Appendix G

Total Dissolved Gas Abatement Plan For Little Goose Dam

March 2010

Table of Contents

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 measures at Little Goose Dam on the Snake River as requested by the State of Washington for their criteria adjustment.

Project Description

Little Goose is located 70.3 miles above the Snake River confluence with the Columbia River, 37.2 miles downstream of Lower Granite. The main structures include the powerhouse, concrete spillway and stilling basin, navigation lock, fish facilities, concrete non-overflow sections, and a rock-fill embankment on the north shore. The entire dam spans 2,655 feet including the earthen non-overflow embankment. The powerhouse is located between the spillway to the north and the navigation lock to the south. It consists of six generator bays with a maximum total discharge capacity of approximately 130 kcfs. The Little Goose spillway has a total length of 512 feet. It consists of eight spillway bays each 50 feet wide. Seven 14-foot-wide intermediate piers separate the spillway bays. The discharge is controlled by radial (or tainter) gates that are 50 feet wide by 60 feet high. The crest of the spillway crest is at elevation 581.0 fmsl and the design capacity is 850 kcfs, with a corresponding maximum pool elevation of 646.5 fmsl. At normal full pool elevation 638.0 fmsl, the spillway will pass a maximum of 676 kcfs.

Powerhouse Hydraulic Capacity

The Little Goose powerhouse unit hydraulic capacity during the fish passage season was estimated assuming the extended-length submersible traveling screens are installed, a total head of 96 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 17.8 kcfs for unit 1-3, and 19.0 kcfs for units 4-6. The total hydraulic capacity of the Little Goose powerhouse with all 6 units available is 110.5 kcfs. If only 5 units are available the hydraulic capacity of the Little Goose powerhouse was estimated as 92.7 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 Snake River Flow at Little Goose Dam

The daily average total river flow, generation flow, and spillway flow was compiled for Little Goose 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 Little Goose Dam are shown in Figure G1 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 G1. The likelihood that the Snake River flow will exceed the powerhouse capacity of 110.5 kcfs was 16.9 percent of the time.

Outside the fish passage season from 1974-2009, the percent exceedance characteristics for the seven-day moving average of daily average flows for the Snake River at Little Goose Dam are shown in Figure G2. 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. The likelihood that the Snake River flow will exceed the powerhouse capacity of 110.5 kcfs outside of the fish passage season was 1.6 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 Little Goose 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 Little Goose 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 guidance of fisheries past the dam 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 fish 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 from Bonneville Dam to Chief Joseph Dam on the Columbia River and from Ice Harbor Dam to Lower Granite Dam on the Snake River. 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 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 Little Goose Dam that influences TDG loading in the Snake River during the fish passage season.

Structural Alternatives

The installation of spillway flow deflectors on 6 of the 8 spillbays was included in the original construction of the spillway at Little Goose Dam. The interior deflectors are 8 ft-long with a no transition radius at an elevation of 532 ft. This structural configuration reflects the current conditions through 2008 and will be referred to as the "Base-6 Deflectors" configuration. The construction of end bay flow deflectors were completed for the 2009 fish passage season where flow deflectors with a 12.5 ft length and 25 ft transition radius were built in spill bays 1 and 8 at an elevation of 532 ft. This alternative "8 Deflectors" configuration allows for spill to be distributed over all 8 spill bays lowering the specific discharge and the associated TDG generation.

The third structural configuration "8 Deflectors/SW" was defined by the existing spillway configuration in 2009 with spillway flow deflectors on 8 spillbays and a spillway weir (SW) located in spillbay 1. The purpose of this SW structure is to more effectively and efficiency guide juvenile fish past Little Goose Dam by providing a surface oriented release over the spillway. The modernization of the Little Goose Powerhouse is not expected to change the hydraulic capacity at this project. The fourth 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 fifth 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 Policy Alternatives

This study also considered the influence of six different spill operations that govern the operations of Little Goose 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 %"). This spill operation was used during the 2008 fish passage season at Little Goose Dam. The second spill operation required the instantaneous spill to equal 27 kcfs ("spill 27 kcfs"). The third operation assumed a constant spill of 17 kcfs subject to powerhouse minimum hydraulic capacity constraints ("spill 17 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 Little Goose 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 spill pattern using only spill bays with flow deflectors. The spill called for the use of all spill bays prior to the 1998 spill season. The near-field TDG exchange study conducted in February of 1998 entitled "Total Dissolved Gas Exchange during Spillway Releases from Little Goose Dam, February 20-22 1998" found that the use of spill bays 1 and 8 significantly increased the TDG levels when compared to using only the six internal spill bays with flow deflectors. The current spill pattern is being reviewed in terms of the effectiveness of fish guidance at Little Goose Dam. A bulk, uniform and alternative spill patterns were employed at Little Goose Dam during the 2008 fish passage season in anticipation of the addition of a spillway weir.

The TDG saturation observed at the tailwater fixed monitoring station from 1998 to 2007 as a function of spillway discharge is shown in Figure G3. 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 G3. The linear regression model between spillway discharge and TDG saturation at Little Goose Dam is shown in Figure G3 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 53 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 Little Goose 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 at the tailwater fixed monitoring station as shown in Equation 1 prior to 1998.

Equation 1

$$\Delta P = 6.488(TWE - 500)(1 - e^{-0.28q_s}) \qquad (mm\,Hg) \qquad (1)$$

r^2=0.79

Std Error = 19.5 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)

$TDG_{sat} = (P_{atm}+\Delta P)/P_{atm} \times 100$ Total Dissolved Gas Saturation (%)

P_{atm} = Local Atmospheric Pressure (mm Hg)

The estimate of TDG exchange in the Snake River at Little Goose Dam during spillway flows using a spill pattern limited to bays with flow deflectors is shown in Equation 2. The upper limit of TDG generation continues to increase as the effective tailwater depth is increased. This exponential relationship also honors a declining rate of increase in TDG generation for successively higher specific spillway flow rates. This relationship is sensitive to the type of spill pattern through the estimation of the specific discharge as shown below.

Equation 2

$$\Delta P = 5.566(TWE - 500)(1 - e^{-0.15q_s}) \qquad (mm\,Hg) \qquad (2)$$

r^2=0.84

Std Error = 11.65 mm Hg

Where

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

Q_{sp} = Total spill discharge (kcfs)

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

Qi = Spill discharge in bay i.

Nbays = Active number of spill bays.

c_w = Weighting coefficient ≥ 1

$TDG_{sat} = (P_{atm}+\Delta P)/P_{atm} \times 100$ Total Dissolved Gas Saturation (%)

P_{atm} = Local Atmospheric Pressure (mm Hg)

The sensitivity of TDG exchange as a function of a change in the tailwater stage from 540 to 541 ft will result in an increase in TDG pressure of 3.3 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 12.6 mm Hg increase in TDG pressure for a tailwater elevation of 540 ft. Equation 2 also illustrates the influence of bulking spill in several bays such as the SW with training flow. A total spillway discharge of 45 kcfs uniformly distributed over 6 spill bays will result in a TDG pressure of 897 mm Hg (120.1%) at a tailwater elevation of 540 ft. The same 45 kcfs spilled uniformly over 3 bays will result in a TDG pressure of 946 mm Hg (126.7%) for an increase in TDG saturation of 6.6 percent over the uniform 6 bay spill pattern. An average local atmospheric pressure of 747 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 Little Goose Dam was determined for each combination of structural and operational alternatives. 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 3.

Equation 3

$$TDG_{avg} = \frac{Q_{sp}TDG_{sp} + Q_{gen}TDG_{gen}}{Q_{tot}} \quad \text{...(3)}$$

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 4. 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 4

$$TDG_{avg} = \frac{(Q_{sp} + Q_{ent})TDG_{sp} + (Q_{gen} - Q_{ent})TDG_{gen}}{Q_{tot}} \qquad (4)$$

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 Monumental Dam (Schneider and Wilhelms, 2004) and 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 5. The entrainment coefficient for applied to Little Goose Dam for this investigation was C_{ent}=1.20.

Equation 5

$$Q_{ent} = C_{ent}Q_{sp} \qquad (5)$$

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 type 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 Little Goose 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 Little Goose Dam should consider the existence of elevated background TDG levels from upstream sources. The presence of elevated background TDG levels at Little Goose 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 Little Goose Dam are summarized from 1995-2007 as a function of total river flow in Figure G4. The observed daily average TDG saturation in the forebay of Little Goose Dam was summarized for 5 kcfs ranges in total river flow from 25 to 225 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 Little Goose 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 116 to 124.5 percent of saturation.

The accuracy of TDG exchange estimates during spillway releases at Little Goose 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 Little Goose 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 G5. One interesting feature of these data is the large range in TDG pressures corresponding with a given spill discharge less than 50 kcfs. The estimated TDG pressures are consistent with observed conditions with the exception of consistently underestimating TDG pressures for spillway flows greater than 100 kcfs. The spill capacity limited by 120 percent saturation ranged from 29 to 52 kcfs for the 2008 spill season. The variability of TDG saturation for a given spill discharge is chiefly attributed to the variation in the spill pattern. Other factors contributing to the wide spread in the TDG data as a function of spill discharge are variations in tailwater elevation, local atmospheric pressure, background TDG levels (during small percent spill events), and water temperature influences.

A hind cast of TDG saturation below Little Goose Dam for a wide range of observed historic operations (total river flow ranged from 45 to 220 kcfs) during May of 2008 were conducted using the relationship shown in Equations 2-3. The spill discharge ranged from 16.5 to 130.1 kcfs and averaged 43.3 kcfs during this month. The tailwater elevation was observed to vary only from 437.1 to 437.8 ft and was likely erroneous data for the higher river flows. The hourly total river and spillway flow are shown in Figure G6 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 both bulk and uniform training spill patterns. The under reporting of tailwater stage was likely the source for TDG estimates to under predict observed TDG pressures during high spillway discharges.

Results

A series of estimates of TDG exchange were generated for a matrix of conditions impacting TDG exchange in the Snake River at Little Goose 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 Little Goose 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 5 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 G2. This table consists of 3240 different cases that provide a comprehensive summary of the TDG management program at Little Goose Dam. The utility of this master table is more manageable when selecting a much 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 Little Goose Dam.

Structural Configuration

The TDG exchange across the five structural configurations investigated at Little Goose Dam for a spill operation of spilling 30 percent of the river for total river flows of 50, 125, and 203 kcfs were examined as shown in Tables G3. The Base-6 Deflectors structural condition utilized a spill pattern involving all 8 spill bays as was the spill operation prior to 1998. 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 river flowrate is a 10 percent exceedance event 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 unusual for the flood flow conditions and generation of TDG supersaturation at upstream projects. A full powerhouse capacity of 110.5 kcfs was assumed for these conditions.

All five structural cases were able to spill 15 kcfs (30 percent of the river) without exceeding the TDG criteria of 120 percent in spillway flows for total river flow of 50 kcfs. The TDG levels in spill ranged widely because of differences in the spill pattern and structural alternatives. The TDG abatement progress realized at Little Goose Dam involved the adoption of the 6 Deflector with 6 bay spill pattern alternative. The change in spill pattern resulted in a 3.5 percent reduction in the average cross sectional TDG saturation when compared to the Base-6 Deflector alternative (8 bay pattern). The 6 Deflector with 6 bay pattern and 8 Deflector alternatives resulted in TDG levels in spill less than forebay conditions resulting in a net reduction in TDG saturation in the Snake River. The three conditions with a SW utilized a bulk spill pattern and generated TDG levels in spill greater than 117 percent. 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 2891) did not influence the TDG conditions in spill but reduced the cross sectional average TDG saturation to 113.3 percent. The addition of the training wall for these conditions resulted in a net reduction in cross section average TDG levels of 2.3 percent when compare to the same structural configuration without the training wall (case 2351).

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 G3. In four out of the six cases, the tailwater criterion of 120 percent was the limiting condition for setting the spill level. The average TDG saturation for the 8 Deflector scenario was only 3.2 percent above background levels. The structural scenario with the smallest impact on TDG saturation in the Snake River involved the complete structural configuration of "8 Deflectors/SW/PH surface bypass/Training Wall" (case 2894) where the effectiveness of the training wall is demonstrated. The base 6-deflector condition (8 bay pattern) allowed a spill of 24.9 kcfs as limited by the 120 percent tailwater TDG threshold. The application of the Base 6-deflector with 6 Bay Pattern allowed a higher spillway discharge of 37.5 kcfs and higher average cross sectional TDG of 115.3 percent when compared to the base 6 Deflectors scenario (case 194).

The high flow conditions during the 203 kcfs river flows required powerhouse capacity flows with the remainder of the river passing over the spillway or powerhouse surface bypass. The high spill discharges during this flood flow resulted in TDG levels in spill water above 125 percent for spill over bays with flow deflectors and well over 130 percent of saturation for the Base 6 Deflectors condition spill. 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 2898). The training wall provided significant benefits during high flow conditions where low TDG forebay levels were available. The highest TDG levels of 134.3 were caused by spilling water through the outside spill bays without flow deflectors for the Base 6 Deflector alternative. The SW was not found to be a detriment to TDG generation at this high spillway flow because of the application of a uniform spill pattern at this spill discharge.

Spill Operation

The influence of spill operation on TDG exchange was explored for the existing 2009 structural configuration of 8 Deflectors/SW for three river flow conditions 50, 125, and 203 kcfs. The maximum powerhouse capacity and forebay TDG level of 110 percent was also held constant for this evaluation as listed in Table G4. The spill operation has considerable influence over the TDG exchange during voluntary spill conditions that exist for 50 and 125 kcfs flows. However, the involuntary spill conditions over ride the influence of the spill operation and the TDG generation is identical for all cases.

The "No voluntary spill" or "Spill capacity at 110 or TDGfb" resulted in a no net increase in TDG levels in the Snake River for 50 and 125 kcfs. The more aggressive "Spill to capacity at 120 percent "caused largest increase (10 percent) in average river TDG level for the 50 kcfs river condition. The current spill operation of "Spill 30 Percent" yielded a much lower TDG conditions than 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 114.9 percent with the spill discharge constrained by the TDG criteria. The "Spill 27 kcfs", "Spill 30%", and "Spill to Capacity @ 120%" converged to the same spill operation for a total river flow of 125 kcfs.

The 7Q10 flow resulted in a spill of 102.8 kcfs attaining a TDG saturation of 126.2 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 influence of spill operation was not important during these high involuntary spill conditions.

Total River Flow

The influence of total river flow on TDG exchange at Little Goose Dam for a spill operation of spill 30 percent of the river is shown in Table G5 for the "8 Deflector with Spillway Weir" configuration. All these conditions assumed a forebay TDG saturation of 110 percent. The TDG saturation in spill reaches 120 percent during a total river flow of 125 kcfs. The cross sectional average TDG saturation exceeds 120 percent during a total river flow of 200 kcfs. The spill conditions at Little Goose Dam during the 7Q10 event result in TDG in excess of 126 percent for the existing structural condition. The frequency of total river flows exceeding 150 kcfs is less then 6 percent of the time.

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 Little Goose 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 G6. The combination of high forebay TDG levels with small spillway flows can result in a net degassing of the Snake River where tailwater TDG levels are less than forebay conditions. The influence of powerhouse entrainment and not dilution is illustrated in the "spill to capacity at 120%"

spill operation TDG estimates. The resultant average TDG levels below the dam range only from 112.3 to 122.6 when spilling 27.7 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 "Spill 30 Percent" will maintain TDG levels below 120 percent in the Snake River as long as forebay TDG levels remain below 125 percent.

Little Goose 2009 configuration TDG and Flow Summary

The TDG saturation in Snake River below Little Goose 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 Little Goose Dam from 1974-2009 are also listed in this table.

The frequency for spilling water above the maximum powerhouse capacity during the fish passage season is nearly 17.3 percent of the time at Little Goose Dam but only about 1.6 percent of the time outside of the fish passage season as listed in Table G7. 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 16 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 126.5 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 113.6 percent when forebay levels are 115 percent. The spillway discharges up to 37 kcfs will either reduce or cause no change in the TDG loading of the Snake River for total river flows up to 147.5 kcfs which occurs only about 6.5 percent of the time during the fish passage season. The spillway flows at Little Goose Dam up to 58 kcfs will result in TDG levels of 120 percent and less which corresponds to a total river discharge of 168.5 kcfs and a frequency of occurrence of 3.0 percent during the fish passage season. The worst case conditions will be associated with the 7Q10 flows and a spill discharge of 92.5 kcfs resulting in TDG saturation in spillway flows of 125.2 percent.

Conclusions

The original Little Goose spillway was built with six of the eight spill bays 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. The spill pattern associated with the base 6 Deflector spillway configuration originally involved spillway flows over all eight bays. A uniform pattern over just the six spillbays with deflectors was developed to lower the TDG generation during both voluntary and involuntary spillway flows.

TDG abatement at Little Goose Dam has been accomplished through changes to the fish spill operation. Previous spill operations involved maximizing spill as limited by the downstream TDG criteria. This operation routinely caused spillway flows to exceed 40 to 50 kcfs during the voluntary fish passage season. The current spill operation for voluntary spill during the fish passage season calls for spilling 30 percent of the instantaneous river flow. The TDG loading impacts of the voluntary spill operation are large especially when considering the median flow during the fish passage season is about 50 kcfs. The 30 percent spill policy during 50 kcfs river flows will result in spillway flows of only 15 kcfs with a corresponding average TDG saturation of 115.1 (Table G4). The old spill operation limited by the 120 percent TDG criteria provided for a spill of about 40 kcfs and an average TDG saturation of 119.9 percent.

The addition of end bay flow deflectors in bays 1 and 8 together with the completion of a spillway weir for the 2009 fish passage season has had a modest impact on the TDG generation at Little Goose Dam. The additional flow defectors will accommodate spillway flows across the entire spillway and lower the TDG production for most involuntary spillway flows. The spillway weir provides surface oriented releases from the forebay with TDG abatement provided by flow deflectors for aerated spillway discharges over this structure. The lowest levels of TDG exchange in spillway flows can be accomplished through applying a uniform spill pattern over all eight spill bays with flow deflectors. This type of operation may be non-optimal for fish guidance purposes for voluntary spill conditions.

The worst case condition at Little Goose Dam for TDG saturation will occur during the 7Q10 river flow where TDG levels of about 126 percent saturation will be generated from the current structural and operational configuration. The frequency of flow at this magnitude is only once during a 10 year period.

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

The TDG levels at the tailwater fixed monitoring station generally remain within the TDG criteria during voluntary spill conditions for river flows up to 150 kcfs. However, the introduction of the bulk spill pattern to support SW spill generates TDG levels that can approach and in certain cases exceed the TDG criteria at low total spillway flows.

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

A training wall separating the powerhouse and spillway flows could 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. Low TDG levels in the forebay translate into greater dilution potential for powerhouse flows partitioned from aerated spillway flow. 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 saturation

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Table G1

Percent of time the seven-day moving average of daily average flows exceed the reference Snake River Flow at Little Goose 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%	
92.7	26.90%	3.50%	Powerhouse capacity 5 units
100	22.50%	2.70%	
110.9	16.9%	1.60%	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 G2

Configuration Matrix for TDG Estimates in the Snake River at Little Goose Dam

Structural Alternative	Spill Policy	Qph-Max (kcfs)	Qtotal (kcfs)	TDGfb (%)
Base-6 Deflectors+	No Voluntary Spill	110.9	25	105
Base-6 Deflectors 6 Bay Pattern*	Spill to Capacity @ 110% or TDG Forebay	92.7	50	110
8 Deflectors	Spill 17 Kcfs		75	115
8 Deflectors/SW	Spill 27 kcfs		100	120
8 Deflectors/SW/ PH Surface Bypass	Spill 30 Percent		125	125
8 Deflectors/SW/ PH Surface Bypass /Training Wall	Spill to Capacity @ 120%		150	
			175	
			200	
			203	

+ Base 6 Deflectors = uniform eight bay spill pattern.

* Base 6 Deflectors 6 Bay Pattern = uniform six bay spill pattern.

Table G3

Summary of Total Dissolved Gas Exchange at Little Goose 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-6 Deflectors	Spill 30 Percent	110.5	50.0	34.3	15.0	0.7	110	114.2	110.0	112.8	2.8
731	Base-6 Deflectors 6 Bay Pattern	Spill 30 Percent	110.5	50.0	34.3	15.0	0.7	110	108.9	110.0	109.3	-0.7
1271	8 Deflectors	Spill 30 Percent	110.5	50.0	34.3	15.0	0.7	110	107.4	110.0	108.3	-1.7
1811	8 Deflectors/SW	Spill 30 Percent	110.5	50.0	34.3	15.0	0.7	110	117.7	110.0	115.1	5.1
2351	8 Deflectors/SW/ PH Surface Bypass	Spill 30 Percent	110.5	50.0	30.0	15.0	5.0	110	117.7	119.8	115.6	5.6
2891	8 Deflectors/SW/ PH Surface Bypass/ Training Wall	Spill 30 Percent	110.5	50.0	30.0	15.0	5.0	110	117.7	119.8	113.3	3.3
194	Base-6 Deflectors	Spill 30 Percent	110.5	125.0	99.4	24.9	0.7	110	120.0	110.0	114.4	4.4
734	Base-6 Deflectors 6 Bay Pattern	Spill 30 Percent	110.5	125.0	86.8	37.5	0.7	110	118.0	110.0	115.3	5.3
1274	8 Deflectors	Spill 30 Percent	110.5	125.0	86.8	37.5	0.7	110	114.9	110.0	113.2	3.2
1814	8 Deflectors/SW	Spill 30 Percent	110.5	125.0	96.6	27.7	0.7	110	120.0	110.0	114.9	4.9
2354	8 Deflectors/SW/ PH Surface Bypass	Spill 30 Percent	110.5	125.0	92.3	27.7	5.0	110	120.0	119.8	115.1	5.1
2894	8 Deflectors/SW/ PH Surface Bypass/ Training Wall	Spill 30 Percent	110.5	125.0	92.3	27.7	5.0	110	120.0	119.8	112.6	2.6
198	Base-6 Deflectors	Spill 30 Percent	110.5	203.0	110.5	91.8	0.7	110	134.3	110.0	134.1	24.1
738	Base-6 Deflectors 6 Bay Pattern	Spill 30 Percent	110.5	203.0	110.5	91.8	0.7	110	127.5	110.0	127.4	17.4
1278	8 Deflectors	Spill 30 Percent	110.5	203.0	110.5	91.8	0.7	110	125.1	110.0	125.1	15.1
1818	8 Deflectors/SW	Spill 30 Percent	110.5	203.0	110.5	102.8	0.7	110	126.2	110.0	126.2	16.2
2358	8 Deflectors/SW/ PH Surface Bypass	Spill 30 Percent	110.5	203.0	110.5	87.5	5.0	110	124.7	119.8	123.9	13.9
2898	8 Deflectors/SW/ PH Surface Bypass/ Training Wall	Spill 30 Percent	110.5	203.0	110.5	87.5	5.0	110	124.7	119.8	116.6	6.6

[1] Powerhouse capacity of 110.5 kcfs based on 6 turbines at 96 ft of head, with extended length STS installed, and operated at upper generation limit defined in FPP.

Case - Case number as listed in Little Goose master TDG management plan.

Q_{ph-max} = Maximum hydraulic capacity of the Little Goose powerhouse (kcfs)

Q_{total} = Snake River Flow at Little Goose Dam (kcfs)
Q_{gen} = Powerhouse Flow (kcfs)
Q_{spill} = Spillway Flow (kcfs)
Q_{aux} = Auxilary Flow including Powerhouse Surface Bypass (kcfs)
TDG_{sp} = Total Dissolved Gas Saturation in spillway flows (%)
TDG_{fb} = Total Dissolved Gas Saturation in forebay (%)
TDG_{aux} = Total Dissolved Gas Saturation in auxiliary release including the surface bypass outfall (%)
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 G4

Summary of Total Dissolved Gas Exchange at Little Goose Dam for Snake River flow of 50, 25, and 203 kcfs, Forebay TDG level of 110% for the 8 Deflector with Spillway Weir Structural alternative and various spill operations

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 (%)
551	8 Deflectors/SW	No Voluntary Spill	110.5	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	110.5	50.0	46.4	2.9	0.7	110	110.0	110.0	110.0	0.0
641	8 Deflectors/SW	Spill 17 Kcfs	110.5	50.0	32.3	17.0	0.7	110	118.1	110.0	116.1	6.1
686	8 Deflectors/SW	Spill 27 kcfs	110.5	50.0	22.3	27.0	0.7	110	119.2	110.0	119.2	9.2
731	8 Deflectors/SW	Spill 30 Percent	110.5	50.0	34.3	15.0	0.7	110	117.7	110.0	115.1	5.1
776	8 Deflectors/SW	Spill to Capacity @ 120%	110.5	50.0	9.5	39.8	0.7	105	119.9	105.0	119.9	14.9
554	8 Deflectors/SW	No Voluntary Spill	110.5	125.0	110.5	13.8	0.7	110	118.1	110.0	112.0	2.0
599	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	110.5	125.0	110.5	13.8	0.7	110	118.1	110.0	112.0	2.0
644	8 Deflectors/SW	Spill 17 Kcfs	110.5	125.0	107.3	17.0	0.7	110	118.8	110.0	112.6	2.6
689	8 Deflectors/SW	Spill 27 kcfs	110.5	125.0	97.3	27.0	0.7	110	120.0	110.0	114.7	4.7
734	8 Deflectors/SW	Spill 30 Percent	110.5	125.0	96.6	27.7	0.7	110	120.0	110.0	114.9	4.9
779	8 Deflectors/SW	Spill to Capacity @ 120%	110.5	125.0	96.6	27.7	0.7	110	120.0	110.0	114.9	4.9
558	8 Deflectors/SW	No Voluntary Spill	110.5	203.0	110.5	102.8	0.7	110	126.2	110.0	126.2	16.2
603	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	110.5	203.0	110.5	102.8	0.7	110	126.2	110.0	126.2	16.2
648	8 Deflectors/SW	Spill 17 Kcfs	110.5	203.0	110.5	102.8	0.7	110	126.2	110.0	126.2	16.2
693	8 Deflectors/SW	Spill 27 kcfs	110.5	203.0	110.5	102.8	0.7	110	126.2	110.0	126.2	16.2
738	8 Deflectors/SW	Spill 30 Percent	110.5	203.0	110.5	102.8	0.7	110	126.2	110.0	126.2	16.2
783	8 Deflectors/SW	Spill to Capacity @ 120%	110.5	203.0	110.5	102.8	0.7	110	126.2	110.0	126.2	16.2

[1] Powerhouse capacity of 110.5 kcfs based on 6 turbines at 96 ft of head, with extended length STS installed, and operated at upper generation limit defined in FPP.

Case - Case number as listed in Little Goose master TDG management plan.
Q_{ph-max} = Maximum hydraulic capacity of the Little Goose powerhouse (kcfs)
Q_{total} = Snake River Flow at Little Goose Dam (kcfs)
Q_{gen} = Powerhouse Flow (kcfs)
Q_{spill} = Spillway Flow (kcfs)
Q_{aux} = Auxiliary Flow including Powerhouse Surface Bypass (kcfs)
TDG_{sp} = Total Dissolved Gas Saturation in spillway flows (%)
TDG_{fb} = Total Dissolved Gas Saturation in forebay (%)
TDG_{aux} = Total Dissolved Gas Saturation in auxiliary release including the surface bypass outfall (%)
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 G5

Summary of Total Dissolved Gas Exchange at Little Goose Dam for Snake River flows ranging from 50 to 203 kcfs, Forebay TDG level of 110% for the 8 Deflector with Spillway Weir 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 (%)
730	8 Deflectors/SW	Spill 30 Percent	110.514	25.0	16.8	7.5	0.7	110	114.9	110.0	113.2	3.2
731	8 Deflectors/SW	Spill 30 Percent	110.514	50.0	34.3	15.0	0.7	110	117.7	110.0	115.1	5.1
732	8 Deflectors/SW	Spill 30 Percent	110.514	75.0	51.8	22.5	0.7	110	119.1	110.0	116.0	6.0
733	8 Deflectors/SW	Spill 30 Percent	110.514	100.0	69.3	30.0	0.7	110	119.9	110.0	116.5	6.5
734	8 Deflectors/SW	Spill 30 Percent	110.514	125.0	96.6	27.7	0.7	110	120.0	110.0	114.9	4.9
735	8 Deflectors/SW	Spill 30 Percent	110.514	150.0	110.5	38.8	0.7	110	120.8	110.0	116.2	6.2
736	8 Deflectors/SW	Spill 30 Percent	110.514	175.0	110.5	63.8	0.7	110	121.7	110.0	119.4	9.4
737	8 Deflectors/SW	Spill 30 Percent	110.514	200.0	110.5	88.8	0.7	110	124.8	110.0	124.5	14.5
738	8 Deflectors/SW	Spill 30 Percent	110.514	203.0	110.5	102.8	0.7	110	126.2	110.0	126.2	16.2

[1] Powerhouse capacity of 110.5 kcfs based on 6 turbines at 96 ft of head, with extended length STS installed, and operated at upper generation limit defined in FPP.

Case - Case number as listed in Little Goose master TDG management plan.
Q_{ph-max} = Maximum hydraulic capacity of the Little Goose powerhouse (kcfs)
Q_{total} = Snake River Flow at Little Goose Dam (kcfs)
Q_{gen} = Powerhouse Flow (kcfs)
Q_{spill} = Spillway Flow (kcfs)
Q_{aux} = Auxiliary Flow including Powerhouse Surface Bypass (kcfs)
TDG_{sp} = Total Dissolved Gas Saturation in spillway flows (%)
TDG_{fb} = Total Dissolved Gas Saturation in forebay (%)
TDG_{aux} = Total Dissolved Gas Saturation in auxiliary release including the surface bypass outfall (%)
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 G6

Summary of Total Dissolved Gas Exchange at Little Goose Dam for Snake River flow of 125 kcfs, Forebay TDG levels ranging from 105 to 125 % for the 8 Deflector with Spillway Weir Structural alternative and various spill operations

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 (%)
545	8 Deflectors/SW	No Voluntary Spill	110.5	125.0	110.5	13.8	0.7	105	118.1	105.0	108.2	3.2
554	8 Deflectors/SW	No Voluntary Spill	110.5	125.0	110.5	13.8	0.7	110	118.1	110.0	112.0	2.0
563	8 Deflectors/SW	No Voluntary Spill	110.5	125.0	110.5	13.8	0.7	115	118.1	115.0	115.8	0.8
572	8 Deflectors/SW	No Voluntary Spill	110.5	125.0	110.5	13.8	0.7	120	118.1	120.0	119.5	-0.5
581	8 Deflectors/SW	No Voluntary Spill	110.5	125.0	110.5	13.8	0.7	125	118.1	125.0	123.3	-1.7
590	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	110.5	125.0	110.5	13.8	0.7	105	118.1	105.0	108.2	3.2
599	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	110.5	125.0	110.5	13.8	0.7	110	118.1	110.0	112.0	2.0
608	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	110.5	125.0	110.5	13.8	0.7	115	118.1	115.0	115.8	0.8
617	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	110.5	125.0	96.6	27.7	0.7	120	120.0	120.0	120.0	0.0
626	8 Deflectors/SW	Spill to Capacity @ 110% or TDG Forebay	110.5	125.0	24.3	100.0	0.7	125	125.0	125.0	125.0	0.0
635	8 Deflectors/SW	Spill 17 Kcfs	110.5	125.0	107.3	17.0	0.7	105	118.8	105.0	109.1	4.1
644	8 Deflectors/SW	Spill 17 Kcfs	110.5	125.0	107.3	17.0	0.7	110	118.8	110.0	112.6	2.6
653	8 Deflectors/SW	Spill 17 Kcfs	110.5	125.0	107.3	17.0	0.7	115	118.8	115.0	116.1	1.1
662	8 Deflectors/SW	Spill 17 Kcfs	110.5	125.0	107.3	17.0	0.7	120	118.8	120.0	119.6	-0.4
671	8 Deflectors/SW	Spill 17 Kcfs	110.5	125.0	107.3	17.0	0.7	125	118.8	125.0	123.1	-1.9
680	8 Deflectors/SW	Spill 27 kcfs	110.5	125.0	97.3	27.0	0.7	105	120.0	105.0	112.1	7.1
689	8 Deflectors/SW	Spill 27 kcfs	110.5	125.0	97.3	27.0	0.7	110	120.0	110.0	114.7	4.7
698	8 Deflectors/SW	Spill 27 kcfs	110.5	125.0	97.3	27.0	0.7	115	120.0	115.0	117.4	2.4
707	8 Deflectors/SW	Spill 27 kcfs	110.5	125.0	97.3	27.0	0.7	120	120.0	120.0	120.0	0.0
716	8 Deflectors/SW	Spill 27 kcfs	110.5	125.0	97.3	27.0	0.7	125	120.0	125.0	122.6	-2.4
725	8 Deflectors/SW	Spill 30 Percent	110.5	125.0	96.6	27.7	0.7	105	120.0	105.0	112.3	7.3
734	8 Deflectors/SW	Spill 30 Percent	110.5	125.0	96.6	27.7	0.7	110	120.0	110.0	114.9	4.9
743	8 Deflectors/SW	Spill 30 Percent	110.5	125.0	96.6	27.7	0.7	115	120.0	115.0	117.4	2.4
752	8 Deflectors/SW	Spill 30 Percent	110.5	125.0	96.6	27.7	0.7	120	120.0	120.0	120.0	0.0
761	8 Deflectors/SW	Spill 30 Percent	110.5	125.0	96.6	27.7	0.7	125	120.0	125.0	122.6	-2.4
770	8 Deflectors/SW	Spill to Capacity @ 120%	110.5	125.0	96.6	27.7	0.7	105	120.0	105.0	112.3	7.3

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 (%)
779	8 Deflectors/SW	Spill to Capacity @ 120%	110.5	125.0	96.6	27.7	0.7	110	120.0	110.0	114.9	4.9
788	8 Deflectors/SW	Spill to Capacity @ 120%	110.5	125.0	96.6	27.7	0.7	115	120.0	115.0	117.4	2.4
797	8 Deflectors/SW	Spill to Capacity @ 120%	110.5	125.0	96.6	27.7	0.7	120	120.0	120.0	120.0	0.0
806	8 Deflectors/SW	Spill to Capacity @ 120%	110.5	125.0	96.6	27.7	0.7	125	120.0	125.0	122.6	-2.4

[1] Powerhouse capacity of 110.5 kcfs based on 6 turbines at 96 ft of head, with extended length STS installed, and operated at upper generation limit defined in FPP.

Case - Case number as listed in Little Goose master TDG management plan.
$Q_{ph\text{-}max}$ = Maximum hydraulic capacity of the Little Goose powerhouse (kcfs)
Q_{total} = Snake River Flow at Little Goose Dam (kcfs)
Q_{gen} = Powerhouse Flow (kcfs)
Q_{spill} = Spillway Flow (kcfs)
Q_{aux} = Auxiliary Flow including Powerhouse Surface Bypass (kcfs)
TDG_{sp} = Total Dissolved Gas Saturation in spillway flows (%)
TDG_{fb} = Total Dissolved Gas Saturation in forebay (%)
TDG_{aux} = Total Dissolved Gas Saturation in auxiliary release including the surface bypass outfall (%)
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 G7

Snake River Flow at Little Goose 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	110.5	110.5	0	na	115.0	17.30%	1.60%
2	Q_{sp}@110%	126.5	110.5	16	110	113.6	11.10%	0.60%
3	Q_{sp}@115%	147.5	110.5	37	115	115.0	6.50%	0.20%
4	Q_{sp}@120%	168.5	110.5	58	120	118.8	3.00%	0.00%
5	7Q10-mean	203	110.5	92.5	125.2	125.2	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 Little Goose 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.

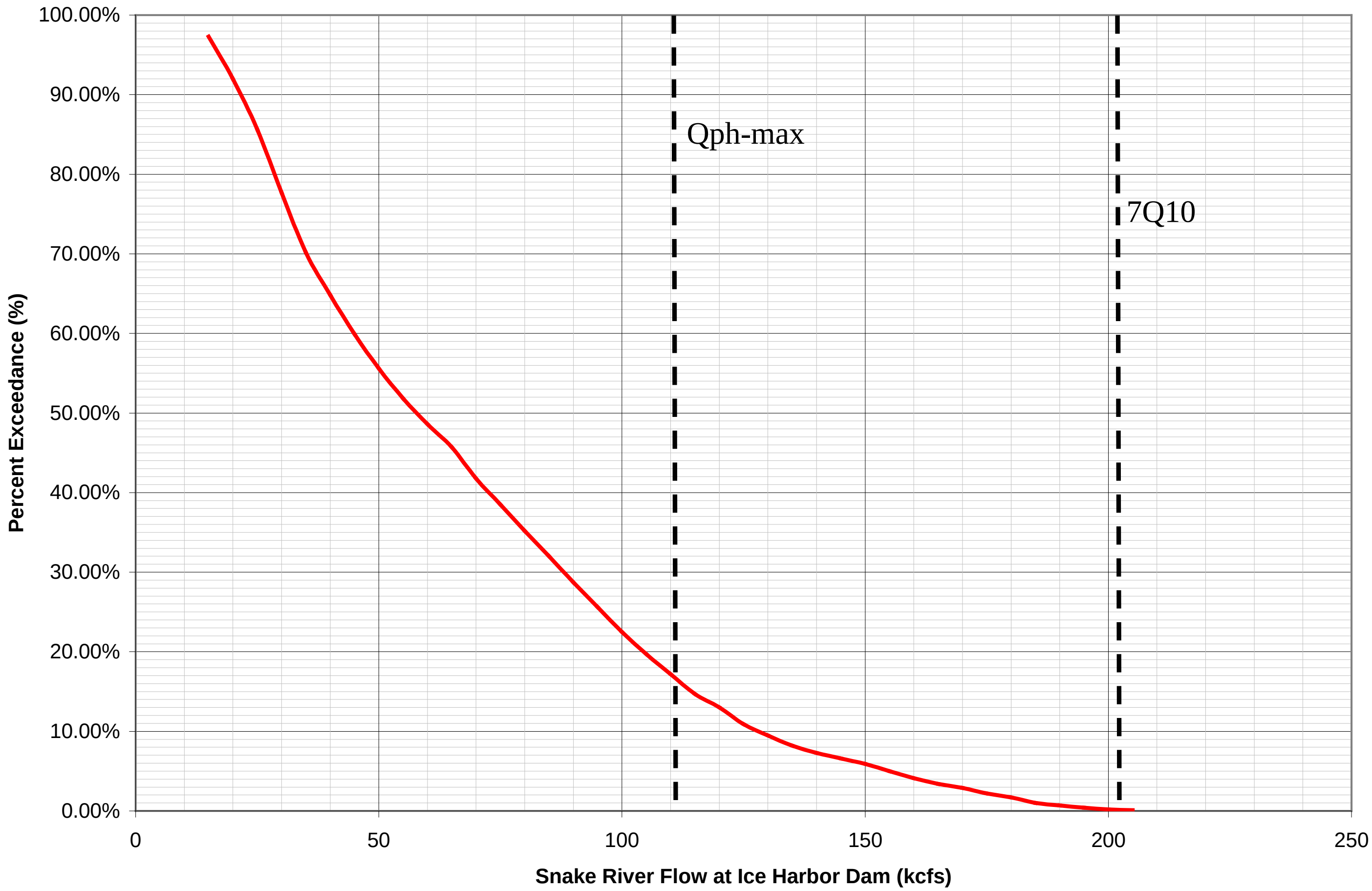

Figure G1. Percent Exceedance versus Seven Day Moving Average of Snake River Flow at Little Goose Dam during April-August 1975-2009.

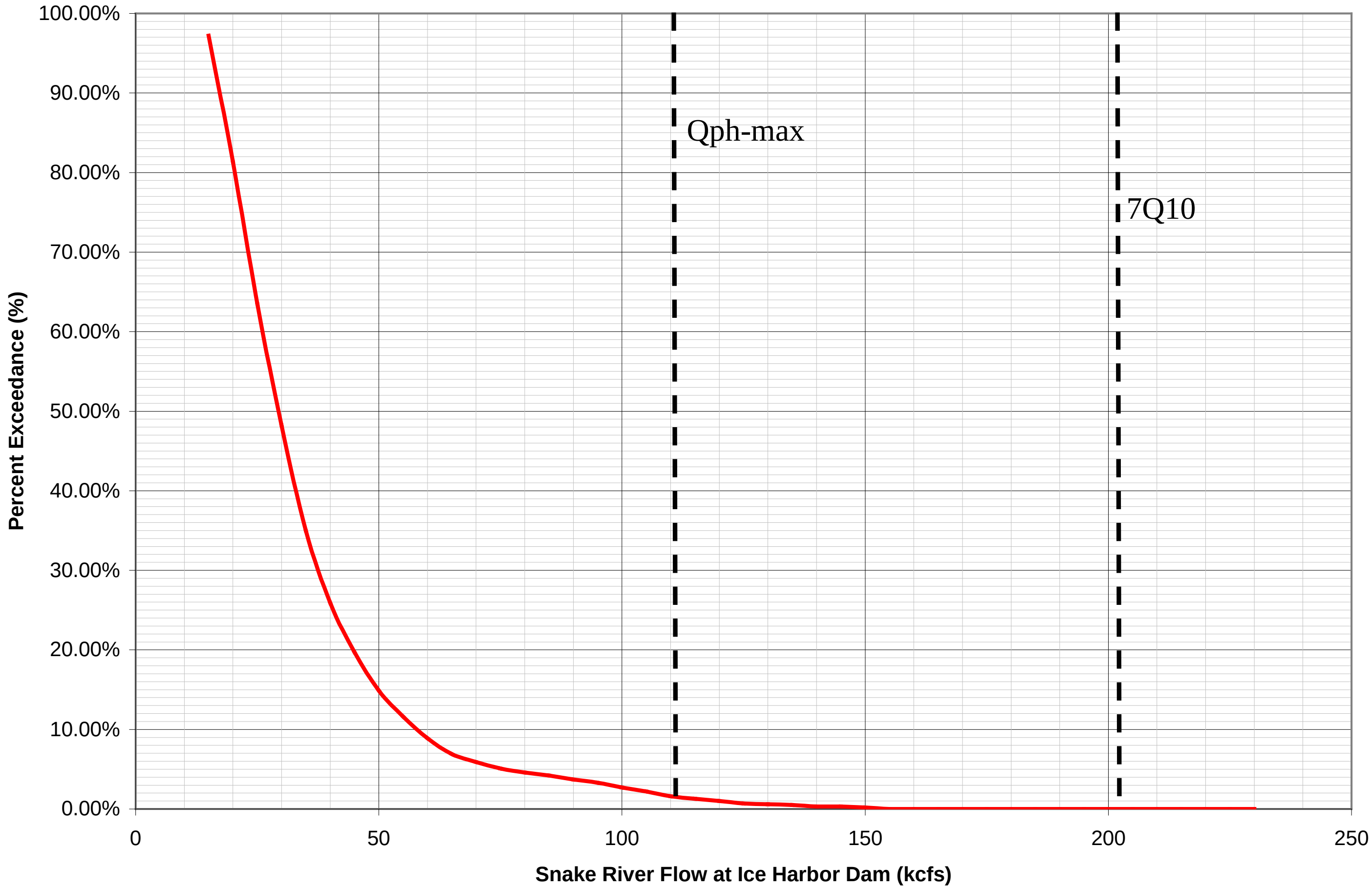

Figure G2 . Percent Exceedance versus Seven Day Moving Average of Snake River Flow at Little Goose Dam during Sept.-March, 1974-2009.

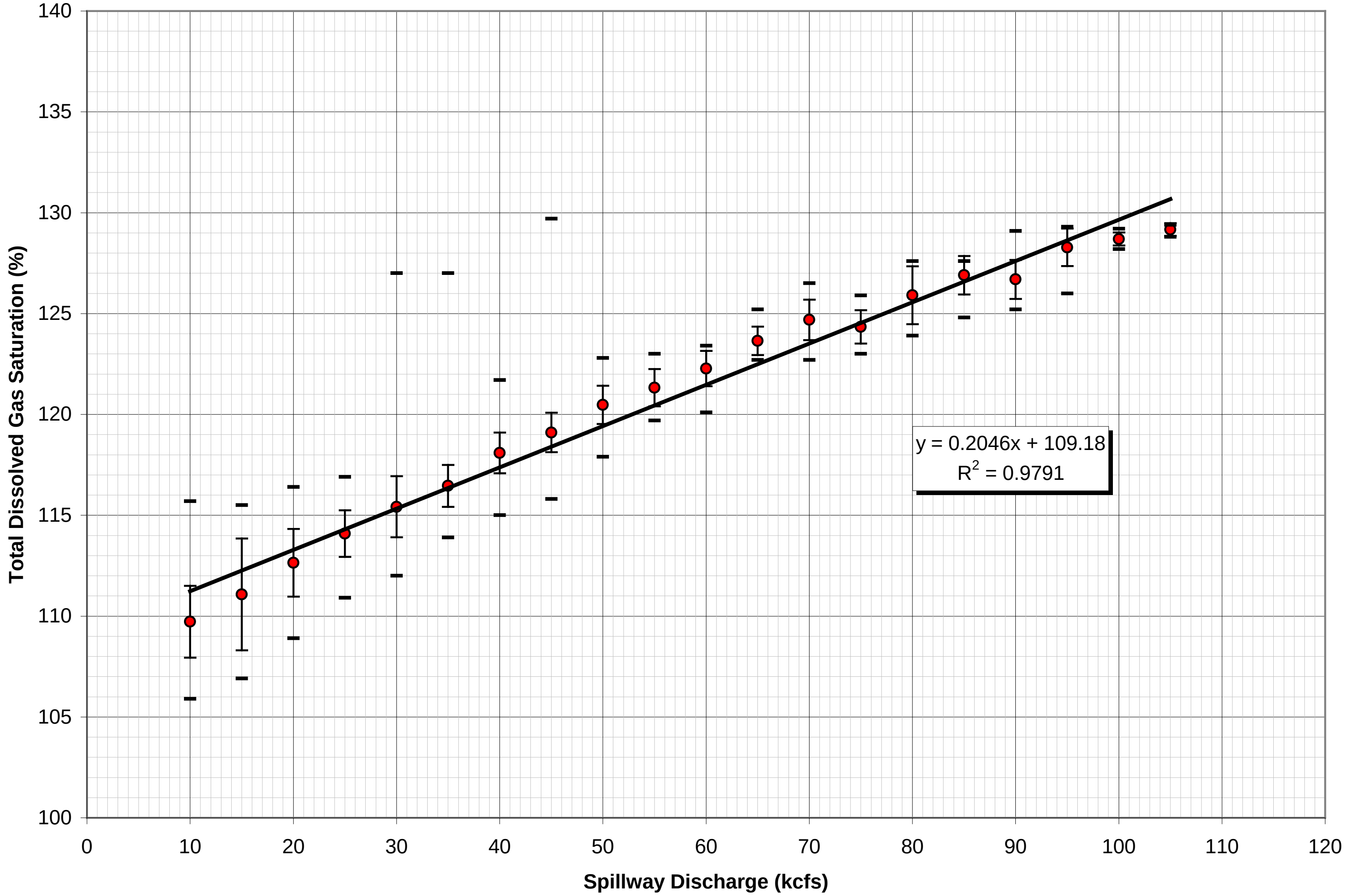

Figure G3. Total Dissolved Gas Saturation at the Tailwater Fixed Monitoring Station at Little Goose Dam as a function of Spillway Discharge, 1998-2007

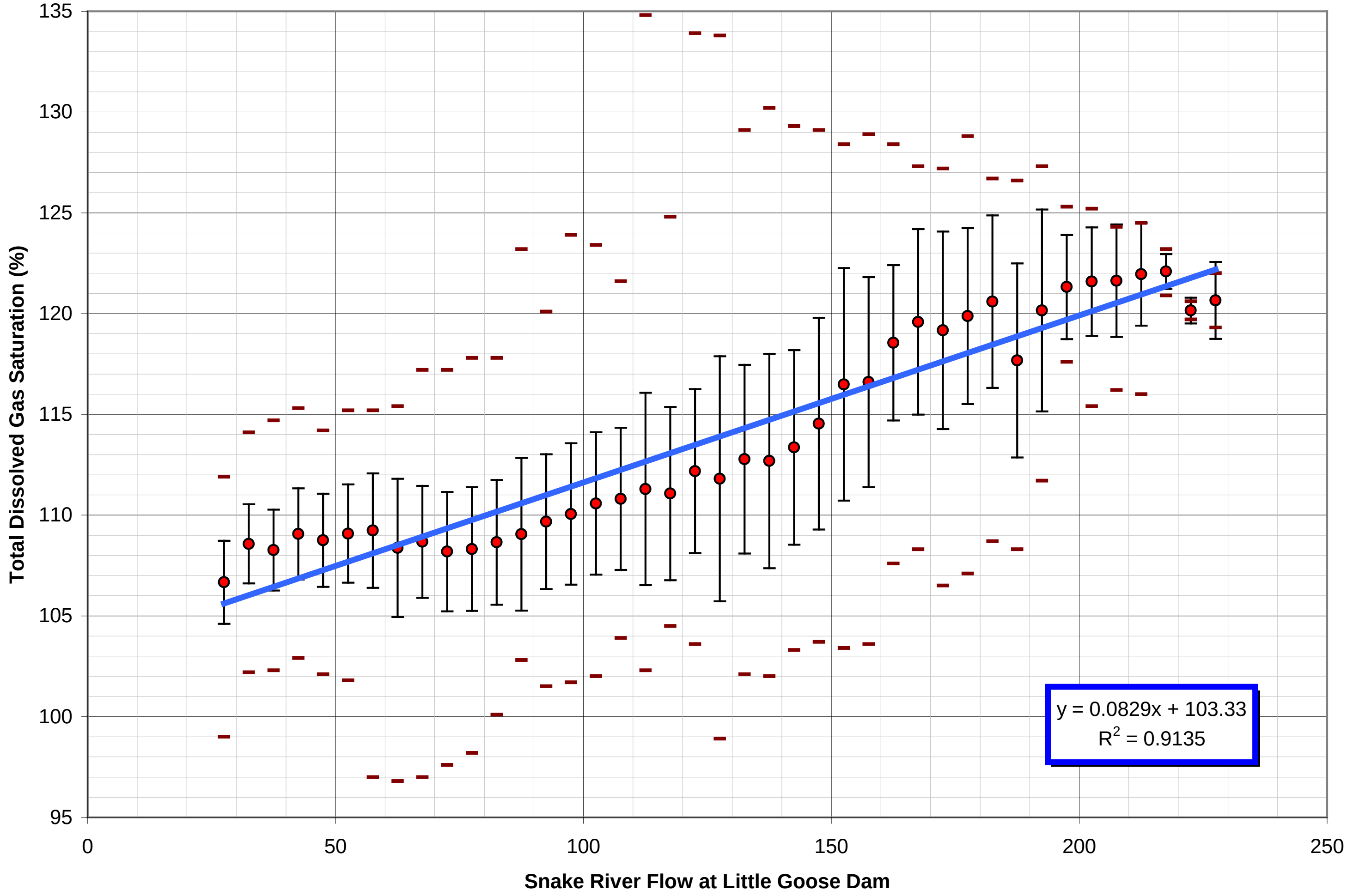

Figure G4. Total Dissolved Gas Saturation in the Forebay of Little Goose Dam as a function of Total Snake River Flow, 1995-2007

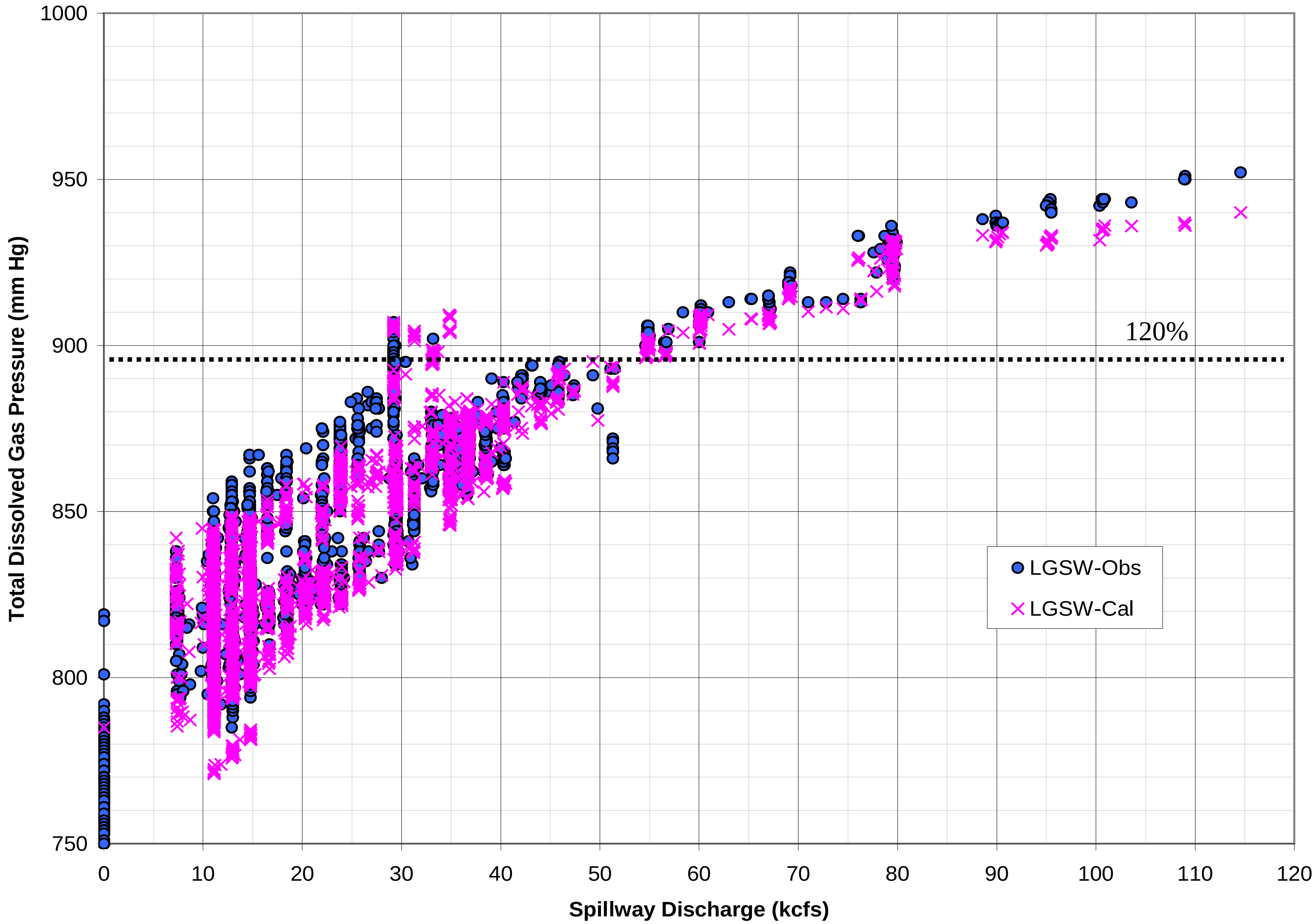

Figure G5. Total Dissolved Gas Saturation at the Tailwater Fixed Monitoring Station at Little Goose Dam as a function of Spillway Discharge, 2008 (Observed and Calculated)

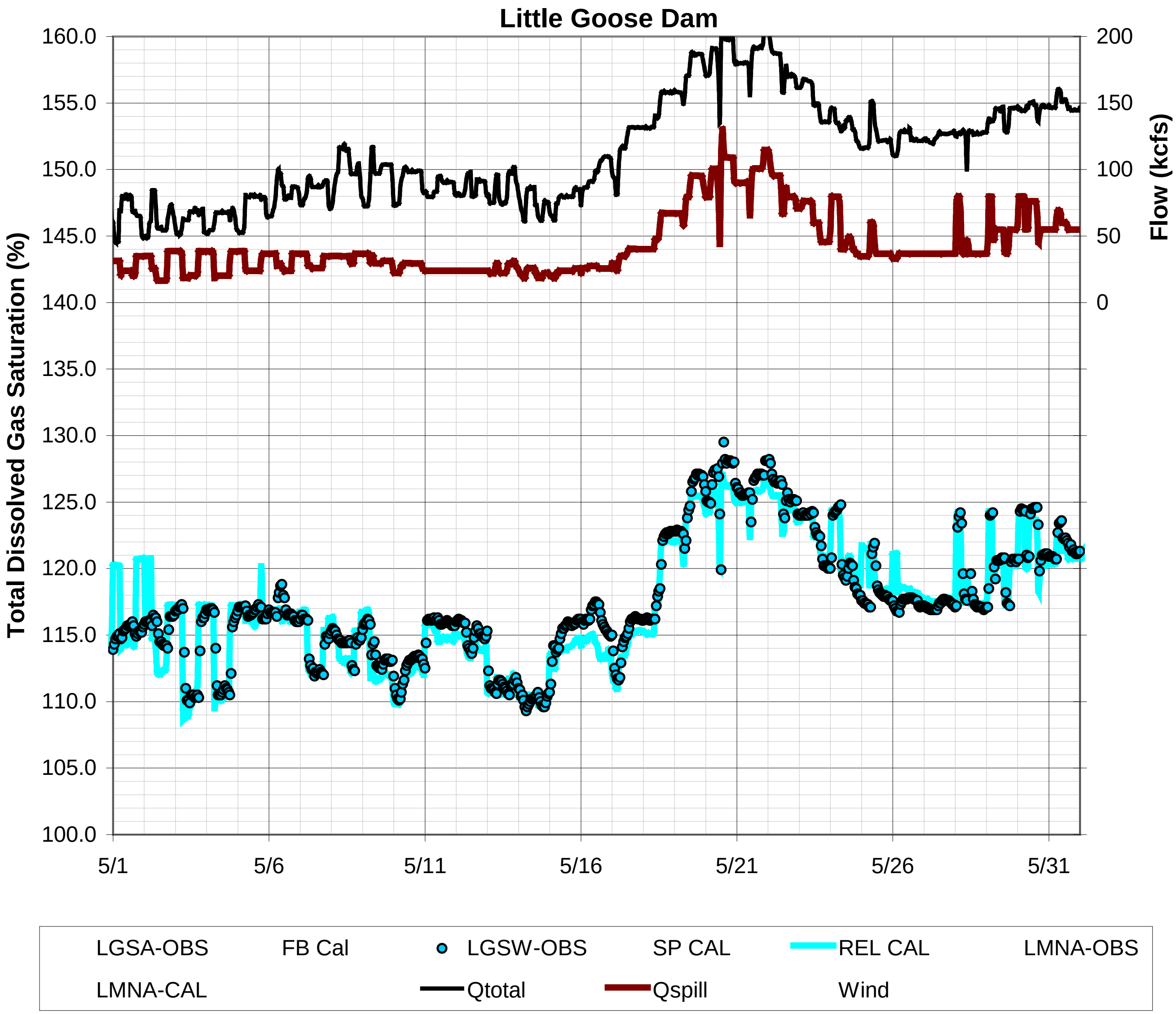

Figure G6 Little Goose Dam Operations and TDG Saturation Observed and Calculated at the Tailwater Fixed Monitoring Station, May 2008 (Rel Cal=Calculated TDG saturation from Equations 2-3, LGSW=Tailwater Fixed Monitoring Station)