Appendix C

Total Dissolved Gas Abatement Plan for John Day 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 main stem 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 John Day Dam on the Columbia River as requested by the State of Washington for their criteria adjustment.

Project Description

John Day is located on the Columbia River 23 river miles upstream of The Dalles at river mile 215. The main structures include a powerhouse, concrete spillway and stilling basin, navigation lock, fish facilities, concrete nonoverflow sections, and earth-fill abutment embankments north of the navigation lock and south of the powerhouse. The dam is roughly 5,900 feet in length at the crest, including the embankments. The powerhouse includes 16 generator bays with a maximum total discharge capacity of approximately 330 kcfs, and four skeleton bays. The turbines are numbered from 1 to 16 from south to north with the four skeleton bays located adjacent to the spillway. The John Day spillway is 1,250 feet long with twenty 50-foot-wide gate controlled spillway bays and nineteen intermediate piers. The design capacity of the spillway is 2,250 kcfs, with a corresponding maximum pool elevation of 276 fmsl. The spillway crest elevation is 210.0 fmsl, allowing the spillway to pass the standard project flood of 1,700 kcfs at normal full pool elevation 265.0 fmsl.

Powerhouse Hydraulic Capacity

The John Day powerhouse unit hydraulic capacity during the fish passage season was estimated assuming the standard-length submersible traveling screens are installed, a total head of 102 ft, and each unit is operated at the upper limit of the peak efficiency constraint as described in the yearly Fish Passage Plan (USACE, 2010). The unit hydraulic capacity for these conditions was estimated to equal 20.6 kcfs/unit. The unit hydraulic capacity reaches a maximum rate of 22.3 kcfs at a head of 90 ft at the upper generator limits required in the FPP. The total hydraulic capacity of the John Day powerhouse with all 16 units available is 329.6 kcfs. If only 15 units are available, the hydraulic capacity of the John Day powerhouse is 309 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 50 kcfs required to meet generation requirements was assumed throughout this evaluation.

Summary of Columbia River Flow at John Day Dam

The daily average total river flow, generation flow, and spillway flow was compiled for John Day 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 Columbia River at John Day Dam are shown in Figure C1 during the fish passage season from 1975-2009. The median river flow during this period is about 200 kcfs. The frequency that the Columbia River flow will exceed 300 kcfs is 14.9 percent and 400 kcfs is only 2.6 percent.

The percent exceedance characteristics for the seven-day moving average of daily average flows for the Columbia River at John Day Dam are shown in Figure C2 outside the fish passage season from 1974-2009. The median river flow during this period is about 135 kcfs. The frequency that the Columbia River flow will exceed 300 kcfs is 1.9 percent and 400 kcfs is 0.0 percent.

The tabular summary of TDG exchange properties at John Day Dam are presented in this report for the following total river flows: 100, 150, 200, 250, 300, 350, 400, 451, 500 kcfs. The frequencies of exceeding these flows within and outside of the fish passage season based on historic flows from 1975 to 2009 are listed in Table C1.

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 WDOE estimated this discharge for the Columbia River at John Day Dam at 454 kcfs as described in the Total Maximum Daily Load for Lower Columbia 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 Columbia River TMDL. The updated mean 7Q10 high flow in the Columbia River at John Day Dam was estimated to equal 441 kcfs with a 80 percent confidence limit ranging from 404.1 to 500.9 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 441 kcfs was exceeded in only 2 of the past 35 water years which infers a return period of once every 17.5 years.

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 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

John Day Dam was one of the largest producers of TDG supersaturation on the Columbia River during the high flow years of 1996 and 1997. The John Day spillway consisted of a standard ogee design with 20 spill bays without spillway flow deflectors. The TDG saturation typically approached and exceeded 120 percent for spillway discharges of about 60-70 kcfs or about 3 kcfs/bay as shown in Figure C3. The tailwater TDG supersaturation routinely exceeded 140 percent for spillway discharge of 120 kcfs and greater and remained at this high level for several weeks during 1997.

The TDG loading of the Columbia River is influenced by both spill 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 at lower spill volumes will also lower the TDG pressures in the receiving waters. Alternatively, a reduction in the injury rate of juvenile salmonids 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 in spillway flows 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 deflectors 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 spillway flow deflectors also transports highly aerated flow conditions well downstream of the stilling basin into the tailrace channel, promoting the exchange of atmospheric gasses at the local depths. The effectiveness of spillway flow deflectors in abating TDG production has been consistently demonstrated at Corps of Engineers projects on the Columbia and the Snake rivers. Other methodologies to reduce TDG loading below main-stem dams 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 abatement. 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 associated with 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 Columbia River during voluntary flow conditions. This increase in TDG loading results from a higher percentage of the river spilled at 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 John Day Dam that influences TDG loading in the Columbia River during the fish passage season.

Structural Alternatives

The Portland District Corps of Engineers developed a design for spillway flow deflectors at John Day Dam using both a 1:80 scale general physical model of the dam and spillway and 1:40 scale sectional physical model of the spillway. Spillway flow deflectors were installed on spillway bays 2 through 19 at elevation 148 fmsl. Each deflector is 12.5 feet long with a 15-foot-radius transition from the spillway slope as shown in Figure C4. The flow deflectors were sited much deeper (14 feet) at John Day when compared to the Snake River projects.

Eighteen of the 20 spillway bays at John Day Dam were modified with flow deflectors during the winter of 1998. New spill patterns were established at that time. End bays (bays 1 and 20) were not modified primarily due to concerns with adverse juvenile salmon egress with deflectors on these bays.

The spillway flow deflectors proved to be very effective in reducing the generation of TDG supersaturation during spillway discharges at John Day Dam. A TDG exchange field study was conducted during February of 1998 to evaluate the TDG exchange with spillway flow deflectors for a range of operating conditions (Schneider and Wilhelms, 1998). This investigation found a reduction in the TDG saturation of 20 percent saturation for some spillway flows when compared to the spillway without flow deflectors. The spillway capacity as limited by 120 percent saturation at the tailwater

fixed monitoring station was a high as 180 kcfs. The post flow deflector construction TDG study also found strong lateral gradients in TDG saturation across the channel near the tailwater fixed monitoring station with peak levels as much as 6 percent saturation higher than observed at the tailwater monitoring station. The TDG saturation as observed at the tailwater fixed monitoring station with and without spillway flow deflectors are shown in Figure C3 as a function of the unit spillway discharge. The spillway capacity at John Day Dam as limited by the 120 percent saturation criterion with spillway flow deflectors was found to have a wide range of values and is influenced by the spill pattern and tailwater elevation.

A surface bypass prototype program at John Day is underway in conjunction with evaluations of alternatives to address tailrace passage survival improvements. Two overflow spillway weirs (SW) were installed in 2008 and were tested again in 2009. The spillway weirs have the potential to reduce turbine entrainment of juvenile fish and provide more efficient juvenile passage compared to conventional spill. The discharge capacity of these SW was about 10 kcfs resulting in a bulked or non-uniform spill pattern for typical voluntary spillway releases.

An additional alternative constructed during the winter of 2010 for tailrace passage improvements includes adding an end bay spillway flow deflector on bay 20 located closest to the powerhouse. This final flow deflector design involves a deflector length of 50 ft at an elevation of 150 fmsl. The additional flow deflector is designed to provide training flow for juvenile fish egress for the SW operation. This deflector will also provide for an additional spillway to be operated for TDG abatement by providing a surface oriented jet.

The future structural configuration of John Day dam as directed by fish passage objectives has been outlined in the John Day Dam configuration and operations plan (USACE, 2007). This planning document addresses potential structural changes to John Day Dam to meet juvenile fish survival standards and include the following: Extended-Length Submersible Bar Screens (ESBS), Surface Flow at Spillway (SFSP), Surface Flow at Skeleton Bays (SFSB), Powerhouse Hydrocombine, Behavioral Guidance System (BGS), Tailrace Improvements, Tailrace Improvements – JBS Outfall Relocation, Turbine Improvements, Powerhouse Surface Collection, and selected combinations of these alternatives. All of these alternatives have the potential to directly or indirectly impact the TDG loading produced at John Day Dam by reducing the reliance on spill to aid fish guidance during voluntary spill flows during the fish passage season or changing the hydraulic condition in the tailrace channel and stilling basin region.

One of the alternatives listed under tailrace improvements includes the addition of a spillway or training wall to divide the flow in the stilling basin to a smaller area to control and to allow better guidance of outmigrants in the JDA tailrace. Although it is not known where the location of a spillwall would be most effective, the wall would extend from approximately 2 feet above normal high tailwater to the stilling basin floor. The length of a wall from the vertical face of the existing spillway piers to the end sill would be approximately 232 feet. An advantage of a spillwall separating the powerhouse from the

spillway is that it eliminates the entrainment of powerhouse flow into the stilling basin and prevents the circulation of flow below the powerhouse. This confines the spill flow as mentioned but also improves egress conditions for turbine and bypassed fish. In addition, it has the potential to reduce TDG saturation by preventing entrained powerhouse flows from becoming saturated within the stilling basin. This alternative would greatly improve tailrace egress. The total costs for design and construction of this alternative are estimated at $20 million.

A second alternative that could directly impact TDG generation at John Day Dam involves the hydrocombine option. The benefit of a hydrocombine is that the spillway bay is located directly above the powerhouse intake. Generally, juvenile fish tend to move upward in the water column as the flow move downward into the turbine intake. A horizontal spillway ogee would be placed above the hydrocombine intake which would split the flow horizontally and provide an outlet for fish being drawn into the intake. This alternative has a benefit similar to the other spillway alternatives in that it is expected to reduce forebay residence time; with appropriate spillway flow, it also would reduce tailrace residence time. In addition, if the high volume of flow currently discharged over the spillway could be passed through "high survival" turbines installed in the skeleton bays coupled with improved egress. The additional turbine(s) could increase the maximum generation capacity of John Day Dam. The additional surface spillway chute could be designed to provide for a surface oriented spill jet that has similar TDG generation properties as spillway discharge with flow deflectors. The total costs for design and construction of this alternative are estimated at $256 million. The O&M costs are estimated at $304,000 annually. Post-construction monitoring costs are estimated at $8 million.

Spill Operation Alternatives

The selection of a spill operation to achieve fish passage objectives at John Day Dam will be closely related to the structural configuration. During the 2009 fish passage season, this operation called for spilling a fixed percentage (30 to 40 percent) of instantaneous river flow during both springtime and summer time. The high survival rates of juvenile fish passing through the spillway at John Day Dam make spill an attractive passage route. Previous spill operations called for spill both 30 and 40 percent of the river flow and scheduled daytime spill outages followed by spilling 60 percent of the river at night. The introduction of spillway weirs has resulted in alternative spill patterns to support juvenile egress from the stilling basin and the adjacent tailwater channel. In 2009, the SW were operated in bays 15 and 16 during the spring time with supporting spill widely distributed over bays 2-18. The summer spill called for uniform spill over bays 2-13. This change in spill pattern resulted in a marked difference in the TDG saturation observed at the tailwater fixed monitoring station with higher TDG levels associated with the summer time spill over a restricted number of bays for a comparable spill discharge. The spill operation will influence the TDG loading generated during the voluntary spill conditions during the fish passage season but will have diminishing impacts on the TDG loading during involuntary spill conditions.

TDG Properties

The TDG exchange properties at John Day Dam have been influenced by the spill operation, spillway flow deflectors, spillway weirs, spill pattern, and tailwater elevation. The spill operation has changed significantly over the past five years. The spill pattern has transitioned from a uniform distribution to a bulk pattern with training flow for the SWs located in spill bays 15 and 16. The summer spill pattern in 2009 involved a uniform spill over bays 2-13. The spill bays 1 and 20 without spillway flow deflectors were not included standard spillway releases.

The TDG saturation observed at the tailwater fixed monitoring station from 2002 to 2009 as a function of spillway discharge is shown in Figure C5. Prior to 2002, the spill pattern was more uniformly distributed across bays 2-19. The TDG saturation observations associated with constant spill operations longer than 3 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 C5. The linear regression model between spillway discharge and TDG saturation at Bonneville Dam is shown Figure C5 with a slope of 0.0489 percent/kcfs. This relationship indicates that a 10 kcfs increase in spill will result in a 0.4 percent increase in TDG saturation. The mean value of the spillway capacity as limited by the 120 percent tailwater TDG criteria is about 155 kcfs. The primary spill pattern used during this period of analysis involved transitioning from a bulk spill pattern to a uniform pattern for spillway discharges greater than 100 kcfs. The bulk spill pattern for spillway flows less than 100 kcfs resulted in a maximum TDG saturation approaching 120 percent at 80 kcfs spill. This transition between the uniform and non-uniform spill patterns resulted in a condition where tailwater TDG levels increase when either increasing or decreasing spillway flows (location minimum in TDG production).

The estimates of TDG exchange in the Columbia River at John Day 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 the standard spill pattern prior to the addition of spillway flow deflectors in 1998 was determined from observations at the tailwater fixed monitoring station during 1997 and 1996 as shown in Equation 1.

Equation 1.

$$\Delta P = 315.3 - 519.1 \exp(-0.365 q_s) \qquad (1)$$

N = 1187

r^2= 0.94

STD error= 15.95 mm Hg

Where

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

N_{eff} = Effective number of active spill bays 1-20.
Q_{sp} = Total spill discharge (kcfs)
$TDG_{sat} = (P_{atm}+\Delta P)/P_{atm} \times 100$ 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 1-20.

Q_i = Spill discharge in bay i.
Nbays = Active number of spill bays.
c_w = 1 spill pattern weighting coefficient

The TDG generation with spillway flow deflectors in place in 1998 at John Day Dam, as influenced by both tailwater elevation and the specific spillway discharge for a wide range of spill conditions was developed from observed TDG data. The data was filtered to include only constant spill events with a duration of 4 hours and longer. The exponential non-linear least squares regression equation generated from 51 observations is show in equation 2 below. The standard error was based on predictions and observations of TDG levels as observed at the tailwater fixed monitoring station.

Equation 2.

$$\Delta P = 4.97(TWE - 125)(1 - \exp(-0.23 q_s)) \qquad (2)$$

N = 51
$r^2 = 0.84$
Std Error = 6.78 mm Hg

Where

TWE = Columbia River stage at John Day tailwater (ft)

The sensitivity of TDG exchange as a function of a change in the tailwater stage from 160 to 161 ft will result in an increase in TDG pressure of 1.3 mm Hg for a specific discharge of 6 kcfs/bay. Alternatively, an increase in the specific spillway discharge from 6 to 7 kcfs/bay will result in a 9.2 mm Hg increase in TDG pressure for a constant tailwater elevation of 160 ft. Equation 2 also illustrates the influence of bulking spill in several bays. A total spillway discharge of 100 kcfs uniformly distributed over 18 spill bays will result in a TDG saturation of 117.1 percent at a tailwater elevation of 160 ft. The same 100 kcfs spilled uniformly over 12 bays will result in a TDG saturation of 120.2 percent for an increase in TDG saturation of 3.1 percent over the uniform 18 bay

spill pattern. An average local atmospheric pressure of 755 mm Hg was applied to estimate the total dissolved gas saturation.

The average flow weighted TDG saturation below John Day Dam was determined for each combination of structural and operation alternative using the equations 1 and 2. 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

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

where:

Q_{tot} = Total River Flow (kcfs)

Q_{sp} = Spillway discharge (kcfs)

Q_{gen} = Generation discharge (kcfs)

Q_{aux} = Auxiliary discharge

TDG_{gen} = TDG saturation of generation discharges (percent)

TDG_{avg} = Average cross sectional TDG saturation in the Columbia River (percent)

TDG_s = TDG saturation of spillway discharges (percent)

TDG_{aux} = TDG saturation of auxiliary discharge (percent)

A comprehensive evaluation of TDG exchange at John Day Dam should consider the existence of elevated background TDG levels from upstream sources. The presence of elevated background TDG levels at John Day 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 John Day Dam are summarized from 1995-2007 as a function of total river flow in Figure C6. The observed daily average TDG saturation in the forebay of John Day Dam was summarized for 5 kcfs blocks for total river flow ranging from 60 to 525 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 John Day Dam and total river flow. This figure shows that when river flows are approaching the 7Q10 level of 441 kcfs, the upstream TDG saturation typically approach 120 percent of saturation. The background TDG saturation for river flows equal to the maximum powerhouse capacity at John Day Dam (329.6 kcfs) are on average around

112.5 percent saturation. The elevated background TDG levels during high river flow are caused by spill from main-stem dams on the Columbia and Snake River.

The contribution of TDG loading of the Columbia River at John Day Dam will be a closely related to background TDG levels transported to the tailwater unaltered by powerhouse flows. The percentage of river flow will determine how much of the total river flow will be impacted by the aerated spillway releases. The mean TDG saturation associated with a spill discharge of 150 kcfs was about 119.2 percent saturation as shown in Figure C5. If a total powerhouse discharge of 250 kcfs is maintained the total river flow would equal 400 kcfs. The summary of forebay TDG levels for total river flows of 400 kcfs (Figure C6) shows the range of forebay TDG saturations all both below and above the range observed in spillway releases. The TDG content in spillway flows undiluted with powerhouse flow has been found to be independent of background TDG pressures. Therefore, the influence of spilling 150 kcfs during a 400 kcfs river flow will result in a net reduction in the TDG loading of the Columbia River when forebay TDG levels are above 121 percent.

A hind cast of TDG saturation below John Day Dam for a wide range of observed historic operations (spillway flow ranged from 40 to 130 kcfs) during May of 2009 were conducted using the relationship shown in Equations 2-3. The hourly total river and spillway flow are shown in Figure C7 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 Columbia River at John Day 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 John Day Dam and the associated TDG exchange. This 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 JDATDGest.xls summarizing the effects of six different structural configurations, six different spill operations, two powerhouse capacities, eight different river flow rates, and five background TDG saturations. A summary of the discrete conditions listed in this table are summarized in Table C2. This table consists of 2880 different cases that

provide a comprehensive summary of the TDG management program at John Day 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 size 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 John Day Dam.

A total of six different structural alternatives were considered in this evaluation and include conditions prior to adding the spillway flow deflectors, existing conditions with 18 deflectors with 2 SW gates, and potential future structural conditions. The base condition (Base-No Deflectors) is defined by the original spillway and stilling basin as completed and put into operation in 1962 with standard length STS installed for each of the 16 turbines. The second alternative includes the existing spillway conditions with type II spillway flow deflectors (18 Deflectors) on 18 or the 20 spillbays that were completed during the winter of 1998. The third structural configuration includes the addition of a spillway weir (18 Deflectors+SW) currently located in spillbay bays 15 and 16. The purpose of these structures is to more effectively and efficiently guide juvenile fish past John Day Dam. The fourth structural alternative involves the addition of a deflector in spill bay 20 (19 Deflectors+SW) which is currently under construction during the winter of 2010. The fifth structural alternative includes the addition of a spillway training wall (19 Deflectors+SW+Training Wall) that will partition powerhouse and spillway releases. The final structural alternative includes the addition of a single hydrocombine (19 Deflectors+SW+Training Wall+Hydrocombine) including the addition of a 17th turbine with similar hydraulic properties as existing turbines and an overflow spillway chute with an exit geometry delivering a surface skimming flow to the tailwater channel. The addition of the training wall and hydrocombine are potential structural changes to John Day Dam that will impact the operations and TDG generation at the project. The naming convention listed here and underlined above is used in the evaluation spreadsheet.

This study also considered the influence of six different possible spill operations that govern the operations of John Day 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 100 kcfs ("spill 100 kcfs"). The third 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 fourth spill operation called for spilling up to the capacity as limited by the 110 percent total dissolved gas saturation criterion at the tailwater fixed monitoring station ("spill to capacity @ 110 %").The fifth spill operation of no net increase in TDG loading of the Columbia River called for flows to be limited by the either the 110 percent criteria or

background TDG level in the Columbia River ("spill to capacity @ 110% or TDGfb"). The final spill operation called for "no voluntary spill" excluding the auxiliary discharge.

The TDG properties in spillway flows at John Day 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 equations for TDG production of the original spillway and existing spillway with flow deflectors are presented TDG properties section of this report. An average local atmospheric pressure of 755 mm Hg was applied to estimate the total dissolved gas saturation. The TDG properties of powerhouse and auxiliary flows were assumed to retain forebay TDG characteristics. The average flow weighted TDG saturation below John Day Dam was determined for each scenario in the master table. The entrainment of powerhouse releases into the aerated stilling basin was estimated by the product of an entrainment coefficient and the spill discharge. The added entrained powerhouse flows were assumed to achieve the same level of TDG saturation as spillway releases. The residual TDG saturation arriving at the forebay of The Dalles Dam was estimated by calculating a degassing rate as a first order exchange rate based on the level of the average TDG supersaturation at John Day Dam.

A comprehensive evaluation of TDG exchange at John Day Dam should consider the existence of elevated background TDG levels from upstream sources. The presence of elevated background TDG levels at John Day 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 hydraulic capacity of the powerhouse at John Day Dam is larger than all upstream dams on the Columbia or Snake River. Therefore, involuntary spillway operations will be triggered at much higher flows at John Day Dam than at upstream projects.

The contents in the master table and related Tables C3-C7 are as follows:

Case - Case number in the master table (1-2880)
Structure Alternative =(Base, Deflectors, RSW/SW, Deflectors w 20 Turbines)
Spill Operation = (Spill @ 120%, Spill % River or 120%, Spill 110%, Spill 110% or TDGfb, Spill fixed rate)
$\mathbf{Q_{ph\text{-}max}}$ = Maximum hydraulic capacity of the John Day powerhouse (kcfs)
$\mathbf{Q_{total}}$ = Columbia River Flow at John Day Dam (kcfs)
$\mathbf{Q_{gen}}$ = Powerhouse Flow (kcfs)
$\mathbf{Q_{spill}}$ = Spillway Flow (kcfs)
$\mathbf{Q_{aux}}$ = Auxiliary Flow (kcfs)
$\mathbf{TDG_{sp}}$ = Total Dissolved Gas Saturation in spillway flows (%)
$\mathbf{TDG_{fb}}$ = Total Dissolved Gas Saturation in forebay (%)
$\mathbf{TDG_{avg}}$ = Flow weighted Total Dissolved Gas Saturation below John Day Dam (%)
ΔTDG = Change in average Columbia River TDG saturation (positive increase in load, negative net decrease in load %)
$\mathbf{TDG_{fb}}$ **@ TDA** = Estimated TDG saturation at The Dalles Dam forebay (%)

TDG_{loss} = Estimated TDG reduction between John Day and The Dalles Dams (%)
Frequency of Exeeding Flow = Percent of time the Columbia River Flow at JDA is exceeded (%)
(based on 1975-2009 seven day average flow during fish passage season)

Structural Configuration The TDG exchange across the six structural configurations investigated at John Day Dam for a spill operation of spilling 30 percent of total river flows of 150, 300, and 441 kcfs were examined as shown in Table C3. The scenarios in Table C3 have been sorted by total river discharge listing the impacts of the six structural alternatives for below average, above average, and high river flows. In general, the significant TDG abatement benefits associated with adding 18 deflectors to the spillway at John Day Dam are summarized in this table. For low river flows at a spillway discharge of 45 kcfs, the Base-No Deflectors operation resulted in the TDG saturation in spill of 119.8 percent compared to only 111.5 percent for the other alternatives with deflectors. The uniform estimate of TDG content in spill of all the alternatives with deflectors was caused by a spill pattern using only a portion of the spillway. The added benefit of using the entire spillway with flow deflectors is realized for small spill discharges. The Base-No Deflectors scenario of spilling 45 kcfs during a total river flow of 150 kcfs resulted in raising the cross sectional average TDG saturation in the river from 110 percent in the forebay to 113.1 percent in the receiving tailwater. The net increase in the cross sectional average TDG saturation for the structural alternatives with flow deflectors was less than 1 percent for these conditions.

During the voluntary spill conditions for a total river flows of 300 kcfs the Base-No Deflectors scenario could not meet the 30 percent spill objective because of the tailwater TDG criteria of 120 percent. A spillway discharge of 63 kcfs for the Base-No Deflectors resulted in a TDG content in spill of 120 percent compared to TDG saturations of 116.3-117.3 percent at 90 kcfs spill for structural alternatives with flow deflectors. The limitation of spill management associated with the Base-No Deflectors scenario will have a direct impact on meeting fish passage objectives. The cross sectional average TDG saturation for the alternatives with spillway deflectors were generally higher than the Base-No Deflectors alternative with the exception of the “19 Deflectors+SW+Training Wall+Hydrocombine” alternative because of the higher percent river spilled. The increase in average cross section TDG saturation for the Base-No Deflectors alternative was also smaller for a river discharge of 300 kcfs when compared to 150 kcfs because of the smaller percent of river spilled. This series of TDG generation scenarios illustrates the impacts of adding spillway flow deflectors on TDG levels in the Columbia River at moderate to high river flows. The higher spill capacities afforded by flow deflectors resulted in higher average TDG saturations compared to the Base-No Deflectors structural configuration.

The impacts of structural alternatives on TDG exchange at John Day Dam during the updated 7Q10 river flow of 441.4 kcfs is contained the bottom section of Table C3. This flow condition reflects the worst case conditions where involuntary spill is required and the TDG generated in the tailwater exceeds the 120 percent level in all cases except the structural alternative of 19 deflectors+SW+Training Wall+Hydrocombine. At a river

flow of 441.4 kcfs, John Day Dam is forced to spill 130.9 kcfs at a powerhouse capacity of 309 kcfs (1 turbine inoperable). Prior to the addition of spillway flow deflectors this operating conditions was estimated to generate a TDG saturation of 135.5 percent in spillway flow resulting in an average cross sectional TDG saturation of 117.9 percent. The background TDG level of 110 percent is unlikely for sustained river flows of this magnitude. The addition of 18 deflectors greatly reduced the TDG content in spillway releases to 122.5 percent and the resultant average cross sectional TDG saturation of 114.1 percent. Adding the SWs to two spill bays had minimal impact on the TDG content in spill but increased the powerhouse entrainment volume and hence average cross sectional TDG levels. The addition of a 19th deflector in spill bay 20 will reduce the TDG levels in spill to a modest amount (0.5 percent) when compared to the 18 deflector structure. The addition of a spillway training wall will minimize the added TDG loading associated with powerhouse entrainment. The training wall will lower the cross sectional average TDG saturation from 116.3 percent to 113.6 percent. The addition of the Hydrocombine will both increase the capacity of the powerhouse by one turbine but also the size of the spillway providing horizontal skimming flow. In this case, with one turbine inoperable, the spillway discharge of 110.4 kcfs will not exceed the 120 percent tailwater criterion and result in a net increase in average cross section TDG saturation of only 2.5 percent. The graphical representation of the impacts of six structural alternatives on TDG generation at John Day Dam during a 7Q10 river flow, background TDG saturation of 110 percent, and one inoperable turbine is shown in Figure C8. The largest reduction in the TDG loading is associated with adding spillway flow deflectors. Incremental benefits in TDG saturation can be achieved through the addition of spillway flows with flow deflectors, training wall, and added hydropower capacity.

Spill Operation

The influence of spill operation on TDG exchange was explored for the current condition 18 deflectors+SW scenario for three river flow conditions 150, 300, and 441 kcfs. The maximum powerhouse capacity with one turbine inoperable and forebay TDG level of 110 percent were also held constant for this evaluation as listed in Table C4. The spill operation has considerable influence over the TDG exchange during voluntary spill conditions that exist for 150 and 300 kcfs flows. The spill to the 120 percent TDG criteria resulted in the highest TDG levels for these two river flow conditions. This spill operation resulted in a spill discharge of 123 kcfs and resulted in an increase in TDG saturation above background levels of 7.2 percent. The “no voluntary spill” operation resulted in no spill and no increase in the TDG levels in the Columbia River. The involuntary spill conditions during a total river flow of 441 kcfs over rides the voluntary spill operation and the TDG generation is identical for all cases exceeding 120 percent.

Three spill operations, “No voluntary spill” , “Spill capacity at 110”, and “Spill capacity at 110 or TDGfb” resulted in no change to the TDG loading of the Columbia River for river flows of 150 and 300 kcfs. It was estimated that a spill of 45 kcfs uniformly distributed over all spill bays with flow deflectors will approach 110 percent saturation in the tailwater. The more aggressive “Spill to capacity at 120 percent“ caused the largest increase in average TDG loading of 7.2 and 6.1 percent saturation for the 300 and 150

kcfs river condition. The spill operation of "Spill 30%" yielded much lower TDG conditions than the "Spill to capacity at 120%" operation. At a total river flow of 300 kcfs, the "Spill 30 Percent" operation resulted in an average cross sectional TDG saturation of 113.8 percent compared to the TDG production of the "Spill to capacity at 120% operation" of 117.2 percent. The spill operations resulting in higher percent spill conditions generated higher TDG pressures but not above the 120 percent criteria for the 150 and 300 kcfs flows. The fixed spill discharge operation of 100 kcfs resulted in the largest increase in TDG levels for the 150 kcfs river flow.

The 7Q10 flow resulted in a spill of 130.9 kcfs attaining a TDG saturation of 122.6 percent in spillway flows and a cross sectional average saturation of 116.5 percent. The spill operation changes from voluntary of involuntary at this 7Q10 river flow causing the uniform response in TDG exchange. The estimated TDG saturation of 122.6 percent falls above the rule adjustment for the State of Washington. The forebay TDG level are likely to above 110 percent as indicated in Figure C6. It is possible for some level of degassing to occur at John Day Dam if forebay TDG levels exceed the TDG content in spillway flows.

Total River Flow Impacts

The operation at John Day Dam requires some level of spill when the total river flow exceeds the powerhouse capacity. The TDG supersaturation in spill is weakly a function of the available depth of flow below the spillway. The operation of the existing structure of "18 deflectors+SW" subject to a spill operation of "spill to capacity @ 110%" is listed in Table C5 for a range of river flows up to the 7Q10 discharge for a background TDG levels of 110 percent. As the tailwater depth of flow rises with increasing river discharge, the spill capacity as limited by 110 percent criteria falls from 48.5 to 39.5 kcfs. The existing structure at John Day Dam is able to maintain TDG levels of 110 percent up to a river flow of 350 kcfs. This estimate assumes the spill discharge is uniformly distributed over the spillway. As the river flow increases above 350 kcfs the spill will increase by the same degree resulting in a spill of 89.5 kcfs at a total river flow of 400 kcfs and 130.9 kcfs for a total river flow of 441. kcfs. For river flows outside of the fish passage season, the total river flow rarely (0.7 percent from Table C1) exceeds 350 kcfs and TDG levels should remain near background levels. Within the fish passage season, involuntary spill will be required much more frequently with peak TDG levels in spill reaching 122.6 percent in spillway flows undiluted from powerhouse flows.

Forebay TDG Level Impacts

During the fish passage season, when the existence of upstream sources of TDG supersaturation at John Day Dam result in background TDG levels exceeding 110 percent. A set of TDG estimates were determined assuming likely forebay TDG levels in the Columbia River for the existing structure "18 deflectors with SW" over a range of river flows for a spill operation of "Spill to Capacity @ 110% of TDGfb" or no increase in TDG loading of the Columbia River as listed in Table C6. For river flows ranging from 100-200 kcfs the spill generate TDG levels of 110 percent while background levels

are typically less than 110 percent. These operations will increase the average TDG loading of the Columbia River but hold levels at or below 110 percent. For intermediate river flows, the project operations can be structured to not increase the TDG loading in the Columbia River. It is only during the higher flow conditions that spill operations at John Day Dam were found to result in small increase in the TDG loading of the Columbia River. At the 7Q10 river flows with background TDG levels of 120 percent a involuntary spill of 110.3 kcfs would be required resulting in a 0.4 percent saturation increase in the average TDG loading of the Columbia River.

Spill to Capacity @ 120 percent

The TDG exchange associated with a spill operation of "spill to capacity @ 120%" was investigated subject to forebay TDG levels of 110 percent, with the existing structure "18 deflectors+SW", at a powerhouse capacity with one inoperable turbine over a range of river discharges up to 441 kcfs. The amounts of spill for small river discharges are limited by minimum powerhouse flows as shown in Table C7. The spill capacity for a river discharge of 200 kcfs was 148.5 kcfs and caused the highest increase in TDG saturation of 9.8 percent saturation. The role of the entrainment of powerhouse flows can be seen in this scenario as the average river TDG levels approach the TDG levels in spillway flows. As the river flow increases above 200 kcfs, the percent river decreases and average cross sectional average TDG levels decrease accordingly.

John Day Dam 2009 configuration TDG and Flow Summary

The TDG saturation in Columbia River below John Day 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 2-5 correspond with maximum river flows with the spillway capacity limited by TDG saturations of 110, 115, and 120 percent. The final case involved worst case conditions of the updated mean 7Q10 flow of 441 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 John Day Dam from 1974-2009 are also listed in Table C8.

The frequency for spilling water above the maximum powerhouse capacity during the fish passage season is slightly above 10 percent of the time at John Day Dam but only 1.0 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 36 kcfs will generate TDG levels at 110 percent of saturation or 5 percent lower than the background conditions. This critical spill discharge was determined from observations during a uniform spill of 30 kcfs over bay 19 bays (Schneider, 1998). Outside of the fish passage season a river flow of 366 kcfs and greater occurs only about 0.3 percent of the time. This spill to the 110

percent capacity operation will result in a net decrease in the average TDG conditions of the river to 114.5 percent when forebay levels are 115 percent. The spillway discharges up to 64 kcfs will either reduce or cause no change in the TDG loading of the Columbia River. The spillway flows at John Day Dam up to 101 kcfs will result in TDG levels of 120 percent and less which corresponds to a total river discharge of 431 kcfs and a frequency of occurrence of 1.4 percent during the fish passage season. The worst case conditions will be associated with the 7Q10 flows and a spill discharge of 110 kcfs resulting in TDG saturation in spillway flows of 121.1 percent and result in an average TDG saturation of 116.7 percent.

Conclusions

Spillway flows will continue to be a regular operation at John Day Dam to support the fish passage during the migration season and to pass flow in excess of the powerhouse capacity or generation demands. Spillway flows create aerated flow conditions in the stilling basin resulting in TDG supersaturation in the Columbia River. For John Day Dam as currently configured, spillway flows larger than about 45 kcfs will generate TDG levels above 110 percent of saturation at the tailwater fixed monitoring station. Spillway discharges up to about 145 kcfs will generate TDG levels near 120 percent of saturation under normal flow conditions. It should be noted that spillway discharge capacities as limited by Washington State TDG rule exemptions can vary greatly as a function of spill discharge, spill pattern, tailwater elevation, powerhouse discharge, water temperatures, local atmospheric pressure, and background TDG levels.

The Columbia River 7Q10 high flow rate was determined to be 441.4 kcfs for this investigation and represents the worst case condition for TDG generation at John Day Dam. The maximum powerhouse capacity at John Day Dam with all 16 turbines fully functional was determined to be equal to 329.6 kcfs resulting in a maximum estimated spill of 110 kcfs during the 7Q10 flow condition. The likelihood river flows exceeding the maximum powerhouse capacity are about 10 percent during the fish passage season but only about 1.1 percent outside of the fish passage season. The current fish spill operation at John Day Dam calls for spilling from 30 to 40 percent of the river flow or 132.4 kcfs and a powerhouse discharge of about 306 kcfs at the 7Q10 river flow.

A number of structural and operational alternatives have been implemented at John Day Dam to reduce TDG supersaturation in spillway flows. Construction of spillway flow deflectors were completed in 1998 on 18 of the 20 spill bays at John Day Dam (bays 2-19). Prior to the addition of spillway flow deflectors, TDG levels in spillway flows at John Day Dam frequently exceeded 140 percent of saturation. The spillway flow deflectors effectively lowered the TDG supersaturation by 50 percent over much of the spill range and increased the spill capacity by over 3 fold. The higher spill capacity with spillway flow deflectors allowed higher volume fish spills to be scheduled at John Day Dam which elevated the TDG loading in the Columbia River for voluntary spill conditions. Spilling a higher percentage of the river at or near the tailwater TDG criteria

will result in higher average TDG levels in the river and higher TDG pressures arriving at the next downstream dam. The spillway flow deflectors have resulted in a marked reduction in TDG generation during involuntary spill conditions when TDG saturations used to exceed 140 percent of saturation.

Two spillway weirs have been added to John Day Dam for the purpose of supporting fish passage objectives. These spillway weirs provide surface releases from the forebay to attract juvenile fish while maintaining suitable skimming flow conditions over the spillway flow deflectors with moderate levels of TDG uptake. The intent of these spillway weirs to increase the efficiency and effectiveness of fish guidance by spillway flows with the potential to influence fish spill operation at John Day Dam.

The powerhouse hydraulic capacity directly influences the magnitude of spill during involuntary spill events when high flows or lack of market does not limit turbine operation. The powerhouse capacity at John Day Dam is the largest on the Lower Columbia River and will result is the smallest involuntary spill during the critical 7Q10 flood flows. The size of the John Day pool and long travel time from McNary Dam causes the residual TDG pressures arriving at John Day Dam to be much smaller than experienced at other dams. Powerhouse releases transport these lower forebay TDG pressures into The Dalles pool to moderate the TDG supersaturation generated in spillway flows. A scheduled monitoring and maintenance program of the turbines, generators, and related fish passage facilities is in place to improve the reliability of powerhouse operations and reduce the likelihood of spilling water in excess of fish operation directives.

The TDG generation at the John Day spillway has been found to be directly related to the specific discharge or discharge per bay as directed by the spill pattern. A spill pattern widely distributing spill over the entire spillway will minimize the unit discharge and TDG generation. The spill patterns at John Day Dam have been designed to tend towards a uniform pattern for high spillway discharges using spill bays with flow deflectors.

An additional spillway flow deflector located in bay 20 is scheduled to be completed for the 2010 fish passage season. This additional flow defector will further reduce the TDG generation for uniformly distributed spills by allowing the spill to be spread across a large width and reduce the spill discharge per bay. The large size of the bay 20 flow deflector will also provide a more gradual transition to horizontal flow in the stilling basin and extend the range of skimming flow which is an important property in limiting TDG uptake

There are several future structural measures that may further reduce the TDG generation in John Day operations. The decision to move forward with these alternatives will depend upon engineering and biological studies and financial resources. These structural changes are all related to fish passage improvements that may result in a smaller commitment to spill to achieve fish passage standards. A training wall between the powerhouse and spillway has the potential to lower powerhouse entrainment rates and reduce the TDG loading to the Columbia River. The degree of TDG abatement will

depend upon the TDG content in the forebay. A hydrocombine would add to the hydraulic capacity of the spillway and powerhouse and result in potential reduction in TDG production at John Day Dam.

During the fish passage season, John Day Dam as currently configured or with the proposed future structural alterations will not meet the 110 percent TDG criteria for river flows up to the 7Q10 flow. However, the ability to stay within the TDG criteria adjustment of 120 percent saturation in the tailwater is achievable up to the 7Q10 river flow. The ability to meet the 115 percent TDG rule exemption in the forebay of The Dalles Dam will depend upon the TDG levels in the forebay of John Day Dam and the rate of degassing throughout The Dalles pool.

The daily management of TDG levels in the Columbia River below John Day Dam as determined from the fixed monitoring program will continue. Maintaining both forebay and tailwater monitoring stations are critical for estimating the impacts of project operations on the TDG loading of the Columbia River.

Outside of the fish passage season, the magnitude and frequency of river flows greater than the powerhouse capacity is limited to 1.1 percent of the time. The spill capacity of the current spillway to the 110 percent limit with 18 flow deflectors is estimated to be 40-45 kcfs assuming a uniform spill pattern is applied. The added capacity with the additional flow deflector in bay 20 would further reduce the likelihood of spilling water with TDG levels in excess of 110 percent during the months of September through March to less than 0.5 percent.

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Table C1. Percent of time the seven-day moving average of daily average flows exceed the reference Columbia River Flow at John Day Dam, 1975-2009 water years.

Columbia River Flow (kcfs)	Fish Passage Season April-Aug (%)	Non-Fish Passage Season Sept.-March (%)	Comments
100	94.8	85.0	
150	70.0	36.1	
200	49.6	12.5	
250	29.6	4.3	
300	15.3	1.8	
309	14.0	1.5	Powerhouse capacity 15 units
329.6	10.1	1.1	Powerhouse capacity 16 units
350	6.8	0.7	
400	2.7	0.1	
441	1.2	0.0	Updated 7Q10
450	1.0	0.0	
500	0.6	0.0	

Table C2. Configuration Matrix for TDG Estimates in the Columbia River at John Day Dam.

Structural Alternative	Spill Operation	$Q_{ph\text{-}Max}$ (kcfs)	Q_{total} (kcfs)	TDG_{fb} (%)
Base-No Deflectors	No Voluntary Spill	309	100	105
18 Deflectors	Spill to Capacity @ 110% or TDG Forebay	329.6	150	110
18 Deflectors+SW	Spill to Capacity @ 110%		200	115
19 Deflectors+SW	Spill 100 kcfs		250	120
19 Deflectors+SW+Training Wall	Spill 30 Percent		300	125
19 Deflectors+SW+Training Wall+Hydrocombine[+]	Spill to Capacity @ 120%		350	
			400	
			441	

[+]Added powerhouse capacity of 17 turbines @ 350.2 kcfs.

Table C3. Summary of Total Dissolved Gas Exchange at John Day Dam for Columbia River flow of 150, 300, and 441 kcfs, Forebay TDG level of 110% by 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 (%)
170	Base-No Deflectors	Spill 30%	309.0	150.0	103.5	45.0	1.5	110.0	119.8	110.0	113.1	3.1
650	18 Deflectors	Spill 30%	309.0	150.0	103.5	45.0	1.5	110.0	111.5	110.0	110.5	0.5
1130	18 Deflectors+SW	Spill 30%	309.0	150.0	103.5	45.0	1.5	110.0	111.5	110.0	110.8	0.8
1610	19 Deflectors+SW	Spill 30%	309.0	150.0	103.5	45.0	1.5	110.0	111.5	110.0	110.8	0.8
2090	19 Deflectors+SW+Training Wall	Spill 30%	309.0	150.0	103.5	45.0	1.5	110.0	111.5	110.0	110.5	0.5
2570	19 Deflectors+SW+Training Wall +Hydrocombine	Spill 30%	329.6	150.0	103.5	45.0	1.5	110.0	111.5	110.0	110.5	0.5
173	Base-No Deflectors	Spill 30%	309.0	300.0	235.5	63.0	1.5	110.0	120.0	110.0	112.2	2.2
653	18 Deflectors	Spill 30%	309.0	300.0	208.5	90.0	1.5	110.0	117.3	110.0	112.4	2.4
1133	18 Deflectors+SW	Spill 30%	309.0	300.0	208.5	90.0	1.5	110.0	117.3	110.0	113.8	3.8
1613	19 Deflectors+SW	Spill 30%	309.0	300.0	208.5	90.0	1.5	110.0	116.8	110.0	113.5	3.5
2093	19 Deflectors+SW+Training Wall	Spill 30%	309.0	300.0	208.5	90.0	1.5	110.0	116.8	110.0	112.0	2.0
2573	19 Deflectors+SW+Training Wall +Hydrocombine	Spill 30%	329.6	300.0	208.5	90.0	1.5	110.0	116.3	110.0	111.9	1.9
176	Base-No Deflectors	Spill 30%	309.0	441.4	309.0	130.9	1.5	110.0	135.5	110.0	117.9	7.9
656	18 Deflectors	Spill 30%	309.0	441.4	309.0	130.9	1.5	110.0	122.6	110.0	114.1	4.1
1136	18 Deflectors+SW	Spill 30%	309.0	441.4	309.0	130.9	1.5	110.0	122.6	110.0	116.5	6.5
1616	19 Deflectors+SW	Spill 30%	309.0	441.4	309.0	130.9	1.5	110.0	122.1	110.0	116.3	6.3
2096	19 Deflectors+SW+Training Wall	Spill 30%	309.0	441.4	309.0	130.9	1.5	110.0	122.1	110.0	113.6	3.6
2576	19 Deflectors+SW+Training Wall +Hydrocombine	Spill 30%	329.6	441.4	329.5	110.4	1.5	110.0	120.0	110.0	112.5	2.5

[1] Powerhouse capacity of 309.0 kcfs based on 15 turbines at 102 ft of head, with STS installed, and operated at upper generation limit defined in FPP.

Table C4. Summary of Total Dissolved Gas Exchange at John Day Dam for Columbia River flow of 150, 300, and 441 kcfs, Structural Alternative 18 Deflectors+SW, Forebay TDG level of 110% for alternative 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 (%)
970	18 Deflectors+SW	No Voluntary Spill	309.0	150.0	148.5	0.0	1.5	110.0	100.1	110.0	110.0	0.0
1050	18 Deflectors+SW	Spill 100 Kcfs	309.0	150.0	50.0	98.5	1.5	110.0	116.1	110.0	116.1	6.1
1130	18 Deflectors+SW	Spill 30%	309.0	150.0	103.5	45.0	1.5	110.0	111.5	110.0	110.8	0.8
1210	18 Deflectors+SW	Spill to Capacity @ 110%	309.0	150.0	102.6	45.9	1.5	110.0	110.0	110.0	110.0	0.0
1290	18 Deflectors+SW	Spill to Capacity @ 110% or TDGfb	309.0	150.0	102.6	45.9	1.5	110.0	110.0	110.0	110.0	0.0
1370	18 Deflectors+SW	Spill to Capacity @ 120%	309.0	150.0	50.0	98.5	1.5	110.0	116.1	110.0	116.1	6.1
973	18 Deflectors+SW	No Voluntary Spill	309.0	300.0	298.5	0.0	1.5	110.0	100.1	110.0	110.0	0.0
1053	18 Deflectors+SW	Spill 100 Kcfs	309.0	300.0	198.5	100.0	1.5	110.0	118.2	110.0	114.8	4.8
1133	18 Deflectors+SW	Spill 30%	309.0	300.0	208.5	90.0	1.5	110.0	117.3	110.0	113.8	3.8
1213	18 Deflectors+SW	Spill to Capacity @ 110%	309.0	300.0	259.0	39.5	1.5	110.0	110.0	110.0	110.0	0.0
1293	18 Deflectors+SW	Spill to Capacity @ 110% or TDGfb	309.0	300.0	259.0	39.5	1.5	110.0	110.0	110.0	110.0	0.0
1373	18 Deflectors+SW	Spill to Capacity @ 120%	309.0	300.0	175.5	123.0	1.5	110.0	120.0	110.0	117.2	7.2
976	18 Deflectors+SW	No Voluntary Spill	309.0	441.4	309.0	130.9	1.5	110.0	122.6	110.0	116.5	6.5
1056	18 Deflectors+SW	Spill 100 Kcfs	309.0	441.4	309.0	130.9	1.5	110.0	122.6	110.0	116.5	6.5
1136	18 Deflectors+SW	Spill 30%	309.0	441.4	309.0	130.9	1.5	110.0	122.6	110.0	116.5	6.5
1216	18 Deflectors+SW	Spill to Capacity @ 110%	309.0	441.4	309.0	130.9	1.5	110.0	122.6	110.0	116.5	6.5
1296	18 Deflectors+SW	Spill to Capacity @ 110% or TDGfb	309.0	441.4	309.0	130.9	1.5	110.0	122.6	110.0	116.5	6.5
1376	18 Deflectors+SW	Spill to Capacity @ 120%	309.0	441.4	309.0	130.9	1.5	110.0	122.6	110.0	116.5	6.5

[1] Powerhouse capacity of 309.0 kcfs based on 15 turbines at 102 ft of head, with STS installed, and operated at upper generation limit defined in FPP.

Table C5. Summary of Total Dissolved Gas Exchange at John Day Dam for Columbia River flow of 100-441 kcfs, Forebay TDG level of 110% for existing structural configuration and spill capacity at 110% at tailwater fixed monitoring station.

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 (%)
1209	18 Deflectors+SW	Spill to Capacity @ 110%	309.0	100.0	50.0	48.5	1.5	110.0	110.0	110.0	110.0	0.0
1210	18 Deflectors+SW	Spill to Capacity @ 110%	309.0	150.0	102.6	45.9	1.5	110.0	110.0	110.0	110.0	0.0
1211	18 Deflectors+SW	Spill to Capacity @ 110%	309.0	200.0	154.9	43.6	1.5	110.0	110.0	110.0	110.0	0.0
1212	18 Deflectors+SW	Spill to Capacity @ 110%	309.0	250.0	207.1	41.4	1.5	110.0	110.0	110.0	110.0	0.0
1213	18 Deflectors+SW	Spill to Capacity @ 110%	309.0	300.0	259.0	39.5	1.5	110.0	110.0	110.0	110.0	0.0
1214	18 Deflectors+SW	Spill to Capacity @ 110%	309.0	350.0	309.0	39.5	1.5	110.0	110.4	110.0	110.1	0.1
1215	18 Deflectors+SW	Spill to Capacity @ 110%	309.0	400.0	309.0	89.5	1.5	110.0	118.4	110.0	113.3	3.3
1216	18 Deflectors+SW	Spill to Capacity @ 110%	309.0	441.4	309.0	130.9	1.5	110.0	122.6	110.0	116.5	6.5

[1] Powerhouse capacity of 309.0 kcfs based on 15 turbines at 102 ft of head, with STS installed, and operated at upper generation limit defined in FPP.

Table C6. Summary of Total Dissolved Gas Exchange at John Day Dam for Columbia River flow of 100-441 kcfs, Typical Forebay TDG levels for existing structural configuration, Full Powerhouse Capacity, and spill capacity as limited by 110% or Forebay level as measured at tailwater fixed monitoring station.

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 (%)
1321	18 Deflectors+SW	Spill to Capacity @ 110% or TDGfb	329.6	100.0	50.0	48.5	1.5	105.0	110.0	105.0	109.2	4.2
1322	18 Deflectors+SW	Spill to Capacity @ 110% or TDGfb	329.6	150.0	102.6	45.9	1.5	105.0	110.0	105.0	107.7	2.7
1323	18 Deflectors+SW	Spill to Capacity @ 110% or TDGfb	329.6	200.0	154.9	43.6	1.5	105.0	110.0	105.0	106.9	1.9
1332	18 Deflectors+SW	Spill to Capacity @ 110% or TDGfb	329.6	250.0	207.1	41.4	1.5	110.0	110.0	110.0	110.0	0.0
1333	18 Deflectors+SW	Spill to Capacity @ 110% or TDGfb	329.6	300.0	259.0	39.5	1.5	110.0	110.0	110.0	110.0	0.0
1342	18 Deflectors+SW	Spill to Capacity @ 110% or TDGfb	329.6	350.0	281.8	66.7	1.5	115.0	115.0	115.0	115.0	0.0
1343	18 Deflectors+SW	Spill to Capacity @ 110% or TDGfb	329.6	400.0	329.6	68.9	1.5	115.0	115.8	115.0	115.3	0.3
1352	18 Deflectors+SW	Spill to Capacity @ 110% or TDGfb	329.6	441.4	329.6	110.3	1.5	120.0	121.0	120.0	120.4	0.4

[1] Powerhouse capacity of 329.6 kcfs based on 16 turbines at 102 ft of head, with STS installed, and operated at upper generation limit defined in FPP.

Table C7. Summary of Total Dissolved Gas Exchange at John Day Dam for Columbia River flow of 100-441 kcfs, Forebay TDG level of 110% for existing structural configuration and spill capacity at 120% at tailwater fixed monitoring station.

Case	Structural Alternative	Spill Operation	$Q_{ph\text{-}max}$ (kcfs)	Q_{total} (kcfs)	Q_{gen} (kcfs)	Q_{spill} (kcfs)	Q_{aux} (kcfs)	TDG_{fb} (%)	TDG_{sp} (%)	TDG_{aux} (%)	TDG_{avg} (%)	ΔTDG (%)
1409	18 Deflectors+SW	Spill to Capacity @ 120%	309[1]	100.0	50.0	48.5	1.5	110.0	111.1	110.0	110.9	0.9
1410	18 Deflectors+SW	Spill to Capacity @ 120%	309	150.0	50.0	98.5	1.5	110.0	116.1	110.0	116.1	6.1
1411	18 Deflectors+SW	Spill to Capacity @ 120%	309	200.0	50.0	148.5	1.5	110.0	119.9	110.0	119.8	9.8
1412	18 Deflectors+SW	Spill to Capacity @ 120%	309	250.0	113.5	135.0	1.5	110.0	120.0	110.0	119.4	9.4
1413	18 Deflectors+SW	Spill to Capacity @ 120%	309	300.0	175.5	123.0	1.5	110.0	120.0	110.0	117.2	7.2
1414	18 Deflectors+SW	Spill to Capacity @ 120%	309	350.0	235.3	113.2	1.5	110.0	120.0	110.0	115.7	5.7
1415	18 Deflectors+SW	Spill to Capacity @ 120%	309	400.0	293.4	105.1	1.5	110.0	120.0	110.0	114.6	4.6
1416	18 Deflectors+SW	Spill to Capacity @ 120%	309	441.4	329.6	110.3	1.5	110.0	121.0	110.0	114.8	4.8

[1] Powerhouse capacity based on 15 turbines at 102 ft of head, with standard length STS installed, and operated at upper generation limit defined in FPP.

Table C8. Columbia River Flow at John Day 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	330	330	0	na	115.0	10.10%	1.00%
2	Q_{sp}@110%	366	330	36	110	114.5	5.10%	0.30%
3	Q_{sp}@115%	394	330	64	115	115.0	3.10%	0.00%
4	Q_{sp}@120%	431	330	101	120	116.3	1.40%	0.00%
5	7Q10-mean	441	330	110	121.1	116.7	1.20%	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 Columbia River below Dam.
Case 1= Total river flow is at powerhouse hydraulic capacity with no voluntary spill
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.

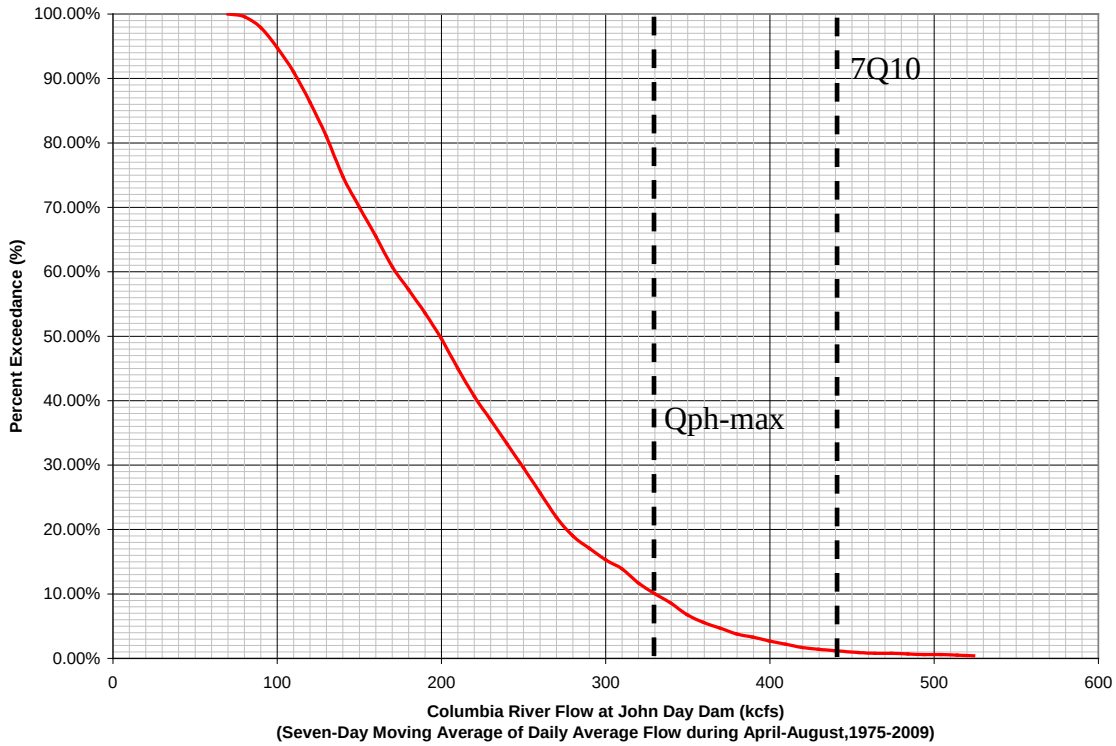

Figure C1. Percent Exceedance versus Columbia River Flow at John Day Dam during April-August 1975-2009.

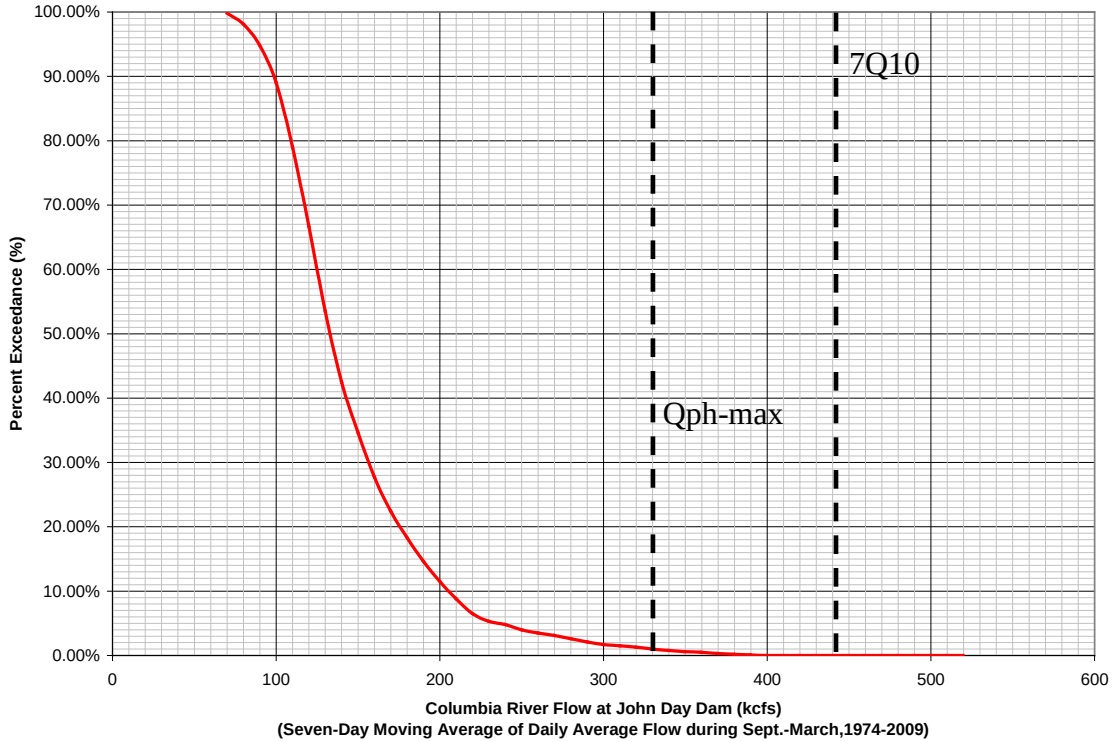

Figure C2. Percent Exceedance versus Columbia River Flow at John Day Dam during Sept.-March, 1974-2009.

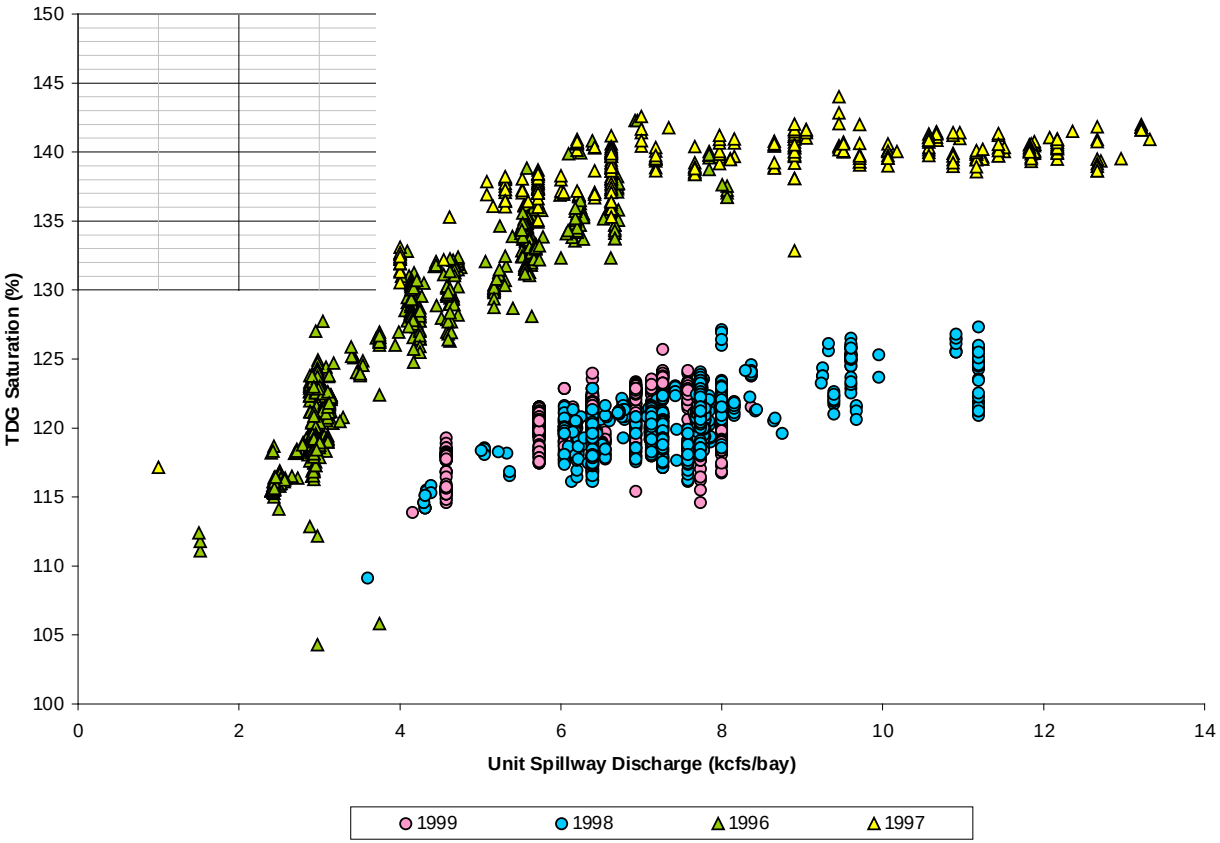

Figure C3 Total Dissolved Gas Saturation at the Tailwater Fixed Monitoring Station (JHAW) as a Function of Unit Spillway Discharge with and without Spillway Flow Deflectors (note: 1996-1997 without deflectors, 1998-1999 with deflectors on bays 2-19)

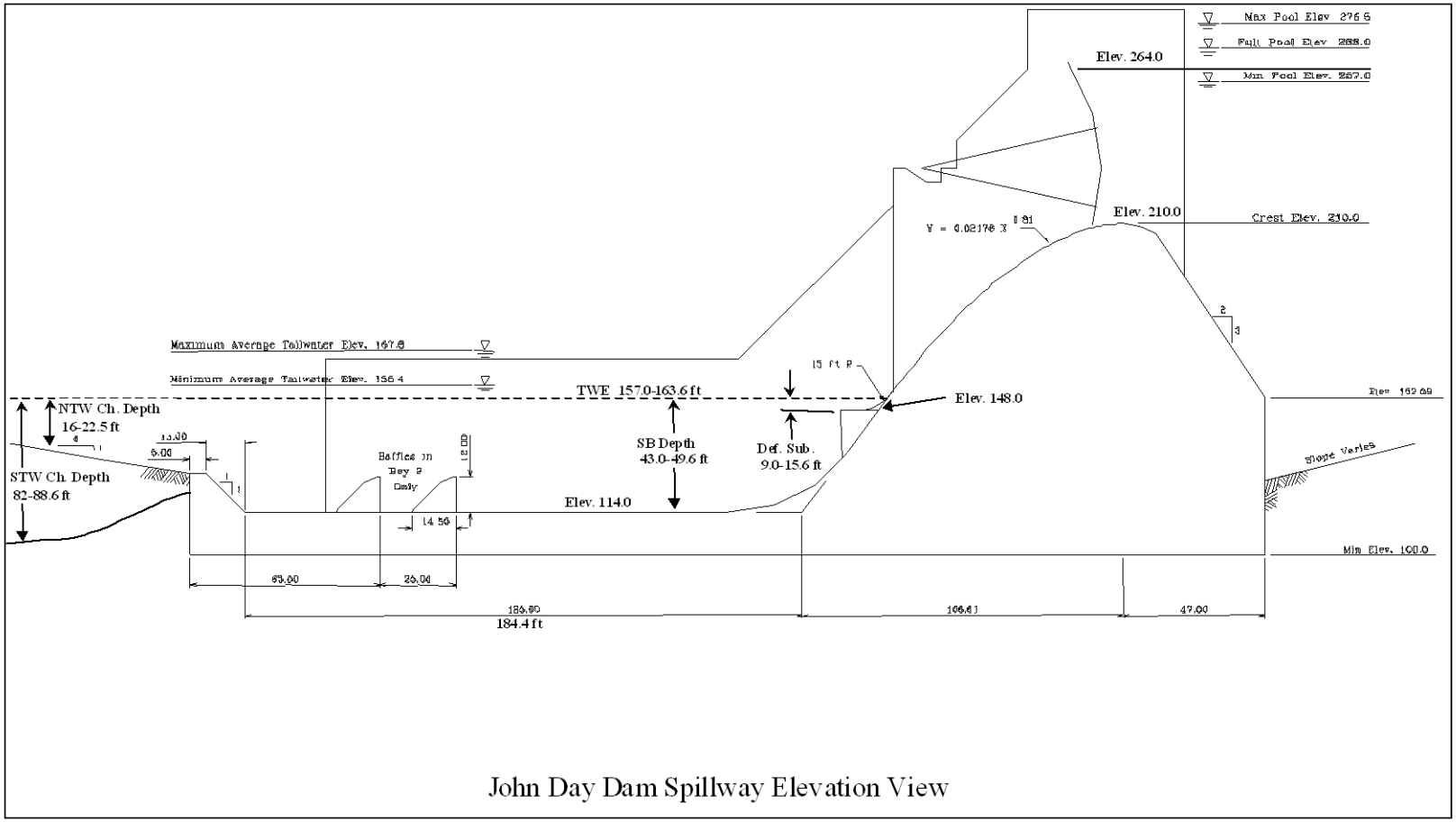

Figure C4 John Day Dam Type II spillway flow deflectors on bays 2-19.

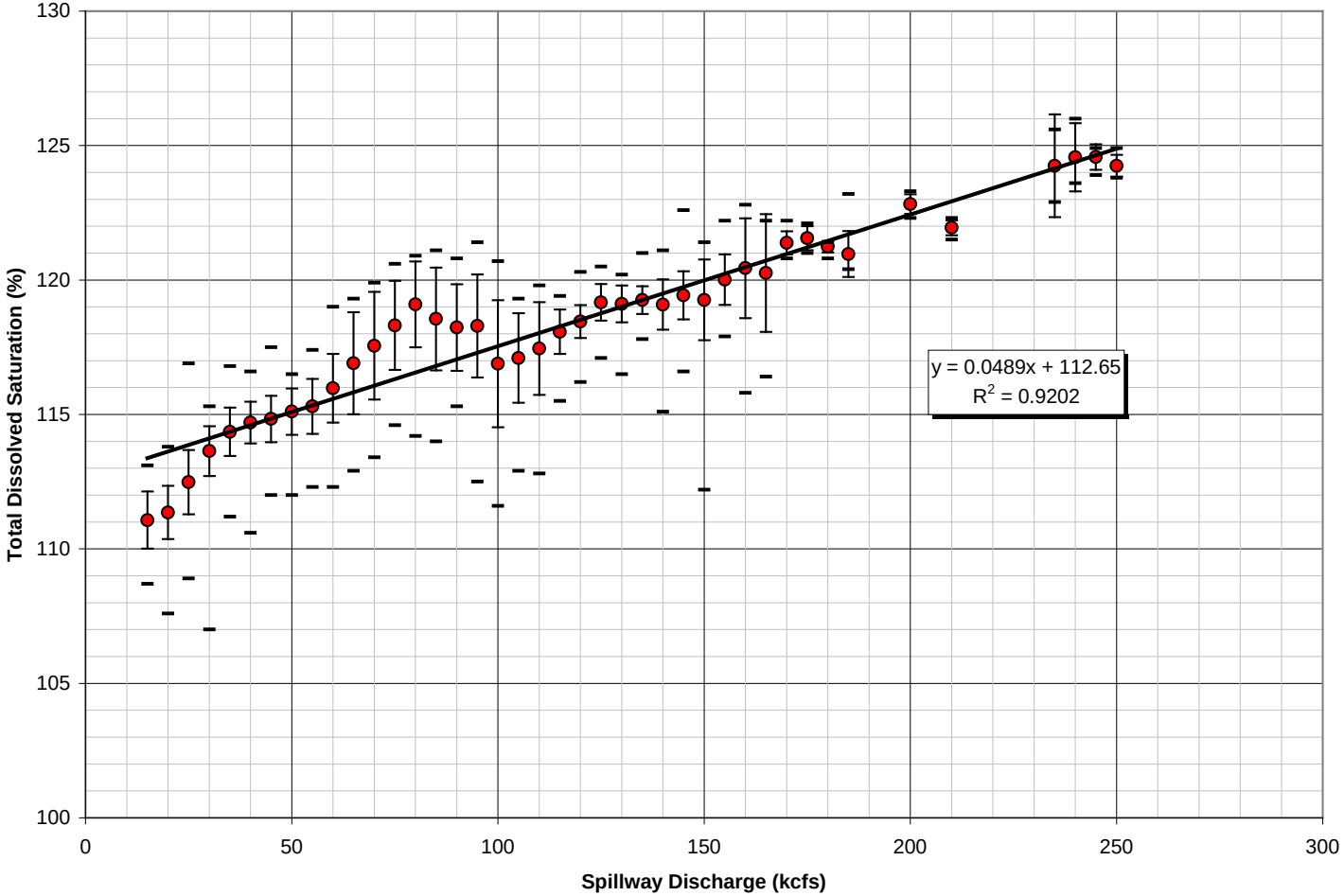

Figure C5 Total Dissolved Gas Saturation at the Tailwater Fixed Monitoring Station at John Day Dam (JHAW) as a function of Spillway Discharge, 2002-2009

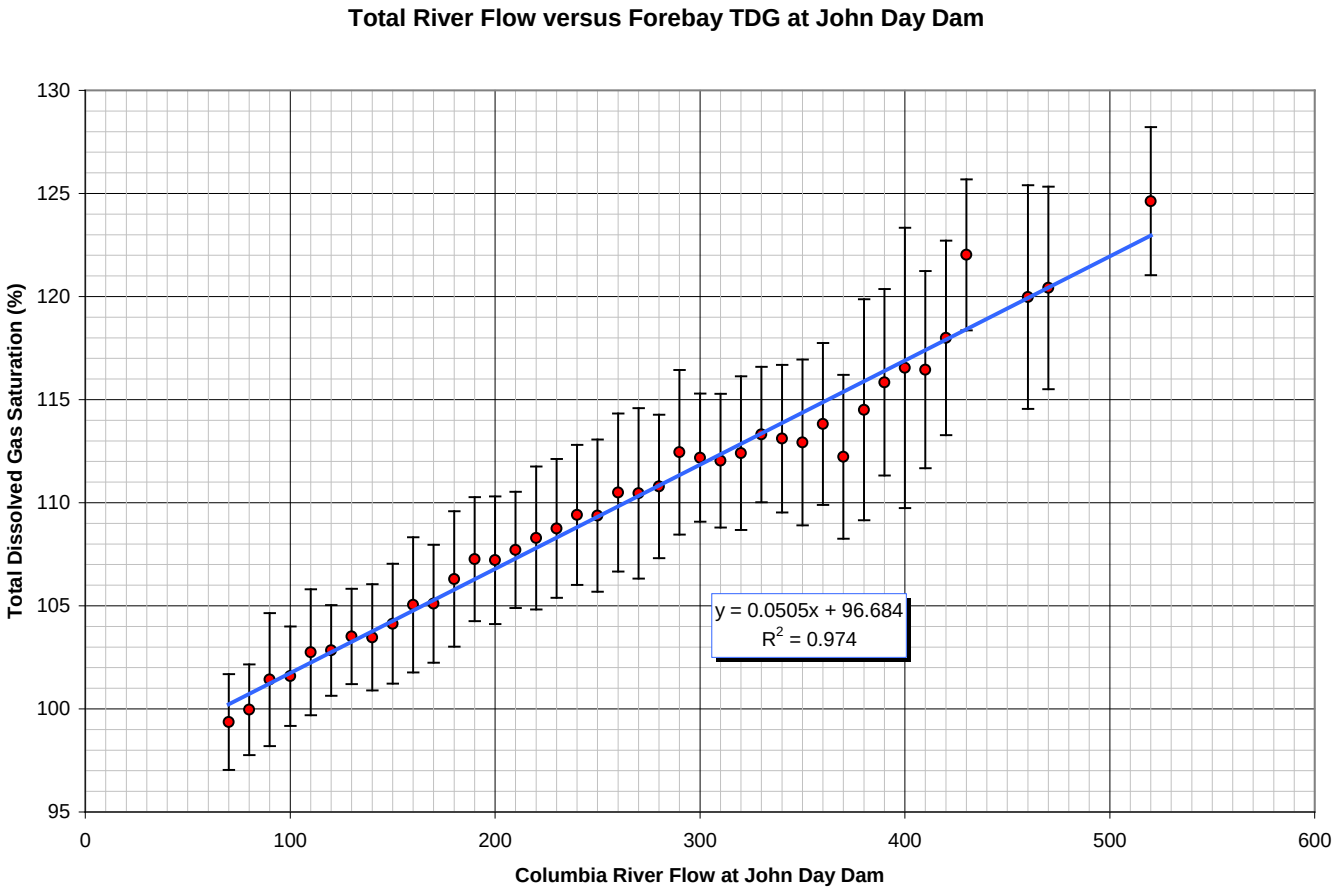

Figure C6 Dissolved Gas Saturation in the Forebay of John Day Dam as a function of Total Columbia River Flow, 1995-2009

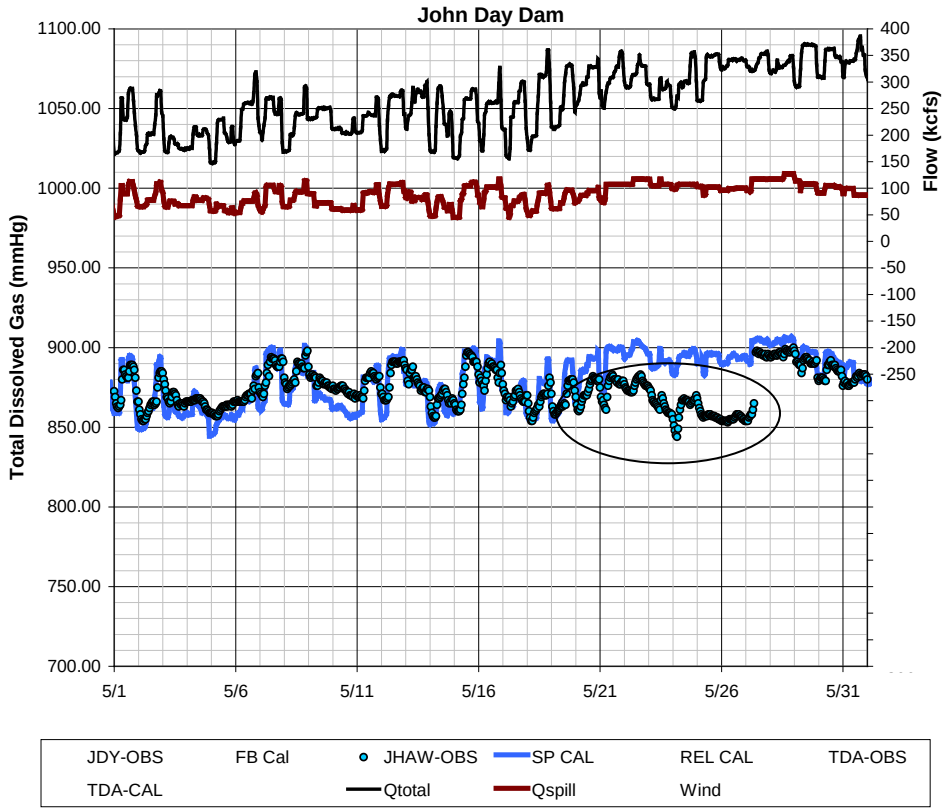

Figure C7 Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, May 2009 (Observed Data in oval are erroneous)

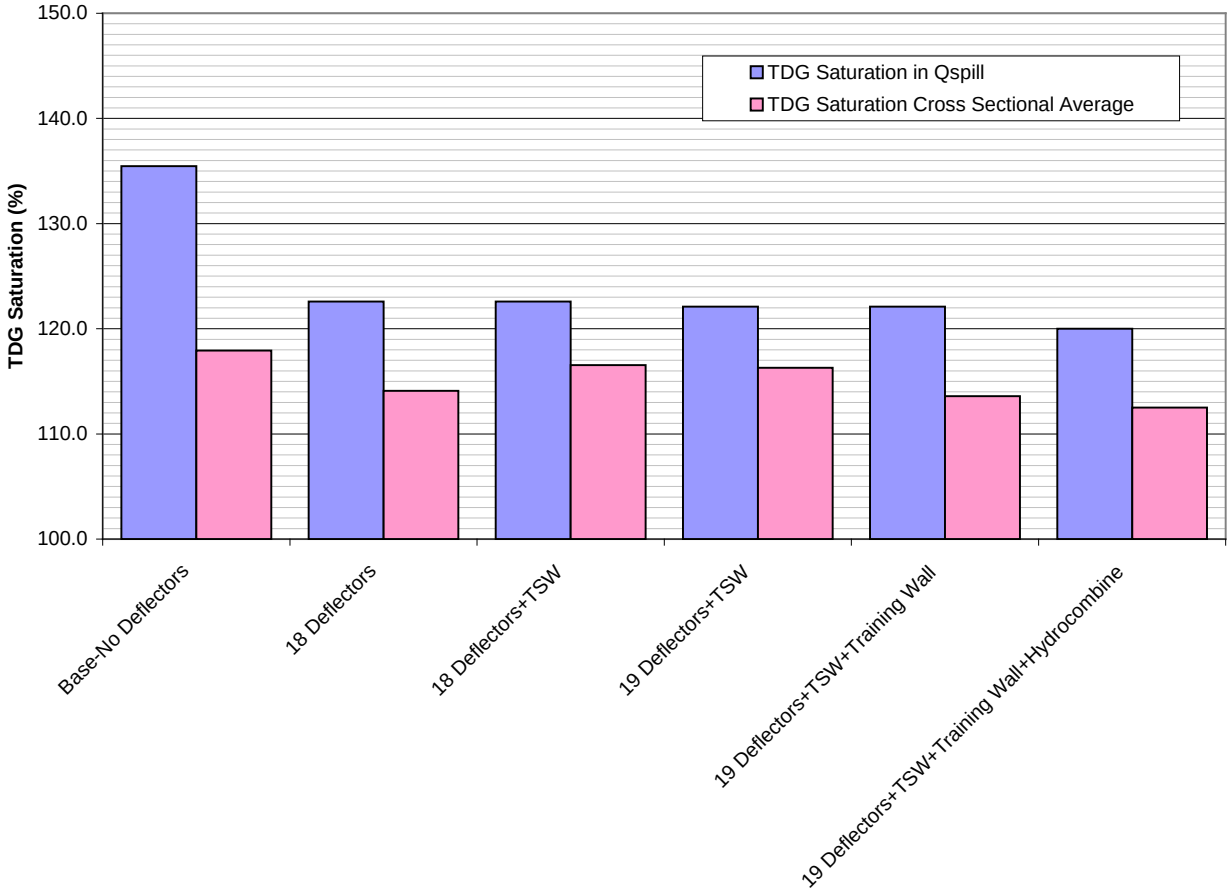

Figure C8 Estimated Total Dissolved Gas Saturation in the Columbia River below John Day Dam for Structural Alternatives during a Total River Flow of 441.4 Kcfs, Background TDG Saturation of 110%, and Powerhouse Capacity 309 kcfs.