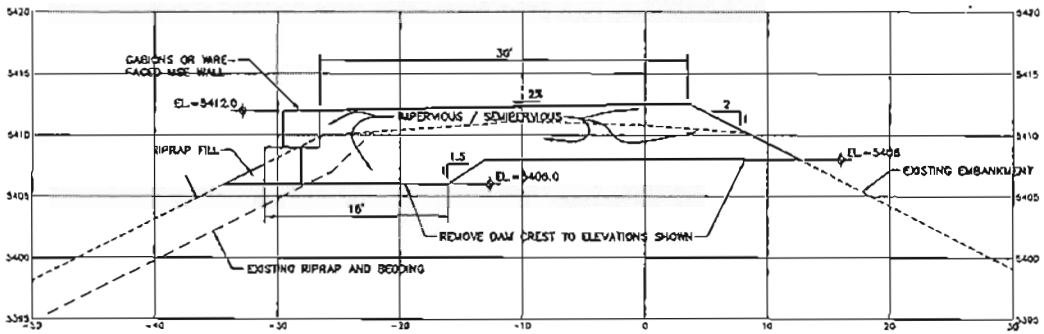
Copyright © 2006 HKM Engineering Inc. All Rights Reserved.



EMBANKMENT CREST PLAN

50 0 50 100
scale feet

CONTOUR INTERVAL = 2 FEET



A SECTION
L2-4 | L2-4 CREST RAISE TYPICAL

5 0 5 10
scale feet

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

EMBANKMENT CREST RAISE PLAN AND SECTION
OPTION L2-100-86.7

WARNING
0 1/2 1
If this bar does not measure 1" then drawing is not to scale

No.	Revision	By	Date

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31516
Billings, MT 59107-1516
(406) 656-6399, Fax (406) 656-6398

Sheet No.
L2-4
of 8

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

APPENDIX A3

OPTION L2-100-96.7

SURVEYING NOTE

1. THE VERTICAL DATUM FOR THIS PROJECT IS THE CONTOUR AT THE TOP OF THE SPILLWAY BEING 5332.00.

2. THE HORIZONTAL COORDINATE SYSTEM FOR THIS JOB IS BASED ON A ORIGINAL NORAD TARGET POINTS AROUND THE RUBY RESERVOIR (POINTS 9, 13, 15 AND 20)

3. FIELD SURVEYS WERE PERFORMED IN OCTOBER AND NOVEMBER OF 2005 USING GPS

4. THE BASELINE FOR CONTROL POINT NUMBER 1 IS:
LATITUDE: 45.1174666443
LONGITUDE: 112.0963710179
ELLIPSOID HEIGHT: 5397.864-E
MEAN ELEVATION: 5432.25' (LOCAL ELEVATION IS 5437.35')
ROTATION FROM GPS NORTH AT CP 1: -0 deg 03'42.42351"
(GPUS SOLUTION ON 10-29-05)

5. NO NGS BM'S WERE SURVEYED.

6. THE OUTLET CHANNEL WAS SURVEYED ON NOVEMBER 30, 2005 AFTER THE WATER WAS SHUT OFF. CONTOURS WERE GENERATED FROM THE OUTLET TO THE CONFLUENCE OF THE RIVER CHANNEL BELOW THE DAM. THE DEPTHS AREA DIRECTLY DOWNSTREAM FROM THE OUTLET STILL COULD NOT BE MEASURED, AND IS LIKELY DEEPER THAN SHOWN. THE NORMAL WATER LINE (10-05) WAS SURVEYED, ALONG WITH THE LOWERED WATER LEVEL (11-05). BOTH WATER LEVELS ARE SHOWN.

NORMAL SURVEYING NOTE

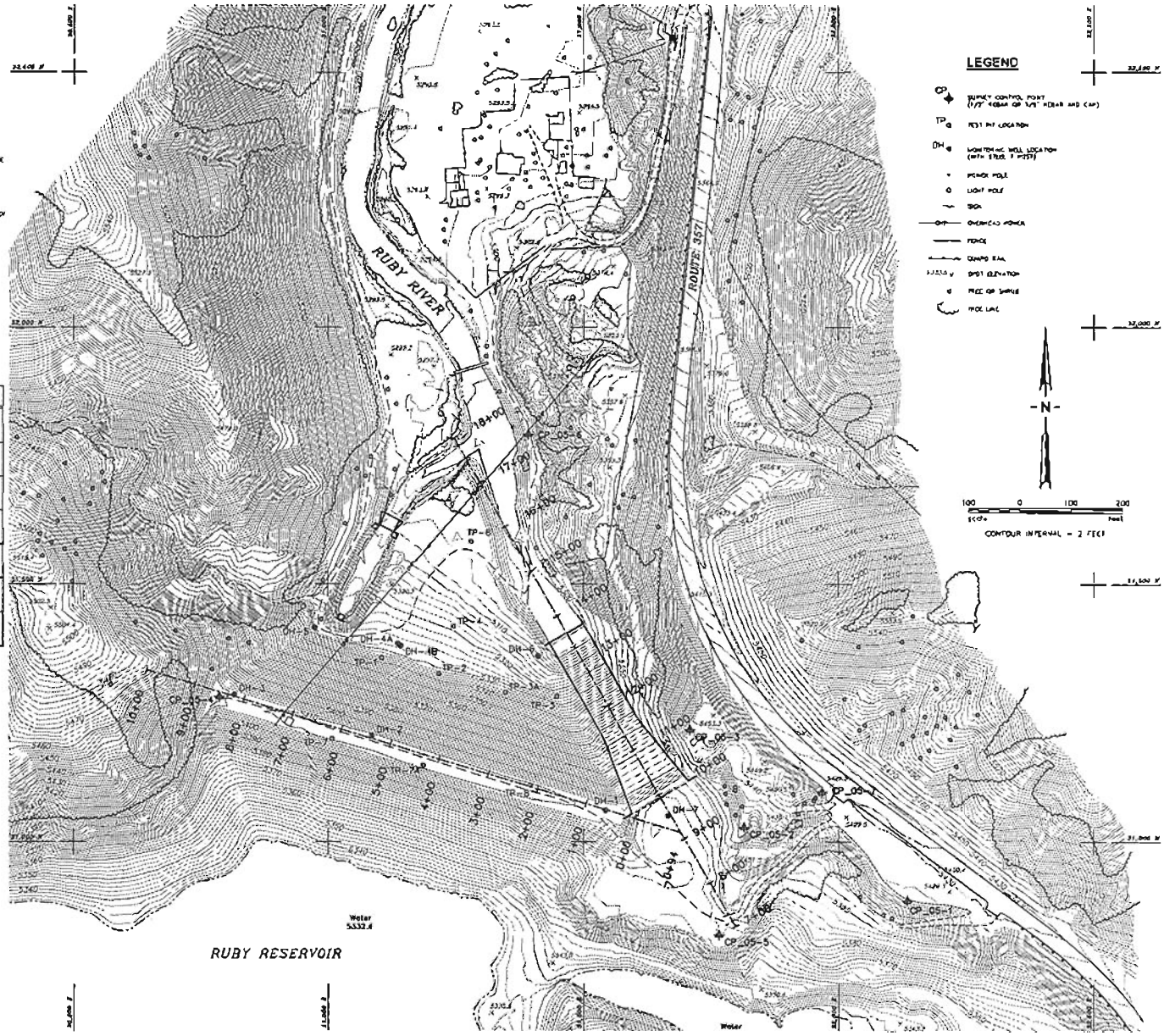
1. SPOT ELEVATIONS IN DESIGNATED AREAS ARE APPROXIMATE AND MAY NOT MEET NATIONAL MAP ACCURACY STANDARDS.

SURVEY CONTROL TABLE

CONTROL POINT	COORDINATES	ELEVATION	DESCRIPTION
CP_05-1	N 30853.984 E 32134.611	5427.31	EXIST. PK NAIL IN ROCK
CP_05-2	N 31028.295 E 31815.810	5432.80	1/2" REBAR
CP_05-3	N 31218.644 E 31710.055	5458.24	1/2" REBAR
CP_05-4	N 31281.772 E 30786.302	5410.32	5/8" REBAR WITH YELLOW PLASTIC CAP
CP_05-5	N 30816.824 E 31766.593	5338.22	5/8" REBAR WITH YELLOW PLASTIC CAP
CP_05-6	N 31793.268 E 31391.484	5302.89	1/2" REBAR
CP_05-7	N 31097.391 E 31968.139	5435.68	MONT. DEPT. OF TRANSPORTATION BRASS CAP BENCHMARK

GEOTECHNICAL EXPLORATION HOLE LOCATIONS

DRILL HOLE	COORDINATES		TEST PIT	COORDINATES
DH-1	N 31061.55 E 31543.24		TP-1	N 31358 E 31165
DH-2	N 31208.93 E 31083.37		TP-2	N 31327 E 31318
DH-3	N 31206.10 E 30816.00		TP-3	N 31283 E 31448
DH-4A	N 31384.70 E 31135.90		TP-3A	N 31291 E 31347
DH-4B	N 31380.84 E 31141.64		TP-4	N 31419 E 31246
DH-5	N 31413.02 E 30973.89		TP-6	N 31583 E 31279
DH-6	N 31361.07 E 31411.92		TP-7	N 31201 E 31008
DH-7	N 31031.19 E 31686.48		TP-7A	N 31150 E 31189
			TP-8	N 31111 E 31398



No.	Revision	By	Date

Project No. 04083.135 Drawing Date JAN 2006 Designed JHT Drawn CAL Checked JHT Approved TT

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

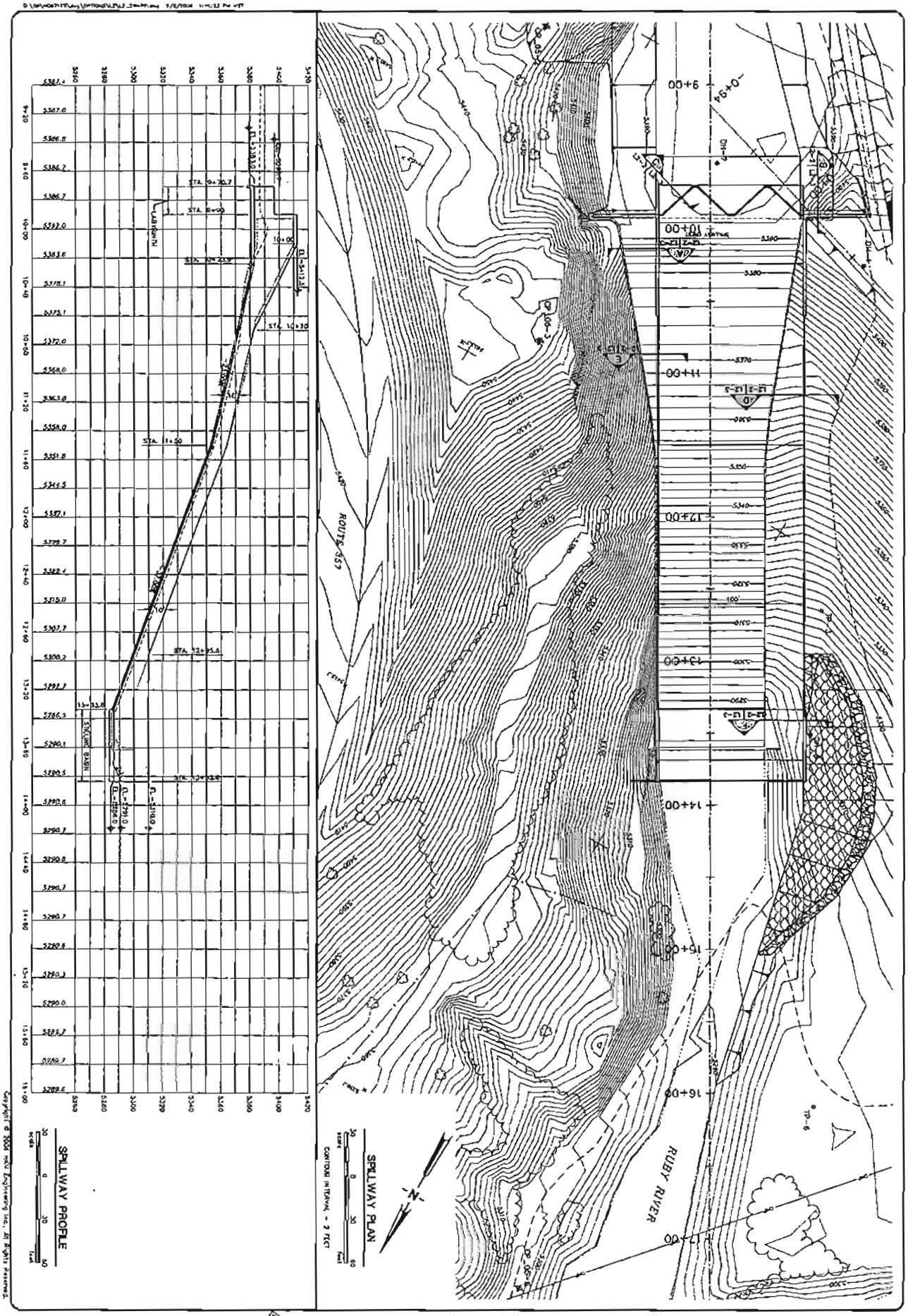
GENERAL SITE PLAN OF EXISTING TOPOGRAPHY
OPTION L2-100-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Crooks Tower Building
1235 Grand Avenue, Suite 306
P.O. Box 31315
Billings, MT 59107-1318
(406) 656-8396, Fax (406) 656-6398

Sheet No.
L2-1

Copyright © 2006 HKM Engineering Inc. All Rights Reserved.



Copyright © 2006 HKM Engineering Inc. All Rights Reserved.

Project No. BM087.175 • L2_SW-PP.dwg • Date MAY, 2006 • Designed JC • Drawn CAE • Checked JHT • Approved JHT

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31316
Billings, MT 59107-1316
(406) 656-6399, Fax (406) 656-6396

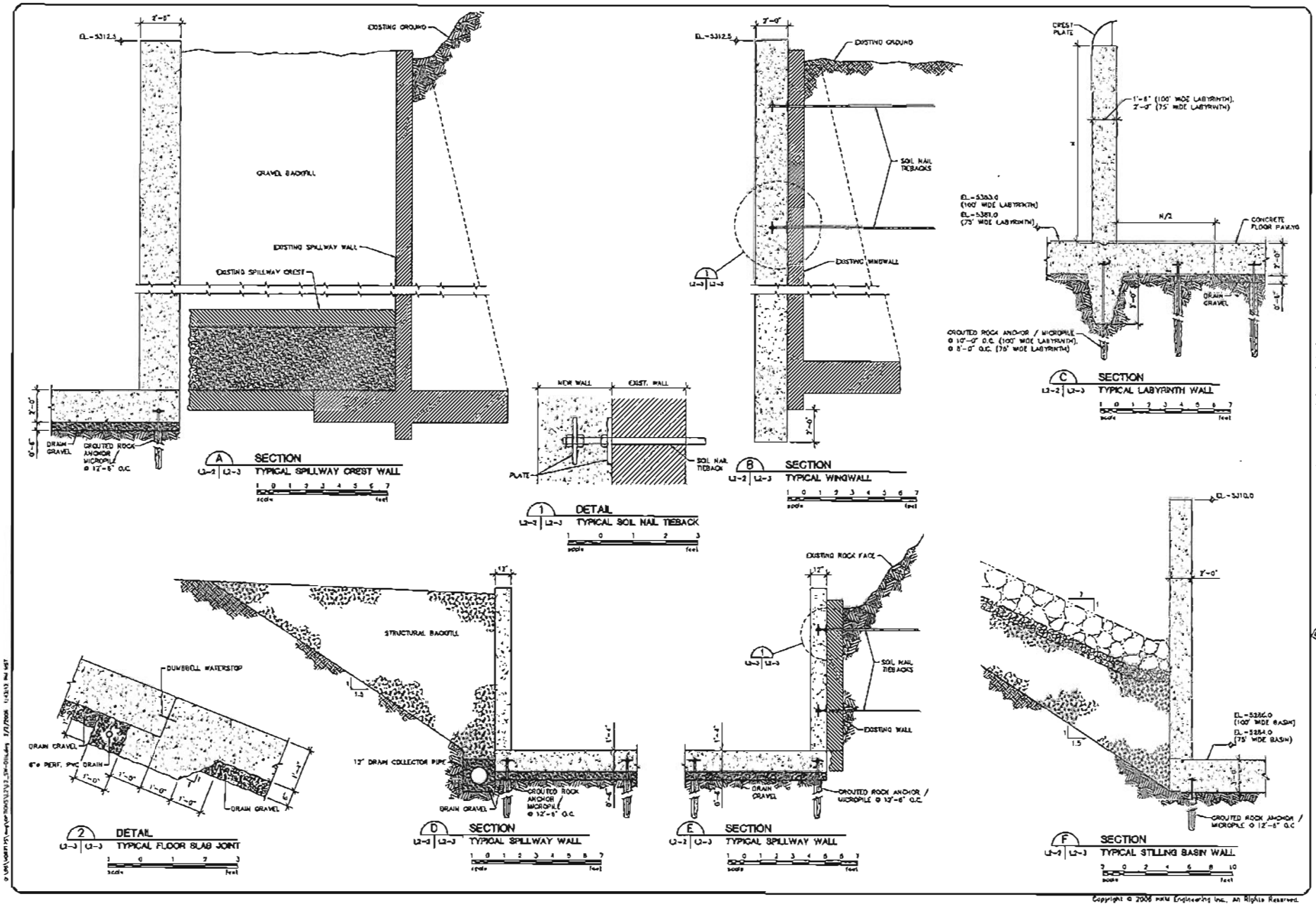
Sheet No. L2-2

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

SPILLWAY PLAN AND PROFILE
OPTION L2-100-96.7

WARNING: IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

No.	Revision	By	Date



RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

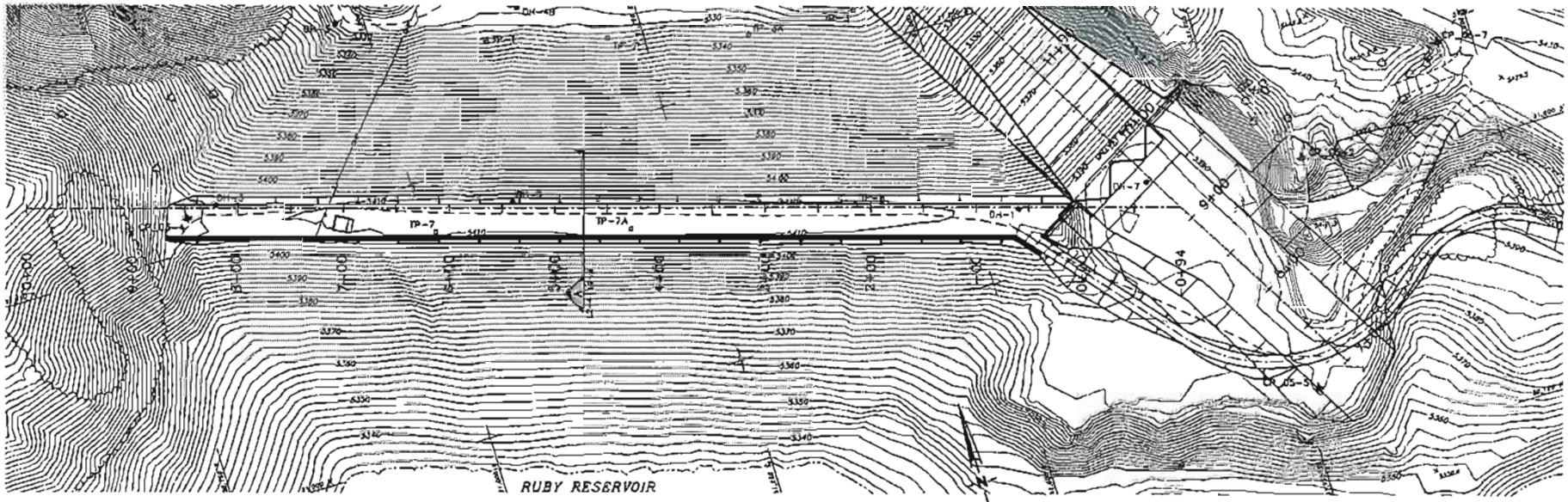
TYPICAL SPILLWAY SECTIONS AND DETAILS
OPTION L2-100-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6395

Sheet No.
L2-3
of 6

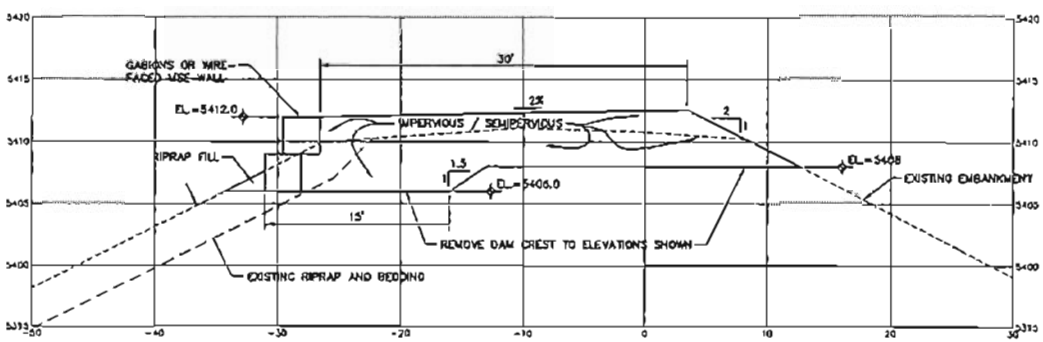
Copyright © 2006 HKM Engineering Inc., All Rights Reserved.



EMBANKMENT CREST PLAN

50 0 50 100
scale feet

CONTOUR INTERVAL = 2 FEET



A SECTION
L2-4 | L2-4 CREST RAISE TYPICAL

5 0 5 10
scale feet

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

EMBANKMENT CREST RAISE PLAN AND SECTION
OPTION L2-100-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 100
P.O. Box 31616
Billings, MT 59107-1316
(406) 656-6399, Fax (406) 656-6388

Sheet No.
L2-4
of 6

Copyright © 2006 HKM Engineering Inc., All Rights Reserved

APPENDIX A4

OPTION LB1-100-96.7

SURVEYOR'S NOTE:

1. THE VERTICAL DATUM FOR THIS PROJECT IS THE CENTERLINE AT THE TOP OF THE SPILLWAY BEING 5372.00.

2. THE HORIZONTAL COORDINATE SYSTEM FOR THIS JOB IS BASED ON 4 ORIGINAL NGVD TARGET POINTS AROUND THE RUBY RESERVOIR (POINTS 8, 13, 18, AND 29).

3. FIELD SURVEYS WERE PERFORMED IN OCTOBER AND NOVEMBER OF 2005 USING GPS.

4. THE LAT/LONG FOR CONTROL POINT NUMBER 8 IS:
LATITUDE: 45.1411856445
W LONGITUDE: 112.0835778079
ELLIPSOID HEIGHT: 5397.8647
NAVD ELEVATION: 5431.28' (LOCAL ELEVATION IS 5427.31')
ROTATION FROM GPS NORTH AT CP 1: -2 deg 57'45.4844"
(GPSUS SOLUTION ON 10-25-05)

5. NO PIPE INV'S WERE SURVEYED.

6. THE OUTLET CHANNEL WAS SURVEYED ON NOVEMBER 30, 2005 AFTER THE WATER WAS SHUT OFF. CONTOURS WERE GENERATED FROM THE OUTLET TO THE CONFLUENCE OF THE RIVER CHANNEL BELOW THE DAM. THE DEEPEST AREA IMMEDIATELY DOWNSTREAM FROM THE OUTLET STILL COULD NOT BE INCREMENTED, AND IS LIKELY DEEPER THAN SHOWN. THE NORMAL WATER LINE (10-05) WAS SURVEYED, ALONG WITH THE LOWERED WATER LEVEL (11-05). BOTH WATER LEVELS ARE SHOWN.

NOTES, MAPPING NOTE:

1. SPOT ELEVATIONS IN DENSELY WOODED AREAS ARE APPROXIMATE AND MAY NOT MEET NATIONAL MAP ACCURACY STANDARDS.

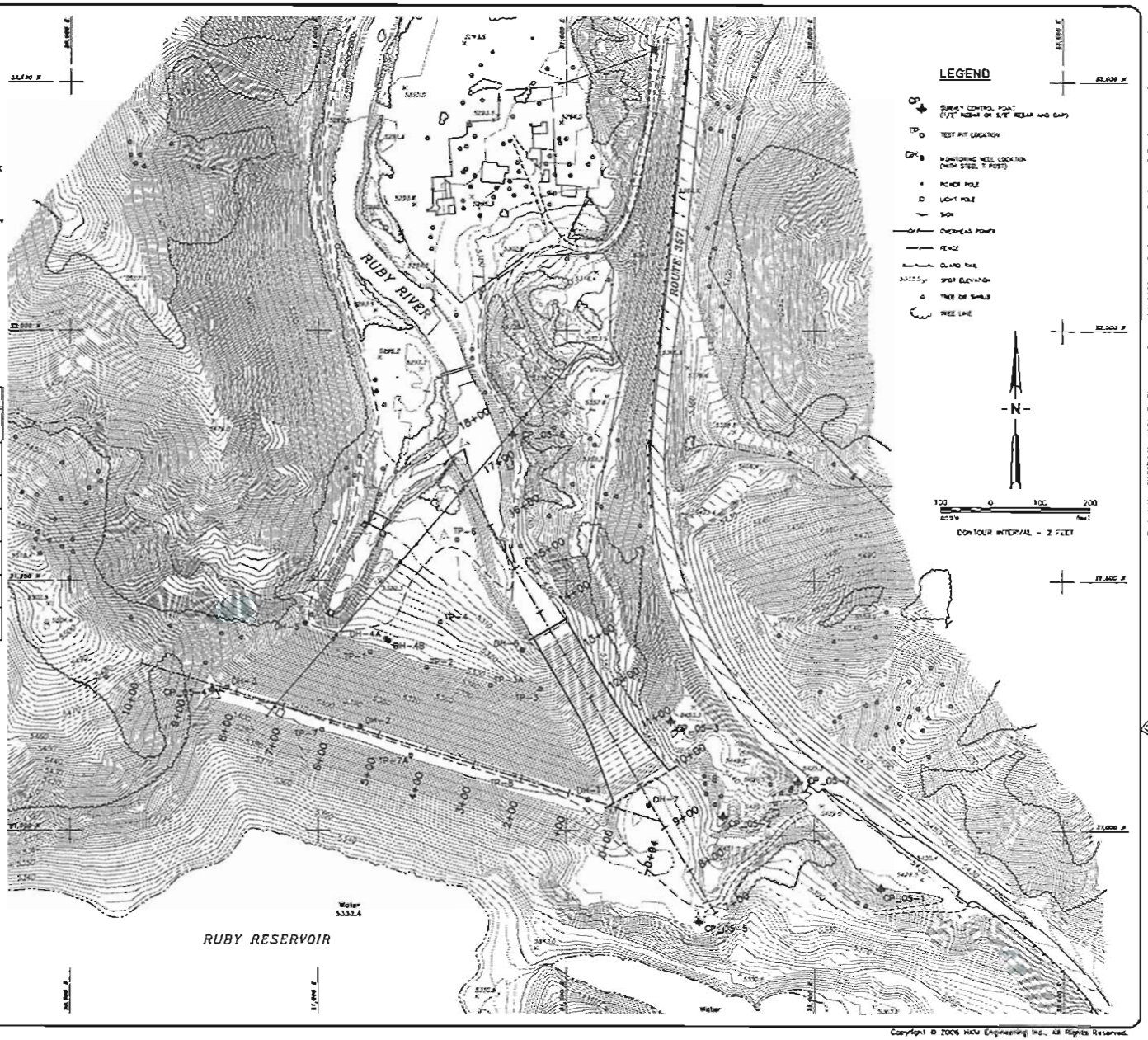
SURVEY CONTROL TABLE

CONTROL POINT	COORDINATES	ELEVATION	DESCRIPTION
CP_05-1	N 30853.984 E 32134.611	5427.31	EXIST. PK NAIL IN ROCK
CP_05-2	N 31028.295 E 31815.810	5432.60	1/2" REBAR
CP_05-3	N 31218.664 E 31740.006	5450.24	1/2" REBAR
CP_05-4	N 31281.772 E 30786.302	5410.32	5/8" REBAR WITH YELLOW PLASTIC CAP
CP_05-5	N 30816.824 E 31366.593	5388.22	5/8" REBAR WITH YELLOW PLASTIC CAP
CP_05-6	N 31793.268 E 31391.464	5302.89	1/2" REBAR
CP_05-7	N 31097.391 E 31968.139	5435.68	MONT. DEPT. OF TRANSPORTATION BRASS CAP BENCHMARK

GEOTECHNICAL EXPLORATION HOLE LOCATIONS

DRILL HOLE	COORDINATES
DH-1	N 31061.55 E 31543.28
DH-2	N 31206.95 E 31085.37
DH-3	N 31286.10 E 30816.00
DH-4A	N 31384.28 E 31135.98
DH-4B	N 31380.64 E 31141.64
DH-5	N 31415.62 E 30973.69
DH-6	N 31361.07 E 31411.22
DH-7	N 31051.19 E 31666.48

TEST PIT	COORDINATES
TP-1	N 31358 E 31105
TP-2	N 31327 E 31218
TP-3	N 31283 E 31443
TP-3A	N 31291 E 31347
TP-4	N 31419 E 31248
TP-6	N 31583 E 31279
TP-7	N 31201 E 31008
TP-7A	N 31150 E 31186
TP-8	N 31111 E 31396



Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

No.	Revision	By	Date

WARNING
Plotted to scale only. Paper may have grown or shrunk since originally plotted.

Project No. 06007.175 • Dwg. Date JAN. 2006 • Designed JKT • Drawn RAE • Checked JHT • Approved TT

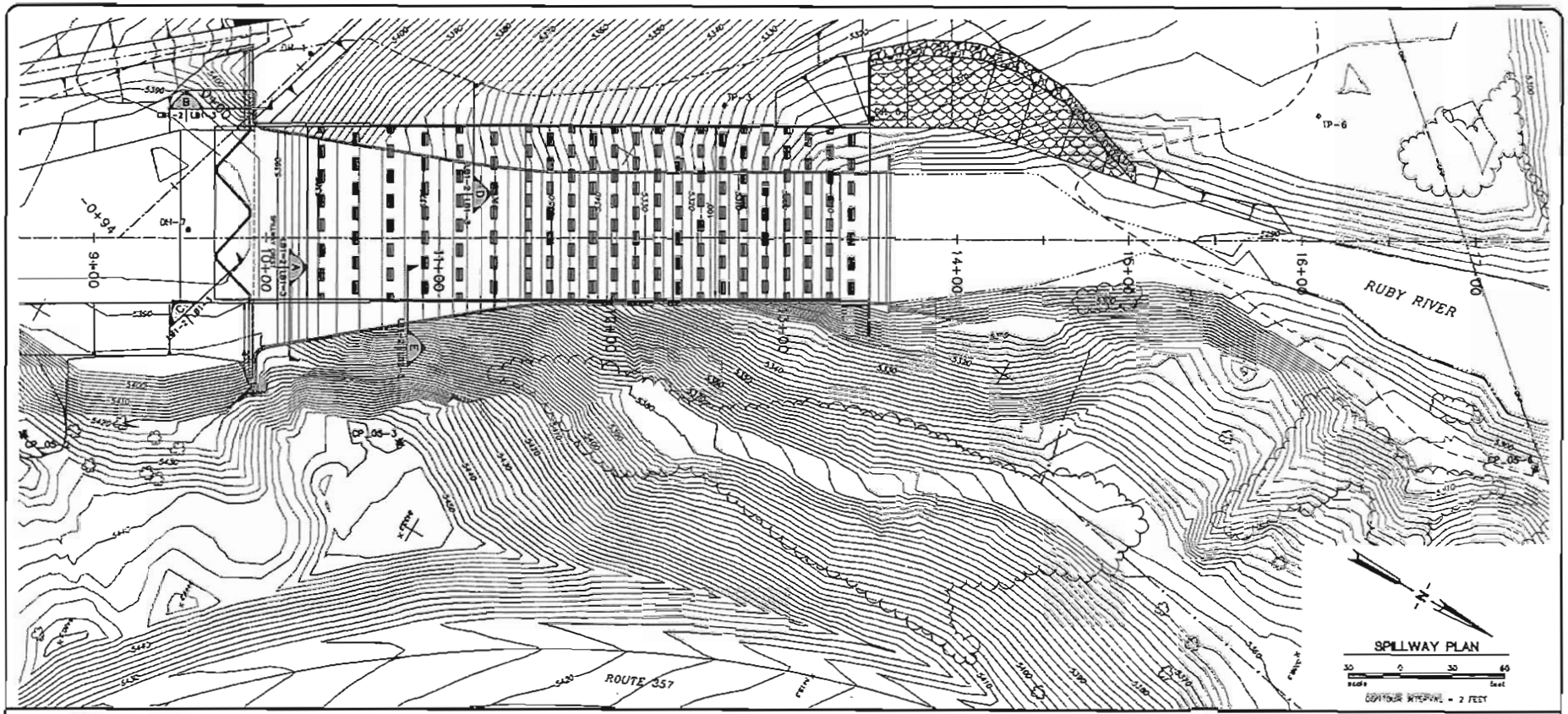
RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

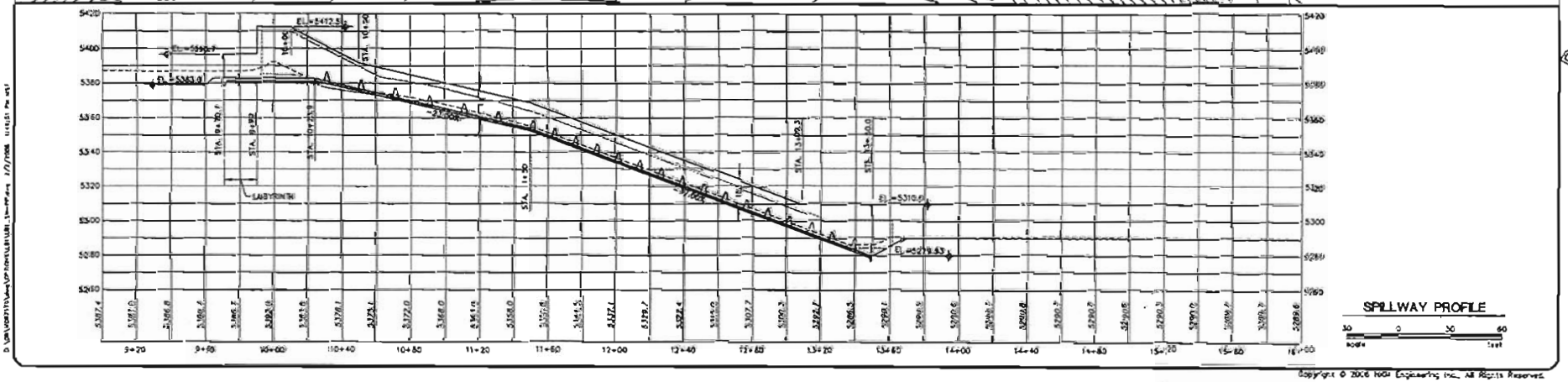
GENERAL SITE PLAN OF EXISTING TOPOGRAPHY
OPTION LB1-100-98.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31116
Billings, MT 59107-1116
(406) 656-4399, Fax (406) 656-6308

Sheet No.
LB1-1
of 1





RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

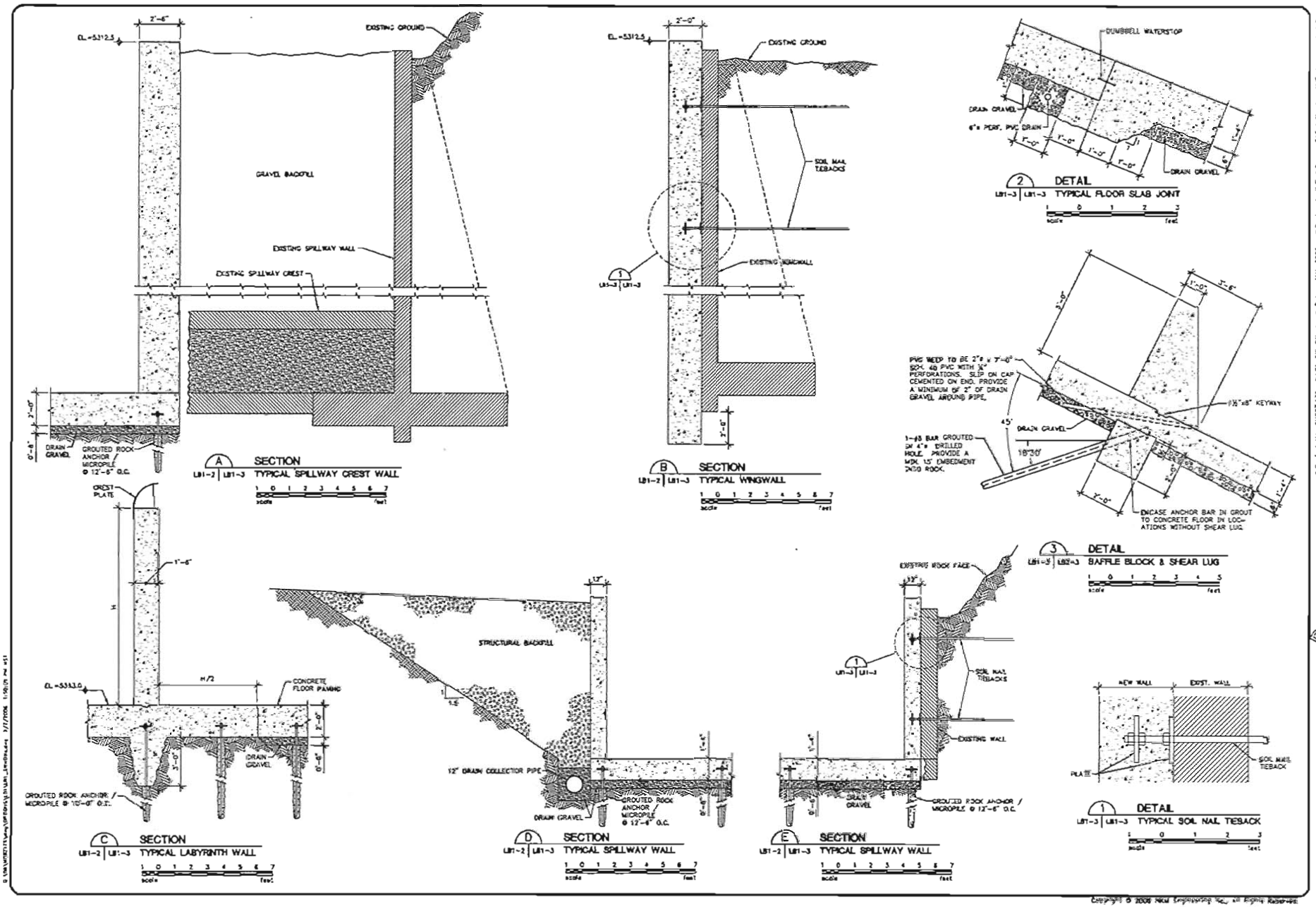
SPILLWAY PLAN AND PROFILE
OPTION LB1-100-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31518
Billings, MT 59107-1518
(406) 656-4390, Fax (406) 656-4398

Sheet No.
LB1-2
of 6

Copyright © 2006 HKM Engineering Inc. All Rights Reserved.



RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

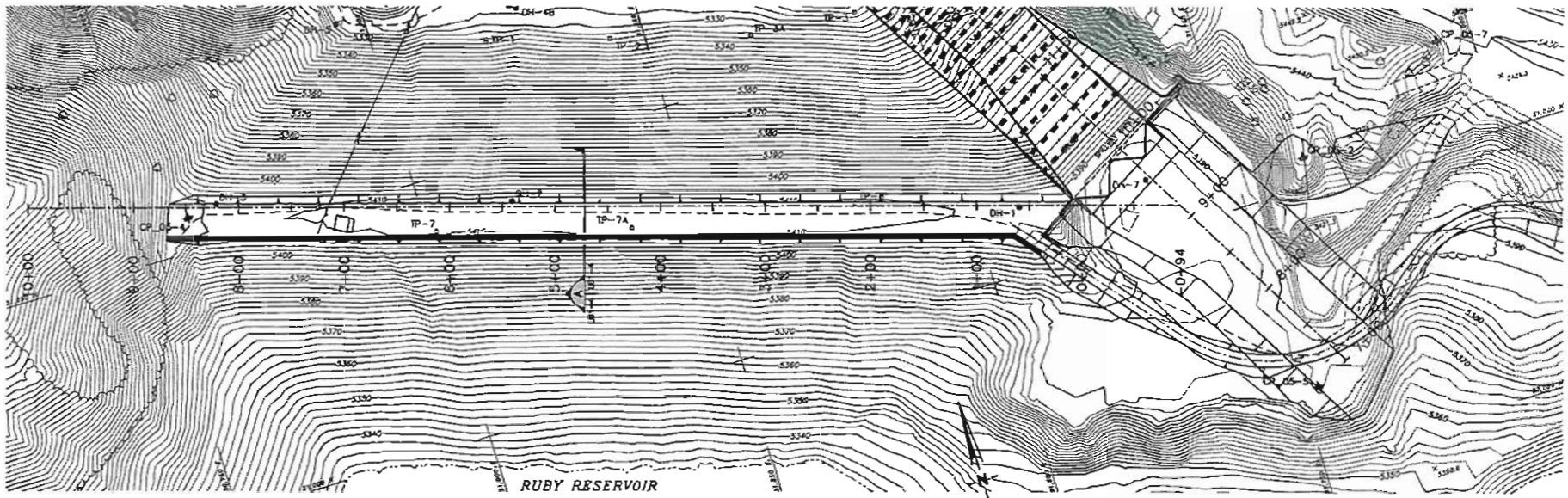
TYPICAL SPILLWAY SECTIONS AND DETAILS
OPTION LB1-100-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
LB1-3
of 6

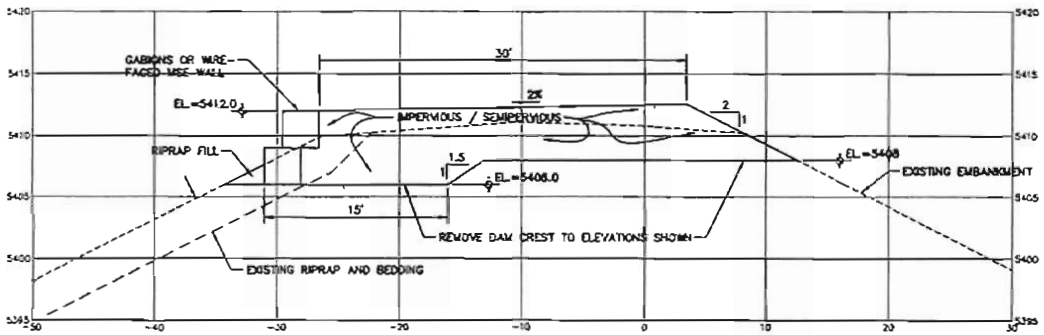
Copyright © 2006 HKM Engineering Inc., all Rights Reserved.



EMBANKMENT CREST PLAN

50 0 50 100
scale feet

CONTOUR INTERVAL = 2 FEET



A SECTION
LB1-4 | LB1-4 CREST RAISE TYPICAL

5 0 5 10
scale feet

No.	Revision	By	Date

WARNING
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWINGS ARE NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

EMBANKMENT CREST RAISE PLAN AND SECTION
OPTION LB1-100-96.7

Project No. 8J0017.170 • LB1_DraftPlan.dwg • Date JAN. 2008 • Designed JRT • Drawn CAL • Checked JRT • Approved JRT

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
23 N. 32nd St., Suite 100
P.O. Box 2115
Billings, MT 59107-1218
(406) 254-8395, Fax (406) 656-6390

Sheet No.
LB1-4
of 6

Copyright © 2008 HKM Engineering Inc., All Rights Reserved

APPENDIX A5

OPTION P1-100-96.7

SURVEYOR'S NOTE:

1. THE VERTICAL DATUM FOR THIS PROJECT IS THE CENTERLINE OF THE SPILLWAY BONE 5393.00

2. THE HORIZONTAL COORDINATE SYSTEM FOR THIS JOB IS BASED ON 4 ORIGINAL NORMAL TARGET POINTS AROUND THE RUBY RESERVOIR (POINTS 6, 15, 16, AND 17)

3. FIELD SURVEYS WERE PERFORMED IN OCTOBER AND NOVEMBER OF 2005 USING GPS.

4. THE LAT/LONG FOR CONTROL POINT NUMBER 1 IS:
LATITUDE: 43.14185643
W LONGITUDE: 112.06257727
ELLIPSOID HEIGHT: 5397.6642'
NAVD ELEVATION: 5431.28' (LOCAL ELEVATION IS 5427.31')
ROTATION FROM GPS NORTH AT CP 1: -0 deg 05'45.49(63)"
(OPUS SOLUTION ON 10-25-05)

5. NO NGS BM'S WERE SURVEYED.

6. THE OUTLET CHANNEL WAS SURVEYED ON NOVEMBER 30, 2005 AFTER THE WATER WAS SHUT OFF. CONTOURS WERE GENERATED FROM THE OUTLET TO THE CONFLUENCE OF THE RIVER CHANNEL BELOW THE DAM. THE DEEPEST AREA IMMEDIATELY DOWNSTREAM FROM THE OUTLET STILL COULD NOT BE MEASURED, AND IS LIKELY DEEPER THAN SHOWN. THE NORMAL WATER LINE (10-05) WAS SURVEYED, ALONG WITH THE LOWERED WATER LEVEL (11-05). BOTH WATER LEVELS ARE SHOWN.

NORMAL MARPOS NOTE:

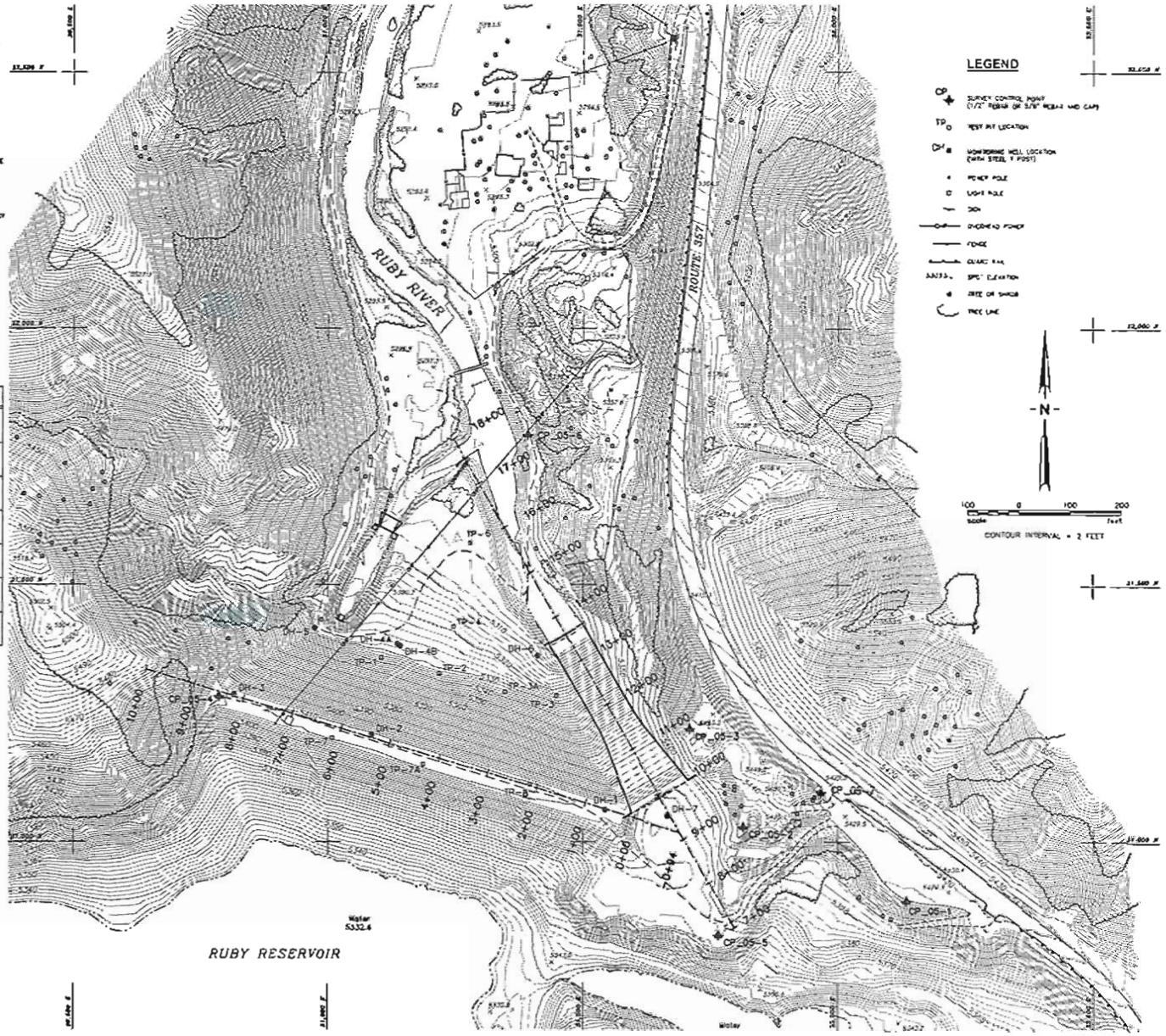
1. SPOT ELEVATIONS IN OBSCURED AREAS ARE APPROXIMATE AND MAY NOT MEET NATIONAL MAP ACCURACY STANDARDS.

SURVEY CONTROL TABLE

CONTROL POINT	COORDINATES	ELEVATION	DESCRIPTION
CP_05-1	N 30883.984 E 32134.611	5427.30	DRST. PK NAIL IN ROCK
CP_05-2	N 31028.295 E 31815.810	5432.50	1/2" REBAR
CP_05-3	N 31218.664 E 31710.055	5450.24	1/2" REBAR
CP_05-4	N 31281.772 E 30786.302	5410.32	5/8" REBAR WITH YELLOW PLASTIC CAP
CP_05-5	N 30818.824 E 31766.593	5388.22	5/8" REBAR WITH YELLOW PLASTIC CAP
CP_05-6	N 31793.268 E 31391.484	5302.89	1/2" REBAR
CP_05-7	N 31097.391 E 31968.139	5435.68	MONT. DEPT. OF TRANSPORTATION BRASS CAP BENCHMARK

GEOTECHNICAL EXPLORATION HOLE LOCATIONS

DRILL HOLE	COORDINATES		TEST PIT	COORDINATES
DH-1	N 31041.55 E 31543.28		TP-1	N 31356 E 31105
DH-2	N 31208.95 E 31083.37		TP-2	N 31327 E 31216
DH-3	N 31286.10 E 30816.00		TP-3	N 31283 E 31446
DH-4A	N 31364.28 E 31126.98		TP-3A	N 31281 E 31347
DH-4B	N 31368.64 E 31140.64		TP-4	N 31419 E 31246
DH-5	N 31415.42 E 30973.19		TP-6	N 31563 E 31279
DH-6	N 31361.07 E 31411.20		TP-7	N 31201 E 31006
DH-7	N 31051.19 E 31466.48		TP-7A	N 31150 E 31188
			TP-8	N 31311 E 31396



No.	Revision	By	Date

WARNING
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWINGS ARE NOT 11X17 SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

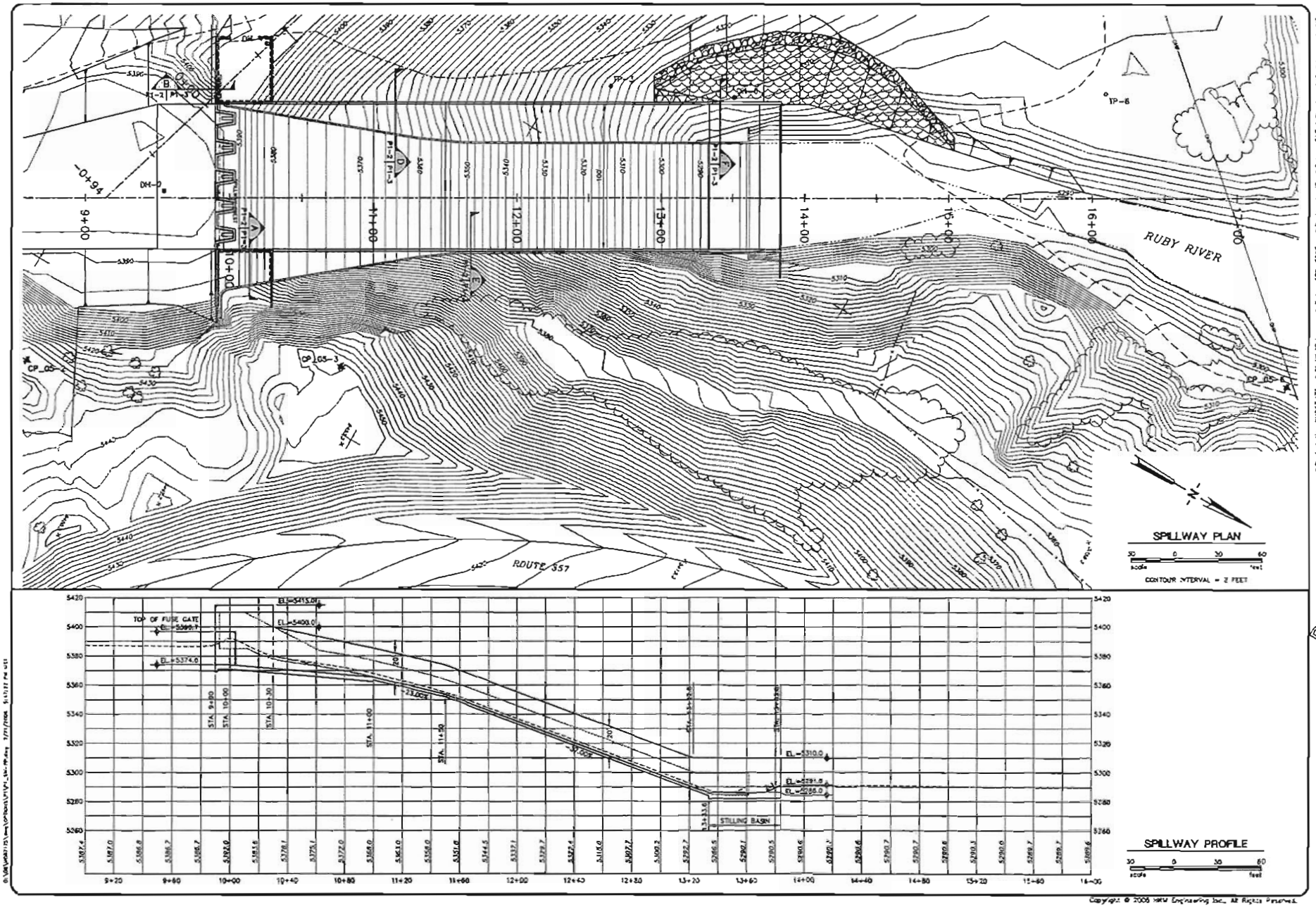
GENERAL SITE PLAN OF EXISTING TOPOGRAPHY
OPTION P1-100-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
2821 2nd Ave N, Suite 100
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-5299, Fax (406) 656-0308

Sheet No.
P1-1

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.



RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

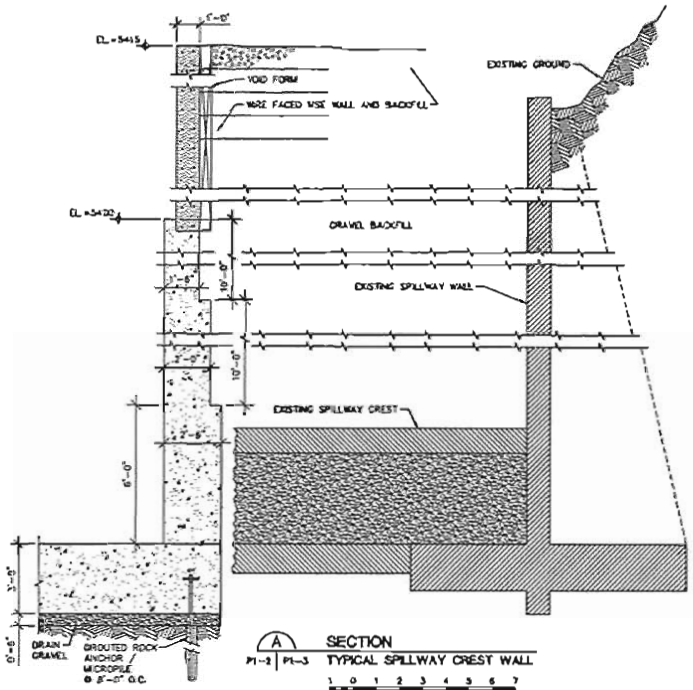
SPILLWAY PLAN AND PROFILE
OPTION P1-100-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

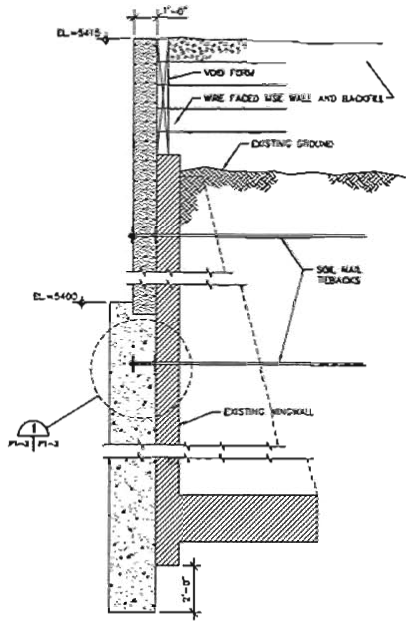
HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6308

Sheet No.
P1-2
of 8

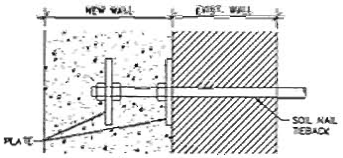
Copyright © 2006 HKM Engineering Inc., All Rights Reserved.



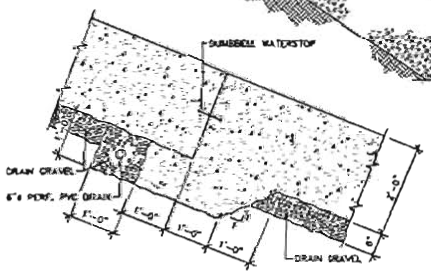
A SECTION
P1-2 | P1-3 TYPICAL SPILLWAY CREST WALL
scale 1 0 1 2 3 4 5 6 7 feet



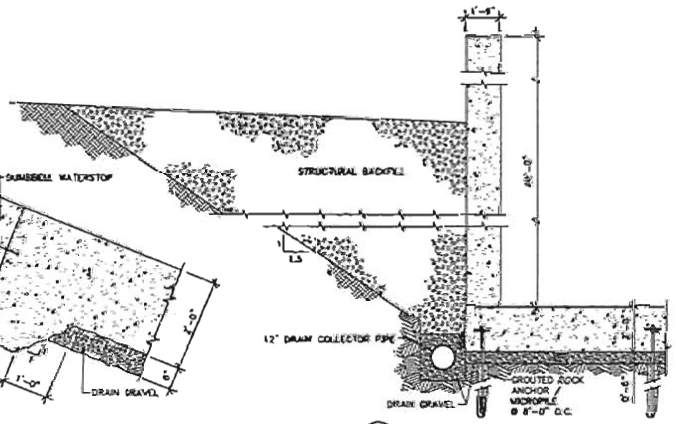
B SECTION
P1-2 | P1-3 TYPICAL WINGWALL
scale 1 0 1 2 3 4 5 6 7 feet



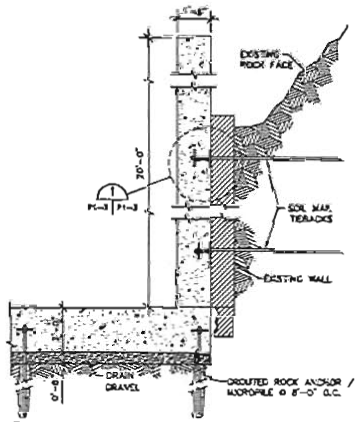
1 DETAIL
P1-2 | P1-3 TYPICAL SOIL NAIL TIEBACK
scale 1 0 1 2 3 feet



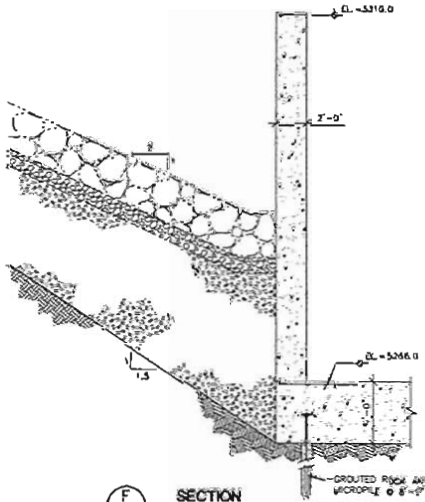
2 DETAIL
P1-3 | P1-3 TYPICAL FLOOR SLAB JOINT
scale 1 0 1 2 3 feet



D SECTION
P1-2 | P1-3 TYPICAL SPILLWAY WALL
scale 1 0 1 2 3 4 5 6 7 feet



E SECTION
P1-2 | P1-3 TYPICAL SPILLWAY WALL
scale 1 0 1 2 3 4 5 6 7 feet



F SECTION
P1-2 | P1-3 TYPICAL STILLING BASIN WALL
scale 3 0 3 6 8 10 feet

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

S:\DRAWINGS\Projects\P1_SK-Site.dwg 1/31/2006 5:31:01 PM MST

• Project No. 8A047.175 • P1_SK-Site.dwg • Date FEB. 2006 • Designed KJF • Drawn OAC • Checked KJF • Approved JEF

No.	Revision	By	Date

WARNING
0 1" IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

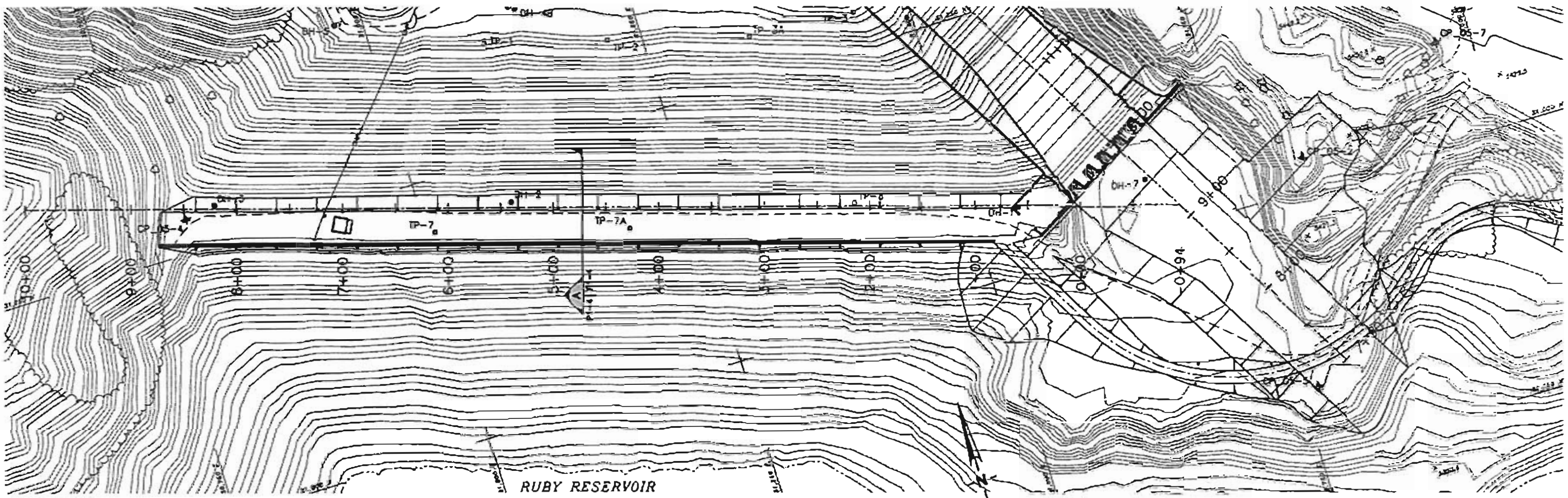
RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

TYPICAL SPILLWAY SECTIONS AND DETAILS
OPTION P1-100-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 2553
Billings, MT 59107-1318
(406) 254-6395, Fax (406) 656-6308

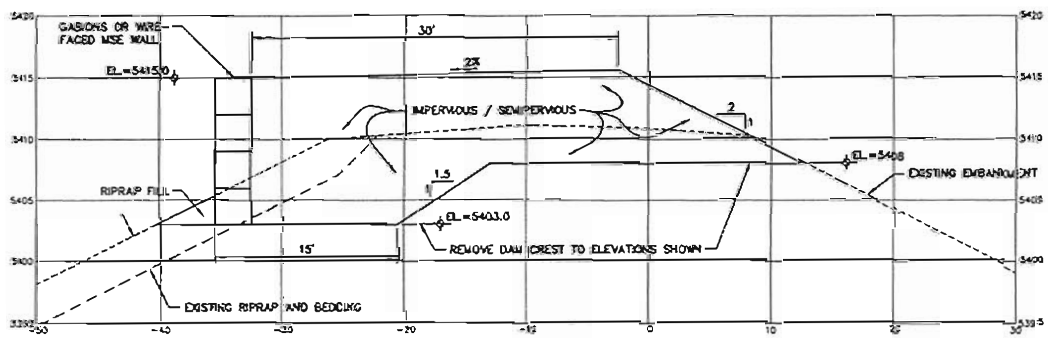
Sheet No.
P1-3
of 8



EMBANKMENT CREST PLAN

50 0 50 100
scale feet

CONTOUR INTERVAL = 2 FEET



SECTION A (P1-4 | P1-4)
CREST RAISE TYPICAL

5 0 5 10
scale feet

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

Project No. 8M057.176 • P1_CrestPlan.dwg • Date FEB. 2006 • Designed JLT • Drawn GAC • Checked JLT • Approved JLT

Mk.	Revision	By	Date

WARNING: IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

EMBANKMENT CREST RAISE PLAN AND SECTION
OPTION P1-100-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

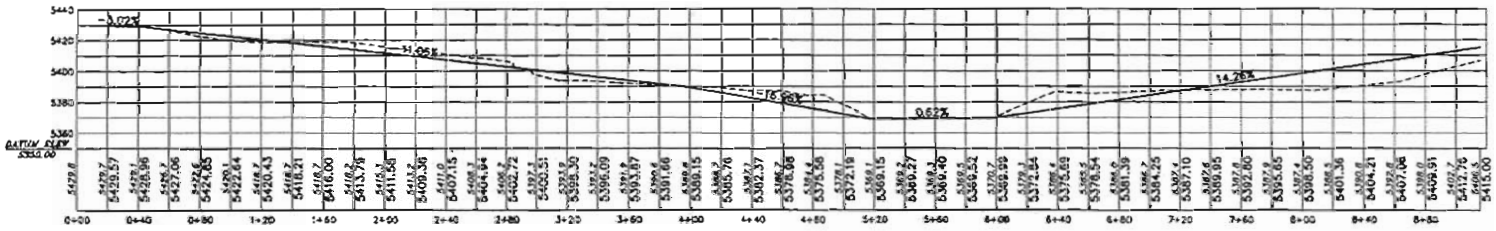
HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
P1-4
of 8

SPILLWAY APPROACH ROAD PLAN

40 0 40 80
scale feet

CONTOUR INTERVAL = 2 FEET



SPILLWAY APPROACH ROAD PROFILE

40 0 40 80
scale feet

PRELIMINARY
NOT FOR CONSTRUCTION

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

SPILLWAY APPROACH PLAN
OPTION P1-100-96.7

WARNING
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

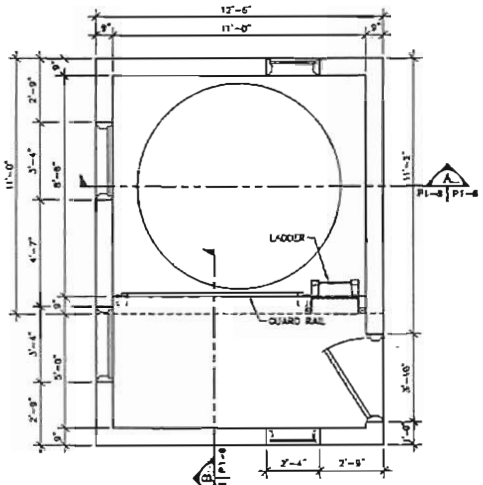
No.	Revision	By	Date

Project No. 8M067.175 • P1_Approach.dwg • Date FEB. 2006 • Designed JHT • Drawn CAC • Checked JHT • Approved JHT

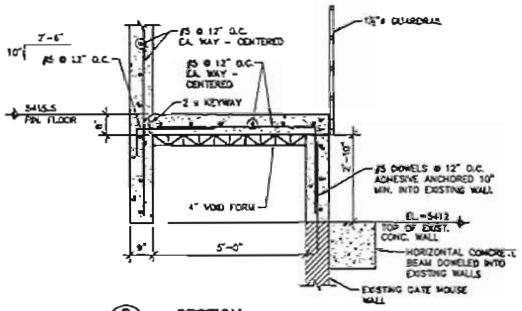
HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
P1-5
of 8

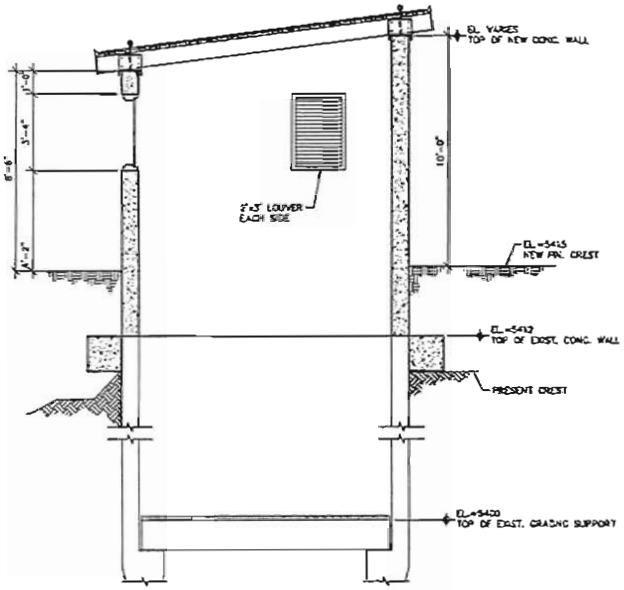
Copyright © 2006 HKM Engineering Inc., All Rights Reserved.



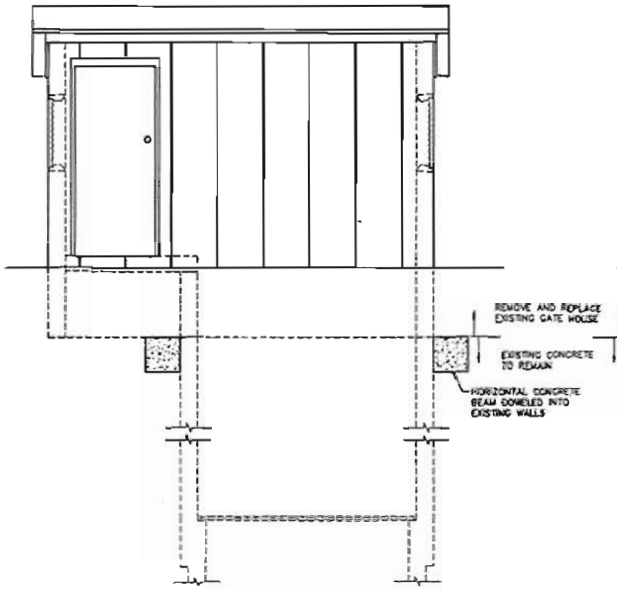
PLAN
GATE HOUSE



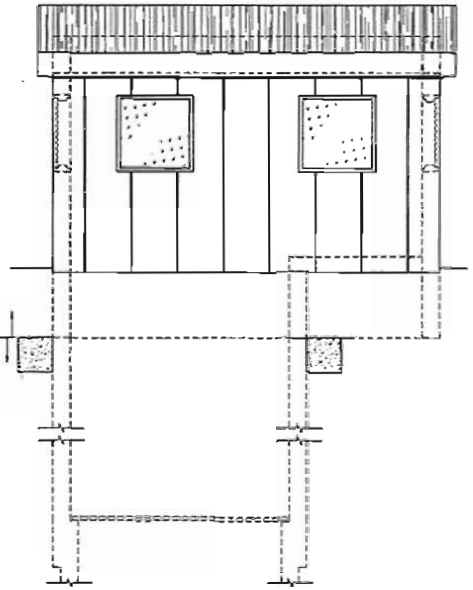
SECTION
GATE HOUSE WALL & FLOOR



SECTION
GATE HOUSE



NORTH ELEVATION
GATE HOUSE



SOUTH ELEVATION
GATE HOUSE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

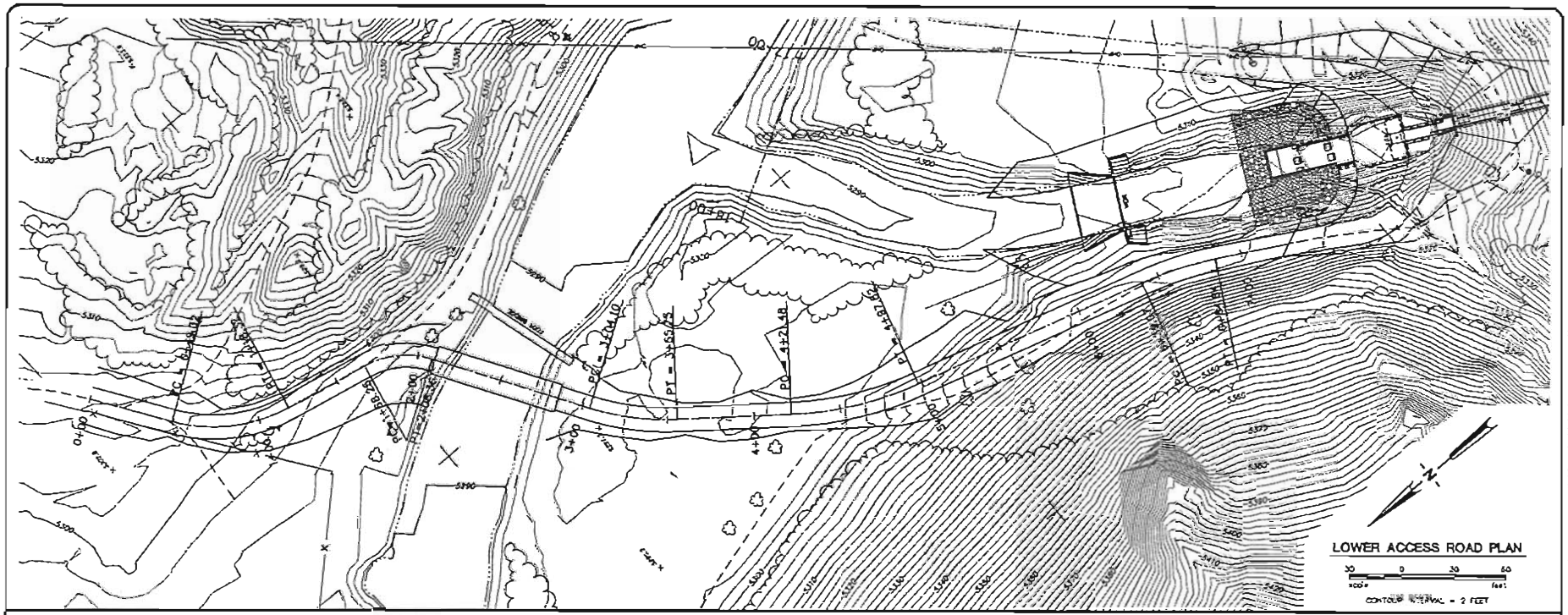
OUTLET WORKS GATE HOUSE REPLACEMENT
OPTION P1-100-96.7

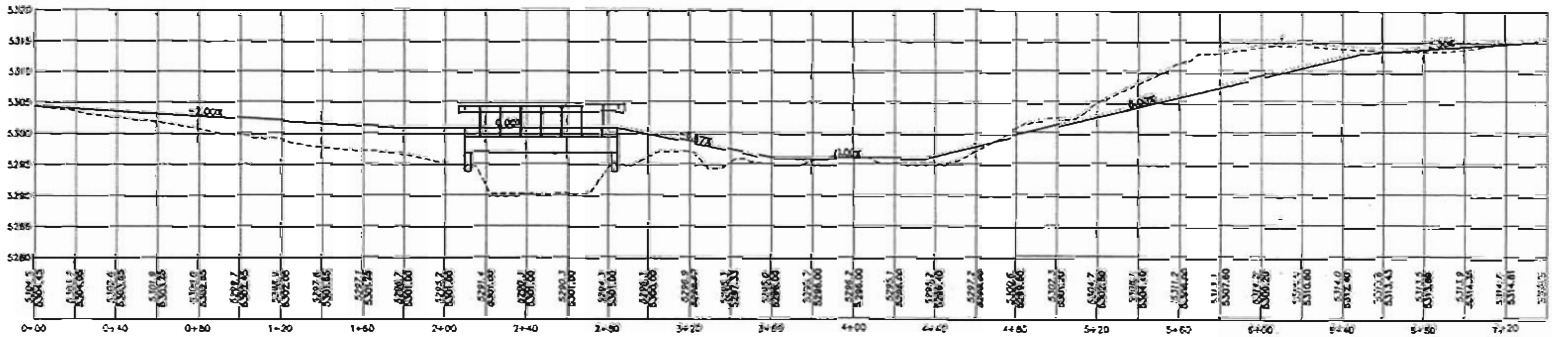
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 100
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
P1-6
of 8

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.





RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

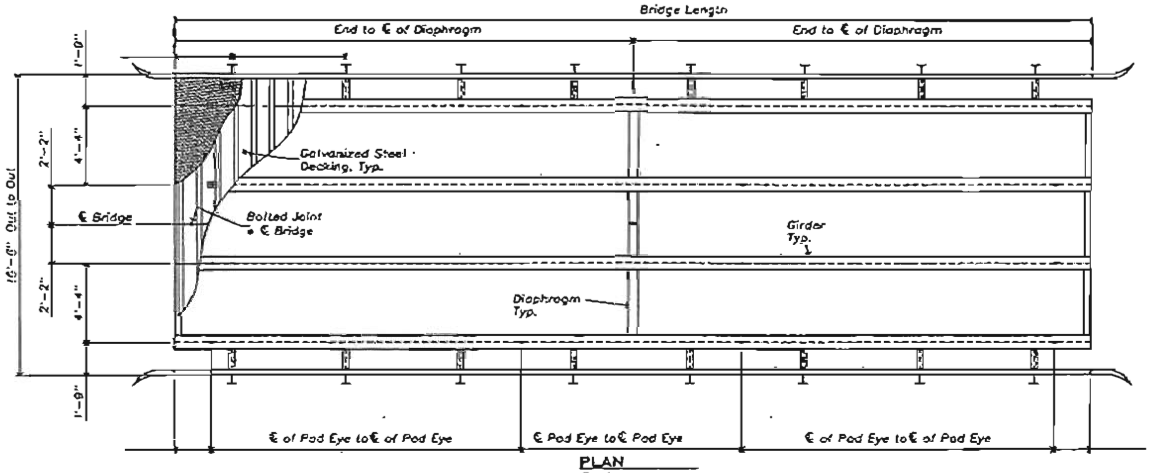
LOWER ACCESS ROAD
OPTION P1-100-96.7

PRELIMINARY
NOT FOR CONSTRUCTION

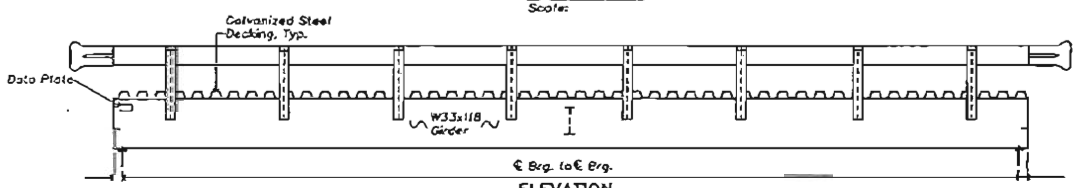
HKM ENGINEERING
Granite Tower Building
222 N. 32nd St. Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6396

Sheet No.
P1-7

Copyright © 2006 HKM Engineering Inc. All Rights Reserved.

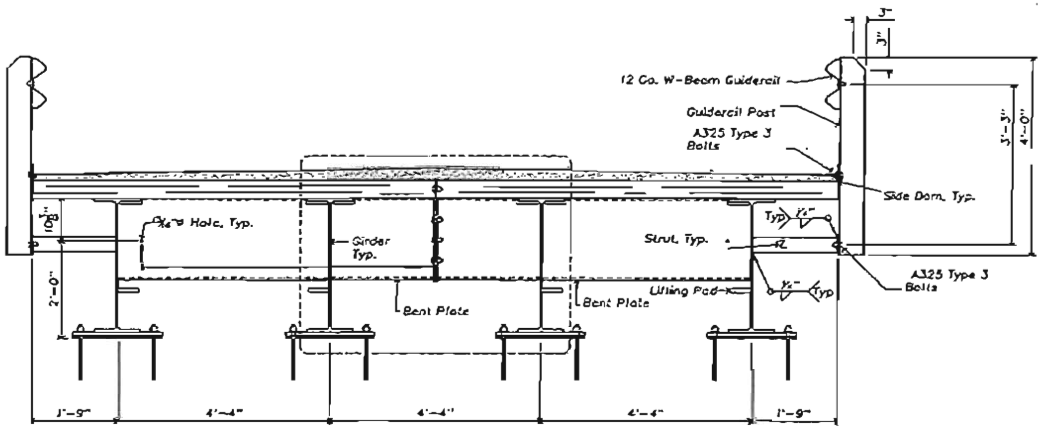


PLAN
Scale:

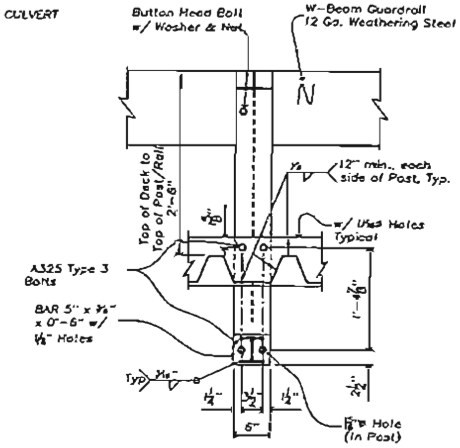


ELEVATION
Scale:

FABRICATED BY:
ROSCOE STEEL & CULVERT



END SECTION
Scale:



1/0 SECTION
Scale:

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

LOWER ACCESS ROAD BRIDGE
OPTION P1-100-98.7

PRELIMINARY
NOT FOR CONSTRUCTION

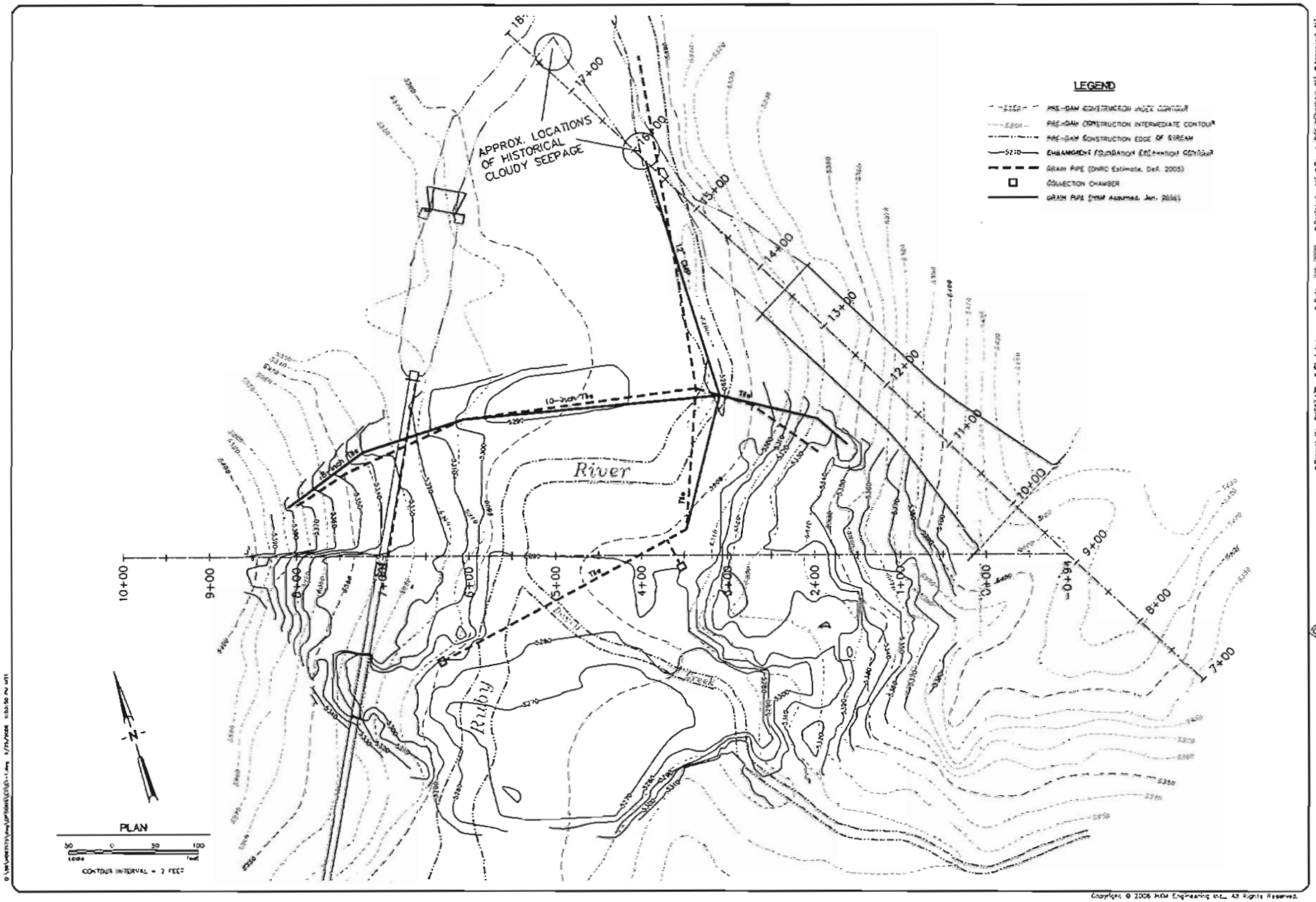
HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6390, Fax (406) 656-6398

Sheet No.
P1-8
of 8

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

APPENDIX B

FOUNDATION EXCAVATION & DRAINS DRAWING



Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

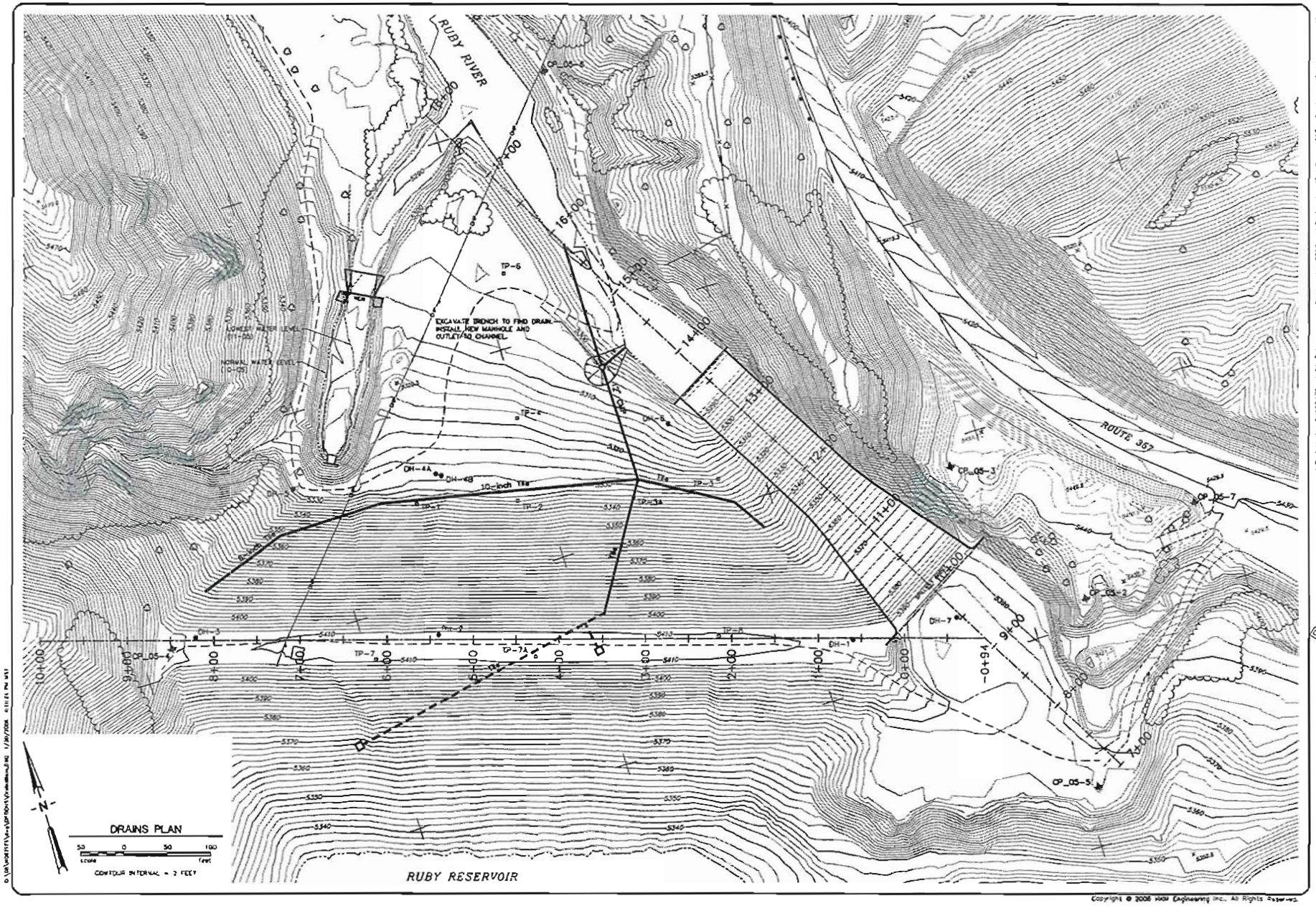
FOUNDATION EXCAVATION AND DRAINS PLAN
FROM ORIGINAL CONSTRUCTION RECORDS

No.	Revision	By	Date

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31314
Billings, MT 59107-1314
(406) 656-6399, Fax (406) 656-6398

Sheet No.
B1-1
of 2



PRELIMINARY
NOT FOR CONSTRUCTION

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

DRAIN SYSTEM MODIFICATIONS
ALL OPTIONS

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

Project No. 8M087.175 • C1n2.dwg • Date JAN 2006 • Designed JHF • Drawn CAE • Checked JHF • Approved JHF

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
B1-2
of 2

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

APPENDIX C

COST ESTIMATES

RUBY DAM REHABILITATION
FEASIBILITY STUDY PARAMETRIC COST ANALYSIS

	Ogee Crest		Labyrinth Crest				Baffled Chute	Fusegate Crest		
Option Name	O1-120-93.0	O1-120-96.7	L1-75-96.7	L2-100-93.0	L2-100-96.7	L2-100-00	LB1-100-96.7	P1-100-93.0	P1-100-96.7	P1-100-00
Top of Dam Elevation (ft)	5410	5412.5	5413.5	5410	5410	5413	5410	5415	5415	5415
Spillway Crest Elevation (ft)	5393.0	5396.7	5396.7	5393.0	5396.7	5400.0	5396.7	5393.0	5396.7	5400.0
Storage (acre-ft)	37,642	41,450	41,450	37,642	41,450	45,115	41,450	37,642	41,450	45,115
Construction Costs										
Spillway	$3,553,966	$3,741,790	$3,634,148	$3,805,036	$3,948,838	$4,300,056	$3,748,378	$6,764,524	$6,648,464	$6,544,584
Dam Crest	$54,400	$342,500	$427,500	$54,400	$54,400	$385,800	$54,400	$578,800	$578,800	$578,800
Outlet	$1,280,000	$1,280,000	$1,280,000	$1,280,000	$1,280,000	$1,280,000	$1,280,000	$1,280,000	$1,280,000	$1,280,000
Upstream Bridge Access	$136,500	$136,500	$136,500	$136,500	$136,500	$136,500	$136,500	$136,500	$136,500	$136,500
Reservoir Impacts	$0	$200,000	$200,000	$0	$200,000	$650,000	$200,000	$0	$200,000	$650,000
Drains	$20,000	$50,000	$50,000	$20,000	$20,000	$50,000	$20,000	$20,000	$100,000	$100,000
Mobilization (15%)	$757,000	$863,000	$859,000	$794,000	$846,000	$1,020,000	$816,000	$1,317,000	$1,342,000	$1,393,000
Unlisted Items (10%)	$580,000	$641,000	$639,000	$609,000	$629,000	$717,000	$606,000	$1,010,000	$1,009,000	$1,003,000
Total Construction Cost	**$6,380,000**	**$7,250,000**	**$7,230,000**	**$6,700,000**	**$7,110,000**	**$8,540,000**	**$6,860,000**	**$11,110,000**	**$11,290,000**	**$11,690,000**
Program Costs										
Geotech Studies	$10,000	$20,000	$20,000	$10,000	$10,000	$20,000	$10,000	$30,000	$30,000	$30,000
Cultural/Environmental Studies	$0	$10,000	$10,000	$0	$10,000	$15,000	$10,000	$10,000	$15,000	$20,000
ROW/Easements	$500,000	$750,000	$750,000	$500,000	$750,000	$1,000,000	$750,000	$500,000	$750,000	$1,000,000
Engineering/Management (10%)	$638,000	$725,000	$723,000	$670,000	$711,000	$854,000	$686,000	$1,110,000	$1,130,000	$1,170,000
Construction Admin (7%)	$447,000	$508,000	$506,000	$469,000	$498,000	$598,000	$480,000	$780,000	$790,000	$820,000
Contingencies (10%)	$638,000	$725,000	$723,000	$670,000	$711,000	$854,000	$686,000	$1,111,000	$1,129,000	$1,169,000
Hydropower Studies	$0	$0	$0	$0	$0	$0	$0	$100,000	$100,000	$100,000
Water Rights	$0	$20,000	$20,000	$0	$20,000	$50,000	$20,000	$0	$20,000	$50,000
FERC License	$0	$0	$0	$0	$0	$0	$0	$50,000	$50,000	$50,000
Total Program Cost	**$2,230,000**	**$2,760,000**	**$2,750,000**	**$2,320,000**	**$2,710,000**	**$3,390,000**	**$2,640,000**	**$3,690,000**	**$4,010,000**	**$4,410,000**
Total Project Cost	**$8,610,000**	**$10,010,000**	**$9,980,000**	**$9,020,000**	**$9,820,000**	**$11,930,000**	**$9,500,000**	**$14,800,000**	**$15,300,000**	**$16,100,000**

APPENDIX C1

OGEE CREST OPTIONS

RUBY DAM REHABILITATION FEASIBILITY
HKM - 8M087.175
Option O1-120-93.0
Cost Estimate

Option O1-120-93.0 - 120' Ogee Crest at elev 5393.0 ft (new concrete over existing); level Dam Crest top 5410.0 ft; 120-75' tapered Spillway Chute; 75' Type II Combination Basin; new Jet Flow Gate outlet works

Spillway Crest Width =	120	
Spillway Crest Elevation =	5393.0	
Reservoir Storage =	37,642	
Spillway Chute Width =	120-75	
Max Res. W.S. =	5405.7	
Dam Crest Elevation =	5410.0	
Spillway Design Capacity =	20,000	
Dam Overtopping Flow =	30,700	
Stilling Basin Length =	70	
Stilling Basin Width =	75	
Stilling Basin Design Flow =	4,000	(500-yr Outflow)

Material Costs			
Floor Concrete	$	800.00	/CY
Wall Concrete	$	1,000.00	/CY
Ogee Concrete	$	850.00	/CY
Labyrinth Wall	$	1,000.00	/CY
Labyrinth Crest	$	105.00	/LF
Rock Anchors	$	575.00	/EA
Excavation	$	12.00	/CY
Rock Fill/Riprap	$	55.00	/CY
Drain Gravel	$	60.00	/CY
Structural Backfill	$	10.00	/CY
Concrete Demo	$	35.00	/CY
6" Drain Pipe	$	15.00	/LF
12" Drain Pipe	$	35.00	/LF
Baffle Concrete	$	850.00	/CY

Spillway Crest STA 9+90 TO 10+20			Unit Cost	Total Material Cost
Wall Concrete	113	CY	$ 1,000.00	$ 113,000.00
Ogee Concrete	393	CY	$ 850.00	$ 334,050.00
Rock Anchors	46	EA	$ 575.00	$ 26,450.00
Excavation	412	CY	$ 12.00	$ 4,944.00
Structural Backfill	370	CY	$ 10.00	$ 3,700.00
Concrete Demo	271	CY	$ 35.00	$ 9,485.00
		Total Crest Cost		$ 491,629.00

Spillway Chute STA 10+20 TO 13+39			Unit Cost	Total Material Cost
Floor Concrete	1364	CY	$ 800.00	$ 1,091,200.00
Wall Concrete	421	CY	$ 1,000.00	$ 421,000.00
Rock Anchors	222	EA	$ 575.00	$ 127,650.00
Drain Gravel	547	CY	$ 60.00	$ 32,820.00
6" Drain Pipe	960	LF	$ 15.00	$ 14,400.00
12" Drain Pipe	336	LF	$ 35.00	$ 11,760.00
Excavation	3902	CY	$ 12.00	$ 46,824.00
Structural Backfill	1479	CY	$ 10.00	$ 14,790.00
Concrete Demo	822	CY	$ 35.00	$ 28,770.00
		Total Chute Cost		$ 1,789,214.00

Stilling Basin STA 13+39 TO 14+09			Unit Cost	Total Material Cost
Floor Concrete	730	CY	$ 800.00	$ 584,000.00
Wall Concrete	305	CY	$ 1,000.00	$ 305,000.00
Rock Anchors	34	EA	$ 575.00	$ 19,550.00
Drain Gravel	98	CY	$ 60.00	$ 5,880.00
Excavation	1858	CY	$ 12.00	$ 22,296.00
Structural Backfill	285	CY	$ 10.00	$ 2,850.00
Concrete Demo	157	CY	$ 35.00	$ 5,495.00
		Total Basin Cost		$ 945,071.00

Outlet Works Modification			Unit Cost	Total Material Cost
Outlet Option OW4	1	LS	$ 1,280,000.00	$ 1,280,000.00
		Total Outlet Works Cost		$ 1,280,000.00

Miscellaneous			Unit Cost	Total Material Cost
Excavation/Backfill				
Approach Excavation	23121	CY	$ 12.00	$ 277,452.00
Downstream Channel Riprap	920	CY	$ 55.00	$ 50,600.00
Raised Embankment				
Gate House/Extension	1	LS	$ 40,000.00	$ 40,000.00
Embankment	1	LS	$ 14,400.00	$ 14,400.00
Upstream Access	1	LS	$ 136,500.00	$ 136,500.00
Embankment Drain Mods	1	LS	$ 20,000.00	$ 20,000.00
Mobilization/Preparation (15%)	1	LS	$ 757,000.00	$ 757,000.00
Unlisted Items (10%)	1	LS	$ 580,000.00	$ 580,000.00
		Total Other Costs		$ 1,875,952.00

TOTAL OPTION O2-120-93.0 COST $ 6,381,866

RUBY DAM REHABILITATION FEASIBILITY
HKM - 8M087.175
Option O1-120-96.7
Cost Estimate

Option O1-120-96.7 - 120' Ogee Crest at elev 5396.7 ft (new concrete over existing); Dam Crest at elev 5412.5 ft; 120-75' tapered Spillway Chute; 75' Type II Combination Basin; new Jet Flow Gate outlet works

Spillway Crest Width =	120	
Spillway Crest Elevation =	5396.7	
Reservoir Storage =	41,450	
Spillway Chute Width =	120-75	
Max Res. W.S. =	5409.3	
Dam Crest Elevation =	5412.5	
Spillway Design Capacity =	20,000	
Dam Overtopping Flow =	27,500	
Stilling Basin Length =	70	
Stilling Basin Width =	75	
Stilling Basin Design Flow =	4,000	(500-yr Outflow)

Material Costs			
Floor Concrete	$	800.00	/CY
Wall Concrete	$	1,000.00	/CY
Ogee Concrete	$	850.00	/CY
Labyrinth Wall	$	1,000.00	/CY
Labyrinth Crest	$	105.00	/LF
Rock Anchors	$	575.00	/EA
Excavation	$	12.00	/CY
Rock Fill/Riprap	$	55.00	/CY
Drain Gravel	$	60.00	/CY
Structural Backfill	$	10.00	/CY
Concrete Demo	$	35.00	/CY
6" Drain Pipe	$	15.00	/LF
12" Drain Pipe	$	35.00	/LF
Baffle Concrete	$	850.00	/CY

Spillway Crest STA 9+90 TO 10+20			Unit Cost	Total Material Cost
Wall Concrete	253	CY	$ 1,000.00	$ 253,000.00
Ogee Concrete	545	CY	$ 850.00	$ 463,250.00
Rock Anchors	46	EA	$ 575.00	$ 26,450.00
Excavation	464	CY	$ 12.00	$ 5,568.00
Structural Backfill	414	CY	$ 10.00	$ 4,140.00
Concrete Demo	271	CY	$ 35.00	$ 9,485.00
		Total Crest Cost		$ 761,893.00

Spillway Chute STA 10+20 TO 13+39			Unit Cost	Total Material Cost
Floor Concrete	1364	CY	$ 800.00	$ 1,091,200.00
Wall Concrete	421	CY	$ 1,000.00	$ 421,000.00
Rock Anchors	222	EA	$ 575.00	$ 127,650.00
Drain Gravel	547	CY	$ 60.00	$ 32,820.00
6" Drain Pipe	960	LF	$ 15.00	$ 14,400.00
12" Drain Pipe	336	LF	$ 35.00	$ 11,760.00
Excavation	3902	CY	$ 12.00	$ 46,824.00
Structural Backfill	1479	CY	$ 10.00	$ 14,790.00
Concrete Demo	822	CY	$ 35.00	$ 28,770.00
		Total Chute Cost		$ 1,789,214.00

Stilling Basin STA 13+39 TO 14+09			Unit Cost	Total Material Cost
Floor Concrete	730	CY	$ 800.00	$ 584,000.00
Wall Concrete	305	CY	$ 1,000.00	$ 305,000.00
Rock Anchors	34	EA	$ 575.00	$ 19,550.00
Drain Gravel	98	CY	$ 60.00	$ 5,880.00
Excavation	1858	CY	$ 12.00	$ 22,296.00
Structural Backfill	285	CY	$ 10.00	$ 2,850.00
Concrete Demo	157	CY	$ 35.00	$ 5,495.00
		Total Basin Cost		$ 945,071.00

Outlet Works Modification			Unit Cost	Total Material Cost
Outlet Option OW4	1	LS	$ 1,280,000.00	$ 1,280,000.00
		Total Outlet Works Cost		$ 1,280,000.00

Miscellaneous			Unit Cost	Total Material Cost
Excavation/Backfill				
Approach Excavation	16251	CY	$ 12.00	$ 195,012.00
Downstream Channel Riprap	920	CY	$ 55.00	$ 50,600.00
Raised Embankment				
Gate House/Extension	1	LS	$ 42,500.00	$ 42,500.00
Embankment/Wall	1	LS	$ 300,000.00	$ 300,000.00
Upstream Access	1	LS	$ 136,500.00	$ 136,500.00
Embankment Drain Mods	1	LS	$ 50,000.00	$ 50,000.00
Reservoir Impacts	1	LS	$ 200,000.00	$ 200,000.00
Mobilization/Preparation (15%)	1	LS	$ 863,000.00	$ 863,000.00
Unlisted Items (10%)	1	LS	$ 641,000.00	$ 641,000.00
		Total Other Costs		$ 2,478,612.00

TOTAL OPTION O1-120-96.7 COST	$ 7,254,790

APPENDIX C2

LABYRINTH CREST OPTIONS

RUBY DAM REHABILITATION FEASIBILITY
HKM - 8M087.175
Option L1-75-96.7
Cost Estimate

Option L1-75-96.7 - 75' Labyrinth Crest at elev 5396.7 ft; Dam Crest at elev 5410 ft; 75' straight Baffled Chute; new Jet Flow Gate outlet works

Spillway Crest Width =	75	
Spillway Crest Elevation =	5396.7	
Reservoir Storage =	41,450	
Spillway Chute Width =	75	
Max Res. W.S. =	5410.3	
Dam Crest Elevation =	5413.5	
Spillway Design Capacity =	20,000	
Dam Overlopping Flow =	25,050	
Stilling Basin Length =	70	
Stilling Basin Width =	75	
Stilling Basin Design Flow =	4,000	(500-yr Outflow)

Material Costs			
Floor Concrete	$	800.00	/CY
Wall Concrete	$	1,000.00	/CY
Ogee Concrete	$	850.00	/CY
Labyrinth Wall	$	1,000.00	/CY
Labyrinth Crest	$	105.00	/LF
Rock Anchors	$	575.00	/EA
Excavation	$	12.00	/CY
Rock Fill/Riprap	$	55.00	/CY
Drain Gravel	$	60.00	/CY
Structural Backfill	$	10.00	/CY
Concrete Demo	$	35.00	/CY
6" Drain Pipe	$	15.00	/LF
12" Drain Pipe	$	35.00	/LF
Baffle Concrete	$	850.00	/CY

Spillway Crest STA 9+90 TO 10+20			Unit Cost	Total Material Cost
Wall Concrete	399	CY	$ 1,000.00	$ 399,000.00
Floor Concrete	185	CY	$ 800.00	$ 148,000.00
Labyrinth Wall	123	CY	$ 1,000.00	$ 123,000.00
Labyrinth Crest	105	FT	$ 105.00	$ 11,025.00
Rock Anchors	46	EA	$ 575.00	$ 26,450.00
Excavation	1293	CY	$ 12.00	$ 15,516.00
Drain Gravel	70	CY	$ 60.00	$ 4,200.00
Structural Backfill	2940	CY	$ 10.00	$ 29,400.00
Concrete Demo	331	CY	$ 35.00	$ 11,585.00
		Total Crest Cost		$ 768,176.00

Spillway Chute STA 10+20 TO 13+34			Unit Cost	Total Material Cost
Floor Concrete	1333	CY	$ 800.00	$ 1,066,400.00
Wall Concrete	390	CY	$ 1,000.00	$ 390,000.00
Rock Anchors	189	EA	$ 575.00	$ 108,675.00
Drain Gravel	528	CY	$ 60.00	$ 31,680.00
6" Drain Pipe	900	LF	$ 15.00	$ 13,500.00
12" Drain Pipe	323	LF	$ 35.00	$ 11,305.00
Excavation	3108	CY	$ 12.00	$ 37,296.00
Structural Backfill	738	CY	$ 10.00	$ 7,380.00
Concrete Demo	767	CY	$ 35.00	$ 26,845.00
		Total Chute Cost		$ 1,693,081.00

Stilling Basin STA 13+39 TO 14+09			Unit Cost	Total Material Cost
Floor Concrete	730	CY	$ 800.00	$ 584,000.00
Wall Concrete	270	CY	$ 1,000.00	$ 270,000.00
Rock Anchors	34	EA	$ 575.00	$ 19,550.00
Drain Gravel	98	CY	$ 60.00	$ 5,880.00
Excavation	1858	CY	$ 12.00	$ 22,296.00
Structural Backfill	285	CY	$ 10.00	$ 2,850.00
Concrete Demo	157	CY	$ 35.00	$ 5,495.00
		Total Basin Cost		$ 910,071.00

Outlet Works Modification			Unit Cost	Total Material Cost
Outlet Option OW4	1	LS	$ 1,280,000.00	$ 1,280,000.00
		Total Outlet Works Cost		$ 1,280,000.00

Miscellaneous			Unit Cost	Total Material Cost
Excavation/Backfill				
Approach Excavation	17685	CY	$ 12.00	$ 212,220.00
Downstream Channel Riprap	920	CY	$ 55.00	$ 50,600.00
Raised Embankment				
Gate House/Extension	1	LS	$ 43,500.00	$ 43,500.00
Embankment/Wall	1	LS	$ 384,000.00	$ 384,000.00
Upstream Access	1	LS	$ 136,500.00	$ 136,500.00
Embankment Drain Mods	1	LS	$ 50,000.00	$ 50,000.00
Reservoir Impacts	1	LS	$ 200,000.00	$ 200,000.00
Mobilization/Preparation (15%)	1	LS	$ 859,000.00	$ 859,000.00
Unlisted Items (10%)	1	LS	$ 639,000.00	$ 639,000.00
		Total Other Costs		$ 2,574,820.00

TOTAL OPTION L1-75-96.7 COST	$ 7,226,148

RUBY DAM REHABILITATION FEASIBILITY
HKM - 8M087.175
Option L2-100-93.0
Cost Estimate

Option L2-100-93.0 - 100' Labyrinth Crest at elev 5393.0 ft; Dam Crest at elev 5410 ft; 100' straight Spillway Chute; 100' Type II Combination Basin; new Jet Flow Gate outlet works

Spillway Crest Width =	100	
Spillway Crest Elevation =	5393.0	
Reservoir Storage =	37,642	
Spillway Chute Width =	100	
Max Res. W.S. =	5406.5	
Dam Crest Elevation =	5410.0	
Spillway Design Capacity =	20,000	
Dam Overlopping Flow =	29,500	
Stilling Basin Length =	50	
Stilling Basin Width =	100	
Stilling Basin Design Flow =	4,000	(500-yr Outflow)

Material Costs			
Floor Concrete	$	800.00	/CY
Wall Concrete	$	1,000.00	/CY
Ogee Concrete	$	850.00	/CY
Labyrinth Wall	$	1,000.00	/CY
Labyrinth Crest	$	105.00	/LF
Rock Anchors	$	575.00	/EA
Excavation	$	12.00	/CY
Rock Fill/Riprap	$	55.00	/CY
Drain Gravel	$	60.00	/CY
Structural Backfill	$	10.00	/CY
Concrete Demo	$	35.00	/CY
6" Drain Pipe	$	15.00	/LF
12" Drain Pipe	$	35.00	/LF
Baffle Concrete	$	850.00	/CY

Spillway Crest STA 9+90 TO 10+20			Unit Cost	Total Material Cost
Wall Concrete	171	CY	$ 1,000.00	$ 171,000.00
Floor Concrete	249	CY	$ 800.00	$ 199,200.00
Labyrinth Wall	92	CY	$ 1,000.00	$ 92,000.00
Labyrinth Crest	110	FT	$ 105.00	$ 11,550.00
Rock Anchors	90	EA	$ 575.00	$ 51,750.00
Excavation	2000	CY	$ 12.00	$ 24,000.00
Drain Gravel	94	CY	$ 60.00	$ 5,640.00
Structural Backfill	2027	CY	$ 10.00	$ 20,270.00
Concrete Demo	463	CY	$ 35.00	$ 16,205.00
		Total Crest Cost		$ 591,615.00

Spillway Chute STA 10+20 TO 13+34			Unit Cost	Total Material Cost
Floor Concrete	1758	CY	$ 800.00	$ 1,406,400.00
Wall Concrete	380	CY	$ 1,000.00	$ 380,000.00
Rock Anchors	259	EA	$ 575 00	$ 148,925.00
Drain Gravel	692	CY	$ 60.00	$ 41,520.00
6" Drain Pipe	1200	LF	$ 15.00	$ 18,000.00
12" Drain Pipe	330	LF	$ 35.00	$ 11,550.00
Excavation	8515	CY	$ 12.00	$ 102,180.00
Structural Backfill	2013	CY	$ 10.00	$ 20,130.00
Concrete Demo	1035	CY	$ 35.00	$ 36,225.00
		Total Chute Cost		$ 2,164,930.00

Stilling Basin STA 13+39 TO 14+09			Unit Cost	Total Material Cost
Floor Concrete	602	CY	$ 800.00	$ 481,600.00
Wall Concrete	159	CY	$ 1,000.00	$ 159,000.00
Rock Anchors	29	EA	$ 575.00	$ 16,675.00
Drain Gravel	84	CY	$ 60.00	$ 5,040.00
Excavation	2609	CY	$ 12.00	$ 31,308.00
Structural Backfill	145	CY	$ 10.00	$ 1,450.00
Concrete Demo	136	CY	$ 35.00	$ 4,760.00
		Total Basin Cost		$ 699,833.00

Outlet Works Modification			Unit Cost	Total Material Cost
Outlet Option OW4	1	LS	$ 1,280,000.00	$ 1,280,000.00
		Total Outlet Works Cost		$ 1,280,000.00

Miscellaneous			Unit Cost	Total Material Cost
Excavation/Backfill				
Approach Excavation	23784	CY	$ 12.00	$ 285,408.00
Downstream Channel Riprap	1150	CY	$ 55.00	$ 63,250.00
Raised Embankment				
Gate House/Extension	1	LS	$ 40,000.00	$ 40,000.00
Embankment/Wall	1	LS	$ 14,400.00	$ 14,400.00
Upstream Access	1	LS	$ 136,500.00	$ 136,500.00
Embankment Drain Mods	1	LS	$ 20,000.00	$ 20,000.00
Mobilization/Preparation (15%)	1	LS	$ 794,000.00	$ 794,000.00
Unlisted Items (10%)	1	LS	$ 609,000.00	$ 609,000.00
		Total Other Costs		$ 1,962,558.00

TOTAL OPTION L2-100-93.0 COST $ 6,698,936

RUBY DAM REHABILITATION FEASIBILITY
HKM - 8M087.175
Option L2-100-96.7
Cost Estimate

Option L2-100-96.7 - 100' Labyrinth Crest at elev 5396.7 ft; Dam Crest at elev 5410 ft; 100' straight Baffled Chute; new Jet Flow Gate outlet works

Spillway Crest Width =	100	
Spillway Crest Elevation =	5396.7	
Reservoir Storage =	41,450	
Spillway Chute Width =	100	
Max Res. W.S. =	5407.0	
Dam Crest Elevation =	5410.0	
Spillway Design Capacity =	20,000	
Dam Overtopping Flow =	27,500	
Stilling Basin Length =	50	
Stilling Basin Width =	100	
Stilling Basin Design Flow =	4,000	(500-yr Outflow)

Material Costs			
Floor Concrete	$	800.00	/CY
Wall Concrete	$	1,000.00	/CY
Ogee Concrete	$	850.00	/CY
Labyrinth Wall	$	1,000.00	/CY
Labyrinth Crest	$	105.00	/LF
Rock Anchors	$	575.00	/EA
Excavation	$	12.00	/CY
Rock Fill/Riprap	$	55.00	/CY
Drain Gravel	$	60.00	/CY
Structural Backfill	$	10.00	/CY
Concrete Demo	$	35.00	/CY
6" Drain Pipe	$	15.00	/LF
12" Drain Pipe	$	35.00	/LF
Baffle Concrete	$	850.00	/CY

Spillway Crest STA 9+90 TO 10+20			Unit Cost	Total Material Cost
Wall Concrete	388	CY	$ 1,000.00	$ 388,000.00
Floor Concrete	290	CY	$ 800.00	$ 232,000.00
Labyrinth Wall	121	CY	$ 1,000.00	$ 121,000.00
Labyrinth Crest	120	FT	$ 105.00	$ 12,600.00
Rock Anchors	90	EA	$ 575.00	$ 51,750.00
Excavation	1937	CY	$ 12.00	$ 23,244.00
Drain Gravel	146	CY	$ 60.00	$ 8,760.00
Structural Backfill	1543	CY	$ 10.00	$ 15,430.00
Concrete Demo	463	CY	$ 35.00	$ 16,205.00
		Total Crest Cost		$ 868,989.00

Spillway Chute STA 10+20 TO 13+34			Unit Cost	Total Material Cost
Floor Concrete	1758	CY	$ 800.00	$ 1,406,400.00
Wall Concrete	380	CY	$ 1,000.00	$ 380,000.00
Rock Anchors	259	EA	$ 575.00	$ 148,925.00
Drain Gravel	692	CY	$ 60.00	$ 41,520.00
6" Drain Pipe	1200	LF	$ 15.00	$ 18,000.00
12" Drain Pipe	330	LF	$ 35.00	$ 11,550.00
Excavation	8515	CY	$ 12.00	$ 102,180.00
Structural Backfill	2013	CY	$ 10.00	$ 20,130.00
Concrete Demo	1035	CY	$ 35.00	$ 36,225.00
		Total Chute Cost		$ 2,164,930.00

Stilling Basin STA 13+39 TO 14+09			Unit Cost	Total Material Cost
Floor Concrete	602	CY	$ 800.00	$ 481,600.00
Wall Concrete	159	CY	$ 1,000.00	$ 159,000.00
Rock Anchors	29	EA	$ 575.00	$ 16,675.00
Drain Gravel	84	CY	$ 60.00	$ 5,040.00
Excavation	2609	CY	$ 12.00	$ 31,308.00
Structural Backfill	145	CY	$ 10.00	$ 1,450.00
Concrete Demo	136	CY	$ 35.00	$ 4,760.00
		Total Basin Cost		$ 699,833.00

Outlet Works Modification			Unit Cost	Total Material Cost
Outlet Option OW4	1	LS	$ 1,280,000.00	$ 1,280,000.00
		Total Outlet Works Cost		$ 1,280,000.00

Miscellaneous			Unit Cost	Total Material Cost
Excavation/Backfill				
Approach Excavation	12653	CY	$ 12.00	$ 151,836.00
Downstream Channel Riprap	1150	CY	$ 55.00	$ 63,250.00
Raised Embankment				
Gate House/Extension	1	LS	$ 40,000.00	$ 40,000.00
Embankment/Wall	1	LS	$ 14,400.00	$ 14,400.00
Upstream Access	1	LS	$ 136,500.00	$ 136,500.00
Embankment Drain Mods	1	LS	$ 20,000.00	$ 20,000.00
Reservoir Impacts	1	LS	$ 200,000.00	$ 200,000.00
Mobilization/Preparation (15%)	1	LS	$ 846,000.00	$ 846,000.00
Unlisted Items (10%)	1	LS	$ 629,000.00	$ 629,000.00
		Total Other Costs		$ 2,100,986.00

TOTAL OPTION L2-100-96.7 COST	$ 7,114,738

RUBY DAM REHABILITATION FEASIBILITY
HKM - 8M087.175
Option L2-100-00
Cost Estimate

Option L2-100-00 - 100' Labyrinth Crest at elev 5400.0 ft; Dam Crest at elev 5413.0 ft; 100' straight Spillway Chute; 100' Type II Combination Basin; new Jet Flow Gate outlet works

Spillway Crest Width =	100	
Spillway Crest Elevation =	5400.0	
Reservoir Storage =	45,115	
Spillway Chute Width =	100	
Max Res. W.S. =	5410.0	
Dam Crest Elevation =	5413.0	
Spillway Design Capacity =	20,000	
Dam Overtopping Flow =	26,400	
Stilling Basin Length =	50	
Stilling Basin Width =	100	
Stilling Basin Design Flow =	4,000	(500-yr Outflow)

Material Costs			
Floor Concrete	$	800.00	/CY
Wall Concrete	$	1,000.00	/CY
Ogee Concrete	$	850.00	/CY
Labyrinth Wall	$	1,000.00	/CY
Labyrinth Crest	$	105.00	/LF
Rock Anchors	$	575.00	/EA
Excavation	$	12.00	/CY
Rock Fill/Riprap	$	55.00	/CY
Drain Gravel	$	60.00	/CY
Structural Backfill	$	10.00	/CY
Concrete Demo	$	35.00	/CY
6" Drain Pipe	$	15.00	/LF
12" Drain Pipe	$	35.00	/LF
Baffle Concrete	$	850.00	/CY

Spillway Crest STA 9+90 TO 10+20			Unit Cost	Total Material Cost
Wall Concrete	365	CY	$ 1,000.00	$ 365,000.00
Floor Concrete	418	CY	$ 800.00	$ 334,400.00
Labyrinth Wall	225	CY	$ 1,000.00	$ 225,000.00
Labyrinth Crest	250	FT	$ 105.00	$ 26,250.00
Rock Anchors	85	EA	$ 575.00	$ 48,875.00
Excavation	1966	CY	$ 12.00	$ 23,592.00
Drain Gravel	108	CY	$ 60.00	$ 6,480.00
Structural Backfill	2386	CY	$ 10.00	$ 23,860.00
Concrete Demo	463	CY	$ 35.00	$ 16,205.00
		Total Crest Cost		$ 1,069,662.00

Spillway Chute STA 10+20 TO 13+34			Unit Cost	Total Material Cost
Floor Concrete	1777	CY	$ 800.00	$ 1,421,600.00
Wall Concrete	466	CY	$ 1,000.00	$ 466,000.00
Rock Anchors	256	EA	$ 575.00	$ 147,200.00
Drain Gravel	621	CY	$ 60.00	$ 37,260.00
6" Drain Pipe	1200	LF	$ 15.00	$ 18,000.00
12" Drain Pipe	330	LF	$ 35.00	$ 11,550.00
Excavation	8377	CY	$ 12.00	$ 100,524.00
Structural Backfill	989	CY	$ 10.00	$ 9,890.00
Concrete Demo	1035	CY	$ 35.00	$ 36,225.00
		Total Chute Cost		$ 2,248,249.00

Stilling Basin STA 13+39 TO 14+09			Unit Cost	Total Material Cost
Floor Concrete	676	CY	$ 800.00	$ 540,800.00
Wall Concrete	194	CY	$ 1,000.00	$ 194,000.00
Rock Anchors	36	EA	$ 575.00	$ 20,700.00
Drain Gravel	95	CY	$ 60.00	$ 5,700.00
Excavation	2470	CY	$ 12.00	$ 29,640.00
Structural Backfill	1760	CY	$ 10.00	$ 17,600.00
Concrete Demo	136	CY	$ 35.00	$ 4,760.00
		Total Basin Cost		$ 813,200.00

Outlet Works Modification			Unit Cost	Total Material Cost
Outlet Option OW4	1	LS	$ 1,280,000.00	$ 1,280,000.00
		Total Outlet Works Cost		$ 1,280,000.00

Miscellaneous			Unit Cost	Total Material Cost
Excavation/Backfill				
Approach Excavation/Fill	1	LS	$ 154,645.00	$ 154,645.00
Downstream Channel Riprap	260	CY	$ 55.00	$ 14,300.00
Raised Embankment				
Gate House/Extension	1	LS	$ 43,000.00	$ 43,000.00
Embankment/Wall	1	LS	$ 342,800.00	$ 342,800.00
Upstream Access	1	LS	$ 136,500.00	$ 136,500.00
Embankment Drain Mods	1	LS	$ 50,000.00	$ 50,000.00
Reservoir Impacts	1	LS	$ 650,000.00	$ 650,000.00
Mobilization/Preparation (15%)	1	LS	$ 1,020,000.00	$ 1,020,000.00
Unlisted Items (10%)	1	LS	$ 717,000.00	$ 717,000.00
		Total Other Costs		$ 3,128,245.00

TOTAL OPTION L2-100-00 COST	$ 8,539,356

APPENDIX C3

OPTION LB1-100-96.7

RUBY DAM REHABILITATION FEASIBILITY
HKM - 8M087.175
Option LB1-100-96.7
Cost Estimate

Option LB1-100-96.7 - 100' Labyrinth Crest at elev 5396.7 ft; Dam Crest at elev 5410 ft; 100' straight Spillway Chute; 100' Type II Combination Basin; new Jet Flow Gate outlet works

Spillway Crest Width =	100	
Spillway Crest Elevation =	5396.7	
Reservoir Storage =	41,450	
Spillway Chute Width =	100	
Max Res. W.S. =	5407.0	
Dam Crest Elevation =	5410.0	
Spillway Design Capacity =	20,000	
Dam Overtopping Flow =	27,500	
Stilling Basin Length =	50	
Stilling Basin Width =	100	
Stilling Basin Design Flow =	4,000	(500-yr Outflow)

Material Costs			
Floor Concrete	$	800.00	/CY
Wall Concrete	$	1,000.00	/CY
Ogee Concrete	$	850.00	/CY
Labyrinth Wall	$	1,000.00	/CY
Labyrinth Crest	$	105.00	/LF
Rock Anchors	$	575.00	/EA
Excavation	$	12.00	/CY
Rock Fill/Riprap	$	55.00	/CY
Drain Gravel	$	60.00	/CY
Structural Backfill	$	10.00	/CY
Concrete Demo	$	35.00	/CY
6" Drain Pipe	$	15.00	/LF
12" Drain Pipe	$	35.00	/LF
Baffle Concrete	$	850.00	/CY

Spillway Crest STA 9+90 TO 10+20			Unit Cost	Total Material Cost
Wall Concrete	388	CY	$ 1,000.00	$ 388,000.00
Floor Concrete	290	CY	$ 800.00	$ 232,000.00
Labyrinth Wall	121	CY	$ 1,000.00	$ 121,000.00
Labyrinth Crest	120	FT	$ 105.00	$ 12,600.00
Rock Anchors	90	EA	$ 575.00	$ 51,750.00
Excavation	1937	CY	$ 12.00	$ 23,244.00
Drain Gravel	146	CY	$ 60.00	$ 8,760.00
Structural Backfill	1543	CY	$ 10.00	$ 15,430.00
Concrete Demo	463	CY	$ 35.00	$ 16,205.00
		Total Crest Cost		$ 868,989.00

Spillway Chute STA 10+20 TO 13+34			Unit Cost	Total Material Cost
Floor Concrete	1729	CY	$ 800.00	$ 1,383,200.00
Wall Concrete	448	CY	$ 1,000.00	$ 448,000.00
Rock Anchors	440	EA	$ 575.00	$ 253,000.00
Drain Gravel	692	CY	$ 60.00	$ 41,520.00
6" Drain Pipe	1200	LF	$ 15.00	$ 18,000.00
12" Drain Pipe	330	LF	$ 35.00	$ 11,550.00
Excavation	8515	CY	$ 12.00	$ 102,180.00
Structural Backfill	2013	CY	$ 10.00	$ 20,130.00
Concrete Demo	1035	CY	$ 35.00	$ 36,225.00
Baffle Concrete	308	CY	$ 850.00	$ 261,800.00
		Total Chute Cost		$ 2,575,605.00

Stilling Basin STA 13+39 TO 13+50			Unit Cost	Total Material Cost
Floor Concrete	58	CY	$ 800.00	$ 46,400.00
Wall Concrete	23	CY	$ 1,000.00	$ 23,000.00
Rock Anchors	8	EA	$ 575.00	$ 4,600.00
Drain Gravel	261	CY	$ 60.00	$ 15,660.00
Excavation	319	CY	$ 12.00	$ 3,828.00
Structural Backfill	145	CY	$ 10.00	$ 1,450.00
Concrete Demo	136	CY	$ 35.00	$ 4,760.00
		Total Basin Cost		$ 99,698.00

Outlet Works Modification			Unit Cost	Total Material Cost
Outlet Option OW4	1	LS	$ 1,280,000.00	$ 1,280,000.00
		Total Outlet Works Cost		$ 1,280,000.00

Miscellaneous			Unit Cost	Total Material Cost
Excavation/Backfill				
Approach Excavation	12653	CY	$ 12.00	$ 151,836.00
Downstream Channel Riprap	950	CY	$ 55.00	$ 52,250.00
Raised Embankment				
Gate House/Extension	1	LS	$ 40,000.00	$ 40,000.00
Embankment/Wall	1	LS	$ 14,400.00	$ 14,400.00
Upstream Access	1	LS	$ 136,500.00	$ 136,500.00
Embankment Drain Mods	1	LS	$ 20,000.00	$ 20,000.00
Reservoir Impacts	1	LS	$ 200,000.00	$ 200,000.00
Mobilization/Preparation (15%)	1	LS	$ 816,000.00	$ 816,000.00
Unlisted Items (10%)	1	LS	$ 606,000.00	$ 606,000.00
		Total Other Costs		$ 2,036,986.00

TOTAL OPTION LB1-100-96.7 COST $ 6,861,278

APPENDIX C4

FUSEGATE CREST OPTIONS

RUBY DAM REHABILITATION FEASIBILITY
HKM - 8M087.175
Option P1-100-93.0
Cost Estimate

Option P1-100-93.0 - 100' Fusegate at elev 5393.0 ft; Dam Crest at elev 5415 ft; 100' straight Spillway Chute; 100' Type II Combination Basin, new Jet Flow Gate outlet works

Spillway Crest Width =	100	
Spillway Crest Elevation =	5393.0	
Reservoir Storage =	37,642	
Spillway Chute Width =	100	
Max Res. W.S. =	5412.0	
Dam Crest Elevation =	5415.0	
Spillway Design Capacity =	75,000	
Dam Overtopping Flow =	156,200	
Stilling Basin Length =	50	
Stilling Basin Width =	100	
Stilling Basin Design Flow =	4,000	(500-yr Outflow)

Material Costs			
Floor Concrete	$	800.00	/CY
Wall Concrete	$	1,000.00	/CY
Ogee Concrete	$	850.00	/CY
Labyrinth Wall	$	1,000.00	/CY
Labyrinth Crest	$	105.00	/LF
Rock Anchors	$	575.00	/EA
Excavation	$	12.00	/CY
Rock Fill/Riprap	$	55.00	/CY
Drain Gravel	$	60.00	/CY
Structural Backfill	$	10.00	/CY
Concrete Demo	$	35.00	/CY
6" Drain Pipe	$	15.00	/LF
12" Drain Pipe	$	35.00	/LF
Baffle Concrete	$	850.00	/CY

Spillway Crest STA 9+90 TO 10+30			Unit Cost	Total Material Cost
Floor Concrete	310	CY	$ 800.00	$ 248,000.00
Wall Concrete	500	CY	$ 1,000.00	$ 500,000.00
Rock Anchors	59	EA	$ 575.00	$ 33,925.00
Drain Gravel	75	CY	$ 60.00	$ 4,500.00
Excavation	3890	CY	$ 12.00	$ 46,680.00
Structural Backfill	2240	CY	$ 10.00	$ 22,400.00
Concrete Demo	900	CY	$ 35.00	$ 31,500.00
Fusegate	1	LS	$ 1,360,000.00	$ 1,360,000.00
		Total Crest Cost		$ 2,247,005.00

Spillway Chute STA 10+30 TO 13+39			Unit Cost	Total Material Cost
Floor Concrete	2587	CY	$ 800.00	$ 2,069,600.00
Wall Concrete	706	CY	$ 1,000.00	$ 706,000.00
Rock Anchors	451	EA	$ 575.00	$ 259,325.00
Drain Gravel	581	CY	$ 60.00	$ 34,860.00
Excavation	6928	CY	$ 12.00	$ 83,136.00
Structural Backfill	2013	CY	$ 10.00	$ 20,130.00
Concrete Demo	800	CY	$ 35.00	$ 28,000.00
6" Drain Pipe	1200	LF	$ 15.00	$ 18,000.00
12" Drain Pipe	310	LF	$ 35.00	$ 10,850.00
		Total Chute Cost		$ 3,229,901.00

Stilling Basin STA 13+39 TO 14+09			Unit Cost	Total Material Cost
Floor Concrete	608	CY	$ 800.00	$ 486,400.00
Wall Concrete	159	CY	$ 1,000.00	$ 159,000.00
Rock Anchors	29	EA	$ 575.00	$ 16,675.00
Drain Gravel	85	CY	$ 60.00	$ 5,100.00
Excavation	2609	CY	$ 12.00	$ 31,308.00
Structural Backfill	149	CY	$ 10.00	$ 1,490.00
Concrete Demo	137	CY	$ 35.00	$ 4,795.00
		Total Basin Cost		$ 704,768.00

Outlet Works Modification			Unit Cost	Total Material Cost
Outlet Option OW4	1	LS	$ 1,280,000.00	$ 1,280,000.00
		Total Outlet Works Cost		$ 1,280,000.00

Miscellaneous			Unit Cost	Total Material Cost
Excavation/Backfill				
Approach Excavation	43300	CY	$ 12.00	$ 519,600.00
Downstream Channel Riprap	1150	CY	$ 55.00	$ 63,250.00
Raised Embankment				
Gate House/Extension	1	LS	$ 45,000.00	$ 45,000.00
Embankment/Wall	1	LS	$ 533,800.00	$ 533,800.00
Upstream Access	1	LS	$ 136,500.00	$ 136,500.00
Embankment Drain Mods	1	LS	$ 20,000.00	$ 20,000.00
Mobilization/Preparation (15%)	1	LS	$ 1,317,000.00	$ 1,317,000.00
Unlisted Items (10%)	1	LS	$ 1,010,000.00	$ 1,010,000.00
		Total Other Costs		$ 3,645,150.00

TOTAL OPTION P1-100-93.0 COST	$ 11,106,824

RUBY DAM REHABILITATION FEASIBILITY
HKM - 8M087.175
Option P1-100-96.7
Cost Estimate

Option P1-100-96.7 - 100' Fusegate at elev 5396.7 ft; Dam Crest at elev 5415 ft; 100' straight Spillway Chute; 100' Type II Combination Basin, new Jet Flow Gate outlet works

Spillway Crest Width =	100	
Spillway Crest Elevation =	5396.7	
Reservoir Storage =	41,450	
Spillway Chute Width =	100	
Max Res. W S. =	5412.0	
Dam Crest Elevation =	5415.0	
Spillway Design Capacity =	75,000	
Dam Overtopping Flow =	137,600	
Stilling Basin Length =	50	
Stilling Basin Width =	100	
Stilling Basin Design Flow =	4,000	(500-yr Outflow)

Material Costs			
Floor Concrete	$	800.00	/CY
Wall Concrete	$	1,000.00	/CY
Ogee Concrete	$	850.00	/CY
Labyrinth Wall	$	1,000.00	/CY
Labyrinth Crest	$	105.00	/LF
Rock Anchors	$	575.00	/EA
Excavation	$	12.00	/CY
Rock Fill/Riprap	$	55.00	/CY
Drain Gravel	$	60.00	/CY
Structural Backfill	$	10.00	/CY
Concrete Demo	$	35.00	/CY
6" Drain Pipe	$	15.00	/LF
12" Drain Pipe	$	35.00	/LF
Baffle Concrete	$	850.00	/CY

Spillway Crest STA 9+90 TO 10+30			Unit Cost	Total Material Cost
Floor Concrete	310	CY	$ 800.00	$ 248,000.00
Wall Concrete	462	CY	$ 1,000.00	$ 462,000.00
Rock Anchors	59	EA	$ 575.00	$ 33,925.00
Drain Gravel	75	CY	$ 60.00	$ 4,500.00
Excavation	3185	CY	$ 12.00	$ 38,220.00
Structural Backfill	1880	CY	$ 10.00	$ 18,800.00
Concrete Demo	900	CY	$ 35.00	$ 31,500.00
Fusegate	1	LS	$ 1,360,000.00	$ 1,360,000.00
		Total Crest Cost		$ 2,196,945.00

Spillway Chute STA 10+30 TO 13+39			Unit Cost	Total Material Cost
Floor Concrete	2587	CY	$ 800.00	$ 2,069,600.00
Wall Concrete	706	CY	$ 1,000.00	$ 706,000.00
Rock Anchors	451	EA	$ 575.00	$ 259,325.00
Drain Gravel	581	CY	$ 60.00	$ 34,860.00
Excavation	6928	CY	$ 12.00	$ 83,136.00
Structural Backfill	2013	CY	$ 10.00	$ 20,130.00
Concrete Demo	800	CY	$ 35.00	$ 28,000.00
6" Drain Pipe	1200	LF	$ 15.00	$ 18,000.00
12" Drain Pipe	310	LF	$ 35.00	$ 10,850.00
		Total Chute Cost		$ 3,229,901.00

Stilling Basin STA 13+39 TO 14+09			Unit Cost	Total Material Cost
Floor Concrete	608	CY	$ 800.00	$ 486,400.00
Wall Concrete	159	CY	$ 1,000.00	$ 159,000.00
Rock Anchors	29	EA	$ 575.00	$ 16,675.00
Drain Gravel	85	CY	$ 60.00	$ 5,100.00
Excavation	2609	CY	$ 12.00	$ 31,308.00
Structural Backfill	149	CY	$ 10.00	$ 1,490.00
Concrete Demo	137	CY	$ 35.00	$ 4,795.00
		Total Basin Cost		$ 704,768.00

Outlet Works Modification			Unit Cost	Total Material Cost
Outlet Option OW4	1	LS	$ 1,280,000.00	$ 1,280,000.00
		Total Outlet Works Cost		$ 1,280,000.00

Miscellaneous			Unit Cost	Total Material Cost
Excavation/Backfill				
Approach Excavation	37800	CY	$ 12.00	$ 453,600.00
Downstream Channel Riprap	1150	CY	$ 55.00	$ 63,250.00
Raised Embankment				
Gate House/Extension	1	LS	$ 45,000.00	$ 45,000.00
Embankment/Wall	1	LS	$ 533,800.00	$ 533,800.00
Upstream Access	1	LS	$ 136,500.00	$ 136,500.00
Embankment Drain Mods	1	LS	$ 100,000.00	$ 100,000.00
Reservoir Impacts	1	LS	$ 200,000.00	$ 200,000.00
Mobilization/Preparation (15%)	1	LS	$ 1,342,000.00	$ 1,342,000.00
Unlisted Items (10%)	1	LS	$ 1,009,000.00	$ 1,009,000.00
		Total Other Costs		$ 3,883,150.00

TOTAL OPTION P1-100-96.7 COST	$ 11,294,764

RUBY DAM REHABILITATION FEASIBILITY
HKM - 8M087.175
Option P1-100-00
Cost Estimate

Option P1-100-00 - 100' Fusegate at elev 5400.0 ft; Dam Crest at elev 5415 ft; 100' straight Spillway Chute; 100' Type II Combination Basin, new Jet Flow Gate outlet works

Spillway Crest Width =	100	
Spillway Crest Elevation =	5400.0	
Reservoir Storage =	45,115	
Spillway Chute Width =	100	
Max Res. W.S. =	5412.0	
Dam Crest Elevation =	5415.0	
Spillway Design Capacity =	75,000	
Dam Overtopping Flow =	121,700	
Stilling Basin Length =	50	
Stilling Basin Width =	100	
Stilling Basin Design Flow =	4,000	(500-yr Outflow)

Material Costs			
Floor Concrete	$	800.00	/CY
Wall Concrete	$	1,000.00	/CY
Ogee Concrete	$	850.00	/CY
Labyrinth Wall	$	1,000.00	/CY
Labyrinth Crest	$	105.00	/LF
Rock Anchors	$	575.00	/EA
Excavation	$	12.00	/CY
Rock Fill/Riprap	$	55.00	/CY
Drain Gravel	$	60.00	/CY
Structural Backfill	$	10.00	/CY
Concrete Demo	$	35.00	/CY
6" Drain Pipe	$	15.00	/LF
12" Drain Pipe	$	35.00	/LF
Baffle Concrete	$	850.00	/CY

Spillway Crest STA 9+90 TO 10+30			Unit Cost	Total Material Cost
Floor Concrete	310	CY	$ 800.00	$ 248,000.00
Wall Concrete	429	CY	$ 1,000.00	$ 429,000.00
Rock Anchors	59	EA	$ 575.00	$ 33,925.00
Drain Gravel	75	CY	$ 60.00	$ 4,500.00
Excavation	2545	CY	$ 12.00	$ 30,540.00
Structural Backfill	1560	CY	$ 10.00	$ 15,600.00
Concrete Demo	900	CY	$ 35.00	$ 31,500.00
Fusegate	1	LS	$ 1,360,000.00	$ 1,360,000.00
		Total Crest Cost		$ 2,153,065.00

Spillway Chute STA 10+30 TO 13+39			Unit Cost	Total Material Cost
Floor Concrete	2587	CY	$ 800.00	$ 2,069,600.00
Wall Concrete	706	CY	$ 1,000.00	$ 706,000.00
Rock Anchors	451	EA	$ 575.00	$ 259,325.00
Drain Gravel	581	CY	$ 60.00	$ 34,860.00
Excavation	6928	CY	$ 12.00	$ 83,136.00
Structural Backfill	2013	CY	$ 10.00	$ 20,130.00
Concrete Demo	800	CY	$ 35.00	$ 28,000.00
6" Drain Pipe	1200	LF	$ 15.00	$ 18,000.00
12" Drain Pipe	310	LF	$ 35.00	$ 10,850.00
		Total Chute Cost		$ 3,229,901.00

Stilling Basin STA 13+39 TO 14+09			Unit Cost	Total Material Cost
Floor Concrete	608	CY	$ 800.00	$ 486,400.00
Wall Concrete	159	CY	$ 1,000.00	$ 159,000.00
Rock Anchors	29	EA	$ 575.00	$ 16,675.00
Drain Gravel	85	CY	$ 60.00	$ 5,100.00
Excavation	2609	CY	$ 12.00	$ 31,308.00
Structural Backfill	149	CY	$ 10.00	$ 1,490.00
Concrete Demo	137	CY	$ 35.00	$ 4,795.00
		Total Basin Cost		$ 704,768.00

Outlet Works Modification			Unit Cost	Total Material Cost
Outlet Option OW4	1	LS	$ 1,280,000.00	$ 1,280,000.00
		Total Outlet Works Cost		$ 1,280,000.00

Miscellaneous			Unit Cost	Total Material Cost
Excavation/Backfill				
Approach Excavation	32800	CY	$ 12.00	$ 393,600.00
Downstream Channel Riprap	1150	CY	$ 55.00	$ 63,250.00
Raised Embankment				
Gate House/Extension	1	LS	$ 45,000.00	$ 45,000.00
Embankment/Wall	1	LS	$ 533,800.00	$ 533,800.00
Upstream Access	1	LS	$ 136,500.00	$ 136,500.00
Embankment Drain Mods	1	LS	$ 100,000.00	$ 100,000.00
Reservoir Impacts	1	LS	$ 650,000.00	$ 650,000.00
Mobilization/Preparation (15%)	1	LS	$ 1,393,000.00	$ 1,393,000.00
Unlisted Items (10%)	1	LS	$ 1,003,000.00	$ 1,003,000.00
		Total Other Costs		$ 4,318,150.00

TOTAL OPTION P1-100-00 COST	$ 11,685,884

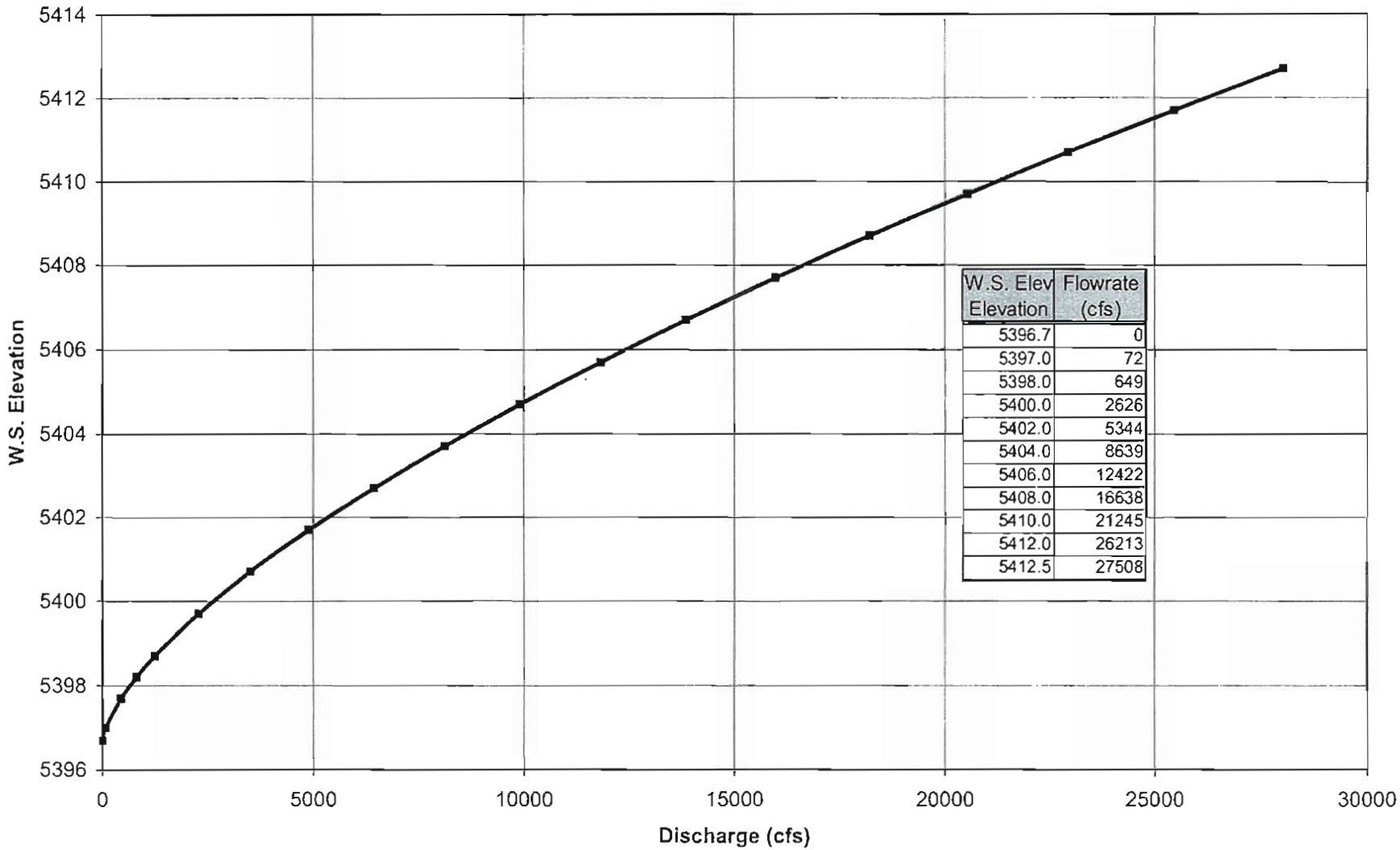
APPENDIX D

SPILLWAY
HYDRAULIC COMPUTATIONS

APPENDIX D1

OPTION O1-120-96.7

Ruby Dam Feasibility
Option O1-120-96.7 - 120' Ogee Rating



W.S. Elev Elevation	Flowrate (cfs)
5396.7	0
5397.0	72
5398.0	649
5400.0	2626
5402.0	5344
5404.0	8639
5406.0	12422
5408.0	16638
5410.0	21245
5412.0	26213
5412.5	27508

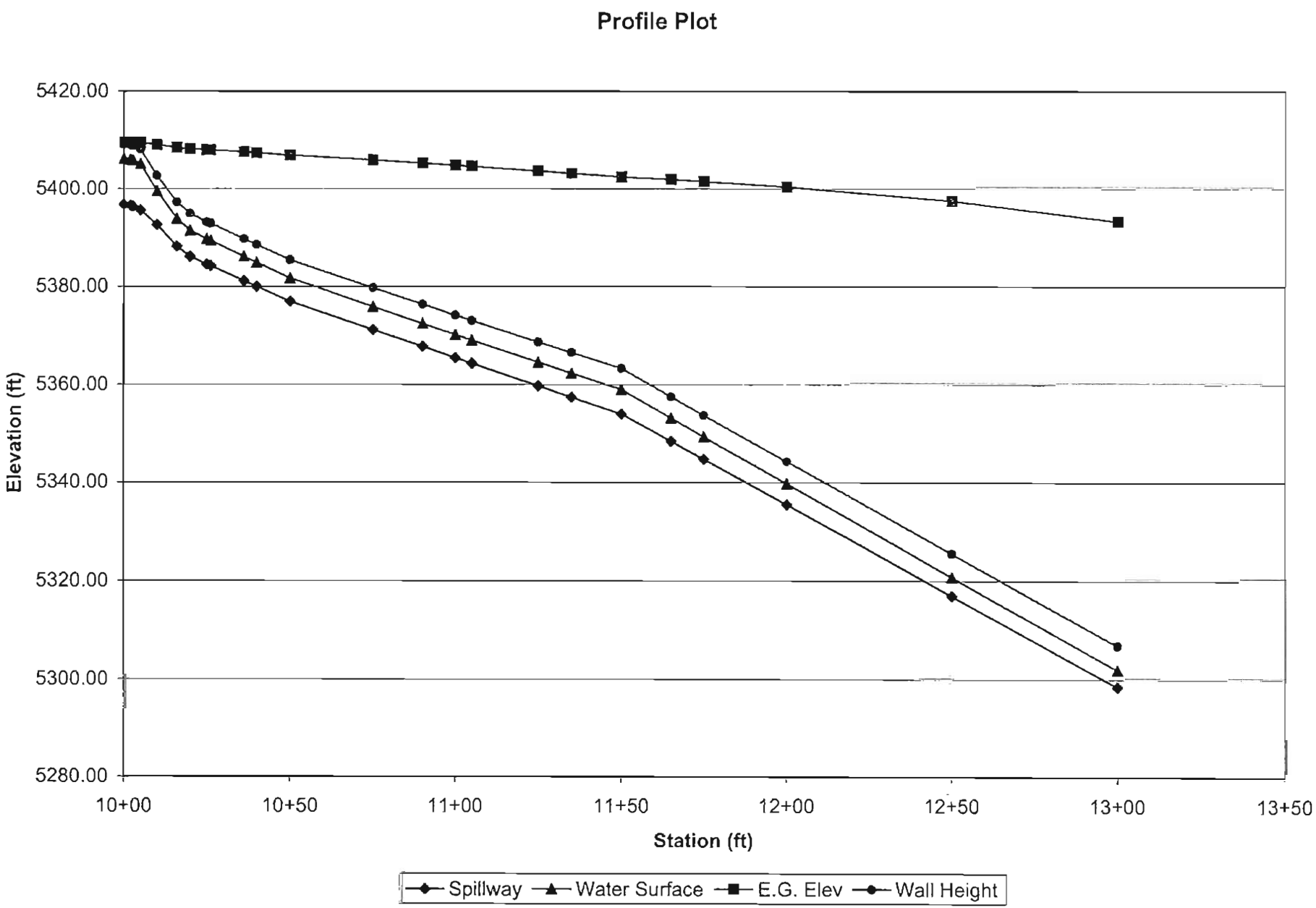
Ruby Dam Spillway Hydraulics at Q = 20,000 cfs (50 LOL)

Design Discharge

Discharge	20000 cfs
Res Elev	5409.50 ft
Spwy Crest	5396.70 ft
Crest Width	120.0 ft
n	0.014
P	10.0 ft
P/H	0.78
C_d	3.65
K_L	0.1

Exp/Cont. Coeff (HEC-RAS default for gradual contraction)

Sta	Elev	Slope	Width	Y	WS Elev	Wall Frbrd	Wall Height	V	H_v	R_h	S_f	H_{vc}	EGL	EGL-Z-Y-Hv	Froude#	Y_c	β	L_t
10+00.00	5396.70		120.00	9.52	5406.22	2.93	12.45	17.51	4.76	8.22			5409.50	-1.47924	1.00	9.52	1.570796	0.00
		-0.10									0.00164	0.00178						
10+02.00	5396.51		119.40	9.55	5406.06	2.93	12.48	17.54	4.78	8.23			5409.49	-1.34110	1.00	9.55	1.550133	1.25
		-0.23									0.00164	0.00085						
10+02.77	5396.33		119.17	9.56	5405.89	2.93	12.49	17.56	4.79	8.24			5409.49	-1.18173	1.00	9.56	1.536738	2.03
		-0.34									0.00164	0.00139						
10+05.00	5395.55		118.50	9.60	5405.16	2.93	12.53	17.58	4.80	8.26			5409.49	-0.47573	1.00	9.60	1.570796	0.00
		-0.59									0.00164	0.47067						
10+10.00	5392.59		117.00	6.91	5399.50	3.18	10.09	24.74	9.51	6.18			5409.01	0.00000	1.66	9.68	0.647022	77.43
		-0.73									0.00479	0.51015						
10+16.00	5388.20		115.20	5.66	5393.86	3.37	9.03	30.67	14.61	5.15			5408.47	0.00000	2.27	9.78	0.455785	117.50
		-0.52									0.00936	0.21632						
10+20.00	5386.11		114.00	5.34	5391.45	3.44	8.77	32.86	16.77	4.88			5408.22	0.00000	2.51	9.85	0.410363	131.02
		-0.32									0.01158	0.15394						
10+25.00	5384.52		112.50	5.18	5389.69	3.49	8.66	34.34	18.31	4.74			5408.00	0.00000	2.66	9.94	0.385471	138.63
		-0.25									0.01314	0.02757						
10+26.20	5384.22		112.14	5.16	5389.38	3.49	8.65	34.60	18.59	4.72			5407.96	0.00000	2.69	9.95	0.381594	139.73
		-0.30									0.01341	0.28372						
10+35.20	5381.19		109.14	4.93	5386.12	3.58	8.51	37.14	21.42	4.52			5407.54	0.00000	2.95	10.14	0.346205	151.27
		-0.30									0.01535	0.10514						
10+40.00	5380.03		108.00	4.87	5384.90	3.61	8.48	38.04	22.47	4.47			5407.38	0.00000	3.04	10.21	0.335327	154.96
		-0.30									0.01747	0.27258						
10+50.00	5377.03		105.00	4.73	5381.73	3.69	8.42	40.29	25.20	4.34			5406.93	0.00000	3.26	10.41	0.311291	163.17
		-0.23									0.02036	0.48218						
10+75.00	5371.25		97.50	4.67	5375.92	3.84	8.50	43.97	30.02	4.26			5405.94	0.00000	3.59	10.93	0.282479	167.96
		-0.23									0.02487	0.27849						
10+90.00	5367.80		93.00	4.63	5372.48	3.92	8.60	45.96	32.81	4.25			5405.29	0.00000	3.74	11.28	0.270311	167.51
		-0.23									0.02723	0.18165						
11+00.00	5365.50		90.00	4.71	5370.21	3.98	8.68	47.22	34.53	4.26			5404.83	0.00000	3.84	11.53	0.263728	166.66
		-0.23									0.02856	0.08980						
11+05.00	5364.35		88.50	4.72	5369.07	4.01	8.73	47.83	35.52	4.27			5404.60	0.00000	3.88	11.66	0.260828	165.79
		-0.23									0.02932	0.35506						
11+25.00	5359.75		82.50	4.83	5364.58	4.12	8.95	50.16	39.07	4.33			5403.66	0.00000	4.02	12.22	0.251313	160.67
		-0.23									0.03169	0.17350						
11+35.00	5357.45		79.50	4.91	5362.36	4.18	9.09	51.27	40.81	4.37			5403.17	0.00000	4.08	12.53	0.247729	157.16
		-0.23									0.03267	0.25652						
11+50.00	5354.00		75.00	5.05	5359.05	4.27	9.31	52.85	43.37	4.45			5402.42	0.00000	4.15	13.02	0.243571	150.99
		-0.37									0.03399							
11+65.00	5348.45		75.00	4.76	5353.21	4.38	9.12	56.00	48.70	4.23			5401.91	0.00000	4.52	13.02	0.22295	165.49
		-0.37									0.04075							
11+75.00	5344.75		75.00	4.60	5349.35	4.41	9.01	57.55	52.15	4.10			5401.50	0.00000	4.76	13.02	0.211611	174.56
		-0.37									0.04545							
12+00.00	5335.50		75.00	4.27	5339.77	4.53	8.80	62.47	60.80	3.83			5400.37	0.00000	5.33	13.02	0.188791	196.27
		-0.37									0.05776							
12+50.00	5317.00		75.00	3.79	5320.79	4.74	8.53	70.27	78.69	3.45			5397.48	0.00000	6.35	13.02	0.157951	235.44
		-0.37									0.08422							
13+00.00	5298.50		75.00	3.48	5301.98	4.90	8.38	76.68	91.29	3.18			5393.27	0.00000	7.25	13.02	0.138457	269.11
		-0.37									0.11147							
13+25.00	5289.25		75.00	3.36	5292.61	4.97	8.33	79.39	97.87	3.06			5390.48	0.00000	7.63	13.02	0.131371	283.81


Profile Plot
5420.00
5400.00
5380.00
5360.00
5340.00
5320.00
5300.00
5280.00
Elevation (ft)
10+00
10+50
11+00
11+50
12+00
12+50
13+00
13+50
Station (ft)
Spillway
Water Surface
E.G. Elev
Wall Height

Ruby Dam Spillway Hydraulics at Q = 4,000 cfs (Routed 500-yr)

Design Discharge

Discharge	4000	cfs
Res Elev	5400.50	ft
Spwy Crest	5396.70	ft
Crest Width	120.0	ft
n	0.014	
P	10.0	ft
P/H	2.63	
C_d	3.65	
K_c	0.1	

Exp/Cont. Coeff (HEC-RAS default for gradual contraction)

Sta	Elev	Slope	Width	Y	WS Elev	Wall Frbrd	Wall Height	V	H_v	R_h	S_f	$H_{v/c}$	EGL	EGL-Z-Y-Hv	Froude#	Y_c	β	L_1
10+00.00	5396.70		120.00	3.26	5399.96	2.38	5.64	10.22	1.62	3.09			5400.50	-1.68344	1.00	3.26	1.570796	0.00
		-0.10									0.00208	0.00063						
10+02.00	5396.51		119.40	3.27	5399.78	2.38	5.65	10.24	1.63	3.10			5400.50	-0.91354	1.00	3.27	1.570796	0.03
		-0.23									0.00206	0.00063						
10+02.77	5396.33		119.17	3.27	5399.60	2.38	5.65	10.26	1.64	3.10			5400.49	-0.74208	1.00	3.27	1.544769	1.55
		-0.34									0.00207	0.00065						
10+05.00	5395.56		118.50	3.28	5398.84	2.38	5.66	10.29	1.64	3.11			5400.49	-0.00099	1.00	3.28	1.516115	3.12
		-0.59									0.00207	0.40483						
10+10.00	5392.59		117.00	1.79	5394.38	2.58	4.37	19.15	5.69	1.73			5400.07	0.00000	2.53	3.31	0.407165	135.65
		-0.73									0.01564	0.42854						
10+16.00	5388.20		115.20	1.37	5389.57	2.70	4.07	25.35	9.98	1.34			5399.55	0.00000	3.82	3.35	0.265078	212.18
		-0.52									0.03869	0.18535						
10+20.00	5386.11		114.00	1.27	5387.38	2.75	4.02	27.60	11.83	1.24			5399.21	0.00000	4.31	3.37	0.233895	239.24
		-0.32									0.05058	0.12578						
10+25.00	5384.52		112.50	1.22	5385.74	2.78	4.00	29.03	13.09	1.20			5398.83	0.00000	4.62	3.40	0.218006	253.92
		-0.25									0.05877	0.02112						
10+26.20	5384.22		112.14	1.22	5385.44	2.78	4.00	29.27	13.30	1.19			5398.74	0.00000	4.67	3.41	0.215714	255.88
		-0.30									0.06010	0.22672						
10+36.20	5381.19		109.14	1.16	5382.34	2.83	3.99	31.66	15.57	1.13			5397.91	0.00000	5.19	3.47	0.194024	277.72
		-0.30									0.07530	0.08031						
10+40.00	5380.03		108.00	1.14	5381.17	2.85	3.99	32.47	16.37	1.12			5397.55	0.00000	5.36	3.49	0.187749	284.23
		-0.30									0.08074	0.20555						
10+50.00	5377.00		105.00	1.11	5378.11	2.89	4.00	34.45	18.43	1.08			5396.53	0.00000	5.77	3.56	0.174105	298.49
		-0.23									0.08470	0.30782						
10+75.00	5371.25		97.50	1.10	5372.35	2.96	4.06	37.21	21.50	1.08			5393.86	0.00000	6.25	3.74	0.160792	300.57
		-0.23									0.11121	0.16087						
10+90.00	5367.80		93.00	1.11	5368.91	3.00	4.11	38.58	23.11	1.09			5392.03	0.00000	6.44	3.85	0.155925	295.80
		-0.23									0.11796	0.10068						
11+00.00	5365.50		90.00	1.13	5366.63	3.03	4.15	39.41	24.12	1.10			5390.75	0.00000	6.54	3.94	0.153455	290.86
		-0.23									0.12141	0.04856						
11+05.00	5364.35		88.50	1.14	5365.49	3.04	4.17	39.81	24.61	1.11			5390.09	0.00000	6.58	3.99	0.152481	287.95
		-0.23									0.12283	0.19142						
11+25.00	5359.75		82.50	1.17	5360.92	3.09	4.26	41.33	26.52	1.14			5387.44	0.00000	6.72	4.18	0.149275	274.28
		-0.23									0.12719	0.09130						
11+35.00	5357.45		79.50	1.20	5358.65	3.12	4.31	42.03	27.43	1.16			5386.08	0.00000	6.77	4.28	0.148247	265.17
		-0.23									0.12836	0.13480						
11+50.00	5354.00		75.00	1.24	5355.24	3.16	4.39	43.05	28.78	1.20			5384.02	0.00000	6.82	4.45	0.147229	252.86
		-0.37									0.12914							
11+65.00	5348.45		75.00	1.17	5349.62	3.20	4.37	45.73	32.47	1.13			5382.08	0.00000	7.46	4.45	0.134427	277.28
		-0.37									0.15746							
11+75.00	5344.75		75.00	1.13	5345.88	3.23	4.36	47.22	34.63	1.10			5380.51	0.00000	7.83	4.45	0.128045	291.26
		-0.37									0.17510							
12+00.00	5335.50		75.00	1.06	5336.56	3.29	4.34	50.48	39.59	1.03			5376.13	0.00000	8.66	4.45	0.115789	322.42
		-0.37									0.21818							
12+50.00	5317.00		75.00	0.97	5317.97	3.36	4.33	55.17	47.26	0.94			5365.22	0.00000	9.89	4.45	0.101313	368.87
		-0.37									0.29232							
13+00.00	5298.50		75.00	0.93	5299.43	3.40	4.33	57.41	51.18	0.91			5350.61	0.00000	10.50	4.45	0.095414	391.83
		-0.37									0.33342							
13+25.00	5289.25		75.00	0.92	5290.17	3.41	4.33	57.92	52.10	0.90			5342.27	0.00000	10.84	4.45	0.09414	397.16

HMS * Summary of Results for Ruby-120' Ogee

5396.7

Project : Ruby_Final_HKM Run Name : Ruby 17, 50 LOL

Start of Run	: 25Feb05 0000	Basin Model	: Ruby-17
End of Run	: 28Feb05 0000	Met. Model	: 24 HR, LOL=50
Execution Time	: 17Jan08 1634	Control Specs	: 24-Hour

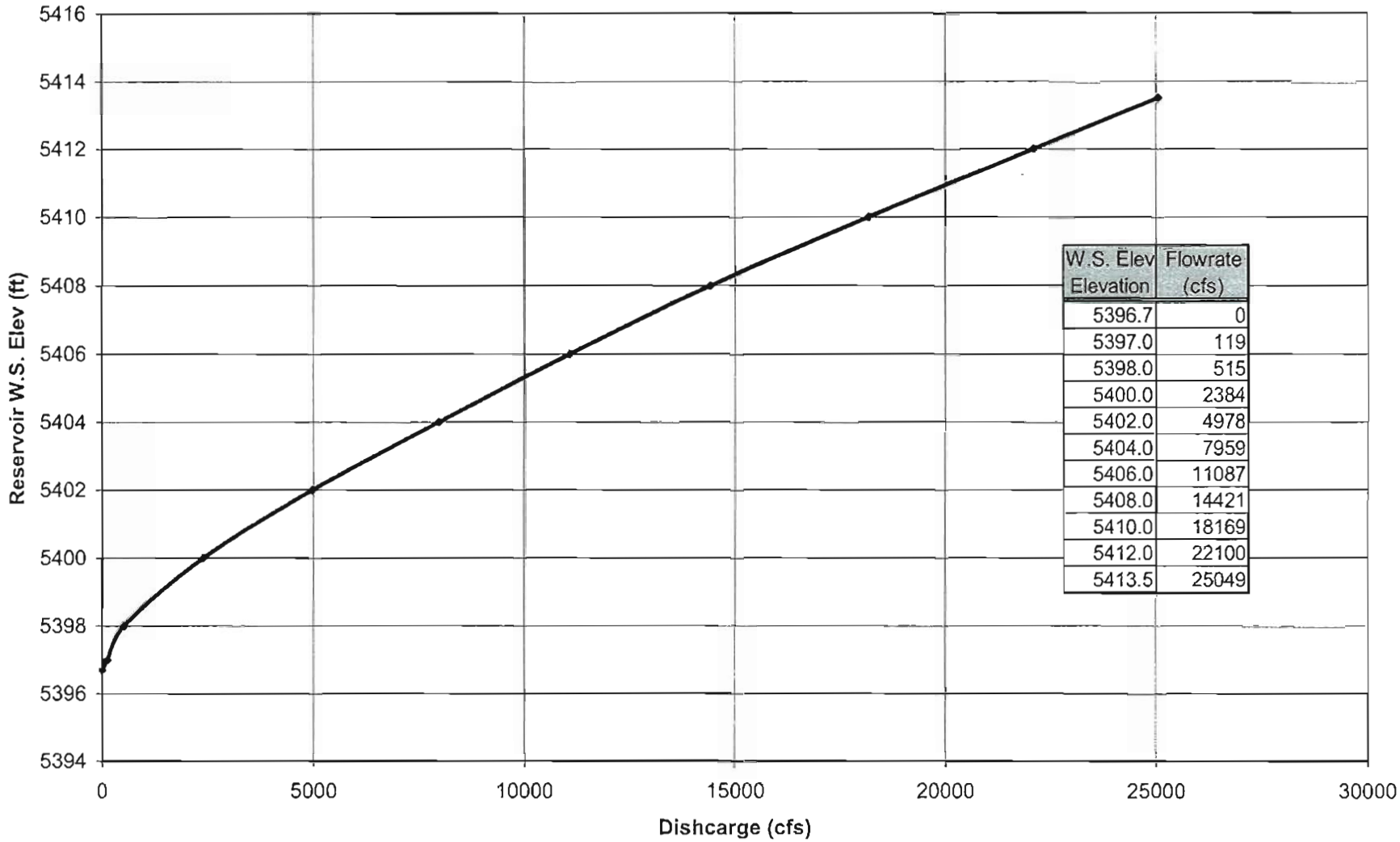
Computed Results

Peak Inflow	: 23881 (cfs)	Date/Time of Peak Inflow	: 26 Feb 05 0900
Peak Outflow	: 19599 (cfs)	Date/Time of Peak Outflow	: 26 Feb 05 1600
Total Inflow	: 60276 (ac-ft)	Peak Storage	: 56482(ac-ft)
Total Outflow	: 53197 (ac-ft)	Peak Elevation	: 5409.3(ft)

APPENDIX D2

OPTION L1-75-96.7

Ruby Dam Feasibility Study
Option L1-75-96.7 - 75' Labyrinth Rating Curve



W.S. Elev Elevation	Flowrate (cfs)
5396.7	0
5397.0	119
5398.0	515
5400.0	2384
5402.0	4978
5404.0	7959
5406.0	11087
5408.0	14421
5410.0	18169
5412.0	22100
5413.5	25049

LABYRINTH WEIR DESIGN
No Approach Velocity

PROJECT:	Ruby Dam	TIME:	14:41:00
PROJECT NO.	08M087.175	DATE:	13-Aug-07
FLOOD CRITERIA:		BY:	KJF

USER INPUT

Max. Res	Zr	5410.3 ft	Thickness			
Crest el.	Zc	5396.7 ft	Wall	Tw	1.75	ft
Floor el.	Zf	5381.0 ft	Slab	Ts	1.33	ft
Spillway width	Ws	75.0 ft	Cutoff Depth			
Apex Width	2a	2 ft	Sheet Pile	Ds	0	ft
No. of cycles	n	2	Conc Wall	Dc	3	ft
Magnification	L/W	1.395				

CHECK ON RATIOS

L_{de}/B =	0.35	USE FEWER CYCLES
H_o/P =	0.87	Ho/P RATIO IS OK
α =	43.90	Angle IS OK

Note: L_{de}/B must be <= 0.35
Ho/P must be <= 0.9
α must be >= 6 deg

LABYRINTH DIMENSIONS (Per Cycle)

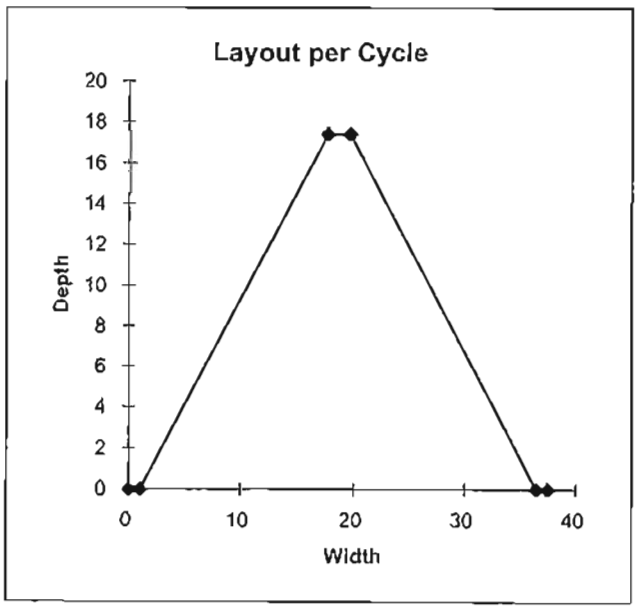
Wall Height	P	15.7	ft
Width	W	37.50	ft
Length	L	52.31	ft
Wall Length	B	24.16	ft
Depth	D	17.41	ft
Head max	H	13.60	ft
Wall Angle	α	43.90	deg
Length of Interference	L_{do}	8.49	

CREST LAYOUT
(One Cycle)

X	Y
0	0
1.00	0
17.75	17.41
19.75	17.41
36.50	0
37.50	0

COST CALCULATION

	Unit price $/unit	Units	Cost $
Weir wall, cy	500	106	53,233
Abutment walls, cy	500	122	60,892
Slab, cy	400	165	65,917
Concrete cutoff, cy	400	102	40,859
Sheet pile, sf	0	0	0
Reinforcement, lb	0	69,327	0



ESTIMATED COST
$220,901

DISCHARGE
Qmax 18,758 cfs

COEFFICIENTS

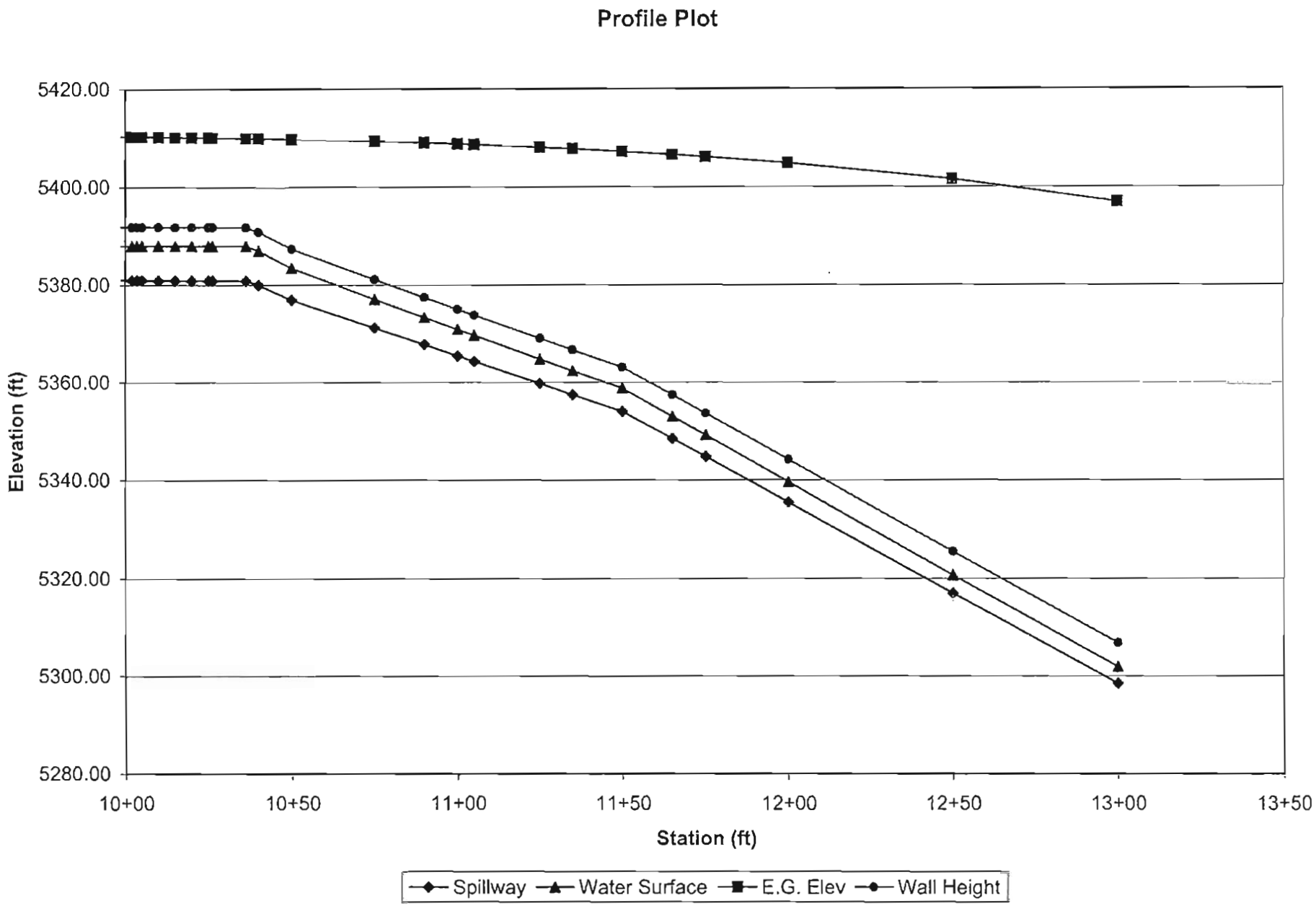
Column	7.00
Cd lower	0.65
Cd Upper	0.77
Cd	0.67
Efficacy	1.21

Ruby Dam Labyrinth Chute Spillway Hydraulics at Q = 20,000 cfs (50 LOL)

Design Discharge

Discharge	20000	cfs
Res Elev	5410.30	ft
Spwy Crest	5396.70	ft
Crest Width	75.0	ft
n	0.014	
P	10.0	ft
P/H	0.74	
Initial Slope	0.00375	ft/ft

Sta	Elev	Slope	Width	Y	WS Elev	Wall Frbrd	Wall Height	V	H_v	R_e	S_f	EGL	EGL-Z-Y-Hv	Froude#	Y_c	β	L_s
10+00.00	5381.00		75.00	13.02	5394.02	3.20	16.22	20.48	6.51	9.66		5410.30	9.76627	1.00	13.02	1.54687	0.90
		-0.004									0.00181						
10+02.00	5380.98		75.00	7.04	5388.04	3.81	10.86	37.86	22.26	5.93		5410.30	0.00060	2.51	13.02	0.409043	85.51
		-0.004									0.01186						
10+03.50	5380.99		75.00	7.05	5388.03	3.81	10.86	37.85	22.25	5.93		5410.28	0.00000	2.51	13.02	0.409254	85.46
		-0.004									0.01184						
10+05.00	5380.98		75.00	7.05	5388.03	3.81	10.86	37.84	22.23	5.93		5410.26	0.00000	2.51	13.02	0.409466	85.41
		-0.004									0.01183						
10+10.00	5380.96		75.00	7.06	5388.02	3.81	10.87	37.80	22.18	5.94		5410.20	0.00000	2.51	13.02	0.41017	85.24
		-0.004									0.01179						
10+15.00	5380.94		75.00	7.06	5388.01	3.81	10.87	37.76	22.14	5.94		5410.14	0.00000	2.50	13.02	0.410875	85.07
		-0.004									0.01175						
10+20.00	5380.93		75.00	7.07	5388.00	3.81	10.88	37.72	22.09	5.95		5410.08	0.00000	2.50	13.02	0.411579	85.91
		-0.004									0.01171						
10+25.00	5380.91		75.00	7.08	5387.98	3.81	10.89	37.68	22.04	5.95		5410.03	0.00000	2.50	13.02	0.412284	85.74
		-0.004									0.01167						
10+26.20	5380.90		75.00	7.08	5387.98	3.81	10.89	37.67	22.03	5.96		5410.01	0.00000	2.49	13.02	0.412452	85.70
		-0.004									0.01167						
10+36.20	5380.86		75.00	7.10	5387.96	3.81	10.90	37.59	21.94	5.97		5409.89	0.00000	2.49	13.02	0.413864	85.38
		-0.22									0.01159						
10+40.00	5380.03		75.00	6.95	5386.98	3.83	10.78	38.38	22.87	5.86		5409.85	0.00000	2.57	13.02	0.400396	88.60
		-0.30									0.01237						
10+50.00	5377.00		75.00	6.49	5383.49	3.92	10.40	41.11	26.24	5.53		5409.73	0.00000	2.84	13.02	0.359259	99.85
		-0.23									0.01534						
10+75.00	5371.25		75.00	5.85	5377.10	4.05	9.91	45.57	32.24	5.06		5409.34	0.00000	3.32	13.02	0.306011	118.70
		-0.23									0.02120						
10+90.00	5367.80		75.00	5.56	5373.36	4.12	9.69	47.92	35.66	4.85		5409.03	0.00000	3.58	13.02	0.283055	128.91
		-0.23									0.02486						
11+00.00	5365.50		75.00	5.40	5370.90	4.17	9.57	49.39	37.88	4.72		5408.78	0.00000	3.75	13.02	0.270246	135.37
		-0.23									0.02735						
11+05.00	5364.35		75.00	5.32	5369.67	4.19	9.51	50.09	38.97	4.66		5408.64	0.00000	3.83	13.02	0.264423	138.50
		-0.23									0.02860						
11+25.00	5359.75		75.00	5.05	5364.80	4.26	9.32	52.79	43.27	4.45		5408.07	0.00000	4.14	13.02	0.244037	150.60
		-0.23									0.03377						
11+35.00	5357.45		75.00	4.93	5362.38	4.30	9.23	54.04	45.35	4.36		5407.73	0.00000	4.29	13.02	0.235432	156.33
		-0.23									0.03638						
11+50.00	5354.00		75.00	4.78	5358.78	4.35	9.13	55.83	48.41	4.24		5407.18	0.00000	4.50	13.02	0.223971	164.62
		-0.37									0.04037						
11+65.00	5348.45		75.00	4.54	5352.99	4.43	8.97	58.75	53.59	4.05		5406.58	0.00000	4.85	13.02	0.207276	178.32
		-0.37									0.04747						
11+75.00	5344.75		75.00	4.40	5349.15	4.48	8.88	60.56	56.95	3.94		5406.10	0.00000	5.09	13.02	0.197906	187.00
		-0.37									0.05230						
12+00.00	5335.50		75.00	4.12	5339.62	4.60	8.71	64.79	65.18	3.71		5404.80	0.00000	5.63	13.02	0.178536	207.69
		-0.37									0.06490						
12+50.00	5317.00		75.00	3.70	5320.70	4.79	8.48	72.16	80.86	3.36		5401.55	0.00000	6.62	13.02	0.15175	245.22
		-0.37									0.09170						
13+00.00	5298.50		75.00	3.41	5301.91	4.94	8.35	78.24	95.06	3.12		5396.97	0.00000	7.47	13.02	0.134295	277.56
		-0.37									0.11897						
13+25.00	5289.25		75.00	3.30	5292.55	5.01	8.31	80.83	101.44	3.03		5393.99	0.00000	7.84	13.02	0.127868	291.67


Profile Plot
5420.00
5400.00
5380.00
5360.00
5340.00
5320.00
5300.00
5280.00
Elevation (ft)
10+00
10+50
11+00
11+50
12+00
12+50
13+00
13+50
Station (ft)
Spillway
Water Surface
E.G. Elev
Wall Height

Ruby Dam Labyrinth Chute Spillway Hydraulics at Q = 4,000 cfs (Routed 500-yr)

Design Discharge	
Discharge	4000 cfs
Res Elev	5401.30 ft
Spwy Crest	5386.70 ft
Crest Width	75.0 ft
n	0.014
P	10.0 ft
P/H	2.17
Initial Slope	0.00375 ft/ft

Sta	Elev	Slope	Width	Y	WS Elev	Wall Frbrd	Wall Height	V	H_v	R_h	S_f	EGL	EGL-Z-Y-Hv	Froude#	Y_c	B	L_1
10+00.00	5381.00		75.00	4.45	5385.45	2.49	6.94	11.99	2.23	3.98		5401.30	13.61955	1.00	4.45	1.521356	1.86
		-0.004									0.00202						
10+02.00	5380.99		75.00	1.53	5382.53	3.00	4.54	34.77	18.77	1.47		5401.30	0.00000	4.95	4.45	0.203553	181.68
		-0.004									0.06397						
10+03.50	5380.99		75.00	1.54	5382.52	3.00	4.54	34.68	18.68	1.48		5401.20	0.00000	4.93	4.45	0.204334	180.96
		-0.004									0.06345						
10+05.00	5380.98		75.00	1.54	5382.52	3.00	4.54	34.59	18.58	1.48		5401.10	0.00000	4.91	4.45	0.205114	180.25
		-0.004									0.06293						
10+10.00	5380.96		75.00	1.55	5382.52	2.99	4.55	34.30	18.27	1.49		5400.79	0.00000	4.85	4.45	0.207747	177.90
		-0.004									0.06122						
10+15.00	5380.94		75.00	1.57	5382.51	2.99	4.56	34.02	17.97	1.50		5400.48	0.00000	4.79	4.45	0.210384	175.61
		-0.004									0.05958						
10+20.00	5380.93		75.00	1.58	5382.51	2.98	4.56	33.74	17.68	1.52		5400.19	0.00000	4.73	4.45	0.213324	173.37
		-0.004									0.05800						
10+25.00	5380.91		75.00	1.59	5382.50	2.98	4.57	33.47	17.40	1.53		5399.90	0.00000	4.67	4.45	0.216559	171.17
		-0.004									0.05648						
10+26.20	5380.90		75.00	1.60	5382.50	2.98	4.57	33.41	17.33	1.53		5399.83	0.00000	4.66	4.45	0.216298	170.66
		-0.004									0.05613						
10+36.20	5380.86		75.00	1.62	5382.49	2.97	4.59	32.87	16.78	1.56		5399.27	0.00000	4.55	4.45	0.221678	166.38
		-0.22									0.05324						
10+40.00	5380.03		75.00	1.59	5381.63	2.98	4.57	33.51	17.44	1.53		5399.05	0.00000	4.68	4.45	0.215281	171.51
		-0.30									0.05671						
10+50.00	5377.00		75.00	1.49	5378.49	3.02	4.51	35.90	20.01	1.43		5398.50	0.00000	5.19	4.45	0.193873	191.00
		-0.23									0.07107						
10+75.00	5371.25		75.00	1.35	5372.60	3.09	4.44	39.41	24.12	1.31		5396.72	0.00000	5.97	4.45	0.168292	220.72
		-0.23									0.09656						
10+90.00	5367.80		75.00	1.30	5369.10	3.12	4.42	41.06	26.17	1.26		5395.27	0.00000	6.35	4.45	0.15619	235.08
		-0.23									0.11046						
11+00.00	5365.50		75.00	1.27	5366.77	3.14	4.41	42.01	27.40	1.23		5394.17	0.00000	6.57	4.45	0.152913	243.48
		-0.23									0.11968						
11+05.00	5364.35		75.00	1.26	5365.61	3.14	4.40	42.44	27.97	1.22		5393.57	0.00000	6.67	4.45	0.150453	247.35
		-0.23									0.12317						
11+25.00	5359.75		75.00	1.21	5360.96	3.17	4.38	44.06	30.15	1.17		5391.11	0.00000	7.06	4.45	0.142159	262.01
		-0.23									0.13938						
11+35.00	5357.45		75.00	1.19	5358.64	3.19	4.38	44.73	31.07	1.16		5389.72	0.00000	7.22	4.45	0.138954	268.13
		-0.23									0.14649						
11+50.00	5354.00		75.00	1.17	5355.17	3.20	4.37	45.64	32.35	1.13		5387.52	0.00000	7.44	4.45	0.134796	276.51
		-0.37									0.15652						
11+65.00	5348.45		75.00	1.11	5349.56	3.24	4.35	47.89	35.61	1.08		5385.17	0.00000	8.00	4.45	0.125387	297.50
		-0.37									0.18331						
11+75.00	5344.75		75.00	1.09	5345.84	3.26	4.35	49.14	37.50	1.05		5383.34	0.00000	8.31	4.45	0.12058	309.49
		-0.37									0.19967						
12+00.00	5335.50		75.00	1.03	5336.53	3.31	4.34	51.89	41.82	1.00		5378.35	0.00000	9.02	4.45	0.11108	335.20
		-0.37									0.23894						
12+50.00	5317.00		75.00	0.95	5317.95	3.38	4.33	55.85	48.44	0.93		5368.40	0.00000	10.07	4.45	0.099438	375.88
		-0.37									0.30455						
13+00.00	5298.50		75.00	0.92	5299.42	3.41	4.33	57.73	51.75	0.90		5351.17	0.00000	10.58	4.45	0.094623	395.13
		-0.37									0.33958						
13+25.00	5289.25		75.00	0.92	5290.17	3.41	4.33	58.15	52.51	0.90		5342.68	0.00000	10.70	4.45	0.093581	399.55

HMS * Summary of Results for Ruby-75'

Labyrinth

Project : Ruby_Final_HKM Run Name : Ruby 18, 50 LOL

Start of Run	: 25Feb05 0000	Basin Model	: Ruby-18
End of Run	: 28Feb05 0000	Met. Model	: 24 HR, LOL=50
Execution Time	: 17Jan08 1626	Control Specs	: 24-Hour

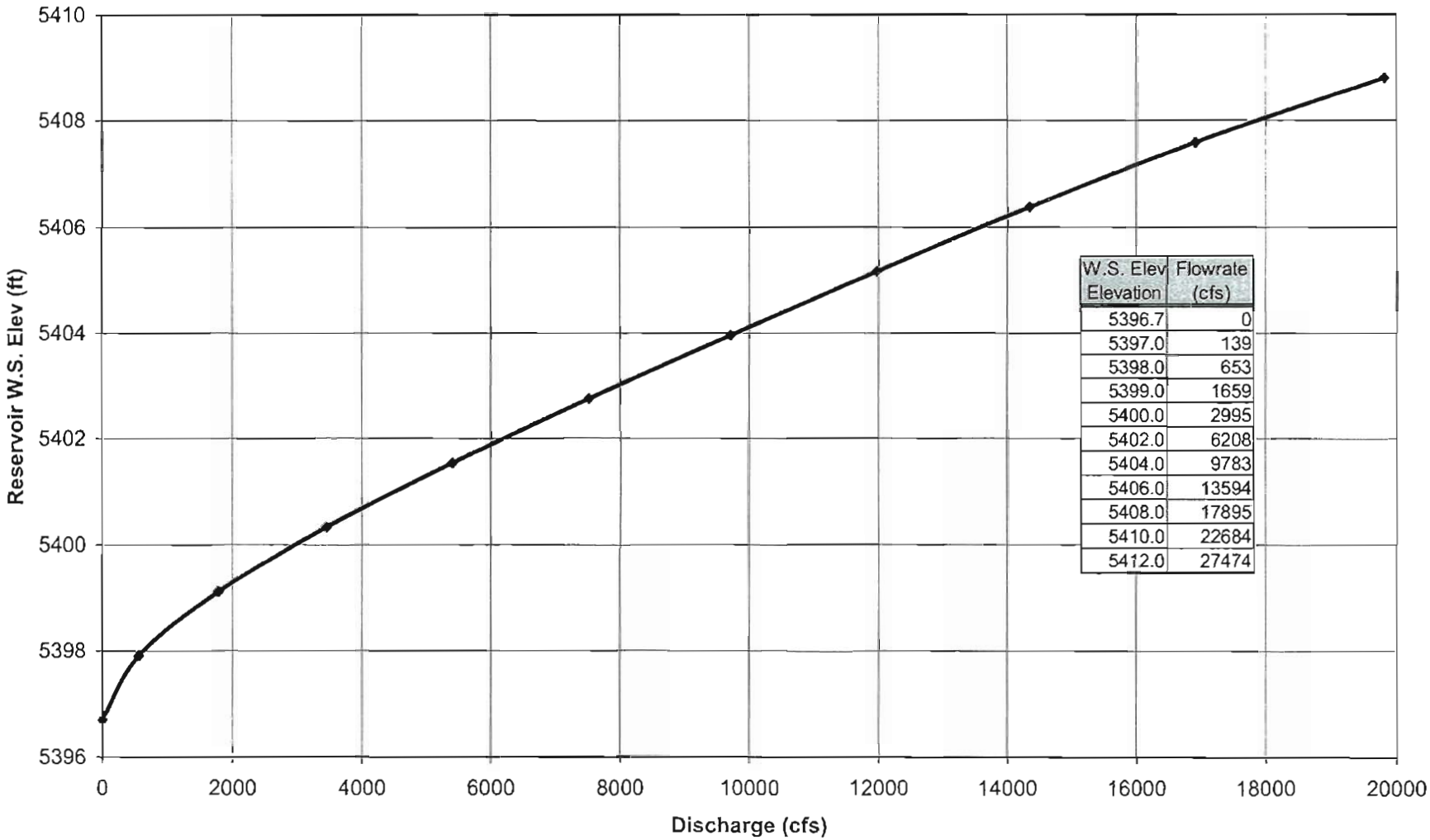
Computed Results

Peak Inflow	: 23881 (cfs)	Date/Time of Peak Inflow	: 26 Feb 05 0900
Peak Outflow	: 18629 (cfs)	Date/Time of Peak Outflow	: 26 Feb 05 1700
Total Inflow	: 60276 (ac-ft)	Peak Storage	: 57769(ac-ft)
Total Outflow	: 52490 (ac-ft)	Peak Elevation	: 5410.2(ft)

APPENDIX D3

OPTION L2-100-96.7

Ruby Dam Feasibility Study
Option L2-100-96.7 - 100' Labyrinth Rating Curve



W.S. Elev Elevation	Flowrate (cfs)
5396.7	0
5397.0	139
5398.0	653
5399.0	1659
5400.0	2995
5402.0	6208
5404.0	9783
5406.0	13594
5408.0	17895
5410.0	22684
5412.0	27474

LABYRINTH WEIR DESIGN
No Approach Velocity

PROJECT:	Ruby Dam	TIME:	14:47:47
PROJECT NO.	08M087.175	DATE:	13-Aug-07
FLOOD CRITERIA:		BY:	KJF

USER INPUT

Max. Res	Zr	5408.8 ft	Thickness			
Crest el.	Zc	5396.7 ft	Wall	Tw	1.75	ft
Floor el.	Zf	5383.0 ft	Slab	Ts	1.33	ft
Spillway width	Ws	100.0 ft	Cutoff Depth			
Apex Width	2a	4 ft	Sheet Pile	Ds	0	ft
No. of cycles	n	2	Conc Wall	Dc	3	ft
Magnification	L/W	1.3				

CHECK ON RATIOS

L_{do}/B =	0.22	Ld/B RATIO IS OK
H_o/P =	0.88	Ho/P RATIO IS OK
α =	47.46	Angle IS OK

Note: L_{do}/B must be <= 0.35
Ho/P must be <= 0.9
α must be >= 6 deg

LABYRINTH DIMENSIONS (Per Cycle)

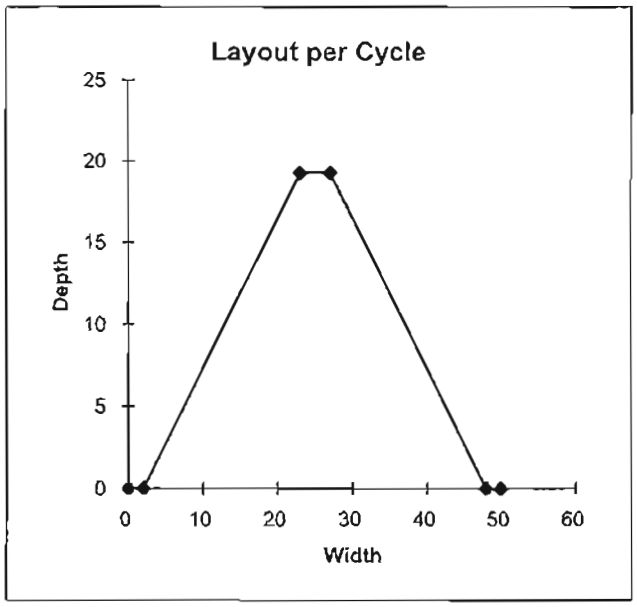
Wall Height	P	13.7	ft
Width	W	50.00	ft
Length	L	65.00	ft
Wall Length	B	28.50	ft
Depth	D	19.27	ft
Head max	H	12.10	ft
Wall Angle	α	47.46	deg
Length of Interference	L_{do}	6.28	

CREST LAYOUT
(One Cycle)

X	Y
0	0
2.00	0
23.00	19.27
27.00	19.27
48.00	0
50.00	0

COST CALCULATION

	Unit price $/unit	Units	Cost $
Weir wall, cy	500	115	57,718
Abutment walls, cy	500	109	54,487
Slab, cy	400	214	85,648
Concrete cutoff, cy	400	114	45,748
Sheet pile, sf	0	0	0
Reinforcement, lb	0	77,406	0



ESTIMATED COST
$243,601

DISCHARGE
Qmax 19,811 cfs

COEFFICIENTS

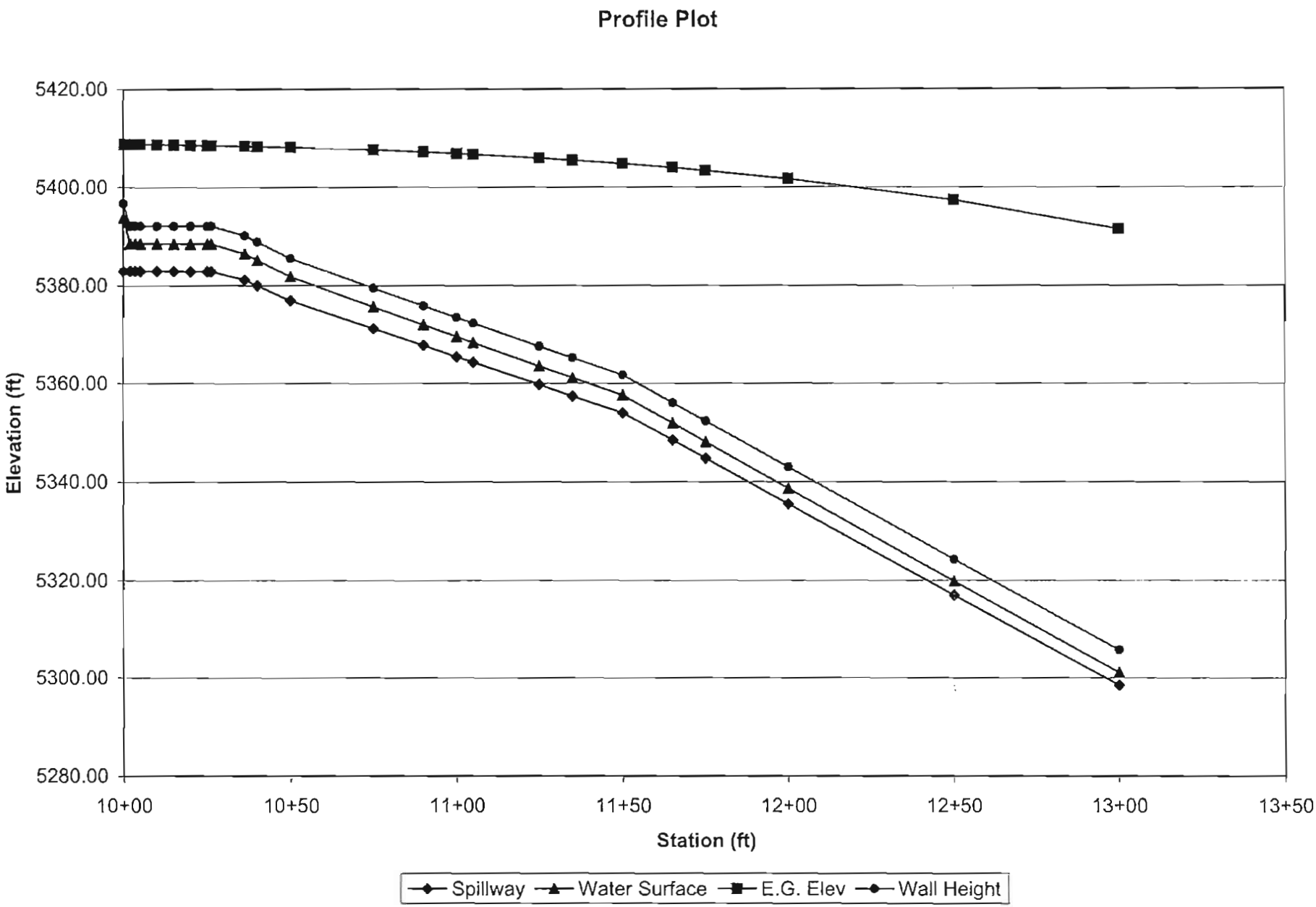
Column	7.00
Cd lower	0.65
Cd Upper	0.77
Cd	0.68
Efficacy	1.14

Ruby Dam Labyrinth Crest Spillway Hydraulics at Q = 20,000 cfs (50 LOL)

Design Discharge

Discharge	20000	cfs
Res Elev	5408.80	ft
Spwy Crest	5396.70	ft
Crest Width	100.0	ft
n	0.014	
P	10.0	ft
P/H	0.83	
Initial Slope	0.00375	ft/ft

Sta	Elev	Slope	Width	Y	W/S Elev	Wall Frbrd	Wall Height	V	H_v	R_h	S_f	EGL	EGL-Z-Y-Hv	Froude#	Y_c	β	L_1
10+00.00	5383.00		100.00	10.75	5393.75	3.03	13.78	18.60	5.37	8.85		5408.80	9.67526	1.00	10.75	1.570796	0.00
		-0.004									0.00168						
10+02.00	5382.99		100.00	5.54	5388.53	3.60	9.13	36.13	20.27	4.98		5408.80	0.00000	2.71	10.75	0.378517	125.72
		-0.004									0.01361						
10+03.50	5382.99		100.00	5.54	5388.52	3.60	9.14	36.11	20.25	4.99		5408.78	0.00000	2.70	10.75	0.378769	125.63
		-0.004									0.01359						
10+05.00	5382.98		100.00	5.54	5388.52	3.60	9.14	36.10	20.23	4.99		5408.76	0.00000	2.70	10.75	0.379021	125.54
		-0.004									0.01357						
10+10.00	5382.96		100.00	5.55	5388.51	3.60	9.14	36.05	20.18	4.99		5408.69	0.00000	2.70	10.75	0.379964	125.23
		-0.004									0.01351						
10+15.00	5382.94		100.00	5.56	5388.50	3.59	9.15	36.00	20.12	5.00		5408.62	0.00000	2.69	10.75	0.380708	124.93
		-0.004									0.01345						
10+20.00	5382.93		100.00	5.56	5388.49	3.59	9.16	35.95	20.06	5.01		5408.55	0.00000	2.69	10.75	0.381548	124.62
		-0.004									0.01339						
10+25.00	5382.91		100.00	5.57	5388.48	3.59	9.16	35.90	20.01	5.01		5408.49	0.00000	2.68	10.75	0.38239	124.32
		-0.004									0.01333						
10+26.20	5382.90		100.00	5.57	5388.48	3.59	9.16	35.88	19.99	5.01		5408.47	0.00000	2.68	10.75	0.382591	124.25
		-0.172									0.01332						
10+36.20	5381.19		100.00	5.34	5386.52	3.64	8.97	37.48	21.81	4.82		5408.34	0.00000	2.86	10.75	0.357269	133.94
		-0.30									0.01531						
10+40.00	5380.03		100.00	5.19	5385.22	3.67	8.88	38.53	23.05	4.70		5408.28	0.00000	2.98	10.75	0.342146	140.39
		-0.30									0.01673						
10+50.00	5377.00		100.00	4.88	5381.88	3.74	8.61	41.11	26.25	4.43		5408.11	0.00000	3.28	10.75	0.309326	156.45
		-0.23									0.02060						
10+75.00	5371.25		100.00	4.41	5375.66	3.86	8.27	45.35	31.94	4.05		5407.60	0.00000	3.81	10.75	0.265884	183.60
		-0.23									0.02825						
10+90.00	5367.80		100.00	4.20	5372.00	3.92	8.12	47.59	35.17	3.88		5407.17	0.00000	4.09	10.75	0.246927	196.36
		-0.23									0.03301						
11+00.00	5365.50		100.00	4.08	5369.58	3.95	8.04	48.98	37.26	3.77		5406.64	0.00000	4.27	10.75	0.235263	207.88
		-0.23									0.03624						
11+05.00	5364.35		100.00	4.03	5368.38	3.98	8.00	49.65	38.28	3.73		5405.66	0.00000	4.36	10.75	0.231421	212.19
		-0.23									0.03788						
11+25.00	5359.75		100.00	3.83	5363.58	4.04	7.87	52.21	42.32	3.56		5405.90	0.00000	4.70	10.75	0.214376	229.65
		-0.23									0.04454						
11+35.00	5357.45		100.00	3.75	5361.20	4.07	7.82	53.39	44.26	3.48		5405.46	0.00000	4.86	10.75	0.207186	237.87
		-0.23									0.04789						
11+50.00	5354.00		100.00	3.63	5357.63	4.12	7.75	55.08	47.11	3.39		5404.74	0.00000	5.09	10.75	0.197595	249.74
		-0.37									0.05298						
11+65.00	5348.45		100.00	3.45	5351.90	4.19	7.64	57.89	52.04	3.23		5403.95	0.00000	5.49	10.75	0.183211	269.85
		-0.37									0.06227						
11+75.00	5344.75		100.00	3.35	5348.10	4.23	7.59	59.63	55.22	3.14		5403.32	0.00000	5.74	10.75	0.175159	282.53
		-0.37									0.06856						
12+00.00	5335.50		100.00	3.14	5338.64	4.33	7.47	63.68	62.97	2.95		5401.61	0.00000	6.33	10.75	0.158583	312.64
		-0.37									0.08468						
12+50.00	5317.00		100.00	2.83	5319.83	4.50	7.33	70.66	77.53	2.68		5397.37	0.00000	7.40	10.75	0.135514	368.70
		-0.37									0.11913						
13+00.00	5298.50		100.00	2.62	5301.12	4.63	7.25	76.25	90.29	2.49		5391.41	0.00000	8.30	10.75	0.120815	411.84
		-0.37									0.15274						
13+25.00	5289.25		100.00	2.55	5291.80	4.68	7.23	78.54	95.79	2.42		5387.59	0.00000	8.67	10.75	0.115543	430.81


Profile Plot
5420.00
5400.00
5380.00
5360.00
5340.00
5320.00
5300.00
5280.00
Elevation (ft)
10+00
10+50
11+00
11+50
12+00
12+50
13+00
13+50
Station (ft)
Spillway
Water Surface
E.G. Elev
Wall Height

Ruby Dam Labyrinth Crest Spillway Hydraulics at Q = 4,000 cfs (Routed 500-yr)

Design Discharge

Discharge	4000	cfs
Res Elev	5400.70	ft
Spwy Crest	5396.70	ft
Crest Width	100.0	ft
n	0.014	
P	10.0	ft
P/H	2.50	
Initial Slope	0.00375	ft/ft

Sta	Elev	Slope	Width	Y	WS Elev	Wall Froud	Wall Height	V	H_v	R_c	S_f	EGL	EGL-Z-Y-Hv	Froudest	Y_c	β	L_f
10+00.00	5383.00		100.00	3.68	5386.68	2.42	6.10	10.87	1.83	3.43		5400.70	12.18541	1.00	3.68	1.570796	0.00
		-0.004									0.00203						
10+02.00	5382.99		100.00	1.23	5384.22	2.87	4.10	32.57	16.48	1.20		5400.70	0.00000	5.18	3.68	0.194268	254.13
		-0.004									0.07397						
10+03.50	5382.99		100.00	1.23	5384.22	2.87	4.10	32.46	16.37	1.20		5400.58	0.00000	5.15	3.68	0.195254	252.81
		-0.004									0.07316						
10+05.00	5382.98		100.00	1.24	5384.22	2.87	4.10	32.36	16.26	1.21		5400.48	0.00000	5.13	3.68	0.19524	251.51
		-0.004									0.07236						
10+10.00	5382.96		100.00	1.25	5384.21	2.86	4.11	32.00	15.90	1.22		5400.11	0.00000	5.04	3.68	0.199573	247.19
		-0.004									0.06976						
10+15.00	5382.94		100.00	1.26	5384.21	2.86	4.12	31.65	15.56	1.23		5399.76	0.00000	4.96	3.68	0.202923	243.01
		-0.004									0.06729						
10+20.00	5382.93		100.00	1.28	5384.20	2.85	4.13	31.31	15.23	1.25		5399.43	0.00000	4.88	3.68	0.206274	238.95
		-0.004									0.06494						
10+25.00	5382.91		100.00	1.29	5384.20	2.84	4.13	30.98	14.91	1.26		5399.10	0.00000	4.81	3.68	0.20963	235.01
		-0.004									0.06271						
10+26.20	5382.90		100.00	1.29	5384.20	2.84	4.14	30.91	14.83	1.26		5399.03	0.00000	4.79	3.68	0.210426	234.10
		-0.004									0.06220						
10+36.20	5382.86		100.00	1.32	5384.19	2.83	4.15	30.26	14.22	1.29		5398.41	0.00000	4.64	3.68	0.217289	226.48
		-0.74									0.05802						
10+40.00	5380.03		100.00	1.21	5381.24	2.88	4.09	33.03	16.94	1.18		5398.19	0.00000	5.29	3.68	0.199199	259.71
		-0.30									0.07745						
10+50.00	5377.00		100.00	1.14	5378.14	2.92	4.05	35.23	19.28	1.11		5397.41	0.00000	5.83	3.68	0.172459	287.04
		-0.23									0.09586						
10+75.00	5371.25		100.00	1.05	5372.30	2.97	4.02	38.25	22.72	1.02		5395.01	0.00000	6.59	3.68	0.152294	325.77
		-0.23									0.12577						
10+90.00	5367.80		100.00	1.01	5368.81	2.99	4.00	39.57	24.32	0.99		5393.13	0.00000	6.94	3.68	0.144668	343.20
		-0.23									0.14073						
11+00.00	5365.50		100.00	0.99	5366.49	3.01	4.00	40.31	25.23	0.97		5391.72	0.00000	7.13	3.68	0.140705	353.01
		-0.23									0.14956						
11+05.00	5364.35		100.00	0.98	5365.33	3.01	3.99	40.63	25.64	0.97		5390.97	0.00000	7.22	3.68	0.139902	357.39
		-0.23									0.15360						
11+25.00	5359.75		100.00	0.96	5360.71	3.03	3.99	41.85	27.20	0.94		5387.90	0.00000	7.54	3.68	0.132955	373.65
		-0.23									0.16933						
11+35.00	5357.45		100.00	0.95	5358.40	3.04	3.98	42.32	27.81	0.93		5385.21	0.00000	7.67	3.68	0.130723	380.31
		-0.23									0.17574						
11+50.00	5354.00		100.00	0.93	5354.93	3.05	3.98	42.95	28.64	0.91		5383.57	0.00000	7.84	3.68	0.127863	388.91
		-0.37									0.18447						
11+65.00	5348.45		100.00	0.89	5349.34	3.08	3.97	45.02	31.47	0.87		5380.80	0.00000	8.42	3.68	0.119108	417.80
		-0.37									0.21555						
11+75.00	5344.75		100.00	0.87	5345.62	3.10	3.97	46.12	33.03	0.85		5378.65	0.00000	8.73	3.68	0.114828	433.52
		-0.37									0.23359						
12+00.00	5335.50		100.00	0.83	5336.33	3.14	3.96	48.47	36.48	0.81		5372.81	0.00000	9.40	3.68	0.106546	467.50
		-0.37									0.27538						
12+50.00	5317.00		100.00	0.78	5317.78	3.18	3.96	51.55	41.26	0.76		5359.04	0.00000	10.31	3.68	0.097117	513.22
		-0.37									0.33767						
13+00.00	5298.50		100.00	0.76	5299.26	3.20	3.96	52.56	42.90	0.75		5342.16	0.00000	10.62	3.68	0.094325	528.51
		-0.37									0.36007						
13+25.00	5289.25		100.00	0.76	5290.01	3.20	3.96	52.71	43.15	0.75		5333.16	0.00000	10.66	3.68	0.093913	530.84

HMS * Summary of Results for Ruby-100'

Labyrinth

Project : Ruby_Final_HKM Run Name : Ruby 18, 50 LOL

Start of Run	: 25Feb05 0000	Basin Model	: Ruby-18
End of Run	: 28Feb05 0000	Met. Model	: 24 HR, LOL=50
Execution Time	: 17Jan08 1628	Control Specs	: 24-Hour

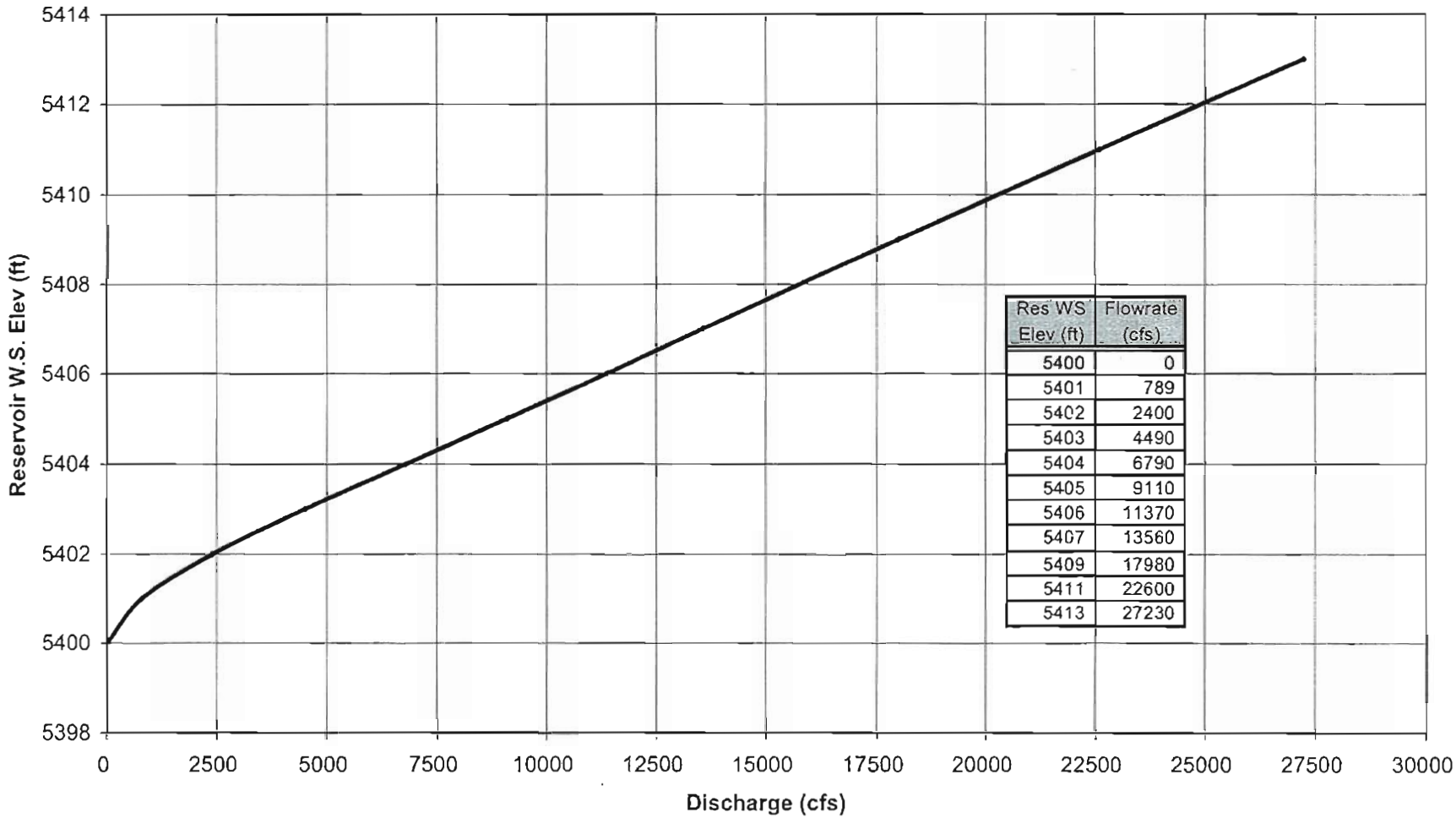
Computed Results

Peak Inflow	: 23881 (cfs)	Date/Time of Peak Inflow	: 26 Feb 05 0900
Peak Outflow	: 19789 (cfs)	Date/Time of Peak Outflow	: 26 Feb 05 1500
Total Inflow	: 60276 (ac-ft)	Peak Storage	: 55820(ac-ft)
Total Outflow	: 53922 (ac-ft)	Peak Elevation	: 5408.8(ft)

APPENDIX D4

OPTION L2-100-00

Ruby Dam Feasibility Study
Preferred Spillway Alternative
Option L2-100-00 - 100' Labyrinth Rating Curve



Res WS Elev (ft)	Flowrate (cfs)
5400	0
5401	789
5402	2400
5403	4490
5404	6790
5405	9110
5406	11370
5407	13560
5409	17980
5411	22600
5413	27230

LABYRINTH WEIR DESIGN
No Approach Velocity

PROJECT:	Ruby Dam	TIME:	11:24:10
PROJECT NO.	08M087.175	DATE:	17-Jan-08
FLOOD CRITERIA:	20,000 cfs	BY:	BSJ

USER INPUT

Max. Res	Zr	5409.9 ft	Thickness		
Crest el.	Zc	5400.0 ft	Wall	Tw	1.33 ft
Floor el.	Zf	5389.0 ft	Slab	Ts	1.33 ft
Spillway width	Ws	100.0 ft	Cutoff Depth		
Apex Width	2a	4 ft	Sheet Pile	Ds	0 ft
No. of cycles	n	2	Conc Wall	Dc	3 ft
Magnification	L/W	2.5			

CHECK ON RATIOS

L_{de}/B =	0.35	Ld/B RATIO IS OK
H_o/P =	0.90	Ho/P RATIO IS OK
α =	21.04	Angle IS OK

Note: L_{de}/B must be <= 0.35
Ho/P must be <= 0.9
α must be >= 6 deg

LABYRINTH DIMENSIONS (Per Cycle)

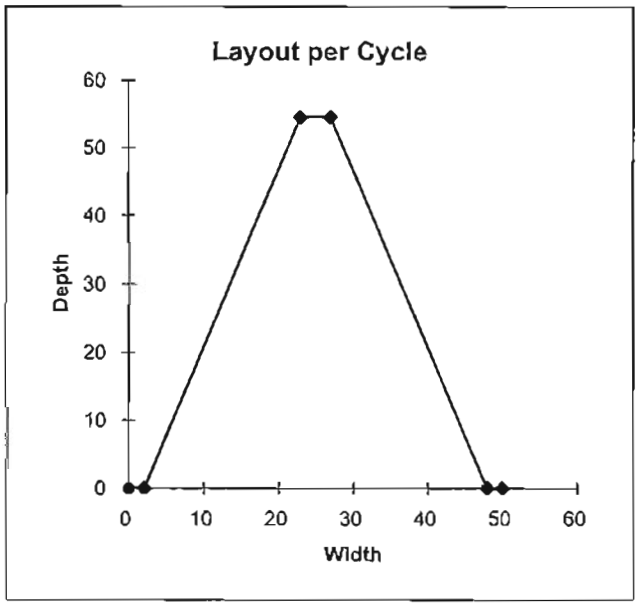
Wall Height	P	11	ft
Width	W	50.00	ft
Length	L	125.00	ft
Wall Length	B	58.50	ft
Depth	D	54.60	ft
Head max	H	9.90	ft
Wall Angle	α	21.04	deg
Length of Interference	L_{de}	20.29	

CREST LAYOUT
(One Cycle)

X	Y
0	0
2.00	0
23.00	54.60
27.00	54.60
48.00	0
50.00	0

COST CALCULATION

	Unit price $/unit	Units	Cost $
Weir wall, cy	350	135	47,412
Abutment walls, cy	350	139	48,707
Slab, cy	225	366	82,461
Concrete cutoff, cy	200	108	21,570
Sheet pile, sf	20	0	0
Reinforcement, lb	0.65	104,856	68,156



ESTIMATED COST
$268,307

DISCHARGE
Qmax 20,062 cfs

COEFFICIENTS

Column	5.00
Cd lower	0.44
Cd Upper	0.54
Cd	0.48
Efficacy	1.54

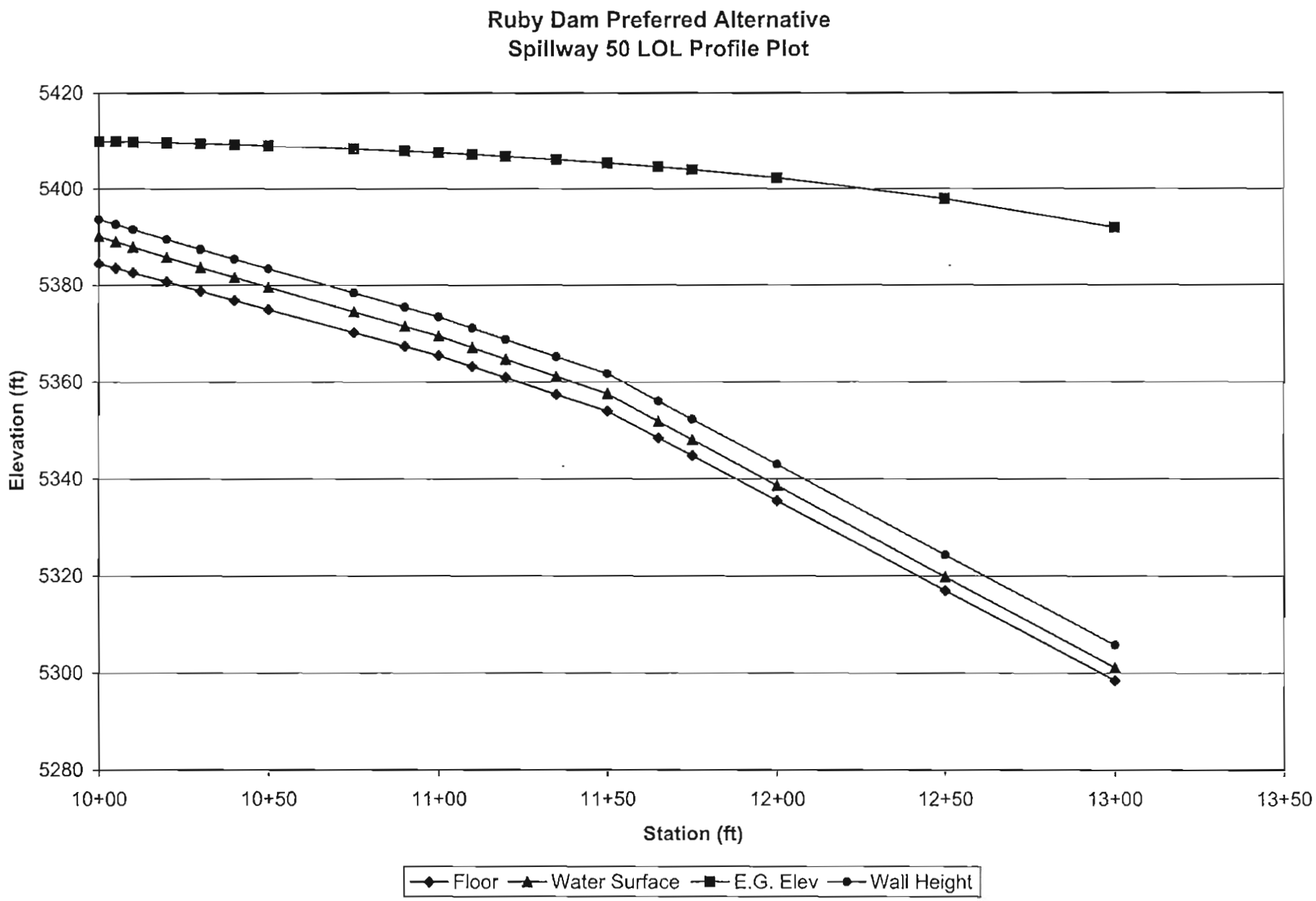
Ruby Dam Labyrinth Crest Spillway Hydraulics at Q = 20,000 cfs (50 LOL)

Design Discharge

Discharge	20000	cfs
Res Elev	5410.00	ft
Spwy Crest	5400.00	ft
Crest Width	100.0	ft
n	0.014	
P	11.0	ft
P/H	1.10	
Initial Slope	0.19000	ft/ft

5344.75

Sta	Elev	Slope	Width	Y	WS Elev	Wall Frbrd	Wall Height	V	H_v	R_h	S_f	EGL	EGL-Z-Y-Hv	Froude#	Y_c	β	L_f
9+90.00	5384.50		100.00	10.75	5395.25	3.03	13.78	18.60	5.37	8.85		5410.00	9.37526	1.00	10.75	1.570796	0.00
		0.00									0.00168						
10+00.00	5384.50		100.00	5.59	5390.09	3.59	9.18	35.80	19.90	5.03		5409.98	0.00000	2.67	10.75	0.384094	123.71
		-0.19									0.01321						
10+05.00	5383.55		100.00	5.45	5389.00	3.61	9.06	36.70	20.92	4.91		5409.92	0.00000	2.77	10.75	0.369234	129.21
		-0.19									0.01431						
10+10.00	5382.60		100.00	5.32	5387.92	3.64	8.95	37.57	21.92	4.81		5409.85	0.00000	2.87	10.75	0.355888	134.51
		-0.19									0.01543						
10+20.00	5380.70		100.00	5.10	5385.80	3.69	8.79	39.23	23.89	4.63		5409.69	0.00000	3.06	10.75	0.332755	144.67
		-0.19									0.01771						
10+30.00	5378.80		100.00	4.91	5383.71	3.73	8.64	40.77	25.81	4.47		5409.51	0.00000	3.24	10.75	0.313394	154.29
		-0.19									0.02005						
10+40.00	5376.90		100.00	4.74	5381.64	3.77	8.51	42.22	27.68	4.33		5409.31	0.00000	3.42	10.75	0.296891	163.43
		-0.19									0.02243						
10+50.00	5375.00		100.00	4.59	5379.59	3.81	8.40	43.59	29.50	4.20		5409.09	0.00000	3.59	10.75	0.282618	172.18
		-0.19									0.02486						
10+75.00	5370.25		100.00	4.28	5374.53	3.90	8.18	46.75	33.94	3.94		5408.47	0.00000	3.98	10.75	0.253757	192.79
		-0.19									0.03117						
10+90.00	5367.40		100.00	4.13	5371.53	3.94	8.07	48.47	36.47	3.81		5408.00	0.00000	4.20	10.75	0.240147	204.19
		-0.19									0.03501						
11+00.00	5365.50		100.00	4.04	5369.54	3.97	8.01	49.54	38.11	3.74		5407.65	0.00000	4.35	10.75	0.232211	211.44
		-0.23									0.03759						
11+10.00	5363.20		100.00	3.93	5367.13	4.01	7.94	50.84	40.14	3.65		5407.27	0.00000	4.52	10.75	0.223205	220.28
		-0.23									0.04088						
11+20.00	5360.90		100.00	3.84	5364.74	4.04	7.88	52.09	42.13	3.57		5406.87	0.00000	4.68	10.75	0.215142	228.81
		-0.23									0.04420						
11+35.00	5357.45		100.00	3.71	5361.16	4.09	7.80	53.86	45.04	3.46		5406.20	0.00000	4.93	10.75	0.204465	241.12
		-0.23									0.04926						
11+50.00	5354.00		100.00	3.60	5357.60	4.13	7.73	55.52	47.86	3.36		5405.46	0.00000	5.15	10.75	0.195233	252.84
		-0.37									0.05436						
11+65.00	5348.45		100.00	3.43	5351.88	4.20	7.63	58.29	52.77	3.21		5404.65	0.00000	5.55	10.75	0.181295	272.77
		-0.37									0.06368						
11+75.00	5344.75		100.00	3.33	5348.08	4.24	7.57	60.02	56.93	3.12		5404.01	0.00000	5.79	10.75	0.173473	285.33
		-0.37									0.07000						
12+00.00	5335.50		100.00	3.12	5338.62	4.34	7.46	64.02	63.64	2.94		5402.26	0.00000	6.38	10.75	0.157321	315.19
		-0.37									0.08635						
12+50.00	5317.00		100.00	2.82	5319.82	4.51	7.32	70.93	78.12	2.67		5397.94	0.00000	7.44	10.75	0.134742	369.83
		-0.37									0.12061						
13+00.00	5298.50		100.00	2.62	5301.12	4.63	7.25	76.47	90.80	2.49		5391.91	0.00000	8.33	10.75	0.120301	413.62
		-0.37									0.15416						
13+25.00	5269.25		100.00	2.54	5291.79	4.69	7.23	78.74	96.27	2.42		5388.06	0.00000	8.71	10.75	0.115113	432.44
		-0.37									0.16963						
13+33.70	5286.00		100.00	2.52	5268.52	4.70	7.22	79.47	98.07	2.40		5386.58	0.00000	8.83	10.75	0.113519	438.56


Ruby Dam Preferred Alternative
Spillway 50 LOL Profile Plot
5420
5400
5380
5360
5340
5320
5300
5280
Elevation (ft)
10+00
10+50
11+00
11+50
12+00
12+50
13+00
13+50
Station (ft)
Floor
Water Surface
E.G. Elev
Wall Height

Ruby Dam Labyrinth Crest Spillway Hydraulics at Q = 4,000 cfs (Routed 500-yr)

Design Discharge

Discharge	4000	cfs
Res Elev	5402.80	ft
Spwy Crest	5400.00	ft
Crest Width	100.0	ft
n	0.014	
P	11.0	ft
P/H	3.93	
Initial Slope	0.19000	ft/ft

Sta	Elev	Slope	Width	Y	WS Elev	Wall Friction	Wall Height	V	H_v	R_h	S_f	EGL	EGL-Z-Y-Hv	Froude#	Y_c	β	L_1
9+90.00	5384.50		100.00	3.68	5388.18	2.42	6.10	10.87	1.83	3.43		5402.80	12.78541	1.00	3.68	1.570796	0.00
		0.000									0.00203						
10+00.00	5384.50		100.00	1.21	5385.71	2.88	4.09	33.16	17.07	1.18		5402.78	0.00000	5.32	3.68	0.189079	261.28
		-0.190									0.07845						
10+05.00	5383.55		100.00	1.19	5384.74	2.89	4.08	33.72	17.65	1.16		5402.39	0.00000	5.45	3.68	0.184365	268.12
		-0.190									0.08289						
10+10.00	5382.60		100.00	1.17	5383.77	2.90	4.07	34.24	18.20	1.14		5401.97	0.00000	5.58	3.68	0.180096	274.62
		-0.190									0.08722						
10+20.00	5380.70		100.00	1.14	5381.84	2.92	4.05	35.22	19.27	1.11		5401.10	0.00000	5.82	3.68	0.172532	286.92
		-0.190									0.09577						
10+30.00	5378.80		100.00	1.11	5379.91	2.93	4.04	36.10	20.23	1.08		5400.14	0.00000	6.04	3.68	0.166233	298.01
		-0.190									0.10387						
10+40.00	5376.90		100.00	1.08	5377.98	2.95	4.03	36.88	21.12	1.06		5399.10	0.00000	6.24	3.68	0.160936	308.00
		-0.190									0.11148						
10+50.00	5375.00		100.00	1.06	5376.06	2.96	4.02	37.58	21.93	1.04		5397.99	0.00000	6.42	3.68	0.156445	316.99
		-0.190									0.11859						
10+75.00	5370.25		100.00	1.02	5371.27	2.99	4.01	39.11	23.75	1.00		5395.02	0.00000	6.82	3.68	0.147261	337.08
		-0.190									0.13537						
10+90.00	5367.40		100.00	1.01	5368.41	3.00	4.00	39.79	24.59	0.99		5392.99	0.00000	6.99	3.68	0.143459	346.14
		-0.19									0.14334						
11+00.00	5365.50		100.00	1.00	5366.50	3.00	4.00	40.18	25.07	0.98		5391.56	0.00000	7.10	3.68	0.141396	351.26
		-0.23									0.14796						
11+10.00	5363.20		100.00	0.98	5364.18	3.01	3.99	40.84	25.90	0.96		5390.08	0.00000	7.27	3.68	0.137935	360.19
		-0.23									0.15522						
11+20.00	5360.90		100.00	0.97	5361.87	3.02	3.99	41.43	26.65	0.95		5388.52	0.00000	7.43	3.68	0.134988	368.15
		-0.23									0.16379						
11+35.00	5357.45		100.00	0.95	5358.40	3.04	3.98	42.21	27.66	0.93		5386.06	0.00000	7.64	3.68	0.13125	378.76
		-0.23									0.17419						
11+50.00	5354.00		100.00	0.93	5354.93	3.05	3.98	42.85	28.52	0.92		5383.45	0.00000	7.82	3.68	0.128283	387.62
		-0.37									0.18315						
11+65.00	5348.45		100.00	0.89	5349.34	3.08	3.97	44.94	31.36	0.87		5380.70	0.00000	8.39	3.68	0.119405	416.75
		-0.37									0.21437						
11+75.00	5344.75		100.00	0.87	5345.62	3.10	3.97	46.06	32.94	0.85		5378.56	0.00000	8.71	3.68	0.11507	432.60
		-0.37									0.23252						
12+00.00	5335.50		100.00	0.83	5336.33	3.14	3.96	48.43	36.42	0.81		5372.75	0.00000	9.39	3.68	0.106688	466.87
		-0.37									0.27457						
12+50.00	5317.00		100.00	0.78	5317.78	3.16	3.96	51.54	41.24	0.76		5359.02	0.00000	10.31	3.68	0.097159	513.00
		-0.37									0.33735						
13+00.00	5298.50		100.00	0.76	5299.26	3.20	3.96	52.55	42.89	0.75		5342.15	0.00000	10.62	3.68	0.094337	528.44
		-0.37									0.35997						
13+25.00	5289.25		100.00	0.76	5290.01	3.20	3.96	52.71	43.14	0.75		5333.15	0.00000	10.66	3.68	0.093921	530.80
		-0.37									0.36349						
13+33.70	5286.00		100.00	0.76	5286.76	3.20	3.96	52.76	43.23	0.75		5329.99	0.00000	10.68	3.68	0.093776	531.62

HMS * Summary of Results for Ruby-100'

Labyrinth

Project : Ruby_Final_HKM Run Name : Run 19

Start of Run	: 25Feb05 0000	Basin Model	: Ruby -19
End of Run	: 28Feb05 0000	Met. Model	: 24 HR, LOL=50
Execution Time	: 17Jan08 1617	Control Specs	: 24-Hour

Computed Results

Peak Inflow	: 23881 (cfs)	Date/Time of Peak Inflow	: 26 Feb 05 0900
Peak Outflow	: 20053 (cfs)	Date/Time of Peak Outflow	: 26 Feb 05 1500
Total Inflow	: 60276 (ac-ft)	Peak Storage	: 57428(ac-ft)
Total Outflow	: 55796 (ac-ft)	Peak Elevation	: 5409.9(ft)

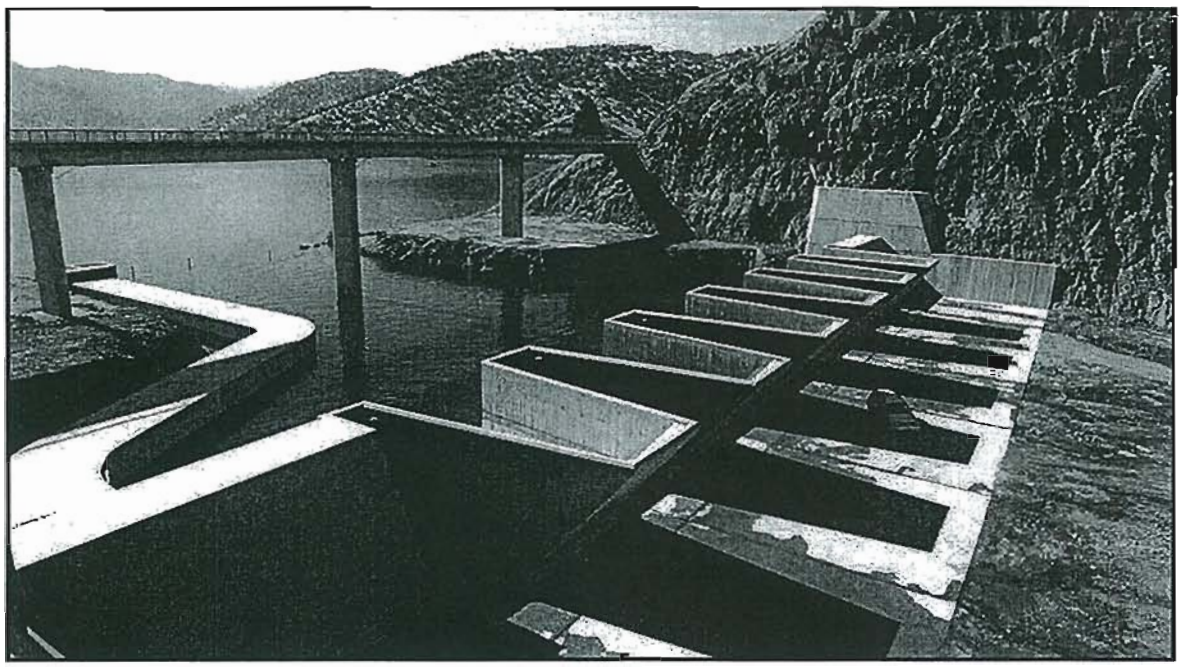
APPENDIX E

HYDROPLUS FUSEGATE TECHNICAL PROPOSAL

RUBY DAM

POSSIBLE USE OF THE HYDROPLUS FUSEGATE SYSTEM

PRELIMINARY TECHNICAL PROPOSAL



21-ft high concrete Fusegates at Terminus dam, CA

To: **HKM ENGINEERING, INC.**
Billings, MT

From: **HYDROPLUS, INC.**
Falls Church, VA

February 2006

PART 1

TECHNICAL PROPOSAL

1. PREAMBLE

HKM Engineering, Inc. is currently performing engineering studies related to increasing the spillway discharge and reservoir capacities at Ruby Dam located near Alden, Montana. HYDROPLUS, INC. has previously studied the budgetary estimates for the three alternatives developed by HKM involving spillway lengths ranging from 80 ft to 120 ft. The current technical proposal covers the potential of the Fusegate System for the second alternative with a 100 ft long spillway set at a floor elevation of El 5,373-ft.

Two different scenarios are developed for this alternative considering different types of Fusegates, namely labyrinth (Narrow Moderate Head configuration) and semi-labyrinth crested Fusegates in order to provide further options based on hydraulic performance or cost. Under both configurations, the PMF is passed below the required Maximum Water Level (i.e. at El 5,412-ft) with the Fusegates having tipped. It has also been confirmed that the 50 year LOL flood does not involve the tipping of any Fusegates under both scenarios.

The present technical proposal serves as a record of the main features of both scenarios.

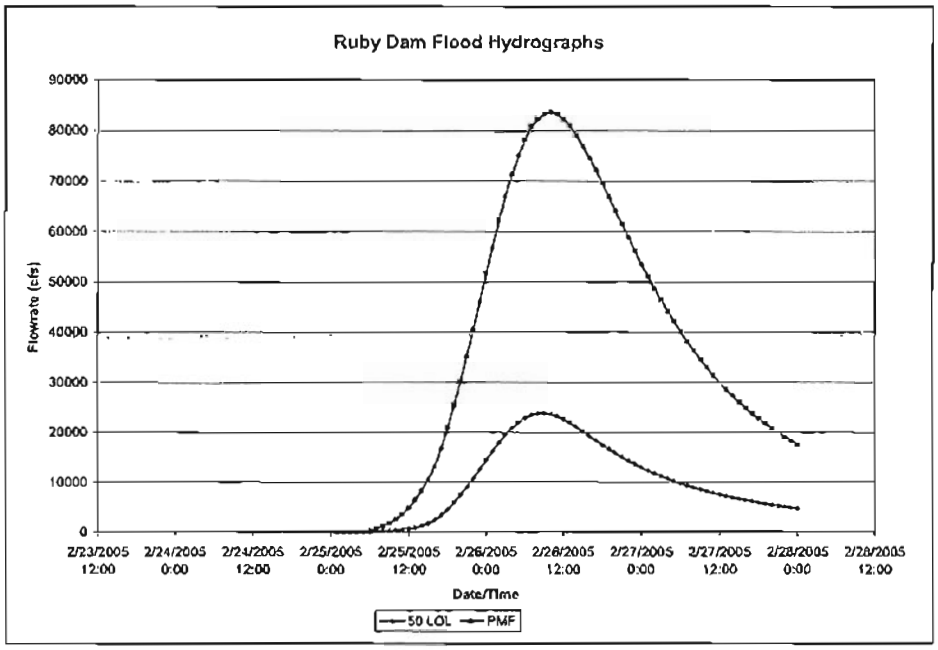
It shall be noted that the technical analyses consider 23.7-ft high Fusegates for both scenarios, whereas the budgetary estimate sent on 10 February 2006 was based on 22.7-ft Fusegates. It is possible to adjust the budgetary estimate by prorating based on area of closure (sq-ft) of Fusegates.

2. BASIC DATA

The following data are extracted from the documents supplied to HYDROPLUS, INC. and are summarized here after for ease of reference:

- Maximum Water Level (MWL): El 5,412.0-ft
- Storage capacity at MWL: 60,484 ac-ft
- Full Supply Level (FSL): El 5,396.7-ft
- Storage capacity at FSL: 41,450 ac-ft
- Length of the spillway: 100.0 ft
- Spillway discharge capacity: 81,902 cfs (estimated)
- Probable Maximum Flood (PMF) peak inflow: 83,727 cfs

- Floods hydrograph:



3. HYDROPLUS ALTERNATIVE

The two scenarios for the 100 ft long spillway alternative (alternative 2) were demonstrated in the budget proposal sent on 10 February 2006, and is summarized hereafter for ease of reference:

		1st scenario	*2nd scenario*
2nd alternative	Type of control system	Labyrinth (Narrow)	Semi-labyrinth
	Spillway length	100-ft	100-ft
	Gates height & width	23.7-ft, 25.0-ft	23.7-ft, 20.0-ft
	Top of spillway sill	El 5,373.0-ft	El 5,373.0-ft
	Top of gate crest	El 5,396.7-ft	El 5,396.7-ft
	Number of gates	4	5
	Lowest tipping level	5,408.5-ft	El 5,409. 0-ft
	Main advantages	Discharge more water before any tip-off due to labyrinth shape, thus reduce the probability of Fusegate tipping (see paragraph 6).	More economical alternative due to less material used for construction (see the sketch in paragraph 4).

The application of the Fusegate System enables to restore the Full Supply Level to the level of the top of their crest (i.e. at El 5,396.7-ft). Most of the floods are discharged by spilling over the crest of the Fusegates as they would do on a fixed labyrinth weir.

For exceptional floods, the Fusegates tip-off for predetermined reservoir elevations in order to pass safely the design flood and to have a progressive release of water during major flood events. Such arrangement also allows for triggering only the tipping of the Fusegates required to pass safely a given flood. It is anticipated that the frequency of the first Fusegate tip-off event is very low in both scenarios (a flood up to 35% and 29% of the PMF can actually be passed by spilling over the Fusegate without triggering any tip-off - see paragraph 6).

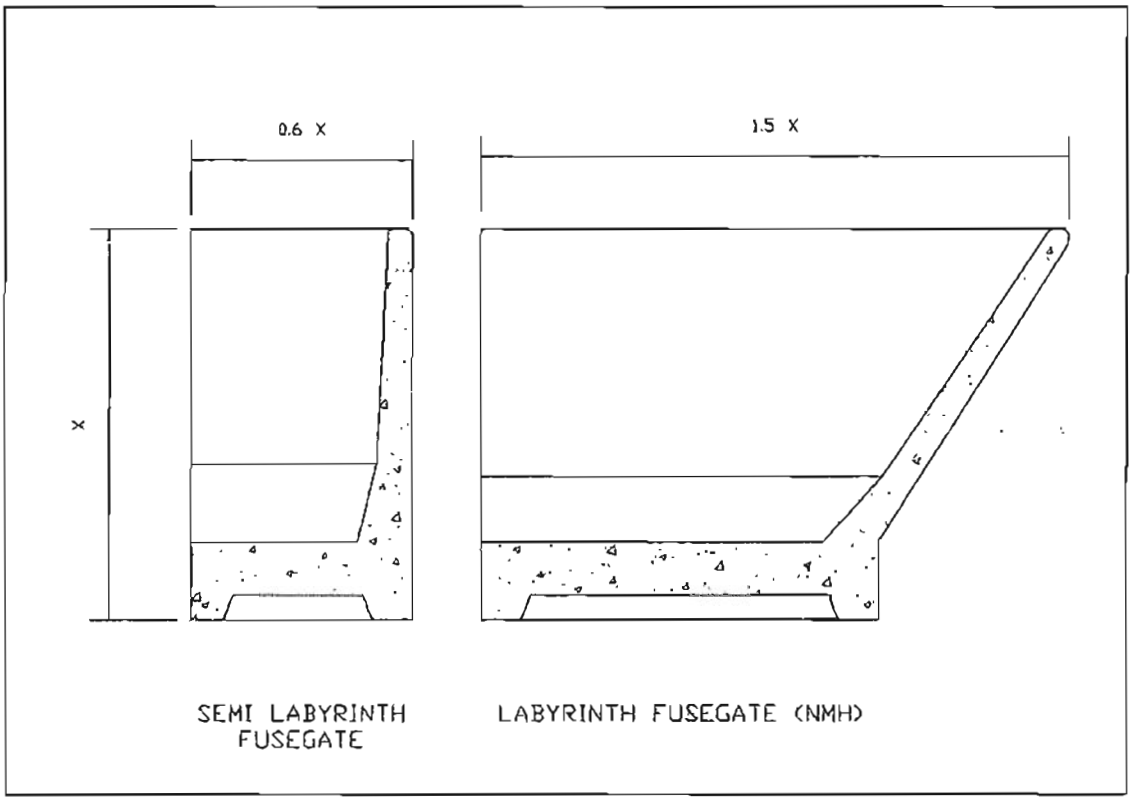
The materials for Fusegates construction are selected to maximize the project life expectancy and to minimize the maintenance associated to the System. In the scope of Ruby Dam, it is proposed to consider the following materials:

- Fusegates main structure: cast-in-situ reinforced concrete
- Tops of the intake wells: steel with adequate corrosion protection
- Seal gasket fixing plates: steel with adequate corrosion protection
- Seal gasket: EPDM

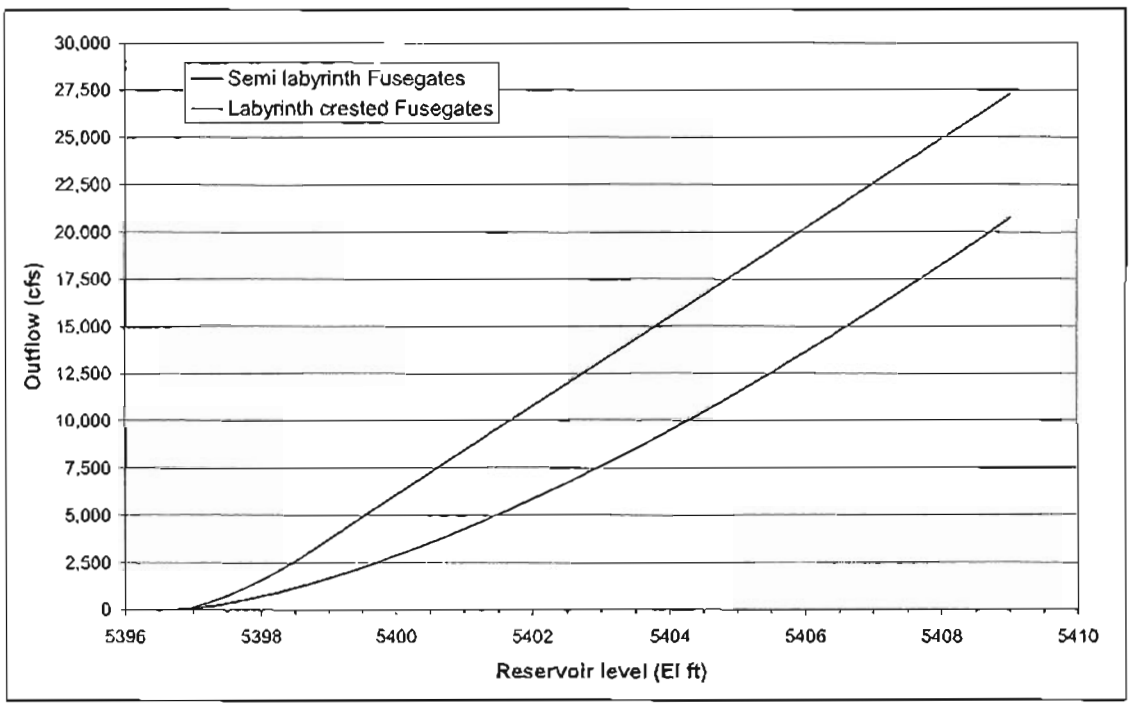
4. COMPARISON OF SCENARIOS

The two scenarios described above are based on the type of Fusegates considered, which offer different construction cost and hydraulic performance.

The variation in the amount of material used for construction between labyrinth and semi-labyrinth Fusegates is further demonstrated on the following sketch showing the cross sections of both types.

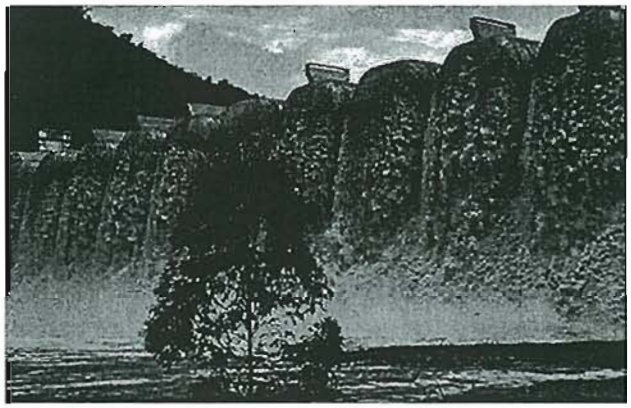


The discharge performances of both labyrinth crested and semi-labyrinth crested Fusegates are given in the following chart in order to better assess the hydraulic efficiencies.

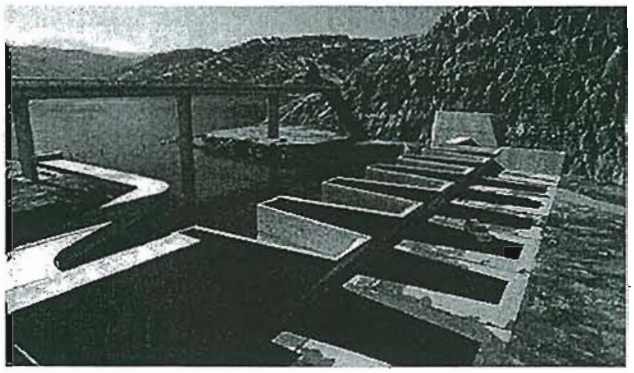


5. SIMILAR REFERENCES

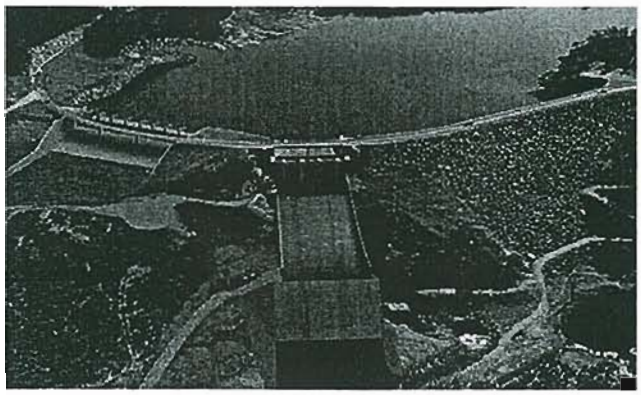
Various projects have been implemented around the world considering similar Fusegates height, and some of our references are given here after.



Shongweni Dam (South Africa)
The spillway sill was lowered in order to pass safely the design flood (revised from 44,000 cfs to 176,500 cfs). The storage capacity was recovered with the installation of 21.5-ft high Fusegates made in a combination of steel and of concrete.



Terminus Dam (California, USA)
The spillway sill was equipped with 21.5-ft high Fusegates made in cast in situ concrete in order to increase the flood attenuation potential of the reservoir as well as the useful storage capacity.



Jindabyne Dam (Australia)
A new emergency spillway is required in order to pass safely the revised design flood. It will be equipped with 25.0-ft high semi-labyrinth Fusegates made in reinforced concrete. Completion of the project is expected late 2006.

6. FUSEGATED FLOOD ROUTING RESULTS

Flood routing simulations were undertaken based on the following assumptions:

Basic assumption:

It has been assumed that, before occurrence of the floods, the reservoir elevation is at elevation El 5,396.7 ft.

Hydraulic parameters of the spillway sill:

The discharge over the spillway sill (once all Fusegates have tipped) per unit length can be closely analyzed by the following formula:

$$Q\ (m^3/s/m) = \sqrt{2g} \times c_d \times H^{3/2}$$

With H: upstream head (in ft).

In which c_d is the discharge coefficient of the spillway sill, which depends on the spillway shape and on the upstream conditions. Considering the spillway configuration at Ruby Dam, it has assumed that the discharge coefficient is equal to $C_d = 0.63$.

Hydraulic parameters of the Hydroplus system:

The hydraulic characteristics of the straight Fusegate crest have been determined through model tests carried out in reputable laboratories in Europe and in the United States. The reports could be forwarded upon request.

Under such assumptions, the hydraulic performances of both scenarios are given in the following table:

	Flood event	Q_{in} (cfs)	Q_{out} (cfs)	Max. Water Level (El ft)	Nb of FG having tipped
First scenario	Highest flood before 1st tip-off (scaled from the PMF hydrograph)	29.450	26,030	5,408.50	0
	50 LOL Flood	23,900	20,700	5,406.19	0
	PMF	83,750	81,900	5,411.95	4
Second scenario	Highest flood before 1st tip-off (scaled from the PMF hydrograph)	23,900	20,700	5,409.00	0
	50 LOL Flood	23,900	19,900	5,408.66	0
	PMF	83,750	82,200	5,412.04	5

It will be noted from the above table that:

- The PMF is discharged at the required Maximum Water Level (set El 5,412.0-ft) with all the Fusegates having tipped,
- No Fusegate overturns until a large portion of the PMF is reached (35% and 29%, respectively). It is anticipated that the corresponding flood event is of extremely low probability of occurrence.
- The 50 LOL Flood can be passed through the spillway without tipping any Fusegates in both scenarios.

7. CONCLUSION

The application of the Fusegate System at Ruby Dam enables to increase the spillway discharge capacity whilst maintaining the Full Supply Level at its present elevation.

In addition to the engineered safeguards considered, the Fusegate System has valuable safety features inherent to the concept:

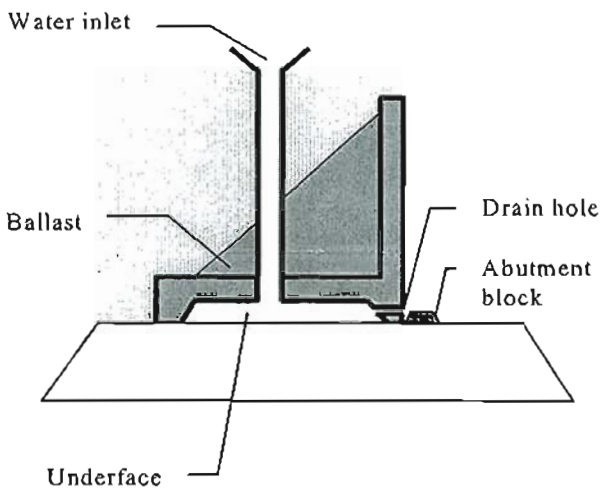
- Fusegates overturn automatically, responding to the physical forces acting upon them.
- Fusegates are entirely self-operating and do not require any source of power to operate.
- Only minimal maintenance is required compared to other mechanical gates.

It will be reminded that the Fusegates will be engineered so that no malfunctions could lead to a tip-off at Full Supply Level. Abnormal operating conditions may affect the precision of the System but not the reliability of tipping in the event of major flooding.

PART 2

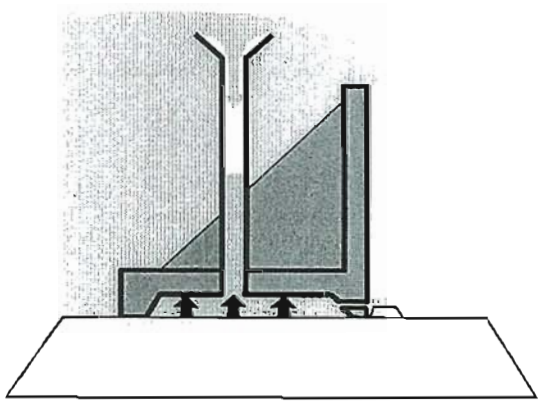
FUSEGATE SYSTEM

1. PRINCIPLE OF THE SYSTEM



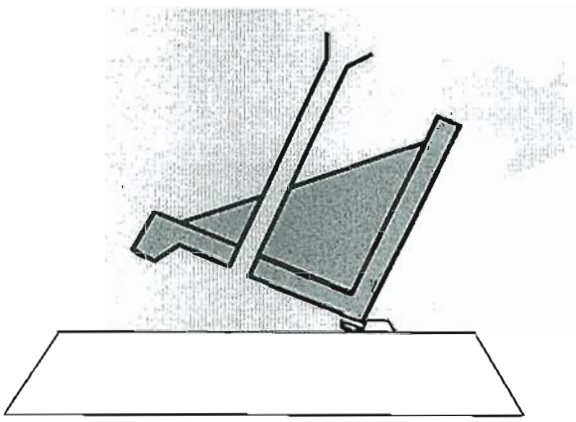
The Fusegate System is based on the following concept:

Fusegates are free-standing units installed side-by-side on a spillway sill to form a watertight barrier.
They bear against small abutment blocks set in the sill to prevent them from sliding before they are required to rotate (under extreme flood conditions).
There is a chamber in the base of each Fusegate, with drain holes to discharge incidental inflow (due to leaking seals for example).
An inlet well on the upstream side of the Fusegate crest discharges water into the chamber when the headwater reaches a predetermined level. (Well lips on individual Fusegates are actually set at different levels).



During very large floods, water entering the chamber over the inlet well causes an uplift pressure to develop in the chamber.

The uplift pressure, combined with the hydrostatic pressure (acting from left to right on the adjacent diagram) is sufficient to overcome the restraining forces and the imbalance causes rotation of the unit off the spillway. The Fusegate is then washed away clear of the spillway by the flood.



If the water level continues to rise after the first breach more Fusegates can rotate, all according to pre-determined upstream water levels until eventually there are no more units remaining and the spillway is free to pass the original maximum design flood. Until rotation of the first Fusegate, (for floods of extremely low risk of occurrence), the user has the benefit of the additional storage.

Each Fusegate has a different overturning level, precisely determined by the height of the water inlet and its own unique stability.

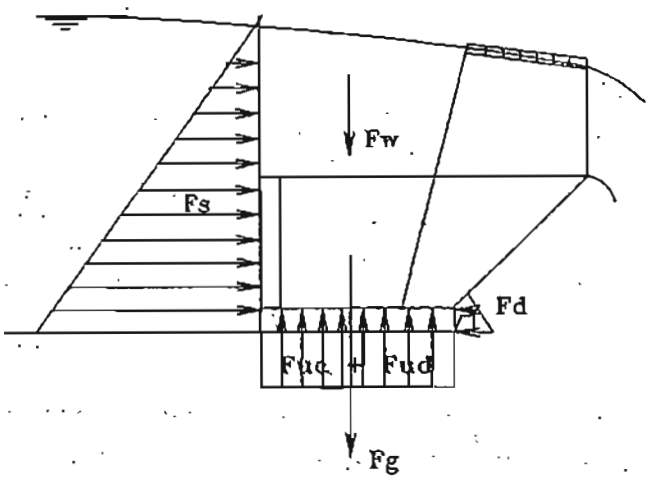
2. SAFETY FEATURES

2.1 Stability

The stability of a Fusegate is dependent upon considerations of sliding and overturning.

- Sliding is prevented by the construction of toe pedestals in the spillway sill.
- The Fusegate rotates about the downstream edge when the overturning moment exceeds the stability moment:

The overturning moments are caused by the hydrostatic forces and the uplift forces (Uplift forces, which act on the Fusegate, are developed in the chamber during large floods feeding the well).
The stability moment is a function of the weight of the Fusegate and the water therein.



Fs	upstream hydrostatic force
Fg	dead load of the Fusegate
Fw	water load above the Fusegate
Fd	downstream hydrostatic force
Fuc	uplift force within the chamber
Fud	uplift forces under the beams

2.2 Operational reliability and safety

Stability margin

The stability margin of a Fusegate is defined as the difference between the stability and the overturning moment for any assumed upstream water level.

The calculations show that the high stability margins, which are achieved, allow the Fusegates for being not likely affected by the impacts of floating debris as well as for withstanding quite large earthquakes.

Minimum tipping level

During a very large flood, the well admits water into the chamber, causing the uplift pressure to rise significantly. The Fusegate starts to tilt about the toe pedestals, and the

chamber is then open to the reservoir, causing a rapid rise in uplift pressure so that the Fusegate finally overturns. When it first lifts off the sill, uplift in the chamber cannot exceed a maximum pressure, which ranges somewhere between the upstream head and the head along the sides of the units. The magnitude of this uplift has been determined by calculation and verified by model testing.

The maximum uplift curve allows for determining the minimum tipping level below which the Fusegate cannot overturn. It will be noticed that the alternative is engineered so that this level is obtained above the Full Supply Level.

As long as headwater remains below this minimum tipping level, the Fusegate will not overturn even if water enters the chamber through the well accidentally, or if the impact of an extremely heavy body causes the upstream edge to lift off the sill momentarily.

Critical situation

The safety analyses conducted to investigate the operational reliability of the Fusegates consider the following extreme critical situations:

- Upstream seal completely destroyed
- Drain holes completely blocked.

These studies highlight that these extremely unlikely cases of malfunctioning would not lead to a possible early tip-off. Furthermore, these are entirely theoretical situations, which could occur only through willful damage or complete dereliction of the dam inspection and maintenance system.

3. ADVANTAGES OF THE SYSTEM

3.1 Reliability of operation and durability

The Fusegate System has valuable safety features inherent to the concept and not shared by other spillway control systems

- Fusegates overturn automatically, responding to those physical forces acting upon them.
- Fusegates are entirely self-operating and do not require any source of power to operate.
- Only minimal maintenance is required compared to other mechanical gates.

The minimum tipping level (defined in paragraph 2) constitutes an engineered safeguard which is of vital importance for the people living and working downstream of the dam since it removes the risk of a sudden downstream artificial flood.

Besides the normal operating condition, Fusegates are engineered in such a way that no malfunction (upstream seal completely destroyed or drain holes completely blocked) could lead to a tip-off before water is admitted through the well.

Unlike other spillway control systems, the Fusegate units do not have any moving part and are therefore less subject to wear and tear and to aging. In addition, their massive structure

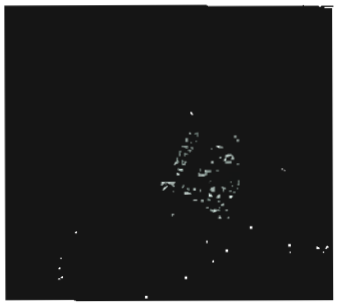
offers little vulnerability to vandalism and, considering their high stability margin, to terrorist threat.

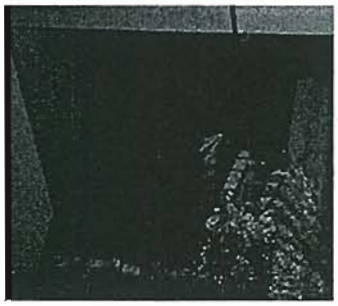
3.2 Stability against abnormal load cases

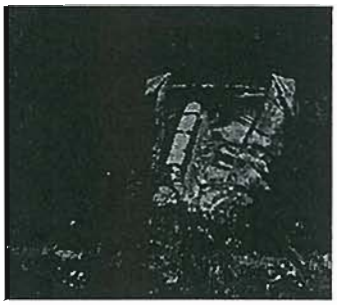
Waves, floating debris and impacts

The effect of waves and impacts have been the subject of specific research in reputable hydraulic laboratories (such as Utah State University, Tennessee Valley Authority), which have demonstrated their minimal incidence on the system. Floating debris are simply discharged over the Fusegates crest when sufficient spillage occurs and do not have any significant impact on the Fusegate stability.

Example of impact of large floating debris (Tennessee Valley Authority) :







Earthquake

Seismic effects are examined in each individual project using a pseudo-static approach or a finite element analysis if required. However, the stability of the Fusegates is usually sufficient to prevent problems induced by earthquakes.

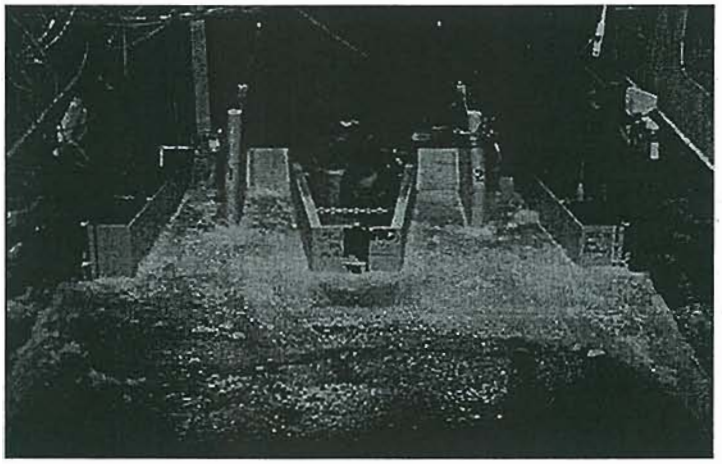
The behavior of the Fusegates during major a seism has been observed in Gujarat State in India that was hit early 2001 by a 7.6 magnitude (on the Richter scale) seism. None of the Fusegates installed on the four dams located within a 50 miles radius from the epicenter has been affected.

Ice-affected environments

The effect of ice is examined with reference to tests undertaken in the hydraulic laboratories of the National Research Council (NRC) in Newfoundland, Canada and of the Institute of Energy Structures in Moscow, Russia. Generally speaking, thermal expansion of ice and ice run off generally has very little influence on the Fusegates stability.

The behavior of the Fusegates in ice-affected environments has been observed on Khorobrovskaya scheme (located in Russia). The 4 ea. 2 m high Fusegate units have successfully withstood the pressure of the 60 cm thick ice coat and to the subsequent ice run-off.

Model tests at the NRC



Khorobrovskaya in winter

3.3 Other advantages

Unlike most spillway control systems, the construction of the Fusegates themselves can often be undertaken in the state where the project takes place and will thus benefit the local industry.

The Fusegate System does not involve any chemical product, which could later involve a pollution of the river stream (such as oil, paint...). In addition, the construction materials are chosen to mitigate the visual impact of the rehabilitation.

The Fusegate massive structure offers little vulnerability to vandalism and, considering their high stability margin, to terrorist threat.

The Fusegates will be fabricated in concrete and stainless steel. The maintenance and life expectancy of the System are therefore optimal. In addition, the Fusegate units do not have any moving parts and are therefore less subject to wear and tear and to aging.

Ruby Dam Rehabilitation

BASIC DATA

		Option	
	P1-80-96.7	P2-100-96.7	P3-120-96.7
Spillway Width (ft)	80	100	120
Max Reservior Elevation (ft)	5412	5412	5412
Spillway Crest Elevation (ft)	5396.7	5396.7	5396.7
Spillway Floor Elevation (ft)	5368	5374	5379

1st ALTERNATIVE

SPILLWAY CONFIGURATION

		Option	
	P1-80-96.7	P2-100-96.7	P3-120-96.7
Spillway capacity (cfs)	78679	78934	76656
Max spilling over	53%	67%	86%
Type	NMH	NMH	WHH
Fusegate height (ft)	28.7	22.7	17.7
Fusegate width (ft)	26.7	25.0	30.0
Nb of Fusegates	3	4	4
Lowest tipping level (ft)	5409.6	5409.0	5410.0
Outflow before 1st tip-off (cfs)	24965	26785	35133

BUDGETARY ESTIMATE

		Option	
	P1-80-96.7	P2-100-96.7	P3-120-96.7
Area of closure (sq-ft)	2296	2270	2124
Budgetary estimate	$1,950,000	$1,840,000	$1,600,000

2nd ALTERNATIVE

SPILLWAY CONFIGURATION

		Option	
	P1-80-96.7	P2-100-96.7	P3-120-96.7
Spillway capacity (cfs)	78679	78934	76656
Max spilling over	53%	67%	86%
Type	SL	SL	SL
Fusegate height (ft)	28.7	22.7	17.7
Fusegate width (ft)	28.7	22.7	24.0
Nb of Fusegates	3	4	5
Lowest tipping level (ft)	5409.6	5409.0	5409.3
Outflow before 1st tip-off (cfs)	17843	20766	25975

BUDGETARY ESTIMATE

		Option	
	P1-80-96.7	P2-100-96.7	P3-120-96.7
Area of closure (sq-ft)	2296	2270	2124
Budgetary estimate	$1,400,000	$1,300,000	$1,190,000

APPENDIX F

MCPHEE DAM MODEL STUDY

GR-81-2

HYDRAULIC MODEL STUDIES OF McPHEE DAM SPILLWAY

Hydraulics Branch
Division of Research
Engineering and Research Center
Bureau of Reclamation

March 1981

MS-230 (3-78)
Water and Power

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. GR-81-2	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Hydraulic Model Studies of McPhee Dam Spillway		5. REPORT DATE March 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Clifford A. Pugh		8. PERFORMING ORGANIZATION REPORT NO. GR-81-2
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bureau of Reclamation Engineering and Research Center Denver, Colorado 80225		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Microfiche and/or hard copy available at the Engineering and Research Center, Denver, Colo.

Editor: LDP

16. ABSTRACT

A 1:36 scale model was used to develop the hydraulic design of the spillway for McPhee Dam located on the Dolores River in southwestern Colorado. The model included the approach channel, spillway crest and radial gates, spillway chute, combination stilling basin-flip bucket, and exit channel. The 18.3-m (60-ft) wide by 303-m (994-ft) long chute spillway is designed for a maximum discharge of 940 m^3/s (33 130 ft^3/s). Ordinarily, energy is dissipated in a hydraulic jump. For large floods, the flow will "sweepout" of the stilling basin into the exit channel. Model studies included investigation of approach flow conditions, pressures and flow distribution in the chute spillway, flow characteristics with the combination stilling basin-flip bucket, and flow conditions and erosion in the exit channel. Details of the testing and recommended design modifications are described.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. *DESCRIPTORS*– / *model studies/ hydraulic models/ *spillways/ energy dissipation/ erosion control/

b. *IDENTIFIERS*– / *McPhee Dam, Colo./ Dolores Project/

c. COSATI Field/Group 13M COWRR: 1313.5

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED	21. NO. OF PAGES 56
	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. PRICE

GPO 864-612

GR-81-2

HYDRAULIC MODEL STUDIES OF McPHEE DAM SPILLWAY

by
Clifford A. Pugh

Hydraulics Branch
Division of Research
Engineering and Research Center
Denver, Colorado
March 1981

SI METRIC

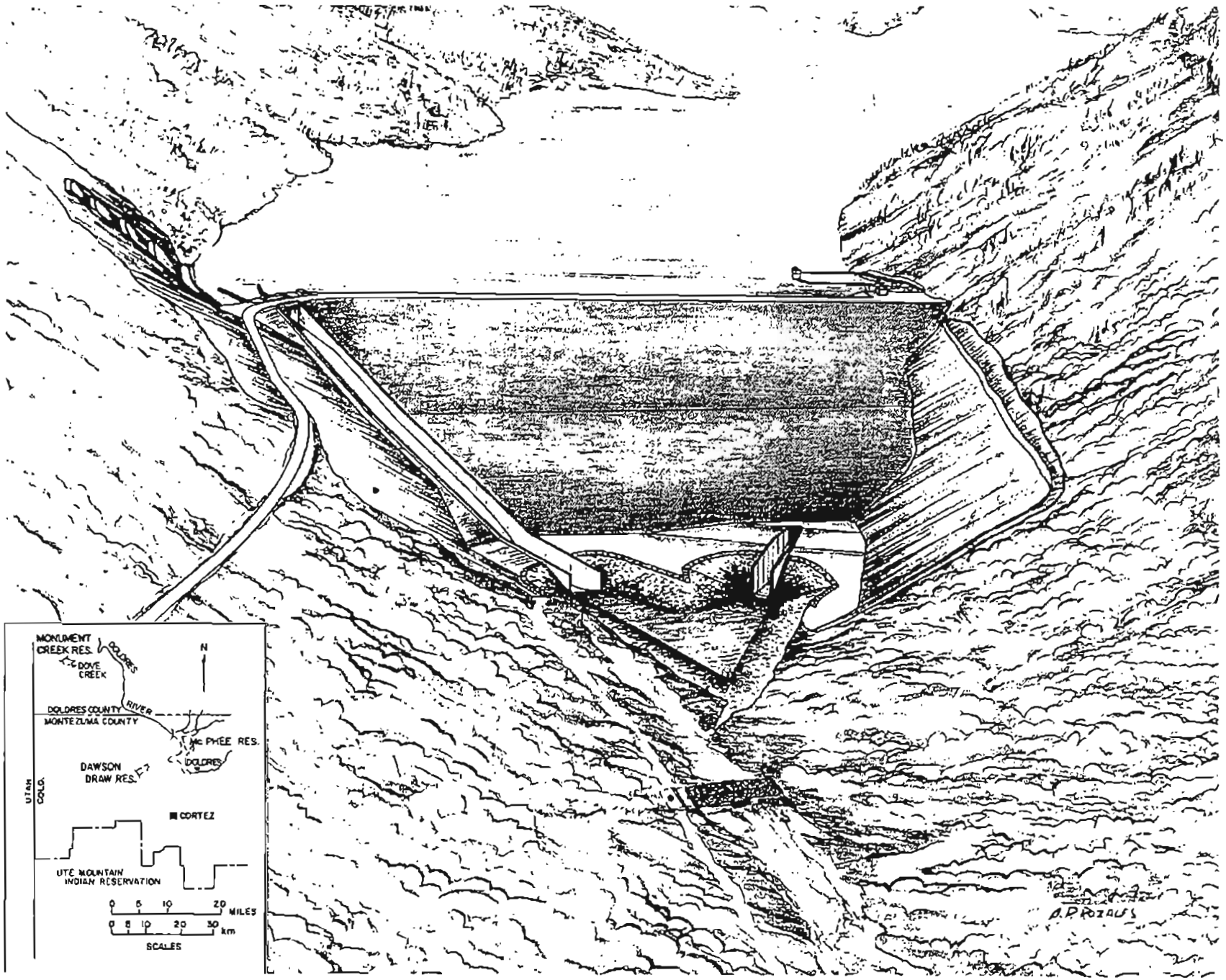
UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

This model study was conducted under the supervision of T. J. Rhone, Head of the Applied Hydraulics Section, and the general supervision of D. L. King, Chief of the Hydraulics Branch. The studies were accomplished through the cooperation of the Hydraulics Branch and Spillways and Outlets Section, Dams Branch, Division of Design of the Water and Power Resources Service, during the period from October 1978 through May 1979.

I also acknowledge Doug Stanton, Charles Cooper, and Marlene Young for their contributions to the hydraulic testing and data analysis, and T. J. Rhone for his technical review.

In May 1981, The Secretary of the Interior changed the Water and Power Resources Service back to its former name, the Bureau of Reclamation.



Location and artist's conception of McPhee Dam

CONTENTS

	Page
Purpose	1
Conclusions	1
Application	2
Introduction	2
The Model	3
Description	3
Scale relationships	4
Spillway chute roughness	5
Investigation	6
Spillway approach channel	6
Intake modification No. 1	6
Intake modification No. 2	7
Intake modification No. 3	7
Recommended design	8
One-gate operation	8
Spillway rating curves	8
Spillway chute	9
Subdrainage outlets	9
Chute drain outlets	10
Combination stilling basin-flip bucket	11
Original stilling basin and flip bucket	11
First flip bucket modification	12

CONTENTS—Continued

	Page
Second flip bucket modification	12
Third flip bucket modification	12
Exit channel excavation	13
Recommended exit channel design	14
Stilling basin debris tests	16
Test procedure	16
Results	16
Bibliography	19

FIGURES

Figure		
	Frontispiece	iii
1	Plan and profile of spillway	21
2	McPhee Dam spillway model in operation	23
3	Model spillway crest structure and radial gates	23
4	Preliminary design approach channel and exit channel	24
5	Approach channel modification No. 1	25
6	Approach channel modification No. 2	26
7	Discharge versus reservoir elevation for nongated flow	27
8	Approach channel modification No. 3	28
9	Recommended approach channel	29
10	Spillway rating curves—two gates	30
11	Spillway rating curves—left gate	31

CONTENTS—Continued

Figure		Page
12	Spillway rating curves—right gate	32
13	Chute blocks	33
14	Wall drains	34
15	Flow deflector and chute drain outlet	35
16	Stilling basin-flip bucket profiles	37
17	Original design stilling basin operation and erosion	39
18	Flip bucket modification No. 1 operating	40
19	Flip bucket modifications No. 2 and 3 operating	41
20	Flip bucket modification No. 3 with exit channel modification	42
21	Initial sweepout and sweepout reversal versus tailwater curve	43
22	Recommended exit channel	44
23	Recommended exit channel and stilling basin operating	45
24	Recommended stilling basin-flip bucket operating at sweepout flows	46
25	Plan of recommended exit channel	47
26	Stilling basin debris tests	48

TABLES

Table		
1	Combination stilling basins-flip bucket flow data	17
2	Stilling basin debris tests	18

PURPOSE

This hydraulic model study was conducted to evaluate the preliminary design of the spillway, investigate possible modifications to minimize downstream channel erosion, and optimize flow conditions in the approach channel.

CONCLUSIONS

1. The height of guide walls in the approach channel was raised above the maximum water surface, and the left wall alinement was changed to open the approach channel and guide the flow smoothly into the spillway chute.

2. Flow in the spillway chute is slightly nonuniform in the upstream portion of the chute due to asymmetric approach conditions. However, the distribution is very uniform where the flow enters the stilling basin.

3. The discharge capacity and pressures in the chute are satisfactory. The minimum freeboard in the chute is 3.28 m (10.75 ft) for the inflow design flood (IDF). Pressures on the chute floor are above atmospheric; however, the concrete finish should be smooth to avoid possible cavitation in the high velocity flow.

4. Pressure measurements were made on a chute block and the stilling basin wall to determine an acceptable location for subdrainage outlets. Chute blocks are not recommended because of the potential for cavitation damage. A wall drain location above the maximum "sweepout" water surface in the stilling basin was recommended. An "eyebrow"-type flow deflector was developed for floor drains in the spillway chute.

5. Four flip bucket configurations were tested. In the final design, the radius of the flip bucket was shorter and the lip elevation higher than in the original design. These changes helped stabilize the hydraulic jump and clear the jet impact away from the basin after sweepout with a minimum amount of damage to the downstream channel.

6. The discharge channel was deepened from elevation 2030.9 m (6663 ft) to elevation 2026.9 m (6650 ft). The channel was also widened so that it flared from 18.3 m (60 ft) wide at the stilling basin to 30.5 m (100 ft) wide downstream from the basin. These changes provide a wider and deeper channel and plunge pool to dissipate the energy of the jet striking the tailwater after sweepout. Removing the sand and gravel overburden in the jet impact area also reduces the possibility of a gravel bar forming downstream. Erosion will occur on the left bank of the outlet works channel after sweepout; however, this damage should not threaten the structures.

7. Flows large enough to cause sweepout will not be likely to occur. The initial sweepout flow is 465 m^3/s (16 500 ft^3/s), as compared to the 100-year flood of 375 m^3/s (13 300 ft^3/s). The outlet works can pass an additional 145 m^3/s (5200 ft^3/s). With the spillway and outlet works operating simultaneously, flows up to about 640 m^3/s (22 700 ft^3/s) could be passed before sweepout occurs.

8. The outlet works should be operated during the spillway sweepout to help supply tailwater in the plunge pool and to help prevent rocks from depositing in the outlet works channel and stilling basin.

9. A spillway flow of 200 m^3/s (7000 ft^3/s) is required to wash 75-mm (3-in) diameter rocks out of the stilling basin. At a flow of 255 m^3/s (9000 ft^3/s), rocks up to 1.5 m (5 ft) in diameter are washed out of the stilling basin.

APPLICATION

The results of this study can be applied to the design of radial gate controlled spillways discharging into a sloping chute and designs with combination stilling basin-flip bucket energy dissipators.

INTRODUCTION

An artist's conception of McPhee Reservoir is shown in the frontispiece of this report. McPhee Reservoir will be located on the Dolores River in southwestern Colorado.

McPhee will be the main storage and regulation reservoir in the Dolores Project. The project will provide irrigation water for the Montezuma Valley area and water supplies for the communities of Dove Creek, Towaoc, Cortez, and the Dolores Water Conservancy District.

The dam will be an earthfill structure 82.3 m (270 ft) high and 396.2 m (1300 ft) wide at the crest. The chute spillway and stilling basin will be located in the right abutment of the dam and will be 18.3 m (60 ft) wide and 303 m (994 ft) long. Figure 1 is a plan and profile of the recommended design for the approach channel, spillway, and exit channel.[1]

THE MODEL

Description

The model was built to a geometric scale of 1:36 and included the approach channel and reservoir topography, the spillway crest structure and radial gates, the chute spillway, the combination stilling basin-flip bucket, and downstream river channel (fig. 2). Provisions were made for controlled releases into the river outlet works channel, as well as the spillway, in order to accurately simulate flow conditions in the downstream channel. However, the outlet works stilling basin was not modeled. Water was supplied to the model through the permanent laboratory system and discharges were measured with one of a bank of venturi meters in the laboratory supply system.

Topography in the approach channel and downstream river channel was molded of concrete. An area in the approach channel and exit channel was formed with gravel to study erosion characteristics and to facilitate changes in topography.

The spillway crest structure was constructed from high density polyurethane. The side walls and center pier were made from acrylic plastic. The radial gates were made of sheet metal with rubber strips fastened to the sides to provide a water seal (fig. 3).

---

[1] All figures follow the Bibliography.

The spillway chute and stilling basin were constructed from 20-mm (0.75-in) thick, resin-coated plywood. The flip bucket and vertical curves in the floor of the chute spillway were formed with sheet metal.

Rock baffles smoothed the flow coming into the approach channel from a 200-mm (8-in) supply line.

The reservoir elevation was measured with a hook gage in a well connected to a piezometer tap in the approach channel.

The tailwater elevation was controlled with a flap gate at the end of the model. Staff gages were located in the downstream river channel, the outlet works, and the stilling basin.

Scale Relationships

Inertia and gravity are the predominant forces acting on flow in open channels. The Froude number is the dimensionless ratio of inertia forces to gravity forces governing most open-channel flow situations. Dynamic similitude exists between the model and prototype when the Froude numbers are the same, equation 1:

$$\frac{V_m}{\sqrt{g_m L_m}} = \frac{V_p}{\sqrt{g_p L_p}} \tag{1}$$

where: V = velocity

g = gravitational acceleration

L = a characteristic length

Subscripts m and p refer to model and prototype. The geometric scale (or length ratio) is denoted by L_r, where $L_r = \frac{L_p}{L_m}$. The scale relations for this study (based on the Froude number) are:

Quantity			Scale ratio
Length		$L_r =$	36:1
Area	$A_r =$	$L_r^2 =$	1296:1
Time	$T_r =$	$L_r^{0.5} =$	6:1
Velocity	$V_r = L_r/T_r =$	$L_r^{0.5} =$	6:1
Discharge	$Q_r = V_r A_r =$	$L_r^{2.5} =$	7776:1

The riprap in the exit channel area was geometrically scaled with gravel averaging 25 mm (1 in) in diameter to simulate 0.9-m (3-ft) riprap in the prototype.

Spillway Chute Roughness

In order for the model velocities entering the stilling basin to correctly simulate the prototype velocities, the model roughness must be scaled correctly. Using the Manning equation and the Froude law, it can be shown that Manning's n ratio, scales as the length ratio to the 1/6 (0.1667) power [1][2], or:

$$n_r = \frac{n_p}{n_m} = L_r^{\ 0.1667} = 1.817 \tag{2}$$

In a long chute spillway, an incorrectly scaled roughness can make a significant difference in the velocity at the end of the chute. It was projected that a smooth painted plywood surface would produce an n value of 0.009. This model n would represent a prototype n of 0.0165 (per equation 2). A backwater computer program [2] was used to determine velocities at the stilling basin for various roughness values in the prototype and in the model. According to Chow [3], the roughness coefficient (n) for concrete can be expected to range from 0.011 to 0.015 with 0.013 being a normal value. Therefore, an n_p value of 0.0165 would cause the velocity at the stilling basin to be too low. There are several possible methods to compensate for excessive roughness in the model. The

[2] Numbers in brackets identify Bibliography entries.

slope of the chute can be increased or the reservoir elevation can be increased to add extra velocity at the gates. In this study, the model chute was extended (at the same slope) an extra 0.91 m (3 ft) horizontally and 0.46 m (1.50 ft) vertically. According to the backwater program, this extra drop as equivalent to reducing n_p from 0.0165 to 0.015.

When the model was built, velocity and depth measurements indicated that the model was smoother than expected. The model n value was 0.007. With the extended chute, this simulates a prototype n of about 0.011. If the chute had not been extended, the simulated n_p would have been about 0.013. The prototype roughness simulated by the model (n_p = 0.011) is on the lower end of the possible prototype roughnesses. Therefore, the velocities at the stilling basin should be as high as would be expected in the prototype for a smooth concrete finish, and model simulations of stilling basin performance should be conservative.

INVESTIGATION

Spillway Approach Channel

In the original design approach channel (fig. 4a), the flow crossed the face of the dam from left to right and over the sloping left wall of the channel causing an asymmetrical approach condition. As a result, a large vortex formed in the right intake. Large contractions also formed along the walls during free flow.

Several approach channel modifications were tested and are described in the following paragraphs.

Intake modification No. 1. — The sloping walls in the preliminary design were increased in height to prevent flow from coming across the face of the dam (fig. 5a). The walls retained the same position and length but extended above the maximum water surface.

This arrangement eliminated the large vortex in the right intake; however, there were large contractions at the ends of the walls during free flow, and the velocity of approach was high in the intake channel.

Curved guide walls were added to the intake walls to eliminate the contractions (fig. 5b). These curved walls smoothed the flow coming into the approach channel. However, the velocity in the channel was still high, and the walls would be long and expensive to build.

Intake modification No. 2. — To eliminate the losses in the intake channel and minimize the wall length and construction costs, short curved walls leading directly into the intake were tested (fig. 6). The alinement of the left bank of the excavated channel and the side slopes were also changed to direct the flow into the intake.

This modified intake channel created much better approach flow. The current across the face of the dam and the large vortex in the right spillway bay were eliminated. With free flow, the pool elevation for the inflow design flood was reduced by 0.30 m (1.01 ft) from the preliminary design, EL 2111.55 to 2111.25 m (El. 6927.67 to 6926.66 ft). Figure 7 gives discharge versus reservoir elevation for nongated (free) flow conditions.

Although the short curved walls worked well hydraulically, problems with stability were anticipated in designing the intake channel and crest structure for this configuration.

Intake modification No. 3. — In this design, the left wall flared out starting 18 m (60 ft) upstream from the crest structure guiding the flow into the spillway. The top of the right wall sloped 2.5:1 (the same as in the preliminary design). This channel created a much better approach flow than the preliminary design. However, a contraction of the flow over the right wall (fig. 8a) caused eddies which moved material from behind the wall. This contraction also decreased the discharge capacity for free flow. The water surface elevation for the inflow design flood was 0.13 m (0.43 ft) higher than for the intake with the shorter curved walls (intake modification No. 2).

The top of the right wall was then raised to elevation 2111.65 m (6928.0 ft) and curved toward the 1:1 slope, 18 m (60 ft) upstream from the crest (fig. 8b). This configuration worked well hydraulically; however, difficulties in design again were anticipated with the curved wall.

Recommended design. — The right wall was then extended straight upstream at elevation 2111.65 m (6928.0 ft). The left wall remained the same. Figures 1 and 9 show the final design. This configuration directs the flow into the spillway with a minimum of contraction losses. The water surface elevation for the inflow design flood was 0.329 m (1.08 ft) less than with the original design (see fig. 7).

One-gate Operation

Slightly more flow passes through the right gate than the left for the same gate opening. Vortices start forming around the center pier at about 225 m^3/s (800 ft^3/s) for one-gate operation. The flow discharges freely over the crest for gate openings of more than 7.16 m (23.5 ft). The reservoir reaches maximum water surface elevation 2111.65 m (6928.0 ft) at a discharge of 480 m^3/s (17 000 ft^3/s). At this discharge, the minimum freeboard at the first vertical curve is about 1.2 m (4 ft). The flow distribution at the stilling basin is fairly uniform; therefore, one-gate operation could be used for prototype operation.

Spillway Rating Curves

The crest section was calibrated for uncontrolled flow and for one- and two-gate operation with the final design intake channel. The crest is capable of discharging the inflow design flood, 940 m^3/s (33 130 ft^3/s) at reservoir elevation 2111.22 m (6926.6 ft). This elevation is 0.43 m (1.4 ft) less than the maximum design reservoir elevation and will allow extra freeboard or extra discharge capacity.

Gate openings were measured vertically from the spillway crest elevation 2102.21 m (6897.0 ft). The flow can be controlled by the gates up to a discharge of 875 m^3/s (31 000 ft^3/s) at reservoir elevation 2111.65 m (6928.0 ft); this requires a 7.16-m (23.5-ft) gate opening. If the gates are

opened more than 7.16 m (23.5 ft), they no longer control and weir flow occurs. Rating curves for two-gate operation are given in figure 10. The data points shown are experimental points measured in the model. The curves were computed according to procedures in Design of Gravity Dams [4]. The coefficients were adjusted to match the experimental data. Figures 11 and 12 are rating curves for one-gate operation.

Spillway Chute

The spillway chute (fig. 1) is 18.3 m (60 ft) wide and drops 76.9 m (252.25 ft) in elevation from the end of the piers to the upstream end of the stilling basin, 227.8 m (747.5 ft).

The slope of the spillway changes three times with vertical curves in the floor of the chute (fig. 1). Piezometers were installed along the centerline of the 33.5-m (110-ft) long vertical curve immediately upstream of the stilling basin. At this point in the chute, prototype velocities of about 27 m/s (90 ft/s) are expected. Pressures were positive for all model flow conditions along the curve. However, small protrusions or bug holes in the concrete surface can cause cavitation in high velocity flows even if low pressures are not indicated in the model.

Standing waves extended downstream from the end of the pier in a diamond pattern. During free flow, the waves intersected the chute wall near the first vertical curve. For the inflow design flow flood, Q = 940 m^3/s (33 130 ft^3/s), the minimum freeboard was 3.28 m (10.75 ft) at this point. The wave intersected the right wall higher in the chute than the left wall. This was due to the asymmetrical approach to the spillway. However, the flow distribution was very uniform where it entered the stilling basin.

Subdrainage Outlets

Initially, drain outlets were to be installed on the downstream face of stilling basin chute blocks (fig. 13). However, chute blocks did not add very much stability to the hydraulic jump and would be a source of cavitation.

Pressures were measured around the fifth chute block from the left, looking upstream (fig. 13), for a range of flows. At Q = 285 m^3/s (10 000 ft^3/s), average pressures on the stilling basin floor immediately downstream from the chute block were about +7 m (+23 ft) with fluctuations from −2 to +13.7 m (−6to+45 ft).[3] As the discharge was increased to 375 m^3/s (13 300 ft^3/s), the average pressure dropped to about atmospheric with fluctuations from −20.8 to +18.6 m (−68 to +61 ft). The maximum subatmospheric pressure recorded was −32.9 m (−108 ft) at Q = 410 m^3/s (14 500 ft^3/s). The pressures listed were scaled from model to prototype; actual negative prototype pressures would be limited to the vapor pressure of water [about −8.2 m (−26.9 ft) at elevation 2100 m (6890 ft)]. As the pressure drops to vapor pressure, cavitation would occur, probably causing damage to the stilling basin.

Because chute blocks were determined to be a probable cavitation source, they were not recommended. Locations for drain outlets in the wall were then investigated. The table on figure 14 lists the measured pressures. At flows less than sweepout, the pressures were about the same as the hydrostatic pressure due to the water depth at the upstream end of the stilling basin. After sweepout, high back pressures developed on the submerged piezometers up to about 15 m (50 ft) during maximum flow. The maximum water depth after sweepout was 1.74 m (5.70 ft); therefore, it was recommended that the wall drains be located above this elevation to prevent high back pressures after sweepout.

Chute Drain Outlets

Low profile "eyebrow"-type flow deflectors were designed for the drain outlets in the chute floor to minimize danger of cavitation damage. Figure 15 shows the recommended design.

A deflector and drain (built to a 1:10 scale) were tested in the model. The dimensions of the deflector were determined by referring to previous air slot studies and the eyebrow deflectors designed by Isbester [5] for the Folsom Dam spillway. The deflectors for the 200-mm (8-in) drains

[3] Pressure values are given as column height of water.

are 460 mm (18 in) long and 300 mm (12 in) wide with a 1:9 slope. The offset at the drain is 50 mm (2 in).

The maximum discharge possible in the model, 0.125 m^3/s (4.4 ft^3/s), simulates 140 m^3/s (5000 ft^3/s) in the prototype. The 0.5-m (20-in) wide model spillway simulates a 5-m (16.67-ft) wide section of the spillway. The prototype velocity simulated was about 19 m/s (62 ft/s) as compared to a maximum possible prototype velocity of 30 m/s (98 ft/s).

Air vents are required to prevent cavitation damage on the chute surface downstream from the flow deflector. Based on model measurements of air demand, the 100-mm (4-in) diameter air vents in each chute wall will have air velocities of about 60 m/s (200 ft/s) at a spillway flow of 140 m^3/s (5000 ft^3/s). If air demand goes up linearly with the flow velocity, the air velocity through the 100-mm (4-in) diameter vents would be about 91 m/s (299 ft/s) at the inflow design flood. When the air supply was cut off to the drain in the model, the spillway flow was drawn back into the drain.

At Q = 140 m^3/s (5000 ft^3/s), the jet was deflected downstream about 2.7 times the length of the drain hole on the spillway surface; therefore, the jet will probably be deflected past the drain hole at larger flows. However, it was not possible to study larger flows at a 1:10 model scale.

Combination Stilling Basin-Flip Bucket

The stilling basin was tested over a range of flows for each design. Figure 4b is a photograph of the original design stilling basin and exit channel. Velocity and depth measurements in the model chute corresponded to a prototype Manning's n value of 0.011 at the 100-year flood flow. The original basin design and the modified designs are shown in figure 16.

Original stilling basin and flip bucket. — At the 100-year flood flow [Q = 375 m^3/s (13 300 ft^3/s)], the jump remained in the basin. Waves surged over the stilling basin walls occasionally, and the jump was unstable. In the exit channel, the flow went through critical depth where it entered the original river channel. This depth control caused a hydraulic jump and could cause erosion in the prototype channel.

The flow swept out of the stilling basin at Q = 500 m^3/s (17 600 ft^3/s). However, the jet did not "flip out" into the downstream channel. As soon as the jet swept out of the basin, it impinged on the 1:5 slope moving the riprap downstream (fig. 17).

First flip bucket modification. — The angle of the flip lip was increased from 15.2 to 30° to cause the flow to flip away from the structure into the exit channel. The jump swept out of the stilling basin at a discharge of 510 m^3/s (18 000 ft^3/s) (fig. 18). As soon as the jump swept out, the tailwater in the downstream channel was swept downstream. The velocity in the exit channel was very high causing violent wave action. The jet leaving the basin impinged on the slope downstream from the basin. This flow condition would cause severe erosion in the exit channel area until a plunge pool develops.

Second flip bucket modification. — In order to avoid erosion on the slope immediately downstream from the flip bucket, the lip elevation was raised to elevation 2027.83 m (6653.0 ft). A flip lip angle of 20° was used to provide a jet trajectory distance of 61 to 82 m (200 to 270 ft).

At discharges up to the 100-year flood, the hydraulic jump operated satisfactorily. However, the tailwater elevation around the basin was 0.9 to 1.2 m (3 to 4 ft) higher than in the downstream channel. The flow passed through critical depth, and a small hydraulic jump formed where the exit channel levels off at elevation 2030.9 m (6663.0 ft). The hydraulic jump turbulence in this area could cause scour. The flow swept out of the stilling basin at 395 m^3/s (14 000 ft^3/s). This discharge is lower than previous designs because the flip bucket slope was more gradual and did not hold the jump in the basin as well as the more abrupt flip bucket.

The trajectory of the jet was low and still impinged on the slope downstream from the basin. Figure 19a shows the low trajectory of the jet and the high downstream velocity component of the flow in the exit channel.

Third flip bucket modification. — It was decided to increase the flip angle even though the jet will impact downstream of the outlet works channel at high flows. The flip lip was set at elevation 2027.83 m (6653.0 ft) at an angle of 37.8°.

The jump swept out of the basin at a discharge of 465 m^3/s (16 500 ft^3/s). The additional capacity over the previous design was attributed to the more abrupt flip bucket. The jet from the flip bucket carried well into the downstream channel for all discharges greater than 465 m^3/s (16 500 ft^3/s) (fig. 19b). Tailwater under the jet prevented the nappe from separating cleanly from the flip lip. When the flow swept out of the basin, most of the tailwater moved out of the exit channel. The jet struck the exit channel bottom and created large waves and surges. For this flow condition and exit channel configuration, a large scour hole and plunge pool would develop. Operational experiences at other structures indicate that a gravel bar may form in the downstream river causing a significant rise in tailwater at the dam. There is also the possibility of gravel and rocks being carried upstream into the outlet works stilling basin.

Exit Channel Excavation

It was decided to remove the sand and gravel overburden in the jet impact area to reduce the possibility of a gravel bar forming downstream. This change also would provide a greater tailwater depth for dissipation of energy from the jet.

This change was made in the model as shown in figure 20a. The channel banks were formed from sand and gravel to observe erosion tendencies. The channel bottom was constructed from plywood because the rate of erosion in the sandstone bottom cannot accurately be simulated in the model. The channel width downstream from the stilling basin was 18.3 m (60 ft), the same as the stilling basin width. The jump swept out of the basin at Q = 465 m^3/s (16 500 ft^3/s) when the tailwater is set according to tailwater curve (fig. 20b). After sweepout, the tailwater was depressed 1.3 m (4.3 ft). However, 5.33 m (17.5 ft) of tailwater depth remained to dissipate the energy of the jet. Figure 20c shows erosion and deposition patterns in the exit channel after sweepout. Erosion in the left bank of the spillway exit channel between the spillway and outlet works was severe. Erosion was also severe in the left bank of the outlet works channel directly in line with the spillway flow. Less severe erosion occurred in the right bank of the spillway exit channel where the excavated channel leads to the original riverbed.

With the stilling basin operating in the hydraulic jump mode, flow in the exit channel area was very smooth and the hydraulic jump was stable (fig. 20a). The tailwater elevation at the stilling

basin was the same as in the downstream channel, and wave action was less severe than in previous designs. Erosion problems in the exit channel are not anticipated for this design with the basin operating in the hydraulic jump mode.

Recommended Exit Channel Design

The floor of the exit channel was flared from 18.3 m (60 ft) wide at the end of the stilling basin to 30.5 m (100 ft) wide, 30.5 m (100 ft) downstream, to prevent erosion of the exit channel banks during flipout. This change provided a wider channel to dissipate the energy of the jet striking the tailwater. The flow swept out of the stilling basin at 465 m^3/s (16 500 ft^3/s). The exit channel riprap remained in place up to a flow of about 565 m^3/s (20 000 ft^3/s). At higher flows, the left bank of the outlet works channel, directly in line with the spillway, washed out. Damage in this area will be unavoidable during sweepout. However, this damage is far enough downstream that it should not cause any threat to the structures. The channel banks immediately downstream from the stilling basin did not erode. Deposition of gravel and debris in the outlet works stilling basin may be a problem during sweepout. However, if the outlet works and spillway are operated simultaneously, debris will be less likely to accumulate in the outlet works channel. Operation of the outlet works also helps supply tailwater to cushion the impact of the jet from the flip bucket.

Figure 21 gives curves for initial sweepout and sweepout reversal flows versus tailwater elevation. When the tailwater follows the projected curve, initial sweepout occurs at $Q = 465$ m^3/s (16 500 ft^3/s). If the outlet works is discharging an additional 140 m^3/s (5000 ft^3/s), the initial sweepout occurs at a spillway flow of about 495 m^3/s (17 500 ft^3/s). This additional stilling basin capacity is due to increased tailwater level resulting from the outlet works flow.

After sweepout occurs, the flow will continue as a free jet until the spillway flow is decreased to about 285 m^3/s (10 000 ft^3/s). At this flow, the sweepout will reverse and the flow will return to the hydraulic jump. If the tailwater curve changes due to channel aggradation or degradation, the initial sweepout and sweepout reversal curves (fig. 21) should remain valid. The sweepout and sweepout reversal will occur where the changed tailwater curve crosses the sweepout curves.

After sweepout, the tailwater will be drawn down about 1 m (3 to 4 ft) due to the aspirating effect of the jet. After the initial drawdown, the tailwater may rise again if a gravel bar is formed, remain the same, or drop. It was not possible to study downstream erosion and deposition patterns in the model.

Figure 22a shows the recommended design of the stilling basin-flip bucket and exit channel; figures 22b and 23 show the recommended design operating at the 100-year flood, 375 m^3/s (13 300 ft^3/s). The hydraulic jump works well in dissipating the energy up to the 100-year flood. However, flows for the transition between the 100-year flood and the initial sweepout cause large waves and surges in the exit channel.

Figure 24 shows the recommended design flip bucket and exit channel operating during sweepout. The tailwater level was not drawn down as far during sweepout as in previous designs. This created a deeper plunge pool to dissipate the energy when the jet strikes the water. High tailwater prevented the bottom of the nappe from separating. The lack of air to the bottom of the jet will cause cavitation to originate at the lip of the flip bucket. However, this should not cause any damage because the vapor cavities should collapse in the flow downstream from the stilling basin.

The photographs in figure 24 show the full range of sweepout flows. Figure 24a shows an initial sweepout flow without the outlet works operating. In figure 24b, the outlet works is operating in addition to the spillway. The outlet works flow reduces the turbulence downstream from the jet impact area and turns the flow direction slightly.

Figure 24c shows the inflow design flood discharging through the spillway and outlet works.

The difference in the height and length of the jet over the range of sweepout flows is illustrated in figure 24. The turbulence downstream from the jet impact area is considerably more for the inflow design flood (fig. 24c) than for initial sweepout (fig. 24b). However, the downstream turbulence for the recommended design is considerably less severe than in earlier designs (figs. 17, 18, and 19).

Table 1 contains data describing water surface profiles and dimensions of the jet during sweepout. Figure 25 is a plan of the recommended design exit channel showing model limits and a length scale. For the inflow design flood, the jet will travel about 125 m (415 ft) downstream from the flip lip and will be 39 m (128 ft) high (above the exit channel floor).

Stilling Basin Debris Tests

A series of tests was conducted to determine the self-cleaning characteristics of the recommended stilling basin. These tests should be useful in determining the flow required to clean the basin for various sizes of debris that may accumulate in the basin.

Test procedure. — Rocks of various sizes and shapes (see table 2) were placed in the stilling basin (fig. 26a). The flow was then gradually increased to the test flow and held constant for a period of 45 minutes (4.5 hours prototype time). The flow was then stopped and the location and number of debris pieces were noted and photographed.

Results. — Table 2 lists the results of the debris tests. At a discharge of 140 m^3/s (5000 ft^3/s), the debris shifted to the base of the flip bucket; however, none of the debris washed out (fig. 26b). At a discharge of 200 m^3/s (7000 ft^3/s), about half of the 75-mm (3-in) rocks, one 0.3-m (1-ft) rock, and one 0.9-m (3-ft) rock were washed out. These rocks had a tendency to deposit immediately downstream from the center of the flip lip (fig. 26c). At a discharge of 255 m^3/s (9000 ft^3/s), all the debris except a few 1.5-m (5-ft) rocks were washed out of the basin. The test at a discharge of 255 m^3/s (9000 ft^3/s) was repeated to verify the results.

The deposition area immediately downstream from the flip lip indicates that a reverse roller exists at the end of the basin. This roller may tend to draw debris into the basin at low flows, although no rocks were drawn into the basin during the testing.

As the flow is increased, the length of the jump in the basin increases. At 255 m^3/s (9000 ft^3/s), the jump extends far enough downstream to wash most of the rocks out of the basin.

Table 1.—*Combination stilling basin-flip bucket flow data*

Q[1] spillway discharge m³/s (ft³/s)	Average water surface elevation in stilling basin			L[3] Length of leading edge of jet	H[4] Maximum height of jet	L - Distance at H	Tailwater elevation		
	At L1[2]	At L2	At L3				At stilling basin	At outlet works	In downstream channel
140 (5 000)	2031.8 (6666.0)	2032.1 (6667.0)	2032.4 (6668.0)	- -	- -	- -	2032.3 (6667.6)	2032.7 (6669.0)	2032.1 (6667.5)
285 (10 000)	2030.0 (6660.0)	2031.2 (6665.0)	2033.3 (6671.0)	- -	- -	- -	(2032.9 (6670.8)	2033.2 (6670.5)	2033.0 (6669.8)
370 (13 000)	2027.2 (6651.0)	2030.0 (6660.0)	2031.8 (6666.0)	- -	- -	- -	2033.3 (6670.8)	2033.6 (6672.0)	2033.3 (6671.0)
455 (16 000)	2023.0 (6637.0)	2022.7 (6636.0)	2022.3 (6635.0)	76.2 (250)	17.7 (58)	36.6 (120)	2031.8 (6666.0)	2031.0 (6663.5)	2031.8 (6666.0)
565 (20 000)	2023.0 (6637.0)	2023.4 (6638.5)	2022.3 (6635.0)	99.1 (325)	21.9 (72)	48.8 (160)	2031.8 (6666.0)	2031.0 (6663.5)	2031.8 (6666.0)
710 (25 000)	2023.3 (6638.0)	2023.9 (6640.0)	2022.7 (6636.0)	106.7 (350)	26.8 (88)	54.9 (180)	2031.8 (6666.0)	2030.9 (6663.0)	2031.8 (6666.0)
940 (33 130)	2023.6 (6639.0)	2024.9 (6643.5)	2023.3 (6638.0)	126.5 (415)	39.0 (128)	64.0 (210)	2032.3 (6667.5)	2032.1 (6667.0)	2032.3 (6667.5)

NOTES: All distances and elevations in meters (feet). See figure 25 for plan of exit channel.

[1]Outlet works discharging 150 m³/s (5260 ft³/s) in addition to spillway flow.
[2]L1 at −39.6 m (−130 ft), L2 at −30.5 m (−100 ft), L3 at −15.2 m (−50 ft).
[3]Lengths are horizontal distances from the flip lip.
[4]Heights are vertical distances above exit channel elevation 2026.9 m (6650 ft).

Table 2. — *Stilling basin debris tests—Number of rocks in basin after test*

Discharge	Size of rocks[1] (diameter)			
m^3/s (ft^3/s)	75 mm (3 in)	300 mm (1 ft)	900 mm (3 ft)	1500 mm (5 ft)
Before test	45	9	20	10
140 (5000)	45	9	20	10
200 (7000)	20	8	19	10
255 (9000)	0	0	0	1
255 (9000)	0	0	0	4

[1] Rock sizes scaled geometrically. Model rock diameter = (1/36) prototype diameter.

Notes:

— Duration of tests was 4.5 hours (45 minutes model time).

— See figure 26 for distribution of rocks in basin.

— Conversion approximations: 1 ft = 300 mm, 1 in = 25 mm.

BIBLIOGRAPHY

[1] Graf, W. H., "Hydraulics of Sediment Transport," McGraw-Hill, Inc., 1971.

[2] Falvey, H. T., "Air-Water Flow in Hydraulic Structures," Engineering Monograph No. 41, U.S. Department of the Interior, Water and Power Resources Service, 1980.

[3] Chow, V.T., "Open Channel Hydraulics," McGraw-Hill, Inc., 1959.

[4] "Design of Gravity Dams" U.S. Department of the Interior, Bureau of Reclamation, Denver, Colo., 1976.

[5] Isbester, T. J., "Hydraulic Model Studies of Folsom Spillway-Outlet Junction," REC-ERC-71-12, U.S. Department of the Interior, Bureau of Reclamation, February 1971.

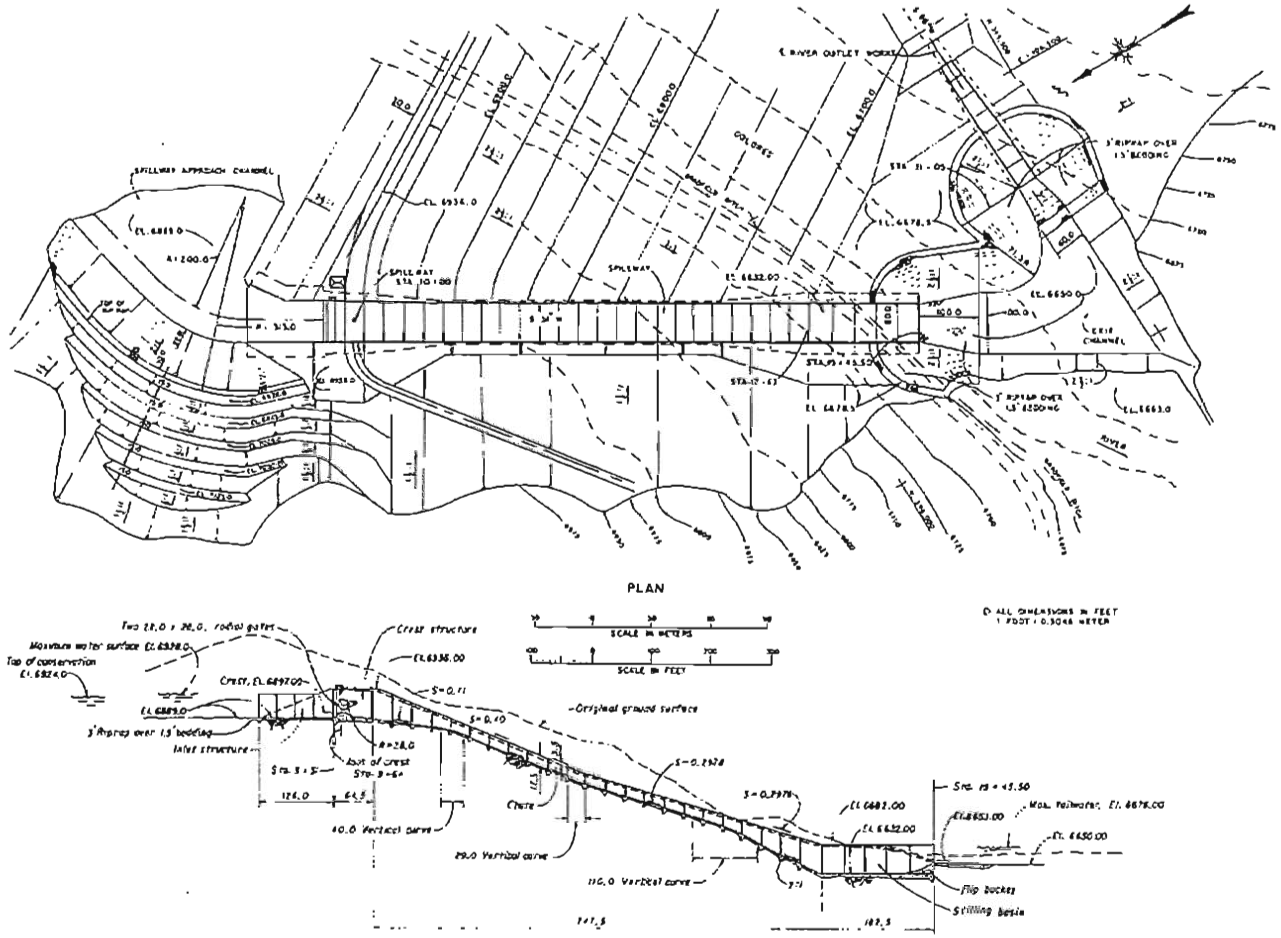
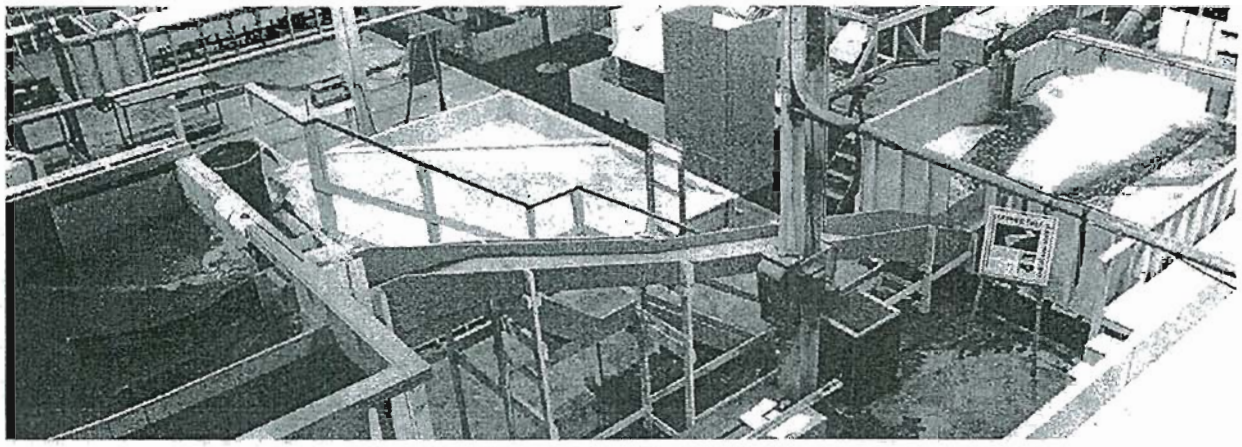


Figure 1.—Plan and profile of spillway



Recommended Design: Q = 940 m^3/s (33 130 ft^3/s), approach channel, spillway crest, chute spillway, combination hydraulic jump stilling basin-flip bucket, and exit channel.

Figure 2.-McPhee Dam spillway model in operation. Photo P801-D-79446

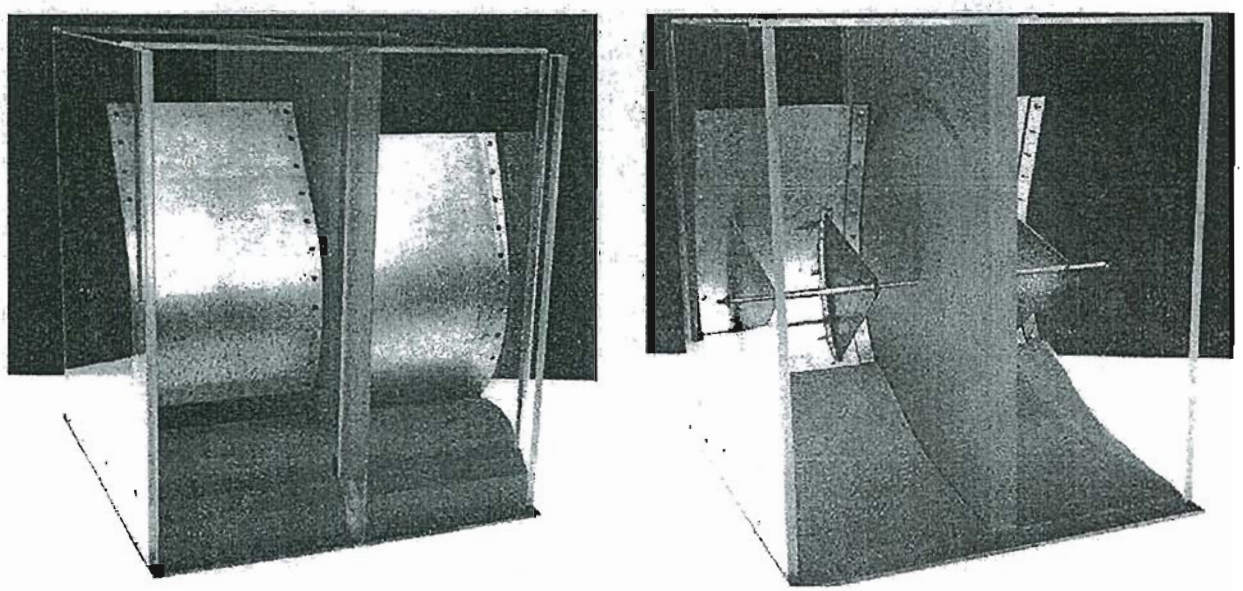
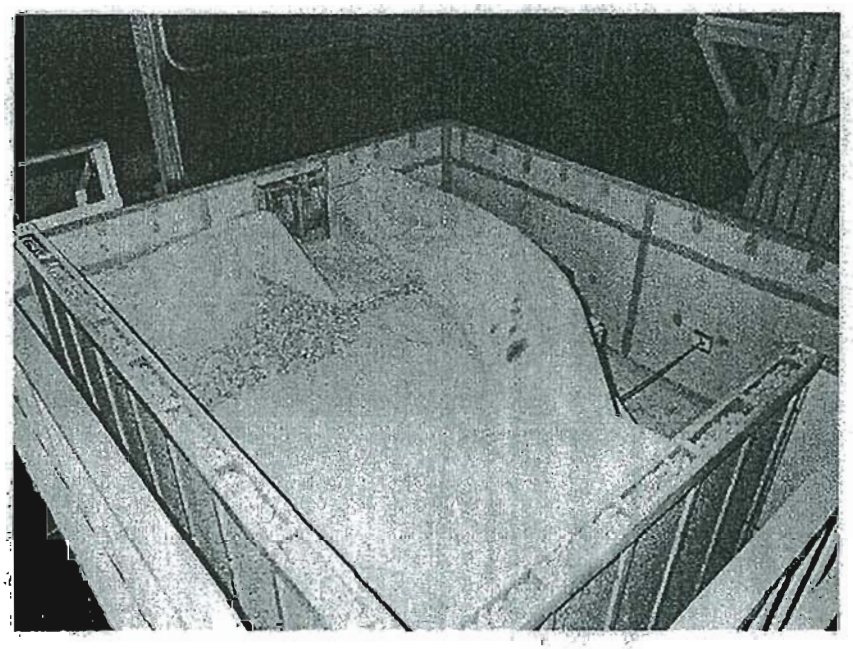
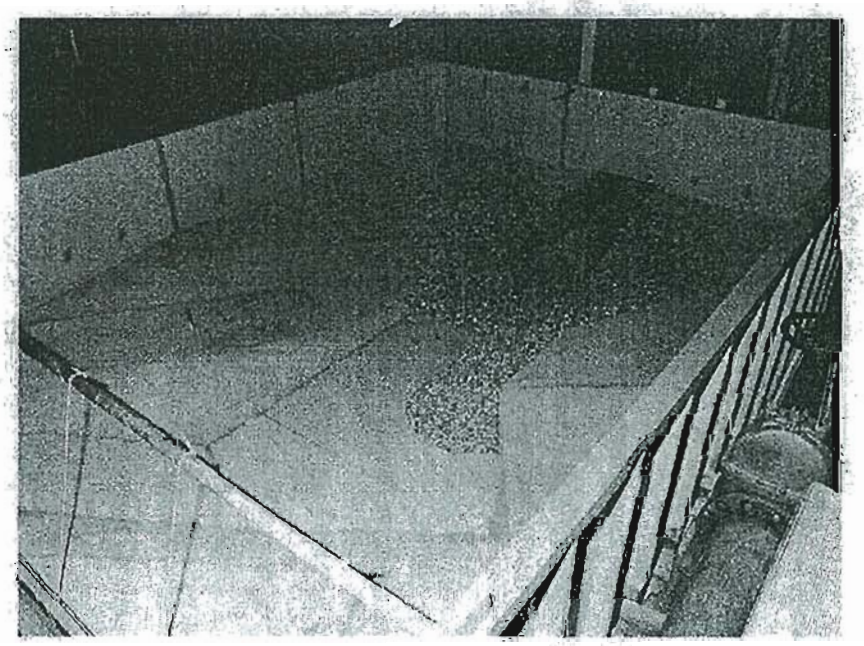


Figure 3.-Model spillway crest structure and radial gates. Photo P801-D-79447

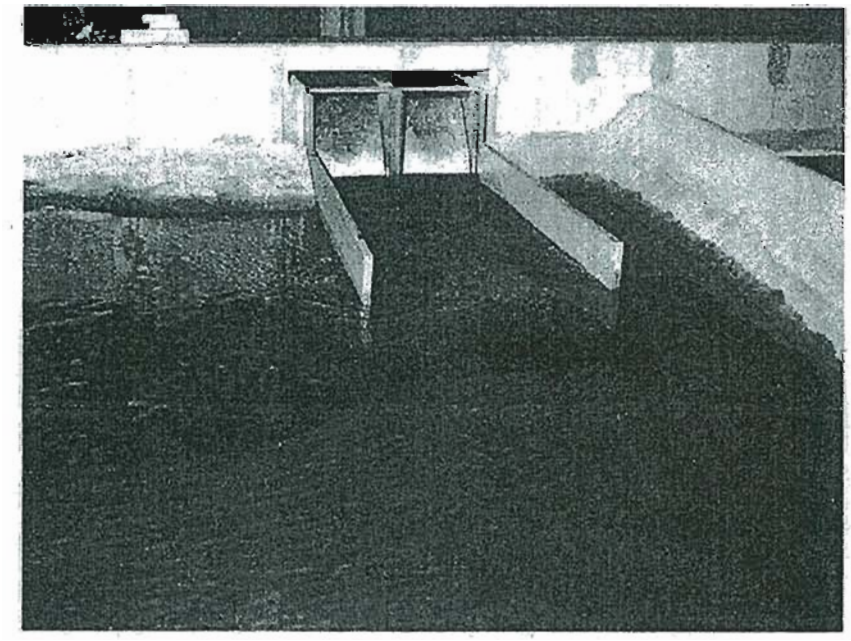


a. Approach channel — Sloping guide walls leading to the spillway. Photo P801-D-79448

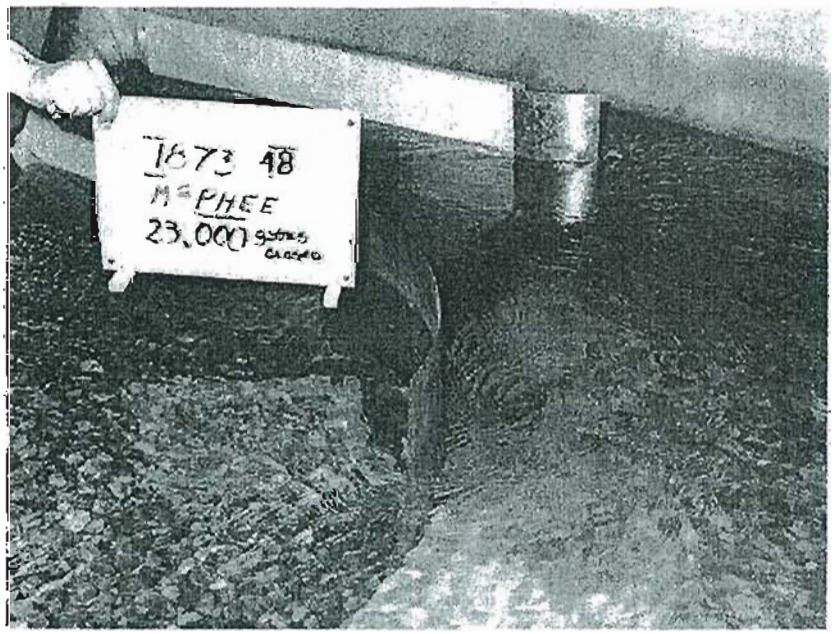


b. Exit Channel - Downstream channel sloping up at 5:1 slope from the stilling basin to the river channel. Photo P801-D-79449

Figure 4.-Preliminary design approach channel and exit channel.



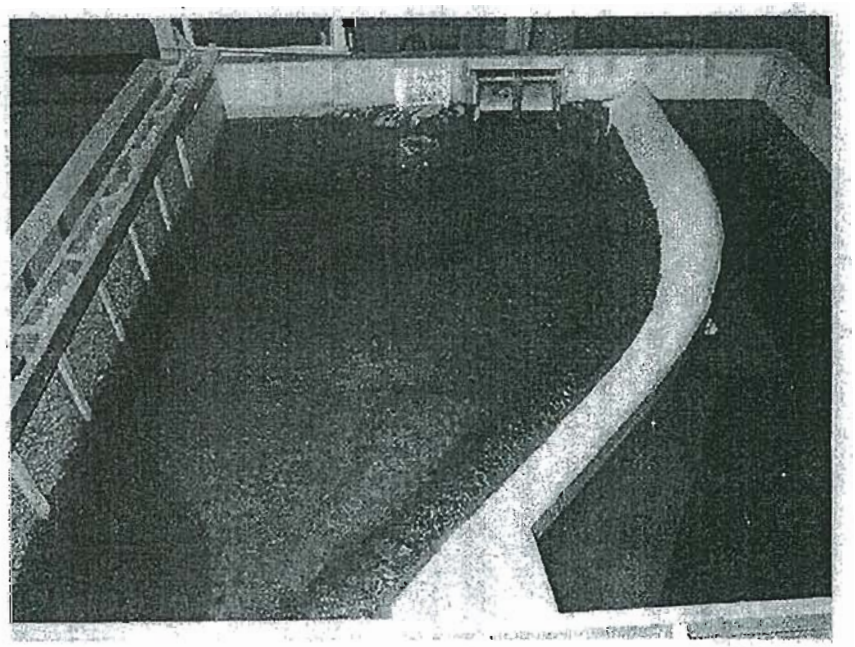
a. Guide walls raised above the maximum water surface (position of the walls is the same as in the preliminary design), Q = 375 m³/s (13 300 ft³/s). Photo P801-D-79450



b. Curved guide walls added, Q = 650 m³/s (23 000 ft³/s). Photo P801-D-79451

Figure 5.-Approach channel modification No. 1

a. Short curved guide walls, radius = 15.24 m (50 ft), leading to spillway. Photo P801-D-79452



b. Q = 940 m³/s (33 130 ft³/s), reservoir elevation = 2111.25 m (6926.7 ft). Photo P801-D-79453

Figure 6.-Approach channel modification No. 2

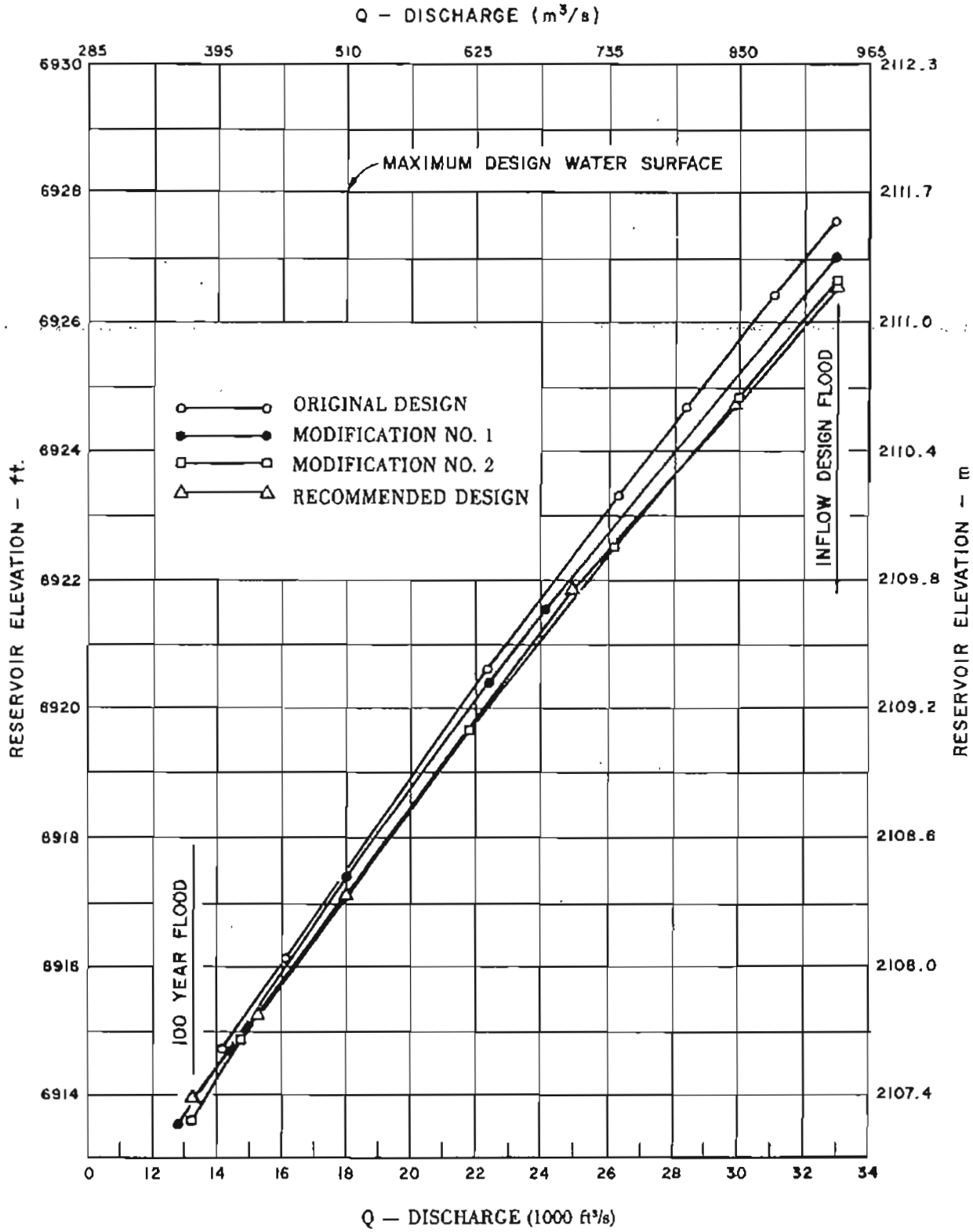
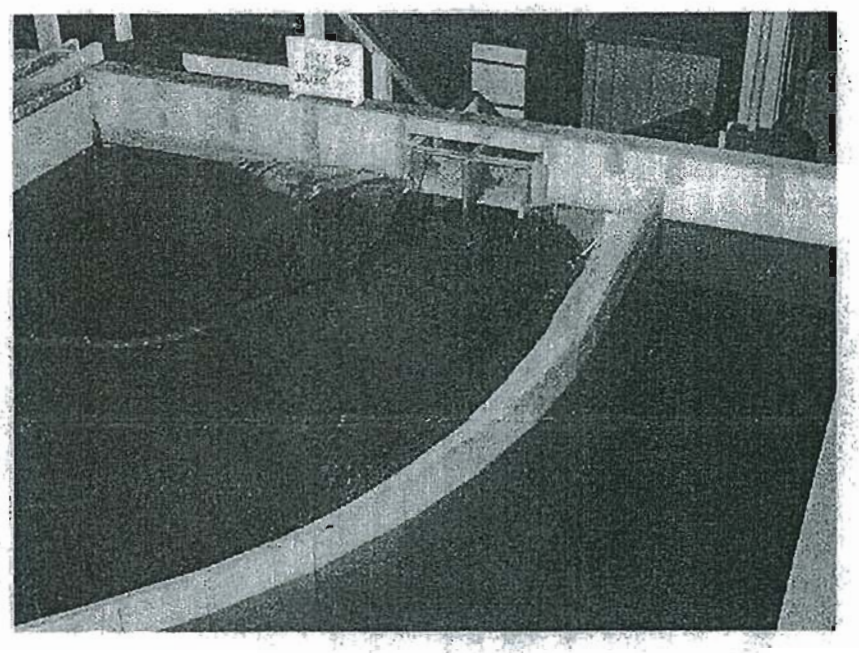
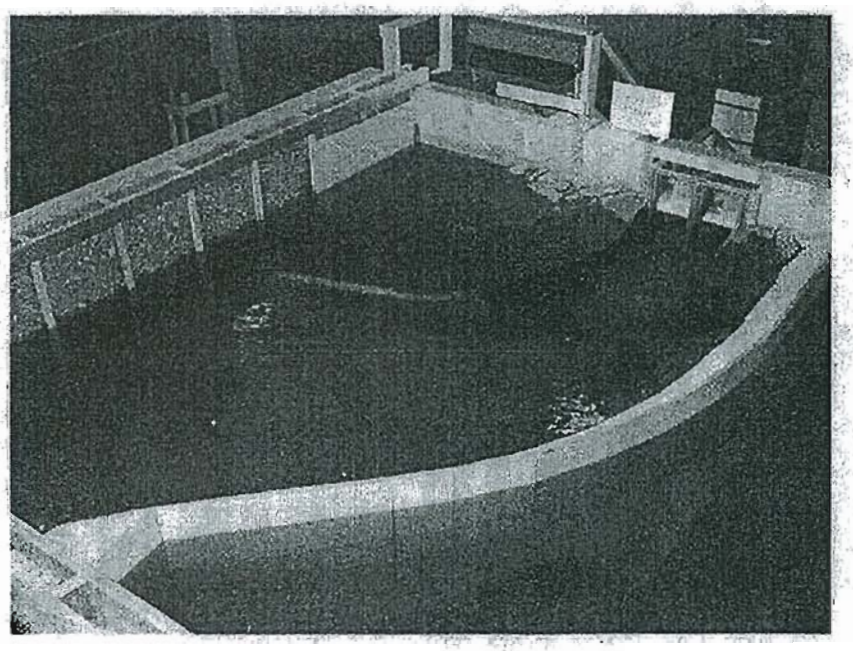


Figure 7.-Discharge versus reservoir elevation for nongated flow (free flow).

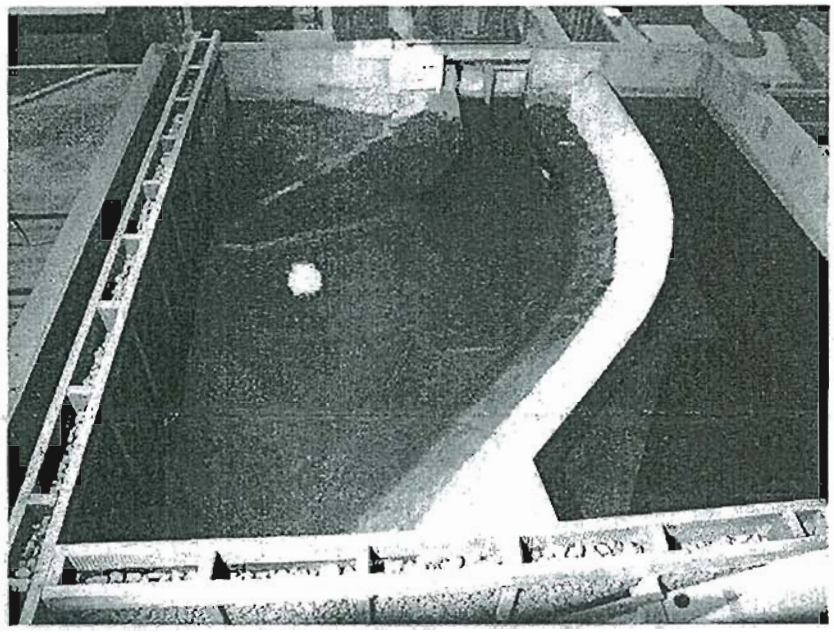


a. Left wall flares out guiding flow into the spillway. Right wall slopes (same as preliminary design), Q = 940 m^3/s (33 130 ft^3/s), reservoir elevation = 2111.38 m (6927.09 ft). Photo P801-D-79434

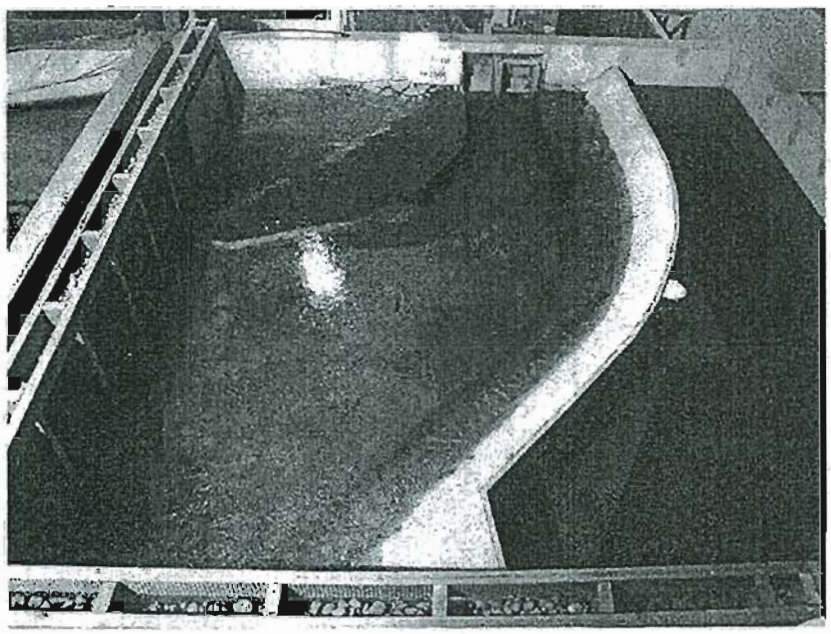


b. Right wall curving toward cut slope, Q = 940 m^3/s (33 130 ft^3/s), reservoir elevation = 2111.23 m (6926.6 ft). Photo P801-D-79455

Figure 8.-Approach channel modification No. 3



a. Q = 375 m^3/s (13 300 ft^3/s), 100-year flood, reservoir elevation = 2110.97 m (6925.75 ft), gate opening = 2.62 m (8.6 ft). Photo P801-D-79456



b. Q = 940 m^3/s (33 130 ft^3/s), inflow design flood, reservoir elevation = 2111.23 m (6926.6 ft). Photo P801-D-79457

Figure 9.-Recommended approach channel

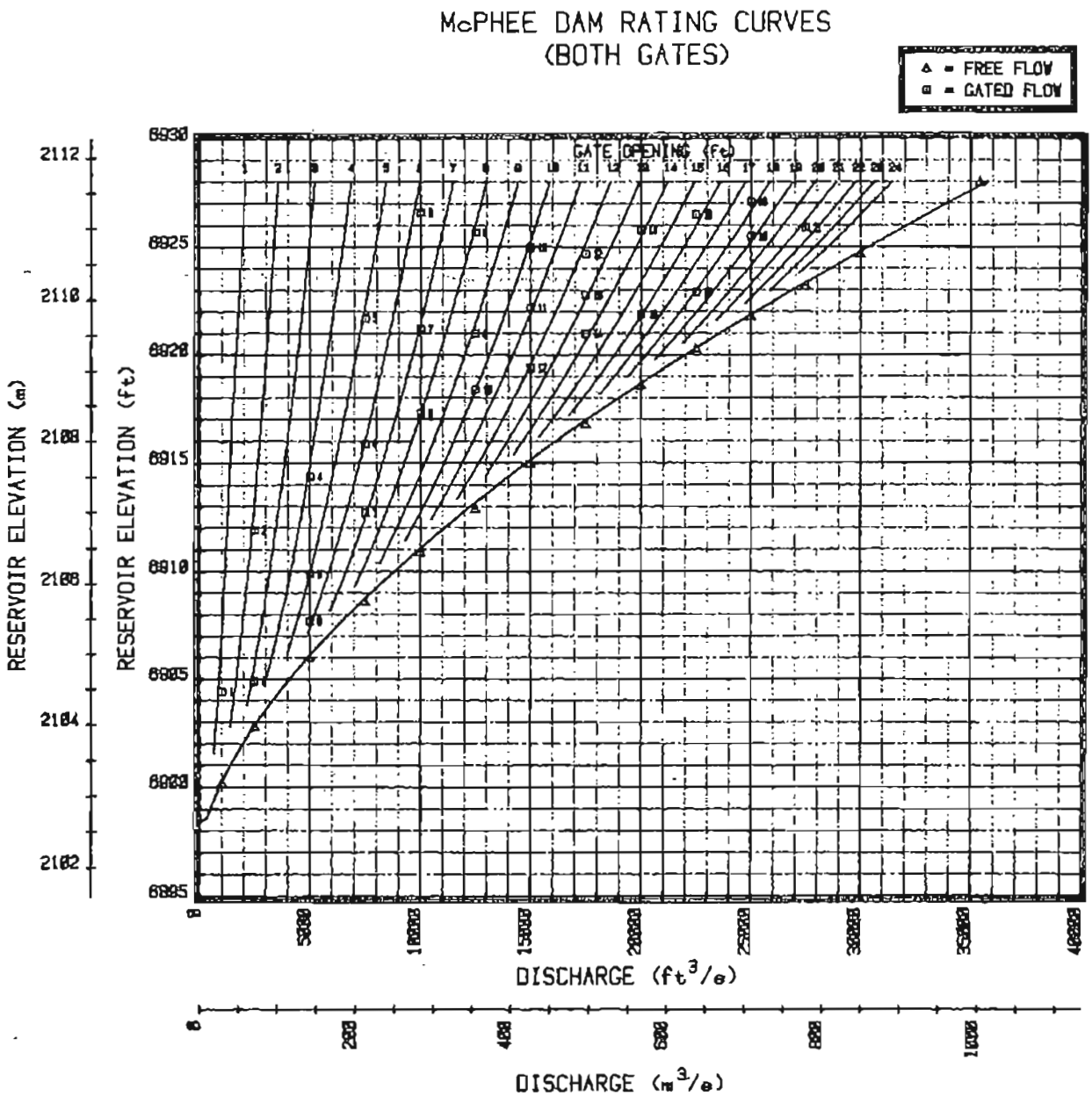


Figure 10.-Spillway rating curves - two gates

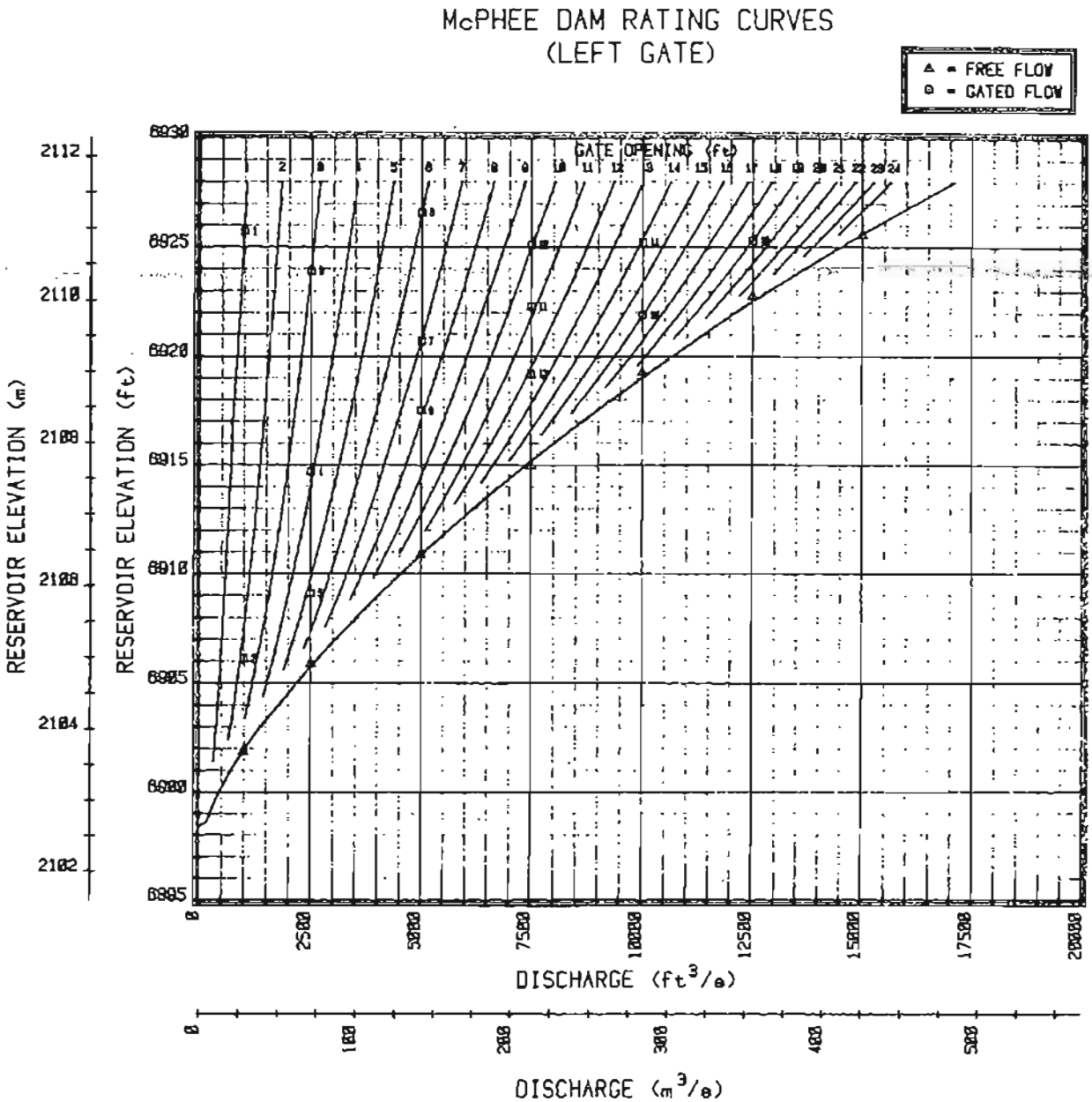


Figure 11. Spillway rating curves - left gate

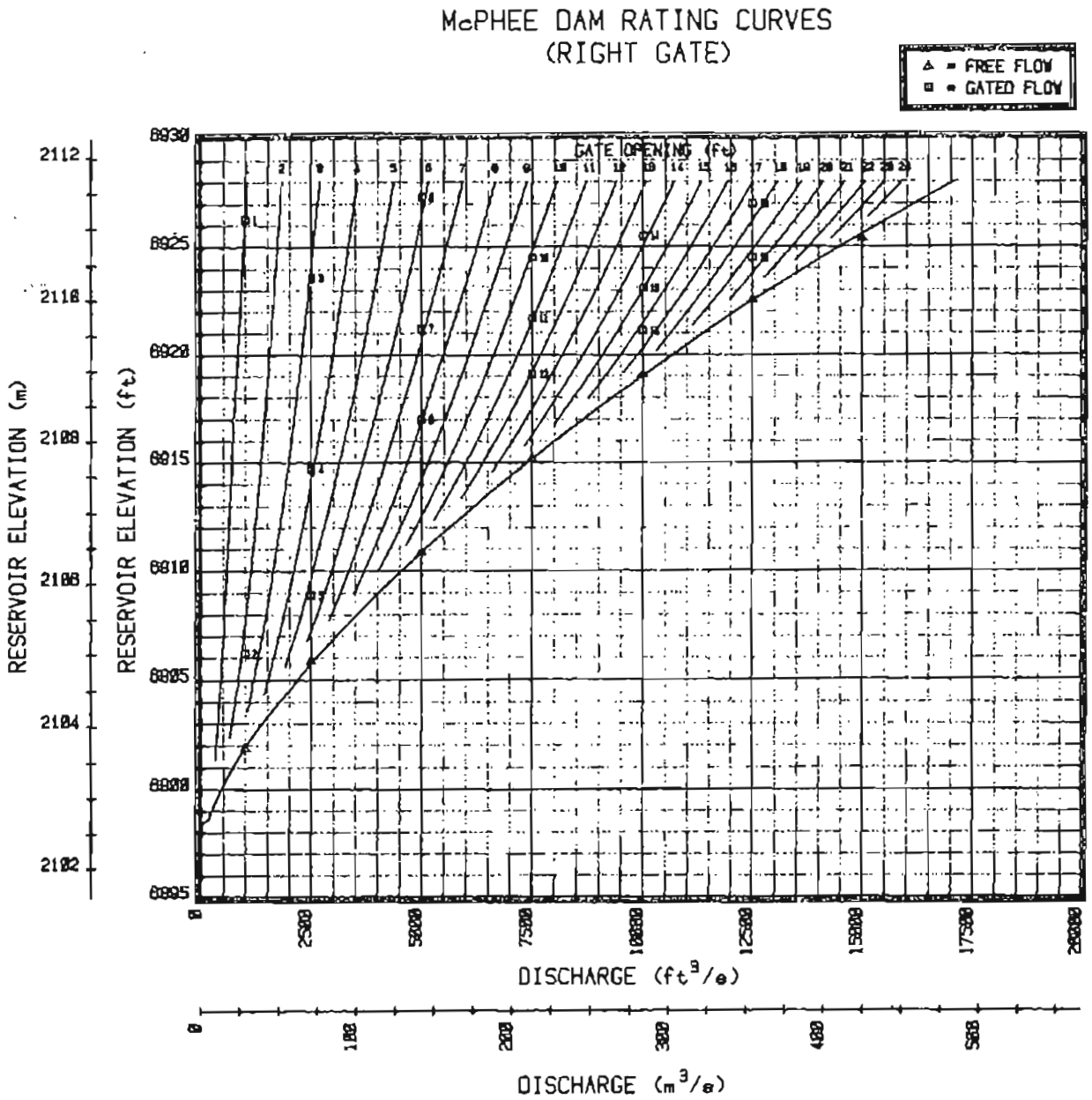
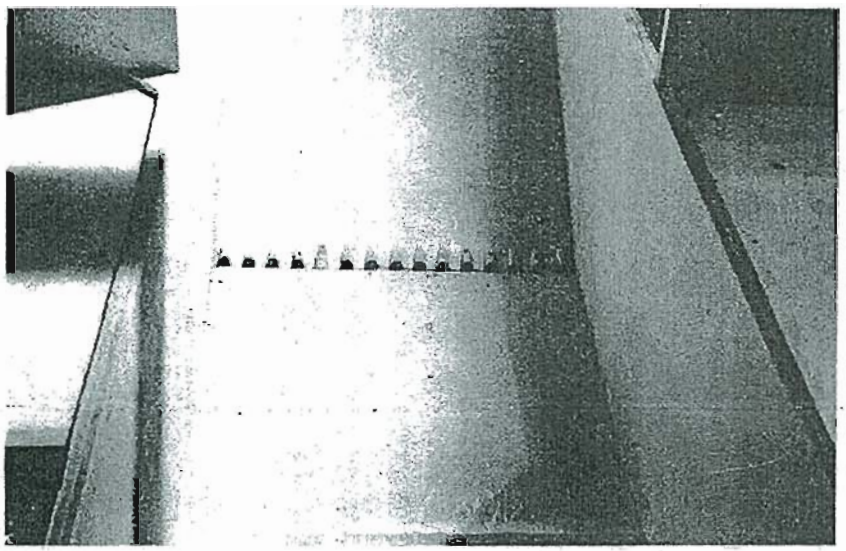
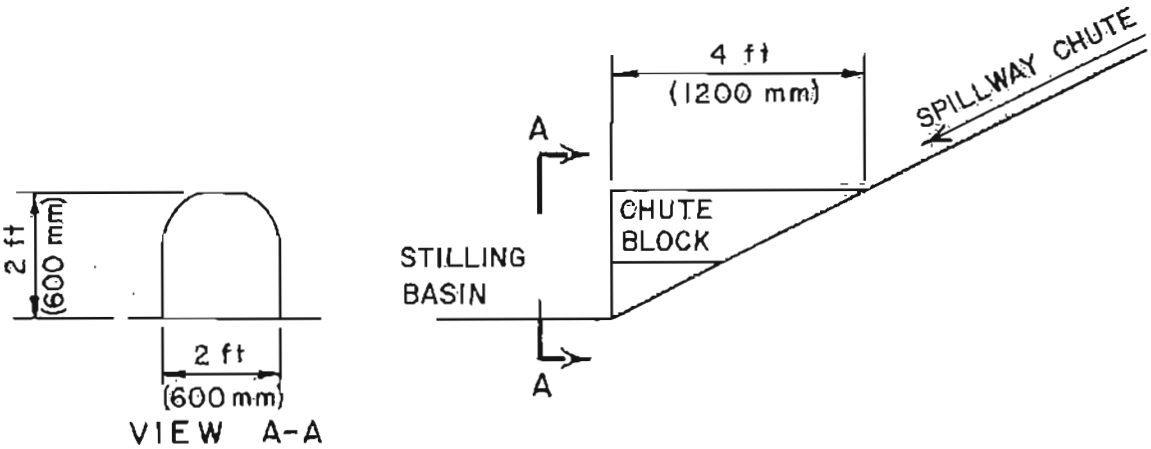


Figure 12.-Spillway rating curves - right gate

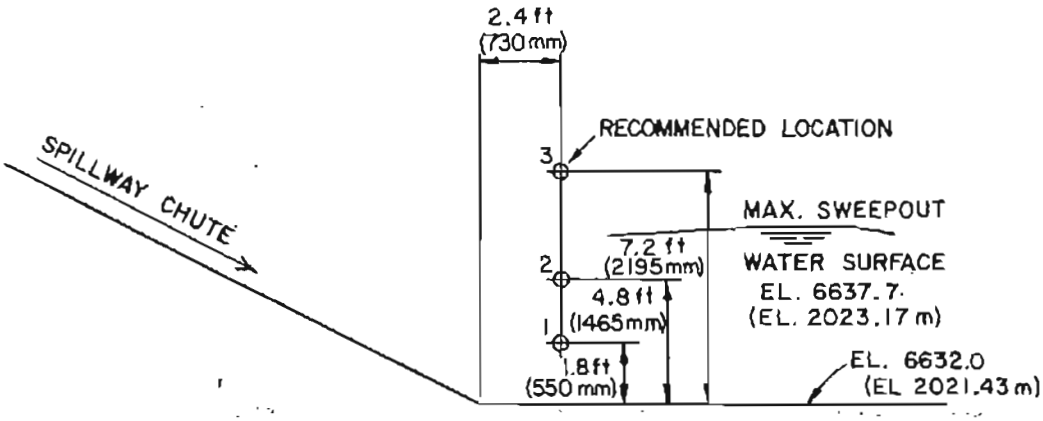


a. Fifteen chute blocks installed at the intersection of the spillway chute and stilling basin. Photo P801-D-79458



b. Chute block detail

Figure 13.-Chute blocks



POTENTIAL WALL DRAIN OUTLET LOCATIONS

DISCHARGE		PIEZOMETERS			
m^3/s	ft^3/s	1 AVG	1 FLUC	2 AVG	3 AVG
140	5 000	8.99 (29.5)	±2.07 (±6.8)	8.14 (26.7)	6.95 (22.8)
285	10 000	9.54 (31.3)	±4.18 (±13.7)	7.83 (25.7)	5.73 (18.8)
375	13 300	8.11 (26.6)	±8.66 (±28.4)	5.70 (18.7)	2.38 (7.8)
435	15 300	5.49 (18.0)	±0.98 (±3.2)	1.89 (6.2)	-0.06 (-0.2)
455	16 000	6.04 (19.8)	±3.72 (±12.2)	*	*
510	18 000	7.13 (23.4)	±2.62 (±8.6)	*	*
565	20 000	10.09 (33.1)	±3.60 (±11.8)	*	*
710	25 000	10.85 (35.6)	±3.29 (±10.8)	*	*
850	30 000	12.62 (41.4)	±3.72 (±12.2)	*	*
940	33 130	14.14 (46.4)	±3.08 (±10.1)	10.12 (33.2)	*

*Drain above water surface (after sweepout)
Pressures in meters of water (feet of water)

WALL DRAIN PRESSURES

Figure 14.-Wall drains

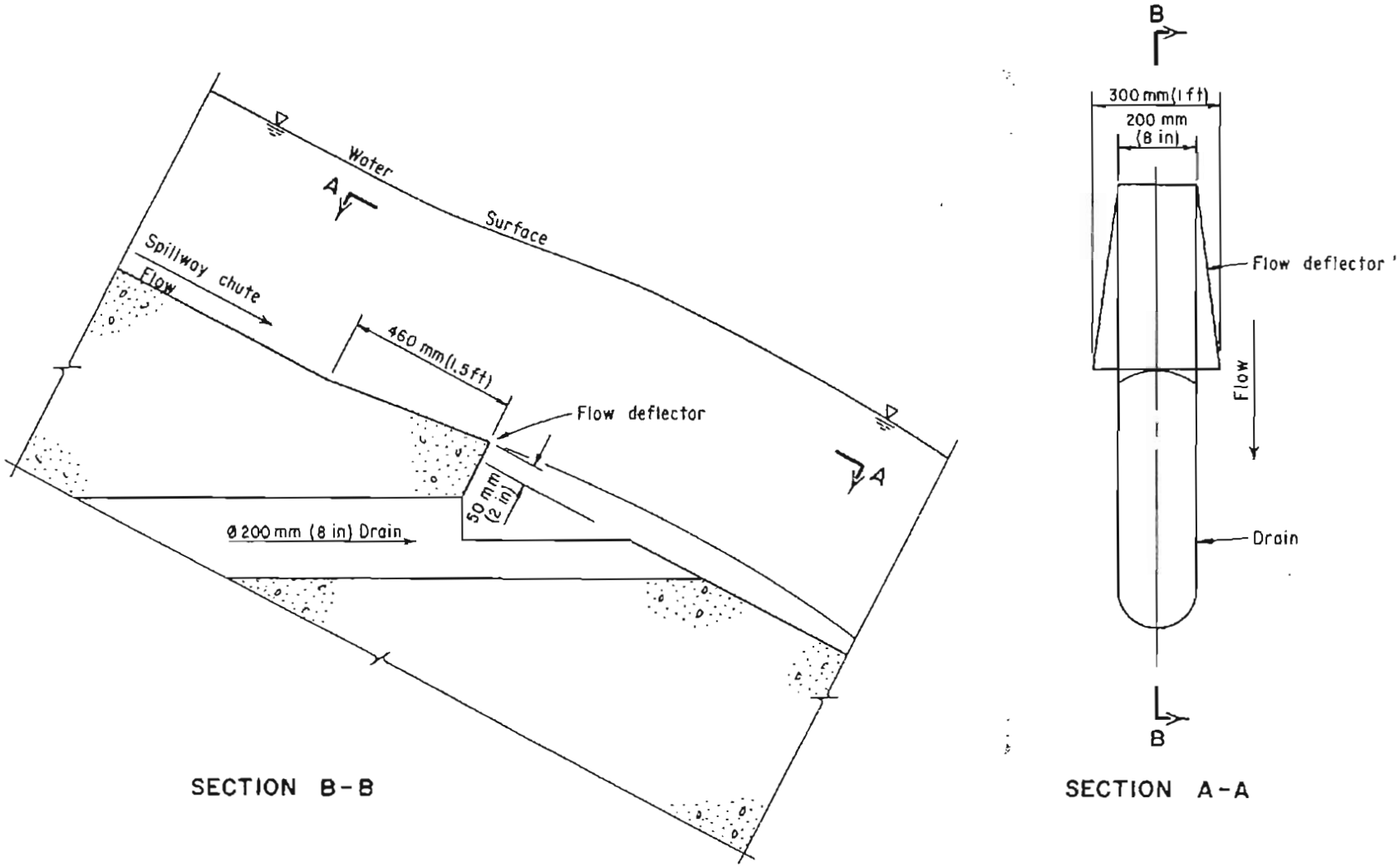


Figure 15.-Flow deflector and chute drain outlet

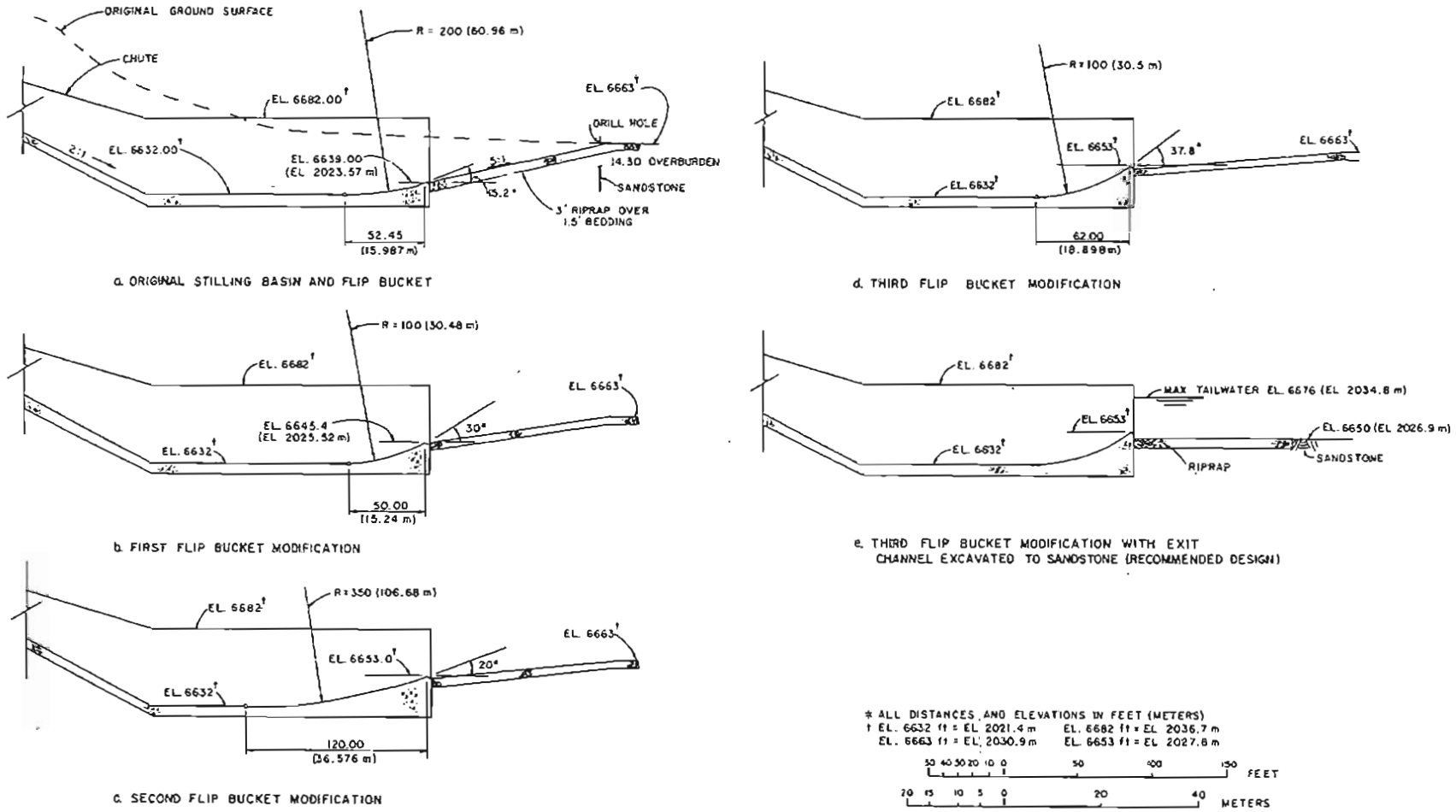
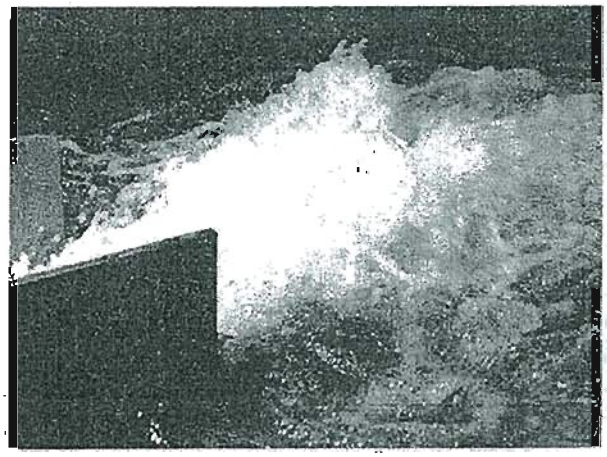
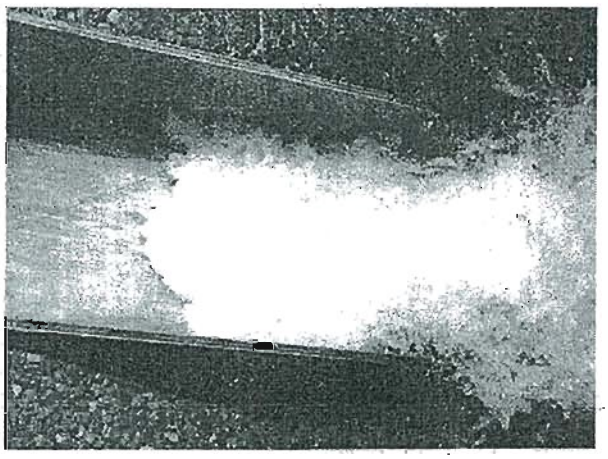


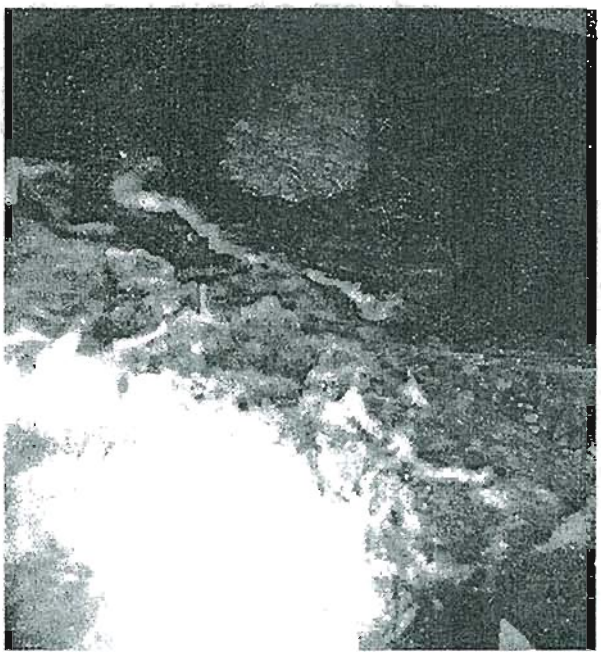
Figure 16.-Stilling basin-flip bucket profiles



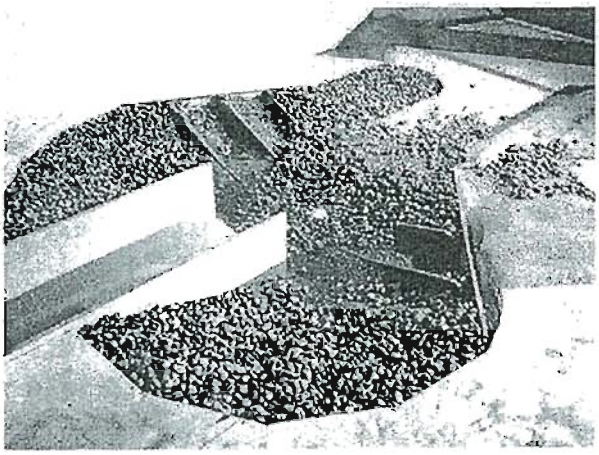
a. Flow sweeping out of stilling basin at Q = 500 m^3/s (17 600 ft^3/s) and impinging on downstream slope. Photo P801-D-79459



b. Jump sweeping out of stilling basin. Photo P801-D-79461

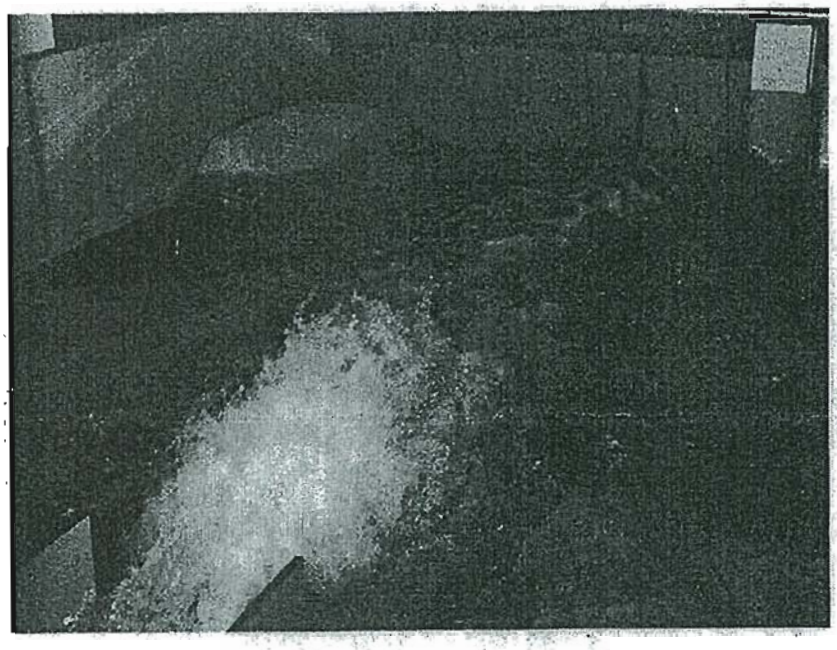


c. Downstream channel during sweepout. Photo P801-D-79462

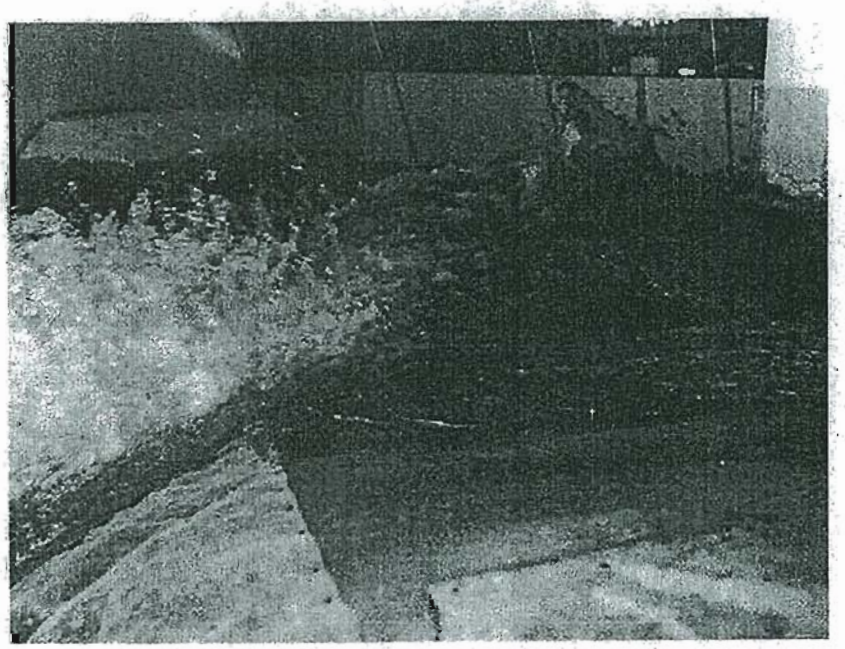


d. Erosion in exit channel after sweepout for a few seconds. Photo P801-D-79460

Figure 17.-Original design stilling basin operation and erosion

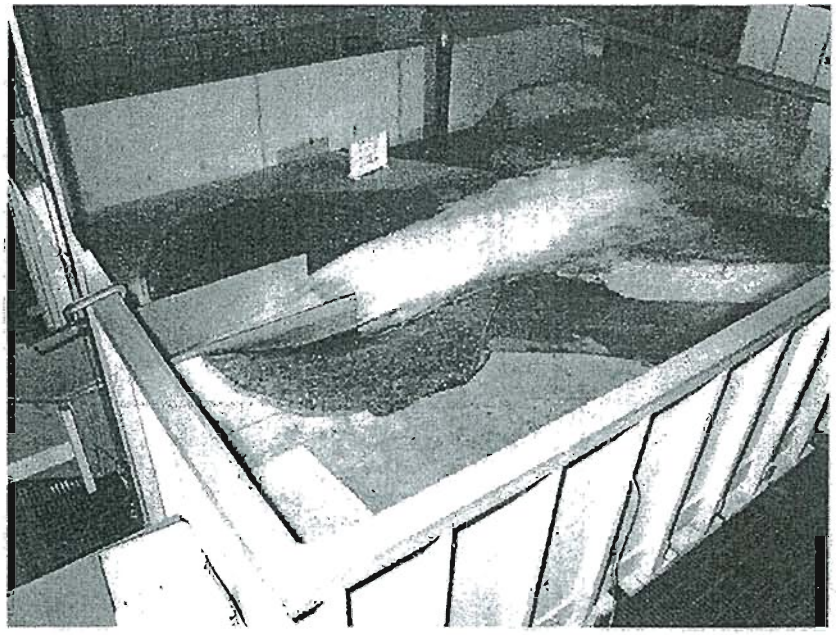


a. Initial sweepout, Q = 510 m³/s (18 000 ft³/s). Photo P801-D-79463

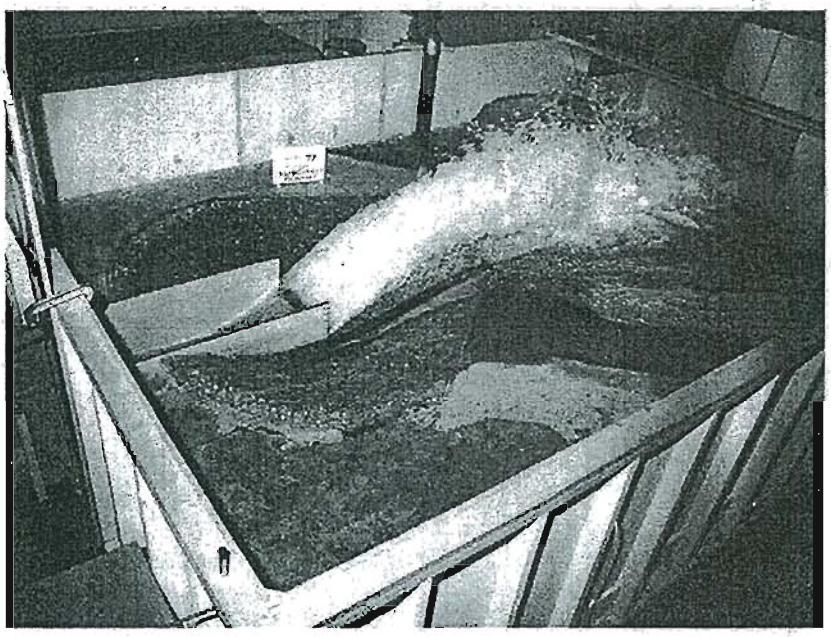


b. Exit channel at Q = 510 m³/s (18 000 ft³/s). Tailwater is washed out and velocity is very high at the model tailgate. Photo P801-D-79464

Figure 18.-Flip bucket modification No. 1 operating

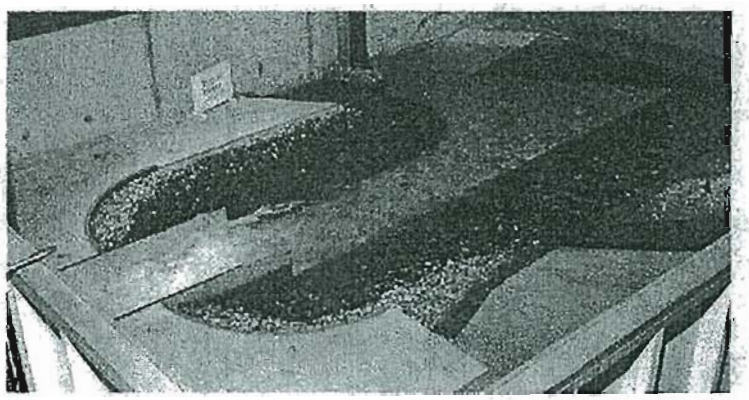


a. Modification No. 2, Q = 940 m^3/s (33 130 ft^3/s), flip angle = 20°. Photo P801-D-79465

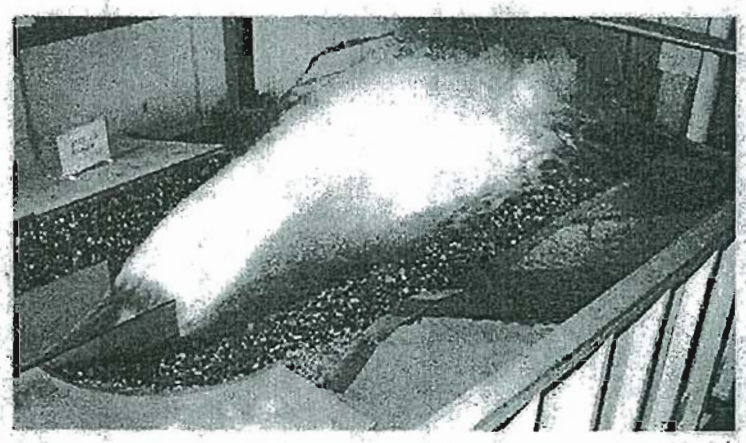


b. Modification No. 3, Q = 940 m^3/s (33 130 ft^3/s), flip angle = 37.8°. Photo P801-D-79466

Figure 19.-Flip bucket modifications No. 2 and 3 operating



a. Hydraulic jump operation at Q = 375 m^3/s (13 300 ft^3/s). Photo P801-D-79467



b. Q = 940 m^3/s (33 130 ft^3/s). Photo P801-D-79468

c. Channel bank erosion after operation at Q = 940 m^3/s (33 130 ft^3/s) for about 1 hour. Photo P801-D-79469

Figure 20.-Flip bucket modification No. 3 with exit channel modification.

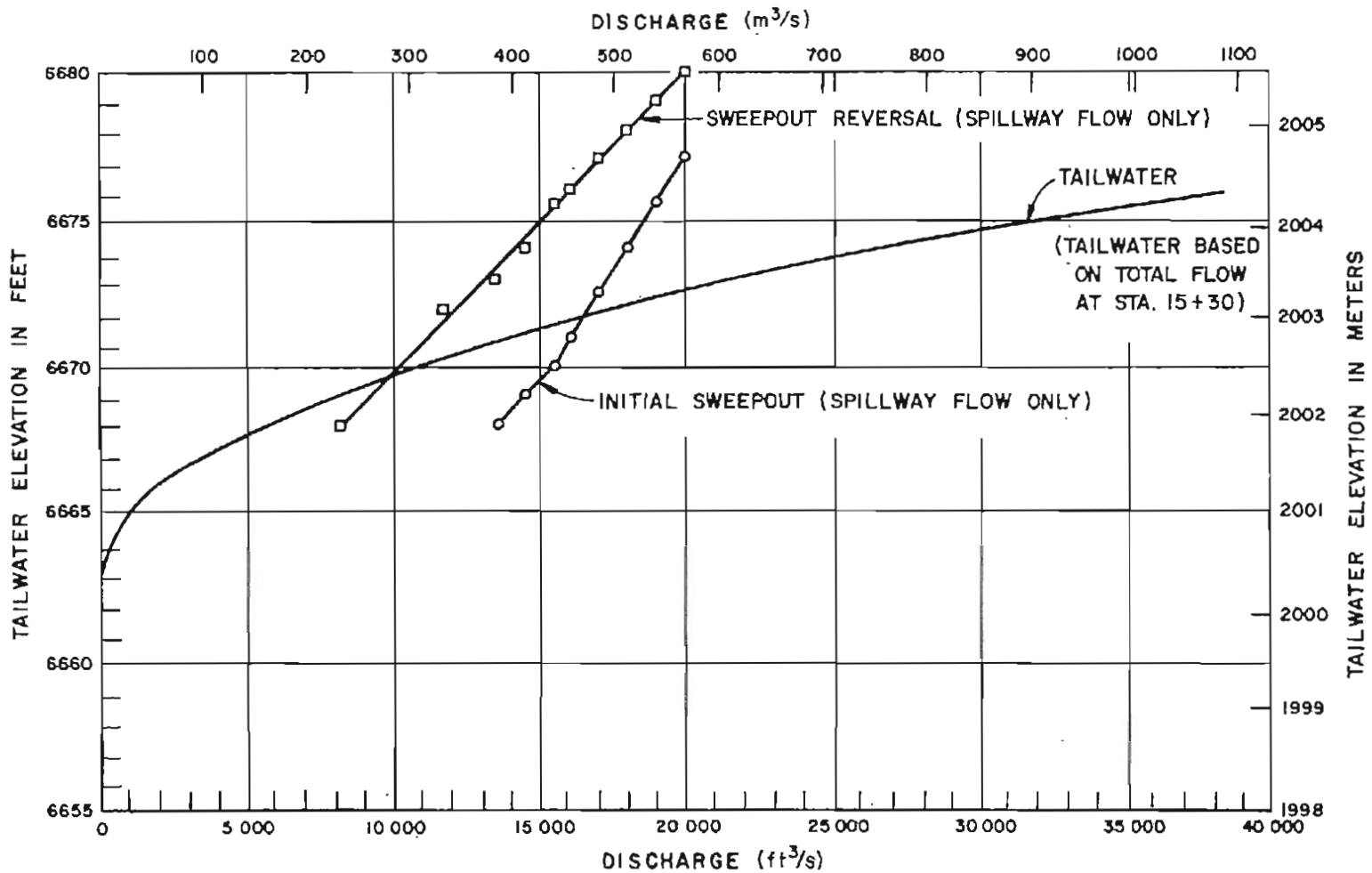
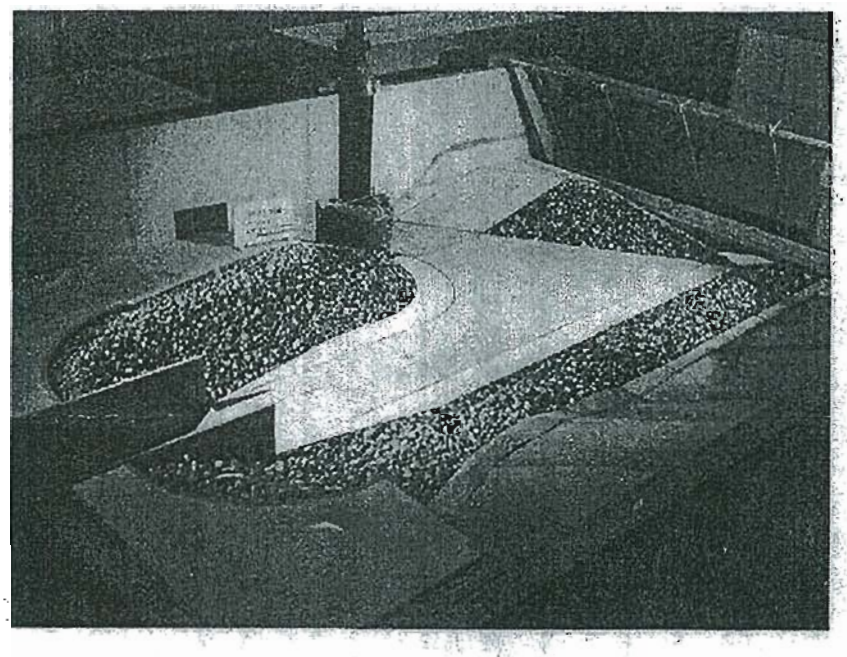
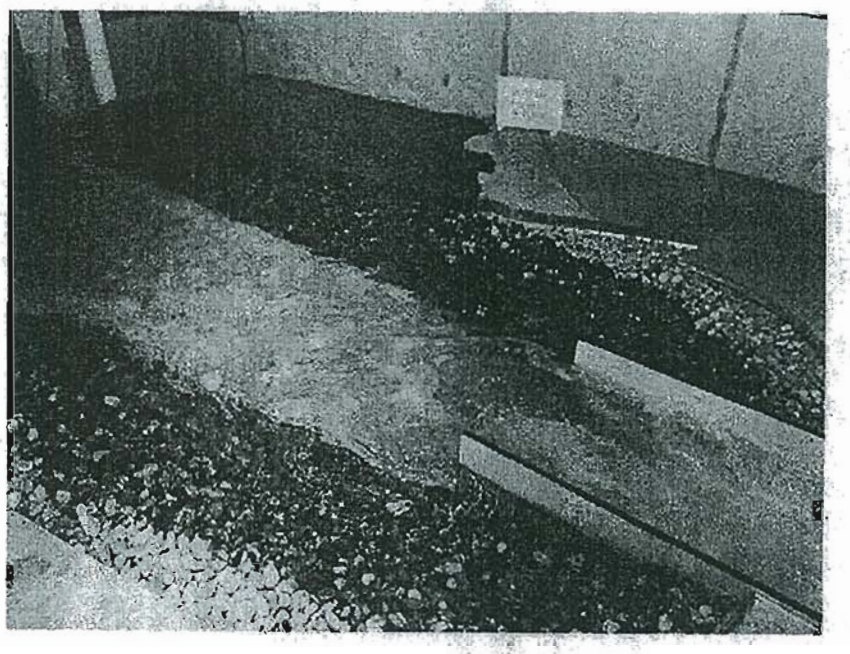


Figure 21.-Initial sweepout and sweepout reversed versus tailwater curve

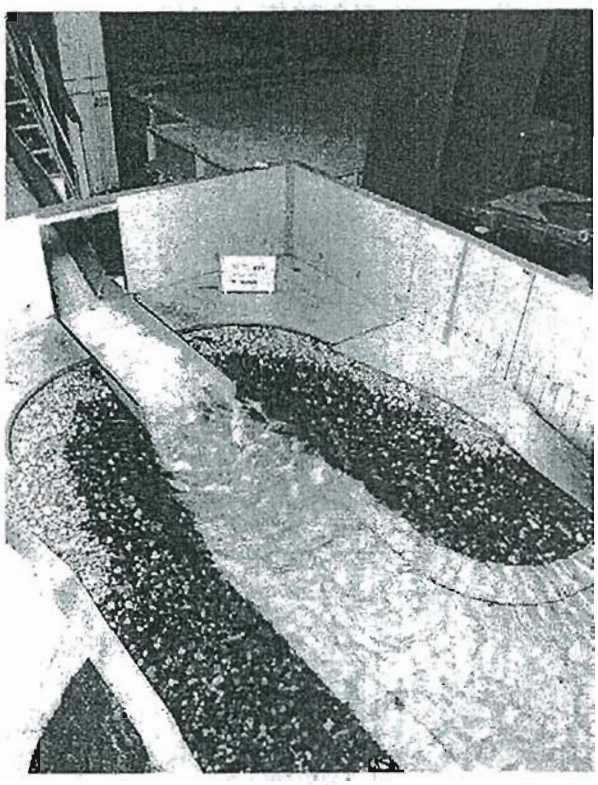


a. Exit channel. Photo P801-D-79470

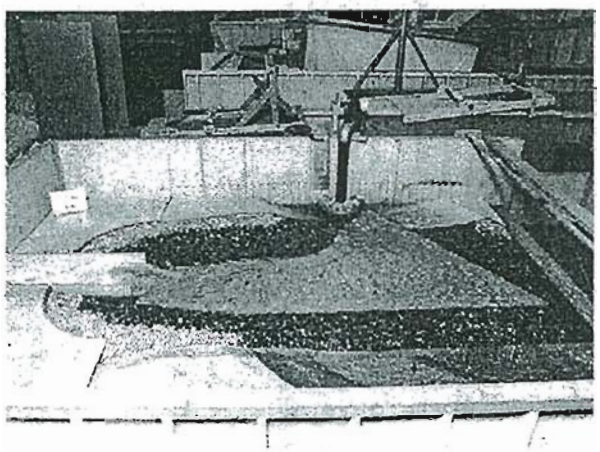


b. Exit channel looking downstream, Q = 375 m^3/s (13 300 ft^3/s). Photo P801-D-79471

Figure 22.-Recommended exit channel

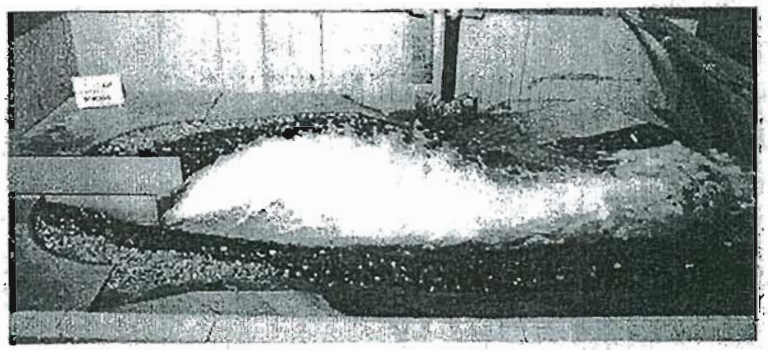


a. Q = 375 m^3/s (13 300 ft^3/s). Photo P-801-D-79472

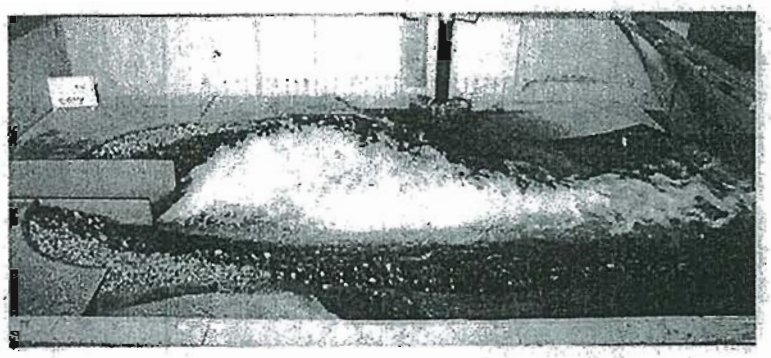


b. Q = 375 m^3/s (13 300 ft^3/s). Photo P-801-D-79473

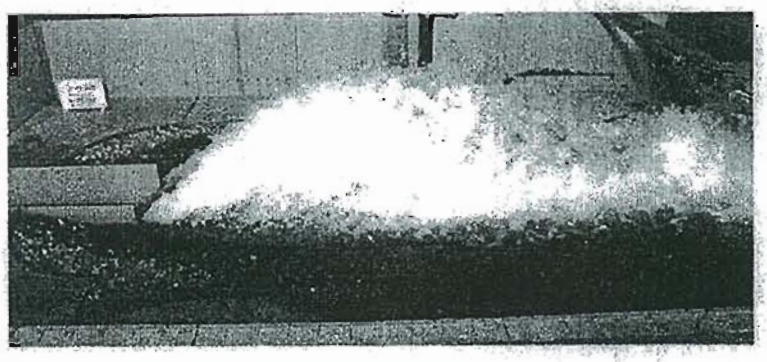
Figure 23.-Recommended exit channel and stilling basin operating



a. Q = 465 m³/s (16 500 ft³/s), no outlet works flow. Photo P801-D-79474

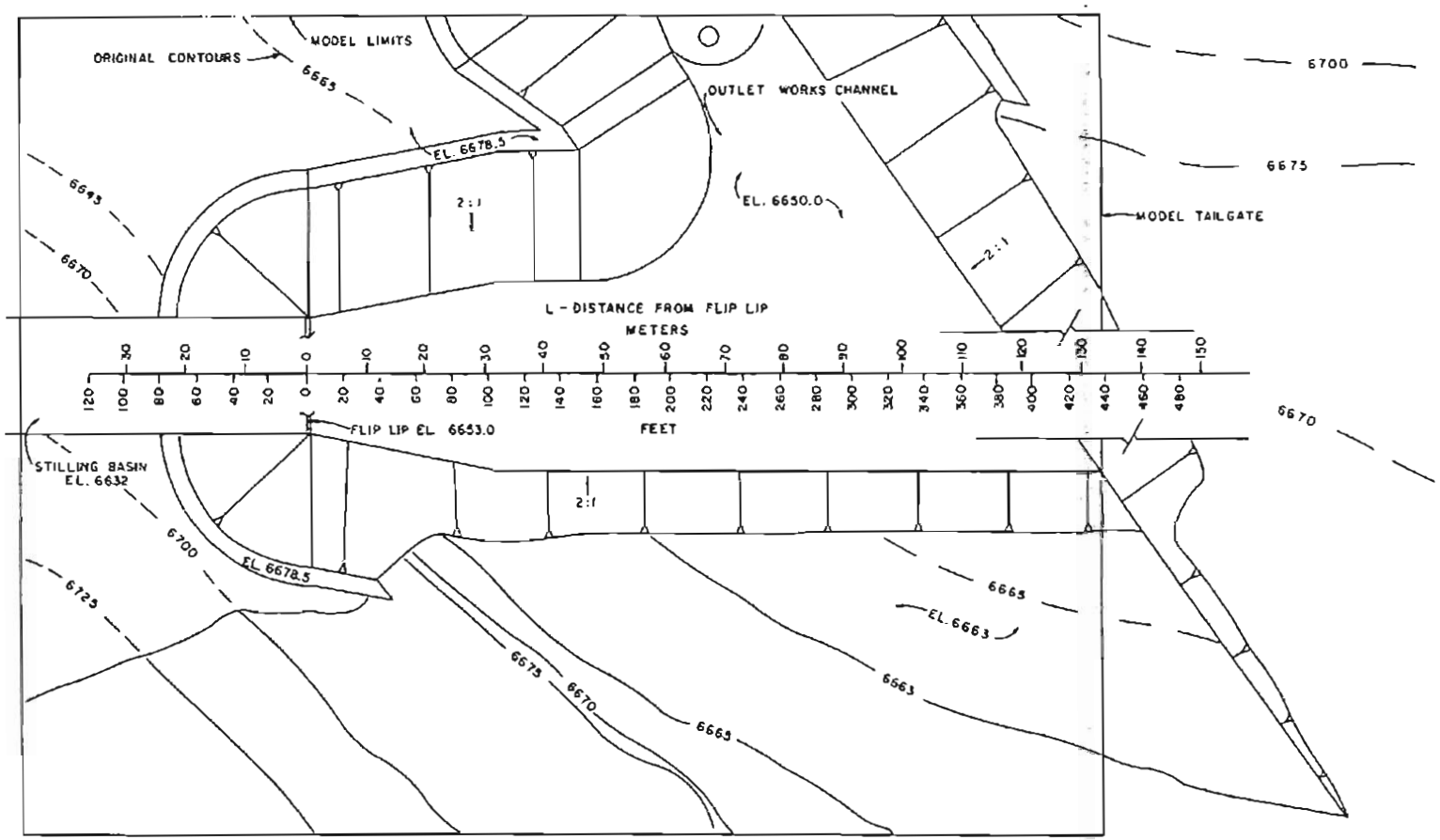


b. Q = 465 m³/s (16 500 ft³/s) with 150 m³/s (5260 ft³/s) outlet works flow. Photo P801-D-79475



c. Q = 940 m³/s (33 130 ft³/s) with 150 m³/s (5260 ft³/s) outlet works flow (inflow design flood). Photo P801-D-79476

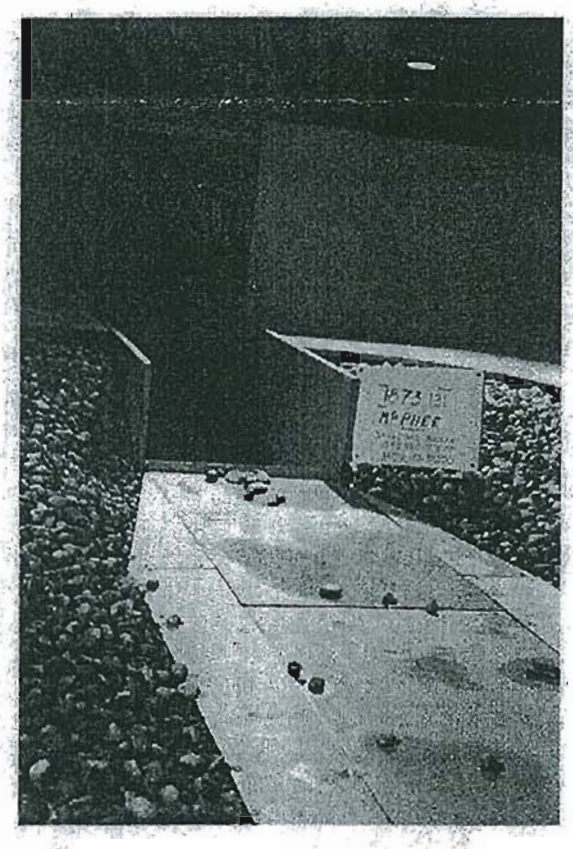
Figure 24.-Recommended stilling basin-flip bucket operating at sweepout flows



Notes:
1. All dimensions in prototype feet
2. All elevations in feet above mean sea level

Figure 25.—Plan of recommended exit channel

a. Debris placed in basin before stilling basin debris tests. Downstream view. Photo P801-D-79477



b. Location of debris after 45 minutes of model operation at Q = 140 m³/s (5000 ft³/s) (4.5 hours prototype time). Downstream view. Photo P801-D-79478

Figure 26.-Stilling basin debris tests. Sheet 1 of 2.

c. Location of debris after 45 minutes model operation at Q = 200 m³/s (7000 ft³/s). Note 75-mm rocks washed out and deposited downstream from the center of the flip lip. Photo P801-D-79479

d. Location of debris after 45 minutes of model operation at Q = 255 m³/s (9000 ft³/s). Most of the debris washed out and deposited in downstream channel. Photo P801-D-79480

Figure 26.-Stilling basin debris tests. Sheet 2 of 2.

GPO 831-366

United States Department of the Interior
BUREAU OF RECLAMATION

ENGINEERING AND RESEARCH CENTER

P O BOX 25007
BUILDING 67, DENVER FEDERAL CENTER
DENVER, COLORADO 80225

IN REPLY
REFER TO:

September 1, 1981

Memorandum

To: Recipients of GR-81-2

From: Chief, Technical Publications Branch

Subject: Correction to GR-81-2, Hydraulic Model Studies of McPhee Dam Spillway

The following correction should be noted and made to figure 26 located on pages 48 and 49:

(1) Transpose photographs a and c.
(2) Transpose photographs b and d.

Sorry for this inconvenience.

Warren Foote

RUBY DAM REHABILITATION
FEASIBILITY STUDY

Low Level Outlet Works Rehabilitation
Summary Report

Prepared for:

Montana Department of Natural Resources and Conservation

State Water Projects Bureau

Helena, MT

Prepared by:

HKM Engineering Inc.

P.O. Box 31318

Billings, MT 59107

January 2008

H:\08\M087175\Ruby Reports\Final\OutletWorks_0108.doc

TABLE OF CONTENTS

1.0 INTRODUCTION 1
2.0 EXISTING OUTLET WORKS STRUCTURE 2
2.1 Physical Characteristics 2
2.1.1 Outlet Conduit 2
2.1.2 Valve Shaft 3
2.1.3 Site Access 3
2.2 Hydraulic Characteristics 3
2.2.1 Butterfly Valve 4
2.2.2 Evaluation of Existing Outlet Works 4
3.0 OUTLET WORKS REHABILITATION ALTERNATIVES 5
3.1 Alternative OW1 6
3.2 Alternative OW2 8
3.3 Alternatives OW3 & OW4 9
3.3.1 Alternative OW3A 10
3.3.2 Alternative OW3B 11
3.3.3 Alternative OW3C 12
3.3.4 Alternative OW4 13
4.0 SUMMARY AND RECOMMENDATIONS 15
5.0 REFERENCES 16

LIST OF TABLES

Table 1 – Alternative OW3A Valve Costs 10
Table 2 – Alternative OW3B Valve Costs 12
Table 3 – Alternative OW3C Valve Costs 13
Table 4 – Alternative OW4 Valve Costs 14
Table 5 – Outlet Alternative Cost Estimates 15

LIST OF APPENDICES

Appendix A HKM Hydraulic Calculations
Appendix A1 Alternative OW1 Hydraulic Calculations
Appendix A2 Alternative OW2 Hydraulic Calculations
Appendix A3 Alternative OW3A Hydraulic Calculations
Appendix A4 Alternative OW3C Hydraulic Calculations
Appendix A5 Alternative OW4 Hydraulic Calculations
Appendix B Cost Estimates
Appendix B1 Alternative OW2 Cost Estimate
Appendix B2 Alternative OW3A Cost Estimate

Appendix B3 Alternative OW3C Cost Estimate
Appendix B4 Alternative OW4 Cost Estimate
Appendix C Drawings
Appendix C1 Alternative OW1 Drawings
Appendix C2 Alternative OW2 Drawings
Appendix C3 Alternative OW3A Drawings
Appendix C4 Alternative OW3C Drawings
Appendix C5 Alternative OW4 Drawings
Appendix D Falvey & Associates Ruby Dam Hydraulic Analysis
Appendix E MWH Ruby Dam Outlet Works Inspection Field Trip Report
Appendix F MWH Ruby Dam Outlet Works Rehabilitation Alternatives Investigation
Appendix G DNRC Ruby Dam Outlet Works Evaluation for Evacuating Ruby Reservoir

Ruby Dam Feasibility Study
Low Level Outlet Works Rehabilitation Summary Report

1.0 INTRODUCTION

The purpose of this report is to summarize the physical and hydraulic characteristics of the existing low level outlet works structure, and present outlet works rehabilitation alternatives and recommendations for the Ruby Dam Rehabilitation Feasibility Study. This report summarizes the existing characteristics of the outlet works, rehabilitation of the existing conduit tunnel, gate tower, valves, and the addition of an exit energy dissipation structure as discussed in the below mentioned reports prepared for HKM Engineering Inc. (HKM).

The hydraulic characteristics of the existing structure were evaluated in the report titled "Ruby Dam Hydraulic Analysis" by Henry T. Falvey & Associates, Inc. dated January 24, 2006. The "Ruby Dam Hydraulic Analysis" report is presented in Appendix D of this report.

MWH, Inc. (MWH) also prepared two reports regarding the outlet works. The first report discusses the outlet works inspection performed by Mike Morgan of MWH in December 2005 titled "Ruby Dam Outlet Works Inspection Field Trip Report". The second, "Ruby Dam Low Level Outlet Works Rehabilitation Alternatives Investigation", discusses several outlet works rehabilitation alternatives. These reports are presented in Appendices E and F, respectively.

The outlet works rehabilitation alternatives are based on meeting required discharge criteria at Ruby Dam. The original criteria established by Montana Department of Natural Resources and Conservation (DNRC) ranged from 20 to 1,500 cfs (between minimum winter discharge rates and the desired reservoir evacuation rate). After the original discharge criteria were established, DNRC prepared the "Ruby Dam Low-Level Outlet Works Evaluation for Evacuating Ruby Reservoir" (Evacuation Report), which reevaluated the discharge criteria for Ruby Dam. The Evacuation Report states that the rehabilitated outlet works shall provide a discharge rate of 1,010 cfs at reservoir elevation 5393.0 ft (top of existing flashboards), and a discharge rate of 1,100 cfs at reservoir elevation 5400.0 ft (preferred rehabilitation option spillway crest elevation). For the purpose of this report, the minimum discharge rate of 20 cfs will also be included in the design of the recommended alternative. A copy of the DNRC Evacuation Report is presented in Appendix G.

When the first draft of this Low Level Outlet Works Rehabilitation Alternatives Summary was composed (HKM, September 2006) the original discharge criteria ranging from 20 to 1,500 cfs were used to define several rehabilitation alternatives for the outlet works (Alternatives OW2, OW3A, and OW3C). The proposed configurations and hydraulic calculations for these three

alternatives have not been revised in this final report to account for the change in discharge criteria. Instead, an additional rehabilitation alternative (Alternative OW4) was created to satisfy the new discharge criteria and incorporate comments and recommendations provided by the DNRC while developing this report.

2.0 EXISTING OUTLET WORKS STRUCTURE

The existing low level outlet works structure at Ruby Dam does not meet discharge criteria defined by DNRC State Water Projects Bureau. This section contains discussion of the existing Ruby Dam outlet works physical and hydraulic characteristics. More details regarding the existing condition and hydraulics of the outlet works is presented in the reports in Appendices D, E and F.

2.1 PHYSICAL CHARACTERISTICS

Located near the left dam abutment, the existing low level outlet works structure consists of a 90-inch wide modified horseshoe concrete lined conduit tunnel approximately 635 ft in length. The conduit intake is constructed of concrete with a sloped trashrack and the outlet structure consists of a concrete apron that a discharges into a small outlet channel. The gate tower is composed of a vertical valve shaft, located in-line with the dam crest. The conduit invert is located at 5299 ft (NAVD88) at the location of the valves at the base of the gate tower; 111 ft below the existing dam crest elevation of 5410 ft. (MHW, 2006)

2.1.1 Outlet Conduit

The Ruby Dam outlet works conduit consists of a modified horseshoe concrete conduit. The modified horseshoe conduit has is 90-in wide with a rectangular bottom with a total height of 90-in. The majority of the conduit was constructed by tunneling through bedrock and then placing concrete inside the tunnel to form the conduit. The outlet works intake was constructed at an angle to the conduit and has converged walls with a sloped (approx. 45°) trashrack. The outlet conduit is approximately 385 ft long upstream of the valve tower and 215 ft long downstream of the valve tower. The outlet terminal structure consists of a concrete apron with diverging wing walls. A discharge channel is located downstream of the outlet; a Cipolleti weir used for flow measurement is located approximately 200 ft downstream of the outlet. The weir also creates a backwater pool that helps dissipate energy at the conduit outlet.

2.1.2 Valve Shaft

The existing valve shaft is located approximately 385 ft downstream of the conduit intake structure near the centerline of Ruby Dam. The valve shaft contains a 72-in maintenance wedge gate and a 72-in regulating butterfly value separated by a 2.5-ft steel spool piece. Both the wedge gate and regulating butterfly valve are approximately 75 years old. Both valves are operated from the gate tower by manual screw-stem hoists from an elevation near the top of the valve shaft. The maintenance gate valve is aerated through a small vent pipe with a shutoff valve located at the top of the bonnet above the valve. A 6-in diameter vent with shut off valve is located at the top of the conduit immediately downstream of the butterfly valve, which connects to an 8-ft high stand pipe in the valve shaft. Additional discussion on the outlet works can be found in the MWH reports contained in Appendices E and F.

2.1.3 Site Access

Vehicle access to the low-level outlet works is provided along an access road and bridge that approach the discharge area from downstream of the dam on the east side of the Ruby River. The access road bridge crosses the river channel approximately 600 feet below the spillway stilling basin and has not been designed to function during the design flood at Ruby Reservoir. Vehicle access to the gate house and top of the dam is currently provided through the area upstream of the spillway crest. The only other method to access the gate house and top of dam is by walking through the area upstream of the spillway crest or by walking up the downstream dam face from the toe of the dam where the downstream access road ends.

The existing access to the dam site has several limitations. In the event of a large flood the bridge providing access to the outlet works discharge area may be damaged or destroyed. The top of dam and gate house cannot be accessed from upstream of the spillway when storage in the reservoir is above an approximate elevation of 5388 feet or in the event of a storm. Storage in the reservoir is typically above this elevation for several months each year and, in all but two years on record, has been recorded above this elevation for at least one month in every year. When the reservoir is above 5388 feet, the only access to the top of dam is from the downstream bridge, which if damaged would leave watercraft as the only means to access the gate house; these methods would be dangerous during a flood or other emergency. Additionally, pedestrian access to the top of the dam may not be available from the outlet works access road in inclement weather.

2.2 HYDRAULIC CHARACTERISTICS

The purpose of evaluating the existing hydraulic characteristics of the Ruby Dam outlet works was to define the cavitation potential of larger flows, evaluate the need to replace the existing

butterfly valve with a configuration less susceptible to cavitation damage, and to determine additional venting requirements.

2.2.1 Butterfly Valve

Cavitation damage and evidence of cavitation repairs have previously been noted at several locations downstream of the regulating butterfly valve during annual inspections at Ruby Dam, and repair of cavitation damage is typically a regular maintenance item.

Cavitation damage can be predicted by comparing the cavitation index associated with a valve configuration with the incipient cavitation index. Cavitation associated with the butterfly valve can occur on the valve, in the downstream conduit, or on the shroud containing the operating arm of the valve. Damage from cavitation at these locations can be evaluated as a function of the percent valve opening or flowrate. If the cavitation index associated with a particular flow results in a value *less than* the incipient cavitation index, that flow can be expected to cause cavitation damage. Based on calculations presented in the report contained in Appendix D, cavitation indices with respect to damaging the shroud for all flows are below the incipient cavitation index for the valve; meaning cavitation damage to the shroud can be expected at all flows. Flows above 500 cfs are expected to cause cavitation damage to the valve itself and damage to the walls of the downstream conduit.

2.2.2 Evaluation of Existing Outlet Works

Hydraulic analysis of the flow at the butterfly valve is presented in Appendix D. This analysis showed that the flow momentum downstream of the valve is so great that the outlet conduit will not be submerged for any discharge, resulting in a large air demand for the valve. Assuming the downstream conduit is swept out and adequate aeration is provided, the theoretical maximum discharge for the outlet works is 1,895 cfs for a reservoir elevation of 5392 ft. If the butterfly valve is opened to 79 percent, a discharge of 1,500 cfs can be passed. These calculations were intended to provide the most conservative flows with respect to cavitation damage and assumed negative pressures were present at the valve outlet (not free discharge). The following coefficients were used in analysis of the butterfly valve:

- Inlet coefficient = 0.5
- Friction factor in the upstream and downstream horseshoe conduits = 0.012
- Loss coefficient across the valves = 0.08
- Exit loss coefficient = 0.8
- Butterfly valve coefficient of discharge = 6.28 (for fully open valve)

Based on results of this analysis, additional air venting should be provided at the butterfly valve to reduce the chance of cavitation damage to the downstream conduit; particularly for flows expected to cause cavitation damage to the butterfly valve (flows above 500 cfs). The size of an enlarged air vent can be determined from tests of the outlet; however, the vent should not be smaller than 12-inches in diameter. (Falvey, 2006)

HKM also performed hydraulic analysis on the existing outlet works system, assuming the downstream conduit is not submerged and adequate aeration is provided (free discharge). From this evaluation, the theoretical maximum discharge for the existing outlet works system is 1,270 cfs at a reservoir water surface elevation of 5393 ft (based on 72% of the total valve area representing effective flow to account for the stem and shroud), and is 1,320 cfs at a reservoir water surface elevation of 5400 ft. HKM calculations were intended to provide a conservatively low analysis with respect to the maximum discharge that can be expected through the existing system. The following coefficients were used in the HKM analysis:

- Inlet coefficient = 1.0
- Friction factor in the upstream and downstream horseshoe conduits = 0.021*
- Loss coefficient across the valves = 0.10
- Flow area reduction factor = 0.72
- Butterfly valve coefficient of discharge = 0.95 (for fully open valve)

*A friction factor of 0.021 was used in HKM calculations instead of a value of 0.012 used in the original hydraulic analysis (Falvey, 2006). This value was determined to be appropriate for use in a fully turbulent rough zone and was determined to be conservative. Dr. Falvey verified that this friction factor was reasonable under the project circumstances through correspondence with HKM following the issuing of his hydraulic analysis.

These computed discharge rates meet the discharge criteria set by DNRC. However substantial work is required to properly vent the valve to achieve these flowrates without causing cavitation damage. Documentation of coefficients used and a rating curve for the existing butterfly valve are included in Appendix A1 of this report.

3.0 OUTLET WORKS REHABILITATION ALTERNATIVES

Several outlet works configurations were considered to meet the large range of discharges required at Ruby Dam. Two alternatives were investigated with valve arrangements in the location of the existing regulating system in the valve shaft at the center of the dam. While these alternatives eliminate the need for lining of the downstream conduit, installing a new system in-line with the existing gate tower would also eliminate the possibility for future hydropower utilization. Three alternatives were considered with valve arrangements at the toe of the dam.

These alternatives include lining of the downstream conduit with a steel penstock which would accommodate the possibility of adding hydropower turbines in the future.

Incorporation of valves (butterfly valves, gate valves, and ball valves) with poor to fair regulatory characteristics in conjunction with smaller well regulated valves was considered for the purpose of releasing high flows while still meeting the minimum 20 cfs discharge requirement. After brief consideration, use of these valves was determined to be economically impractical because little to no energy dissipation would be provided in conjunction with mediocre regulatory characteristics. Standard gate valves are not designed to handle large flow velocities, and large diameter ball valves (capable of supporting high flowrates and velocities) are comparable in cost to valves with much better regulatory capability (such as jet flow gates).

Following this preliminary screening, five alternatives were considered for further evaluation to upgrade the existing outlet works. Outlet works rehabilitation alternatives are summarized below and Alternatives OW1, OW2, OW3A, and OW3C are discussed in detail in the MWH report in Appendix F. Alternative OW4 was developed after completion of the MWH report in Appendix F, and was designed to meet reduced discharge criteria established in the "Ruby Dam Low-Level Outlet Works Evaluation for Evacuating Ruby Reservoir" (Appendix G). Alternative OW4 also incorporates comments and recommendations which were provided by DNRC during development of this report. Hydraulic calculations for each alternative are presented in Appendix A, cost estimates for alternatives are in Appendix B, and preliminary drawings are included in Appendix C. All alternatives utilize the existing maintenance wedge gate, valve tower, and gate house to provide upstream control for maintenance of the regulatory system.

3.1 ALTERNATIVE OW1

Design considerations for Alternative OW1 are discussed in this section. This alternative involves rehabilitation of the existing flow regulation system for the outlet works. Main items of work associated with the rehabilitation of the existing flow regulation system of Alternative OW1 include:

- Rehabilitation of the existing butterfly valve;
- Construction of a larger air vent downstream of the butterfly valve;
- Reshaping of the stem shroud to reduce cavitation potential;
- Inspect and rehabilitate existing valve hoists as needed;
- Rehabilitation of the exposed portions of the conduit within the valve shaft;
- Stem packing replacement on the maintenance wedge gate; and
- Improvements to existing valve shaft sump (jet pump).

According to HKM calculations presented in Appendix A1, the rehabilitated existing valve system has the ability to pass up to 1,320 cfs with adequate ventilation and the reservoir water surface at the proposed spillway crest elevation of 5400 ft, which satisfies discharge criteria. Hydraulic calculations for Alternative OW1 include losses from the conduit entrance, friction losses through the upstream conduit, losses through the 6-foot gate valve located at the center of the dam, and exit losses. A flow of this magnitude would introduce a significant increase in forces on the valve, resulting in a need for thorough inspection and non-destructive testing prior to selection of this alternative to verify the existing valve could withstand the greater forces.

Alternative OW1 would include the following modifications to the outlet works terminal structure:

- Concrete outlet extension chute providing some energy dissipation, maintenance access, and ventilation. The structure would be 30 ft in length, with a 10-ft square cross section.
- Concrete stilling basin, designed according to USBR standards for normal maximum flow of 600 cfs. The structure would be approximately 50 ft in length, 10 ft wide, with the outlet sill at El. 5298 and the top of basin walls at El. 5312.

This Alternative also includes providing vehicle access to the dam tower and outlet works flow regulation controls. Currently, the dam tower and gate controls are inaccessible by vehicle when the reservoir pool is above approximate El. 5386. Access would be provided with the construction of an access road consisting of a bridge over the rehabilitated spillway crest.

Currently, the butterfly valve is in fair condition and the downstream portion of the valve frame is considered to be in poor condition. The potential unknowns associated with rehabilitation of the valve would demand a large contingency and could impact the construction schedule if additional problems are identified in the valve (e.g. cracking) during rehabilitation which would require replacement and the lead time for a replacement valve is several months. Modification of the stem shroud would be a difficult repair since the valve is of cast iron. With the present shroud arrangement, cavitation repairs will continue to be required. The confined area within the valve shaft would also make any in-situ repairs very difficult.

Based on the age of the regulating valve, the uncommon use of a butterfly valve in this configuration for flow regulation, the summation of potential construction and maintenance problems, the flow obstruction caused by the valve shroud and stem, and the existing system's inability to reliably meet maximum flow requirements without modifications; Alternative OW1 is not considered a viable long-term rehabilitation solution. Because OW1 was not considered a viable rehabilitation option, a cost estimate for Alternative OW1 was not produced however drawings for Alternative OW1 are included in Appendix C1.

3.2 ALTERNATIVE OW2

Alternative OW2 involves the replacement of the existing regulating butterfly valve with a new 66-inch jet flow gate in-line with the gate tower. Main items of work associated with Alternative OW2 include:

- Design and installation of a new jet flow gate and operating system (a sectionalized design may be required for installation through the existing valve shaft);
- Removal of the existing butterfly valve;
- Rehabilitation and modification of existing conduit to interface with new gate;
- Construction of a large air vent to aerate flow;
- Inspect and upgrade existing maintenance gate valve hoist as needed;
- Rehabilitation of the exposed portions of the existing conduit;
- Stem packing replacement on the maintenance wedge gate;
- Improvements to existing valve shaft sump (jet pump); and
- Removing the Cipolleti weir and regrading outlet channel may be required.

Alternative OW2 has the ability to pass up to 1,340 cfs (reservoir water surface at 5400 ft) with adequate ventilation. Hydraulic calculations for Alternative OW2 include losses from the conduit entrance, friction losses through the upstream conduit, losses through the 6-foot gate valve located at the center of the dam, and exit losses. A rating curve for this alternative along with hydraulic calculations is presented in Appendix A2. An option for OW2 would be to use a smaller (60-inch) JFG instead of a 66-inch, which would decrease the capacity and may ease installation which would decrease the construction time and cost of this alternative.

Alternative OW2 would include the following modifications to the outlet works terminal structure:

- Concrete outlet extension chute providing some energy dissipation, maintenance access, and ventilation. The structure would be 30 ft in length, with a 10-ft square cross section.
- Concrete stilling basin, designed according to USBR standards for normal maximum flow of 600 cfs. The structure would be approximately 50 ft in length, 10 ft wide, with the outlet sill at El. 5298 and the top of basin walls at El. 5312.

Alternative OW2 also includes providing vehicle access to the dam tower and outlet works flow regulation controls. As mentioned under Alternative OW1, the dam tower and gate controls are often inaccessible by vehicle. Access during flooding would need to be provided by constructing an access road and bridge over the spillway crest.

This alternative offers a superior means of flow regulation and little maintenance complication when compared to Alternative OW1. Alternative OW2 would incorporate a similar terminal structure to OW1. The additional cost of a sectionalized gate design and installation may be substantial ($665,000 for specialized design, fabrication, and delivery).

In addition to installation difficulties and increased cost associated with a specialized sectionalized design, placing a new gate in-line with the existing gate tower would also eliminate the possibility for hydropower utilization in the future. Cost estimates and drawings for Alternative OW2 are presented in Appendix B1 and C2, respectively.

3.3 ALTERNATIVES OW3 & OW4

Design considerations for Alternatives OW3A, OW3B, OW3C, and OW4 are discussed in the following sections. These alternatives involve the addition of a steel penstock so the existing regulating butterfly valve can be replaced with new regulating valves at the toe of the dam. Four different discharge valve systems were considered as part of Alternatives OW3 and OW4.

All discharge valve systems incorporate removal of the existing butterfly valve and the addition of a 72-in diameter steel penstock to be installed into the existing outlet tunnel. The penstock would be approximately 250 ft in length and would mate with the existing 72-in pipe immediately downstream of the existing maintenance gate valve. Penstock installation would involve sections approximately 50 ft in length to be pushed or pulled into the existing conduit with each joint welded prior to being drawn into the tunnel. At a minimum, the bottom third of the tunnel would be grouted after installation for support, which would require accommodation for drainage around the perimeter of the tunnel. Based on information provided by MWH the penstock for Alternatives OW3 & OW4 would cost approximately $300,000, not including valve outlet bifurcations or the outlet terminal structure.

All regulating discharge valve arrangements will require providing vehicle access to the valve control building and outlet works flow regulation controls at the toe of the dam. Access to the control building would be provided with construction of a vehicle bridge over the Ruby River downstream of the outlet channel and an access road over the proposed concrete outlet extension. This downstream bridge would only be designed for a 100-yr flood event due to the high costs of designing a bridge for a larger flood event. Emergency access during floods would be provided with the construction of a pedestrian bridge over the spillway crest. This bridge will allow pedestrian/ATV access to the dam crest and pedestrian access to the dam toe for valve operation. The emergency access bridge is required because flooding of downstream areas during large spillway flows would prevent access to the vehicle bridge.

The discharge valve systems associated with each OW3 & OW4 Alternative are discussed in the following sections. Maximum flow rates based on 45 ft of effective head at the valve were computed for each OW3 Alternative valve system by MWH and are included in their report presented in Appendix F. HKM performed hydraulic calculations for Alternatives OW3A, OW3C, and OW4 based on a reservoir water surface at the proposed spillway crest elevation of 5400 ft (presented in Appendix A3, A4, and A5, respectively); accounting for system losses through the intake, conduit, penstock, joints, and valves. Detailed hydraulic calculations were not performed for Alternative OW3B because the relatively high cost associated with the proposed valve arrangement removed this option from consideration for rehabilitation.

3.3.1 Alternative OW3A

Alternative OW3A consists of the addition of a steel penstock and an arrangement of three fixed cone valves (FCV), one 24-inch and two 54-inch diameter valves near the dam toe. FCVs are also known as Howell-Bunger valves. Discharge ranges and approximate fabrication and delivery cost of these valves are presented in Table 1 (see Appendix B3 for a more detailed cost estimate). This three valve combination allows minimum flows to be passed through the 24-in valve and the two larger valves provide redundancy in the event maintenance must be performed. All valves discharging together could pass a maximum discharge of 1,385 cfs. Hydraulic calculations for Alternative OW3A include losses from the conduit entrance, friction losses through the upstream conduit, losses through the 6-foot gate valve located at the center of the dam, friction losses through the downstream conduit, and exit losses.

TABLE 1 – ALTERNATIVE OW3A VALVE COSTS

Valve Type and Size	Minimum Recommended Discharge	Max. Discharge @ Preferred Alternative Spillway Crest	Approximate Fabrication and Delivery Cost
1 - 24 in. FCV	15 cfs	125 cfs	$90,000
2 - 54 in. FCV	70 cfs	630 cfs (each)	$265,000 (each)
TOTAL DISCHARGE CAPACITY & COST		**1,385 cfs**	**$620,000**

NOTE: Maximum discharges reported from HKM calculations.

Bifurcation piping would connect with the end of the 72-in diameter penstock to divide the flow into the three valves. The 24-inch valve would be the central valve, aligned horizontally with the conduit and penstock with a centerline elevation of 5297.75. The two 54-inch valves would be placed on each side of the 24-inch valve with a centerline elevation of 5301.5.

Alternative OW3A would include the following modifications to the outlet works terminal structure:

- Concrete outlet extension providing a base for new access roadway. The structure would be approximately 35 ft in length, with the same cross section as the conduit and penstock.
- Concrete encased stainless steel energy dissipation sleeve for each valve. Sleeves were designed with a diameter and length of three and five times the valve diameter, respectively.
- New control building, aligned on top of the proposed piping bifurcations and stilling basin.

Because standard FCVs are intended for free discharge (rather than submerged discharge), design measures have been taken to prevent the outlet from becoming submerged. The existing channel will be lowered approximately 8 ft at the outlet of the proposed stilling basin to prevent submergence.

The arrangement proposed for Alternative OW3A provides a desirable redundancy, because one 54-in valve meets typical discharge rates for Ruby Dam. The maintenance gate upstream could be used to shut down the system while a valve is removed for maintenance and replaced with a blind flange. When the valve is being repaired, the other valves could be used to discharge flows, limiting the downtime associated with maintenance.

Because Alternative OW3A requires dissipation sleeves for each valve (total cost estimated at $131,000) and added excavation to lower the channel alignment below the structure (addition cost of $34,000), this additional cost and the complicated 3-valve layout may make this alternative less desirable than others. Cost estimates and drawings for Alternative OW3A are presented in Appendix B2 and C3, respectively.

3.3.2 Alternative OW3B

Alternative OW3B consists of the addition of a steel penstock and an arrangement of three sleeve valves (SV) to pass the required discharge range. Approximate cost of these valves is presented in Table 2. The size and arrangement of SVs presented below was determined based on calculations performed by MWH (presented in Appendix F) and on the assumption of 94 ft of effective head at the valves.

TABLE 2 – ALTERNATIVE OW3B VALVE COSTS	
Valve Type and Size	Approximate Fabrication and Delivery Cost
1 - 24 in. Sleeve Valve	$130,000
2 - 60 in. Sleeve Valve	$335,000 (each)
TOTAL VALVE COST	**$800,000**

As with Alternative OW3A, incorporating two 60-in SVs offers a desirable redundancy and could facilitate future maintenance needs. One 60-in SV meets the typical outflows at Ruby Dam and could function singularly if there is a need for repair of the other valves.

Alternative OW3B could be a preferred discharge arrangement if space is limited for a large energy dissipation structure or submerged discharge is preferred. (MWH, 2006) The discharge jet from SVs would provide enough energy dissipation to minimize the size of an outlet energy dissipation structure and eliminate the need for dissipation sleeves over each valve.

It was determined that Alternative OW3B was not a viable option because the high costs associated with the valves alone do not compensate for the cost savings of eliminating an energy dissipation structure. Detailed cost estimates and drawings were not prepared for Alternative OW3B.

3.3.3 Alternative OW3C

Alternative OW3C consists of the addition of a 72-in diameter steel penstock and installation of one 72-in jet flow gate (JFG) at the toe of the dam. The maximum discharge of a 72-in JFG installed at the toe of the dam is 1,405 cfs (reservoir water surface at 5400 ft). Because a 72-in JFG is not recommended to function at low discharges for long periods of time, a secondary valve would also be incorporated into this alternative to meet the minimum discharge criteria. Table 3 provides the approximate fabrication and delivery cost for the 72-in valve (see Appendix B4 for a more detailed cost estimate). Hydraulic calculations for Alternative OW3C include losses from the conduit entrance, friction losses through the upstream conduit, losses through the 6-foot gate valve located at the center of the dam, friction losses through the downstream conduit, and exit losses. Hydraulic calculations in Appendix A4 do not account for the secondary valve as it is not anticipated that this valve will be used other than to meet minimum discharge rates.

TABLE 3 – ALTERNATIVE OW3C VALVE COSTS		
Valve Type and Size	Max. Discharge @ Preferred Alternative Spillway Crest	Approximate Fabrication and Delivery Cost
1 - 72-inch JFG	1,405 cfs	$350,000
TOTAL DISCHARGE CAPACITY & COST	**1,405 cfs**	**$350,000**

NOTE: Maximum discharges reported from HKM calculations

Bifurcation piping would mate with the end of the 6-ft penstock to divide the flow into the two valves. The 72-in valve would be aligned horizontally and vertically with the conduit and penstock at a centerline elevation of 5301.5 with bifurcation piping to the secondary valve placed to one side of the large valve with the same centerline elevation.

Alternative OW3C would include the following modifications to the outlet works terminal structure:

- Concrete outlet extension providing a base for new access roadway. The structure would be approximately 35 ft in length, with the same cross section as the conduit and penstock.
- Concrete expansion chamber. This structure would be approximately 25 ft in length and would distribute flows into the stilling basin.
- New control building, aligned on top of the piping bifurcations and expansion chamber.

Alternative OW3C is desirable because JFGs function well under submerged conditions, alleviating the need for major realignment of the existing channel (unlike Alternative OW3A). Cost estimates and drawings for Alternative OW3C are presented in Appendix B3 and C4, respectively.

3.3.4 Alternative OW4

Alternative OW4 is very similar to Alternative OW3C and was developed to meet reduced discharge criteria established in the DNRC Evacuation Report and to incorporate comments and recommendations provided by DNRC while developing this report. Alternative OW4 consists of the addition of a steel penstock and installation of one 60-in JFG at the toe of the dam. The maximum discharge of a 60-in JFG installed at the toe of the dam is 1,110 cfs (reservoir water surface at 5400 ft), which meets the DNRC maximum discharge criteria of 1,100 cfs. JFGs have a large air demand at partial gate openings which if not met can cause damage to the valve seat. To prevent damage to the large and expensive JFG a secondary valve could be incorporated into this alternative to meet minimum discharge criteria. The secondary valve would consist of an

18-in bonneted gate valve or similar valve. Table 4 provides the approximate fabrication and delivery cost for the 60-in JFG and the secondary valve (see Appendix B5 for a more detailed cost estimate). Hydraulic calculations for Alternative OW4 include losses from the conduit entrance, friction losses through the upstream conduit, losses through the 6-foot gate valve located at the center of the dam, friction losses through the downstream conduit, and exit losses. Hydraulic calculations in Appendix A5 for the maximum capacity do not account for the secondary valve as it is not anticipated that this valve will be used other than to meet minimum discharge rates.

TABLE 4 – ALTERNATIVE OW4 VALVE COSTS		
Valve Type and Size	Max. Discharge @ Preferred Alternative Spillway Crest	Approximate Fabrication and Delivery Cost
1 - 18-inch Gate Valve	Not Computed	$6,000
1 - 60-inch JFG	1,110 cfs	$265,000
TOTAL DISCHARGE CAPACITY & COST	**1,110 cfs**	**$271,000**

NOTE: Maximum discharges reported from HKM calculations

Bifurcation piping for the secondary valve would join with the 72-in penstock upstream of the flange for the JFG. The 60-in JFG would be aligned with the conduit and penstock at a centerline elevation of 5301.5 with bifurcation piping to the 18-inch secondary gate valve placed to one side of the large valve.

The outlet terminal structure for Alternative OW4 consists of a 12-ft wide by 8-ft high concrete box that extends approximately 40 feet downstream of the JFG. A large air vent is located in the concrete extension. Additional air vents closer to the valve maybe required depending on the final design of the valve alignment. A stilling basin was designed for the end of the extension. The stilling basin was designed as a USBR Type VI basin which is also known as an impact basin. Calculations for sizing of the stilling basin are included with the hydraulic calculations for Alternative OW4 in Appendix A5.

Alternative OW4 is desirable because JFGs function well under submerged conditions (eliminating the need for major realignment of the existing channel), the cost of this alternative is significantly less than other valve arrangements, and this valve arrangement has high regulatory characteristics in comparison to the existing system or to a system with fixed cone valves. Cost estimates and drawings for Alternative OW4 are presented in Appendix B4 and C5, respectively.

4.0 SUMMARY AND RECOMMENDATIONS

HKM recommends that Alternative OW4 be considered as the preferred alternative for rehabilitation of the Ruby Dam outlet works. In comparison with other alternatives, Alternative OW4 offers better regulatory characteristics, a valve arrangement that can function under submerged conditions, a cost significantly less than the other valve arrangements, and allows for the possibility of future hydropower adaptation. The complete cost estimates for outlet alternatives that were considered acceptable for rehabilitation are summarized in Table 5. The details for these estimates are included in Appendix B, and they include costs for valves and piping, materials installation, outlet and stilling basin structures, and bridge and road access.

TABLE 5 – OUTLET ALTERNATIVE COST ESTIMATES

Outlet Rehabilitation Alternative	Max. Discharge @ Elevation 5400 ft	Estimated Rehabilitation Cost
OW2	1,340 cfs	$1,717,719
OW3A	1,385 cfs	$2,298.373
OW3C	1,405 cfs	$1,623,075
OW4	1,110 cfs	$1,282,269

5.0 REFERENCES

Falvey, Henry T. "Ruby Dam Hydraulic Analysis". Henry T. Falvey & Associates, Inc. Conifer, CO 80433. January 24, 2006.

HKM Engineering, Inc. "Ruby Dam Rehabilitation Feasibility Study; Low Level Outlet Works Rehabilitation Summary Report." September 2006.

Montana Department of Natural Resources and Conservation, State Water Projects Bureau. "Ruby Dam Low-Level Outlet Works Evaluation for Evacuating Ruby Reservoir. March, 2007.

Morgan, Mike. "Ruby Dam Outlet Works Inspection Field Trip Report". MWH. Denver, CO 80202. December 1, 2005.

MWH. "Ruby Dam Low Level Outlet Works Rehabilitation Alternatives Investigation". MWH. Denver, CO 80202. 2006.

Peterka, A.J. "Hydraulic Design of Stilling Basins and Energy Dissipators". United States Department of the Interior; Bureau of Reclamation. Denver, CO. 1978.

APPENDIX A

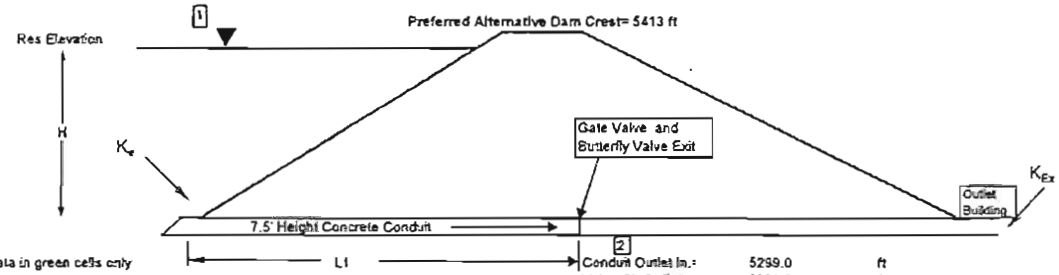
HKM HYDRAULIC CALCULATIONS

APPENDIX A1

ALTERNATIVE OW1 HYDRAULIC CALCULATIONS

HKM Engineering
Ruby Dam Feasibility
08M087.175
Existing Butterfly Valve Maximum Capacity (72" Valve; 60" Effective Diameter)

ALTERNATIVE OW1



- Enter data in green cells only

Conduit Outlet In.= 5299.0 ft
Valve CL Outlet= 5302.0 ft

Darcy-Weisbach Equation

$$h_f = f\frac{L}{D}\frac{v^2}{2g}$$

Friction Loss Coefficients for 7.5' Horseshoe

ε/D_F =	0.001250	Relative Roughness
f_F =	0.021	Friction Factor

~~Friction Loss Coefficients for 6' Penstock~~

~~ε/D_P =~~	~~0.0000833~~	~~Relative Roughness~~
~~f_P =~~	~~0.009~~	~~Friction Factor~~

Loss Coefficients for 7.5' Horseshoe

K_{ent} =	1.00	Entrance & Trashrack
K_{gate} =	0.10	Gate Valve

~~Loss Coefficients for 6' Penstock~~

~~K_e =~~	~~0.00~~	~~Contraction at Penstock End~~

Loss Coefficients for Butterfly Valve

C_{eff} =	0.72	% Reduction in Effective Flow
C_d =	0.95	Butterfly Discharge Coefficient

7.5' Concrete Horseshoe

L =	385.0	ft
Hyd. Diam ($4*R_h$) =	7.50	ft
A =	50.21	ft^2
A_{gate} =	28.27	ft^2

~~6' Steel Penstock~~

~~L =~~	~~0.0~~	~~ft~~
~~ID =~~	~~6.00~~	~~ft~~
~~A =~~	~~28.27~~	~~ft^2~~

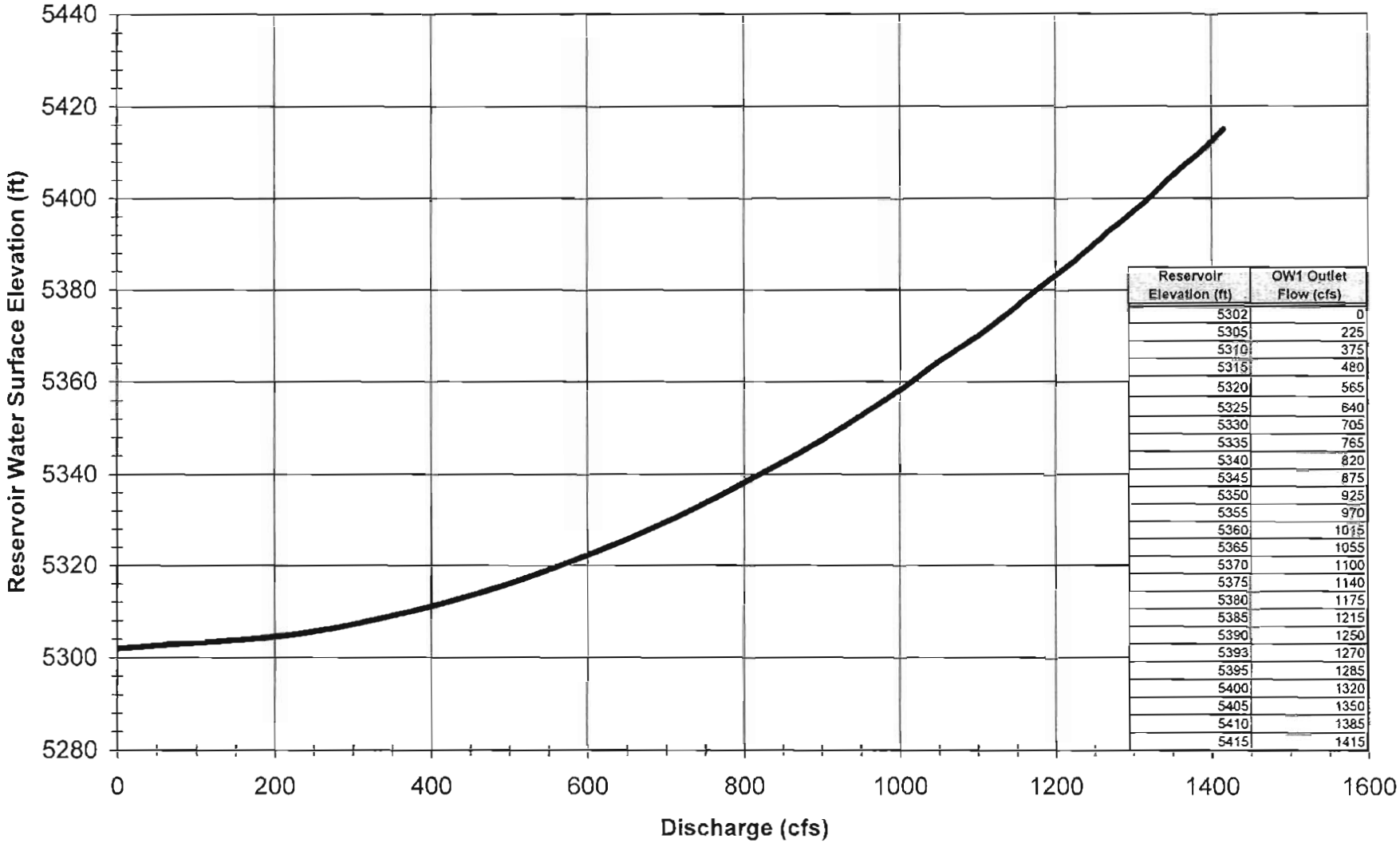
Butterfly Valve

ID =	6.00	ft
A =	28.27	ft^2
A_{eff} =	20.36	ft^2

Flowrate (cfs)	8' Conduit Velocity (ft/s)	h_{vf} (ft)	8' Conduit Friction Loss (ft)	Conduit Entrance Losses (ft)	6' Gate Valve Velocity (ft/s)	h_{vGate} (ft)	Gate Valve Minor Losses (ft)	~~6' Penstock Velocity (ft/s)~~	h_{vP} (ft)	~~6' Penstock Friction Loss (ft)~~	~~Penstock Minor Losses (ft)~~	Total Head Loss Prior to Valve (ft)	Butterfly Valve Velocity (ft/s)	Butterfly Valve h_{vB} (ft)	Required Head at Valve (ft)	Req. Water Depth Above 5302 (ft)	Reservoir W.S. Elevation
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	~~0.00~~	~~0.00~~	~~0.00~~	~~0.00~~	0.00	0.00	0.00	0.00	0.0	5302.0
100.0	1.99	0.06	0.07	0.06	3.54	0.19	0.02	~~2.54~~	~~0.19~~	~~0.00~~	~~0.00~~	0.15	4.91	0.37	0.42	0.6	5302.6
200.0	3.98	0.25	0.27	0.25	7.07	0.78	0.08	~~7.07~~	~~0.78~~	~~0.00~~	~~0.00~~	0.59	9.82	1.50	1.66	2.3	5304.3
300.0	5.97	0.55	0.60	0.55	10.61	1.75	0.17	~~10.61~~	~~1.75~~	~~0.00~~	~~0.00~~	1.33	14.74	3.37	3.74	5.1	5307.1
400.0	7.97	0.99	1.06	0.99	14.15	3.11	0.31	~~14.15~~	~~3.11~~	~~0.00~~	~~0.00~~	2.36	19.65	5.99	6.64	9.0	5311.0
500.0	9.96	1.54	1.66	1.54	17.68	4.86	0.49	~~17.68~~	~~4.86~~	~~0.00~~	~~0.00~~	3.68	24.56	9.37	10.38	14.1	5316.1
600.0	11.95	2.22	2.39	2.22	21.22	6.99	0.70	~~21.22~~	~~6.99~~	~~0.00~~	~~0.00~~	5.31	29.47	13.49	14.95	20.3	5322.3
700.0	13.94	3.02	3.25	3.02	24.76	9.52	0.95	~~24.76~~	~~9.52~~	~~0.00~~	~~0.00~~	7.22	34.39	18.36	20.34	27.6	5329.6
800.0	15.93	3.94	4.25	3.94	28.29	12.43	1.24	~~28.29~~	~~12.43~~	~~0.00~~	~~0.00~~	9.43	39.30	23.98	26.57	36.0	5338.0
900.0	17.92	4.99	5.38	4.99	31.83	15.73	1.57	~~31.83~~	~~15.73~~	~~0.00~~	~~0.00~~	11.94	44.21	30.35	33.63	45.6	5347.6
1000.0	19.91	6.16	6.64	6.16	35.37	19.42	1.94	~~35.37~~	~~19.42~~	~~0.00~~	~~0.00~~	14.74	49.12	37.47	41.52	56.3	5358.3
1100.0	21.91	7.45	8.03	7.45	38.90	23.50	2.35	~~38.90~~	~~23.50~~	~~0.00~~	~~0.00~~	17.83	54.03	45.34	50.23	68.1	5370.1
1200.0	23.90	8.87	9.56	8.87	42.44	27.97	2.80	~~42.44~~	~~27.97~~	~~0.00~~	~~0.00~~	21.22	58.95	53.95	59.78	81.0	5383.0
1300.0	25.89	10.41	11.22	10.41	45.98	32.83	3.28	~~45.98~~	~~32.83~~	~~0.00~~	~~0.00~~	24.91	63.86	63.32	70.16	95.1	5397.1
1400.0	27.88	12.07	13.01	12.07	49.51	38.07	3.81	~~49.51~~	~~38.07~~	~~0.00~~	~~0.00~~	28.89	68.77	73.44	81.37	*110.3*	*5412.3*
1500.0	29.87	13.86	14.94	13.86	53.05	43.70	4.37	~~53.05~~	~~43.70~~	~~0.00~~	~~0.00~~	33.16	73.68	84.30	93.41	*126.6*	*5428.6*
1600.0	31.86	15.77	17.00	15.77	56.59	49.72	4.97	~~56.59~~	~~49.72~~	~~0.00~~	~~0.00~~	37.73	78.60	95.92	106.28	*144.0*	*5446.0*
1700.0	33.86	17.80	19.19	17.80	60.13	56.13	5.61	~~60.13~~	~~56.13~~	~~0.00~~	~~0.00~~	42.60	83.51	108.28	119.98	*162.6*	*5464.6*
1800.0	35.85	19.95	21.51	19.95	63.66	62.93	6.29	~~63.66~~	~~62.93~~	~~0.00~~	~~0.00~~	47.76	88.42	121.40	134.51	*182.3*	*5484.3*
1900.0	37.84	22.23	23.97	22.23	67.20	70.12	7.01	~~67.20~~	~~70.12~~	~~0.00~~	~~0.00~~	53.21	93.33	135.26	149.87	*203.1*	*5505.1*
2000.0	39.83	24.63	26.55	24.63	70.74	77.69	7.77	~~70.74~~	~~77.69~~	~~0.00~~	~~0.00~~	58.96	98.24	149.87	166.06	*225.0*	*5527.0*

Figure 1A

Outlet Works Rating Curve - Alternative OW1 (Existing Butterfly Valve)



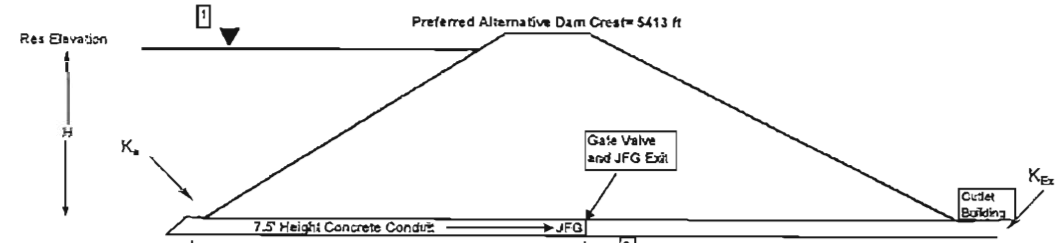
Reservoir Elevation (ft)	OW1 Outlet Flow (cfs)
5302	0
5305	225
5310	375
5315	480
5320	565
5325	640
5330	705
5335	765
5340	820
5345	875
5350	925
5355	970
5360	1015
5365	1055
5370	1100
5375	1140
5380	1175
5385	1215
5390	1250
5393	1270
5395	1285
5400	1320
5405	1350
5410	1385
5415	1415

APPENDIX A2

ALTERNATIVE OW2 HYDRAULIC CALCULATIONS

HKM Engineering
Ruby Dam Feasibility
08M087.175
JFG Maximum Capacity (66" Valve at Dam CL)

ALTERNATIVE OW2



- Enter data in green cells only

Pipe Outlet Inv	5299.0	ft
Pipe CL Outlet	5302.0	ft

Darcy-Weisbach Equation

$$h_f = f\frac{L}{D}\frac{v^2}{2g}$$

Friction Loss Coefficients for 7.5' Horseshoe

ε/D_F =	0.001250	Relative Roughness
f_F =	0.021	Friction Factor

~~Friction Loss Coefficients for 6" Penstock~~

~~ε/D_P =~~	~~0.0000188~~	~~Relative Roughness~~
~~f_P =~~	~~0.009~~	~~Friction Factor~~

Loss Coefficients for 7.5' Horseshoe

K_{ent} =	1.00	Entrance & Trashrack
K_{gate} =	0.10	Gate Valve

~~Loss Coefficients for 6" Penstock~~

~~K_e =~~	~~0.00~~	~~Contraction from Penstock to JFG~~

Loss Coefficients for Jet Flow Valve

C_d =	0.83	JFG Discharge Coefficient

7.5' Concrete Horseshoe

L =	385.0	ft
Hyd. Diam ($4*R_h$) =	7.50	ft
A =	50.21	ft^2
A_{gate} =	28.27	ft^2

~~6" Steel Penstock~~

~~L =~~	~~0.0~~	~~ft~~
~~ID =~~	~~6.00~~	~~ft~~
~~A =~~	~~28.27~~	~~ft^2~~

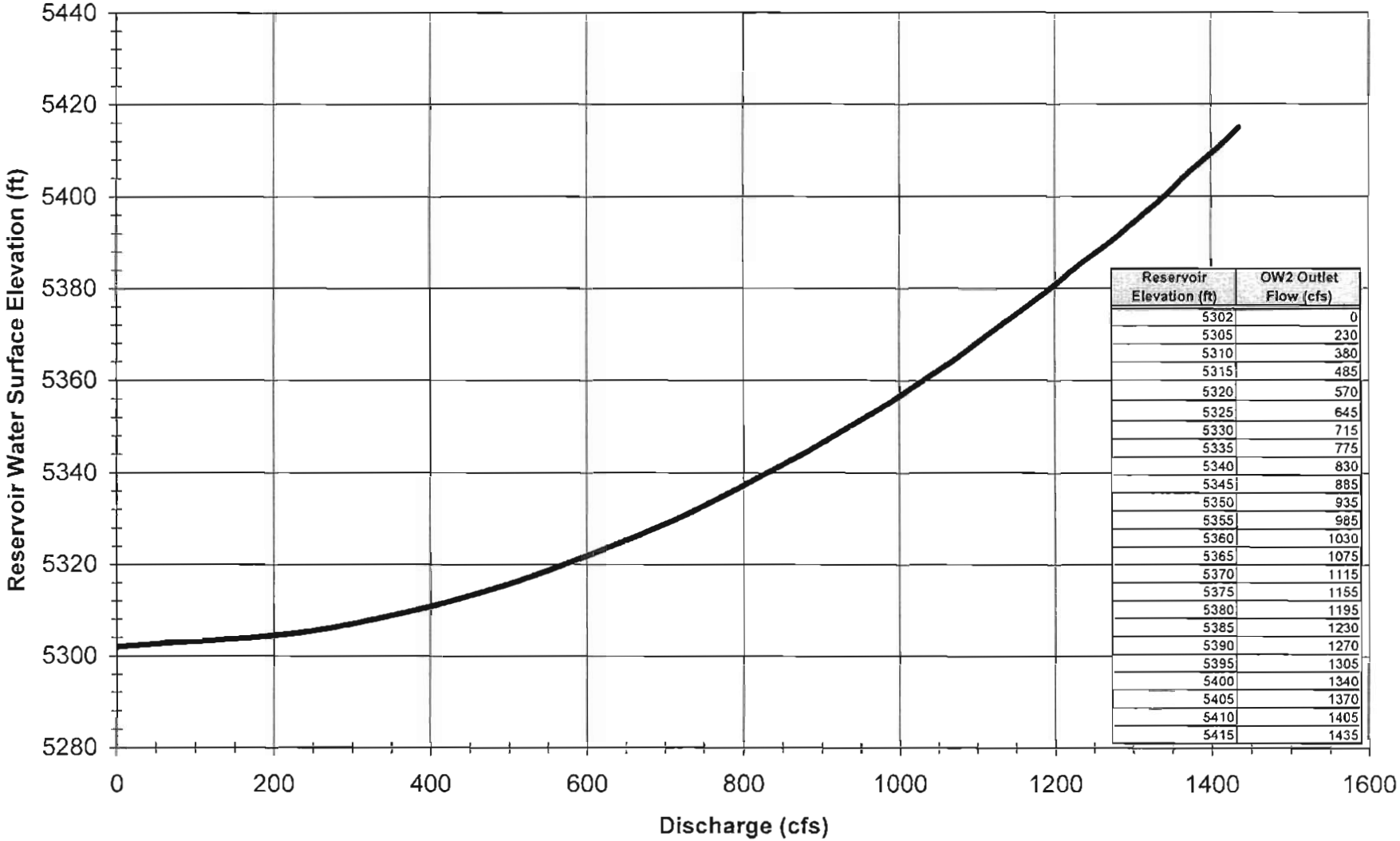
Jet Flow Valve (JFV)

ID =	5.50	ft
A =	23.76	ft^2

Flowrate (cfs)	8' Conduit Velocity (ft/s)	h_{vel} (ft)	8' Conduit Friction Loss (ft)	Conduit Minor Losses (ft)	6' Gate Valve Velocity (ft/s)	$h_{v,Gate}$ (ft)	Gate Valve Minor Losses (ft)	~~6" Penstock Velocity (ft/s)~~	h_{vel} (ft)	~~6" Penstock Friction Loss (ft)~~	~~Penstock Minor Losses (ft)~~	Total Head Loss Prior to JFG (ft)	66" JFG Velcity (ft/s)	66" JFG h_{vel} (ft)	Required Head at Valve (ft)	Req. Water Depth Above 5302 (ft)	Reservoir W.S. Elevation
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	5302.0
100.0	1.99	0.06	0.07	0.06	3.54	0.19	0.02	3.54	0.19	0.00	0.00	0.15	4.21	0.28	0.40	0.5	5302.5
200.0	3.98	0.25	0.27	0.25	7.07	0.78	0.08	7.07	0.78	0.00	0.00	0.59	8.42	1.10	1.60	2.1	5304.2
300.0	5.97	0.55	0.60	0.55	10.61	1.75	0.17	10.61	1.75	0.00	0.00	1.33	12.63	2.48	3.59	4.9	5306.9
400.0	7.97	0.99	1.06	0.99	14.15	3.11	0.31	14.15	3.11	0.00	0.00	2.36	16.84	4.40	6.39	8.7	5310.7
500.0	9.96	1.54	1.66	1.54	17.68	4.86	0.49	17.68	4.86	0.00	0.00	3.68	21.05	6.88	9.98	13.7	5315.7
600.0	11.95	2.22	2.39	2.22	21.22	6.99	0.70	21.22	6.99	0.00	0.00	5.31	25.25	9.90	14.38	19.7	5321.7
700.0	13.94	3.02	3.25	3.02	24.76	9.52	0.95	24.76	9.52	0.00	0.00	7.22	29.46	13.46	19.57	26.8	5328.8
800.0	15.93	3.94	4.25	3.94	28.29	12.43	1.24	28.29	12.43	0.00	0.00	9.43	33.67	17.61	25.56	35.0	5337.0
900.0	17.92	4.99	5.38	4.99	31.83	15.73	1.57	31.83	15.73	0.00	0.00	11.94	37.88	22.28	32.35	44.3	5346.3
1000.0	19.91	6.16	6.64	6.16	35.37	19.42	1.94	35.37	19.42	0.00	0.00	14.74	42.09	27.51	39.93	54.7	5356.7
1100.0	21.91	7.45	8.03	7.45	38.90	23.50	2.35	38.90	23.50	0.00	0.00	17.83	46.30	33.29	48.32	66.2	5368.2
1200.0	23.90	8.87	9.56	8.87	42.44	27.97	2.80	42.44	27.97	0.00	0.00	21.22	50.51	39.61	57.50	78.7	5380.7
1300.0	25.89	10.41	11.22	10.41	45.98	32.83	3.28	45.98	32.83	0.00	0.00	24.91	54.72	46.49	67.49	92.4	5394.4
1400.0	27.88	12.07	13.01	12.07	49.51	38.07	3.81	49.51	38.07	0.00	0.00	28.89	58.93	53.92	78.27	107.2	5409.2
1500.0	29.87	13.86	14.94	13.86	53.05	43.70	4.37	53.05	43.70	0.00	0.00	33.16	63.14	61.90	89.85	123.0	5425.0
1600.0	31.86	15.77	17.00	15.77	56.59	49.72	4.97	56.59	49.72	0.00	0.00	37.73	67.34	70.42	102.23	140.0	5442.0

Figure 2A

Outlet Works Rating Curve - Alternative OW2 (66" JFG)



Reservoir Elevation (ft)	OW2 Outlet Flow (cfs)
5302	0
5305	230
5310	380
5315	485
5320	570
5325	645
5330	715
5335	775
5340	830
5345	885
5350	935
5355	985
5360	1030
5365	1075
5370	1115
5375	1155
5380	1195
5385	1230
5390	1270
5395	1305
5400	1340
5405	1370
5410	1405
5415	1435

APPENDIX A3

ALTERNATIVE OW3A HYDRAULIC CALCULATIONS

Ruby Dam
DNRC
HKM Job No. 08M087.175
Energy Balance for Computation of FCV Split Flows

ALTERNATIVE OW3A

From FCV Documentation: Discharge Coefficient = 0.85

$$Q = CA\sqrt{2gH}$$

Assumed energy through all valves can be equated using:

$$Q = v_{24} A_{24} + 2 v_{54} A_{54}$$

$$E_{24} = E_{54}$$

$$\frac{v_{24}^2}{2g} + h_{L24} - \Delta Elev = \frac{v_{54}^2}{2g} + h_{L54}$$

		FCV	
24in.	ID =	2.00	ft
	A =	3.14	ft^2
	CL Elev =	5297.75	ft
2 - 54in.	ID =	4.50	ft
	A =	15.90	ft^2
	CL Elev =	5301.50	ft

Loss Coefficients for FCV Arrangement

$K_{b\,24}$ =	0.15	2 - 22.5° Bends
$K_{c\,24}$ =	0.56	Contraction into center valve
$K_{b\,54}$ =	0.40	4 - 45° Bends (2 per valve)

Total Flow (cfs)	24" FCV v_{24} (ft/s)	h_{v24} (ft)	h_{L24} (ft)	E_{24} (ft)	Q_{24} (cfs)	Head Required Above 5301.5 (ft)	54" FCV v_{54} (ft/s)	h_{v54} (ft)	h_{L54} (ft)	E_{54} (ft)	Q_{54} (cfs)	Head Required Above 5301.5 (ft)	Energy Balance
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00000
50	11.40	2.02	1.74	0.01	35.82	0.78	0.45	0.00	0.00	0.01	7.09	0.01	0.00000
100	11.56	2.08	1.79	0.11	36.33	0.91	2.00	0.06	0.05	0.11	31.84	0.14	0.00000
150	11.91	2.20	1.90	0.35	37.43	1.20	3.54	0.19	0.16	0.35	56.28	0.42	0.00000
200	12.43	2.40	2.06	0.72	39.06	1.64	5.06	0.40	0.32	0.72	80.47	0.87	0.00000
250	13.10	2.66	2.29	1.20	41.15	2.23	6.57	0.67	0.54	1.20	104.43	1.46	0.00000
300	13.88	2.99	2.57	1.82	43.61	2.97	8.06	1.01	0.81	1.82	128.19	2.20	0.00000
350	14.77	3.39	2.91	2.55	46.39	3.85	9.55	1.41	1.13	2.55	151.81	3.09	0.00000
400	15.73	3.84	3.30	3.40	49.41	4.87	11.02	1.89	1.51	3.40	175.29	4.12	0.00000
450	16.76	4.36	3.75	4.36	52.65	6.04	12.49	2.42	1.94	4.36	198.68	5.29	0.00000
500	17.84	4.94	4.25	5.44	56.05	7.34	13.96	3.02	2.42	5.44	221.97	6.61	0.00000
550	18.97	5.59	4.81	6.64	59.60	8.79	15.42	3.69	2.95	6.64	245.20	8.06	0.00000
600	20.13	6.29	5.41	7.96	63.25	10.38	16.87	4.42	3.54	7.96	268.37	9.66	0.00000
650	21.33	7.06	6.08	9.39	67.01	12.10	18.33	5.22	4.17	9.39	291.50	11.39	0.00000
700	22.55	7.90	6.79	10.94	70.84	13.97	19.78	6.08	4.86	10.94	314.58	13.27	0.00000
750	23.79	8.79	7.56	12.60	74.74	15.97	21.23	7.00	5.60	12.60	337.63	15.28	0.00000
800	25.05	9.74	8.38	14.37	78.69	18.11	22.68	7.98	6.39	14.37	360.65	17.44	0.00000
850	26.32	10.76	9.25	16.26	82.70	20.40	24.12	9.04	7.23	16.26	383.65	19.73	0.00000
900	27.61	11.84	10.18	18.27	86.75	22.82	25.57	10.15	8.12	18.27	406.63	22.17	0.00000
950	28.91	12.98	11.16	20.39	90.83	25.38	27.01	11.33	9.06	20.39	429.59	24.74	0.00000
1000	30.22	14.18	12.20	22.63	94.94	28.08	28.45	12.57	10.06	22.63	452.53	27.46	0.00000
1050	31.54	15.45	13.28	24.98	99.08	30.91	29.89	13.88	11.10	24.98	475.46	30.31	0.00000
1100	32.86	16.77	14.42	27.45	103.25	33.89	31.34	15.25	12.20	27.45	498.38	33.30	0.00000
1150	34.20	18.16	15.62	30.03	107.43	37.00	32.78	16.68	13.35	30.03	521.28	36.43	0.00000
1200	35.54	19.61	16.86	32.72	111.64	40.25	34.22	18.18	14.54	32.72	544.18	39.70	0.00000
1250	36.88	21.12	18.16	35.53	115.86	43.64	35.66	19.74	15.79	35.53	567.07	43.11	0.00000
1300	38.23	22.69	19.52	38.46	120.10	47.17	37.09	21.37	17.09	38.46	589.95	46.66	0.00000
1350	39.58	24.33	20.92	41.50	124.35	50.84	38.53	23.05	18.44	41.50	612.83	50.35	0.00000
1400	40.94	26.02	22.38	44.65	128.61	54.65	39.97	24.81	19.85	44.65	635.70	54.18	0.00000
1450	42.30	27.78	23.89	47.92	132.88	58.59	41.41	26.62	21.30	47.92	658.56	58.15	0.00000
1500	43.66	29.60	25.46	51.31	137.17	62.68	42.84	28.50	22.80	51.31	681.42	62.26	0.00000
1550	45.03	31.48	27.07	54.81	141.46	66.90	44.28	30.45	24.36	54.81	704.27	66.50	0.00000
1600	46.40	33.43	28.75	58.42	145.76	71.26	45.72	32.46	25.96	58.42	727.12	70.89	0.00000

Estimate of C_d value for entire system (manifold + valves): Performed linear regression on required head vs. velocity head for both valves.

SUMMARY OUTPUT: 24" Valve

Regression Statistics	
Multiple R	1.0
R Square	1.0
Adjusted R St	1.0
Standard Erro	0.6
Observations	33.0

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0	44679.1	44679.1	106422.2	0.0
Residual	31.0	13.0	0.4		
Total	32.0	44692.1			

	Coefficients	*Standard Erro*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-3.5	0.2	-19.6	0.0	-3.8
X Variable 1	**2.2**	0.0	326.2	0.0	2.2

SUMMARY OUTPUT: 54" Valve

Regression Statistics	
Multiple R	1.0
R Square	1.0
Adjusted R S	1.0
Standard Err	0.0
Observations	33.0

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0	45139.9	45139.9	##########	0.0
Residual	31.0	0.0	0.0		
Total	32.0	45139.9			

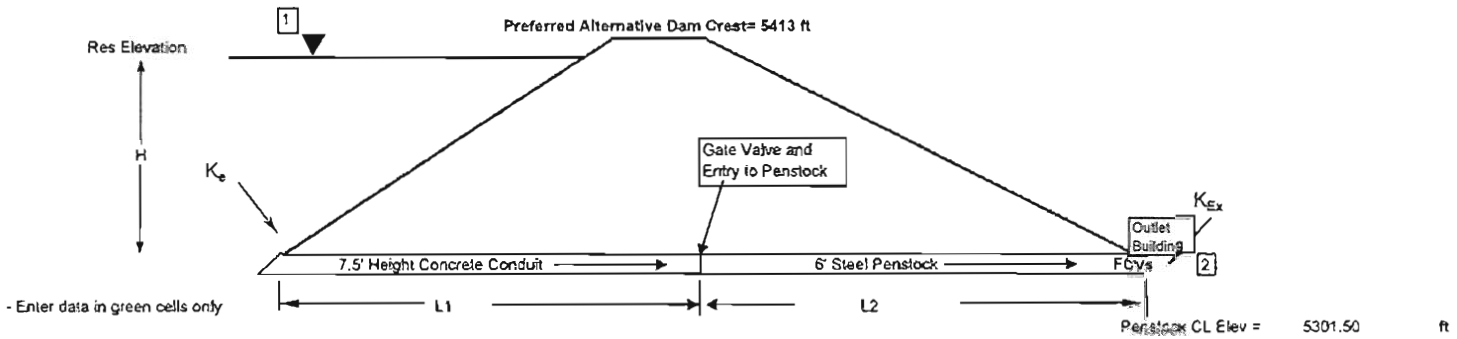
	Coefficients	*Standard Erro*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0.0	0.0	-16.5	0.0	0.0
X Variable 1	**2.2**	0.0	########	0.0	2.2

From Summary Output:

$$Rqd.Head = 2.2h_v$$
$$C_d = 0.67$$

HKM Engineering
Ruby Dam Feasibility
08M087.175
FCV Maximum Capacity (2-54" Valves, 24" Valve)

ALTERNATIVE OW3A



- Enter data in green cells only

Darcy-Weisbach Equation

$$h_f = f \frac{L}{D} \frac{v^2}{2g}$$

Friction Loss Coefficients for 7.5' Horseshoe

$\varepsilon/D_{7.5'}$ =	0.001250	Relative Roughness
$f_{7.5'}$ =	0.021	Friction Factor

Friction Loss Coefficients for 6' Penstock

$\varepsilon/D_{6'}$ =	0.0000188	Relative Roughness
$f_{6'}$ =	0.009	Friction Factor

Loss Coefficients for 7.5' Horseshoe

K_{ent} =	1.00	Entrance & Trashrack

Loss Coefficients for 6' Penstock

K_c =	0.00	Loss from Penstock to Manifold
K_{gate} =	0.10	Gate Valve and Entry to Penstock

Loss Coefficients for FCV and Manifold

C_d =	0.67	FCV Discharge Coefficient

7.5' Concrete Horseshoe

L =	385.0	ft
Hyd. Diam ($4*R_h$) =	7.50	ft
A =	50.21	ft^2
A_{gate} =	28.27	ft^2

6' Steel Penstock

L =	250.0	ft
ID =	6.00	ft
A =	28.27	ft^2

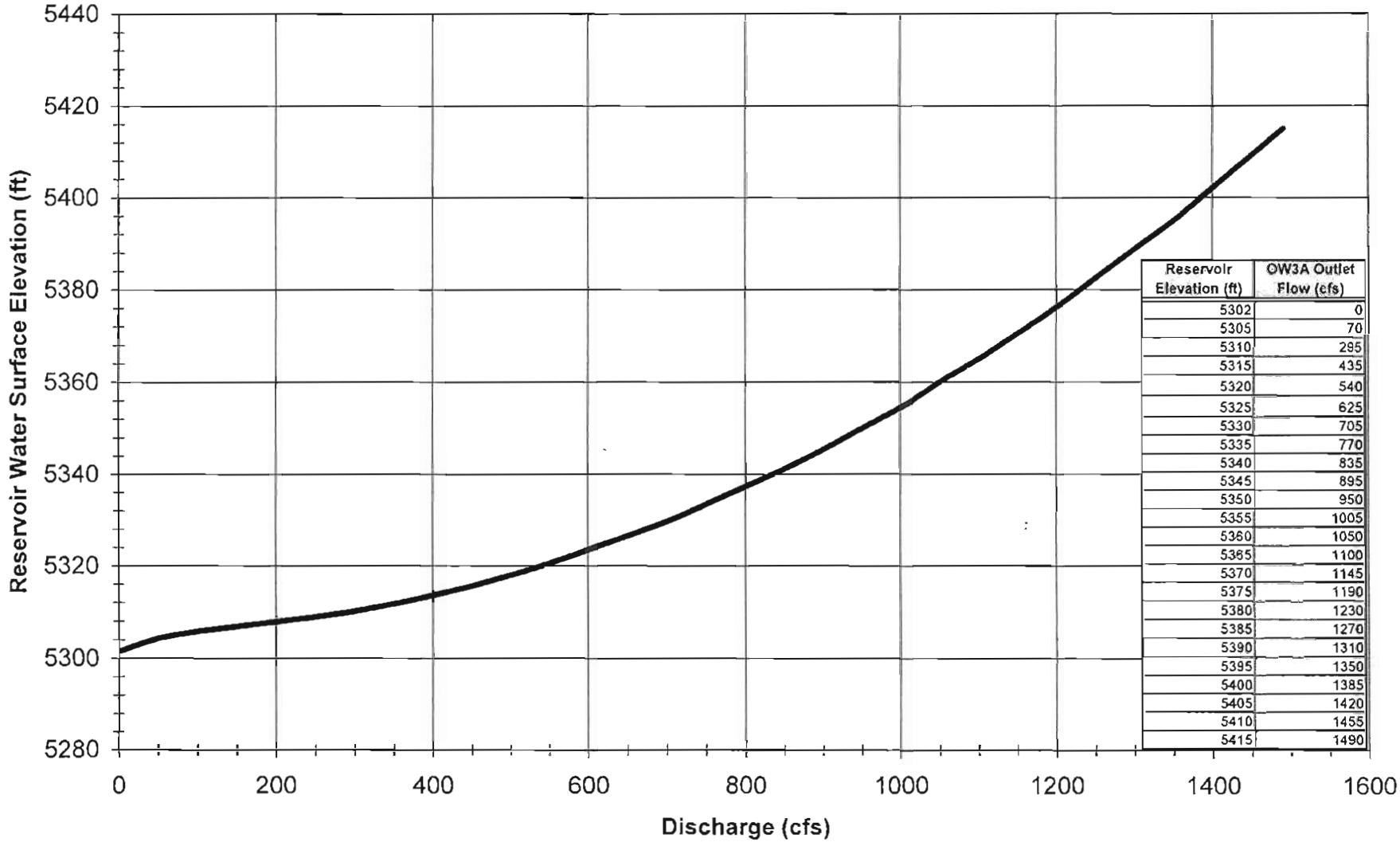
FCV

54in.	ID =	4.50	ft
	A =	15.90	ft^2
24in.	ID =	2.00	ft
	A =	3.14	ft^2

Flowrate (cfs)	8' Conduit Velocity (ft/s)	$h_{v8'}$ (ft)	8' Conduit Friction Loss (ft)	Conduit Minor Losses (ft)	6' Penstock Velocity (ft/s)	$h_{v6'}$ (ft)	6' Penstock Friction Loss (ft)	Gate Valve Minor Losses (ft)	Total Head Loss Prior to FCVs (ft)	24" FCV Velocity (ft/s)	24" FCV h_{v24} (ft)	54" FCV Velocity (ft/s)	54" FCV h_{v54} (ft)	Required Head at Valve (ft)	Req. Water Depth Above 5301.5 (ft)	Reservoir W.S. Elevation
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	5301.5
100.0	1.99	0.06	0.07	0.06	3.54	0.19	0.07	0.02	0.22	11.56	2.08	2.00	0.05	4.63	4.8	5306.3
200.0	3.98	0.25	0.27	0.25	7.07	0.78	0.28	0.08	0.85	12.43	2.40	5.06	0.40	5.35	8.2	5307.7
300.0	5.97	0.55	0.60	0.55	10.61	1.75	0.62	0.17	1.95	13.88	2.99	8.06	1.01	6.67	8.6	5310.1
400.0	7.97	0.99	1.06	0.99	14.15	3.11	1.10	0.31	3.46	15.73	3.84	11.02	1.89	8.56	12.0	5313.5
500.0	9.96	1.54	1.66	1.54	17.68	4.86	1.72	0.49	5.40	17.84	4.94	13.96	3.02	11.01	16.4	5317.9
600.0	11.95	2.22	2.39	2.22	21.22	6.99	2.48	0.70	7.78	20.13	6.29	16.87	4.42	14.02	21.8	5323.3
700.0	13.94	3.02	3.25	3.02	24.76	9.52	3.37	0.95	10.59	22.55	7.90	19.78	6.08	17.59	28.2	5329.7
800.0	15.93	3.94	4.25	3.94	28.29	12.43	4.40	1.24	13.84	25.05	9.74	22.68	7.98	21.70	35.5	5337.0
900.0	17.92	4.99	5.38	4.99	31.83	15.73	5.57	1.57	17.51	27.61	11.84	25.57	10.15	26.37	43.9	5345.4
1000.0	19.91	6.16	6.64	6.16	35.37	19.42	6.88	1.94	21.62	30.22	14.18	28.45	12.57	31.59	53.2	5354.7
1100.0	21.91	7.45	8.03	7.45	38.90	23.50	8.32	2.35	26.16	32.86	16.77	31.34	15.25	37.36	63.5	5365.0
1200.0	23.90	8.87	9.56	8.87	42.44	27.97	9.91	2.80	31.13	35.54	19.61	34.22	18.18	43.68	74.8	5376.3
1300.0	25.89	10.41	11.22	10.41	45.98	32.63	11.63	3.28	36.54	38.23	22.69	37.09	21.37	50.55	87.1	5388.6
1400.0	27.88	12.07	13.01	12.07	49.51	36.07	13.48	3.81	42.37	40.94	26.02	39.97	24.81	57.97	*100.3*	*5401.8*
1500.0	29.87	13.86	14.94	13.86	53.05	43.70	15.48	4.37	48.64	43.66	29.60	42.84	28.50	65.94	*114.6*	*5416.1*
1600.0	31.86	15.77	17.00	15.77	56.59	49.72	17.61	4.97	55.34	46.40	33.43	45.72	32.46	74.46	*129.8*	*5431.3*

Figure 3A

Outlet Works Rating Curve - Alternative OW3A (FCVs)



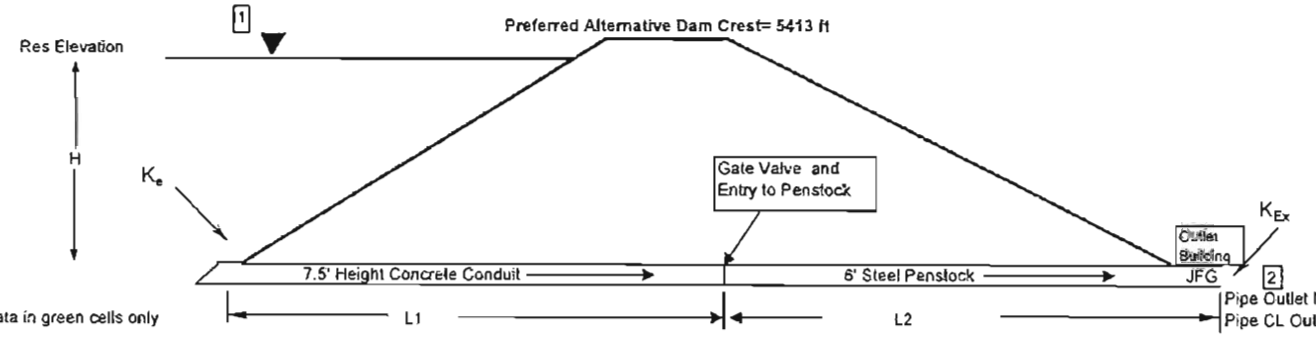
Reservoir Elevation (ft)	OW3A Outlet Flow (cfs)
5302	0
5305	70
5310	295
5315	435
5320	540
5325	625
5330	705
5335	770
5340	835
5345	895
5350	950
5355	1005
5360	1050
5365	1100
5370	1145
5375	1190
5380	1230
5385	1270
5390	1310
5395	1350
5400	1385
5405	1420
5410	1455
5415	1490

APPENDIX A4

ALTERNATIVE OW3C HYDRAULIC CALCULATIONS

HKM Engineering
Ruby Dam Feasibility
08M087.175
JFG Maximum Capacity (72" Valve)

ALTERNATIVE OW3C



- Enter data in green cells only

Pipe Outlet Inv.=	5298.5	ft
Pipe CL Outlet=	5301.5	ft

Darcy-Weisbach Equation

$$h_f = f\frac{L}{D}\frac{v^2}{2g}$$

Friction Loss Coefficients for 7.5' Horseshoe

$\varepsilon/D_{7.5'}$ =	0.001250	Relative Roughness
$f_{7.5'}$ =	0.021	Friction Factor

Friction Loss Coefficients for 6' Penstock

$\varepsilon/D_{6'}$ =	0.0000188	Relative Roughness
$f_{6'}$ =	0.009	Friction Factor

Loss Coefficients for 7.5' Horseshoe

K_{ent} =	1.00	Entrance & Trashrack

Loss Coefficients for 6' Penstock

K_e =	0.00	Loss from Penstock to Manifold
K_{gate} =	0.10	Gate Valve and Entry to Penstock

Loss Coefficients for Jet Flow Valve

C_d =	0.83	JFG Discharge Coefficient

7.5' Concrete Horseshoe

L =	385.0	ft
Hyd. Diam ($4*R_h$) =	7.50	ft
A =	50.21	ft^2

6' Steel Penstock

L =	250.0	ft
ID =	6.00	ft
A =	28.27	ft^2

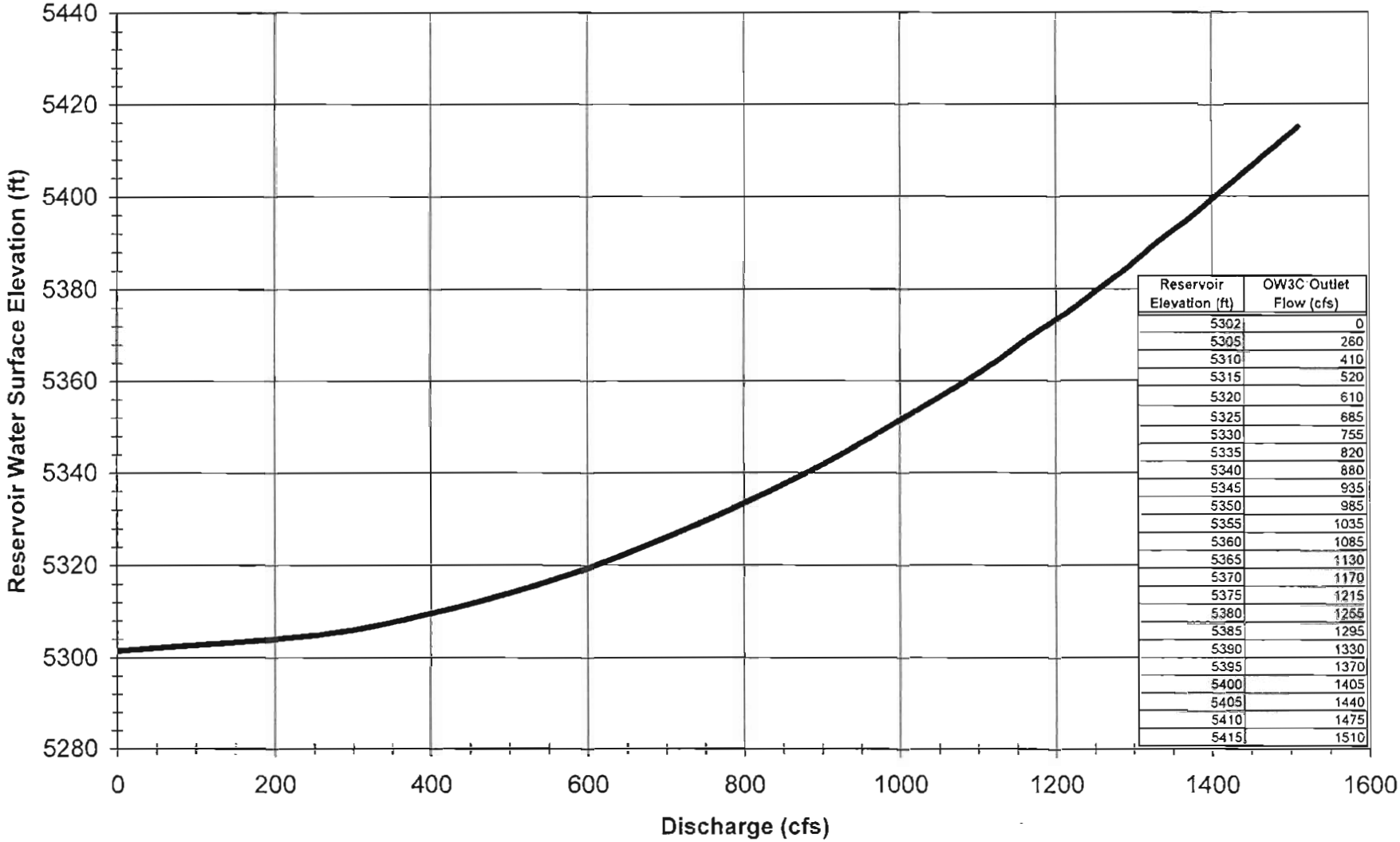
Jet Flow Valve (JFV)

ID =	6.00	ft
A =	28.27	ft^2

Flowrate (cfs)	8' Conduit Velocity (ft/s)	$h_{v8'}$ (ft)	8' Conduit Friction Loss (ft)	Conduit Entrance Losses (ft)	6' Penstock Velocity (ft/s)	$h_{v6'}$ (ft).	6' Penstock Friction Loss (ft)	Gate Valve Minor Losses (ft)	Total Head Loss Prior to JFG (ft)	72" JFG Velcity (ft/s)	72" JFG $h_{v72'}$ (ft)	Required Head at Valve (ft)	Req. Water Depth Above 5302 (ft)	Reservoir W.S. Elevation
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	5301.5
100.0	1.99	0.06	0.07	0.06	3.54	0.19	0.07	0.02	0.22	3.54	0.19	0.28	0.5	5302.0
200.0	3.98	0.25	0.27	0.25	7.07	0.78	0.28	0.08	0.86	7.07	0.78	1.13	2.0	5303.5
300.0	5.97	0.55	0.60	0.55	10.61	1.75	0.62	0.17	1.95	10.61	1.75	2.54	4.5	5305.0
400.0	7.97	0.99	1.06	0.99	14.15	3.11	1.10	0.31	3.46	14.15	3.11	4.51	8.0	5309.5
500.0	9.96	1.54	1.66	1.54	17.68	4.86	1.72	0.49	5.40	17.68	4.86	7.05	12.5	5314.0
600.0	11.95	2.22	2.39	2.22	21.22	6.99	2.48	0.70	7.78	21.22	6.99	10.15	17.9	5319.4
700.0	13.94	3.02	3.25	3.02	24.76	9.52	3.37	0.95	10.59	24.76	9.52	13.82	24.4	5325.9
800.0	15.93	3.94	4.25	3.94	28.29	12.43	4.40	1.24	13.84	28.29	12.43	18.04	31.9	5333.4
900.0	17.92	4.99	5.38	4.99	31.83	15.73	5.57	1.57	17.51	31.83	15.73	22.84	40.3	5341.8
1000.0	19.91	6.16	6.64	6.16	35.37	19.42	6.88	1.94	21.62	35.37	19.42	28.20	49.8	5351.3
1100.0	21.91	7.45	8.03	7.45	38.90	23.50	8.32	2.35	26.16	38.90	23.50	34.12	60.3	5361.8
1200.0	23.90	8.87	9.56	8.87	42.44	27.97	9.91	2.80	31.13	42.44	27.97	40.60	71.7	5373.2
1300.0	25.89	10.41	11.22	10.41	45.98	32.83	11.63	3.28	36.54	45.98	32.83	47.65	84.2	5385.7
1400.0	27.88	12.07	13.01	12.07	49.51	38.07	13.48	3.81	42.37	49.51	38.07	55.26	97.6	5399.1
1500.0	29.87	13.86	14.94	13.86	53.05	43.70	15.48	4.37	48.64	53.05	43.70	63.44	*112.1*	*5413.6*
1600.0	31.86	15.77	17.00	15.77	56.59	49.72	17.61	4.97	55.34	56.59	49.72	72.18	*127.5*	*5429.0*

Figure 4A

Outlet Works Rating Curve - Alternative OW3C (72" JFG)



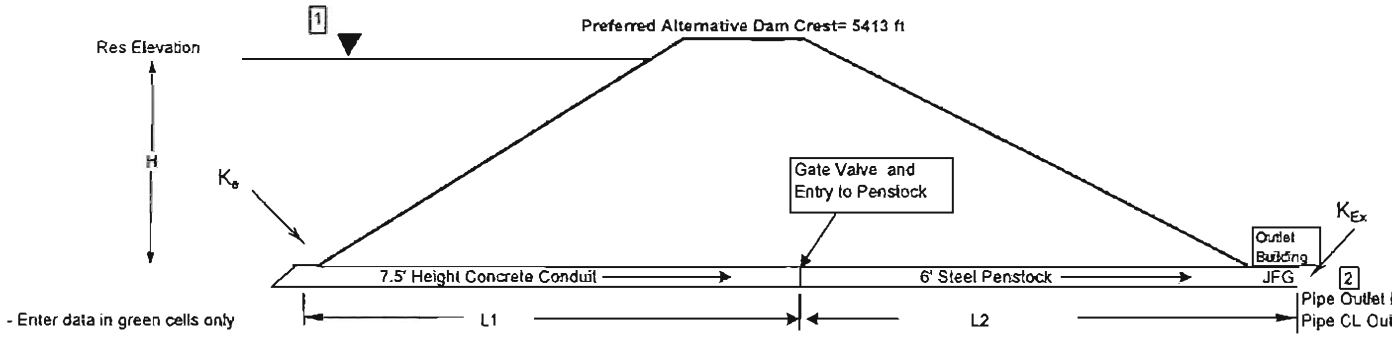
Reservoir Elevation (ft)	OW3C Outlet Flow (cfs)
5302	0
5305	260
5310	410
5315	520
5320	610
5325	685
5330	755
5335	820
5340	880
5345	935
5350	985
5355	1035
5360	1085
5365	1130
5370	1170
5375	1215
5380	1255
5385	1295
5390	1330
5395	1370
5400	1405
5405	1440
5410	1475
5415	1510

APPENDIX A5

ALTERNATIVE OW4 HYDRAULIC CALCULATIONS

HKM Engineering
Ruby Dam Feasibility
08M087.175
JFG Maximum Capacity (60" Valve)

ALTERNATIVE OW4



Pipe Outlet Inv.=	5299.0	ft
Pipe CL Outlet=	5301.5	ft

- Enter data in green cells only

Darcy-Weisbach Equation

$$h_f = f\frac{L}{D}\frac{v^2}{2g}$$

Friction Loss Coefficients for 7.5' Horseshoe

ε/D_{hr} =	0.001250	Relative Roughness
f_{hr} =	0.021	Friction Factor

Friction Loss Coefficients for 6' Penstock

ε/D_{hs} =	0.0000188	Relative Roughness
f_{hs} =	0.009	Friction Factor

Loss Coefficients for 7.5' Horseshoe

K_{ent} =	1.00	Entrance & Trashrack

Loss Coefficients for 6' Penstock

K_c =	0.00	Loss from Penstock to Manifold
K_{gate} =	0.10	Gate Valve and Entry to Penstock

Loss Coefficients for Jet Flow Valve

C_d =	0.83	JFG Discharge Coefficient

7.5' Concrete Horseshoe

L =	385.0	ft
Hyd. Diam ($4*R_h$) =	7.50	ft
A =	50.21	ft^2

6' Steel Penstock

L =	250.0	ft
ID =	6.00	ft
A =	28.27	ft^2

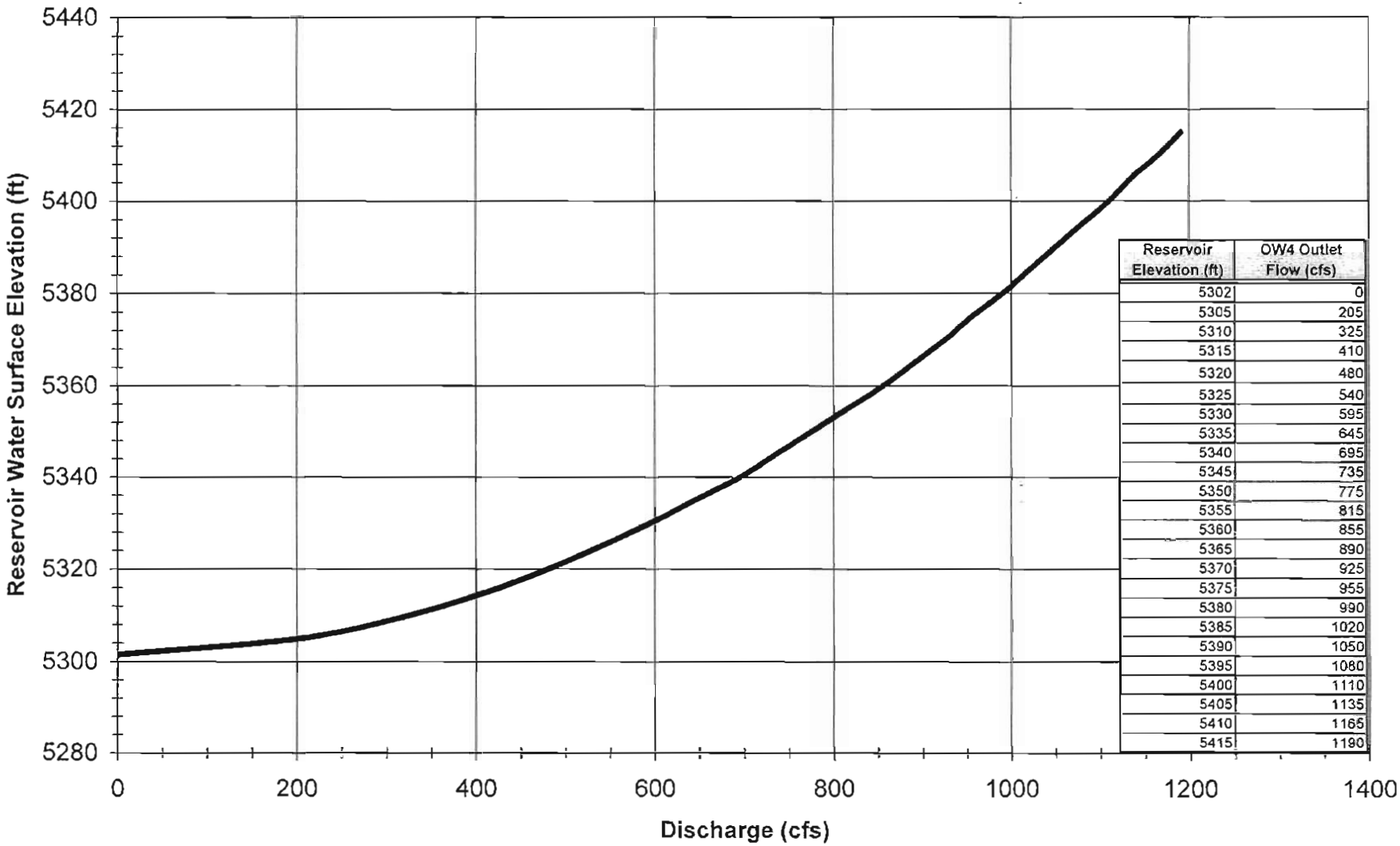
Jet Flow Valve (JFV)

ID =	5.00	ft
A =	19.63	ft^2

Flowrate (cfs)	8" Conduit Velocity (ft/s)	h_{vel} (ft)	8" Conduit Friction Loss (ft)	Conduit Entrance Losses (ft)	6' Penstock Velocity (ft/s)	h_{vel} (ft)	6' Penstock Friction Loss (ft)	Gate Valve Minor Losses (ft)	Total Head Loss Prior to JFG (ft)	60" JFG Velcity (ft/s)	60" JFG h_{vel60}^2 (ft)	Required Head at Valve (ft)	Req. Water Depth Above 5302 (ft)	Reservoir W.S. Elevation
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	5301.5
100.0	1.99	0.06	0.07	0.06	3.54	0.19	0.07	0.02	0.22	5.09	0.40	0.58	0.8	5302.3
200.0	3.98	0.25	0.27	0.25	7.07	0.78	0.28	0.08	0.86	10.19	1.61	2.34	3.2	5304.7
300.0	5.97	0.55	0.60	0.55	10.61	1.75	0.62	0.17	1.95	15.28	3.62	5.26	7.2	5308.7
400.0	7.97	0.99	1.06	0.99	14.15	3.11	1.10	0.31	3.46	20.37	6.44	9.35	12.8	5314.3
500.0	9.96	1.54	1.66	1.54	17.68	4.86	1.72	0.49	5.40	25.46	10.07	14.62	20.0	5321.5
600.0	11.95	2.22	2.39	2.22	21.22	6.99	2.48	0.70	7.78	30.56	14.50	21.05	28.8	5330.3
700.0	13.94	3.02	3.25	3.02	24.76	9.52	3.37	0.95	10.59	35.65	19.74	28.65	39.2	5340.7
800.0	15.93	3.94	4.25	3.94	28.29	12.43	4.40	1.24	13.84	40.74	25.78	37.42	51.3	5352.8
900.0	17.92	4.99	5.38	4.99	31.83	15.73	5.57	1.57	17.51	45.84	32.62	47.36	64.9	5366.4
1000.0	19.91	6.16	6.64	6.16	35.37	19.42	6.88	1.94	21.62	50.93	40.28	58.47	80.1	5381.6
1100.0	21.91	7.45	8.03	7.45	38.90	23.50	8.32	2.35	26.16	56.02	48.73	70.74	96.9	5398.4
1200.0	23.90	8.87	9.56	8.87	42.44	27.97	9.91	2.80	31.13	61.12	58.00	84.19	*115.3*	*5416.8*
1300.0	25.89	10.41	11.22	10.41	45.98	32.83	11.63	3.28	36.54	66.21	68.07	98.81	*135.3*	*5436.8*
1400.0	27.88	12.07	13.01	12.07	49.51	38.07	13.48	3.81	42.37	71.30	78.94	114.59	*157.0*	*5458.5*
1500.0	29.87	13.86	14.94	13.86	53.05	43.70	15.48	4.37	48.64	76.39	90.62	131.55	*180.2*	*5481.7*
1600.0	31.86	15.77	17.00	15.77	56.59	49.72	17.61	4.97	55.34	81.49	103.11	149.67	*205.0*	*5506.5*

Figure 5A

Outlet Works Rating Curve - Alternative OW4 (60" JFG)



Reservoir Elevation (ft)	OW4 Outlet Flow (cfs)
5302	0
5305	205
5310	325
5315	410
5320	480
5325	540
5330	595
5335	645
5340	695
5345	735
5350	775
5355	815
5360	855
5365	890
5370	925
5375	955
5380	990
5385	1020
5390	1050
5395	1080
5400	1110
5405	1135
5410	1165
5415	1190

Ruby Dam - Outlet Alternatives
Option 3C - JFG at Outlet
Stilling Basin Design

Evaluation of potential for Impact Basin
Assume rectangular channel for 30 ft downstream from JFG, then impact basin.

JFG size (inches)	60
Design Flow (cfs)	1100
Area JFG (ft^2)	19.6
Vel JFG (ft/sec)	56.02
Assume Vel enter basin	55
vel head	46.97

width	q	y	D	F	W/D	W	H	L	a	b	c	d
8	137.50	2.50	2.50	6.13	8.00	20.00	15.00	26.67	10.00	7.50	10.00	3.33
10	110.00	2.00	2.00	6.85	8.30	16.60	12.45	22.13	8.30	6.23	8.30	2.77
12	91.67	1.67	1.67	7.51	9.00	15.00	11.25	20.00	7.50	5.63	7.50	2.50
14	78.57	1.43	1.43	8.11	9.20	13.14	9.86	17.52	6.57	4.93	6.57	2.19
Assume lower inlet velocity			40									
12	91.67	2.29	2.29	4.66	7.00	16.04	12.03	21.39	8.02	6.02	8.02	2.67
Assume lower inlet velocity			30									
12	91.67	3.06	3.06	3.02	5.50	16.81	12.60	22.41	8.40	6.30	8.40	2.80
Assume conduit width of 12 ft and set W at 20 ft.												
12	91.67	1.67	1.67	7.51	12.00	20.00	15.00	26.67	10.00	7.50	10.00	3.33
AT 500 cfs with velocity = 40												
12	41.67	1.04	1.04	6.91	19.20	20.00	15.00	26.67	10.00	7.50	10.00	3.33

Momentum force for v=55

vel head	46.97	ft. H2O
equiv pressure	2931.06	psf
flow area	20	sq.ft.
Force	58,621	lbs

APPENDIX B

COST ESTIMATES

APPENDIX B1

ALTERNATIVE OW2
COST ESTIMATE

OUTLET WORKS OPTION - OW2
COST ESTIMATE

Outlet Works Modifications OW2 - 66" Jet Flow Gate	Quantity		Unit Cost	Total Material Cost
Concrete Demo	10	CY	$ 35.00	$ 350.00
Excavation	2816	CY	$ 12.00	$ 33,792.00
Drain/Filter Gravel/Bedding	94	CY	$ 60.00	$ 5,640.00
Sectional 66-inch JFG/Demo/Install	1	LS	$ 900,290.00	$ 900,290.00
Floor Concrete	190	CY	$ 800.00	$ 152,000.00
Wall Concrete	369	CY	$ 1,000.00	$ 369,000.00
Structural Backfill	1520	CY	$ 10.00	$ 15,200.00
Riprap	113	CY	$ 55.00	$ 6,215.00
Channel Excavation	693	CY	$ 12.00	$ 8,316.00
Dam Crest Access Road				
Excavation	4448	CY	$ 12.00	$ 53,376.00
Fill	350	CY	$ 10.00	$ 3,500.00
Bridge	1	LS	$ 170,040.00	$ 170,040.00
			OW2 Total Cost	**$ 1,717,719**

APPENDIX B2

ALTERNATIVE OW3A
COST ESTIMATE

OUTLET WORKS OPTION - OW3A
COST ESTIMATE

Outlet Works Modifications OW3a - Fixed Cone Valve			Unit Cost	Total Material Cost
Concrete Demo	10	CY	$ 35.00	$ 350.00
Excavation	2328	CY	$ 12.00	$ 27,936.00
Drain/Filter Gravel/Bedding	94	CY	$ 60.00	$ 5,640.00
72" Penstock and Bifurcation Pipe	1	LS	$ 524,500.00	$ 524,500.00
FCVs with Dissipation Sleeves	1	LS	$ 751,000.00	$ 751,000.00
FCV Installation	1	LS	$ 95,000.00	$ 95,000.00
Floor Concrete	289	CY	$ 800.00	$ 231,200.00
Wall Concrete	360	CY	$ 1,000.00	$ 360,000.00
Gate House	1000	SF	$ 100.00	$ 100,000.00
Electrical Service	1	LS	$ 10,000.00	$ 10,000.00
Structural Backfill	1945	CY	$ 10.00	$ 19,450.00
Riprap	107	CY	$ 55.00	$ 5,885.00
Channel Excavation	2849	CY	$ 12.00	$ 34,188.00
Downstream Access Road				
Excavation	797	CY	$ 12.00	$ 9,564.00
Fill	679	CY	$ 10.00	$ 6,790.00
Road Gravel Surfacing	460	CY	$ 60.00	$ 27,600.00
Bridge	1	LS	$ 89,270.00	$ 89,270.00
			OW3A Total Cost	**$ 2,298,373**

APPENDIX B3

ALTERNATIVE OW3C
COST ESTIMATE

OUTLET WORKS OPTION - OW3C
COST ESTIMATE

Outlet Works Modifications OW3c - 72" Jet Flow Gate			Unit Cost	Total Material Cost
Concrete Demo	10	CY	$ 35.00	$ 350.00
Excavation	3046	CY	$ 12.00	$ 36,552.00
Drain/Filter Gravel/Bedding	94	CY	$ 60.00	$ 5,640.00
72-inch Penstock and Installation	1	LS	$ 378,500.00	$ 378,500.00
72-inch JFG	1	LS	$ 350,000.00	$ 350,000.00
18-inch JFG	1	LS	$ 75,000.00	$ 75,000.00
Gate Install (10% Gate Costs)	1	LS	$ 42,500.00	$ 42,500.00
Floor Concrete	211	CY	$ 800.00	$ 168,800.00
Wall Concrete	284	CY	$ 1,000.00	$ 284,000.00
Gate House	1000	SF	$ 100.00	$ 100,000.00
Electrical Service	1	LS	$ 10,000.00	$ 10,000.00
Structural Backfill	2741	CY	$ 10.00	$ 27,410.00
Riprap	101	CY	$ 55.00	$ 5,555.00
Channel Excavation	462	CY	$ 12.00	$ 5,544.00
Downstream Access Road				
Excavation	797	CY	$ 12.00	$ 9,564.00
Fill	679	CY	$ 10.00	$ 6,790.00
Road Gravel Surfacing	460	CY	$ 60.00	$ 27,600.00
Bridge	1	LS	$ 89,270.00	$ 89,270.00
			OW 3C Total Cost	**$ 1,623,075**

APPENDIX B4

ALTERNATIVE OW4
COST ESTIMATE

OUTLET WORKS OPTION - OW4
COST ESTIMATE

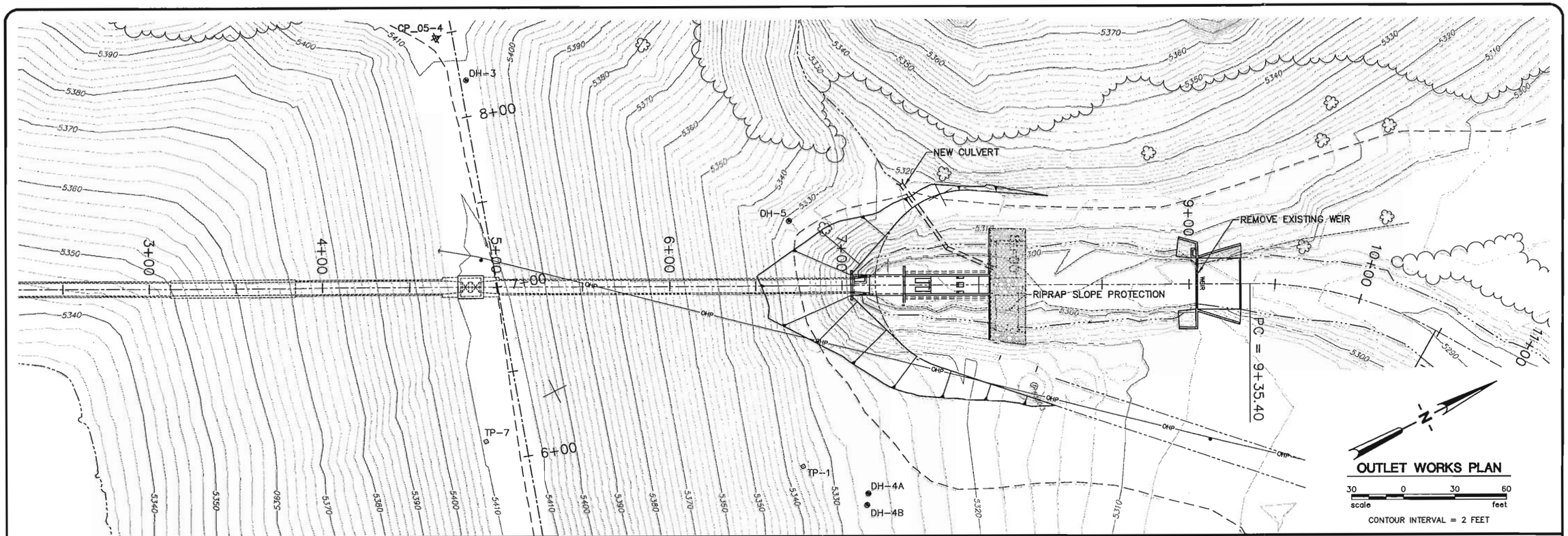
Outlet Works Modifications OW4 - 60" Jet Flow Gate			Unit Cost	Total Material Cost
Demo for Penstock	1	LS	$ 36,750.00	$ 36,750.00
Excavation	350	CY	$ 12.00	$ 4,200.00
Drain/Filter Gravel/Bedding	215	CY	$ 60.00	$ 12,900.00
72" Penstock and Installation	1	LS	$ 282,150.00	$ 282,150.00
18" Bypass Piping	1	LS	$ 3,600.00	$ 3,600.00
60" Jet Flow Gate	1	LS	$ 265,000.00	$ 265,000.00
18" Gate Valve	1	LS	$ 6,000.00	$ 6,000.00
Gate Install (10% Gate Costs)	1	LS	$ 27,100.00	$ 27,100.00
Floor Concrete	152	CY	$ 800.00	$ 121,600.00
Wall Concrete	279	CY	$ 1,000.00	$ 279,000.00
Gate House	672	SF	$ 100.00	$ 67,200.00
Electrical Service	1	LS	$ 10,000.00	$ 10,000.00
Structural Backfill	850	CY	$ 10.00	$ 8,500.00
Riprap	307	CY	$ 55.00	$ 16,885.00
Channel Excavation	680	CY	$ 12.00	$ 8,160.00
Downstream Access Road				
Excavation	797	CY	$ 12.00	$ 9,564.00
Fill	679	CY	$ 10.00	$ 6,790.00
Road Gravel Surfacing	460	CY	$ 60.00	$ 27,600.00
Vehicle Bridge	1	LS	$ 89,270.00	$ 89,270.00
			OW4 Total Cost	**$ 1,282,269**

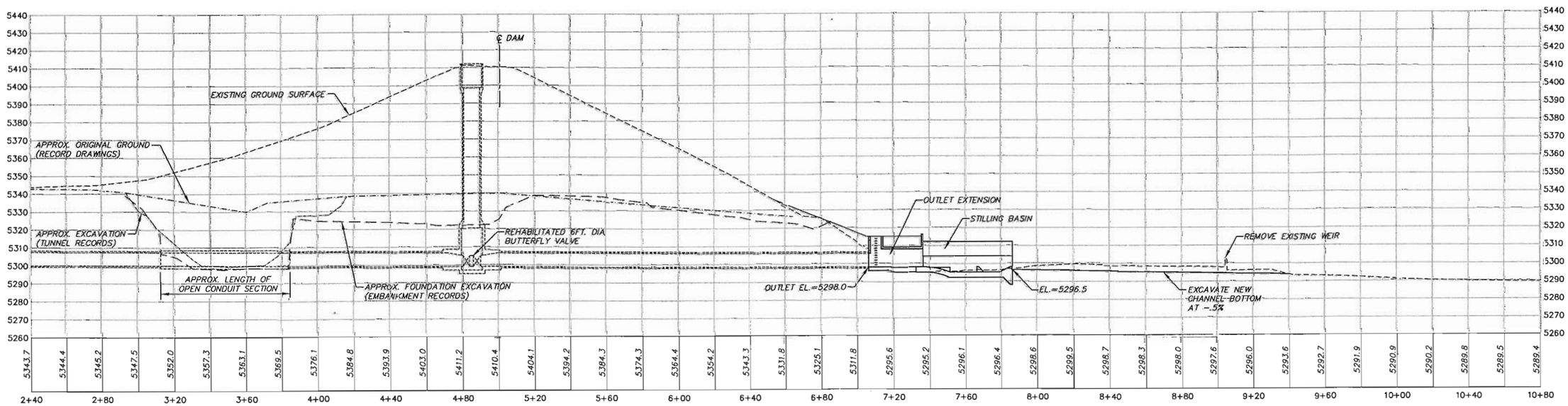
APPENDIX C

DRAWINGS

APPENDIX C1

ALTERNATIVE OW1 DRAWINGS





No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS PLAN AND PROFILE
OPTION OW1

• Project No. BM087.175 • NEW OW1-1.DWG • Date SEPT. 2006 • Designed JHT • Drawn GAE • Checked JHT • Approved JHT

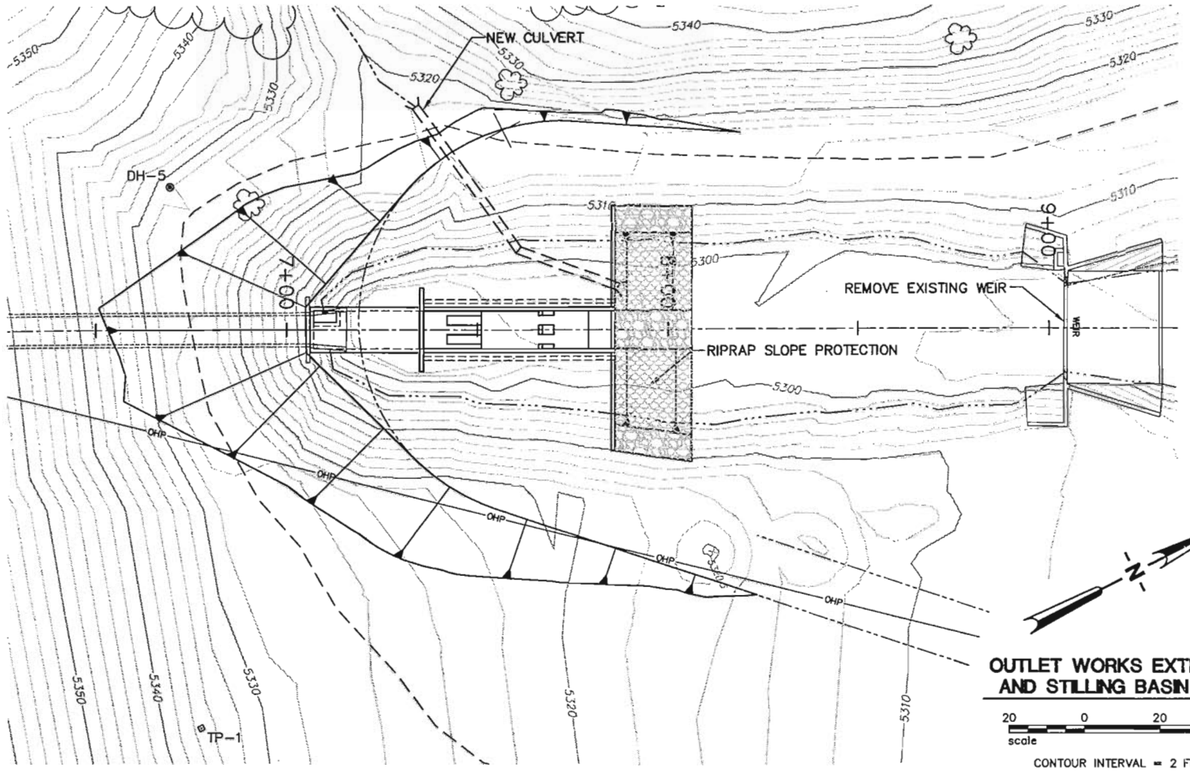
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW1-1
of 3

O:\08\M087175\dwg\Prelpl\NEW OW1-1.DWG 9/29/2006 11:53:25 AM MST

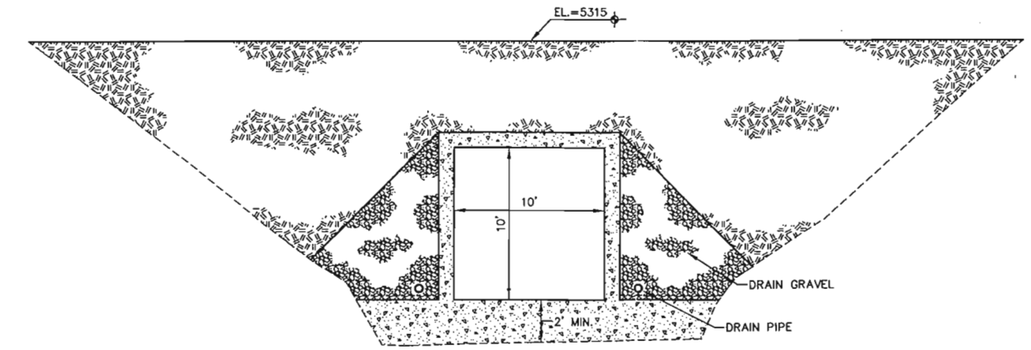
Copyright © 2006 HKM Engineering Inc., All Rights Reserved.



OUTLET WORKS EXTENSION AND STILLING BASIN PLAN

scale 20 0 20 40 feet

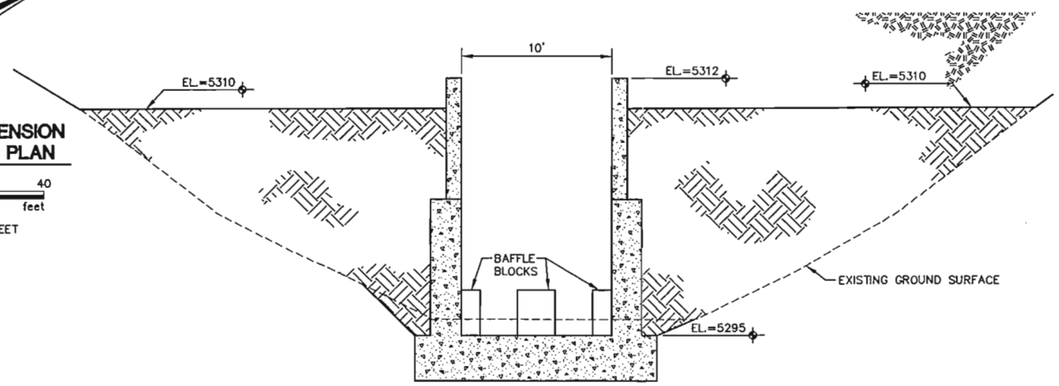
CONTOUR INTERVAL = 2 FEET



A SECTION

OW1-2 | OW1-2 OUTLET EXTENSION

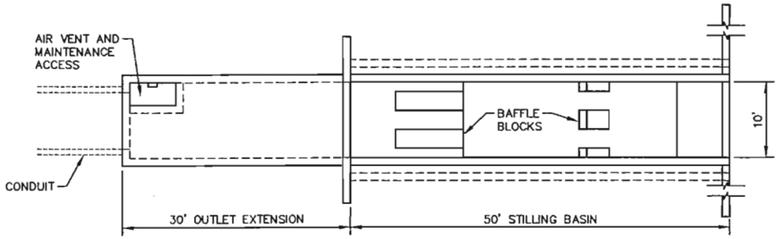
scale 5 0 5 10 feet



B SECTION

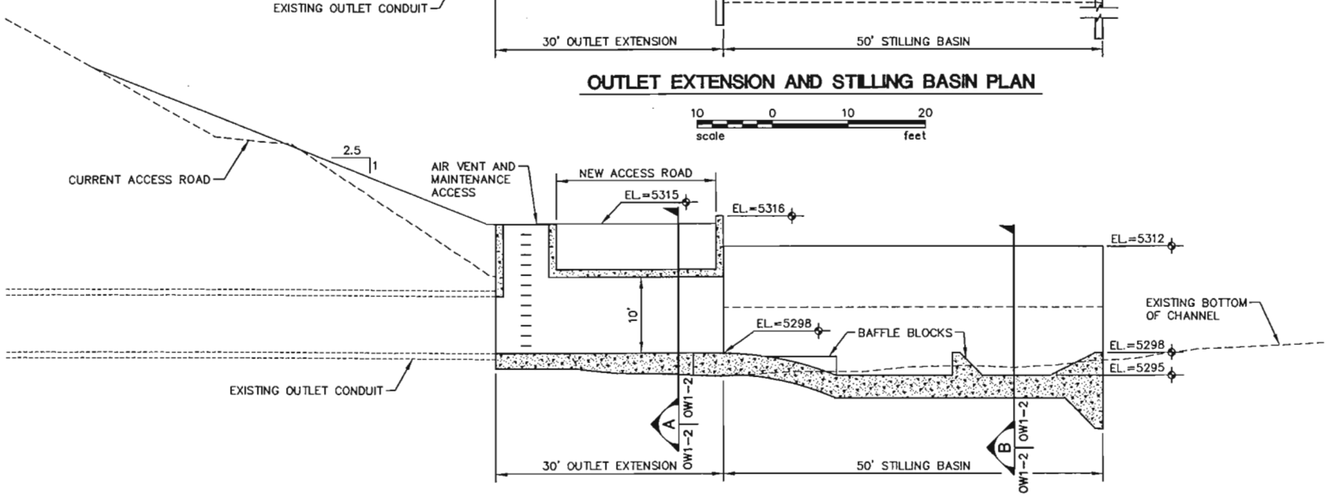
OW1-2 | OW1-2 STILLING BASIN

scale 5 0 5 10 feet



OUTLET EXTENSION AND STILLING BASIN PLAN

scale 10 0 10 20 feet



OUTLET EXTENSION AND STILLING BASIN PROFILE

scale 10 0 10 20 feet

No.	Revision	By	Date

WARNING 0 ½ 1 IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

Project No. BM087.175 ● NEW OW1-2.DWG ● Date SEPT. 2006 ● Designed JHT ● Drawn GAE ● Checked JHT ● Approved JHT

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS EXTENSION AND STILLING BASIN OPTION OW1

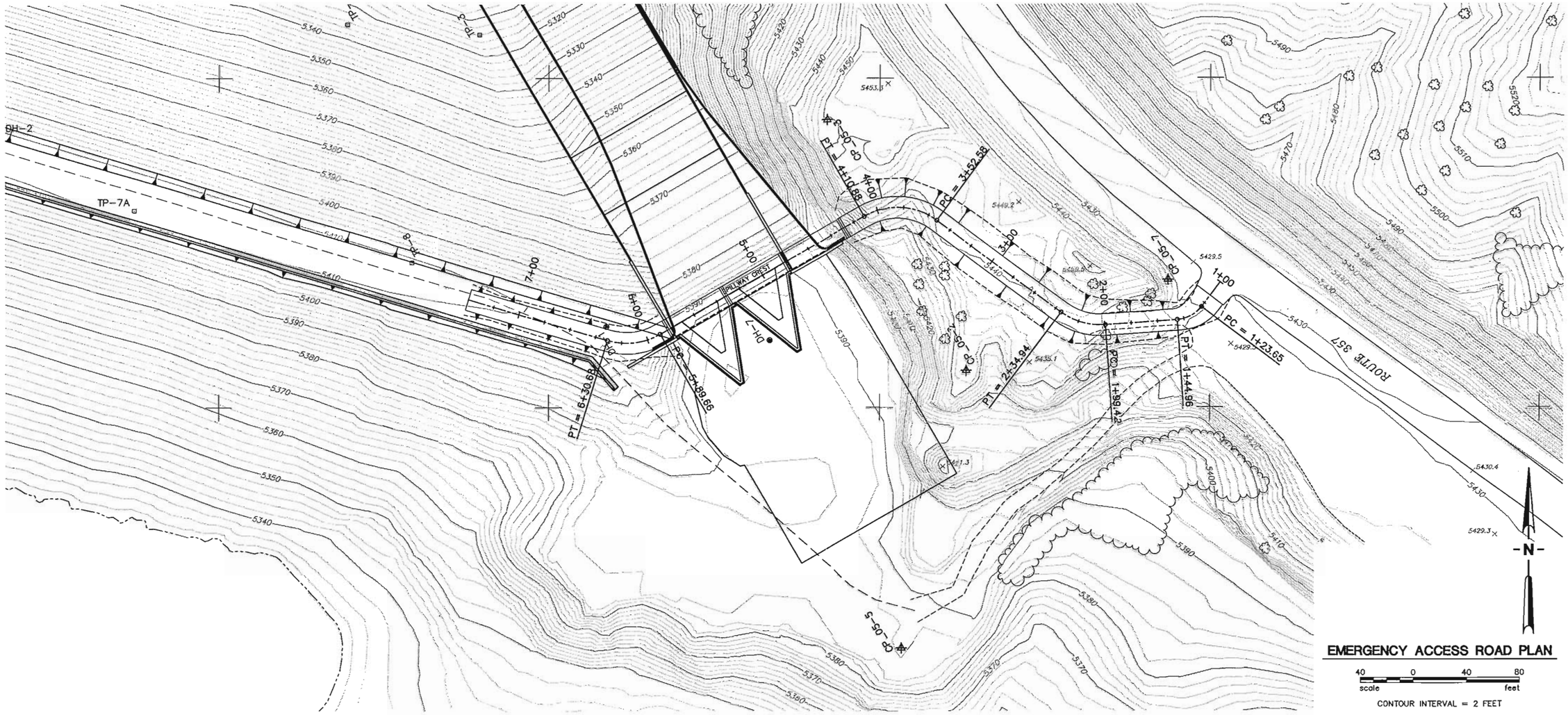
PRELIMINARY NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No. OW1-2 of 3

O:\08\M087175\dwg\Prelim\NEW OW1-2.DWG 9/28/2006 2:48:24 PM MST

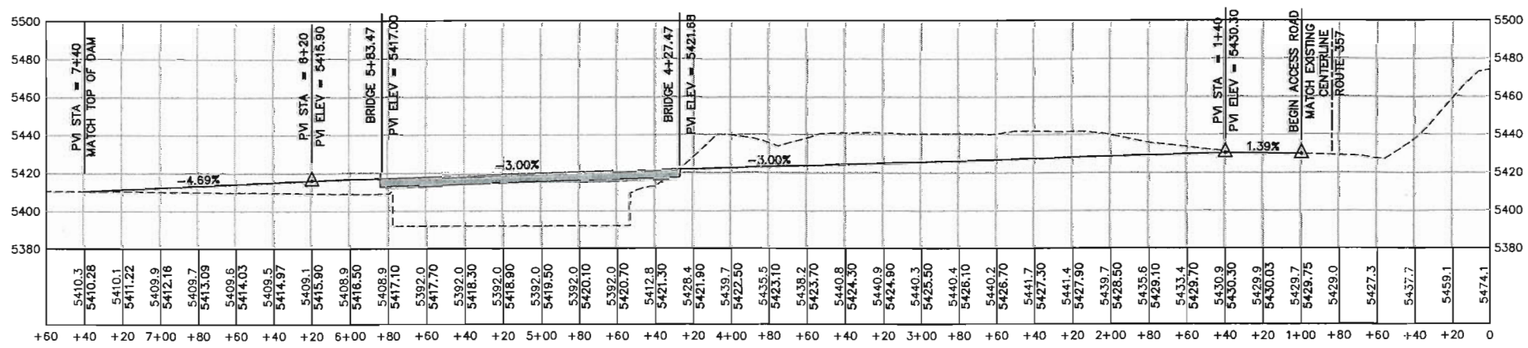
Copyright © 2006 HKM Engineering Inc., All Rights Reserved.



EMERGENCY ACCESS ROAD PLAN

40 0 40 80
scale feet

CONTOUR INTERVAL = 2 FEET



EMERGENCY ACCESS ROAD PROFILE

40 0 40 80
scale feet

No.	Revision	By	Date

WARNING
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

EMERGENCY ACCESS ROAD PLAN
OPTION OW1

● Project No. 8M087.175 ● NEW OW1-3.dwg ● Date SEPT. 2006 ● Designed JHT ● Drawn KK ● Checked JHT ● Approved JHT

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St. Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

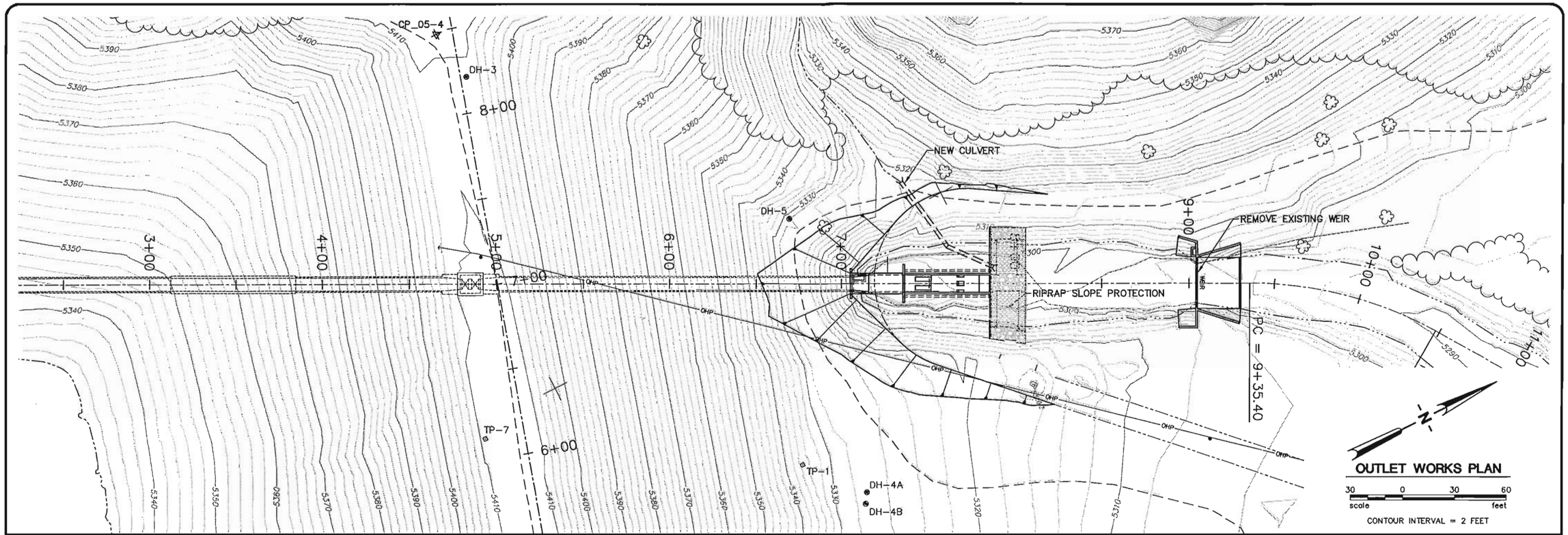
Sheet No.
OW1-3
of 3

Q:\08\M087175\dwg\PrelOpt\NEW OW1-3.DWG 9/28/2006 2:49:30 PM MST

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

APPENDIX C2

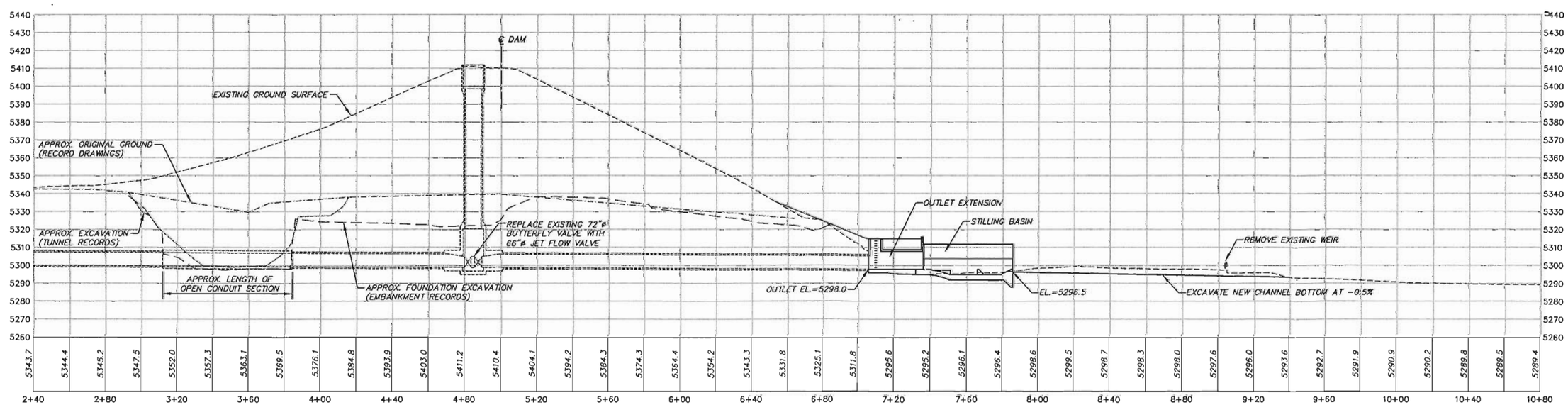
ALTERNATIVE OW2 DRAWINGS



OUTLET WORKS PLAN

30 0 30 60
scale feet

CONTOUR INTERVAL = 2 FEET



OUTLET WORKS PROFILE

30 0 30 60
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS PLAN AND PROFILE
OPTION OW2

PRELIMINARY
NOT FOR CONSTRUCTION

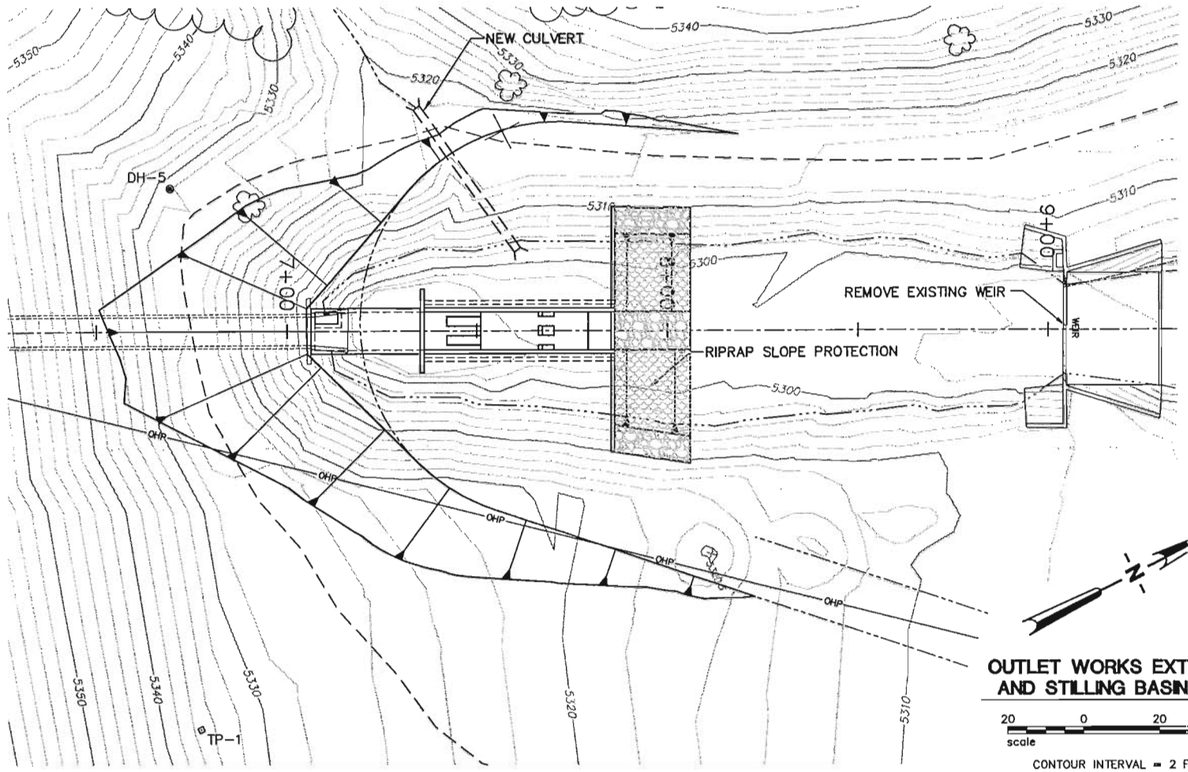
HKM ENGINEERING
Granite Tower Building
2271 Zoot Ski Ski
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW2-1
of 3

• Project No. 8M087.175 • NEW OW2-1.DWG • Date SEPT. 2006 • Designed JHT • Drawn GAE • Checked JHT • Approved JHT

Q:\08\M087175\dwg\PrelOpt\NEW OW2-1.DWG 9/28/2006 2:45:33 PM MST

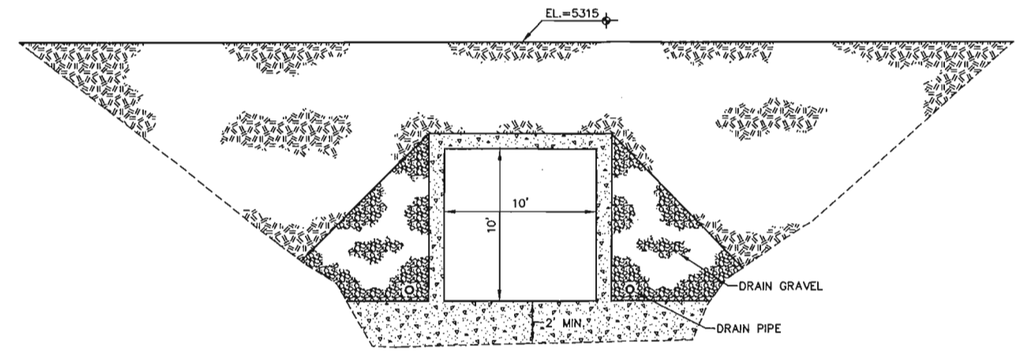
Copyright © 2006 HKM Engineering Inc., All Rights Reserved.



OUTLET WORKS EXTENSION AND STILLING BASIN PLAN

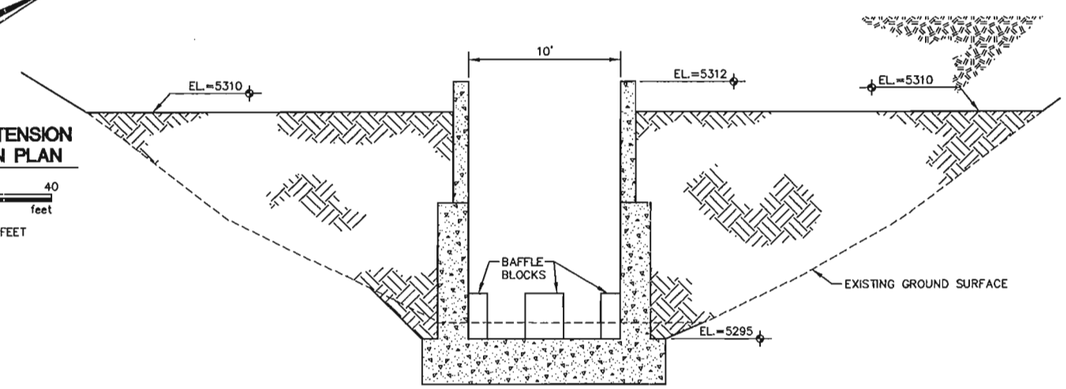
20 0 20 40
scale feet

CONTOUR INTERVAL = 2 FEET



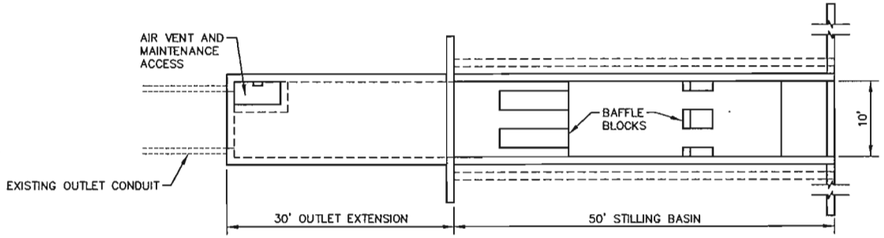
A SECTION
OW2-2 | OW2-2 OUTLET EXTENSION

5 0 5 10
scale feet



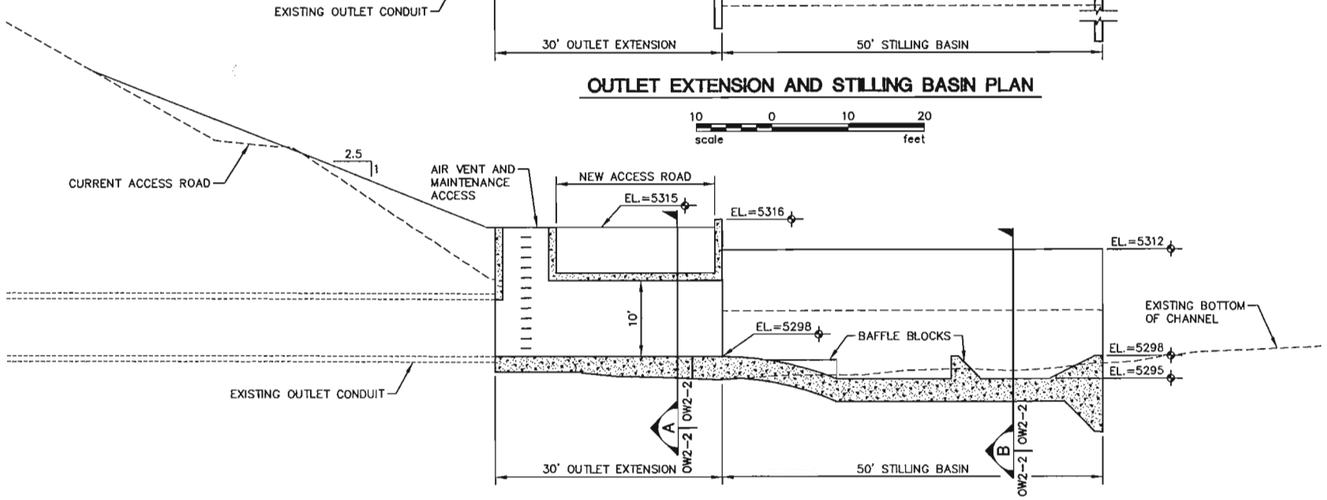
B SECTION
OW2-2 | OW2-2 STILLING BASIN

5 0 5 10
scale feet



OUTLET EXTENSION AND STILLING BASIN PLAN

10 0 10 20
scale feet



OUTLET EXTENSION AND STILLING BASIN PROFILE

10 0 10 20
scale feet

Q:\08\M087175\dwg\PrefOpt\NEW OW2-2.DWG 9/28/2006 2:44:20 PM MST

● Project No. 8M087.175 ● NEW OW2-2.DWG ● Date SEPT. 2006 ● Designed JHT ● Drawn GAE ● Checked JHT ● Approved JHT

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

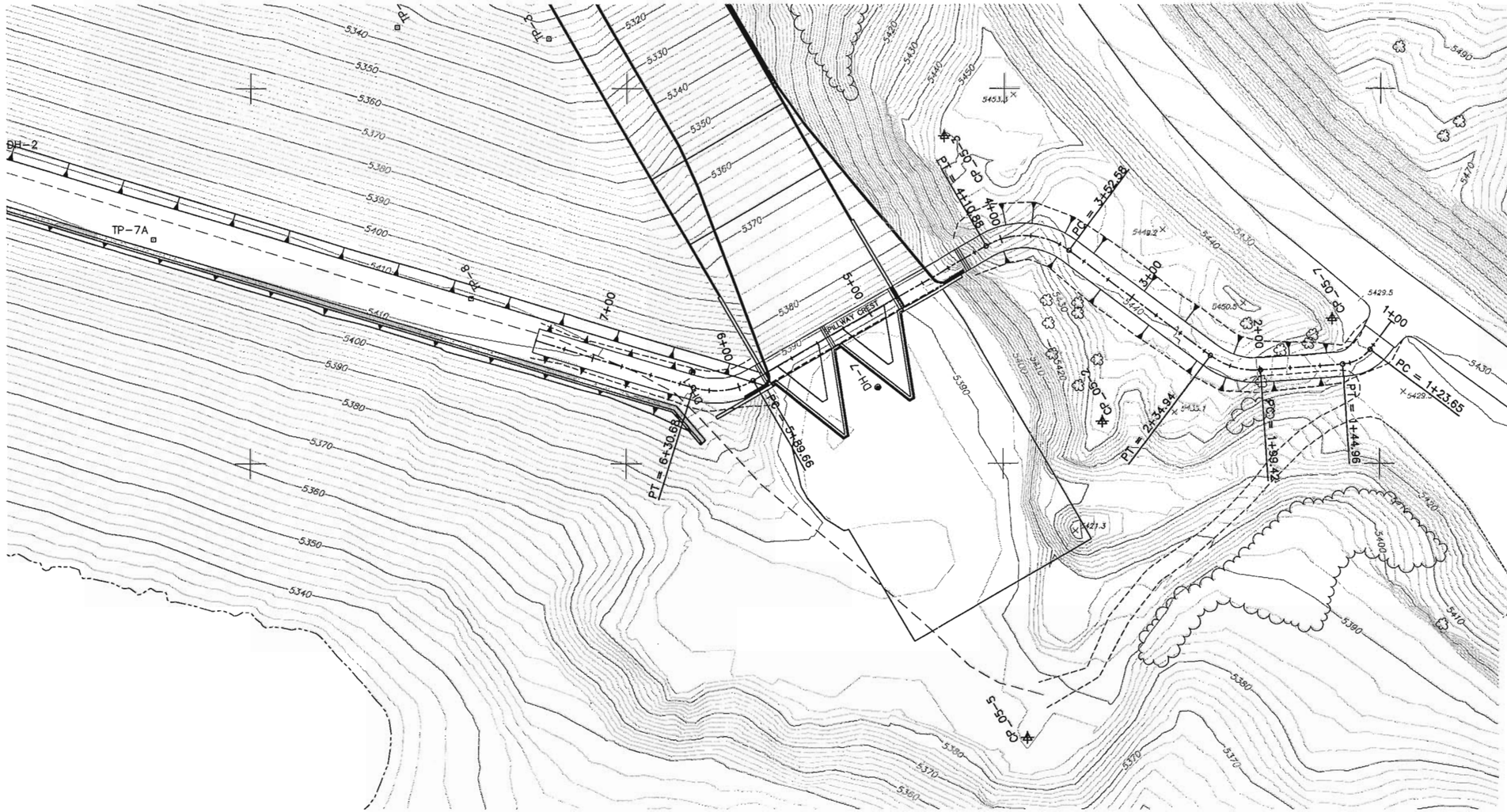
OUTLET WORKS EXTENSION AND STILLING BASIN
OPTION OW2

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW2-2
of 3

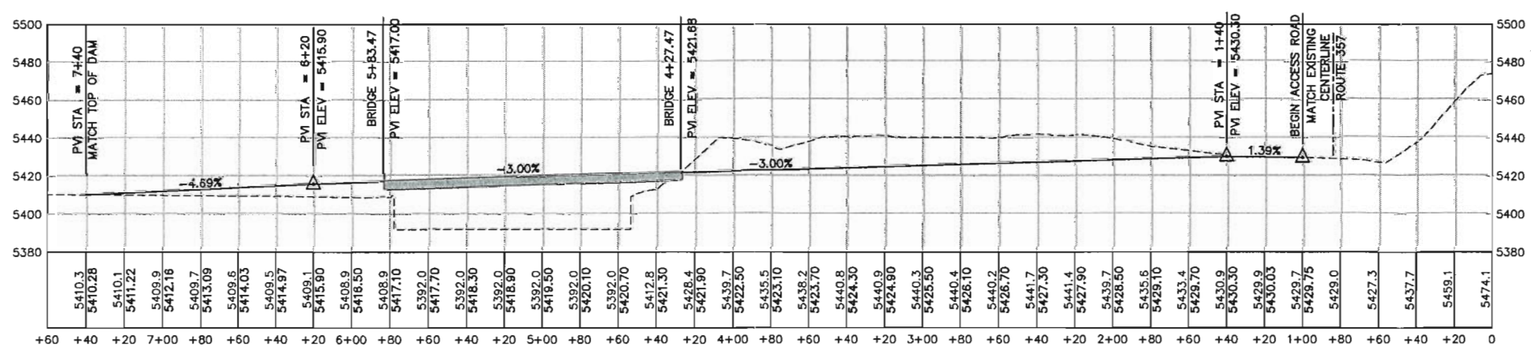
Copyright © 2006 HKM Engineering Inc., All Rights Reserved.



EMERGENCY ACCESS ROAD PLAN

40 0 40 80
scale feet

CONTOUR INTERVAL = 2 FEET



EMERGENCY ACCESS ROAD PROFILE

40 0 40 80
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

EMERGENCY ACCESS ROAD PLAN
OPTION OW2

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW2-3
of 3

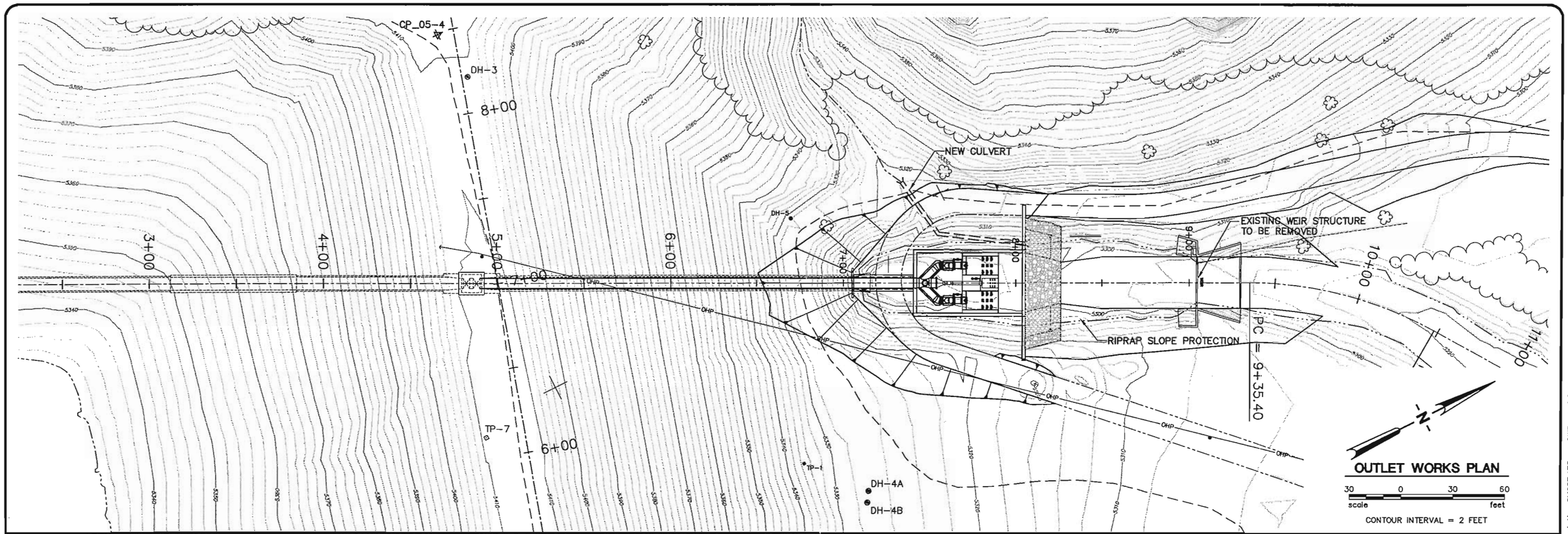
● Project No. 8M087.175 ● NEW OW2-3.dwg ● Date SEPT. 2008 ● Designed JHT ● Drawn KK ● Checked JHT ● Approved JHT

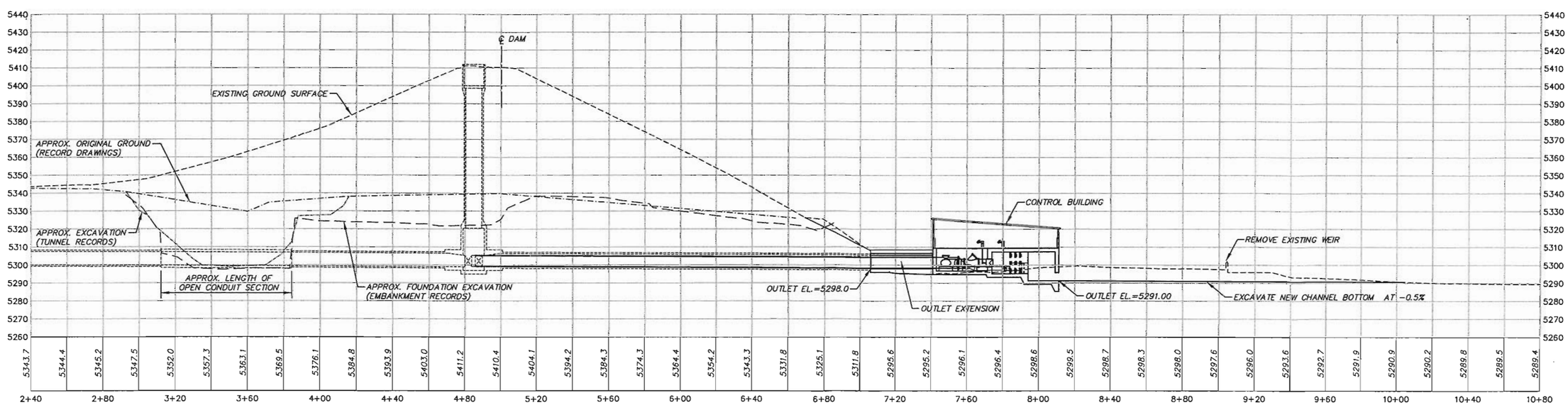
Q:\08\M087175\dwg\PreOpt\NEW OW2-3.DWG 9/28/2008 2:46:44 PM MST

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

APPENDIX C3

ALTERNATIVE OW3A DRAWINGS





No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS PLAN AND PROFILE
OPTION OW3a

• Project No. 8M087.175 • OW3a-1_2.DWG • Date SEPT. 2006 • Designed JHT • Drawn GAE • Checked JHT • Approved JHT

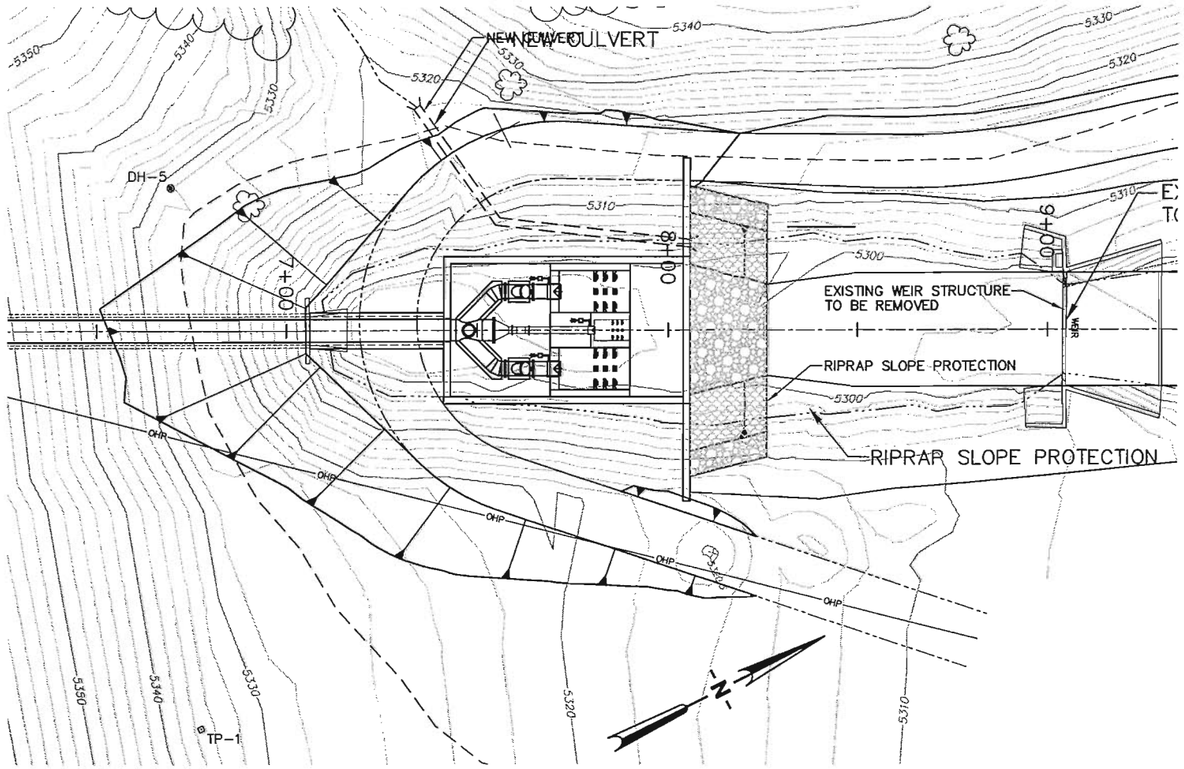
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW3a-1
of 4

D:\08\M087175\dwg\Prelim\OW3a-1_2.DWG 9/29/2006 12:01:01 PM MST

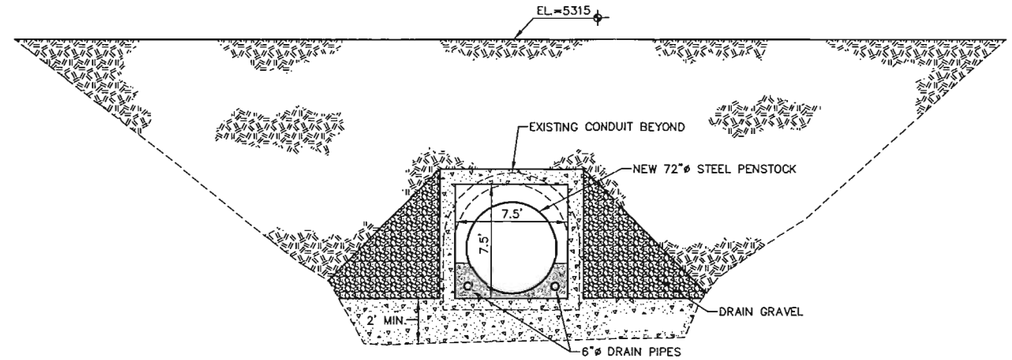
Copyright © 2006 HKM Engineering Inc., All Rights Reserved.



OUTLET WORKS EXTENSION AND STILLING BASIN PLAN

20 0 20 40
scale feet

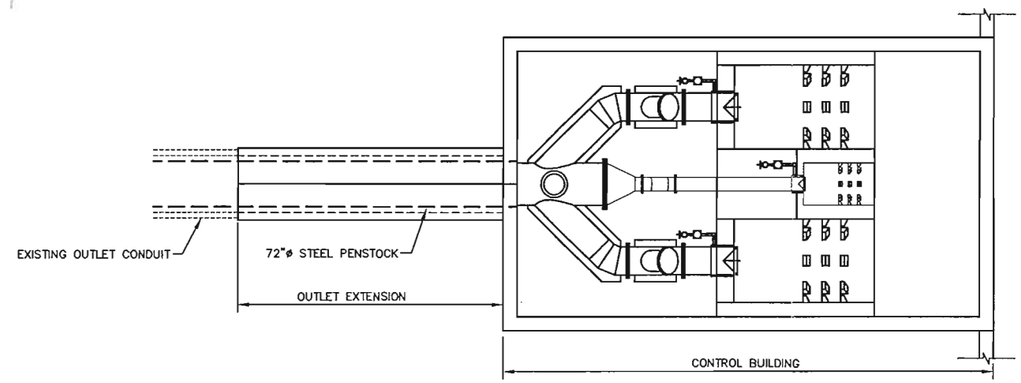
CONTOUR INTERVAL = 2 FEET



A SECTION

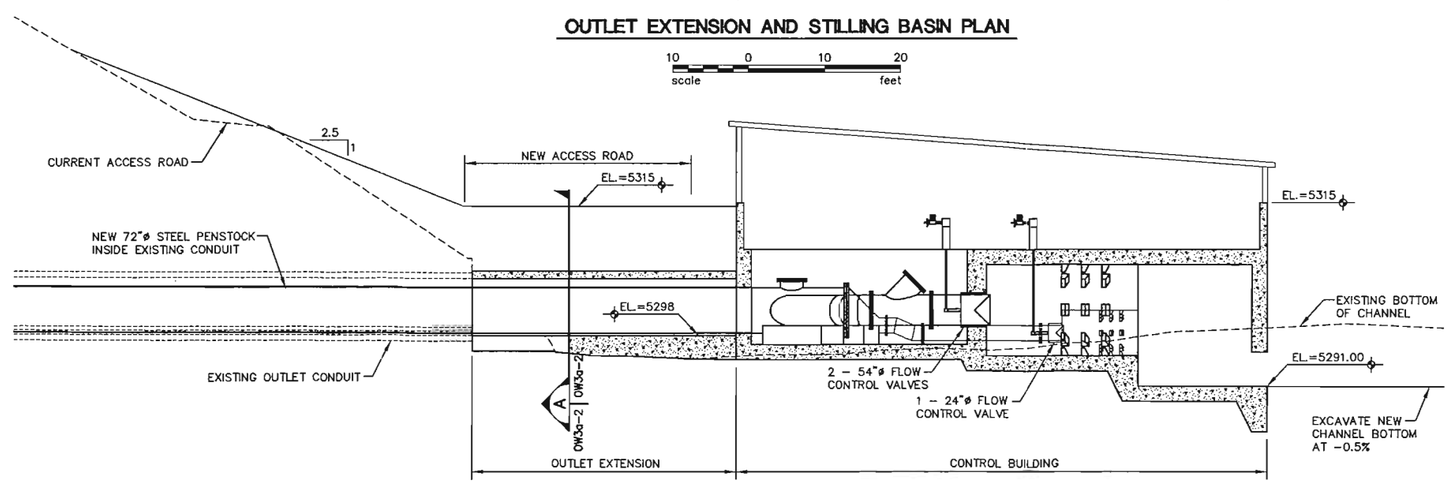
OW3a-2 | OW3a-2 OUTLET EXTENSION

5 0 5 10
scale feet



OUTLET EXTENSION AND STILLING BASIN PLAN

10 0 10 20
scale feet



OUTLET EXTENSION AND STILLING BASIN PROFILE

10 0 10 20
scale feet

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

Q:\08\M087175\dwg\PreOpt\OW3a-1_2.DWG 9/29/2006 12:01:01 PM MST

● Project No. 8M087.175 ● OW3a-1_2.DWG ● Date SEPT. 2006 ● Designed JHT ● Drawn GAE ● Checked JHT ● Approved JHT

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

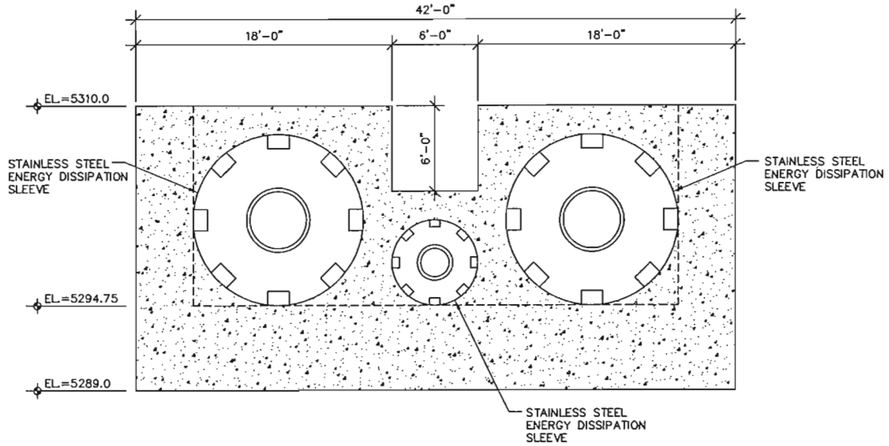
RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS EXTENSION & CONTROL BUILDING
OPTION OW3a

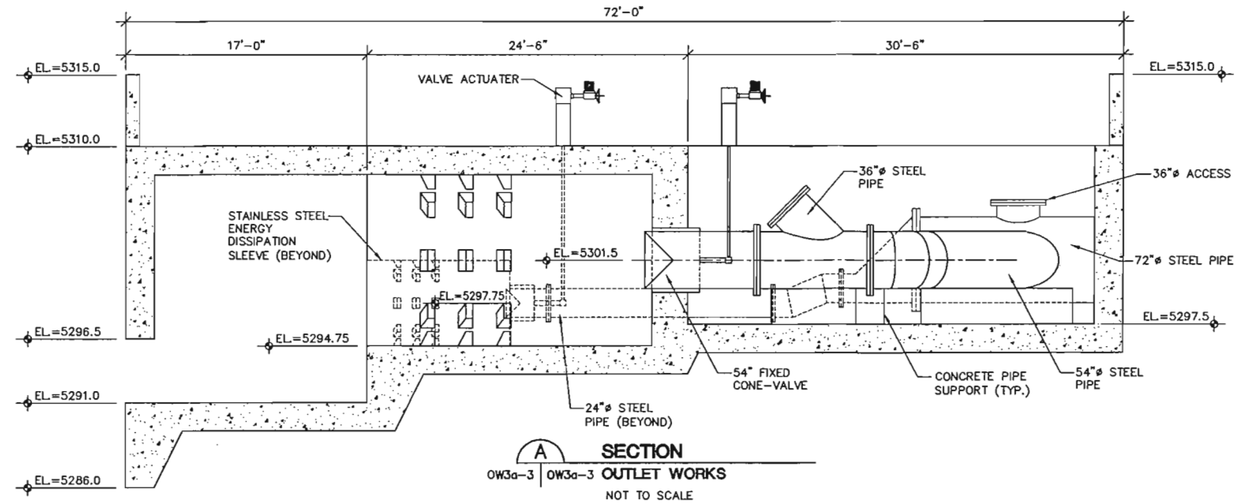
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

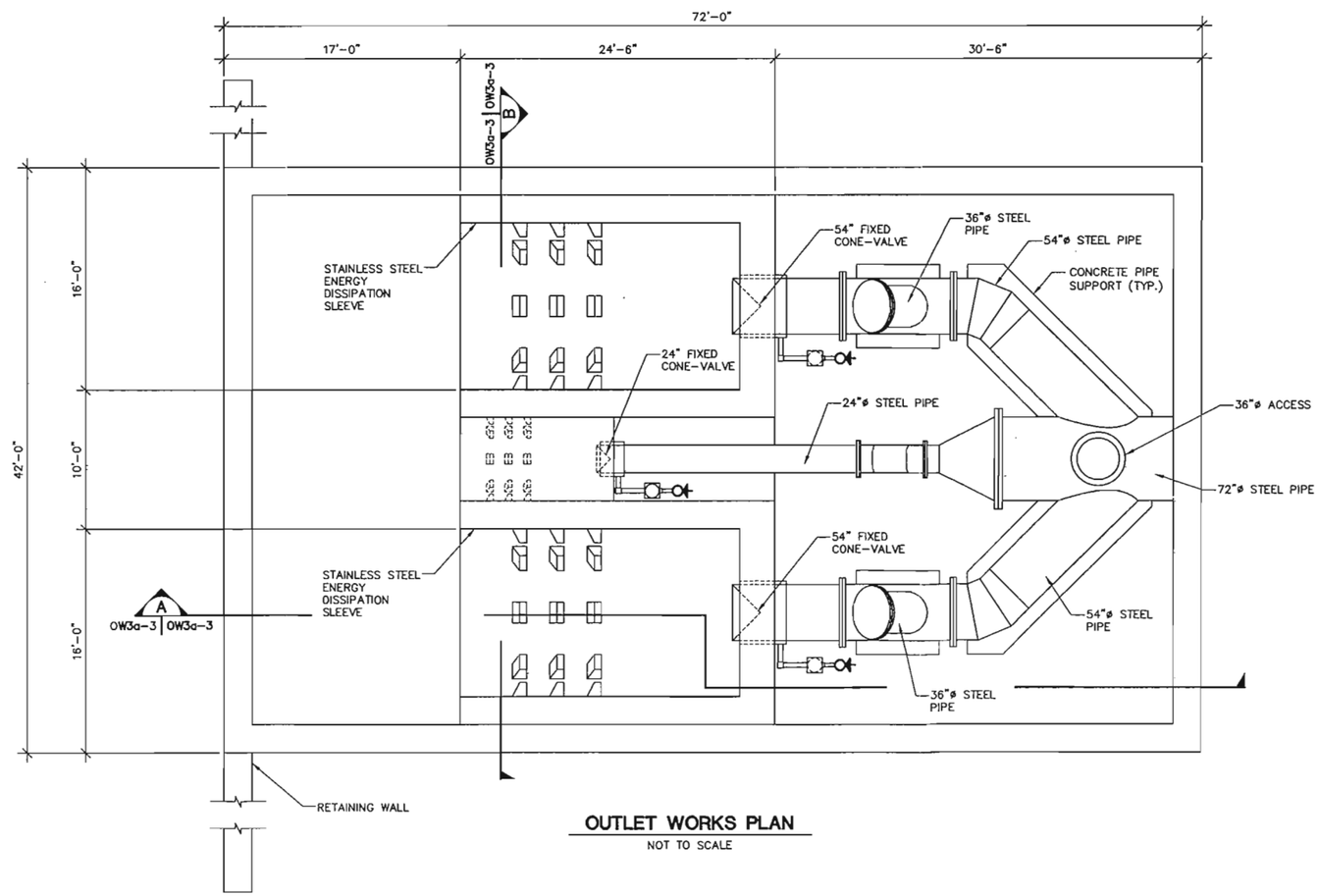
Sheet No.
OW3a-2
of 4



B SECTION
OW3a-3 | OW3a-3 OUTLET WORKS
NOT TO SCALE



A SECTION
OW3a-3 | OW3a-3 OUTLET WORKS
NOT TO SCALE



OUTLET WORKS PLAN
NOT TO SCALE

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

● Project No. 8M087.175 ● OW3a-3.DWG ● Date SEPT. 2006 ● Designed KJF ● Drawn DNM ● Checked KJF ● Approved JHT

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

CONTROL BUILDING
OPTION OW3a

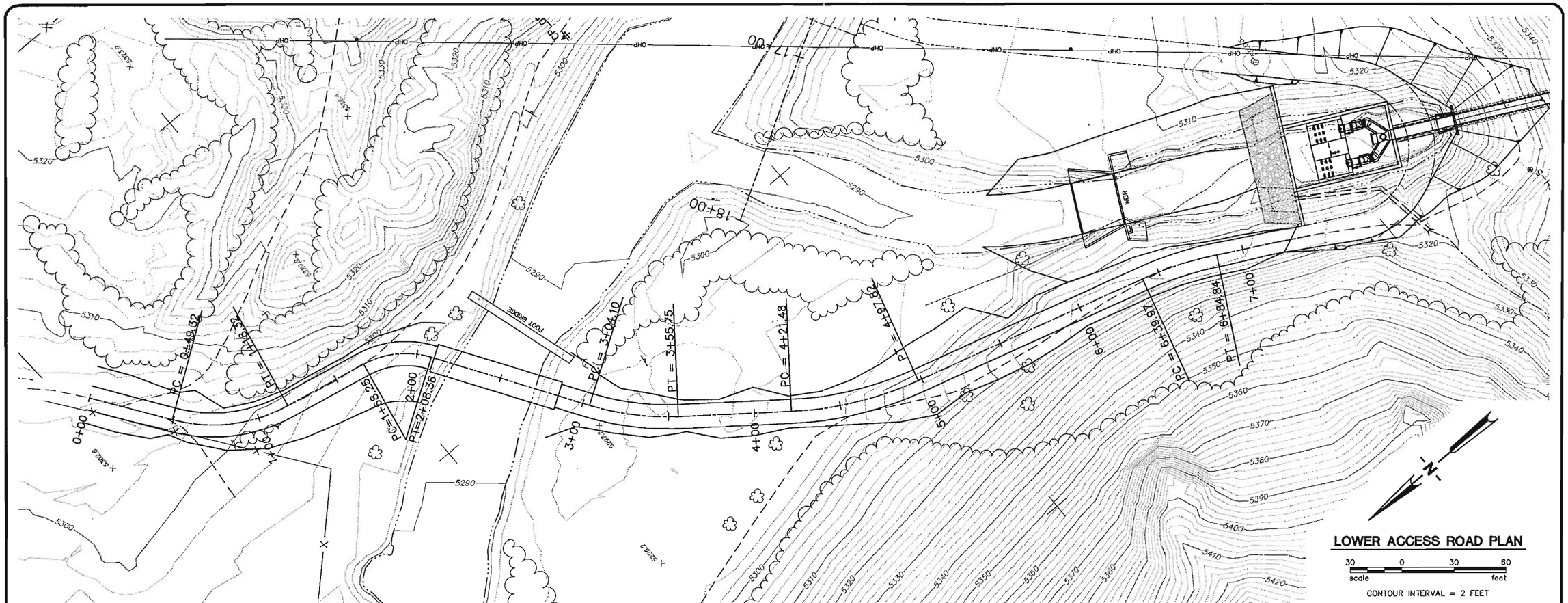
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW3a-3
of 4

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

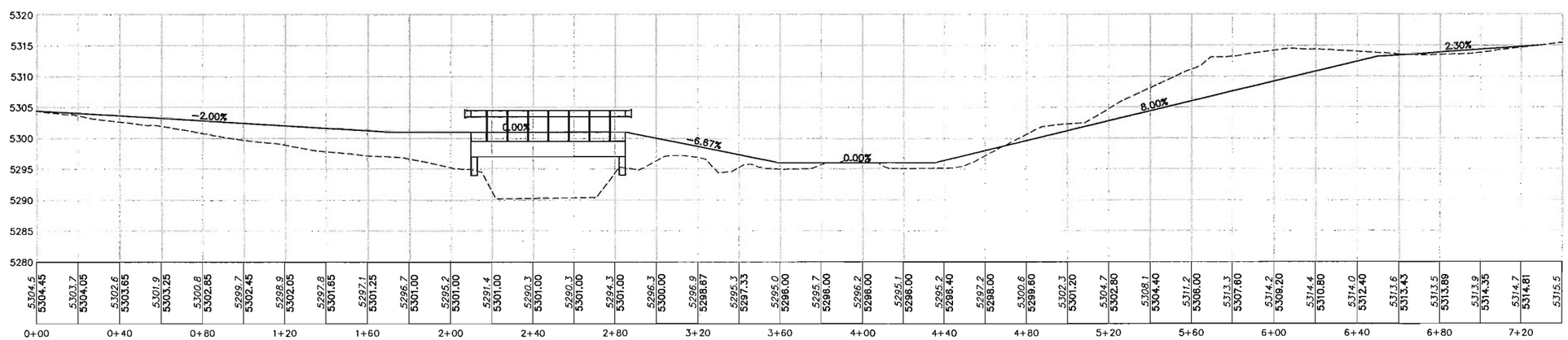
Q:\08\M087175\dwg\PrefOpt\OW3a-3.dwg 9/29/2006 11:59:29 AM MST



LOWER ACCESS ROAD PLAN

30 0 30 60
scale feet

CONTOUR INTERVAL = 2 FEET



LOWER ACCESS ROAD PROFILE

30 0 30 60 HORIZ.
scale feet

10 0 10 20 VERT.
scale feet

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

No.	Revision	By	Date

● Project No. 8M087.175 ● OW3a-4.dwg ● Date SEPT. 2006 ● Designed KJF ● Drawn GAE ● Checked JHT ● Approved JHT

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

LOWER ACCESS ROAD
OPTION OW3a

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

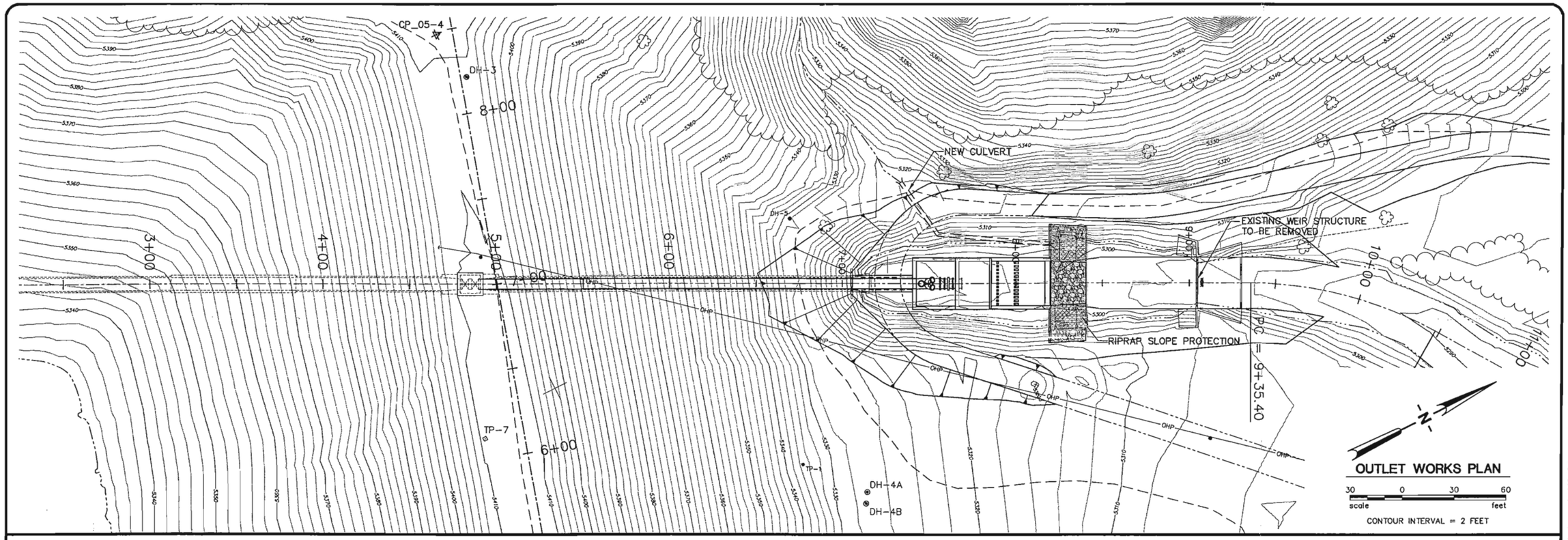
Sheet No.
OW3a-4
of 4

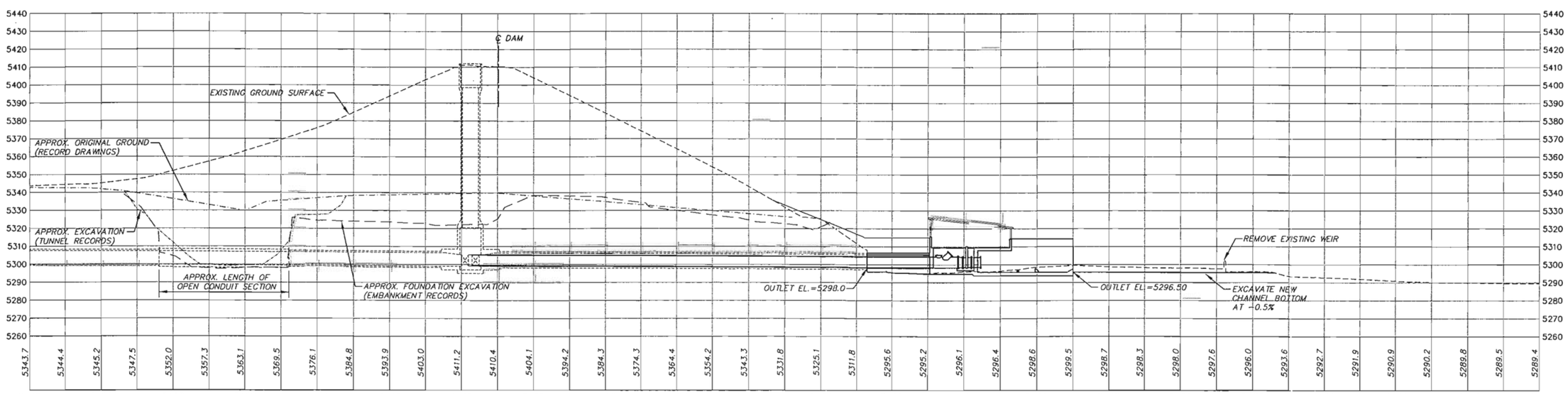
Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

Q:\08\M087175\dwg\Prelim\OW3a-4.dwg 9/29/2006 11:02:47 AM MST

APPENDIX C4

ALTERNATIVE OW3C DRAWINGS





No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

• Project No. 8M087.175 • OW3c1_2.DWG • Date SEPT. 2006 • Designed JHT • Drawn GAE • Checked JHT • Approved JHT

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS PLAN AND PROFILE
OPTION OW3c

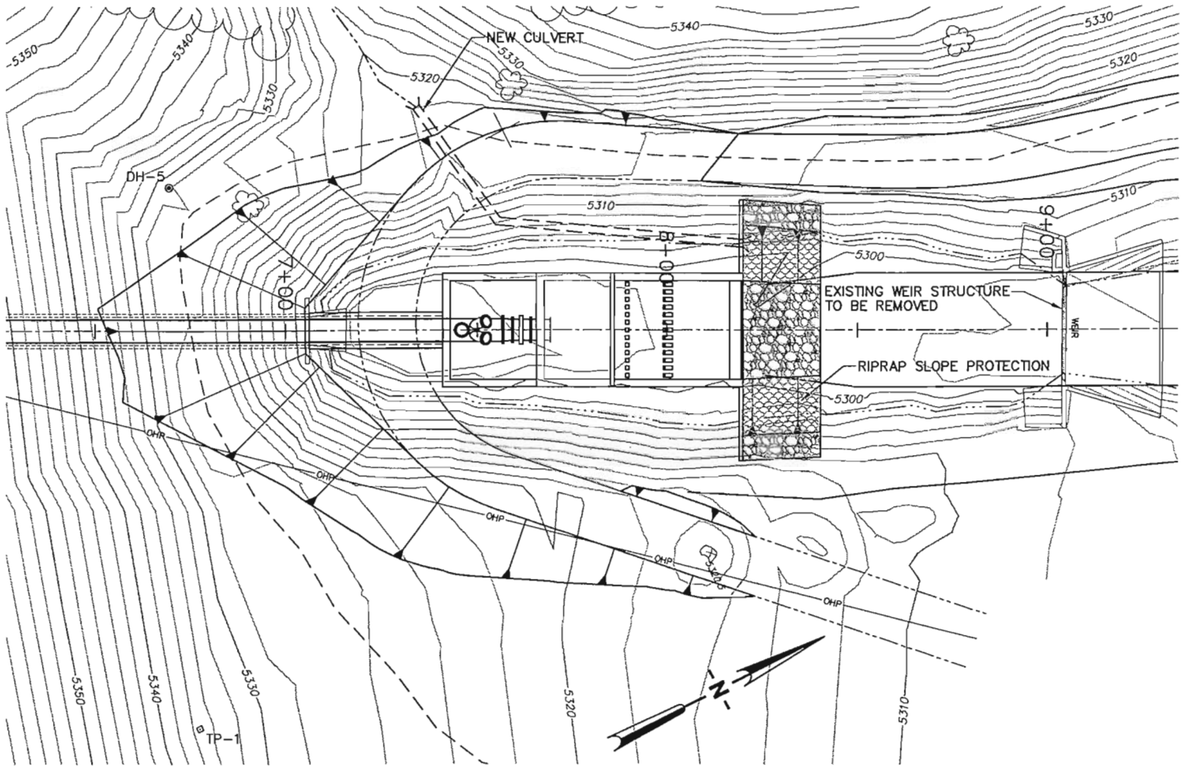
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
Billings, MT 59101
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW3c-1
of 4

Q:\08\M087175\dwg\Prelim\OW3c-1_2.DWG 9/29/2006 12:03:56 PM MST

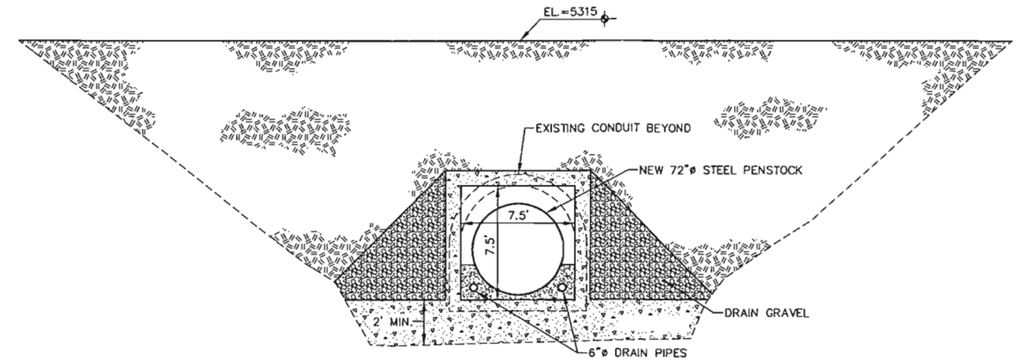
Copyright © 2006 HKM Engineering Inc., All Rights Reserved.



OUTLET WORKS EXTENSION AND STILLING BASIN PLAN

20 0 20 40
scale feet

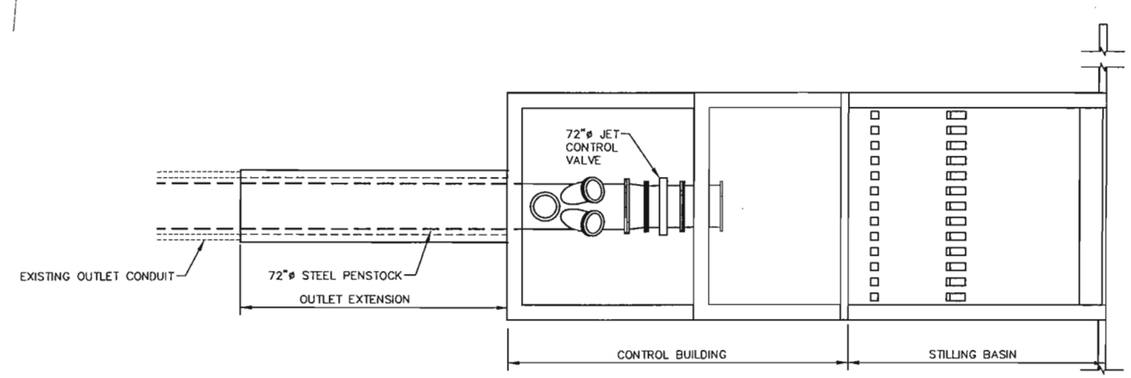
CONTOUR INTERVAL = 2 FEET



A SECTION

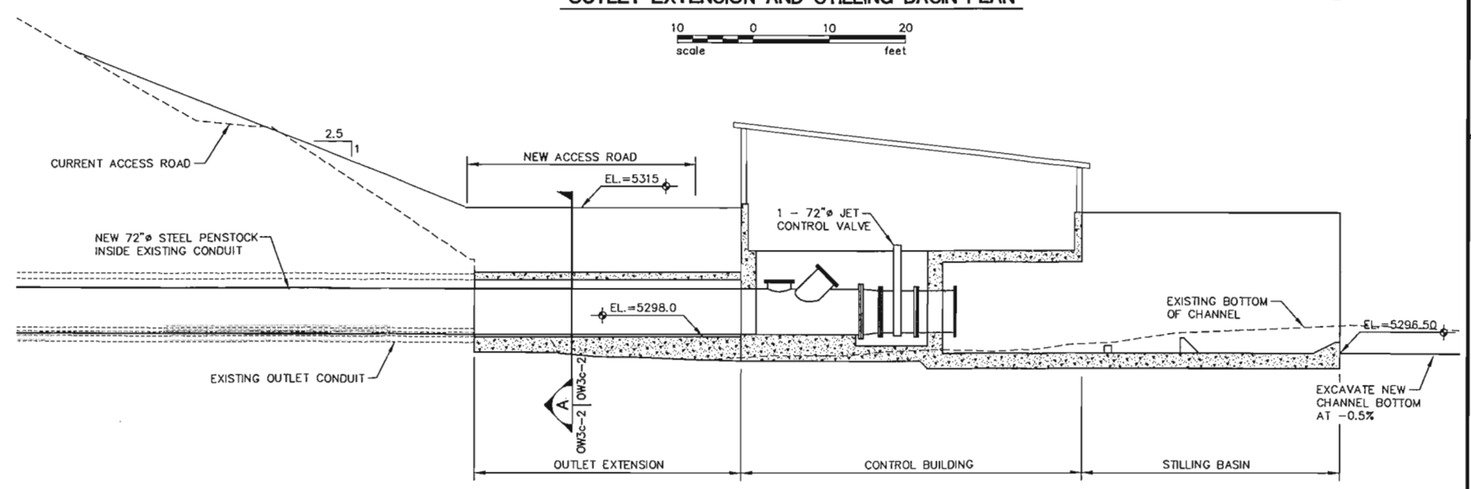
OW3c-2 | OW3c-2 OUTLET EXTENSION

5 0 5 10
scale feet



OUTLET EXTENSION AND STILLING BASIN PLAN

10 0 10 20
scale feet



OUTLET EXTENSION AND STILLING BASIN PROFILE

10 0 10 20
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS EXTENSION & CONTROL BUILDING
OPTION OW3c

• Project No. 8M087.175 • OW3c-1_2.DWG • Date SEPT. 2006 • Designed JHT • Drawn GAE • Checked JHT • Approved JHT

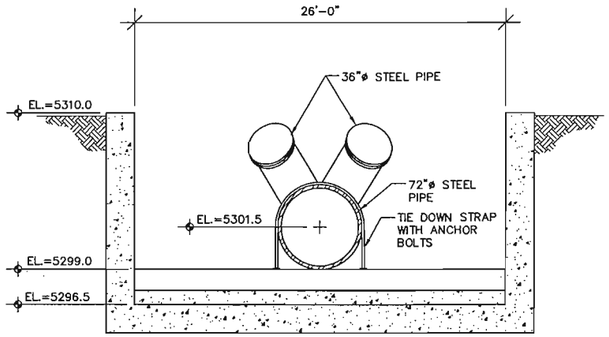
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 2318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

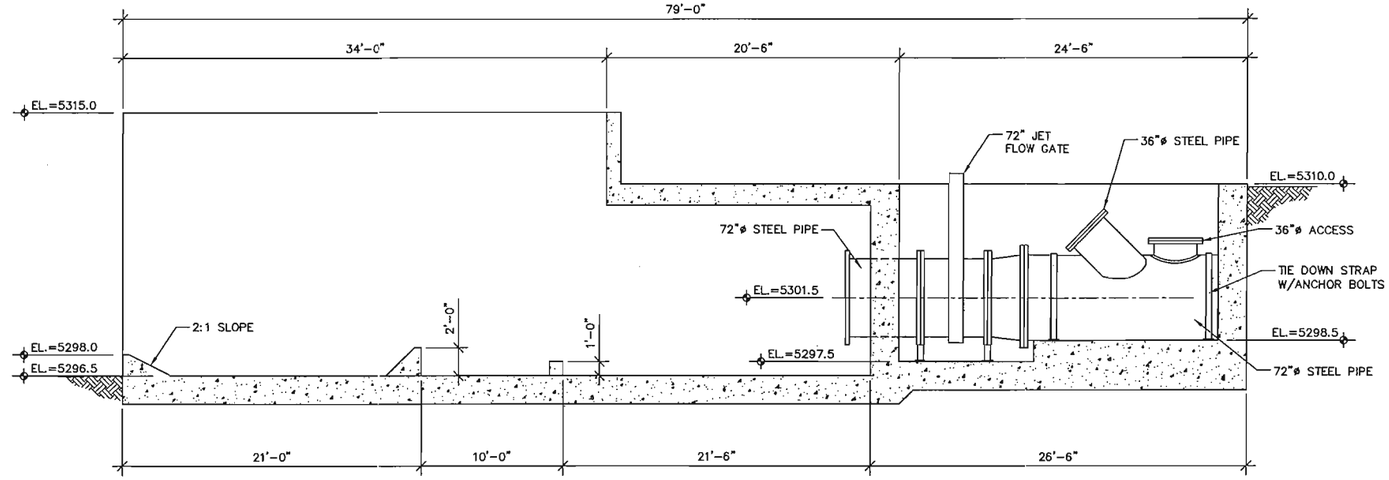
Sheet No.
OW3c-2
of 4

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

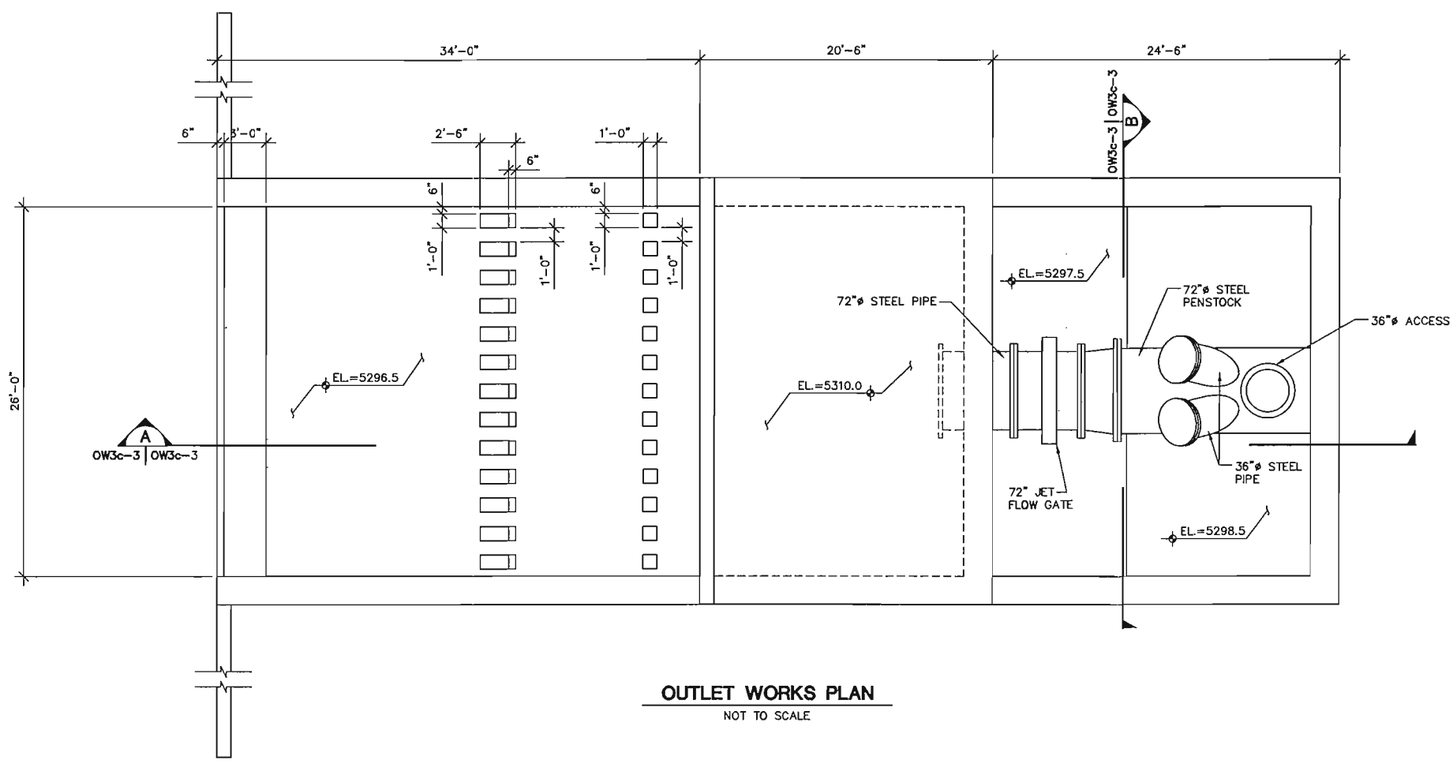
Q:\08\M087175\dwg\Prelim\OW3c-1_2.DWG 9/29/2006 12:03:56 PM MST



B SECTION
OW3c-3 | OW3c-3 OUTLET WORKS
NOT TO SCALE



A SECTION
OW3c-3 | OW3c-3 OUTLET WORKS
NOT TO SCALE



OUTLET WORKS PLAN
NOT TO SCALE

PRELIMINARY
NOT FOR CONSTRUCTION

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

CONTROL BUILDING
OPTION OW3c

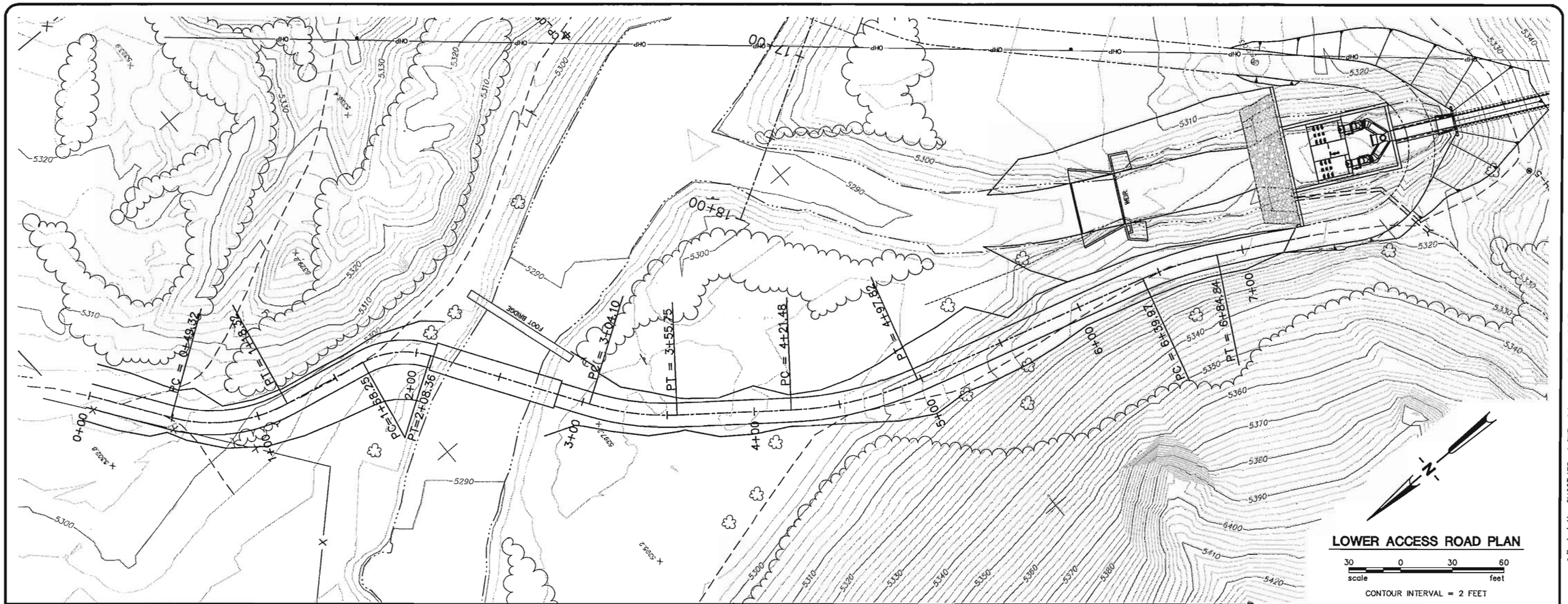
HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

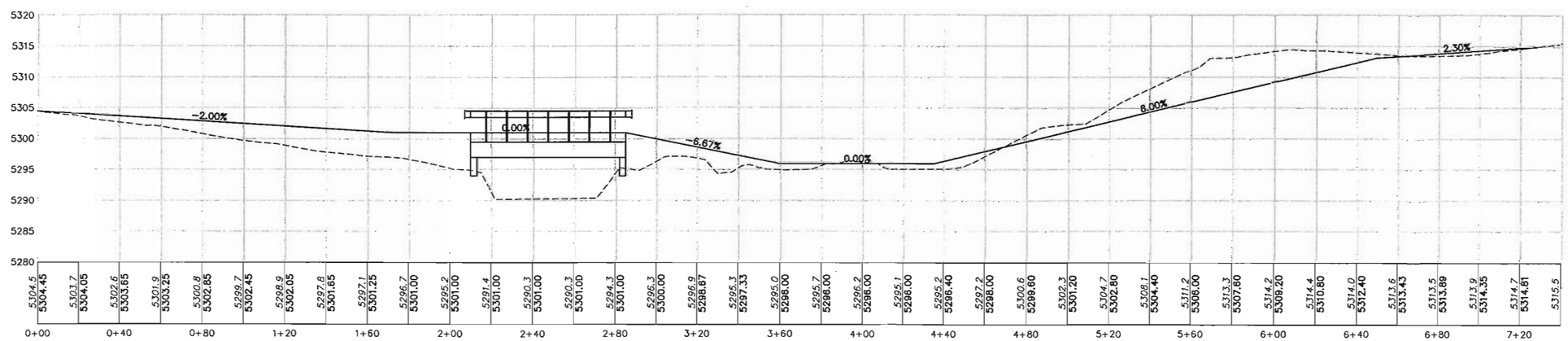
Sheet No.
OW3c-3
of 4

Project No. 8M087.175 • OW3c-3.DWG • Date SEPT. 2006 • Designed KJF • Drawn DNM • Checked KJF • Approved JHT

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

Q:\08\M087175\dwg\Prelim\OW3c-3.dwg 9/29/2006 12:18:35 PM MST





LOWER ACCESS ROAD PROFILE

30 0 30 60 HORIZ.
scale feet

10 0 10 20 VERT.
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

Project No. 8M087.175 • OW3c-4.dwg • Date SEPT. 2006 • Designed KJF • Drawn GAE • Checked JHT • Approved JHT

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

LOWER ACCESS ROAD
OPTION OW3c

PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

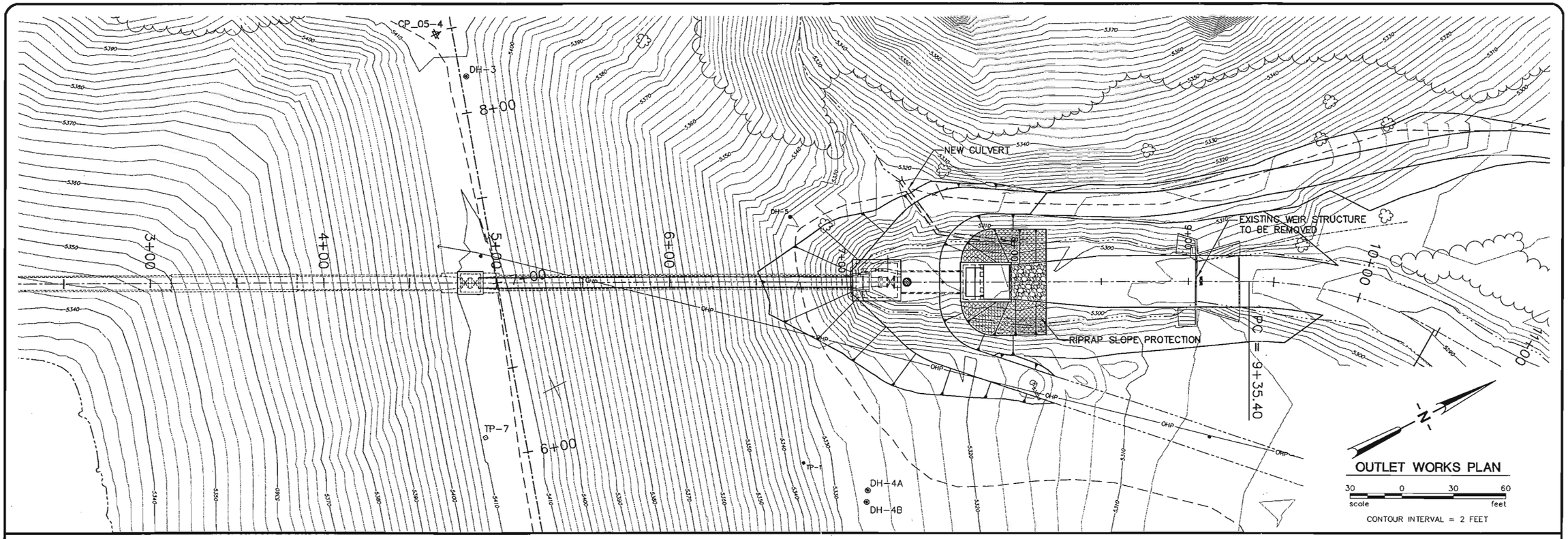
Sheet No.
OW3c-4
of 4

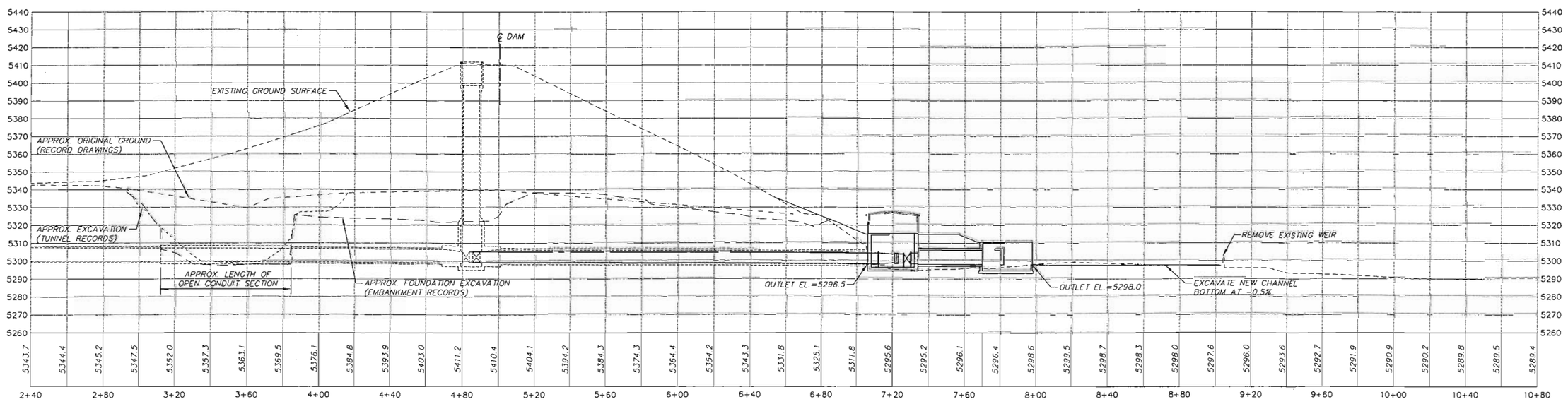
Q:\08\M087175\dwg\Prelfig1\ow3C-4.dwg 9/29/2006 10:50:27 AM MST

Copyright © 2006 HKM Engineering Inc., All Rights Reserved.

APPENDIX C5

ALTERNATIVE OW4 DRAWINGS





No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

• Project No. BM087.175 • OW4.DWG • Date JULY 2007 • Designed JHT • Drawn GAE • Checked JHT • Approved JHT

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS PLAN AND PROFILE
OPTION OW4

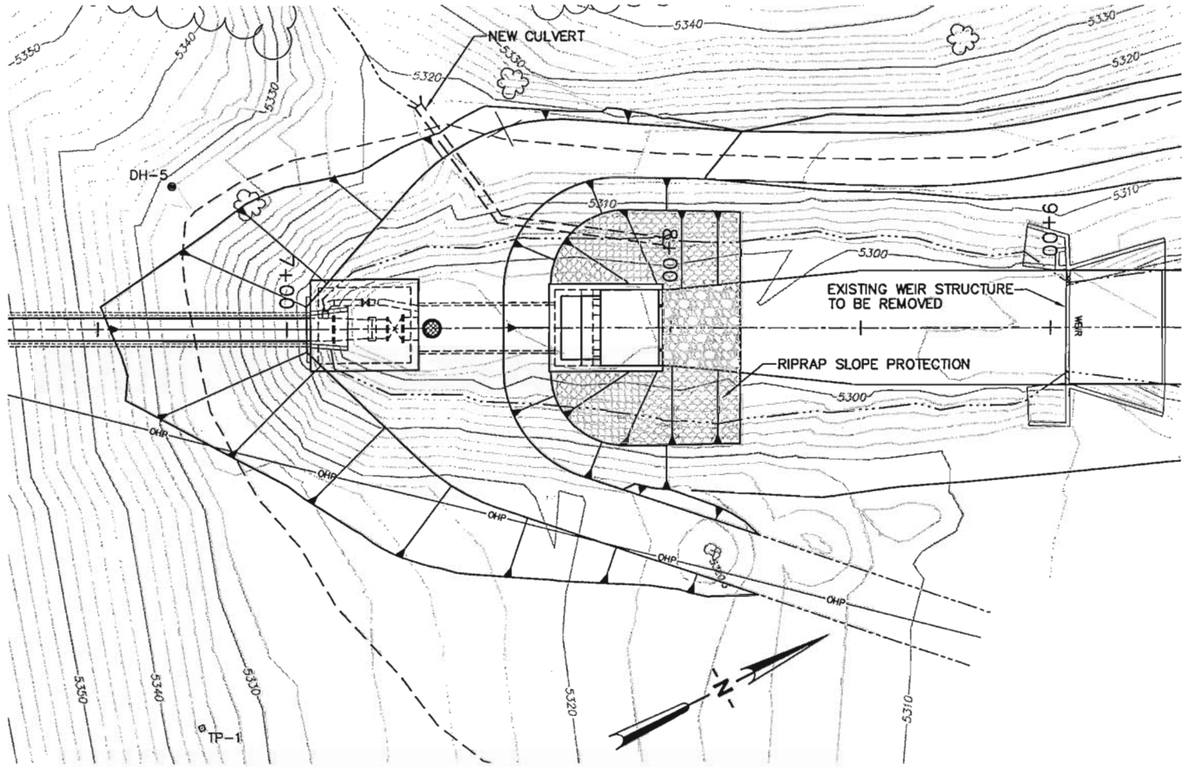
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW4-1
of 5

Q:\08\M087175\dwg\OutletWorks\OW4.DWG 9/17/2007 1:44:57 PM MDT

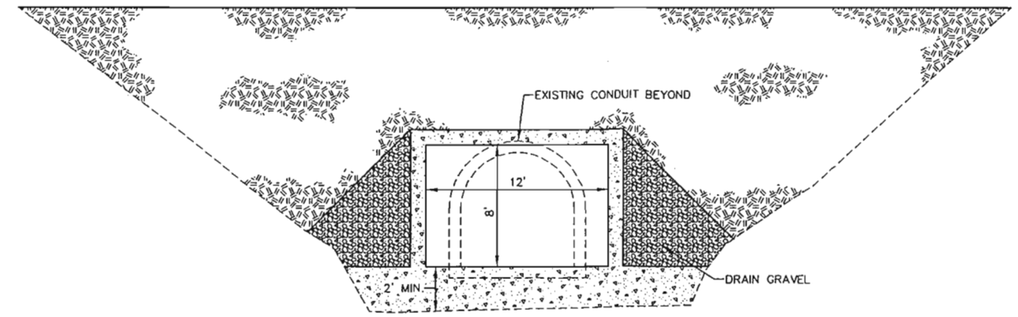
Copyright © 2007 HKM Engineering Inc., All Rights Reserved.



OUTLET WORKS EXTENSION AND STILLING BASIN PLAN

20 0 20 40
scale feet

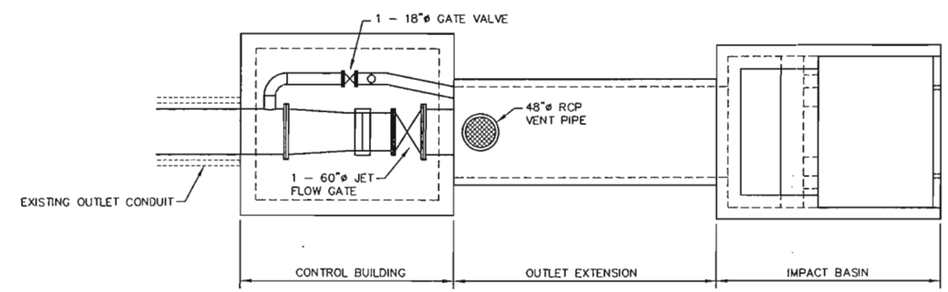
CONTOUR INTERVAL = 2 FEET



A SECTION

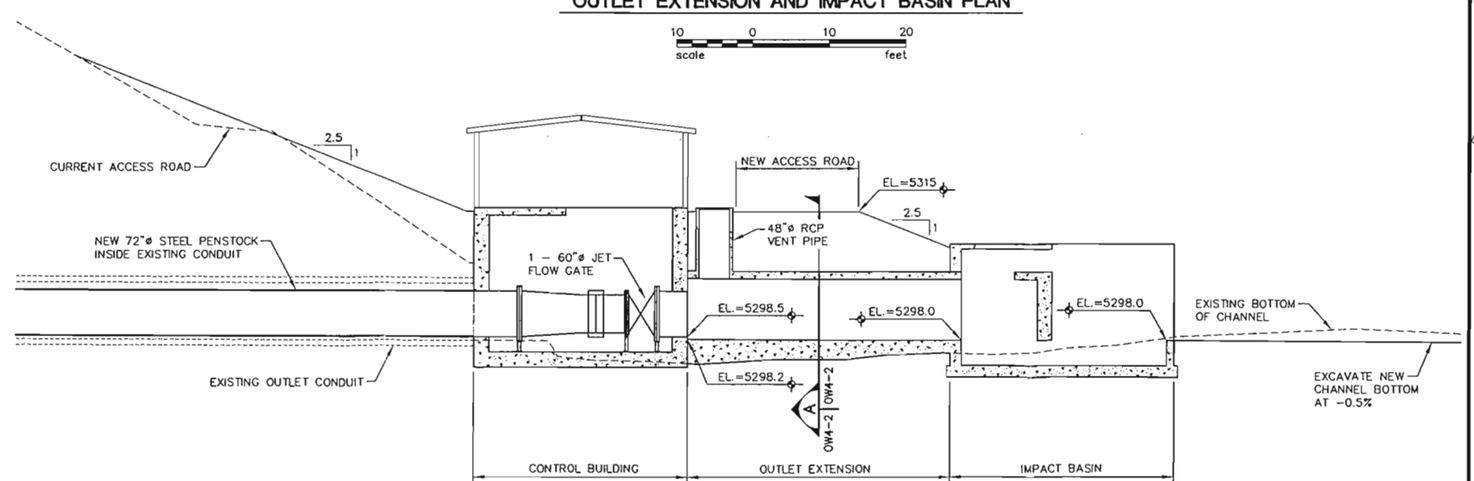
OW4-2 | OW4-2 OUTLET EXTENSION

5 0 5 10
scale feet



OUTLET EXTENSION AND IMPACT BASIN PLAN

10 0 10 20
scale feet



OUTLET EXTENSION AND IMPACT BASIN PROFILE

10 0 10 20
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS EXTENSION & CONTROL BUILDING
OPTION OW4

• Project No. 8M087.175 • OW4.DWG • Date JULY 2007 • Designed JHT • Drawn GAE • Checked JHT • Approved JHT

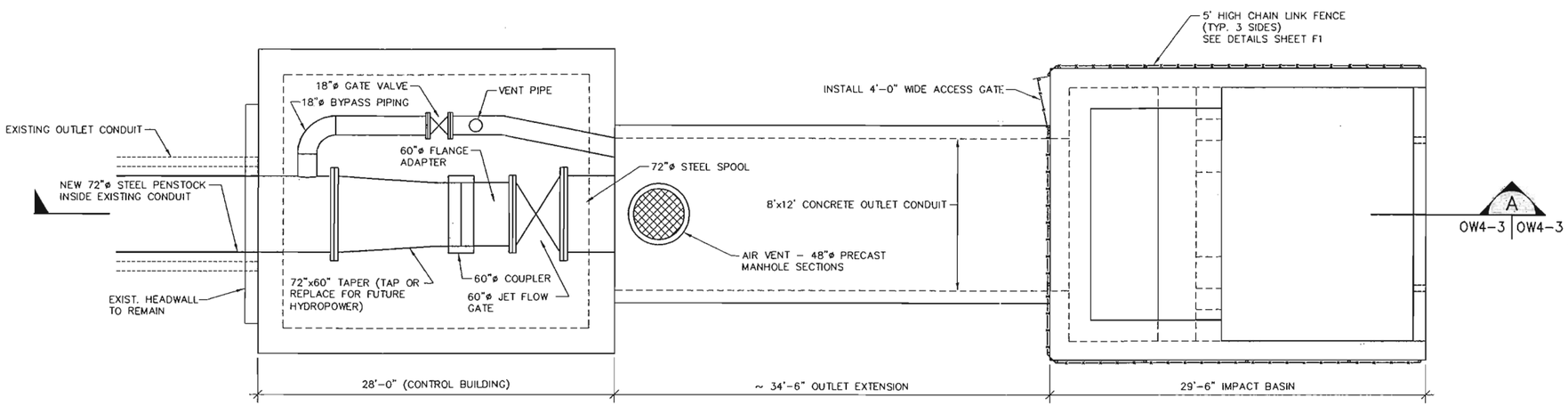
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW4-2
of 5

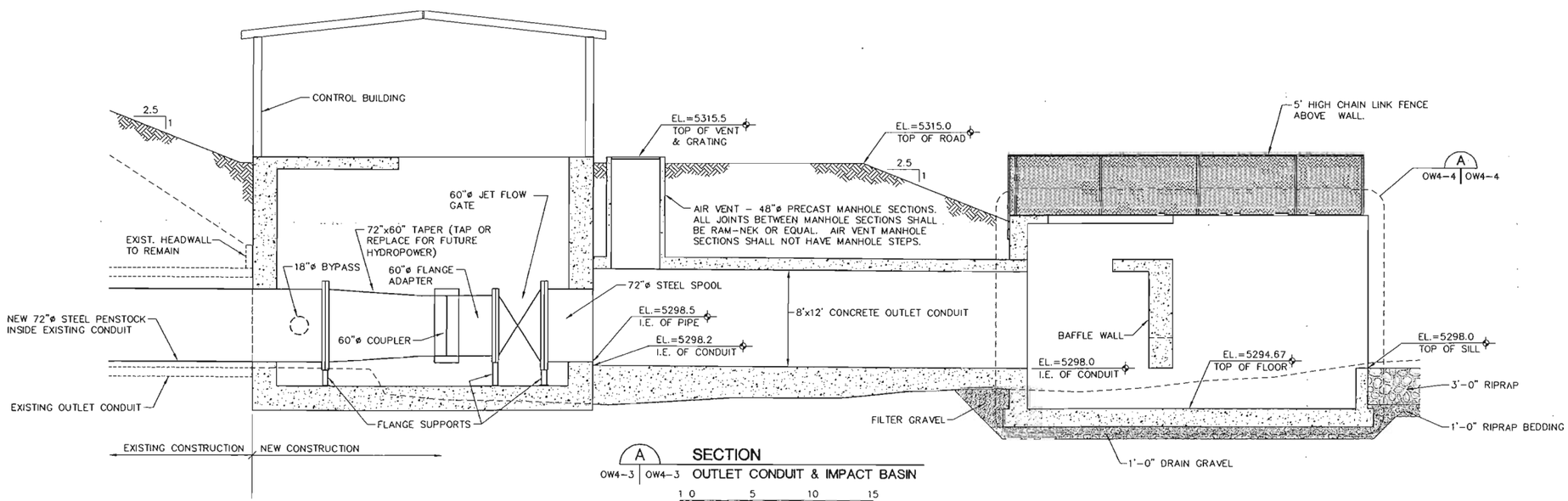
O:\08\M087175\dwg\Prelim\OW3c-1_2.DWG 9/29/2006 12:03:56 PM MST

Copyright © 2007 HKM Engineering Inc., All Rights Reserved.



PLAN VIEW
OUTLET CONDUIT & IMPACT BASIN

1 0 5 10 15
scale feet



A SECTION
OW4-3 | OW4-3 OUTLET CONDUIT & IMPACT BASIN

1 0 5 10 15
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

● Project No. 8M087.175 ● OW4_basin.DWG ● Date JULY 2007 ● Designed JHT ● Drawn GAE ● Checked JHT ● Approved JHT

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET CONTROL BUILDING, CONDUIT & IMPACT BASIN
OPTION OW4

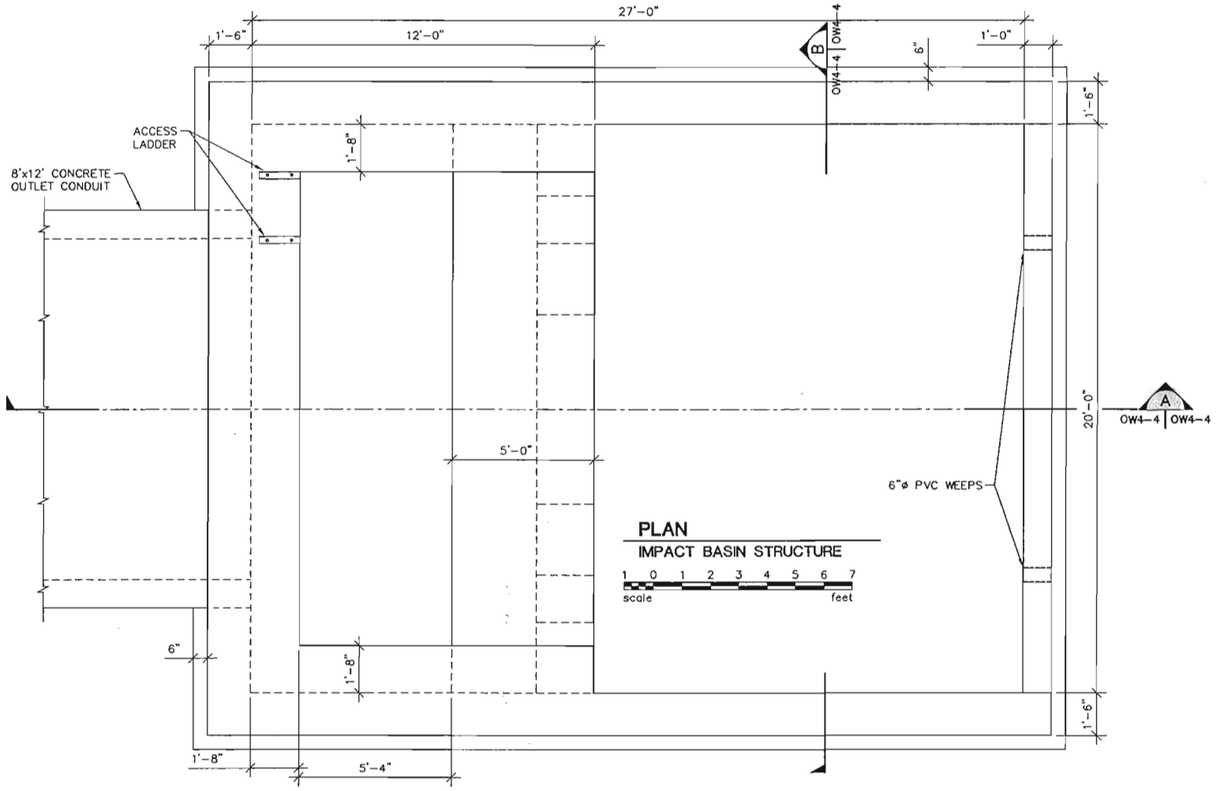
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31313
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW4-3
of 5

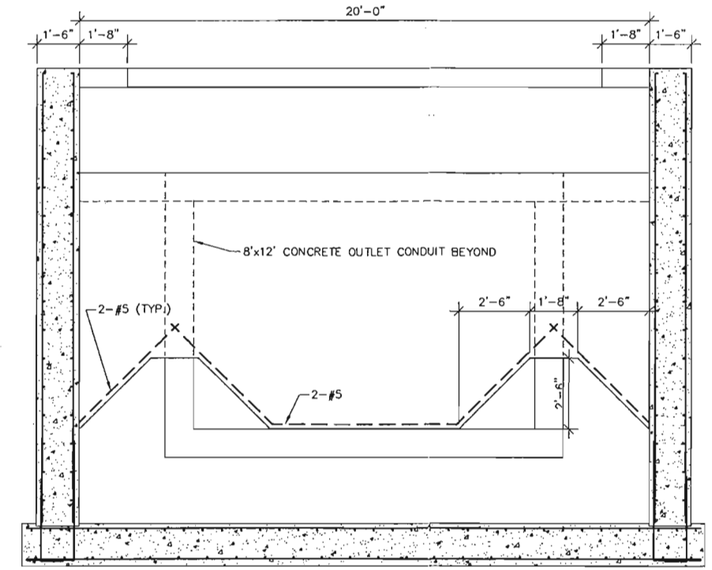
O:\08\M087175\dwg\PrelOpt\OW4_basin.DWG 7/10/2007 5:32:40 PM MDT

Copyright © 2007 HKM Engineering Inc., All Rights Reserved.



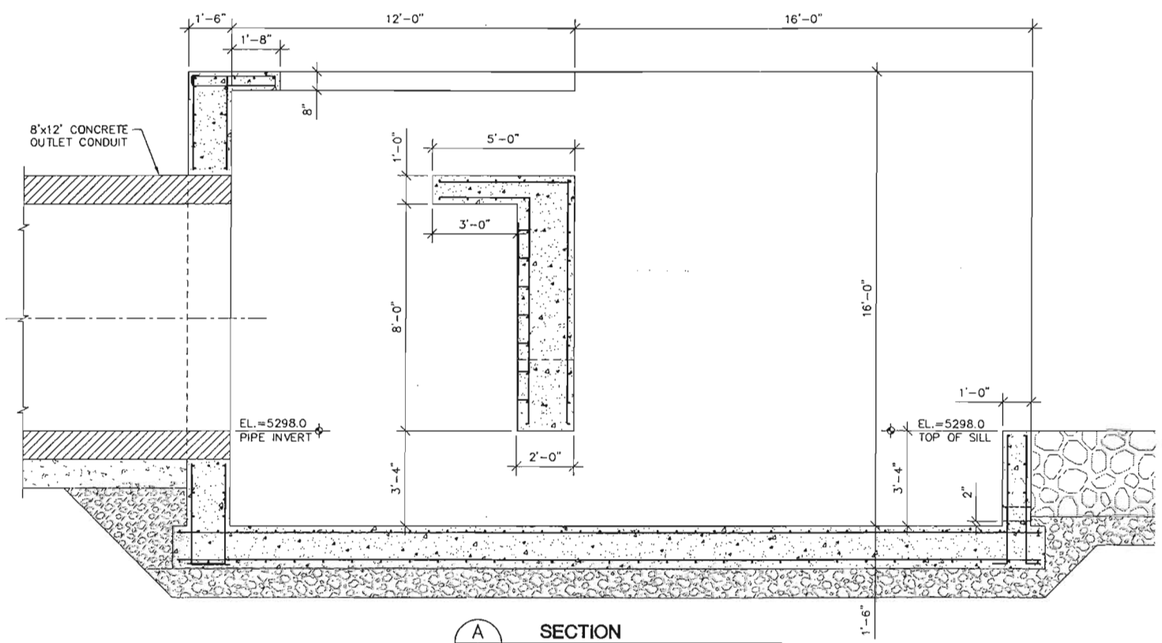
PLAN
IMPACT BASIN STRUCTURE

1 0 1 2 3 4 5 6 7
scale feet



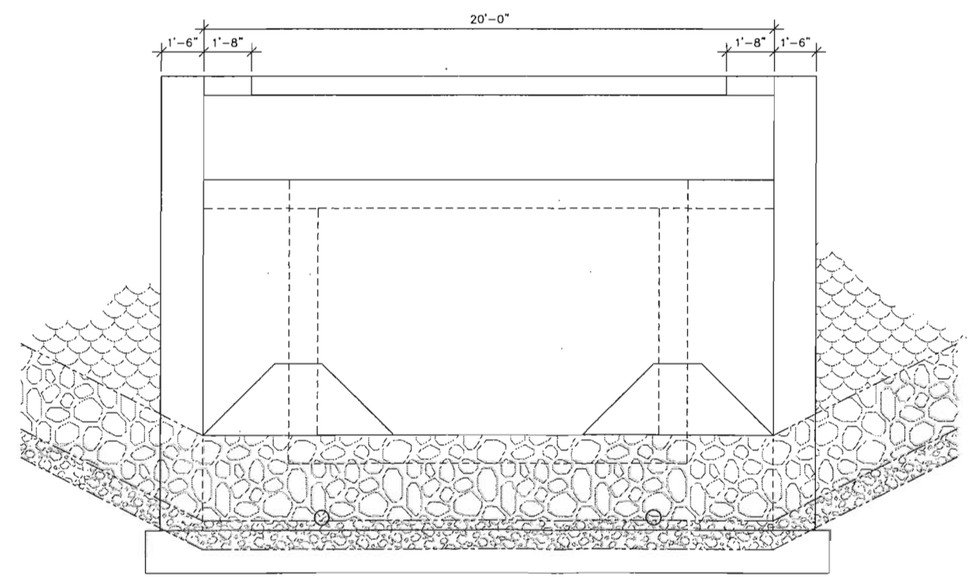
B SECTION
OW4-4 | OW4-4 IMPACT BASIN BAFFLE WALL

1 0 1 2 3 4 5 6 7
scale feet



A SECTION
OW4-4 | OW4-4 IMPACT BASIN STRUCTURE

1 0 1 2 3 4 5 6 7
scale feet



ELEVATION
IMPACT BASIN STRUCTURE

1 0 1 2 3 4 5 6 7
scale feet

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

OUTLET WORKS IMPACT BASIN
OPTION OW4

• Project No. 8M087.175 • OW4_basin.DWG • Date JULY 2007 • Designed JHT • Drawn GAE • Checked JHT • Approved JHT

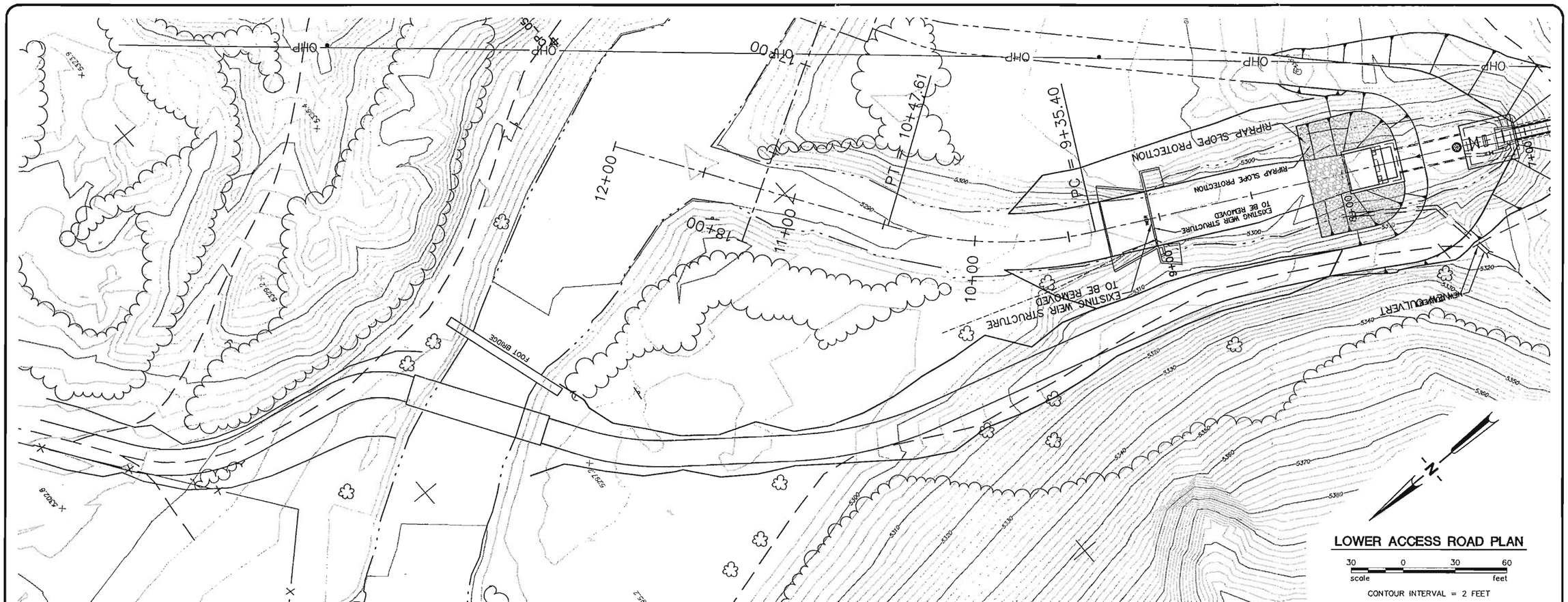
PRELIMINARY
NOT FOR CONSTRUCTION

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW4-4
of 5

O:\08\M087175\dwg\Prelim\OW4_basin.DWG 7/10/2007 5:32:40 PM MDT

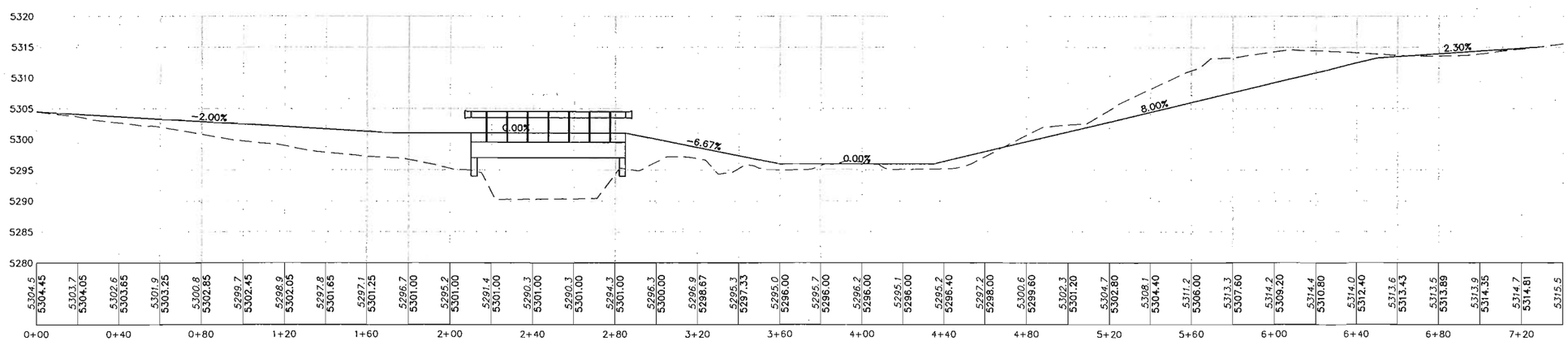
Copyright © 2007 HKM Engineering Inc., All Rights Reserved.



LOWER ACCESS ROAD PLAN

30 0 30 60
scale feet

CONTOUR INTERVAL = 2 FEET



LOWER ACCESS ROAD PROFILE

30 0 30 60 HORIZ.
scale feet

10 0 10 20 VERT.
scale feet

PRELIMINARY
NOT FOR CONSTRUCTION

No.	Revision	By	Date

WARNING
0 ½ 1
IF THIS BAR DOES NOT MEASURE 1" THEN DRAWING IS NOT TO SCALE

RUBY DAM REHABILITATION FEASIBILITY STUDY
MADISON COUNTY, MONTANA

LOWER ACCESS ROAD OPTION OW4

• Project No. 8M087.175 • OW4.dwg • Date SEPT. 2006 • Designed KJF • Drawn GAE • Checked JHT • Approved JHT

HKM ENGINEERING
Granite Tower Building
222 N. 32nd St., Suite 700
P.O. Box 31318
Billings, MT 59107-1318
(406) 656-6399, Fax (406) 656-6398

Sheet No.
OW4-5
of 5

D:\08\M087175\dwg\OutletWorks\OW4.DWG 9/17/2007 1:44:57 PM MDT

APPENDIX D

HENRY FALVEY
RUBY DAM
HYDRAULIC ANALYSIS

11624 Blackfoot Road
Conifer, CO 80433
Tel & Fax: (303) 838-4920
Email: falvey@members.asce.org

Henry T. Falvey & Associates, Inc.

Ruby Dam Hydraulic Analysis

January 24, 2006

Outlet Works Analysis

INTRODUCTION

The outlet works consists of an inlet transition, 380-ft of modified horseshoe conduit, a 6-ft diameter guard gate followed by a 6-ft butterfly valve and about 210-ft of modified horseshoe conduit. The butterfly valve is used for control. A Cipoletti weir located downstream of the outlet creates a backwater on the outlet for flows exceeding 240 cfs. A small air vent connects the downstream horseshoe conduit with the control tower that is located above the valves. The control tower is accessed from the crest of the dam. The modified horseshoe is 7.5-ft wide with a rectangular bottom and has a total height of 7.5-ft.

The current operational guidelines limit the flow to 600 cfs for short duration and 450 cfs for long duration releases. Historically, releases above 450 cfs have resulted in cavitation damage to the butterfly valve.

Analysis by DNRC indicated that a discharge of 1000 to 1500 cfs is needed to provide adequate reservoir evacuation capacity. The maximum capacity of the outlet works from the DNRC Operation & Maintenance Manual July 2001 to be on the order of 1750 cfs with the pool at.5409.2 El. The peak demand on the outlet works is about 500 cfs.

The purpose of this analysis is to provide input on the following

- The cavitation potential of larger flows,
- The need to replace the butterfly valve with another type of valve that is less susceptible to cavitation damage.
- The requirement for additional venting,

LOSS COEFFICIENTS

The head across the outlet works is governed by a Cipoletti weir located downstream of the outlet. The characteristics of the Cipoletti weir indicate that the outlet becomes submerged at a discharge of about 425 cfs. The discharge at which submergence begins is influenced somewhat by the aeration provided at the butterfly valve. The maximum discharge can be estimated by equating

the formula for the loss in the outlet works conduit with the discharge characteristics of the Cipoletti weir. The system loss coefficients were taken to be the following

- Inlet coefficient = 0.5
- Friction factor in the upstream and downstream horseshoe conduits = 0.012
- Loss coefficient across the valves = 0.08
- Exit loss coefficient = 0.8

BUTTERFLY VALVE CHARACTERISTICS

The characteristics of the butterfly valve were determined from an assembly drawing of a similar but smaller valve. The valve at Ruby Dam is 72-inches in diameter, whereas, the diameter of the valve in the assembly drawing was for a 60-inch valve. Nevertheless, the two are sufficiently similar that the dimensions from the 60-inch valve can be scaled up to the 72-inch size. The relationship between the discharge coefficient and the valve opening is shown in figure 1. The coefficient for the 100 percent opening was obtained from McPherson et al[1]. The open area of the valve as a function of the angle of opening is shown in figure 2.

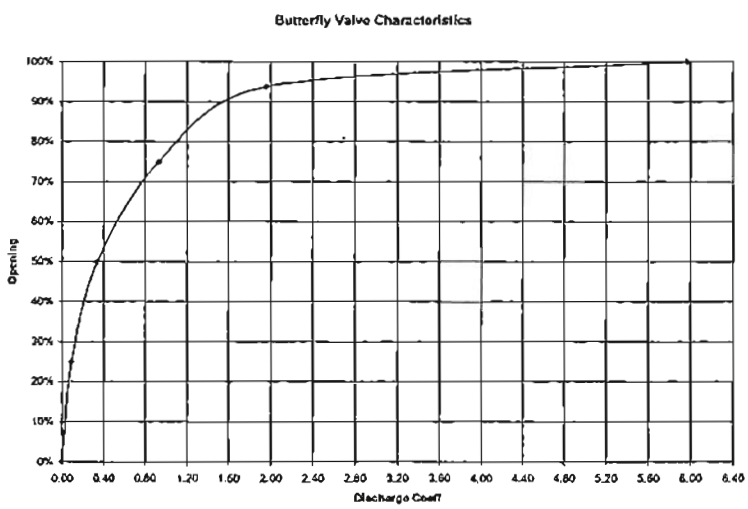


Figure 1. Discharge Characteristics of the Butterfly Valve

[1] McPherson, M.B., Strausser, H.S. and Williams, J.C., 1957, "Butterfly Valve Flow Characteristics," *Journal of the Hydraulics Division ASCE*, Vol. 83, No. HY 1, pp. 1167-1 to 1167-28.

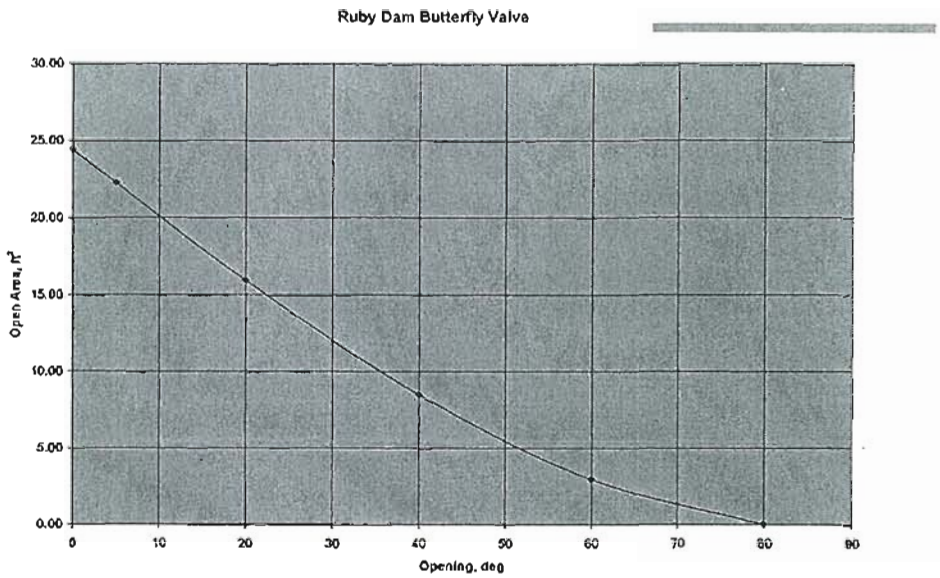


Figure 2. Open Area of Butterfly Valve

The cavitation characteristics of the butterfly valve were determined by Sarpkaya[2] and are shown in figure 3.

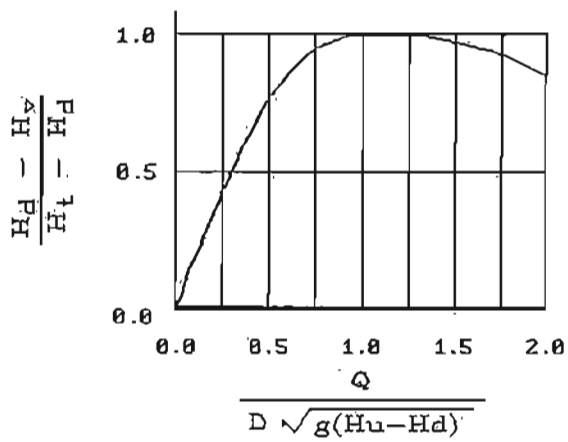


Figure 3. Cavitation Characteristics of a Butterfly Valve

[2] Sarpkaya, T., 1961, "Torque and Cavitation Characteristics of Butterfly Valves," *Journal of Applied Mechanics*, Transactions of ASME, pp. 511-517

The dimensionless flow rate term in figure 3 is equal to the discharge coefficient in figure 1. The cavitation index of the flow for the valve is defined as

$$\sigma_{flow} = \frac{H_d - H_v}{H_t - H_d} \tag{1}$$

In this equation,
Hd is the downstream pressure head
Hv is the vapor pressure head
Ht is the total upstream head.

Equation 1 is calculated from the flow characteristics of the system. The cavitation index of the valve can be determined from the values of pressure and discharge. If the cavitation index of the valve is less than the incipient cavitation index as given in figure 3, then the water jets downstream of the valve will cavitate.

Another type of cavitation occurs on the shroud that contains the operating arm of the valve. The incipient cavitation index for a rounded nose as was used for the shroud is 1.09. However, all of the cavitation indices for the shroud as shown in the Appendix, Table 2 are less than a value of 1.09. Therefore, the shroud can be expected to have damage at all flows. An elliptical shape on the shroud having a ratio of the major to the minor axis of 6 is required to produce a cavitation free shape for the shroud. The supply of air to the valve will not prevent caviation damage to the shroud because the air cannot be introduced into an area that will protect the shroud from damage.

OUTLET PRESSURE AND CAVITATION

The pressures in the outlet works and the cavitation characteristics at partial openings of the butterfly valve can be determined calculating the overall loss coefficient for each discharge. Then the loss coefficient for the partially open valve can be determined by subtracting the entrance, exit and friction losses in the outlet from the overall loss coefficient. Once the loss coefficient for the valve opening is known, then the pressures throughout the outlet can be determined. The original computations considered the entire conduit to be filled with water. With these considerations, a large negative pressure developed at the valve for discharges greater than about 1,500 cfs. A check of the momentum of the flow at the valve showed that the momentum of the flow from the valve is so great that the entire downstream outlet conduit will be swept out. That is, the downstream conduit will not fill for any discharge. As a result, the air demand for the valve will be large.

The theoretical maximum discharge for the outlet works with the downstream conduit swept out is 1895 cfs for a reservoir elevation of 5392 feet and the butterfly valve open 100 percent. The valve can be opened to 79 percent and pass a discharge of 1500 cfs if the valve is provided with adequate aeration. The safe operation of the valve at this discharge can be verified with field testing.

Table 1 in the appendix shows the computations for a reservoir elevation of 5392. The shaded red zone corresponds to conditions in which the cavitation index of the flow is less than the incipient cavitation index of the valve or conditions in which the pressure downstream of the valve is severely negative. For discharges less than about 200 cfs, cavitation of the valve is not likely.

The cavitation described above occurs in the jets downstream of the valve and will damage the walls of the downstream conduit. Air should be provided to the valve to reduce the chance for damage to the downstream conduit during discharges greater than 500 cfs. The size of the air vent can be determined from tests of the outlet. However, the vent should not be smaller than 12-inches in diameter. The vent should extend about 10 feet into the control shaft to prevent overflowing at small gate openings.

EFFECT OF CIPOLETTI WEIR

Due to the sweepout of the water, the Cipoletti weir has no effect on the flow in the downstream outlet conduit. However, the Cipoletti weir is needed to provide sufficient tailwater on the energy dissipater.

ENERGY DISSIPATOR

An energy dissipater is needed at the end of the outlet works to prevent erosion damage downstream of the outlet. A sudden 10- by 10-foot expansion will be constructed at the end of the outlet portal. The length of this section will be 30 feet. The purpose of the expansion is to provide room for a service road without cutting into the embankment. The dissipater begins at the end of the expansion.

The dissipater consists of an expansion chute that goes from a width of 10 feet to 14.0 feet in a distance of 73.75 feet. The invert of the dissipater is at elevation 5290 ft or 8 feet below the existing elevation of the exit portal. The length of the basin is 44 feet. The basin is designed according to the specifications for a USBR Type III containing a chute block, a baffle block and an end sill. The chute block is 1.25 feet high, the baffle block is 3.6 feet high and the end sill is 2.2 feet high. The total length of the chute and the basin is 117.75 feet.

The cavitation index for the baffle block is 0.25. The incipient cavitation index for the USBR type of block is about 1.9. Damage to the block can be minimized by shaping the block as shown in figure 4.

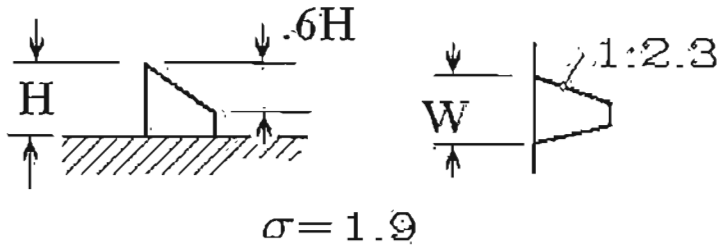


Figure 4. Baffle Shape

OUTLET TESTS

The analysis given above is based upon the best available information. However, better estimates of the maximum flow rate and air demand can be obtained by prototype tests. The purpose of the tests would be to obtain an accurate evaluation of the air demand and system loss coefficient for various butterfly valve openings. In addition, some information about the cavitation characteristics of the valve could be inferred from vibration measurements. The test program would need to measure the following for a variety of butterfly valve settings.

- Reservoir elevation.
- Tail water elevation at tunnel portal.
- Butterfly valve position.
- Air flow rate.
- Observation of vibration on butterfly valve operating stem and on the downstream flange of the butterfly valve.

The air flow rate can be determined by measuring the pressure differential across an orifice placed in a sheet of plywood that seals the shaft to the tower. Two accelerometers are needed to obtain the cavitation data. The position of the butterfly valve needs to be calibrated before the tests begin.

The results of the tests would provide information concerning

- Air demand
- Overall loss coefficient
- Cavitation characteristics (gate openings for which the cavitation is the most severe, etc.)

Since the tests will be conducted when the reservoir is high enough to spill, the results need to be presented in dimensionless form so that the three variables can be estimated at other reservoir elevations. The tests should be performed during periods when the flows in the river are large to reduce the chance of damage to the downstream channel.

CONCLUSIONS

- The butterfly valve will probably cavitate at all discharges greater than 500 cfs or valve openings greater than 50 percent at a reservoir elevation of 5392.
- Cavitation damage will occur to the shroud for all releases unless the shape of the shroud is changed to an ellipse with a ratio of the major to the minor axis of 6.
- The momentum of the flow from the valve will cause the downstream portion of the outlet conduit to sweep out.
- Removal of the Cipoletti weir will affect the design of the energy dissipater, but will not affect the flow in the downstream portion of the outlet tunnel..
- With a reservoir elevation of 5392, the maximum discharge that can be passed through the outlet is approximately 1895 cfs.
- Field testing during a period of high runoff is recommended to verify the computations. This is necessary because the analysis is based on valve characteristics that are not exactly the same as those for the installed valve.

Spillway Analysis

INTRODUCTION

The existing spillway consists of an ogee crest, a converging rectangular chute, a steeper constant width rectangular chute, and a combination flip bucket and hydraulic jump energy dissipater. The chute converges from a width of 125-ft at the crest to a constant width of 75-ft. Stop logs have been placed on the crest of the spillway. The supports for the stop logs form nappe breakers at low flows.

The typical flood is 2,500 cfs, which has a return period of about 50 years. The flood of record occurred in 1984 and had a discharge of 3,010 cfs. The project has been in operation for nearly 70 years. The design flood for the current loss of life design standard of 30 is 32,200 cfs. The spillway design flood for a loss of life design standard of 50 is 42,400 cfs. The probable maximum flood standard for federal regulation is 132,400 cfs. The design flood for the spillway has not be definitely established because reductions in the maximum precipitation and, hence, in the flood magnitude are possible. If hydropower is developed at this site, the spillway will be designed to pass a flow of 80- to 90-thousand cfs. Without hydropower, the spillway will be designed to pass a flow of 20,000 cfs.

Some geological features constrain the spillway chute design. Widening the chute into the right abutment would require excavation into the existing road and require the removal of large quantities of earth. A rock outcrop upstream of the entrance to the spillway creates a partial blockage of the flow at large discharges.

CHUTE HYDRAULICS AND CAVITATION CHARACTERISTICS

The water depths and cavitation indices in the chute were calculated for reservoir elevations of about 5423. These calculations gave a maximum flow depth of 4.74 feet at station 11+65. The USBR criteria free board requirements is given by

$$Freeboard(ft) = 2.0 + .025V\sqrt[3]{d}$$

The free board equation is an empirical relationship that accounts for surface roughness, wave action, air bulking, splash and spray. Therefore, the wall height for a discharge of 20,000 cfs is 9.1 feet.

The minimum cavitation index is 0.28 and occurs at station 13+36.38. Normally the cavitation index is minimum for a discharge that is less than the design flow. However for Rudy Dam, the minimum cavitation index occurs for the design flow.

A study was conducted to determine if a stepped spillway would have enough loss to enable the stilling basin to be smaller. This study showed that a 2-foot high step would decrease the length of a USBR Type III basin from 92.5 ft to 53.3 ft. However, construction of the steps would be difficult to achieve on the relatively flat slope. For instance, where the slope is equal to .15, the 2-foot high step would have to be over 13-feet long.

LABYRINTH WEIR

The current dam crest is at elevation 5410.6 and the present crest elevation is 5393.0 at the top of the flashboards. If the crest is raised to elevation 5394.2, the increase in storage will restore the sediment loss in the reservoir. A labyrinth designed for a discharge of 20,000 at the raised dam crest elevation will pass a discharge of 28,600 cfs with about 5.6-ft of freeboard.

References

Sarpkaya, T., 1961, "Torque and Cavitation Characteristics of Butterfly Valves," American Society of Mechanical Engineers, *Journal of Applied Mechanics*, pp. 511-518

APPENDIX

Table 1
Butterfly Valve Cavitation Characteristics with Reservoir Elevation = 5392 ft

Normal Reservoir Elevation

Reservoir 5392 ft

Pressure Profile and Cavitation Index

Station		00+00	03+80	03+89	03+98							
Q	K	P/γ_1	P/γ_2	P/γ_3	P/γ_4	*ELG Bal*	Y_6	V_6	Cd	Open	σ_{flow}	σ_i
cfs		ft	ft	ft	ft	ft	ft	ft/sec				
50	5771.29	92.98	92.97	95.93	0.00	0.00	0.11	58.66	0.02	10%	0.29	0.04
100	1435.70	92.91	92.87	95.74	0.00	0.00	0.25	53.12	0.05	18%	0.29	0.08
200	356.10	92.63	92.48	94.95	0.00	0.00	0.38	71.10	0.09	24%	0.29	0.16
250	227.12	92.42	92.19	94.36	0.00	0.00	0.52	63.53	0.11	30%	0.29	0.20
423	78.62	91.35	90.68	91.31	0.00	0.00	0.78	72.20	0.19	39%	0.30	0.34
450	69.26	91.13	90.37	90.68	0.00	0.00	0.88	68.37	0.21	42%	0.30	0.36
500	55.95	90.69	89.75	89.44	0.00	0.00	0.91	73.41	0.23	43%	0.30	0.40
600	38.65	89.67	88.33	86.55	0.00	0.00	1.08	74.17	0.28	48%	0.31	0.48
750	24.55	87.80	85.70	81.24	0.00	0.00	1.18	84.63	0.37	51%	0.32	0.60
1000	13.66	83.76	80.02	69.75	0.00	0.00	1.57	85.16	0.53	61%	0.36	0.78
1250	8.69	78.57	72.72	54.99	0.00	0.00	1.90	87.85	0.74	69%	0.42	0.92
1500	6.04	72.22	63.79	36.94	0.00	0.00	2.34	85.42	1.09	79%	0.54	1.00
1700	4.65	66.30	55.48	20.15	0.00	0.00	2.73	83.13	1.67	89%	0.72	0.92
1895	3.72	59.84	46.39	1.77	0.00	0.00	3.35	75.43	6.28	100%	1.15	0.34

Point 1 D/S of Inlet

Point 2 End of Horseshoe

Point 3 U/S Valve

Point 4 D/S Valve

Point 6 Outlet Portal

Table 2

Cavitation Characteristics of Shroud

Cavitation on Shroud											
Q	$H_{U/S}$ Valve	$H_{D/S}$ Valve	Open	Angle	Cu	Yu	Minor Axis	Blockage	Area	V	σ_{flow}
cfs	ft	ft		deg		ft	ft		ft^2	ft/sec	
50.00	114.68	5.13	10%	72.0	0.62	0.10	2.90	97.04%	0.84	59.81	0.59
100.00	114.61	5.54	18%	65.6	0.64	0.23	2.77	93.51%	1.84	54.47	0.72
200.00	114.33	6.08	24%	60.8	0.66	0.34	2.66	90.20%	2.77	72.17	0.41
250.00	114.12	6.27	30%	56.0	0.68	0.47	2.53	86.35%	3.86	64.80	0.52
422.68	113.05	6.60	39%	48.8	0.71	0.71	2.29	79.64%	5.76	73.43	0.41
450.00	112.83	6.61	42%	46.4	0.72	0.79	2.21	77.17%	6.46	69.71	0.45
500.00	112.39	6.61	43%	45.6	0.72	0.82	2.18	76.32%	6.70	74.67	0.39
600.00	111.37	6.50	48%	41.6	0.74	0.98	2.02	71.89%	7.95	75.49	0.38
750.00	109.50	6.11	51%	39.2	0.75	1.07	1.93	69.10%	8.74	85.83	0.29
1000.00	105.46	4.87	61%	31.2	0.79	1.42	1.58	59.11%	11.56	86.49	0.28
1250.00	100.27	2.92	70%	24.0	0.82	1.76	1.24	49.36%	14.32	87.30	0.26
1500.00	93.92	0.28	79%	16.8	0.86	2.12	0.88	39.05%	17.23	87.04	0.24
1750.00	91.98	-3.04	90%	8.0	0.91	2.58	0.42	25.92%	20.95	83.55	0.22
1922.00	-4.43	-5.79	100%	0.0	0.95	3.00	0.00	13.73%	24.39	78.80	0.22

APPENDIX E

MWH
RUBY DAM
OUTLET WORKS INSPECTION
FIELD TRIP REPORT

Prepared for

HKM Engineering, Inc.
222 N. 32nd Street
Billings, MT 59107

Ruby Dam
Outlet Works Inspection
Field Trip Report

December 1, 2005

Prepared by:

MWH
1801 California Street, Suite 2900
Denver, CO 80202
303-291-2222

Table of Contents

	Page No.
INTRODUCTION	**1**
LOW LEVEL OUTLET WORKS ARRANGEMENT	**1**
Low Level Outlet Tunnel and Gate Shaft	1
Butterfly Valve	3
Emergency Gate	4
SUMMARY OF PAST INSPECTION FINDINGS	**4**
CURRENT OBSERVATIONS (DECEMBER 2005)	**5**
Butterfly Valve	5
Emergency Gate	6
Jet Pump	6
Gate Shaft and Roof	7
Operating Stems and Floor Stands	7
CONCLUSIONS AND RECOMMENDATIONS	**7**

Ruby Dam
Outlet Works Inspection
Field Trip Report
December 1, 2005

INTRODUCTION

On December 1, 2005, Mike Morgan of MWH inspected the low level outlet works, Gate and valve equipment at the Montana Department of Natural Resources and Conservation's (MDNRC) Ruby Dam. The inspection was performed as part of the MDNRC's annual inspection for the project. The inspection was limited to a visual inspection of the accessible portions of the gate and valve equipment in the low-level outlet tunnel.

MDNRC personnel as well as HKM personnel also participated in the inspection. Art Taylor of the MDNRC provided background information for the project. The MDNRC Operations and Maintenance staff provided access to the equipment.

At the time of the inspection, the emergency gate was in the full closed position and the downstream tunnel was dewatered. Water approximately 6 in. deep in the tunnel, downstream of the valves. The regulating butterfly valve was opened to approximately 50% (45 degrees) for the inspection. The internal inspection of the outlet conduit, butterfly valve and emergency gate was performed by walking up the 200-ft. long outlet tunnel from the downstream end. Extensive discharge from the jet pump drain obstructed a full inspection of the butterfly valve. The upstream emergency slide gate could only be observed through the opened butterfly valve.

The external portion of the emergency gate, butterfly valve, steel liners and spool piece were also inspected via the vertical gate shaft which was accessed from the crest of the dam. At the time of the inspection, the gate shaft was flooded to the crown of the steel liner and limited the inspection to those portions above the waterline. This report documents the findings of the inspection and is supplemented with annotated photographs and figures.

LOW LEVEL OUTLET WORKS ARRANGEMENT

Low Level Outlet Tunnel and Gate Shaft. The outlet works for the Ruby Dam is located near the left dam abutment. Based on the design drawings provided, the intake is composed of slightly converging wing walls and a slanted (approximately 45 degrees) intake trashrack. The concrete lined tunnel is a 90-in. diameter, straight-legged horseshoe section approximately 635 ft. long. The tunnel invert is located at El. 5299 at the location of the valves;111 ft. below the dam crest El. 5410.

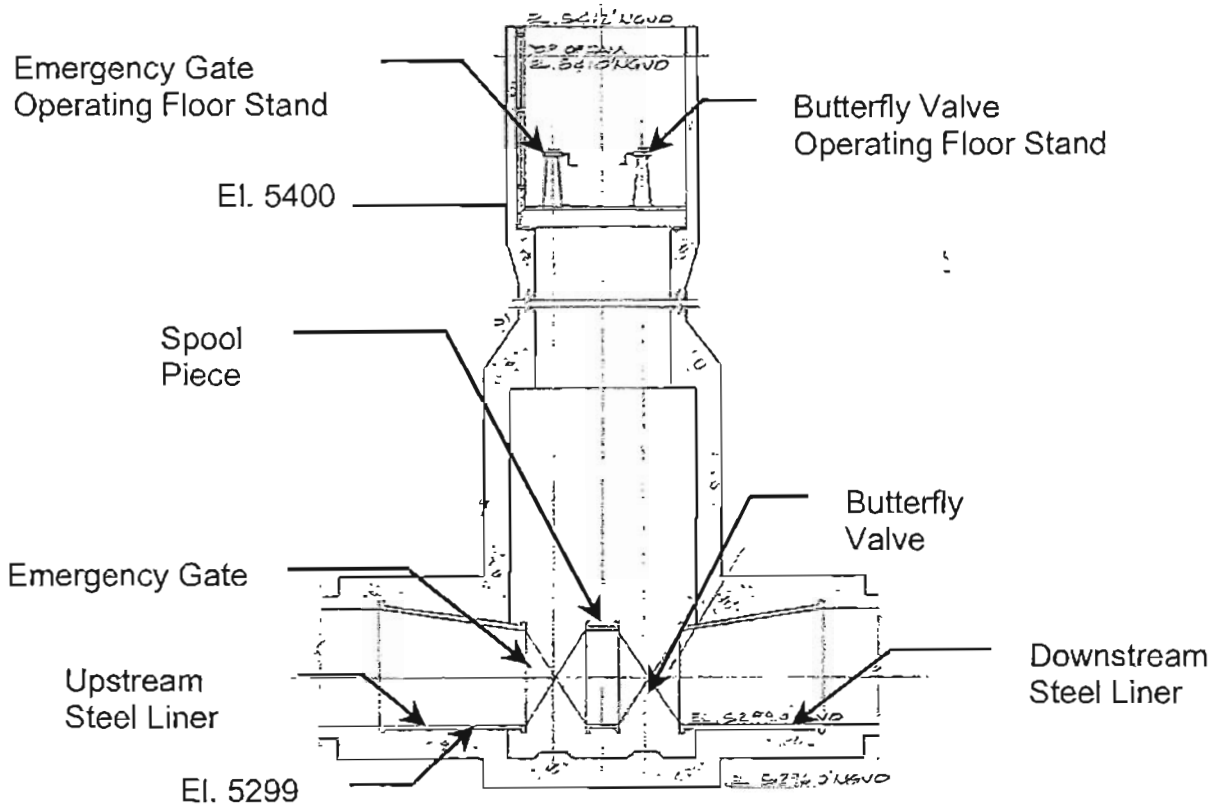


Figure 1. Gate Shaft.

The gate shaft is located approximately 400 ft. downstream from the intake structure near the dam centerline. **Figure 1** illustrates its configuration. The base of the shaft (El. 5299) contains the regulating valve and upstream emergency gate. The regulating valve is a 72-in. butterfly valve and the upstream emergency gate is a 72-in. diameter bonneted slide gate. The two are separated by a 2.5-ft. long steel spool piece. The conduit, 9 ft. upstream of the emergency gate is a steel lined concrete transition section. All but the last 12-in. of the liner is embedded in concrete. The downstream 12-in. of the steel liner daylights into the gate shaft and is fitted with a mating flange to the emergency gate frame. The conduit, 9 ft. downstream of the butterfly valve is also a steel lined concrete transition section. All but the upstream 12-in. of the liner is embedded in concrete. The upstream end of the liner daylights into the gate shaft and is fitted with a mating flange to the butterfly valve. The emergency gate and the butterfly valve are both provided with flanged connections on each side and are bolted to the upstream/downstream liner and the spool piece. The valves and spool piece are exposed at the base of the gate shaft.

The regulating butterfly valve and the emergency slide gate are operated by means of manual screw stem hoists on a grated platform. Stem hoists can either be operated by means of hand cranks or using an electric rotary tool. Refer to **Photographs 16 and** 17. The floor stands for the hoists are located near the top of the gate shaft at El. 5400 and the screw stems extend down to the gate/valve, supported by several, equally spaced stem guides.

The gate shaft is drained by means of a jet pump sump system that uses a connecting line between the high and low pressure sides of the conduit to draw water from the gate shaft by venturi action. A ladder with fall prevention extends the full height of the gate shaft.

E-4

The gate shaft is enclosed by a timber-framed structure with locked door. Three ceiling vents are provided in the roof. Two of the vents are shown in **Photograph 18.**

Butterfly Valve. The butterfly valve is a 72-in. cast iron valve, fabricated in the 1930's. The valve is of a somewhat unique design that has also been used at several other MDNRC projects. The valve uses a linkage type stem attached to the bottom of the disc on the downstream side to open and close the valve. The stem, consequently, is located in the flow path. A stem deflector casting is mounted to the crown of the tunnel where the stem penetrates the conduit ceiling. The valve is opened and closed via a screw stem hoist through a series of several connecting stems, up to the floor stand at El. 5400. Refer to **Photographs 1 and 2** for views of the butterfly valve from the downstream side. A 6 to 8-in. diameter vent is located at the top of the conduit, immediately downstream of the disc seat on the right side of the conduit. The vent outlets into the gate shaft through a shutoff valve and a 6 to 8-ft. long stand pipe. Refer to **Figure 2** for a drawing of the butterfly valve.

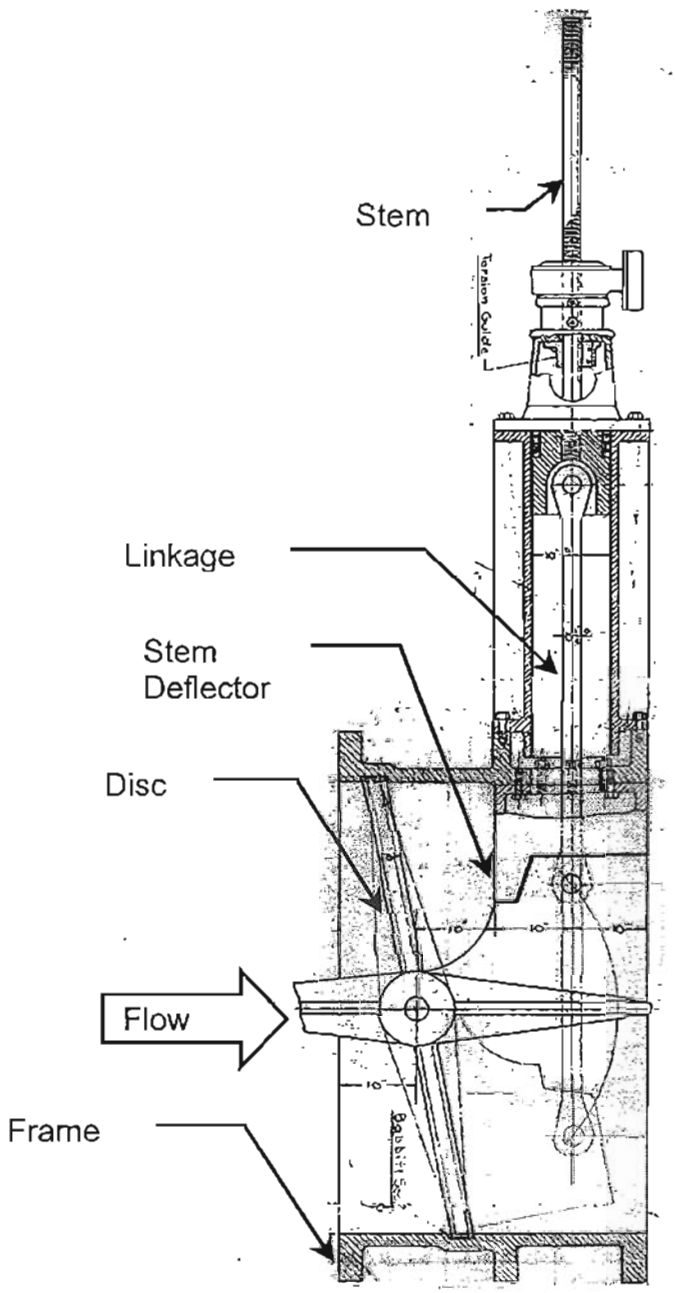


Figure 2. Butterfly Valve

Emergency Gate. The emergency gate is a 72-in. bonneted slide (knife) gate located approximately 2.5-ft. upstream of the butterfly valve. The slide gate is of cast iron has a circular disc with bronze seat rings. The gate disc is opened and closed via a screw stem hoist through a series of several connecting stems, up to the floor stand at El. 5400. The stem extends through the bonnet and is sealed with a packing gland. The top of the bonnet is also equipped with a vent pipe with a shutoff valve. Refer to **Figure 3** for a drawing of the emergency gate.

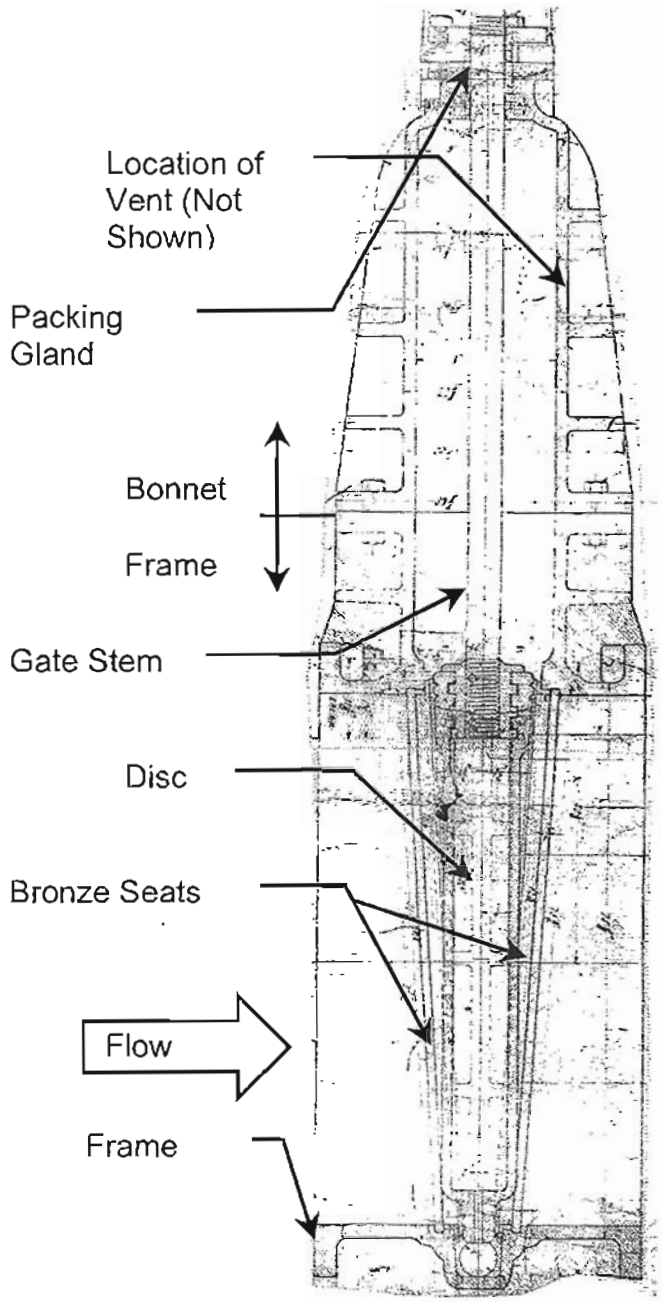


Figure 3. Emergency Gate

SUMMARY OF PAST INSPECTION FINDINGS

According to available information, the butterfly valve and upstream emergency gate were last inspected in October 2004. At that time the following significant observations and recommendations were made in the inspection report.

- Cavitation damage was identified at several locations in the conduit downstream of the butterfly valve. Note that very similar damage was observed during the December 2005 inspection.
- Emergency gate stem packing leakage was significant and the connecting bolts were observed as loose and not properly tightened. Note that this condition was unchanged at the time of the December 2005 inspection.
- The jet pump was noted to be leaking into the downstream conduit an estimated 1 gpm. Note that leakage at the time of the December 2005 inspection was significantly more than the 1 gpm amount.
- Water was found backflowing into the downstream conduit through the butterfly valve air vent indicating that the water in the gate shaft may have been above the standpipe level. Note that the water level in the gate shaft was significantly lower at the time of the December 2005 inspection.

CURRENT OBSERVATIONS (DECEMBER 2005)

The following observations were made during the inspection of the butterfly valve, emergency slide gate, surrounding steel conduits, drain and vent systems.

Butterfly Valve

- Cavitation was identified at several locations, which match previous inspection findings. The observed location of the cavitation damage is as follows:

  1. immediately downstream of the stem deflector on either side. More significant damage was observed on the left side (looking downstream) where the area was approximately 18 in. long with a depth of between 1/8 and ¼-in. The right side indicated similar damage, although over a smaller area. Refer to **Photograph 4**.

  2. both sides of the stem deflector near the interface with the conduit liner crown. Refer to **Photographs 5 and 7**.

  3. on the underside of the lip of the stem deflector as shown in **Photographs 7 and 8**.

  4. near the crown of the conduit immediately upstream of the butterfly valve babbitt seat. The most significant damage was in a narrow strip approximately 2 ft. along the circumference at the crown. It appears this area was subject to cavitation in the past as evidenced by past weld repairs. The cavitation is located immediately downstream of an offset between the connecting spool piece and the upstream flange of the valve. Refer to **Photographs 9 and 10**. This area is not affecting the sealing or operation of the valve.

  5. immediately downstream of the jet pump discharge in an area approximately 6-in. diameter with a depth of between 1/8 in and ¼-in. as shown in **Photograph 12**.

- Several cavitation repairs appear to have been made in the past using various filler materials and weld filler. Refer to **Photographs 3, 6 and 9** for views of the past repairs. In general the past repairs were adhering well.

- The babbitt disc seating surface around the circumference of the valve frame looked to be in acceptable condition and free of noticeable offsets, pits, erosion, etc. Refer to **Photographs 9 and 10**.

- The sealing edge of the valve disc was somewhat rough due to corrosion and pitting but was free of significant erosion or cavitation damage.

- The valve was operated during the inspection and moved slowly and smoothly with no jerking motions.

- The external portions of the valve in the vertical gate shaft could only be observed above the crown of the conduit because the remainder was submerged. No noticeable defects were observed on the external portions other than a general corroded state of the cast iron

components. It could not be determined whether there was a paint coating on the valve components, but if so, the metal is no longer being protected as evidenced by surface corrosion at several locations.

- All connecting bolts visible both above the water line (on stem housing) and immediately below the waterline (upper flange bolts between the spool piece and valve and the valve and downstream liner) were lightly corroded. However, when cleaned off, there was minimal section loss. Refer to **Photographs 22 and 23**.

- The shutoff valve on the vent pipe was caked with corrosion and sediment. Whether this valve is still operable is unknown.

- According to operating staff, banging and popping sounds become excessive at a discharge of around 450 to 500 cfs and therefore the valve is not operated beyond this point.

Emergency Gate

- The valve was in the closed position during the inspection and significant differential head. The disc formed a nearly leak tight seal around the perimeter of the conduit. No significant leakage was observed around the perimeter of the disc. The valve could only be inspected from a distance but the disc and downstream liner appeared to be free of cavitation damage and free of significant corrosion. Refer to **Photograph 13 and 14**.

- The packing around the gate stem leaks heavily into the gate shaft. This condition has been noted for several years and does not appear to have ever been repaired. Refer to **Photograph 19**.

- The external portions of the valve could only be observed above the crown of the conduit because the remainder was submerged. The bonnet and connection to the frame was above water at the time of the inspection. Refer to **Photographs 19 through 21**. No noticeable defects were observed on the external portions other than a general corroded state of the cast iron components. The corrosion did not appear to be significant. It could not be determined whether there was a paint coating on the valve components because of caked on sediment and corrosion.

- The connecting bolts visible both above the water line (bonnet connection to the frame) and immediately below the waterline (upper flange bolts between the spool piece and valve and the valve and upstream liner) were lightly corroded. However, when cleaned off, there was minimal section loss. Refer to **Photographs 21**.

- The shutoff valve on the vent pipe of the bonnet cover was caked with corrosion and sediment. Whether this valve is still operable is unknown.

Jet Pump

The shutoff valves for the jet pump were all submerged during the site visit and could not be inspected. The 2004 inspection report indicated that the shutoff valves for the jet pump were not functioning properly. As stated above, the jet pump discharge leaked heavily during the inspection and the valves were likely in a near full open position. The jet pump, however, did not appear to drain the gate shaft significantly during the inspection.

Gate Shaft and Roof

The gate shaft was flooded with approximately 8 to 10 ft. of water (up to the crown of the conduit) and appears to flood to even greater depths as evidenced from water level marks on the gate shaft concrete liner. The observed condition of the external portions of the valves and conduit are described in their respective sections. The ladder in the shaft was equipped with an operable fall prevention system and the ladder appeared to be secure and of heavy duty construction. There was no lower operating platform present at the lower elevation as shown on the original design drawings. It appears that the emergency gate floor stand used to be mounted directly to the top of the gate. This is no longer the case and likely resulted in the removal of the lower platform.

Operating Stems and Floor Stands.

The operating stems, stem guides and floor stands were all observed to be in acceptable condition. The stems were free of significant corrosion buildup and appear to slide freely through the stem guides. Refer to **Photograph 25**. The extent of lubrication or caked on sediment present on the stem threads was not observed.

CONCLUSIONS AND RECOMMENDATIONS

The existing gate and valve system is presently functional although several annual maintenance items are required to correct deficiencies that have been recurring for several years. Also, the present valve system and the air supply limitations downstream of the butterfly valve appear to severely limit the amount of discharge that can be safely passed through the outlet conduit. According to MDNRC personnel, they presently do not operate the regulating valve beyond 450 to 500 cfs although the theoretical capacity of the tunnel is significantly more if the air demand could be met.

It is recommended that the MDNRC investigate replacement of the existing control valve with an updated valve design, better suited for flow regulation and that is capable of providing increased discharge capacity. The butterfly valve is nearly 70 years old, provides a significant flow obstruction, has insufficient venting and continually requires repair of cavitation damage caused by discontinuities in the design. The use of a jet flow should be considered.

Considering the present state of the gate and valve, the following recommendations are provided for the short-term:

1. Continue to monitor and repair cavitation damage using suitable filler material such as Belzona 2100 Series D&A Elastomer System. Continue to inspect and repair damage annually.

2. Within the next 3 to 6 months, attempt to tighten the packing of the emergency gate seal to reduce leakage into the gate shaft. Replace bolts and packing as necessary.

3. Within the next 3 to 6 months, pump out the gate shaft with a sump pump (assuming the jet pump is not operational) and inspect the remaining portions of the valves and conduit.

4. Immediately evaluate what spare parts may be needed for the operation of the gate and valve that are not readily available and inventory what is available on site. Make sure long-lead replacement components are on hand in the event of failure.

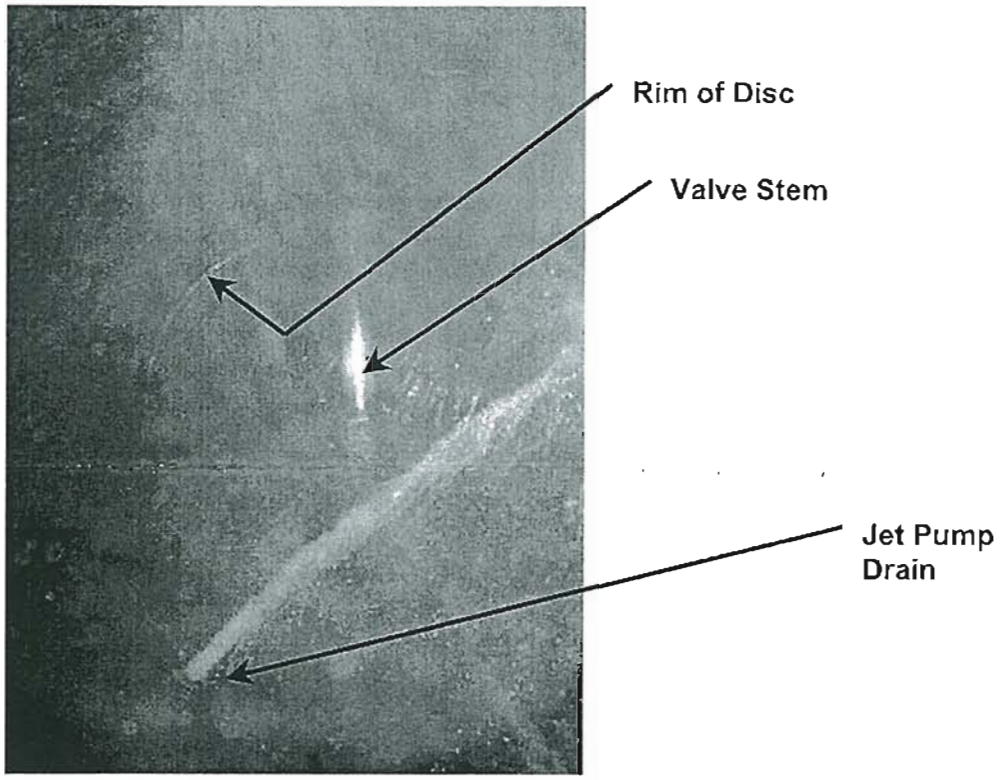
5. Lubricate the threads of the stem at the floor stand of the valve and emergency gate prior to each operation. Periodically clean the threads of the stem to remove buildup that can increase wear and result in operating equipment seizure.

6. Within the next 3 to 6 months, evaluate the air demand needed for proper venting of the butterfly valve and consider additional venting in the roof of the gate house in the short term to potentially increase the venting capacity into the shaft.

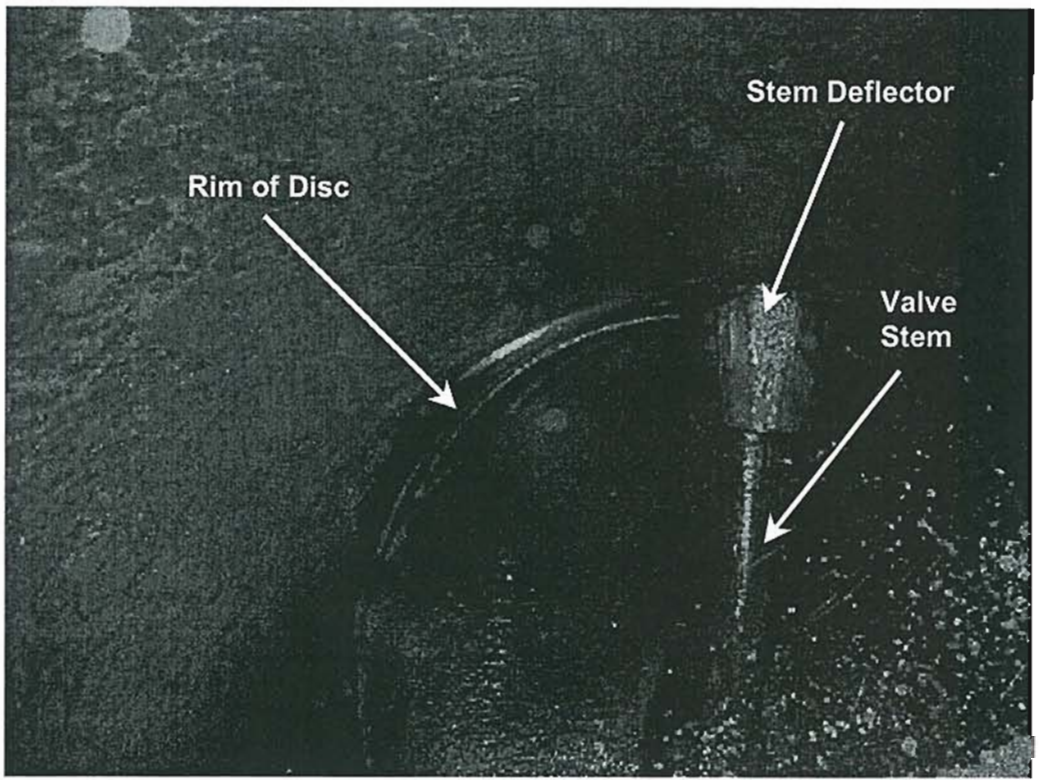
7. Immediately evaluate the security of the existing gatehouse and consider upgrades to increase the difficulty for entry by vandals.

Michael J. Morgan, P.E.
Principal Engineer

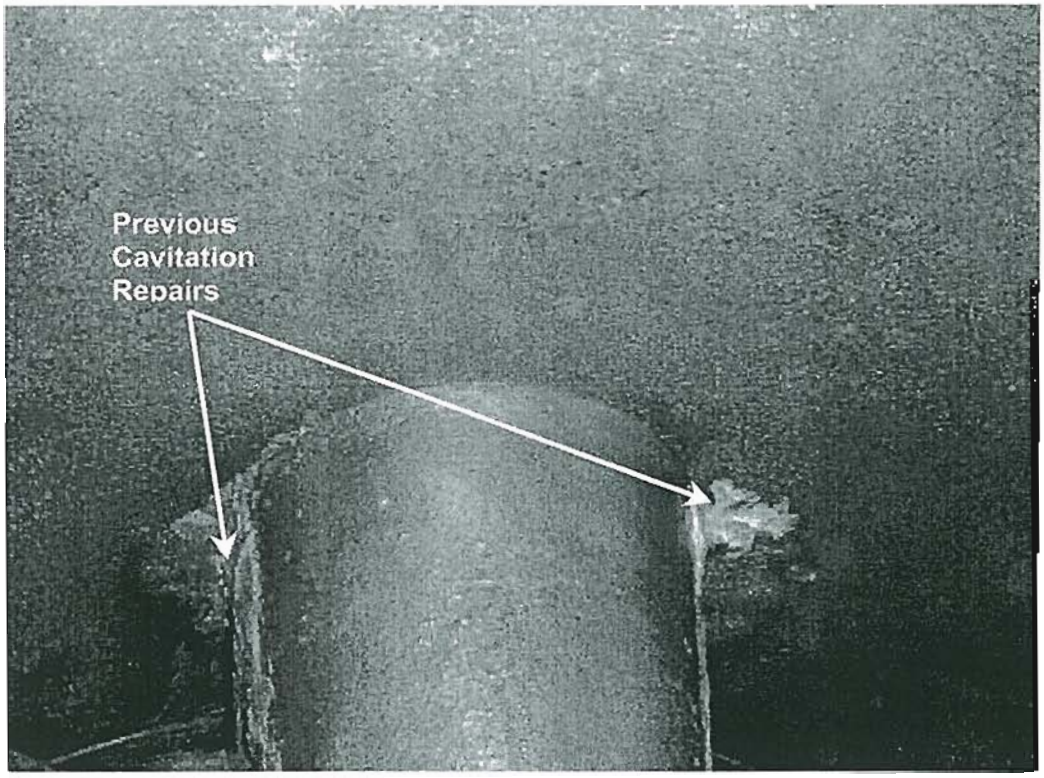
REV:tea



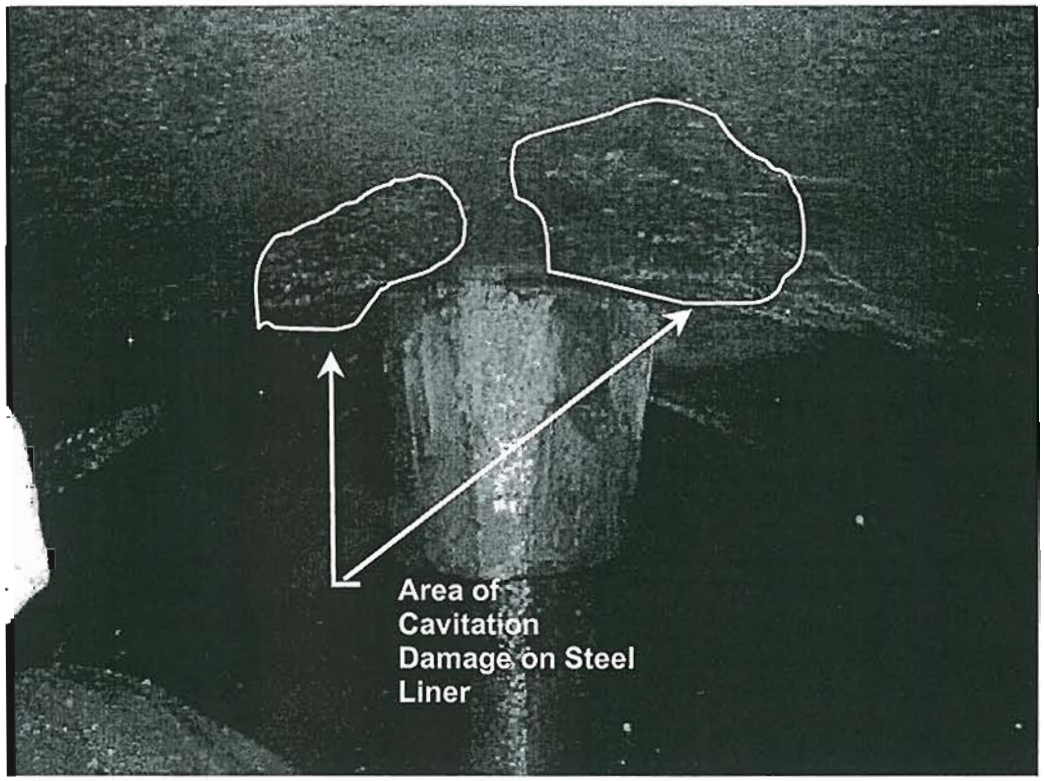
Photograph 1. Outlet Control Butterfly Valve.



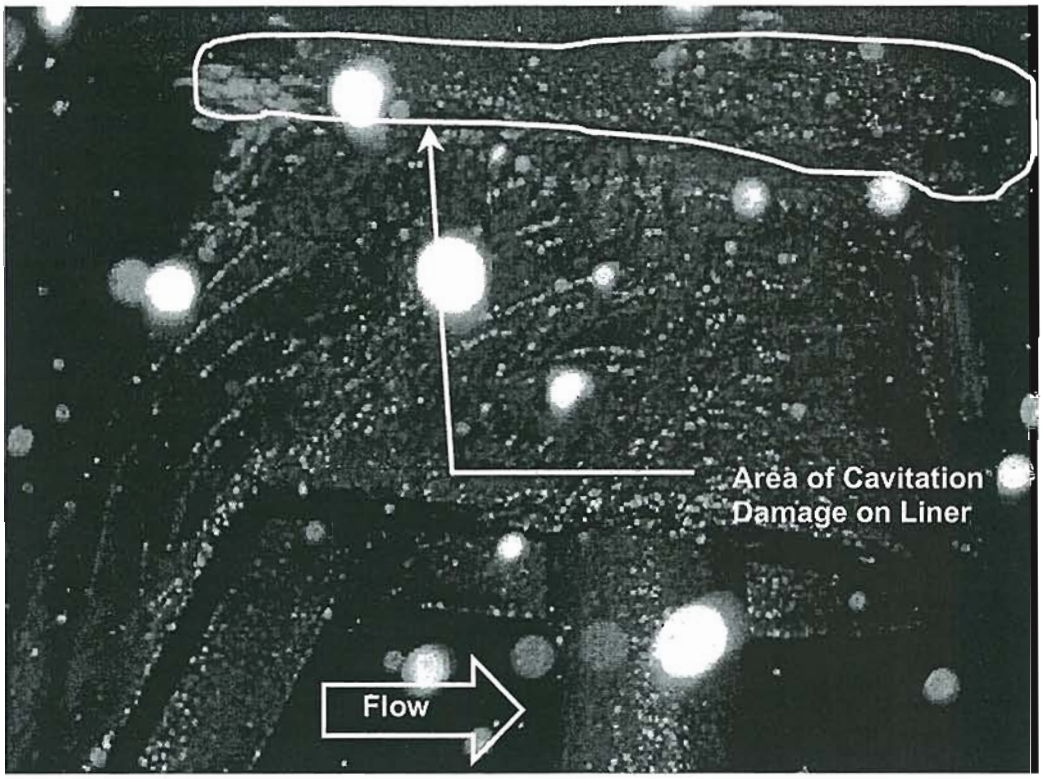
Photograph 2. View of Butterfly Valve Looking Upstream.



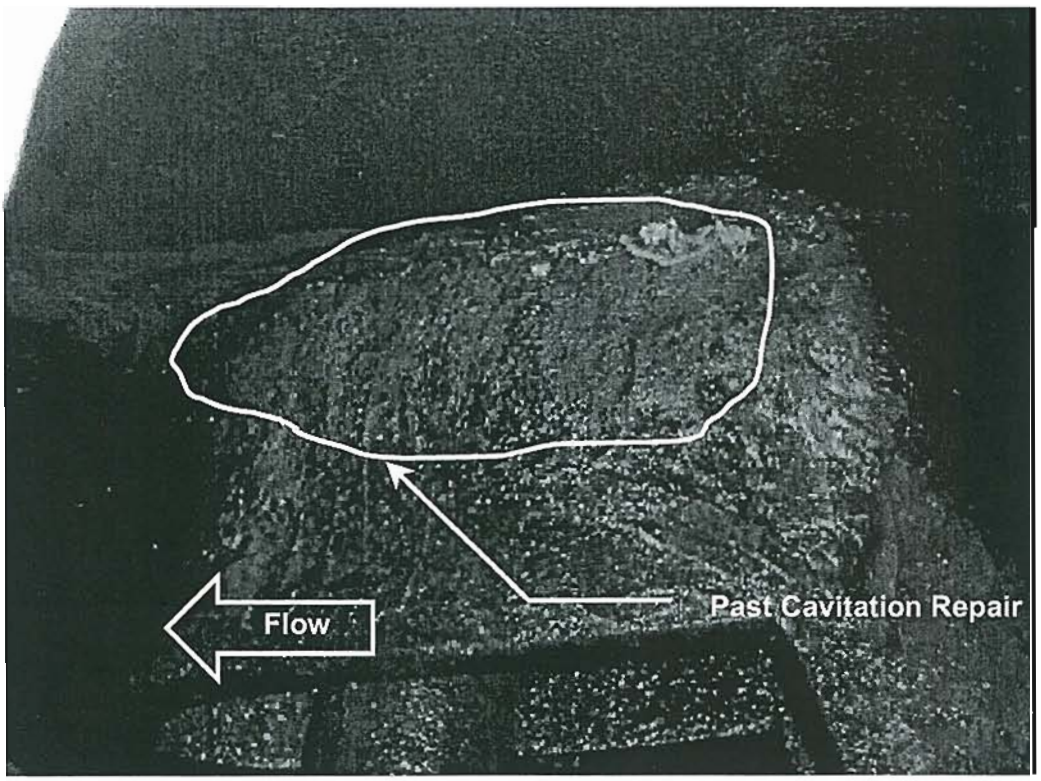
Photograph 3. Stem Deflector. View of Upstream End of Deflector.



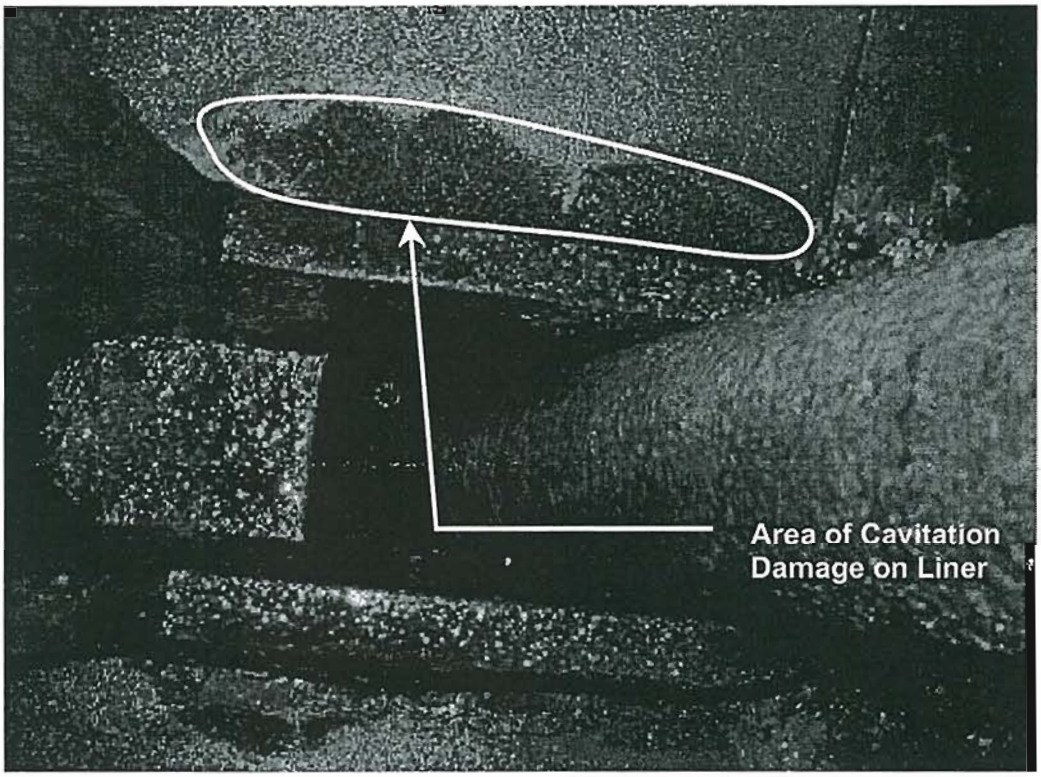
Photograph 4. Stem Deflector. View of Downstream End of Deflector



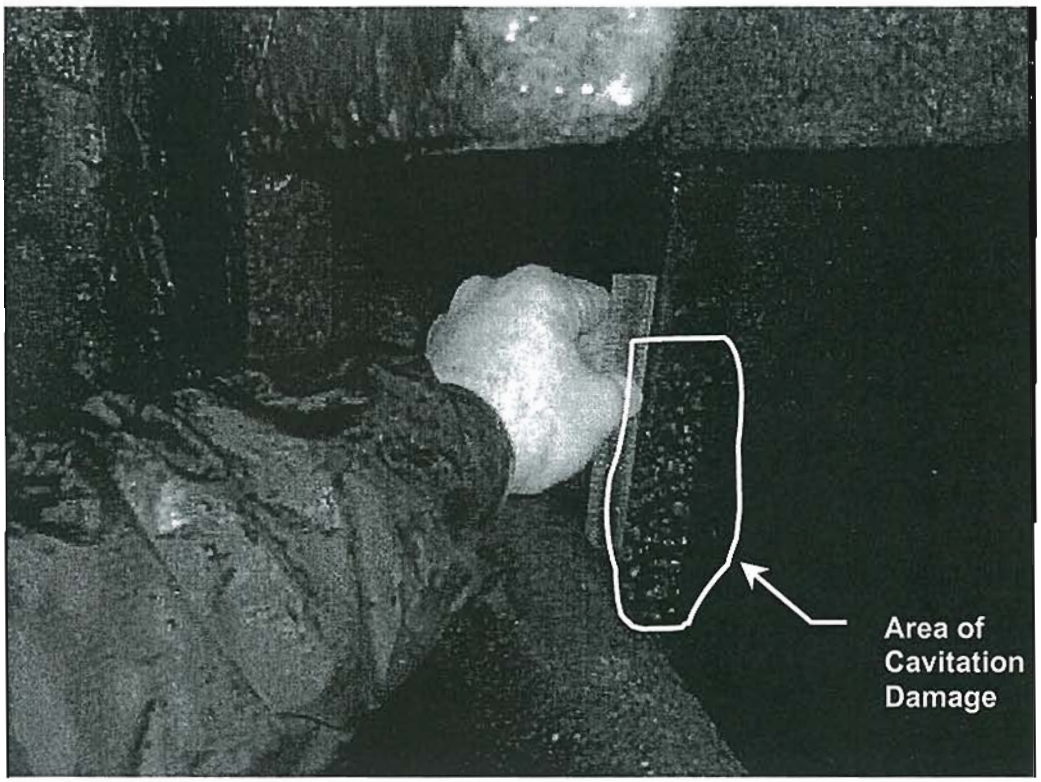
Photograph 5. Stem Deflector. Right Side.



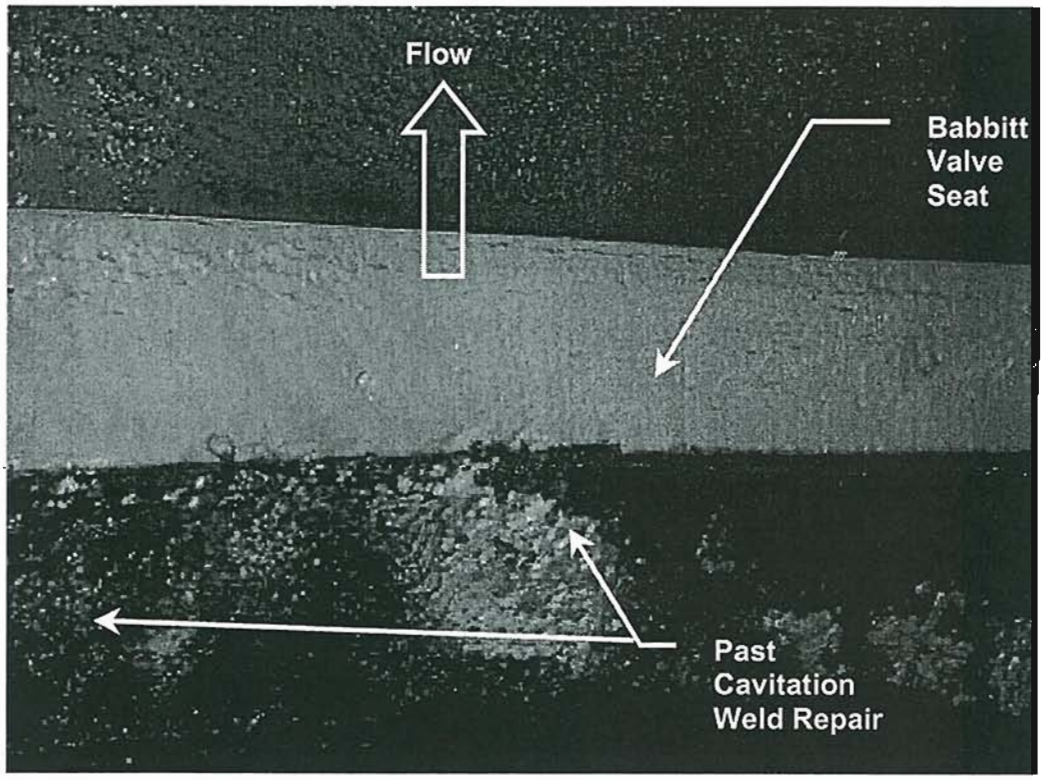
Photograph 6. Stem Deflector. Left Side.



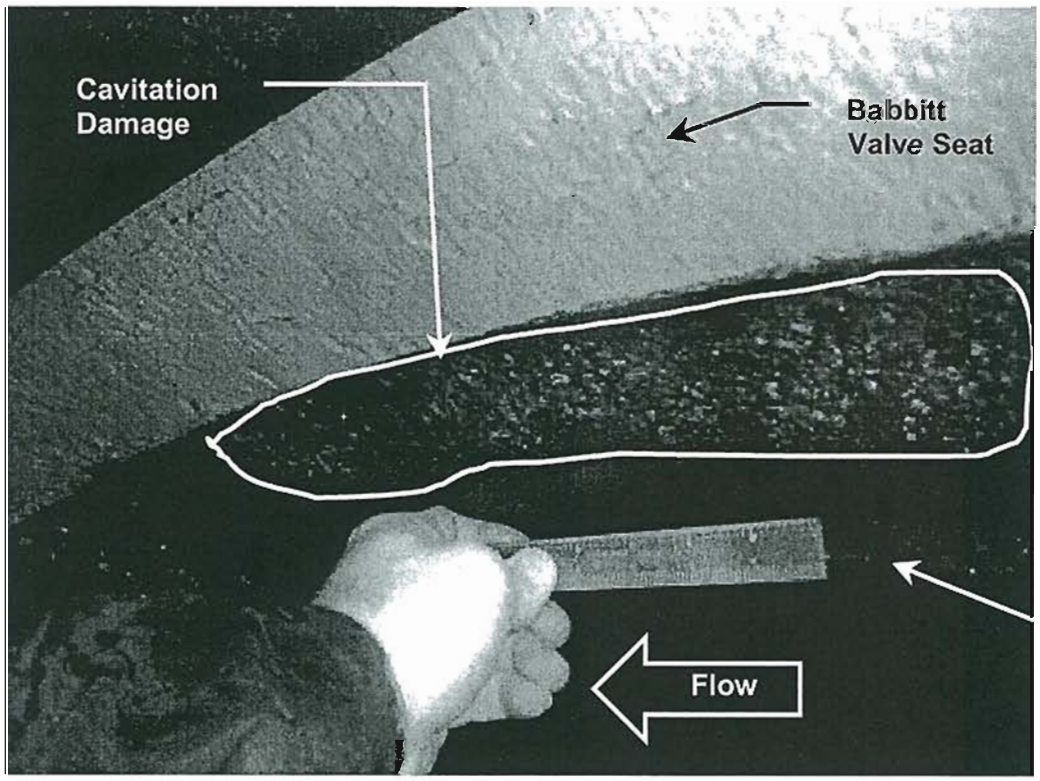
Photograph 7. Stem Deflector. Underside.



Photograph 8. Cavitation Damage on Lip of Stem Deflector.

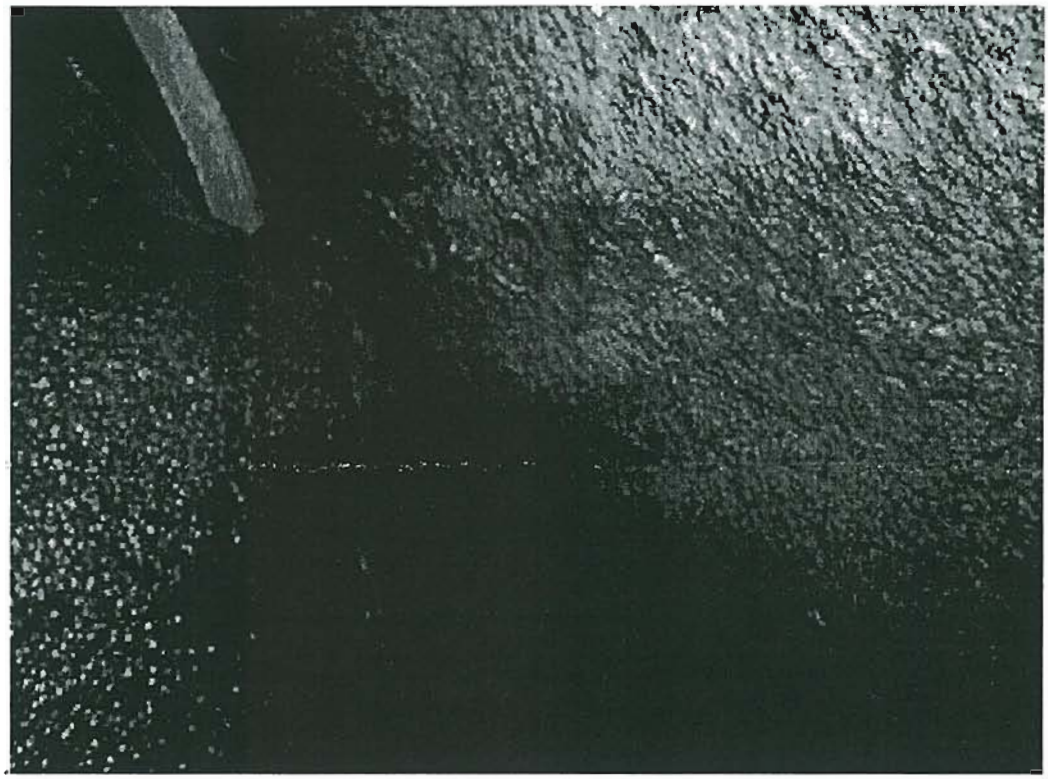


Photograph 9. Butterfly Valve Babbitt Seat. Note Cavitation Repair Upstream of Seat.

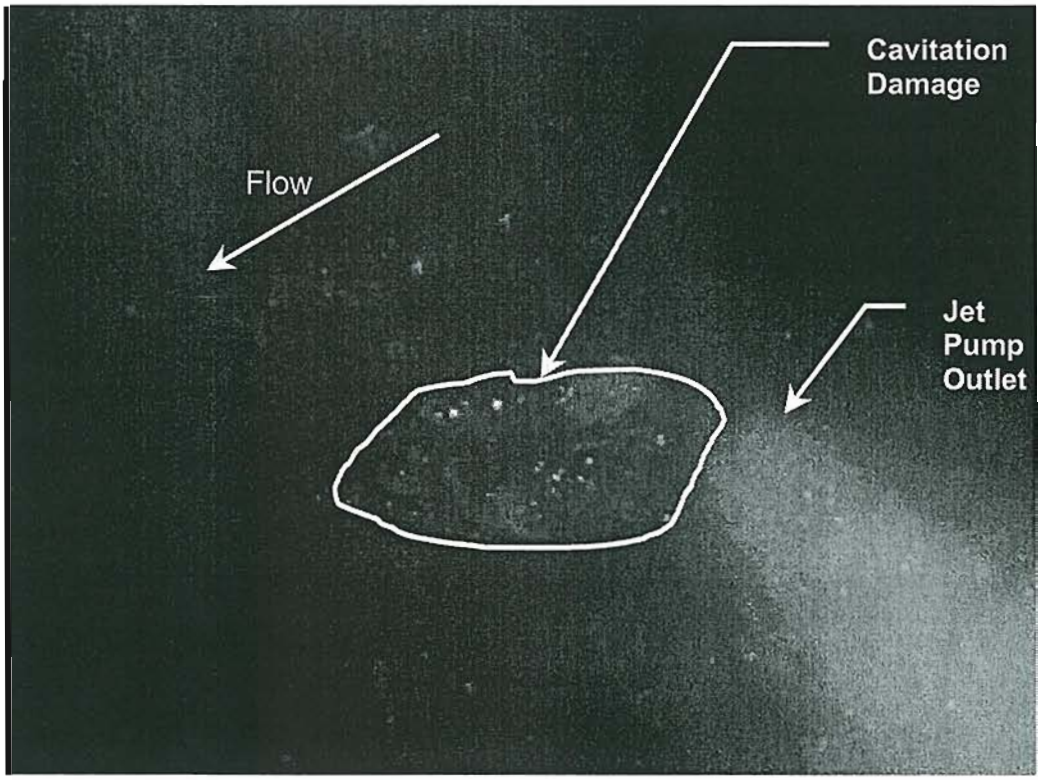


Step at Spool Piece/Valve Interface

Photograph 10. View of Cavitation Damage Immediately Upstream of Valve Seat.

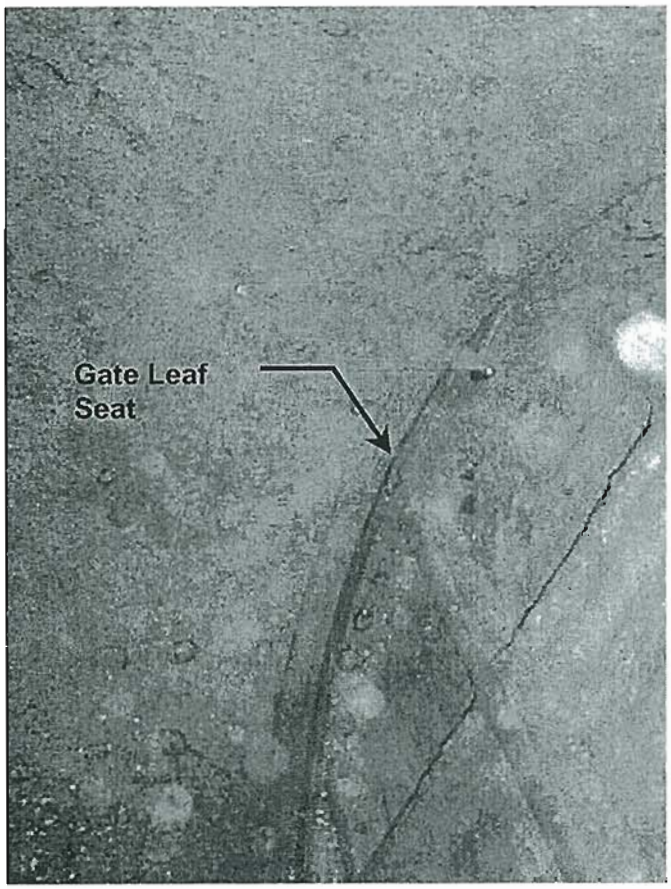


Photograph 11. Butterfly Valve Trunnion. Typical Condition (No Significant Cavitation Damage Observed).

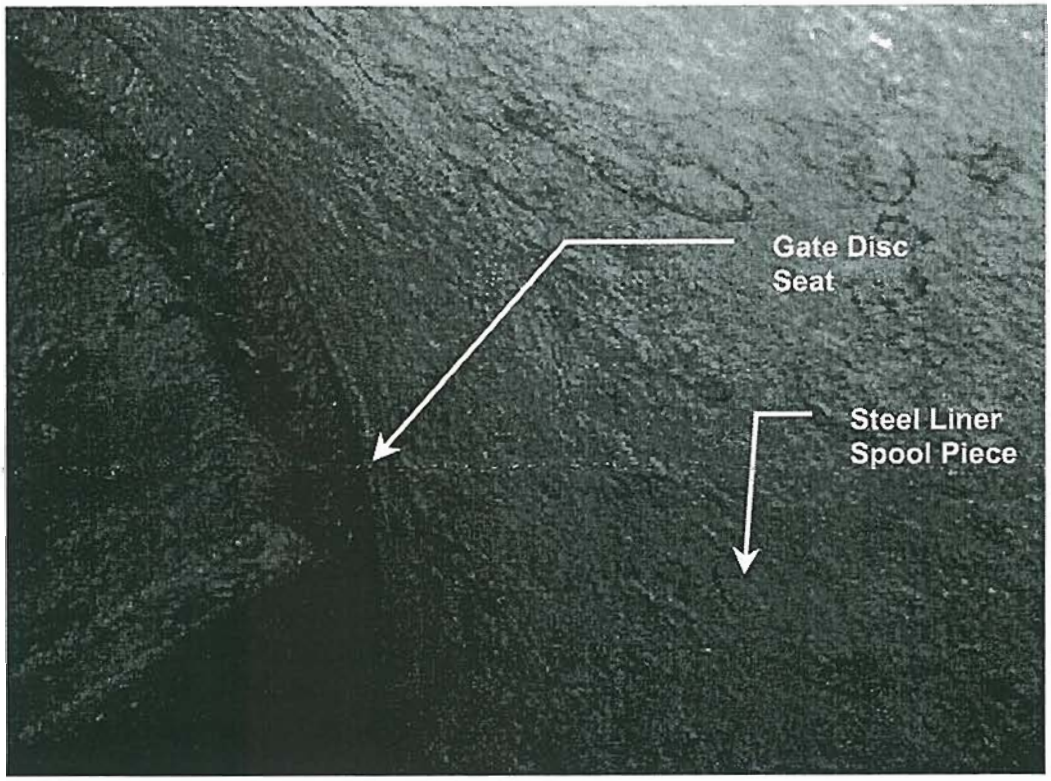


Photograph 12. Jet Pump Drain Outlet. Note Cavitation Damage Immediately Downstream of the Drain Outlet.

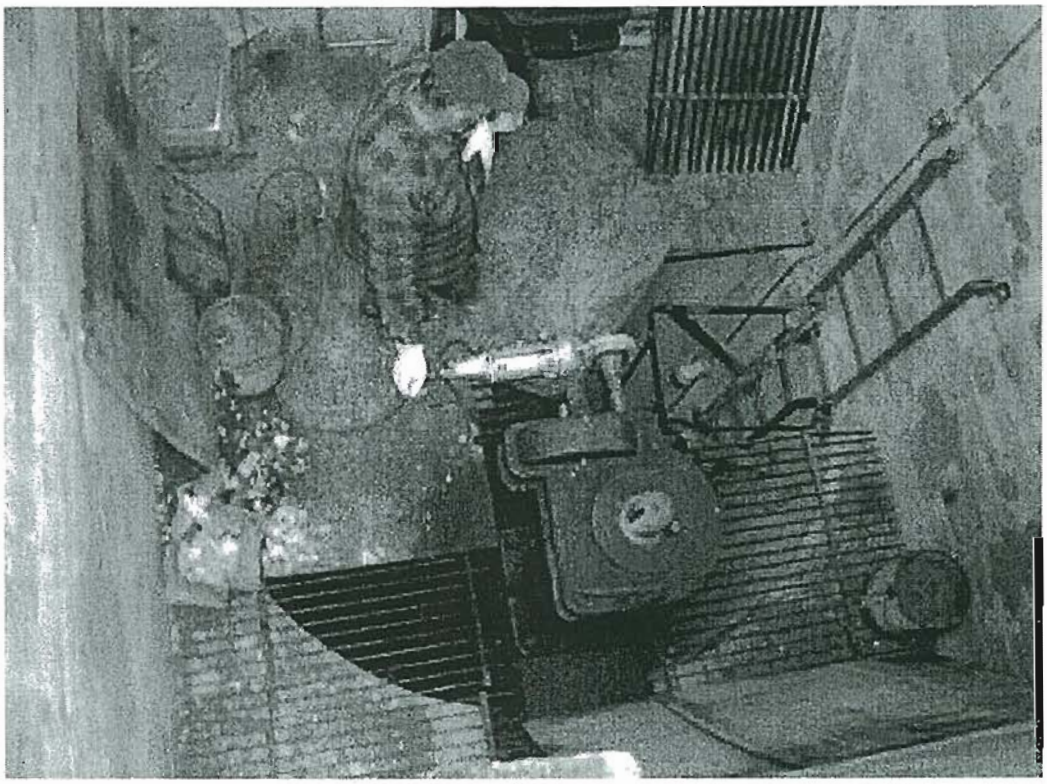
Photograph 13. Downstream Face of Emergency Gate Disc.



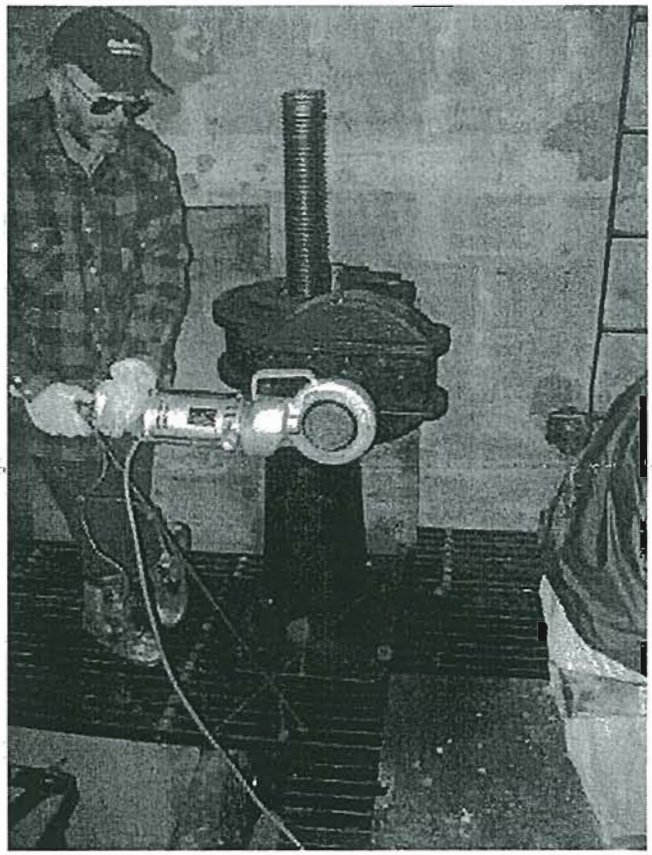
Photograph 14. Emergency Gate Disc and Downstream Spool Liner.



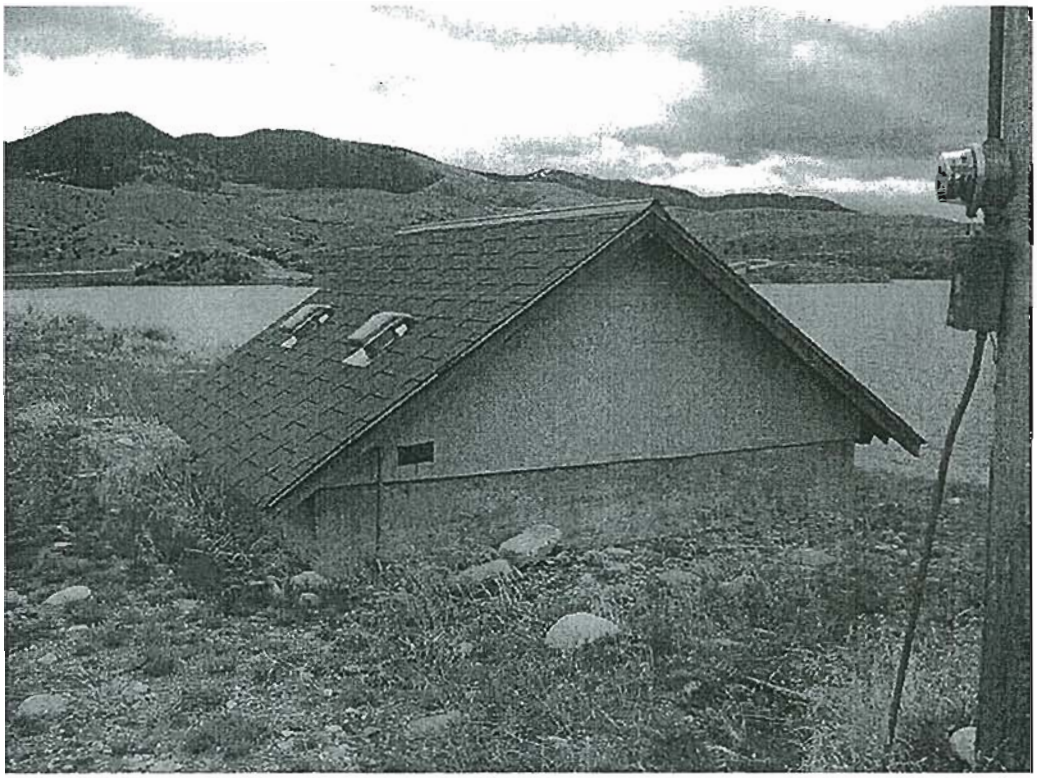
Photograph 15. Emergency Gate Leaf and Downstream Spool Liner.



Photograph 16. Outlet Gate Shaft. View of Upper Platform and Emergency Gate Operator.

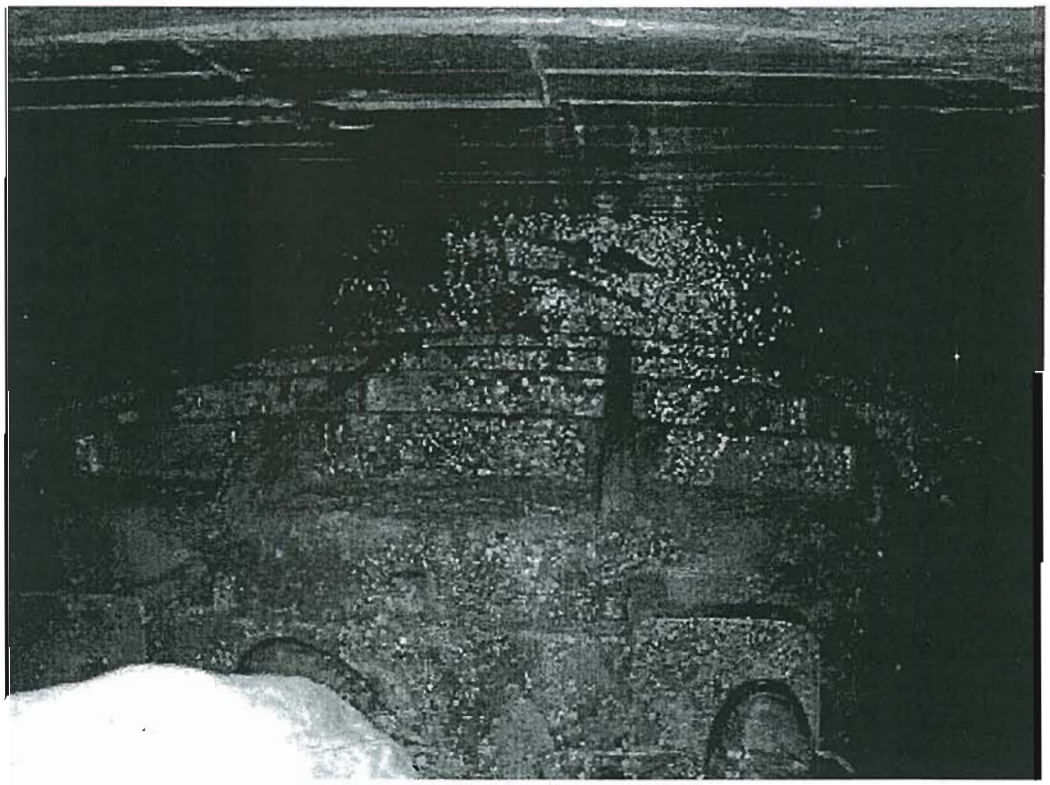


Photograph 17. Emergency Gate Screw Stem Hoist with Electric Rotary Actuator.

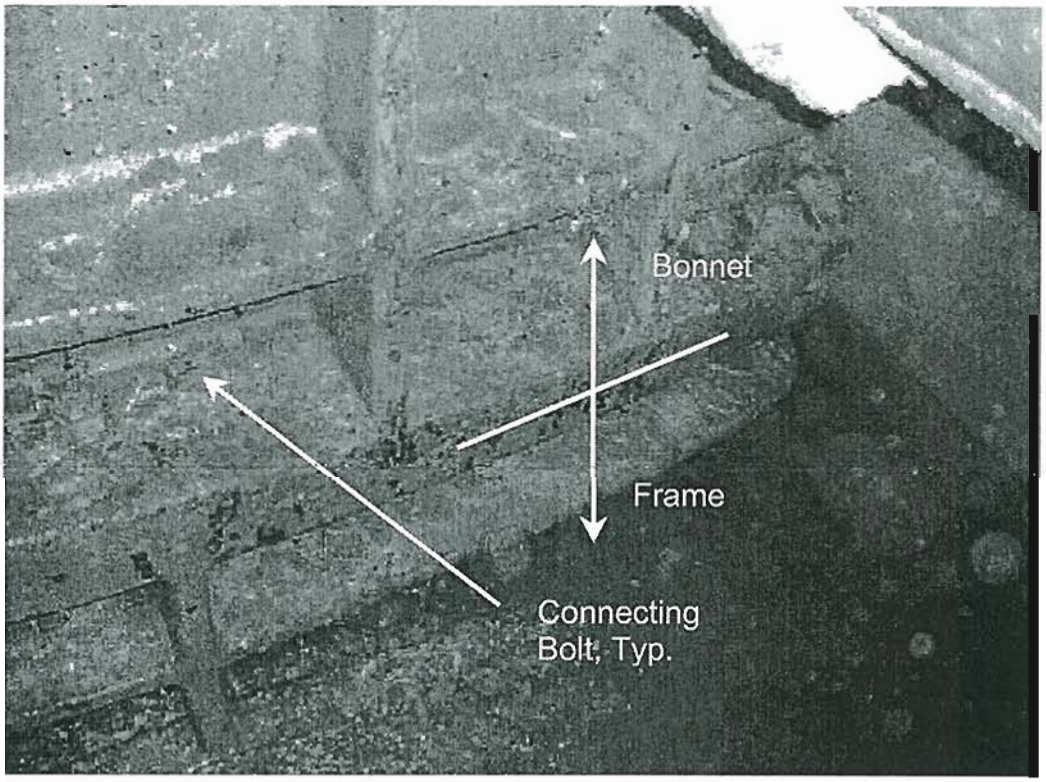


Photograph 18. Gate Shaft Roof and Vents (2 of 3 Vents).

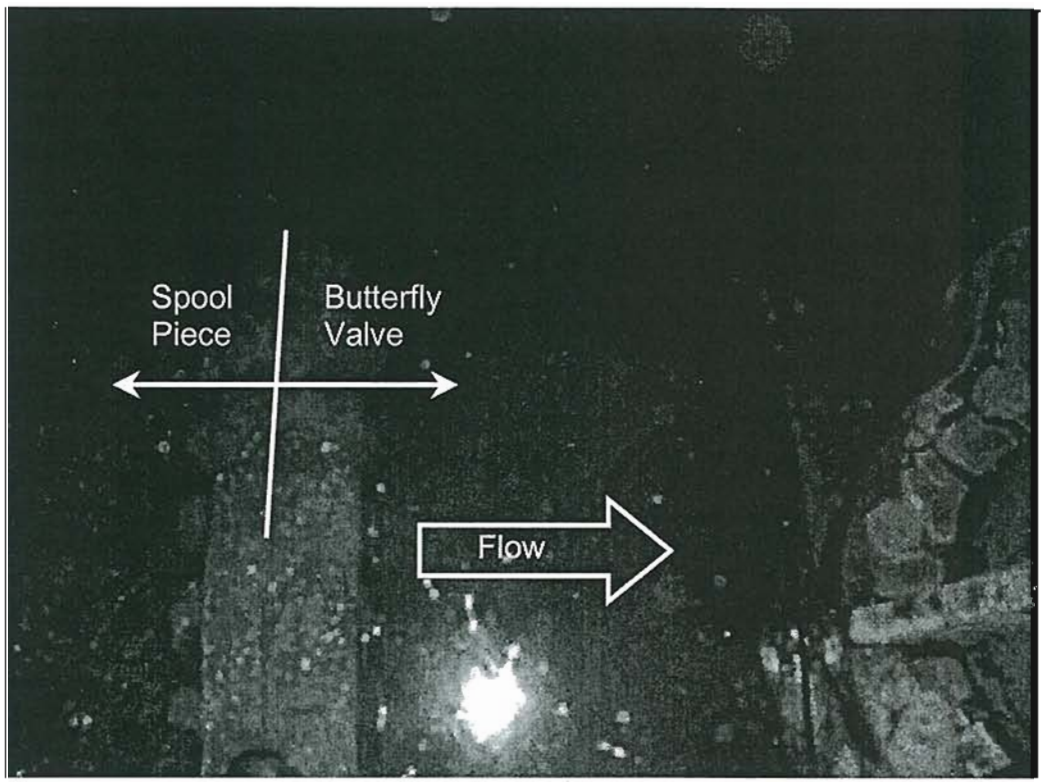
Photograph 19. Emergency Gate. Leaking Stem Packing.



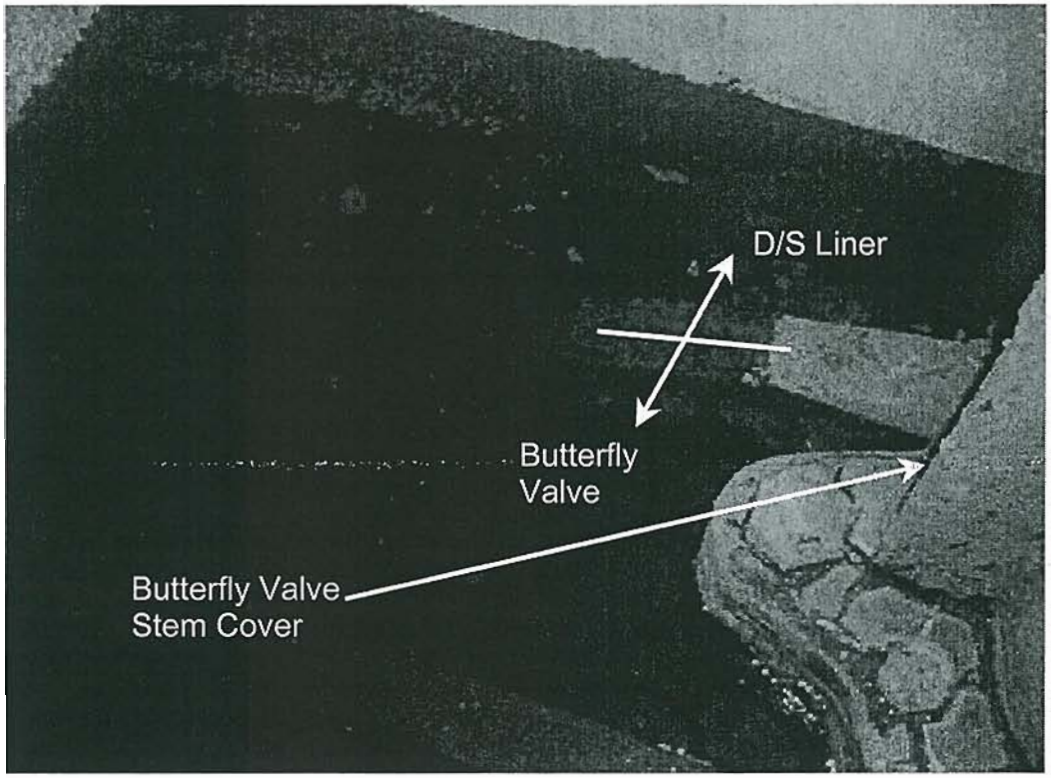
Photograph 20. Emergency Gate Bonnet, Looking Down from Above.



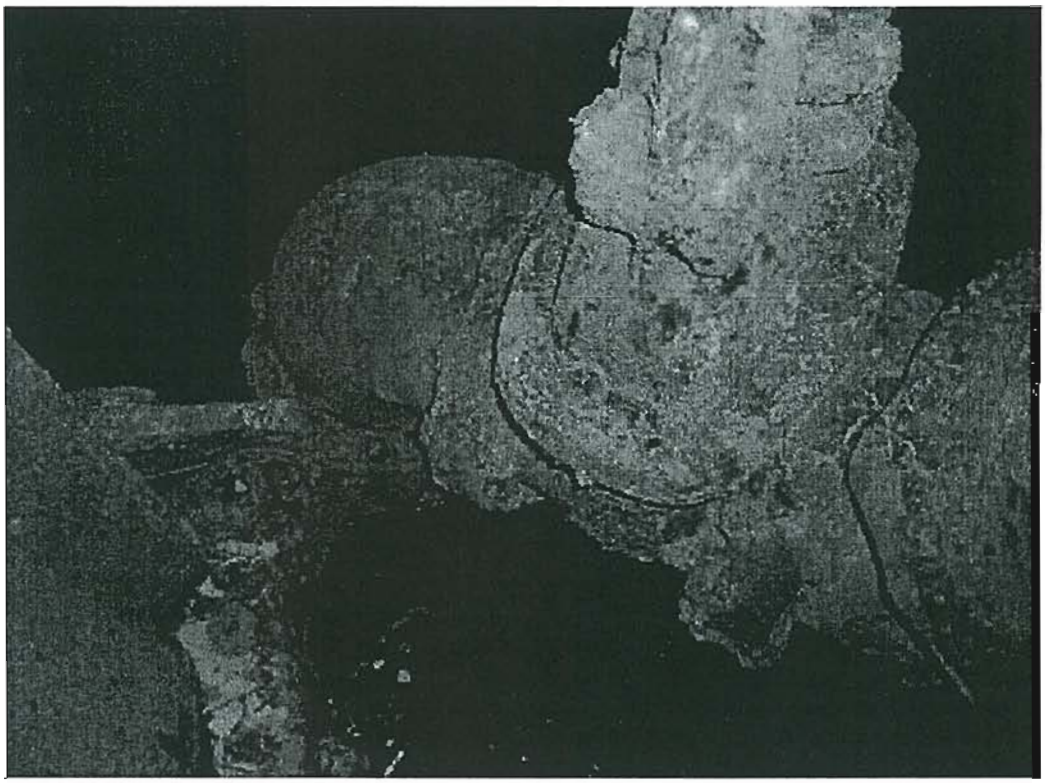
Photograph 21. Emergency Gate Bonnet. Connection of Bonnet to Gate Frame.



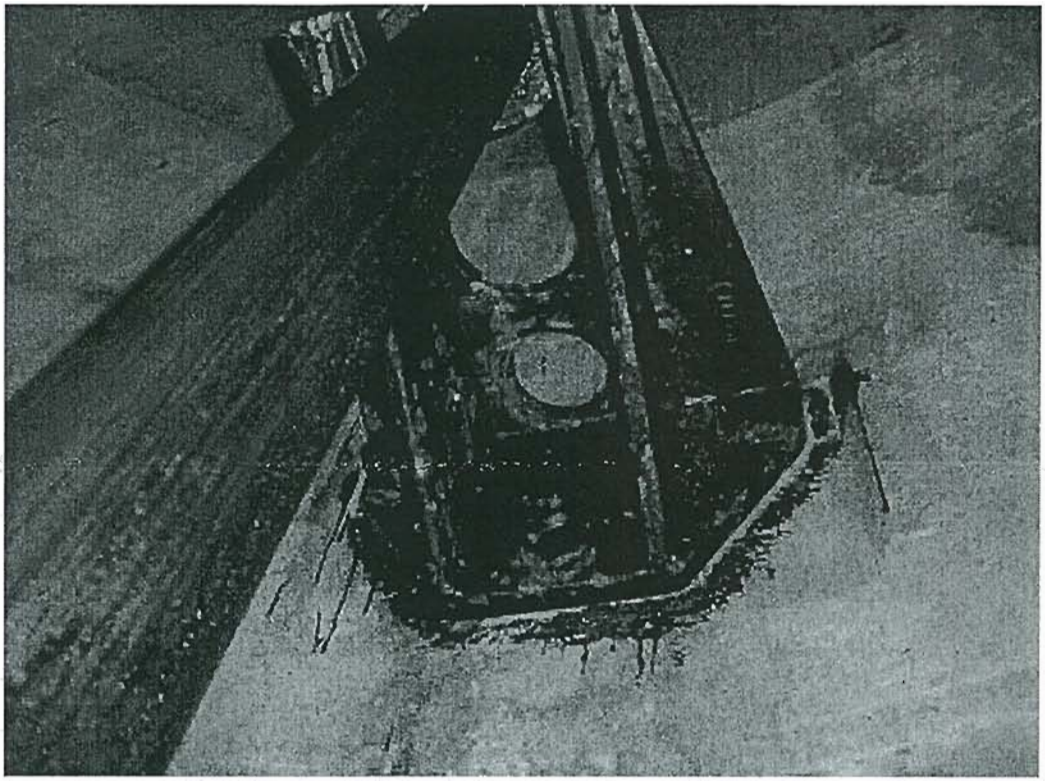
Photograph 22. Mating Flange of Spool Piece and Butterfly Valve Frame.



Photograph 23. Butterfly Valve Frame.



Photograph 24. Butterfly Valve Vent Line and Shutoff Valve.



Photograph 25. Emergency Gate Operating Stem and Stem Guide.

APPENDIX F

MWH
RUBY DAM
OUTLET WORKS
REHABILITATION ALTERNATIVES
INVESTIGATION

RUBY DAM – LOW LEVEL OUTLET WORKS GATE/VALVE REPLACEMENT ALTERNATIVES

TABLE OF CONTENTS

1 EXISTING OUTLET WORKS SYSTEM 1

1.1 DESCRIPTION 1
1.2 MODIFICATION NEEDS 3

2 TYPICAL LOW LEVEL OUTLET WORKS FEATURES 3

2.1 GENERAL 3
2.2 DISCHARGE VALVE OPTIONS 4
2.2.1 GENERAL 4
2.2.2 JET FLOW GATES (JFG) 4
2.2.3 FIXED CONE VALVES (FCV) 5
2.2.4 SLEEVE VALVES (SV) 7
2.2.5 OTHER DISCHARGE VALVE OPTIONS 10
2.3 ENERGY DISSIPATION STRUCTURES 10
2.3.1 GENERAL 10
2.3.2 JET FLOW GATE ENERGY DISSIPATION 11
2.3.3 FIXED CONE VALVE ENERGY DISSIPATION 11
2.3.4 SLEEVE VALVE ENERGY DISSIPATION 12

3 OUTLET WORKS REHABILITATION ALTERNATIVES 13

3.1 GENERAL 13
3.2 ALTERNATIVE 1 – UPGRADE OF EXISTING REGULATING VALVE SYSTEM 13
3.3 ALTERNATIVE 2 – REPLACEMENT OF BUTTERFLY VALVE WITH REGULATING GATE. 14
3.4 ALTERNATIVE 3 – PENSTOCK ADDITION AND NEW DISCHARGE VALVE SYSTEM 15

4 CONCLUSIONS 17

1 EXISTING OUTLET WORKS SYSTEM

1.1 DESCRIPTION

General. The low level outlet works system for the Ruby Dam is located near the left dam abutment The outlet consists of a 90-in. diameter, concrete lined, straight-legged horseshoe tunnel approximately 635 ft. long. Based on the design drawings provided, the intake is composed of slightly converging wing walls and trashrack and the exit portal has slightly diverging wing walls and discharges into a small outlet channel. A vertical shaft, located in line with the dam crest, houses the control valves for the outlet. The tunnel invert is located at El. 5299 at the location of the valves; 111 ft. below the dam crest El. 5410.

Valve Shaft. The valve shaft is located approximately 400 ft. downstream from the intake structure, near the dam centerline. **Figure 1** illustrates its configuration. The upper 80-ft. of the valve shaft is 8.83-ft. diameter. The bottom of the shaft opens up to a chamber 11.66-ft. x 10.5-ft. The base of the shaft (El. 5299) contains the regulating valve, upstream maintenance valve and portions of the steel tunnel liners. The regulating valve is a 72-in. butterfly valve and the upstream maintenance valve is a 72-in. diameter wedge type gate valve. The two valves are separated by a 2.5-ft. long steel spool piece. The conduit, 9 ft. upstream of the maintenance valve is a steel lined concrete transition section. The steel lining is embedded in concrete except for the downstream-most 12-in. which daylights into the gate shaft and is fitted with a mating flange to the valve frame.

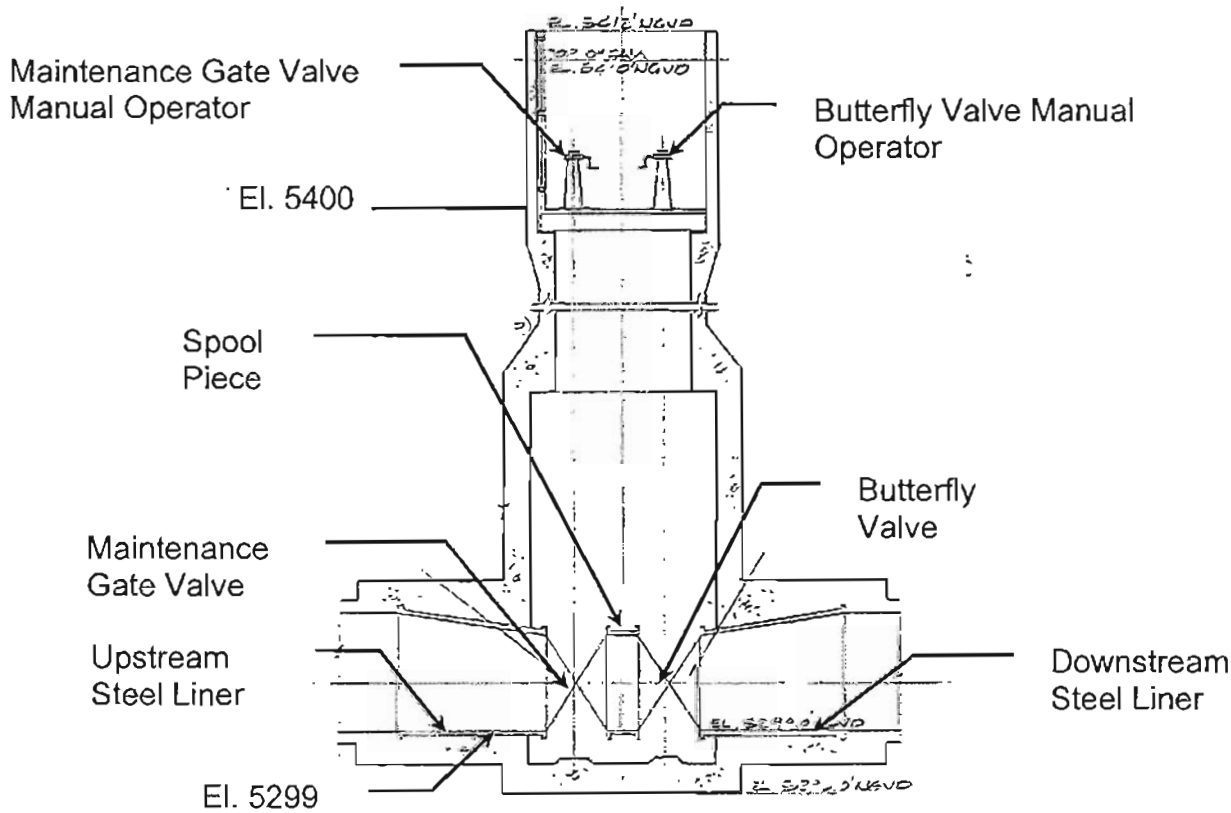


Figure 1. Valve Shaft

The tunnel, 9 ft. downstream of the butterfly valve is also a steel lined concrete transition section with all but the upstream-most 12-in. embedded in concrete. The upstream end of the liner daylights into the valve shaft and is fitted with a mating flange to the butterfly valve. The maintenance valve and the butterfly valve are both provided with flanged connections on each side and are bolted to the upstream/downstream liner and the spool piece. Per available drawings, it appears a spacer ring is fitted between the spool piece and the downstream flange of the gate valve, although this could not be verified in the field at the time of the inspection because the conduit was submerged. The valves and spool piece are exposed at the base of the gate shaft.

The regulating butterfly valve and the maintenance gate valve are operated by means of manual screw stem hoists on a grated platform near the top of the gate shaft at El. 5400 and the screw stems extend down to the valves, supported by several, equally spaced stem guides.

Regulating Butterfly Valve. The regulating butterfly valve is a 72-in. cast iron valve, fabricated in the 1930's. The valve uses a linkage type stem attached to the bottom of the disc on the downstream side to open and close the valve. The stem is located in the flow path. A stem deflector casting is mounted to the crown of the conduit where the stem penetrates it. The valve is opened and closed via a screw stem hoist through a series of several connecting stems, up to the floor stand at El. 5400. A 6-in. diameter vent is located at the top of the conduit, immediately downstream of the disc seat on the right side of the conduit. The vent outlets into the valve shaft through a shutoff valve and an 8-ft. long stand pipe. Refer to **Figure 2** for a drawing of the butterfly valve.

Maintenance Gate Valve. The maintenance valve is a 72-in. cast iron wedge-type gate valve, fabricated in the 1930's. The valve is located approximately 2.5-ft. upstream of the butterfly valve. The valve is of cast iron has a circular disc with bronze seat rings. The valve disc is opened and closed via a screw stem hoist through a series of several connecting stems, up to the floor stand at El. 5400. The stem extends through the bonnet and is sealed with a packing gland. The

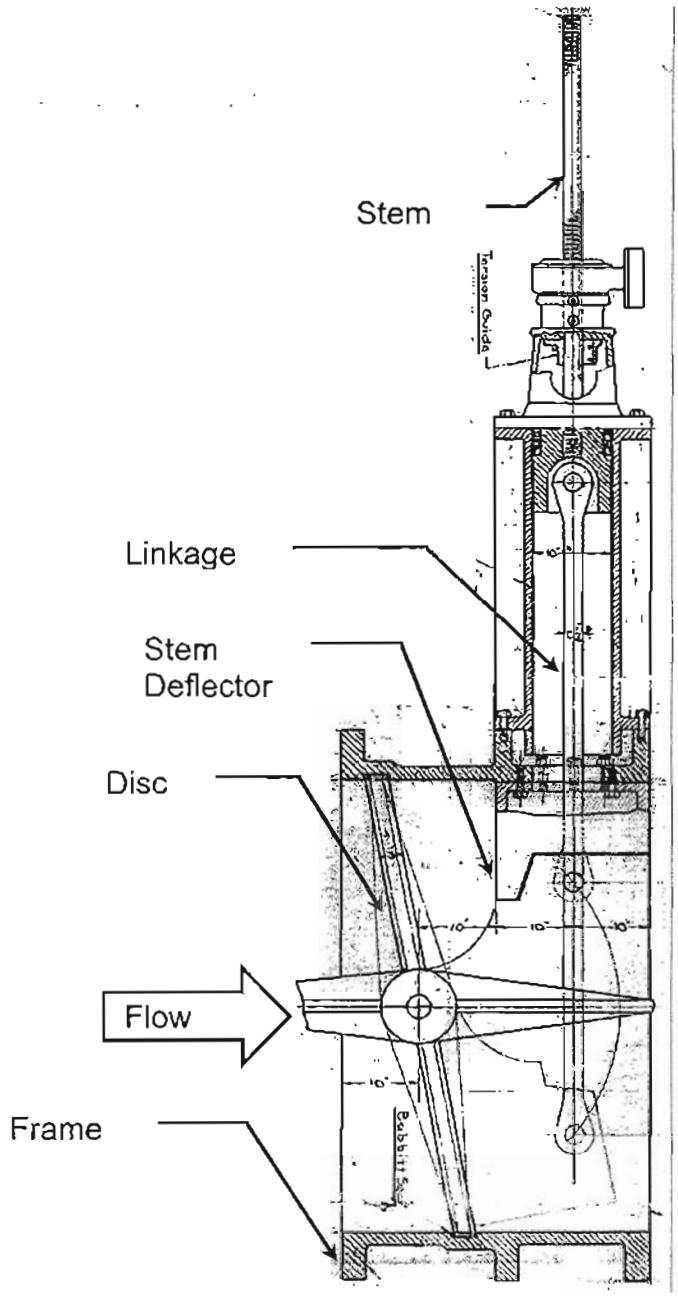


Figure 2. Exist. Butterfly Valve

F-3

top of the bonnet is also equipped with a vent pipe with a shutoff valve. Refer to Figure 3 for a drawing of the valve.

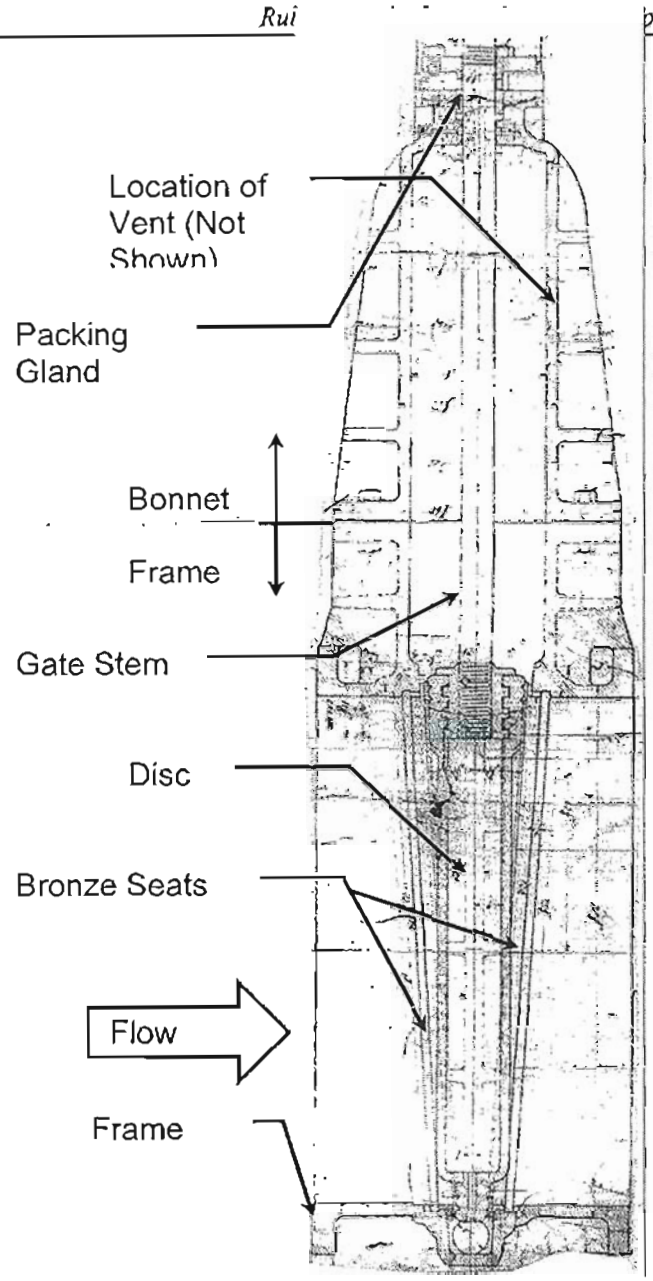


Figure 3. Maintenance Gate Valve

1.2 MODIFICATION NEEDS

The following issues have resulted in the need to investigate rehabilitation alternatives for the present low-level outlet works system.

- Presently, the operation of the butterfly valve regulating gate is restricted to flows no higher than 600 cfs. Although this is adequate for normal flow releases, it is insufficient to meet the discharge criteria established by the DNRC State Water Projects Bureau. The selected discharge criteria for the outlet works is 20 cfs-1500 cfs; 20 cfs is required to meet minimum downstream flow requirements, approximately 600 cfs is required to meet normal peak discharges and 1,500 cfs is needed to fulfill the desired reservoir evacuation rate.

- The maximum safe operating discharge for the existing butterfly valve with the present venting is approximately 500 cfs. Significantly more venting would be required to achieve the desired maximum discharge of 1500 cfs.

- The existing butterfly valve continually requires cavitation damage repairs. This repair is not easily made in the confined quarters of the conduit. During operation of the valve at flows over approximately 500 cfs, there are audible indications of cavitation in the conduit.

- The existing regulating valve is approximately 75 years old and nearing the end of its dependable design life.

2 TYPICAL LOW LEVEL OUTLET WORKS FEATURES

2.1 GENERAL

Several options exist to upgrade the existing system to accommodate the new discharge requirements. Two main components of the upgrade will involve the selection of replacement gates/valves and the arrangement of a new outlet structure. In addition, pressurizing the outlet

F-4

tunnel and moving control to the downstream toe of the dam is considered. Steel lining of the tunnel would be required to accomplish this and is discussed herein. This section will provide some background information in order to lay the groundwork for the development of rehabilitation alternatives.

2.2 DISCHARGE VALVE OPTIONS

2.2.1 GENERAL

Assuming the existing regulating butterfly valve is eliminated from the present low level outlet control system, Ruby Dam will require the installation of a replacement control gate or valve system capable of throttling discharge over a relatively large range to meet the minimum and maximum discharge criteria established by the DNRC. The control gates/valves that are discussed below provide good regulation characteristics. These valves also provide varying degrees of energy dissipation that may or may not be needed depending upon the final positioning of the outlet valves. Gates/valves preferences for this application are described briefly below.

2.2.2 JET FLOW GATES (JFG)

Description. Jet flow gates (JFG's), as shown in Figure 4, have and are widely used for precise flow regulation, free-discharge or submerged discharge at dams and hydro projects. The principle features of JFG's are the truncated conical nozzle; floating seal ring, which forms a circular discharge orifice at the downstream end of the nozzle; and a flat, rectangular-shaped leaf, installed in a steel body. The nozzle section causes the discharge jet to contract and spring free of the gate slots for cavitation-free operation. The leaf is contained in slots on either side of the body. Moving the gate leaf vertically up opens the gate to regulate flows. Once open, flows pass under the bottom lip of the gate leaf until the leaf is full open.

Advantages/Disadvantages. JFG's can be operated at nearly any opening without sustaining cavitation damage. A JFG is a good choice for flow regulation because of design simplicity and excellent flow regulation characteristics. JFG's are typically operated by motor operators or oil hydraulic cylinders.

JFG's provide the following advantages:

- Good coefficient of discharge (0.83-0.84).
- Excellent flow regulation and will not cavitate at small gate openings.
- Good access to valve seats and operating mechanism for inspection and maintenance.
- Compact footprint for close spacing.

Disadvantages of JFG's include:

- Cost (most large jet flow gates are custom designed)
- Minimal energy dissipation of the discharge resulting in long discharge jet. .

Evaluation of Usage. The use of a JFG could be considered for replacement of the regulating butterfly valve within the valve shaft. This valve would discharge into the exit tunnel as at present. The JFG could also be used as a free discharge valve at the downstream toe of the dam assuming suitable energy dissipation is provided downstream to dampen the jet. In order to pass the maximum discharge of 1500 cfs, a 66-in. valve would be required. This type of valve will require significant venting immediately downstream if discharging into the outlet tunnel. A valve of this is size is not unusual but it would be a custom design. Two suppliers of Jet Flow Gates include Hilton Valve and Steel Fab.

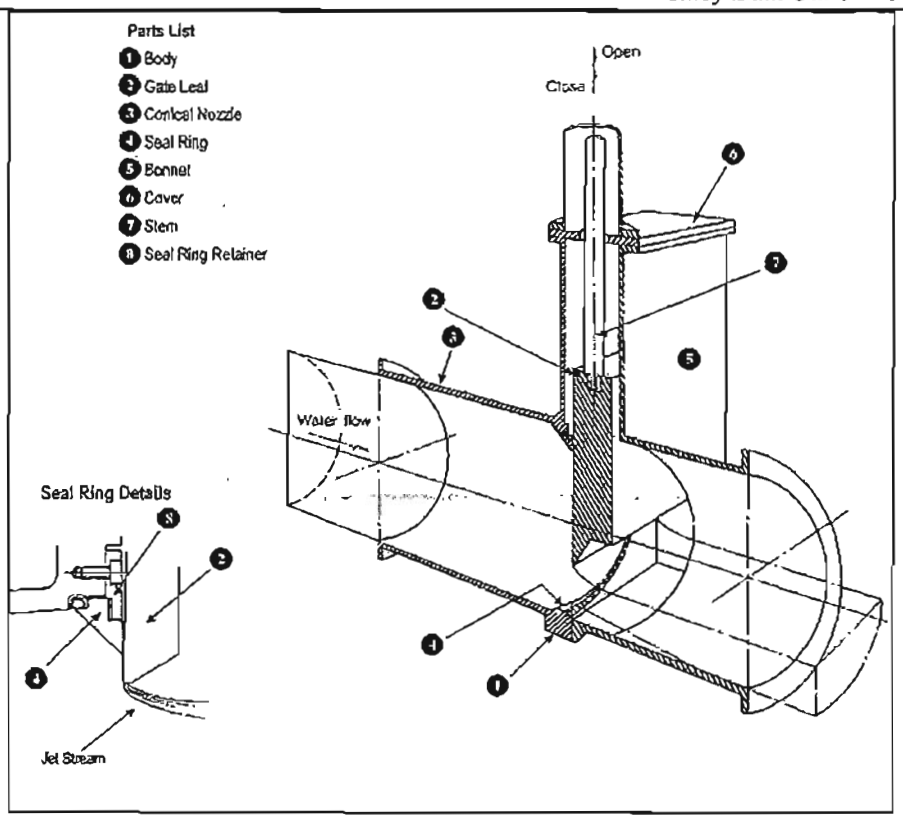


Figure 4. Schematic View of Jet Flow Gate.

The estimated footprint of a JFG of this size is expected to be between 108 and 120 in. wide, which would fit within the space of the existing 126-in. gate chamber. However, the valve would need to be sectionalized to fit down the 8.83-ft. (106-in) diameter valve shaft and therefore, would have to be further customized. The estimated fabrication cost of a sectionalized 66-in. JFG would be approximately $620,000 based on a budgetary estimate from Hilton Valve, Seattle.

2.2.3 FIXED CONE VALVES (FCV)

Description. Fixed cone valves (FCV's), also known as Howell-Bunger valves, are the most widely used valves for use as free-discharge control valves throughout the dams and hydro industry. The major valve components are shown in Figure 5.

Moving the sleeve (Item 2) axially upstream over the valve body opens the valve to regulate flows. For the valve shown in Figure 4, operation of the valve is via twin-screw stems driven by an electric motor operator mounted above the valve. Once open, flows pass over an upstream-facing internal "fixed" cone (Item 5) and disperses a conical discharge jet. Acceptable flow velocities for normal discharge applications through the valve can be as high at 75 fps; therefore these valves have very high capacities compared to standard AWWA valves and sleeve valves. For extreme conditions, 100 fps can usually be tolerated.

In the closed position the gate seals against the outer edge of the fixed cone at the seat ring (Item 3). When valve seals are designed properly and backpressure is maintained on the fixed vanes, a FCV can be operated between 10% and 90% of maximum theoretical discharge without cavitation damage. FCV's have a tendency to cavitate at small gate openings less than 10%. It may also be difficult for FCV's to control releases less than 10% open. Also, unless the valve is conservatively designed, vibration can result at gate openings over 80%.

F-6

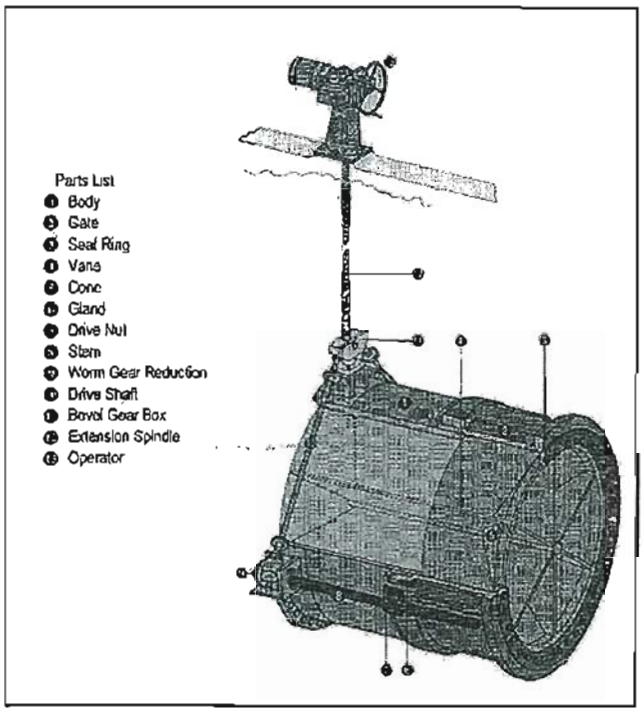


Figure 5. Schematic View of Fixed Cone Valve.

In a typical installation the valve is bolted to the downstream end of the outlet pipe. Energy dissipation is achieved by dispersing the jet into the atmosphere. In a free discharge application, the expanding conical discharge sprays into the air in a "rooster tail" formation. See Figure 6.

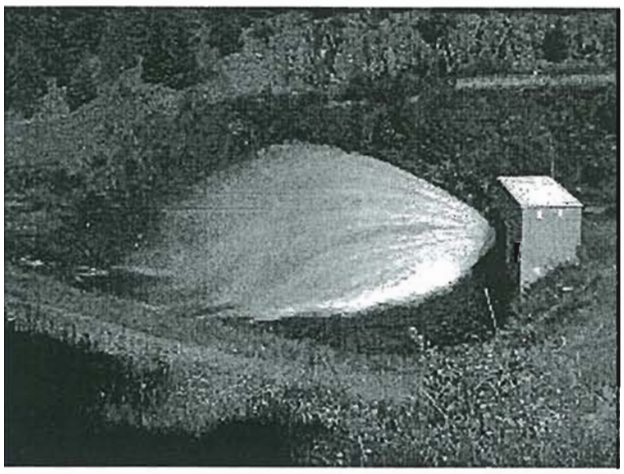


Figure 6. Discharge from FCV.

A "hooded" fixed cone valve could be used to restrict full dispersion of the jet, if desired, however, the energy dissipation effect of the hood would be minimal. The hood is usually a steel shell, around the valve discharge area. It should be noted that proper care must be taken when fixed cone valves are fitted with hoods, so air admission is adequate and uniform around the jet periphery.

Advantages and Disadvantages. The major advantages of FCV's are:

F-7

- Relatively simple construction.
- Economical
- Can withstand high flow velocities and therefore can be provided in smaller sizes than other types of valves.
- Good access to valve seats and operating mechanism.
- Good flow regulation.
- Energy dissipation through rooster tail spray into atmosphere
- Available from numerous suppliers in many standard sizes.

Disadvantages of FCV's includes:

- Heavy spray at discharge.
- Discharge at flows less than 10% of valve capacity for extended periods could result in cavitation damage and vibration. Considering the extended period of time that discharges of 20-60 cfs are required, a minimum of 2 valves would be required to cover the discharge range.
- More complicated operating mechanism than jet flow gates (JFG's) in that twin-screw stems, shafting, U-joints, and multiple gearboxes are required.

Evaluation of Usage. For a free discharge application, the use of FCV's is the preferred and most economical choice for a discharge valve. At Ruby Dam, a minimum of two valves would be required to cover the large variance between the minimum and maximum discharges (20 cfs to 1500 cfs). The following valve sizes would be considered for free discharge valves for usage for the Ruby Dam Project.

FC Valve Size	Minimum Recommended Discharge (10% Theoretical Max.) (Assumed 45 ft. net head at valve)	Max. Recommended Discharge (90% Theoretical Max.) (Assumed 45 ft. nnet head at valve)	Approximate Fabrication and Delivery Cost
18 in. Valve	10 cfs	70 cfs	$55,000
24 in. Valve	15 cfs	130 cfs	$85,000
48 in. Valve	60 cfs	515 cfs	$212,000
54 in. Valve	70 cfs	660 cfs	$250,000
66 in. Valve	100 cfs	980 cfs	$360,000

(Note 45 ft. net head considers estimated losses through the tunnel system.)

The need for an energy dissipation structure would depend upon the size of the outlet basin and the DNRC's tolerance for spray and noise at the project. See Section 2.3 for additional discussion on these structures.

2.2.4 SLEEVE VALVES (SV)

Sleeve valves are energy dissipation valves that use the principle of throttling pressure across multiple orifices. The orifices are specially sized and are positioned around a circular sleeve. A sliding sleeve gate is advanced or retracted to expose the required nozzles for a desired flow rate.

There are multiple arrangements of sleeve valves with the most common being in-line valve arrangement and pit valve arrangements. Both would be submerged discharges. Refer to Figures 7 and 8 for these configurations.

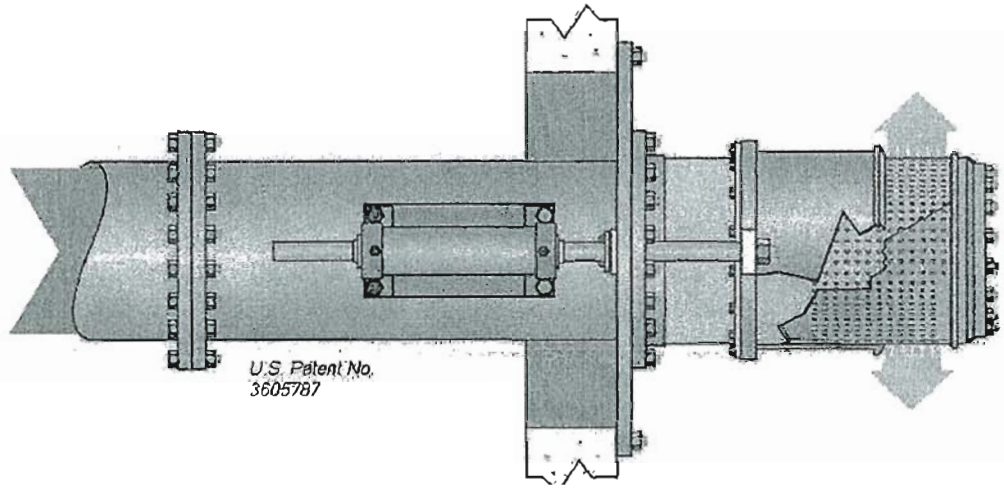


Figure 7. In Line Sleeve Valve.

Sleeve valves are typically operated by means of screw stem electric actuators.

Sleeve valves are considered the superior choice for applications where submerged discharge is required and space is limited. The configuration of a sleeve valve requires limiting flow velocities to the 40 to 45 fps range. As a result, significantly larger valves are required to pass a given flow than a FCV. These valves are also more complicated to fabricate than FCV's. As a result, the cost of a SV is significantly higher than a FCV.

Sleeve Valves are presently manufactured by Bailey Valves, Inc. Polyjet, previously a major supplier of these valves has been acquired by WATTS Water Technologies and has presently halted the manufacture of large diameter sleeve valves.

The major advantages of Sleeve Valves are:

- Good energy dissipation.
- Excellent flow regulation.
- Reduced size of energy dissipation structure needed.

Disadvantages of sleeve valves include:

- Significantly higher cost than FCV.
- Less flow capacity for a given size.
- Subject to clogging by debris.
- Subject to erosion when used for continuous duty.
- Limited suppliers of such valves (only 1 supplier of such valves was located in the US)

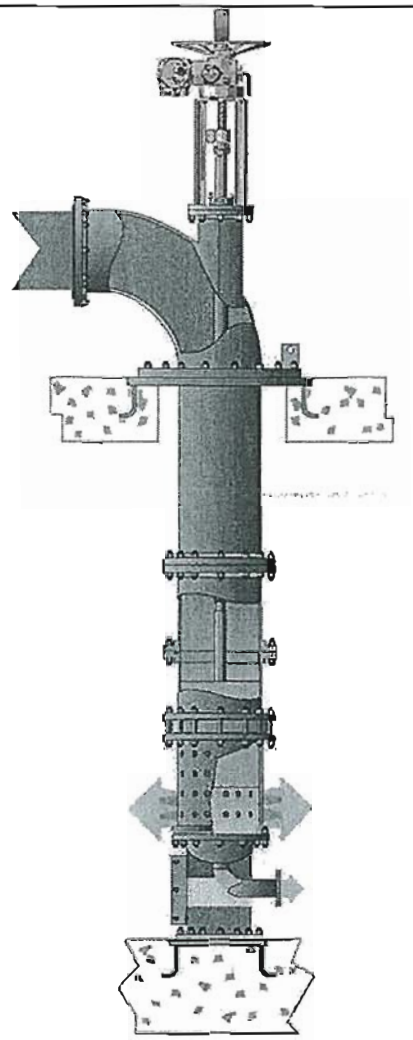


Figure 8. Pit Sleeve Valve.

Evaluation of Usage. For a free discharge application into the air, SV's cannot economically compete with FCV's. Depending upon the final outlet arrangement, if a better outlet structure arrangement lends itself to a submerged discharge and if the discharge basin is severely limited, a sleeve valve arrangement may have merit. Unfortunately, a minimum of three valves would be required to cover the large variance between the minimum and maximum discharges (20 cfs to 1500 cfs). The following valve sizes would be considered for the passage of the required flows.

Sleeve Valve Size	Minimum Recommended Discharge (94 ft. head)	Maximum Discharge (94 ft. head) (Continuous)	Max. Discharge (94 ft. head) (Short Duration)
24 in. Valve	20 cfs	90 cfs	100 cfs
60 in. Valve	100 cfs	590 cfs	750 cfs.

A typical outlet arrangement for a SV is explained in Section 2.3.

2.2.5 OTHER DISCHARGE VALVE OPTIONS

"Dump" valves were briefly considered as an alternative to multiple discharge valves (for the downstream discharge arrangement option) to release flows above 600 cfs which would only be needed if a reservoir evacuation is needed. This idea would only have merit if a significant cost savings could be realized. Butterfly valves, gate valves and ball valves were considered for this use. It is determined that this idea would not be economically viable for the following reasons:

1. These valves would provide negligible energy dissipation and could result in significant erosion of the banks downstream if no energy dissipation structure was provided. The maximum residual discharge of 900-cfs emanating from this discharge would produce a tremendous amount of energy. It is believed that some sort of energy dissipation structure or lining would need to be provided to dissipate a portion of this energy to prevent significant damage downstream. The need for this structure would significantly reduce any economical benefit gained by a less expensive valve.
2. Standard off-the-shelf gate valves and butterfly valves meeting AWWA standards 500,504 and 509 are supposed to be sized for flow velocities around 16 fps. This would require valves on the order of 96 in. to achieve this requirement FCV's can discharge at much higher velocities (around 75-fps max), reducing the required size of the valve, conduit, support and surrounding structure. Specially designed butterfly valves can be designed for higher velocities, however, this would result in a custom design of significantly more expense than a standard AWWA valve and eliminate any significant economical benefit over a discharge valve.
3. Ball valves can be designed for high flows (75 fps) and could therefore be relatively small, (48 in). However, these valves are similar to FCV's in terms of cost.

Based on the above, it is determined that a "Dump" Valve would not provide a cost savings and would likely be a more expensive arrangement in the end. It will not be considered further.

2.3 ENERGY DISSIPATION STRUCTURES

2.3.1 GENERAL

The JFG, FCV and SV are all commonly used for low-level outlet discharge with good success. These three valves dissipate energy to various degrees and provide very different discharge profiles. Under normal applications, the following discharges would be expected for each of the three valves above without additional energy dissipation:

- JFG – Compact spray beam with high residual energy.
- FCV - Rooster tail spray (Figure 6 above), high spray with moderate residual energy.
- SV- Submerged radial spray with boiling water and least amount of residual energy.

The arrangement of the outlet structure depends upon what degree spray can be tolerated and how large a discharge basin is provided.

2.3.2 JET FLOW GATE ENERGY DISSIPATION

For this project, the JFG is considered only for discharge into the outlet tunnel as is done in the present butterfly valve arrangement. In this case, a suitable outlet would be sized based on the exit velocities from the tunnel.

Regarding the use of a JFG as a discharge valve at the tunnel exit, unless there could be provided a very large stilling basin area for the jet to dissipate energy into the air, its use would not be preferred in this case. An energy dissipation structure for this type of valve can be provided but would make the combination valve/dissipation structure cost more expensive than the FCV or SV designs described below.

2.3.3 FIXED CONE VALVE ENERGY DISSIPATION

Two examples of energy dissipation structures are provided herein for FCV's assuming discharge into the air is not preferable. Refer to Figures 9 and 10 (Note these have been taken from other projects, and are intended to only show the concept and not the final arrangement). Both will result in a somewhat tranquil flow once exiting the outlet structure with no significant spray.

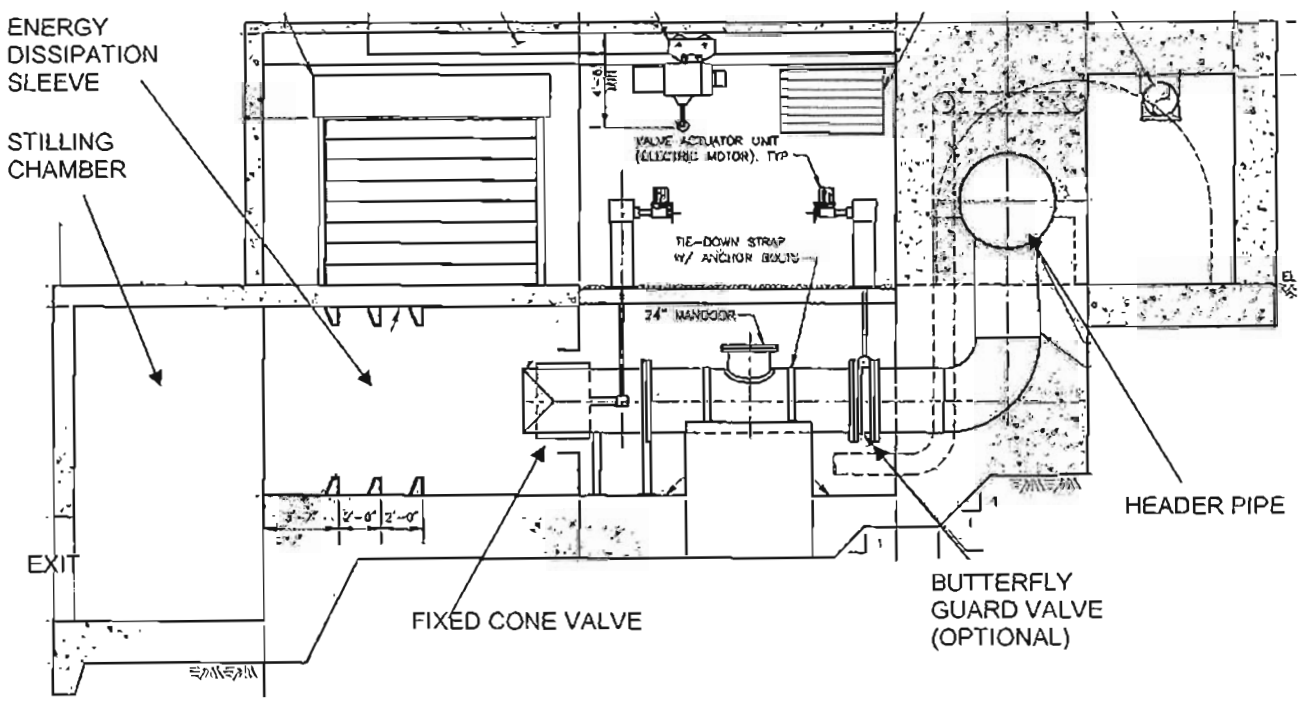


Figure 9. FCV Discharge Arrangement 1

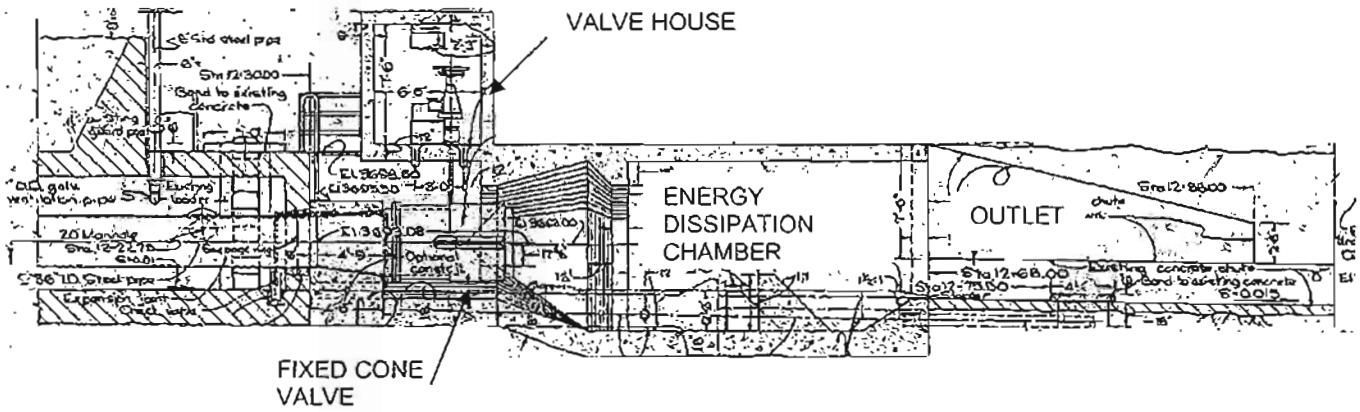


Figure 10. FCV Discharge Arrangement 2

2.3.4 SLEEVE VALVE ENERGY DISSIPATION

For Sleeve Valves, it was recommended above that the discharge be submerged. Sample arrangements are provided in Figures 11 and 12 for in-line and pit valve arrangements, respectively.

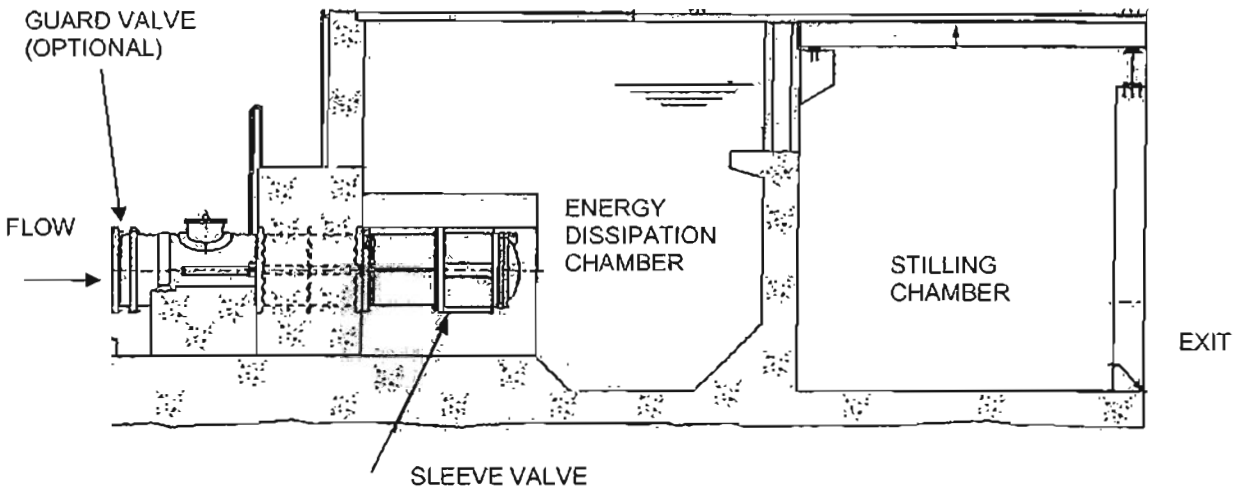


Figure 11. SV Discharge Arrangement

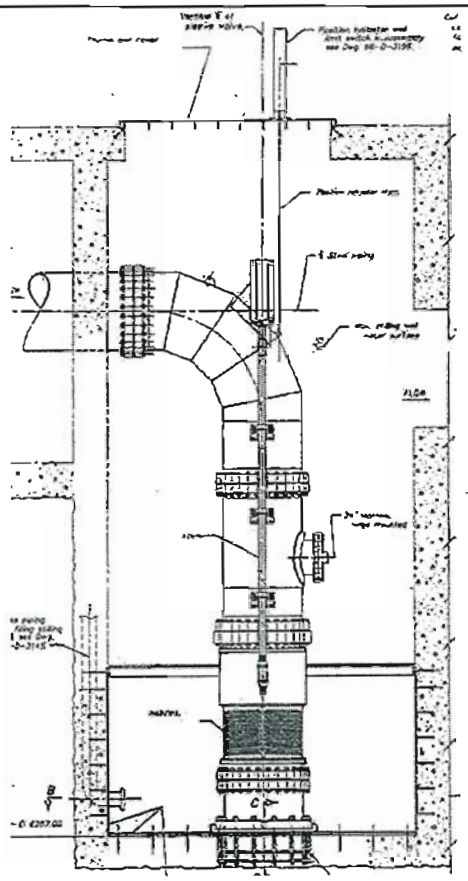


Figure 12. SV Pit Discharge Arrangement

Sizing of the various chamber dimensions would be determined by hydraulic evaluation.

3 OUTLET WORKS REHABILITATION ALTERNATIVES

3.1 GENERAL

Three alternatives were considered below for the upgrading the existing outlet works system to meet the new project requirements.

3.2 ALTERNATIVE 1 – UPGRADE OF EXISTING REGULATING VALVE SYSTEM

This alternative would involve the rehabilitation of the existing flow regulation system for the outlet works and would include the following main work items:

- Disassembly, inspection and refurbishment of the existing butterfly valve including non-destructive testing, bearing inspection/rehabilitation, packing replacement, etc.
- Introduction of larger air vent to aerate flow for higher discharges (sizing would require field or model testing to determine optimum sizing and verify capacity can be achieved).
- Reshaping of the stem shroud to reduce cavitation damage.
- Modification to the terminal structure to accommodate higher discharges and improve access as described in the Hank Falvey & Associates "Ruby Dam Hydraulic Analysis" report.

- Inspect and upgrade of existing valve hoists as needed, add electric operators.
- Dewatering, inspection and rehabilitation of the exposed portions of the conduit within the valve shaft.
- Stem packing replacement on Maintenance Gate Valve.
- Improvements to present gate shaft sump (apparently recently performed by the DNRC).

According to the Hank Falvey & Associates "Ruby Dam Hydraulic Analysis" report, the existing conduit has the ability to pass up to 1900 cfs under a head of 92 ft with proper venting, this would have to be verified by testing. However, this would introduce significantly increased forces on the valve. As a result, extensive inspection, non-destructive testing and structural analysis would have to be performed to verify the valve's ability to withstand these forces in its present condition. Presently, the valve is in fair condition. The downstream portion of the valve frame is considered to be in poor condition due to the extensive patching required to repair past cavitation damage. Placing larger dynamic forces, including hydraulically-induced vibratory forces, on the valve at its present age would be undesirable. Due to the age of the valve, the unusual application of using a butterfly valve for flow regulation, and the obstruction caused by the stem and shroud, the rehabilitation of the present valve would not be considered as a long-term solution. In addition, the economic effect of potential unknowns associated with rehabilitation of the valve would demand a large contingency and could negatively impact schedule if additional problems are identified in the valve (cracking). Finally, the modification of the stem shroud would be a difficult repair since the valve is of cast iron. If the present shroud arrangement is retained, cavitation repairs will continue to be required. The confined area within the valve shaft would also make any in-situ repairs very difficult. As a result of the above, this alternative is not recommended.

3.3 ALTERNATIVE 2 – REPLACEMENT OF BUTTERFLY VALVE WITH REGULATING GATE.

This alternative would involve the replacement of the existing butterfly valve with a new, regulating jet flow gate. A discussion of this type of valve is described above in Section 2. This alternative would require the following:

- Design, fabrication and delivery of a new jet flow gate and operating system (note a sectionalized designed may be required to fit the existing shaft).
- Removal of the existing butterfly valve.
- Rehabilitation and modification of existing conduit to interface with the new gate.
- Introduction of a large air vent to aerate flow.
- Modification to the terminal structure to accommodate higher discharges and improve access as described in the Hank Falvey & Associates "Ruby Dam Hydraulic Analysis" report.
- Inspect and upgrade of existing Maintenance Gate Valve hoist as needed, add electric operator.
- Dewatering, inspection and rehabilitation of the exposed portions of the conduit.
- Stem packing replacement on Maintenance Gate Valve.
- Improvements to present gate shaft sump (apparently recently performed by the DNRC).

This alternative is expected to be somewhat impractical because it would be the most expensive and difficult solution to implement due to the cost of the JFG and the difficulties associated with its retrofit into the existing conduit at the base of the valve shaft. Since Alternative 3 below would be cost competitive, while providing a superior means of control and

maintenance. Alternative 2 is not recommended unless Alternative 3 is not acceptable to the DNRC.

3.4 ALTERNATIVE 3 –PENSTOCK ADDITION AND NEW DISCHARGE VALVE SYSTEM

This alternative would involve the removal of the existing butterfly valve and the addition of a steel penstock placed inside the present discharge tunnel, with new control valves located at the terminal structure. The alternative is broken into sub-alternatives 3A and 3B below to distinguish between two types of discharge valve systems available. This alternative would consist of the following:

- Penstock Addition. A 3/8-in. thick steel penstock would be installed into the existing outlet tunnel. The penstock would be approximately 220 to 250 ft. long and would be designed to mate with the existing 72-in. pipe immediately downstream of the existing maintenance gate valve. The penstock would be pushed or pulled into the tunnel in approximately 50-ft.long sections with each joint welded prior to being drawn into the tunnel. The penstock would likely be installed using a track/roller system. For the purpose of this study, it is assumed that the bottom third of the tunnel would be grouted after installation for support. More preferably, the entire tunnel could be fully grouted to encase the steel liner. However, drainage around the perimeter of the tunnel would have to be accommodated in another manner.

  MWH discussed this construction option with Barnard Construction. This is a rehabilitation measure that has been successfully performed at several projects and could be implemented at Ruby Dam without considerable difficulty. Based on budgetary price quotations from Northwest Pipe and Barnard Construction, this component of the work would be on the order of $300,000, not including bifurcations and the outlet structure.

- Control Valve Selection and Energy Dissipation. Multiple valve combinations were considered to achieve the desired discharge range for the system. FCV's (Alternative 3A) and SV's (Alternative 3B) were both considered. A description of these valves is described in Section 2.2.

  Alternative 3A. For a free-discharge arrangement into the atmosphere, Alternative 3A would be the preferred discharge valve arrangement. The arrangement would consist of 3 valves to pass the required discharge:

Alternative 3A			
Valve Type and Size	Minimum Recommended Discharge (10% Theoretical Max.) (Assumed 45 ft. net head at valve))	Maximum. Theoretical Discharge (45 ft. head)	Approximate Fabrication and Delivery Cost
18 in. FCV Valve	12 cfs	100 cfs	$50,000
54 in. FCV Valve	70 cfs	730 cfs	$250,000
54 in. FCV Valve	70 cfs	730 cfs	$250,000

TOTAL DISCHARGE CAPACITY	**1560 cfs**	**$550,000**

The above arrangement would be capable of meeting the minimum discharge requirement of 20 cfs by using the 18-in. FCV during periods of low flow. For normal flows, either 54-in. valve could be used to pass normal flows up to the 600-cfs limit while the other provides desirable redundancy. For this arrangement upstream isolation valves could be used to enable maintenance of one of the valves while letting the remaining valves discharge. Otherwise, the existing maintenance gate valve could be used to temporarily shut off the entire flow to enable removal of one of the valves for maintenance. The 1500-cfs discharge would be accomplished by opening all valves.

If the discharge jet is considered acceptable to the DNRC, an energy dissipation structure would not be required and a significant cost could be realized. An energy dissipation structure similar to that shown in Figure 9 would be used if free discharge into the air is not desirable. This structure would be placed at each valve location and would be capable of dissipating approximately 90% of the residual energy based on recent published model study results.

Alternative 3B. In the event submerged discharge is desired and/or if space downstream is too limited for a large energy dissipation structure, Alternative 3B would be the preferred discharge valve arrangement, although significantly more expensive. The arrangement would consist of 3 Sleeve Valves to pass the required discharge as follows:

Alternative 3B			
Valve Type and Size	Minimum Recommended Discharge (10% Theoretical Max.) (94 ft. head)	Maximum. Recommended Discharge (94 ft. head)	Approximate Fabrication and Delivery Cost
24 in. Sleeve Valve	20 cfs	100 cfs	$125,000
60 in. Sleeve Valve	100 cfs	750 cfs*	$320,000
60 in. Sleeve Valve	100 cfs	750 cfs*	$320,000
TOTAL DISCHARGE CAPACITY		**1600 cfs**	**$765,000**

* - Maximum discharge, short duration. Normal maximum discharge is 590 cfs.

The above arrangement would be capable of meeting the minimum discharge requirement of 20 cfs by using the SV during periods of low flow. For normal flows, either 60-in. valve could be used to pass normal flows up to the 600-cfs limit while the other provides desirable redundancy. For this arrangement upstream isolation valves could be used to enable maintenance of one of the valves while letting the remaining valves discharge. Otherwise, the existing maintenance gate valve could be used to temporarily shut off the entire flow to enable removal of one of the valves for maintenance.

Either energy dissipation structure shown in Figures 11 or 12 could be considered for use with the sleeve valve arrangement.

- Ancillary Features. Depending upon the final arrangement of the new outlet works, some ancilllary features would likely be required as follows:

  a) Air/Vacuum Valve. The penstock downstream of the guard valve will be equipped with a combination air and vacuum valve for air venting during penstock filling and air intake during penstock draining. The air/vacuum valve would be provided with an isolation valve.

  b) Isolation Valves. As stated above, upstream isolation valves could be provided immediately upstream of each discharge valve to permit isolation of a valve/s for maintenance while the other valve/s is/are still in service. These isolation valves, however, would add significant cost to the project.

  c) Roof Hatch and Maintenance Hoist: Roof hatches would be required to provide access to the valves for major maintenance. Also, depending upon the final arrangement, a monorail or jib hoist system could be provided for added convenience.

4 CONCLUSIONS

The preferred alternative from a cost and technical perspective is Alternative 3A (the three-valve FCV arrangement). The final arrangement of the outlet structure is dependent upon the desired type of discharge. The arrangement of the penstock and bifurcations and the layout of the discharge structure and stilling basin must be finalized before an overall project cost can be developed. Hydraulic sizing will be required to finalize the layout of the energy dissipation structure Other issues to be resolved are as follows:

- Determine the space availability at the discharge.
- Level of debris and silt in the water that passes through the outlet
- Future hydropower considerations.

APPENDIX G

DNRC
RUBY DAM OUTLET WORKS EVALUATION FOR EVACUATING RUBY RESERVOIR

Ruby Dam Low-Level Outlet Works Evaluation for Evacuating Ruby Reservoir

Based upon

ACER TECHNICAL MEMORANDUM NO. 3
ASSISTANT COMMISSIONER - ENGINEERING AND RESEARCH
DENVER, COLORADO

CRITERIA AND GUIDELINES FOR EVACUATING STORAGE RESERVOIRS AND SIZING LOW-LEVEL OUTLET WORKS

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
1980

By

State of Montana
Department of Natural Resources and Conservation
State Water Projects Bureau

March 2007

INTRODUCTION:

The Montana Department of Natural Resources and Conservation, State Water Projects Bureau (DNRC) has begun a feasibility study to evaluate options for the rehabilitation of Ruby Dam. Ruby Dam is located in Southwest Montana near Alder, Montana on the Ruby River. The irrigation project is an earth-filled dam that has a hydraulic height of 111-feet at the top of its crest. Outlets for the project include 7.5-feet high by 7.5-feet wide horse-shoe-shaped low-level outlet and a principal spillway that consists of a 100-foot wide ogee crest, 100 to 75-foot tapered concrete chute and a hydraulic-jump stilling basin. The low-level outlet contains two 6-feet diameter control gates, a slide-gate for emergencies and a butterfly gate for operating. The project controls an approximate 596-square mile watershed at the dam. The USGS has been operating stream flow gages both upstream and downstream of the project for over 40-years. The Ruby Dam project is owned by the State of Montana and has been in operation since 1938. Many of the original project features are nearing the end of their design life. This report will evaluate the capacity necessary for low-level outlets at Ruby Dam in regards to evacuation time based on procedures outlined in USBR ACER Technical Memorandum No.3 (TM3.)

Overview - ACER Technical Memorandum No.3:

TM3 describes procedures in which new and existing outlet structures may be evaluated for their adequacy in evacuating a reservoir during an emergency situation. TM3 provides guidance on the amount of time deemed necessary to evacuate a reservoir based upon downstream hazards and physical risk. Risk and hazard are defined in TM3 as follows: "*Risk is the probability of occurrence of an adverse event. Hazard is the consequence of having an adverse event.*" Hazards are locally defined based upon the existing downstream infrastructure. Hazards are given three classifications in TM3; low, significant and high. Guidance for hazard classification is given in TM3 and is directly related to both economic and human life losses as shown in the following figure.

Table 2. - Downstream hazard classification system

Classification	Population at risk	Economic loss
Low	0	Minimal (undeveloped agriculture, occasional uninhabited structures, or minimal outstanding natural resources)
Significant	1-6	Appreciable (rural area with notable agriculture, industry, or work sites, or outstanding natural resources)
High	More than 6	Excessive (urban area including extensive community, industry, agriculture, or outstanding natural resources)

Figure 1. ACER TM3, Table 2 – Downstream Hazard Classification Guidance.

Risk is more difficult to classify than hazard as it contains many random variables and unknowns. This makes risk classification even more subjective than hazard classification. For this reason, TM3 has given a list of elements to consider when identifying a risk classification. Risk classification in TM3 is broken into the same three categories as that for hazards (low, significant and high.) Examples of structures that would be given a "high risk" classification are given in TM3 such as those structures that lie within active faults. Structures with a low risk are those in absence of any known risks. Significant risk is a grey area that falls between. Elements of the structure to consider in identifying risk are shown in the following figure.

Table 3. - Elements of risk for dams

Hydrologic factors

- Floods exceeding those used for design
- Uncertainty of flood estimation
- Ratio of flood to storage volumes in the reservoir
- Reservoir sediment deposition potential

Geologic factors

- General foundation conditions
- Seismicity of site
- Faulting at site
- Liquefaction potential of dam and foundation
- Rock condition (fractures, shear zones, relief jointing, solubility)
- Seepage potential

Structural factors

- Dam type and design
- Unprecedented size
- Unusual complexity
- Age and condition

Construction and material factors

- Construction material characteristics such as permeability, erodibility, and strength
- Quality of construction

Operating factors

- Remoteness and accessibility of site
- Training and experience of operating personnel
- Reliability of commercial and auxiliary power
- Complexity of equipment and operating procedures

Figure 2. ACER TM3, Table 3 - Elements of Risk for Dams.

TM3 provides a general guide for determining evacuation time based upon levels of hazard and risk and reported at four significant reservoir levels. Reservoir levels include: 75% of hydraulic height, 50% of hydraulic height, 25% of hydraulic height and 10% of initial reservoir storage. A range of acceptable times for each combination of hazard and risk level is shown in the following figure from TM3.

Table 4.- General guide for determining emergency evacuation time (in days)

Evacuation stage	High hazard, high risk	High hazard, significant risk	High hazard, low risk	Significant hazard, high risk	Significant hazard, significant risk	Significant hazard, low risk	Low hazard, high risk	Low hazard significant risk	Low hazard, low risk
75% Height*	10-20	20-30	30-40	20-30	30-40	40-50	40-50	50-60	60-90
50% Height*	30-40	40-50	50-60	40-50	50-60	60-70	60-70	70-90	90-120
10% Storage**	40-50	50-60	60-70	50-60	60-70	70-80	70-80	80-120	120-160
25% Height*	60-80	70-90	80-100	70-90	80-100	90-110	90-110	100-160	150-220

* Height is measured from the initial pool as defined in subsection A.3 of part I for determining evacuation requirements.

** Reservoir storage between original streambed and the initial reservoir water surface level as defined in section A.3 of part I for determining evacuation requirements.

Figure 3. ACER TM3, Table 4 – General guide for determining emergency evacuation time.

Critical outlet design capacities are project dependent and should factor in other design parameters such as safe level of drawdown and downstream risks. However, a general rule of thumb is given in TM3, which states:

"In general, low-level outlet works in conjunction with other release facilities should be located and sized to draw down the reservoir, within a period of 1 to 4 months, to the lower of the following levels:

a. A reservoir level commensurate with a storage capacity that is 10 percent of that at the initial reservoir level.
b. A reservoir level which is less than 50 percent of the hydraulic height of the dam."

PROCEDURE:

A simple reservoir storage model was developed in Microsoft Excel® for Ruby Dam that relates changes in storage over time based upon the equation:

$$\textbf{Inflow} - \textbf{Outflow} = \Delta\ \textbf{Storage}$$

Inflows:

Inflows were determined based upon guidance from TM3, which states that the highest mean monthly inflows are used for any given evaluation. Mean monthly inflows calculated by the USGS for their upstream gage, Ruby River above reservoir near Alder, MT (USGS Gage No. 06019500) were downloaded from the USGS website. This gage has a period of record between 1938 and 2006 and measures approximately 534 square-miles of the upstream watershed. Calculated mean monthly inflows at the gage were then adjusted to account for the full 596 square miles at the dam-site by a linear relation of drainage-area ratio as shown in the following table.

Location	April	May	June	July	August
At USGS Gage 06019500	164	418	468	193	120
At Dam	183	467	522	215	134

Table 1. Mean-monthly inflows at Ruby Dam in cubic feet per second.

Timing of inflows to create an inflow hydrograph for each outflow scenario is based upon the highest mean-monthly sequence. This process is iterative in that one must estimate the amount of evacuation time needed to provide the maximum possible inflow sequence for the estimated duration for each individual evaluation. For Ruby Dam, when evacuation times were one-month or less, June was chosen. When evacuation times were 2-months or less the months of May and June were chosen. However, June has a higher mean-monthly flow than May, therefore, a portion of May was used initially and then June was added and this was iterated upon until the desired water surface was reached at the end of June. For evacuation times of 2 to 3-months, the months of May, June and July were evaluated.

Outflows:

The existing low-level outlet at Ruby Dam consists of a tunnel with two slide gates and a submerged outlet. When the gates are fully opened, outflow can be generalized to vary with net hydraulic head (H) by the submerged orifice equation as follows:

$$Q = CA\sqrt{2gH}$$

Where:

A = area of the opening
C = discharge coefficient
H = difference in head between upstream and downstream

An assumed outflow capacity at the spillway crest was entered into this equation with "H" equal to the difference between the spillway crest elevation and an average submerged downstream head based upon estimates of tail water hydraulics by HKM, Inc. (5307.0 feet.) The combined inlet coefficient "CA" was then computed. Outflow (Q) was then computed for each increment of time in the Excel® model based upon upstream hydraulic head and the computed combined inlet coefficient.

Change in Storage:

Storage contents were computed for each inflow and outlet scenario in the Excel® model, which computed the net storage from inflows minus outflows for a time increment of 0.1 days over the evacuation period. Initial reservoir elevation and storage contents were set at the spillway flash-boards elevation of 5393.0 feet for the existing condition and an elevation of 5400.0 feet for the future dam raise option. The two initial water surface

elevations had corresponding storage volumes of 37,642 and 45,115 acre-feet respectively. Storage contents were calculated and corresponding reservoir elevations were read from the existing Ruby Reservoir elevation-storage table for each scenario.

RESULTS:

Nine initial flow rate capacities were evaluated for Ruby Dam low-level outlet works ranging between 700 and 1500 cfs. The four elevation targets of 75%, 50% and 25% hydraulic height and 10% of initial storage were examined. For existing conditions, evacuation times ranged between 11.1 to 96 days for all criteria and flow rates evaluated. For future conditions, evacuation times ranged between 13.5 to 100.0 days for all criteria and flow rates evaluated. Therefore, the range of flow rates examined met the TM3 criteria of a 1 to 4 month evacuation period. The following two tables shows hazard-risk combination versus flow rate meeting each of the four criteria targets for Ruby Dam for both existing and future conditions.

Hazard	Risk	75% H	50% H	10% Storage	25% H	All Criteria
High	High	1100 cfs 19.4 days	1100 cfs 36.2 days	1100 cfs 46.1 days	900 cfs 71.5 days	1100 cfs
High	Significant	1000 cfs 23.9 days	1000 cfs 45.0 days	1010 cfs 59.0 days	800 cfs 81.3 days	1010 cfs
Significant	Significant	800 cfs 41.7 days	900 cfs 60.0 days	900 cfs 65.9 days	700 cfs 95.0 days	900 cfs

Table 2. **Existing Conditions** - Ruby Dam low-level outlet capacities necessary at spillway crest to meet listed hazard-risk level and target elevation criteria.

Hazard	Risk	75% H	50% H	10% Storage	25% H	All Criteria
High	High	1200 cfs 19.8 days	1200 cfs 35.9 days	1200 cfs 44.1 days	900 cfs 76.3 days	1200 cfs
High	Significant	1000 cfs 28.9 days	1100 cfs 42.9 days	1100 cfs 54.0 days	800 cfs 88.2 days	1100 cfs
Significant	Significant	900 cfs 36.5 days	1000 cfs 53.0 days	900 cfs 69.9 days	700 cfs 100.0 days	1000 cfs

Table 3. **Future Conditions** - Ruby Dam low-level outlet capacities necessary at spillway crest to meet listed hazard-risk level and target elevation criteria.

Risk based studies have been performed at Ruby Dam to determine the downstream hazards that exist in the event of failure of this structure. Risk-based study has shown that a loss of life would occur and would be on the order of 30 to 50 persons. Therefore, Ruby Dam should be considered a "**high hazard**" dam in terms of this evaluation. Risk levels at Ruby Dam are currently "high" due to the age of the dam and spillway capacity concerns. However, most risk associated with the age of Ruby Dam will be alleviated in the rehabilitation of this structure and the increased spillway capacity that is currently being designed. Therefore, it can be estimated that risk at Ruby Dam is within the "**significant risk**" category.

RECOMMENDATIONS:

Existing Conditions:

Based upon TM3 guidance, it is recommended that a low-level outlet be constructed at Ruby Dam that has the evacuation capability that meets the lower elevation of the 50% hydraulic height or 10% of initial storage contents for a "high hazard" and "significant risk" combination. Fifty-percent of the hydraulic height at Ruby Dam is at elevation 5345.5 feet and 10% of the initial storage contents lie at an elevation of 5334.5 feet. Therefore, Ruby Dam should be designed to meet the 10% initial storage elevation in terms of evacuation capacity, which is equal to **1010 cfs** at the existing spillway flashboards elevation of 5393.0 feet. This outlet capacity meets all evacuation time criteria listed in TM3 for Ruby Dam when considered high hazard and significant risk. The following table lists the calculated evacuation times for the four TM3 levels considered in this evaluation for a 1010 cfs outlet capacity at the top of flashboards.

Outflow Capacity	# Days 75% H	# Days 50% H	# Days 10% Storage	# Days 25% H
Elevation →	*5369.5'*	*5346.0'*	*5334.9'*	*5322.5'*
1010 cfs	**23.3 days**	**44.0 days**	**59.0 days**	**65.3 days**

Table 4. **Existing Conditions** - Ruby Dam - time to evacuate to elevation levels shown in days based upon 1000 cfs capacity at existing spillway crest. (Note: H = hydraulic height)

Future Conditions:

Fifty-percent of the hydraulic height at Ruby Dam would be at elevation 5349.5 feet and 10% of the initial storage contents would lie at an elevation of 5337.5 feet for a future condition option with a spillway crest at 5400.0 feet. Therefore, Ruby Dam should be designed to meet the 10% initial storage elevation in terms of evacuation capacity, which is equal to **1100 cfs** at the crest of a new spillway at elevation of 5400.0 feet. This outlet capacity meets all evacuation time criteria listed in TM3 for Ruby Dam when considered high hazard and significant risk. The following table lists the calculated evacuation times for the four TM3 levels considered in this evaluation for a 1100 cfs outlet capacity at the future spillway crest of 5400.0 feet.

Outflow Capacity	# Days 75% H	# Days 50% H	# Days 10% Storage	# Days 25% H
Elevation →	*5374.75'*	*5349.5'*	*5337.5'*	*5324.5'*
1100 cfs	**23.5 days**	**42.9 days**	**54.0 days**	**63.9 days**

Table 5. **Future Conditions** - Ruby Dam - time to evacuate to elevation levels shown in days based upon 1000 cfs capacity at existing spillway crest. (Note: H = hydraulic height)

Appendix A

Calculations

Ruby Dam Low-Level Outlet Works
Evaluation for Evacuating Ruby Reservoir

EXISTING CONDITIONS - Normal Pool at Top of Flashboards = 5393.0 feet

Ruby Dam Low-Level Outlet Sizing

Based on Evacuation Criteria from USBR ACER Technical Memorandum No.3

MT Dept. of Natural Resources and Conservation - State Water Projects Bureau

Inflows:

Mean Average Monthly Flows (from USGS)

Ruby River above Reservoir near Alder, MT USGS Gage No. 06019500

Period of Record 1938-2006

D.A. = 534 sq mi

Location	May	June	July	August	
at gage	418 cfs	468 cfs	193 cfs	120 cfs	
at Dam	467 cfs	522 cfs	215 cfs	134 cfs	<----Adjusted to Include Ungaged Area (D.A. at Dam = 596 sq mi)

Hydrograph Routing Results:

Outflow Capacity at Spillway Crest	# of Days to Evacuate to 75% H	# of Days to Evacuate to 50% H	# of Days to Evacuate to 10% Storage	# of Days to Evacuate to 25% H
Elevation-->	5369.6	5346	5334.9	5322.6 ft
1500 cfs	11.1 days	20.0 days	24.2 days	30.0 days
1400 cfs	12.4 days	22.5 days	27.6 days	35.0 days
1300 cfs	14.1 days	25.9 days	31.9 days	42.8 days
1200 cfs	16.3 days	30.5 days	37.6 days	61.3 days
1100 cfs	19.4 days	36.2 days	46.1 days	62.6 days
1010 cfs	23.3 days	44.0 days	59.0 days	65.3 days
1000 cfs	23.9 days	45.0 days	60.9 days	65.7 days
900 cfs	30.9 days	60.0 days	65.9 days	71.5 days
800 cfs	41.7 days	68.0 days	74.1 days	81.3 days
700 cfs	62.2 days	79.5 days	87.4 days	>92 days

Results:

Risk	Hazard	Meets All Criteria	Meets 50% Criteria	Meets 10% Storage Criteria	Meets 25% Criteria
High	High	1100 cfs	1100 cfs	1100 cfs	900 cfs
Significant	High	1010 cfs	1000 cfs	1010 cfs	800 cfs
Significant	Significant	900 cfs	800 cfs	900 cfs	700 cfs

Ruby Dam

1-Month Maximum Mean Monthly Hydrograph (June)

Change In Storage Versus Outflow Worksheet

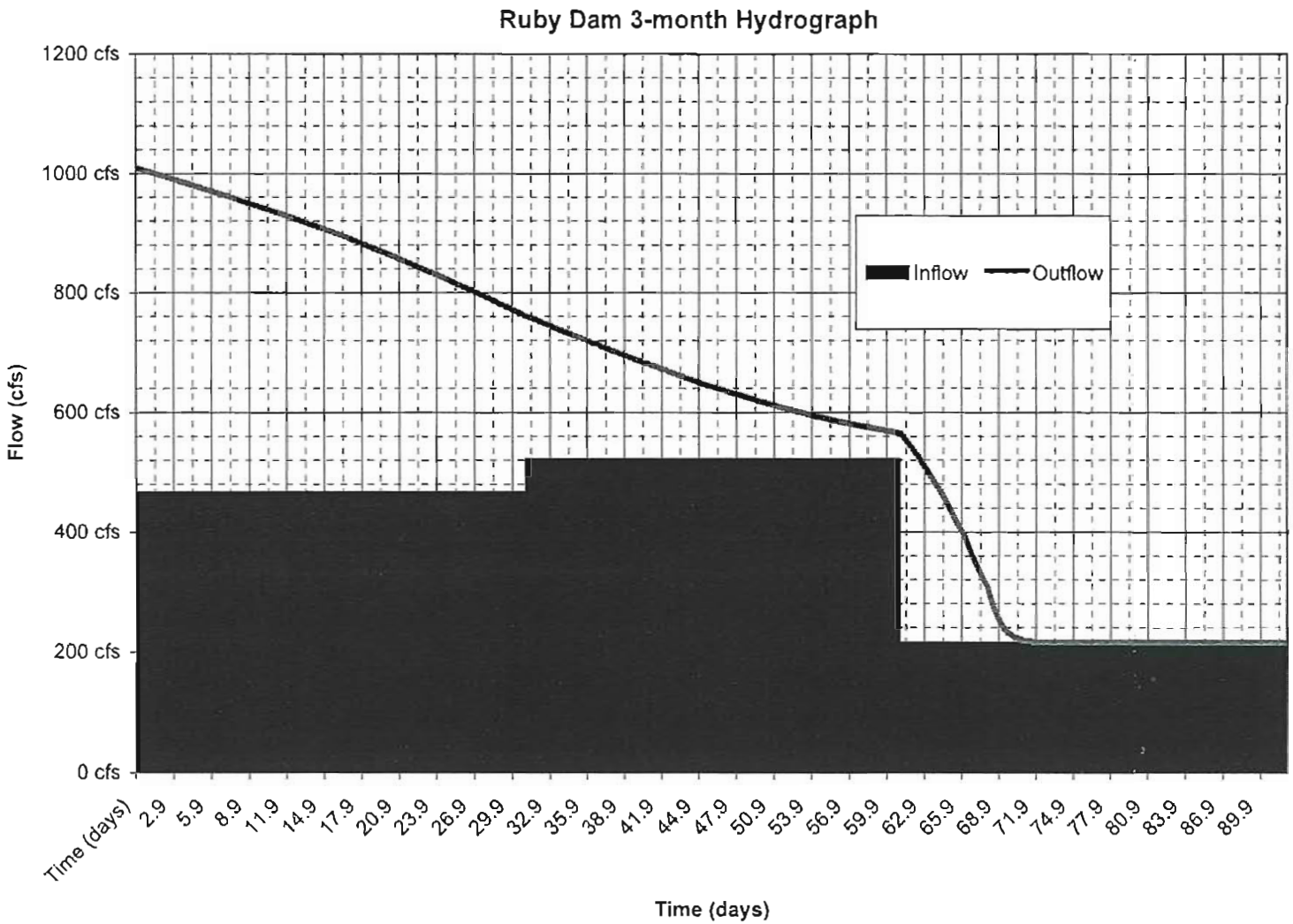
Outflow Capacity at Spillway Crest = 1010 cfs Outflow Constant = 13.58 sq ft

Time (days)	Inflow	Inflow Volume	Outflow	Outflow Volume	Elevation	Storage	Change In Storage
0	522 cfs	103.54 ac-ft	1010 cfs	200.33 ac-ft	5393.0 ft	37642.00 ac-ft	-96.79 ac-ft
0.1	522 cfs	103.54 ac-ft	1009 cfs	200.21 ac-ft	5392.9 ft	37545.21 ac-ft	-96.68 ac-ft
0.2	522 cfs	103.54 ac-ft	1009 cfs	200.10 ac-ft	5392.8 ft	37448.53 ac-ft	-96.56 ac-ft
0.3	522 cfs	103.54 ac-ft	1008 cfs	199.98 ac-ft	5392.7 ft	37351.97 ac-ft	-96.44 ac-ft
0.4	522 cfs	103.54 ac-ft	1008 cfs	199.86 ac-ft	5392.6 ft	37255.53 ac-ft	-96.33 ac-ft
0.5	522 cfs	103.54 ac-ft	1007 cfs	199.75 ac-ft	5392.5 ft	37159.20 ac-ft	-96.21 ac-ft
0.6	522 cfs	103.54 ac-ft	1006 cfs	199.63 ac-ft	5392.4 ft	37062.99 ac-ft	-96.09 ac-ft
0.7	522 cfs	103.54 ac-ft	1006 cfs	199.51 ac-ft	5392.3 ft	36966.90 ac-ft	-95.98 ac-ft
0.8	522 cfs	103.54 ac-ft	1005 cfs	199.40 ac-ft	5392.2 ft	36870.92 ac-ft	-95.86 ac-ft
0.9	522 cfs	103.54 ac-ft	1005 cfs	199.28 ac-ft	5392.1 ft	36775.07 ac-ft	-95.74 ac-ft
1	522 cfs	103.54 ac-ft	1004 cfs	199.16 ac-ft	5392.0 ft	36679.32 ac-ft	-95.62 ac-ft
1.1	522 cfs	103.54 ac-ft	1004 cfs	199.04 ac-ft	5391.9 ft	36583.70 ac-ft	-95.51 ac-ft
1.2	522 cfs	103.54 ac-ft	1003 cfs	198.93 ac-ft	5391.8 ft	36488.19 ac-ft	-95.39 ac-ft
1.3	522 cfs	103.54 ac-ft	1002 cfs	198.81 ac-ft	5391.7 ft	36392.80 ac-ft	-95.27 ac-ft
1.4	522 cfs	103.54 ac-ft	1002 cfs	198.69 ac-ft	5391.6 ft	36297.53 ac-ft	-95.16 ac-ft
1.5	522 cfs	103.54 ac-ft	1001 cfs	198.58 ac-ft	5391.5 ft	36202.37 ac-ft	-95.04 ac-ft
1.6	522 cfs	103.54 ac-ft	1001 cfs	198.46 ac-ft	5391.4 ft	36107.34 ac-ft	-94.92 ac-ft
1.7	522 cfs	103.54 ac-ft	1000 cfs	198.34 ac-ft	5391.3 ft	36012.41 ac-ft	-94.80 ac-ft
1.8	522 cfs	103.54 ac-ft	999 cfs	198.22 ac-ft	5391.2 ft	35917.61 ac-ft	-94.69 ac-ft
1.9	522 cfs	103.54 ac-ft	999 cfs	198.10 ac-ft	5391.1 ft	35822.93 ac-ft	-94.57 ac-ft
2	522 cfs	103.54 ac-ft	998 cfs	197.99 ac-ft	5391.0 ft	35728.36 ac-ft	-94.45 ac-ft
2.1	522 cfs	103.54 ac-ft	998 cfs	197.87 ac-ft	5390.9 ft	35633.91 ac-ft	-94.33 ac-ft
2.2	522 cfs	103.54 ac-ft	997 cfs	197.75 ac-ft	5390.8 ft	35539.58 ac-ft	-94.21 ac-ft
2.3	522 cfs	103.54 ac-ft	996 cfs	197.63 ac-ft	5390.7 ft	35445.38 ac-ft	-94.10 ac-ft
2.4	522 cfs	103.54 ac-ft	996 cfs	197.51 ac-ft	5390.6 ft	35351.27 ac-ft	-93.98 ac-ft
2.5	522 cfs	103.54 ac-ft	995 cfs	197.40 ac-ft	5390.5 ft	35257.29 ac-ft	-93.86 ac-ft
2.6	522 cfs	103.54 ac-ft	995 cfs	197.28 ac-ft	5390.4 ft	35163.43 ac-ft	-93.74 ac-ft
2.7	522 cfs	103.54 ac-ft	994 cfs	197.16 ac-ft	5390.3 ft	35069.69 ac-ft	-93.62 ac-ft
2.8	522 cfs	103.54 ac-ft	993 cfs	197.04 ac-ft	5390.2 ft	34976.07 ac-ft	-93.50 ac-ft
2.9	522 cfs	103.54 ac-ft	993 cfs	196.92 ac-ft	5390.1 ft	34882.56 ac-ft	-93.39 ac-ft
3	522 cfs	103.54 ac-ft	992 cfs	196.80 ac-ft	5390.0 ft	34789.18 ac-ft	-93.27 ac-ft
3.1	522 cfs	103.54 ac-ft	992 cfs	196.69 ac-ft	5389.9 ft	34695.91 ac-ft	-93.15 ac-ft
3.2	522 cfs	103.54 ac-ft	991 cfs	196.57 ac-ft	5389.8 ft	34602.76 ac-ft	-93.03 ac-ft
3.3	522 cfs	103.54 ac-ft	990 cfs	196.45 ac-ft	5389.7 ft	34509.73 ac-ft	-92.91 ac-ft
3.4	522 cfs	103.54 ac-ft	990 cfs	196.33 ac-ft	5389.6 ft	34416.82 ac-ft	-92.79 ac-ft
3.5	522 cfs	103.54 ac-ft	989 cfs	196.21 ac-ft	5389.5 ft	34324.03 ac-ft	-92.67 ac-ft
3.6	522 cfs	103.54 ac-ft	989 cfs	196.09 ac-ft	5389.4 ft	34231.35 ac-ft	-92.55 ac-ft
3.7	522 cfs	103.54 ac-ft	988 cfs	195.97 ac-ft	5389.3 ft	34138.80 ac-ft	-92.44 ac-ft
3.8	522 cfs	103.54 ac-ft	987 cfs	195.85 ac-ft	5389.2 ft	34046.36 ac-ft	-92.32 ac-ft
3.9	522 cfs	103.54 ac-ft	987 cfs	195.73 ac-ft	5389.1 ft	33954.04 ac-ft	-92.20 ac-ft
4	522 cfs	103.54 ac-ft	986 cfs	195.62 ac-ft	5389.0 ft	33861.85 ac-ft	-92.08 ac-ft
4.1	522 cfs	103.54 ac-ft	986 cfs	195.50 ac-ft	5388.9 ft	33769.77 ac-ft	-91.96 ac-ft
4.2	522 cfs	103.54 ac-ft	985 cfs	195.38 ac-ft	5388.8 ft	33677.81 ac-ft	-91.84 ac-ft
4.3	522 cfs	103.54 ac-ft	984 cfs	195.26 ac-ft	5388.7 ft	33585.97 ac-ft	-91.72 ac-ft
4.4	522 cfs	103.54 ac-ft	984 cfs	195.14 ac-ft	5388.6 ft	33494.25 ac-ft	-91.60 ac-ft
4.5	522 cfs	103.54 ac-ft	983 cfs	195.02 ac-ft	5388.5 ft	33402.65 ac-ft	-91.48 ac-ft
4.6	522 cfs	103.54 ac-ft	983 cfs	194.90 ac-ft	5388.4 ft	33311.17 ac-ft	-91.36 ac-ft
4.7	522 cfs	103.54 ac-ft	982 cfs	194.78 ac-ft	5388.3 ft	33219.81 ac-ft	-91.24 ac-ft
4.8	522 cfs	103.54 ac-ft	981 cfs	194.66 ac-ft	5388.2 ft	33128.56 ac-ft	-91.12 ac-ft
4.9	522 cfs	103.54 ac-ft	981 cfs	194.54 ac-ft	5388.1 ft	33037.44 ac-ft	-91.00 ac-ft
5	522 cfs	103.54 ac-ft	980 cfs	194.42 ac-ft	5388.0 ft	32946.44 ac-ft	-90.88 ac-ft
5.1	522 cfs	103.54 ac-ft	980 cfs	194.30 ac-ft	5387.9 ft	32855.56 ac-ft	-90.76 ac-ft
5.2	522 cfs	103.54 ac-ft	979 cfs	194.18 ac-ft	5387.8 ft	32764.80 ac-ft	-90.64 ac-ft
5.3	522 cfs	103.54 ac-ft	978 cfs	194.06 ac-ft	5387.7 ft	32674.15 ac-ft	-90.52 ac-ft
5.4	522 cfs	103.54 ac-ft	978 cfs	193.94 ac-ft	5387.6 ft	32583.63 ac-ft	-90.40 ac-ft
5.5	522 cfs	103.54 ac-ft	977 cfs	193.82 ac-ft	5387.5 ft	32493.23 ac-ft	-90.28 ac-ft
5.6	522 cfs	103.54 ac-ft	977 cfs	193.70 ac-ft	5387.4 ft	32402.95 ac-ft	-90.16 ac-ft
5.7	522 cfs	103.54 ac-ft	976 cfs	193.58 ac-ft	5387.3 ft	32312.79 ac-ft	-90.04 ac-ft
5.8	522 cfs	103.54 ac-ft	975 cfs	193.46 ac-ft	5387.2 ft	32222.75 ac-ft	-89.92 ac-ft
5.9	522 cfs	103.54 ac-ft	975 cfs	193.34 ac-ft	5387.1 ft	32132.83 ac-ft	-89.80 ac-ft
6	522 cfs	103.54 ac-ft	975 cfs	193.34 ac-ft	5387.1 ft	32043.03 ac-ft	-89.80 ac-ft
6.1	522 cfs	103.54 ac-ft	974 cfs	193.22 ac-ft	5387.0 ft	31953.23 ac-ft	-89.68 ac-ft
6.2	522 cfs	103.54 ac-ft	974 cfs	193.09 ac-ft	5386.9 ft	31863.55 ac-ft	-89.56 ac-ft
6.3	522 cfs	103.54 ac-ft	973 cfs	192.97 ac-ft	5386.8 ft	31774.00 ac-ft	-89.44 ac-ft
6.4	522 cfs	103.54 ac-ft	972 cfs	192.85 ac-ft	5386.7 ft	31684.56 ac-ft	-89.32 ac-ft
6.5	522 cfs	103.54 ac-ft	972 cfs	192.73 ac-ft	5386.6 ft	31595.25 ac-ft	-89.19 ac-ft
6.6	522 cfs	103.54 ac-ft	971 cfs	192.61 ac-ft	5386.5 ft	31506.05 ac-ft	-89.07 ac-ft
6.7	522 cfs	103.54 ac-ft	970 cfs	192.49 ac-ft	5386.4 ft	31416.98 ac-ft	-88.95 ac-ft
6.8	522 cfs	103.54 ac-ft	970 cfs	192.37 ac-ft	5386.3 ft	31328.03 ac-ft	-88.83 ac-ft
6.9	522 cfs	103.54 ac-ft	969 cfs	192.25 ac-ft	5386.2 ft	31239.19 ac-ft	-88.71 ac-ft
7	522 cfs	103.54 ac-ft	969 cfs	192.13 ac-ft	5386.1 ft	31150.48 ac-ft	-88.59 ac-ft
7.1	522 cfs	103.54 ac-ft	968 cfs	192.00 ac-ft	5386.0 ft	31061.90 ac-ft	-88.47 ac-ft

7.2	522 cfs	103.54 ac-ft	967 cfs	191.88 ac-ft	5385.9 ft	30973.43 ac-ft	-88.35 ac-ft
7.3	522 cfs	103.54 ac-ft	967 cfs	191.76 ac-ft	5385.8 ft	30885.08 ac-ft	-88.22 ac-ft
7.4	522 cfs	103.54 ac-ft	966 cfs	191.64 ac-ft	5385.7 ft	30796.86 ac-ft	-88.10 ac-ft
7.5	522 cfs	103.54 ac-ft	966 cfs	191.52 ac-ft	5385.6 ft	30708.76 ac-ft	-87.98 ac-ft
7.6	522 cfs	103.54 ac-ft	965 cfs	191.40 ac-ft	5385.5 ft	30620.78 ac-ft	-87.86 ac-ft
7.7	522 cfs	103.54 ac-ft	964 cfs	191.27 ac-ft	5385.4 ft	30532.92 ac-ft	-87.74 ac-ft
7.8	522 cfs	103.54 ac-ft	964 cfs	191.15 ac-ft	5385.3 ft	30445.18 ac-ft	-87.61 ac-ft
7.9	522 cfs	103.54 ac-ft	963 cfs	191.03 ac-ft	5385.2 ft	30357.57 ac-ft	-87.49 ac-ft
8	522 cfs	103.54 ac-ft	962 cfs	190.91 ac-ft	5385.1 ft	30270.08 ac-ft	-87.37 ac-ft
8.1	522 cfs	103.54 ac-ft	962 cfs	190.78 ac-ft	5385.0 ft	30182.71 ac-ft	-87.25 ac-ft
8.2	522 cfs	103.54 ac-ft	961 cfs	190.66 ac-ft	5384.9 ft	30095.46 ac-ft	-87.13 ac-ft
8.3	522 cfs	103.54 ac-ft	961 cfs	190.54 ac-ft	5384.8 ft	30008.34 ac-ft	-87.00 ac-ft
8.4	522 cfs	103.54 ac-ft	960 cfs	190.42 ac-ft	5384.7 ft	29921.33 ac-ft	-86.88 ac-ft
8.5	522 cfs	103.54 ac-ft	959 cfs	190.30 ac-ft	5384.6 ft	29834.45 ac-ft	-86.76 ac-ft
8.6	522 cfs	103.54 ac-ft	959 cfs	190.17 ac-ft	5384.5 ft	29747.69 ac-ft	-86.64 ac-ft
8.7	522 cfs	103.54 ac-ft	958 cfs	190.05 ac-ft	5384.4 ft	29661.06 ac-ft	-86.51 ac-ft
8.8	522 cfs	103.54 ac-ft	958 cfs	189.93 ac-ft	5384.3 ft	29574.55 ac-ft	-86.39 ac-ft
8.9	522 cfs	103.54 ac-ft	957 cfs	189.80 ac-ft	5384.2 ft	29488.16 ac-ft	-86.27 ac-ft
9	522 cfs	103.54 ac-ft	956 cfs	189.68 ac-ft	5384.1 ft	29401.89 ac-ft	-86.14 ac-ft
9.1	522 cfs	103.54 ac-ft	956 cfs	189.56 ac-ft	5384.0 ft	29315.75 ac-ft	-86.02 ac-ft
9.2	522 cfs	103.54 ac-ft	955 cfs	189.43 ac-ft	5383.9 ft	29229.73 ac-ft	-85.90 ac-ft
9.3	522 cfs	103.54 ac-ft	954 cfs	189.31 ac-ft	5383.8 ft	29143.83 ac-ft	-85.77 ac-ft
9.4	522 cfs	103.54 ac-ft	954 cfs	189.19 ac-ft	5383.7 ft	29058.05 ac-ft	-85.65 ac-ft
9.5	522 cfs	103.54 ac-ft	953 cfs	189.06 ac-ft	5383.6 ft	28972.40 ac-ft	-85.53 ac-ft
9.6	522 cfs	103.54 ac-ft	953 cfs	188.94 ac-ft	5383.5 ft	28886.87 ac-ft	-85.40 ac-ft
9.7	522 cfs	103.54 ac-ft	952 cfs	188.82 ac-ft	5383.4 ft	28801.47 ac-ft	-85.28 ac-ft
9.8	522 cfs	103.54 ac-ft	951 cfs	188.69 ac-ft	5383.3 ft	28716.19 ac-ft	-85.16 ac-ft
9.9	522 cfs	103.54 ac-ft	951 cfs	188.57 ac-ft	5383.2 ft	28631.03 ac-ft	-85.03 ac-ft
10	522 cfs	103.54 ac-ft	950 cfs	188.45 ac-ft	5383.1 ft	28546.00 ac-ft	-84.91 ac-ft
10.1	522 cfs	103.54 ac-ft	949 cfs	188.32 ac-ft	5383.0 ft	28461.09 ac-ft	-84.79 ac-ft
10.2	522 cfs	103.54 ac-ft	949 cfs	188.20 ac-ft	5382.9 ft	28376.30 ac-ft	-84.66 ac-ft
10.3	522 cfs	103.54 ac-ft	948 cfs	188.08 ac-ft	5382.8 ft	28291.64 ac-ft	-84.54 ac-ft
10.4	522 cfs	103.54 ac-ft	948 cfs	187.95 ac-ft	5382.7 ft	28207.10 ac-ft	-84.41 ac-ft
10.5	522 cfs	103.54 ac-ft	947 cfs	187.83 ac-ft	5382.6 ft	28122.69 ac-ft	-84.29 ac-ft
10.6	522 cfs	103.54 ac-ft	946 cfs	187.70 ac-ft	5382.5 ft	28038.40 ac-ft	-84.17 ac-ft
10.7	522 cfs	103.54 ac-ft	946 cfs	187.58 ac-ft	5382.4 ft	27954.24 ac-ft	-84.04 ac-ft
10.8	522 cfs	103.54 ac-ft	945 cfs	187.45 ac-ft	5382.3 ft	27870.19 ac-ft	-83.92 ac-ft
10.9	522 cfs	103.54 ac-ft	944 cfs	187.33 ac-ft	5382.2 ft	27786.28 ac-ft	-83.79 ac-ft
11	522 cfs	103.54 ac-ft	944 cfs	187.20 ac-ft	5382.1 ft	27702.49 ac-ft	-83.67 ac-ft
11.1	522 cfs	103.54 ac-ft	943 cfs	187.08 ac-ft	5382.0 ft	27618.82 ac-ft	-83.54 ac-ft
11.2	522 cfs	103.54 ac-ft	943 cfs	186.96 ac-ft	5381.9 ft	27535.28 ac-ft	-83.42 ac-ft
11.3	522 cfs	103.54 ac-ft	942 cfs	186.83 ac-ft	5381.8 ft	27451.86 ac-ft	-83.29 ac-ft
11.4	522 cfs	103.54 ac-ft	941 cfs	186.71 ac-ft	5381.7 ft	27368.56 ac-ft	-83.17 ac-ft
11.5	522 cfs	103.54 ac-ft	941 cfs	186.58 ac-ft	5381.6 ft	27285.40 ac-ft	-83.04 ac-ft
11.6	522 cfs	103.54 ac-ft	940 cfs	186.46 ac-ft	5381.5 ft	27202.35 ac-ft	-82.92 ac-ft
11.7	522 cfs	103.54 ac-ft	940 cfs	186.46 ac-ft	5381.5 ft	27119.44 ac-ft	-82.92 ac-ft
11.8	522 cfs	103.54 ac-ft	939 cfs	186.33 ac-ft	5381.4 ft	27036.52 ac-ft	-82.79 ac-ft
11.9	522 cfs	103.54 ac-ft	939 cfs	186.20 ac-ft	5381.3 ft	26953.72 ac-ft	-82.67 ac-ft
12	522 cfs	103.54 ac-ft	938 cfs	186.08 ac-ft	5381.2 ft	26871.06 ac-ft	-82.54 ac-ft
12.1	522 cfs	103.54 ac-ft	938 cfs	185.95 ac-ft	5381.1 ft	26788.51 ac-ft	-82.42 ac-ft
12.2	522 cfs	103.54 ac-ft	937 cfs	185.83 ac-ft	5381.0 ft	26706.10 ac-ft	-82.29 ac-ft
12.3	522 cfs	103.54 ac-ft	936 cfs	185.70 ac-ft	5380.9 ft	26623.81 ac-ft	-82.17 ac-ft
12.4	522 cfs	103.54 ac-ft	936 cfs	185.58 ac-ft	5380.8 ft	26541.64 ac-ft	-82.04 ac-ft
12.5	522 cfs	103.54 ac-ft	935 cfs	185.45 ac-ft	5380.7 ft	26459.60 ac-ft	-81.91 ac-ft
12.6	522 cfs	103.54 ac-ft	934 cfs	185.33 ac-ft	5380.6 ft	26377.69 ac-ft	-81.79 ac-ft
12.7	522 cfs	103.54 ac-ft	934 cfs	185.20 ac-ft	5380.5 ft	26295.90 ac-ft	-81.66 ac-ft
12.8	522 cfs	103.54 ac-ft	933 cfs	185.07 ac-ft	5380.4 ft	26214.23 ac-ft	-81.54 ac-ft
12.9	522 cfs	103.54 ac-ft	932 cfs	184.95 ac-ft	5380.3 ft	26132.70 ac-ft	-81.41 ac-ft
13	522 cfs	103.54 ac-ft	932 cfs	184.82 ac-ft	5380.2 ft	26051.29 ac-ft	-81.28 ac-ft
13.1	522 cfs	103.54 ac-ft	931 cfs	184.70 ac-ft	5380.1 ft	25970.00 ac-ft	-81.16 ac-ft
13.2	522 cfs	103.54 ac-ft	931 cfs	184.57 ac-ft	5380.0 ft	25888.85 ac-ft	-81.03 ac-ft
13.3	522 cfs	103.54 ac-ft	930 cfs	184.44 ac-ft	5379.9 ft	25807.81 ac-ft	-80.91 ac-ft
13.4	522 cfs	103.54 ac-ft	929 cfs	184.32 ac-ft	5379.8 ft	25726.91 ac-ft	-80.78 ac-ft
13.5	522 cfs	103.54 ac-ft	929 cfs	184.19 ac-ft	5379.7 ft	25646.13 ac-ft	-80.65 ac-ft
13.6	522 cfs	103.54 ac-ft	928 cfs	184.06 ac-ft	5379.6 ft	25565.48 ac-ft	-80.53 ac-ft
13.7	522 cfs	103.54 ac-ft	927 cfs	183.94 ac-ft	5379.5 ft	25484.95 ac-ft	-80.40 ac-ft
13.8	522 cfs	103.54 ac-ft	927 cfs	183.81 ac-ft	5379.4 ft	25404.56 ac-ft	-80.27 ac-ft
13.9	522 cfs	103.54 ac-ft	926 cfs	183.68 ac-ft	5379.3 ft	25324.28 ac-ft	-80.14 ac-ft
14	522 cfs	103.54 ac-ft	925 cfs	183.55 ac-ft	5379.2 ft	25244.14 ac-ft	-80.02 ac-ft
14.1	522 cfs	103.54 ac-ft	925 cfs	183.43 ac-ft	5379.1 ft	25164.12 ac-ft	-79.89 ac-ft
14.2	522 cfs	103.54 ac-ft	924 cfs	183.30 ac-ft	5379.0 ft	25084.23 ac-ft	-79.76 ac-ft
14.3	522 cfs	103.54 ac-ft	923 cfs	183.17 ac-ft	5378.9 ft	25004.47 ac-ft	-79.64 ac-ft
14.4	522 cfs	103.54 ac-ft	923 cfs	183.05 ac-ft	5378.8 ft	24924.83 ac-ft	-79.51 ac-ft
14.5	522 cfs	103.54 ac-ft	922 cfs	182.92 ac-ft	5378.7 ft	24845.33 ac-ft	-79.38 ac-ft
14.6	522 cfs	103.54 ac-ft	922 cfs	182.79 ac-ft	5378.6 ft	24765.94 ac-ft	-79.25 ac-ft
14.7	522 cfs	103.54 ac-ft	921 cfs	182.66 ac-ft	5378.5 ft	24686.69 ac-ft	-79.13 ac-ft
14.8	522 cfs	103.54 ac-ft	920 cfs	182.53 ac-ft	5378.4 ft	24607.57 ac-ft	-79.00 ac-ft
14.9	522 cfs	103.54 ac-ft	920 cfs	182.41 ac-ft	5378.3 ft	24528.57 ac-ft	-78.87 ac-ft

15	522 cfs	103.54 ac-ft	919 cfs	182.28 ac-ft	5378.2 ft	24449.70 ac-ft	-78.74 ac-ft
15.1	522 cfs	103.54 ac-ft	918 cfs	182.15 ac-ft	5378.1 ft	24370.96 ac-ft	-78.61 ac-ft
15.2	522 cfs	103.54 ac-ft	918 cfs	182.02 ac-ft	5378.0 ft	24292.34 ac-ft	-78.49 ac-ft
15.3	522 cfs	103.54 ac-ft	917 cfs	181.89 ac-ft	5377.9 ft	24213.86 ac-ft	-78.36 ac-ft
15.4	522 cfs	103.54 ac-ft	916 cfs	181.77 ac-ft	5377.8 ft	24135.50 ac-ft	-78.23 ac-ft
15.5	522 cfs	103.54 ac-ft	916 cfs	181.64 ac-ft	5377.7 ft	24057.27 ac-ft	-78.10 ac-ft
15.6	522 cfs	103.54 ac-ft	915 cfs	181.51 ac-ft	5377.6 ft	23979.17 ac-ft	-77.97 ac-ft
15.7	522 cfs	103.54 ac-ft	914 cfs	181.25 ac-ft	5377.4 ft	23901.20 ac-ft	-77.71 ac-ft
15.8	522 cfs	103.54 ac-ft	913 cfs	181.12 ac-ft	5377.3 ft	23823.48 ac-ft	-77.59 ac-ft
15.9	522 cfs	103.54 ac-ft	913 cfs	180.99 ac-ft	5377.2 ft	23745.90 ac-ft	-77.46 ac-ft
16	522 cfs	103.54 ac-ft	912 cfs	180.87 ac-ft	5377.1 ft	23668.44 ac-ft	-77.33 ac-ft
16.1	522 cfs	103.54 ac-ft	911 cfs	180.74 ac-ft	5377.0 ft	23591.11 ac-ft	-77.20 ac-ft
16.2	522 cfs	103.54 ac-ft	911 cfs	180.61 ac-ft	5376.9 ft	23513.91 ac-ft	-77.07 ac-ft
16.3	522 cfs	103.54 ac-ft	910 cfs	180.48 ac-ft	5376.8 ft	23436.84 ac-ft	-76.94 ac-ft
16.4	522 cfs	103.54 ac-ft	909 cfs	180.35 ac-ft	5376.7 ft	23359.90 ac-ft	-76.81 ac-ft
16.5	522 cfs	103.54 ac-ft	909 cfs	180.22 ac-ft	5376.6 ft	23283.09 ac-ft	-76.68 ac-ft
16.6	522 cfs	103.54 ac-ft	909 cfs	180.22 ac-ft	5376.6 ft	23206.41 ac-ft	-76.68 ac-ft
16.7	522 cfs	103.54 ac-ft	908 cfs	180.09 ac-ft	5376.5 ft	23129.73 ac-ft	-76.55 ac-ft
16.8	522 cfs	103.54 ac-ft	907 cfs	179.96 ac-ft	5376.4 ft	23053.17 ac-ft	-76.42 ac-ft
16.9	522 cfs	103.54 ac-ft	907 cfs	179.83 ac-ft	5376.3 ft	22976.75 ac-ft	-76.29 ac-ft
17	522 cfs	103.54 ac-ft	906 cfs	179.70 ac-ft	5376.2 ft	22900.46 ac-ft	-76.16 ac-ft
17.1	522 cfs	103.54 ac-ft	905 cfs	179.57 ac-ft	5376.1 ft	22824.29 ac-ft	-76.03 ac-ft
17.2	522 cfs	103.54 ac-ft	905 cfs	179.44 ac-ft	5376.0 ft	22748.26 ac-ft	-75.90 ac-ft
17.3	522 cfs	103.54 ac-ft	904 cfs	179.31 ac-ft	5375.9 ft	22672.36 ac-ft	-75.77 ac-ft
17.4	522 cfs	103.54 ac-ft	903 cfs	179.18 ac-ft	5375.8 ft	22596.58 ac-ft	-75.64 ac-ft
17.5	522 cfs	103.54 ac-ft	903 cfs	179.05 ac-ft	5375.7 ft	22520.94 ac-ft	-75.51 ac-ft
17.6	522 cfs	103.54 ac-ft	902 cfs	178.92 ac-ft	5375.6 ft	22445.43 ac-ft	-75.38 ac-ft
17.7	522 cfs	103.54 ac-ft	901 cfs	178.79 ac-ft	5375.5 ft	22370.04 ac-ft	-75.25 ac-ft
17.8	522 cfs	103.54 ac-ft	901 cfs	178.66 ac-ft	5375.4 ft	22294.79 ac-ft	-75.12 ac-ft
17.9	522 cfs	103.54 ac-ft	900 cfs	178.53 ac-ft	5375.3 ft	22219.67 ac-ft	-74.99 ac-ft
18	522 cfs	103.54 ac-ft	899 cfs	178.40 ac-ft	5375.2 ft	22144.68 ac-ft	-74.86 ac-ft
18.1	522 cfs	103.54 ac-ft	899 cfs	178.27 ac-ft	5375.1 ft	22069.82 ac-ft	-74.73 ac-ft
18.2	522 cfs	103.54 ac-ft	898 cfs	178.14 ac-ft	5375.0 ft	21995.09 ac-ft	-74.60 ac-ft
18.3	522 cfs	103.54 ac-ft	897 cfs	178.00 ac-ft	5374.9 ft	21920.49 ac-ft	-74.47 ac-ft
18.4	522 cfs	103.54 ac-ft	897 cfs	177.87 ac-ft	5374.8 ft	21846.02 ac-ft	-74.34 ac-ft
18.5	522 cfs	103.54 ac-ft	896 cfs	177.74 ac-ft	5374.7 ft	21771.69 ac-ft	-74.21 ac-ft
18.6	522 cfs	103.54 ac-ft	895 cfs	177.48 ac-ft	5374.5 ft	21697.48 ac-ft	-73.94 ac-ft
18.7	522 cfs	103.54 ac-ft	894 cfs	177.35 ac-ft	5374.4 ft	21623.54 ac-ft	-73.81 ac-ft
18.8	522 cfs	103.54 ac-ft	893 cfs	177.22 ac-ft	5374.3 ft	21549.73 ac-ft	-73.68 ac-ft
18.9	522 cfs	103.54 ac-ft	893 cfs	177.08 ac-ft	5374.2 ft	21476.05 ac-ft	-73.55 ac-ft
19	522 cfs	103.54 ac-ft	892 cfs	176.95 ac-ft	5374.1 ft	21402.50 ac-ft	-73.42 ac-ft
19.1	522 cfs	103.54 ac-ft	891 cfs	176.82 ac-ft	5374.0 ft	21329.09 ac-ft	-73.28 ac-ft
19.2	522 cfs	103.54 ac-ft	891 cfs	176.69 ac-ft	5373.9 ft	21255.80 ac-ft	-73.15 ac-ft
19.3	522 cfs	103.54 ac-ft	890 cfs	176.56 ac-ft	5373.8 ft	21182.65 ac-ft	-73.02 ac-ft
19.4	522 cfs	103.54 ac-ft	889 cfs	176.42 ac-ft	5373.7 ft	21109.63 ac-ft	-72.89 ac-ft
19.5	522 cfs	103.54 ac-ft	889 cfs	176.29 ac-ft	5373.6 ft	21036.74 ac-ft	-72.76 ac-ft
19.6	522 cfs	103.54 ac-ft	887 cfs	176.03 ac-ft	5373.4 ft	20963.99 ac-ft	-72.49 ac-ft
19.7	522 cfs	103.54 ac-ft	887 cfs	175.89 ac-ft	5373.3 ft	20891.50 ac-ft	-72.36 ac-ft
19.8	522 cfs	103.54 ac-ft	886 cfs	175.76 ac-ft	5373.2 ft	20819.14 ac-ft	-72.23 ac-ft
19.9	522 cfs	103.54 ac-ft	885 cfs	175.63 ac-ft	5373.1 ft	20746.92 ac-ft	-72.09 ac-ft
20	522 cfs	103.54 ac-ft	885 cfs	175.50 ac-ft	5373.0 ft	20674.82 ac-ft	-71.96 ac-ft
20.1	522 cfs	103.54 ac-ft	884 cfs	175.36 ac-ft	5372.9 ft	20602.86 ac-ft	-71.83 ac-ft
20.2	522 cfs	103.54 ac-ft	883 cfs	175.23 ac-ft	5372.8 ft	20531.04 ac-ft	-71.69 ac-ft
20.3	522 cfs	103.54 ac-ft	883 cfs	175.10 ac-ft	5372.7 ft	20459.34 ac-ft	-71.56 ac-ft
20.4	522 cfs	103.54 ac-ft	882 cfs	174.96 ac-ft	5372.6 ft	20387.78 ac-ft	-71.43 ac-ft
20.5	522 cfs	103.54 ac-ft	881 cfs	174.83 ac-ft	5372.5 ft	20316.36 ac-ft	-71.29 ac-ft
20.6	522 cfs	103.54 ac-ft	881 cfs	174.70 ac-ft	5372.4 ft	20245.06 ac-ft	-71.16 ac-ft
20.7	522 cfs	103.54 ac-ft	880 cfs	174.56 ac-ft	5372.3 ft	20173.90 ac-ft	-71.03 ac-ft
20.8	522 cfs	103.54 ac-ft	879 cfs	174.43 ac-ft	5372.2 ft	20102.88 ac-ft	-70.89 ac-ft
20.9	522 cfs	103.54 ac-ft	879 cfs	174.30 ac-ft	5372.1 ft	20031.99 ac-ft	-70.76 ac-ft
21	522 cfs	103.54 ac-ft	877 cfs	174.03 ac-ft	5371.9 ft	19961.23 ac-ft	-70.49 ac-ft
21.1	522 cfs	103.54 ac-ft	877 cfs	173.89 ac-ft	5371.8 ft	19890.74 ac-ft	-70.36 ac-ft
21.2	522 cfs	103.54 ac-ft	876 cfs	173.76 ac-ft	5371.7 ft	19820.38 ac-ft	-70.22 ac-ft
21.3	522 cfs	103.54 ac-ft	875 cfs	173.63 ac-ft	5371.6 ft	19750.16 ac-ft	-70.09 ac-ft
21.4	522 cfs	103.54 ac-ft	875 cfs	173.49 ac-ft	5371.5 ft	19680.07 ac-ft	-69.95 ac-ft
21.5	522 cfs	103.54 ac-ft	874 cfs	173.36 ac-ft	5371.4 ft	19610.12 ac-ft	-69.82 ac-ft
21.6	522 cfs	103.54 ac-ft	873 cfs	173.22 ac-ft	5371.3 ft	19540.30 ac-ft	-69.68 ac-ft
21.7	522 cfs	103.54 ac-ft	873 cfs	173.09 ac-ft	5371.2 ft	19470.61 ac-ft	-69.55 ac-ft
21.8	522 cfs	103.54 ac-ft	872 cfs	172.95 ac-ft	5371.1 ft	19401.06 ac-ft	-69.41 ac-ft
21.9	522 cfs	103.54 ac-ft	871 cfs	172.82 ac-ft	5371.0 ft	19331.65 ac-ft	-69.28 ac-ft
22	522 cfs	103.54 ac-ft	871 cfs	172.68 ac-ft	5370.9 ft	19262.37 ac-ft	-69.14 ac-ft
22.1	522 cfs	103.54 ac-ft	870 cfs	172.55 ac-ft	5370.8 ft	19193.22 ac-ft	-69.01 ac-ft
22.2	522 cfs	103.54 ac-ft	869 cfs	172.41 ac-ft	5370.7 ft	19124.21 ac-ft	-68.87 ac-ft
22.3	522 cfs	103.54 ac-ft	869 cfs	172.28 ac-ft	5370.6 ft	19055.34 ac-ft	-68.74 ac-ft
22.4	522 cfs	103.54 ac-ft	868 cfs	172.14 ac-ft	5370.5 ft	18986.60 ac-ft	-68.60 ac-ft
22.5	522 cfs	103.54 ac-ft	867 cfs	172.01 ac-ft	5370.4 ft	18918.00 ac-ft	-68.47 ac-ft
22.6	522 cfs	103.54 ac-ft	867 cfs	171.87 ac-ft	5370.3 ft	18849.53 ac-ft	-68.33 ac-ft
22.7	522 cfs	103.54 ac-ft	866 cfs	171.73 ac-ft	5370.2 ft	18781.20 ac-ft	-68.20 ac-ft

22.8	522 cfs	103.54 ac-ft	865 cfs	171.60 ac-ft	5370.1 ft	18713.00 ac-ft	-68.06 ac-ft
22.9	522 cfs	103.54 ac-ft	864 cfs	171.46 ac-ft	5370.0 ft	18644.94 ac-ft	-67.92 ac-ft
23	522 cfs	103.54 ac-ft	864 cfs	171.33 ac-ft	5369.9 ft	18577.02 ac-ft	-67.79 ac-ft
23.1	522 cfs	103.54 ac-ft	863 cfs	171.19 ac-ft	5369.8 ft	18509.23 ac-ft	-67.65 ac-ft
23.2	522 cfs	103.54 ac-ft	862 cfs	170.92 ac-ft	5369.6 ft	18441.58 ac-ft	-67.38 ac-ft
23.3	522 cfs	103.54 ac-ft	861 cfs	170.78 ac-ft	5369.5 ft	18374.20 ac-ft	-67.24 ac-ft
23.4	522 cfs	103.54 ac-ft	860 cfs	170.64 ac-ft	5369.4 ft	18306.95 ac-ft	-67.11 ac-ft
23.5	522 cfs	103.54 ac-ft	860 cfs	170.51 ac-ft	5369.3 ft	18239.85 ac-ft	-66.97 ac-ft
23.6	522 cfs	103.54 ac-ft	859 cfs	170.37 ac-ft	5369.2 ft	18172.88 ac-ft	-66.83 ac-ft
23.7	522 cfs	103.54 ac-ft	858 cfs	170.23 ac-ft	5369.1 ft	18106.05 ac-ft	-66.70 ac-ft
23.8	522 cfs	103.54 ac-ft	858 cfs	170.10 ac-ft	5369.0 ft	18039.35 ac-ft	-66.56 ac-ft
23.9	522 cfs	103.54 ac-ft	856 cfs	169.82 ac-ft	5368.8 ft	17972.79 ac-ft	-66.28 ac-ft
24	522 cfs	103.54 ac-ft	855 cfs	169.68 ac-ft	5368.7 ft	17906.51 ac-ft	-66.15 ac-ft
24.1	522 cfs	103.54 ac-ft	855 cfs	169.55 ac-ft	5368.6 ft	17840.36 ac-ft	-66.01 ac-ft
24.2	522 cfs	103.54 ac-ft	854 cfs	169.41 ac-ft	5368.5 ft	17774.35 ac-ft	-65.87 ac-ft
24.3	522 cfs	103.54 ac-ft	853 cfs	169.27 ac-ft	5368.4 ft	17708.48 ac-ft	-65.73 ac-ft
24.4	522 cfs	103.54 ac-ft	853 cfs	169.13 ac-ft	5368.3 ft	17642.75 ac-ft	-65.60 ac-ft
24.5	522 cfs	103.54 ac-ft	852 cfs	168.99 ac-ft	5368.2 ft	17577.16 ac-ft	-65.46 ac-ft
24.6	522 cfs	103.54 ac-ft	851 cfs	168.86 ac-ft	5368.1 ft	17511.70 ac-ft	-65.32 ac-ft
24.7	522 cfs	103.54 ac-ft	850 cfs	168.58 ac-ft	5367.9 ft	17446.38 ac-ft	-65.04 ac-ft
24.8	522 cfs	103.54 ac-ft	849 cfs	168.44 ac-ft	5367.8 ft	17381.34 ac-ft	-64.90 ac-ft
24.9	522 cfs	103.54 ac-ft	849 cfs	168.30 ac-ft	5367.7 ft	17316.43 ac-ft	-64.77 ac-ft
25	522 cfs	103.54 ac-ft	848 cfs	168.16 ac-ft	5367.6 ft	17251.67 ac-ft	-64.63 ac-ft
25.1	522 cfs	103.54 ac-ft	847 cfs	168.03 ac-ft	5367.5 ft	17187.04 ac-ft	-64.49 ac-ft
25.2	522 cfs	103.54 ac-ft	846 cfs	167.89 ac-ft	5367.4 ft	17122.55 ac-ft	-64.35 ac-ft
25.3	522 cfs	103.54 ac-ft	846 cfs	167.75 ac-ft	5367.3 ft	17058.20 ac-ft	-64.21 ac-ft
25.4	522 cfs	103.54 ac-ft	845 cfs	167.61 ac-ft	5367.2 ft	16993.99 ac-ft	-64.07 ac-ft
25.5	522 cfs	103.54 ac-ft	844 cfs	167.47 ac-ft	5367.1 ft	16929.92 ac-ft	-63.93 ac-ft
25.6	522 cfs	103.54 ac-ft	844 cfs	167.33 ac-ft	5367.0 ft	16865.99 ac-ft	-63.79 ac-ft
25.7	522 cfs	103.54 ac-ft	842 cfs	167.05 ac-ft	5366.8 ft	16802.20 ac-ft	-63.51 ac-ft
25.8	522 cfs	103.54 ac-ft	842 cfs	166.91 ac-ft	5366.7 ft	16738.69 ac-ft	-63.37 ac-ft
25.9	522 cfs	103.54 ac-ft	841 cfs	166.77 ac-ft	5366.6 ft	16675.31 ac-ft	-63.23 ac-ft
26	522 cfs	103.54 ac-ft	840 cfs	166.63 ac-ft	5366.5 ft	16612.08 ac-ft	-63.09 ac-ft
26.1	522 cfs	103.54 ac-ft	839 cfs	166.49 ac-ft	5366.4 ft	16548.99 ac-ft	-62.95 ac-ft
26.2	522 cfs	103.54 ac-ft	839 cfs	166.35 ac-ft	5366.3 ft	16486.03 ac-ft	-62.81 ac-ft
26.3	522 cfs	103.54 ac-ft	838 cfs	166.21 ac-ft	5366.2 ft	16423.22 ac-ft	-62.67 ac-ft
26.4	522 cfs	103.54 ac-ft	837 cfs	166.07 ac-ft	5366.1 ft	16360.55 ac-ft	-62.53 ac-ft
26.5	522 cfs	103.54 ac-ft	837 cfs	165.93 ac-ft	5366.0 ft	16298.01 ac-ft	-62.39 ac-ft
26.6	522 cfs	103.54 ac-ft	836 cfs	165.79 ac-ft	5365.9 ft	16235.62 ac-ft	-62.25 ac-ft
26.7	522 cfs	103.54 ac-ft	835 cfs	165.65 ac-ft	5365.8 ft	16173.37 ac-ft	-62.11 ac-ft
26.8	522 cfs	103.54 ac-ft	834 cfs	165.51 ac-ft	5365.7 ft	16111.26 ac-ft	-61.97 ac-ft
26.9	522 cfs	103.54 ac-ft	834 cfs	165.37 ac-ft	5365.6 ft	16049.29 ac-ft	-61.83 ac-ft
27	522 cfs	103.54 ac-ft	833 cfs	165.22 ac-ft	5365.5 ft	15987.46 ac-ft	-61.69 ac-ft
27.1	522 cfs	103.54 ac-ft	832 cfs	165.08 ac-ft	5365.4 ft	15925.77 ac-ft	-61.55 ac-ft
27.2	522 cfs	103.54 ac-ft	832 cfs	164.94 ac-ft	5365.3 ft	15864.23 ac-ft	-61.40 ac-ft
27.3	522 cfs	103.54 ac-ft	830 cfs	164.66 ac-ft	5365.1 ft	15802.82 ac-ft	-61.12 ac-ft
27.4	522 cfs	103.54 ac-ft	829 cfs	164.52 ac-ft	5365.0 ft	15741.70 ac-ft	-60.98 ac-ft
27.5	522 cfs	103.54 ac-ft	829 cfs	164.38 ac-ft	5364.9 ft	15680.72 ac-ft	-60.84 ac-ft
27.6	522 cfs	103.54 ac-ft	828 cfs	164.23 ac-ft	5364.8 ft	15619.88 ac-ft	-60.70 ac-ft
27.7	522 cfs	103.54 ac-ft	827 cfs	164.09 ac-ft	5364.7 ft	15559.19 ac-ft	-60.55 ac-ft
27.8	522 cfs	103.54 ac-ft	827 cfs	163.95 ac-ft	5364.6 ft	15498.63 ac-ft	-60.41 ac-ft
27.9	522 cfs	103.54 ac-ft	826 cfs	163.81 ac-ft	5364.5 ft	15438.22 ac-ft	-60.27 ac-ft
28	522 cfs	103.54 ac-ft	825 cfs	163.66 ac-ft	5364.4 ft	15377.95 ac-ft	-60.13 ac-ft
28.1	522 cfs	103.54 ac-ft	824 cfs	163.38 ac-ft	5364.2 ft	15317.83 ac-ft	-59.84 ac-ft
28.2	522 cfs	103.54 ac-ft	823 cfs	163.24 ac-ft	5364.1 ft	15257.99 ac-ft	-59.70 ac-ft
28.3	522 cfs	103.54 ac-ft	822 cfs	163.09 ac-ft	5364.0 ft	15198.29 ac-ft	-59.56 ac-ft
28.4	522 cfs	103.54 ac-ft	822 cfs	162.95 ac-ft	5363.9 ft	15138.73 ac-ft	-59.41 ac-ft
28.5	522 cfs	103.54 ac-ft	821 cfs	162.81 ac-ft	5363.8 ft	15079.32 ac-ft	-59.27 ac-ft
28.6	522 cfs	103.54 ac-ft	820 cfs	162.66 ac-ft	5363.7 ft	15020.05 ac-ft	-59.13 ac-ft
28.7	522 cfs	103.54 ac-ft	819 cfs	162.52 ac-ft	5363.6 ft	14960.93 ac-ft	-58.98 ac-ft
28.8	522 cfs	103.54 ac-ft	819 cfs	162.38 ac-ft	5363.5 ft	14901.94 ac-ft	-58.84 ac-ft
28.9	522 cfs	103.54 ac-ft	817 cfs	162.09 ac-ft	5363.3 ft	14843.11 ac-ft	-58.55 ac-ft
29	522 cfs	103.54 ac-ft	816 cfs	161.94 ac-ft	5363.2 ft	14784.55 ac-ft	-58.41 ac-ft
29.1	522 cfs	103.54 ac-ft	816 cfs	161.80 ac-ft	5363.1 ft	14726.15 ac-ft	-58.26 ac-ft
29.2	522 cfs	103.54 ac-ft	815 cfs	161.66 ac-ft	5363.0 ft	14667.89 ac-ft	-58.12 ac-ft
29.3	522 cfs	103.54 ac-ft	814 cfs	161.51 ac-ft	5362.9 ft	14609.77 ac-ft	-57.97 ac-ft
29.4	522 cfs	103.54 ac-ft	814 cfs	161.37 ac-ft	5362.8 ft	14551.79 ac-ft	-57.83 ac-ft
29.5	522 cfs	103.54 ac-ft	813 cfs	161.22 ac-ft	5362.7 ft	14493.96 ac-ft	-57.68 ac-ft
29.6	522 cfs	103.54 ac-ft	812 cfs	161.08 ac-ft	5362.6 ft	14436.28 ac-ft	-57.54 ac-ft
29.7	522 cfs	103.54 ac-ft	811 cfs	160.93 ac-ft	5362.5 ft	14378.74 ac-ft	-57.40 ac-ft
29.8	522 cfs	103.54 ac-ft	810 cfs	160.64 ac-ft	5362.3 ft	14321.34 ac-ft	-57.10 ac-ft
29.9	522 cfs	103.54 ac-ft	809 cfs	160.50 ac-ft	5362.2 ft	14264.24 ac-ft	-56.96 ac-ft
30	522 cfs	103.54 ac-ft	808 cfs	160.35 ac-ft	5362.1 ft	14207.28 ac-ft	-56.81 ac-ft


Ruby Dam 3-month Hydrograph
1200 cfs
1000 cfs
800 cfs
600 cfs
400 cfs
200 cfs
0 cfs
Flow (cfs)
Inflow
Outflow
Time (days)
2.9
5.9
8.9
11.9
14.9
17.9
20.9
23.9
26.9
29.9
32.9
35.9
38.9
41.9
44.9
47.9
50.9
53.9
56.9
59.9
62.9
65.9
68.9
71.9
74.9
77.9
80.9
83.9
86.9
89.9
Time (days)

APPENDIX H

DNRC OUTLET WORKS REHABILITATION COMMENTS AND HKM RESPONSES

September 12, 2006

Mr. Jay Thom
HKM Inc.
PO Box 31318
Billings, MT 59107-1318

Re: Low Level Outlet Works Alternatives
Ruby Dam Feasibility Study

Dear Jay:

The DNRC has reviewed the MWH draft report describing their evaluation of the outlet works gates and alternatives for the operating gate. We have the following comments and questions regarding the report.

- Are there any potential impacts to fish/aquatics with the various valve types? For example, with the FCV would levels of dissolved oxygen in the water, or temperature of water be adversely affected?
- Noise for the FCV will likely be a concern that will need to be discussed in the feasibility study.
- Are there differences in maintenance requirements with the different valve types? In particular, we are concerned that the FCV option will likely include three valves that may require more intensive maintenance than the other valves considered.
- If a valve is installed at the downstream toe, could icing problems occur that may result in maintenance issues?
- Literature reviewed on the internet indicates that a FCV is intended primarly for free discharge. If it is installed in a submerged condition cavitation problems can result unless it is properly designed. Also a FCV installed in a submerged condition would likely have a reduced flow rate, and therefore be less efficient.
- The cost estimates are limited to only gate fabrication and do not include other cost differences between the various alternatives. For example: 1) none of the alternatives requiring downstream valves include costs for penstock installation; 2) ancillary costs for the FCV such as freeze protection, penstock bifurcations, inspection access portal, etc. are not accounted for; 3) costs for providing venting for a JFG installed in the existing gatehouse are not included, and; 4) terminal structure costs are not included.

- It is appealing to have just one valve that can be used for the full range of anticipated flows. Would this be possible with either a JFG, or another type of slide gate?
- The report dismisses the option of placing a JFG at the toe of the dam due to the cost of adequately dissipating the energy. We would like to see more discussion on stilling basin options (i.e. how big would a concrete basin need to be, would a trajectory – impact type basin be an option, etc.).
- The report indicates that a sectionalized JFG will cost approximately $500,000. If it is feasible to place a JFG at the toe of the dam, would it need to be sectionalized, and would there be a significant cost reduction?
- In Section 2.2.5 gate valves are discussed and determined to not be economically viable, primarily due to the large size that would be required to keep velocities below 16 fps. There are many instances where gate valves (sluice gate, bonneted slide gate, etc.) are successfully utilized with flow velocities that greatly exceed 16 fps. We believe that this option merits a more thorough discussion, whether the gate is mounted in the tower, or at the toe of the dam.
- In the feasibility we would like to see at least one option considered where a new gate is installed in the tower.
- More detailed analysis and costing of the valve options appears warranted before a preferred valve arrangement is selected.
- The flow velocities are very high within the penstock at the larger discharges. Will there be any difficulties with splitting the high velocity flows for multiple valves?

After reviewing our comments and questions please contact us so that we may discuss them further.

Kind Regards,

Brian Grant, PE
Project Engineer
State Water Projects Bureau

Rob Kingery, PE
Supervisor
Rehab Section

Cc: Kevin Smith
Ruby Files

Ruby Dam Feasibility Study
Montana Department of Natural Resources and Conservation
HKM Job No.: 08M087.175
Response to DNRC Comments on Outlet Works Alternatives Investigation Report

The DNRC has reviewed the MWH draft report describing their evaluation of the outlet works gates and alternatives for the operating gate. We have the following comments and questions regarding the report.

- DNRC Comment: Are there any potential impacts to fish/aquatics with the various valve types? For example, with the FCV would levels of dissolved oxygen in the water, or temperature of water be adversely affected?

  MWH Response: Further site investigation would be needed to verify the potential detrimental effects on aquatics and the outlet and stilling basin. The design of the outlet and stilling basin would have to consider these effects and be optimized to minimize them. In general, we provide the following thoughts on the issue:
  - *We assume trout would be the main form of aquatic life in the stream and it did not appear that there would be a large abundance of the fish in the area immediately downstream of the discharge.*
  - *The key to limiting the detrimental effect of the supersaturated water released from the valves would be to keep this water near the surface where the air could easily release into the atmosphere in the stilling basin. As long as the water stays near the surface and is not driven deep (say over 10 ft.), there should be minimal detrimental affect downstream. The preferred method would be free discharge into the air. However, if that is not permissible, the design of the discharge structure would have to be done in a way to release water as close to the surface as possible.*
  - *Water temperature should be no more of an issue than at present.*

- DNRC Comment: Noise for the FCV will likely be a concern that will need to be discussed in the feasibility study.

  MWH Response: In a free discharge situation into the air, FCV's would emit a "roar" that would be quite loud (A recent paper from Intl. Water Power and Dam Construction measured the noise from a hooded 78 in. FCV valve under approximately 120-ft. head at Salt Springs Dam in California to be on the order of 80 to 100 dbA). If an energy dissipation structure is used, such as that shown in Figure 9, it would seem that the sound would be heavily muffled within the structure.

- DNRC Comment: Are there differences in maintenance requirements with the different valve types? In particular, we are concerned that the FCV option will likely include three valves that may require more intensive maintenance than the other valves considered.

MWH Response: *Any type of valve would need to be exercised regularly. The maintenance for a FCV would depend upon the type of operating system used as follows:*

- *The most common means of operation of this valve type would be via dual screw stems, a single electric motor actuator, and three gearboxes. The screw stems would be protected by a protective sleeve but would need to be lubricated periodically. Gearboxes would need to be lubricated periodically as well. All of these components are external to the FCV, therefore readily accessible.*
- *The other means of operation of an FCV would be via dual hydraulic cylinders. This operator type would require minimal maintenance that would consist of periodic testing and changing of oil in the hydraulic reservoir. If a hydraulic cylinder system is used, all FCV valve operators would be controlled via a common hydraulic power unit.*

Regarding a JFG, assuming a hydraulic cylinder operator is used, it would have similar maintenance upkeep as that required for the FCV with a hydraulic operator.

- DNRC Comment: If a valve is installed at the downstream toe, could icing problems occur that may result in maintenance issues?

  MWH Response: *Icing caused by the emitted jet from a valve could cause problems downstream, especially with a FCV that discharges into the air because of the large spray and mist pattern. We are not aware of past problems with icing causing the malfunction of the valve; however, the icing of the surrounding structures could result in maintenance issues that would have to be addressed in design.*

- DNRC Comment: Literature reviewed on the internet indicates that a FCV is intended primarly for free discharge. If it is installed in a submerged condition cavitation problems can result unless it is properly designed. Also a FCV installed in a submerged condition would likely have a reduced flow rate, and therefore be less efficient.

  MWH Response: *Agreed. A standard FCV is intended for free discharge and not submerged discharge. See discussion in Section 3.4, Alternative 3A. We do not recommend this valve be used for submerged discharge. If submerged discharge is a necessity, SV's would be the preferred option as discussed in Section 3.4, Alternative 3B. JFG's could also be used in submerged discharge applications but require careful design, specifically for this purpose.*

  HKM Response: *Outlet works design alternatives incorporating FCVs will be aligned to prevent the outlet from becoming submerged.*

- DNRC Comment: The cost estimates are limited to only gate fabrication and do not include other cost differences between the various alternatives. For example: 1) none of the alternatives requiring downstream valves include costs for penstock installation; 2) ancillary costs for the FCV such as freeze protection, penstock bifurcations, inspection access portal, etc. are not accounted for; 3) costs for providing venting for a JFG installed in the existing gatehouse are not included, and; 4) terminal structure costs are not included.

  MWH Response: HKM to provide costs in the final report. Costs contained in the MWH report only include budgetary fabrication and delivery cost estimates.

  HKM Response: Costs included in the MWH Report were produced on a conceptual basis to identify potential preferred valve alternatives. A detailed cost estimate for an alternative may not have been developed due to the cost of the valves in comparison to other alternatives or complications associated with installation. The cost estimate for the selected preferred alternative will be further refined to include the above mentioned items.

- DNRC Comment: It is appealing to have just one valve that can be used for the full range of anticipated flows. Would this be possible with either a JFG, or another type of slide gate?

  MWH Response: A single, 66-in. JFG could be used for this application as discussed in Section 2.2.2. However, there would be a concern of a "threading" condition occurring if the valve is left open a very small amount for a long period of time. This condition is generally caused by erosion of the seats due to the high velocity jet concentrated in a single location of the valve for an extended time. SV's could potentially be throttled this low but the valve is not preferred because of maximum discharge limitations and cost. For the required discharge range, it would be preferable to have a minimum of 2 valves to cover the full range of discharges. MWH has previously designed a bonnetted slide gate with an integral Jet Flow gate to handle the small discharges. Something similar could be done in this instance as well.

  HKM Response to MWH Response: A single, 72-in. JFG was considered as an Alternative (rather than a 66-in. JFG) to increase outlet maximum capacity.

- DNRC Comment: The report dismisses the option of placing a JFG at the toe of the dam due to the cost of adequately dissipating the energy. We would like to see more discussion on stilling basin options (i.e. how big would a concrete basin need to be, would a trajectory – impact type basin be an option, etc.).

HKM Response: *An Alternative incorporating a JFG at the toe of the dam and associated stilling basin design will be presented in the Low Level Outlet Works Rehabilitation Summary Report.*

- DNRC Comment: The report indicates that a sectionalized JFG will cost approximately $500,000. If it is feasible to place a JFG at the toe of the dam, would it need to be sectionalized, and would there be a significant cost reduction?

  MWH Response: *No, it would not require sectionalization as long as there is easy access to the toe of the dam where it would be placed and a crane of sufficient capacity is available to install it. For feasibility level design purposes, MWH recommends that $500,000 be assumed as the fabrication and delivery cost whether it is sectionalized or not. The cost difference for a sectionalized vs. assembled valve would come in the form of increased installation costs for the former.*

- DNRC Comment: In Section 2.2.5 gate valves are discussed and determined to not be economically viable, primarily due to the large size that would be required to keep velocities below 16 fps. There are many instances where gate valves (sluice gate, bonneted slide gate, etc.) are successfully utilized with flow velocities that greatly exceed 16 fps. We believe that this option merits a more thorough discussion, whether the gate is mounted in the tower, or at the toe of the dam.

  MWH Response: *The report states that standard AWWA butterfly valves and gate valves are designed for the flow velocities identified in the report. These "off the shelf" valves are quite economical. There are numerous instances where custom designed butterfly valves and slide gates are used for much higher flows, however these gates and valves are significantly more expensive because of their custom design requirements.*

  Note that a JFG is essentially a slide gate for a circular opening and would not provide a dramatic cost increase over a typical bonnetted slide gate. In addition, the JFG is specially designed to handle a larger range of flows as described in the report. For these reasons, further research of the other gate/valve types does not seem necessary.

- DNRC Comment: In the feasibility we would like to see at least one option considered where a new gate is installed in the tower.

  MWH Response: *This is handled from a gate perspective in Alternative 2, Section 3.3.*

HKM Response: *Alternative 2 was not considered a viable option because it would incorporate a similar terminal structure to Alternative 1 (rehabilitation of existing structure) with the additional cost of a sectionalized gate design and installation. Also, the additional cost of a bridge over the spillway required to provide emergency access would further increase the cost of this Alternative. Thirdly, placing a new gate inline with the tower would eliminate the possibility for hydropower utilization in the future.*

- DNRC Comment: More detailed analysis and costing of the valve options appears warranted before a preferred valve arrangement is selected.

  HKM Response: *A detailed cost estimate for two Alternatives will be presented in the Low Level Outlet Works Summary Report. These two Alternatives will be selected based on the fabrication and delivery cost of the valves, the ability of the configuration to operate under the 20-1500 cfs discharge range per DNRC, and the total construction cost.*

- DNRC Comment: The flow velocities are very high within the penstock at the larger discharges. Will there be any difficulties with splitting the high velocity flows for multiple valves?

  HKM Response: *Considerations associated with bifurcating flows will be accounted for and presented in the Low Level Outlet Work Summary Report. Additional head losses resulting from splitting flows are discussed in conjunction with Alternative 3A.*