Appendix H

Total Dissolved Gas Abatement Plan For Lower Granite Dam

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Introduction

In its operation of the Federal Columbia River Power System (FCRPS) projects, the U.S. Army Corps of Engineers (Corps) is responsible for providing for the authorized project purposes consistent with applicable laws and regulations. The operation of the Corps FCRPS project has effects on water quality and Endangered Species Act (ESA) listed fish. Accordingly the Corps considers the ecological objectives of the Clean Water Act and the ESA, and complies with the applicable water quality standards to the extent practicable as well conducting operations consistent with applicable Biological Opinions.

The 2008 NOAA Fisheries Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) relies on spill operations at Corps mainstem projects for listed juvenile salmon and steelhead passage. Currently, the spill operations during the juvenile fish passage season (generally early April into August) at Corps dams are consistent with court-ordered operations and the adaptive management provisions in the 2008 NOAA BiOp as implemented through the Adaptive Management Implementation Plan (AMIP). The intent of the spill operations is to help meet juvenile fish survival performance standards identified in the BiOp. These fish passage spills may result in the generation of total dissolved gas (TDG) supersaturation in the Columbia and lower Snake rivers at levels above current state and federal water quality standards. The states of Washington and Oregon have authorized exceptions to these standards as long as the elevated TDG levels provide for improved fish passage through the spillway without causing more harm to fish populations than through other passage routes. The purpose of this document is to summarize past, present, and future structural and operational TDG abatement as requested by the State of Washington for their criteria adjustment.

The following document contains the TDG abatement plan for Lower Granite Dam. The Total Dissolved Gas (TDG) exchange properties in the Snake River at Lower Granite dam have been formulated as a function of alternative structural configurations, spill operations, total river flow rates, background TDG properties and powerhouse hydraulic capacity. The following document contains a description of the assumptions used to generate these TDG estimates and a series of tables that describe the TDG exchange properties at Lower Granite Dam for past, present, and future scenarios.

Project Description

Lower Granite is the uppermost project on the lower Snake River, located 107.5 miles above the Snake River confluence with the Columbia River. The main structures include the powerhouse, spillway and stilling basin, navigation lock, fish facilities, concrete non-overflow sections, and a rock-fill embankment on the north shore. The dam spans 3,200 feet including the earthen non-overflow embankment. The powerhouse is located near the south shore with the spillway and navigation lock to the north. It consists of six generator bays with a maximum total discharge capacity of 130 kcfs. The Lower Granite spillway is 512 feet long. It has eight 50-foot-wide spillway bays separated by seven 14-foot-wide

piers. The spillway bays are numbered consecutively from north to south. The spillway crest elevation is 681.0 fmsl. The spillway discharge is controlled by eight radial (tainter) gates that are 50 feet wide by 60 feet high. The spillway will pass the project design flood of 850 kcfs, with the maximum pool elevation of 746.5 fmsl and the standard project flow of 678 kcfs with the normal full pool elevation 738.0 fmsl.

Powerhouse Hydraulic Capacity

The Lower Granite powerhouse unit hydraulic capacity during the fish passage season was estimated assuming the extended-length submersible traveling screens are installed, a total head of 100 ft, and each unit is operated at the upper limit of the peak efficiency constraint as described in the yearly Fish Passage Plan (FPP, 2010). The unit hydraulic capacity for these conditions was estimated to equal 18.8 kcfs for unit 1-3, and 17.2 kcfs for units 4-6. The total hydraulic capacity of the Lower Granite powerhouse with all 6 units available is 108.0 kcfs. If only 5 units are available the hydraulic capacity of the Lower Granite powerhouse was estimated as 90.8 kcfs. In general, turbine maintenance and repair activities are scheduled to provide for maximum capacity during peak flow periods during each year. A minimum powerhouse discharge of 9.5 kcfs required to meet generation requirements was assumed throughout this evaluation.

Flow Frequency Analysis of the Snake River at Lower Granite Dam

The daily average total river flow, generation flow, and spillway flow was compiled for Lower Granite Dam as contained in the Corps of Engineers CROHMS database (http://www.nwd-wc.usace.army.mil/perl/dataquery.pl) for the time period of October 1974 to October 2009. The time centered seven-day moving average of daily flow was computed throughout this 35 year period. This time period was chosen to correspond with the completion of major storage projects in the Columbia River Basin. This period of record was partitioned into two seasons: Fish Passage Season April 1-August 31 for a total of five months; and Non-Fish Passage Season January 1-March 31 and September 1-December 31 for a total of seven months.

The percent exceedance characteristics for the seven-day moving average of daily average flows for the Snake River at Lower Granite Dam are shown in Figure H1 during the fish passage season from 1975-2009. The median river flow during this period is about 58 kcfs. The frequency that the Snake River flow will exceed 100 kcfs is 22.5 percent and 200 kcfs is only 0.2 percent as listed in Table H1. The likelihood that the Snake River flow will exceed the powerhouse capacity of 108 kcfs was 18.2 percent of the time.

The percent exceedance characteristics for the seven-day moving average of daily average flows for the Snake River at Lower Granite Dam outside the fish passage season

from 1974-2009 are shown in Figure H2. The median river flow during this period is about 29 kcfs. The frequency that the Snake River flow will exceed 100 kcfs is 2.7 percent and 200 kcfs is 0.0 percent. Outside of the fish passage season, the likelihood that the Snake River flow will exceed the powerhouse capacity of 108 kcfs was 1.9 percent of the time.

The Washington water quality standards for TDG are applicable during river flows up to the high seven-day average flow with a return period of 10 years (7Q10). The 7Q10 is the average peak annual flow for seven consecutive days that has a recurrence interval of ten years. The WDOE estimated this discharge for the Snake River at Lower Granite Dam at 214 kcfs as described in the Total Maximum Daily Load for Lower Snake River Total Dissolved Gas (WDOE, 2002). The period of record used in the TMDL analysis was from 1975-2000. The 7Q10 flow was updated using the extended period of record from 1975-2009 using the methodology described in Bulletin #17B (USGS, 1982) and the data identified in the Lower Snake River TMDL. The updated mean 7Q10 high flow in the Snake River at Lower Granite Dam was estimated to equal 203 kcfs with an 80 percent confidence limit ranging from 184.4 to 247.6 kcfs. This evaluation did not correct the skew coefficient of the station record. A review of the historic records show that the updated 7Q10 flow of 203 kcfs was exceeded in only 2 of the past 35 water years which infers a return period of once every 17.5 years.

Water Quality Standards

The current Washington water quality standards allow for operations resulting in TDG levels of up to 120 percent at tailwater monitoring stations and 115 percent at the forebay of the next downstream dam based on a 12 hour moving average of consecutive observations for the purpose of aiding the passage of ESA listed species from April 1 through August 31. The hourly maximum TDG saturation is not to exceed 125 percent of saturation during the fish passage season. The Washington TDG water quality standard outside of the fish passage season is 110 percent of saturation.

TDG Abatement Activities

The TDG loading of the Snake River is influenced by both operations and the structural configuration of the Dam. Operational strategies to aid fish passage may have a direct influence on the TDG conditions in the river. An alternative spill pattern that more effectively guides fish during spillway operations and at lower spill volumes will also lower the TDG pressures in the receiving waters. Alternatively, a reduction in the injury rate of juvenile passing through the powerhouse may also reduce the reliance on spill for fish guidance resulting in an enhancement in TDG conditions.

The general approach for TDG abatement activities focuses on limiting the entrainment of air into the water column, the water flow rate that encounters the bubble plume and thirdly, the effective depth of the air that does become entrained. Spillway flow deflector commonly referred to as flip lips, redirect the spill jet from a plunging flow that transports air bubbles deep into the stilling basin to a horizontal jet that maintains

entrained air much closer to the water surface. The influence of spillway flow deflectors is also to transport highly aerated flow conditions well downstream of the stilling basin into the tailrace channel, promoting the exchange of atmospheric gasses at shallow depths. The effectiveness of spillway flow deflectors in abating TDG production has been consistently demonstrated at Corps of Engineers projects on the Columbia and Snake rivers. Other methodologies to reduce TDG loading below main-stem dam involve minimizing the use of spillways for involuntary spill. Limiting the entrainment of powerhouse flows into the turbulence bubbly flow in the stilling basin can also be an effective method of TDG enhancement. A spill pattern that widely distributes spillway flows uniformly across the entire spillway has been found to lower TDG exchange rates.

It is recognized that a potential outcome of implementing gas abatement measures at a project is for greater reliance on spill to achieve fish passage goals. This is accomplished through increasing the spill discharge capacity generating acceptable TDG levels. The ability to spill significantly larger volumes of water at or below the tailwater TDG criteria of 120 percent has resulted in a net increase in the TDG loading on the Snake River during voluntary flow conditions. This increase in TDG loading results from a higher percentage of the river spilled at safe levels below the TDG criterion causing an increase in the cross sectional average TDG pressures. The following sections will discuss both the operational and structural configuration at Lower Granite Dam that influences TDG loading in the Snake River during the fish passage season.

Structural Alternatives

The installation of spillway flow deflectors on all 8 spill bays was included in the original construction of the spillway at Lower Granite Dam. The Type I deflector consists of a 12.5-ft-long deflector with a small fillet radius toe curve at an elevation of 630 ft. This structural configuration reflected conditions up to 2002 and will be referred to as the "Base-8 Deflectors" configuration. The second structural configuration "8 Deflectors/SW" was defined by the existing spillway configuration in 2008 with spillway flow deflectors on 8 spill bays and a spillway weir (SW) located in spill bay 1. The purpose of this SW structure is to more effectively and efficiency guide juvenile fish past Lower Granite Dam by providing a surface oriented release over the spillway. The modernization of the Lower Granite Powerhouse is not expected to change the hydraulic capacity at this project. The third structural alternative "8 Deflectors/SW/Powerhouse Bypass (IT Sluice)" consisted of 8 spillway flow deflectors, spillway weir plus a powerhouse surface bypass using a sluiceway with a hydraulic capacity of 5 kcfs. This passageway was assumed to discharge into the tailrace channel downstream from the powerhouse. The forth structural alternative "8 Deflectors/SW/Powerhouse Bypass/Training wall" consisted of a full complement of spillway flow deflectors, SW, plus a Powerhouse surface bypass system and a training wall separating the spillway and powerhouse. This training wall was anticipated to improve fish egress and reduce the entrainment of powerhouse flows into the aerated spillway discharge.

Spill Operation Alternatives

This study also considered the influence of six different spill operations that govern the operations of Lower Granite Dam and resultant generation of TDG supersaturation. The spill operations for the Federal Columbia River Power System are described in the Fish Operations Plan that are devised each year based on the Biological Opinion adaptive management strategy. The first spill operation called for an instantaneous spill equal to 30 percent of the total river flow ("spill 30 %"). The second spill operation required the instantaneous spill to equal 20.5 kcfs ("spill 20 kcfs"). The third operation assumed a constant spill of 18 kcfs subject to powerhouse minimum hydraulic capacity constraints ("spill 18 kcfs"). The fourth spill operation called for spilling up to the capacity as limited by the 120 percent total dissolved gas saturation criterion at the tailwater fixed monitoring station ("spill to capacity @ 120%"). The fifth spill operation of no net increase in TDG loading of the Snake River called for flows to be limited by the either the 110 percent criteria or background TDG level in the Snake River ("spill to capacity @ 110% or TDGfb"). The final spill operation called for "no voluntary spill" excluding the discharge through the powerhouse surface bypass system.

TDG Properties

The TDG exchange properties at Lower Granite Dam have been influenced by the spill operation, spillway flow deflectors and the associated spill pattern. The spill operation has changed significantly over the past five years. The spill pattern has transitioned from a spillway operation using all 8 spill bays to a bulk spill pattern featuring SW discharge with training flow.

The TDG saturation observed at the tailwater fixed monitoring station from 1998 to 2007 as a function of spillway discharge is shown in Figure H3. The TDG saturation observations associated with constant spill operations longer than 2 hours were grouped for spillway discharges in increments of 5 kcfs. The mean value of TDG saturation is shown as a red symbol within each spill discharge grouping and the standard deviation is indicated by the cross hairs. The minimum and maximum observations are also indicated by a short dash in Figure H3. The linear regression model between spillway discharge and TDG saturation at Lower Granite Dam is shown Figure H3 with a slope of 0.2 percent/kcfs. This relationship indicates that a 10 kcfs increase in spill will result in a 2 percent increase in TDG saturation. The mean value of the spillway capacity as limited by the 120 percent tailwater TDG criteria is about 55 kcfs. The typical spillway capacity as limited by the 120 percent TDG criteria is likely to decrease if a bulk spill pattern is implemented.

The estimates TDG exchange in the Snake River at Lower Granite Dam were based on applying a set of empirical equations that describe the TDG exchange as a function of the effective depth of flow and specific spillway discharge. The relationship between TDG saturation and spillway discharge using all eight spill bays was estimated from observed TDG levels collected during a 2002 TDG exchange study at Lower Granite Dam (Schneider, 2003) as shown in Equation 1.

Equation 1

$$\Delta P = 5.3(TWE - 585)(1 - e^{-0.12 q_s}) \qquad (mm\,Hg) \qquad (1)$$

$r^2 = 0.92$

Std Error = 12.2 mm Hg

Where

$$q_s = \frac{Q_{sp}}{N_{eff}} \qquad \text{(kcfs/ft)}$$

N_{eff} = Effective number of active spill bays 1-8.
Q_{sp} = Total spill discharge (kcfs)
TWE = Tailwater surface elevation (ft)
TDG_{sat} = $(P_{atm}+\Delta P)/P_{atm}$ x 100 Total Dissolved Gas Saturation (%)
P_{atm} = Local Atmospheric Pressure (mm Hg)

$$N_{eff} = \frac{\sum_{i=1}^{nbays} Q_i \sum_{i=1}^{nbays} Q_i^{C_w - 1}}{\sum_{i=1}^{nbays} Q_i^{C_w}}$$ = Effective number of active spill bays 1-8.

Q_i = Spill discharge in bay i.
Nbays = Active number of spill bays.
c_w = 2 Spill pattern weighting coefficient

The sensitivity of TDG exchange as a function of a change in the tailwater stage from 630 to 631 ft will result in an increase in TDG pressure of 2.7 mm Hg during a specific spillway discharge of 6 kcfs/bay. Alternatively, an increase in the specific spillway discharge from 6 to 7 kcfs/bay will result in a 13.1 mm Hg increase in TDG pressure for a tailwater elevation of 630 ft. Equation 1 also illustrates the influence of bulking spill in several bays such as with the SW with training flow. A total spillway discharge of 45 kcfs uniformly distributed over 8 spill bays will result in a TDG pressure of 861.1 mm Hg (115.7 percent) at a tailwater elevation of 630 ft. The same 45 kcfs spilled uniformly over 4 bays will result in a TDG pressure of 920.7 mm Hg (123.7 percent) for an increase in TDG saturation of 8 percent over the uniform 8 bay spill pattern. An average local atmospheric pressure of 744 mm Hg was applied to estimate the total dissolved gas saturation.

The TDG properties of powerhouse flows were assumed to retain forebay TDG characteristics. However, the fate of the TDG characteristics of powerhouse releases is complicated by the subsequent entrainment of a portion of this discharge into the highly aerated flow conditions downstream of the spillway. The spillway flow deflectors generate a turbulent surface oriented jet that draws water adjacent to and beneath this jet into this flow feature. The associated TDG exchange of the entrained flow ranges from

complete incorporation into the spillway flows within the stilling basin attaining identical TDG saturations as spillway flows to mixing with spillway releases in the tailwater channel where TDG exchange is less prominent due to the air/water ratios and shallower depth of entrained bubbles.

The average flow weighted TDG saturation below Lower Granite Dam was determined for each combination of structural and operation alternative. A simple mass conservation statement can be developed for computing the flow-weighted average TDG saturation exiting the dam by associating a TDG saturation with the powerhouse and spillway flows as shown in Equation 2.

Equation 2

$$TDG_{avg} = \frac{Q_{sp}TDG_{sp} + Q_{gen}TDG_{gen}}{Q_{tot}} \quad \text{.....(2)}$$

where:

Q_{tot}	=	Total River Flow (kcfs)
Q_{sp}	=	Spillway discharge (kcfs)
Q_{gen}	=	Generation discharge (kcfs)
TDG_{gen}	=	TDG saturation of generation discharges (percent)
TDG_{avg}	=	Average cross sectional TDG saturation in the Snake River (percent)
TDG_{sp}	=	TDG saturation of spillway discharges (percent)

To account for the added TDG loading associated with the entrainment of powerhouse releases into the aerated spillway flow, an added mass term was included in the conservation statement as shown in Equation 3. This added mass discharge estimates the effective powerhouse flow entrainment into spillway releases where a portion of powerhouse release encounters the aerated flow conditions caused by spillway flows and experiences a similar level of TDG uptake. This formulation reduces the amount of flow from the powerhouse releases retaining forebay TDG levels available for dilution with spillway releases while increasing the volume of water exposed to highly aerated flow below the spillway.

Equation 3

$$TDG_{avg} = \frac{(Q_{sp} + Q_{ent})TDG_{sp} + (Q_{gen} - Q_{ent})TDG_{gen}}{Q_{tot}} \qquad (3)$$

where:

Q_{tot}	=	Total River Flow (kcfs)
Q_{sp}	=	Spillway discharge (kcfs)
Q_{gen}	=	Generation discharge (kcfs)
Q_{ent}	=	Effective entrainment discharge (kcfs)
TDG_{gen}	=	TDG saturation of generation discharges (percent)
TDG_{avg}	=	Average TDG saturation on transect USGS (percent)
TDG_{sp}	=	TDG saturation of spillway discharges (percent)

A simple functional form for the effective entrainment discharge has been estimated from field studies of TDG exchange at Lower Granite Dams (Schneider, 2003). The effective entrainment discharge was found to be linearly proportional to the spillway discharge in each case where the constant of proportionality is called the effective entrainment coefficient C_{ent}. The functional form for the estimation of the entrainment discharge is shown in Equation 4. The entrainment coefficient for applied to Lower Granite Dam for this investigation was C_{ent}=1.0.

Equation 4

$$Q_{ent} = C_{ent} Q_{sp} \qquad (4)$$

Where

$$0 < Q_{ent} < Q_{ph}$$

The return of diverted flow associated with the powerhouse surface bypass alternatives has the potential to generate elevated TDG pressures in the Snake River. The experience of TDG exchange associated with the ice and trash (IT) chute at The Dalles Dam has been evaluated and was found to cause an increase TDG pressure in the Columbia River by several percent for low background TDG conditions. The outfall below Bonneville Dam associated with the Bonneville 2nd Powerhouse Corner collector (B2CC) was also found to add to the TDG loading in the Columbia River during low tailwater conditions. The types of outfall flow conditions below these two surface bypass systems are quite different. A plunge pool was constructed at the outfall of the B2CC increasing the potential for aerated flow to experience large hydrostatic pressures and TDG uptake. In contrast, the IT chute at The Dalles Dam discharges into a shallow basin and is directed at an angle to releases from the powerhouse. These outfalls do provide some reference for estimating the TDG exchange for surface bypass flows at Lower Granite Dam. For this study a constant TDG saturation of 119.8 percent was applied for all surface bypass flows. The basis for this estimate was the observed level of TDG exchange associated

with surface bypass flows at Bonneville and The Dalles Dams and the additional influence of designing a surface collector outfall that would limit the amount of TDG exchange during operation. The design attributes would involve the receiving channel depth of flow, trajectory, chute width, invert elevation, and proximity to other project flows.

A comprehensive evaluation of TDG exchange at Lower Granite Dam should consider the existence of elevated background TDG levels from upstream sources. The presence of elevated background TDG levels at Lower Granite Dam is caused by the voluntary spill at upstream projects to aid fish passage or involuntary spill resulting from river flows exceeding powerhouse capacity or the presence of surplus generation capacity in the system. The forebay TDG levels at Lower Granite Dam are summarized from 1995-2007 as a function of total river flow in Figure H4. The observed daily average TDG saturation in the forebay of Lower Granite Dam was summarized for 5 kcfs ranges in total river flow from 25 to 235 kcfs. The average forebay TDG saturation is indicated by the red circle and the standard deviation in TDG saturation is indicated by the range bars. A well defined linear relationship was evident between observed TDG saturation in the forebay of Lower Granite Dam and total river flow. This figure shows that when river flows are approaching the 7Q10 level of 203 kcfs, the background TDG saturation typically ranges from 104 to 111 percent. The elevated TDG levels during high river flow are caused by spill from Hells Canyon Dam on the Snake River and Dworshak Dam on the Clearwater River.

The accuracy of TDG exchange estimates during spillway releases at Lower Granite Dam based on Equations 2-3 can be evaluated by conducting a hind caste of historic operations and comparing the calculated TDG pressures to observed conditions at the tailwater fixed monitoring station. The tailwater TDG saturation at Lower Granite as a function of spillway discharge filtered for constant spill events of 3 hours and longer for the 2008 spill season is shown in Figure H5. One interesting feature of these data is the large range in TDG pressures corresponding with a given spill discharge less than 20 kcfs. The variation in TDG pressure for small spill discharges is likely related to the encroachment of the mixing zone at the tailwater fixed monitoring station. The estimated TDG pressures are consistent with observed conditions with the exception of consistently overestimating TDG pressures for spillway flows greater than 110 kcfs. The spill capacity limited by 120 percent saturation ranged from 60 to 70 kcfs for the 2008 spill season. The variability of TDG saturation for a given spill discharge is chiefly attributed to the variation in the tailwater elevation.

A hind cast of TDG saturation below Lower Granite Dam for a wide range of observed historic operations (spillway flow ranged from 20 to 145 kcfs) during May of 2008 were conducted using the relationship shown in Equations 2-3. The hourly total river and spillway flow are shown in Figure H6 along with the TDG saturation as observed and calculated at the tailwater fixed monitoring station. The TDG production model described by equations 2-3 does a good job of estimating both the peak levels of TDG saturation produced during peak involuntary spill events as well as simulating the voluntary TDG pressures in response to the bulk spill patterns.

Results

A series of estimates of TDG exchange were generated for a matrix of conditions impacting TDG exchange in the Snake River at Lower Granite Dam. This matrix consisted of the structural configuration, spill operation, total river flow, forebay TDG levels, and powerhouse capacity. This large matrix of conditions provides a comprehensive summary of past, present, and potential future configurations at Lower Granite Dam. The type of summary also provides for a comparison of TDG exchange conditions for controlled system components. Often times observed historical data is used as the basis for evaluating the progress of a TDG management program. However, the influence of the runoff hydrograph, changes to spill operation or the structural layout of the dam introduces variables that cloud the assessment of TDG abatement progress.

A master table of TDG estimates was developed in an Excel spreadsheet called lgsTDGest.xls summarizing the effects of 4 different structural configurations, six different spill operations, two powerhouse capacities, 9 different river flow rates, and five background TDG saturations. A summary of the discrete conditions listed in this table are summarized in Table H2. This table consists of 1350 different cases that provide a comprehensive summary of the TDG management program at Lower Granite Dam. The interpretation of data in the master table is more manageable when selecting a smaller subset of conditions to review. It is useful to hold all but one case component constant when reviewing these results. The spreadsheet utility "file/filter/auto" allows the user to reduce this master table into a more meaningful format by allowing the selection of a narrower range of case components. The following discussion provides a general overview of the past, present, and potential future prospects of TDG exchange at Lower Granite Dam.

Structural Configuration

The TDG exchange across the four structural configurations investigated at Lower Granite Dam for a spill operation of spilling 30 percent of the river for total river flows of 50, 125, and 203 kcfs was examined as shown in Tables H3. The Base-8 Deflectors structural conditions utilized a spill pattern involving all 8 spill bays as was the spill operation prior to 2002. The structural alternatives with a SW all utilize a bulk spill pattern for spill less then 40 kcfs transitioning to a uniform pattern at higher spill discharges. All other structural alternatives use a uniform spill pattern over spill bays with flow deflectors. The total river flow of 50 kcfs reflects an average flow condition during the fish passage season. The 125 kcfs is a 10 percent exceedance flow and falls into a category of flow in excess of the powerhouse capacity but generally below the TDG compliance thresholds at the tailwater station. The river flow of 203 kcfs represents the 7Q10 high Snake River discharge that can be expected to occur once every ten years on average. The background TDG levels were assumed to be 110 percent of saturation which would be typical for the flood flow conditions and generation of TDG supersaturation at upstream projects. A full powerhouse capacity of 108 kcfs was assumed for these conditions.

All four structural cases were able to spill 15 kcfs (30 percent of the river) without exceeding the TDG criteria of 120 percent in spillway flows. The TDG levels in spill ranged from 106 .9 to 110.7 percent because of differences in the spill pattern and structural alternative. The uniform distribution of 15 kcfs over all 8 spill bays in the Base 8-deflectors scenario resulted in a net lowering of average cross sectional TDG saturation from 110 percent in the forebay to 108.2 percent in the tailwater. The addition of the surface bypass system provided little change in the TDG loading of the Snake River. The addition of the training wall (case 1811) did not influence the TDG conditions in spill or the cross sectional average TDG saturation.

The intermediate river flow condition of 125 kcfs resulted in TDG levels in spill that remained at or below 120 percent for all conditions listed in Table H3. The average TDG saturation for the Base 8 Deflector scenario was only 3.3 percent above background levels. The structural scenario with the smallest impact on TDG saturation in the Snake River involved case 1814 where the effectiveness of the training wall is demonstrated. The addition of a powerhouse surface bypass structure is estimated to increase TDG pressures modestly.

The high flow conditions during the 203 kcfs river flows required powerhouse capacity flows with the remainder of the river spilled. The high spill discharges during this flood flow resulted in TDG levels in spill water about 129 percent. The only case where the cross sectional average TDG saturation was maintained below 120 percent was associated with the 8 Deflector/SW/PH surface bypass/training wall scenario (Case 1818). The training wall provided significant benefits during high flow conditions where low TDG forebay levels were available. The training wall structure will provide greater benefits at Lower Granite Dam than other projects because of the relatively low background TDG levels maintained at this project. The SW was not found to be a major detriment to TDG generation at this high spillway flow because of the application of a uniform spill pattern at this spill discharge.

Spill Operation Plans

The influence of spill operations on TDG exchange was explored for the current condition 8 deflectors with SW structural configuration for three river flow conditions 50, 125, and 203 kcfs. The maximum powerhouse capacity and forebay TDG level of 110 percent were also held constant for this evaluation as listed in Table H4. The spill operation has considerable influence over the TDG exchange during voluntary spill conditions that exist for 50 and 125 kcfs flows. The spill to the 120 percent TDG criteria resulted in the highest TDG levels. Spill operations resulting in spill discharges of 21 kcfs or less generally resulted in minimal increases in TDG saturation above background levels. However, the involuntary spill conditions during a total river flow of 203 kcfs over rides the influence of the spill operation plans and the TDG generation is identical for all cases exceeding 129 percent.

The “No voluntary spill” or “Spill capacity at 110 or TDGfb” result less than a 1 percent saturation increase in TDG levels in the Snake River for 50 and 125 kcfs. The more

aggressive “Spill to capacity at 120 percent “ caused largest increases of 5.4 and 8.6 percent in average river TDG level for the 50 and 125 kcfs river condition. The current spill operations of “Spill 18 or 20.5 kcfs” yielded much lower TDG conditions than generated with the previously applied “Spill to capacity at 120%” operation. At a total river flow of 125 kcfs, the “Spill 30 Percent” operation resulted in an average cross sectional TDG saturation of 113.3 percent compared to the TDG production of the “Spill to capacity at 120% operation” of 118.6 percent. The spill operations resulting in higher percent spill conditions generated higher TDG pressures but not above the 120 percent criteria for the 50 and 125 kcfs flows.

The 7Q10 flow resulted in a spill of 105.3 kcfs attaining a TDG saturation of 129 percent in both spill and as a cross sectional average. The entire powerhouse discharge was entrained into the aerated spillway flows for these conditions causing it to attain similar TDG levels as spillway discharges. The increase in TDG saturation during high total river conditions is greatest at Lower Granite Dam because of the relatively low background levels that are maintained in the forebay. The influence of spill operation plans are not important during these high involuntary spill conditions.

Total River Flow

The influence of total river flow on TDG exchange at Lower Granite Dam for a spill operation of spill 30 percent of the river is shown in Table H5. All these conditions assumed a forebay TDG saturation of 110 percent. In a separate computation, the total river flow where TDG levels begin to exceed the tailwater criteria of 120 percent assuming the capacity powerhouse discharge of 108 kcfs for current condition was estimated to be 161 kcfs and occurs less than 5 percent of the time (Figure H1). The cross sectional average TDG saturation exceeds 120 percent during a total river flow of 175 kcfs. The spill operations during the total river flows less than 75 kcfs resulted in a net increase in TDG saturation of less than 1 percent saturation in the Snake River. The spill conditions at Lower Granite Dam during the 7Q10 event result in TDG in excess of 129% for the existing structural condition.

Forebay TDG Levels

Forebay TDG conditions are important in shaping the average conditions below the dam when spill is a small component of total river flow. The high powerhouse entrainment rates at Lower Granite Dam tend to diminish the importance of upstream conditions at high spill discharges. Spill operations that limit the percent spill allow sufficient powerhouse flows to dilute spillway releases as listed in Table H6. However, the location of upstream sources of TDG pressure resulting in peak forebay TDG saturations of only 110 percent at Lower Granite Dam limits the likelihood of cases with forebay TDG levels of 115 percent and greater. The influence of powerhouse entrainment and not dilution is illustrated in the “spill to capacity at 120 percent” spill operation TDG estimates. The resultant average TDG levels below the dam range only from 111.3 to 119.3 when spilling 53.9 kcfs out of 125 kcfs total river flow with forebay TDG levels ranging from 105 to 125 percent. The influence of upstream sources of TDG

supersaturation is lost during high percent spill events because of the exposure of nearly all the river flows to highly aerated flow conditions. The current spill operation of a constant spill rate of 21 kcfs and less will maintain TDG levels below 120 percent in the Snake River and limit the uptake of TDG saturation to several percent of saturation.

Lower Granite 2009 configuration TDG and Flow Summary

The TDG saturation in Snake River below Lower Granite Dam was estimated for 5 different river flows assuming the 2009 spillway configuration for a uniform spill pattern and a forebay TDG saturation of 115 percent. In case 1, the total river flow conditions was chosen to correspond with the hydraulic capacity of the powerhouse will all turbines operating at the upper 1 percent range of best gate with fish screens in place. Cases 2-4 correspond with river flows at maximum powerhouse discharge with the spillway capacity limited by TDG saturations of 110, 115, and 120 percent. The final case corresponded with the updated mean 7Q10 flow of 203 kcfs. An auxiliary project discharge of 0 kcfs was also assumed in this analysis. The frequency of exceeding the total river flow for each case within the fish passage season (Apr-Aug) and during the non-fish passage season (Sep-Mar) based on observed flows at Lower Granite Dam from 1974-2009 are also listed in Table H7.

The frequency for spilling water above the maximum powerhouse capacity during the fish passage season is nearly 18.8 percent of the time at Lower Granite Dam but only about 2.0 percent of the time outside of the fish passage season. The powerhouse operations will simply pass the background TDG levels to the receiving pool resulting in no change to the TDG conditions. A uniformly distributed spill of 22 kcfs will generate TDG levels at 110 percent of saturation or 5 percent lower than the initial conditions. Outside of the fish passage season a river flow of 129.4 kcfs occurs less than 0.60 percent of the time. This operation will result in a net decrease in the average TDG conditions of the river to 113.4% when forebay levels are 115 percent. The spillway discharges up to 36 kcfs will either reduce or cause no change in the TDG loading of the Snake River for total river flows up to 133.4 kcfs which occurs only about 8.9 percent of the time during the fish passage season. The spillway flows at Lower Granite Dam up to 53 kcfs will result in TDG levels of 120 percent and less which corresponds to a total river discharge of 160.4 kcfs and a frequency of occurrence of 4.1 percent during the fish passage season. The worst case conditions will be associated with the 7Q10 flows and a spill discharge of 95.6 kcfs resulting in TDG saturation in spillway flows of 128.2 percent.

Conclusions

Lower Granite spillway was built with flow deflectors designed to minimize the production of TDG supersaturation during spillway releases. This technology is still recognized as being the most effective means of reducing the TDG production during aerated spillway flows. Lower Granite Dam is unique in that the background TDG levels remain at 110 percent or less for all flow conditions. This results in the greatest uptake in TDG saturation during involuntary spill at high river flows. These lower forebay

conditions also present an opportunity for abating TDG loading at Lower Granite Dam if these properties can be used to dilute current spillway flows.

A spill pattern has been developed at Lower Granite Dam that is designed to effectively guide fish during voluntary spill events over the SW and minimize the generation of TDG pressures during involuntary spill conditions. This pattern is based around maintaining a uniform distribution of flow over all active spill bays during high involuntary spill conditions.

A third applied element of reducing the TDG generation at Lower Granite Dam involves the adoption of a spill operation that accommodates both fish passage goals and water quality objectives. Previous spill operations at Lower Granite Dam called for spilling as much water as possible without exceeding the TDG criteria at the downstream tailwater FMS (120 percent) or at the next forebay station located at Little Goose Dam (115 percent). This operation routinely caused spillway flows to exceed 40 to 50 kcfs during the voluntary fish passage season. The spill operation for the 2008 spill season called for spilling a fixed discharge of 21 kcfs or less. The TDG loading impacts of this spill operation are large especially when looking at the median flow of about 50 kcfs. The current spill operation of 20 kcfs will generate a TDG saturation of sightly less than 110 percent when forebay TDG levels are at 105 percent. The old spill to the 120 percent TDG criteria provides for a spill of about 40 kcfs and an average TDG saturation of 115.4 percent.

The current structural and spill operation result in TDG levels of about 129 percent saturation when spill is involuntary during the 7Q10 flood flow. The frequency of flow at this magnitude is only once during a 10 year period. There is sufficient depth of flow below Lower Granite Dam to afford relief from these conditions. The depth adjusted TDG saturation one meter below the surface would be 119 percent and meet WDOE criteria during the fish passage season.

The addition of the powerhouse surface bypass channel will have little direct impact on the TDG loading in the Snake River considering a typical range of seasonal flows. The potential secondary impact of reducing the reliance on spill for fish guidance could further reduce the voluntary spill flow rate and resulting in further lowering the TDG loading of the Snake River.

A training wall separating the powerhouse and spillway flows can have a large impact on TDG loading in the Snake River. The degree of TDG enhancement of the training wall is closely related to TDG levels in the forebay and the spill operation. The low TDG levels in the forebay at Lower Granite Dam translate into greater dilution potential for powerhouse flows with spillway flows. A higher percent of river spilled will tend to entrain a larger portion of powerhouse flows. For a 7Q10 river flow the training wall can cut the increase in TDG saturation in half compared to current conditions if forebay levels are 110 percent or saturation or less.

The TDG levels at the tailwater fixed monitoring station generally remain within the TDG criteria during voluntary spill conditions for river flows up to 161 kcfs provided that the full powerhouse capacity is available. It is more appropriate to describe the spill capacity as limited by the 120 percent TDG criteria as a range of flows since other influences like the tailwater depth and local atmospheric pressure also influence the determination of the TDG saturation observed below the dam.

The entrainment of powerhouse flows is an important component shaping the TDG loading at Lower Granite Dam. Spill operations that restrict the percentage of river spilled can positively limit the degree of entrainment.

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Table H1

Percent of time the seven-day moving average of daily average flows exceed the reference Snake River Flow at Lower Granite Dam, 1975-2009 water years.

Snake River Flow (kcfs)	Fish Passage Season April-Aug (%)	Non-Fish Passage Season Sept.-March (%)	Comments
25	85.60%	63.50%	
50	55.60%	14.90%	
75	38.50%	5.10%	
90.8	28.20%	3.70%	Powerhouse capacity 5 units
100	22.50%	2.70%	
108	18.2%	1.90%	Powerhouse capacity 6 units
125	10.90%	0.70%	
150	5.90%	0.20%	
175	2.20%	0.00%	
200	0.20%	0.00%	
203	0.00%	0.00%	Updated 7Q10 flow rate

Table H2
Configuration Matrix for
TDG Estimates in the Snake River at Lower Granite Dam

Structural Alternative	Spill Operation	$Q_{ph\text{-}Max}$ (kcfs)	Q_{total} (kcfs)	TDG_{fb} (%)
Base-8 Deflectors	No Voluntary Spill	108.0	25	105
8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	90.8	50	110
8 Deflectors/SW/PH Surface Bypass	Spill 18 Kcfs		75	115
8 Deflectors/SW/PH Surface Bypass/Training Wall	Spill 20.5 kcfs		100	120
	Spill 30 Percent		125	125
	Spill to Capacity @ 120%		150	
			175	
			200	
			203	

Table H3

Summary of Total Dissolved Gas Exchange at Lower Granite Dam for Snake River flow of 50, 125, AND 203 kcfs, Forebay TDG level of 110% by Structural alternative and spill operation of spill 30 percent.

Case	Structural Alternative	Spill Operation	Q_{ph-max} (kcfs)[1]	Q_{total} (kcfs)	Q_{gen} (kcfs)	Q_{spill} (kcfs)	Q_{aux} (kcfs)	TDG_{fb} (%)	TDG_{sp} (%)	TDG_{aux} (%)	TDG_{avg} (%)	ΔTDG (%)
191	Base-8 Deflectors	Spill 30 Percent	108.0	50.0	34.3	15.0	0.7	110	106.9	110.0	108.2	-1.8
731	8 Deflectors/SW	Spill 30 Percent	108.0	50.0	34.3	15.0	0.7	110	110.7	110.0	110.4	0.4
1271	8 Deflectors/SW/PH Surface Bypass	Spill 30 Percent	108.0	50.0	30.0	15.0	5.0	110	110.7	119.8	111.0	1.0
1811	8 Deflectors/SW/PH Surface Bypass/Training Wall	Spill 30 Percent	108.0	50.0	30.0	15.0	5.0	110	110.7	119.8	111.2	1.2
194	Base-8 Deflectors	Spill 30 Percent	108.0	125.0	86.8	37.5	0.7	110	115.5	110.0	113.3	3.3
734	8 Deflectors/SW	Spill 30 Percent	108.0	125.0	86.8	37.5	0.7	110	115.5	110.0	113.3	3.3
1274	8 Deflectors/SW/PH Surface Bypass	Spill 30 Percent	108.0	125.0	82.5	37.5	5.0	110	115.5	119.8	113.5	3.5
1814	8 Deflectors/SW/PH Surface Bypass/Training Wall	Spill 30 Percent	108.0	125.0	82.5	37.5	5.0	110	115.5	119.8	112.0	2.0
198	Base-8 Deflectors	Spill 30 Percent	108.0	203.0	108.0	105.3	0.7	110	129.4	110.0	129.1	19.1
738	8 Deflectors/SW	Spill 30 Percent	108.0	203.0	108.0	105.3	0.7	110	129.4	110.0	129.1	19.1
1278	8 Deflectors/SW/PH Surface Bypass	Spill 30 Percent	108.0	203.0	108.0	101.0	5.0	110	128.9	119.8	127.9	17.9
1818	8 Deflectors/SW/PH Surface Bypass/Training Wall	Spill 30 Percent	108.0	203.0	108.0	101.0	5.0	110	128.9	119.8	119.2	9.2

[1] Powerhouse capacity of 108.0 kcfs based on 6 turbines at 100 ft of head, with extended length STS installed, and operated at upper generation limit defined in FPP.

Case - Case number as listed in Lower Granite master TDG management plan.

$\mathbf{Q_{ph-max}}$ = Maximum hydraulic capacity of the Lower Granite powerhouse (kcfs)

$\mathbf{Q_{total}}$ = Snake River Flow at Lower Granite Dam (kcfs)

$\mathbf{Q_{gen}}$ = Powerhouse Flow (kcfs)

$\mathbf{Q_{spill}}$ = Spillway Flow (kcfs)

$\mathbf{Q_{aux}}$ = Auxiliary Flow including Powerhouse Surface Bypass (kcfs)
$\mathbf{TDG_{sp}}$ = Total Dissolved Gas Saturation in spillway flows (%)
$\mathbf{TDG_{fb}}$ = Total Dissolved Gas Saturation in forebay (%)
TDG_{aux} = Total Dissolved Gas Saturation in auxiliary release including the surface bypass outfall (%)
$\mathbf{TDG_{avg}}$ = Flow weighted Total Dissolved Gas Saturation below Dam (%)
ΔTDG = Change in average cross sectional Snake River TDG saturation (average tailwater TDG saturation minus forebay TDG saturation %)

Table H4

Summary of Total Dissolved Gas Exchange at Lower Granite Dam for Snake River flow of 50, 25, and 203 kcfs, Forebay TDG level of 110% for the 6 Deflector Structural alternative and various spill operations.

Case	Structural Alternative	Spill Operation	$Q_{ph\text{-}max}$ (kcfs)[1]	Q_{total} (kcfs)	Q_{gen} (kcfs)	Q_{spill} (kcfs)	Q_{aux} (kcfs)	TDG_{fb} (%)	TDG_{sp} (%)	TDG_{aux} (%)	TDG_{avg} (%)	ΔTDG (%)
551	8 Deflectors/SW	No Voluntary Spill	108.0	50.0	49.3	0.0	0.7	110	100.0	110.0	110.0	0.0
596	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	108.0	50.0	28.2	21.1	0.7	110	110.7	110.0	110.6	0.6
641	8 Deflectors/SW	Spill 18 Kcfs	108.0	50.0	31.3	18.0	0.7	110	110.7	110.0	110.5	0.5
686	8 Deflectors/SW	Spill 20.5 kcfs	108.0	50.0	28.8	20.5	0.7	110	110.7	110.0	110.6	0.6
731	8 Deflectors/SW	Spill 30 Percent	108.0	50.0	34.3	15.0	0.7	110	110.7	110.0	110.4	0.4
776	8 Deflectors/SW	Spill to Capacity @ 120%	108.0	50.0	9.5	39.8	0.7	110	115.4	110.0	115.4	5.4
554	8 Deflectors/SW	No Voluntary Spill	108.0	125.0	108.0	16.3	0.7	110	111.3	110.0	110.3	0.3
599	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	108.0	125.0	104.8	19.5	0.7	110	111.3	110.0	110.4	0.4
644	8 Deflectors/SW	Spill 18 Kcfs	108.0	125.0	106.3	18.0	0.7	110	111.3	110.0	110.4	0.4
689	8 Deflectors/SW	Spill 20.5 kcfs	108.0	125.0	103.8	20.5	0.7	110	111.3	110.0	110.4	0.4
734	8 Deflectors/SW	Spill 30 Percent	108.0	125.0	86.8	37.5	0.7	110	115.5	110.0	113.3	3.3
779	8 Deflectors/SW	Spill to Capacity @ 120%	108.0	125.0	70.4	53.9	0.7	110	120.0	110.0	118.6	8.6
558	8 Deflectors/SW	No Voluntary Spill	108.0	203.0	108.0	105.3	0.7	110	129.4	110.0	129.1	19.1
603	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	108.0	203.0	108.0	105.3	0.7	110	129.4	110.0	129.1	19.1
648	8 Deflectors/SW	Spill 18 Kcfs	108.0	203.0	108.0	105.3	0.7	110	129.4	110.0	129.1	19.1
693	8 Deflectors/SW	Spill 20.5 kcfs	108.0	203.0	108.0	105.3	0.7	110	129.4	110.0	129.1	19.1
738	8 Deflectors/SW	Spill 30 Percent	108.0	203.0	108.0	105.3	0.7	110	129.4	110.0	129.1	19.1
783	8 Deflectors/SW	Spill to Capacity @ 120%	108.0	203.0	108.0	105.3	0.7	110	129.4	110.0	129.1	19.1

[1] Powerhouse capacity of 108.0 kcfs based on 6 turbines at 100 ft of head, with extended length STS installed, and operated at upper generation limit defined in FPP.

Case - Case number as listed in Lower Granite master TDG management plan.

$\mathbf{Q_{ph\text{-}max}}$ = Maximum hydraulic capacity of the Lower Granite powerhouse (kcfs)

$\mathbf{Q_{total}}$ = Snake River Flow at Lower Granite Dam (kcfs)

$\mathbf{Q_{gen}}$ = Powerhouse Flow (kcfs)

$\mathbf{Q_{spill}}$ = Spillway Flow (kcfs)

$\mathbf{Q_{aux}}$ = Auxiliary Flow including Powerhouse Surface Bypass (kcfs)

$\mathbf{TDG_{sp}}$ = Total Dissolved Gas Saturation in spillway flows (%)

$\mathbf{TDG_{fb}}$ = Total Dissolved Gas Saturation in forebay (%)

TDG_{aux} = Total Dissolved Gas Saturation in auxiliary release including the surface bypass outfall (%)

$\mathbf{TDG_{avg}}$ = Flow weighted Total Dissolved Gas Saturation below Dam (%)

ΔTDG = Change in average cross sectional Snake River TDG saturation (average tailwater TDG saturation minus forebay TDG saturation %)

Table H5

Summary of Total Dissolved Gas Exchange at Lower Granite Dam for Snake River flows ranging from 50 to 203 kcfs, Forebay TDG level of 110% for the 6 Deflector Structural alternative and spill operation of Spill 30 Percent.

Case	Structural Alternative	Spill Operation	$Q_{ph\text{-}max}$ (kcfs)[1]	Q_{total} (kcfs)	Q_{gen} (kcfs)	Q_{spill} (kcfs)	Q_{aux} (kcfs)	TDG_{fb} (%)	TDG_{sp} (%)	TDG_{aux} (%)	TDG_{avg} (%)	ΔTDG (%)
730	8 Deflectors/SW	Spill 30 Percent	108.0	25.0	16.8	7.5	0.7	110	110.5	110.0	110.3	0.3
731	8 Deflectors/SW	Spill 30 Percent	108.0	50.0	34.3	15.0	0.7	110	110.7	110.0	110.4	0.4
732	8 Deflectors/SW	Spill 30 Percent	108.0	75.0	51.8	22.5	0.7	110	110.9	110.0	110.6	0.6
733	8 Deflectors/SW	Spill 30 Percent	108.0	100.0	69.3	30.0	0.7	110	112.9	110.0	111.7	1.7
734	8 Deflectors/SW	Spill 30 Percent	108.0	125.0	86.8	37.5	0.7	110	115.5	110.0	113.3	3.3
735	8 Deflectors/SW	Spill 30 Percent	108.0	150.0	104.3	45.0	0.7	110	117.9	110.0	114.7	4.7
736	8 Deflectors/SW	Spill 30 Percent	108.0	175.0	108.0	66.3	0.7	110	123.2	110.0	120.0	10.0
737	8 Deflectors/SW	Spill 30 Percent	108.0	200.0	108.0	91.3	0.7	110	127.6	110.0	126.0	16.0
738	8 Deflectors/SW	Spill 30 Percent	108.0	203.0	108.0	105.3	0.7	110	129.4	110.0	129.1	19.1

[1] Powerhouse capacity of 108.0 kcfs based on 6 turbines at 100 ft of head, with extended length STS installed, and operated at upper generation limit defined in FPP.

Case - Case number as listed in Lower Granite master TDG management plan.

$\mathbf{Q_{ph\text{-}max}}$ = Maximum hydraulic capacity of the Lower Granite powerhouse (kcfs)

$\mathbf{Q_{total}}$ = Snake River Flow at Lower Granite Dam (kcfs)

$\mathbf{Q_{gen}}$ = Powerhouse Flow (kcfs)

$\mathbf{Q_{spill}}$ = Spillway Flow (kcfs)

$\mathbf{Q_{aux}}$ = Auxiliary Flow including Powerhouse Surface Bypass (kcfs)

$\mathbf{TDG_{sp}}$ = Total Dissolved Gas Saturation in spillway flows (%)

$\mathbf{TDG_{fb}}$ = Total Dissolved Gas Saturation in forebay (%)

TDG_{aux} = Total Dissolved Gas Saturation in auxiliary release including the surface bypass outfall (%)

$\mathbf{TDG_{avg}}$ = Flow weighted Total Dissolved Gas Saturation below Dam (%)

ΔTDG = Change in average cross sectional Snake River TDG saturation (average tailwater TDG saturation minus forebay TDG saturation %)

Table H6

Summary of Total Dissolved Gas Exchange at Lower Granite Dam for Snake River flow of 125 kcfs, Forebay TDG levels ranging from 105 to 125% for the 6 Deflector Structural alternative and various spill operations.

Case	Structural Alternative	Spill Operation	$Q_{ph\text{-}max}$ (kcfs)[1]	Q_{total} (kcfs)	Q_{gen} (kcfs)	Q_{spill} (kcfs)	Q_{aux} (kcfs)	TDG_{fb} (%)	TDG_{sp} (%)	TDG_{aux} (%)	TDG_{avg} (%)	ΔTDG (%)
545	8 Deflectors/SW	No Voluntary Spill	108.0	125.0	108.0	16.3	0.7	105	111.3	105.0	106.6	1.6
554	8 Deflectors/SW	No Voluntary Spill	108.0	125.0	108.0	16.3	0.7	110	111.3	110.0	110.3	0.3
563	8 Deflectors/SW	No Voluntary Spill	108.0	125.0	108.0	16.3	0.7	115	111.3	115.0	114.0	-1.0
572	8 Deflectors/SW	No Voluntary Spill	108.0	125.0	108.0	16.3	0.7	120	111.3	120.0	117.7	-2.3
581	8 Deflectors/SW	No Voluntary Spill	108.0	125.0	108.0	16.3	0.7	125	111.3	125.0	121.4	-3.6
590	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	108.0	125.0	104.8	19.5	0.7	105	111.3	105.0	107.0	2.0
599	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	108.0	125.0	104.8	19.5	0.7	110	111.3	110.0	110.4	0.4
608	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	108.0	125.0	88.5	35.8	0.7	115	115.0	115.0	115.0	0.0
617	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	108.0	125.0	70.4	53.9	0.7	120	120.0	120.0	120.0	0.0
626	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	108.0	125.0	45.6	78.7	0.7	125	125.0	125.0	125.0	0.0
635	8 Deflectors/SW	Spill 18 Kcfs	108.0	125.0	106.3	18.0	0.7	105	111.3	105.0	106.8	1.8
644	8 Deflectors/SW	Spill 18 Kcfs	108.0	125.0	106.3	18.0	0.7	110	111.3	110.0	110.4	0.4
653	8 Deflectors/SW	Spill 18 Kcfs	108.0	125.0	106.3	18.0	0.7	115	111.3	115.0	113.9	-1.1
662	8 Deflectors/SW	Spill 18 Kcfs	108.0	125.0	106.3	18.0	0.7	120	111.3	120.0	117.5	-2.5
671	8 Deflectors/SW	Spill 18 Kcfs	108.0	125.0	106.3	18.0	0.7	125	111.3	125.0	121.0	-4.0
680	8 Deflectors/SW	Spill 20.5 kcfs	108.0	125.0	103.8	20.5	0.7	105	111.3	105.0	107.1	2.1
689	8 Deflectors/SW	Spill 20.5 kcfs	108.0	125.0	103.8	20.5	0.7	110	111.3	110.0	110.4	0.4
698	8 Deflectors/SW	Spill 20.5 kcfs	108.0	125.0	103.8	20.5	0.7	115	111.3	115.0	113.8	-1.2
707	8 Deflectors/SW	Spill 20.5 kcfs	108.0	125.0	103.8	20.5	0.7	120	111.3	120.0	117.1	-2.9
716	8 Deflectors/SW	Spill 20.5 kcfs	108.0	125.0	103.8	20.5	0.7	125	111.3	125.0	120.5	-4.5
725	8 Deflectors/SW	Spill 30 Percent	108.0	125.0	86.8	37.5	0.7	105	115.5	105.0	111.3	6.3
734	8 Deflectors/SW	Spill 30 Percent	108.0	125.0	86.8	37.5	0.7	110	115.5	110.0	113.3	3.3
743	8 Deflectors/SW	Spill 30 Percent	108.0	125.0	86.8	37.5	0.7	115	115.5	115.0	115.3	0.3
752	8 Deflectors/SW	Spill 30 Percent	108.0	125.0	86.8	37.5	0.7	120	115.5	120.0	117.3	-2.7
761	8 Deflectors/SW	Spill 30 Percent	108.0	125.0	86.8	37.5	0.7	125	115.5	125.0	119.3	-5.7

Case	Structural Alternative	Spill Operation	$Q_{ph\text{-}max}$ (kcfs)[1]	Q_{total} (kcfs)	Q_{gen} (kcfs)	Q_{spill} (kcfs)	Q_{aux} (kcfs)	TDG_{fb} (%)	TDG_{sp} (%)	TDG_{aux} (%)	TDG_{avg} (%)	ΔTDG (%)
770	8 Deflectors/SW	Spill to Capacity @ 120%	108.0	125.0	70.4	53.9	0.7	105	120.0	105.0	117.9	12.9
779	8 Deflectors/SW	Spill to Capacity @ 120%	108.0	125.0	70.4	53.9	0.7	110	120.0	110.0	118.6	8.6
788	8 Deflectors/SW	Spill to Capacity @ 120%	108.0	125.0	70.4	53.9	0.7	115	120.0	115.0	119.3	4.3
797	8 Deflectors/SW	Spill to Capacity @ 120%	108.0	125.0	70.4	53.9	0.7	120	120.0	120.0	120.0	0.0
806	8 Deflectors/SW	Spill to Capacity @ 120%	108.0	125.0	70.4	53.9	0.7	125	120.0	125.0	120.7	-4.3

[1] Powerhouse capacity of 108.0 kcfs based on 6 turbines at 100 ft of head, with extended length STS installed, and operated at upper generation limit defined in FPP.

Case - Case number as listed in Lower Granite master TDG management plan.

$\mathbf{Q_{ph\text{-}max}}$ = Maximum hydraulic capacity of the Lower Granite powerhouse (kcfs)

$\mathbf{Q_{total}}$ = Snake River Flow at Lower Granite Dam (kcfs)

$\mathbf{Q_{gen}}$ = Powerhouse Flow (kcfs)

$\mathbf{Q_{spill}}$ = Spillway Flow (kcfs)

$\mathbf{Q_{aux}}$ = Auxiliary Flow including Powerhouse Surface Bypass (kcfs)

$\mathbf{TDG_{sp}}$ = Total Dissolved Gas Saturation in spillway flows (%)

$\mathbf{TDG_{fb}}$ = Total Dissolved Gas Saturation in forebay (%)

TDG_{aux} = Total Dissolved Gas Saturation in auxiliary release including the surface bypass outfall (%)

$\mathbf{TDG_{avg}}$ = Flow weighted Total Dissolved Gas Saturation below Dam (%)

ΔTDG = Change in average cross sectional Snake River TDG saturation (average tailwater TDG saturation minus forebay TDG saturation %)

Table H7.

Snake River Flow at Lower Granite Dam and associated Total Dissolved Gas Saturation for 2009 Spillway Configuration assuming a uniform spill pattern and forebay TDG saturation of 115 percent.

Case	Description	Q_{river}	Q_{gen} [+]	Q_{sp}	TDG_{sp} [#]	TDG_{avg} [*]	Frequency (Apr-Aug)	Frequency (Sep-May)
1	Qriver=Qphmax	107.4	107.4	0	na	115.0	18.80%	2.00%
2	Q_{sp}@110%	129.4	107.4	22	110	113.4	10.10%	0.60%
3	Q_{sp}@115%	133.4	107.4	36	115	115.0	8.90%	0.50%
4	Q_{sp}@120%	160.4	107.4	53	120	118.4	4.10%	0.10%
5	7Q10-mean	203	107.4	95.6	128.2	127.4	0.10%	0.00%

[+] Total powerhouse flow with all turbines operation at upper 1% of best gate with fish screens in place.
[#] Total dissolved saturation in spillway flows undiluted by powerhouse flows.
[*] Average flow weighted total dissolved gas saturation in the Snake River below Ice Harbor Dam.
Case 1= Total river flow is at powerhouse hydraulic capacity with no voluntary spill operation
Case 2= Total river flow with maximum powerhouse flow and spill capacity at 110%.
Case 3= Total river flow with maximum powerhouse flow and spill capacity at 115%
Case 4= Total river flow with maximum powerhouse flow and spill capacity at 120%
Case 5= Total river flow at 7Q10 flow rate.

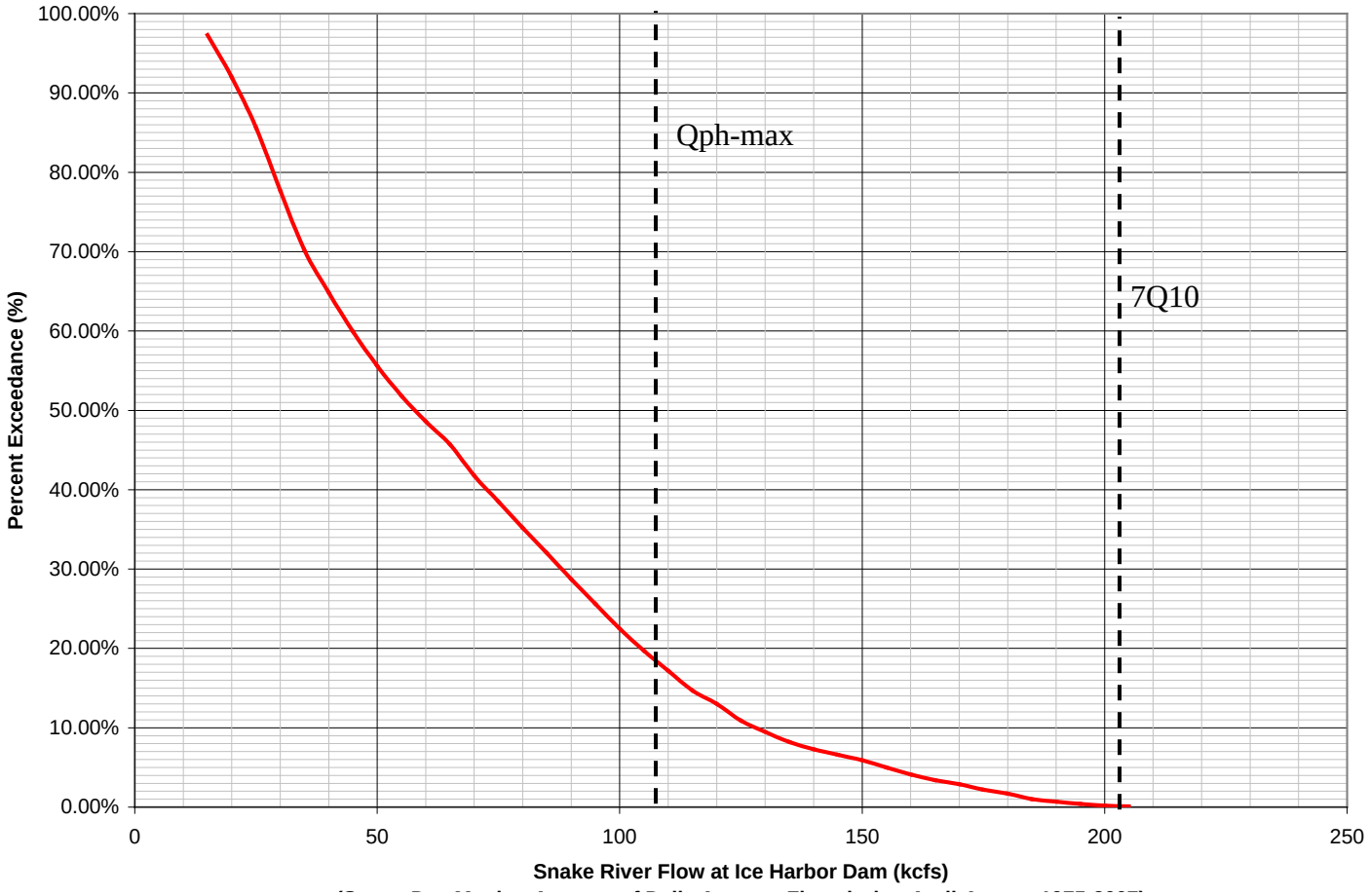

Figure H1. Percent Exceedance versus Snake River Flow at Lower Granite Dam during April-August 1975-2009.

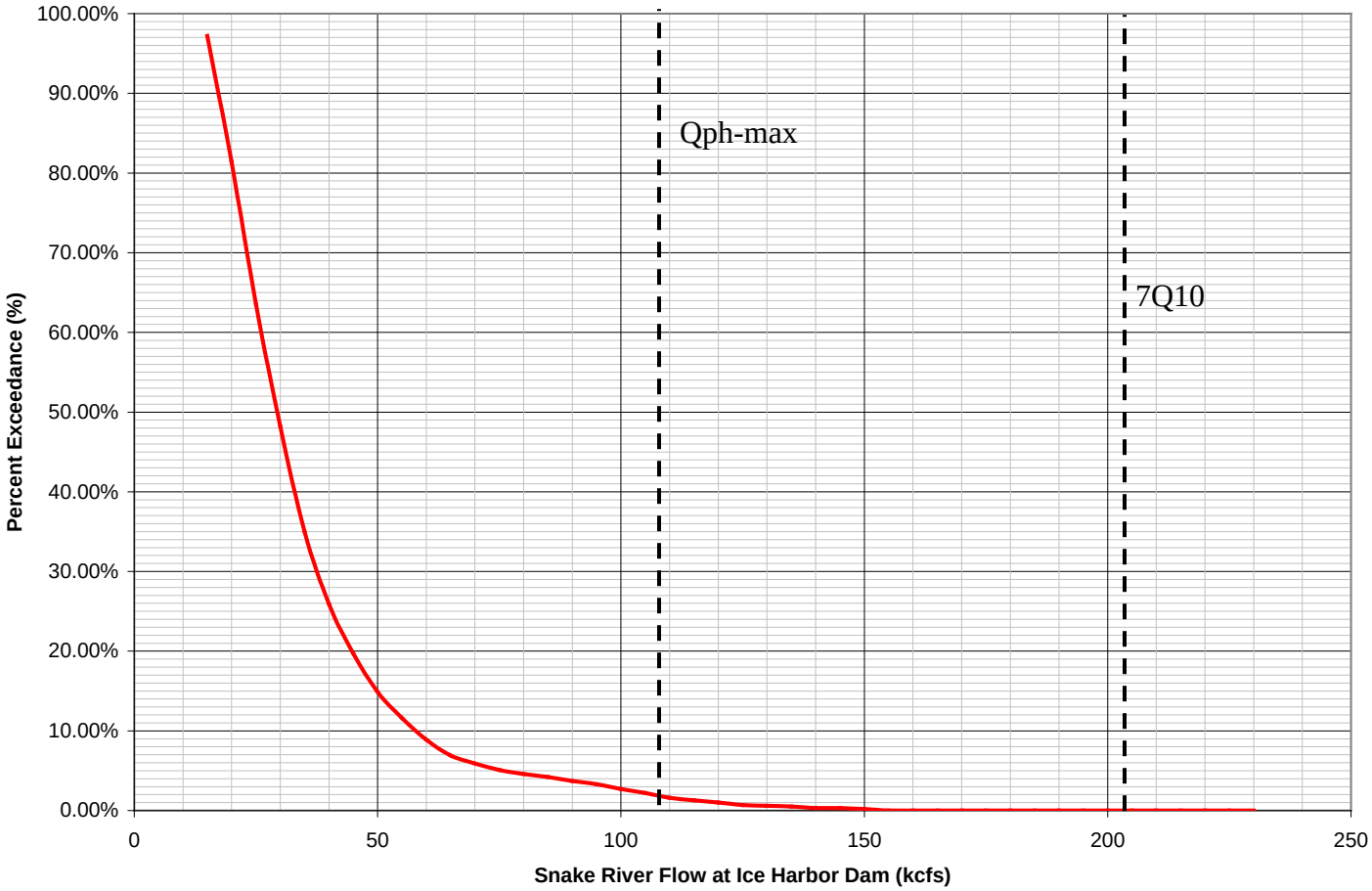

Figure H2. Percent Exceedance versus Snake River Flow at Lower Granite Dam during Sept.-March, 1974-2009.

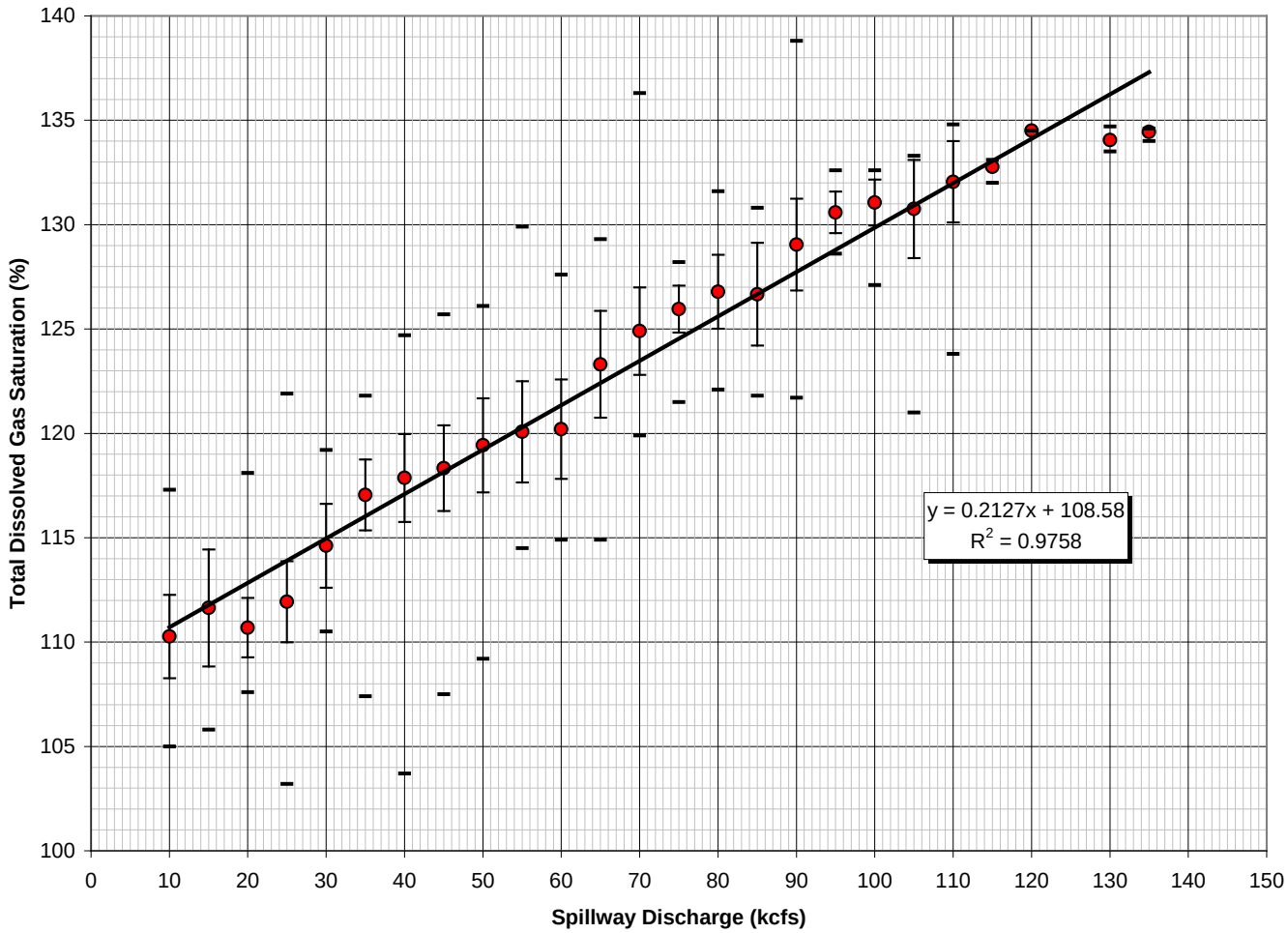

Figure H3. Total Dissolved Gas Saturation at the Tailwater Fixed Monitoring Station at Lower Granite Dam as a function of Spillway Discharge, 1998-2009

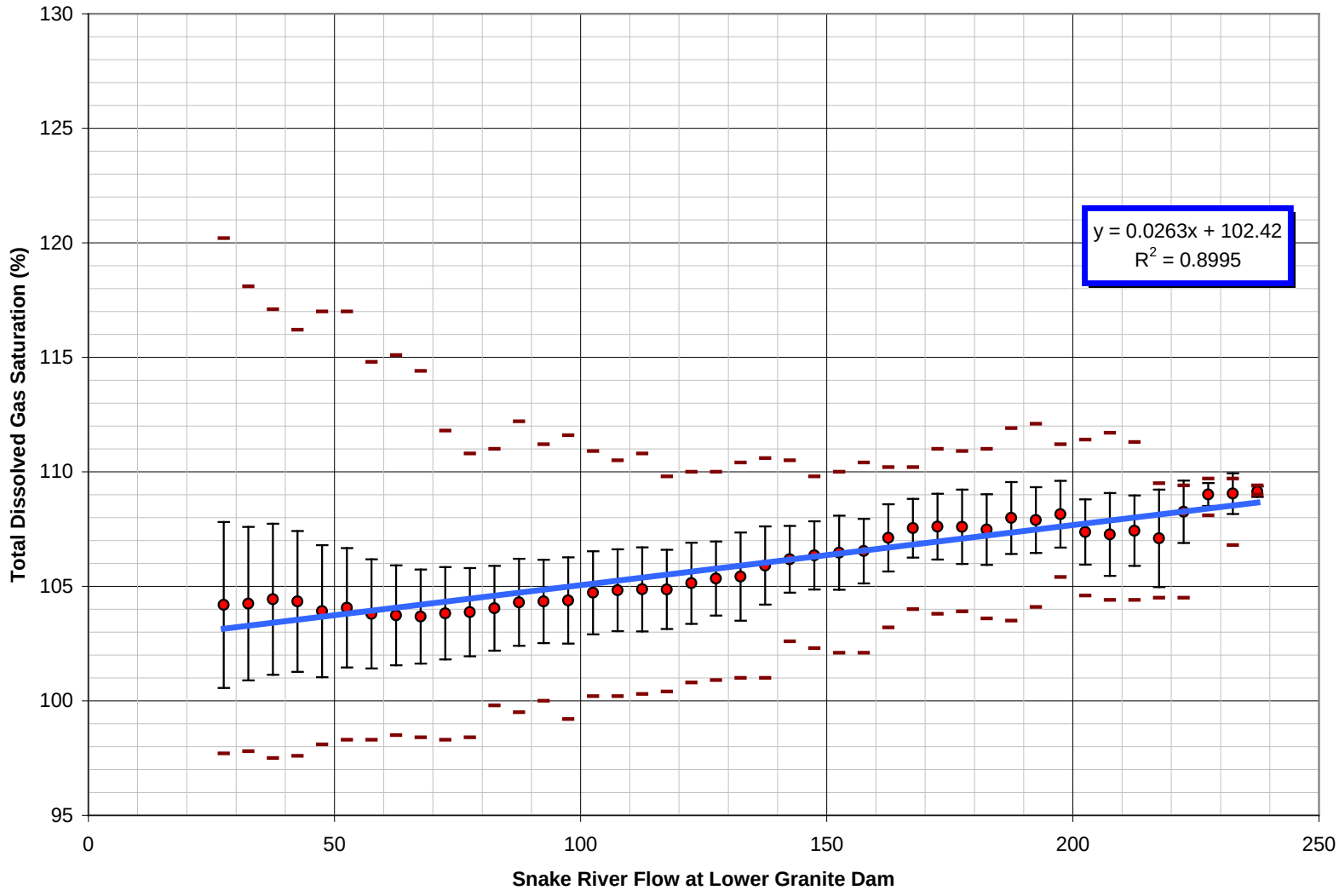

Figure H4. Total Dissolved Gas Saturation in the Forebay of Lower Granite Dam as a function of Total Snake River Flow, 1995-2009

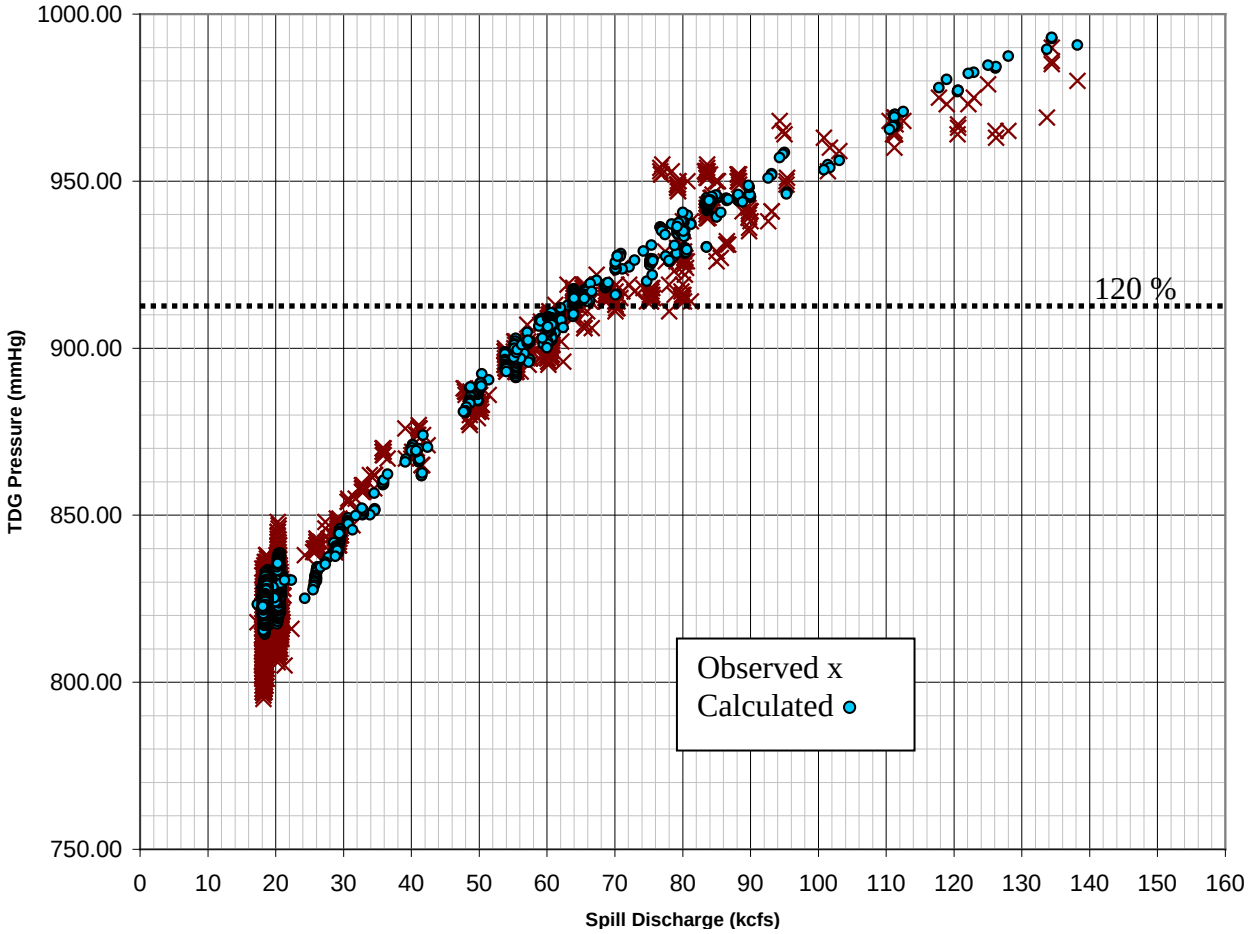

Figure H5. Total Dissolved Gas Saturation at the Tailwater Fixed Monitoring Station At Lower Granite Dam as a function of Spillway Discharge, 2008 (Observed and Calculated)

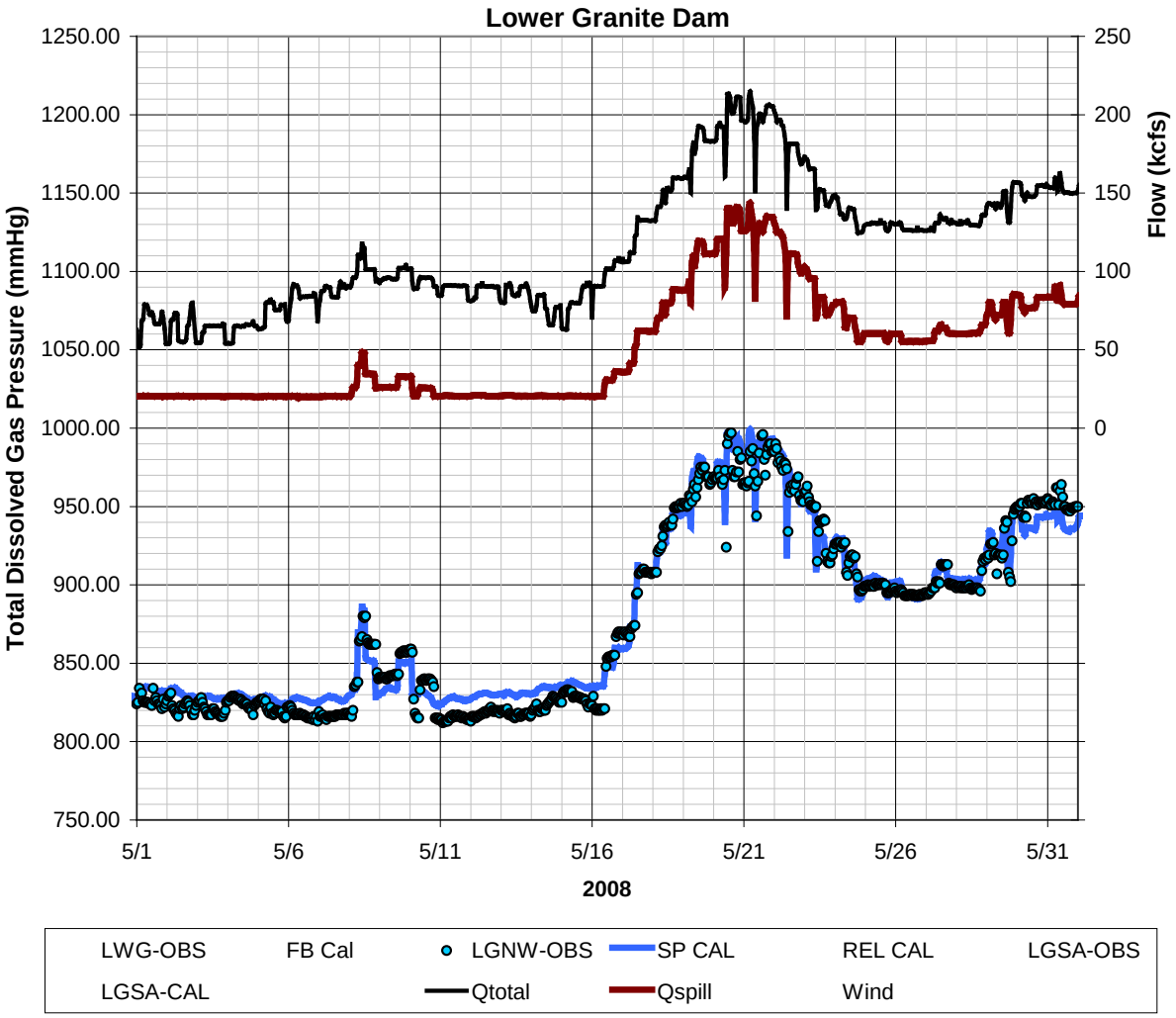

Figure H6 Lower Granite Dam Operations and TDG Saturation Observed and Calculated at the Tailwater Fixed Monitoring Station, May 2008 (Rel Cal=Calculated TDG saturation from Equations 2-3, LGNW=Tailwater Fixed Monitoring Station)