Revised Study Plan

Boundary Hydroelectric Project (FERC No. 2144)

Study No. 3
Evaluation of Total Dissolved Gas and Potential Abatement Measures

Seattle City Light

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1.0 INTRODUCTION

The FERC relicensing process and the related application for certification under Section 401 of the federal Clean Water Act (401 certification) requires characterization of existing water quality conditions in the Boundary Project area and a determination of whether water quality meets the Washington Department of Ecology (Ecology) regulatory standard of 110 percent total dissolved gas (TDG) saturation for aquatic biota. Based on existing information, the Project at times does not meet this standard and increases levels of TDG in the Pend Oreille River downstream of Boundary Dam. The purpose of this study is to better define the relationship between TDG levels and Boundary Project (Project) operations and to identify and evaluate potential operational and/or structural measures that could reduce elevated TDG levels that can impair beneficial uses for fish and other aquatic species downstream of the dam. The study will involve monitoring of TDG and detailed assessment of potential abatement measures. This study plan was developed in consultation with USDA Forest Service (USFS), U.S. Fish and Wildlife Service (USFWS), Washington State Department of Ecology (Ecology), Washington Department of Fish and Wildlife (WDFW), Confederated Tribes of the Colville Reservation, Kalispel Tribe of Indians, BC Hydro, and Teck Cominco, Ltd., as described in section 2.8, below.

The Pend Oreille River system (which includes the Clark Fork River basin upstream of Lake Pend Oreille) is highly regulated, with operations controlled at dams associated with several energy production and/or storage projects. Flows into Boundary Reservoir are controlled by flows from upstream projects, including the Box Canyon Project (Pend Oreille County PUD), Albeni Falls Project (U.S. Army Corps of Engineers [USACE]), and other upstream projects such as Hungry Horse (U.S. Bureau of Reclamation).

Boundary Reservoir has a small useable storage capacity relative to the average daily river flow, as illustrated in Figure 1.0-1. As a result, instream flow releases to the Pend Oreille River from Boundary Dam on annual, seasonal, or monthly time intervals are largely controlled by the amount of water delivered from upstream projects such as Albeni Falls and Hungry Horse. Load-following operations at Boundary Dam primarily affect instream flow releases on a daily or hourly interval.

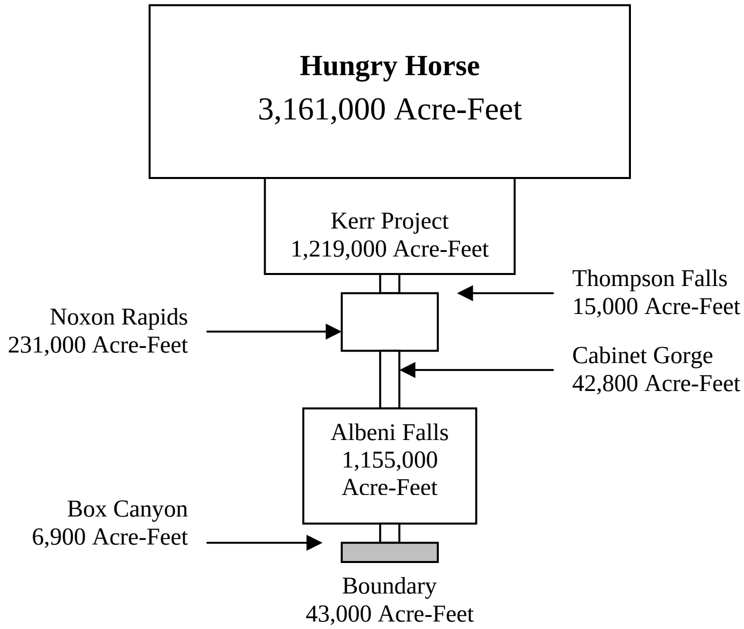

Figure 1.0-1. Hungry Horse to Boundary useable storage (acre-feet).

2.0 STUDY PLAN ELEMENTS

2.1. Nexus between Project Operations and Effects on Resources

TDG is a water quality constituent of concern in relation to the Project because past monitoring has shown that TDG measurements upstream and downstream of Boundary Dam exceeded the Ecology standard (110 percent saturation). Based on this monitoring, it has been determined that during times of spill, the Project increases TDG concentrations above this standard or increases TDG concentrations above upstream levels when upstream levels already exceed the standard.

2.2. Agency Resource Management Goals

In addition to providing information needed to characterize Project effects, this study will provide information to help agencies with jurisdiction primarily over water quality and aquatic resources in the Project area identify appropriate conditions for the new Project license pursuant to their respective mandates. The Evaluation of TDG and Potential Abatement Measures is specifically designed to meet 401 certification and relicensing requirements, but may also be relevant to recent or ongoing management activities by other agencies. A brief description of relevant resource management goals follows.

Washington Department of Ecology (Ecology) and the U.S. Environmental Protection Agency (EPA)

Washington State water quality standards related to TDG are summarized in Table 2.2-1. This table presents two sets of standards: the 1997 federally approved standards and revised standards adopted by Ecology in July of 2003. The 2003 revised standards cannot be used for regulating federal Clean Water Act actions until approved by the U.S. Environmental Protection Agency (EPA). EPA is in the process of reviewing these standards and in February 2005 provided a partial approval. Ecology is currently using the 2003 rule for the parts that EPA has approved (including TDG), but employs the 1997 rule for the parts that EPA has not yet approved (i.e., temperature). The last column of Table 2.2-1 identifies the TDG standard that is currently applicable. Both standards specify that all reservoirs with a mean detention time of 15 days or less are classified the same as the river section in which they are located. Boundary Reservoir has a residence time of less than 4 days, and is therefore categorized under the Pend Oreille River water quality standards.

Table 2.2-1. Applicable Washington State surface water total dissolved gas (TDG) standards for the Pend Oreille River between the Idaho border and the Canadian border (WAC 1997; WAC 2003).

1997 Standard (Class A) [1]	2003 Standard (salmon and trout spawning, non-core rearing, and migration) [2]	Applicable Standard
Not to exceed 110 percent of saturation at any point of sample collection	Not to exceed 110 percent of saturation at any point of sample collection	2003 Standards

1 Chapter 173-201A WAC Water Quality Standards for Surface Waters of the State of Washington. November 1997.

2 Chapter 173-201A WAC Water Quality Standards for Surface Waters of the State of Washington. July 2003.

From 2001 through 2004, the USACE and Pend Oreille County Public Utility District (PUD) monitored TDG at the Idaho state line near Newport. The U.S. Geological Survey (USGS) has been monitoring in the forebay and tailrace of Boundary Dam, with supplemental monitoring performed by Ecology. Data from this monitoring show that total TDG frequently exceeds the State of Washington water quality standards. As a result, Ecology listed the Pend Oreille River on its 2002/2004 303(d) list of impaired waters and is in the process of developing the total maximum daily load (TMDL) for TDG in the Pend Oreille River jointly with the EPA and the Kalispel Tribe. The EPA is issuing this TMDL for all waters of the Kalispel Tribe of Indians, and Ecology is issuing this TMDL for all waters in the state (A TMDL identifies how much pollution needs to be reduced or eliminated to achieve applicable water quality standards and establishes acceptable loads to achieve this end.).

Water quality standards established by both the State of Washington and the Kalispel Tribe set a criterion of 110 percent of saturation designed for the protection of fish and other aquatic organisms. Washington provides an exemption from the standards when flows exceed the seven-day, ten-year frequency (7Q10) flood flow, while Tribal standards apply at all flows.

Ecology's Water Quality Improvement Report documenting the Pend Oreille River TMDL for TDG, currently scheduled to be filed by March 2007, will consist of two parts: Volume I, Study Findings, and Volume II, Implementation Strategy. TMDL allocations will be met primarily through TDG abatement plans developed under 401 certifications for FERC relicensing. Monitoring will continue to assess compliance with standards and effectiveness of the TMDL.

The 401 certification process will consider the Project's compliance with the Clean Water Act, water quality standards, and other appropriate requirements of state law, including what measures can be employed to protect the beneficial use of the waters associated with the Project (Ecology 2005). These beneficial uses include water supply, fish and wildlife habitat, generation of electricity, and recreation. Ecology, through the 401 certification process, may require that specific actions or measures be included in the Project's license to support beneficial uses.

Water Resource Inventory Area (WRIA) 62

Numerous agencies and stakeholders in 1998 formed the Water Resource Inventory Area (WRIA) 62 planning unit, the goal of which is to "develop strategies that will balance competing demands for water, while at the same time addressing local concerns, preserving and enhancing the health of the watershed and considering the economic stability of the watershed." In January 2005, a Watershed Management Plan for WRIA 62 was completed (Golder and Associates 2005). This plan identified the following five goals and related objectives for water quality:

- WQUAL-1: WRIA-wide coordination of water quality monitoring.
- WQUAL-2: Watershed Planning Implementing Body support of actions that aim to reduce Eurasian watermilfoil and other aquatic nuisance weeds in WRIA 62.

  Objective: Reduce Eurasian watermilfoil and other aquatic nuisance weeds in WRIA 62.
- WQUAL-3a: Watershed Planning Implementing Body to participate in (interact and provide input to) the TMDL process for tributary streams that originate within WRIA 62.

  Objective: Remove tributary streams in WRIA 62 from the 3030(d) list of impaired waters by meeting State and tribal (where appropriate) water quality standards in impaired tributary streams.
- WQUAL-3b: Watershed Planning Implementing Body to participate in (interact and provide input to) the TMDL process for the mainstem of the Pend Oreille River.

  Objective: Meet State and tribal (where appropriate) water quality standards in the mainstem Pend Oreille River.
- WQUAL-5: Protect water bodies of high water quality and improve water quality of impaired water bodies.

  Objective: Maintain compliance with state water quality standards and prevent degradation of waters that meet or exceed state water quality standards in WRIA 62.

Columbia River Subbasin Plans

In 2004, the Northwest Power Planning Council completed the Intermountain Province Subbasin Plan. This plan identifies recommended management actions that will be used to guide the review, selection, and funding of projects in Columbia River subbasins (GEI 2004). The relevant management plan objectives identified in the subbasin plan as related to the Pend Oreille River are outlined below:

- Subbasin Objective 1B2: Improve water quality to meet or exceed applicable water quality standards in the Subbasin.

  Strategy c: Identify pollution sources, causes, and constituents on tributaries and mainstem Pend Oreille River; determine and implement actions necessary to eliminate or mitigate effects.

  Proposed Strategy e: Continue monitoring the water quality of Lake Pend Oreille, Clark Fork River and Pend Oreille River to insure it meets State and Federal standards.

The Evaluation of TDG and Potential Abatement Measures for the Project will provide information relevant to the objectives and strategies described above.

USDA Forest Service (USFS)

The Colville National Forest is located within the Pend Oreille River basin and as such, the USFS is a participating stakeholder in the relicensing of the Project. The USFS developed and completed the Land and Resource Management Plan for the Colville National Forest in 1988 (USFS 1988). Specific standards and guidelines in this plan related to TDG include:

1. Maintain water quality parameters within the range of good fish habitat conditions, and within State water quality standards, including the following:
   - *Total dissolved gas* – not to exceed 110 percent of saturation
2. Complying with State of Washington requirements in accordance with the Clean Water Act for protection of waters of the state through planning, application, and monitoring of Best Management Practices in conformance with the Clean Water Act, regulations, and federal guidance issued thereto.
3. In watersheds where project scoping identifies an issue or concern regarding the cumulative effects of activities on water quality or stream channels, a cumulative effects assessment will be made. This will include land in all ownerships in the watershed. Activities on National Forest System lands in these watersheds should be dispersed in time and space to the extent practicable, and at least to the extent necessary to meet management requirements. On intermingled ownerships, coordinate scheduling efforts to the extent practicable.

US Fish and Wildlife Service (USFWS)

The US Fish and Wildlife Service is responsible for some federally listed species, including threatened bull trout (*Salvelinus confluentus*), migratory birds, and the habitats that support them.

A short reach of Sullivan Creek, commencing at its confluence with the Pend Oreille River, has been designated as critical habitat for bull trout. The draft Bull Trout Recovery Plan identifies as a recovery objective, "restore and maintain suitable habitat conditions for all bull trout life history stages and strategies," and identifies investigation and improvement of water quality as a specific action to address this objective.

2.3. Study Goals and Objectives

The goal of the proposed Evaluation of TDG and Potential Abatement Measures is to identify all "reasonable and feasible" (Ecology 2005) improvements that could be used to meet the 110 percent standard by evaluating operational and/or structural modification alternatives to reduce TDG impairment at the Project in support of the Pend Oreille River TMDL for TDG and application for 401 certification. This goal will be accomplished by the following eight primary objectives for this study, which will be accomplished in two phases (with Phase 1 initiated in 2007 and Phase 2 following, as early as 2008):

1. Analyze hourly and 15-minute interval TDG data reported by the USGS from 1999 to 2005 for the forebay and tailrace fixed monitoring stations (FMS) relative to Pend Oreille River flow data, Project discharge and spill volumes to assess gas saturation.
2. Continue to monitor and collect Project forebay and tailrace FMS TDG data and assess the dissipation of TDG downstream of the Project.
3. Identify and provide brief summaries of the scope and results of the various TDG-related studies and evaluations that have been conducted since 1998 concerning gas supersaturation at the Project.
4. Evaluate methods and controls to reduce air admission requirements for generating units #55 and #56 to reduce total dissolved gas.
5. Identify, describe, and evaluate a shortlist of alternatives and potential combinations of alternatives consisting of operational and structural control measures for reducing TDG production relative to the established criteria.
6. Conduct a comparative analysis of the shortlist of operational and/or structural modification alternatives based on TDG reduction performance, hydraulic engineering methods, field testing, and modeling.
7. Identify the "preferred alternative modification strategy" (preferred alternative) for controlling and mitigating for TDG impairment based on the results of this study.
8. Identify the TDG and other monitoring and reporting activities that will be undertaken during the new license term, including those needed to evaluate the effectiveness of TDG control measures or other mitigation.

The following sections of this document provide a more detailed description of the study plan for addressing these objectives in association with the Pend Oreille River TMDL for TDG, application for 401 certification, and economic feasibility analysis (Ecology 2006) processes.

2.4. Need for Study

Many hydroelectric projects in the state of Washington — including the Grand Coulee Dam (USBR 1998), Cabinet Gorge Dam (Avista 2000), Chief Joseph Dam (USACE 2000), Priest Rapids Dam (Grant County PUD 2002), and Rocky Reach Project (Chelan County PUD 2003) — have conducted various TDG-related studies to assess operational and structural alternative measures. The need for this study and development of this study plan is informed by and benefits from these previous evaluations to ascertain a reasonable and feasible approach for assessing TDG impairment and potential abatement measures at the Project.

Summary of Existing Project Information

TDG has been documented in exceedance of Ecology standards throughout the Pend Oreille River. TDG levels in the river often exceed these standards during spill events at the hydropower facilities. TDG exceedances have been documented at the Albeni Falls, Box Canyon, and Boundary projects on the Pend Oreille River system.

Seattle City Light (SCL) has carried out numerous investigations and peer reviews from 1998 through 2006 to initially assess and characterize the effect of existing operations at the Project on TDG levels in the Pend Oreille River downstream of the Project. These investigations consisted of collection and analysis of dissolved gas data and preliminary assessment of potential alternatives to reduce TDG supersaturation in the river below the Project. In addition, several steps were performed to determine the objectives of this study plan. SCL collected relevant data, information on the TDG measurements, drawings of Boundary Dam, and regional reports. SCL then retained several consultants experienced with regional gas abatement techniques to participate in brainstorming sessions to identify potential operational and structural alternatives for reducing TDG. The list of potential alternatives was conceptually reviewed by SCL to assess the applicability of solutions previously studied at other projects. Finally, SCL has consulted with Ecology and other relicensing participants regarding the objectives for this study.

TDG data collected by the USGS since 1999 in the Boundary Dam forebay and tailrace are available on the USGS online NWIS website at http://waterdata.usgs.gov/nwis/qw. Spill and non-spill testing reports from 1998 through 2003, which comprise SCL's historic TDG assessment activities collected prior to initiating assessment of potential operational and structural alternatives in 2004, are also available in the online Information Library on the Boundary Project relicensing website (www.seattle.gov/light/news/issues/bndryRelic/), as is the subsequent peer review of Columbia Basin Environmental's (CBE) 2002 spill testing (CBE 2003), conducted by Michael Schneider (USACE 2006). For a more detailed discussion regarding existing TDG data, please refer to section 4.4.5.3.7 of the Boundary Project relicensing Pre-Application Document (PAD; SCL 2006a), filed by SCL with FERC on May 5, 2006, and available on the Documents page of the relicensing website.

As described in Attachment 1, section 3.1 of this RSP, compilation and analyses of existing hydrology data have been undertaken by SCL to produce the reliable hydrologic dataset that is needed to conduct environmental and energy production analyses (as described in Attachment 1, section 3.2 of this RSP) for FERC relicensing of the Project. This hydraulic dataset will serve as the Project hydrologic record to be used consistently for evaluations of Project operations, resource effects, and potential alternative operational scenarios, and is therefore integral to the evaluation of TDG conditions and potential abatement measures as described in this study plan. The hydrologic record for the Pend Oreille River system and the Boundary Project will be completed by March 2007 and will also be available in the Information Library on the Boundary Project relicensing website.

USGS Data for the Boundary Project

Since 1999, a continuous data logger has been recording TDG at a USGS gage (#12398600) located approximately 0.75 miles downstream of Boundary Dam. SCL has an ongoing contract with the USGS for station maintenance and daily TDG data management for this TDG station. From 1999 to 2005, exceedances of the 110 percent standard occurred in five of the six years during 5.3 percent of the total number of days monitored (primarily from April through the beginning of July). Daily TDG values for this period, estimated assuming a barometric pressure of 760 mmHG, are presented in Figure 2.4-1.

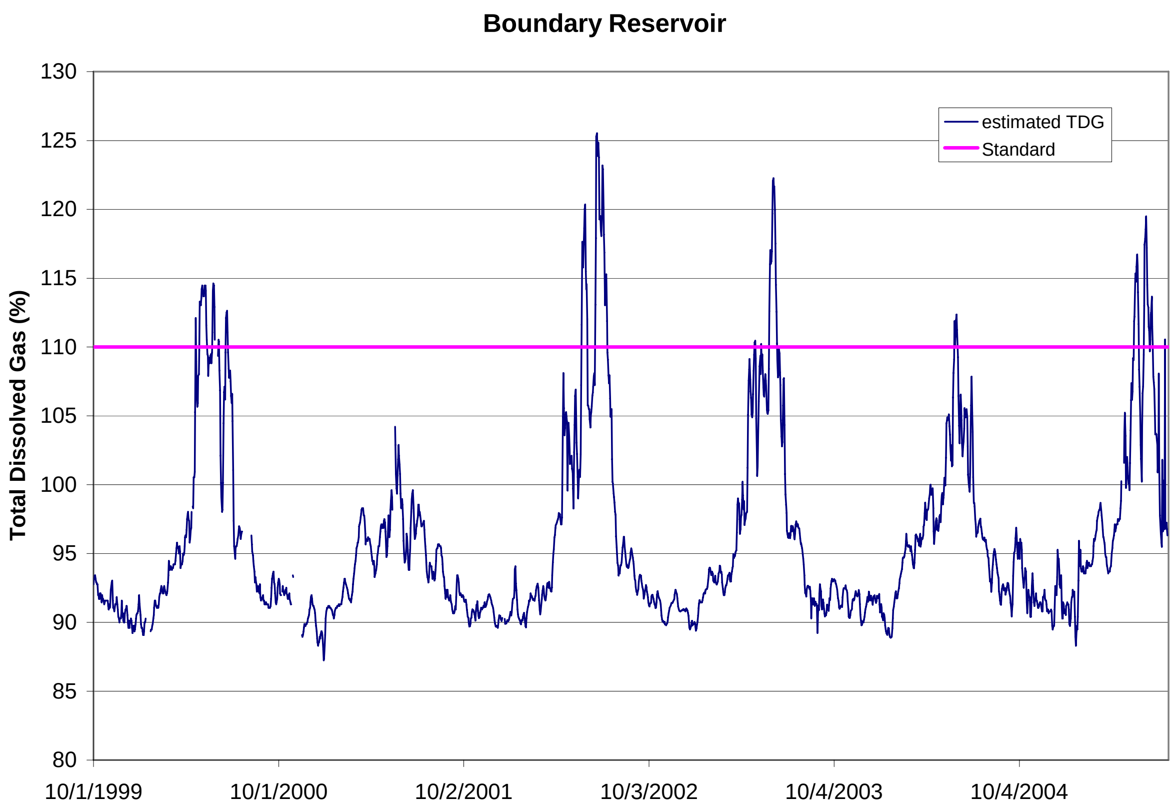

Figure 2.4-1. Measured TDG just downstream of Boundary Dam from 1999–2005 (Gage # 12398550). Note: Assumes an atmospheric pressure of 760 mmHg for the percent calculation (USGS 2005).

The elevated TDG measurements above the 110 percent standard occurring between the months of April through early July in Figure 2.4-1 correlate to approximately 4 days of spill in 2000, 1 hour of spill in 2001 (drought year), 43 days of spill in 2002 due to high flows and spillway testing (CBE 2003), 11 days of spill in 2003, and 1 hour of spill in 2004 based on SCL System Control Center dispatch data.

Pend Oreille River TMDL for TDG

The Pend Oreille River was listed on the Ecology 2002/2004 303(d) list, based on TDG in exceedance of the 110 percent saturation criterion at multiple locations. This standard is to be met for all river flows downstream of the Kalispel Reservation up to the seven-day average, ten-year high flow (7Q10 flow), which is about 108,300 cfs for the Pend Oreille River in Washington state below the Project. As a result of this listing, Ecology will take action in accordance with its memorandum of understanding with EPA, and will develop a water cleanup plan for TDG based on establishment of a TMDL. A project schedule for the TDG TMDL was reported in the Quality Assurance Project Plan (Pickett 2004) and updated (J. Jones, WDOE, personal communication, January 22, 2007; included in Attachment 4) as listed in Table 2.4-1.

Table 2.4-1. Pend Oreille River Total Maximum Daily Load for Total Dissolved Gas Schedule.

Report	Schedule
TMDL Report Submittal:	
Draft Technical Report (Vol. I, Study Findings)	May 16, 2006 (completed)
Draft TMDL (Vol. I and Vol. II, Implementation Strategy)	January 2007
Final TMDL (Volumes I and II)	March 2007

In completing the TDG TMDL, Ecology expects to rely heavily on historical and current data collected by the Pend Oreille County PUD, USGS, and USACE. Data from these sources and additional data collected by the USGS in 2004 will be used by Ecology to perform a simple spreadsheet-based analysis and, if necessary, a more complex modeling analysis of TDG in the Pend Oreille River system. Ecology's analysis will help determine loading capacity, pollutant allocations, and TMDL implementation to address the effects of TDG from hydroelectric projects and natural phenomena on the Pend Oreille River.

TDG Objective for the Project

State of Washington regulations require that the Project pass the 7Q10 flow while preventing the TDG concentration from exceeding 110 percent saturation. SCL is assuming that the Project will only be responsible for the TDG added relative to the difference between forebay and tailrace FMS TDG levels for flows less than the 7Q10. Depending on review of Project outage records, the 401 certificate may require SCL to accommodate the 7Q10 during a single unit outage; therefore, for a conservative design, SCL will assume that one generating unit (8,000 to 10,000 cfs) has an outage decreasing the total capacity of the plant from approximately 55,000 cfs to 45,000 cfs during high flows. This assumption creates a *design flow rate* of approximately 63,300 cfs, or the difference between the 7Q10 (108,300 cfs) and the assumed plant capacity of 45,000 cfs, for assessing an alternative or combination of alternatives without adding TDG when the level exceeds the 110 percent standard.

Need for Additional Information

Additional testing and ongoing TDG data collection is needed to further characterize Project effects on TDG in the Pend Oreille River downstream of the dam. Information is also needed to further evaluate potential measures that could be undertaken to help the Project achieve compliance with the Ecology standard for TDG. The potential gas abatement alternatives will require further analysis or evaluation to predict TDG performance and reduction benefits associated with specific flow(s) relative to the percent of the 7Q10 flow. Further investigation will also include assessment of and need for the following:

1. Potential combination of alternatives.
2. Additional field testing and monitoring.
3. Identify TDG predictive tools (numerical analysis, etc.).
4. Physical and computational modeling methods.

The study may identify significant structural modifications that will require further evaluation and refinement prior to construction. Such additional work may include on-site geotechnical investigations, physical and computer hydraulic modeling, and final design work. The major uncertainties, anticipated future evaluations, and potential actions may include:

- Sources of incoming TDG and the ability, likelihood, and implications/results of any upstream TDG reduction efforts (e.g., at upstream hydroelectric developments).
- Estimated TDG abatement performance for potential alternatives.
- Numerous engineering design and construction issues and associated requirements (e.g., bedrock integrity and other characteristics, tunnel lining and/or strengthening needs, and flow regulation capabilities [e.g., specific gate structure requirements, optimal inlet, outlet, and other optimal shaping and design considerations]).
- Potential impacts to other resources due to construction and operation.
- Benefits to the target resources as a result of the TDG Monitoring and Abatement Plan (401 certification).
- Actual TDG abatement performance of the implemented alternative by monitoring and other methods.

Assessment of Fish for Gas Bubble Trauma

TDG concentrations in excess of 110 percent saturation have been shown to cause gas bubble trauma in fish. Symptoms of gas bubble trauma vary from blistering beneath the skin when fish are exposed to low exceedances of the TDG standard to mortality when fish are exposed to extreme exceedances. Bubbles on external surfaces of juvenile salmonids have been shown to persist for up to 4 days (Hans et al. 1999).

SCL will examine fish for external signs of gas bubble trauma during surveys conducted downstream of the Project, as part of the Fish Distribution, Timing, and Abundance Study (Attachment 2, Study No. 9 of this RSP). This evaluation would only occur if a scheduled fish sampling event occurs within one week of spill; no sampling events will be scheduled specifically to address the effects of TDG on fish in the tailrace. Although a systematic appraisal of all fish captured will only be conducted during the one-week period following spill, records will be kept of any fish showing obvious signs of gas bubble trauma, regardless of when those fish are captured in relation to spill. The following information will be recorded for each fish showing signs of trauma: species, life-stage, and capture location, time, and date. All fish showing signs of trauma will be photographed.

2.5. Detailed Description of Study

Study Area

The total reach of the Pend Oreille River from Boundary Dam (river mile [RM] 17.0) upstream (southerly direction) to Box Canyon Dam (RM 34.5) is the Boundary Reservoir. There are no major tributaries to the Pend Oreille River between Boundary Dam and Box Canyon Dam, but minor flows are contributed to the reservoir from creeks such as Sullivan and Slate. For the purposes of this study, the reach of the Pend Oreille River from Boundary Dam downstream (northerly direction) to the U.S.-Canada border is considered the Project tailrace.

The study area extends from the Box Canyon tailrace FMS (#12396500) downstream through the Project area to the US-Canada border along the Pend Oreille River mainstem. TDG monitoring will be conducted at the existing USGS FMSs in the Project forebay (#12398550) and tailrace (#12398600) locations as shown in Figure 2.5-1.

SCL Efforts to Date to Assess Potential TDG Abatement Measures

Historic and current efforts to identify, describe, preliminarily assess and rank operational and structural alternatives for gas abatement controls are presented in Appendix 1. Building on the results of the assessment presented in Appendix 1, the following sections discuss the possible TDG abatement measures that have been identified and describe the Phase 1 and Phase 2 study efforts.

Identification and Preliminary Assessment

Approximately 30 alternatives to reduce TDG were identified by SCL in 2003 and 2004. Twenty-four of the original 30 alternatives were preliminarily assessed by SCL as documented in the July 2005 options matrix (see Appendix 3). The 24 alternatives are categorized in the options matrix as follows:

- Operational Alternatives
- Structural Alternatives:
  - Spillway Structural Modification Alternatives
  - Sluice Gate Structural Alternatives
  - New Structure Alternatives
- Lower River Modification Alternatives

Figure 2.5-1. Project Forebay and Tailrace Total Dissolved Gas Monitoring Locations.

Many of the alternatives were further assessed by SCL in late 2005 and early 2006 as further described in this study plan. Initial findings from this exercise included the following:

- No 'Operational Alternatives' were considered to have the potential to significantly reduce TDG levels. This initial finding was stated prior to conducting sluice gate testing in April 2006. A combination of operational and structural alternatives will be considered in this study.
- No 'Spillway Structural Modification Alternatives' were selected for further consideration. These alternatives are currently not promising due to the inability to predict the effect on TDG levels before the alternative is constructed. Previous spill test reports and subsequent peer review in 2006 support this general conclusion.
- Most of the 'Sluice Gate Structural Alternatives' were discarded, except for one option. These alternatives were rejected over concerns about reducing the sluice gate capacity to pass the required Probable Maximum Flood (PMF), inability to predict the effect on TDG levels, and constructability issues.
- Changes to the river channel downstream of the Boundary Project were initially considered, but were eliminated in early 2006 because they would be largely ineffective in reducing downstream TDG levels as measured at the tailrace FMS. The addition of new powerhouse capacity as a significant means of reducing downstream TDG was also dismissed due to the limited amount of new capacity that could be reasonably achieved and economically justified due to the relatively short period of high flows.

Only the operational and structural alternatives proposed for further evaluation are described in this study plan.

Ranking of Alternatives

SCL further assessed the 2006 list of operational and structural alternatives based on nine specific criteria prior to the June 2006 Water Quality work group meeting. These criteria, described in Table 2.5-1, are as follows:

- Hydraulic Capacity: Percent of 7Q10 (108,300 cfs)
- Effect on Ability of Project to Pass the PMF
- Potential TDG Benefit
- Constructability
- Operation and Maintenance (O&M) Challenge
- Cost
- Dam Safety
- Effects on Other Resources
- Effects on Fish (exclusion/passage)

Table 2.5-1. Criteria used for filtering TDG abatement alternatives for the Project.

Criterion	Description and Matrix Scoring
Hydraulic capacity (percent of 7Q10 flow)	How much flow can the alternative pass? A score of 10 implies the option can pass the remainder of the 7Q10 after powerhouse flows (about 64,000 cfs). A 9 implies it can pass 90%, etc.
Effect on Ability to of Project to Pass PMF	The current FERC license requires that the Project be capable of passing the probable maximum flood (PMF) of 316,000 cfs through a combination of generation discharge, spillway and sluiceway discharges. The Project is currently capable of passing a total flow of approximately 360,000 cfs. Theoretically, the difference of approximately 44,000-cfs is the maximum impairment due to a modification. A score of 10 means the option will have no affect on the Project's ability to pass the PMF. A score of 1 means the option will certainly prevent the Project from passing the PMF. A score between 1 and 10 would be assessed if there is some uncertainty as to the effect of the option. An option should also be given a score between 1 and 10 if it will reduce the Project's capacity to pass water but it is yet unknown how much flow it will impair.
Potential TDG Benefit	One of the most challenging criteria to determine and the primary objective of the study. Would the option add gas to the river? No impairment (a score of 10) means that the water passed through this option would maintain at the same TDG level as the forebay level or if the structure will strip gas (tailrace TDG levels are lower than incoming).
Constructability	How has this type of alternative been constructed before? Is construction fairly standard or is this alternative difficult to construct due to other factors? A score of 1 would be assigned if the option required new, innovative, uncertain or risky construction methods that have not been industry tested. An option would be assigned a 10 if it required little or no construction such as an operational alternative.
Operation and Maintenance (O&M) Challenge	If the alternative consists of components not typically encountered at hydroelectric projects, does it require other training by City crew to maintain? Is access to the alternative or specific areas of the alternative problematic? This score reflects if the option requires typical O&M or requires new skills not currently available at the Project. A score of 10 would indicate a very small or non-existent O&M challenge, and a 1 would indicate a large O&M challenge.
Cost	What is a reasonable cost relative to the benefits? How does initial Capital Improvement Project (CIP) cost compare to on-going O&M cost? Total costs (minus fish exclusion/passage cost) of designing, building, operating and maintaining the option (above existing plant O&M costs). An option would be assigned a 10 if there were little or no costs involved, and a 1 if costs were very high.
Dam Safety	Does the alternative modify the structure of the dam and/or powerhouse? Would the alternative affect current dam safety monitoring equipment? If so, how? What is the potential of the option to impact the structural integrity of the dam? An option that has no potential impact to the dam structure is given a score of 10.
Effect on Other Resources	Will this alternative adversely affect or conflict with other environmental and operational resources? Is so, how? This criterion is a measure of how the option affects other Project or utility resources such as the recreation areas, habitat, access roads, head on Project, aesthetics, etc. An alternative would be assigned a 10 if it had little or no effect on other resources, and a 1 for highly significant adverse effects.
Effects on Fish (exclusion/passage)	Will be informed by the findings of the Fish and Aquatic Resources studies. A score of 10 implies that no additional cost is required for fish exclusion or passage, nor will the option impair fish.

A matrix was developed using these nine criteria to compare TDG options to each other as shown in Appendix 1, Alternatives Matrix and Ranking Criteria. These criteria are the basis for filtering and identifying the most promising alternatives for further evaluation as described in this study plan.

The criteria were given relative importance factors. For example, the ability to reduce TDG and effects on fish were given full weight or 100 percent, while constructability factors were weighted at 70 percent. Following the July 2006 Water Quality Workgroup meeting, the operational and structural alternatives were ranked by muting the "Cost" criteria to assess the sensitivity of the options to specific non-cost criteria and eventually, with other criteria filtering methods, provide a technical basis for further assessing alternatives as listed in Appendix 1, Matrix #1.

Sensitivity Analysis

Method

A sensitivity analysis was performed using Matrix #1, Matrix #2, and Matrix #3 in Appendix 1. Matrix #1 (see Appendix 1) assesses if one or more of the criteria were having a more dominant effect on the relative ranking of the alternatives. The analysis was accomplished in two steps. First, the options were ranked according to individual criteria and compared to the ranking positions using all the criteria as presented in Matrix #2 in Appendix 1. Second, each criterion was muted successively and the option ranks were compared to the ranking positions using all the criteria as presented in Matrix #3 in Appendix 1. The results of the muted rankings in Matrix #3 use a color coding scheme. If the option rank order increased, it is shown in yellow. If the option rank order remained the same, it is shown in green. If the option rank order decreased, it is shown in blue. The bottom table on Matrix #3 only sorts the upper table to numerically list the six proposed alternatives for further evaluation in this study.

Observations

As a result of the sensitivity analysis, the following observations are noted among alternatives on Matrix #2 and enlarged as the first table on Matrix #3 relative to assessing the influence of each of the nine criteria on the *Rank with All Criteria*:

- Rank without *Hydraulic Capacity* criterion:

  Muting this criterion replaced only one of the top six alternatives, Option 4-8A, with Option 4-1, Underwater Outlet through Midsection of Dam, since Option 4-1 has a lower score of "4" relative to Option 4-8A's score of "10." Muting the lower score of Option 4-1 increased its overall rank.

- Rank without *Effect on Ability of Project to Pass the PMF* criterion:

  Muting this criterion only switched the rankings of two alternatives, Options 3-2 and 4-9, yet all six alternatives remained in the top six rankings. This result assumes that Option 3-2, Roughen Sluice Gate Discharge, will not significantly reduce the current, total discharge capacity of seven gates. Again, Option 3-2's score of "9" was muted relative to Option 4-9's score of "10," causing the switch in rank between 1 and 2.

- Rank without *Potential TDG Benefit* criterion:

  Muting this criterion elevated the ranking of Option 2-1, Spillway Modifications, to the top six alternatives with Option 4-8A dropping to a rank of 8. Option 2-1's score of "2.5" was muted relative to other channel/tunnel options. All scores listed for this criterion are based on industry experience and judgment reflecting on an alternative's proven ability to reduce TDG. This is the primary criterion to be further evaluated in Phase 1 of the study.

- Rank without *Constructability* criterion:

  Muting this criterion allows the lower scores of Options 4-7A and 4-8 to increase rank into the top six alternatives, yet Option 1-3, Throttle Sluice Gates and Option 4-8A, New Left Abutment Tunnel Intercepts Diversion Tunnel, maintain high ranks. This criterion creates a broad distribution of scores. The apparent consistency of high ranking tunnel options may reflect more confidence in this construction method.

- Rank without *O&M Challenge* criterion:

  Muting this criterion switches the ranking of Option 4-7A with Option 4-8A, and reorders the top 2 through 4 ranking alternatives due to relatively close scores. This option has a broad distribution of scores reflecting the challenge of assessing the O&M impact due to new structures.

- Rank without *Dam Safety* criterion:

  Muting this criterion did not change any of the top six ranks based on all criteria because many alternatives scored a "10" that, when muted, does not appreciably change the overall rank.

- Rank without *Effects on Other Resources* criterion:

  Muting this criterion allowed Option 4-10 to increase in rank due to a lower score relative to Option 3-2, yet both options remain in the top six alternatives. The subtle rank change is perceived as more potential for Option 4-10 to create some impacts at the inlet and/or outlet versus the sluice gate discharge. Option 4-10 has a lower score, indicative of potentially more impacts downstream. The study will assess the potential impacts of tunnel options on other resources including habitats and changing circulation patterns in the forebay and tailrace.

- Rank without *Effects on Fish (exclusion/passage)* criterion:

  Muting this criterion only switched the top six alternative rankings. The two shorter tunnel alternatives, Option 4-9 and Option 4-10, both rank as "1." The apparent rank movement between Option 4-7 and Option 4-8A may indicate a higher sensitivity for tunnels originating in the forebay (left bank) versus tunnels on the right bank.

Conclusions

Based on the sensitivity analysis of the assessment criteria, four criteria have the greatest potential to reorder the options. These include *O&M Challenge*, *Effects on Other Resources*, *Constructability*, and *Effects on Fish*. Currently, only minor changes in ranking are observed when individual criteria are muted. This suggests that no single criterion is keeping any options out of the upper ranking. As more information is developed through the course of implementing this study plan, the options' sensitivity to specific criteria will be better understood.

Possible Alternatives for TDG Abatement

As a result of the sensitivity analysis and ranking the alternatives (see Appendix 1), the following six alternatives (in numerical option order, not rank) appeared most technically promising:

- Option 1-3. Throttle Sluice Gates
- Option 3-2. Roughen Sluice Gate Discharge
- Option 4-7. New Right Abutment Tunnel with Submerged Discharge
- Option 4-8A. New Left Abutment Tunnel Intercepts Diversion Tunnel
- Option 4-9. Penstock/Draft Tube By-Pass
- Option 4-10. New Short Left Abutment Tunnel Next to Unit #51

Conceptual drawings of the six alternatives are presented in Appendix 2 to this study plan. Additional alternatives may be added to this shortlist as potential replacements for any alternatives discarded based on further evaluation; as a result of new information; or, to complete a viable combination of alternatives. Reasons for discarding an alternative will result from conducting Phase 1 or Phase 2 activities described in this study plan, as applicable.

The "undeveloped" options listed in Appendix 3 result from the initial brainstorming and preliminary assessment sessions and include reasons for discarding the options based on preliminary hydraulic capacity assessment, constructability, dam safety, and potential effects on fish similar to the listed criteria in previous sections. None of these options are anticipated to be evaluated in the study; however, the possibility exists that these options could be revisited in the future to create a combination alternative (i.e., two or more options to achieve TDG reduction). Most of the undeveloped alternatives have limited or no practical industry applications at other projects. Unless one of these options can be combined with another option to create a more viable alternative as identified in Phase 1 of this study, SCL will recommend that all of these undeveloped alternatives be discarded from consideration.

The six most promising alternatives on the shortlist, as illustrated in Appendix 2, are further described in the following sections.

Operational Alternative

Generally, the identified operational alternatives would be simpler to implement than structural alternatives. A detailed description of each option, with conceptual drawings, is presented in the *Alternatives to Reduce Total Dissolved Gas Supersaturation* document. Only the single operational alternative proposed to be further evaluated in this study is described in this study plan.

Option 1-3. Throttle Sluice Gates

As originally designed and constructed, the sluice gates normally operate either fully opened or fully closed. The objective of this operational alternative is to operate a sluice gate at a throttled position to determine the maximum possible flow that may be passed while not causing TDG impairment.

This alternative appears more promising than originally anticipated based on observations during the April through June 2006 testing periods. During this testing period, sluice gates No. 3, No. 4, and No. 5 were throttled to 2-, 3-, 4-, and 5-foot openings for 2 to 4 hours with fairly consistent plant discharge (cfs). The results of the 2006 testing will be completed by March 2007 and will be available in the Information Library on the Boundary Project relicensing website at: www.seattle.gov/light/news/issues/bndryRelic/). Michael Schneider (USACE) will peer review the 2006 testing protocol, data analysis, and results.
To throttle the sluice gates on a permanent short- or long-term basis, design modifications must be implemented and may require enclosing the sluice gate to minimize vibration and leakage, and installation of a redundant or auxiliary gate on the upstream side of the dam to seal off the existing sluice gate (downstream side of dam). The auxiliary gate is an anticipated modification to prevent an uncontrolled release of water due to a potential malfunction of the existing sluice gate(s) in accordance with the FERC dam safety requirements. The current ranking of this option assumes few or no fish are present at elevation 1,800 feet NGVD 29 (1,804 feet NAVD 88), or approximately 190 feet below the normal pool elevation of 1,990 feet NGVD 29 (1,994 feet NAVD 88).

Structural Alternatives

The most promising shortlist of structural alternatives are generally described below relative to each conceptual idea to reduce TDG and illustrated in Appendix 2. A detailed description of each option, with conceptual drawings, is presented in the *Alternatives to Reduce Total Dissolved Gas Supersaturation* document.

Option 3-2. Roughen Sluice Gate Discharge

The intended results would be to break up the jet and increase the surface area of the jet impact zone in the tailrace, thereby limiting the depth of plunge. Modifications for this option included adding deflectors. The sluiceways have been designed to enhance flow by minimizing any disturbance to the flowline. The bulbous piers at the entrance to the sluiceways are designed to minimize flow separation. The introduction of roughening blocks and flow deflectors would disrupt the original design capabilities of the sluiceway. Any modification cannot reduce the flow more than approximately 40,000 cfs, which is the difference between the total hydraulic capacity (approximately 360,000 cfs) and the PMF (approximately 316,000 cfs). The current ranking of this option assumes few or no fish are present at elevation 1,800 feet NGVD 29 (1,804 feet NAVD 88).

Option 4-7. New Right Abutment Tunnel with Submerged Discharge

This tunnel alternative[1] would have an inlet on the right side of the lake and discharge at some point below the dam at a submerged elevation. There are many parameters requiring consideration and include, but are not limited to, the following: routing based on structural integrity analysis and abutment geotechnical analysis; inlet and outlet locations and elevations dependent on submergence requirements, topography, and bathymetry; and, optimized hydraulic capacity. Two smaller-diameter, right abutment tunnels may be a variation of this option.

Option 4-8A. New Left Abutment Tunnel Intercepts Diversion Tunnel

The tunnel inlet would be in the existing forebay near the intake tunnel and emergency generator building on the left side of the dam, and discharge would be deeper than the diversion tunnel below the tailwater for submerged discharge. There could be a number of routing alternatives for the tunnel. The outlet for the existing diversion tunnel would require enlargement and re-alignment for optimal submergence and TDG reduction performance.

Option 4-9. Penstock / Draft Tube By-Pass

This option assumes evaluation of different size tunnels that bifurcate from the existing penstock and bypass the water around the turbine within the boundaries of the headgate and the draft tube gate. SCL anticipates modeling of the test turbine bypass option either with a new turbine design or with existing turbines with a new turbine design potentially designed for maximum capacity and flow, not peak efficiency. If implemented, the standard approach is to design (including hydraulic modeling) and construct one bypass, then monitor for TDG reduction performance, followed by potential design modification to further reduce TDG, then construct the second bypass. A plant outage will be required for construction, and if the construction and testing of a new bypass takes longer than approximately 9 months, excess spill may be produced due to the outage.

Option 4-10. New Short Left Abutment Tunnel Next to Unit #51

The tunnel inlet would be in the existing forebay on the left side of the generating unit #51 intake and conceptually be a seventh penstock. This option would require re-sizing the existing forebay to accommodate this new intake. There may be a couple of routing alternatives for the tunnel. This option would require hydraulic modeling to optimize resizing the forebay for all existing generating units including this new tunnel. This option may present an opportunity to improve capacity, efficiency, and reduce TDG production through the penstocks and turbines.

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[1] For all tunnel options, it is assumed that conventional drill and shoot methods would be used to excavate the rock from the tunnel outlet. The shafts for the gate controls and accessory equipment would employ the “drop raise” mining technique of drilling closely spaced holes from the ground surface, vertically down to and intersecting the tunnel. The drill holes outline the perimeter of the shaft and are loaded with charge delays from the bottom, then sequentially detonate, moving up the shaft from the tunnel, to release rock material into the tunnel where it can be mucked out.

Proposed Methodology

The methodology proposed for this study is to describe existing conditions within the study area including hydrology, hydraulics, operations, water quality, and environmental resources as the basis for evaluating the benefits of each alternative. The nine criteria for screening TDG abatement measures discussed previously (as presented in Appendix 1) provide the basis for the initial comparison of potential benefits of each alternative.

The Phase 1 and Phase 2 components of this study will focus on the most promising alternatives and identify potential alternative combinations that may be promising to achieve the highest attainable level of improvement to TDG impairment at the Project, with the goal of determining an alternative or combination of alternatives to maximize gas abatement up to the 7Q10 (108,300 cfs) flow.

Desktop analysis, field studies, hydraulic analysis, and hydraulic modeling efforts are needed to complete Phase 1 and Phase 2 identification and detailed design of the alternatives. These efforts include topographic, bathymetric and geologic surveys; physical and numerical modeling of the Project and specific features of the alternatives; and, constructability analyses that may include geotechnical investigations.

Depending on review of the Project outage record, SCL may assume that one generating unit (8,000 to 10,000 cfs) has an emergency outage decreasing the total capacity of the plant from approximately 55,000 cfs to 45,000 cfs during high flows. This assumption creates a *design flow rate* of approximately 63,300 cfs, or the difference between the 7Q10 (108,300 cfs) and the assumed plant capacity of 45,000 cfs, for assessing an alternative or combination of alternatives that would not add TDG when the level exceeds the 110 percent standard.

In addition to the documents that have been developed to date (as available on the Boundary Project relicensing website and referenced in this study plan), this study will use the following sources of TDG-related data to further evaluate gas abatement alternatives:

- TDG forebay and tailrace FMS data from mid-1999 through 2005 (USGS 2006) for Gage Nos. 12398550 and 12398600.
- Hourly flow data from the U.S. Geological Survey for the Pend Oreille River below Box Canyon Dam (Gage No. 12396500) and below Boundary Dam (Gage No. 12398600) near the U.S.-Canada border.
- Hourly flow data from SCL for total flow release from Boundary Reservoir (energy generation plus spill) from 1987 through 2005.
- Hydrologic Record (dataset and statistics) for Boundary Project (March 2007) as referenced in Attachment 1, section 3.1 of this RSP.
- 2006 Sluice Gate Operational and TDG Testing Assessment (March 2007).
- SCL Drawings of Pertinent Project Features such as Plans and Sections of the Dam, Forebay, Powerhouse, Diversion Tunnel, Geology, and Rock Cores.

This study will be conducted in two phases in close coordination with relicensing participants and Ecology. Together, the Phase 1 and Phase 2 components of the study will represent a progressively more detailed and refined assessment of the operational and structural alternatives for reducing TDG levels downstream of the Project.

Phase 1 Activities and Content for Study Report

Phase 1 of this study will generally consist of the ongoing, desktop, and fieldwork tasks listed and described below.

Ongoing Activities

- The USGS will continue to collect and perform QA/QC on the forebay and tailrace FMS data. One probe exists at the forebay FMS and two probes exist at the tailrace FMS. One forebay probe and one tailwater probe have recorded hourly data from 1999 to 2005. In 2005, a second tailwater probe was added to provide redundant data in case of meter outage; in addition, the frequency of readings for all three probes changed from hourly to 15-minute intervals. The two tailwater probes are closer to the left bank. A third probe was installed by SCL at the tailrace FMS closer to the right bank in spring 2006 to better assess mixing characteristics across the tailrace transect during high flows and retrieved in late summer 2006. Deployment of a third probe in the tailrace is expected to be repeated in 2007.
- Throttle testing of two or more sluice gates is not anticipated to continue in 2007. Depending on the Phase 1 results and TDG TMDL process, throttle testing may be planned for 2008/2009.

Tasks for Phase 1 of Study

Task 1.1 Familiarization with Existing TDG-related Studies and Reports

Review and provide brief summaries of the scope and results of the various TDG-related studies and evaluations that have been conducted since 1998 (through early 2007) concerning gas supersaturation at the Project to serve as part of background information for 2007 study report. The studies and reports will include documents prepared by internal staff and consultants. Study and report references in this document include Parametrix (1998), Lemons (2000), Columbia Basin Environmental (2001, 2003), SCL (2003, 2005), and Schneider (2006). Documents related to the Ecology Pend Oreille River TMDL for TDG will require review and familiarization.

Task 1.2 Detailed Scope of Work for Phase 1 and Phase 2 Tasks

Based on the results of the review conducted in Task 1.1, develop a detailed scope of work for performing the remaining Phase 1 tasks and Phase 2 tasks including deliverables, cost estimates, and schedule in accordance with current SCL requirements relative to FERC, Ecology, and other regulatory processes. Performing Task 1.1 may suggest the need for additional investigations to address unresolved conditions such as: the effect of operational alternatives on spill through the various structures; the effect of the submerged cofferdam in the tailrace from original construction; and the conditions creating, and the amount of, powerhouse flow entrainment into the spill.

Task 1.3 Existing Conditions – Data Collection, Analysis, Graphs and Tables

This task requires the Technical Consultant to work closely with SCL staff experienced with analyzing spill and non-spill related TDG impairment at the Project.

1.3.1 Analyze hourly and 15-minute interval TDG data reported by the USGS for the forebay and tailrace FMSs relative to Pend Oreille River flow data, Project discharge and spill volumes to provide gas saturation duration, frequency and related statistics for the 2007 study report. Describe and present data and statistics in tables and graphs.

1.3.2 Identify and describe TDG uptake mechanisms and hydrodynamics in the tailrace.

1.3.3 Briefly summarize the Project hydrologic record (March 2007) for the 2007 study report.

1.3.4 Evaluate methods and controls to reduce air admission requirements to decrease total dissolved gas. Under specific operating conditions, generating units #55 and #56 add TDG due to air admission at low gate openings (Lemons 2000; SCL 2003). This potential TDG impairment will be evaluated to identify gas abatement control measures.

1.3.5 Develop and implement 2007 TDG Monitoring Plan. The purpose of this task is to describe and/or verify the TDG exchange process and uptake mechanisms in the forebay, turbine discharge area (afterbay), and tailwater channel. This task will require planning, procuring, installation, collection of TDG data, and retrieval of TDG monitoring transects. The collected TDG data will be properly reduced to comply with or exceed current USGS QA/QC methods for water quality instruments, calibration, maintenance, and precision. Collect Acoustic Doppler Current Profiler (ADCP) velocity data in the Project tailrace for calibrating analyses.

Task 1.4 7Q10 Flow Conditions

Evaluate 7Q10 flow relative to forebay elevations, generation, and tailwater ranges. The powerhouse capacity will decrease during extreme flood events due to increased tailwater elevations. This reduction in capacity will be estimated to refine the estimated required capacity of the TDG abatement alternatives (differences between 7Q10 and plant discharge flow).

Task 1.5 Estimate TDG Performance for Alternatives, Identify and Assess Potential Alternative Combinations

Parts A and B of this Task will occur concurrently to identify a potentially reasonable alternative or alternative combination that satisfies particular engineering analysis and design goals.

Task 1.5.A. Estimate TDG Performance for Alternatives or Alternative Combinations

Part A of Task 1.5 is to estimate TDG performance for the shortlist of most promising alternatives.

1.5.A.1 Propose and describe rationale for utilizing a specific method or analytical approach for estimating TDG performance based on existing information considering the unique characteristics of the Project.

1.5.A.2 Estimate or predict gas abatement performance for the shortlist of operational and structural alternatives including potential alternative combinations.

1.5.A.2 (1) Briefly describe specific field-testing, surveys, and numerical techniques (DGAS-type of regression analysis, CRiSP methods, etc.) to estimate or predict TDG reduction performance to further assess each alternative based on previous analyses and professional judgment.

1.5.A.2 (2) Provide alternatives comparison of TDG performance relative to existing conditions and variable, forebay TDG levels.

1.5.B. Selecting Gas Abatement Alternatives

Part B of Task 1.5 is to assess whether a selected alternative or combination has a greater potential for gas abatement based on the following design goals defined for Alternative #1, #2, and #3:

Alternative #1 Maximum gas abatement measure to achieve the highest attainable level of improvement resulting in downstream TDG levels that are at least equal to or less than the TDG level at the forebay FMS during the 7Q10 flow, assuming the forebay TDG level is greater than 110 percent. This alternative shall reflect the alternative or alternative combination that comes closest to achieving the 110 percent standard.

Alternative #2 No net increase in TDG relative to forebay FMS TDG levels. This alternative shall pass the *design flow rate* (63,300 cfs) resulting in downstream TDG levels similar to the forebay FMS TDG levels during the 7Q10 flow.

Alternative #3 Account for other potential resource impacts. This alternative shall significantly reduce downstream TDG compared to existing conditions, while minimizing environmental impact, and cost of construction and operation of this alternative.

Task 1.6 Preliminary Design and Construction Approach

For the alternatives and alternative combinations resulting from Task 1.5, briefly identify and describe geologic conditions at the Project, and identify potential location(s) and/or alignment(s) using existing SCL drawings and related documents, as applicable. Identify and describe design and construction approach, constraints, and limitations associated with each alternative.

Task 1.7 Field Reconnaissance, Surveys, and Hydraulic Analysis

Summarize existing topography, bathymetry, depositional areas, and geologic characteristics where significant construction activities will occur based on assessing alignment or location of an alternative or alternative combination as a result of performing Tasks 1.5 and 1.6. This information is required to better estimate gas abatement performance and cost.

- 1.7.1 Provide design details required to minimize gas uptake at the discharge of any new alternative.
- 1.7.2 Estimate survival rates of fish passing through a new alternative to minimize potential negative effects on fish passing through the new structure.
- 1.7.3 Assess flow interactions downstream during a major flood event due to existing and new alternative discharge.
- 1.7.4 Assess effects of the new alternative on the operational efficiency of the powerplant.

Task 1.8 Preliminary Cost Estimates for Design and Construction

Prepare preliminary cost estimates for design and construction of the alternatives resulting from Tasks 1.5 through 1.7; identify applicable risk assessment methodologies relative to dam safety concerns (Hartford 2004); and conduct economic feasibility analysis (Ecology 2006). Identify and describe all assumptions, constraints, and limitations to inform the Phase 2 and SCL planning efforts.

Task 1.9 Proposal for Phase 2 Activities

Propose activities for Phase 2 of this study effort to review with relicensing participants as a result of performing Tasks 1.1 through 1.8. Further refinement of the alternatives developed in Phase 1 are anticipated to require field reconnaissance studies and hydraulic modeling to identify and resolve uncertainties associated with the alternative designs and specific application at the Project.

Task 1.10 Draft and Final Phase 1 Reports

Prepare Draft and Final Phase 1 study reports for review by relicensing participants including photographs, graphs, tables, and other illustrations needed to effectively describe the tasks, methodologies, and their results.

Phase 2 Activities and Content for Study Report

Phase 2 of this study will generally consist of the following ongoing, desktop, and fieldwork tasks as listed and described below. The Phase 1 report will inform refinements to the Phase 2 tasks listed in this study plan and as a result, the Phase 2 tasks will be updated in 2007/2008.

On-going Activities

- The USGS will continue to collect and perform QA/QC on the forebay and tailrace FMS data.
- Results will be developed and made available from other studies in 2007 that inform the TDG study process.

Tasks for Phase 2 of Study

Task 2.1 2008 TDG Monitoring Plan

The purpose of this task is to describe and/or verify the TDG exchange process and uptake mechanisms in the forebay, turbine discharge area (afterbay), tailwater channel, and other locations identified as a selected Alternative Nos. 1, 2, and 3 (refer to Phase 1, Task 1.5). This task will require planning, procuring, installation, collection of TDG data, and retrieval of TDG monitoring transects. The collected TDG data will be properly reduced to comply with or exceed current USGS QA/QC methods for water quality instruments, calibration, maintenance, and precision.

2.1.1 Evaluate mixing zone dynamics for the USGS tailrace FMS based on 2006 and 2007 monitoring data for the two probes.

Task 2.2 Phase 2 Report Content for Executive Summary

Summarize Phase 1 study efforts and existing dissolved gas conditions for 2008/2009 Study report. Identify and describe operational, structural and/or combination of gas abatement measures resulting from Phase 1 efforts.

Task 2.3 Conceptual and Feasibility Analysis of Alternatives

Perform and present results of hydraulic analysis, total dissolved gas evaluation, surveys, specific field testing, and hydraulic modeling for each applicable gas abatement alternative. The hydraulic analyses for the penstock bypass and tunnel alternatives primarily consist of determining acceptable tunnel/pipe, valve, gates, and submergence requirements. Potential cavitation will need to be accounted for in the analysis. The feasibility level of evaluation will include hydraulic model studies to assist with the final feasibility level designs and evaluation of TDG abatement measures.

2.3.1 Field Surveys and Hydraulic Modeling. Computational and/or physical hydraulic modeling is anticipated to characterize existing conditions and to optimize new proposed modifications. The hydraulic modeling will provide a better understanding of gas transfer mechanisms where the plant and spill flow interact, and contribute to testing and optimizing the design of an alternative or alternative combination. A reasonable assumption is that model testing continues for at least one year.

Task 2.4 Effects of Alternatives on Other Resources

Describe and estimate potential effects on resources due to gas abatement alternative(s) selected as a result of Phase 1 tasks. Resources include water quality, fish and aquatics, operations, in-river construction, plant and wildlife, air quality, cultural, and aesthetics. (Refer to the criteria used to screen alternatives). Based on other resource study results, the evaluation and determination of a "preferred alternative" may need to assess the effects on fish (Neitzel 2000).

Task 2.5 Cost Estimates for Design and Construction

Refine and update Phase 1 cost estimates for design and construction based on final Phase 1 report and results of Phase 2, Tasks 2.1 through 2.4. An economic feasibility analysis (Ecology 2006), dam safety risk assessment (Hartford 2004), or other pertinent analysis of alternatives may need to be performed based on Phase 2 study results.

Task 2.6 Planning the TDG Elements of Application for 401 Certification

Discuss evaluation and implementation of TDG alternative(s) relative to 401certification process. This task includes proposed schedule, licensing, permitting, and environmental reviews required by Ecology, USACE, EPA, USFWS, WDFW, SHPO, and other agencies as applicable.

Task 2.7 Gas Abatement Plan

Draft a gas abatement plan for the 401 certification application including monitoring and reporting activities that will be undertaken during the new license term, such as those needed to evaluate the effectiveness of TDG control measures or other mitigation. This is a separate document from the study reports.

Study Implementation Planning

TDG study efforts and associated evaluations may extend into 2009 and beyond during development of the application for 401 certification, Preliminary Licensing Proposal (PLP), and License Application.

As described in Attachment 1, section 2.2 of this RSP, SCL has selected and retained the Technical Consultant that will implement the relicensing study program. Prior to initiation of the studies, the Technical Consultant will participate, with SCL and relicensing participants, in developing and refining any remaining details related to implementation of the studies.

2.6. Work Products

The following official work products are required for completion of this study:

- *Draft and Final Phase 1 study reports*—The Phase 1 report is expected to include (but not be limited to) the following contents:
    - Section 1: Executive Summary. Background, study goals, and summarize existing and Phase 1 information.

- Section 2: Existing Project Conditions and Facilities. Describe existing hydrologic and TDG conditions relative to Project facilities. Include existing drawings of Project features, graphs and tables showing rating curves, generation, flow and TDG data. Describe TDG uptake mechanisms and hydrodynamics in the tailrace.
- Section 3: Gas Abatement Alternatives. Summarize identification and development of alternatives. Identify and present rationale for determination of top three ranked alternatives (i.e., Alternative Nos. 1, 2, and 3).
- Section 4: Gas Abatement Performance. Describe estimated gas abatement performance for the most promising alternatives and Alternative Nos. 1, 2, and 3. Describe and graphically provide a comparison and summary of the results.
- Section 5: Field Reconnaissance, Surveys, and Hydraulic Analysis. Summarize existing topography, bathymetry, depositional areas, and geologic characteristics where significant construction activities will occur based on assessing alignments or locations of alternatives listed in Section 3.
- Section 6: Design and Construction Cost Estimates. Preliminary estimates for design and construction costs including O&M will be developed for Alternative Nos. 1, 2, and 3 resulting from performing Phase 1, Task 1.5. All assumptions will be identified and described for each specific cost line item. Line items will include, but not be limited to: (1) survey(s), potential land acquisition, engineering design, analysis and modeling required to design the alternative; (2) construction materials and installation cost including taxes and contingencies; (3) permitting and environmental review document preparation and meetings; and (4) City of Seattle and SCL contracting administration and overhead.

- *Draft and Final Phase 2 study reports*—The Phase 2 report is expected to consist of similar contents as the final Phase 1 report, with updates and modifications, and the addition of the following work efforts and report contents:
  - Environmental Effects of Alternative and Alternative Combination
  - Identification of environmental resources and how they may be affected by the alternatives, including potential impacts during construction and longer-term operational effects
  - Field Surveys, Hydraulic Modeling and Prototyping
  - Revised Gas Abatement Performance
  - Revised Design and Construction Estimates
  - Identification of Permits and Environmental Review for the 401 certification process
  - Gas Abatement Plan for the 401 certification application

2.7. Consistency with Generally Accepted Scientific Practice

The methods described herein have been developed based on review of regional TDG-related efforts (USBR 1998, Avista 2000, USACE 2000, Grant County PUD 2002, and Chelan County PUD 2003) and in consultation with relicensing participants. The study approach and methods are consistent with Ecology's Water Quality Certifications for Existing Hydropower Dams, Guidance Manual (Ecology 2005).

2.8. Consultation with Agencies, Tribes, and Other Stakeholders

As indicated above, SCL met with Ecology in 2005 to identify issues to be addressed as part of the 401 certification process. Workshops on the Project relicensing were held in Spokane, Washington, on November 30, 2005, and February 16, 2006. Water Quality Workgroup meetings were held in Spokane on May 22, 2006, July 25, 2006 and August 16, 2006, and in Metaline Falls, Washington, on June 29, 2006. Parties attending the Water Quality Workgroup meetings included Ecology, USFS, USFWS, Confederated Tribes of the Colville Reservation, the Kalispel Tribe of Indians, Columbia River Intertribal Fisheries Commission, BC Hydro, Pend Oreille County PUD, and Columbia Power Corporation.

At the May 22, 2006 Water Quality Workgroup meeting, SCL and relicensing participants discussed SCL's proposed TDG monitoring, testing, and study plan development process including 1) existing TDG operational testing and assessment, 2) Ecology's approach to the Pend Oreille River TDG TMDL, 3) gas abatement measures applied at other dams in the region, 4) SCL's TDG abatement measures matrix, and 5) potential PSP study plan elements. SCL confirmed that the eventual solution to TDG abatement at the Project could consist of a combination of structural and operational elements.

At the June 29, 2006 Water Quality Workgroup meeting, SCL and relicensing participants discussed the process by which SCL had developed a series of potential TDG abatement alternatives and preliminarily assessed the application and function of those alternatives. SCL explained that when a shortlist of potential alternatives was identified, study plans would be developed to fully evaluate the effectiveness of the alternatives on the list. SCL provided an overview of potential TDG abatement alternatives from the four following categories: operational alternatives for existing structures, spillway structural modification alternatives, sluice gate structural alternatives, and new structure alternatives. SCL then presented a system developed to rank potential alternatives based on a range of weighted criteria.

At the July 25, 2006 Water Quality Workgroup meeting, SCL and relicensing participants discussed the ongoing preliminary assessment of the concepts and function of potential TDG abatement alternatives identified at the June 29 meeting. SCL described the criteria used to preliminarily evaluate the effectiveness of the alternatives and the ranking of the alternatives based on the criteria. SCL explained that it was currently performing a sensitivity analysis to assess the effect of individual criteria on the overall ranking of alternatives. SCL stated that a proposed shortlist of alternatives — that would be subjected to more detailed analysis — would be presented at the August 2006 workgroup meeting. SCL solicited comments from relicensing participants on the TDG alternatives matrix, including suggestions for additional or improved criteria for evaluating potential alternatives. SCL suggested that relicensing participants share the matrix of alternatives and assessment criteria with engineers in their respective organizations.

At the August 16, 2006 Water Quality Workgroup meeting, SCL and relicensing participants discussed the process by which a shortlist of potential TDG abatement measures for the Boundary Project was identified. SCL explained that the cost criterion had been muted so that abatement measures had been evaluated solely on the basis of technical merit. SCL outlined the sensitivity analysis undertaken to assess the degree to which individual evaluation criteria had affected the overall ranking of potential measures and noted that the results of the sensitivity analysis showed that the following, most promising alternatives selected by SCL for further analysis were consistently indicated as the best potential approaches by the ranking criteria:

- Throttle Sluice Gates
- Roughen Sluice Gate Discharge
- New Right Abutment Tunnel with Submerged Discharge
- New Left Abutment Tunnel Intercepts Diversion Tunnel
- Penstock/Draft Tube By-Pass
- New Short Left Abutment Tunnel Next to Unit #51

Comments provided by relicensing participants on the draft study plan are summarized in the PSP Attachment 3-5 (SCL 2006b) and can also be found in the workgroup meeting summaries available on SCL's relicensing website (http://www.seattle.gov/light/news/issues/bndryRelic/). Written comments provided on this study plan are also included in PSP Attachment 3-5 (SCL 2006b).

In its PAD/Scoping comment letter (USFS 2006), the USFS requested that "Any fish captured below the dam, in conjunction with other studies and during the spill periods, should be analyzed for characteristics of gas bubble trauma and documented with location, date, species, life stage and photo." SCL plans to conduct this analysis as described in section 2.4 (under Need for Additional Information) of the Fish Distribution, Timing, and Abundance Study plan (Study No. 9).

Since filing the PSP, SCL has continued to work with relicensing participants on its proposed study plans. Comments made during the November 15 study plan meeting and comments filed with FERC by the USFS (2007) stated that "The Forest Service agrees with SCL's proposed Evaluation of Total Dissolved Gas and Potential Abatement Measures. This study plan is very well organized and provides the needed detail for the issue. The agency [USFS] appreciates SCL's collaborative effort to provide a consensus based study proposal." No other PSP comments were filed with FERC regarding this study. (Comments are summarized in Attachment 3 and consultation documentation is included in Attachment 4 of this RSP). As a result, SCL has made only minor modifications to this plan to add clarification and detail.

2.9. Schedule

The schedule for completing this study is provided in Table 2.9-1 and includes the current FERC deadlines and potential opportunities (tentative dates) for relicensing participants to review study plans and study results with SCL.

Table 2.9-1. Project Schedule for Evaluation of Total Dissolved Gas and Potential Gas Abatement Measures.

Phase	Target Date
Phase 1 of study — Data Collection and Alternatives Assessment	March 2007 – October 2007
Prepare draft Phase 1 study report (first-year results)	November–December 2007
Distribute draft Phase 1 study report for relicensing participant review	January 2008
Meet with relicensing participants to review first year efforts and results and discuss plans for second year efforts	February 2008
Include final Phase 1 report in Initial Study Report (ISR) filed with FERC	March 2008
Hold ISR meeting and file meeting summary with FERC	March 2008
Phase 2 of study — Evaluation of Alternatives	February–October 2008
Prepare draft Phase 2 study report	October–November 2008
Distribute draft Phase 2 study report for relicensing participant review	December 2008
Meet with relicensing participants to review study efforts and results and “cross-over” study results	January 2009
Include final Phase 2 study report in Updated Study Report (USR) filed with FERC	March 2009
Hold USR meeting and file meeting summary with FERC	March 2009

2.10. Progress Reports, Information Sharing, and Technical Review

Both the draft and final study reports will be available to relicensing participants. Prior to release of the Initial and Updated Study Reports (which will include the results of this study), SCL will meet with relicensing participants to discuss the study results, as described in Attachment 1, section 2.3 of this RSP.

2.11. Anticipated Level of Effort and Cost

The estimated effort and cost for performing Phase 1 of the study ranges from $450,000 to $600,000, subject to review and revisions as additional details are developed. The estimated effort and cost for performing Phase 2 of the study and developing a gas abatement plan for the Boundary Project ranges from $1,300,000 to $1,800,000.

3.0 LITERATURE CITED

Avista Corporation. 2000. Gas Supersaturation Abatement Alternatives, Cabinet Gorge Hydroelectric Project, Phase 3 Study Report, December 2000. Report prepared by Duke Engineering & Services in association with Oakwood Consulting, Inc.

Chelan County, Public Utility District No. 1. 2003. Gas Abatement Techniques at Rocky Reach Hydroelectric Project (Final Report), prepared by MWH. August 2003.

Columbia Basin Environmental. 2001. Boundary Dam Total Dissolved Gas Study, Draft Report.

Columbia Basin Environmental. 2003. Boundary 2002 Spill Evaluation, 1 May – 25 July 2002. Draft Report dated January 2003, The Dalles, Oregon.

Ecology (Washington State Department of Ecology). 2005. Water Quality Certifications for Existing Hydropower Dams, Guidance Manual. March 2005, Revised April 2005.

Ecology. 2006. *Draft* Guidance for Evaluating the Feasibility of Controls to Meet Water Quality Standards for Dams in Washington. August 2006.

EPA. 1993. Clark Fork - Pend Oreille Basin water quality study: A summary of findings and a management plan. United States Environmental Protection Agency Regions VIII and X. Report for Section 525 of the Clean Water Act of 1987.

Golder Associates. 2005. Pend Oreille River Watershed Management Plan. Report prepared for the WRIA 62 Watershed Planning Unit. March 2005. Available at URL: http://www.pocd.org/wmp/plan/WRIA%2062%20WMP%20032305.pdf. Accessed October 25, 2005.

GEI Consultants, Inc. 2004. Intermountain Province Subbasin Plan, Pend Oreille Subbasin. Submitted to: Northwest Power and Conservation Council, Portland, Oregon, on behalf of: Intermountain Province Oversight Committee and Intermountain Province Subbasin Work Teams.

Grant County, Public Utility District No. 2. 2003. Total Dissolved Gas Exchange at Priest Rapids Dam, July 21 – August 4, 2002, prepared by U.S. Army Corps of Engineers. August 14, 2003.

Hans, K. M., and M. G. Mesa, and A. G. Maule. 1999. Rate of disappearance of gas bubble trauma signs in juvenile salmonids. Journal of Aquatic Animal Health, Volume 11(4), pages 383–390.

Hartford, Desmond N.D. and Gregory B. Baecher. 2004. Risk and Uncertainty in Dam Safety. CEA Technologies, Inc., Dam Safety Interest Group.

Lemons, J. and M. Gunter. 2000. Boundary Dam Total Dissolved Gas Evaluation: TDG Dynamics Associated with Power Generation.

Neitzel, Duane A., et. al. 2000. Laboratory Studies on the Effects of Shear on Fish, Pacific Northwest National Laboratory. DOE/ID-10822 published September 2000.

Parametrix. 1998. Dissolved Gas Assessment, Boundary Dam.

Pickett, P.J. 2004. Quality Assurance Project Plan. Pend Oreille River Total Dissolved Gas Total Maximum Daily Load Technical Study. Washington State Department of Ecology Environmental Assessment Program, Olympia.

Schneider, Michael L. 2006. Report Review Comments on "Boundary 2002 Spill Evaluation" and "TDG Analysis During the 2002 Spill Event," City of Seattle, Seattle City Light Department (SCL) dated June 21, 2006.

SCL (Seattle City Light). 2003. Seattle City Light Memorandum to Mike Harrison, Mike Haynes, and Mike Sinowitz, and the Boundary Relicensing Team regarding Recommendations to reduce total dissolved gas levels at Boundary.

SCL. 2005. Seattle City Light TDG Analysis During the 2002 Spill Event. July 13, 2005.

SCL. 2006a. Pre-Application Document for the Boundary Hydroelectric Project (FERC No. 2144). Seattle, Washington. May 2006. Available online at http://www.seattle.gov/light/news/issues/bndryRelic/br_document.asp

SCL. 2006b. Proposed Study Plan for the Boundary Hydroelectric Project (FERC No. 2144). Seattle, Washington. October 2006. Available online at http://www.seattle.gov/light/news/issues/bndryRelic/br_document.asp

U.S. Army Corps of Engineers. 2000. Chief Joseph Dam, Columbia River, Washington, Gas Abatement Study, General Reevaluation Report (Final). May 2000.

U.S. Bureau of Reclamation. 1998. Structural Alternatives for TDG Abatement at Grand Coulee Dam, Conceptual Design Report prepared by Kathleen H. Frizell and Elizabeth Cohen for USBR, Pacific Northwest Region. October 1998.

USFS (USDA Forest Service). 1988. Alternative maps, final environmental impact statement for the land and resource management plan, Colville National Forest. USDA Forest Service, Pacific Northwest Region.

USFS. 2006. Boundary Hydroelectric Project, FERC No. 2144-035, Response to Scoping Document 1, Comments on Pre-Application Document, and Study Requests. Colville National Forest. August 31, 2006.

USFS. 2007. Boundary Hydroelectric Project, No. 2144-035, comments to Proposed Study Plan. Letter dated January 9, 2007.

USGS (U.S. Geological Survey). 2005. Gages #12398550 and #12398600. Tacoma, Washington.

USGS. 2006. Online NWIS web data for the nation. http://waterdata.usgs.gov/nwis/qw.

Washington Administrative Code Chapter 173-201A. 1997. Water Quality Standards for Surface Waters of the State of Washington. Olympia, Washington.

Washington Administrative Code Chapter 173-201A. 2003. Water Quality Standards for Surface Waters of the State of Washington. Olympia, Washington.

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Appendix 1: Total Dissolved Gas Abatement Alternatives Matrix and Ranking Criteria

Matrix #1 - Original Matrix with Scores and Overall Rank, and Muted "Cost" Column

Top Six Alternatives Based on "Rank" Column (1 through 6)

No.	Option	Hydraulic Capacity: Percent of 7Q10	Effect on Ability of Project to pass PMF	Potential TDG benefit (no impairment)	Construct-ability	Cost (capital and O&M)	O&M Challenge	Dam Safety	Effect on Other Resources	Effects on Fish (exclusion / passage)	Weighted Score	Normalized Score	Rank
		1	1	1	0.7	0.7	0.5	1	0.5	0.8			
1-1	Existing Spillway Limited Ops	TBD	TBD	TBD	TBD		TBD	TBD	TBD	TBD	0	0.0%	25
1-2	Existing Skimmer Gate Limited Ops	TBD	TBD	TBD	TBD		TBD	TBD	TBD	TBD	0	0.0%	25
1-3	Throttle Sluice Gates	6	10	7	10		8	10	10	9	56.2	96.9%	5
1-4	Operate Gates #1 and #7	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A	0	0.0%	25
2-1	Spillway Modifications	10	10	2.5	9		10	10	10	1	49.6	85.5%	10
2-2	Skimmer Gate Modifications	0.5	10	8	7		9	8	10	4	44.1	76.0%	17
2-3A	Raise Plunge Floor--Spillway	10	10	2	5		4	10	10	1	43.3	74.7%	21
2-3B	Raise Plunge Floor--Sluiceway	10	10	2	5		4	10	10	1	43.3	74.7%	21
2-7	Floating Spill Dissipater	10	10	5	3		3	10	9	1	43.9	75.7%	18
3-1	Armor Area Downstream of Sluice #1 and #7	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A	0	0.0%	25
3-2	Roughen Sluice Discharge	10	9	7	9		8	10	10	8	57.7	99.5%	2
3-4	Add Fixed-Cone Valves to Sluices	6	10	9	1		4	10	10	7	48.3	83.3%	11
3-5A	Add Branch Outlet to Sluice Liner (submerged discharge)	5	10	10	4		7	1	10	8	43.7	75.3%	20
3-7	Floating Barge Deflector	10	10	5	3		3	10	9	1	43.9	75.7%	18
4-1	Underwater Outlet through Midsection of Dam	4	10	10	4		5	7	7	10	47.8	82.4%	12
4-4	Bridge-type Spillway Apron	10	10	3	3		3	9	10	1	41.4	71.4%	23
4-4A	New Right Abutment Spillway w/Tunnel Outlet	8	10	6	6		8	10	9	1	47.5	81.9%	13
4-4B	New Right Abutment Spillway w/Long Flume	8	10	6	4		8	10	9	2	46.9	80.9%	14
4-4C	New Right Abutment Spillway with Natural Rock Shoot	6	10	10	2		7	9	10	1	45.7	78.8%	16
4-4D	New Right Abutment Long Side-Channel Spillway	3	10	8	2		7	9	10	1	40.7	70.2%	24
4-5	New Left Abutment Spillway w/Flume along Road	10	10	6	2		7	10	7	3	46.8	80.7%	15
4-5B	New Left Abutment Spillway Along Road, Forebay Intake	10	10	6	2		8	10	7	7	50.5	87.1%	9
4-7	New Right Abutment Tunnel w/Submerged Discharge	10	10	10	5		5	10	8	8	56.4	97.2%	4
4-7A	New Right Abutment Tunnel w/Fixed Cone Valve	10	10	10	2		3	10	8	8	53.3	91.9%	7
4-8	Open Existing Diversion Tunnel and Add Control Struct	10	10	10	1		1	10	7	8	51.1	88.1%	8
4-8A	New Left Abutment Tunnel Meeting Diversion Tunnel	10	10	10	5		5	10	7	5	53.5	92.2%	6
4-9	Penstock/Draft Tube ByPass	10	10	10	7		8	10	7	7	58	100.0%	1
4-10	New Short Left Abutment Tunnel Next to U51	10	10	10	7		8	10	7	6	57.2	98.6%	3
											58	100%	

Matrix #2 - Rank of Alternatives Muting Each Criteria Based on Matrix #1

No.	Options	Hydraulic Capacity: Percent of 7Q10	Effect on Ability of Project to pass PMF	Potential TDG benefit (no impairment)	Construct-ability	Cost (capital and O&M)	O&M Challenge	Dam Safety	Effect on Other Resources	Effects on Fish (exclusion / passage)	Weighted Score	Normalized Score	Rank Based on All Criteria, Except Cost	Rank w/o Hydraulic Capacity	Rank w/o PMF	Rank w/o TDG Benefit	Rank w/o Construct-ability	Rank w/o O&M	Rank w/o Dam Safety	Rank w/o Other Resource Effects	Rank w/o Fish Effects
		1	1	1	0.7	0.7	0.5	1	0.5	0.8											
1-1	Existing Spillway Limited Ops	TBD	TBD	TBD	TBD		TBD	TBD	TBD	TBD	0	0.0%	25	25	25	25	25	25	25	25	25
1-2	Existing Skimmer Gate Limited Ops	TBD	TBD	TBD	TBD		TBD	TBD	TBD	TBD	0	0.0%	25	25	25	25	25	25	25	25	25
1-3	Throttle Sluice Gates	6	10	7	10		8	10	10	9	56.2	96.9%	5	1	5	2	8	5	5	5	6
1-4	Operate Gates #1 and #7	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A	0	0.0%	25	25	25	25	25	25	25	25	25
2-1	Spillway Modifications	10	10	2.5	9		10	10	10	1	49.6	85.5%	10	14	10	5	15	12	12	10	7
2-2	Skimmer Gate Modifications	0.5	10	8	7		9	8	10	4	44.1	76.0%	17	7	17	21	24	23	18	19	20
2-3A	Raise Plunge Floor--Spillway	10	10	2	5		4	10	10	1	43.3	74.7%	21	22	21	11	20	19	21	21	18
2-3B	Raise Plunge Floor--Sluiceway	10	10	2	5		4	10	10	1	43.3	74.7%	21	22	21	11	20	19	21	21	18
2-7	Floating Spill Dissipater	10	10	5	3		3	10	9	1	43.9	75.7%	18	20	18	17	17	16	19	17	15
3-1	Armor Area Downstream of Sluice #1 and #7	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A	0	0.0%	25	25	25	25	25	25	25	25	25
3-2	Roughen Sluice Discharge	10	9	7	9		8	10	10	8	57.7	99.5%	2	3	1	1	5	3	2	3	3
3-4	Add Fixed-Cone Valves to Sluices	6	10	9	1		4	10	10	7	48.3	83.3%	11	10	11	16	10	10	13	12	17
3-5A	Add Branch Outlet to Sluice Liner (submerged discharge)	5	10	10	4		7	1	10	8	43.7	75.3%	20	17	20	23	19	21	8	20	24
3-7	Floating Barge Deflector	10	10	5	3		3	10	9	1	43.9	75.7%	18	20	18	17	17	16	19	17	15
4-1	Underwater Outlet through Midsection of Dam	4	10	10	4		5	7	7	10	47.8	82.4%	12	6	12	20	12	11	10	11	23
4-4	Bridge-type Spillway Apron	10	10	3	3		3	9	10	1	41.4	71.4%	23	24	23	19	22	22	23	23	21
4-4A	New Right Abutment Spillway w/Tunnel Outlet	8	10	6	6		8	10	9	1	47.5	81.9%	13	15	13	10	15	13	14	14	9
4-4B	New Right Abutment Spillway w/Long Flume	8	10	6	4		8	10	9	2	46.9	80.9%	14	16	14	14	14	15	15	15	10
4-4C	New Right Abutment Spillway with Natural Rock Shoot	6	10	10	2		7	9	10	1	45.7	78.8%	16	13	16	22	13	18	17	16	11
4-4D	New Right Abutment Long Side-Channel Spillway	3	10	8	2		7	9	10	1	40.7	70.2%	24	18	24	24	22	24	24	24	22
4-5	New Left Abutment Spillway w/Flume along Road	10	10	6	2		7	10	7	3	46.8	80.7%	15	19	15	15	11	14	16	13	14
4-5B	New Left Abutment Spillway Along Road, Forebay Intake	10	10	6	2		8	10	7	7	50.5	87.1%	9	12	9	7	9	9	11	9	11
4-7	New Right Abutment Tunnel w/Submerged Discharge	10	10	10	5		5	10	8	8	56.4	97.2%	4	5	4	6	2	2	4	4	4
4-7A	New Right Abutment Tunnel w/Fixed Cone Valve	10	10	10	2		3	10	8	8	53.3	91.9%	7	9	7	9	4	6	7	7	8
4-8	Open Existing Diversion Tunnel and Add Control Struct	10	10	10	1		1	10	7	8	51.1	88.1%	8	11	8	13	6	8	9	8	13
4-8A	New Left Abutment Tunnel Intercepts Diversion Tunnel	10	10	10	5		5	10	7	5	53.5	92.2%	6	8	6	8	7	7	6	6	5
4-9	Penstock/Draft Tube ByPass	10	10	10	7		8	10	7	7	58	100.0%	1	2	2	3	1	1	1	1	1
4-10	New Short Left Abutment Tunnel Next to U51	10	10	10	7		8	10	7	6	57.2	98.6%	3	4	3	4	3	4	3	2	1
											58	**100%**									

Matrix #3 - Rank of Alternatives Muting Each Criteria and Comparison to Overall Rank

Green - Unchanged; Yellow - Increased; Blue - Decreased.

No.	Option	Rank w/o Hydraulic Capacity	Rank w/o PMF	Rank w/o TDG Benefit	Rank w/o Constructability	Rank w/o Cost	Rank w/o O&M	Rank w/o Dam Safety	Rank w/o Other Resource Effects	Rank w/o Fish Effects	Rank w/all Criteria
1-1	Existing Spillway Limited Ops	25	25	25	25		25	25	25	25	25
1-2	Existing Skimmer Gate Limited Ops	25	25	25	25		25	25	25	25	25
1-3	Throttle Sluice Gates	1	5	2	8		5	5	5	6	5
1-4	Operate Gates #1 and #7	25	25	25	25		25	25	25	25	25
2-1	Spillway Modifications	14	10	5	15		12	12	10	7	10
2-2	Skimmer Gate Modifications	7	17	21	24		23	18	19	20	17
2-3A	Raise Plunge Floor--Spillway	22	21	11	20		19	21	21	18	21
2-3B	Raise Plunge Floor--Sluiceway	22	21	11	20		19	21	21	18	21
2-7	Floating Spill Dissipater	20	18	17	17		16	19	17	15	18
3-1	Armor Area Downstream of Sluice #1 and #7	25	25	25	25		25	25	25	25	25
3-2	Roughen Sluice Discharge	3	1	1	5		3	2	3	3	2
3-4	Add Fixed-Cone Valves to Sluices	10	11	16	10		10	13	12	17	11
3-5A	Add Branch Outlet to Sluice Liner (submerged discharge)	17	20	23	19		21	8	20	24	20
3-7	Floating Barge Deflector	20	18	17	17		16	19	17	15	18
4-1	Underwater Outlet through Midsection of Dam	6	12	20	12		11	10	11	23	12
4-4	Bridge-type Spillway Apron	24	23	19	22		22	23	23	21	23
4-4A	New Right Abutment Spillway w/Tunnel Outlet	15	13	10	15		13	14	14	9	13
4-4B	New Right Abutment Spillway w/Long Flume	16	14	14	14		15	15	15	10	14
4-4C	New Right Abutment Spillway with Natural Rock Shoot	13	16	22	13		18	17	16	11	16
4-4D	New Right Abutment Long Side-Channel Spillway	18	24	24	22		24	24	24	22	24
4-5	New Left Abutment Spillway w/Flume along Road	19	15	15	11		14	16	13	14	15
4-5B	New Left Abutment Spillway Along Road, Forebay Intake	12	9	7	9		9	11	9	11	9
4-7	New Right Abutment Tunnel w/Submerged Discharge	5	4	6	2		2	4	4	4	4
4-7A	New Right Abutment Tunnel w/Fixed Cone Valve	9	7	9	4		6	7	7	8	7
4-8	Open Existing Diversion Tunnel and Add Control Struct	11	8	13	6		8	9	8	13	8
4-8A	New Left Abutment Tunnel Intercepts Diversion Tunnel	8	6	8	7		7	6	6	5	6
4-9	Penstock/Draft Tube ByPass	2	2	3	1		1	1	1	1	1
4-10	New Short Left Abutment Tunnel Next to U51	4	3	4	3		4	3	2	1	3

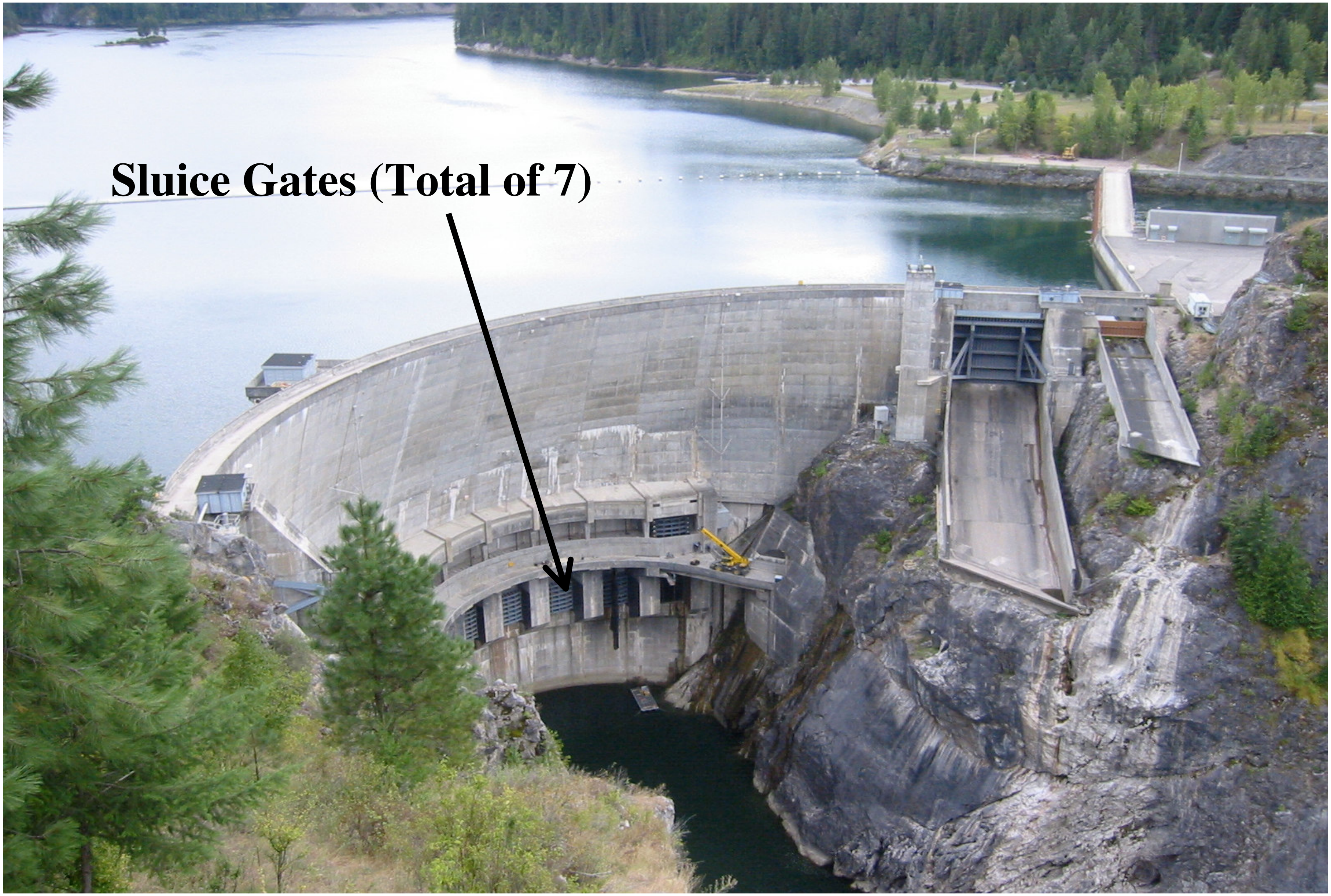
Matrix #3 - Top Six Alternatives from Sorting Matrix #3

No.	Option	Rank w/o Hydraulic Capacity	Rank w/o PMF	Rank w/o TDG Benefit	Rank w/o Constructability	Rank w/o Cost	Rank w/o O&M	Rank w/o Dam Safety	Rank w/o Other Resource Effects	Rank w/o Fish Effects	Rank w/all Criteria
4-9	Penstock/Draft Tube ByPass	2	2	3	1		1	1	1	1	1
3-2	Roughen Sluice Discharge	3	1	1	5		3	2	3	3	2
4-10	New Short Left Abutment Tunnel Next to U51	4	3	4	3		4	3	2	1	3
4-7	New Right Abutment Tunnel w/Submerged Discharge	5	4	6	2		2	4	4	4	4
1-3	Throttle Sluicegates	1	5	2	8		5	5	5	6	5
4-8a	New Left Abutment Tunnel Meeting Diversion Tunnel	8	6	8	7		7	6	6	5	6
4-7A	New Right Abutment Tunnel w/Fixed Cone Valve	9	7	9	4		6	7	7	8	7
4-8	Open Existing Diversion Tunnel and Add Control Struct	11	8	13	6		8	9	8	13	8
4-5B	New Left Abutment Spillway Along Road, Forebay Intake	12	9	7	9		9	11	9	11	9
2-1	Spillway Modifications	14	10	5	15		12	12	10	7	10
3-4	Add Fixed-Cone Valves to Sluices	10	11	16	10		10	13	12	17	11
4-1	Underwater Outlet through Midsection of Dam	6	12	20	12		11	10	11	23	12
4-4A	New Right Abutment Spillway w/Tunnel Outlet	15	13	10	15		13	14	14	9	13
4-4B	New Right Abutment Spillway w/Long Flume	16	14	14	14		15	15	15	10	14
4-5	New Left Abutment Spillway w/Flume along Road	19	15	15	11		14	16	13	14	15
4-4C	New Right Abutment Spillway with Natural Rock Chute	13	16	22	13		18	17	16	11	16
2-2	Skimmer Gate Modifications	7	17	21	24		23	18	19	20	17
2-7	Floating Spill Dissipater	20	18	17	17		16	19	17	15	18
3-7	Floating Barge Deflector	20	18	17	17		16	19	17	15	18
3-5A	Add Branch Outlet to Sluice Liner (submerged discharge)	17	20	23	19		21	8	20	24	20
2-3A	Raise Plunge Floor--Spillway	22	21	11	20		19	21	21	18	21
2-3B	Raise Plunge Floor--Sluiceway	22	21	11	20		19	21	21	18	21
4-4	Bridge-type Spillway Apron	24	23	19	22		22	23	23	21	23
4-4D	New Right Abutment Long Side-Channel Spillway	18	24	24	22		24	24	24	22	24
1-1	Existing Spillway Limited Ops	25	25	25	25		25	25	25	25	25
1-2	Existing Skimmer Gate Limited Ops	25	25	25	25		25	25	25	25	25
1-4	Operate Gates #1 and #7	25	25	25	25		25	25	25	25	25
3-1	Armor Area Downstream of Sluice #1 and #7	25	25	25	25		25	25	25	25	25

Appendix 2: Illustration of Six Total Dissolved Gas Abatement Alternatives

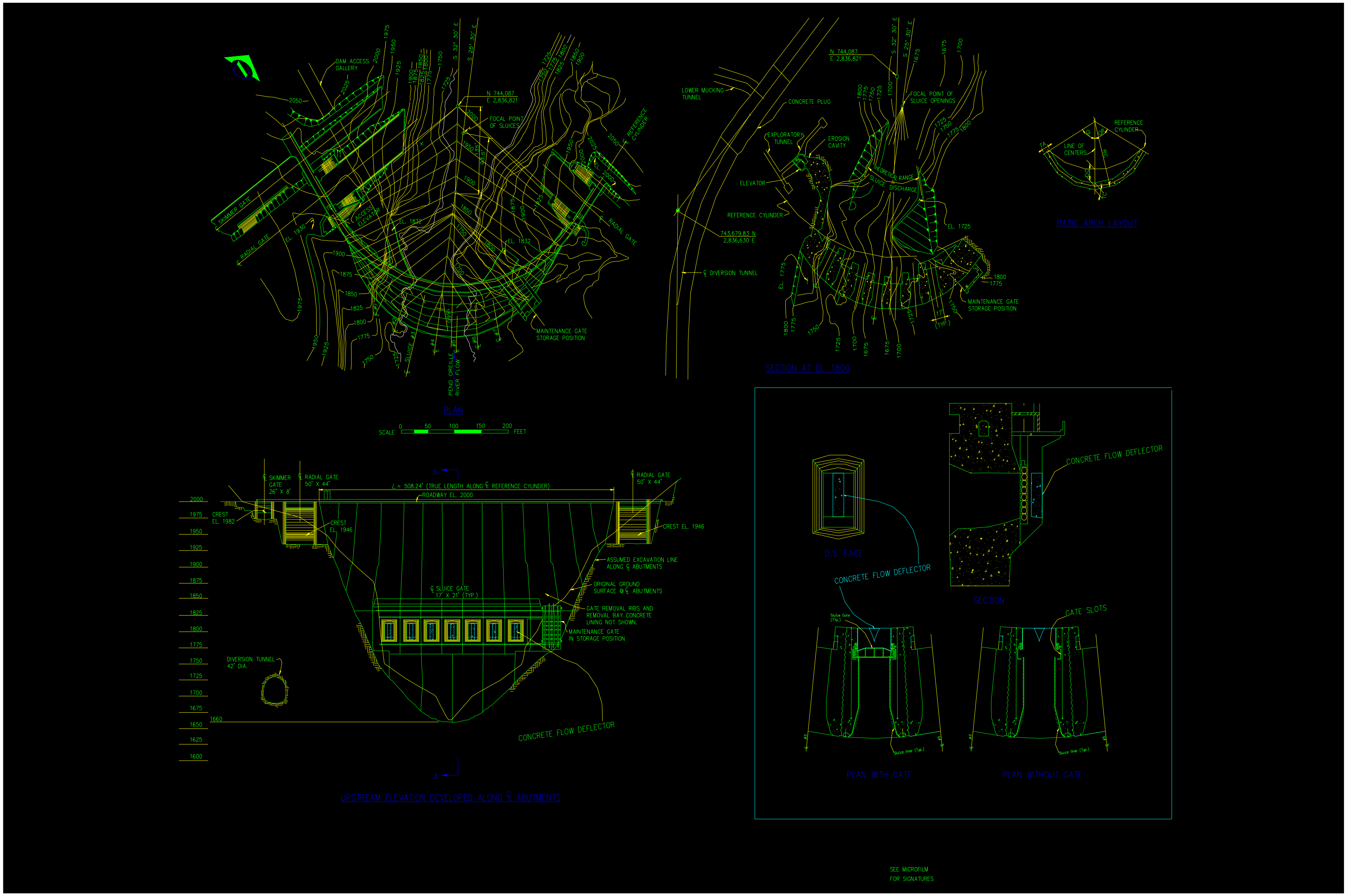
SCL TDG Revised Study Plan(RSP)
Appendix 2: Illustrations of Six Alternatives

Option 1-3. Throttle Sluice Gates



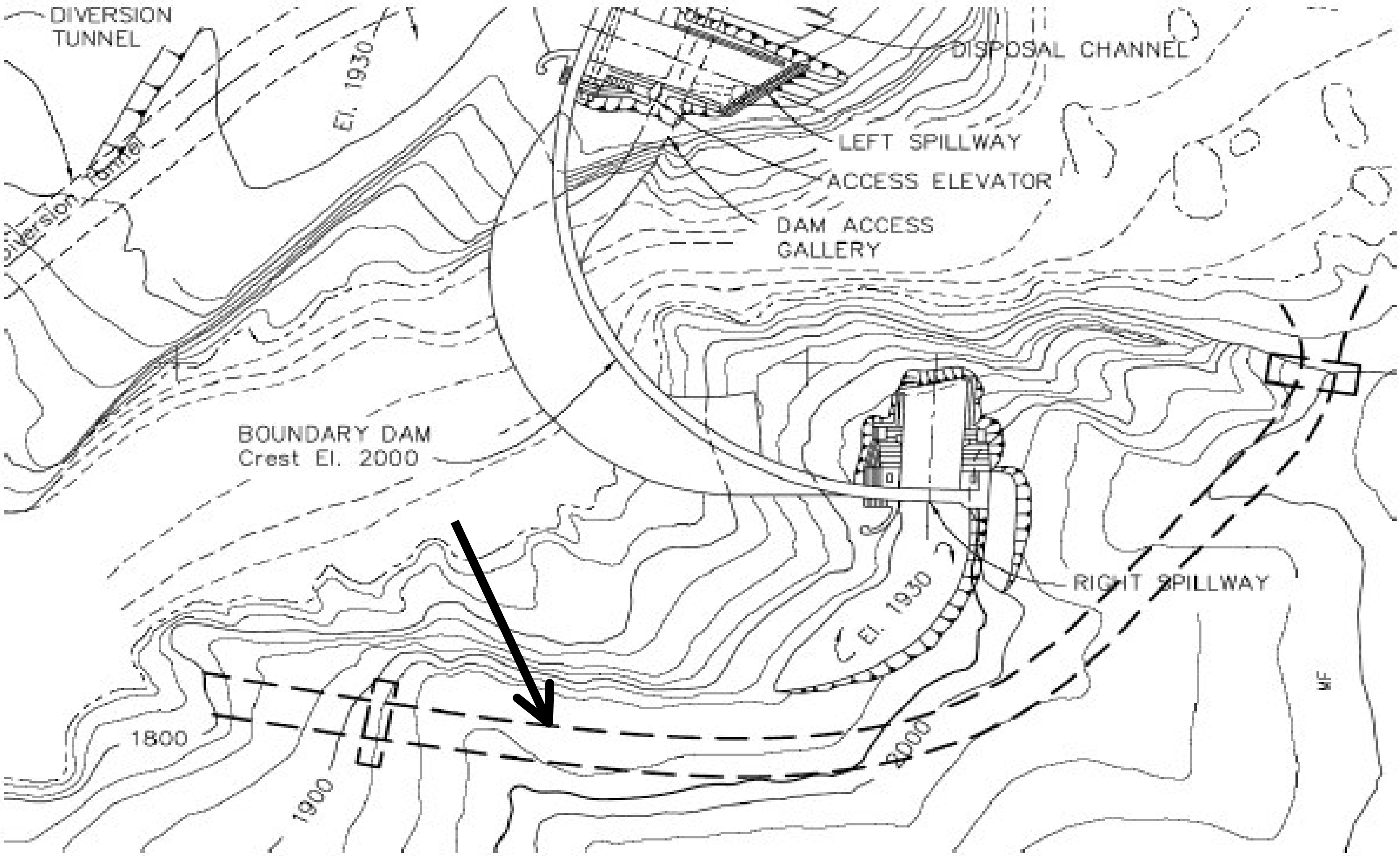
Option 1-3. Throttle Sluice Gates

Option 3-2. Roughen Sluice Gate Discharge

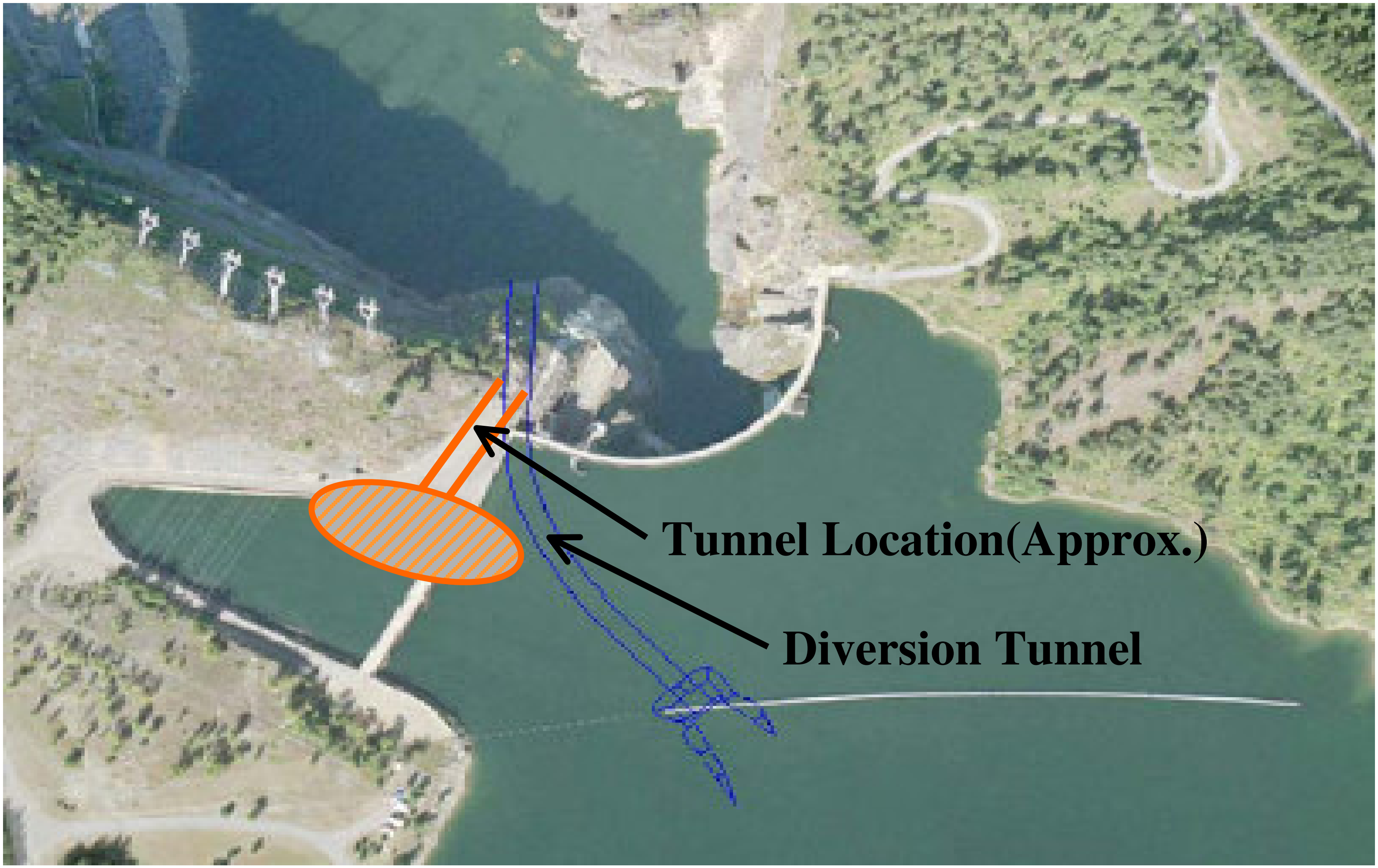


Option 4-7. New Right Abutment Tunnel with Submerged Discharge

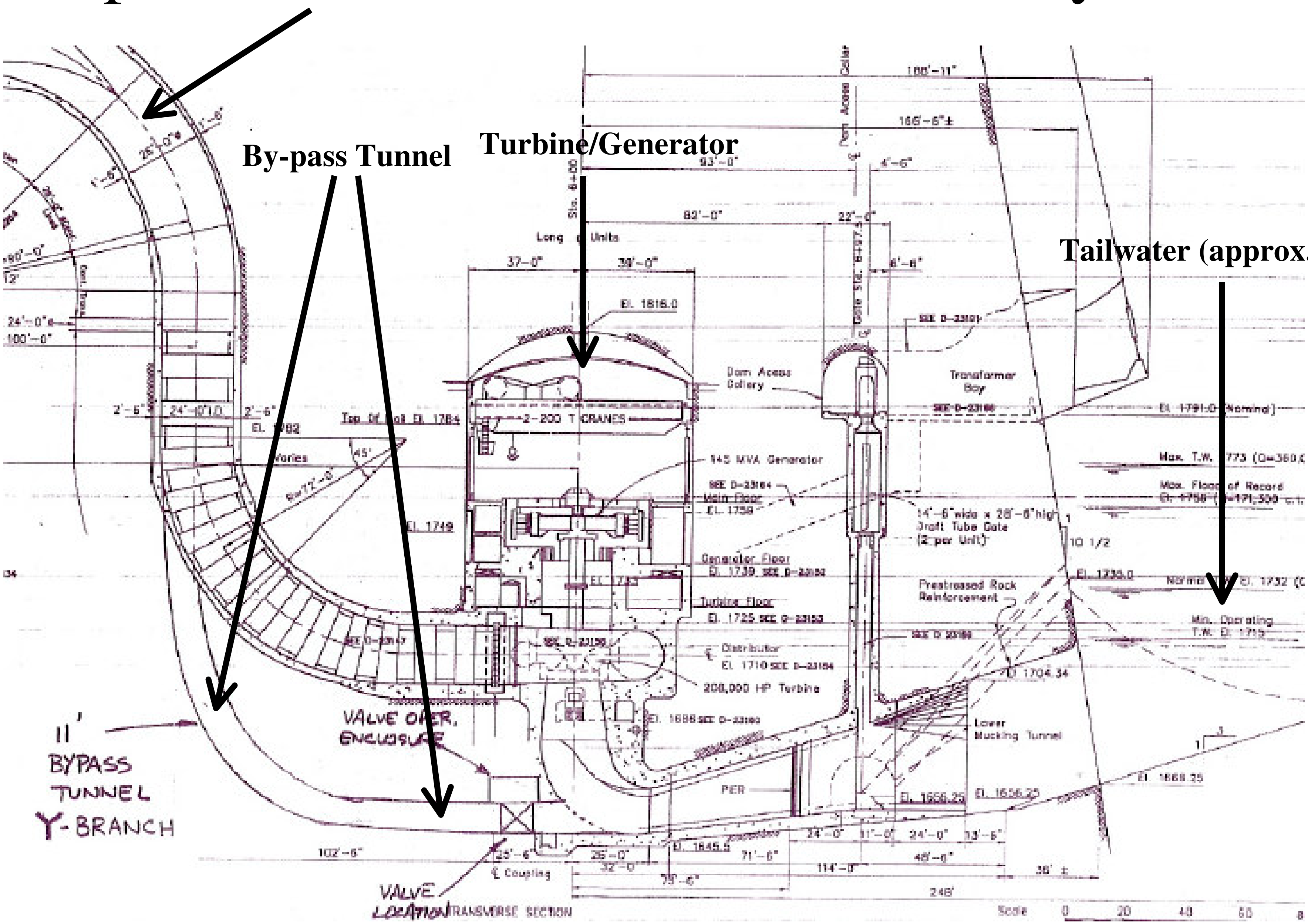
Long curved alternative



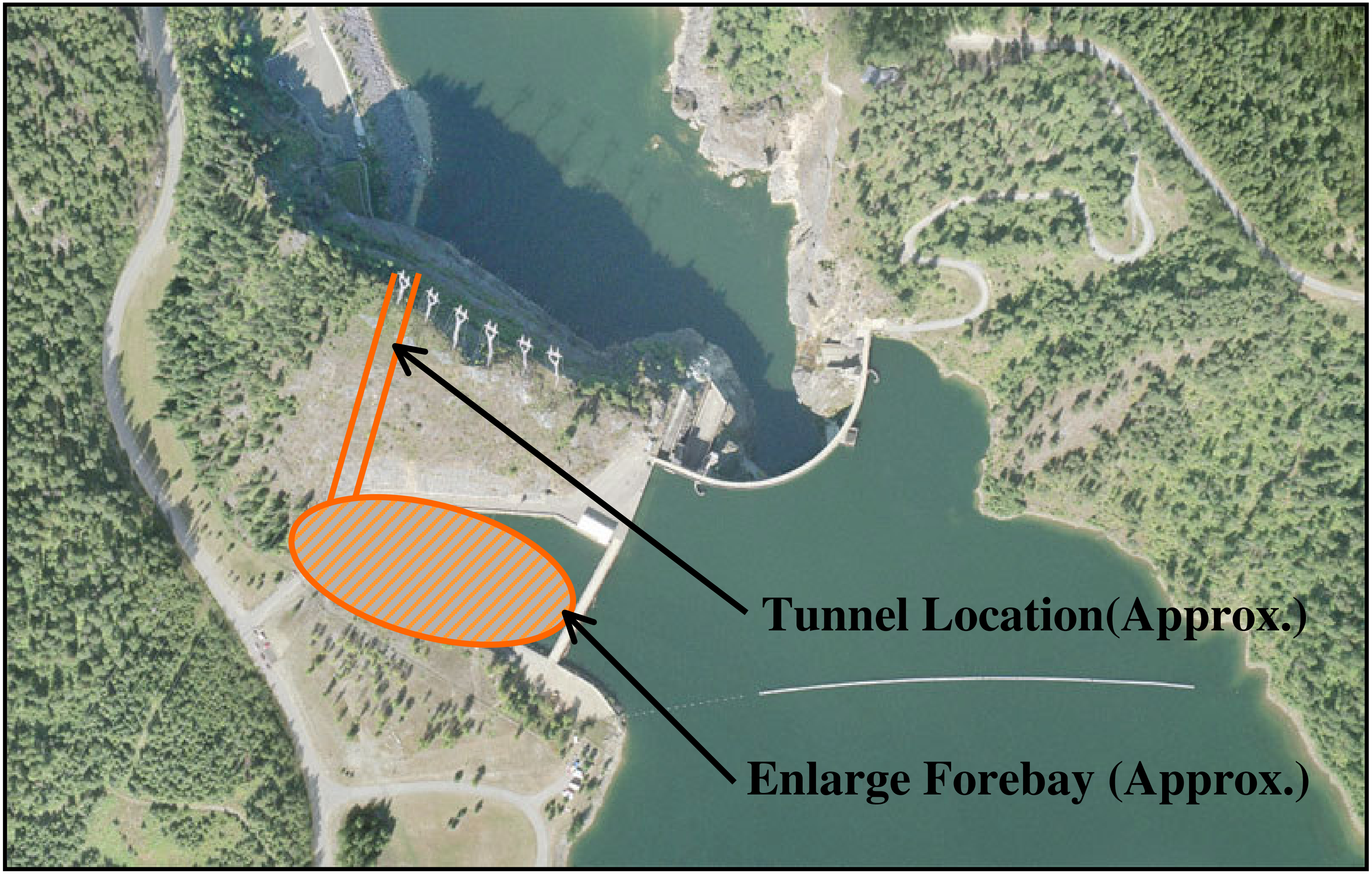
Option 4-8A. New Left Abutment Tunnel Intercepts Diversion Tunnel



Option 4-9. Penstock/Draft Tube By-Pass



Option 4-10. New Left Abutment Tunnel Next to Unit #51 Intake



Appendix 3: Undeveloped Total Dissolved Gas Abatement Alternatives

Appendix 3, Table 1 - Operational Alternatives for Existing Structures

Alt. No.	Name	Expected capacity, cfs	Potential TDG Benefit [1]	Testing Required to Assess Viability	Constructability and Other Assessment Required to Evaluate	Comments
1	Existing Spillway-Limited Spill Operation	18,000	2 - 3	Yes-Confirm gas levels for a range of flows and gate combinations	1. Assess 2002/2003 Spill Test results. 2. Third party review of 2002 data (CBE 2003 report) by Michael Schneider (ACE).	Possibly work with the spillway modifications to boost total spillway flow
2	Existing Skimmer gate-Limited spill operation	1,800	2	Yes-confirm gas level for range of flows	1. Assess during spill test. 2. Evaluate/verify hydraulic capacity.	Perform with testing of main spillway gates
3	Throttling of sluice gates	unknown	3	Yes-confirm gas levels for a range of flows and gate combinations	1. Assess gate vibration when throttling during a spill test. 2. Assess the potential for foundation erosion due to a steeper diving jet when throttling. This is a potential dam safety issue.	Started (1.) in April 2006. (Note: The 1968 Bechtel Leedshill Design Report, Section VI-8 *design criteria for sluice gates* indicates that the gates may be stopped and held in any position of travel. SCL throttled the sluice gates during a 1972 safety inspection.)
4	Operate sluice gates 1 and 7 (outer gates) in lieu of 3-5 (central gates)	36,000 to 72,000	3	Yes-operate the gates during spill and confirm gas levels	1. Test procedure to protect abutment. 2. Evaluate probable need for armoring of abutments where gate discharge hits. This is a dam safety issue. (Note: This option is may be considered a structural option, i.e., armoring of downstream abutments and this option may be moved to a different table.)	These gates historically not used due to abutment erosion.

(1) Potential benefits rated 1 (best-strips gas) to 5 (worst-adds gas). Benefit of 3 is assumed to pass the upstream gas level (no addition of gas or stripping).

Appendix 3, Table 2 - Spillway Structural Modification Alternatives

Alt. No.	Name	Expected capacity, cfs	Potential TDG Benefit (1)	Testing Required to Assess Viability	Constructability and Other Assessment Required to Evaluate	Comments
1	Spillway Modifications: (includes 2004 alternatives) 1a – roughen 1b – deflectors 1c – flared training walls 3a-aim towards shallower area in pool 3b-increase landing area 3c-air entrainment	20,000-60,000	2	Requires prototype modifications of spillways.	1. Hydraulic evaluation of spillway structure needed to predict possible flow rate. 2. Evaluate risk of abutment erosion.	Benefits may be uncertain. All 5 sub-alternatives from April 2004 are really one—modify spillways to spread the flow and reduce the plunge, or to hit the abutments to break fall of water and limit gas uptake. For 3a, add passive air admission towards top of spillway
2	Skimmer gate modification to increase flow capacity (existing is 1,800 cfs)	4,000	2	Use results of testing existing gate. (See Table 1, Alt.#2)	Hydraulic evaluation needed to predict flow rate and shape of flow onto left abutment	4,000 cfs assumes gate sill is cut to double gate height. Very expensive for minor increase in flow.
3A	Raise plunge pool floor, for sluice gate discharge	60,000	4	None possible	Concept development for physical, structural, and hydraulic arrangement	Larger area than for spillway gates, may interfere with spillway flows. Assess interlocking jacks. Potential problems may include erosion, movement, and lateral force.
3B	Raise plunge pool floor, for spillway gate discharge	60,000	4	None possible	Concept development for physical, structural, and hydraulic arrangement	More attractive than sluice gate option (Table 2-3A). Smaller area near dam. (Still need to meet PMF)
6A **Delete**	Modify right abutment spillway to add long flume	52,000	2	None possible	This alternative was **discarded** due to its structural concept being infeasible. The height and length of the flume and problems with sluice gate flows impacting the supports make it unrealistic.	
6B **Delete**	Modify right abutment spillway to add stripping structure	52,000	1-2	None possible	This alternative was **discarded** due to its structural concept being infeasible. The height and length of the downstream structure and problems with sluice gate flows impacting the supports make it unrealistic.	
6C **Delete**	Modify right abutment spillway to shape discharge flows onto the right abutment	2,000 to 5,000	2-3	None possible	This alternative was **discarded.** It is essentially the same as alternative 1c, which is shaping the spillway discharge to hit the abutment.	
7	Floating spill dissipater (Note: Similar to raising plunge pool floor)	60,000?	2-3	None possible	Concept development for physical, structural, and hydraulic arrangement	Added in May 2004. Could be floating pipe sections to limit plunge depth.

(1) Potential benefits rated 1 (best - strips gas) to 5 (worst-adds gas). Benefit of 3 is assumed to pass the upstream gas level (no addition of gas or stripping).

Appendix 3, Table 3 - Sluice Gates Structural Modification Alternatives

Alt. No.	Name	Expected capacity, cfs	Potential TDG Benefit (1)	Testing Required to Assess Viability	Constructability and Other Assessment Required to Evaluate	Comments
1	Armor area downstream of sluice gates 1 or 7	36,000	3?	Field test possible, after abutment erosion assessment.	Concept development required for physical, structural, and hydraulic arrangement	Potential problems with abutment impacts. Will sluice stream even reach abutments?
2	Roughen sluice gate discharge to spread flow and limit plunge	6,000 per gate	3?	May be possible to prototype one gate	Concept development required for physical, structural, and hydraulic arrangement	Assumes throttling of gates is feasible and structurally acceptable.
3 **Delete**	Install "tubing" from gate discharge to lower pool	36,000	3	None possible	This alternative **discarded** due to concerns on dam safety, lack of upstream shutoff, and risk in throttling and structural concerns with the "tube" being impacted by spill from other gates.	
4	Modify sluice gates to add fixed cone or jet-flow valves to gate leaf	3,000 to 6,000 per gate	2	None possible	Concept study needed to determine valve configuration on sluice gate	Possibly 2 or 3 valves added to gate. 72 inch valve diameter assumed. • Decreases the capacity of the sluiceways • Add air / energy dissipater
5 **Delete**	Alter sluice gates to be bonneted slide gates and add downstream tube	36,000	3	None possible	This alternative **discarded** due to infeasibility of downstream "tube" and dam safety risks with the gate modification.	
5A	Add branch outlet from sluice liner to point below sluice gates, submerged discharge at bottom of dam	3,000 cfs per gate	2-3	None possible	Concept study needed.	Added this alternative during May 2004 meeting. Downstream conduit would be attached to dam. Possible use of dam sump gallery.
6 **Delete**	Enclose discharge from 2 sluice gates in an open flume	36,000	2-3	None possible	This alternative **discarded** due to concerns on dam safety, risk in throttling and structural concerns with the flume being impacted by spill from other gates.	
7	Floating Barge deflector to shape sluice gate flow, reduce plunge	60,000?	2	None possible	Concept development required for physical, structural, and hydraulic arrangement	Comparable to filling plunge pool (See Table 2).

(1) Potential benefits rated 1 (best-strips gas) to 5 (worst-adds gas). Benefit of 3 is assumed to pass the upstream gas level (no addition of gas or stripping).

Appendix 3, Table 4 - New Structure Alternatives

Alt. No.	Name	Expected capacity, cfs	Potential TDG Benefit (1)	Testing Required to Assess Viability	Constructability and Other Assessment Required to Evaluate	Comments
1	Underwater outlet through mid-section of dam	2,800 cfs per 6-ft outlet	3	None possible	Concept analysis required, especially for dam safety	Similar and possibly much less attractive than conduit tapping the sluice gate liners (Table 3, Alt. #5A)
3 **Delete**	Siphon discharge around project	1,500 cfs for 8-ft pipe	2?	None possible	This concept **discarded**. A siphon intake is simply an option for any type of surface release from the reservoir. Other intake options have more capacity and reliability at less cost	
4	Bridge-type spillway apron, span across abutments	60,000	2?	None possible	Concept development required for physical, structural, and hydraulic arrangement	Structure may get blown out (destroyed) in major floods
4A	New right abutment spillway with tunnel outlet gate	40,000	3	None possible	Concept development for physical, structural, and hydraulic arrangement.	Capacity estimated, based on approx 30-ft dia tunnel and 50 fps velocity in tunnel.
4B	New right abutment spillway with long flume	30,000	1-2	None possible	Concept development for physical, structural, and hydraulic arrangement.	Surface intake capacity likely limited by approach flow conditions. Open channel system can degas flows effectively
4C	New right abutment spillway with flow over the right abutment.	30,000	1-2	None possible	Concept development for physical, structural, and hydraulic arrangement.	Abutment shaping and armoring likely required
5	New left abutment spillway with long flume along access road	12,000	1	None possible	Concept development for physical, structural, and hydraulic arrangement.	Capacity limited by space along road. Could effectively strip gas on large flat area below powerhouse.
7	New right abutment tunnel with submerged discharge	40,000	3	None possible	Concept development required for physical, structural, and hydraulic arrangement	
7A	New right abutment tunnel with fixed cone valve discharge	4,000 cfs per valve	2	None possible	Concept development required for physical, structural, and hydraulic arrangement	Valve maximum size estimated at 120 inch dia. Max velocity at valve possibly 50 fps.
7B **Delete**	New right abutment tunnel with powerplant	30,000	3	None possible	This alternative **discarded** based on cost. At $3,000 per kW of capacity a 30,000 cfs option (545 MW), this system's powerplant would cost $1.6 billion	
8	Open existing diversion tunnel and add control structure	27,000	3	None possible	Concept development required for physical, structural, and hydraulic arrangement	Capacity based on limit of 20 fps in unlined 42-ft dia. rock tunnel. May be too optimistic. Need to vent valve to prevent cavitation—TDG increase, or could tunnel to the surface and place valve at intake?

(1) Potential benefits rated 1 (best-strips gas) to 5 (worst-adds gas). Benefit of 3 is assumed to pass the upstream gas level (no addition of gas or stripping).

Appendix 3, Table 5 - Lower River Modification Alternatives

<table>
<tr><th>Alt. No.</th><th>Name</th><th>Expected capacity, cfs</th><th>Potential TDG Benefit (1)</th><th>Testing Required to Assess Viability</th><th>Constructability and Other Assessment Required to Evaluate</th><th>Comments</th></tr>
<tr><td>1</td><td>Add downstream control weir</td><td>118,000</td><td>3?</td><td>None possible</td><td>Concept study required. May be infeasible due to foundation and length requirements</td><td>Requires fall of about 3 ft (with 1-ft depth) to allow partial degassing. 3 to 5 miles of weir required to attain 1-ft for less of depth over weir (needed to degas).</td></tr>
<tr><td>2A</td><td>Add structure to prevent mixing of powerhouse flow and spill gate flow</td><td>60,000</td><td>3</td><td>None possible</td><td>Concept study required. May be infeasible due to foundation and length requirements</td><td>Only reduces potential powerhouse entrainment</td></tr>
<tr><td>2B</td><td>Add structure to prevent mixing of powerhouse flow and spill gate flow, include weir overflow</td><td>60,000</td><td>2</td><td>None possible</td><td>Concept study required. May be infeasible due to foundation and length requirements</td><td>Requires fall of about 3-ft to allow partial degassing.</td></tr>
<tr><td rowspan="2">3
Delete</td><td rowspan="2">Add turbulent mixers to surface of downstream river</td><td rowspan="2">unknown</td><td rowspan="2">2</td><td rowspan="2">Mixer could be installed and tested</td><td colspan="2">This alternative **discarded.** It could not treat the river until well below the project, downstream of the water quality monitoring point.</td></tr>
<tr><td>Cost and effectiveness of mixers would need evaluation. Small size may make this system unrealistic</td><td>Could only install below area where river flow is free of bubbles</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

(1) Potential benefits rated 1 (best-strips gas) to 5 (worst-adds gas). Benefit of 3 is assumed to pass the upstream gas level (no addition of gas or stripping).