TOTAL DISSOLVED GAS ABATEMENT PLAN

BAKER RIVER HYDROELECTRIC PROJECT
FERC PROJECT NO. 2150

Puget Sound Energy
Bellevue, Washington

November 2, 2009

CONTENTS

List of Figures

1.0 Introduction

1.1 Background

Puget Sound Energy (PSE) owns and operates the Baker River Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2150. The Project consists of two concrete dams located on the Baker River near the town of Concrete, Washington (figure 1).

On October 17, 2008, the FERC issued a new license to PSE to operate the Project. The license incorporates the Project's water quality certification (WQC), Ecology Order No. 2525, in Appendix C. Section 5.4(5) of the Project's WQC and article 401(a) of the license require PSE to prepare a total dissolved gas (TDG) abatement plan proposing options for minimizing TDG production associated with spillway releases (spills) and air-injected turbine rampdowns. The TDG abatement plan must be approved by the Washington State Department of Ecology (Ecology) and the FERC before it can be implemented.

The Project's WQC authorizes a seven-year compliance period from the date of license issuance to achieve TDG standards. If TDG standards are not met by the end of the compliance period, PSE is required to conduct a feasibility analysis within six months. The feasibility analysis would identify the reasonable and feasible methods to achieve compliance. Following review of this analysis, Ecology would either issue an order that includes compliance actions or, if appropriate, evaluate whether modifications of the application of the TDG standard is warranted.

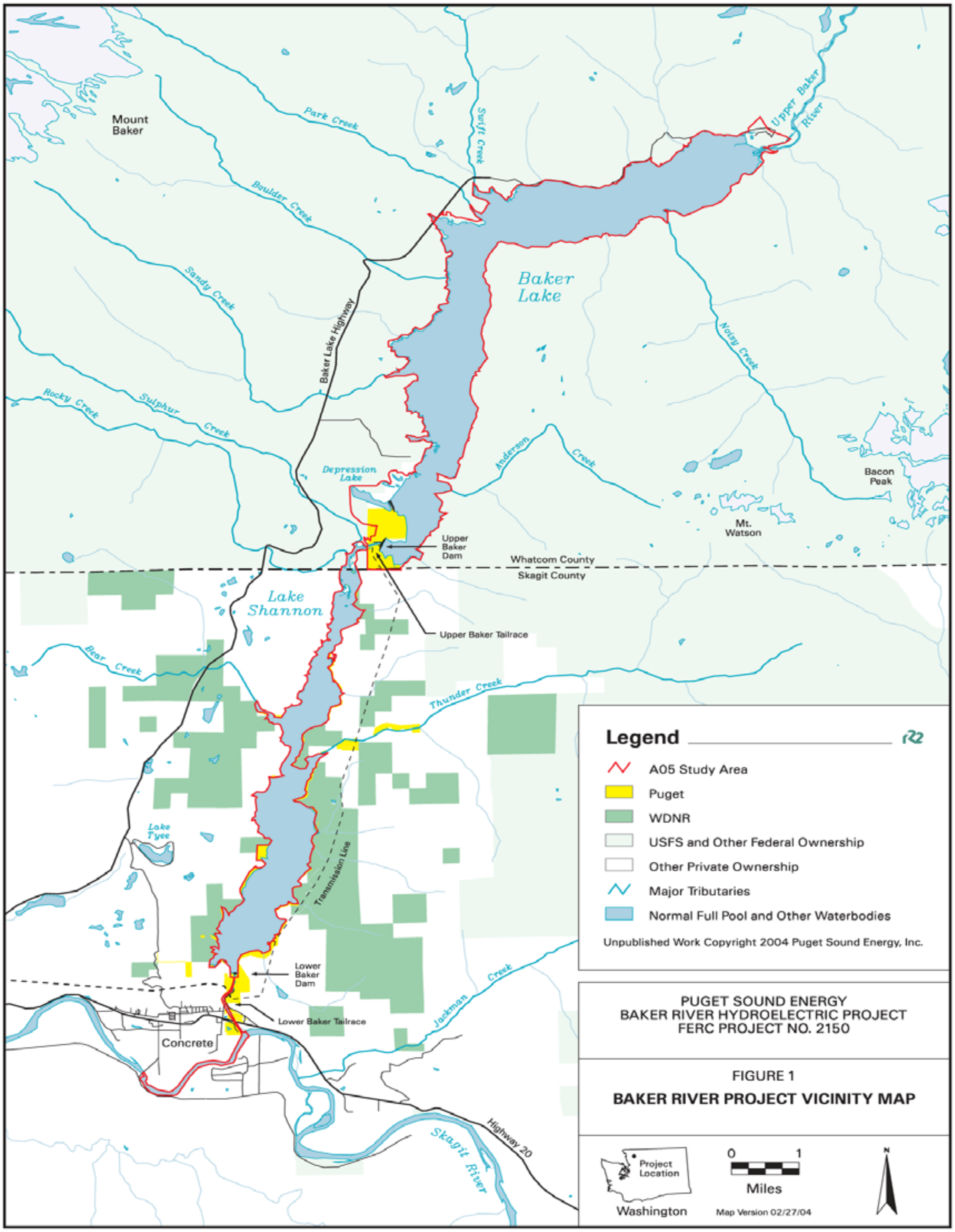

Figure 1. Baker River Project vicinity map.

1.2 Purpose of this TDG Abatement Plan

This plan describes the measures PSE will implement to minimize TDG production during rampdowns at the Lower Baker powerhouse and spills at the Project.

1.3 Organization of This TDG Abatement Plan

This plan is divided into the following sections:

- **Section 1 – Introduction.** This section summarizes the purpose and organization of this plan and the main Project facilities.
- **Section 2 – TDG Information.** This section provides general background information about TDG in the environment – its characteristics, sources, and effects.
- **Section 3 – TDG Conditions at the Project.** This section describes specific TDG characteristics at the Project, including the applicable TDG standards, TDG sources, and the observed effects.
- **Section 4 – TDG Abatement Measures.** This section describes the proposed TDG abatement measures, including the proposed monitoring program and reporting.

1.4 Project Features

Upper Baker Dam, constructed in 1959, is approximately 312 feet high and 1,200 feet long at its crest and its powerhouse has a generating capacity of 91 MW. Water is conveyed from the intake at the dam via two 320-foot-long penstocks to the powerhouse. The powerhouse's two Francis-type vertical-shaft hydraulic turbines (units 1 and 2) have a combined hydraulic capacity of 4,400 cfs and discharge directly to the Upper Baker tailrace at the upper end of Lake Shannon. An integral part of the main gravity dam is a 93-foot-wide spillway section, which contains three 25-foot-wide by 30-foot-high radial spill gates. Each gate is served by a bridge-mounted, electrically operated drum hoist of 30 tons capacity.

Lower Baker Dam, constructed in 1925, is about 285 feet high and 550 feet long at its crest. The powerhouse, located about 0.3 miles downstream of the dam, has a single 79-MW turbine generator unit (unit 3). The Francis-type vertical-shaft hydraulic turbine, which was upgraded in 2001, has a hydraulic capacity of 4,100 cfs and discharges directly to the Lower Baker tailrace. Currently, water for hydropower production is conveyed 1,488 feet from the dam intake to the powerhouse via a single penstock. Lower Baker Dam has 23 9.5-foot-wide by 14-foot-high vertical-slide spill gates. Thirteen of these spill gates are operated by motorized cable hoists, and the other 10 spill gates are manually operated with an electrically-powered gate car. The base of the dam and the tailrace are located approximately 0.9 miles upstream of the confluence of the Baker River and the Skagit River.

2.0 TDG Information

2.1 TDG Sources at Hydroelectric Projects

There are two primary sources of elevated TDG at hydroelectric projects[1]:

- **Spillway releases.** Water plunging over a spillway entrains air and carries it to a depth in a plunge pool at the toe of the dam where the pressure forces the gas into solution with the water. This is the same process that occurs at waterfalls.
- **Turbine rampdowns.** Cavitation is a significant cause of turbine damage and can be minimized by venting or injecting air into the turbines. Air introduced into turbines becomes dissolved in the water under high pressure, and can increase TDG levels in tailrace waters.

Water with elevated TDG levels is supersaturated and out of equilibrium. To return to its normal equilibrium, the water must dissipate the excess dissolved gas. Shallow river channels dissipate excess TDG more readily than deeper channels because of increased turbulence and greater surface area relative to the river's water volume. Hydrostatic pressure at depth prevents the release of gasses, whereas shallow, well-aerated surface waters dissipate excess gas. For this reason, turbulence reduces TDG levels as gas-rich waters from deeper in the water column are brought in contact with the atmosphere and release gasses (Weitkamp and Katz, 1980).

2.2 Effects of TDG

Elevated TDG levels are primarily of concern because of the potential harm to fish. If fish inhabit supersaturated water for extended periods or rise in the water column, TDG may come out of solution within the fish, thus forming bubbles in their body tissues (Ecology et al., 2007). This condition can lead to what is commonly called gas bubble disease (GBD) or gas bubble trauma (GBT).

The effects of elevated TDG on fish depend on many factors, including:

- **Depth compensation.** Fish may not experience problems with elevated TDG if they are below the compensation depth[2] (that is, deep enough for higher water pressures to keep high TDG in solution). Each increase in depth of about one meter reduces the TDG level experienced by fish by about 10% of saturation (Weitkamp and Katz, 1980). For example, when TDG is at 110% at the surface, the TDG saturation one meter below the surface is 100%. Similarly, when the surface TDG is 120%, a fish two meters down is exposed to a TDG level of 100% (Point Four Systems.com, 2005).
- **TDG level.** The presence of GBD symptoms occurring at TDG levels of less than 120% is rare (Backman and Evans, 2002; Backman et al., 2002; Cochnauer, 2000; Dunnigan et al., 2003; Ryan et al., 2000; Weitkamp et al., 2003; Beeman and Maule, 2006).

---

[1] Additional sources of TDG include elevated temperature and increased primary productivity.

[2] Compensation depth is the water depth required to prevent the formation of air bubbles within fish tissues.

- **Duration** – At TDG levels less than 120%, fish must be exposed for several days to show symptoms of GBD (Antcliffe et al. 2002; 2003).

3.0 TDG Conditions at the Project

Data collected during the Project's relicensing period indicated TDG compliance was met at the Project except during rampdown periods at the Lower Baker powerhouse and during some spill[3] events at both dams (PSE, 2004).

3.1 TDG Standards

Under Washington state surface water quality standards, TDG is not allowed to exceed 110% of saturation at any point (WAC 173-201A-200(1)(f)). The criterion does not apply when flows exceed the seven-day, ten-year (7Q10) frequency high flows (WAC 173-201A-200(1)(f)(i)). The Project's 7Q10 high flows at Lower Baker have been identified as either 13,300 cfs regulated (Ecology, 2007) or 12,930 cfs unregulated (Ecology, 2009).

As applied to the Project, PSE is also exempt from the TDG criteria either when 2.3 inches of precipitation in 48 hours is forecasted by the National Weather Service[4], or during a measured 7Q10 high flow, until 72 hours after the storm event (Ecology, 2009). TDG levels above criteria at the adult fish trap in the Lower Baker tailrace are not considered exceedances if the elevated levels are due to a qualifying 7Q10 high flow event at Upper Baker Dam (Ecology, 2007). Elevated TDG levels from Upper Baker Dam spills can take several days to pass through Lake Shannon and show up in the Lower Baker tailrace.

The Project is also exempt from the TDG standards when spills are necessary to comply with the minimum instream flow provisions during maintenance, inspection, or when testing limit flows through the powerhouse (Ecology, 2007)[5].

3.2 TDG in Lower Baker Tailrace During Rampdown Periods

The typical TDG pattern in the Lower Baker tailrace during current complete rampdown operations is shown in figure 2. Unpressurized air is vented into the single turbine during the rampdown period to prevent turbine damage caused by cavitation. Complete rampdown periods usually last about 3 to 4 hours and occur once or twice a day, corresponding to the end of the daily peak power periods.

[3] Spills at the Project are defined as the release of water through the spill gates.

[4] The closest site listed at the NWS web site is near Upper Baker Dam and is listed as "9 Miles NNE Concrete Washington" (http://forecast.weather.gov/MapClick.php?lat=48.66194284607008&lon=-121.6845703125&site=sew&smap=1&marine=0&unit=0&lg=en)

[5] PSE must apply in advance for a short-term modification in writing to Ecology and the Washington State Department of Fish and Wildlife for these TDG exemptions.

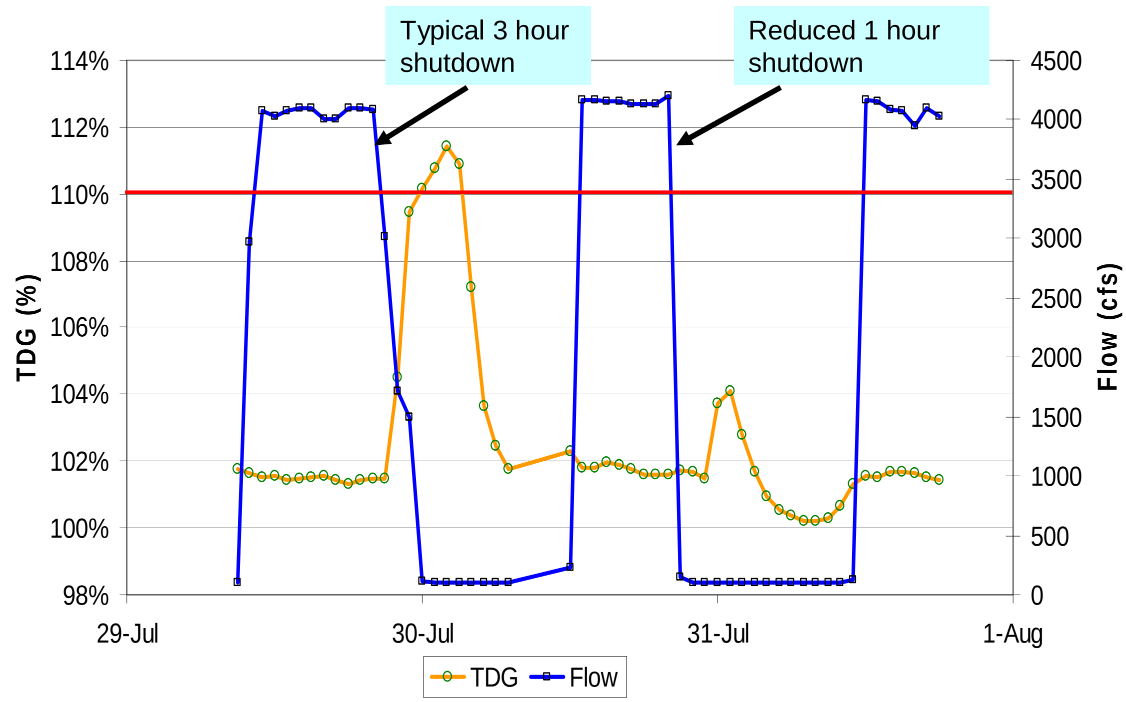

Figure 2. TDG levels in the Lower Baker tailrace (at the adult fish trap) during typical operating conditions.

This rampdown pattern typically leads to TDG levels above the 110% standard for a two- to three-hour period, with a maximum TDG level of about 112%. A shorter rampdown period would reduce TDG levels; however, this is not an acceptable option due to concerns about fish stranding in the Skagit River.

3.3 TDG Associated with Project Spillway Releases

Spillway releases (spills) at the Project are primarily conducted to provide flood control storage in advance of a high flow event. Spills at the Project are rare, typically occurring no more than twice a year, because there is usually an economic incentive to eliminate spill, and because winter operations typically provide enough storage to hold the higher flows. Spills are very rarely required as a result of market prices for energy when PSE must pay power purchasers to take excess power.

A maximum TDG level of 120% was recorded at the Project during a large flood in October 2003, when spills reached about 36,000 cfs at Upper Baker Dam and 28,800 cfs at Lower Baker Dam. However, the spills of concern for the Project have flows that are high enough to produce TDG levels above the 110% of the TDG standard but are less than the Project's 7Q10 high flows. Spills in excess of about 6,300 cfs at Lower Baker Dam produce TDG levels above the standard[6].

The frequency of flows at the Lower Baker Dam within the flow range of 6,300 cfs and 13,300 cfs represent about one percent of the average daily flows at Lower Baker (figure

[6] Based on data collected during the relicensing study at Lower Baker Adult Fish trap (PSE 2004). This value (6,300 cfs) assumes that the Lower Baker turbine is being operated at full power.

3). These results indicate that Lower Baker dam spill events contribute to TDG exceedances of the standard less than one percent of the time (figure 3). Spills at Lower Baker Dam above 6,300 cfs have lasted between 2 to 124 hours over the last four years[7].

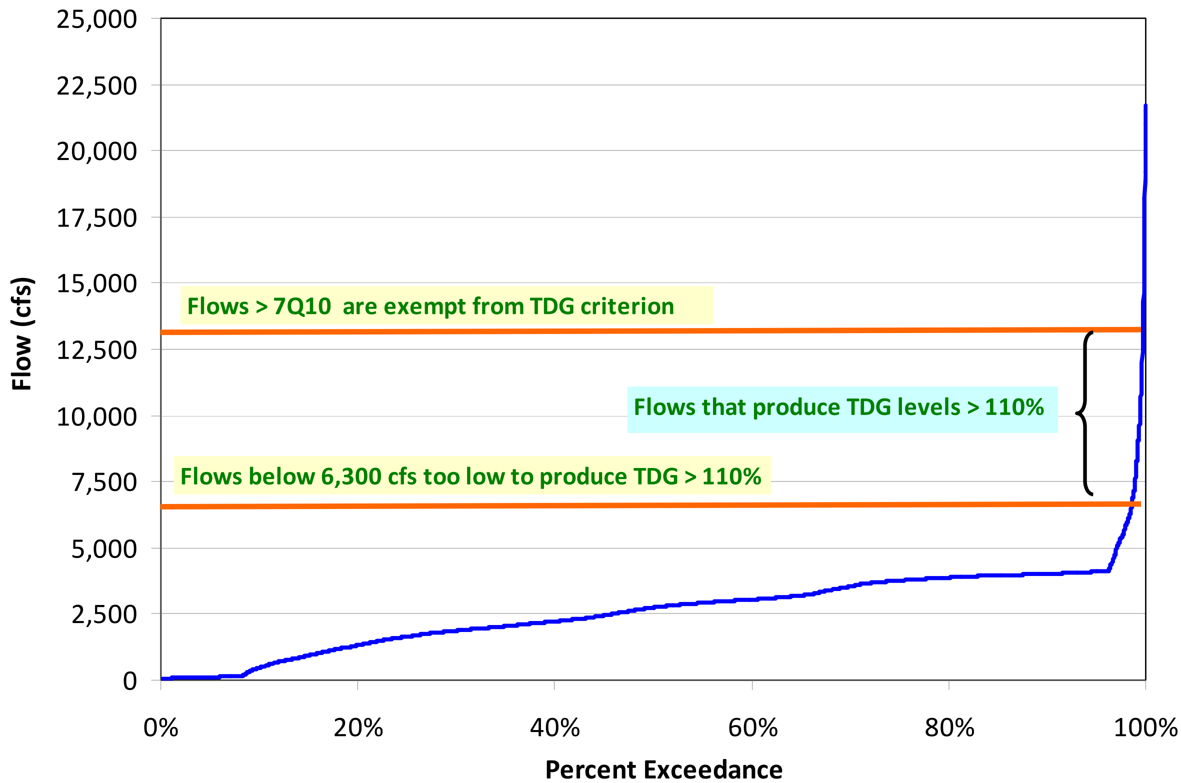

Figure 3. Percent exceedance for average daily flows measured at Lower Baker between 1974 and 2002 (water years).

3.4 Effects of TDG on Fish at the Project

TDG-related effects, including mortalities or chronic symptoms, have not been observed in fish at the Project. Fish management activities over many years have provided considerable opportunity to detect TDG-related symptoms. These activities include fish handling operations at the adult fish trap and fish rearing at spawning beaches. Additionally, some of the Project's features limit fish exposure to elevated TDG levels. Studies to specifically examine the effects of TDG on fish, however, have not been conducted at the Project.

The observations and Project features that indicate an absence of TDG-related impacts to the fisheries resources are summarized below.

- **Absence of adult fish above the Lower Baker tailrace fish weir.** The Lower Baker dam and powerhouse are located 0.6 and 0.3 miles, respectively, upstream of the adult fish trap and weir (figure 4), with a backwater of the weir forming a flat

---

7 Based on data collected during the 4 spill events at Lower Baker since 2005

channel to the powerhouse. Adult fish migrating upstream are prevented from entering the channel above the weir. Therefore, there are no adult fish above the weir (near the powerhouse and dam) where they might be susceptible to elevated levels of TDG potentially generated during rampdowns or spills. Surveys during Project relicensing confirmed the absence of fish in this reach.

- **Low susceptibility to elevated TDG levels in the Lower Baker Fish trap.** Given the absence of fish above the weir, the primary areas in which Project-generated TDG might affect fish are the Lower Baker adult fish trap and the Lower Baker tailrace below the weir. Relatively higher TDG levels would be expected in the adult fish trap than the river below the weir due to dissipation caused by turbulence as water flows over and downstream of weir.

  Adult fish migrating upstream in the Lower Baker tailrace are captured in the fish trap holding ponds next to the weir. The holding pond water intake is immediately upstream of the weir. Adult fish captured in the trap are not susceptible to elevated TDG levels because:

  - The adult fish are generally held for short periods. The fish are typically held up to about 16 hours in the holding ponds[8]. When numbers are low, they have been held for up to two days prior to transport to the spawning beaches and hatchery.
  - The holding ponds are sufficiently deep—deeper than the compensation depth. Assuming that the maximum TDG level associated with either spills or rampdowns will not exceed 120%, the compensation depth will be approximately 6 feet (2 meters). The water depth in the holding ponds varies from about 8 to 14 feet. Under these conditions, fish will not likely be held within the trap at a depth less than the compensation depth for a sufficient period of time to create GBD symptoms.

- **Documented low fish mortalities based on long-term records.** After entering the adult fish trap, fish are transported to Baker Lake and then held for months until naturally or artificially spawned. Adult fish mortality has averaged less than 2% over the period of record[9].

- **Lack of juvenile fish that would be susceptible to TDG generated by the Project.** Juvenile fish inhabit the Project's reservoirs and spawning beaches. TDG levels in the reservoirs are below the TDG criterion, based on data collected during the Project's relicensing (PSE, 2004; Ecology, 2007). Juvenile fish migrating downstream are captured by barrier nets in the reservoirs and then transported and released in the Skagit River/Baker River confluence, downstream of the Project.[10]

  Approximately 69,000 juvenile steelhead were held in the adult fish trap for acclimation for one week in May 2003, and another 69,000 for one week in

[8] Returning adults are, in cases of competing trap use, extended maintenance periods or upgrades, compelled to hold in the river (below the weir) for periods of up to two weeks.

[9] Based on Sockeye Spawning Beach prespawn mortality records between 1998 and 2008.

[10] A small number of juvenile fish pass through the spill gates during flood flow or the guidenets and into the penstocks.

May/June 2004. No dead fish were found caught on the outlet panel or recovered after trap dewatering. Elevated TDG levels, if they occurred, were not sufficient to induce mortality.

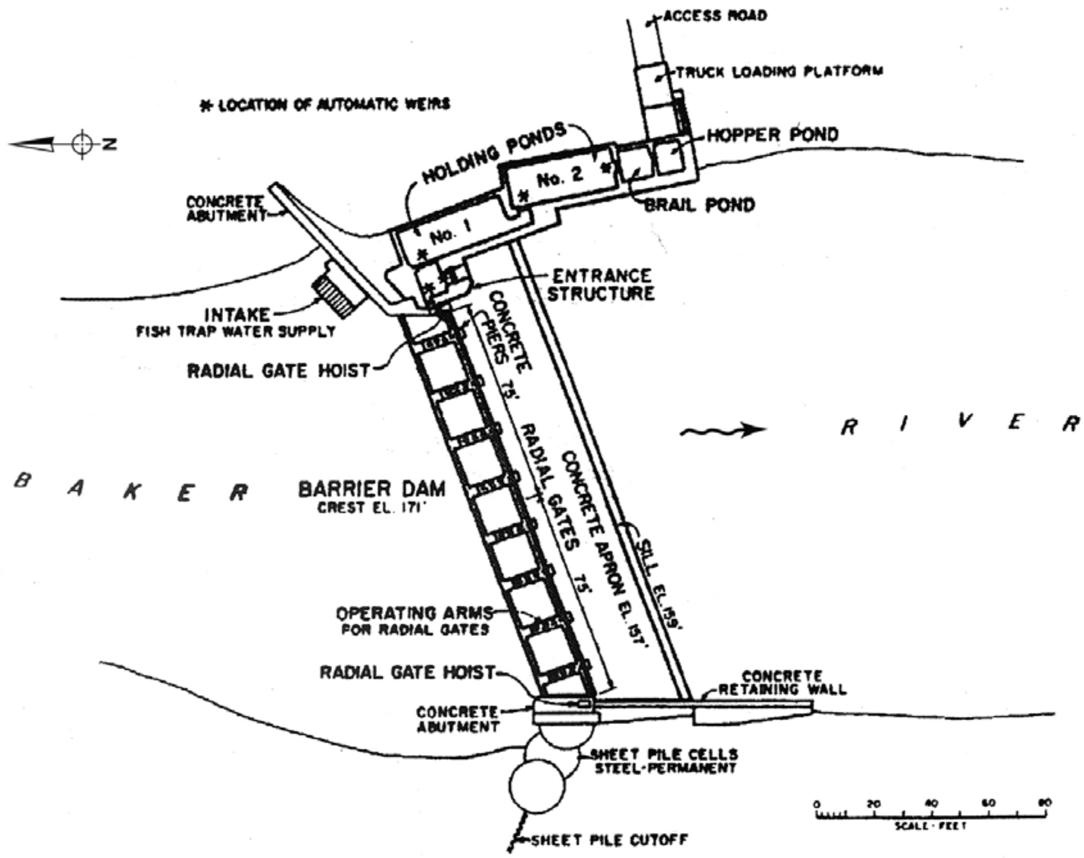

Figure 4. Baker River adult fish trap – plan view.

4.0 TDG Abatement Measures

The TDG abatement measures at the Project will consist of:

- Installing new turbines at Lower Baker powerhouse that are anticipated to reduce TDG generated during rampdowns to levels below the TDG criterion.
- Improving real-time operations and water management at the Project, which would reduce the number and duration of spills.
- TDG monitoring.
- Reporting and plan implementation.

4.1 Rampdown Generated TDG

The new Lower Baker turbines will be used for base load operation to maintain the minimum instream flow requirements as listed in table 1 of the Project's WQC. The existing unit 3 will operate in series with the new turbines (that is, the new turbines will ramp up as unit 3 ramps down) to comply with the new ramping rate requirements listed in table 1 of the Project's WQC. This operation will allow the water from the new turbines, which will have relatively lower TDG levels, to mix with water from the unit 3 turbine. Operation of these units is anticipated to result in TDG levels below the 110% TDG criterion. The new turbines are currently scheduled to be installed in 2013.

In addition, the minimum instream flow will increase from 80 cfs to between 1,000 and 1,200 cfs within 90 days following the installation of the new turbines. The greater flow through the powerhouse may also help to reduce the downstream TDG levels and reduce the need to spill (see below).

4.2 TDG Generated During Spills

Our proposed approach for TDG associated with spills will be to manage Baker Lake and Lake Shannon to avoid spills to the extent possible, and minimize TDG during exempted periods.

The potential measures to reduce TDG production through spill gates include: the preferential use of spillways; modifying spillways to increase turbulence; modifying the stilling basin or tailrace to accelerate de-gassing; providing auxiliary spillway bypass; and/or installing lower water ports. These measures are not included in this TDG abatement plan due to the minimal benefit these measures would provide at this Project given the relatively few number of spills that produce TDG levels of concern, the lack of observed impacts to the aquatic resources, and the high costs of these measures. The Project has high head dams, with approximately 300 feet of head, in very narrow, rocky canyons so the opportunities to provide auxiliary spillway bypasses are very limited as are the possibilities to modify the stilling basins and tailraces. For the current assessment, it will be anticipated that the new units at Lower Baker will provide a cost-effective means of achieving compliance as it will reduce the need to spill, and the duration and quantity of spill necessary.

In addition, over the near term (within 10 years), we will implement several measures to improve our real-time operations that will optimize water management at the Project. These measures will likely reduce the frequency and duration of spills in the future. These measures include:

- **Preparing a reservoir operations plan.** This plan will document reservoir management procedures under our new license conditions and other operational constraints. This plan will include improved standard operating plans, best management practices, and guidelines for monitoring and adjusting generation procedures.
- **Developing and implementing rule curves for the Project's reservoirs**. Operating with defined annual rule curves at Baker Lake and Lake Shannon with adjustments as needed to provide the needed guidance to optimize water use at the Project.
- **Improving the automation of our generation system**. We will be making several enhancements to the generation automation system concurrent with the installation of the new Lower Baker powerhouse. These measures include improvements to our hydrologic monitoring network in the Baker watershed, increasing our inflow

forecasting capabilities, improving flow routing in the reservoirs, and increasing automation of the facilities to optimize generation and improve flow management.

- **Improving the implementation of our outage management plan**. This task will improve our current system to better prepare for planned outages.
- **Implementing a central generation management system ("Gen Desk")**. A centralized generation management system will focus on the continuous coordination of PSE's generation facilities.

4.3 TDG Monitoring

The TDG monitoring program will consist of two elements:

- Monitoring in the Lower Baker tailrace below the fish weir.
- Monitoring associated with the installation of the new Lower Baker turbines.

Fish Weir Monitoring

Monitoring below the fish weir will be conducted to assess whether the weir causes sufficient turbulence to reduce TDG levels below the standard (thus protecting the fisheries resources downstream of the weir) during rampdown periods. The fish weir TDG monitoring will begin within one year following FERC approval of this plan.

TDG will be monitored at 15-minute intervals using Hydrolab® MS5 Multiprobe® instruments with TDG, temperature, and depth sensors downstream of the fish weir over a one-month period.

Procedures outlined by the manufacturer's specifications will be used for operation and maintenance of the water quality instruments. Calibration results and field sheets will be documented by PSE and made available to Ecology as requested.

Lower Baker Turbine Installation

Hourly TDG monitoring at the Adult Fish Trap will be conducted to determine TDG compliance following installation of the new Lower Baker turbines. TDG monitoring will begin one month before the installation of the new turbines and continue at least four months after initial operation.

4.4 Reporting and Plan Implementation

The annual water quality report, submitted to Ecology and the FERC by June 30th of each year, will include information regarding spills and the methods and results of any TDG monitoring conducted at the Project, including compliance with TDG standards.

This TDG abatement plan will be updated and re-submitted to Ecology and the FERC for approval prior to any Project modifications that could substantially affect TDG production. The Project will be operated according to this plan once approved by Ecology and the FERC.

This TDG Abatement Plan satisfies the submittal requirements for the new Lower Baker powerhouse project. However, after installation of the Lower Baker powerhouse and prior to the end of the TDG compliance period on October 17, 2015, PSE will re-assess the Project's progress toward achieving compliance with TDG standards. This assessment will be summarized and submitted to Ecology and the FERC as a revision or addendum to this TDG Abatement Plan.

5.0 References

Antcliffe, B. L., L. E. Fidler, and I. K. Birtwell. 2002. Effect of dissolved gas supersaturation on the survival and condition of juvenile rainbow trout (Oncorhynchus mykiss) under static and dynamic exposure scenarios. Canadian Technical Reports Fisheries and Aquatic Sciences 2370: 70 pp.

Antcliffe, B. L., I. K. Birtwell, and L. E. Fidler. 2003. Lethal and sublethal responses of rainbow trout (Oncorhynchus mykiss) and (Oncorhynchus kisutch) fry to elevated dissolved gas supersaturation and temperature. Canadian Technical Report Fisheries and Aquatic Sciences 2500. 18 pp.

Backman, T. W. H., and A. F. Evans. 2002. Gas bubble trauma incidence in adult salmonids in the Columbia River Basin. North American Journal of Fisheries Management 22:579–584.

Backman, T. W. H., A. F. Evans, M. S. Robertson, M. A. Hawbecker. 2002. Gas bubble trauma incidence in juvenile salmonids in the lower Columbia and Snake Rivers. North American Journal of Fisheries Management 22:965–972.

Beeman, J. W., and A. G. Maule. 2006. Migration depths of juvenile Chinook salmon and steelhead relative to total dissolved gas supersaturation in a Columbia River reservoir. Transactions of the American Fisheries Society 135:584-594.

Cochnauer, T. 2000. Summarization of gas bubble trauma monitoring in the Clearwater River, Idaho, 1995-1999. Project Report by Idaho Department of Fish and Game to Bonneville Power Administration, Portland, Oregon

Dawley, E.M., M. Schiewe and B. Monk. 1974. Effects of Long-Term Exposure to Supersaturation of Dissolved Atmospheric Gases on Juvenile Chinook Salmon and Steelhead Trout in Deep and Shallow Test Tanks. National Marine Fisheries Service, Northwest Fisheries Center, Seattle, WA. Proceedings of Gas Bubble Diseases Workshop, Battelle-Northwest Laboratories, Richland, WA, 1976, pp 1-10.

Dunnigan, J., B. Marotz, J. DeShazer, L. Garrow, and T. Ostrowski. 2003. Mitigation for the construction and operation of Libby Dam, Annual Report 2001-2002. BPA Report DOE/BP-00006294-3. June 2003. 220 pp.

Point Four Systems.com, 2005. Total Gas Pressure Information Sheet http://www.pointfour.com/PDFs/Articles/TGP_information.pdf

Puget Sound Energy (PSE). 2004. Baker River Relicense FERC Project No. 2150 Study A05 - Water Quality Final Study Report Appendix B Historic Water Quality Information (pages 23-24; 44-54; +appendices).

Ryan, B. A., E. M. Dawley, and R. A. Nelson. 2000. Modeling the effects of supersaturated dissolved gas on resident aquatic biota in the main-stem Snake and Columbia Rivers. North American Journal of Fisheries Management 20:192-204.

Washington State Department of Ecology (Ecology). 2007. RE: Baker River Hydroelectric Project (FERC No. 2150), Order No. 2525 Water Quality Certification and Coastal Zone Management Consistency Determination.

Washington State Department of Ecology and the U.S. Environmental Protection Agency (Ecology et al.). 2007. Pend Oreille River Total Dissolved Gas Total Maximum Daily Load, Water Quality Improvement Report. Prepared in cooperation with the Kalispel Tribe. Washington State Department of Ecology Publication No. 07-03-003.

Washington State Department of Ecology, U.S. Environmental Protection Agency, and Spokane Tribe of Indians (Ecology et al.). 2004. Total Maximum Daily Load for Total Dissolved Gas in the Mid-Columbia River and Lake Roosevelt Submittal Report. Washington State Department of Ecology Publication No. 04-03-002.

Ecology. 2009. Memo from Kevin Fitzpatrick (Ecology) to Jory Oppenheimer (PSE). July 9. 2009. Re: Baker River Hydroelectric Project 7Q10 Determination. 2pp.

Ecology. 2007. RE: Baker River Hydroelectric Project (FERC No. 2150), Order No. 2525 Water Quality Certification and Coastal Zone Management Consistency.

Weitkamp, D. E. 2008. Total Dissolved Gas Literature 1980-2007, An Annotated Bibliography. Parametrix, Bellevue, Washington.

Weitkamp, D. E., R. P. Sullivan, T. Swant, and J. DosSantos. 2003. Behavior of resident fish relative to TDG supersaturation in the Lower Clark Fork River. Transactions of the American Fisheries Society 132:856-864.