Appendix B

Total Dissolved Gas Abatement Plan For The Dalles Dam

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Introduction

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

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

Project Description

The Dalles is located on the Columbia River about 47 river miles upstream of Bonneville at river mile 192.5 and 23 miles downstream of John Day River. The main structures include a powerhouse, concrete spillway and stilling basin, navigation lock, fish facilities, concrete non-overflow sections, and an earth-fill non-overflow embankment east of the powerhouse. The dam is roughly 8,735 feet in length at the crest, including the embankment. The powerhouse includes 22 generator units with a maximum total discharge capacity of approximately 350 kcfs. It also includes two fishway units for supplying flow to the adult fish collection channels and two station service units. The powerhouse is oriented 270 degrees from the spillway and is parallel to the south channel bank. The Dalles spillway is 1,467 feet long with twenty-three 50-foot-wide spillway bays each separated by 10-foot-wide piers. Large tainter gates control flow through each of the spillway bays. These gates are 50 feet wide by 42.5 feet high and supported by the spillway piers. The spillway crest elevation is 121.0 fmsl with a design capacity of 2,290,000 cfs at the maximum pool elevation of 182.3 fmsl. At normal

full pool (elevation 160.0 fmsl), the spillway will pass the project standard flood of 1,050 kcfs.

Powerhouse Hydraulic Capacity

The Dalles powerhouse unit hydraulic capacity during the fish passage season was estimated assuming a total head of 77 ft, and each unit is operated at the upper limit of the peak efficiency constraint as described in the yearly Fish Passage Plan (FPP, 2007). The unit hydraulic capacity for these conditions was estimated to equal 12.356 kcfs for unit 1-14, 13.91 kcfs for units 15-22. The total hydraulic capacity of The Dalles powerhouse with all 22 units available is 284.3 kcfs. If only 21 units are available the hydraulic capacity of The Dalles powerhouse was estimated as 271.9 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. Additional flow provided to the adult fish ladder system is provided through two fish turbines located at the west end of the powerhouse and from a turbine operated by the Wasco County Public Utility District.

Summary of Columbia River Flow at The Dalles Dam

The daily average total river flow, generation flow, and spillway flow was compiled for The Dalles 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 5 months; and Non-Fish Passage Season January 1-March 31 and September 1-December 31 for a total of 7 months. A tabular summary of the seven day moving average flows within and outside of the fish passage season from October 1974 to October 2009 are listed in Table B1.

The percent exceedance characteristics for the seven-day moving average of daily average flows for the Columbia River at The Dalles Dam during the fish passage season from 1975-2009 are shown in B1. The median river flow during this period is about 194 kcfs. The frequency that the Columbia River flow will exceed 300 kcfs is 13.5 percent and 400 kcfs is only 2 percent.

Outside the fish passage season from 1974-2009, the percent exceedance characteristics for the seven-day moving average of daily average flows for the Columbia River at The Dalles Dam are shown in Figure B2. The median river flow during this period is about135 kcfs. The frequency that the Columbia River flow will exceed 200 kcfs is 11.9 percent and 300 kcfs is 1.8 percent. The frequency of spill outside of the fish passage

season is small as indicated by only a 2.4 percent frequency of flow exceeding the maximum powerhouse capacity.

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 Columbia River at The Dalles Dam at 461 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 The Dalles Dam was estimated to equal 448.3 kcfs with a 80 percent confidence limit ranging from 410.7 to 507.4 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 448.3 kcfs was exceeded in only 1 of the past 35 in 1997 where the 7Q10 flow of 556 kcfs was recorded. This observation may indicate flow conditions in 1997 unduly influences the determination of the 7Q10 estimate.

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 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 Columbia 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 at lower spill volume will also lower the TDG pressures in the receiving waters. Alternatively, a reduction in the injury rate of juvenile passing through the powerhouse may reduce the reliance on spill for fish guidance resulting in an enhancement in TDG conditions.

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

is also to transport highly aerated flow conditions well downstream of the stilling basin into the tailrace channel, promoting the exchange of atmospheric gasses at shallow depths. The effectiveness of spillway flow deflectors in abating TDG production has been consistently demonstrated at Corps of Engineers projects on the Columbia and Snake rivers. The Dalles Dam remains the only project operated by the Corps of Engineers on the Columbia River where spillway flow deflectors have not been added. The shallow stilling basin and adjoining tailrace channel below The Dalles spillway moderate TDG exchange and create hydraulic conditions that are quite different than experienced at other Corps projects.

The hydraulic conditions and channel topography at The Dalles Dam also have a direct impact on the monitoring program for TDG. The forebay TDG fixed monitoring station is located on the Oregon side of the powerhouse at the face of the dam. The station is located in an active flow environment and has not experienced any significant bias caused by surface warming. The tailwater station is located about 3 miles downstream of the spillway on the Oregon shore in mixed waters influenced by both spillway and powerhouse flows. Attempts to establish a tailwater TDG monitoring station on the shelf below the spillway have proven to be unsuccessful. The TDG samples taken from shore based stations below the spillway have underestimated TDG levels in spillway flows. The unreliability of TDG samples taken from shore based sampling stations below the spillway were likely related to the shallow sampling environment, high velocities, and proximity to highly aerated flow conditions.

The location of the tailwater fixed monitoring station in well mixed waters below The Dalles Dam has a direct impact on factors contributing to compliance with water quality standards for TDG. The operational decisions involving the percentage of water spilled at The Dalles Dam will be a prominent component in shaping the average TDG levels observed at the tailwater fixed monitoring station. The residual levels of TDG saturation generated from upstream sources observed in the forebay of The Dalles Dam will be an important influence on cross sectional average TDG levels observed below the dam. The third component influencing TDG conditions at the tailwater fixed monitoring station involve the TDG content generated during aerated spillway flows**.**

Structural Alternatives

The installation of spillway flow deflectors was investigated for The Dalles Dam in a scale physical model of the spillway and stilling basin. The findings from this study stated that a well behaved skimming flow regime could not be reliably established at The Dalles Spillway. The effectiveness of spillway flow deflectors for abating TDG exchange at The Dalles was assessed to be highly uncertain. The shallow stilling basin and adjoining tailwater channel at The Dalles Dam are effective means of moderating the TDG exchange during spillway releases. The average elevation of the tailwater channel is 68 ft resulting in typical depths of flow of only 11 ft.

A total of three different structural alternatives were considered in this evaluation of TDG exchange at The Dalles Dam. The “base” condition consisted of the spillway and stilling basin as built. The second structural configuration “base with 6-7 Spill wall” was

completed prior to the 2004 spill season. This structure was primarily designed to aid in the guidance of juveniles past the dam. This structure was estimated to have a small influence on TDG exchange by eliminating a return current for spill from the first six spill bays. The third structural alternative considered was the "base with 8-9 spill wall" that is completed and will be operational for the 2010 fish passage season. TDG exchange effects will be measured in a performance test this spill season.

Spill Operation Alternatives

This study also considered the influence of six different spill operations that govern the operations of The Dalles 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 the instantaneous voluntary "spill to 40 percent of river flow". The second spill operation required the instantaneous spill to "60 percent of river flow". The third operation assumed a "constant spill of 40 kcfs" subject to powerhouse minimum hydraulic capacity constraint of 50 kcfs. The fourth spill operation called for spilling up to the capacity as limited by the 120 percent total dissolved gas saturation criterion ("spill to capacity at 120 %") at the tailwater fixed monitoring station (FMS). 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 at 110% or TDG_{fb}"). The final spill operation called for "no voluntary spill" excluding the discharge through the powerhouse surface bypass system. The operation of the surface bypass system was assumed to be active for each of the spill operations described above.

TDG Properties

The TDG exchange properties at The Dalles Dam are influenced by the shallow stilling basin and tailrace channel. The shallow tailwater conditions moderate the exchange of gasses into the water column in spillway flows. The tailwater elevation can be influenced by the river stage maintained in the forebay of Bonneville Dam and is directly related to the total river flow in the Columbia River at The Dalles Dam. Increasing the river level in the Bonneville forebay will directly cause an increase in the TDG production in spillway flows at The Dalles Dam. By the same token, increasing the powerhouse discharge and total project discharge from The Dalles Dam will also increase the TDG content in spillway flows as a consequence of the higher tailwater stage. The TDG exchange at The Dalles Dam has been found to be highly correlated with the depth of flow below the spillway and weakly correlated to the spill pattern and magnitude.

As noted earlier, the tailwater fixed monitoring station at The Dalles Dam is located 3 miles downstream on the left bank in mixed waters and is influenced by the TDG content of both powerhouse and spillway discharges. Typically, the ambient forebay TDG levels are well below the TDG pressures generated during spill and tend to moderate the TDG levels in the Columbia River as observed at the tailwater water quality monitor. The

TDG saturation in spillway flow generally ranges from 120 to 130 percent of saturation. The occurrences of TDG levels exceeding 120 percent at the tailwater fixed monitoring station have been rare during voluntary spill conditions at The Dalles Dam.

The relationship between TDG saturation and project operating conditions were investigated in spillway discharge during several field studies conducted in 1999 and 2002. These investigations included the direct measurement of TDG pressures in spillway releases prior to mixing with powerhouse flows. These studies concluded that TDG generation during spillway flows at The Dalles Dam were moderated by the shallow depth of flow below the stilling basin. The TDG saturation in spillway flow generally ranged from 120-130 percent of saturation which was significantly less than comparable levels observed at John Day and Ice Harbor Dam of over 140 percent saturation prior to the installation of spillway flow deflectors.

The TDG saturation observed in the Columbia River at the tailwater fixed monitoring station below The Dalles Dam was summarized from 1998 to 2007 as shown in Figure B3. The linear relationship between spillway discharge and TDG saturation is indicated from this data with an intercept of 120 percent of saturation of the mean response at a spill discharge of 235 kcfs. The spillway capacity as limited by the 120 percent tailwater TDG criteria is influenced by the TDG content in both powerhouse and spillway flows and can be highly variable as a result.

The estimates of TDG exchange in the Columbia River at The Dalles Dam were based on applying a set of empirical equations that describe the TDG exchange as a function of the effective depth of flow. A detailed TDG exchange study was conducted during 1996 (Schneider and Wilhelms, 1996) and 2000 (Schneider, 2000) fish passage seasons at The Dalles Dam. The TDG data collected during the 2000 fish passage season for juvenile spill up to 250 kcfs and tailwater elevations ranging from 77.3 ft to 84.7 ft indicate that TDG pressures in spill are a linear function of the tailwater stage or depth of flow below the spillway as shown in Equation 1. The correlation coefficient for the linear regression equation for the delta total dissolved gas pressure as a function of tailwater elevation was 0.85 and the standard error was 4.8 mm Hg.

Equation 1

$$\Delta P = 8.401\, TWE - 484.8 \qquad (mm\, Hg) \qquad (1)$$

r^2=0.85
Standard Error = 4.8 mm Hg

Where

ΔP = Total Dissolved Gas Pressure minus Local Atmospheric Pressure (mm Hg)
TWE = Tailwater elevation ft
$TDG_{sat} = (\Delta P + P_{atm})/P_{atm} * 100$ Total Dissolve Gas Saturation (%)
P_{atm} = Local Atmospheric Pressure (mm Hg)

A spillway training wall was added in 2004 between spill bays 6 and 7 and the spill pattern was changed to a bulk pattern concentrated in spill bays 1-6. A near-field TDG exchange study was conducted at The Dalles Dam to quantify the TDG exchange associated with the new structural and operation conditions. The equations for TDG production were updated for the existing spillway with training wall as presented in Equation 2. The TDG exchange was found to be a linear function of tailwater elevation and was based on spill discharges up to 108 kcfs and a tailwater stage range from 75 to 81.3 ft.

Equation 2

$$\Delta P = 4.87\,TWE - 207.51 \qquad (mm\,Hg) \qquad (2)$$

r^2=.81
Std Error = 3.1 mm Hg

Where

TWE = Tailwater elevation (ft)
$TDG_{sat} = (P_{atm}+\Delta P)/P_{atm} \times 100$ Total Dissolved Gas Saturation (%)
P_{atm} = Local Atmospheric Pressure (mm Hg)

An increase in the tailwater stage of one foot will result in an increase in TDG pressure of 4.9 mm Hg. The influence of the spill pattern and magnitude was highly correlated with the tailwater elevation since the spill operation called for spilling a fixed percentage of the instantaneous total river flow. An increase in the spillway discharge was always accompanied by an increase in total river flow and tailwater elevation. The correlation coefficient of .81 for the production equation was considerable less than found at other projects. However, the standard error of estimate of this relationship at The Dalles Dam of only 3.1 mm Hg was significantly smaller than found at other projects.

The average flow weighted TDG saturation below The Dalles Dam was determined for each combination of structural and operational alternative.
A simple mass conservation statement was 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

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

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 Columbia River (percent)

TDG_{sp} = TDG saturation of spillway discharges (percent)

The return of diverted flow associated with the powerhouse surface bypass alternatives has the potential to generate elevated TDG pressures in the Columbia 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 IT chute at The Dalles Dam discharges into a shallow basin and is directed at an angle to releases from the powerhouse. For this study a constant TDG saturation of 131.6 percent was applied for all surface bypass flows. This TDG estimate reflects an effective TDG loading that accounts for the interaction of aerated surface bypass discharges with powerhouse flows.

The TDG exchange formulation for The Dalles Dam presented in Equations 2-3 was applied to conditions during the 2008 spill season during the month of May. The hourly project operations for spill and total river flow along with the observed and calculated TDG saturation at The Dalles Dam are presented in Figure B4. The dark blue line (SP-calc) represents estimates of the TDG content ranging from 122 to 128 percent in spillway flows undiluted from powerhouse flows. The light blue line (Rel-calc) represents estimates of the cross sectional average TDG saturation which is highly correlated with observed conditions shown by the blue circles (TDDO-obs). The operations experienced during May of 2008 generally fell outside of the conditions used to develop Equation 2. The generally good agreement between the observed and calculated conditions during this period supports the application Equation 2 outside the range of conditions upon which Equation 2 was developed (extrapolation of TDG exchange).

A comprehensive evaluation of TDG exchange at The Dalles Dam must consider the influence of elevated background TDG levels from upstream sources as an integral component of TDG pressures observed at the tailwater fixed monitoring station. The presence of elevated background TDG levels at The Dalles 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. Figure B5 shows the forebay TDG levels at The Dalles Dam are

summarized from 1995-2007 as a function of total river flow. The observed daily average TDG saturation in the forebay of The Dalles Dam was summarized for 5 kcfs ranges in total river flow from 70 to 495 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 The Dalles Dam and total river flow. This figure shows that when river flows are approaching the 7Q10 level of 461 kcfs, the background TDG saturation typically ranges from 114 to 118 percent of saturation.

Results

A series of estimates of TDG exchange were generated for a matrix of conditions impacting TDG exchange in the Columbia River at The Dalles 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 The Dalles Dam. The type of summary also provides 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 tdaTDGest.xls summarizing the effects of 3 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 contained in this table are summarized in Table B2. This table consists of 1845 different cases that provide a comprehensive summary of the TDG management program at The Dalles 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 of a small subset of the scenarios contained in this analysis, highlight the TDG exchange and management status at The Dalles Dam for past, current, and future conditions.

Structural Configuration

The TDG exchange across the three structural configurations investigated at The Dalles Dam for a spill operation of spilling 40 percent of total river flow during total river flows of 200, 300, and 461 kcfs was examined as shown in Tables B3. The total river flow of 200 kcfs reflects a near median flow condition during the fish passage season. The 300 kcfs is a 14 percent exceedance flow and falls into a category of flow in excess of the powerhouse capacity but below the TDG compliance thresholds at the tailwater station. The river flow of 461 kcfs represents the 7Q10 high Columbia River discharge that can be expected to occur once every ten years on average. For evaluation purposes, the

background TDG levels were assumed to be 110 percent of saturation which would be unusual during the high flow conditions. A full powerhouse capacity of 284.3 kcfs was assumed for these conditions.

All three structural cases resulted in the same operating conditions for all three river flows. In each case, The Dalles Dam was able to spill 40 percent of the total river flow without being constrained by the 120 percent TDG constraint at the tailwater fixed monitoring station. These outcomes were closely related to the influence of powerhouse flows containing TDG levels of 110 percent of saturation. These forebay TDG levels become less likely for high river flows when upstream sources of TDG supersaturation increase in response to higher involuntary spill operations. The TDG levels in spillway flow were similar for all three structural alternatives at a total river flow of 200 kcfs as shown in Table B3 for cases 57, 597, and 1137. The TDG saturation was estimated to range from 123.8 to 124.4 percent in spillway releases and the cross sectional average TDG saturation was found to range only from 116.1 to 116.4 percent.

It should be noted that the primary function of the spillway training wall was to support juvenile fish egress through the tailwater exit channel and not for the abatement of TDG generation. The impacts on TDG exchange were however factored into the design and operation. The influence of spill operation on TDG exchange will be evaluated in the next section.

The involuntary spill conditions during a total river flow of 300 kcfs remained well below 120 percent at the tailwater fixed monitoring station. The TDG exchange properties of the three structural alternatives were similar with the TDG saturation in spill ranging from 125.6 to 127.5 percent and the cross sectional average TDG saturation ranging from 116.7 to 117.4 percent.

The involuntary spill conditions during a total river flow of 461 kcfs also remained below 120 percent at the tailwater fixed monitoring station. The TDG exchange properties of the base condition without a training wall resulted in slightly higher TDG conditions in spill and mixed river conditions as shown in Table B3. The TDG saturation associated with the 8-9 training wall was slightly higher than with the 6-7 training wall because of the slightly deeper flow conditions generated in the tailwater channel. If forebay TDG levels are closer to historic levels for river flows approaching the 7Q10 discharge of 115 percent as shown in Figure B5, the cross sectional average TDG conditions would also increase and exceed 120 percent for these conditions. The 7Q10 discharge is a rare occurrence and updated estimates of the 7Q10 flow suggest that a flow of 461 kcfs is more infrequent than one every ten years.

Spill Operation

The influence of spill operation on TDG exchange was explored for the existing 2008 structural configuration of base condition with a 6-7 training wall for three river flow conditions 200, 300, and 461 kcfs. The maximum powerhouse capacity and forebay TDG level of 110 percent was also held constant for this evaluation as listed in Table B4. The degree of spill afforded by the various spill operations ranged from 0 kcfs during the

no voluntary spill operation to 136 kcfs for the spill to 120 percent capacity operation. The smaller the spill discharge, the smaller the change in the average TDG saturation in the Columbia River. The spill capacity limited by 110 percent forebay TDG saturation does not allow any spill because this would elevate TDG levels above this constraint. The powerhouse surface bypass discharge was estimated to increase average TDG levels by only 0.6 percent saturation above forebay conditions. The TDG saturation in spill for a similar total river flow for all non-zero spill operations were estimated to be the same because these events all had the same tailwater stage and depth of flow. The average cross sectional TDG saturation ranged from 113.4 for the constant 40 kcfs spill to 120 percent for the capacity spill of 136 kcfs. The highest spill event possible as constrained by TDG criteria for a total river flow of 200 kcfs will result in the TDG saturation increasing from 110 percent in the forebay to 120 percent in the tailwater (average cross sectional properties).

The average TDG levels increase in the Columbia River below The Dalles Dam during the 300 kcfs total river flow with the exception of the capacity spill at the 120 percent criteria. The higher TDG conditions are caused by slightly higher TDG levels in spill of 125.6 percent. The Dalles Dam is involuntary to spill a small amount (9.7 kcfs) during a 300 kcfs total river flow resulting in the elevation of average TDG levels by less than 1 percent saturation (cases 779 and 824). A spill as high as 183.5 kcfs is possible without exceeding the tailwater TDG criteria of 120 percent during a 300 kcfs river flow. A spill of 40 percent of total river flow will cause an increase in average TDG saturation in the Columbia River from 110 percent to 116.7 percent. The high degassing rates in the Bonneville pool will likely yield TDG levels in the Bonneville forebay well below the 115 percent criteria for these conditions.

The range in spillway discharge diminishes for the different spill operations for higher river flows approaching the 7Q10 discharge of 461 kcfs because of the amount of involuntary spill. The range in spillway discharge from 170.7 to 239.7 kcfs is still considerable because the tailwater TDG criterion is not a limiting constraint for most of these operations. The minimum TDG impact spill operations during a 7Q10 river flow calls for spilling 170.7 kcfs causing average TDG levels to increase from 110 percent in the forebay to 117.2 percent in the tailwater. The maximum amount of spill allowed during these conditions without exceeding the 120 percent criteria is 239.7 kcfs. The 60 percent spill operation was constrained by the tailwater TDG criteria and thereby limited to 239.7 kcfs (case 648). The 40 percent spill operation calling for a spill of 184.4 kcfs will result in an increase in average TDG levels from 110 percent in the forebay to 117.8 percent in the tailwater. The higher forebay TDG levels that have accompanied higher flood flows historically will result in the 120 percent tailwater criteria dictating spillway flow rates for the 40 percent spill operation alternative.

Total River Flow

The total river flow has a surprising moderate impact on the TDG exchange at The Dalles Dam with a structural configuration of base conditions with 6-7 spillway wall subject to a spill operation of spilling 40 percent of the total river flow. The estimates of TDG

exchange for different total river flows of 100, 150, 200, 250, 300, 350, 400, 450, and 461 kcfs for a constant forebay TDG level of 110 percent and a constant spill of 40 percent of total river flow is shown in Table B5. The average TDG saturation in the Columbia River ranged from 121.9 to 128.7 percent in spillway flows exclusively and from 116.0 to 117.8 percent for average river conditions. Spilling a fixed percentage of the river moderates differences in average cross sectional TDG levels in the Columbia River as a function of total river flow. The TDG levels in spill remain above 120 percent for all river flows while the cross sectional average TDG levels remain well below the tailwater criteria of 120 percent.

Forebay TDG Levels

Forebay TDG conditions are important in shaping the average TDG conditions below the dam when spill is a small component of total river flow. Spill operations that are based on percent spill allow sufficient powerhouse flows to dilute spillway releases as listed in Table B6. The 40 percent spill operation is not constrained by the tailwater TDG criteria for forebay TDG levels as high as 115 percent. When forebay TDG levels reach 120 percent the tailwater TDG levels will equal or exceed 120 percent for any project operation. The operating conditions shown in Table B6 are based on minimizing the increase in TDG saturation at The Dalles Dam by minimizing spill discharge when forebay TDG levels are 120 percent and higher. These operations don't reflect the biological benefits of spilling water for these river conditions. The forebay TDG levels begin to constrain the 40 percent spill operation at The Dalles Dam when they exceed 115 percent for prolonged time periods. It may be necessary to reduce spill at upstream projects to meet spill objectives at TDA Dam when TDG constraints are exceeded downstream.

The combination of high forebay TDG levels with some spillway flows can result in a net degassing of the Columbia River where TDG levels in spillway flows are less than forebay conditions. The occurrence of 130 percent in the forebay (not listed in Table B6) at The Dalles Dam during a total river flow of 300 kcfs will result in a net reduction in the TDG loading of the Columbia River.

The Dalles 2009 configuration TDG and Flow Summary

The TDG saturation in Columbia River below The Dalles 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. Cases 2-5 correspond with river flows of 300, 350, 400, and 448 kcfs. The final case 5 involved worst case conditions of the updated mean 7Q10 flow of 448 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 The Dalles Dam from 1974-2009 are also listed in Table B7.

The frequency for spilling water above the maximum powerhouse capacity during the fish passage season is slightly above 16 percent of the time at John Day Dam but only 2.4 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 spillway operation yielding a TDG saturation of 110 percent or 115 percent in spillway flows has not been observed at The Dalles Dam because of the standard spillway design. The tailwater fixed monitoring station at The Dalles is located downstream at a location where powerhouse and spillway flows are well mixed. For river flows of 350 kcfs, a spillway release of 59.7 kcfs will generate TDG levels of 126.6 percent saturation in spillway flows raising the TDG level to 117.3 percent at the tailwater fixed monitoring station. The worst case conditions will be associated with the 7Q10 flows and a spill discharge of 254.4 kcfs resulting in TDG saturation in spillway flows of 128.4 percent and result in an average TDG saturation of 120.0 percent. When forebay levels are limited to 115 percent or less, The Dalles TDG generation will be limited to 120 percent or less at the tailwater fixed monitoring station for flows up to the 7Q10 river flow at maximum powerhouse capacity.

Conclusions

The shallow spilling basin and adjoining tailwater channel at The Dalles Dam result in moderate levels of TDG exchange during spillway releases. The shallow flow conditions below the spillway result in a highly aerated flow regime that limits the ability to directly monitor the TDG content in these discharges from a shore based station. The tailwater fixed monitoring station located 3 miles below the dam accurately measures the TDG content in the Columbia River and provides the basis for spill management decisions as limited by Oregon and Washington water quality standards. The TDG content in both powerhouse and spillway flows contribute to the TDG levels observed at the tailwater fixed monitoring station. Therefore, the powerhouse TDG loading at The Dalles Dam generated by upstream sources of TDG supersaturation, provides considerable influence over the TDG response at the tailwater fixed monitoring station.

The Dalles Dam is the only project operated by the Corps of Engineers without spillway flow deflectors on the Columbia River. The potential TDG abatement benefits of spillway flow deflectors were investigated in scale physical models. The shallow tailwater flow conditions limited the effectiveness of spillway flow deflectors in generating a surface jet responsible for minimizing the TDG uptake.

The construction of a spillway training wall between spill bays 6 and 7 was completed during the winter of 2004. This structure was designed to improve juvenile egress during spillway flows. The impacts of this structure on TDG exchange were minimal for comparable flow conditions.

The spill wall between bays 8 and 9 has been constructed and will be operational for the 2010 fish passage season. This structure is estimated to have a small impact on TDG exchange during spillway operations. However, the improvements in fish guidance that result in higher survival rates may provide for less reliance on spill to meet fish passage goals in the future and a corresponding TDG abatement benefit during voluntary spillway operations.

The TDG levels at the tailwater fixed monitoring station generally remains within the TDG criteria of 120 percent during voluntary and involuntary spill conditions as high as the 7Q10 flow provided forebay TDG levels do not exceed 115 percent of saturation. The 40 percent spill operation is not impacted by tailwater TDG criteria when forebay levels fall below 115 percent.

The TDG levels at the tailwater fixed monitoring station are sensitive to TDG conditions in the forebay at The Dalles Dam. The location of the tailwater fixed monitoring station at a location where powerhouse and spillway flows are well mixed is unique to The Dalles Dam. When forebay TDG levels rise above 115 percent the TDG levels at the tailwater fixed monitoring station can exceed 120 percent. However, these excursions above the criteria are caused in part by contributions from upstream sources of TDG supersaturation.

The TDG levels below The Dalles Dam are sensitive to the spill operation. The spill operation at The Dalles Dam has tended toward a smaller reliance on spill to meet fish passage objectives. The commitment to spill over 60 percent of the river prior to the 2000 fish passage season resulted in TDG levels well above the TDG conditions experienced by the current 40 percent spill operation.

The influence of total river flow on TDG exchange at The Dalles Dam is small because of the relationship between TDG exchange and tailwater depth of flow and the influence of powerhouse releases on tailwater TDG levels. The average TDG saturation in the Columbia River experiences an increase of less than 2 percent saturation over a flow range of 100 to 461 kcfs when forebay levels are held constant and a 40 percent spill operation of applied.

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Table B1

Percent of time the seven-day moving average of daily average flows exceed the reference Columbia River Flow at The Dalles Dam, 1975-2007 water years

Columbia River Flow (kcfs)	Fish Passage Season April-Aug (%)	Non-Fish Passage Season Sept.-March (%)	Comments
100	94.80%	90.20%	
150	69.10%	34.70%	
200	47.60%	11.10%	
250	27.60%	3.80%	
271.9	19.20%	2.80%	Powerhouse capacity 21 units
284.3	16.60%	2.30%	Powerhouse capacity 22 units
300	13.90%	1.60%	
350	5.40%	0.50%	
400	1.90%	0.00%	
448	0.80%	0.00%	Updated 7Q10 flow rate
450	0.80%	0.00%	

Table B2
Configuration Matrix
For TDG Estimates in the Columbia River at The Dalles Dam

Structural Alternative	Spill Operation	Qph-Max (kcfs)	Qtotal (kcfs)	TDGfb (%)
Base	No Voluntary Spill	284.3	150	105
Base with 6-7 Training Wall	Spill to Capacity @ 110% Or TDG_{fb}	271.9	200	110
Base with 8-9 Training Wall	Constant Spill of 40 Kcfs		250	115
	Spill to 40 % of River		300	120
	Spill to 60 % of River		350	125
	Spill to Capacity @ 120%		400	
			448	
			450	

Table B3

Summary of Total Dissolved Gas Exchange at The Dalles Dam for Columbia River flow of 200, 300, and 448 kcfs, Forebay TDG level of 110% by Structural alternative and spill operation of a spilling 40 percent of total river flow

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_{spill} (%)	TDG_{aux} (%)	TDG_{avg} (%)	ΔTDG (%)
57	Base	Spill to 40% of River Flow	284.3	200	114.0	80.0	6.0	110	124.2	131.6	116.3	6.3
59	Base	Spill to 40% of River Flow	284.3	300	174.0	120.0	6.0	110	127.5	131.6	117.4	7.4
63	Base	Spill to 40% of River Flow	284.3	448	262.8	179.2	6.0	110	132.3	131.6	119.2	9.2
597	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	200	114.0	80.0	6.0	110	123.8	131.6	116.1	6.1
599	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	300	174.0	120.0	6.0	110	125.6	131.6	116.7	6.7
603	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	448	262.8	179.2	6.0	110	128.4	131.6	117.7	7.7
1137	Base-with 8/9 Training Wall	Spill to 40% of River Flow	284.3	200	114.0	80.0	6.0	110	124.4	131.6	116.4	6.4
1139	Base-with 8/9 Training Wall	Spill to 40% of River Flow	284.3	300	174.0	120.0	6.0	110	126.6	131.6	117.1	7.1
1143	Base-with 8/9 Training Wall	Spill to 40% of River Flow	284.3	448	262.8	179.2	6.0	110	130.0	131.6	118.3	8.3

[1] Powerhouse capacity of 284.3 kcfs based on 76 ft of head, operated at upper generation limit defined in FPP.

Case - Case number as listed in The Dalles Dam master TDG management plan.

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

$\mathbf{Q_{total}}$ = Columbia River Flow at The Dalles Dam (kcfs)

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

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

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

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

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

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

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

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

Table B4

Summary of Total Dissolved Gas Exchange at The Dalles Dam for Columbia River flow of 200, 300, and 448 kcfs, Forebay TDG level of 110% for the Base case with 7-8 Training Wall under various spill operations

Case	Structural Alternative	Spill Operation	$Q_{ph\text{-}max}$ (kcfs)[1]	Q_{total} (kcfs)	Q_{gen} (kcfs)	Q_{spill} (kcfs)	Q_{aux} (kcfs)	TDG_{fb} (%)	TDG_{spill} (%)	TDG_{aux} (%)	TDG_{avg} (%)	ΔTDG (%)
552	Base-with 6/7 Training Wall	Spill to Capacity @ 120%	284.3	200	58.0	136.0	6.0	110	123.8	131.6	120.0	10.0
597	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	200	114.0	80.0	6.0	110	123.8	131.6	116.1	6.1
642	Base-with 6/7 Training Wall	Spill to 60% of River Flow	284.3	200	74.0	120.0	6.0	110	123.8	131.6	118.9	8.9
687	Base-with 6/7 Training Wall	Constant Spill 40 kcfs	284.3	200	154.0	40.0	6.0	110	123.8	131.6	113.4	3.4
777	Base-with 6/7 Training Wall	Spill to Capacity @ 110% or TDGfb	284.3	200	194.0	0.0	6.0	110	110.0	131.6	110.6	0.6
822	Base-with 6/7 Training Wall	No Voluntary Spill	284.3	200	194.0	0.0	6.0	110	110.0	131.6	110.6	0.6
554	Base-with 6/7 Training Wall	Spill to Capacity @ 120%	284.3	300	110.5	183.5	6.0	110	125.6	131.6	120.0	10.0
599	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	300	174.0	120.0	6.0	110	125.6	131.6	116.7	6.7
644	Base-with 6/7 Training Wall	Spill to 60% of River Flow	284.3	300	114.0	180.0	6.0	110	125.6	131.6	119.8	9.8
689	Base-with 6/7 Training Wall	Constant Spill 40 kcfs	284.3	300	254.0	40.0	6.0	110	125.6	131.6	112.5	2.5
779	Base-with 6/7 Training Wall	Spill to Capacity @ 110% or TDGfb	284.3	300	284.3	9.7	6.0	110	125.6	131.6	110.9	0.9
824	Base-with 6/7 Training Wall	No Voluntary Spill	284.3	300	284.3	9.7	6.0	110	125.6	131.6	110.9	0.9
558	Base-with 6/7 Training Wall	Spill to Capacity @ 120%	284.3	448	206.1	235.9	6.0	110	128.4	131.6	120.0	10.0
603	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	448	262.8	179.2	6.0	110	128.4	131.6	117.7	7.7
648	Base-with 6/7 Training Wall	Spill to 60% of River Flow	284.3	448	206.1	235.9	6.0	110	128.4	131.6	120.0	10.0
693	Base-with 6/7 Training Wall	Constant Spill 40 kcfs	284.3	448	284.3	157.7	6.0	110	128.4	131.6	116.8	6.8

783	Base-with 6/7 Training Wall	Spill to Capacity @ 110% or TDGfb	284.3	448	284.3	157.7	6.0	110	128.4	131.6	116.8	6.8
828	Base-with 6/7 Training Wall	No Voluntary Spill	284.3	448	284.3	157.7	6.0	110	128.4	131.6	116.8	6.8

[1] Powerhouse capacity of 284.3 kcfs based on 76 ft of head, operated at upper generation limit defined in FPP.

Case - Case number as listed in The Dalles Dam master TDG management plan.

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

$\mathbf{Q_{total}}$ = Columbia River Flow at The Dalles Dam (kcfs)

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

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

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

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

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

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

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

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

Table B5

Summary of Total Dissolved Gas Exchange at The Dalles Dam for Columbia River flows ranging from 100 to 448 kcfs, Forebay TDG level of 110% for the Base condition with 6-7 Training Wall and spill operation of a spilling 40 % total river flow

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 (%)
595	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	100	54.0	40.0	6.0	110	121.9	131.6	116.0	6.0
596	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	150	84.0	60.0	6.0	110	122.8	131.6	116.0	6.0
597	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	200	114.0	80.0	6.0	110	123.8	131.6	116.1	6.1
598	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	250	144.0	100.0	6.0	110	124.7	131.6	116.4	6.4
599	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	300	174.0	120.0	6.0	110	125.6	131.6	116.7	6.7
600	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	350	204.0	140.0	6.0	110	126.6	131.6	117.0	7.0
601	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	400	234.0	160.0	6.0	110	127.5	131.6	117.3	7.3
602	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	448	262.8	179.2	6.0	110	128.4	131.6	117.7	7.7
603	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	450	264.0	180.0	6.0	110	128.5	131.6	117.7	7.7

[1] Powerhouse capacity of 284.3 kcfs based on 76 ft of head, operated at upper generation limit defined in FPP.

Case - Case number as listed in The Dalles Dam master TDG management plan.

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

$\mathbf{Q_{total}}$ = Columbia River Flow at The Dalles Dam (kcfs)

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

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

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

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

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

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

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

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

Table B6

Summary of Total Dissolved Gas Exchange at The Dalles Dam for Columbia River flow of 300 kcfs, Forebay TDG levels ranging from 105 to 125% for the Base Condition with 6-7 Training Wall Structural alternative and various spill operations

Case	Structural Alternative	Spill Operation	$Q_{ph\text{-}max}$ (kcfs)[1]	Q_{total} (kcfs)	Q_{gen} (kcfs)	Q_{spill} (kcfs)	Q_{aux} (kcfs)	TDG_{fb} (%)	TDG_{sp} (%)	TDG_{aux} (%)	TDG_{avg} (%)	ΔTDG (%)
590	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	300	174.0	120.0	6.0	105	125.6	131.6	113.8	8.8
599	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	300	174.0	120.0	6.0	110	125.6	131.6	116.7	6.7
608	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	300	174.0	120.0	6.0	115	125.6	131.6	119.6	4.6
617	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	300	284.3	9.7	6.0	120	125.6	131.6	120.4	0.4
626	Base-with 6/7 Training Wall	Spill to 40% of River Flow	284.3	300	284.3	9.7	6.0	125	125.6	131.6	125.2	0.2

[1] Powerhouse capacity of 284.3 kcfs based on 76 ft of head, operated at upper generation limit defined in FPP.

Case - Case number as listed in The Dalles Dam master TDG management plan.

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

$\mathbf{Q_{total}}$ = Columbia River Flow at The Dalles Dam (kcfs)

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

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

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

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

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

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

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

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

Table B7
Columbia River Flow at The Dalles 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	284.3	284.3	0	Na	115.0	16.20%	2.40%
2	Q_{river}=300	300	284.3	9.7	125.6	115.7	13.50%	1.80%
3	Q_{river}=350	350	284.3	59.7	126.6	117.3	5.20%	0.50%
4	Q_{river}=400	400	284.3	109.7	127.5	118.7	2.00%	0.00%
5	7Q10-mean	448	284.3	254.4	128.4	120.0	0.80%	0.00%

+ Total powerhouse flow with all turbines operation at upper 1% of best gate.
# Total dissolved saturation in spillway flows undiluted by powerhouse flows.
* Average flow weighted total dissolved gas saturation in the Columbia River below The Dalles Dam.
Case 1= Total river flow is at powerhouse hydraulic capacity with no voluntary spill operation
Case 2= Total river flow of 300 kcfs.
Case 3= Total river flow of 350 kcfs
Case 4= Total river flow of 400 kcfs
Case 5= Total river flow at 7Q10 flow rate.

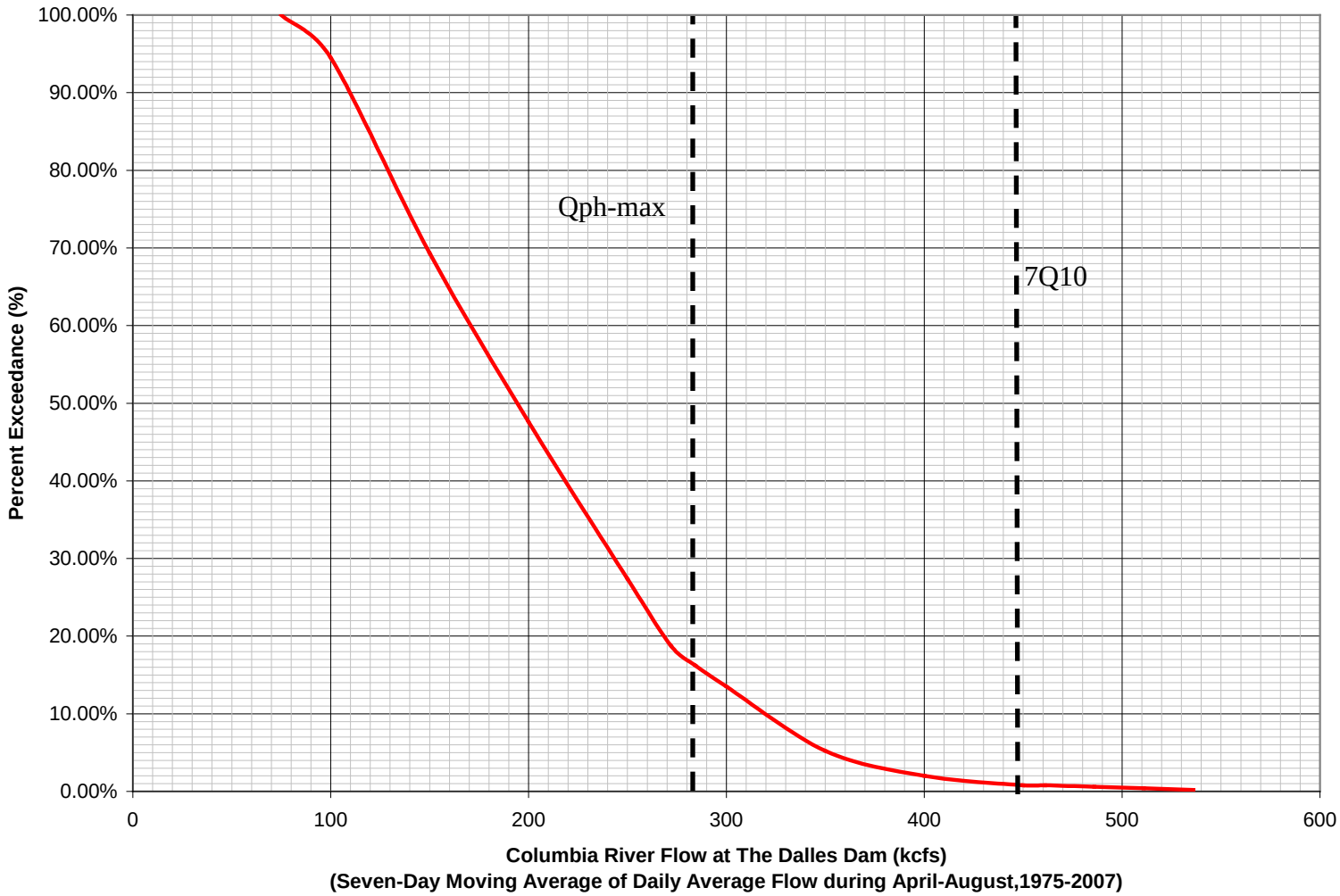

Figure B1. Percent Exceedance versus Columbia River Flow at The Dalles Dam during April-August 1975-2007.

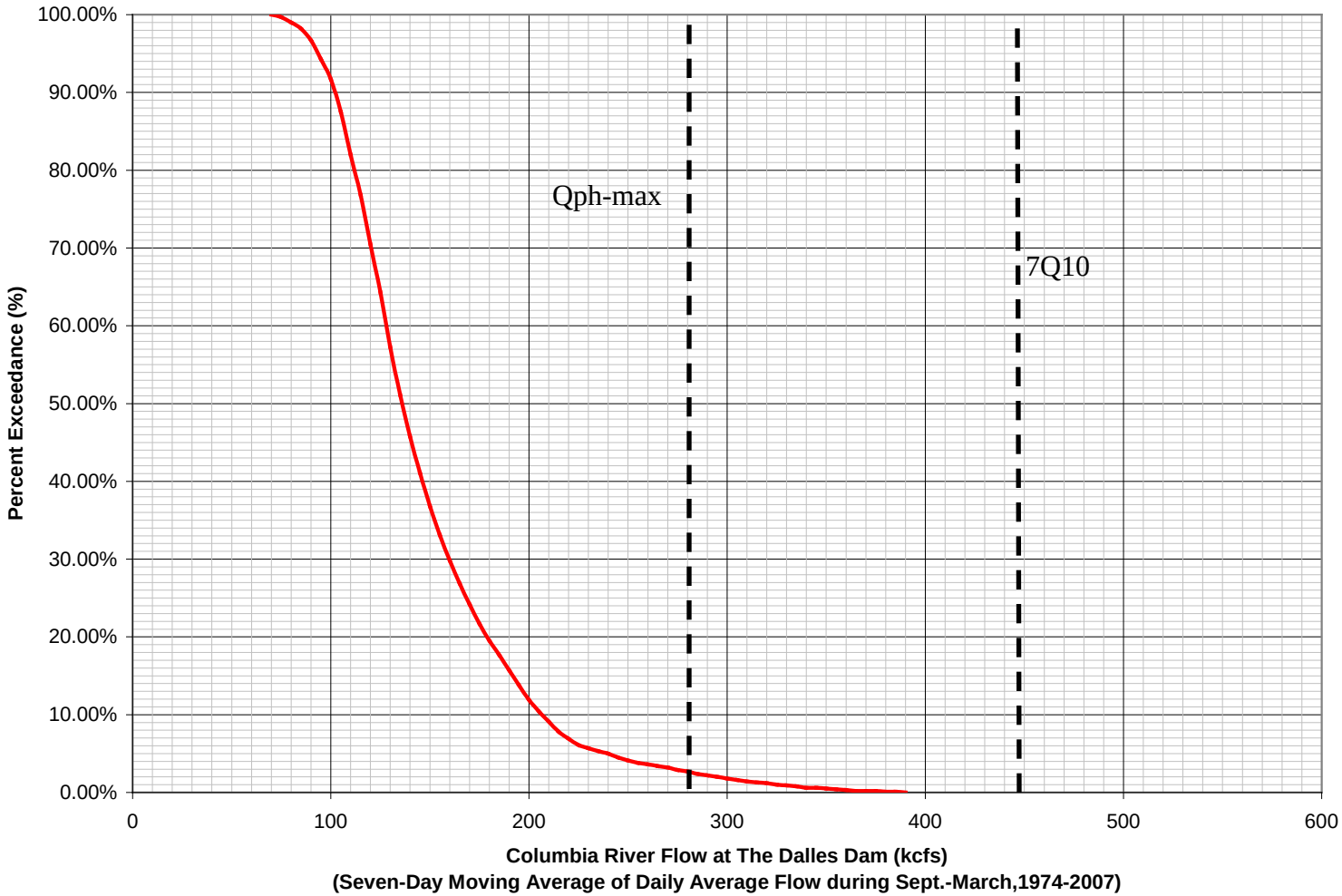

Figure B2. Percent Exceedance versus Columbia River Flow at The Dalles Dam during Sept.-March, 1974-2007.

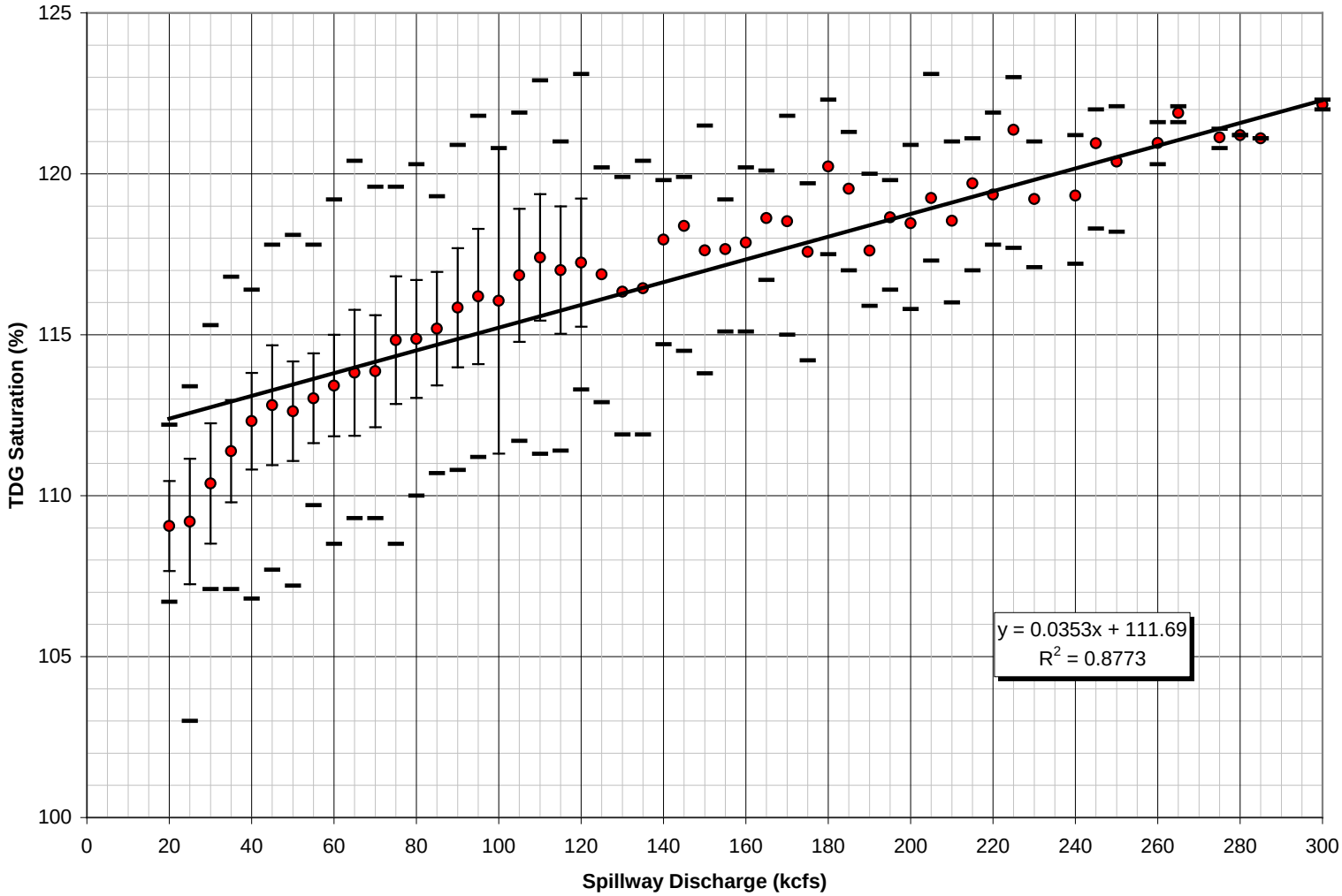

Figure B3. Total Dissolved Gas Saturation at the Tailwater Fixed Monitoring Station at The Dalles Dam as a function of Spillway Discharge, 1998-2007

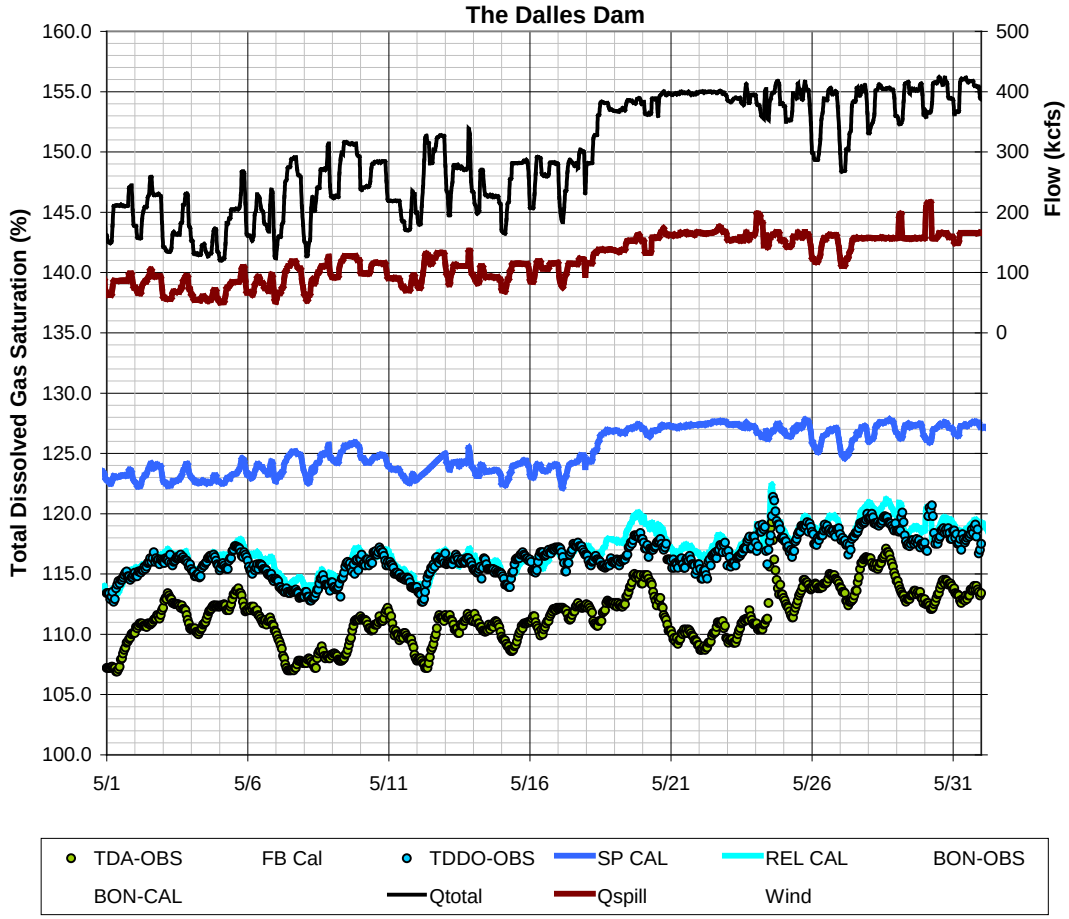

Figure B4 Observed and Calculated Total Dissolved Gas Saturation as a Function of Operations at The Dalles Dam, May 2008.
(Rel-Cal = Calculated cross sectional average TDG Saturation at tailwater fixed monitoring station, TDDO=Observed TDG saturation at the tailwater fixed monitoring station, SP-Cal =Calculated TDG Saturation in spillway flow only, TDA-Obs=Observed TDG saturation at the forebay fixed monitoring station)

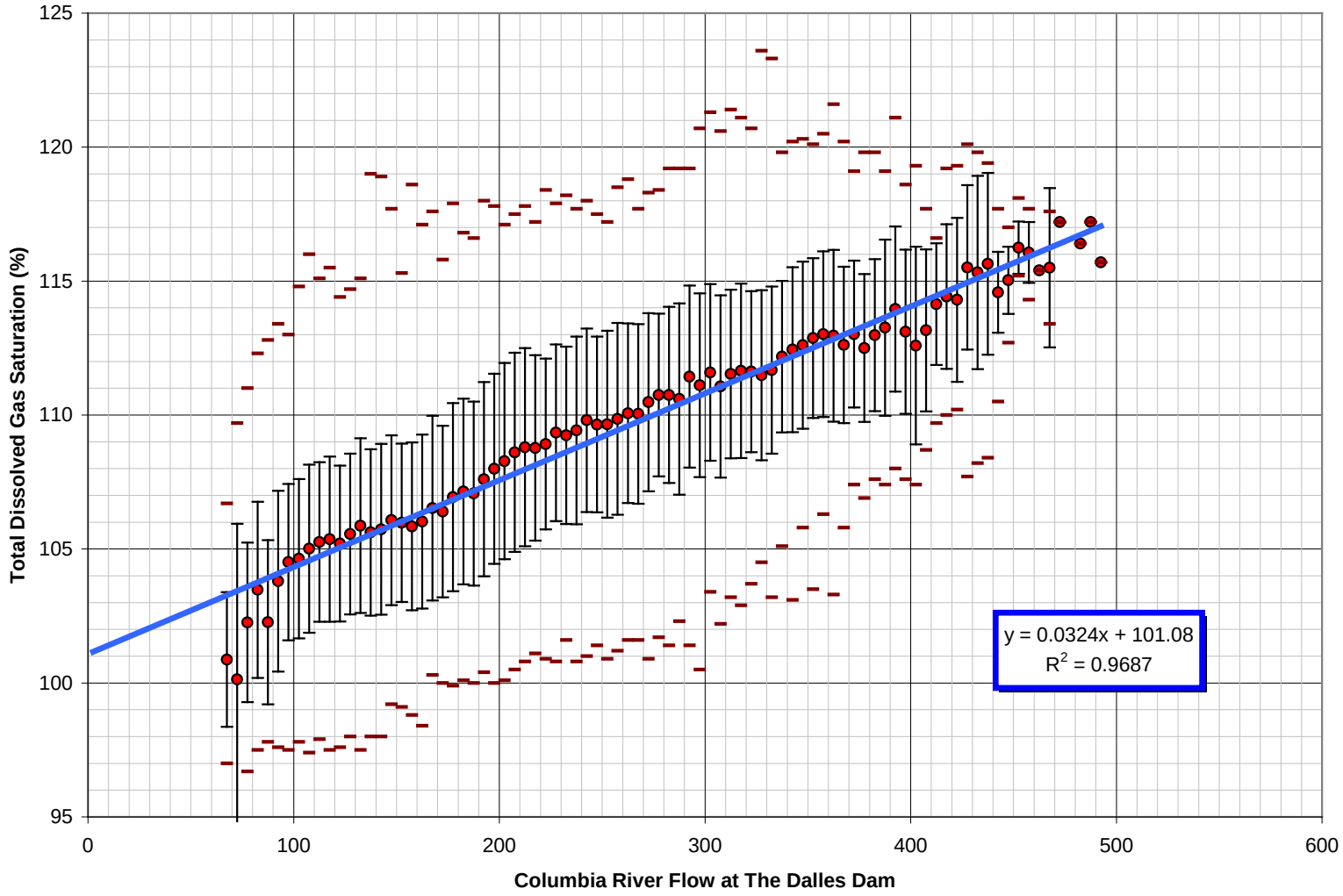

Figure B5. Total Dissolved Gas Saturation in the Forebay of The Dalles Dam as a function of Total Columbia River Flow, 1995-2007