PAP-795

Structural Alternatives for TDG Abatement at Grand Coulee Dam, Conceptual Design Report

October 1998

by

Kathleen H. Frizell
Elisabeth Cohen

PAP-795

United States Department of the Interior

BUREAU OF RECLAMATION
Pacific Northwest Region
1150 North Curtis Road, Suite 100
Boise, Idaho 83706-1234

IN REPLY REFER TO:
PN-6520
RES-3.00

Mr. Bill Hevlin
System Configuration Co-Chair
National Marine Fisheries Service
525 NE Oregon Street Suite 500
Portland OR 97232

Subject: System Configuration Team Review of Structural Alternatives for Total Dissolved Gas Abatement at Grand Coulee Dam, Conceptual Design Report

Dear ~~Mr. Hevlin~~ Bill:

Reclamation is completing concept designs for five structural alternatives to abate total dissolved gas (TDG) at Grand Coulee Dam under the Grand Coulee Gas Management Study. The goal of the study is to complete a feasibility-level report which evaluates structural gas management measures by the end of fiscal year 2000.

The enclosed Conceptual Design Report describes the five alternatives that have been investigated since completion of the Preliminary Concepts Report in February 1998 and provides refined costs and gas evaluations. Study results will be summarized at the October 21, 1998, System Configuration Team (SCT) meeting, and technical issues will be discussed at a technical subcommittee meeting to be held in the National Marine Fisheries Service 5th floor conference room from 8 a.m. to noon on October 22, 1998. Please note the early start time.

We anticipate selecting three alternatives to be carried forward to feasibility-level investigations, which will be completed at the end of fiscal year 2000. We request that the SCT provide a summary of written comments and recommendations for further studies by November 30, 1998.

Please direct any questions regarding information in this report to Ms. Kathleen Frizell at (303) 425-2144, or e-mail: kfrizell@do.usbr.gov.

Sincerely,

Monte McClendon

Monte McClendon
Program Manager, Ecosystems Analysis

Enclosure

cc: System Configuration Team and Dissolved Gas Team members

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CONCEPTUAL DESIGN REPORT

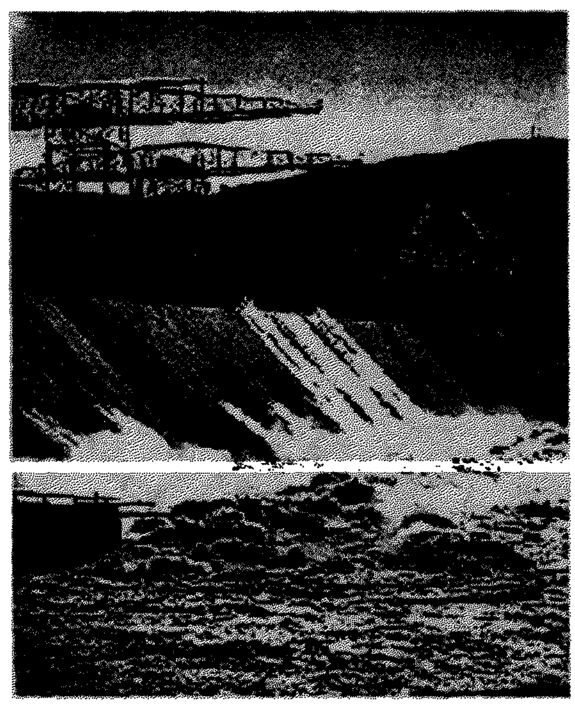

Figure 1. - Original construction of Grand Coulee Dam with river diversion flows, 1940.
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OCTOBER 1998

Prepared for USBR, PN REGION
by Kathleen H. Frizell and Elisabeth Cohen
Filename: C:\Kathy's files\98super\concept\CONCEPT4.WPD

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Acknowledgments

The information compiled in this report was prepared with the assistance of the entire Technical Service Center Grand Coulee Dam Total Dissolved Gas Team. The team included Elisabeth Cohen, Design lead, and Ernest Hall, D-8130; Donald Read, D-8420; Larry Rossi, D-8430; Keith Copeland, Barb Schuelke, and Robert Baumgarten, D-8170; Mike Rasmussen, D-8160; and Steve Young, D-8311.

Internal, Technical Service Center, peer review was provided by Chuck Cooper, D-8130. Peer review was also provided by the following PN region staff:

Darryl Beckmann (PN-3000)
Steve Clark (PN-1000)
John Dooley (PN-1060)
Ron McKown (PN-1070)
Monte McClendon (PN-6500)
Ken Pedde (PN-1050)
Lori Postlewait (PN-6400)
Steve Sauer (GCP-5000)
Dave Zimmer (PN-6520)

External peer review was provided under contract by Mr. Perry Johnson, ENSR.

Background

Total dissolved gas (TDG) levels in the Columbia River downstream from Grand Coulee Dam commonly exceed the Washington State and Colville Confederated Tribes' water quality standard of 110 percent of saturation. Exceedances are due to the combined impacts of spill operations at Grand Coulee Dam and to downstream transfer of flow with high levels of TDG generated at dams in Canada. Concerns regarding Columbia River dissolved gas supersaturation problems and potential for gas bubble disease and mortality in anadromous fish have received increasing attention over the past several years. These concerns have been raised because of above average flow conditions requiring flood control spills, and Endangered Species Act (ESA) salmon recovery efforts which utilize increased spill to accommodate fish passage through reservoir facilities on the lower Columbia and Snake Rivers. The 1997 flood season required months of spill along the entire river system.

At the request of the National Marine Fisheries Service (NMFS), the states of Washington and Oregon waived the 110 percent TDG water quality standard in the lower Snake and Columbia Rivers during the 1995 through 1998 spill seasons. A short-term waiver was also obtained to allow voluntary spills from Grand Coulee for endangered salmon migration in the Columbia River in 1996. Temporary standards of 115 percent in reservoir forebays and 120 percent in tailwaters were adopted based on scientific evaluations which weighed the improved salmon migration conditions accomplished through increased spill against the mortality associated with gas bubble disease. The standards waiver applies only to dissolved gas conditions induced by salmon migration spills, and does not apply to flood control spills. Washington State standards contain a clause which waives the 110 percent dissolved gas standard when flows exceed the 10-year 7-day high flow, which provides some regulatory relief during flood control operations. Standards apply at the point of measurement which is located in the river 6 miles downstream from Grand Coulee Dam.

Reclamation is aware of the concerns of regional fish managers and water quality management agencies regarding potential for damage to aquatic resources downstream of the project and has been working within the NMFS regional forum to achieve long-term resolution of the problem. A number of teams have been established within the NMFS regional forum, including the Technical Management Team (TMT), the Dissolved Gas Team (DGT), the Implementation Team (IT), the System Configuration Team (SCT), and the Executive Committee (EC). These teams have been actively involved in defining and managing dissolved gas problems associated with operation of the Columbia and Lower Snake system. The Mid and Upper Columbia River segments, including Grand Coulee Dam, Chief Joseph Dam, and the Canadian Dams are included in the system-wide TDG Management Plans. The recently formed Transboundary Gas Group (TGG) is dealing with ways to manage TDG into and out of Canada along the Pend O'reille River and the Spokane and Columbia Rivers. Reclamation continues to be an active member of these teams through the PN region personnel.

As a participant in the regional forum, Reclamation is working on a Gas Management Program for Grand Coulee Dam. As part of this program, Reclamation has initiated a series of outlet works operational changes during spill that will reduce the TDG added to the river and defined a range of beneficial spillway operation. These short-term benefits are being combined with long-term efforts to define possible structural modifications for gas abatement during spills from Grand Coulee Dam as described in this report.

Introduction

Reclamation has been tasked in the new 1998 Biological Opinion to investigate operational and structural gas abatement measures at Grand Coulee Dam. The Biological Opinion states in Chapter XII, 3.d., "The Action Agencies, in coordination with NMFS and the Regional Forum, shall jointly investigate operational and structural gas abatement measures at Grand Coulee and Chief Joseph Dams as part of system-wide evaluation of gas abatement measures. The Bureau of Reclamation shall submit an interim status report to the NMFS by April 1999 stating the findings of the investigations at Grand Coulee. The Corps of Engineers shall develop and coordinate through the Regional Forum the scope and implementation schedule for a similar investigation at Chief Joseph Dam by October 1998. The Action Agencies shall coordinate with the DGT and SCT to identify gas abating alternatives, future actions, implementation schedules, and future funding requirements for gas abatement at Grand Coulee and Chief Joseph Dams. The Action Agencies shall seek congressional authority and funding, as necessary, to implement the selected preferred alternatives.".

"Lower dissolved gas levels from Grand Coulee and Chief Joseph Dams would reduce background TDG levels caused by these projects, which may limit the duration of exposure of adult steelhead to high dissolved gas concentrations. Further, the passage survival of juvenile steelhead would be improved because increased spill would be allowed at downstream projects under the current dissolved gas cap."

The inevitable filing of this final 1998 Biological Opinion led Reclamation to begin investigations into potential structural modifications to Grand Coulee for TDG abatement purposes in 1997. The study began in October 1997 and the alternatives considered for conceptual level designs were outlined in the document "Structural Alternatives for TDG Abatement at Grand Coulee Dam Preliminary Concepts Report" prepared in February 1998 [1]. This document listed about 36 ideas with 9 alternatives listed as feasible for further investigation. The five alternatives that are presented in this conceptual-level study were selected from this document and input from the agencies in the Regional Forum.

Grand Coulee Dam

Grand Coulee Dam (figure 1) is located at the upper end of the Columbia River about 90 miles west of Spokane, Washington. The dam was constructed from 1933 to 1942 with the forebay dam and additional powerhouse completed in 1974. All Third Powerplant generating units were operational by 1979. The dam forms Franklin Delano Roosevelt (FDR) Lake which stretches approximately 150 miles to the Canadian border. The dam has a hydraulic height of 350 ft. The hydraulic structures are a 1,650-ft-wide gated spillway, an outlet works comprised of 40 active conduits through the dam in two tiers of 20 each, original left and right powerplants on either side of the spillway, and the Third Powerplant located almost parallel to the right dam abutment (figures 2 and 3). The bottom tier of outlets is no longer in service.

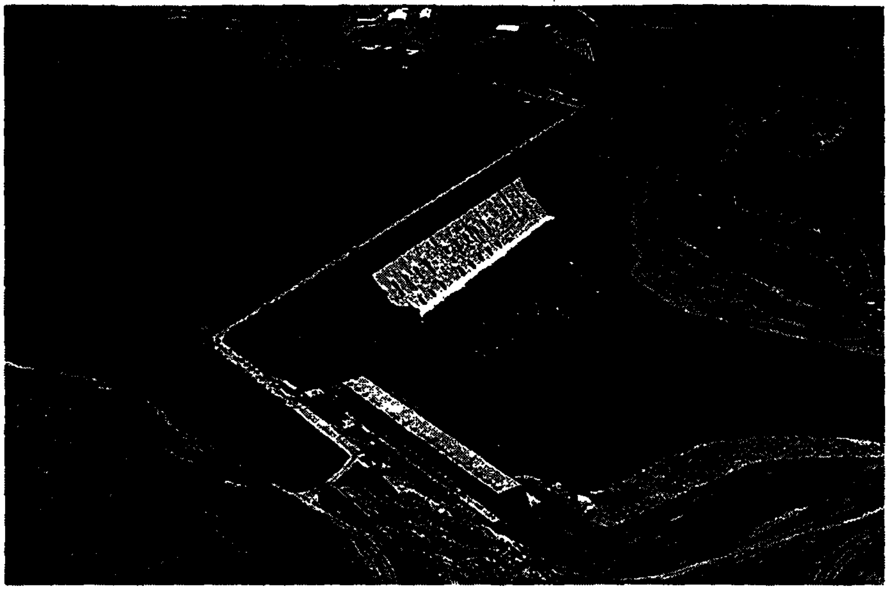

Figure 2. - Overall view of Grand Coulee Dam and Third Powerplant.
Notice the north service yard adjacent to the Third Powerplant.
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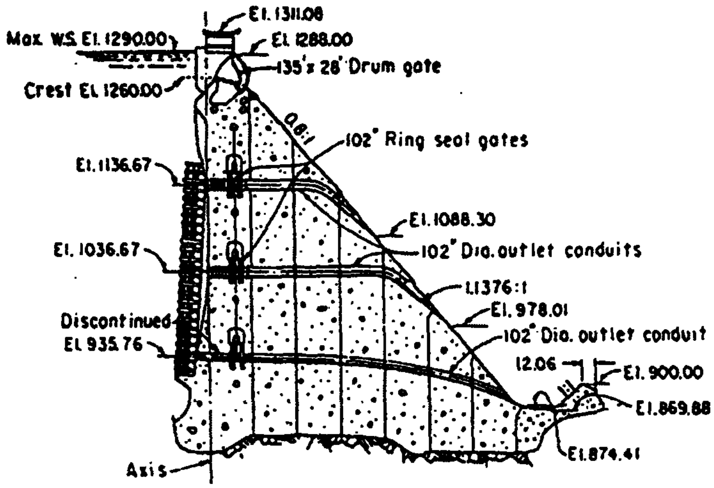
The spillway is located in the center of the dam with eleven 28- by 135-ft drum gates, atop a crest at El. 1260, controlling releases up to a maximum water surface of El. 1290. The spillway capacity is 1,000,000 ft^3/s. The spillway has a submerged roller bucket energy dissipater at El. 874.4 and discharges onto the rock surface downstream.

The 8.5-ft-diameter outlet works conduits discharge onto the downstream face of the spillway, also utilizing the roller bucket dissipater. Under normal reservoir operations, each outlet tube is capable of discharging from approximately 3,000 to 5,000 ft^3/s, depending upon the outlet elevation and the lake level. The centerline of the mid-level outlets is located at El. 1036.67, with the centerline elevation of the upper outlets 100 ft higher. The capacity of the outlet works at reservoir elevation 1290 is 191,920 ft^3/s. The outlet works are generally used to lower the lake level in the spring when high runoff is expected and the lake level is below the spillway crest (El. 1260).

The powerplants have a total capacity of 280,000 ft^3/s and discharge from the reservoir to the tailrace under submerged conditions. The centerline elevation for intakes of the original left and right powerplants is at El. 1041. The left and right powerplants each contain nine 125,000 kilowatt units which in terms of discharge pass a total of about 100,000 ft^3/s. The left powerplant also houses three small station service units of 10,000 kilowatts each, for a total generating capacity of 2,250,000 kilowatts for the left and right powerplants. The Third Powerplant intake has a centerline elevation of 1130. The Third Powerplant has 6 units, 3 with a capacity of 700,000 kilowatts each, and 3 which are rated at 805,000 kilowatts each, for a total of 4,515,000 kilowatts. The Third Powerplant is capable of passing 180,000 ft^3/s when generating power. When not generating power, the left and right powerplant turbine units can pass 500 ft^3/s each and the Third Powerplant turbines 3,000 ft^3/s each, for a total speed-no-load capacity of



SPILLWAY SECTION

Figure 3. - Section of the Grand Coulee spillway showing the locations of the spillway crest and drum gates, the three tiers of outlet works, and the roller bucket energy dissipater.

27,000 ft^3/s. The tailwater depth varies for a normal powerplant discharge range from about 80 to 100 ft referenced to the invert of the roller bucket.

The Grand Coulee Pump-Generating Plant consists of six pumping units and six pump generators, which lift water to irrigation facilities to the south of the river. The pump generators may also be used to generate power during peak power demand periods, at a capacity of 50,000 kilowatts each. The pump-generating plant intake is located at centerline elevation 1193.27. The extensive irrigation works of the project extend southward on the Columbia Plateau, 125 miles to the vicinity of Pasco, Washington, where the Snake and Columbia Rivers join.

The geometry of the hydraulic structures at Grand Coulee has a major influence on the gas transfer characteristics at the dam and makes addressing the TDG issue more complicated than at many of the lower dams on the Columbia and Snake River systems.

Concept Design Discharge and Tailwater

A design discharge for TDG evaluation was developed during the preliminary concept phase [1]. The design discharge is based upon the highest flow event that occurs for 7 consecutive days, once every 10 years. A portion of the event includes a base powerplant flow. The design flow was determined to be 50,000 ft^3/s based upon a 7-day 10-year event of 210,000 ft^3/s and a base powerplant flow of 160,000 ft^3/s. The design flow rate of 50,000 ft^3/s has been used to size the structural modifications under consideration in this concept phase. The discharge values are under review by members of the SCT and will likely change for the feasibility-level evaluations. The decision regarding the final design discharge will be made in November 1998, coincident with the selection of the final alternatives for further investigation in the feasibility level.

Tailwater elevations associated with various discharges were also determined at the time of the preliminary concept report. There is an operating restriction that limits tailwater fluctuation during any 24-hour period to 22 ft to maintain slope stability in the channel below the dam. For the preliminary concept investigations, a maximum fluctuation of 6 ft was assumed based upon a base flow of 160,000 ft^3/s in the river (tailwater El. 966) then added spill which would make a total discharge of 210,000 ft^3/s and tailwater El. 972. The minimum tailwater elevation was assumed to be 951.

The reservoir at Chief Joseph Dam is normally operated between elevations 950 to 956 during the spill season and backs water up to Grand Coulee Dam tailrace. Also, tailwater data from the river gage located at the bridge ½-mile downstream from the dam was obtained from the Corps of Engineers (COE) web site for 1997. The tailwater information, shown on figure 4, was developed from the actual data below the dam. As may be seen from figure 4, there is quite a bit of scatter in the data. This is most likely caused by reservoir fluctuations at Chief Joseph Dam and the location of the gage which may be influenced by the high flow velocity exiting the pool below the dam and near the gage site.

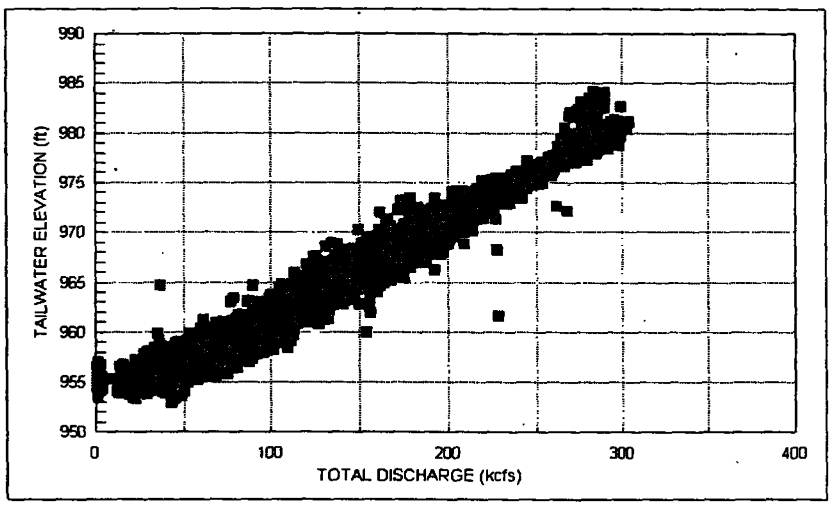


Figure 4. - Tailwater data from the gage located at the highway bridge below Grand Coulee Dam for 1997.
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The tailwater range for design could vary more than the previously assumed 6 ft depending upon what the conditions are when the spill is initiated. Recent past spill records for outlet works operation show that the flow rate varied from about 100,000 to 260,000 ft^3/s for the 1996 and 1997 spill seasons [2]. Spillway flows were used from 200,000 to 300,000 ft^3/s. This means that the design tailwater for the outlet works deflector could vary from about El. 958 to El. 978 using the maximum scatter in the tailwater plot. The minimum tailwater used in this study was revised to be at elevation 956, based upon this information, and the fact that spill will generally only occur when flows are high in the system. This tailwater range is very large and will hopefully be better defined at the time that the final 7-day, 10-year event and base powerplant flow are determined. The tailwater will be critical to the performance of the deflector and the forebay cascade options. Operation outside the expected range of tailwater will not produce the expected TDG performance.

Concept TDG Evaluation for Existing Conditions

The analysis used in the TDG evaluation is explained in this section. The mixing of flows of differing TDG levels and the existing operational data used in this analysis was reported fully in the previous document "Operational Alternatives for Total Dissolved Gas Management at Grand Coulee Dam" [2].

Flow Mixing

The location of all the hydraulic structures at the dam with respect to each other, the tailwater pool, and the river channel influence tailrace mixing and consequently local TDG concentrations. The spillway and outlet works releases travel down the face of the dam and plunge into the roller bucket energy dissipater at the base of the spillway. The tailwater produces a deep plunge depth during normal operation.

The spillway and spacing of the outlet works conduits across the spillway face are wider than the river channel. The outlet works conduits on the right or east side (looking downstream) of the spillway are used most often because they are the best aligned with the river channel (figure 2). The left powerplant discharges to the left or west of the spillway and has a capacity of about 50,000 ft^3/s. This flow is relatively isolated from the main tailwater pool, particularly when the spillway is operating. The right powerplant, also with a capacity of about 50,000 ft^3/s, discharges adjacent to the spillway but normal to the discharge from the Third Powerplant. The Third Powerplant has a capacity of about 180,000 ft^3/s and discharges almost parallel to the original dam axis and normal to all the other hydraulic structures and the river channel. The large capacity of the Third Powerplant highly influences the flow conditions in the tailwater pool and in the river channel downstream. Third Powerplant use is preferred by Bonneville Power Administration (BPA) and the dam operators. Flow generally crosses the tailwater pool and travels along the left river bank for quite a distance downstream. During the investigative trip [2], flow was still not fully mixed about 1½ miles downstream under a total flow of about 110,000 ft^3/s. With higher flows, the distance for complete mixing will be even longer.

The Third Powerplant flow, which is not aerated, discharges far enough away from the roller bucket that its release should not be entrained and supersaturated by outlet or spillway releases. The adjacent left and right powerplant releases have a greater probability of mixing with and being supersaturated by the outlet or spillway release. This could be further evaluated in the feasibility stage.

The total flow, both spill and power release, travels down river about 6 miles to the permanent TDG fixed monitor, GCGW, located out in the river about 20 feet from the left bank at a depth of about 15 ft. The flow is fully mixed by this point [2] and some degassing has occurred with travel to this location.

The TDG percent at the fixed monitor, GCGW, is described by the following equation:

$$\%TDG_{GCGW} = \frac{Q_{OW}(\%TDG_{OW}) + Q_{SPWY}(\%TDG_{SPWY}) + Q_{POWER}(\%TDG_{POWER})}{Q_{OW} + Q_{SPWY} + Q_{POWER}} \qquad (1)$$

The TDG readings at the fixed monitor represent fully mixed flow. This equation combines the potentially different TDG concentrations associated with outlet works or spillway releases, and power generation and the corresponding discharge volumes. Degassing in the river channel is not well defined. This analysis doesn't include degassing between the dam and the fixed monitor and is therefore conservative.

Existing Outlet Works TDG Generation

Figure 3 shows the three outlet levels through the dam; upper, mid and lower. The lower outlets are no longer operable. The upper- and mid-level outlets can be operated four different ways; 1) the upper outlets alone, 2) the mid outlets alone, 3) the upper and mid outlets combined in an over/under fashion simultaneously, and 4) mixed operation of upper and mid outlets randomly open. Operation of the upper and mid outlets together in an over/under fashion has shown to provide the least increase in TDG production and is now the preferred method of operation. The data set for combined over/under outlet works spill is shown in figure 5 for both 1996 and 1997. Operation with combined over/under spill was up to about 55,000 ft^3/s in 1996 and 75,000 ft^3/s in 1997.

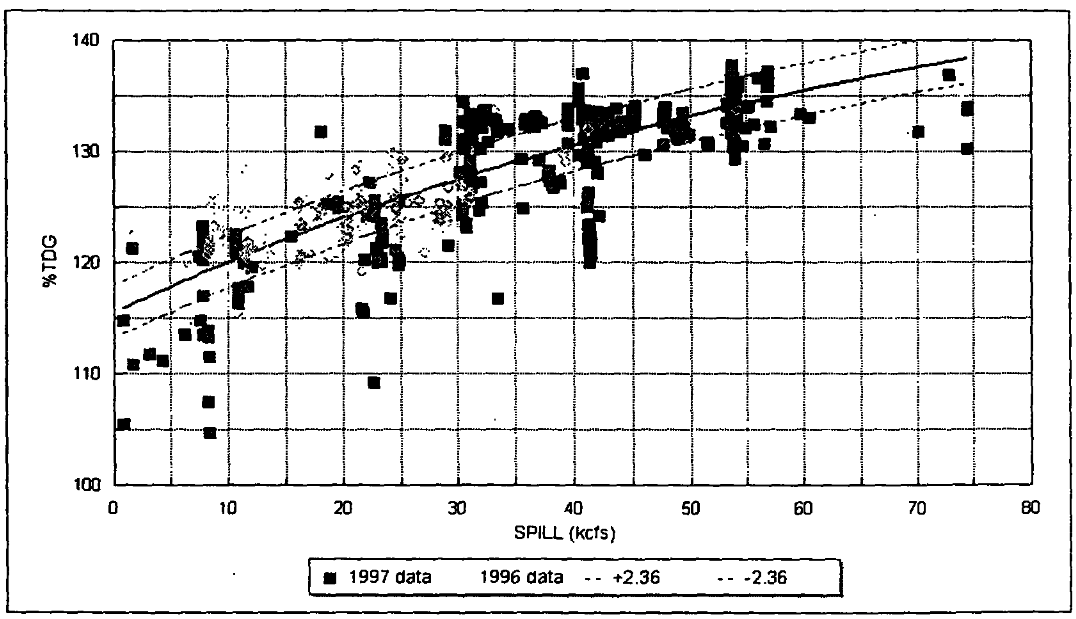

Figure 5. - Combined over/under outlet works spill TDG data for 1996 and 1997.
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Figure 5 also shows the error bands of ±2.36 percent associated with instrument accuracy. The combined over/under operation produces TDG levels from 105 to 138 percent depending upon the spill discharge.

The equation describing TDG levels generated by combined over/under outlet spill is:

$$TDG_{o/u} = 152.13 - 36.59e^{-0.0132Q} \quad (2)$$

where Q is in 1000 ft³/s.

This equation was developed directly from field data. This equation was used to compute the TDG characteristics of the existing outlet works for comparison to the TDG characteristics of the proposed conceptual alternatives. The existing outlet works percent TDG production for 50,000 ft³/s, measured at the GCGW river site, is 133.22 percent. This is the mixed TDG percent that is reported by equation 1 at the fixed monitor. For the design operation (160,000 ft³/s power release, 50,000 ft³/s outlet or spillway release) the 133.22 percent TDG level establishes the existing baseline. Equation 1 may be used to determine the effect of different reservoir and subsequent power release gas concentrations on the eventual mixed TDG percent in the river.

Existing Spillway TDG Generation

Observed TDG generated by spillway releases in 1996 and 1997 is shown in figure 6. These were both high spill years at Grand Coulee with spills approaching 65,000 ft³/s in 1996 and 110,000 ft³/s in 1997.

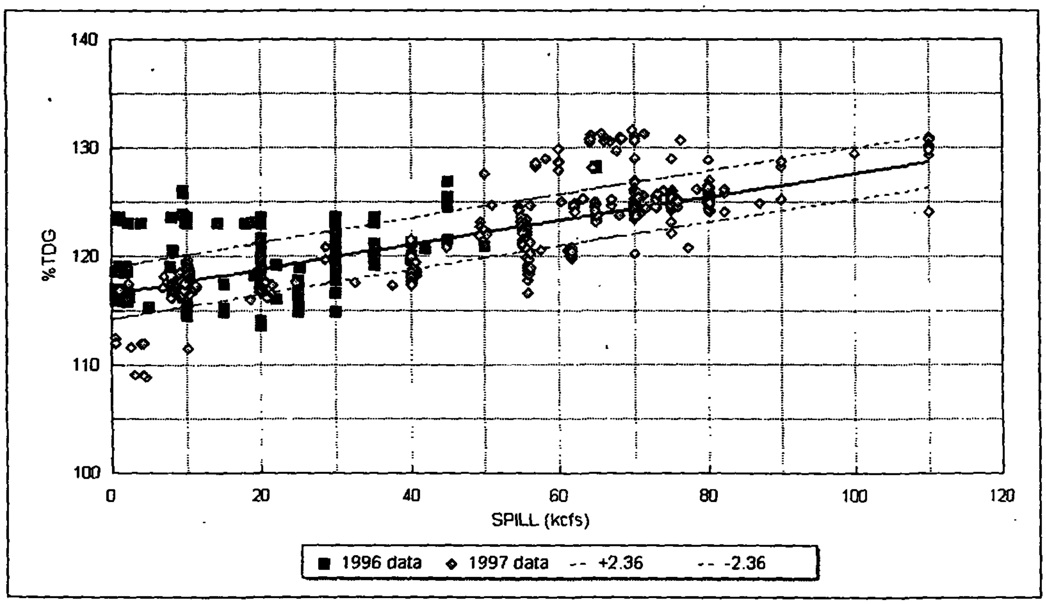

Figure 6. - Spillway TDG data from 1996 and 1997.
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The equation describing TDG levels generated by spillway releases is:

$$TDG_{spwy} = 242.55 - 126e^{-0.0009Q} \qquad (3)$$

where Q is in 1000 ft^3/s.

This equation is developed directly from field data and as such is empirical. Figure 6 also shows the bands of expected instrument uncertainty plotted at ±2.36 percent saturation. This equation will be used to compare TDG produced by spillway flow to the TDG characteristics of the conceptual modifications under investigation.

The resulting mean TDG concentration measured at the GCGW monitor for a spillway release of 50,000 ft^3/s is 122.1 percent. This is the mixed TDG percent that is reported by equation 1. Scatter in the monitored data set reflects variations in reservoir and thus power release TDG levels and various amounts of dilution.

Concept Designs

The following sections will describe the development of the five alternatives that have been investigated and refined over the last several months. Each section contains a description of the alternative, updated drawings showing more complete components and dimensions, a refined cost estimate, and further evaluation of the expected TDG characteristics. The alternatives have been renumbered in sequential order from the preliminary concept report [1]. For example, the alternative to extend and cover the mid-level outlet works, previously numbered 2 is now alternative 1 in this report. A table of the alternatives that were presented in the preliminary concept report is given in the Appendix for reference. The description of each alternative has been updated from the pre-concept stage to reflect a further level of study and modifications to original components within the concept. When possible, the cost estimates were prepared as a per unit cost of the total for easy multiplication to obtain a cost for a different number of needed components.

Cover and Extend Mid-level Outlet Works (Alternative 1)

Description

This alternative involves extending the mid-level outlet works along the downstream face of the dam to obtain a submerged discharge directly into the tailwater pool, figure 7. The outlet works is currently controlled at the 102-inch ring seal gates or at the outlet release point where the 8'-6" pipe reduces to 7'-9". An air vent currently supplies air to the conduit downstream of the ring seal gates. The submerged release must not contain entrained air to prevent production of TDG. To ensure that the extended pipe does not entrain air and will be pressurized, the exit of the conduit must be reduced to maintain control over the expected range of reservoir operation. The existing air vent will be modified with a valve added to allow air to escape during pipe filling. Control will be maintained by reducing the pipe exit to an estimated 6'-0". This reduction in the pipe diameter was selected to produce downstream control and also accommodate reservoir evacuation criteria. For the conceptual study, the 6'-0" diameter outlet control was assumed with the maximum number of blocks modified to preserve maximum evacuation capability. This provides a conservative estimate of the pipe size for the concept phase. Evacuation concerns may not need to be addressed in the design and will be evaluated further in the feasibility level.

With a 6'-0" diameter exit, 18 outlets must be modified to pass the 50,000 ft^3/s design discharge under the minimum operating reservoir El. 1208. The modification will be made in pairs of outlets because the outlets are built in pairs. Therefore, if an odd number of outlets are needed to pass the design discharge, an additional outlet works would be modified. Each pair of outlets to be modified requires modification of a full block of concrete. With 18 outlets requiring modification, 9 blocks of concrete will be modified. Each block is 50 ft wide. Only one more pair of mid-level outlets are available for use, should the design discharge be significantly increased.

Extending the outlets requires excavation of trenches about 18 feet deep by 34 feet wide and approximately 175 feet long on the concrete face of the dam in nine blocks, figure 7. Modification to the existing end of the steel pipe and reshaping of the roller bucket in the stilling basin will be required. There are high velocities at the conduit exits. The surface at the end of the conduits entering the roller bucket will be shaped to prevent cavitation damage. The conduits will direct the flow into the roller bucket of the spillway to continue to allow energy dissipation. The lower conduits will be backfilled for a short distance to ensure there are no flow concerns and to support the conduit extensions.

The existing mid-level outlet conduits are steel lined. There are existing air vents downstream from the ring-seal gates which will be used to facilitate the transition from open channel flow to pressurized flow in the conduit. The air vents will be replaced with air relief valves installed in the gate chamber on the downstream side of the gates. There will be some excavation of concrete required in the gate chambers to facilitate this modification.

The steel lining will be continued at a 8'-6" diameter for most of the extension and the last 20 feet will transition from a 8'-6" diameter to a 6'-0" diameter opening. The conduit has an upper bend of approximately 41 degrees at a radius of about 39 feet. There are two layers of reinforcement around the conduit which will extend down the face of the dam.

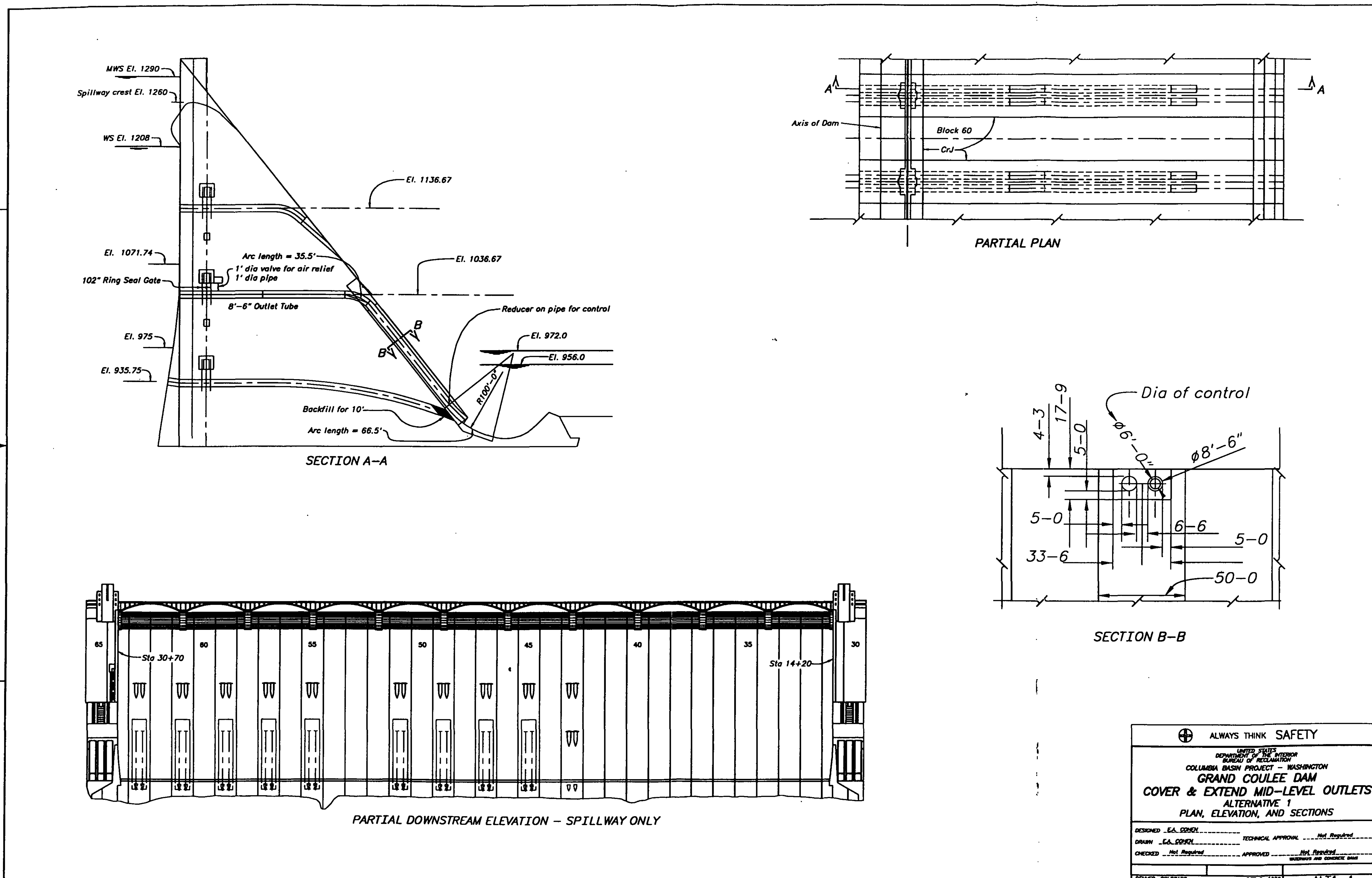

Figure 7. Alternative 1. Cover and extend mid-level outlets.

Hydraulic and Total Dissolved Gas Evaluation

Hydraulic Analysis

To maintain pressurized flow in the extended conduit, the downstream exit area must be reduced. The existing capacities of the mid-level outlets are 5336 ft^3/s at El. 1290 and 4486 ft^3/s at El. 1208. The appropriate reduction in pipe diameter must consider the required operation under current flood control operation and reservoir evacuation for emergencies. The smaller area required to maintain control at the pipe exit will reduce the discharge from the outlet works. The discharge capacity of the outlet works with a 6-ft-diameter control at the exit is estimated to be 3250 ft^3/s at reservoir water surface elevation 1290 and 2800 ft^3/s at minimum pool elevation 1208. It is assumed that the decreased discharge capacity will be acceptable. At minimum reservoir elevation 18 outlets will require modification to release the design spill of 50,000 ft^3/s. The use of a larger diameter control section is possible but this must be balanced against concerns during evacuation of the reservoir. Downstream control is not maintained with a larger diameter outlet. A larger diameter on the reduction reduces the dam's evacuation capability because the larger diameter outlet could only be used to water surface elevation 1100 feet, whereas the 6 ft diameter outlet could be used to water surface elevation 1065 and meet existing evacuation criteria.

A water surface profile and hydraulic grade line program, CTAC, was used to model the pressure flow on the face of the dam for the extension of the outlet works modification and the water surfaces for the deflector alternatives. The program uses inputs of initial depth (or energy grade line) and discharge, and then computes the energy and hydraulic grade lines, velocity, specific forces, Froude numbers, Reynolds Number, and cavitation index. The program includes losses due to expansions, contractions, etc., and uses the Manning equation to compute friction losses with open channel flow. The program can model pressure or open channel flow, with varying cross sections and user input of head loss for expansions and contractions.

In addition, the hydraulic grade line was computed for the outlet works extension using a spreadsheet and assumed losses. This approach indicated the pressures drop in the pipe as it follows the downstream face of the dam. These computations and the results from the CTAC program indicated that there would be a positive head at all points along the profile.

The velocities computed at the exit of the pipe reached 100 ft/s. This velocity indicates that cavitation could be a concern at the exit. This could be a problem at the end of the pipe and/or on the surface of the concrete at the exit point. The high pressures due to the submergence would hopefully assist with the problem. Cavitation indices indicated that cavitation could also potentially be a problem at the existing vertical bend. Some further modification of the vertical bend may be necessary. Cavitation has not been a problem at the bend since installation of "eyebrows" over the existing pipe exits. However, the flow has been aerated whereas with the proposed modification air will not be entrained.

The orientation of the conduit exit with respect to the roller bucket and the submergence influences on pressure fields and air entrainment will need to be model studied.

Total Dissolved Gas Evaluation

The concerns for the TDG evaluation are ensuring that no air is entrained during this transfer of the discharge from the reservoir to the tailwater or river. This requires that the air must be removed from the conduits during initial opening or filling of the conduits, that the submergence be adequate, and that no air can be drawn out of solution if cavitation were to occur at either the vertical bend or at the exit.

The outlet gates will be operated as they currently are - either fully open or fully closed. Air will uptake during the opening and filling, and during the closing and emptying process, as control switches between the gate and the downstream reducer, and the flow changes from free flow to fully pressurized pipe flow. This process will cause a period of rough operation that will exist as the flow is transitioning between free and pressure flow and air is released through the air relief valves. Some air may be released downstream, but this should be a small amount for a short duration. After pressurized flow is attained, no further air entrainment should occur in the conduit.

The question is then whether submergence will be adequate to prevent surface turbulence and entrainment of surface air to depth. Submergence will depend upon the tailwater elevation at the time of the release and the relation between the elevations of the outlet exit, the roller bucket invert and/or the invert of the river bed downstream from the roller bucket. Minimum submergence, with the tailwater at El. 956, with respect to the invert of the roller bucket will be 82 ft. Submergence under the expected tailwater of the total design discharge is 98 ft. Referenced to the river bed elevation of 900 ft, the minimum and maximum submergences would be 56 and 72 ft, respectively.

The question of adequate tailwater was briefly explored by comparing unit discharges of the spillway and current outlet works flows that the roller bucket was designed for versus the expected unit discharges of the modification. The roller bucket has a radius of 50 ft. The characteristic flow from a solid bucket energy dissipater consists of two rollers; one occurs on the surface, moves counterclockwise, and is contained within the bucket; and the other is a ground roller, moving clockwise downstream from the bucket. The ground roller is formed by the flow being directed upward from the end of the bucket and the return flow heading downstream. The severity of the ground roller depends upon the tailwater elevation.

In the current situation, air is entrained through the conduit and down the spillway face entering the tailwater and plunging to depth. In addition, the surface turbulence is most likely entraining air and contributing to the TDG when replunging. In the modification, no air should be entrained by the pressurized jet prior to the submerged release to the tailwater, however, it is possible that air may be entrained and taken to some depth by the action of the jet from the roller bucket. It is not clear whether secondary turbulence-generated air entrainment that would increase the TDG can be prevented.

The minimum unit discharge of the modification would be approximately 50 $ft^3/s/ft$ assuming the maximum spread of the jet across the entire 50 ft concrete block. Assuming no spread from the 6 ft diameter nozzle, the maximum unit discharge entering the bucket would be 463 $ft^3/s/ft$. Assuming that the roller bucket was designed for the maximum spillway discharge, then these unit discharges would be compared to a unit discharge of 606 $ft^3/s/ft$. If this is the case, then the roller bucket should perform with less turbulence under the modification, thus reducing the possibility of adding TDG from the surface turbulence. A model study should be performed to ensure proper performance of this alternative based on the discussion given previously.

If the roller bucket will not perform adequately, then the jet from the pipe may need to be directed horizontally over the top of the roller bucket to prevent secondary surface entrainment. In this case, there would be no energy dissipation and erosion and surface waves could present a major problem.

It appears valid to assume that extending and covering the outlet works for submerged discharge will transfer the TDG levels from the reservoir to the tailwater. Thus, if the reservoir has TDG concentration levels of 100 or 120 percent, the fixed monitor will be also recording 100 or 120 percent. The outlet release will generate no additional supersaturation.

Construction Features and Cost Estimate

The cofferdam will be constructed similar to a bulkhead and anchored off the face of the dam. The bulkhead will need to be about 100 feet tall and about 50 feet wide (to cover one block). Work will be accomplished using barges and cranes. The estimated time for work completion on one block is estimated at 6 months for a total of 54 months to complete the job. The estimate assumes the use of two bulkheads to reduce the overall time of construction.

The listed items and costs are shown in table 1. The field cost for this alternative is estimated at $81,000,000. The significant difference in cost from the preliminary study is the increase in the number of outlets needing modification to pass the design spill under minimum reservoir head and the larger volume of excavated concrete to accommodate the conduit. The PN region requested that non-contract costs at 30 percent be added to the field cost for a closer evaluation of total costs. The non-contract costs are design costs, construction management, etc. The non-contract cost would be $24,300,000. The total cost for alternative 1 is estimated at $105,300,000.

This alternative has construction issues involving the excavation and removal of concrete from the downstream face of the dam. Mechanical excavation of the concrete would be feasible but with the large extent and volume of material, it will be time consuming and wire saw cutting is not viewed as practicable at this time. The contractor will probably want to use blasting to increase production rates. However, with the nearest outlets less than 100 feet from the right powerplant, the issue of blasting will need to be reviewed in greater detail prior to its use as the approved method of excavation. Also, the concern of debris falling and damaging concrete in the roller bucket, and removal of concrete to a disposal site are other concerns.

The design of the cofferdam will impact the size of the cranes for delivering material. The slope of the face is at 0.8:1 and with a 100-foot-tall cofferdam a crane will have to have a reach of about 80 to 100 feet loaded with material and supplies to reach the farthest point on the face of the dam.

The cofferdam for this alternative must withstand a differential head of up to 100 foot. The base of this cofferdam will rest in the concrete roller bucket and no damage of the roller bucket will be allowed. The sealing of the cofferdam to the existing concrete may require a fairly elaborate dewatering system during construction.

Total construction time is estimated at 3 years. This is based on 6 months of work per block for work, with work ongoing for two blocks at the same time. Unknowns with cofferdam construction and potential work area constrictions could negatively impact costs in the feasibility stage. No loss of power generation capability or revenue is anticipated. Typically, the cofferdams are the property of the contractor.

CODE:D-3531 ESTIMATE WORKSHEET SHEET _1_ OF _1

FEATURE: 08-Oct-98 Grand Coulee Dam Total Dissolved Gas Study Extend Outlet Works - Alt.1 for 9 BLOCKS	PROJECT: Columbia River Project DIVISION: UNIT: FILE: c:\kathy's files\98super\concept\gclest.wk4

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Mobilization		1	LS	$2,700,000.00	$2,700,000
		Furnish cofferdam *		2	ea	$700,000.00	$1,400,000
		Install cofferdam (H=100', W=	D8130	9	ea	$100,000.00	$900,000
		Excavation - concrete	D8130	41,400	cyds	$600.00	$24,840,000
							$0
		Sawcut (3 inch deep)	D8130	5,040	lf	$25.00	$126,000
							$0
		Drilling for anchor bars	D8130	3,240	lf	$20.00	$64,800
		Concrete:	D8130				$0
		Reinforced - Face of dam		32,400	cyds	$215.00	$6,966,000
		Reinforced - Backfill		190	cyds	$215.00	$40,850
							$0
		Furnishing and handling cemen	D8130	9,000	tons	$100.00	$900,000
							$0
		Furnish and install reinforcing	D8130	6,500,000	lbs	$0.45	$2,925,000
							$0
		Furnish and install 8-6 and 6-0	D8420	2,380,000	lbs	$1.60	$3,808,000
		175 feet of 11/16"thick steel	pipe times 2 for	one block, 754	lbs/lf		$0
		Furnish and install 1-0 dia. vent	D8420	54,000	lbs	$1.50	$81,000
		Unwatering (10 blocks)		9	ea	$10,000.00	$90,000
							$0
		Dewatering (10 blocks, 5 mo/block)		45	mo	$10,000.00	$450,000
							$0
		Mobilize Barges (1 large, 1 transit)		1	LS	$100,000.00	$100,000
		Mobilize Cranes (1 shore, 1 barge)		1	LS	$40,000.00	$40,000
		Barge Rental (6 mo/block)		54	mo.	$40,000.00	$2,160,000
		Crane Rate (operated), large cranes on barge &		54	mo.	$160,000.00	$8,640,000
							$0
		Subtotal					$56,231,650
		Unlisted Items, 15% (+ or -)					$8,768,350
		Construction Cost					$65,000,000
		Contingencies, 25% (+ or -)					$16,000,000
		Field Cost					$81,000,000
		Non contract costs, 30%					$24,300,000
		(Changed by D-8560, 10/1/98)					
		Total Cost					$105,300,000

QUANTITIES		PRICES	
BY E Cohen & D Read	CHECKED LS & EH	BY Schuelke/Baumgarten	CHECKED
DATE PREPARED 06/25/98	APPROVED	DATE 08-Oct-98	PRICE LEVEL Appraisal

Table 1. - Cost estimate for extending and covering the mid-level outlets, alternative 1.
* Typically, the cofferdam is the property of the contractor.

Forebay Pipe and Diffuser (Alternative 2)

Description

This alternative involves construction of a new pipeline to transfer water from the forebay to the tailrace of Grand Coulee Dam. The pipeline will be constructed in the area of the right abutment, extending from the end of the existing forebay dam to the current north service yard where a gate chamber and diffuser will be constructed, figures 8 and 9. The work requires removal and construction of a new forebay end wall as a gravity dam with the same cross section as the existing forebay dam. The end wall will contain a wheel mounted guard gate with air vent for a 40-foot diameter tunnel through the right abutment. A trashrack will be installed on the upstream face of the new end wall. The tunnel, gate chamber and diffuser will be excavated about 140 ft below the original ground level. The gate chamber will be a 650-foot long manifold structure that will house both 39 butterfly valves and 39 slide gates that will discharge into a 53-ft-wide diffuser. The diffuser will be used to dissipate the energy with no air entrainment before releasing the flow into the tailrace of the dam. Releases will be controlled using 39 butterfly valves in either open or closed position. The butterfly valves will range in size from 6-0 foot diameter to 4-0 foot diameter to aid in distributing the flow into the diffuser. The diffuser will consist of approximately two-hundred-ninety 5-foot-diameter ports in a horizontal concrete cover located downstream of the butterfly valves. This alternative will increase the discharge capacity of the dam.

Mechanical

Numerous mechanical items are required for this alternative. There will be thirteen 6-0 ft-, thirteen 5-0 ft-, and thirteen 4-0 ft-diameter butterfly valves for control of releases. There will also be 39 commercial slide gates acting as bulkheads downstream from the butterfly valves. Stoplog slots upstream of the butterfly valves may then be used to permit isolation, maintenance, and repair of the butterfly valves.

The valves are located underground with access via an elevator and a continuous gate chamber. The design includes furnishing and installing a ventilation system consisting of a 4000 ft^3/min centrifugal fan, 100 feet of 18-inch diameter schedule 10 carbon steel pipe, and 660 feet of 18-inch diameter schedule 40 PVC pipe in the gate chamber.

Access to the gate chamber will be by elevator with emergency stairs or ladders. The design includes furnishing and installing one geared electric traction freight elevator with a capacity of 3,500 lbs. The elevator will have two landings with a car size of 8'-0" by 8'-0" and a total travel of 137 feet.

Electrical

The electrical features and equipment will include a centralized control board, a power distribution panel board, gallery lighting, and all conduit, cable, and grounding to complete the installation.

The control board will most likely be located at some convenient location within the Third Powerplant. A selector switch would be provided to allow operation locally at each gate or valve, at the centralized control board, or remotely at the main control room. A set of OPEN and CLOSE pushbuttons would be provided for each of the 39 guard slide gates and 39 butterfly valves to operate any gate/valve from the control board. The motor operator at each gate or valve would also contain pushbuttons for local operation at that particular gate or valve. The wheel mounted gate will be operated locally by the existing gantry crane.

Power requirements for the valves, gates, and lighting are estimated to be between 100-150 kVA at a supply voltage of 480 volts. It is assumed that the station service system within the Third Powerplant could accommodate a feeder of this size to service this power load. A 480 volt distribution panel(s) would provide power to the various gates, valves, and lighting system. The conduit, cabling, and grounding systems needed to complete the electrical system have been examined conceptually and do not present any significant design problems. These systems would be fully designed in the final design process.

Diversion Requirements

This alternative will require the construction of two cofferdams. One cofferdam will be required in the forebay and one in the tailrace adjacent to the Third Powerplant. The forebay cofferdam is anticipated to be a cellular cofferdam, 180 feet high and 220 feet long. Construction of this cofferdam would block a minimum of one unit of the Third Powerplant. After construction of the forebay cofferdam, power production should be interrupted until its removal.

The second cofferdam will be constructed in the tailrace adjacent to the Third Powerplant. This cofferdam will be approximately 50 feet high and 1320 feet long. The purpose of this cofferdam would be to allow construction of the gate chamber and energy diffuser. This cofferdam is presently designed as a cellular cofferdam to limit the impact on the power production at the Third Powerplant.

Hydraulic and Total Dissolved Gas Evaluation

Hydraulic Analysis

The hydraulic analysis for this alternative consisted primarily of determining acceptable pipe/tunnel, valve, gate, and diffuser sizes and submergence requirements. The pipe and tunnel were sized to conform to the existing penstocks in the Third Powerplant and for a velocity of 40 ft/s. The wheel mounted gate will be used only fully open or closed and will not provide control. With the initial filling, an air valve is provided downstream from the wheel mounted gate to allow the air to evacuate for fully pressurized flow.

The valves along the manifolded gate chamber were sized to pass the 50,000 ft^3/s discharge while attempting to account for the expected hydrostatic head distribution in the manifold. The losses for the entire system were analyzed to size and determine the number of the valves at the downstream end. There will be a conversion from velocity head to static head in the system prior to exiting through the butterfly valves. To balance the flow and achieve uniform conditions throughout the basin length, the valves at the upstream end of the manifold will be slightly larger than the valves at the downstream end. Standard sizes of valves in 4-ft-, 5-ft-, and 6-ft-diameters were selected to minimize costs using "off-the-shelf" items. The total number of valves was determined by the length required for the exit channel and dissipating the full head in the system. The velocity through the butterfly gates is approximately 67 ft/s. The butterfly valves will be used only to regulate the amount of release by being fully open or closed. Cavitation could be a potential problem with operation of the butterfly valves. The downstream end of the conduits could perhaps be restricted to maintain positive pressure at the valve and cause potential cavitation to occur out in the diffuser. The slide gates are used only as bulkheads for maintenance purposes.

The length of the diffuser was based upon adequate spacing of the valves and providing adequate area for the release back to the tailrace. The invert for the diffuser was chosen to ensure adequate submergence during operation of the entire bank of valves. The submergence depth varies from 81 to 97 feet over the invert of the basin. The depth of the system was based on having a minimum of 20 feet of water over the top of the diffuser plate to prevent air entrainment in the stilling basin diffuser. The area of the diffuser ports was designed to dissipate the energy of the spill while limiting the through velocity to 10 ft/s. An actual velocity of 8.7 ft/s was achieved. The width and depth of the riprap return channel provide a return velocity to the tailrace of about 4 ft/s.

Total Dissolved Gas Evaluation

The objective for control of TDG is very similar to alternative number 1 where the flow is intended to enter the tailwater without entraining air. Efforts are made to control energy dissipation and supply adequate submergence to prevent surface entrainment of air with transport to depth.

This alternative was designed to pass the flow from the reservoir to the diffuser basin without introducing air. Once in the basin, the exit velocity is controlled by the area of the diffuser plate and the submergence. The return channel to the river should see quiet flow with no possibility for surface entrainment. The proposed design should actually allow more control of the surface entrainment than alternative number 1, because a new energy dissipating structure will be constructed. The dissipating system will be modeled to determine an optimum configuration of the system and the submergence necessary to prevent entrainment of surface aeration to depth.

The forebay pipe with diffuser is expected to transfer the TDG level in the reservoir to the tailwater. Thus, if the reservoir has TDG concentration levels of 100 or 120 percent, the fixed monitor will be also recording 100 or 120 percent with spill. The forebay pipe and diffuser release will generate no additional supersaturation.

Construction Features and Cost Estimate

The forebay pipe with diffuser alternative is anticipated to require 4 years to construct. The construction issues in this alternative are straight-forward. One concern is the location of the contractor's use area, since the north service yard will be in the middle of the construction area. Disposal of excavated material will also be an issue because this alternative will have the greatest amount of waste. Assuming a swell factor and no compaction of the approximately 1,100,000 yd^3 of material, the required disposal area could be as large as 20 ft deep over 52 acres.

The actual construction efforts are straight-forward with no unusual or new construction methods required. The 40-ft-diameter pipe will have to be shipped in sections and welded on site. The construction of a 200-ft-tall cofferdam in the reservoir forebay blocking portions of the Third Powerplant will require detailed design. Both cofferdams were estimated as cellular to minimize space required. The construction will not permanently impact power production, but the loss of revenue during the construction due to use of the forebay cofferdam will be significant. Third Powerplant revenues will be lost during construction of the cofferdam, completion of the new end dam, installation of the fixed wheel gate and trashrack, and removal of the cofferdam. Every effort should be made to complete this portion of the work as quickly as possible to minimize power revenue losses.

The power loss during construction was computed based on information from the UBBR power plant data contained on the world wide web (www.usbr.gov/power/data). The 10-year average power production at Grand Coulee Dam is approximately 20.5 billion kWh/year and the 1997 production was 27 billion kWh with a 1994 wholesale firm price of 26.9 mills per kWh. The unit most likely to be idle during construction is Unit No. 24, which contributes a minimum of 12.4 percent of the total power capability if all units are operating. It was assumed that 12.4 percent of the 27 billion kWh times the firm price is the revenue from unit No. 24 over 1 year. Therefore, the loss of power during construction is the percentage of the year the unit is out of service times the power production of Unit No. 24 for 1 year. Using this analysis, the power revenue lost is estimated at $66,000,000, if 1 unit is out-of-service for a 9 month construction period.

At this level of estimate, no loss of power revenues is anticipated due to the cofferdam in the tailrace for construction of the diffuser, but it could also impact power by blocking the tailrace.

Unwatering and dewatering design and capital costs for operation and maintenance purposes would be covered in the feasibility stage. The cost of these items is generally covered by the contingencies at this time.

The listed items and costs are shown in table 2 (2 sheets). The field cost for this alternative is estimated at $200,000,000. The major difference between this cost and the greater cost in the preliminary study is the use of the standard tandem butterfly valves and slide gates instead of the large jet flow gate. The total cost, including non-contract costs at 30 percent and power revenue lost during construction of $66,000,000, is estimated at $326,000,000.

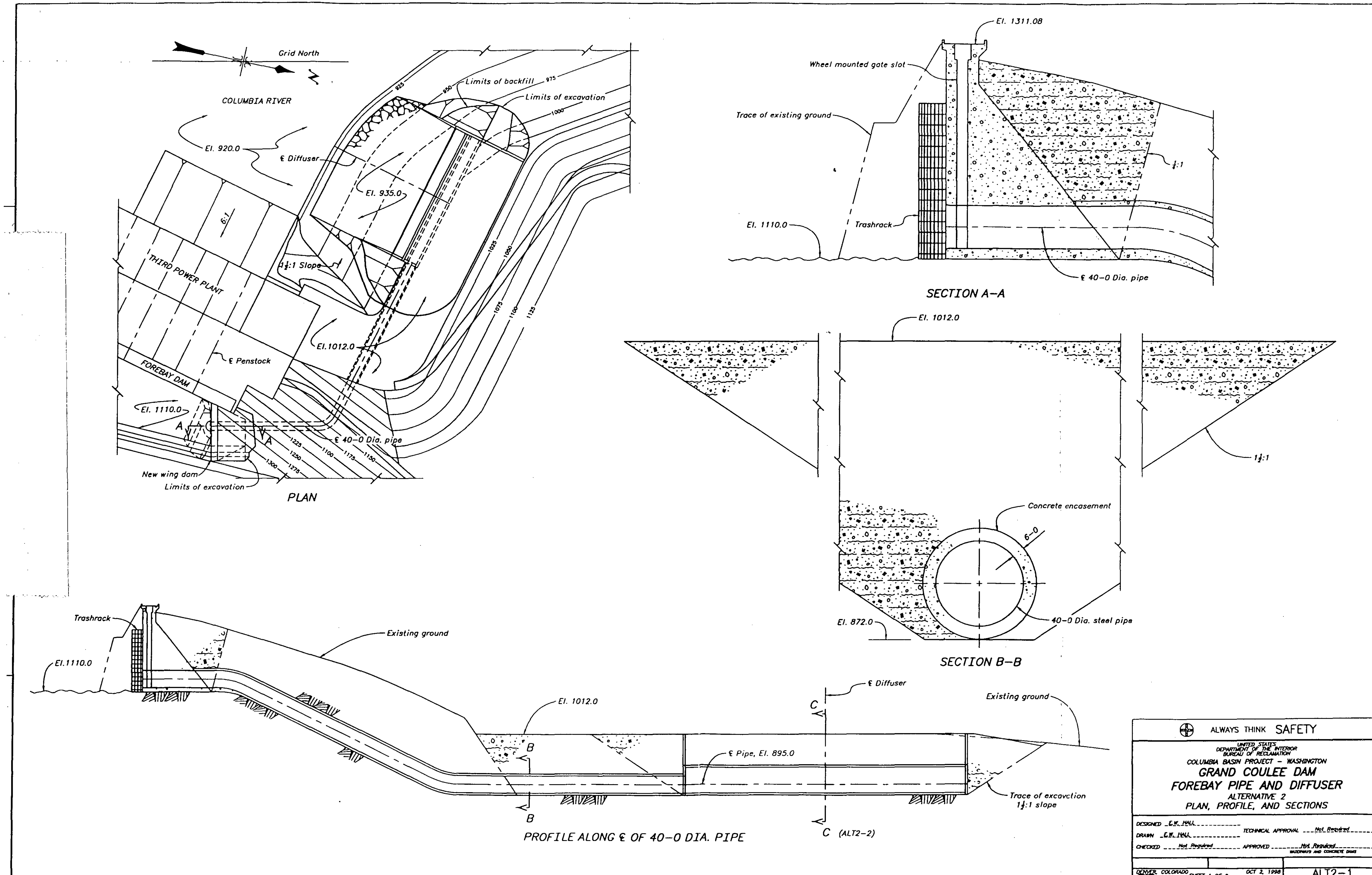

Figure 8. Alternative 2. Forebay pipe with diffuser.

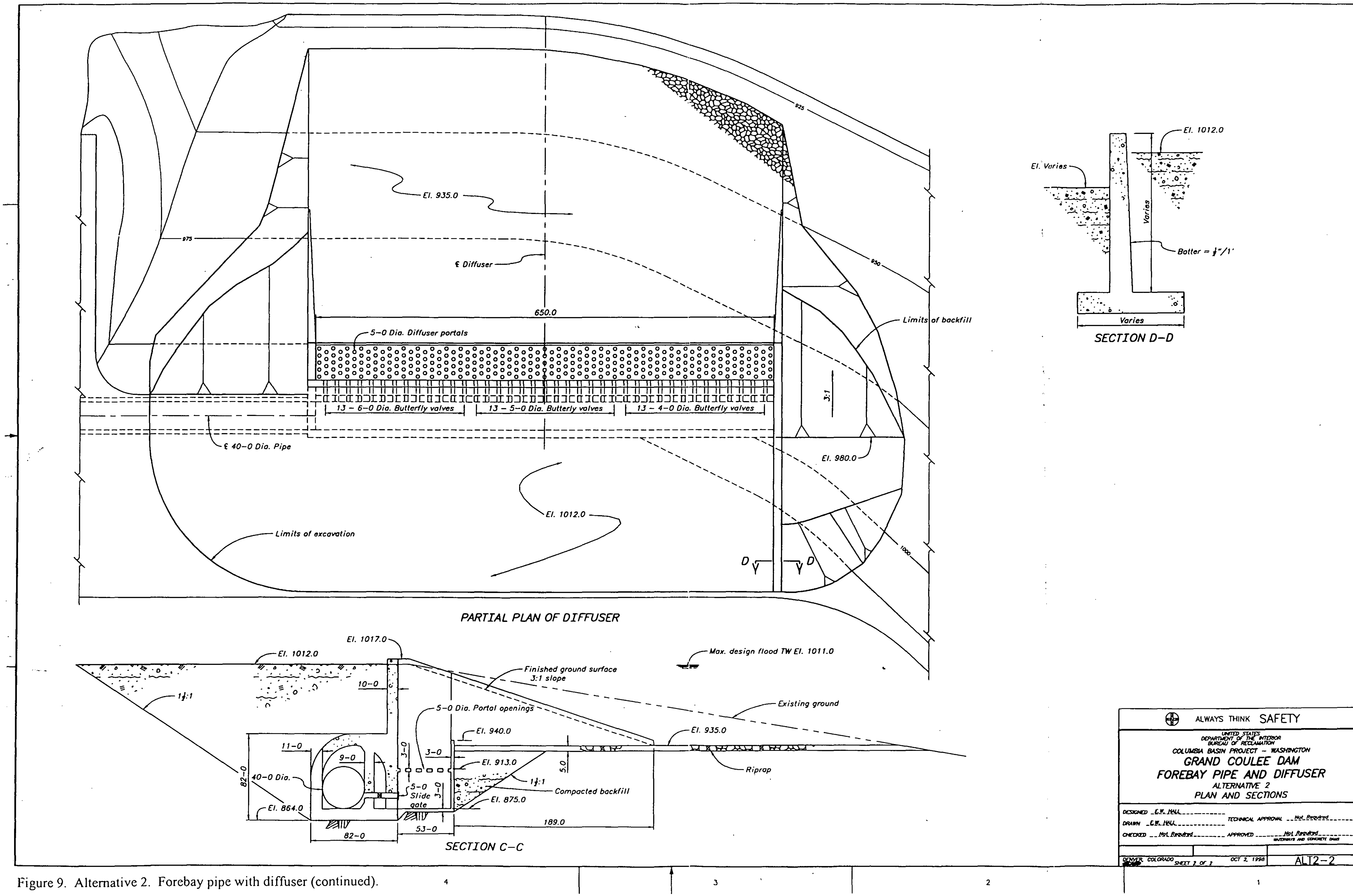

Figure 9. Alternative 2. Forebay pipe with diffuser (continued).

CODE:D-3521 **ESTIMATE WORKSHEET** SHEET 1 OF 2

FEATURE: 05-Oct-98	PROJECT: Columbia River Project
Grand Coulee Dam **Total Dissolved Gas Study** **FOREBAY PIPE - ALT. 2**	DIVISION:
	UNIT:
	FILE: c:\kathy's files\98super\concept\gc2est.wk4

PLANT ACCT	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Mobilization		1	LS		$6,700,000
							$0
		F & I cellular cofferdam. H=18	D8130	1	LS		$7,000,000
		F & I cellular cofferdam. H=50	D8130	1	LS		$6,000,000
							$0
		Concrete:	D8130				$0
		Reinforced - Chamber structure		140,000	cyds	$180	$25,200,000
		Reinforced - Tunnel		25,000	cyds	$215	$5,375,000
		Mass		160,000	cyds	$130	$20,800,000
							$0
							$0
		Furnishing and handling cemen	D8130	75,000	tons	$90	$6,750,000
							$0
		Furnish and install reinforcing	D8130	24,000,000	lbs	$0.45	$10,800,000
							$0
		Furnish and install 40-0 dia. ste	D8420	15,000,000	lbs	$1.50	$22,500,000
							$0
		Furnish and install 40-0 dia. wh	D8420	615,000	lbs	$5.00	$3,075,000
							$0
		Furnish and install regulating ga	D8420				$0
		13 - 6' dia. Butterfly valves		162,500	lbs	$6.50	$1,056,250
		13 - 5' dia. Butterfly valves		104,000	lbs	$6.50	$676,000
		13 - 4' dia. Butterfly valves		65,000	lbs	$6.50	$422,500
							$0
		Furnish and install bulkhead gat	D8420				$0
		13 - 6' dia. slide gates		182,000	lbs	$5.00	$910,000
		13 - 5' dia. slide gates		143,000	lbs	$5.00	$715,000
		13 - 4' dia. slide gates		78,000	lbs	$5.00	$390,000
							$0
		Furnish and install trashrack	D8420	600,000	lbs	$2.50	$1,500,000
							$0
		Unwatering		1	LS	$400,000	$400,000
		Dewatering		1	LS	$100,000	$100,000
		Crane Mobilization (1 barge, 1 shore)		1	LS	$40,000	$40,000
		Barge Mobilization (1 mob. to set cofferdams,		2	LS	$100,000	$200,000
		Barge Rent		8	mo.	$40,000	$320,000
		Crane Rate (operated). 1 large crane for coffer		8	mo.	$80,000	$640,000

QUANTITIES		PRICES	
BY E. Hall & D. Read	CHECKED	BY Schuelke/Baumgarten	CHECKED
DATE PREPARED 06/01/98	APPROVED	DATE 05-Oct-98	PRICE LEVEL Appraisal

Table 2. - Cost estimate for the forebay pipe with diffuser, alternative 2.

CODE:D-3511 **ESTIMATE WORKSHEET** SHEET _1_ OF _1_

FEATURE: 05-Oct-98	PROJECT: Columbia River Project
Grand Coulee Dam Total Dissolved Gas Study FOREBAY PIPE - ALT. 2	DIVISION: 0
	UNIT: FILE: c:\kathy's files\98super\concept\gc2est.wk4

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Excavation - common	D8130	2,050,000	cyds	$3.00	$6,150,000
							$0
		Excavation - rock	D8130	350,000	cyds	$8.00	$2,800,000
							$0
		Excavation - rock tunnel	D8130	47,000	cyds	$120.00	$5,640,000
							$0
		Compacted backfill	D8130	1,350,000	cyds	$2.00	$2,700,000
							$0
		Riprap (say 2-foot diameter)	D8130	32,600	cyds	$25.00	$815,000
							$0
		Riprap bedding	D8130	8,900	cyds	$30.00	$267,000
		Furnish & install ventilation sys	D8410	1	LS		$100,000
		4000 cfm centrifugal fan and 100 feet of					
		18" diameter schedule 10 carbon steel pipe and					
		660 feet of 18" diameter schedule 40 PVC pipe					
		Furnish and install one geared	D8410	1	LS		$150,000
		freight elevator with a capacity of 3,500 lbs.					
		Elevator will have two landings with a car size of					
		8'-0" x 8'-0" and a total travel of 137 feet.					
		Subtotal					$140,191,750
		Unlisted Items, 15% (+ or -)					$19,808,250
		Construction Cost					$160,000,000
		Contingencies, 25% (+ or -)					$40,000,000
		Field Cost					**$200,000,000**
		Non contract costs, 30%					$60,000,000
		Lost power revenue during construction					$66,000,000
		(Changed by D-8560, 10/1/98)					
		Total Cost					**$326,000,000**

QUANTITIES		PRICES	
BY E. Hall & D. Read	CHECKED	BY Schuelke/Baumgarten	CHECKED
DATE PREPARED 06/01/98	APPROVED	DATE 05-Oct-98	PRICE LEVEL Appraisal

Table 2 (continued). - Cost estimate for the forebay pipe with diffuser, alternative 2.

Deflectors - Minimal Number of Outlets (Alternative 3)

Description

This alternative involves adding a minimum number of deflectors on the downstream face of the spillway underneath 6 pairs or 12 outlets, figure 10. The outlet control gates will not be modified, therefore, the discharges will match those currently experienced. The fully open mid-level outlets will each deliver approximately 4400 ft^3/s when the reservoir is at elevation 1208 (the minimum during drafting). Therefore, to accommodate a total spill of 50,000 ft^3/s, with no modification to the 102-inch ring seal gates, a total of 12 outlets will be utilized. A minimum of 6 blocks will need to be modified. The 5,000 ft^3/s per outlet used in the preliminary concept report could be delivered at higher reservoir head which would require use of 10 outlets.

Spreading of the flow is assumed and additional structural support for the deflectors in individual blocks is needed. Therefore, the deflectors will be continued across the full section effecting a total of 12 blocks, figure 10. This should provide for spreading of the flow and ensure structural stability during high spillway flows.

The deflectors will have a minimum reverse radius of 50 feet, with a horizontal extension of about 6 ft for a total deflector length out from the dam of about 45 ft, figure 10. The discharge is 4400 ft^3/s per outlet and 8,800 ft^3/s per block, with the unit discharge ranging from approximately 170 $ft^3/s/ft$ when spreading the discharge over the entire 50 ft block width to 560 $ft^3/s/ft$ assuming no jet spread. At this time, it is assumed all deflectors will be constructed at the same elevation and all would be effective. No additional construction was included if additional deflectors are required to address differing tailwater conditions.

The estimate assumes a separate cofferdam, 65-ft-high, will be built with forming for the deflector inside the cofferdam. There needs to be unwatering and dewatering due to leakage of the cofferdam. A cofferdam was constructed as part of the downstream form for the deflectors at the Corps of Engineers (COE) John Day Dam [3]. The COE design will reduce costs but for this level of estimate was not included.

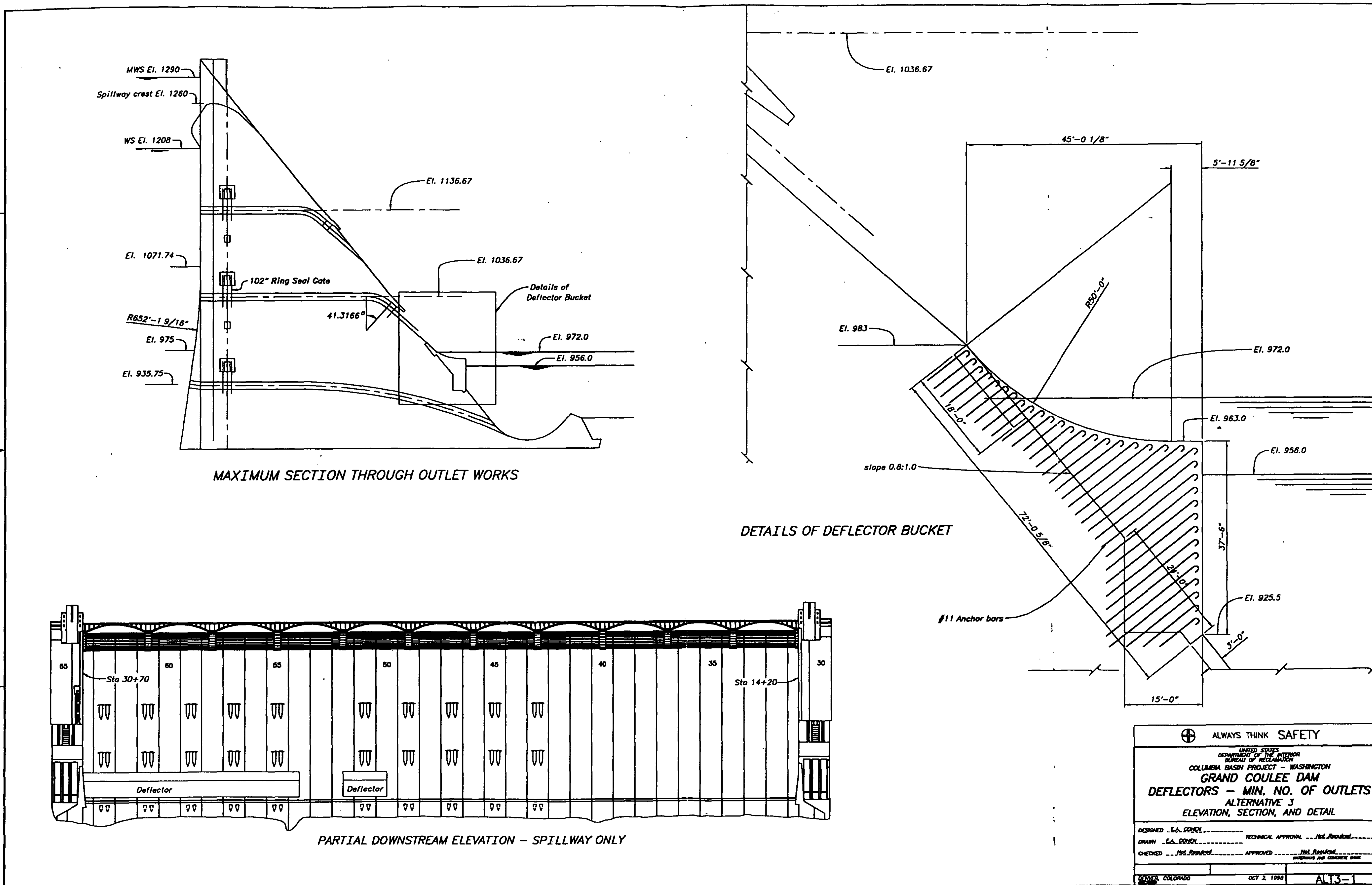

Figure 10. Alternative 3. Deflectors - minimum number of outlets.

Hydraulic and Total Dissolved Gas Evaluation

Hydraulic Analysis

The hydraulic analysis was undertaken to determine the water surface profiles, velocities, and depths through the outlets and down the dam face to the various tailwater elevations under consideration. The analysis for both the deflector alternatives, 3 and 4, used the water surface profile program, CTAC. The maximum 5,000 ft^3/s discharge per outlet was assumed for designing the radius of the deflector bucket instead of the minimum discharge of 4400 ft^3/s based upon minimum reservoir elevation 1208 used to determine the number of outlets required.

Two cases were considered; 1) outlet flow control at the conduit exit (diameter 7.75 ft) on the downstream face of the dam with a tailwater elevation of 972; 2) flow control at the upstream face of the dam with velocity head loss at the downstream face exit point, no expansion of flow across the face with a tailwater elevation of 957.

For case 1, the energy grade line was assumed to be 1201 feet based on losses in the conduit upstream of the exit point. At tailwater elevation 972, the energy grade line is at elevation 1191 with a velocity of about 117 ft/s and depth of 6.6 ft approaching the deflector.

For case 2, the velocity was computed to be 100 ft/s at the deflector at elevation 957.

The following analysis was performed primarily for structural concerns. In addition, it was performed to ensure that a smooth transition would be provided between the dam slope and the deflector given the high velocities. A velocity of 100 ft/s was used to compute the radius of curvature for the deflectors. The radius of curvature for the deflectors was determined from the following static equation for flip bucket design from Design of Small Dams [4], page 385:

$$p = \frac{2qv}{R} \qquad (4)$$

where p = dynamic pressures (lbs/ft^2) (assuming 1000 lbs/ft^2 if no model test performed)

q = unit discharge ($ft^3/s/ft$), v = velocity (ft/s), R = radius (ft)

An approximate range of radii for the deflector alternatives were determined using a dynamic pressure of 1000 lbs/ft^2 and various unit discharges based on the spread of the jet. The calculated radius required to turn the flow ranged from a 115 foot radius (at 560 ft^3/s /ft, 100 ft/s) to a 34 foot radius (170 $ft^3/s/ft$, 100 ft/s).

This equation was applied to the COE John Day Dam using the unit discharge, velocity, and dynamic pressures. With a dynamic pressure limited to 1000 lb/ft^2, the calculated radius was larger than that used for the fillet on the deflectors under higher unit discharges at John Day. Based on the acceptable model studies for John Day Dam, the dynamic pressure allowed must have been higher than 1000 lbs/ft^2, because this pressure corresponds to a discharge of only about 60 percent of the maximum discharge.

The Grand Coulee deflector design for alternative 3 assumes a 50-foot radius will be appropriate, assuming some spreading of the discharge over less than the full block width. If the dynamic pressures at Grand Coulee are limited to 1000 lbs/ft^2, the radius selected for both 3 and 4 are appropriate for approximately 60 percent of the maximum unit discharge. If the unit discharges are less (due to spreading of the jet) or the dynamic pressures were allowed to increase, as in the deflector design for John Day, then the radius should be suitable for the deflectors for alternative 3.

It is realized that the COE used only a 15 ft radius as a fillet to transition the flow from the spillway face to the horizontal deflector. Therefore, this analysis should be conservative and will be refined during hydraulic model testing.

The cavitation indices were 0.22 and 0.27 for cases 1 and 2, respectively. The "rule-of-thumb" regarding cavitation potential is that indices above 0.2 should not produce cavitation problems [5]. COE investigations have also determined that cavitation should not be a problem.

The deflector design will have to be model studied during feasibility design. The model study will also be required to determine deflector performance over potential tailwater ranges and required length of the horizontal section to stabilize the flow off the deflector..

A shear zone will be created by the high velocity jet traveling along the surface of the tailwater. A reverse roller forms underneath the surface jet that could potentially include high velocities. Whether or not this is a harmful disadvantage will depend upon the availability of material that can be drawn back into the roller bucket at the base of the spillway with operation of the deflectors. This problem has been documented at Reclamation's Yellowtail Afterbay Dam when metal deflectors were added; however, with the deep basin at Grand Coulee Dam this is probably not a concern.

Total Dissolved Gas Analysis

The COE has performed many hydraulic model studies and field tests developing the design parameters and evaluating TDG effectiveness of deflectors. This TDG analysis was based upon results of these studies, the velocities and depths computed in the hydraulic analysis, and general indicators for depth of plunge. The unit discharge will vary from 170 to 560 $ft^3/s/ft$ depending upon the assumed jet spread. A velocity of 100 ft/s and a depth of 6 ft was used in the method proposed by Johnson [6] to predict TDG.

The deflectors were located on the dam face according to criteria determined by COE hydraulic model studies where the objective was to obtain skimming flow as the prominent flow condition. Results from these tests have shown that skimming flow will occur for submergence depths of 3 to 11 feet for design unit discharges of 50 to 100 $ft^3/s/ft$ [7]. The deflectors for Grand Coulee were located at El. 963 to be within the range of the submergence depth recommended to produce skimming flow.

General rules of thumb when dealing with TDG indicate that a plunge depth of 5 ft would increase TDG by 10 percent and a depth of 11 ft by 25 percent. This approach would predict generated TDG levels of 109 to 125 percent for an initial reservoir TDG level of

100 percent, and 129 to 145 percent for an initial reservoir TDG level of 120 percent, for 3 and 11 ft submergence depths, respectively. These values represent local TDG. After mixing with powerplant flow based on the current design discharge ratios, the TDG at the fixed monitor would range from 102 to 107 percent for a reservoir TDG level of 100 percent and from 122 to 126 percent for a reservoir TDG level of 120 percent, for the 3- to 11-foot submergence range.

The analysis of Johnson was then used to determine the expected TDG with the deflectors and discharge as described above. Several different assumptions were used to determine the parameter "k" which is dependant upon the hydraulic action of the basin or in the tailwater pool for this case with flow from the deflectors. In the analysis, one factor requiring judgement is the path length or the "basin length." Using this type of analysis, the TDG levels predicted ranged from 102 to 119 percent for a reservoir TDG level of 100 percent, and 109 to 120 percent for a reservoir TDG level of 120 percent, for 3 and 11 ft submergence depths, respectively. After mixing with powerplant flow in the current design ratios, the TDG at the fixed monitor would range from 100 to 105 percent for a reservoir TDG level of 100 percent and from 117 to 120 percent for a reservoir TDG level of 120 percent, for the 3 to 11 percent submergence range. This analysis indicates, in general, a range from slight degassing to a slight increase in TDG depending upon the assumptions made in the analysis. The degassing values seem too optimistic given the unit discharges and known COE field results. If the tailwater varies up to the possible 20 ft discussed earlier, then deflector performance will be significantly worse.

The COE claims 110 percent TDG with unit discharges up to 68 $ft^3/s/ft$ at Ice Harbor Dam with field testing of deflectors. The unit discharges from the deflectors designed for alternative 3 will be considerably higher than the unit discharge under which the Ice Harbor deflectors operated, therefore, it is expected that the TDG levels will increase with spill. Ice Harbor Dam also has a comparatively shallow tailrace and the Ice Harbor deflectors are expected to generate 120 percent TDG at 180 $ft^3/s/ft$, which is at the minimum expected unit discharge for Grand Coulee deflectors.

The range of TDG levels predicted for mixed flow given in the preliminary concept report was from 121.2 to 123.6 percent for a reservoir TDG level of 120 percent. Depending upon which method is used the TDG for this alternative may vary from 102 to 108 percent for a reservoir level of 100 percent and from 117 to 126 for a reservoir level of 120 percent.

In addition, the performance of the deflector alternatives must be evaluated under spillway flows for cavitation and the energy dissipating performance of the roller bucket. The deflectors could significantly change the trajectory of the spillway jet and reduce the effectiveness of the roller bucket energy dissipater.

Obviously, the TDG levels need further investigation to improve the accuracy of these predictions. The analysis would be greatly enhanced by conducting a hydraulic model study, which would better define skimming action generated by the deflectors.

Construction Features and Cost Estimate

The minimal number of deflectors, alternative 3, is expected to require 3 years for completion of construction assuming work on a single block at a time. About 3 months will be needed to construct a deflector on each of the 12 blocks being modified on the dam. The work can be accelerated working on multiple blocks at a time. The original construction time was estimated at 2 years based on the COE experience at their dams with construction on 5 blocks. Due to the increased number of blocks and the complexity of the work, the duration of construction was lengthened by 1 year.

The construction of deflectors applies proven technology developed by the COE at dams on the Lower Snake and Lower Columbia River in Washington. The design for the deflectors at Grand Coulee Dam is more complicated because the design unit discharges and forces on the deflector are higher, and the operating head is considerably larger than these previous designs.

Some of the unresolved construction issues involve the cofferdam, dewatering, and forming scheme for the deflectors. Costs for the conceptual estimate were based on a separate cofferdam and forming system. It may be possible to incorporate the cofferdam and form into one to save costs.

The minimum height of the cofferdam will be from elevation 980 to elevation 915, or 65 ft tall. Dewatering may be significant because the cofferdam will have an unbalanced head or water pressure of about 55 ft. The length of the cofferdam will be 50 ft wide or the block width plus the triangular end sections.

There may also be some difficult work involving the excavation of concrete for this alternative, since the excavation is 15 ft deep at deepest. This work was estimated as being mechanically excavated, but may ultimately involve blasting (if allowed).

The listed items and costs are shown in table 3. The cost estimate was prepared by assuming a pair of outlets or 1 block was modified and then multiplied by the number of blocks needed to support the deflectors. The field cost for this alternative is estimated at $30,000,000. The major difference between this cost and the lower cost in the preliminary study is the cost of the concrete excavation on the dam face and the barge rentals which were significantly higher upon further investigation. The total cost includes a 30 percent non-contract cost of $9,000,000 for a total estimated job cost of $39,000,000.

CODE:D-3521 **ESTIMATE WORKSHEET** SHEET _1_ OF _2_

FEATURE: 05-Oct-98	PROJECT: Columbia River Project
Grand Coulee Dam Total Dissolved Gas Study Add Deflectors on to Spillway - Alt 3 50-FT RADIUS, Price is for 12 Blocks	DIVISION: 0 UNIT: FILE: C:\KATHY~1\98SUPER\CONCEPT\FLIPAB.WK4

PLANT ACCT	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Mobilization		1	LS		$990,000
		Furnish cofferdam		1	ea	$500,000.00	$500,000
		Install cofferdam (H= 70', W=	D8130	12	ea	$65,000.00	$780,000
							$0
		Excavation - concrete	D8130	4,320	cyds	$1,000.00	$4,320,000
							$0
		Surface preparation of concret	D-8130	52,800	Sq. Ft	$2.50	$132,000
		Sawcut (3 inch deep)	D-8130	2,400	lf	$25.00	$60,000
		Mobilize Barges (1 large, 1 transit)		1	LS	$100,000.00	$100,000
		Mobilize Cranes (1 shore, 1 barge)		1	LS	$40,000.00	$40,000
		Barge Rental		36	mo.	$40,000.00	$1,440,000
		Crane Rate (operated), large barge crane & sm		36	mo.	$110,000.00	$3,960,000
		Drilling for #11 anchor bars (2	D8130	54,000	lf	$15.00	$810,000
							$0
		Concrete:	D8130				$0
		Reinforced - Face of dam		23,040	cyds	$250.00	$5,760,000
							$0
		Furnishing and handling cemen	D8130	6,480	tons	$100.00	$648,000
							$0
		Furnish and install reinforcing	D8130	1,500,000	lbs	$0.55	$825,000
		Unwatering		12	ea	$5,000.00	$60,000
		Dewatering		36	mo	$10,000.00	$360,000
		Subtotal					$20,785,000
		Unlisted Items, 15% (+ or -)					$3,215,000
		Construction Cost					$24,000,000
		Contingencies, 25% (+ or -)					$6,000,000
		Field Cost					**$30,000,000**
		Non contract cost, 30%					$9,000,000
		(Changed by D-8560, 10/1/98)					
		Total Cost					**$39,000,000**

QUANTITIES		PRICES	
BY E. Cohen	CHECKED	BY Schuelke/Baumgarten	CHECKED
DATE PREPARED 07/24/98	APPROVED	DATE 26-Aug-98	PRICE LEVEL Appraisal

Table 3. — Cost estimate for the minimal number of deflectors, alternative 3.

Deflectors - All Outlets with Gate Replacement (Alternative 4)

Description

This alternative involves adding deflectors below the entire expanse of mid-level outlets on the downstream face of the dam to redirect flow from both the mid- and upper-level outlet works, figure 11. The upper- and mid-level outlets will be modified to allow regulation of the discharge to a capacity of 1250 ft^3/s when the reservoir is at elevation 1208 (the minimum during drafting). Therefore, to accommodate a total release of 50,000 ft^3/s there will be modification to the entire control system. This will require excavation of forty 102-inch ring seal control gates and replacement with jet flow gates capable of partial opening operation. All 40 outlets will be modified in 10 blocks.

Spreading of the flow is assumed and structural support for the individual blocks is needed. Therefore, the deflectors will be continued across the full section for a total of 20 blocks, figure 11. This should provide for spreading of the flow and ensure structural stability during high spillway flows.

The deflectors will have a minimum radius of 30 feet, with a horizontal extension of 6.6 ft for a total deflector length out from the dam of about 30 ft, figure 11. The total design discharge of 50,000 ft^3/s will be passed using all 40 upper- and mid-level outlet conduits. The discharge is 1,250 ft^3/s per outlet or 5,000 ft^3/s per block, with unit discharges ranging from 100 $ft^3/s/ft$ when spreading the discharge over the entire block width to 320 $ft^3/s/ft$ if there is no jet spreading.

At this time, it is assumed all deflectors will be constructed at the same elevation and all would be effective. No additional construction was included if additional deflectors are required for differing tailwater conditions, although this is likely to be the case after further investigation.

The estimate assumes separate cofferdam and forming systems. However, cofferdam can be constructed as part of the downstream form for the deflector buckets (similar to COE John Day Dam). The cofferdam would range from elevation 980 to elevation 925, or 55 feet tall (water pressure of about 45 feet). The bulkhead will be 50 feet wide (block width) plus the triangular end sections.

Hydraulic and Total Dissolved Gas Evaluation

Hydraulic Analysis

The hydraulic analysis for this alternative is the same as used for the deflector in 3, other than the discharge per outlet is significantly less. The existing ring follower gates that are only used in the fully open or closed positions would be replaced by jet flow gates that provide control of the discharge. This will enable more outlets to be used to pass the same spill discharge. To pass the design discharge of 50,000, each of the 40 outlet conduits will discharge 1250 ft^3/s. The energy grade line and water surface profile was computed from the control gate downstream to tailwater elevation 957. The velocity was computed to be about 95 ft/s. The calculated required radii from equation 4 ranged from 61 ft (at 320 ft^3/s /ft, 95 ft/s) to 20 ft (100 $ft^3/s/ft$, 95 ft/s). The design assumes a 30-foot radius for the deflector bucket will be appropriate, assuming spreading of the discharge over less than the full block width.

The computed cavitation index was 0.24. The same concerns exist with the flow conditions in the roller bucket or in the downstream riverbed as with alternative 3. In addition, the performance of spillway flows must also be evaluated.

Total Dissolved Gas Analysis

The purpose for modifying all the outlets was to decrease the unit discharge, thus hopefully improve the TDG characteristics of the flow. After the analysis for alternative 3 was completed, it was decided that the values presented by the preliminary concept report were adequate for this deflector alternative. This is due to the uncertain nature of the analysis as presented for alternative 3. The discharge for all the outlets used is 1250 ft^3/s per outlet. The unit discharge depends upon the assumptions used for spreading of the flow and varies from 100 to 320 $ft^3/s/ft$. The TDG is expected to range from 120 to 125 percent for a reservoir TDG of 100 percent and from 120 to 127 percent for a reservoir TDG level of 120 percent. After mixing with powerplant flow in the current design ratios the TDG at the fixed monitor would range from 105 to 106 percent for a reservoir TDG level of 100 percent and from 120 to 122 percent for a reservoir TDG level of 120 percent. These TDG levels do indicate an improvement over alternative 3 with a reduction in the unit discharge caused by flow control with the gates.

The deflector design and performance as influenced by tailwater depth will have to be model studied during feasibility design.

Construction Features and Cost Estimate

Construction to add deflectors beneath all the outlets and remove and replace all the gates is expected to take 5 years. The original estimated construction time was 3 years. The revised construction time estimate is based on 3 months per deflector block for all 20 blocks, plus the exactness of work required to remove and replace all of the control gates. The work for the gates is estimated to take 6 months per gate based upon previous recent Reclamation experience with gate replacements at Flaming Gorge and Hoover Dam. To complete the replacement of 40 gates in 60 months will require working on 4 gates at a time.

This alternative has many of the same unresolved construction issues as discussed in alternative 3, with fewer deflectors, for the cofferdam, dewatering, and forming issues. The cofferdam will have approximately 50 feet of unbalanced head and dewatering will depend on the cofferdam construction. The forms are estimated as a separate item for purposes of this cost estimate. Dewatering will be necessary due to leakage. The construction will require barges for the work on the downstream face of the dam. One additional unresolved issue deals with the delicate nature of the work removing the downstream control ring seal gates and replacing them with jet flow gates, while working in very close proximity to the upstream guard ring seal gate. There are provisions for a bulkhead gate on the upstream face of the dam as the primary flow control into the outlet works during this work. The delivery of concrete to enclose the new jet flow gates will also need additional attention during future work for this alternative.

The listed items and costs are shown in table 4. The field cost for this alternative is estimated at $100,000,000, or $35,000,000 less than the pre-concept price. The major difference between this cost and the greater cost in the preliminary study is that the price of the 40 jet flow gates was estimated to be significantly less. The total cost, including the non-contract cost, is estimated to be $130,000,000.

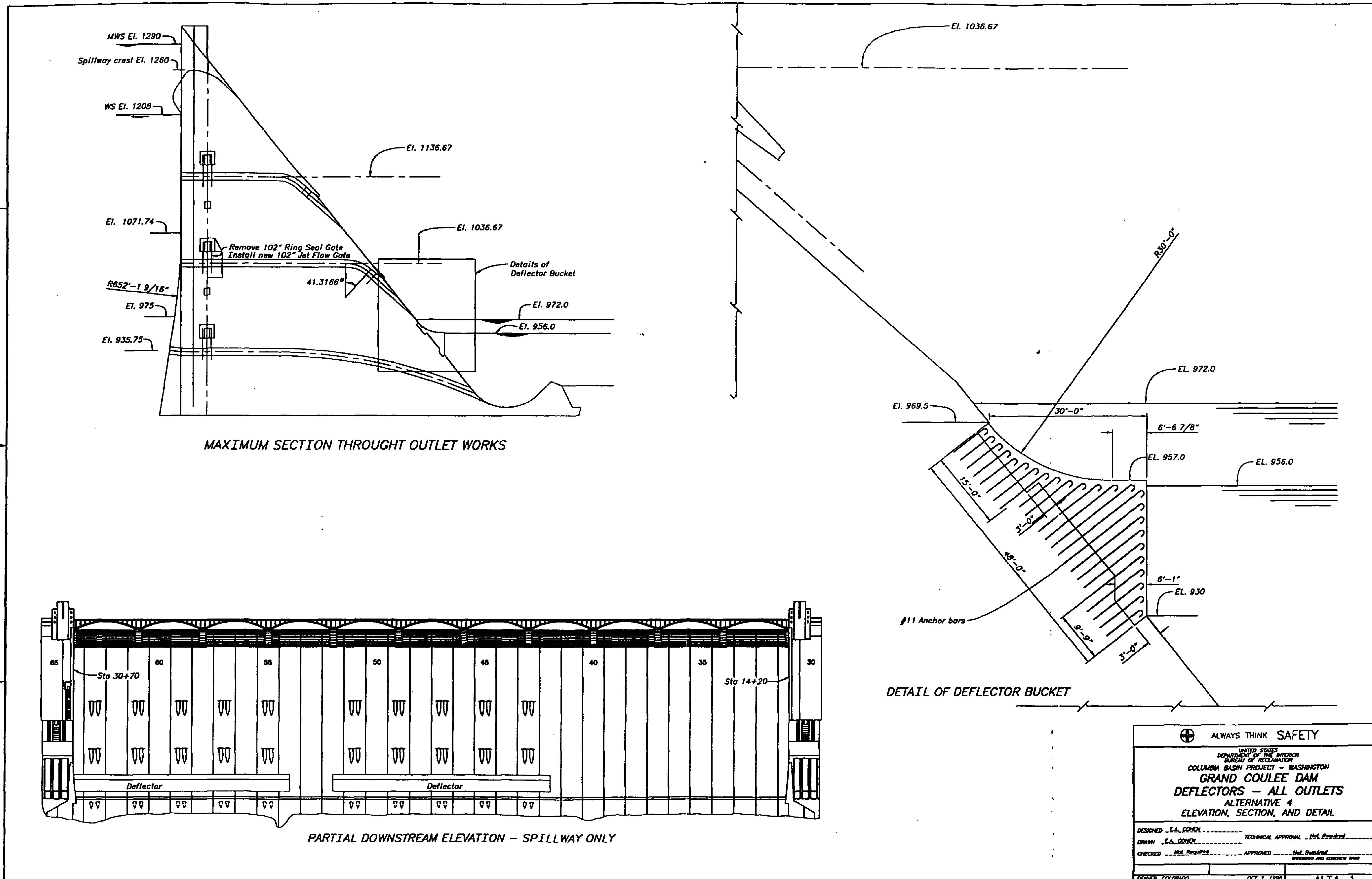

Figure 11. Alternative 4. Deflectors - all outlets.

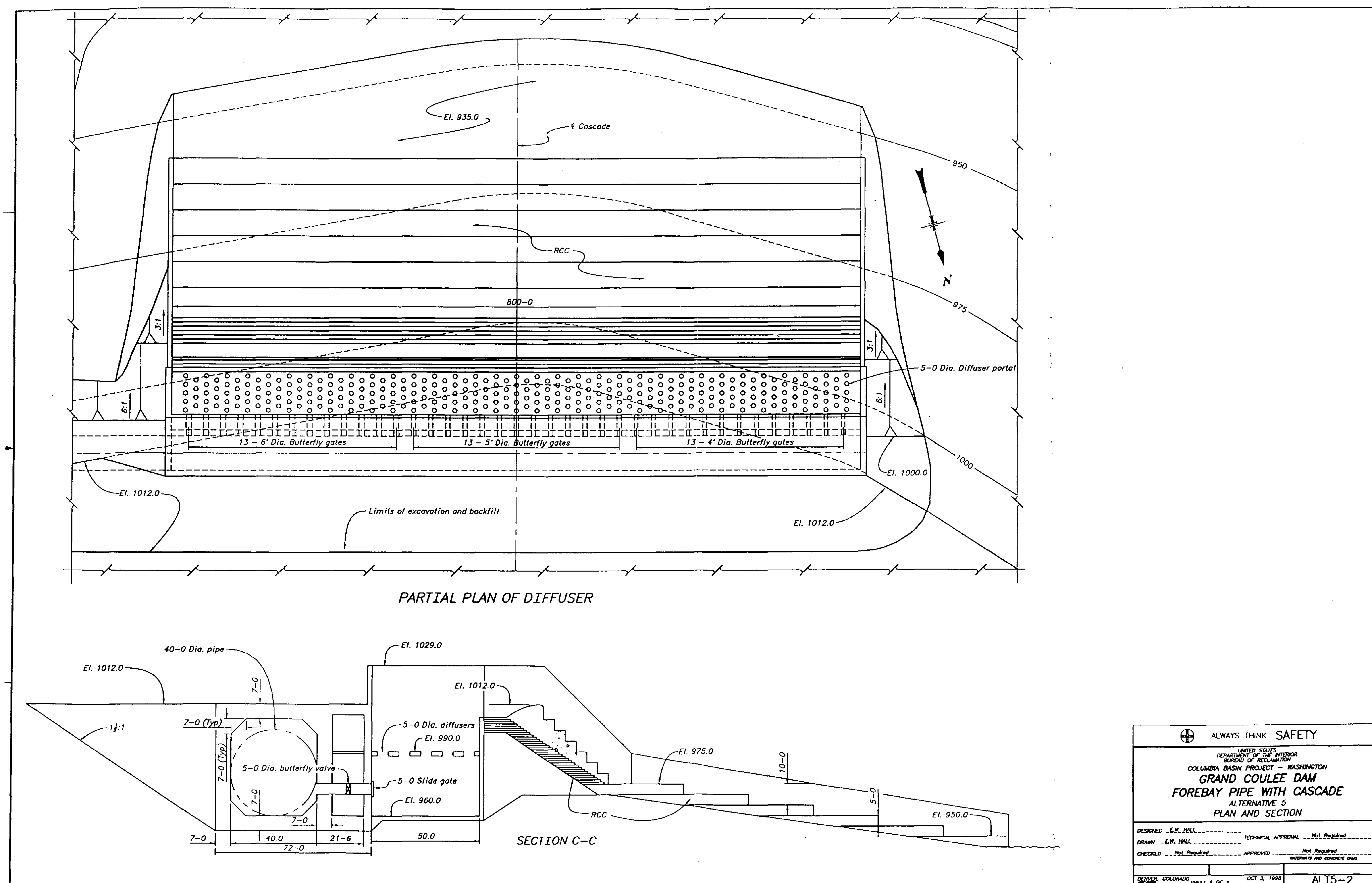

Figure 13. Alternative 5. Forebay pipe with cascade (continued).

CODE:D-3621 **ESTIMATE WORKSHEET** SHEET_2_OF_2

FEATURE: 05-Oct-98 **Grand Coulee Dam** **Total Dissolved Gas Study** **Add Deflectors on to Spillway - Alt 4** **30-FT RADIUS, Price is for 10 Block Sets of 2**	**PROJECT:** Columbia River Project **DIVISION:** **UNIT:** **FILE:** C:\KATHY'~1\98SUPER\CONCEPT\FLIPAB.WK4

PLANT ACCT	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Mobilization			LS		$3,300,000
		Furnish cofferdam		1	LS	$500,000.00	$500,000
		Install cofferdam (H= 70', W=	D8130	20	ea	$65,000.00	$1,300,000
							$0
		Excavation - concrete	D8130	2,600	cyds	$1,000.00	$2,600,000
		- regulating g	D8130	4,300	cyds	$1,200.00	$5,160,000
		Sawcut (3 inch deep)	D8130	5,000	lf	$25.00	$125,000
		Mobilize Barges (1 large, 1 transit)		1	LS	$100,000.00	$100,000
		Mobilize Cranes (1 shore, 1 bar		1	LS	$40,000.00	$40,000
		Barge Rental		60	mo.	$40,000.00	$2,400,000
		Crane Rate (operated), large barge crane & sm		60	mo.	$110,000.00	$6,600,000
		Drilling for anchor bars	D8130	64,000	lf	$15.00	$960,000
		Surface preparation for concre	D-8130	58,000	Sq Ft.	$2.50	$145,000
							$0
		Concrete:	D8130				$0
		Reinforced - Face of dam		17,000	cyds	$250.00	$4,250,000
		Reinforced - Gate chambers		4,300	cyds	$350.00	$1,505,000
		Furnishing and handling cemen	D8130	6,000	tons	$100.00	$600,000
							$0
		Furnish and install reinforcing	D8130	2,250,000	lbs	$0.55	$1,237,500
							$0
		Remove and dispose 40 102-in	D-8420	6,800,000	lbs	$0.50	$3,400,000
		each gate is 170,000 lbs					$0
		Furnish and install 40 new 102	D-8420	8,800,000	lbs	$4.00	$35,200,000
		each gate is 220,000 lbs					$0
		Unwatering		10	ea	$5,000.00	$50,000
		Dewatering		25	mo.	$10,000.00	$250,000
		Subtotal					$69,722,500
		Unlisted Items, 15% (+ or -)					$10,277,500
		Construction Cost					$80,000,000
		Contingencies, 25% (+ or -)					$20,000,000
		Field Cost					$100,000,000
		Non contract cost, 30%					$30,000,000
		(Changed by D-8560, 10/1/98)					
		Total Cost					$130,000,000

QUANTITIES		PRICES	
BY E Cohen	CHECKED LS & EH	BY Schuelke/Baumgarten	CHECKED
DATE PREPARED 07/24/98	APPROVED	DATE 09-Sep-98	PRICE LEVEL Appraisal

Table 4. - Cost estimate for installing deflectors under all outlets and replacing the gates, alternative 4.

Forebay Pipe with Cascade (Alternative 5)

Description

This alternative is similar to alternative number 2, the Forebay Pipe with Diffuser, with the addition of a gas stripping drop structure. The alternative involves the construction of a new pipeline, gate chamber, basin and drop structure to degas water as it is transferred from the forebay to the tailrace of Grand Coulee Dam. The new pipeline will be constructed in the area of the right abutment, extending from the end of the existing forebay dam to the current north service yard where a gate chamber, basin, diffuser and drop structure will be constructed, figures 12 and 13. The work requires removal and construction of a new end wall as a gravity dam with the same cross section as the existing forebay dam. The end wall will contain a wheel mounted guard gate with air vent for a 40-ft-diameter tunnel through the right abutment. A trashrack will be installed on the upstream face of the new end wall. The tunnel, gate chamber, and diffuser will require excavation; however, the majority of the tunnel will only require about 55 ft of excavation below the original ground level. The gate chamber will be a 800-ft-long manifold structure that will house both 39 butterfly valves and 39 slide gates that will discharge into a 50-ft-wide diffuser. The diffuser will be used to dissipate the energy in the flow providing good approach flow for the drop structure. This diffuser may not be necessary, but was kept during this phase of study. The butterfly valves and diffuser design remained the same as alternative number 2.

Roller compacted concrete (RCC) and conventional concrete will be used to construct a drop structure to strip supersaturated gas from the flow downstream of the diffuser and prior to flow entering into the tailrace adjacent to the Third Powerplant. The drop structure will be comprised of RCC steps each 5-foot thick and varying in length from 5-feet to 30-feet-long to accommodate the varying tailwater elevation.

Mechanical

The mechanical items will be identical to those outlined in alternative 2.

Access to the gate chamber will be by elevator with emergency stairs or ladders. The elevator will be identical to that in alternative 2 except the travel need only be 60 feet.

Electrical

The electrical features and equipment for this alternative will be identical to those in alternative 2.

Diversion Requirements

This alternative will also require the construction of two cofferdams. One cofferdam will be required in the forebay and one in the tailrace adjacent to the Third Powerplant. The forebay cofferdam is anticipated to be a cellular cofferdam, 180 feet high and 220 feet long. Construction and use of this cofferdam would block a minimum of 1 unit of the Third Powerplant.

The second cofferdam will be constructed in the tailrace adjacent to the Third Powerplant. This cofferdam will not be as tall, but will be longer than the tailrace cofferdam of alternative 2. This cofferdam will be approximately 40 feet high and 1520 feet long. The purpose of this cofferdam would be to allow construction of the gate chamber, diffuser, basin and drop structure, and energy diffuser. This cofferdam is presently designed as a cellular cofferdam to limit the projected footprint of the structure to limit the impact on the power production at the Third Powerplant.

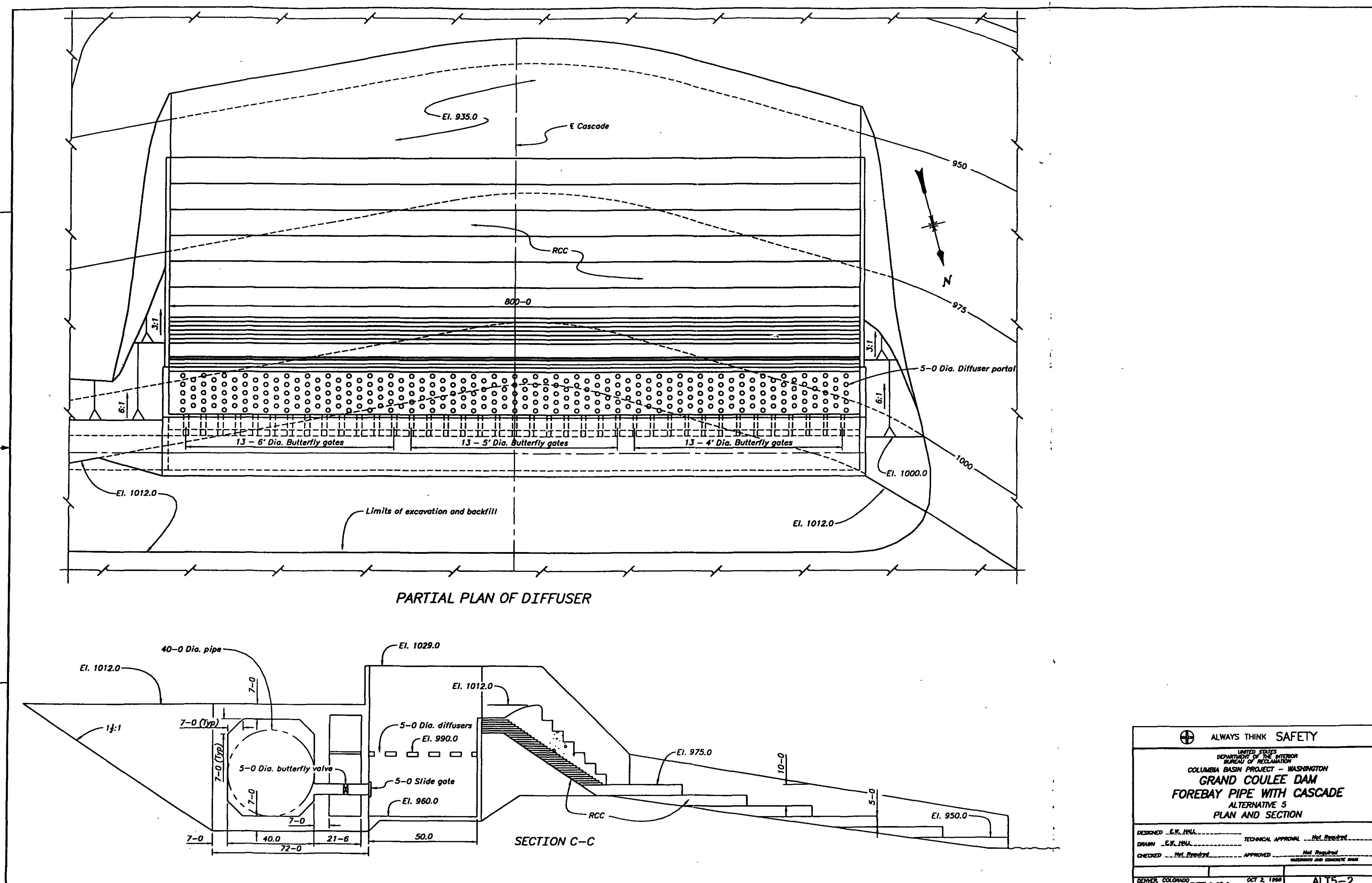

Figure 13. Alternative 5. Forebay pipe with cascade (continued).

Hydraulic and Total Dissolved Gas Evaluation

Hydraulic Analysis

The hydraulic analysis is the same for this alternative as for alternative number 2 to the point of adding the cascade to strip supersaturated gas or degas the water. The diffuser may not be needed in this alternative, but should increase the efficiency of the crest on the cascade and will ensure calm flow conditions in the basin before flowing over the crest. The depth of the stilling basin was decreased because TDG added at this location will be removed by the cascade. The height of the cascade was chosen to provide adequate drop for stripping gas before entering the tailwater. The head, H, over the cascade was chosen to be limited to 10 ft to ensure reasonable flow depths for effective degassing. The length of the cascade structure was then computed using:

$$Q = CLH^{1.5} \qquad (5)$$

where Q = 50,000 ft^3/s; L=length of the crest in ft; C= discharge coefficient

The unit discharge over the 800-ft-long crest is 62.5 $ft^3/s/ft$ under a head of 8.4 ft. The discharge coefficient of 2.6 is that of a broad crested weir and could be conservative.

The steps in the cascade will increase turbulence and also dissipate some additional energy. The transition steps from the drop in the cascade to the tailwater are used to prevent plunging of the jet to depth under a varying tailwater situation.

Total Dissolved Gas Evaluation

The TDG evaluation focuses on the RCC stepped cascade structure from the diffuser basin to the tailwater. The two portions of the RCC steps designed for the cascade will strip supersaturated gas from the water and prevent the discharge from plunging to depth in the discharge channel. The steep 1:1 sloping portion of the cascade will be above the tailwater and produce stripping of supersaturated gas. The transition steps on the flatter slope underneath the tailwater will prevent plunge of the flow more than 5 ft, regardless of the tailwater elevation. The unit discharge over the crest of the cascade is 62.5 $ft^3/s/ft$ under a head of 8.4 ft. The total drop from El. 1022 to the maximum design tailwater at El. 972 is 50 ft. Stepped spillway studies have shown both jet breakup and velocity reduction over 50 ft drops. Further benefit would be expected if the tailwater were lower and the jet flowed over the flatter 6:1 transition slope.

The expected TDG level resulting from the spill is expected to be 110 to 117 percent depending upon the performance of the stepped cascade. Mixed with powerplant release concentrations of 100 and 120 percent would yield concentrations of 102.4 to 104 and 117.7 to 119.3 percent, respectively. These values are very similar to those given in the preliminary report.

The width of the basin and the head over the crest may need adjustment to ensure the expected TDG stripping performance. A baffled apron type drop might be more effective and could be looked at in a model study, if necessary. These aspects of the cascade with verifying plunging control and evaluating the necessity of the diffuser in the basin upstream would be model studied in the feasibility stage.

Construction Features and Cost Estimate

The forebay pipe with cascade alternative will take about 4 years to construct. The construction issues in this alternative are fairly straight-forward. One concern is the location of the contractor's use area, because the north service yard will be in the middle of the construction area. The location for the concrete batch plant and delivery system will require additional study. Disposal of excavated material will also be somewhat of an issue because there will be approximately 700,000 cubic yards of waste. This could cover an area of 30 acres to depths of 20 feet.

The actual construction efforts are reasonably conventional. The construction of a 200-ft-tall cofferdam in the reservoir forebay blocking portions of the Third power will require detailed design. The cofferdams were estimated as cellular to minimize space required. The work will not permanently impact power production, but the loss of revenue during the construction and use of the forebay cofferdam will be significant. Third Powerplant revenues will be lost during construction of the cofferdam, completion of the new end dam, installation of the fixed wheel gate and trashrack, and removal of the cofferdam. Every effort should be made to complete this portion of the work as quickly as possible to minimize loss of power revenues. The power loss revenues were computed the same as for alternative 2. At this level of estimate, no loss of power revenues is anticipated due to the cofferdam in the tailrace for construction of the cascade, but it could also impact power by blocking the tailrace.

Unwatering and dewatering design and capital costs for operation and maintenance purposes would be covered in the feasibility stage. The cost of these items is generally covered by the contingencies at this time.

The listed items and costs are shown in table 5 (2 sheets). The field cost for this alternative is estimated at $175,000,000. The major difference between this cost and the greater cost in the preliminary study is the use of the tandem butterfly valves and slide gates instead of the large top seal radial gate and decreased rock excavation. The non-contract cost at 30 percent is $52,500,000. Loss of power revenue from 1 unit during an estimated 9 month construction period, the same as alternative 2, is estimated at $66,000,000. The total cost would be $293,500,000.

CODE:D-3521

ESTIMATE WORKSHEET

SHEET 1 OF 2

FEATURE: 05-Oct-98	PROJECT: Columbia River Project
Grand Coulee Dam Total Dissolved Gas Study FOREBAY CASCADE - ALT. 5	DIVISION:
	UNIT: FILE: c:\kathy's files\98super\concept\gc5est.wk4

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Mobilization		1	LS		$5,800,000
							$0
		F & I cellular cofferdam. H=18	D8130	1	LS		$7,000,000
		F & I cellular cofferdam. H=40	D8130	1	LS		$6,000,000
							$0
		Concrete:	D8130				$0
		Reinforced - Chamber structure		80,000	cyds	$200.00	$16,000,000
		Reinforced - Tunnel		18,500	cyds	$225.00	$4,162,500
		Mass		160,000	cyds	$130.00	$20,800,000
		RCC		46,000	cyds	$60.00	$2,760,000
							$0
		Furnishing and handling cemen	D8130	65,000	tons	$90.00	$5,850,000
							$0
		Furnish and install reinforcing	D8130	15,000,000	lbs	$0.45	$6,750,000
							$0
		Furnish and install 40-0 dia. ste	D8420	16,000,000	lbs	$1.50	$24,000,000
							$0
		Furnish and install 40-0 dia. wh	D8420	615,000	lbs	$5.00	$3,075,000
							$0
		Furnish and install regulating ga	D8420			-	$0
		13 - 6' dia. Butterfly valves		162,500	lbs	$6.50	$1,056,250
		13 - 5' dia. Butterfly valves		104,000	lbs	$6.50	$676,000
		13 - 4' dia. Butterfly valves		65,000	lbs	$6.50	$422,500
							$0
		Furnish and install bulkhead gat	D8420				$0
		13 - 6' dia. slide gates		182,000	lbs	$5.00	$910,000
		13 - 5' dia. slide gates.		143,000	lbs	$5.00	$715,000
		13 - 4' dia. slide gates		78,000	lbs	$5.00	$390,000
							$0
		Furnish and install trashrack	D8420	600,000	lbs	$2.50	$1,500,000
							$0
		Unwatering		1	LS	$400,000.00	$400,000
		Dewatering		1	LS	$100,000.00	$100,000
		Crane Mobilization (1 barge, 1 shore)		1	LS	$40,000.00	$40,000
		Barge Mobilization (1 to set cofferdams, 1 to re		2	LS	$100,000.00	$200,000
		Barge Rent		8	mo.	$40,000.00	$320,000
		Crane Rate (operated). 1 large crane for coffer		8	mo.	$80,000.00	$640,000

QUANTITIES		PRICES	
BY E Hall & D. Read	CHECKED	BY Schuelke/Baumgarten	CHECKED
DATE PREPARED 06/01/98	APPROVED	DATE 05-Oct-98	PRICE LEVEL Appraisal

Table 5. - Cost estimate for the forebay pipe with cascade, alternative 5.

FEATURE:	09-Oct-98	PROJECT: Columbia River Project
Grand Coulee Dam Total Dissolved Gas Study FOREBAY CASCADE - ALT. 5		DIVISION: 0
		UNIT: FILE: C:\123R5W\WORK\FILE0001.WK4

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Excavation - common	D8130	650,000	cyds	$3.50	$2,275,000
							$0
		Excavation - rock	D8130	345,000	cyds	$10.00	$3,450,000
							$0
		Excavation - rock tunnel	D8130	34,000	cyds	$125.00	$4,250,000
							$0
		Compacted backfill	D8130	330,000	cyds	$4.00	$1,320,000
							$0
		Furnish & install ventilation sys	D8410	1	LS		$100,000
		4000 cfm centrifugal fan and 100 feet of					$0
		18" diameter schedule 10 carbon steel pipe and					$0
		660 feet of 18" diameter schedule 40 PVC pipe					
		Furnish and install one geared	D8410	1	LS		$150,000
		freight elevator with a capacity of 3,500 lbs.					
		Elevator will have two landings with a car size of					
		8'-0" x 8'-0" and a total travel of 137 feet.					
		Subtotal					$121,112,250
		Unlisted Items, 15% (+ or -)					$18,887,750
		Construction Cost					$140,000,000
		Contingencies, 25% (+ or -)					$35,000,000
		Field Cost					$175,000,000
		Non contract cost, 30%					$52,500,000
		Lost power revenue during constuction					$66,000,000
		(Changed by D-8560, 10/1/98)					
		Total Cost					293,500,000

QUANTITIES		PRICES	
BY E Hall & D. Read	CHECKED	BY Schuelke/Baumgarten	CHECKED
DATE PREPARED 06/01/98	APPROVED	DATE 09-Oct-98	PRICE LEVEL Appraisal

Table 5 (continued). - Cost estimate for the forebay pipe with cascade, alternative 5.

Comparisons

The existing outlet works using an over/under spill pattern will generate a TDG concentration of 110 percent with small flows and a TDG concentration up to 133.22 percent with 50,000 ft^3/s, assuming upstream dissolved gas problems have been resolved and the reservoir is at 100 percent TDG.

Comparisons of the effectiveness of the alternatives for TDG can be made by computing the reduction of TDG for each alternative relative to a standard of the TDG production using the outlet works, table 6. Percent difference in table 6 is based upon a comparison to the existing outlet works spill condition. Alternatives 1 and 2 are transfer alternatives. These alternative will not reduce the TDG to any level below that found in the reservoir. Alternatives 3 and 4 have the greatest variability in TDG reduction effectiveness. This is a function of the varying tailwater and the ability to locate the deflectors where they will be most effective. Alternatives 3 and 4 have the potential to increase the level of TDG over the base existing condition due to the potential for plunging of the jet with varying tailwater levels. Alternative 5 is the only alternative that will reduce the TDG when the reservoir is at high TDG levels (see the 120 percent TDG level).

Table 6. - Expected TDG performance of the existing structure and each alternative for varying initial reservoir TDG levels.

Alternative No.	Discharge Values			TDG%		Total Combined TDG%	Percent Difference in TDG%
	Power kcfs	Outlet Spill kcfs	Spillway Spill kcfs	Power	Spill		
Existing Condition	160	50	0	100	133.22	107.91	0.00
Existing Condition	160	50	0	120	133.22	123.15	0.00
Existing Condition	160	0	50	100	122.09	105.26	-2.5
Existing Condition	160	0	50	120	122.09	120.50	-2.2
1	160	50	0	100	100	100	-7.3
1	160	50	0	120	120	120	- 2.6
2	160	50	0	100	100	100	-7.3
2	160	50	0	120	120	120	-2.6
3	160	50	0	100	100 -125	102 - 108	-5.5 to 0
3	160	50	0	120	109-145	117 - 126	-5 to +2.3
4	160	50	0	100	120-125	105 - 106	-2.7 to -1.8
4	160	50	0	120	120-127	120 - 122	-2.6 to -1.0
5	160	50	0	100	110-117	102.4 - 104	-5.1 to -3.6
5	160	50	0	120	110-117	117.6 - 119.3	-4.5 to -3.1

Summary comparisons of the construction times, field and non-contract costs, and the expected TDG levels generated for the reservoir at TDG concentrations of 100 and 120 percent are given in table 7. These are updated values from the preliminary concept report. The TDG values are given for the fixed monitoring station located 6 miles downstream from the dam and are for fully mixed flow. Thus, the ratio of design spill to powerplant flow is being used to determine the mixed TDG levels. The effect of different reservoir TDG levels may be seen.

Table 7. - Comparison of concept level structural alternatives for TDG abatement for Grand Coulee Dam.

Alternative	Construction Duration (years)	TDG lake @ 100%	TDG lake @ 120%	Cost (millions)		TDG Ranking	Cost Ranking
				Field	Total		
Extend and cover outlets (1)	4.5	100	120	81	105.3	3	2
Forebay pipe with diffuser (2)	4	100	120	200	326*	2	5
Deflectors - some (3)	3	102-108	117-126	30	39	5	1
Deflectors -all (4)	5	105-106	120-122.	100	130	4	3
Forebay pipe with cascade (5)	4	102.4-104	117.6-119.3	175	293.5*	1	4

* These alternatives have an additional estimated power revenue loss of about 66 million dollars spanning a 9 month construction period.

Conclusions

Conceptual-level designs have been presented in this report. There does appear to be an inverse relationship between TDG benefit and cost, i.e. the least expensive alternative to construct will most likely provide the least TDG benefit. These designs will be further evaluated and up to three will be selected for further evaluation in the feasibility level studies to begin in early FY99 and be completed at the end of FY2000. This effort will require finalizing the design discharge for the proposed structural modification. The feasibility level evaluation will include hydraulic model studies to assist with final feasibility level designs and evaluation of TDG.

References

[1] Frizell, Kathleen H., "Structural Alternatives for TDG Abatement at Grand Coulee Dam, Preliminary Concepts Report" PAP-793, U.S. Bureau of Reclamation, Technical Service Center, Denver CO, February 1998.

[2] Frizell, Kathleen H., "Operational Alternatives for Total Dissolved Gas Management at Grand Coulee Dam," PAP-794, U.S. Bureau of Reclamation, Technical Service Center, Denver CO, October 1998.

[3] __________, "John Day Lock and Dam Spillway Flow Deflectors", Design Memorandum #50, U.S. Army Corps of Engineers, Portland District, August 1996.

[4] "Design of Small Dams, third edition", U.S. Bureau of Reclamation, GPO, Denver, CO, 1987.

[5] Falvey, Henry T., "Cavitation in Chutes and Spillways", U.S. Bureau of Reclamation, Engineering Monograph No. 42, Denver, CO, 1990.

[6] Johnson, P.L., "Prediction of Dissolved Gas At Hydraulic Structures", U.S. Bureau of Reclamation, GR-8-75, Denver, CO, July 1975.

[7] Cain, James D., "Design of Spillway Deflectors for Ice Harbor Dam to Reduce Supersaturated Dissolved Gas Levels Downstream", IAHR Conference, pp.607-611, San Francisco CA, August 1997.

Appendix

Upon completion of the brainstorming session, all ideas were discussed with respect to TDG benefit, feasibility of construction, power generating concerns, and acceptability. The alternatives were not discarded due to overall cost. Alternatives were discarded based upon relative comparison between alternatives, i.e. alternative E would give comparable TDG benefit to alternative H for much less cost. This was a quick process and did not involve any laborious calculations; only approximate numbers and judgment. The items listed in table A1 are all the ideas developed during the spontaneous brainstorming session and were developed from the notes taken during that time.

The alternatives that were thought worthy of further study were carried forward from this initial brainstorming stage to the preliminary concept study and are shown in bold. Of these nine ideas, five were eventually carried forward for further study in this current concept-level report.

Table A1. Full listing of brainstormed ideas with advantages and disadvantages listed.

No.	Alternative	Advantages	Disadvantages
A.	Abandon powerplant units for submerged flow.	• transfers TDG • precedent for doing this • could be inexpensive	• large power loss with about 10 in old pp or 2 in 3rd pp
B.	Bifurcate off existing penstocks for submerged flow.	• transfers TDG	• geometry of old pp won't work • large power loss when in use • complicated geometry if units can even remain on line
C.	Reactivate lower outlets (el. 950) submerged flow.	**CARRIED FORWARD AS #1** • transfers TDG • adds capacity to dam • conduit is already bored • no lifetime power loss	• relocate power cables • new gates/controls needed • concrete waste removal and new concrete delivery • not meant for operation under high head • cavitation potential • documented poor flow conditions • high downstream cofferdam • upstream bulkhead problems • large amount of work performed in dam • access and space difficult
D.	Baffled apron-type structure on dam face with free surface flow.	• could reduce production of TDG • cause turbulence and jet break up	• cavitation potential • high flow problems structurally • still need terminal structure

No.	Alternative	Advantages	Disadvantages
E.	Cover and extend outlet works conduits down face of dam for submerged flow.	**CARRIED FORWARD AS #2** • Transfers TDG • easy construction, 2nd to deflectors • minimum dewatering • no lifetime power loss	• 105-ft-high cofferdam • disposal of excavated concrete • access by barge or scaffolding • concrete pumped or trammed • need to study energy dissipation
F.	Flare release from outlet works to achieve smaller unit discharge, add flip bucket, spreader, raised crown, splitter, combine paired tunnels.	• could reduce TDG production • could combine with other alternative	• probably won't spread as much as anticipated • cavitation potential • redesign of eyebrows
G.	Deflectors or flip lips to produce skimming flow.	**CARRIED FORWARD AS #4A AND #4B** • reduce spill TDG production • easiest to construct • no impact to power • small cofferdam attached to face • pass flow through o.w. not under construction • precedence	• barge or scaffold work • pump or tram concrete • structurally designed for PMF • minimal certainty about TDG performance due to tailwater fluctuations • least TDG abatement potential • potential influence on spillway operation
H.	New outlet works through dam where there are currently no outlets on left side of dam.	• transfer • potentially easier than reactivating lower level o.w. • adds capacity	• 10 outlets needed to be bored through dam • dewater u/s and d/s • more expensive than extending existing o.w. for submerged releases • reservoir level restricts location

No.	Alternative	Advantages	Disadvantages
I.	Drop elevation of a few spillway bays to lower than el. 1260. Free flow.	• would reduce TDG production • would replace o.w. spill	• might need to dedicate 4 bays to flow • very large gates, high velocities • baffles/stepped needed • terminal structure needed • cofferdam/dewatering huge • PMF concerns if limit flow to TDG spill only • construction access poor - 3 yrs
J.	Unhooded Howell Bunger valves attached to end of existing o. w. at el. 1050. Free flow.	• degas to saturation • extreme jet break up	• spray! • ice! Either could damage power lines, buildings, etc • must excavate out o.w. conduits to recess valves for spillway flow • impractical
K.	Stepped spillway on dam face to break up jet - below outlet works only - Below spillway gates on entire face. Free surface flow.	• degas spill • breaks jet	• not enough fall to be effective on o.w. also high velocities • cavitation potential • limited use for spillway flows
L.	Flow over left and/or right powerplant sections with submerged or free flow.	• transfers submerged • degas spill if free	• no room inside blocks to perform submerged release alternative • flow over would interrupt pp use • relocate transmission lines • more complex than other alternatives
M.	Combination of baffled apron/lower elevation of existing spillway/flips.	• reduce spill TDG levels • concepts combined with other alternatives	• complex

No.	Alternative	Advantages	Disadvantages
N.	Pipe through forebay dam abutment for submerged flow.	**CARRIED FORWARD AS #3** • Transfer TDG • minimal disruption to operation • potential to add power • minimal cofferdam • good construction access • no disruption to releases	• previously never designed jet flow gate • lose North service yard • large tunneling/excavation needed
O.	Left-side abutment pipe for submerged release.	• transfers gas	• pumping plant interference • town interference • left powerplant interference • construction access • longer pipe than 3rd pp forebay side
P.	Cascade release from forebay dam through abutment by 3rd powerplant. Free flow.	**CARRIED FORWARD AS #5** • low unit q • degas • construction access reasonably good • minimal cofferdam • potential for new power production • additional capacity obtained	• major construction will take entire area • lose north service yard • similar to No. 3
Q.	Install additional powerplant by forebay dam for submerged flow.	• additional power and Q obtained	• not all power used now • other submerged release alternatives less expensive
R.	Elevated tailrace in the river.	• treat all the water • creates shallow free surface flow	• not reliable structurally during higher flows • lose power revenue life time • huge quantities of fill • high velocities • no entrained air bubbles in flow after stilling basin • huge cofferdam • huge cost

No.	Alternative	Advantages	Disadvantages
S.	Elevated tailrace immediately below the stilling basin.	• creates shallow free surface flow • reduce TDG production	• treats spill only • not reliable structurally during higher flows • cofferdam • channel stability • other alternatives better from a TDG standpoint
T.	*Build low head structures with low unit q in the river channel, such as baffle drop, rock cascades, labyrinths, infusers.	• treat all the water • creates shallow free surface flow • incorporated into other alternatives in some manner	• lose power revenue • huge structures • $21 million lost power with 15 ft of head
U.	Raised basin - Fill in roller bucket spillway with horizontal apron. Create shallow free surface flow.	• creates shallow free surface flow • reduce production	• treats spill only • potential for extremely poor energy dissipation, downstream apron likely • replunging downstream of basin likely • cofferdam • PMF problem • high velocities • minimal gas benefit
V.	*Inject microbubbles into stepped spillway surface water.	• degas	• must be used with shallow depth option • unknown performance • power demand high • couldn't use air because under pressure would transfer more gas into flow • possibly pure oxygen needed

No.	Alternative	Advantages	Disadvantages
W.	*Widen river with other structures.	**CARRIED FORWARD AS #7** • only option with potential for good degas benefit for entire flow • lifetime power loss during spill season	• lost power $1.4 m/ft of head loss/year • long weir • cofferdams and river diversion structure • huge excavation • bank stabilization • baffled apron drop and d/s stepped apron needed to achieve performance • large Obermeyer gates across river ever constructed • possible mitigation • large waste area needed • blocks river access
X.	*Widen river with piers for turbulence.	• creates shallow free surface flow	• huge excavation needed • huge cofferdam • no air bubbles or high enough velocity in flow
Y.	*Create bends in the river.	• potentially create turbulence and mixing of flow to strip gas	• huge excavation needed • huge cofferdam • no air bubbles or high enough velocity in flow
Z.	*Channelize and bend river.	• potentially create turbulence and mixing of flow to strip gas	• huge excavation needed • huge cofferdam • no air bubbles or high enough velocity in flow
AA.	*Pump and/or flood side channel along river and drop to river with free flow.	**CARRIED FORWARD AS #8** • medium-sized cofferdam • treats ½ the total flow, thus 2nd best TDG abatement	• tailwater fluctuation • dedicate 3 units in 3rd powerplant to supply flow • lost power estimated at 20%/year out of the 3 units • space/location problem along river • large excavation
BB.	*Aerators - fountains	• degasses all or a portion of the water depending upon the number used about 115% • Mixing pp ½ & ½ • Can add more or disband fairly easily	• need thousands of them • O&M problems • anchorage problem for high flows • power cost would be significant, 30-35,000 hp @ 10 psi, Q=100,000 cfs • Piping for system

No.	Alternative	Advantages	Disadvantages
CC.	Enclose roller bucket energy dissipater with walls and gradient drop.	**CARRIED FORWARD AS #6** • reduce TDG production from all spill • proven dam construction technique	• temporarily take 4 to 6 units out of service • permanently take 4 units out of service • large cofferdam • foundation adequate? • reduction of flood capacity during construction • basin not self-cleaning • possible hydraulic concerns
DD.	Construct a selective withdrawal system in reservoir to withdraw from higher levels - less saturation in summer months.	• reduce saturation of withdrawn water • proven technology	• only effective during summer months when reservoir is temperature stratified
EE.	Construct a barrier at the entrance to the 3rd powerplant forebay to release less saturated flow in the summer. curtain, stoplog, fill, etc.	• transfers TDG • could be relatively inexpensive	• only effective during summer months when reservoir is temperature stratified
FF.	Strip TDG in reservoir with introduction of microbubbles of pure oxygen.	• degas	• transfer is slow • must be in conjunction with other structure • power demand high • unproven • pure oxygen
GG.	Introduce blue-green algae to change composition of N_2 to organic forms thus reducing TDG.	• non-structural • degas reservoir, thus all releases	• could be aesthetically unattractive • in summer only therefore limited benefit

No.	Alternative	Advantages	Disadvantages
HH.	Develop Las Vegas Grand Coulee or other power hungry business causing increased power demand to eliminate spill.	• good for local economy • would make money in the long run	• not likely • doesn't address problem
II.	Buy out net pen operator.	• potentially inexpensive	• doesn't address the problem
JJ.	Lower net pens/fish to bring TDG levels closer to equilibrium.	• fish have less exposure to high TDG levels	• doesn't address the problem
KK.	Shift power in system to Grand Coulee.	• reduce spills at Grand Coulee, thus reducing gas production	• could cause other problems in system operation
LL.	Mitigation payments every 5-6 years with fines for violating TDG levels about $10,000/day.	• could potentially be inexpensive	• doesn't address the problem