Appendix D

Total Dissolved Gas Abatement Plan For McNary 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 McNary Dam as requested by the State of Washington for their criteria adjustment.

Project Description

McNary is located on the Columbia River near river mile 292. The main structures include the powerhouse, concrete spillway and stilling basin, navigation lock, adult and juvenile fish passage facilities, concrete non-overflow sections with rock-fill embankments on the north and south shores. The dam is 7,365 feet long including the embankments. The McNary powerhouse includes 14 generator units and has a maximum discharge capacity of approximately 215 kcfs with a rated capacity of 966 megawatts. The hydraulic capacity of the McNary powerhouse is comparable to many of the powerhouses on the mid-Columbia River but is considerably smaller than the three projects located downstream on the lower Columbia River. The McNary spillway is 1,310 feet long with 22 spillway bays, each separated by 10-foot-wide piers. The spillway crest elevation is 291.0 fmsl. Discharges are controlled by two-piece, 50-by-51.8-foot, fixed-wheel vertical lift gates. The split leaf design allows flow to pass under either the upper or lower panel. The design capacity of the spillway is 2,200 kcfs at reservoir pool elevation 356.5 fmsl and 1,368 kcfs (standard project flood) at the normal full pool elevation of 340 fmsl.

Summary of Columbia River Flow at McNary Dam

The daily average total river flow, generation flow, and spillway flow was compiled for McNary 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 McNary Dam during the fish passage season from 1975-2009are shown in Figure D1. The median river flow during this period is about 198 kcfs. The frequency that the Columbia River flow will exceed 300 kcfs is 14.2 percent and 400 kcfs is only 1.7 percent.

The percent exceedance characteristics for the seven-day moving average of daily average flows for the Columbia River at McNary Dam outside the fish passage season from 1974-2009 are shown in Figure D2. The median river flow during this period is about 129 kcfs. The frequency that the Columbia River flow will exceed 300 kcfs is 1.2 percent and 400 kcfs is 0.0 percent.

The tabular summary of TDG exchange properties at McNary Dam are presented in this report for the following total river flows: 100, 150, 200, 250, 300, 350, 400, 433 kcfs. The frequency of exceeding these flows within and outside of the fish passage season based on historic flows from 1975 to 2009 are listed in Table D1. The seven day moving average flow of the Columbia River exceeds the McNary maximum hydraulic capacity of 172.9 kcfs about 60 percent of the time during the fish passage season. McNary Dam spillway releases during powerhouse capacity releases of 172.9 kcfs will exceed 110% of saturation about 28.6 percent of the time during the fish passage season and 3.5 percent of the time outside of the fish passage season. The estimated spillway discharge of about 75 kcfs assuming a uniform spill pattern over all 22 spill bays will result in a TDG saturation of 110% in the tailwater.

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 McNary Dam at 447 kcfs as described in the Total Maximum Daily Load for Lower Columbia River Total Dissolved Gas (TMDL, 2002). The period of record used in the TMDL analysis was from 1975-2000. The 7Q10 flow was estimated using the extended period of record from 1975-2009 using the methodology described in Bulletin #17B (USGS, 1982). The resultant mean 7Q10 high flow was estimated to equal 433.4 kcfs with a 80 percent confidence limit ranging from 395.5 to 489.7 kcfs. This evaluation did not correct the

skew coefficient of the station record. A review of the historic records show that the 7Q10 flow of 433.4 kcfs was exceeded in just 2 of the past 35 water years during the high flows years of 1996 and 1997.

Water Quality Standards

The current Washington water quality standards allow for operations resulting in TDG levels of up to 120% at tailwater monitoring stations and 115% 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% of saturation during the fish passage season. The Washington water quality outside of the fish passage season is 110% of saturation.

Powerhouse Hydraulic Capacity

The McNary powerhouse unit hydraulic capacity during the fish passage season was estimated assuming the extended-length submersible traveling screens are installed, a total head of 72 ft, and each unit is operated at the upper limit of the peak efficiency constraint as described in the yearly Fish Passage Plan (FPP, 2010). The unit hydraulic capacity for these conditions was estimated to equal 12.35 kcfs/unit. The total hydraulic capacity of the McNary powerhouse with all 14 units available is 172.9 kcfs. If only 13 units are available, the hydraulic capacity of the McNary powerhouse is 160.6 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.

Structural Alternatives

A total of seven different structural alternatives were considered in this evaluation of TDG exchange at McNary Dam. The base condition was defined by the original spillway and stilling basin as configured and operated at the beginning of 1995 with extended length submersible traveling screens installed for each of the 14 turbines. This base condition includes spillway flow deflectors on bays 3-20 with split leaf discharges scheduled on several bays. The second alternative includes the existing spillway conditions with type II spillway flow deflectors on all in bays 1, 2, 21, and 22. The third structural configuration includes the addition of two spillway weirs (SW) located in spill bays 19 and 20 which are currently operational. The fourth and fifth proposed structural alternatives involve the development of the Ice and Trash sluiceway and powerhouse surface bypass channel. The purpose of these structures is to more effectively and efficiently guide juvenile fish past McNary Dam. A proposed spillway training wall about 800 ft in length added between the spillway and powerhouse was the sixth structural alternative considered in this evaluation. The final proposed structural alternative involves the modernization of the McNary Powerhouse where new turbine

runners are added in 12 of the 14 units. The new turbine are estimated to have about a 50% greater hydraulic capacity compared to the existing units.

Spill Operation Alternatives

This study also considers the influence of spill for fish passage and survival that governs the operations of McNary Dam and resultant generation of TDG loadings. The spill operations for the Federal Columbia River Power System is described in the Fish Operations Plan that is devised each year based on the Biological Opinion adaptive management strategy. The first spill operation calls for voluntary spill to be limited by the 120% saturation criterion at the tailwater fixed monitoring station (FMS). Two alternative spill operations based on spillway discharges equal to 40 and 50 percent of the total river flow as limited by the 120% saturation constraint at the tailwater FMS were considered. A spill operation maintaining a constant 100 kcfs discharge was considered in these analyses subject to powerhouse capacity constraints. The spill operation defined by not exceeding 110% at the tailwater FMS when background TDG levels are below 110% and not exceeding the background TDG levels when they are above 110% was considered. This results in voluntary spill operations that do not increase the TDG loading when upstream sources of TDG are present in the forebay at levels above 110% of saturation. The final spill operation followed a no-voluntary spill condition.

TDG Properties

The TDG exchange properties at McNary 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 been modified several times, most recently to accommodate the bulk flow from the spillway weirs located in spill bays 18 and 19. The passage of spill between the split leaf gates was a standard operation for some bays prior to 2000.

The TDG saturation observed at the tailwater fixed monitoring station from 2004 to 2009 as a function of spillway discharge is shown in Figure D3. 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 D3. The linear regression equation between spillway discharge and TDG saturation at McNary Dam is shown Figure D3 with a slope of 0.0414 %/kcfs. This relationship indicates that a 10 kcfs increase in spill will result in a 0.4% increase in TDG saturation. The mean value of the spillway capacity as limited by the 120 percent tailwater TDG criteria is about 190 kcfs. The primary spill pattern used during this period with the spillway weirs in place involved transitioning from a bulk spill pattern to a uniform pattern for spillway discharges greater than 150 kcfs. The bulk spill pattern for spillway flows less than 100 kcfs resulted in increasing TDG pressures observed at the tailwater monitoring station as a function of decreasing spillway discharge.

The estimates for TDG exchange in the Columbia River at McNary 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 the four end bay spillway flow deflectors in 2001 was determined from observations at the tailwater fixed monitoring station during 1996-2000 as shown in Equation 1.

Equation 1

$$\Delta P = (TWE - 217.2)^{1.1} q_s^{0.38} \qquad (1)$$

N = 3721

r^2= 0.95

STD error= 8.3 mm Hg

Where

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

N_{eff} = Effective number of active spill bays 1-22.

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 1-22.

Q_i = Spill discharge in bay i.

Nbays = Active number of spill bays.

c_w = spill pattern weighting coefficient

The TDG generation with spillway flow deflectors in place in all 22 spill bays at McNary Dam, is 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 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

$$\Delta P = 5.02(TWE - 228)(1 - \exp(-0.155 q_s)\ ) \qquad (2)$$

N = 251
r^2= 0.93
Std Error = 8.7 mm Hg

Where

TWE = Columbia River stage at McNary tailwater (ft)

The sensitivity of TDG exchange as a function of a change in the tailwater stage from 268 to 269 ft will result in an increase in TDG pressure of 3.1 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 11.4 mm Hg increase in TDG pressure for a constant tailwater elevation of 268 ft. This equation also illustrates the influence of bulking spill in several bays. A total spillway discharge of 100 kcfs uniformly distributed over 22 spill bays will result in a TDG saturation 113.4% at a tailwater elevation of 268 ft. The same 100 kcfs spilled uniformly over 11 bays will result in a TDG saturation of 120.1% for an increase in TDG saturation of 6.7% over the uniform 22 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 McNary Dam was determined for each combination of structural and operation alternative using the above equations.
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_{sp} = TDG saturation of spillway discharges (percent)

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

A comprehensive evaluation of TDG exchange at McNary Dam should consider the existence of elevated background TDG levels from upstream sources. The presence of elevated background TDG levels at McNary 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 McNary Dam is smaller than all downstream dams on the Columbia. The forebay TDG levels at McNary Dam are summarized from 1995-2007 as a function of total river flow in Figure D4. The observed daily average TDG saturation in the forebay of McNary Dam was summarized for 5 kcfs ranges in total river flow from 75 to 525 kcfs. The average forebay TDG saturation is indicated by the red circle and the range in TDG saturation is defined by the standard deviation indicated by the range bars. A well defined linear relationship was evident between observed TDG saturation in the forebay of McNary Dam and total river flow. This figure shows that when river flows are approaching the 7Q10 level of 433.4 kcfs, the background TDG saturation typically ranges from 115 to 122 % of saturation. It would be unreasonable to assume forebay TDG levels of 110% or less will occur at river flows of 300 kcfs and higher unless major alterations in main-stem dams upstream of McNary Dam are put in place.

Results

A series of estimates of TDG exchange were generated for a matrix of conditions impacting TDG exchange in the Columbia River at McNary Dam. This matrix consisted of the structural configuration, spill operations, 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 McNary 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 pperation 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 MCNTDGest.xls summarizing the effects of seven different structural configurations, six different spill policies, four powerhouse capacities, eight different river flow rates, and five background TDG saturations. A summary of these discrete conditions are summarized in Table D2. This table consists of 5660 different cases that provide a comprehensive summary of the TDG management program at McNary 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 McNary Dam.

A total of seven different structural alternatives were considered in this evaluation and include conditions at the start of the TDG Abatement program in 1995. The base condition included spillway flow deflectors on bay 3-20 with a standard spillway face on the four end bays. The base condition (Base-18 Deflectors) included split leaf spill through the end bay without the benefits of flow deflectors as described by the TDG exchange equation 1. The second alternative includes the addition of spillway deflectors in all bay (22 deflectors) and the implementation of a uniform spill pattern. The third structural configuration includes the addition of a two spillway weirs (22 Deflectors+SW) currently located in spill bays 19 and 20. The purpose of these structures is to more effectively and efficiently guide juvenile fish past McNary Dam. The fourth structural alternative involves the addition modified Ice and Trash sluiceway (22 Deflectors+SW-IT20) located between the powerhouse and spillway. The capacity of this sluiceway was assumed to equal 20 kcfs and the channel exit expands to a width of 50 ft with a horizontal orientation generating a surface jet flow regime. The TDG production was assumed to be similar to the McNary spillway flow deflectors at the corresponding specific discharge. The fifth structural alternative includes the addition of a powerhouse surface bypass channel to the existing structure with two spillway weirs and 22 flow deflectors (22 Deflectors+SW+PHsb8). The powerhouse surface bypass channel will induce a surface oriented flow of 8 kcfs from the forebay and transition the aerated discharge to the tailrace channel through an ogee transition downstream of spill bay 21. The TDG exchange performance of the powerhouse surface bypass channel was assumed to be similar to the McNary spillway at the corresponding specific discharge. A spillway training wall added to the current structural configuration was the sixth structural alternative considered in this evaluation (22 Deflecfors+SW+WL800). The training wall was assumed to extend about 800 downstream from the dam between the powerhouse and spillway and to completely eliminate the added TDG uptake estimated from the entrainment of powerhouse flows into the stilling basin. The final structural alternative under consideration includes the update of 12 of the 14 turbine with a hydraulic capacity of 18.3 kcfs with the existing configuration of 22 deflectors with two surface weirs (22 Deflectors+SW+PHmod). The modernization of the powerhouse will result in a total hydraulic capacity of 244.3 kcfs or a 71.4 kcfs increase in flow.

This study also considered the influence of six different spill operations that govern the operations of McNary Dam and resultant generation of TDG supersaturation. The spill policies 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 "no voluntary spill" excluding the auxiliary discharge. This is the operation in place outside of the fish passage season.

The second and third spill operations called for an instantaneous spill equal to 40 and 50 percent of the total river flow ("Spill 40%" and "Spill 50%"). The fourth different spill operation required the instantaneous spill to equal 100 kcfs ("spill 100 kcfs"). The fifth 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 final spill operation called for spilling up to the capacity as limited by the 110 percent total dissolved gas saturation criterion or background TDG level in the Columbia River, the larger of these conditions, at the tailwater fixed monitoring station ("spill to capacity @ 110% or TDGfb"). This is equivalent to operations not increasing the TDG levels in the Columbia River during project operations. The current planned spill operation includes spilling a fixed percentage of the river.

The TDG properties in spillway flows at McNary 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 base conditions spillway (18 Deflectors) and existing spillway (22 Deflectors) 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 Ice and Trash (IT) sluiceway flows and Powerhouse Surface Bypass flows (PHsb) were assumed to be similar with the McNary spillway TDG exchange formulation (equation 2) with the corresponding specific discharge applied. The average flow weighted TDG saturation below McNary 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 of 0.30 and the spill discharge (entrainment discharge 30 percent spillway 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 John Day Dam was estimated by calculating a degassing rate as a first order exchange rate based on the level of the average TDG supersaturation generated at McNary Dam.

A comprehensive evaluation of TDG exchange at McNary Dam should consider the existence of elevated background TDG levels from upstream sources. In this case, the background TDG sources are derived from the Mid-Columbia River where Priest Rapids Dam is the upstream neighbor to McNary Dam and the Snake River where Ice Harbor Dam is the closest project. The presence of elevated background TDG levels at McNary 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 McNary Dam is smallest of the four lower Columbia River projects with one of the largest spillways. Therefore, involuntary spill operations will be triggered at much smaller flows at McNary Dam than at the downstream projects.

The contents in the master table and related Tables D3-D7 are as follows:

Case - Case number in the master table (1-2880)
Structure Alternative = (Base 18 Deflectors, 22 Deflectors+other structural features)
Spill Operation = (Spill @ 120%, Spill % River, Spill 100, Spill 110% or TDGfb, No spill)
$\mathbf{Q_{ph\text{-}max}}$ = Maximum hydraulic capacity of the McNary powerhouse (kcfs)
$\mathbf{Q_{total}}$ = Columbia River Flow at McNary 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 also generation release(%)
$\mathbf{TDG_{aux}}$ = Total Dissolved Gas Saturation of auxiliary discharge (%)
$\mathbf{TDG_{avg}}$ = Flow weighted Total Dissolved Gas Saturation below McNary Dam (%)
$\mathbf{\Delta TDG}$ = Change in average Columbia River TDG saturation (positive increase in load, negative net decrease in load %)

Structural Configuration

The TDG exchange across the seven structural configurations investigated at McNary Dam for a spill operation of spilling 40 percent of total river flows of 150, 300, and 433 kcfs were examined as shown in Table D3 for a forebay TDG saturation of 110 percent and a powerhouse capacity discharge with one inoperable turbine. The current spill operation is most closely approximated by the "40% Spill" condition. The scenarios in Table D3 have been sorted by total river discharge listing the impacts of the structural alternatives for below average, above average, and high (7Q10) river flows.

In general, the non-turbine flows of 60 kcfs were maintained for a total river discharge of 150 kcfs at TDG levels well below the tailwater criteria of 120 percent saturation. During the fish passage season 31 percent of the time the total river flow is less than 150 kcfs. In two cases a net decrease in the TDG saturation was predicted where the spill discharge was uniformly distributed over all 22 bay with flow deflectors. The average TDG level in the Columbia River dropped from 110 percent in the forebay to 109.2 percent as a cross sectional average downstream of the dam. The non-uniform spill pattern with the spillway weirs causes much higher TDG levels in spillway flows (117.3%) due to the non-uniform spill pattern. The additional powerhouse capacity had no impact at this small river flow. The two cases with auxiliary channels and discharges generated the highest TDG levels in the river of 114 and 114.4 with the added 8 kcfs flow through the Powerhouse surface bypass channel and 20 kcfs flow through the Ice and Trash sluiceway channel. The influence of the training wall can be estimated by comparing case 490 with case 770. The wall prevents entrainment of powerhouse flows into aerated spillway releases causing tailwater TDG levels to drop from 113.8 percent to 112.9 percent.

The Columbia River flow of 300 kcfs exceeds the powerhouse hydraulic capacity for all scenarios resulting in non-turbine flows exceeding 40 percent (120 kcfs) in all cases but the scenario with the powerhouse modernization (case 533). The range in average TDG levels below McNary Dam were only slightly higher than estimated during the 150 kcfs river discharge. The highest estimated average TDG saturation was 116.3 percent for the base 18 Deflector scenario while the lowest TDG level of 112.6 percent was with the 22 Deflectors with added powerhouse capacity (case 533). The Base 18 Deflectors scenario did exceed 120 percent in spillway flows. The TDG levels in auxiliary flows also exceeded 120 percent but will be masked by the much larger TDG loading released from the spillway. The influence of the spill pattern is responsible for the flat response in TDG generation between the 150 and 300 kcfs river flows. The training wall was estimated to reduce average TDG levels by about 1 percent saturation.

The TDG response at the 7Q10 river flow corresponds with spillway discharges over 200 kcfs in all cases and TDG levels in spillway releases greater than 120 percent in all scenarios. With the added powerhouse capacity reflected by the "22 Deflector+PH mod", the spillway TDG levels were estimated as 121.8 percent or about 1.8 percent above the tailwater criteria but the cross sectional average TDG levels were 117.3 percent. The base condition "Base 18 Deflectors" generated TDG levels in spill of 128.3 percent and cross sectional average TDG levels of 125.0 percent. The TDG contribution for the Ice and Trash Sluiceway (IT20) and powerhouse surface bypass channel (PHsb8) were small for these conditions. The spillway / powerhouse training wall reduced the average CR TDG levels from 121.9 percent to 119.2 percent for these conditions.

The addition of the four spillway deflectors has resulted in a measurable reduction in TDG levels both in the TDG content in spillway flow (3-4 percent reduction) and average project release. The influence of the spillway weirs on TDG exchange occurs at levels below the TDG criteria for average to low river flows. The influence of the additional bypass channels (IT20 and PHsb8) again were not significantly higher than current conditions at the high river flow levels (7Q10 flows). The additional powerhouse capacity will reduce spill discharges at the highest river flow conditions to levels approaching the WDOE tailwater standards. The training wall provided small levels of TDG reduction (1-2%) in average TDG loadings under favorable forebay conditions of 110 percent but little influence on TDG levels in spillway flows

Spill Operations

The influence of spill operation on TDG exchange was explored for the current condition 22 deflectors+SW scenario for three river flow conditions 150, 300, and 433 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 D4.

The spill operation has considerable influence over the TDG exchange during voluntary spill conditions that exist for 150 kcfs flows. The spill magnitude was limited to 100 kcfs for a total river flow of 150 kcfs due to the minimum powerhouse discharge of 50 kcfs. The TDG levels for 100 kcfs spill were less than spills of 75 kcfs due to the influence of

the spill patterns high discharges over the spillway weirs. In all cases, the TDG levels in spillway flows were well below 120 percent of saturation.

At a river discharge of 300 kcfs, a minimum spill discharge of 139.5 kcfs is required with spill levels as high as 193 kcfs as limited by the tailwater TDG constraint of 120 percent saturation. All the spill policies will yield operations within the TDG criteria established by WDOE during the fish passage season for flows up to 300 kcfs. Average cross section TDG levels for a river flow of 300 kcfs ranged from 114.2 to 118.4 kcfs with the "spill to capacity at 120 percent" spill operation causing twice the uptake in TDG level above background conditions compared to the minimum spillway release at this river flow.

The 7Q10 flow resulted in a spill of 272.9 kcfs attaining a TDG saturation of 124.6 percent in spillway flows and a cross sectional average saturation of 121.9 percent. The spill operations become irrelevant as river flows increase above 350 kcfs because of the limited powerhouse capacity for current conditions. System management of TDG saturation will become important when over-generation of hydropower is present and idling turbines at selected power plants is required. The relevancy of spill operations is critical to TDG loading for most river flows by becomes irrelevant for only the highest 5.6 percent of the flow conditions.

Total River Flow Impacts

The operation at McNary Dam requires some level of spill when the total river flow exceeds the powerhouse capacity. The TDG exchange at McNary Dam with "22 deflectors +SW" for river flows of 150, 200, 250, 300, 350, 400, 434 kcfs with a powerhouse capacity with one inoperable turbine, a forebay TDG level of 110 percent, subject to a spill operation of "Spill to capacity at 120 percent" are listed in Table D5. The amount of spill for river flows up to 250 kcfs was limited only by the minimum powerhouse capacity of 50 kcfs. A river flow of 300 kcfs will allow a maximum spill discharge of 192 kcfs without tailwater TDG levels exceeding 120 percent of saturation. As river flows increase above 300 kcfs the additional spill volume will slowing increase above 120 percent reaching peak levels at the 7Q10 condition.

The expanded hydropower capacity associated with the modernization of the McNary turbines would allow for a much wider range of acceptable spillway releases relative to the WDOE standards. The TDG exchange associated with "22 deflectors + PH mod" for river flows of 150-434 kcfs, a forebay TDG level of 110 percent, subject to a spill operation of "spill to capacity at 120 percent of saturation are listed in Table D6. The spill levels can be managed to generate TDG levels of 120 percent and less up through total river flows of 400 kcfs. For river flows at the 7Q10 conditions, the estimated TDG content in spill exceeds 120 percent of saturation by only 0.9 percent.

Forebay TDG Level Impacts

The existence of upstream sources of TDG supersaturation at McMary Dam result in background TDG levels exceeding 110 percent during the fish passage season. A set of

TDG estimates were determined assuming likely forebay TDG levels in the Columbia River for the existing structure "22 deflectors with SW" over a range of river flows for a spill operation of "Spill to Capacity @ 110% or TDGfb" as listed in Table D7. The capability to spill at 110 percent with the existing bulk spill pattern with spillway weirs is limited. As the typical forebay TDG level approached and exceeds 110 percent the operation limiting the increase in TDG pressure involves minimizing spill by maximizing powerhouse flows. The increase in the average river TDG saturation ranged from 3.1 to 5.6 percent for river flows of 250 kcfs and greater.

McNary 2009 configuration TDG and Flow Summary

The TDG saturation in Columbia River below McNary Dam was estimated for six different river flows assuming the 2009 spillway configuration for a uniform spill pattern and a forebay TDG saturation of 115 percent as listed in Table D8. In Case 1, the total river flow conditions were chosen to correspond with the hydraulic capacity of the powerhouse with all turbines operating at the upper 1 percent range of best gate efficiency 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 two cases correspond with high river flows of 400 kcfs and the updated mean 7Q10 flow of 433.4 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 McNary Dam from 1974-2009 are also listed in this table.

The frequency for spilling water above the maximum powerhouse capacity during the fish passage season is nearly 60 percent of the time at McNary Dam but only about 19 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 70 kcfs will generate TDG levels at 110 percent of saturation or 5 percent lower than the initial conditions. Outside of the fish passage season a river flow of 248 kcfs occurs only about 3.8 percent of the time. This operation will result in a net decrease in the average TDG conditions of the river to 113.2 percent when forebay levels are 115 percent. The spillway discharges up to 120 kcfs will either reduce or cause no change in the TDG loading of the Columbia River for total river flows up to 298 kcfs which occurs only about 1.3 percent of the time outside of the fish passage season. The spillway flows at McNary Dam up to 188 kcfs will result in TDG levels of 120 percent and less which corresponds to a total river discharge of 366 kcfs and a frequency of occurrence of 4 percent during the fish passage season. 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 123.7 percent.

Conclusions

McNary Dam operations will continue to include spillway flows to support the fish passage during the migration season and to pass flow in excess of the powerhouse

capacity or power generation demand. Spillway flows create aerated flow conditions in the stilling basin resulting in TDG supersaturation in the Columbia River.

For McNary Dam as currently configured with flow deflectors on all 22 spill bays, spillway flows larger than about 66 kcfs will generate TDG levels above 110 percent of saturation at the tailwater fixed monitoring station assuming a uniform spill pattern. Assuming the maximum powerhouse capacity of 173 kcfs can be delivered, a total river flow of 239 kcfs can be maintained at 110 percent given background levels are also at110 percent. This river discharge has been exceeded about 4 percent of the time outside of the fish passage season over the time period from 1974-2009.

Spillway discharges up to about 192 kcfs will generate TDG levels near 120 percent of saturation under normal flow conditions. Assuming a maximum powerhouse capacity of 173 kcfs can be delivered concurrently with a spillway discharge of 192 kcfs will yield a total river flow of 365 kcfs. This total river flow has been exceeded about 3.5 percent of the time during the fish passage season based on observed flows from 1974-2009. 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 7Q10 high river flow was updated for the Columbia River at McNary Dam to 433 kcfs based on an extended period of record. The critical spillway discharge of 260 kcfs will be released during a 7Q10 river flow if the maximum powerhouse capacity can be delivered. A spill of 255 kcfs was estimated to generate a TDG saturation of 124.2 percent.

Spill flow defectors were installed on 4 of the 22 spill bays at McNary dam in 2001 to complete the full installation of this TDG abatement measure. The development of spill patterns utilizing all 22 bays resulted in the reduction of TDG supersaturation during both voluntary and involuntary spill conditions. The TDG generation associated with 100 kcfs spill uniformly distributed over 18 and 22 bays was reduced from 114.6 percent to 112.8 percent. The spill capacity as limited by the tailwater TDG criteria increased by about 37 kcfs as a result of the added end bay flow deflectors. Four new gate hoists were also added to the spillway to allow automated gate changes to the entire spillway. The new flow deflector also included a turning radius to allow for a smoother hydraulic transition from the spillway to stilling basin.

A surface bypass program at McNary Dam includes the addition of two spillway weirs that are designed to improve fish survival. The non-uniform spill pattern associated with these spillway weirs has not significantly influenced the spill capacity as limited by tailwater TDG criteria.

The powerhouse at McNary Dam has the smallest hydraulic capacity of any of the Federal Dams on the Columbia River and largest critical spillway discharge at the 7Q10 river flow of 255 kcfs. The spillway at McNary is the second longest spillway on the

Columbia River behind the spillway at The Dalles Dam which allows spillway flows to be broadly distributed moderating TDG exchange. Increasing the hydraulic capacity of the McNary powerhouse through upgrading turbines will lower the involuntary spill at the 7Q10 river flow to about 189 kcfs with an estimated TDG saturation in spillway flow undiluted by powerhouse releases of 120.9 percent. It is reasonable to assume that this structural configuration of McNary Dam may consistently generate TDG levels at or below the WDOE standards given the uncertainty in the 7Q10 flows and the modeled TDG exchange relationship.

Expanding the capacity of either the Ice and Trash sluiceway or powerhouse surface bypass channel will result in a small increase in TDG loading for voluntary spill conditions provided the commitment to spillway flows does not change. These measures can provide for a substantial reduction in TDG loading for voluntary spill operations if they result in fish spill operation that relies on smaller volumes of spill.

The TDG generation at the McNary 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 McNary Dam have been designed to tend towards a uniform pattern for high spillway discharges using all 22 spill bays.

The daily management of TDG levels in the Columbia River below McNary 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.

References

Wilhelms, S. C. and Schneider, M. L. 1997. “Near-Field Study of TDG in the McNary Spillway Tailwater,” CEWES-CS-L Memorandum for Record dated 22 August 1997, US Army Engineer Waterways Experiment Station.

USACE, March 2010 , “Fish Passage Plan Corps of Engineers Projects”, U.S. Army Corps of Engineers, Northwest Division, Portand Oregon.

USGS, March 1982, “Guidelines for Determining Flood Flow Frequency, #17B Bulletin”, U.S. Department of the Interior, Geological Survey, Reston, Virginia

Table D1. Percent of time the seven-day moving average of daily average flows exceed the reference Columbia River Flow at McNary Dam, 1975-2007 water years.

Columbia River Flow (kcfs)	Fish Passage Season April-Aug (%)	Non-Fish Passage Season Sept.-March (%)	Comments
100	94.80%	87.30%	
150	69.00%	29.30%	
160.6	64.20%	23.20%	Powerhouse capacity 13 units
172.9	59.60%	17.70%	Powerhouse capacity 14 units
200	49.20%	9.00%	
235.6	33.80%	4.20%	Powerhouse capacity 13 units + 75 kcfs spill at 110%
247.9	28.60%	3.50%	Powerhouse capacity 14 units + 75 kcfs spill at 110%*
250	28.00%	3.40%	
300	14.20%	1.20%	
350	5.60%	0.20%	
400	1.70%	0.0%	
433.4	0.90%	0.0%	Updated 7Q10 flow

Table D2. Configuration Matrix for TDG Estimates in the Columbia River at McNary Dam.

Structural Alternative	Spill Operation	$Q_{ph\text{-}Max}$ (kcfs)	Q_{total} (kcfs)	TDG_{fb} (%)
Base-18 Deflectors	No Voluntary Spill	166.6	100	105
22 Deflectors	Spill to Capacity @ 110% or TDG Forebay	172.9	150	110
22 Deflectors+SW	Spill 40 Percent	226	200	115
22 Deflectors+PH Mod	Spill 50 percent	244.3[+]	250	120
22 Deflectors+SW+IT20	Spill 100 kcfs		300	125
22 Deflectors+SW+PHsb8	Spill to Capacity @ 120%		350	
22 Deflectors+SW+WL800			400	
			433.4	

[+]Added powerhouse capacity of with turbine upgrade 12 turbines @ 18.3kcfs.

Table D3. Summary of Total Dissolved Gas Exchange at McNary Dam for Columbia River flow of 150, 300 kcfs, and 433.4 kcfs for Forebay TDG level of 110%, Spill Operation of 40 Percent by Structural alternative.

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_{avg} (%)	TDG_{avg} (%)	ΔTDG (%)
410	Base-18 Deflectors	Spill 40 Percent	160.55[a]	150	90.0	60.0	0.0	110	113.9	110	112.0	2.0
450	22 Deflectors	Spill 40 Percent	160.55	150	90.0	60.0	0.0	110	108.4	110	109.2	-0.8
490	22 Deflectors + TSW	Spill 40 Percent	160.55	150	90.0	60.0	0.0	110	117.3	110	113.8	3.8
530	22 Defl+PH Mod	Spill 40 Percent	226[b]	150	90.0	60.0	0.0	110	108.4	110	109.2	-0.8
610	22 Deflectors+TSW+IT20	Spill 40 Percent	160.55	150	90.0	40.0	20.0	110	117.6	123.3	114.4	4.4
690	22 Deflectors+TSW+PHsb8	Spill 40 Percent	160.55	150	90.0	52.0	8.0	110	117.4	123.3	114.0	4.0
770	22 Deflectors+TSW+WL800	Spill 40 Percent	160.55	150	90.0	60.0	0.0	110	117.3	110	112.9	2.9
413	Base-18 Deflectors	Spill 40 Percent	160.55	300	160.6	139.5	0.0	110	120.5	110	116.3	6.3
453	22 Deflectors	Spill 40 Percent	160.55	300	160.6	139.5	0.00	110	116.5	110	113.9	3.9
493	22 Deflectors + TSW	Spill 40 Percent	160.55	300	160.6	139.5	0.00	110	116.9	110	114.2	4.2
533	22 Defl+PH Mod	Spill 40 Percent	226	300	180.0	120.0	0.00	110	115.0	110	112.6	2.6
613	22 Deflectors+TSW+IT20	Spill 40 Percent	160.55	300	160.6	119.5	20.0	110	115.4	125.2	113.8	3.8
693	22 Deflectors+TSW+PHsb8	Spill 40 Percent	160.55	300	160.6	131.5	8.0	110	116.4	125.2	114.0	4.0
773	22 Deflectors+TSW+WL800	Spill 40 Percent	160.55	300	160.6	139.5	0.00	110	116.9	110	113.2	3.2
416	Base-18 Deflectors	Spill 40 Percent	160.55	433.4	160.6	272.9	0.0	110	128.3	110	125.0	15.0
456	22 Deflectors	Spill 40 Percent	160.55	433.4	160.6	272.9	0.00	110	124.2	110	121.6	11.6
496	22 Deflectors + TSW	Spill 40 Percent	160.55	433.4	160.6	272.9	0.00	110	124.6	110	121.9	11.9
536	22 Defl+PH Mod	Spill 40 Percent	226	433.4	226.0	207.4	0.00	110	121.8	110	117.3	7.3
616	22 Deflectors+TSW+IT20	Spill 40 Percent	160.55	433.4	160.6	252.9	20.0	110	124.0	127.1	121.4	11.4
696	22 Deflectors+TSW+PHsb8	Spill 40 Percent	160.55	433.4	160.6	264.9	8.0	110	124.4	127.1	121.7	11.7
776	22 Deflectors+TSW+WL800	Spill 40 Percent	160.55	433.4	160.6	272.9	0.00	110	124.6	110	119.2	9.2

[a] Powerhouse capacity based on 13 turbines at 96 ft of head, with extended length STS installed, and operated at upper generation limit defined in FPP.

[b] Powerhouse modernization capacity based on 13 turbines at 96 ft of head, with extended length STS installed, and operated at upper generation limit defined in FPP.

Table D4. Summary of Total Dissolved Gas Exchange at McNary Dam for Columbia River flow of 150, 300, and 433 kcfs, Structural Alternative 22 Deflectors+SW, Forebay TDG level of 110% for alternative spill policies.

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_{avg} (%)	TDG_{avg} (%)	ΔTDG (%)
490	22 Deflectors + TSW	Spill 40 Percent	160.55	150	90.0	60.0	0.0	110	117.3	110	113.8	3.8
1290	22 Deflectors + TSW	Spill 50 Percent	160.55	150	75.0	75.0	0.0	110	117.2	110	114.6	4.6
2890	22 Deflectors + TSW	Spill 100 kcfs	160.55	150	50.0	100.0	0.0	110	113.8	110	113.3	3.3
3690	22 Deflectors + TSW	Spill to Capacity @ 120%	160.55	150	50.0	100.0	0.0	110	113.6	110	113.1	3.1
4490	22 Deflectors + TSW	Spill to Capacity @ 110% or TDGfb	160.55	150	147.3	2.7	0.0	110	110.0	110	110.0	0.0
5290	22 Deflectors + TSW	No Spill	160.55	150	150.0	0.0	0.0	110	100.0	110	110.0	0.0
493	22 Deflectors + TSW	Spill 40 Percent	160.55	300	160.6	139.5	0.00	110	116.9	110	114.2	4.2
1293	22 Deflectors + TSW	Spill 50 Percent	160.55	300	150.0	150.0	0.00	110	117.6	110	115.0	5.0
2893	22 Deflectors + TSW	Spill 100 kcfs	160.55	300	160.6	139.5	0.00	110	116.9	110	114.2	4.2
3693	22 Deflectors + TSW	Spill to Capacity @ 120%	160.55	300	107.1	192.9	0.00	110	120.0	110	118.4	8.4
4493	22 Deflectors + TSW	Spill to Capacity @ 110% or TDGfb	160.55	300	160.6	139.5	0.00	110	116.9	110	114.2	4.2
5293	22 Deflectors + TSW	No Spill	160.55	300	160.6	139.5	0.00	110	116.9	110	114.2	4.2
496	22 Deflectors + TSW	Spill 40 Percent	160.55	433.4	160.6	272.9	0.00	110	124.6	110	121.9	11.9
1296	22 Deflectors + TSW	Spill 50 Percent	160.55	433.4	160.6	272.9	0.00	110	124.6	110	121.9	11.9
2896	22 Deflectors + TSW	Spill 100 kcfs	160.55	433.4	160.6	272.9	0.00	110	124.6	110	121.9	11.9
3696	22 Deflectors + TSW	Spill to Capacity @ 120%	160.55	433.4	160.6	272.9	0.00	110	124.6	110	121.9	11.9
4496	22 Deflectors + TSW	Spill to Capacity @ 110% or TDGfb	160.55	433.4	160.6	272.9	0.00	110	124.6	110	121.9	11.9
5296	22 Deflectors + TSW	No Spill	160.55	433.4	160.6	272.9	0.00	110	124.6	110	121.9	11.9

Table D5. Summary of Total Dissolved Gas Exchange at McNary Dam for Columbia River flow of 100-433 kcfs, Forebay TDG level of 110% for existing structural configuration with 22 Deflectors and spillway weirs 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_{avg} (%)	TDG_{avg} (%)	ΔTDG (%)
3689	22 Deflectors + SW	Spill to Capacity @ 120%	160.55	100	50.0	50.0	0.0	110	119.6	110	116.2	6.2
3690	22 Deflectors + SW	Spill to Capacity @ 120%	160.55	150	50.0	100.0	0.0	110	113.6	110	113.1	3.1
3691	22 Deflectors + SW	Spill to Capacity @ 120%	160.55	200	50.0	150.0	0.00	110	116.8	110	116.6	6.6
3692	22 Deflectors + SW	Spill to Capacity @ 120%	160.55	250	50.0	200.0	0.00	110	119.8	110	119.8	9.8
3693	22 Deflectors + SW	Spill to Capacity @ 120%	160.55	300	107.1	192.9	0.00	110	120.0	110	118.4	8.4
3694	22 Deflectors + SW	Spill to Capacity @ 120%	160.55	350	160.6	189.5	0.00	110	120.4	110	117.3	7.3
3695	22 Deflectors + SW	Spill to Capacity @ 120%	160.55	400	160.6	239.5	0.00	110	123.1	110	120.2	10.2
3696	22 Deflectors + SW	Spill to Capacity @ 120%	160.55	433.4	160.6	272.9	0.00	110	124.6	110	121.9	11.9

Table D6. Summary of Total Dissolved Gas Exchange at McNary Dam for Columbia River flow of 100-433 kcfs, Forebay TDG level of 110% for structural alternative consisting of 22 Deflectors and Powerhouse modernization subject to spill capacity at 120% at the 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_{avg} (%)	TDG_{avg} (%)	ΔTDG (%)
3329	22 Defl+PH Mod	Spill to Capacity @ 120%	244.3	100	50.0	50.0	0.0	110	108.0	110	108.7	-1.3
3330	22 Defl+PH Mod	Spill to Capacity @ 120%	244.3	150	50.0	100.0	0.0	110	112.4	110	112.0	2.0
3331	22 Defl+PH Mod	Spill to Capacity @ 120%	244.3	200	50.0	150.0	0.00	110	116.3	110	116.2	6.2
3332	22 Defl+PH Mod	Spill to Capacity @ 120%	244.3	250	50.0	200.0	0.00	110	119.4	110	119.4	9.4
3333	22 Defl+PH Mod	Spill to Capacity @ 120%	244.3	300	97.9	202.1	0.00	110	120.0	110	118.8	8.8
3334	22 Defl+PH Mod	Spill to Capacity @ 120%	244.3	350	159.4	190.6	0.00	110	120.0	110	117.1	7.1
3335	22 Defl+PH Mod	Spill to Capacity @ 120%	244.3	400	220.0	180.0	0.00	110	120.0	110	115.8	5.8
3336	22 Defl+PH Mod	Spill to Capacity @ 120%	244.3	433.4	244.3	189.1	0.00	110	120.9	110	116.2	6.2

Table D7. Summary of Total Dissolved Gas Exchange at McNary Dam for Columbia River flow of 100-433 kcfs, Typical Forebay TDG levels for existing structural configuration, Full Powerhouse Capacity, and spill operation as limited by 110% or Forebay level as measured 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_{avg} (%)	TDG_{avg} (%)	ΔTDG (%)
4081	22 Deflectors + TSW	Spill to Capacity @ 110% or TDGfb	172.9	100	97.2	2.8	0.0	105	110.0	105	105.2	0.2
4082	22 Deflectors + TSW	Spill to Capacity @ 110% or TDGfb	172.9	150	147.3	2.7	0.0	105	110.0	105	105.1	0.1
4091	22 Deflectors + TSW	Spill to Capacity @ 110% or TDGfb	172.9	200	172.9	27.1	0.00	110	118.7	110	111.5	1.5
4092	22 Deflectors + TSW	Spill to Capacity @ 110% or TDGfb	172.9	250	172.9	77.1	0.00	110	118.4	110	113.4	3.4
4093	22 Deflectors + TSW	Spill to Capacity @ 110% or TDGfb	172.9	300	172.9	127.1	0.00	110	116.0	110	113.3	3.3
4102	22 Deflectors + TSW	Spill to Capacity @ 110% or TDGfb	172.9	350	172.9	177.1	0.00	115	119.7	115	118.1	3.1
4103	22 Deflectors + TSW	Spill to Capacity @ 110% or TDGfb	172.9	400	172.9	227.1	0.00	115	122.6	115	120.6	5.6
4112	22 Deflectors + TSW	Spill to Capacity @ 110% or TDGfb	172.9	433.4	172.9	260.5	0.00	120	124.2	120	123.3	3.3

Table D8. Columbia River Flow at McNary 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	173	173	0	na	115.0	59.60%	18.90%
2	Q_{sp}@110%	248	173	70	110	113.2	28.60%	3.80%
3	Q_{sp}@115%	298	173	120	115	115.0	14.70%	1.30%
4	Q_{sp}@120%	366	173	188	120	118.4	4.00%	0.10%
5	Q_{river}=400	400	173	222	121.1	120.1	1.70%	0.00%
6	7Q10-mean	433.4	173	254.4	123.7	121.7	0.90%	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 McNary 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 with maximum powerhouse flow at 400 kcfs
Case 6= Total river flow at 7Q10 flow rate.

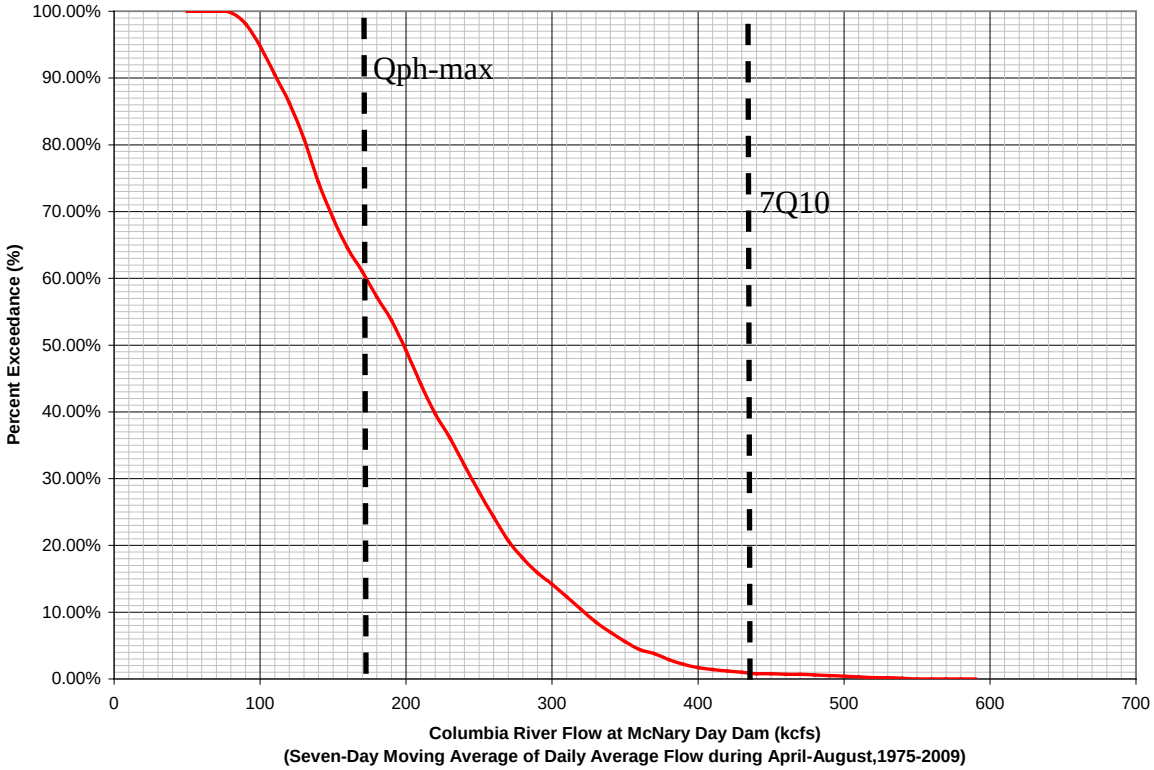

Figure D1. Percent Exceedance versus Columbia River Flow at McNary Dam during April-August 1975-2009.

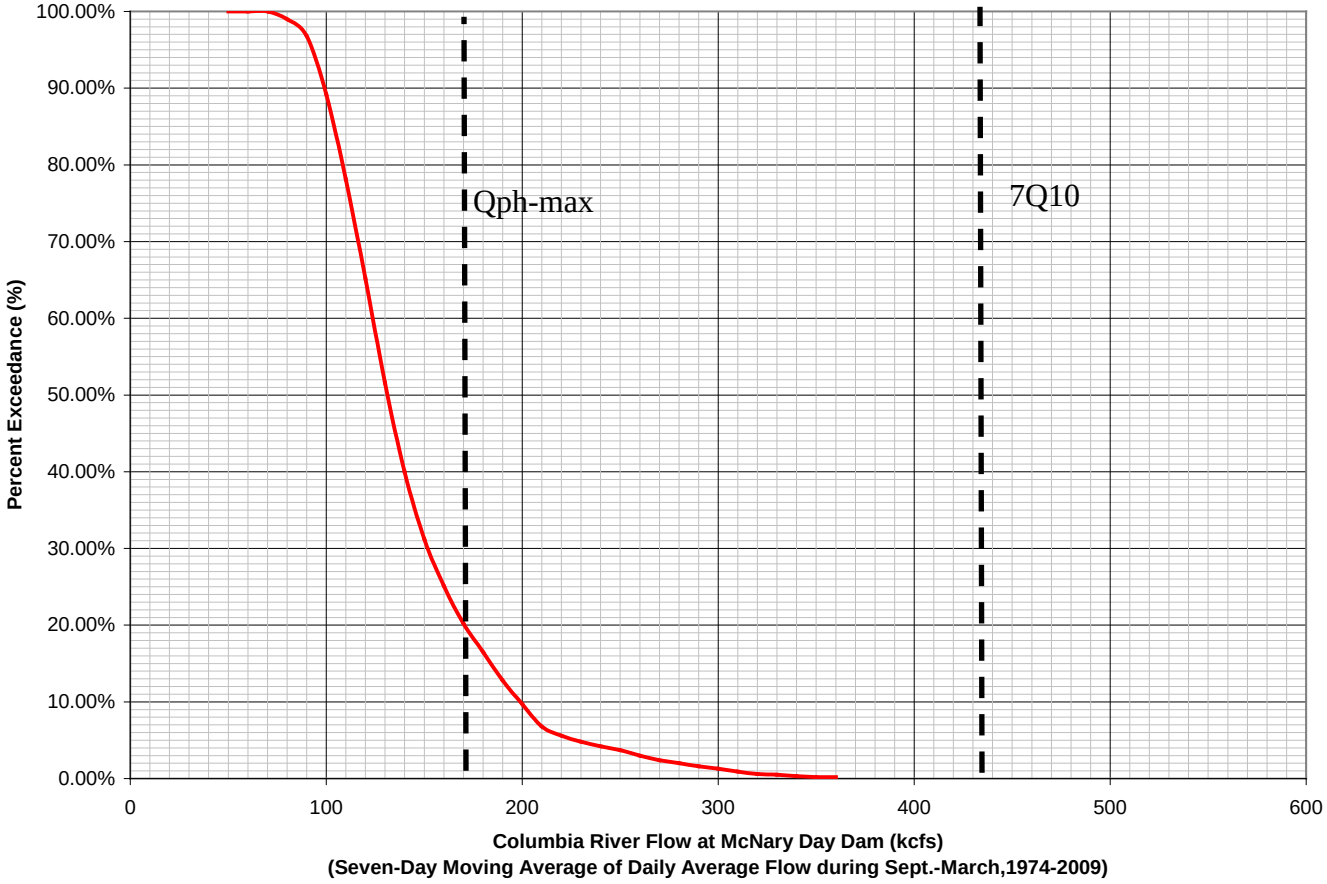

Figure D2. Percent Exceedance versus Columbia River Flow at McNary Dam during Sept.-March, 1974-2009.

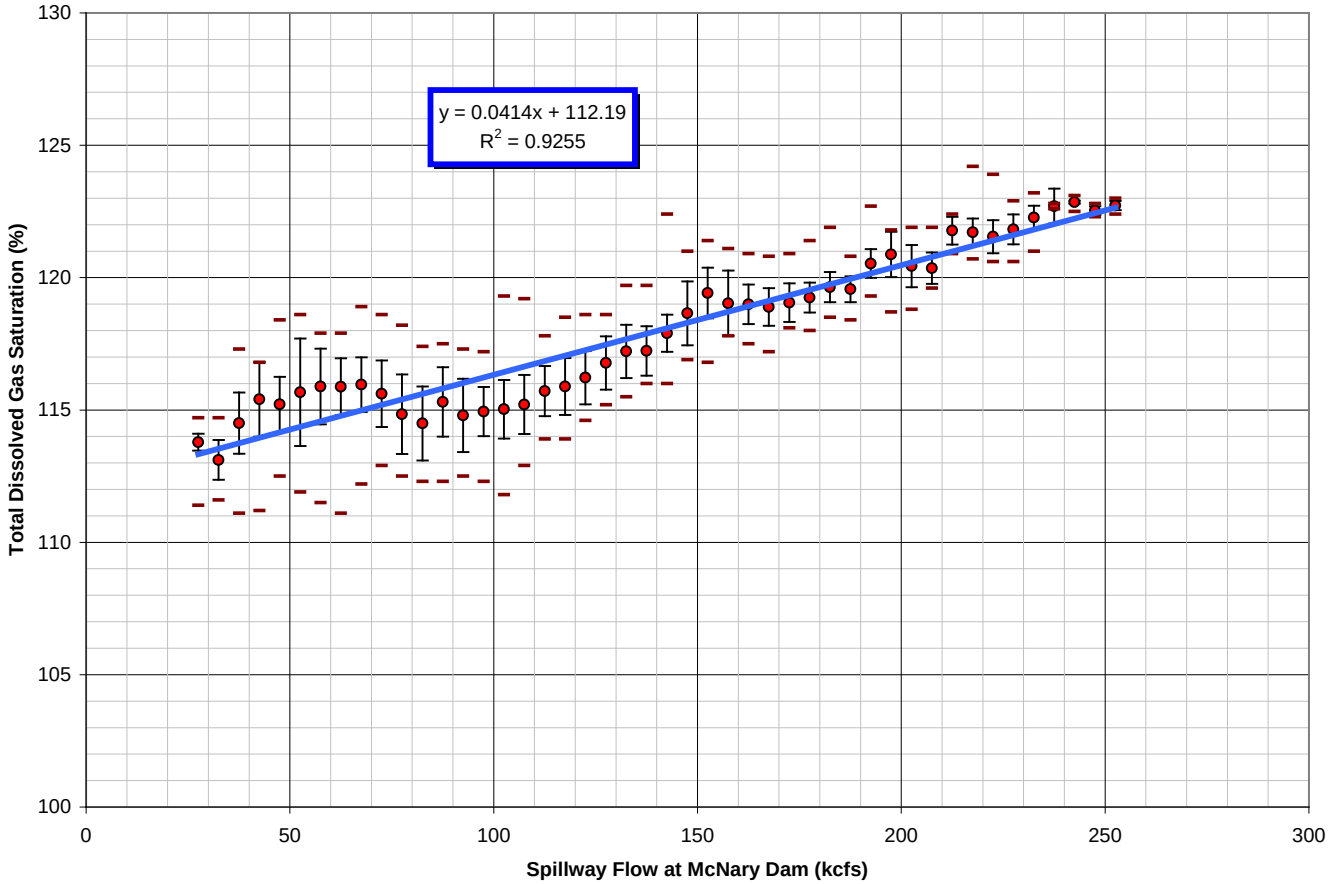

Figure D3. Total Dissolved Gas Saturation in the Tailwater of McNary Dam as a function of Spillway Discharge, 2004-2009

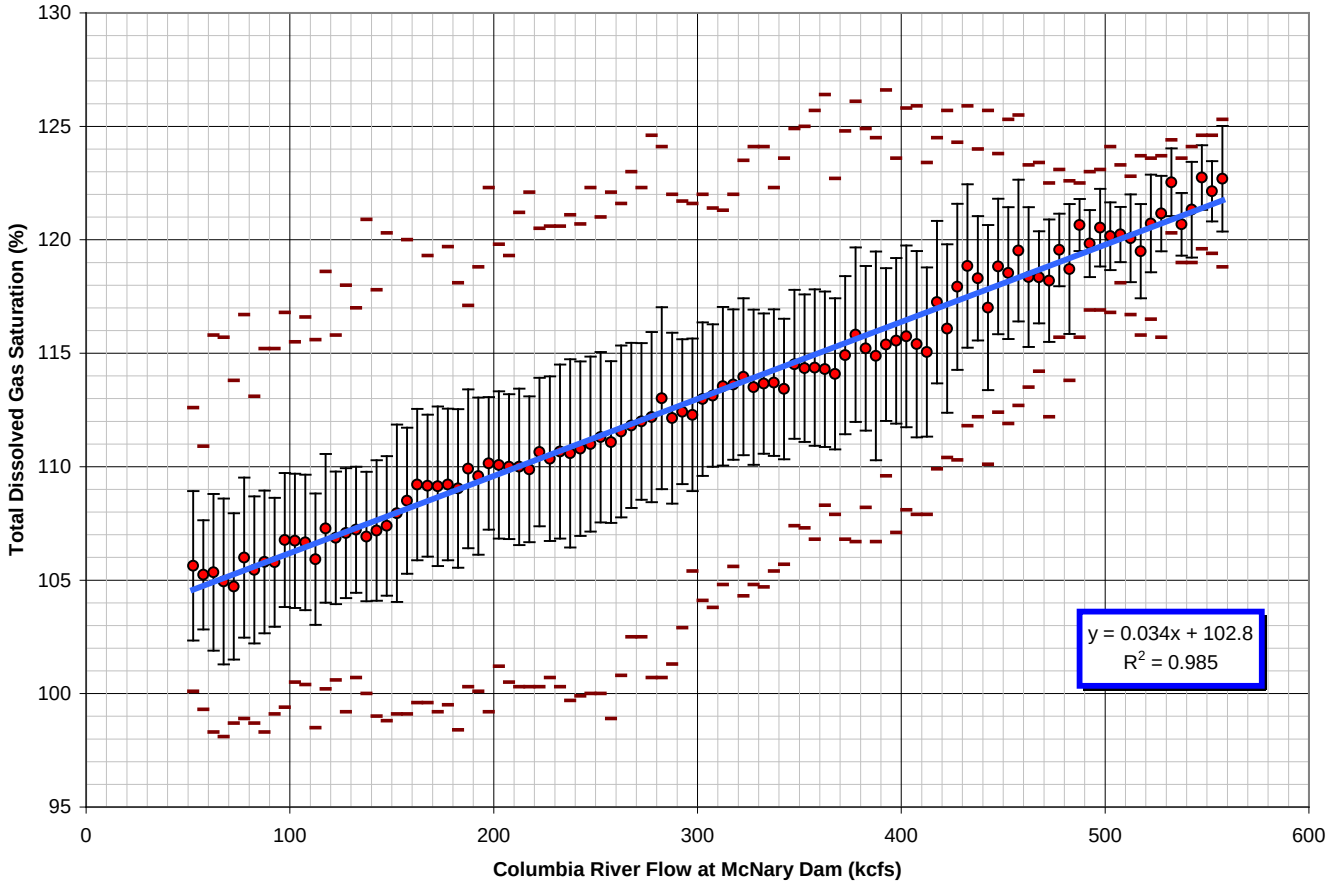

Figure D4. Total Dissolved Gas Saturation in the Forebay of McNary Dam as a function of Total Columbia River Flow, 1995-2009