U.S. Army Corps of Engineers Update to the Total Dissolved Gas Abatement Plan

Lower Columbia River and Lower Snake River Projects

Final

August 2016

I. 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. Through the operation of the Corps' FCRPS projects, water quality can be affected; and Endangered Species Act (ESA) listed fish are also impacted. Accordingly, the Corps considers the ecological objectives of both the Clean Water Act and the ESA, and complies with the applicable water quality standards to the extent practicable, as well as conducting operations consistent with applicable ESA Biological Opinions.

The 2014 NOAA Fisheries Federal Columbia River Power System Supplemental Biological Opinion (2014 Supplemental BiOp) relies on specified spill operations at the Corps' lower Snake and lower Columbia River projects for listed juvenile salmon and steelhead passage. The intent of the fish passage spill operations is to reduce the proportion of fish that pass through turbines and contribute to meeting juvenile fish survival performance standards identified in the 2014 Supplemental BiOp. This fish passage spill often results in the generation of total dissolved gas (TDG) supersaturation in the Columbia and lower Snake Rivers at levels above the current state and Federal TDG water quality standard of 110%.

The states of Washington and Oregon have provided exceptions to their 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.

In a letter dated April 2, 2015, the Washington Department of Ecology (WDOE) extended the TDG criteria adjustment for fish passage spill while the Corps prepared this update to the TDG Gas Abatement Plan (GAP). Subsequently, in the letter dated June 10, 2016, WDOE approved the draft TDG GAP and the request to apply the adjusted TDG criteria. They supported finalization of this document and requested that the Corps provide a final hard copy to WDOE, and post the final plan on the Corps' Northwestern Division water quality website at:
http://www.nwd.usace.army.mil/Missions/Water/Columbia/WaterQuality.aspx
Per WDOE, this approval allows the application of the adjusted TDG criteria at the following FCRPS hydropower dams within Washington State: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite. This approval is in effect through December 31, 2018. This approval is subject to the following conditions:

- The Corps must continue to pursue operational and structural actions that will reduce TDG saturation levels throughout the FCRPS system.
- Continue to develop and maintain the Corps' spill priority list in a manner that will most effectively reduce the effects of TDG on aquatic life in the Columbia and Snake rivers.
- Plan maintenance schedule and activities as much as possible to minimize increased TDG saturation in the Columbia and Snake rivers.
- Notify Ecology within 48 hours of initiation of spring and summer spill operations required for juvenile fish migration.
- Continue to provide Ecology with Annual Water Quality Monitoring Reports, Fish Operations Plans, Fish Operations Implementation Reports, and TDG Exceedance Tracking Reports.

This update summarizes modifications, both configuration and operational, that the Corps has made at its Columbia and lower Snake River projects in an attempt to address TDG exceedances while avoiding harm to ESA listed fish. The information provided in the Corps' 2009 TDG Exchange Evaluation is unchanged and no update to this information was necessary.

The current BiOp requirement for achieving performance standards for juvenile fish passage at the Corps' lower Columbia and lower Snake River projects includes spilling water during the spring and summer migration. Although significant TDG abatement actions have been implemented, such as flow deflectors at seven of the eight lower Snake and Columbia River fish passage projects, the spill volumes needed to meet the 2014 Supplemental BiOp performance standards result in exceeding the 110 percent TDG standard[1]. The Oregon and Washington TDG water quality standards, as provided by the standard modification and criteria adjustment, are instrumental in achieving the requisite ESA-listed juvenile fish passage performance objectives. In general, the configuration and operation actions taken at many of the dams to increase the survival of yearling Chinook salmon and juvenile steelhead have met the benefits anticipated in the 2014 Supplemental BiOp. The Corps anticipates a continuation of the ESA-listed fish passage spill program and does not foresee the likelihood of a significant reduction in spill volumes required to meet the requirements for ESA listed fish.

The Total Maximum Daily Load (TMDL) addressing TDG in the lower Snake River and the Mid-Columbia River and Lake Roosevelt, includes the Washington Department of Ecology (WDOE) TDG criteria adjustments for fish passage. The Lower Columbia River TMDL targeted fish passage spill in accordance with the standard modification and rule adjustment for the first 5 years, and then for the last 5 years, targets 110 percent TDG year round as expressed by the delta TDG pressure. As noted in this report, the Corps has implemented numerous gas abatement modifications that have been incorporated into measures and operations designed to benefit ESA-listed fish; however, the Corps is not aware of additional measures or operations that will meet the ESA requirements for listed fish and reduce TDG to 110%.

II. Background

Actions taken by the Corps to reduce the amount of spill and TDG supersaturation predate the TDG abatement program with the expansion of powerhouse capacities and installation of spillway flow deflectors at many of the projects beginning in the 1970s. A review of historic operations prior to the completion of upstream dams reveals large amounts of spill were routinely scheduled at projects due to the higher peak system flows with limited power plant capacity.

The Dissolved Gas Abatement Study (DGAS) was initiated in 1994 to examine potential methods for reducing TDG supersaturation produced by spillway operations on the Corps' dams on the lower Snake and Columbia rivers. Some of the alternatives were promising including the addition or modification of spillway flow deflectors, powerhouse/spillway separation walls, submerged spillway gates, and additional spillbays. These actions were considered to achieve both acceptable fish passage and provide for TDG abatement benefits at significantly less risk and cost than the other alternatives. Other alternatives evaluated were found to be detrimental to

[1] The Dalles Dam is the exception. The shallow spillway stilling basin and tailrace at The Dalles Dam provides degassing properties comparable to flow deflectors installed at other dams.

fish and were not included in recommended future actions. The redesigned baffled chute spillway, side channel spillway, and submerged conduit alternatives were found to have potential for achieving state and Federal water quality standards for TDG saturation; because there is a significant degree of uncertainty regarding TDG exchange and safe fish passage conditions with these alternatives, they were not considered for further development.

Since 1994, many of the feasible alternatives have been constructed and implemented for TDG abatement at the Corps' projects. A summary of these efforts are included in the TDG Abatement Accomplishment Section presented later in the report.

III. Water Quality Standards

The Washington State TDG water quality standards criteria state that the TDG saturation shall not exceed 110 percent at any point of collection. However, a TDG criteria adjustment for the Columbia and Snake rivers is also specified to aid fish passage at dams. The criteria adjustment allows TDG saturations based on a moving 12 hour average to not exceed 120 percent in the tailwater of a dam and 115 percent in the forebay of the next downstream dam. A maximum one hour average TDG saturation of 125 percent is also prescribed.

IV. Flow Frequency Analysis and TDG Exchange Evaluation

In order to provide a comprehensive description of the Corps past and proposed TDG abatement measures in the Columbia and lower Snake rivers, a series of estimates of TDG generation have been developed describing the TDG exchange properties as a function of alternative structural configurations, operational policies, total river flow rate, background TDG properties and powerhouse capacity. This information was provided in the Corps' 2009 TDG Exchange Evaluation, and no update to this information was necessary. This comprehensive set of conditions provides a summary of past, present, and potential future configurations at each dam and the associated TDG exchange properties. This type of analysis also provides a comprehensive comparison of TDG exchange conditions for a controlled system. The estimated TDG exchange for a range of flows up to the seven day moving average with a ten year return period (7Q10) were determined. The base conditions for each project were the structural configurations in 1994 at the beginning of the TDG abatement program managed by the Corps Portland and Walla Walla Districts. The evaluation of observed TDG data as the sole basis for assessing the progress of a TDG management program is problematic because of the influences from many uncontrolled sources such as the variation in runoff hydrographs, upstream sources of TDG supersaturation, and structural configuration of the dam. This section describes the critical components and associated assumptions used to generate TDG estimates and a summary of key findings from the evaluation. A more detailed description of the evaluation and a series of tables that quantify the TDG exchange properties at each of the dams for past, present, and future structural and operational configurations are contained in the Appendices A-H of the 2010 Gas Abatement Plan available here: http://www.nwd-wc.usace.army.mil/tmt/wqnew/gas_abatement/2010_Final/

Powerhouse Capacity

The powerhouse discharge is an important component in this evaluation because powerhouse releases do not change the TDG content from conditions in the forebay as a general rule.

Therefore, a project could be operated without altering the TDG loading in the river up to the hydraulic capacity of the powerhouse. The TDG content of powerhouse releases are generally less than the TDG content generated in spillway releases and can act to dilute the TDG levels in spill outside of the zone of highly aerated flow. The evaluation considered the maximum powerhouse capacity to consist of either all turbines (N) or all turbines less one (N-1) operating at the upper limit of one percent of peak efficiency, although in reality the percentage of turbine outages is typically higher (e.g., for 2015 ranged from 5-32%, with an average of 20%). The difference between the 7Q10 flows and powerhouse capacity flows determines the largest spillway discharge or critical spillway flow rate for which water quality standards apply. This critical spill discharge ranged from a maximum of 255 kcfs at McNary Dam to a minimum of 92 kcfs at Little Goose Dam (Table 1). Measures taken to increase the hydraulic capacity or reliability of individual turbines reduce the magnitude and frequency of the spill discharges and the corresponding TDG loading associated with unit outages.

7Q10 Flow Evaluation

The water quality standards for TDG are not applicable for river flows higher than the seven day, ten year frequency flood flow abbreviated as 7Q10. The 7Q10 is the average peak annual flow based on a seven day average flow with a recurrence interval of once every ten years. River conditions associated with flow greater than the 7Q10 flow are exempt from the Washington State water quality standards since it is impossible for dam operators to abate TDG saturation of these natural origin flows.

The 7Q10 flow rate was updated using the data from 1975-2009 and methodology as applied in the Lower Columbia River TMDL for TDG. These analyses determined the mean 7Q10 flows on the Columbia River to be 13 kcfs less than determined in the Lower Columbia River TMDL for TDG. The Snake River 7Q10 flows were estimated to be about 11 kcfs less than previously determined in the Snake River TMDL for TDG. The 7Q10 flow rate identifies the upper flow limit for which Washington State TDG standards are applicable and therefore represents the "worst case" conditions for TDG generation at mainstem dams in this analysis. The high river flow conditions generate high spill events across the entire hydrosystem resulting in the elevation of background TDG pressures generated at upstream dams. Based on 2008-2015 data, these high flow events are infrequent and short lived on the Snake River, but can last up to 30 days on the Columbia River. Overall they represent only a very small portion of the TDG loading generated by the dams considered in this report. Measures that increase fish survival by reducing the dependence on voluntary spill during most of the fish passage season can result in more sizable reductions in TDG loadings.

Critical Spillway Discharge

The evaluation of TDG exchange characteristics for a broad range of conditions can be further characterized by the frequency of occurrence of river flow conditions within and outside of the fish passage season for flows up to the 7Q10 discharge. The critical spillway discharge required to meet Washington State water quality standards for TDG was determined by subtracting the maximum powerhouse hydraulic capacity and auxiliary project flows from the updated 7Q10 discharge for each project as listed in Table 1. McNary Dam has the highest critical spillway discharge of 254.8 kcfs of the four lower Columbia River projects. However, the large length of the spillway at McNary Dam results in a critical specific discharge of 11.6 kcfs/spillbay or only slightly larger than conditions at Bonneville. John Day Dam has a small critical discharge of 110.4 kcfs due to the large powerhouse capacity and the smallest critical specific discharge of 5.5 kcfs/spillbay. The critical discharges on the Snake River were fairly similar ranging from 92.1 kcfs at Little Goose Dam to 109.8 kcfs at Ice Harbor Dam. The critical specific discharges on the Snake River projects were similar to conditions at McNary Dam. The TDG production at all projects except The Dalles Dam is directly proportional to the specific spillway discharge.

Table 1. Critical Spillway Discharge for Lower Columbia and Snake River Projects (2010 TDG GAP).

Project	7Q10 (kcfs)	Q_{phmax} (kcfs)	Q_{spcr} (kcfs)	Spillbays	Q_{spcr}/Spillbay (kcfs/Spillbay)
BON	454.3	251.9	190.8	18	10.6
TDA	448.3	284.3	158.1	23	6.9
JDA	441.4	329.6	110.4	20	5.5
MCN	433.4	173.9	254.8	22	11.6
IHR	203	92.4	109.8	10	11
LMN	203	97.6	105.4	8	13.2
LGS	203	110.9	92.1	8	11.5
LWG	203	108	95	8	11.9

7Q10 = The seven day moving average high discharge with a return period of 10 years
Q_{phmax} = All turbines in operation (kcfs)
Q_{spcr} = 7Q10 – Qphmax-Qaux Critical spillway discharge subject to WDOE TDG standards
Spillbays = Number of spillbays
Q_{spcr}/Spillbay = Specific Discharge (kcfs/spillbay)

Excursions Above 110 Percent Saturation

All projects in this evaluation, assuming fully configured structural and operational TDG actions in place, produce TDG saturations in excess of 110 percent saturation during the 7Q10 river flows which occur during the fish passage season. The critical spill discharge at the 7Q10 flow requires sizable spillway flows (Table 1) generating aerated flow conditions throughout the stilling basin and into the tailrace channel. The estimated spill discharge resulting in tailwater TDG levels of 110 percent were far below the estimated critical spill discharge and below the voluntary fish spill flows.

The critical peak river flows outside of the fish passage season infrequently exceed the maximum powerhouse capacity and require spill discharge which generates TDG levels in excess of 110 percent.

Excursions Above 120 Percent Saturation

With the exception of John Day Dam, the critical spill discharge during the 7Q10 flow event generate TDG levels in excess of 120 percent of saturation in the tailwater of each dam for fully configured future structural and operational scenarios in the evaluation. The estimated TDG saturation in spillway releases for the fully configured future scenarios for each project during the 7Q10 spill with powerhouse capacity minus one turbine ranged from 120 percent at John Day Dam to 129.6 percent at Bonneville Dam. The favorable conditions at John Day Dam can be attributed to the large powerhouse capacity and wide spillway with an additional spillway chute. For comparison purposes, all the projects were forecast to achieve a flow weighted average TDG saturation of less than 120 percent at the 7Q10 flow for the fully configured future structural configuration assuming forebay levels of 110 percent.

Project 2009 Structural Configuration TDG and Flow Summary

The flow and TDG saturation in the Columbia and Snake rivers at each project was estimated for the 2009 structural configuration for a range of flow conditions, forebay TDG conditions of 115 percent saturation, and with a uniform spill pattern over the spillway with flow deflectors. The frequency of exceeding river flows with forced spill conditions with TDG saturations greater than 110 percent were determined by adding the powerhouse hydraulic capacity (all turbines operating at upper end of 1 percent of best gate efficiency) to the spill capacity as limited by 110 percent saturation in spillway flows within and outside of the fish passage season. The higher river flows are contained within the fish passage season as shown in Figure 1 where the frequency of TDG levels in spillway flows exceeding 110 percent ranged from a low of 5 percent at John Day Dam (JDA) to a maximum frequency of 28.5 percent at McNary Dam. The influence of the limited powerhouse capacity at McNary Dam causes the higher frequency of TDG levels above 110 percent while the large hydraulic capacity at the John Day powerhouse caused the low frequency of TDG levels above 110 percent. The frequency of exceeding 110 percent drops off significantly outside of the fish passage season where the frequency of exceeding 110 percent ranged from 0.3 percent at John Day Dam to 3.8 percent at McNary Dam. Although spillway flows can generate TDG levels in excess of 110 percent outside of the fish passage season at all projects, the frequency of occurrence is low, the duration is limited, and the magnitude of spill will be much smaller than spill during peak river flows.

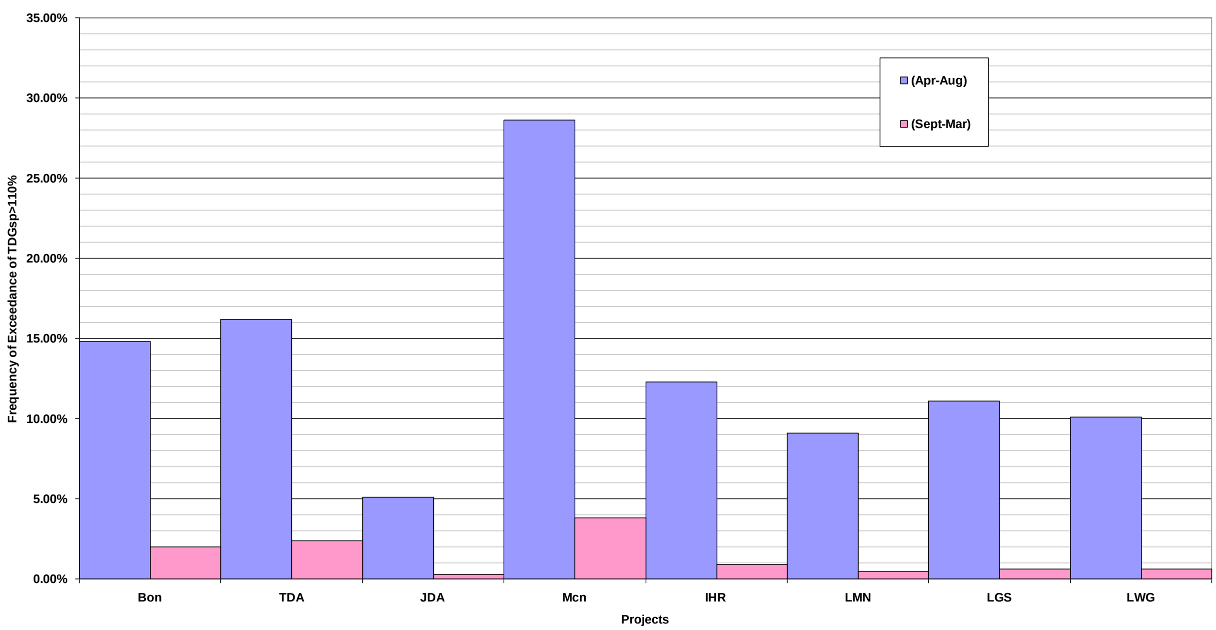

Figure 1. Frequency of TDG Saturation in Spillway Flows exceeding 110 percent of saturation assuming historic river flows at maximum powerhouse capacity with 2009 structural configuration. (Total River Flow summary 1974-2009)

The frequency of exceedance of river flows with forced spill conditions with TDG saturations in spillway flows greater than 120 percent were determined by adding the powerhouse hydraulic capacity to the spill capacity as limited by 120 percent saturation in spillway flows within and outside of the fish passage season. The flow and TDG saturation in Columbia and Snake rivers at each project were estimated for the 2009 structural configuration for a range of flow conditions, forebay TDG conditions of 115 percent saturation, and with a uniform spill pattern over the spillway with flow deflectors. The higher river flows are contained within the fish passage season as shown in Figure 2 where the frequency of TDG levels in spillway flows exceeding 120 percent ranged from a low of less than 1 percent at The Dalles Dam (TDA) to a maximum frequency of 4.5 percent at Bonneville Dam (BON). The frequency of exceeding 120 percent of saturation in spillway releases at Bonneville, McNary, and Lower Granite dams were similar at about 4 to 4.5 percent which averages out to be about 7 days per year. The frequency of exceeding 120 percent in spillway flows drops off significantly outside of the fish passage season. Bonneville Dam is the only project where the likelihood of TDG levels in spillway flows exceeding 120 percent was clearly greater than zero.

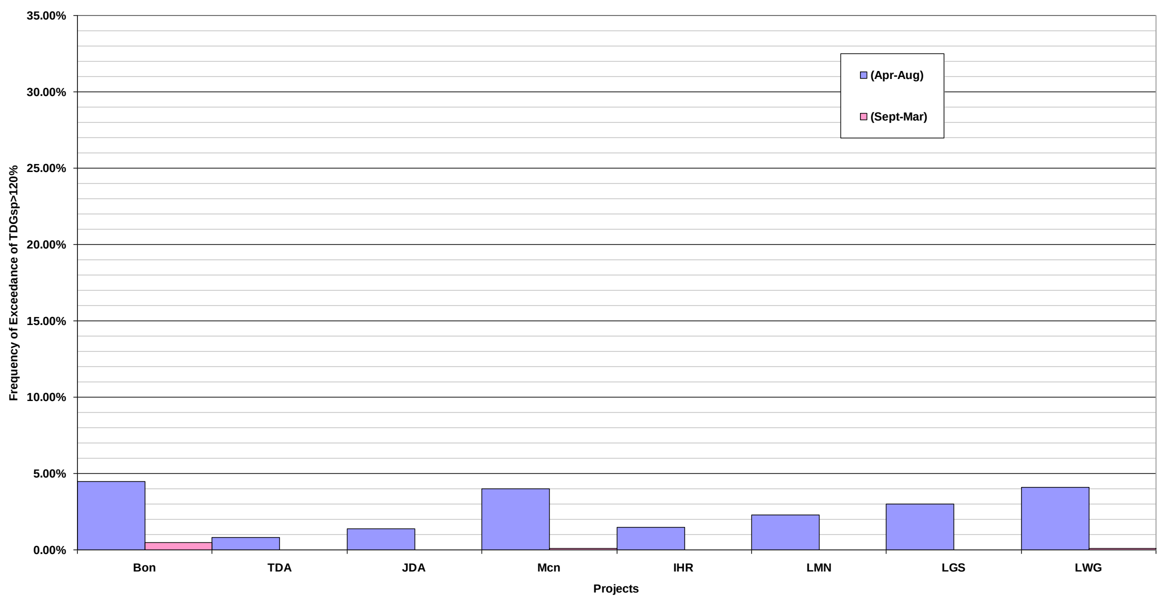

Figure 2. Frequency of TDG Saturation in Spillway Flows exceeding 120% of saturation assuming historic river flows at maximum powerhouse capacity with 2009 structural configuration. (Total River Flow summary 1974-2009)

Summary of the TDG Evaluation Findings

Through the TDG exchange evaluation process, several conclusions emerged related to the past and future TDG generation at the lower Snake and Columbia rivers:

- TDG management measures are currently in place for limiting Columbia and Snake River environments to acceptable TDG criteria levels for fish during most of the fish passage season.
- Significant TDG abatement has been accomplished through structural and operational improvements, but limited opportunities are available for further TDG reduction during flood flow conditions.
- Structural and operational alternatives that reduce dependence upon spill to achieve fish

passage objectives provide the best opportunities to further reduce TDG loading of the Columbia and Snake rivers.

- TDG abatement measures that increase the spill capacity can provide system-wide TDG abatement benefits when lack of market spill events must be scheduled.
- A spillway training wall can effectively reduce the TDG loading at projects where powerhouse flows are entrained into the aerated spillway when forebay TDG levels are less than TDG pressures generated in spillway releases.

V. TDG Abatement Accomplishments

The Corps is committed to providing fish passage spill at the lower Snake and lower Columbia River projects while also operating consistent with applicable state water quality standards for TDG saturation to the extent practicable. The general approach of using both operational and structural TDG abatement activities focuses on limiting the entrainment of air into the water column by project releases, limiting the effective depth of the entrained air, and limiting the water flow rate in direct contact with the bubble plume. Maximizing the powerhouse discharge is generally consistent with minimizing TDG generation but does not provide optimal juvenile fish passage survival.

A. Operational Accomplishments

A number of operational alternatives have been identified and are currently an important component of managing the TDG levels throughout the Columbia River system. These operational alternatives involve daily spill management, spill patterns, water regulation, powerhouse operations, and system spill operations.

Daily Spill Management

The Total Dissolved Gas Monitoring Plan is a critical component in managing TDG supersaturation in the Columbia River Basin[2]. It is critical that a monitoring system be maintained in both the forebay and tailwater of each dam to provide a comprehensive description of projects impacts on the TDG loading of the Columbia and Snake rivers and identify any excursions above the water quality standards. The location of several forebay fixed monitoring stations (FMS) have been moved to provide a more representative sample of TDG pressures approaching the dam by reducing the occurrence of thermally induced TDG fluctuations. The tailwater fixed monitoring stations have also been moved at several projects to provide a more accurate estimate of TDG exchange in spillway discharges. The TDG instrumentation has been improved and consequently the reliability and consistency of TDG measures also continue to improve. The quality assurance and maintenance of TDG instrumentation has been standardized and performance records are maintained. The water quality and project operations data have been used to develop a predictive mathematical model of TDG saturation called SYSTDG, which is used as a management tool to forecast TDG on the Columbia and Snake rivers and set daily spill caps.

Spill Operations for Fish Passage

[2] The link to the TDG Management Plan is: http://www.nwd-wc.usace.army.mil/tmt/documents/wmp/2014/Appendices/Appendix_4_-_2014_TDG_Management_Plan_final2.pdf. This was included in the information transmitted to Washington DOE on April 2, 2015.

Spill operations to facilitate downstream fish passage, coupled with fish passage configuration improvements completed at dams, is a key component of the 2014 Supplemental BiOp. The 2014 Supplemental BiOp identifies juvenile dam passage survival performance standards of 96 percent dam passage survival for spring migrants and 93 percent dam passage survival for summer migrants to ensure the survival of juvenile salmonids remains at adequate levels to avoid jeopardy of the species as they pass Columbia and Snake River dams. Current fish passage spill levels called for in the 2014 Supplemental BiOp and listed in Table 2 often generate TDG in excess of the 110 percent saturation water quality standard; however NOAA has determined that the benefit of providing controlled spill above 110 percent TDG outweighs any potential deleterious effects that elevated TDG up to modified standards provided by the states may have on ESA-listed salmon and steelhead species[3].

Table 2. Fish passage spill levels specified in the 2014 Supplemental Biological Opinion[1].

Project	2014 Supplemental BiOp Spring Spill Levels	Spring Planning Dates
Bonneville	100 kcfs	4/10-6/15
The Dalles	40%	4/10-6/15
John Day	April 10-April 27: 30% April 27-June 15: 30% and 40%	4/10-6/15
McNary	40%	4/10-6/15
Ice Harbor	April 3-April 28: 45 kcfs/Gas Cap April 28-May 30: 30% and 45 kcfs/Gas Cap	4/3-5/31
Lower Monumental	Gas Cap (~27 kcfs; bulk spill pattern)	4/3-5/31
Little Goose	30%	4/3-5/31
Lower Granite	20 kcfs	4/3-5/31
Project	**2014 Supplemental BiOp Summer Spill Levels**	**Summer Planning Dates**
Bonneville	95 kcfs and 85 kcfs/121 kcfs	6/16[2]-8/31
The Dalles	40%	6/16[2]-8/31
John Day	June 16-July 20: 30% and 40% July 20-August 31: 30%	6/16[2]-8/31
McNary	50%	6/16[2]-8/31
Ice Harbor	June 1-July 13: 30% and 45 kcfs/Gas Cap July13-August 31: 45 kcfs/Gas Cap	6/1[3]-8/31[4]
Lower Monumental	17 kcfs	6/1[3]-8/31[4]
Little Goose	30%	6/1[3]-8/31[4]
Lower Granite	18 kcfs	6/1[3]-8/31[4]

1 Voluntary spill operations and planning dates may be adjusted (increased or decreased) for research purposes or through the adaptive management process (to better match juvenile outmigration timing, and/or to achieve or maintain performance standards).
2 Transitions from spring to summer spill has changed from July 1 to June 16 based on updated run timing of subyearling fall Chinook salmon.
3 The spring to summer spill transition date at Lower Granite Dam will be based on a 95 percent passage of spring migrants and would occur no earlier than June 1. The transition date at Little Goose, Lower Monumental, and Ice Harbor dams will be staggered to factor for fish travel time from Lower Granite Dam to these dams. The stagger will be based on in-season river

[3] NOAA 2014. Risk Assessment for the Spill Program Described in the 2014 Supplemental Biological Opinion – A 2014 Update. NOAA Fisheries, January 29, 2014. NOAA Fisheries, Northwest Region, Portland, Oregon. 5 pp.

flow conditions and a calculation of water travel time between Lower Granite and the other dams.

4 Beginning August 1, curtailment of summer spill may occur first at Lower Granite Dam if subyearling Chinook collection counts fall below 300 fish per day for 3 consecutive days (beginning July 29, 30, and 31 for August 1 curtailment). Using the same 300 fish criterion, the curtailed spill would then progress downstream with each successive dam on the Snake River, with spill at Little Goose Dam (LGS) ending no earlier than 3 days after the termination of spill at Lower Granite Dam (LGR), and ending at Lower Monumental Dam (LMN) no earlier than 3 days after the termination of spill at LGS assuming the 300 fish criterion has been met at those projects. Spill would be curtailed at Ice Harbor Dam (IHR) no earlier than 2 days after LMN, without use of the 300 fish criterion. Spill will end at 0600 hours on the day after the necessary curtailment criteria are met. If after cessation of spill at any one of the Snake River projects on or after August 1, subyearling Chinook collection counts again exceed 500 fish per day for two consecutive days, spill will resume at that project only. Thereafter, fish collection count numbers will be reevaluated daily to determine if spill should continue using the criteria above (300 fish per day) until August 31. Additionally, in any year where natural-origin adult returns of Snake River fall Chinook salmon are equal to or less than 400 fish, summer spill in the following year would continue at Snake River projects through August 31, even in years where subyearling Chinook counts fall below the 300 fish per day for three consecutive days as stated above.

Spill Patterns

The spillway discharge and distribution of spill over the spillway as defined by the spill pattern, is one of the most important determinants of TDG exchange. As a general rule, the application of a uniform spill pattern over spillbays with flow deflectors minimizes the TDG exchange during a spillway operation. A uniform spill pattern is often not the most effective or efficient operation for fish passage and is not achievable with spillway weirs in place for typical river discharges. For higher river flows spill patterns have been structured to transition to a uniform pattern to minimize TDG generation. The presence of irregular bathymetry directly downstream of the stilling basin may provide an opportunity to minimize TDG exchange by developing a non-uniform pattern.

Water Regulation

The management of water storage on a daily or weekly basis can influence the magnitude and frequency of both voluntary and involuntary spill at Federal and non-Federal dams on the Columbia and Snake rivers. The scheduling of large discharges from storage reservoirs during high tributary inflows can result in involuntary spill at projects throughout the Columbia River basin. The regulation of the receiving pool elevation can have a significant impact on the tailwater elevation at the upstream project, influencing the spill jet flow regime and depth of aerated flow. System wide water regulation activities are updated on an hourly and daily basis to manage both power generation and voluntary and involuntary spillway operations.

Powerhouse Operations

A number of operational measures associated with hydropower plant operation are available to help manage TDG generation from spill by maximizing powerhouse capacity and setting unit priorities. Scheduling routine turbine maintenance and repair activities during low-power demand and river flow conditions will enable more reliable powerhouse operations during high river flows. The identification of priority turbine usage can influence the interaction of powerhouse and spillway flows. This guidance on powerhouse operations can directly influence powerhouse entrainment into the spillway or influence the habitat impacted within the mixing zone of project discharges. At low loading rates, the operation of turbines can in some cases result in the aspiration of air into the turbines resulting in the uptake of TDG. The ability to operate turbines at the upper capacity limits will maximize powerhouse flows and limit involuntary spill.

System TDG Management Operations

The Spill Priority List is a lack of load TDG management plan that has been developed for involuntary spill that results in exceeding the 110 percent TDG standard when lack of load conditions require spill. The Corps works with the region to develop the spill priority list that identifies the order in which projects spill in order to minimize TDG system wide. This list calls for adding spill incrementally across all federally owned projects to prevent excessively high TDG levels from being generated in concentrated river reaches. Excess spill is spread evenly over Federal projects to hold peak TDG levels to targeted TDG thresholds in 5 percent increments. Chief Joseph Dam is one of the projects on the spill priority list, in part, because it is an effective tool for managing system TDG levels under conditions that require spill (either lack of load or over capacity spill conditions) when TDG levels exceed the 110 percent standard. The spill priority list utilizes abatement measures implemented across the system to effectively alleviate the overall TDG production in the system. Spill priority lists may also be utilized to inform other decisions such as how to allocate reserves to the projects or manage other system obligations. The Corps' Reservoir Control Center (RCC) prepares spill priority lists based on the factors described below and revisions are discussed in the Technical Management Team (TMT) meetings as appropriate. Estimated spill levels are grouped into different TDG production levels (spill cap target levels such as 100%, 115%, and 120%) on the spill priority list such as the examples shown below:

SPILL PRIORITY LIST

Effective 1-APR-2016 until further notice (no later than 31-AUG-2016). [a]

The Spill Priority List defines the project priority order for lack-of-load spill in order to manage TDG on a system-wide basis.

If necessary to spill above FOP rates due to lack-of-load, spill will be allocated to projects in the following priority order.

Priority Order	Project	TDG Cap (%)	Example Spill Caps (kcfs)	
LEVEL 1 (State TDG Standards [a])				
1	LWG	120% / 115%	41	
2	LGS	120% / 115%	40	
3	LMN (bulk)	120% / 115%	28	
4	LMN (uniform)	120% / 115%	36	
5	IHR (night)	120% *	95 [b]	* No downstream forebay standard.
6	IHR (day)	120% *	75 [b]	* No downstream forebay standard.
7	MCN	120% / 115%	146	
8	JDA	120% / 115%	90	
9	TDA	120% / 115%	135	
10	BON	120% *	130	* No downstream forebay standard.
11	CHJ	110%	20	
12	GCL [c]	110%	OT=0; DG=5	
13	DWR	110%	30%	
LEVEL 2				
14	LWG	120%	45	
15	LGS	120%	52	
16	LMN (uniform)	120%	44	
17	MCN	120%	146	
18	JDA	120%	146	
19	TDA	120%	135	
20	CHJ	120% / 115% *	60	* Assumes spill duration ≤6 hrs.
21	GCL [c]	115%	OT=5; DG=15	
LEVEL 3 (LEVELS 4-7: same order as LEVEL 3)				
22	LWG	122%	52	
23	LGS	122%	59	
24	LMN (uniform)	122%	60	
25	IHR (night)	122%	95 [b]	
26	IHR (day)	122%	85 [b]	
27	MCN	122%	152	
28	JDA	122%	177	
29	TDA	122%	160	
30	BON	122%	160	
31	CHJ	120%	100	
32	GCL [c]	120%	OT=15; DG=40	

[a] Apr 1-Aug 31 (FOP Spring and Summer Spill) TDG standards in effect at LWG, LGS, LMN, IHR, MCN, JDA, TDA, BON for ≤120% in the tailrace (OR, WA) and ≤115% in next downstream forebay (WA), except BON which does not have a downstream forebay standard. Current spill caps are online at: http://www.nwd-wc.usace.army.mil/tmt/documents/ops/spill/caps/

[b] IHR Spill Caps based on: Night 1800-0500 (11 hrs) = FOP spill; Day 0500-1800 (13 hrs) = lack of load spill (>FOP Day 45 kcfs).

[c] GCL spill is via outlet tubes (OT) or drumgates (DG). Transition to DG at forebay elevation 1267-1270 ft.

When establishing the order dams will spill above the specified fish spill levels, the following factors are considered:

- Location of fish: Location and number of adult and juvenile fish in the migratory corridor is a factor in establishing the spill priority order on the spill priority list.
- Location of high TDG: When TDG levels are elevated (above 120 percent), dams may be shifted on the list to manage system-wide TDG levels. These decisions are coordinated with TMT members.
- Location of fish research: When fish research is planned or in progress, those dams are low on the spill priority list to minimize detrimental impact to the studies.
- River reaches: Dams are considered in one of three blocks: the lower Snake River, the lower Columbia River, and the middle Columbia River. For example, if several of the lower Snake River dams need to be moved to a lower priority on the spill priority list, then the whole block of dams (Lower Granite, Little Goose, Lower Monumental, and Ice Harbor dams) may be moved to last position on the list.
- Special operations: Dams with special operations such as construction, maintenance, repair, or dam safety concerns are placed last on the spill priority list.
- Collector dams: During low flow years, the collector dams (Lower Granite, Little Goose, and Lower Monumental dams) are placed low on the spill priority list.
- Special fish conditions: If there are special fish conditions, such as disease or a special release, the dam may be moved higher or lower on the spill priority list, depending on circumstances.
- System-wide TDG management: Grand Coulee, Chief Joseph, Dworshak, and other projects may be used to help balance system-wide TDG levels during periods of involuntary spill.

B. Structural Accomplishments

The Corps has constructed a number of structures that have resulted in TDG abatement benefits since the initiation of the TDG abatement evaluation program in 1994. TDG abatement projects on the Columbia and lower Snake rivers include the addition of spillway flow deflectors at all projects except The Dalles Dam, spillway training walls, and fish passage improvements including spillway weirs and surface bypass structures. Spillway flow deflectors are recognized as being the most effective means of reducing the TDG production during spillway operations for a wide range of flow conditions. Spillway flow deflectors prevent the turbulent spill jet from plunging to the bottom of the spillway by creating a surface oriented jet that entrains and transports air bubbles much closer the water surface. In many cases, specific structural and operational modifications have been implemented in addition to TDG abatement measures to maintain dam safety, navigation, hydropower, flood control, and fish guidance functions. A general overview of the structural and operational TDG abatement improvements for each dam is listed below.

Bonneville Dam – Spillway flow deflectors on 6 of the 18 spillbays were designed and built in 2002 and new spill patterns developed to optimize TDG exchange and fish conveyance properties in the spillway exit channel. These updated spillway flow deflectors when coupled with original flow deflectors on spillbays 4-15 resulted in deflectors present in all 18 spillbays. The combined effect of these structural and operational actions resulted in a significant reduction in TDG exchange. Prior to the application of these TDG abatement measures, a spillway release of 100 kcfs generated a TDG saturation of 125 percent and higher compared to 118 percent for current conditions. Improvements to fish passage facilities such as the Bonneville II Powerhouse Corner Collector (B2CC) and juvenile bypass outfall have improved fish passage and survival and reduced the amount of spill required to meet fish passage objectives. Additionally, the TDG fixed monitoring program at Bonneville Dam has been improved by relocating the tailwater monitoring station from a mixed river location to a station directly measuring the TDG levels in undiluted spillway flows.

The Dalles Dam – The Dalles Dam remains the only Corps project without spillway flow deflectors. Shallow bathymetry characteristics immediately below the spillway moderate TDG generation during spillway flows but also limit the potential effectiveness of spillway flow deflectors. The Dalles Dam is equipped with a spillway training wall between spillbays 6 and 7 and a newly constructed extended wall located between spillbays 8 and 9 was completed in 2010. Although the extended wall was primarily built to improve fish passage and survival, the impacts on TDG exchange were factored into the design and operation. Efforts to improve fish passage at The Dalles Dam have resulted in a reduction on the reliance of spill for fish passage from over 60 percent spill in years past to the current spill operations of 40 percent of the total river flow. This reduction in voluntary spillway flows has resulted in reductions in TDG saturation as measured at the tailwater fixed monitoring station from 120.0 to 116.9 percent saturation for a total river flow of 250 kcfs and background TDG saturation of 110 percent.

John Day Dam – A number of structural and operational alternatives have been implemented at John Day Dam to reduce TDG supersaturation in spillway flows. Construction of spillway flow deflectors was completed in 1998 on 18 of the 20 spillbays (2-19) and new spill patterns developed. Prior to the addition of spillway flow deflectors, spillway flows of 100 kcfs at John Day Dam generated TDG levels of 135 percent saturation compared to current levels of 118 percent when spilling 100 kcfs. The addition of spillway flow deflectors allowed for higher volume fish spills subject to the TDG criteria adjustments. A surface bypass program at John Day Dam is underway and includes the addition of two spillway weirs that are designed to improve fish passage while maintaining effective skimming flow throughout the tailrace channel for TDG abatement. An extended-length deflector was constructed in spillbay 20 in 2010 to provide additional TDG gas abatement.

McNary Dam – A total of four new spillway flow deflectors were installed in spillbays 1, 2, 21, and 22 at McNary Dam in 2001 to complete the full installation of this TDG abatement measure. The development of spill patterns utilizing all 22 spillbays resulted in a reduction of TDG supersaturation during both voluntary and involuntary spill conditions. Distributing spill uniformly over 22 spillbays, instead of 18, reduced the TDG generation associated with a spill of 100 kcfs 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 adding four new 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 passage. The non-uniform spill pattern associated with these spillway weirs has not significantly influenced the spill capacity as limited by tailwater TDG criteria.

Ice Harbor Dam – Prior to the TDG abatement program, spillway flows of 50 kcfs at Ice Harbor Dam resulted in TDG saturations of 135 percent and higher. Spillway flow deflectors were installed on all ten spillbays over a three year period from 1997-1999 resulting in significant reductions in TDG generation. Spillway releases of 50 kcfs today can result in TDG saturations as low as 113 percent of saturation. Spillway flows as high as 95 kcfs can be maintained at Ice Harbor Dam subject to the TDG tailwater criteria adjustment of 120 percent. Additional structural modifications to the spillway and downstream lock approach were required in conjunction with spillway flow deflectors to provide for suitable flow conditions for navigation and fish passage concerns. A spillway weir was designed and put into operation in 2005 for the purpose of improving fish passage while maintaining effective TDG abatement flow conditions in the tailwater channel. Currently, voluntary spillway flows at Ice Harbor Dam generate the lowest TDG levels of the eight dams included in this study as a consequence of the efficient skimming flow caused by flow deflectors and the shallow tailrace channel properties.

Lower Monumental Dam – The original spillway at Lower Monumental Dam contained spillway flow deflectors on 6 out of the 8 spillbays. The spill patterns were revised during the TDG abatement program to restrict spill to spillbays with flow deflectors resulting in a doubling of the spill capacity as limited by the tailwater TDG criteria. Spillway flow deflectors were added to the end spillbays for the 2004 fish passage season. The addition of two new flow deflectors resulted in an updated spill patterns using the entire spillway causing a reduction in TDG saturations from 132.1 to 118.2 percent for a spillway discharge of 50 kcfs. A spillway weir was put into service at Lower Monumental Dam for the 2008 fish passage season. The "bulk" spill pattern resulting from the high discharge through the spillway weir and associated training spill does increase the TDG generation for voluntary fish spill but the influence of the spillway weir on TDG generation dissipates at high spillway flows.

Little Goose Dam – Two new spillway flow deflectors were built at Little Goose Dam in 2008-9 to complete spillway flow deflector development across the entire spillway. The updated deflector designs included a longer deflector with a 25 ft radius toe curve to support safe juvenile fish passage. The flow deflectors were built in conjunction with a spillway weir designed to support downstream fish passage. The additional spillway flow deflectors will provide for TDG abatement during involuntary spillway releases. The additional spillway flow deflectors and updated spill patterns are estimated to produce TDG saturations of 121.1 percent during an involuntary spill of 64 kcfs compared with 131.5 percent for a uniform spill without the end spillbay deflectors. The spillway weir was put into service for the 2009 fish passage season. The "bulk" spill pattern resulting from operation of the spillway weir at Little Goose Dam was found to generate higher TDG levels when compared to a uniform pattern over the seven spillbays with a spillway weir.

Lower Granite Dam – Lower Granite spillway was built with spillway flow deflectors designed to minimize the production of TDG supersaturation during spillway releases. Lower Granite Dam is unique in that the background TDG levels remain at 110 percent or less for all flow conditions. In 2001, a spillway weir and spill pattern were designed and implemented to effectively guide fish during voluntary spill events while minimizing the generation of TDG pressures during involuntary spill conditions. The introduction of the spillway weir reduced the dependence on spillway flows to aid fish passage. Previous fish spill policies at Lower Granite

Dam called for spilling as much water as possible, generally 40 to 50 kcfs, without exceeding the tailwater TDG criteria. The current voluntary spill operation is a fixed discharge of 20 kcfs. The TDG loading impacts of this new spill operation change were significant reducing the average TDG saturations in the Snake River below Lower Granite Dam from as high as 115.4 percent to 110 percent.

Chief Joseph Dam[4] – The Chief Joseph Dam total dissolved gas abatement report recommended that spillway flow deflectors be implemented in combination with joint operations with Grand Coulee Dam. The spillway flow deflectors were completed in October of 2008 on all 19 spillbays. The field evaluation of the TDG exchange performance was conducted in April and May of 2009 with the final report describing the test results and proposed joint operations policy scheduled to be completed during the summer of 2010.

The spillway flow deflectors installed at Chief Joseph Dam have been successful at reducing TDG levels during spill. During testing and actual operations, these spillway flow deflectors reduce TDG levels in the tailrace associated with spill at Chief Joseph Dam when inflow TDG levels are above 120 percent. Consequently, spilling at Chief Joseph Dam when incoming TDG levels are elevated can reduce system TDG loading, therefore Chief Joseph Dam has been placed on the spill priority list to help manage overall system TDG production under lack of load spill conditions.

Results of Increased Spill Capacity Due to Implementation of Flow Deflectors

The addition of spillway flow deflectors has been the primary structural alternative employed to abate TDG generation at Corps projects on the Snake and Columbia rivers. Since the initiation of the Corps gas abatement program in 1994, 14 flow deflectors were added to the Snake River projects. In addition, a total of 30 flow deflectors were added to the Columbia River projects. A summary of the spill capacity as limited by the tailwater TDG criteria of 120 percent before and after the installation of spillway flow deflectors is listed in Table 3; Table 3 also includes spill cap ranges as observed in 2015. The conditions in 1995 assumed the structural configuration and spill patterns applied at that date. The updated conditions in 2009 reflect the application of a uniform spill pattern without the impacts of spillway weirs. This scenario reflects the ideal conditions upon which to minimize the generation of TDG supersaturation. The addition of these flow deflectors has increased spill capacity from 319 kcfs in 1995 to 775 kcfs in 2009.

[4] Chief Joseph Dam is not a project that passes juvenile fish, but with the addition of flow deflectors, use of this project to manage system TDG levels has been very effective.

Table 3. Project summary of spill capacity in kcfs limited by tailwater TDG of 120% as impacted by the construction of spillway flow deflectors.

	1995	2009[1]	2015	Comment
Project	Spill (kcfs) @ 120%			
Bonneville	0	120	100-140	Deflectors in all 18 bays
John Day	65	150	144-165	Deflectors in 19 of 20 bays
McNary	140	190	146-209	Deflectors in all 22 bays
Ice Harbor	23	95	85-95	Deflectors in all 10 bays
Lower Monumental	34	60	44-60 (uniform spill pattern)	Deflectors in all 8 bays
Little Goose	25	60	52-55	Deflectors in all 8 bays
Chief Joseph	32	100	60-110	Deflectors in all 19 bays
	5[2]	20[2]	20[2]	

[1] Assumes uniform pattern without spillway weirs

[2] Spill at 110% TDG (kcfs)

Actions Completed to Reduce Systemwide Total Dissolved Gas Production, 2010-2014

Table 4 includes actions completed to reduce systemwide total dissolved gas since 2010. Additional operational improvements, such as spill level and spill pattern refinements at the eight fish passage dams have further contributed to reducing systemwide TDG production. Spill patterns for each project are defined in the annual Fish Passage Plan (FPP), and are revised through regional coordination as necessary for improved fish passage conditions. Since 2010, spill patterns have been revised to account for fish passage structural modifications (e.g., The Dalles Dam spillwall; Little Goose Dam spillway weir crest changes; John Day Dam relocation of spillway weirs) and for in-season adaptive management (e.g., patterns at lower spill rates during low flow conditions; Ice Harbor Dam modified patterns for juvenile egress during spillbay outage). Additionally, TDG production during lack of load involuntary spill conditions is managed throughout the FCRPS with implementation of the spill priority list. During periods of lack of load involuntary spill the spill priority list is utilized to evenly distribute spill throughout the FCRPS in an effort to manage/minimize TDG production to the extent possible. Furthermore, the spill priority list is coordinated with regional sovereigns to ensure implementation in a manner that does not adversely impact salmon.

Table 4. Configuration actions completed at FCRPS projects since 2010 to reduce systemwide TDG production.

Location	Improvement	Year	Purpose
John Day Dam	Spillbay 20 Extended-length Flow Deflector	2010	Improve tailrace egress conditions for fish passing through the spillway weirs. Reduce TDG production at Bay 20.
The Dalles Dam	Spillwall between spillbays 8 and 9	2010	Improve tailrace egress conditions for fish passing through the spillway.

VI. Future Opportunities for TDG Abatement

There are limited additional structural alternatives available to significantly reduce TDG production levels that are not detrimental to fish passage survival. As noted above, the Corps has installed flow deflectors at most projects to reduce TDG production across all flow conditions. Modification of spillway flow deflectors could further reduce TDG production during 7Q10 flow events, but these modifications would likely prove to be detrimental to fish survival and not be as effective at reducing TDG production during voluntary spill conditions. The development of spillway training walls can impact the cross-sectional average TDG pressures at some projects, but will have little impact on TDG levels generated in spillway flows. The expansion of the spillway capacity through additional chutes or spillbays may also have relatively small impacts because of the large size of existing spillway structures compared to additional channels created. Measures taken to increase the hydraulic capacity of the powerhouses of any of the projects evaluated in this study may have a small impact on critical spill magnitude and the resultant TDG pressures. The Corps conducted the Dissolved Gas Abatement Study (DGAS, 2002) to evaluate structural and operational modifications to assess options to achieve applicable TDG standards at Corps dams. These included flow deflectors which were added to the Corps dams for gas abatement. Additional options were considered, but none successfully achieved the current water quality standard of 110% without having negative impacts on ESA-listed migrating fish.

Pursuant to the 2014 Supplemental BiOp and its Incidental Take Statement[5], the Corps will continue to implement configuration actions and refine voluntary fish passage spill operations necessary to meet the juvenile dam passage survival performance standards. Some of these refinements may provide a reduction in systemwide TDG production at times. In general, the configuration and operation actions taken at many of the dams to increase the survival of yearling Chinook salmon and juvenile steelhead have produced the benefits anticipated in the 2014 Supplemental BiOp (Figures 3 and 4), and it is likely these will continue into the foreseeable future.

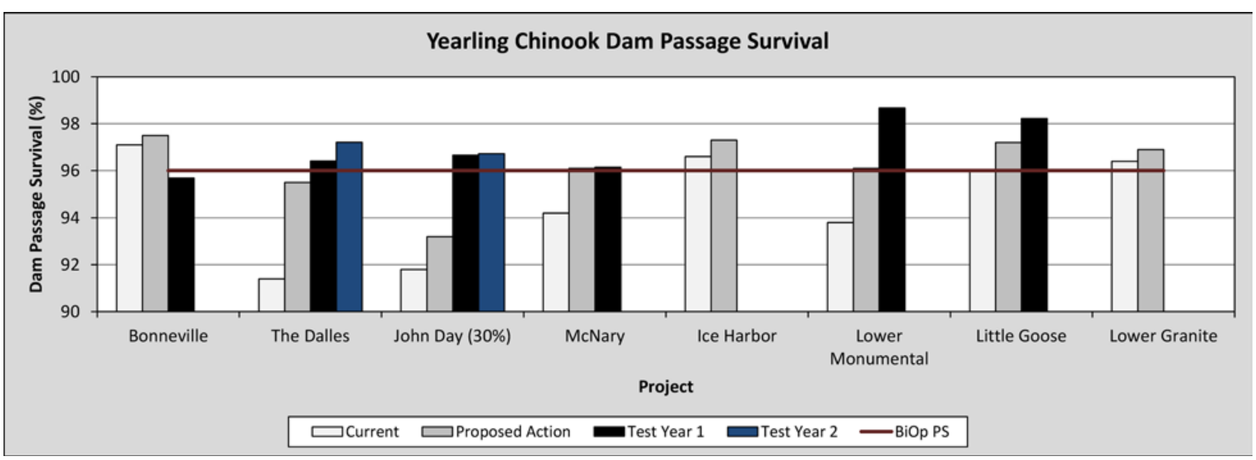

Figure 3. Yearling Chinook COMPASS Dam Passage Survival Estimates Compared to Recent Empirical Test Results. "Current" = COMPASS-based expected survival based

[5] The ESA provides for authorized incidental take of ESA listed species within defined parameters.

on improvements in place at the time of the FCRPS BiOp. "Proposed Action" = COMPASS-based expected survival after implementation of the improvements called for in the FCRPS BiOp's RPA. Empirical survival estimates derived from post-construction juvenile dam passage survival studies.

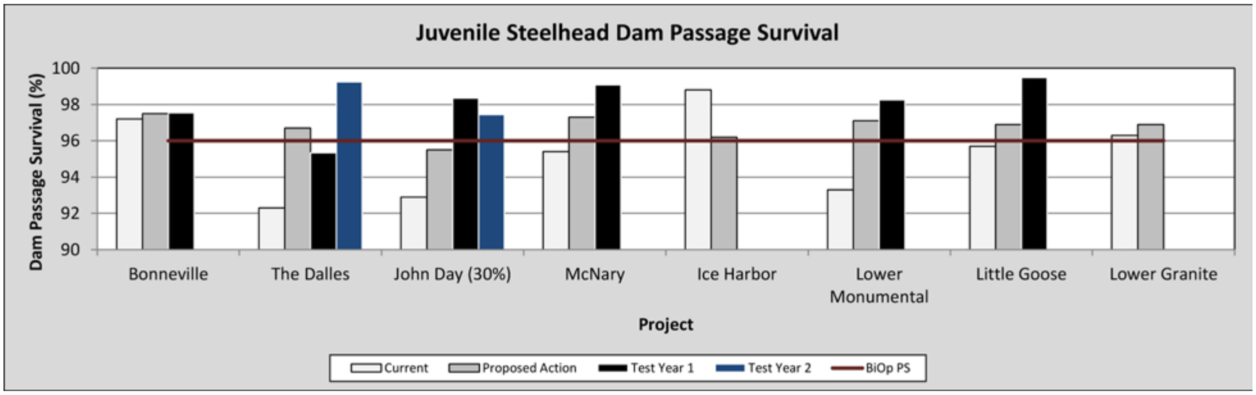

Figure 4. Juvenile Steelhead COMPASS Dam Passage Survival Estimates Compared to Recent Empirical Test Results. "Current" = COMPASS-based expected survival based on improvements in place at the time of the FCRPS BiOp. "Proposed Action" = COMPASS-based expected survival after implementation of the improvements called for in the FCRPS BiOp's RPA. Empirical survival estimates derived from post-construction juvenile dam passage survival studies.

Fish Passage Improvements

Structural and operational measures designed to achieve BiOp performance standards focus efforts on producing fish survival benefits being mindful of achieving the TDG water quality standards. Future potential changes in fish spill operations towards lesser spill could reduce the TDG loading.

Surface passage structures are now in place at all eight dams to improve juvenile fish passage conditions, reduce fish delay in forebays, increase overall juvenile fish survival and potentially reduce TDG by spilling less water to achieve juvenile dam passage survival performance standards specified in the 2014 Supplemental BiOp. Most juvenile salmon tend to migrate in the upper 10 – 35 feet of the water column as they migrate downstream to the ocean. Spillway weirs provide surface flow outlets that take advantage of the surface-oriented behavior of juvenile salmon to facilitate more expedient passage at the dams.

Juvenile bypass systems guide fish away from turbines by means of submerged screens installed in front of the turbine intakes. As fish follow currents down toward the turbines, the screens guide the fish back up to channels in the dam. The fish are then either routed to the river below the dam or loaded into barges or trucks for transport. Although bypass systems are in operation at seven of the eight lower Columbia and Snake River dams, modifications to these systems are ongoing to improve fish survival.

Programs designed to improve fish survival through turbines, predatory removal programs, surface bypass improvements, tailwater egress operations or structural modification, and behavioral guidance barriers are just several of the areas where significant improvement to fish passage have been demonstrated. For example, fish spill operations at The Dalles Dam previously called for spilling over 60 percent of the instantaneous flow in the Columbia River during the fish passage season, as compared to the current operation of spilling 40 percent of the flow. Because the commitment to fish passage spill makes up the majority of the TDG loading produced at the lower Columbia and lower Snake river dams during the course of the year, small reductions in the reliance on spill to guide fish can translate into sizable reduction in the TDG loading when integrated over the entire year.

Future TDG Abatement Opportunities by Project

The prospects for further improvements in reducing the TDG loading at each project through structural and operational measures are discussed below.

A. Bonneville Dam

The modification of spillway flow deflectors for the interior spillbays 4-15 would have a de minimis TDG abatement benefit. Incremental improvements in fish passage facilities and operations may lead to a less important reliance on spill to meet juvenile fish dam passage survival standards. Performance standard testing has supported the adoption of the 95 kcfs (vs 85 / 121 kcfs) spill operation during summer fish passage operation. This operation is under regional review and when adopted may slightly reduce TDG production at Bonneville Dam during summer.

B. The Dalles Dam

The addition of the spillwall located between spillbays 8/9 and the revised spill pattern concentrating spill to the northern end of the spillway modified the hydraulic flow field defining the TDG exchange characteristics at this project. In addition, juvenile fish passage survival at the dam increased under current spill levels (40 percent of river flow) to meet the juvenile fish dam passage survival performance standards. The implementation of system-wide TDG management practices (e.g. spill priority list) can reduce the scheduled spillway flows at high river flows given the large hydraulic powerhouse capacity at The Dalles Dam.

C. John Day Dam

The completion of a flow deflector in spillbay 20 at John Day Dam has resulted in an increase in the critical spill discharge generating TDG levels at 120 percent while providing improved juvenile egress conditions in the tailrace channel. The powerhouse at John Day Dam has the largest hydraulic capacity of any of the Federal dams on the Columbia River and smallest critical spillway discharge at the 7Q10 river flow of 110 kcfs. The TDG exchange associated with uniform spill over 18 spillbays as high as 180 kcfs have been observed to generate TDG levels at 120 percent and less at John Day Dam. The model estimates of TDG generation at John Day with the additional completed flow deflector in spillbay 20 at the 7Q10 river flow were slightly above (4 mm Hg) the 120 percent criteria but fall well within the confidence limits of the TDG generation model. The TDG monitoring of future spill activities at John Day Dam with the new structural configuration should continue to document TDG generation and attainment of TDG standards. Fish passage spill levels at John Day Dam are under review to determine what spill level in combination with structural improvements made at the dam will provide a level of juvenile fish passage survival that will satisfy the juvenile fish dam passage survival performance standards specified in the 2014 Supplemental BiOp.

D. McNary Dam

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. Increasing the hydraulic capacity of the McNary powerhouse through upgrading turbines can lower the forced 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. Turbine upgrades are planned at McNary Dam to increase turbine capacity; however the upgrade will likely take many years to complete once initiated. Expanding the capacity of either the ice and trash sluiceway or powerhouse surface bypass channel would result in a small increase in TDG loading for voluntary spill conditions provided the commitment to spillway flows does not change. However, these measures can only provide for a substantial reduction in TDG loading for voluntary spill operations if they result in a fish spill operation that relies on smaller volumes of spill.

E. Ice Harbor Dam

The spill capacity at Ice Harbor Dam as limited by the tailwater TDG criteria is the largest of the eight projects evaluated in this study when taking into account the spillway size. A component of the fish spill operation at Ice Harbor involves "spilling to capacity at 120 percent" which can result in spilling nearly the entire river during moderate to low river flows. The greatest potential to reduce the TDG involves reducing the reliance on spill to guide juvenile salmonids. Fish passage spill levels at Ice Harbor Dam are still under review to determine what spill level in combination with structural improvements made at the dam will provide a level of juvenile fish passage survival that will satisfy the juvenile fish dam passage survival performance standards specified in the 2014 Supplemental BiOp. The resulting spill level(s) may be less than current spill to 115/120 percent TDG. In addition, turbine replacement of units 2 and 3 that is currently underway may help reduce TDG production somewhat, but the effect will be minimal.

F. Lower Monumental Dam

The critical spill discharge at Lower Monumental Dam is the largest of the eight projects considered in this study when factoring the size of the spillway. The highly variable and non-uniform spill pattern at Lower Monumental Dam can produce TDG levels that approach and exceed TDG limits at the tailwater and downstream forebay monitoring stations for modest spillway discharges as low as 27 kcfs. The unique reservoir configuration combined with environmental conditions downstream of Lower Monumental Dam often results in very little degassing of the water spilled at Lower Monumental Dam once the water reaches the Ice Harbor Dam forebay. As a result, balancing the need to provide adequate fish passage spill at Lower Monumental Dam while not exceeding the 115 percent TDG limit in the Ice Harbor Dam forebay is challenging and often results in TDG levels that exceed 115 percent TDG. Consequently, maintaining performance standard spill for fish passage is prioritized over managing to 115 percent in the Ice Harbor Dam forebay. A review of spill operations during preparation for the next BiOp to reduce spill from the current gas cap spill levels during spring may help reduce TDG loading during voluntary spill operations at Lower Monumental Dam.

G. Little Goose Dam

Little Goose Dam is currently configured with 8 deflectors and a spillway weir. The spillway training wall was one of several alternatives under consideration to improve juvenile fish survival. The spillway training wall was eliminated from further consideration because it would not reduce TDG production at the spillway during spill, and further analysis identified a spillway weir as the preferred alternative to meet juvenile fish survival standards. The spillway weir was installed, tested, and met the juvenile survival standards.

H. Lower Granite Dam

The positioning of Lower Granite Dam on the Snake River far removed from potential upstream sources of TDG supersaturation results in low background TDG levels. The spillway training wall was one of several alternatives under consideration to improve juvenile fish survival. The spillway training wall was eliminated from further consideration because it would not reduce TDG production at the spillway during spill. No additional actions have been identified to further reduce TDG production in the tailrace during fish passage spill operations.

VII. Conclusion

The implementation of structural and operational alternatives has steadily made headway over the past 20 years to moderate TDG supersaturation in the Columbia and Snake rivers. Considering that significant TDG abatement has been accomplished through structural and operational improvements, limited opportunities are available for further TDG reduction. However, with aging turbine units, the Corps anticipates the need for turbine rehabilitation at all mainstem projects, in addition to Ice Harbor and McNary. The Corps is committed to meeting its Clean Water Act and ESA responsibilities, which currently requires fish passage spill at the lower Columbia and lower Snake River projects while operating the projects consistent with applicable state water quality standards for TDG saturation to the extent practicable.

In addition, as noted in the 2009 TDG exchange evaluation achieving the TMDL(s) goal of 110 percent TDG outside of the fish passage season is not achievable during high flows, but meeting 115/120 percent TDG during fish passage season is feasible. The Corps will continue to implement configuration actions and refine fish passage spill operations to meet the juvenile dam passage survival performance standards specified in the 2014 Supplemental BiOp. No further configuration actions aimed to improve juvenile dam passage survival have been identified that will significantly reduce TDG production. However, the Corps will continue to refine fish passage spill operations and implement configuration actions in accordance with the BiOp performance standards and these refinements may provide some reduction in systemwide TDG production (Table 5).

Table 5. Configuration or operation actions that may slightly reduce TDG production during fish spill operations.

Location	Improvement
Bonneville Dam	Adopting 95 kcfs spill operation during the summer fish passage season
John Day Dam	Adopting 30 percent spill operations during spring and summer fish passage seasons
McNary Dam	Turbine unit upgrades
Ice Harbor Dam	Adopting spill operations below TDG spill cap during spring and summer fish passage seasons Turbine unit upgrades
Lower Monumental Dam	Adopting spill operations below the TDG spill cap during the spring fish passage season