

Total Maximum Daily Load for Lower Snake River Total Dissolved Gas



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Total Maximum Daily Load for Lower Snake River Total Dissolved Gas

*by
Paul J. Pickett and Mike Herold*

Washington State Department of Ecology
Environmental Assessment Program
Olympia, Washington 98504-7710

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Acronyms and Abbreviations

Corps	U.S. Army Corps of Engineers
CRITFC	Columbia River Inter-Tribal Fish Commission
DGAS	Dissolved Gas Abatement Study
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FMS	Fixed Monitoring Station
fmsl	feet above mean sea level
kcf/s	thousand cubic feet per second
mm Hg	Millimeters of Mercury
MOA	Memorandum of Agreement
NOAA	National Oceanic and Atmospheric Administration
NOAA Fisheries	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
TDG	Total Dissolved Gas
TMDL	Total Maximum Daily Load
WAC	Washington Administrative Code
303(d)	Section 303(d) of the federal Clean Water Act
7Q10	Seven-day, ten-year frequency flow
ΔP	Excess gas pressure over barometric pressure

Abstract

This Total Maximum Daily Load (TMDL) addresses total dissolved gas (TDG) in the mainstem Snake River from its confluence with the Clearwater River to its mouth at the Columbia River. Washington State has listed multiple reaches of the Lower Snake River on its federal Clean Water Act 303(d) list due to TDG levels exceeding (violating) state water quality standards. The entire reach is considered impaired for TDG. Washington State is issuing this TMDL and submitting it to the U.S. Environmental Protection Agency for its approval.

Spill events at four hydroelectric projects on the Lower Snake River – Lower Granite, Little Goose, Lower Monumental, and Ice Harbor dams – elevate TDG to levels that violate state standards. Water plunging from a spill entrains air and carries it to a depth where hydrostatic pressure forces gas into solution at high levels. High TDG can cause “gas bubble trauma” in fish, which can cause chronic or acutely lethal effects, depending on TDG levels. A spill can be caused by several conditions. A “voluntary” spill is provided to meet juvenile fish passage goals. An “involuntary” spill is caused by lack of powerhouse capacity for river flows. An involuntary spill can result from turbine maintenance or breakdown, lack of power load demand, or high river flows. The load allocations do not apply at river flows greater than the 7Q10 flow rate. Measurements of TDG levels in the pool at the upstream boundary of the TMDL area occasionally exceed standards, and appear to be related to solar heating and photosynthesis in the Lower Granite pool.

This TMDL sets a TDG loading capacity for the Lower Snake River in terms of percent saturation for fish passage spills, and in terms of excess pressure above ambient during non-fish passage conditions. Load allocations also are expressed in the same terms as loading capacity, and must be met within compliance areas above and below each dam, from the Idaho border to the Columbia River. The compliance area boundary at each dam’s tailrace begins at a specified distance below the spillway, corresponding to the end of the aerated zone. Allocations are set for each dam’s tailrace and forebay under fish passage spills, and for the entire river during non-fish passage conditions.

An implementation plan is provided that describes short-term compliance with the federal Endangered Species Act requirements. Long-term compliance is described for both Endangered Species Act and TMDL requirements.

Acknowledgements

The Washington State Department of Ecology wishes to acknowledge the cooperation of the following agencies in the production of this TMDL.

- The U.S. Army Corps of Engineers (Walla Walla District and Northwest Division) has provided extensive technical information for this TMDL. Large tracts of the technical analysis have been quoted or paraphrased from the Corps' Dissolved Gas Abatement Study (DGAS). This TMDL would have been much more difficult without the understanding of total dissolved gas production resulting from the DGAS study.
- The National Marine Fisheries Service has provided valuable advice and review. The Biological Opinion issued in December 2000 pursuant to the Endangered Species Act was invaluable in describing the studies that have been conducted to date, and in specifying the effects of total dissolved gas on fish.
- The U.S. Environmental Protection Agency provided assistance, both financial and technical, in the production of this TMDL.
- The Columbia River Inter-Tribal Fish Commission (CRITFC) has provided valuable review and coordination. Staff from the Yakama, Nez Perce, Colville, Spokane, and Umatilla Tribes also have contributed to the process.
- Many other individuals have provided review and input.

Nothing in this TMDL purports to represent the technical or policy positions of any of the above agencies or organizations. This TMDL is entirely the responsibility of the Washington State Department of Ecology.

Executive Summary

Description of Waterbody, Pollutant of Concern, and Pollutant Sources

This Total Maximum Daily Load (TMDL) addresses total dissolved gas (TDG) in the mainstem Snake River from its confluence with the Clearwater River (the Idaho state line) to its mouth at the Columbia River. The state of Washington has listed multiple reaches of the Lower Snake River on its federal Clean Water Act 303(d) lists due to TDG levels exceeding (violating) state water quality standards. The entire reach is considered impaired for TDG. Washington is issuing this TMDL and submitting it to the U.S. Environmental Protection Agency for its approval.

Elevated TDG levels are caused by spill events at four hydroelectric projects on the Lower Snake River: Lower Granite, Little Goose, Lower Monumental, and Ice Harbor dams. Water spilled over the spillway of a dam entrains air. When carried to depth in the dam's stilling basin, the higher hydrostatic pressure forces air into solution. The result is water supersaturated, relative to equilibrium at the surface, with dissolved nitrogen, oxygen, and the other constituents of air.

Fish in this water may not display signs of difficulty if the higher water pressures at depth offset high TDG pressure passing through the gills into the blood stream. However, if the fish inhabit supersaturated water for extended periods, or rise in the water column to a lower water pressure at shallower depths, TDG may come out of solution within the fish, forming bubbles in their body tissues. This gives rise to gas bubble trauma, which can be lethal at high levels, or give rise to chronic impairment at lower levels. There is extensive research reported in the literature on the forms of physical damage to fish that represent the symptoms of gas bubble trauma.

Spill can occur at any time for several reasons:

- Fish passage spill (voluntary spill) conducted under the Biological Opinion in compliance with the federal Endangered Species Act.
- Spill required when flow exceeds powerhouse capacity (involuntary spill).

There are three main reasons for involuntary spill:

- The powerhouse cannot pass flood flows.
- The powerhouse is off-line due to lack of power demand.
- The powerhouse is off-line for maintenance or repair.

Dams on the Lower Snake River are run-of-the-river dams with very little storage capacity. Therefore, spills are often forced due to operational decisions at upstream storage reservoirs, such as Dworshak Dam or Idaho Power's Hells Canyon Complex.

This document describes the production of TDG at the four projects in the Lower Snake River. It presents general equations representing the production of TDG, and specific equations taking into account each project's particular physical characteristics. Any other sources of TDG in the TMDL area, such as tributaries, are considered negligible compared to the four dams. TDG is also affected by barometric pressure, wind, biological productivity (photosynthesis), and water temperature. These influences are addressed in the TMDL.

Description of Applicable Water Quality Standards and Numeric Target

The water quality standards for Washington have a TDG criterion of *110% of saturation not to be exceeded at any point of measurement*. This criterion does not apply to flows above the seven-day, ten-year frequency flow (7Q10) flood flow. In addition, special "waiver" limits for TDG have been established as a special condition in Washington rules. They allow higher criteria with specific averaging periods during periods of spill for fish passage, subject to the Washington State Department of Ecology (Ecology) approval of a gas abatement plan. This TMDL addresses both the 110% criterion and the waiver limits, recognizing that waiver limits will only apply under conditions designated by Ecology.

Loading Capacity

Loading capacity for TDG under non-fish passage conditions has been defined in terms of excess pressure over barometric pressure (ΔP). This parameter was chosen because it can be directly linked to the physical processes by which spill generates high TDG, and it has a simple mathematical relationship to TDG percent saturation. A loading capacity of 74 mm Hg has been assigned to the Snake River in this TMDL area, based on meeting 110% saturation during critically low barometric pressure conditions.

Loading capacity for fish passage conditions have been set equal to the criteria for the tailrace and forebays of the dams.

Pollutant Allocations

Because of the unique nature of TDG, load allocations for dam spills are not directly expressed in terms of mass loading. Like loading capacity, load allocations for non-fish passage conditions are made in terms of ΔP defined site-specifically for each dam's forebay and tailrace. A load allocation is also specified for the upstream boundary of the TMDL area. The wasteload allocation under this TMDL is zero, because no NPDES-permitted sources produce TDG.

The temperature change during the pool's time of travel under critical conditions was evaluated. An analysis of wind patterns indicates that winds produce very little degassing during conditions of high temperature increase. Therefore the effect of wind-induced degassing is not included in allocations. However, allocations were set at both the forebay and tailrace, which helps take into account the effect of temperature changes.

The allocation for Ice Harbor Dam is based on the upstream boundary allocation for the Lower Columbia River TDG TMDL. During Phase 1 of the implementation of the Lower Columbia River TDG TMDL, approval of gas abatement plans allows for higher TDG levels from spills that promote fish passage.

Long-term compliance with load allocations in dam tailraces will be at the downstream end of the aerated zone below each spillway. Distances are specified for the upstream end of the compliance area at each dam. As a result, the load allocation must be met in the spill from each dam individually at a specified boundary of the compliance area, with allowance made for degassing in the tailrace below the spillway and above the compliance area. Compliance with the forebay load allocations will be at the forebay of the downstream dam, and throughout the pool for non-fish passage conditions. Compliance with the upstream boundary allocation will be at the Idaho state line.

Compliance with load allocations are tied to structural changes at each dam, and are intended as long-term targets. Short-term compliance will be established under the implementation plan, and will be based on operational management of spills, implementation of the “fast-track” Dissolved Gas Abatement Study (DGAS) structural modifications, and compliance with Endangered Species Act requirements and TDG waiver criteria.

Margin of Safety

A margin of safety is supplied implicitly by use of conservative critical conditions for ambient barometric pressure, time of travel, and water temperature, and by the low probability that these critical conditions will occur at the same time. The potential for wind-induced degassing, which may occur on occasion but was not included in the TMDL, also provides a margin of safety. The TDG criterion itself provides a margin of safety due to its stringency as compared to site-specific effects documented by extensive site-specific research on TDG and aquatic life in the Snake River. Due to extensive data collection in the TMDL area, the margin of safety required for data uncertainty is small.

Seasonal Variation

Spills and associated high TDG levels, although most likely to occur in the spring and early summer, can potentially occur at any time. Therefore, TMDL load allocations apply year-round. Seasonal effects have been evaluated in the development of critical conditions, but seasonal variations appear to be small. The TMDL also takes seasonal variability into account by providing separate allocation for fish spill and non-fish spill conditions. The TMDL only applies for flows below the 7Q10 flood flows, which have been calculated for the TMDL area.

Monitoring Plan

Long-term compliance with load allocation will be monitored at the compliance location below the aerated zone with special studies in the tailrace of the dam, following structural

modifications. Also, continuous monitoring will be used for long-term compliance by determining the statistical relationship between continuous monitors and conditions at the compliance location, and between the tailrace and downstream forebay monitor. Synoptic surveys may also be useful for establishing temperature increases in the pools, but will probably only be needed if changes in water temperature management are implemented. Monitoring of implementation and operational controls in the short term will use continuous monitoring at fixed monitoring station sites.

Summary Implementation Strategy

The Summary Implementation Strategy incorporates actions described and analyzed by the National Marine Fisheries Service in the Biological Opinion and by the U.S. Army Corps of Engineers in its Dissolved Gas Abatement Study. Both short-term (Phase I) and long-term (Phase II) measures are described with specific TDG and spill reduction measures. Phase I is in effect through 2010; Phase II begins in 2011 and continues through 2020. The Summary Implementation Strategy has been developed in consultation with the National Marine Fisheries Service, so that TMDL implementation will be coordinated with requirements of the Endangered Species Act.

Public Participation

Extensive public involvement activities, organized by the inter-agency TMDL Coordination Team, have occurred under this TMDL for several years. Activities have included websites, focus sheets, coordination meetings, stakeholder meetings, conference presentations, and public workshops. A 40-day public comment period began on February 24, 2003 and ended April 4, 2003. A public hearing was held in Kennewick, Washington on March 25, 2003.

Introduction

State water quality standards establish criteria at levels that ensure the protection of the water's beneficial uses. Water that fails to meet water quality standards triggers a state action in Washington. The Washington State Department of Ecology is charged to assess, manage, and protect the beneficial uses of state waters.

A number of waterbodies fail to meet water quality standards. Washington is charged with returning waterbodies to standards. The requirement under the federal Clean Water Act for achieving this is known as a Total Maximum Daily Load (TMDL).

Washington has established criteria for total dissolved gas (TDG), which at high levels has deleterious effects on fish and other aquatic life. This document details a TMDL approach for TDG in the mainstem Snake River from the Idaho state line (just below the Clearwater River) to its mouth at the Columbia River (Figure 1). This report will describe the sources of TDG, explain why high TDG is a problem, and present a strategy for managing TDG so water quality standards will be met.

Compliance with Clean Water Act

The area for the Lower Snake River TDG TMDL begins at the Idaho border and falls entirely within Washington State. The state has adopted water quality standards for TDG to protect aquatic life. This entire reach of the river is out of compliance with the TDG water quality standard for Washington, and is listed on the state's 1998 list of waterbodies failing to meet standards pursuant to Section 303(d) of the federal Clean Water Act. As a result of the standards exceedances and subsequent listings, this TMDL is being prepared by Washington State.

A TMDL determines the quantity (load) of a pollutant that can enter a waterbody and still meet water quality standards. This load is then allocated among the various sources. An implementation component (Summary Implementation Strategy or SIS) is included to identify actions that appropriate agencies and stakeholders will undertake to achieve the allocated loads.

The TMDL, as described in this document, must be submitted to the U.S. Environmental Protection Agency (EPA) for approval. Washington operates under a Memorandum of Agreement (MOA) with EPA, which guides TMDL submittals. This document has been organized by the components described in the MOA.

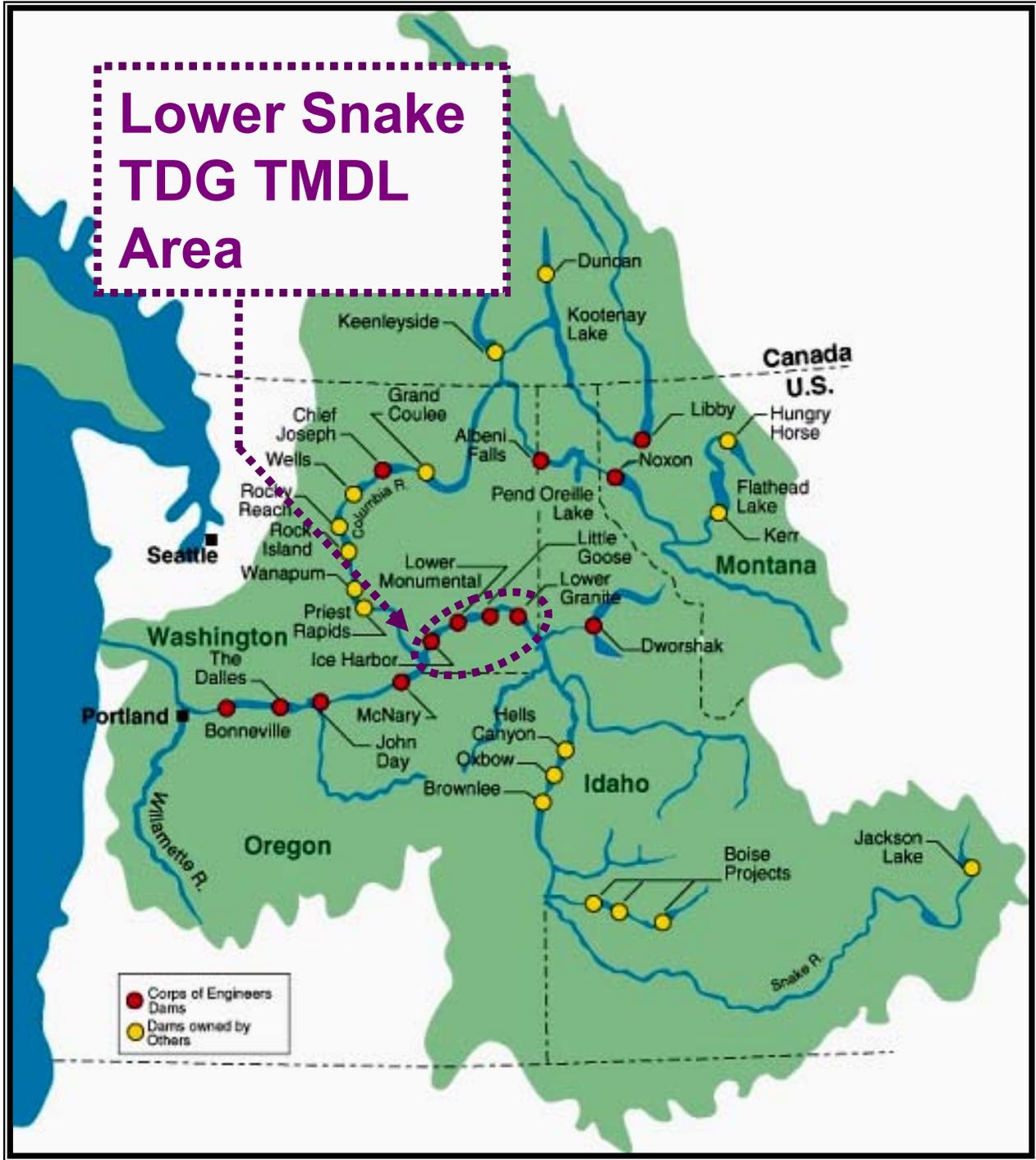


Figure 1. Map of Lower Snake TMDL Area.

Coordination with Endangered Species Act

A TMDL is a planning tool, not a rule of law or other stand-alone enforceable document. It does not take precedence over the federal Endangered Species Act, Indian Treaties, or federal hydropower system enabling legislation. It takes no action that would trigger a review under the National Environmental Policy Act or Washington State Environmental Policy Act. TMDLs may be used to condition exemptions, modifications, variances, permits, administrative orders, licenses, and certifications.

There is much overlap between this TMDL established pursuant to the federal Clean Water Act and other plans to protect salmonids listed as threatened or endangered under the Endangered Species Act, administered by the National Marine Fisheries Service. It is therefore important that there is a clear understanding of the requirements of this TMDL relative to measures required by Biological Opinions issued in relation to the threatened and endangered species of the Snake and Columbia rivers.

The 2000 Federal Columbia River Power System (hydrosystem) Biological Opinion requires that the action agencies – U.S. Army Corps of Engineers, Bonneville Power Administration, and U.S. Bureau of Reclamation – meet specific hydrosystem biological performance standards for both adult and juvenile salmon. The purpose of these standards is to help reverse the downward trend in listed salmon populations and therefore ensure viable salmon resources in the Columbia River Basin. The juvenile hydrosystem goals are one part of a three-tiered approach to assessing performance of implementation of the Reasonable and Prudent Alternative Section items presented in the Biological Opinion. These hydrosystem standards are combined with standards for harvest, habitat, and hatcheries and other life-stage indicators to arrive at a population level standard.

The hydrosystem survival performance standards can be met by a combination of controlled spills, fish passage facilities to divert juvenile salmon from passing through the turbines, or juvenile transportation by truck or barge. Due to the current configuration of the hydroelectric projects along the Columbia and Snake rivers, the National Marine Fisheries Service sees spill as the available tool that is most effective for fish survival. However, these performance standards are not being met at the current implementation level of the spill program. Therefore, in the short-term, structural gas abatement solutions may result in higher spills rather than lower TDG levels. But as new, more effective fish passage facilities are completed and evaluated, their contribution to the attainment of hydrosystem performance standards will hopefully allow spill levels for fish passage and associated TDG levels to be reduced, but only so long as the performance standards are met.

Spills for fish passage under the Biological Opinion cause TDG supersaturation above the 110% criterion. The state water quality standards are meant to be sufficiently protective so as to prevent damage to beneficial use of the state waters. However, the criteria apply to percent saturation only, and do not address duration of exposure or the levels of mass loading. The effects of elevated dissolved gas on migrating juvenile and adult salmon due to voluntary spill have been monitored each year of spill program implementation. Based on five years of data

from the biological monitoring program, the average incidence of gas bubble disease signs has been low, although the state-allowed maximum TDG due to spill was 120% in the tailrace and 115% in forebays. In 1995 and 1996, only 1.6% of all the juveniles sampled, nearly 200,000 fish, showed signs of disease (Schneider, 2001). These results suggest that, in weighing the benefit gained in increased salmon survival by spills for fish passage against the benefit to the beneficial use from strict adherence to the 110% standard, it would be reasonable to find flexibility in application of the standards. That increased flexibility is reflected in the criteria established for fish passage spill.

In summary, the provisions of both Acts must be met. Notwithstanding that, it is not the purpose of the Clean Water Act to usurp functions properly undertaken pursuant to the Endangered Species Act. On the contrary, the Endangered Species Act contains provisions that encourage EPA to consult with the National Marine Fisheries Service prior to approval of a TMDL that affects threatened or endangered species to ensure the TMDL is consistent with species recovery goals. The 2000 Biological Opinion issued pursuant to the Endangered Species Act requires attainment of certain fish passage performance standards. One of the means of attaining these is through spilling water over hydroelectric dam spillways. This action, though, results in elevated TDG. Control of TDG is the purpose of this TMDL. The Clean Water Act does not envisage trade-offs of fish passage for TDG; it requires, rather, attainment of water quality standards. This is one of the significant challenges posed by this TMDL.

This TMDL must be written to reflect ultimate attainment of the TDG water quality standard. Fish passage requirements can be facilitated under an implementation plan, but the clear expectation of the Clean Water Act is that water quality standards will be attained in a limited amount of time. The National Marine Fisheries Service and EPA have been discussing how to meet biological performance standards under the Endangered Species Act at the same time as meeting the water quality standards of the Clean Water Act. However, the primary purpose of this TMDL must be to comply with the Clean Water Act, although finding a means of compliance with both laws is also a goal.

Applicable Criteria

The laws of Washington State apply to the Snake River from the Idaho border just below the mouth of the Clearwater River to its mouth at the Columbia River. All of these waters have been included on Washington's 1996 303(d) list, and have been identified as impaired or have been included on Washington's 1998 303(d) list. The segments covered by this TMDL are listed in Table 1, along with the Water Resource Inventory Area (WRIA) and Waterbody Identification (WBID) numbers.

A TMDL has been completed for the Lower Columbia River from the mouth of the Snake River to the Pacific Ocean, and another is planned for the Mid-Columbia River (Canada border to confluence with Snake River). This TMDL and the Mid Columbia TMDL at their downstream ends will address compliance with the Lower Columbia River TDG TMDL at its upstream end.

Table 1. Washington's Lower Snake River TDG Listed and Impaired Segments

Segment description	WRIA	WBID	1996 303(d) listings	1998 303(d) listings	1998 impaired but unlisted
Lower Snake from Palouse River to mouth at Columbia River	33	WA-33-1010	1		
Lower Snake above and below Lower Monumental and Ice Harbor dams		YB86JO		5	
Middle Snake from Clearwater River to Palouse River	35	WA-35-1010	1		
Middle Snake above and below Little Goose Dam		VB86JO		1	1
Middle Snake below Lower Granite Dam		YB86JO		1	
Middle Snake above Lower Granite Dam		YB86JO			1
Totals			2	7	2

Washington's Water Quality Standards, Chapter 173-201A Washington Administrative Code (WAC), classify the reaches of the Columbia River covered by this TMDL as Class A. The following standards specifically apply to this TMDL:

WAC 173-201A-030 (old): WAC 173-201A-200(1)(f) (new):

Total dissolved gas shall not exceed 110% of saturation at any point of sample collection.

WAC 173-201A-060 (4) (old): WAC 173-201A-200(1)(f) (new):

(a)(i) The water quality criteria herein established for total dissolved gas shall not apply when the stream flow exceeds the seven-day, ten-year frequency flood.

WAC 173-201A-060 (4) (old):

(b) The total dissolved gas criteria may be adjusted to aid fish passage over hydroelectric dams when consistent with a department approved gas abatement plan. This (gas abatement) plan must be accompanied by fisheries management and physical and biological monitoring plans. The elevated total dissolved gas levels are intended to allow increased fish passage without causing more harm to fish populations than caused by turbine fish passage. (The specific allowances for total dissolved gas exceedances are listed as special conditions for sections of the Snake and Columbia rivers in WAC 173-201A-130 and as shown in the following exemption:

Special fish passage exemption for sections of the Snake and Columbia rivers: When spilling water at dams is necessary to aid fish passage, total dissolved gas must not exceed an average of one hundred fifteen percent as measured at Camas/Washougal below Bonneville dam or as measured in the forebays of the next downstream dams. Total dissolved gas must also not exceed an average of one hundred twenty percent as measured in the tailraces of each dam. These averages are based on the twelve highest hourly readings in any one day of total dissolved gas. In addition, there is a maximum total dissolved gas one hour average of one hundred twenty-five percent, relative to atmospheric pressure, during spillage for fish passage. These special conditions for total dissolved gas in the Snake and Columbia rivers are viewed as temporary and are to be reviewed by the year 2003.

(c) Nothing in these special conditions allows an impact to existing and characteristic uses.

WAC 173-201A-200(1)(f) (new):

(ii) The TDG criteria may be adjusted to aid fish passage over hydroelectric dams when consistent with a department approved gas abatement plan. This plan must be accompanied by fisheries management and physical and biological monitoring plans. The elevated TDG levels are intended to allow increased fish passage without causing more harm to fish populations than caused by turbine fish passage. The following special fish passage exemptions for the Snake and Columbia rivers apply when spilling water at dams is necessary to aid fish passage:

- TDG must not exceed an average of one hundred fifteen percent as measured in the forebays of the next downstream dams and must not exceed an average of one hundred twenty percent as measured in the tailraces of each dam (these averages are measured as an average of the twelve highest consecutive hourly readings in any one day, relative to atmospheric pressure); and
- A maximum TDG one hour average of one hundred twenty-five percent must not be exceeded during spillage for fish passage.

The “ten-year, seven-day average flood” or “seven-day, ten-year frequency flood” are usually termed the “7Q10” flood flows.

The criteria in WAC section 173-201A-060 (old) -200(1)(f) (new) are sometimes termed the “waiver” TDG limits for fish passage. The Washington waiver limits are in effect during spill for fish passage for dams that have submitted a gas abatement plan that is approved by the department (Ecology). Loading capacity, load allocations, or any other requirements of this TMDL based on the regulations for TDG waivers based on fish passage will be in effect only while waiver levels are in effect. If the water quality standards regulations are revised in any way that affects this TMDL, then the TMDL could be revisited and modified at that time.

The standards that authorize and describe the use of a mixing zone can be found in WAC 173-201A-400. Due to their length, they will not be presented verbatim.

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Background

Sources of Total Dissolved Gas

Total dissolved gas (TDG) levels can be increased above the water quality criteria by spilling water over spillways of dams. These are the major sources of elevated TDG in the Snake River mainstem. There are a variety of other ways that TDG may be elevated: passage of water through turbines, fishways, or locks; and natural processes such as natural waterfalls, low barometric pressure, high water temperatures, or high levels of biological productivity. However, the vast majority of the high TDG levels found in the Snake River are caused by spills from dams. Manmade sources other than spill are minor and can be considered negligible. Natural processes may have a significant effect on TDG and are addressed in setting load allocations.

Spill at dams occurs for several reasons:

1. To enhance downstream fish passage (i.e., to aid in the pursuit of Biological Opinion “Performance Standards” for fish survival under the Endangered Species Act).
2. To bypass water that exceeds the available hydraulic capacity of the powerhouse due to:
 - High river flows.
 - Lack of power market.
 - Maintenance, breakdown, or other reasons.

The first type of spill is sometimes called “voluntary spill”, while the second types are termed “involuntary spills”. Figure 2 illustrates the typical configuration of a dam on the Lower Snake River. The reservoir impounded by the dam is often termed the “pool”. The forebay is the area immediately above the dam. Most of the river passes the dam through the powerhouse or spillways (other than leakage and fish by-pass facilities). The stilling basin is the area below the spillway, usually lined with reinforced concrete, into which the discharge dissipates energy to avoid downstream channel degradation. The tailwater is the river below the dam, and the tailrace is the area immediately below the powerhouse and the stilling basin.

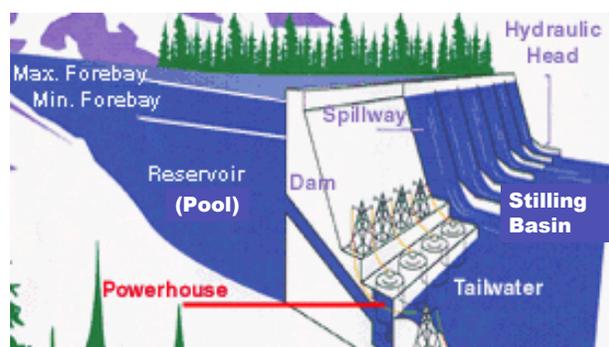


Figure 2. Typical Dam Configuration.

Spill for Fish Passage

Spill for purposes of fish passage involves water deliberately released over dam spillways, rather than being discharged through turbines or fish bypass facilities. The intent is to increase juvenile passage number and survival by redirecting fish to the spill, which has lower levels of mortality than turbine passage. For example, Schoeneman et al. (1961) found that mortality in Chinook juveniles spilled over McNary Dam (Columbia River) and Big Cliff Dam (Santiam River) was less than 2%. Subsequent studies confirmed this estimate, and research is ongoing. The requirement for spring and summer spills to pass juvenile salmon was included in the 1995 and 2000 Biological Opinions for the Columbia and Snake River dam operations. Washington's approach to conform with the Biological Opinion was to adopt a rule revision specifying the TDG criteria for fish passage spill (see above).

Involuntary Spill

Like spills for fish passage, involuntary spill involves water being discharged over dam spillways. The causes and intended consequences, though, are different. As its name suggests, there is no alternative to an "involuntary" spill once one is required. (However, sometimes involuntary spill could possibly have been avoided by better planning.) At times of very high river flows, the quantity of water exceeds the capacity of a dam to either temporarily store the water upstream of the dam or pass the water through its turbines. In these circumstances, water is released over the spillway, because there is nowhere else for it to go.

The Lower Snake River dams have very little storage capacity relative to the quantity of spring runoff. At times of rapid runoff, the dams cannot constrain the quantity of water, and the water is spilled with attendant high TDG levels. Often dissolved gas levels from involuntary spill exceed those experienced during periods of spill for fish. However, high river flows under these circumstances are often in excess of the 7Q10 high flow, in which case the TDG standard would not apply.

Involuntary spill as a result of lack of power market is a variant of the above. In this scenario, the power marketing authority cannot sell any more power, and even though turbines are available, water is released over the spillway because there is nowhere for electricity generated to go. Running water through the turbines with no load increases wear and tear with attendant higher maintenance costs, and also may reduce fish survival. Lack of power load demand can occur at times of both high and low flows (e.g., in the spring or fall when power demands are low both in California and the Pacific Northwest). Also releases from upstream storage dams during high load times (morning and evening) can result in high flows at downstream dams during low load times (middle of the night), causing an involuntary spill.

Involuntary spill can also occur at low flows when powerhouses are taken off-line for maintenance, breakdown, or other needs. Maintenance is usually scheduled to prevent a spill, by doing maintenance on one or two generating units at a time during low power demand periods. Nonetheless, releases from upstream dams can complicate management of spills during powerhouse maintenance. Also, unscheduled maintenance and repairs sometimes occur, which may require a powerhouse shut-down and involuntary spill.

In general, involuntary spill conditions at the “run-of-the-river” dams may result from reservoir control and power marketing decisions made by the federal project operators having storage capacity upstream. Improved accuracy in water forecasting could help avoid understating or overstating available water supply, which could cause the federal project operators to spill water because they left too little or too much room in the reservoirs. Additionally, a water management plan could also identify uncoordinated releases and manage daily fluctuations in river flows. These events often result in isolated involuntary spill events, because reservoir elevation must be maintained within limits at run-of-the-river projects.

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Water Quality and Resource Impairments

TDG Generation from Spills

Spills for fish passage typically occur during the spring and summer months. During periods of fish spills, deviations of ambient conditions from the water quality standard are frequent but usually small. This is because spill quantities are managed to meet the waiver levels for fish passage through Washington's Special Conditions (described above), which allow TDG levels to rise to 120% of saturation relative to atmospheric pressure in the tailrace of the dam that is spilling, and 115% in the forebay of the next dam downstream.

The excursions beyond this level usually have been no more than 1 or 2% of saturation above the waiver levels, due mainly to the many sources of TDG variability. Generally, the fishery management agencies have sought spill quantities that remain right at the TDG variance limit at the fixed monitoring station sites in order to maximize the juvenile passage and survival benefits. Any small change in conditions that influence TDG – such as change in barometric pressure, water temperature, degassing rates, incoming gas, total river flow, or tailwater elevation – will cause an exceedance when operated this way. Also, these levels do not meet the 110% criterion of Washington State.

Nonetheless, the fisheries agencies and the Corps of Engineers are quick to note the exceedances and make necessary corrections to bring the levels into compliance. Also, TDG levels within the range of these small excursions above the waiver levels have been incorporated into the fish recovery spill program. The program includes biological monitoring for gas bubble trauma, which has consistently shown minimal levels of symptoms in downstream migrants.

Involuntary spills can occur at any time. Involuntary spills caused by river flows above powerhouse capacity are most likely to occur from late fall to early summer, depending on rainfall or snowmelt in the tributary watersheds. However, high flows could also occur due to releases from upstream dams with significant storage, such as Brownlee or Dworshak dams. Involuntary spill due to low power demand is most likely in the spring, although this is also dependent on regional power management by the Bonneville Power Administration. Loss of powerhouse capacity to maintenance or repair is usually scheduled so that no more than one or two turbines are out at any given time, but an emergency powerhouse shutdown and spill could occur at any time as the result of a fire or other disaster.

At times of involuntary spill, exceedances above the standard can rise dramatically, peaking above 130% of saturation, and even 140%. Absolute TDG pressures at these levels, which usually occur only in shallow waters, can be lethal to fish. Usually fish are protected from fatal pressures in deeper waters by compensation from hydrostatic pressures, which reduces absolute TDG levels.

For all spills, the highest TDG levels, and therefore the area most likely to exceed standards, are in the stilling basin directly below the spillway. In this area, the “aerated zone”, the plunging and air entrainment of the spill generates high levels of TDG, but then quickly degasses while

the water remains turbulent and full of bubbles. As this water moves from the stilling basin into the tailrace, the bubbles rise and dissipate, degassing slows, and the TDG levels stabilize.

In the pools, if TDG pressures are not at 100%, gas in the water will be seeking equilibrium with the air. High TDG levels will produce degassing, but the loss rate is controlled by conditions such as the depth of water, surface area, and surface mixing. Degassing rates increase as the wind speed rises, or as the river gets wider, shallower, or more turbulent (such as in a rapid or cascades).

Snake River reservoirs are generally deep and slow, and in the absence of wind degassing rates are very low. Under these conditions TDG concentrations remain essentially constant, but the percent saturation of TDG can increase if the water temperature increases or barometric pressure drops (Figure 3). Also, primary productivity (periods of algal growth) can increase dissolved oxygen levels, which results in a higher TDG percent saturation. However, because oxygen is metabolized by the aquatic life, its physical effects are minor compared to nitrogen and therefore can also be considered *de minimus*.

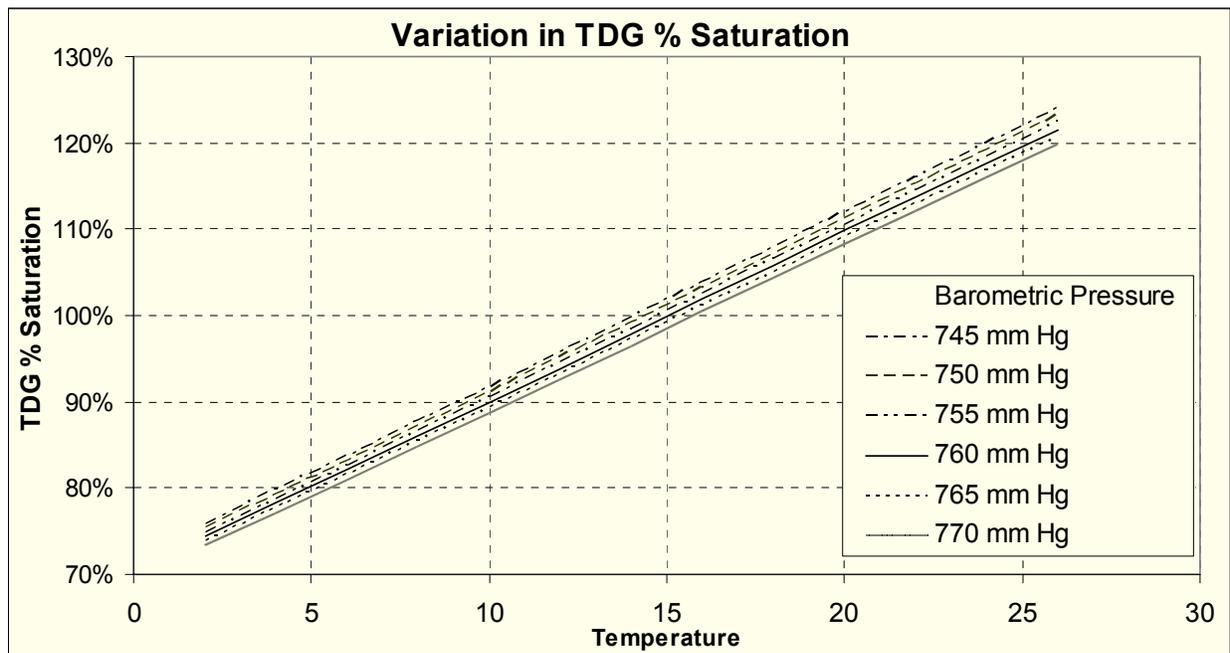


Figure 3. Variation in TDG Percent Saturation with Temperature and Barometric Pressure at Constant Concentration.

Due to the hydraulic properties of the spill, a proportion of the powerhouse flow entrains with the spill and is aerated as if it were part of the spill. (This amount may be negligible where physical structures separate powerhouse from spillway flows, such as islands at Bonneville Dam, but no such structures currently exist on the Lower Snake River.) The rest of the powerhouse flow mixes with the spillway flows at varying rates, sometimes quite slowly, as the river moves downstream from the dam. Powerhouse TDG levels are typically identical with forebay TDG levels: very little gas exchange occurs as water passes through the powerhouse. Therefore, if the

forebay TDG levels are lower than levels below the spillway, the powerhouse flows that mix slowly and farther downstream will reduce the TDG levels in the spillway waters by dilution.

TDG Impacts on Aquatic Life

Fish and other aquatic life inhabiting water supersaturated with TDG may tend to display signs of difficulty, especially if higher dissolved gas pressure gradients occur. Gas bubbles form only when the TDG pressure is greater than the sum of the compensating pressures. Compensating pressures include water (hydrostatic) and barometric pressure. For organisms, tissue or blood pressure may add to the compensating pressures. Gas bubble development in aquatic organisms is then a result of excessive uncompensated gas pressure. The primary actions which will enhance the likelihood of bubbles forming in the fish are (1) continued exposure to the highly saturated water, (2) rising higher in the water column bringing about a higher pressure gradient (decreased hydrostatic pressure), (3) decreases in barometric pressure, and (4) increasing water temperature.

The damage caused by release of gas bubbles in the affected organism is termed gas bubble trauma or gas bubble disease. There is a wide body of research on this condition. Effects of gas bubble trauma include emphysema, circulatory emboli, tissue necrosis, and hemorrhages in brain, muscle, gonads, and eyes (Weitkamp and Katz, 1980). Nebeker et al. (1976) found that death in adults was due to massive blockages of blood flow from gas emboli in the heart, gills, and other capillary beds. Investigators in the 1970s reported many and varied lesions in fish exposed in the 115-to-120% TDG range in shallow water. At higher gas exposures (e.g., 120 to 130% TDG), death frequently ensued before gas bubble trauma signs appeared (Bouck et al., 1976). External signs of gas bubble trauma (e.g., blisters forming in the mouth and fins of fish exposed to chronic high gas) often disappeared rapidly after death. The signs were largely gone within 24 hours (Coutant and Genoway, 1968).

Water quality standards for TDG were set at 110%, the threshold for chronic effects found in the literature. The severity of gas bubble trauma increases as the absolute TDG level increases, until at higher levels death can occur swiftly. However, there are a number of factors that affect a particular organism's response to high TDG levels. Different species respond to changing TDG differently, and the response also varies by life stage. Juvenile salmonids appear to be relatively resilient compared to adults or to non-salmonids.

The duration of exposure to high TDG appears to have an impact on the severity of gas bubble trauma symptoms. Although the standards are not specific on this issue, defining a duration of exposure to be applied to the criteria is appropriate. The waiver limits developed for fish passage provide two levels: a one hour maximum, and the average of the 12 highest hourly readings in any 24-hour period. Based on the 110% criteria representing chronic impacts, use of the longer averaging period is appropriate.

Extensive research has been conducted on the effects of TDG on anadromous fish in the Columbia and Snake rivers. It is beyond the scope of this TMDL to review that literature. The Clean Water Act requires compliance with existing standards, although existing research can be used to aid in interpretation of those standards. A review of the standards to look at adoption of

different criteria, duration, frequency, and spatial application, if appropriate, would occur through a completely separate process. If new standards were adopted, then the TMDL could be reviewed and possibly revised.

It is possible that TDG became elevated under historical natural conditions in the Columbia and Snake rivers, such as below Celilo Falls. However, elevated TDG may also have dissipated quickly as it passed over shallows and rapids. Conditions different from natural conditions exist at the Columbia and Snake River dams that create high TDG levels. These conditions include the height of the dams, the shape of the spillways, and the presence of the long, deep pools below the dams. Allowing a point of compliance below the aerated portion of the tailrace can be considered to reflect gas generation patterns in a natural system.

Monitoring of TDG

Routine monitoring of instream TDG levels occurs at fixed monitoring station (FMS) sites above and below each dam. The tailwater FMS sites in some cases may be a mile or two downstream of the dam. The FMS sites have been the primary point of compliance and assessment of TDG levels, especially for compliance with waiver limits during fish passage spills. The locations have been chosen for a variety of reasons, a primary one being the logistics and feasibility of long-term monitoring. However, studies suggest that data from some of these sites may not be consistently representative of river conditions. The FMS sites will continue to be the primary location for determining compliance with waiver limits used for fish passage management. For the purposes of TMDL compliance, TMDL requirements do not need to drive FMS siting issues.

The interagency Water Quality Team manages issues regarding the fish passage program and FMS. The Water Quality Team, jointly chaired by the National Marine Fisheries Service and EPA, is charged with providing technical guidance on temperature and TDG water quality in the context of the National Marine Fisheries Service 2000 Biological Opinion relating to the Columbia River Hydropower System. A subgroup of that team has been addressing concerns with the FMS sites, and the appropriateness of the current FMS locations has been the subject of vigorous debate between the resource agencies and U.S. Army Corps of Engineers within the subgroup. The subgroup has concluded that the “representativeness” of FMS data is a very difficult characteristic to define. The TDG measurements at a given location in the river are influenced significantly by environmental factors such as water temperature, biological productivity, barometric pressure, and wind, as well as the spill. The Water Quality Team will continue to study and discuss these issues in order to achieve a mutually satisfactory monitoring end product.

To gain additional knowledge of TDG conditions in the river, the Corps has conducted a number of detailed special studies of TDG levels below the dams (e.g., Schneider and Wilhelms, 1996, 1997, 1998a, 1998b, and 1998c). These studies have shown that TDG levels measured at the FMS sites (1) are usually lower than levels longitudinally upstream towards the spillway, (2) may be lower than levels laterally across the river if powerhouse flows are not fully mixed, and (3) in some conditions, may be lower than levels longitudinally downstream.

Technical Analysis

Analysis of TDG generation processes

Introduction

The discussion that follows is taken (sometimes verbatim) from the Dissolved Gas Abatement Study (DGAS) conducted by the U.S. Army Corps of Engineers, and in particular from Appendix G: “Spillway Discharge Production of Total Dissolved Gas Pressure” (USACE, 2001a).

The material in this section provides a general overview of TDG generation processes at the Lower Snake River dams. Specific details may change over time as structural changes are made to these projects. These processes provide the basis for the determination of loading capacity.

The TDG exchange associated with spillway operation at a dam is a process that couples both the hydrodynamic and mass exchange processes. The hydrodynamics are shaped by the structural characteristics of spillway, stilling basin, and tailrace channel as well as the operating conditions that define the spill pattern, turbine usage, and tailwater stage. The hydrodynamic conditions are influenced to a much smaller extent by the presence of entrained bubbles.

The air entrainment will influence the density of the two-phase flow and impose a vertical momentum component associated with the buoyancy in the entrained air. The entrained air content can result in a bulking of the tailwater elevation and influence the local pressure field. The transfer of atmospheric gasses occurs at the air-water interface, which is composed of the surface area of entrained air at the water surface. The exchange of atmospheric gases is greatly accelerated when entrained air is exposed to elevated pressures because of the higher saturation concentrations. The pressure time history of entrained air will, therefore, be critical in determining the exchange of atmospheric gases during spill.

The volume, bubble size, and flow path of entrained air will be dependent on the hydrodynamic conditions associated with project releases. The bubble size has been found to be a function of the velocity fluctuations and turbulent eddy length. The bubble size can also be influenced by the coalescence of bubbles during high air concentration conditions. The volume of air entrained is a function of the interaction of the spillway jet with the tailwater. The entrained bubble flow path will be dependent upon the development of the spillway jet in the stilling basin and associated secondary circulation patterns. The turbulence characteristics are important to the vertical distribution of bubbles and the determination of entrainment and de-entrainment rates.

Physical Processes

The exchange of TDG is considered to be a first order process where the rate of change of atmospheric gases is directly proportional (linear relationship) to the ambient concentration. The driving force in the transfer process is the difference between the TDG concentration in the water

and the saturation concentration with the air. The saturation concentration in bubbly flow will be greater than that generated for non-bubbly flow where the saturation concentration is determined at the air-water interface. The flux of atmospheric gasses across the air-water interface is typically described by Equation 1.

$$J = K_l(C_s - C) \quad \text{Equation 1}$$

Where:

J	=	gas flux (mass per surface area per time)
K_l	=	the composite liquid film coefficient
C_s	=	the saturation concentration (mass per volume)
C	=	the ambient concentration in water (mass per volume)

The rate of change of concentration in a well-mixed control volume, $\frac{dC}{dt}$, can be estimated by multiplying the mass flux by the surface area and dividing by the volume over which transfer occurs as shown by Equation 2:

$$\frac{dC}{dt} = K_l \frac{A}{V} (C_s - C) \quad \text{Equation 2}$$

Where:

A	=	the surface area associated with the control volume
V	=	the volume of the waterbody over which transfer occurs

This relationship shows the general dependencies of the mass transfer process. In cases where large volumes of air are entrained, the time rate of change of TDG concentrations can be quite large, as the ratio of surface area to volume becomes large. The entrainment of air will also result in a significant increase in the saturation concentration of atmospheric gases, thereby increasing the driving potential over which mass transfer takes place. Outside of the region of aerated flow during transport through the pools, the contact area is limited to the water surface and the ratio of the surface area to the water volume becomes small, thereby limiting the change in TDG concentration. The turbulent mixing will influence the surface renewal rate and hence the magnitude of the exchange coefficient K_l .

Equation 2 can be integrated, provided the exchange coefficient, area, and volume are held constant over the time of flow. The initial TDG concentration at time=0 is defined as C_i and the final TDG concentration time=t is defined as C_f shown in Equation 3. The resultant concentration C_f exponentially approaches the saturation concentration for conditions where the

term $K_l \frac{A}{V}$ is large. The final concentration becomes independent of the initial concentration under these conditions.

$$C_f = C_s(1 - e^{-K_l \frac{A}{V} t}) + C_i e^{-K_l \frac{A}{V} t} \quad \text{Equation 3}$$

Modeling TDG Transfer

The TDG exchange process involves the coupled interaction of project hydrodynamics and mass transfer between the atmosphere and the water column. Mechanistic models of TDG transfer must simulate the two-phase (liquid and gas phases) flow conditions that govern the exchange process. Several mechanistic models have been developed to simulate the TDG exchange in spillway flows.

Orlins and Gulliver (2000) solved the advection-diffusion equation for spillway flows at Wanapum Dam for different spillway deflector designs. Physical model data were used to develop the hydraulic descriptions of the flow conditions throughout the stilling basin and tailrace channel. The model results were also compared to observations of TDG pressure collected during field studies of the existing conditions.

A second model developed by Urban et al. (2000), used the same mass transport relationships together with the hydraulic descriptions associated with plunging jets. This approach does not require the specific hydraulic information to be derived from a physical model, but it can be applied to any hydraulic structure that has plunging jet flow. This model accounted for the TDG exchange occurring across the bubble-water interface and the water surface. This model was calibrated to observations of TDG exchange at The Dalles Lock and Dam (The Dalles) and was developed as part of DGAS. This model successfully simulated the absorption and desorption exchange caused by the highly aerated flow during spillway operations.

As a part of its DGAS study, the Corps decided to use empirically derived equations of TDG exchange, based on the recognition that data were not available to support mechanistic models of the mass exchange process at all the projects in the Columbia/Snake River system. The greatest unknowns associated with the development of a mechanistic model of highly aerated flow conditions in a stilling basin revolve around the entrainment of air and subsequent transport of the bubbles. The surface area responsible for mass transfer will require estimates of the total volume and bubble size distribution of entrained air. In addition, the roughened water surface is thought to contribute to the net exchange of atmospheric gasses. The pressure time history of entrained air would also need to be accounted for to determine the driving potential for TDG mass exchange.

A description of the highly complex and turbulent three-dimensional flow patterns in the stilling basin and adjoining tailrace channel would need to be defined for a wide range of operating conditions. The influence of turbulence on both the mass exchange coefficients and redistribution of buoyant air bubbles would also need to be quantified throughout a large channel reach and for a wide range of operating conditions.

The flow conditions generated by spillway flow deflectors have been found to be sensitive to both the unit spillway discharge and submergence of the flow deflector. The presence of flow deflectors has significantly changed the rate of energy dissipation in the stilling basin and promotes the lateral entrainment of flow. These entrainment flows are often derived from powerhouse releases, which reduce the available volume of water for dilution of spillway releases.

TDG Exchange Formulation

The accumulated knowledge generated through observations of flow conditions during spill at Columbia/Snake River projects and in-scale physical models at the Waterways Experiment Station in Vicksburg, MS, along with mass exchange data collected during site-specific near-field TDG exchange studies and from the fixed monitoring stations, has led to the development of a model for TDG exchange at dams throughout the Columbia/Snake river system for the federal hydropower projects. The general framework is based upon the observation that TDG exchange is an equilibrium process that is associated with highly aerated flow conditions that develop below the spillway. It recognizes that flow passing through the powerhouse is not generally exposed to entrained air under pressure and, therefore, does not experience a significant change in TDG pressure. It also recognizes that powerhouse releases can directly interact with the aerated flow conditions below the spillway and experience similar changes in TDG pressure that are found in spill.

The large volume of air entrained into spillway releases initiates the TDG exchange in spill. This entrained air is exposed to elevated total pressures and the resulting elevated saturation concentrations. The exposure of the bubble to elevated saturation concentrations greatly accelerates the mass exchange between the bubble and water. The amount and trajectory of entrained air is greatly influenced by the structural configuration of the spillway and the energy associated with a given spill.

The presence of spillway flow deflectors directs spill throughout the upper portion of the stilling basin, thereby preventing the plunging of flow and transport of bubbles throughout the depth of the stilling basin. Spillway flow deflectors also greatly change the rate of energy dissipation in the stilling basin, transferring greater energy and entrained air into the receiving tailrace channel.

Generally, spill water experiences a rapid absorption of TDG pressure throughout the stilling basin region where the air content, depth of flow, flow velocity, and turbulence intensity are generally high. As the spillway flows move out into the tailrace channel, the net mass transfer reverses and component gases are stripped from the water column as entrained air rises and is vented back to the atmosphere. The region of rapid mass exchange is limited to the highly aerated flow conditions within 1,000 feet of the spillway.

In general, downstream of the aerated flow conditions, the major changes to the TDG pressures occur primarily through the redistribution of TDG pressures through transport and mixing processes. The in-pool equilibrium process established at the water surface is chiefly responsible for changes to the total TDG loading in the river.

One of the more important observations regarding TDG exchange in spillway flow is the high rate of mass exchange that occurs below a spillway. The resultant TDG pressure generated during a spill is almost entirely determined by physical conditions that develop below the spillway and is effectively independent from the initial TDG content of this water in the forebay. The TDG exchange in spill is not a cumulative process where higher forebay TDG pressures will generate yet higher TDG pressures downstream in spillway flow. The TDG exchange in spill is an equilibrium process where the time history of entrained air below the spillway will determine the resultant TDG pressure exiting the vicinity of the dam.

One consequence of this observation is that spilling water can result in a net reduction in the TDG loading in a system if forebay levels are above a certain value. This was a common occurrence at The Dalles during the high-flow periods during 1997 where the forebay TDG exceeded 130% saturation. A second consequence of the rapid rate of TDG exchange in spill flow is that the influence from upstream projects on TDG loading will be passed downstream only through powerhouse releases. If project operations call for spilling a high percentage of the total river flow, the contribution of TDG loading generated from upstream projects will be greatly diminished below this project.

Given the conceptual framework for TDG exchange described above, the average TDG pressures generated from the operation of a dam can be represented by the mass conservation statement using TDG pressure shown in Equation 4:

$$P_{avg} = \frac{(Q_{sp} + Q_e)P_{sp} + (Q_{ph} - Q_e)P_{ph}}{Q_{sp} + Q_{ph}} \quad \text{Equation 4}$$

Where:

Q_{sp}	=	Spillway discharge [thousands of cubic feet per second (kcfs)]
Q_{ph}	=	Powerhouse discharge (kcfs)
Q_e	=	Entrainment of powerhouse discharge in aerated spill (kcfs)
Q_{se}	=	$Q_{sp} + Q_e$
	=	Effective spillway discharge (kcfs)
Q_{tot}	=	$Q_{sp} + Q_{ph}$
	=	Total river flow (kcfs)
P_{ph}	=	TDG pressure releases from the powerhouse [mm Hg]
P_{sp}	=	TDG pressure associated with spillway flows (mm Hg)
P_{avg}	=	Average TDG pressure associated with all project flows (mm Hg)

This conservation statement assumes the water temperature of powerhouse and spillway flows are similar, and that the heat exchange during passage through the dam and aerated flow region is minimal. Some projects have other water passage routes besides the powerhouse and spillway, such as fish ladders, lock exchange, juvenile bypass systems, and other miscellaneous sources.

These sources of water have generally been lumped into powerhouse flows and are not accounted for separately.

Equation 4 contains three unknowns: Q_e = powerhouse entrainment discharge, $P_{sp} = TDG$ pressure associated with spillway flows, and $P_{ph} = TDG$ pressure associated with powerhouse releases. The TDG pressure associated with the powerhouse release is generally assumed to be equivalent to the TDG pressure observed in the forebay. Numerous data sets support the conclusion that turbine passage does not change the TDG content in powerhouse releases. All of the near-field TDG exchange studies have deployed TDG instruments in the forebay of a project and directly below the powerhouse in the water recently discharged through the turbines. An example of this type of data is shown in Figure 4 during the 1998 post-deflector John Day Lock and Dam (John Day) TDG exchange study (Schneider and Wilhelms, 1999a).

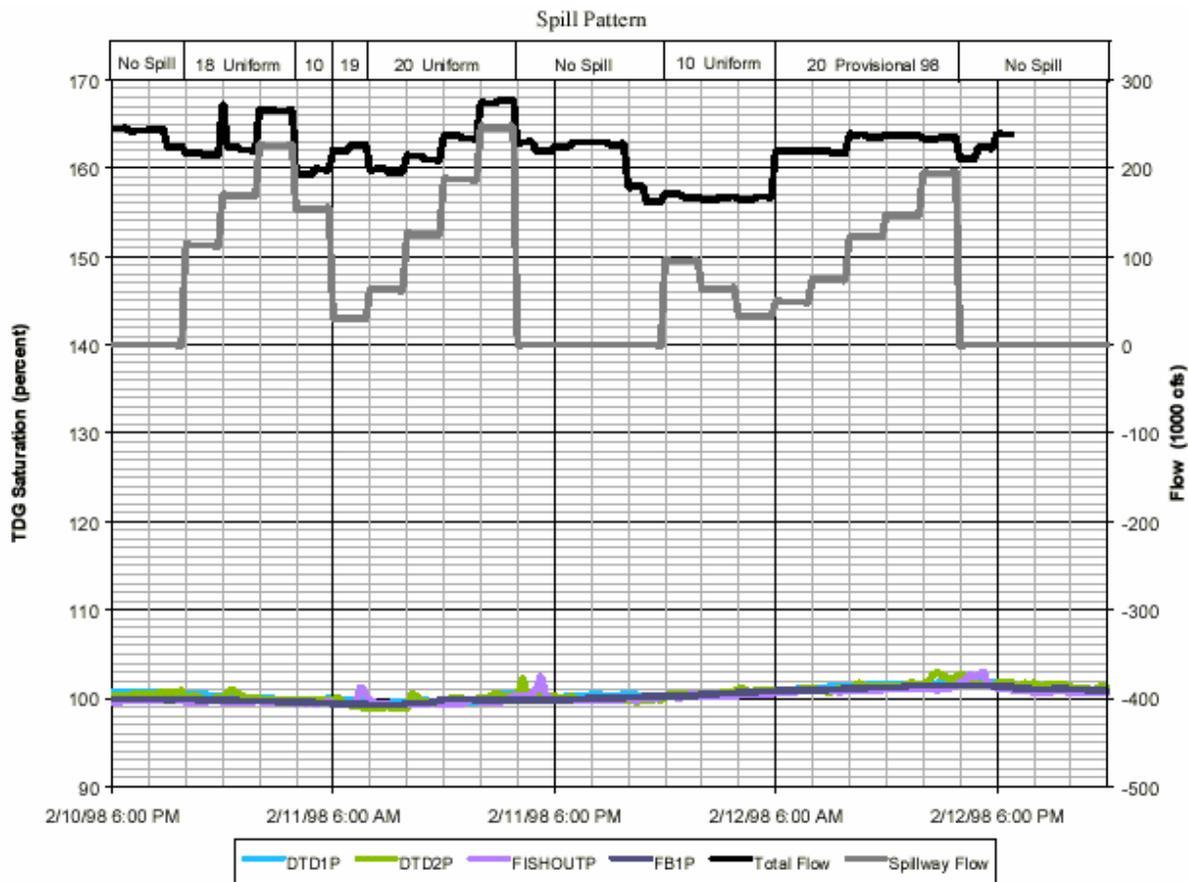


Figure 4. TDS Saturation in the Forebay and Below the Powerhouse Draft Tube Deck of John Day Dam, February 1998.

The TDG instruments were deployed in the forebay of John Day (station FB1P) and in the tailwater below powerhouse draft tube deck (station DTD1P and DTD2P), near the fish outfall (FISHOUTP). The TDG pressure was logged on a 15-minute interval at each of these stations

throughout the testing period. All four stations recorded the same TDG saturations throughout the testing period, even during operating events calling for spilling nearly the entire river on February 11 and 12. The TDG pressure from the forebay and tailwater fixed monitoring stations should also be similar during periods of no spill, provided that these stations are sampling water with similar water temperatures. In cases where a turbine aspirates air or air is injected into a turbine to smooth out operation, the above assumption will not hold.

Spillway TDG Exchange

The TDG exchange associated with spillway flows has been found to be governed by the geometry of the spillway (standard or modified with flow deflector), unit spillway discharge, and depth of the tailrace channel. The independent variable used in determining the exchange of TDG pressure in spillway releases is the delta TDG pressure (ΔP) defined by the difference between the TDG pressure (P_{tdg}) and the local barometric pressure (P_{bar}) as listed in Equation 5. The selection of TDG pressure as expressed as the excess pressure above atmospheric pressure accounts for the variation in the barometric pressure as a component of the total pressure.

$$\Delta P = P_{tdg} - P_{bar} \quad \text{Equation 5}$$

Restating the exchange of atmospheric gases in terms of mass concentrations introduces a second variable (water temperature) into the calculation. The added errors in calculating the TDG concentration as a function of temperature and TDG pressure were the main reasons for using pressure as the independent variable. The TDG concentration would also vary seasonally with the change in water temperature.

The TDG pressure is often summarized in terms of the percent saturation or supersaturation. The TDG saturation (S_{tdg}) is determined by normalizing the TDG pressure by the local barometric pressure as expressed as a percentage. The delta pressure has always been found to be a positive value when spillway flows are sampled. The TDG saturation (S_{tdg}) is determined by Equation 6.

$$S_{tdg} = \frac{P_{tdg}}{P_{bar}} * 100 = \frac{(P_{bar} + \Delta P)}{P_{bar}} * 100 \quad \text{Equation 6}$$

Unit Spillway Discharge

The TDG exchange associated with spillway flows has been found to be a function of unit spillway discharge (q_s) and the tailrace channel depth (D_{tw}). The unit spillway discharge is a surrogate measure for the velocity, momentum, and exposure time of aerated flow associated with spillway discharge. The higher the unit spillway discharge, the greater the TDG exchange during spillway flows. An example of the dependency between the change in TDG pressure and unit spillway discharge is shown in Figure 5 at Ice Harbor Lock and Dam (Ice Harbor).

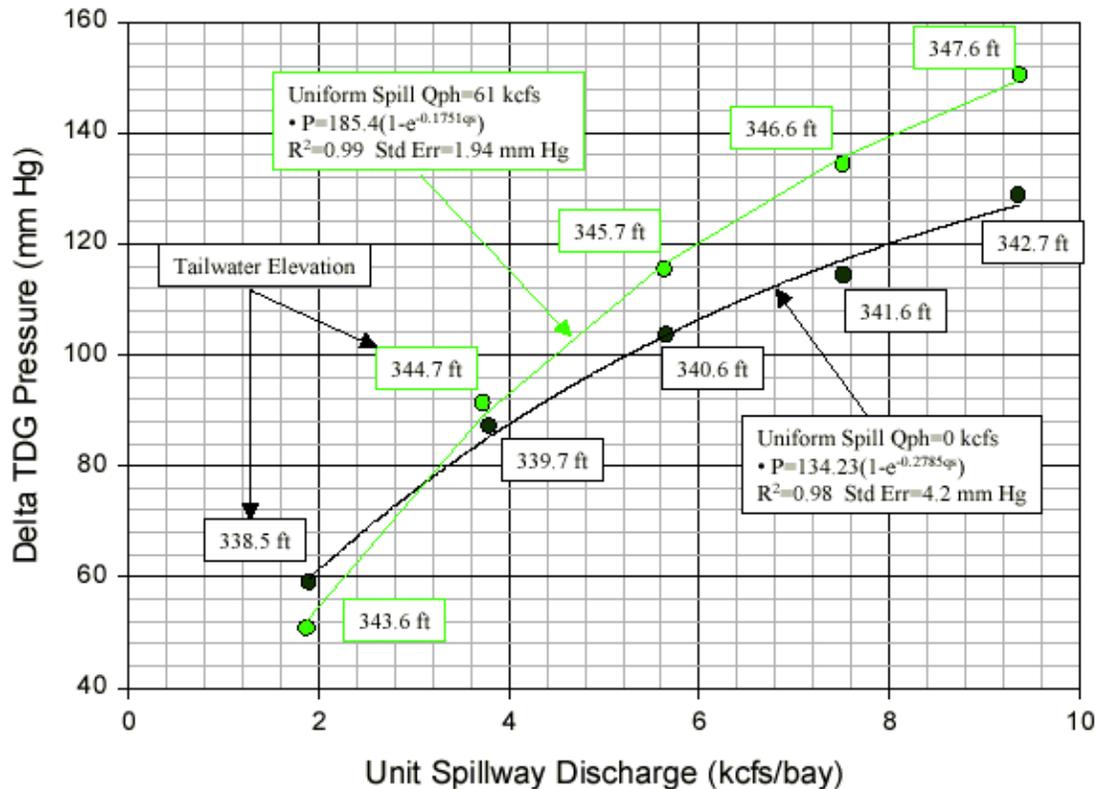


Figure 5. TDG Pressure (Delta P) as a Function of Unit Spillway Discharge and Tailwater Elevation at Ice Harbor Dam, March 1998.

This figure shows two sets of tests involving a uniform spill pattern over eight bays with flow deflectors. The two sets of tests were distinguished only by the presence of powerhouse releases. In both cases, the resultant spill TDG pressure was found to be an exponential function of the unit spillway discharge. The determination of a single representative unit discharge becomes problematic in the face of a non-uniform spill pattern. The flow-weighted specific discharge was found to be a better determinant of spillway TDG production in cases where the spill pattern is highly non-uniform. The flow-weighted unit discharge places greater weight on bays with the higher discharges. The following Equation 7 describes the determination of the specific discharge used in the estimation of TDG exchange relationships:

$$q_s = \frac{\sum_{i=1}^{nb} Q_i^2}{\sum_{i=1}^{nb} Q_i} \quad \text{Equation 7}$$

Where:

- q_s = Specific discharge (flow-weighted unit discharge)
- Q_i = Flow for spill bay i (for nb number of bays)

Depth of Flow

The large amount of energy associated with spillway releases has the capacity to transport entrained air throughout the water column. In many cases, the depth of flow is the limiting property in determining the extent of TDG exchange below a spillway. An example of the influence of the depth of flow on TDG exchange is shown in Figure 5 at Ice Harbor. The only difference between the two sets of data in this figure was the presence of powerhouse flow. The events with powerhouse flow resulted in higher TDG pressure than comparable spill events without powerhouse releases at higher spillway flows. The observed tailwater elevation is also listed in Figure 5 for each test event. The tailwater elevation was about five feet higher during the events corresponding with powerhouse operation.

The depth of flow in the tailrace channel was hypothesized to be more relevant to the exchange of TDG pressure than the depth of flow in the stilling basin because of the influence of the flow deflectors and resultant surface jet, and the high rate of mass exchange observed below the stilling basin. The average depth of flow downstream of the stilling basin was represented as the difference between the tailwater elevation as measured at the powerhouse tailwater gauge and the average tailrace channel elevation within 300 feet of the stilling basin. The tailrace channel reach within 300 feet of the stilling basin was selected because most of the TDG exchange (degassing) occurs in this region. A summary of project features at the time of the Corps DGAS study are listed in Table 2, including stilling basin elevation, deflector elevation, and tailrace channel elevation.

Table 2. Snake River Project Features (April 2001)

Project	Spillway Crest Elev. (ft)	Number Spillways: Deflectors		Deflector Elevation (ft)	Stilling Basin Elev. (ft)	Tail-water Channel Elev. (ft)	Normal Tail-water Pool (ft)	Normal Tail-water Depth (ft)
		w/	w/out					
Ice Harbor	391	10	0	338	304	327	344	17
Lower Monumental	483	6 (8) ¹	2 (0) ¹	434	392	400	441	41
Little Goose	581	6	2	532	466	500	539	39
Lower Granite	681	8	0	630	580	604	635	39

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-8 (USACE, 2001a)

¹Additional deflectors are under construction to be completed by March 2003.

The functional form of the relationship between the change in TDG pressure change and the prominent dependent variables unit spillway discharge and tailrace channel depth of flow, takes the same form as the exponential formulation shown in Equation 3. The delta TDG pressure was found to be a function of the product of the depth of flow and the exponential function of unit spillway discharge as shown in Equation 8.

$$\Delta P = C_1 D_{tw} (1 - e^{-C_2 q_s}) + C_3 \quad \text{Equation 8}$$

The coefficients C_1 , C_2 , and C_3 were determined from nonlinear regression analyses. The product of C_1 and the tailwater depth (D_{tw}) represents the effective saturation pressure in Equation 3 while the product of C_2 and the unit spillway discharge (q_s) reflects the combined contribution from the mass exchange coefficient, ratio of surface area to control volume, and time of exposure.

A second formulation used in this study relating the delta TDG pressure and independent variable involves a power series as shown in Equation 9. This equation can also result in a linear dependency between the delta TDG pressure and either tailwater depth or unit spillway discharge. A linear dependency in the tailwater depth occurs when $C_2=1$ and $C_3=0$. A linear dependency between TDG pressure and unit spillway discharge occurs when $C_2=0$ and $C_3=1$.

$$\Delta P = C_1 D_{tw}^{C_2} q_s^{C_3} + C_4 \quad \text{Equation 9}$$

Entrainment of Powerhouse Flow

The interaction of powerhouse flows and the highly aerated spillway releases can be considerable at many of the projects. Observations of the flow conditions downstream of projects where the powerhouse is adjacent to the spillway often indicate a strong lateral current directed toward the spillway.

The clearest example of the influence of the entrainment of powerhouse flow on TDG exchange was documented during the near-field TDG exchange study at Little Goose. The study at Little Goose was conducted during February 1998 when the ambient TDG saturation in the Snake River ranged from 101 to 103%. The test plan called for adult and juvenile fish passage spill of up to 60 kcfs with the powerhouse discharging either 60 kcfs or not operating. The cross-sectional average TDG pressure in the Snake River below Little Goose was determined from seven separate sampling stations located across the river from the tailwater FMS. The project operations and resultant TDG saturation are summarized in Figure 6 where the observations from the forebay and tailwater fixed monitoring stations are shown as LGS and LGSW respectively, the cross-sectional average TDG saturation at the tailwater FMS is labeled $T5_{avg}$, and the flow-weighted average TDG saturation assuming no entrainment of powerhouse flow is labeled FWA (flow-weighted average).

The TDG saturation estimated by assuming that powerhouse releases were available to dilute spillway flows during this test (FWA) were significantly less than estimates derived from averaging information from the seven sampling stations at the tailwater fixed monitoring station ($T5_{avg}$). This study demonstrated that nearly all of the powerhouse flows from Little Goose were entrained and acquired TDG pressures similar to those in spillway flows during this study.

The circulation patterns below the dam during the test clearly supported the TDG data indicating high rates of entrainment of powerhouse flows into the stilling basin.

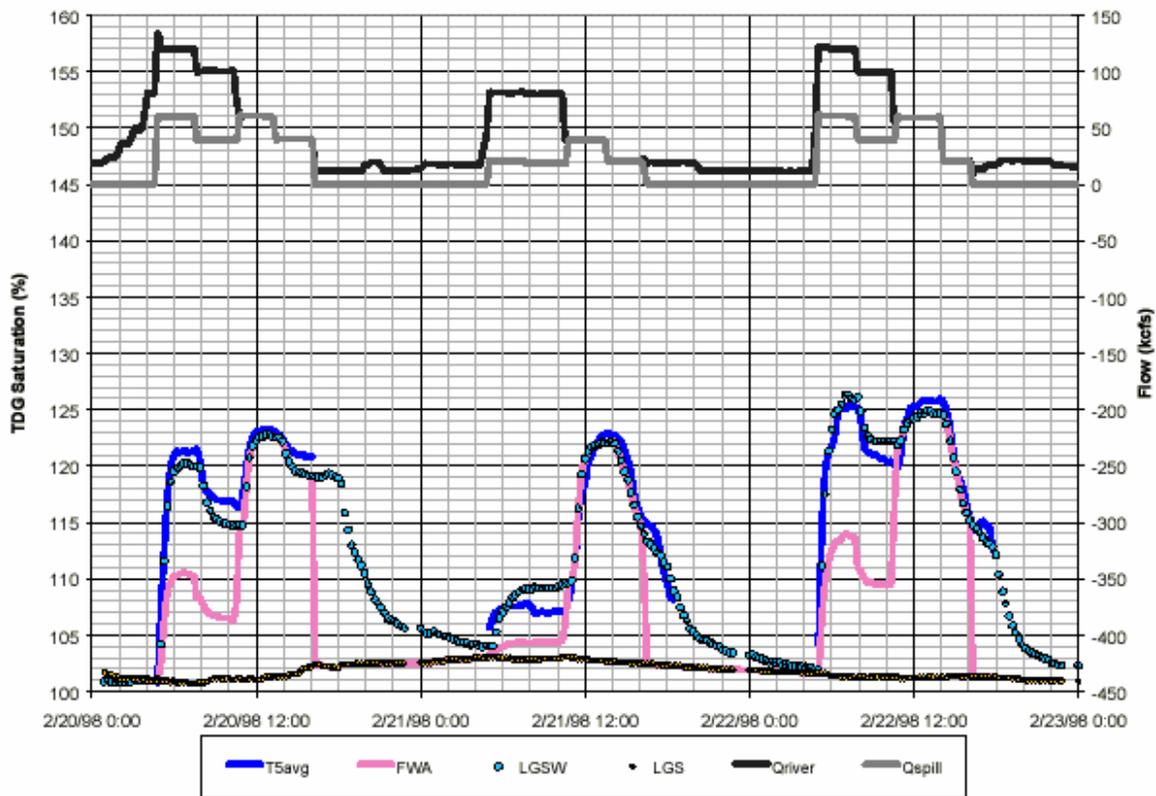


Figure 6. Project Operation and TDG Saturation at Little Goose Dam, February 1998. ($T5_{avg}$ Average TDG Level at Tailwater FMS, LGS- Forebay FMS, LGSW- Tailwater FMS, FWA- Flow Weighted Average Assuming No Entrainment)

The entrainment of powerhouse flow was modeled as a simple linear function of spillway discharge. The relationship shown in Equation 10 was used to estimate the entrainment discharge for each project. The coefficients C_1 and C_2 are project-specific constants. The entrainment of powerhouse flow was assumed to be exposed to the same conditions that spillway releases encounter and, hence, achieve the same TDG pressures.

$$Q_e = C_1 Q_{sp} + C_2 \tag{Equation 10}$$

The loading capacity of the river segments identified for this TMDL are the water quality standard, namely 110% of saturation relative to atmospheric pressure.

Identification of Sources

There are four major sources of TDG within the geographic scope of this TMDL. They are:

1. Lower Granite Dam
2. Little Goose Dam
3. Lower Monumental Dam
4. Ice Harbor Dam

Other potential minor sources of elevated TDG in the Lower Snake River include: increases in TDG caused by natural changes in barometric pressure, temperature, or biological activity; and tributary sources of TDG (Palouse Falls).

Measurements of TDG in the water above Lower Granite Dam, which are the closest to the upstream boundary of this TMDL, occasionally exceed the TDG standard. The source of these elevated levels is not clear. Review of FMS data indicates that TDG levels from the Dworshak or the Hells Canyon dams are not sufficiently elevated to be responsible for the high downstream levels. This suggests that the cause may be related to solar heating and photosynthesis in the Lower Granite pool.

This TMDL addresses those loads of TDG introduced by dams on the Lower Snake River that fall within Washington below the confluence of the Snake and Clearwater rivers. The cause of elevated TDG measurements above Lower Granite Dam and the Idaho border is unknown and will require future study.

The discussion of gas generation at each dam provided in this section is based on the U.S. Army Corps of Engineers analysis reported in the DGAS report (USACE, 2001a) and other sources. The information is provided to illustrate processes at the dams with their configuration at the time of the studies described. As structural modifications are made at the dams, the specific gas generation equations will change.

Analysis of Current Conditions

Data Sources

TDG data were available on many of the projects from several sources: the fixed monitoring station (FMS) system; near field (tailrace) and spillway performance tests; and in-pool transport and dispersion tests. Operational data were obtained from each project detailing the individual spillway and turbine discharge on an interval ranging from five minutes to one hour. These sources of data are discussed below. With these data sources, the most appropriate analysis was selected for each project. Individual mathematical relationships were developed on a project-by-project basis.

Data Quality

TDG data collected in the Snake River has undergone rigorous evaluation for data quality. For the TDG controlled spill studies, Wilhelms, Carroll, and Schneider (1997) reported on a workshop attended by a team of experts who evaluated the quality of data collections and recommended area for improvement. The workshop built on previous data quality evaluations.

The U.S. Army Corps of Engineers Walla Walla District office collects FMS data for the Snake River. Basic data quality procedures are provided in the annual Plan of Action (e.g., USACE, 2001b). Data collection methods and quality assurance procedures have been established for the Columbia and Snake rivers FMS system (e.g., Tanner and Johnston, 2001). The Corps annual water quality reports provide detailed data quality analysis (e.g., USACE, 2000). The TDG data quality target for the FMS stations is a precision of no greater than 1% for paired readings.

In general, the data quality assurance/quality control procedures for the source information used in this TMDL meet or exceed the standards applied by the Washington State Department of Ecology for its own data collection and analysis for TMDL development.

The Fixed Monitoring Station (FMS) Data

The TDG data from the FMSs consisted of remotely monitored TDG pressure, dissolved oxygen, water temperature, and atmospheric pressure from a fixed location in the forebay and tailwater of each project. Data from the FMSs provide a long-term hourly record of TDG throughout the season, capturing detailed temporal and extreme events. However, the FMSs provide only limited spatial resolution of TDG distribution. In some cases, the TDG observed in the tailwater at the FMS location was not representative of average spillway conditions and misrepresented the TDG loading at a dam.

Spillway Performance Tests and Near-Field Studies

Spillway performance tests and near-field tailwater studies were conducted at several projects by the Corps to define the relationship between spill operation and dissolved gas production more clearly. Water temperature, TDG, and dissolved oxygen were monitored in the immediate tailrace region, just downstream of the project stilling basin. These observations provided a means to relate the local TDG saturation to spill operations directly, and to define gas transfer in different regions of the tailrace area. Studies were conducted at Lower Granite Dam in April through July 2002 (USACE, 2003); Little Goose in February 1998 (Schneider and Wilhelms, 1998a); Lower Monumental in August 1996 (Schneider and Wilhelms, 1996); and Ice Harbor in May and June 1996 (Schneider, 1996; and Schneider and Wilhelms, 1997) and March 1998 (Schneider and Wilhelms, 1998b).

In these studies, automated sampling of TDG pressures in spillway discharges during uniform and standard spill patterns was conducted with an array of instruments in the stilling basin and tailwater channel of the project. Automated sampling of TDG levels provide the opportunity to assess three-dimensional characteristics of the exchange of TDG immediately downstream of the stilling basin on a sampling interval ranging from five to 15 minutes. The integration of the

distribution of flow and TDG pressure can yield estimates of the total mass loading associated with a given event. Most of these tests were of short duration, generally lasting only several days and, therefore, pertain to the limited range of operations scheduled during testing. The 2002 monitoring at Lower Granite Dam was continuous for about 3 months, and included the evaluation of a raised spillway weir (RSW), a new technology for passing larger number of juvenile salmon at smaller spills.

In-Pool Transport and Dispersion Studies

During the 1996 spill season, in-pool transport and dispersion investigations were conducted to define the lateral mixing characteristics between hydropower and spillway releases. Water temperature, TDG levels, and dissolved oxygen were measured at several lateral transects located over an entire pool length. These studies focused on the lateral and longitudinal distribution of TDG throughout a pool during a period lasting from a few days to a week. In-pool transport and mixing studies were conducted below Little Goose, Lower Monumental, and Ice Harbor during the 1996 spill season. In most cases, a lateral transect of TDG instruments was located below the dam to establish the level of TDG entering the pool, with additional transects throughout the pool. These studies provided observations of the TDG saturation in project releases as they moved throughout an impoundment. However, only a limited range of operations was possible during the relatively short duration of these tests.

Operational Data

Operational data were obtained from each project detailing the spillway and powerhouse unit discharge on time intervals ranging from five minutes to one hour. The average hourly total spillway and generation releases, and forebay and tailwater pool elevations were summarized in the DGAS database. The tailwater pool gauge was generally located below the powerhouse of each dam. The tailwater elevation at the powerhouse was found to be within one foot of the water elevation downstream of the stilling basin in most instances.

Data Interpretation

The objective of this analysis was to develop mathematical relationships between observed TDG and operational parameters such as discharge, spill pattern, and tailwater channel depth. These relationships were derived with observations from the FMSs and spillway performance tests. However, before the analysis could be conducted, the monitored data had to be evaluated to determine its reliability for this kind of analysis. For example, the monitored TDG data from the FMSs provide a basis for defining the effects of spillway operation on dissolved gas levels in the river below a dam, but the following limitations should be noted:

- The FMSs sample water near-shore, which may not reflect average TDG levels of the spill. The monitor sites were, in general, located on the spillway side of the river to measure the effects of spillway operation. However, with a non-uniform spill distribution and geometry across the gates of the spillway, the FMS may be more representative of the spillbays closest to the shore. Outside spillbays without flow deflectors can create elevated TDG levels downstream from these bays compared to adjacent deflected bays. A spill pattern that

dictates higher unit discharges on these outside bays can further elevate the TDG levels downstream of these bays relative to the releases originating from the deflected interior bays.

- Depending upon the lateral mixing characteristics, the FMS downstream of a project may be measuring spillway releases that have been diluted with hydropower releases. Under most conditions, the TDG saturation of generation releases is less than the TDG level associated with spillway releases. The TDG at the tailwater FMS will be a function of the discharge and level of TDG from both generation and spillway releases. Obviously, if there is no spill, then the monitored TDG levels will reflect the TDG saturation released by the hydropower facility.
- Passage of generation flows through a power plant does not significantly change the TDG levels associated with this water. However, there can be a significant near-field entrainment of powerhouse flow by spillway releases at some projects, especially if flow deflectors are present. Observed data suggest that, under these conditions, some portion of the powerhouse discharges will be subjected to the same processes that cause absorption of TDG by spillway releases. In these cases, the TDG levels measured immediately downstream of a spillway will be associated with the spillway release plus some component of the powerhouse discharge.

The observations of tailwater TDG pressure need to be paired up with project operations to conduct an evaluation of the data. A set of filters or criteria were established to select correctly-paired data for inclusion in this analysis. The travel time for project releases from the dam to the tailwater FMS was typically less than two hours and steady-state tailwater stage conditions were usually reached within this time period. Thus, the data records were filtered to include data pairs corresponding with constant operations of duration greater than two hours to exclude data corresponding with unsteady flow conditions. This filtering criterion eliminated data associated with changing operations and retained only a single observation for constant operating conditions equal to three hours in duration.

- *Manual and Automated Inspections for Obviously Inaccurate Observations.* An automated search for values above or below expected extremes identified potential erroneous and inaccurate data in the database. These data were inspected and, if appropriate, excised from the database.
- *Comparison of Measurements from Forebay and Tailwater Instruments During Non-Spill Periods.* During the non-spill periods, downstream measurements should approach the forebay concentration when only the hydropower project is releasing water. Inspection of the data was conducted to identify errors when this condition was not met.
- *Comparison of Measurements from Redundant Tailwater TDG Monitors, if Available.* TDG tailwater data was rejected when measurements of two instruments at the same site varied by more than 3% saturation.

1. Lower Granite Dam

TDG Exchange

The spillway operation at Lower Granite often results in the highest increase in the TDG loading within the study area. This fact is mainly caused by the low ambient TDG conditions approaching the dam. During 1997, the forebay TDG pressure was generally about 800 mm Hg (107%), and the tailwater TDG pressure during peak forced spill events exceeded 1,000 mm Hg (133%). The resultant TDG levels transported to Little Goose often reached maximum levels of 950 mm Hg (127%) or a net 150 mm Hg (20%) increase in the average TDG pressure as a result of spillway operations. The absence of detailed near-field data below Lower Granite caused the description of project TDG exchange to be based solely on observations from the FMS. The seasonally low and relatively constant background TDG pressures in the forebay of Lower Granite provided a unique opportunity to quantify the impacts of spill operation at Lower Granite on TDG conditions in the Lower Snake River.

The TDG exchange properties at Lower Granite were explored through the evaluation of data from the tailwater FMS. The data collected during the 1997 spill season was filtered to include only events associated with a constant spill operation of three hours. The data filtering resulted in a total of 98 independent observations as summarized in Table 3. The delta TDG pressure ranged from 61.4 to 266.9 mm Hg for these events. The unit spillway discharge ranged from 3.1 to 26.4 kcfs/bay, and the tailwater depth ranged from 48.7 to 55.5 feet.

Table 3. Statistical Summary of Regression Variables for Lower Granite Dam

	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	98	98	98
Minimum	61.4	3.1	48.7
Maximum	266.9	26.4	55.5
Average	166.3	9.4	52.4
Standard Deviation	46.0	4.2	1.4

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-13

A more detailed study in 2002 (USACE, 2003) examined spill operations of about a three month period, including the operation of the raised spillway weir. The generation of TDG by spill was found to be a function of the spill discharge, spill pattern, and powerhouse discharge.

Regression

The TDG production during spillway releases from Lower Granite as defined by $\Delta P = P_{tw} - P_{bar}$, was found to be proportional to the product of tailwater depth and an exponential function of the specific discharge as shown in Equation 11. Both of the coefficients determined by the nonlinear

regression analysis were significant to the 99% confidence interval as shown in Table 4. This formulation explained much of the variability in the data with an r-squared of 0.93 and a standard error of 11.60 mm Hg. This relationship indicates that the upper limit for TDG exchange for large unit spillway discharge is influenced by the tailwater depth below Lower Granite. As the total river flow increases, the tailwater stage will increase and higher TDG pressures will be generated for the same spill operation. The storage in Little Goose pool can also influence the tailwater conditions below Lower Granite.

Table 4. Statistical Summary of Nonlinear Regression at Lower Granite, 1997 Spill Season

$\Delta P = c_1 * D_{tw} * (1 - \exp(c_2 * q_s))$ Number of Observations n=98 $r^2 = 0.93$ Std Error = 11.60 mm Hg				
Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
c_1	5.307	0.151	35.17	<0.0001
c_2	-0.106	0.0056	-19.02	<0.0001

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-14

This equation also implies that increasing the unit spillway discharge will result in higher TDG pressures. The unit spillway discharge can be very high for debris spill at Lower Granite, resulting in high TDG pressures for relatively low total spillway discharges. The spill pattern at Lower Granite spillway has also changed during the study period to accommodate the operation of the surface bypass system. Other structural changes to the spillway at Lower Granite, such as the raised spillway weir, will also affect the spill pattern and resultant TDG exchange through changes to the average unit spillway discharge.

$$\Delta P = 5.307 D_{tw} (1 - e^{-0.1059 q_s}) \quad \text{Equation 11}$$

Where:

- ΔP = $P_{tw} - P_{bar}$
- P_{tw} = TDG pressure at the tailwater FMS (mm Hg)
- q_s = Flow-weighted unit spillway bay discharge (kcfs/bay)
- D_{tw} = Tailrace channel depth (feet) ($E_{tw} - E_{ch}$)
- E_{tw} = Elevation of the tailwater (ft)
- E_{ch} = Average elevation of the tailrace channel (320 fmsl¹)
- P_{bar} = Barometric pressure at the tailwater FMS (mm Hg)

¹ feet above mean sea level

The unit spillway discharge was plotted against the observed and calculated tailwater TDG pressure difference in Figure 7. The exponential relationship between the TDG pressure and specific discharge is evident in this figure as the TDG pressure approached an upper limit as the specific discharge becomes large. Much of the variability in the TDG pressure for a constant unit discharge can be accounted for by the variation in the tailrace channel depth.

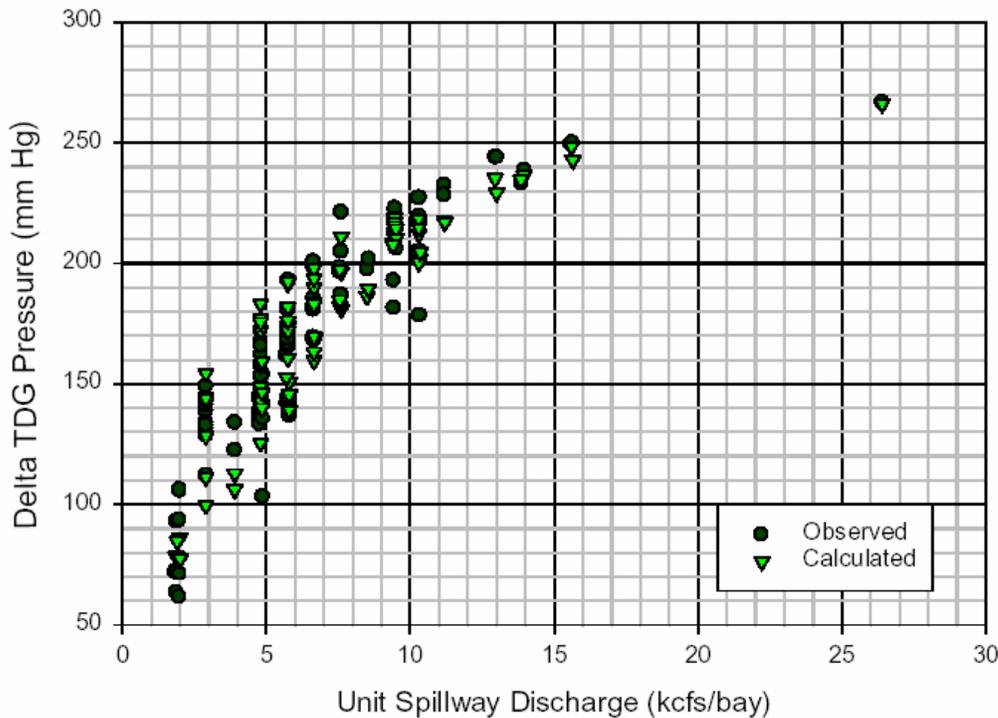


Figure 7. Unit Spillway Discharge versus TDG Pressure Above Barometric Pressure at Lower Granite Dam, 1997.

Most of the variability in the TDG production can be accounted for by the specific discharge. The specific discharge is a surrogate measure for the velocity, momentum, and exposure time of aerated flow associated with spillway discharge. The three-dimensional response surface for Equation 11 is shown in Figure 8 along with the observed data. The TDG pressure increases for a constant unit spillway discharge as the tailrace channel depth increases. However, the influence of the tailwater depth is small as evidenced by the small slope in the response surface for a constant unit discharge. The tailrace channel depth is a function of the total river flow and the pool elevation of the lower reservoir. This relationship couples the operation of the powerhouse at Lower Granite and the storage management in Little Goose pool to the TDG production in spillway releases from the Lower Granite spillway.

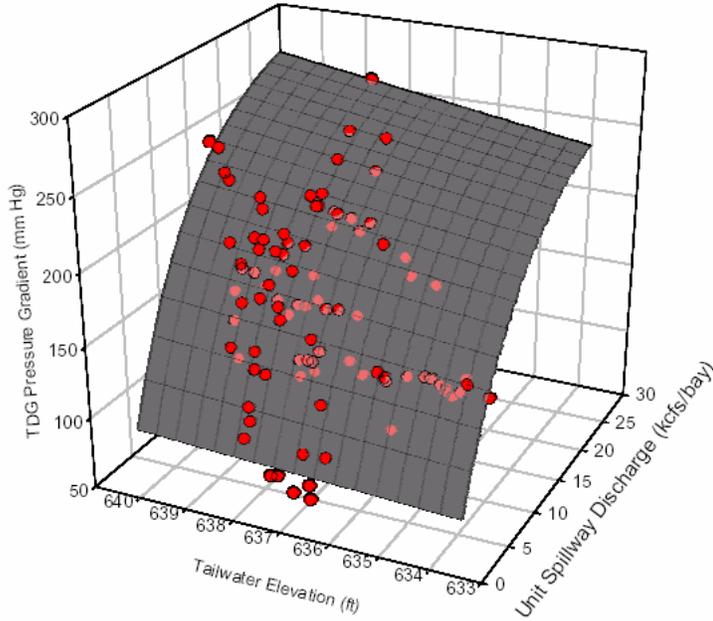


Figure 8. Unit Spillway Discharge, Tailwater Elevation, and TDG Pressure Above Barometric Pressure at Lower Granite Dam, 1997.

The response function as defined in Equation 11 was used to create a hindcast of the TDG production observed during the 1997 spill season. The hourly project operation and TDG pressure at the Lower Granite FMS's for the month of June 1997 are shown in Figure 9 along with the estimates of TDG saturation based on Equation 11. In general, the estimated TDG pressure was generally within 10 mm Hg of the observed tailwater TDG saturation. The tailwater TDG instrument malfunctioned during June 7-10, resulting in the large difference between observed and calculated values. The TDG production relationship could be used to screen data coming from the FMS system for the purpose of assuring the quality of information used for real time management decision-making. The occurrence of atypical spill patterns, measurement error, and dilution with powerhouse releases probably accounts for much of the estimation error shown during this period.

Monitoring in 2002 developed regressions that predicted TDG levels from unit discharge. Draft equations found a relationship in the form of Equation 12, with an R-squared coefficient of 0.92.

$$\Delta P = C_1(1 - e^{C_2 q_s}) \quad \text{Equation 12}$$

Where:

- ΔP = $P_{tw} - P_{bar}$
- C_1 = Regression Coefficient
- C_2 = Regression Coefficient
- q_s = Flow-weighted unit spillway bay discharge (kcfs/bay)
- P_{tw} = TDG pressure at the tailwater FMS (mm Hg)
- P_{bar} = Barometric pressure at the tailwater FMS (mm Hg)

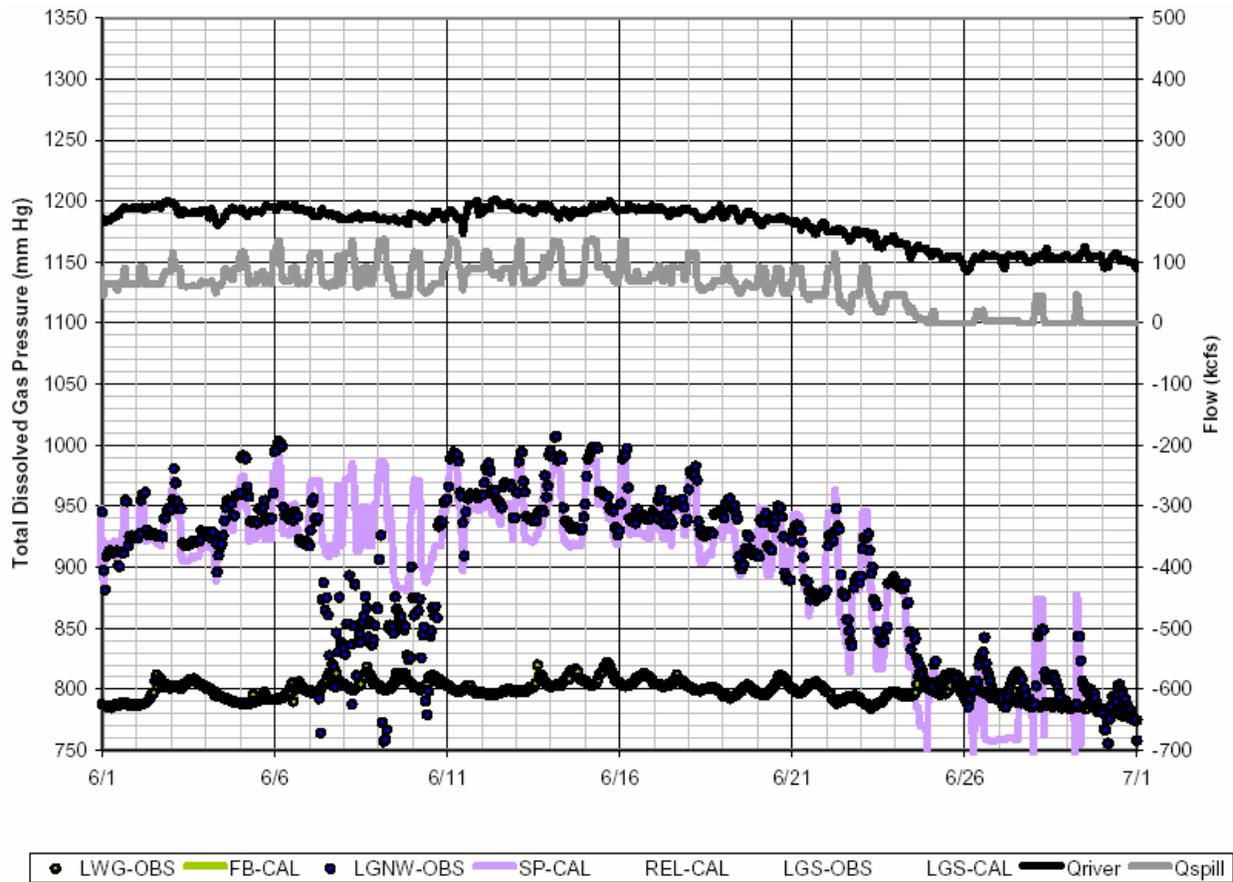


Figure 9. Observed and Estimated TDG Pressure at the Tailwater Fixed Monitoring Station at Lower Granite Dam, 1997.
(LGW-Obs Observed Forebay TDG , LGNW-Obs Observed Tailwater TDG, SP-Cal Calculated Tailwater TDG, Qriver-Hourly Total River Flow, Qspill-Hourly Spillway Flow)

When the effect of powerhouse generation flows was included in the regression, using the equation format shown in Equation 13, the R-squared coefficient increased to 0.93.

$$\Delta P = C_1(1 - e^{C_2 q_s}) + C_3 Q_{gen} \quad \text{Equation 13}$$

Where:

- ΔP = $P_{tw} - P_{bar}$
- C_1 = Regression Coefficient
- C_2 = Regression Coefficient
- C_3 = Regression Coefficient
- q_s = Flow-weighted unit spillway bay discharge (kcfs/bay)
- Q_{gen} = Generation discharge (kcfs)
- P_{tw} = TDG pressure at the tailwater FMS (mm Hg)
- P_{bar} = Barometric pressure at the tailwater FMS (mm Hg)

Entrainment of Powerhouse Discharge

This formulation defined by Equations 11 and 12 do not account for the added mass of TDG associated with entrainment of powerhouse releases into the aerated flow regime below a spillway. The observations of surface flow patterns below Lower Granite have demonstrated the vigorous interaction that occurs between spillway and powerhouse releases. A recirculation cell has been observed to form directly below the Lower Granite powerhouse, which draws water back towards the powerhouse and promotes the lateral entrainment of powerhouse flows into the stilling basin.

The importance of the entrainment of powerhouse flows into the bubbly flow in the stilling basin was demonstrated by routing Lower Granite releases through the Little Goose pool for the historic conditions observed during 1997. The average TDG pressure generated by Lower Granite operations was estimated by using a flow-weighted average of powerhouse and spillway flows. The TDG content of spillway flows were determined from Equation 11 while the TDG pressure associated with powerhouse releases was set to the observed forebay TDG pressure. A simple hydrologic routing of project releases was performed to estimate the TDG pressure arriving at Little Goose.

The results from this analysis are shown in Figure 10 where the observed hourly TDG pressure at Little Goose (LGS-obs) is shown as the shaded circles while the estimated TDG pressure in the forebay of Little Goose (LGS-cal) is shown as a light pink line (the lower gray line in black-and-white copies). The difference between the estimated and observed TDG pressure was as large as 80 mm Hg. The largest prediction errors tended to be associated with operating conditions resulting in a smaller percent of the river spilled. The simulation of TDG exchange was repeated using a simple linear relationship between spillway discharge and the estimated entrainment of powerhouse flow. The entrainment of powerhouse flow was assumed to equal 75% of the total spillway discharge as limited by available powerhouse releases. The entrained powerhouse flows were assumed to be exposed to the same conditions as spillway releases and experience comparable TDG uptake.

The results from this formulation for TDG exchange at Lower Granite are shown in Figure 11. The estimated TDG pressure in the Little Goose forebay much more closely predicted the observed TDG pressure throughout the month of June. The average prediction error was small for the simulation shown in Figure 11 with the peak TDG pressures well represented. The short travel time through Little Goose pool during this evaluation will lessen the influence of changing water temperatures and TDG exchange across the water surface on TDG pressure. As a consequence of this evaluation, the effective spillway flow (actual+entrainment) was estimated to be about 175% of the rated spillway release. The effective spillway discharge at Lower Granite can be calculated as $Q_{se}=1.75Q_s$ provided that the powerhouse flows exceed the entrainment discharge.

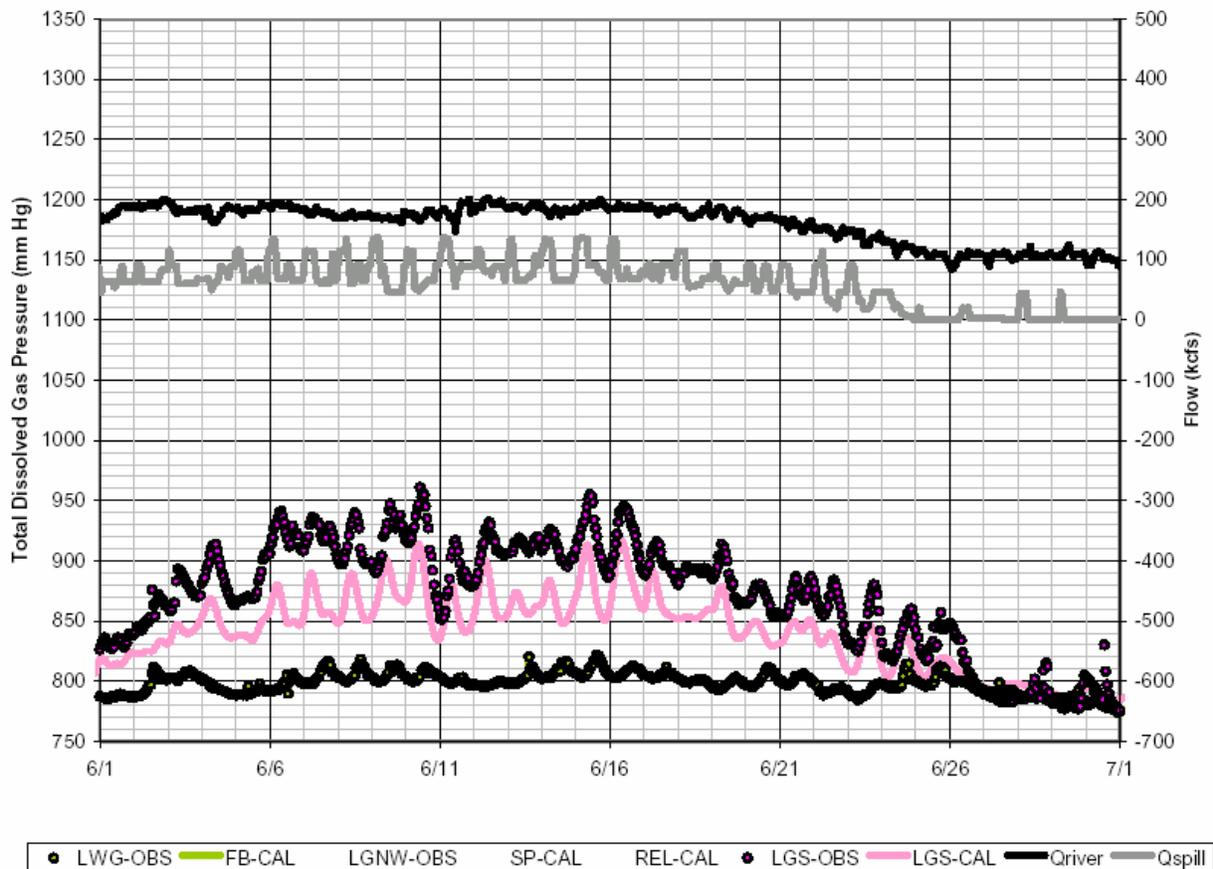


Figure 10. Observed and Estimated TDG Pressure in the Forebay of Lower Granite and Little Goose Dams, June 1997 (No Entrainment of Powerhouse Releases).

Monitoring in 2002 vividly illustrated the effect of powerhouse entrainment. Under conditions below peak flows (less than 100 kcfs total river flow), or when more that 40% or the river was being spilled, a large eddy occurred that recirculated powerhouse flows into the spill and spill flows back to the powerhouse. The amount of powerhouse flow entrained was roughly equal to the spill flow (up to the entire powerhouse flow), resulting in a doubling of the mass of water exposed to TDG generation processes.

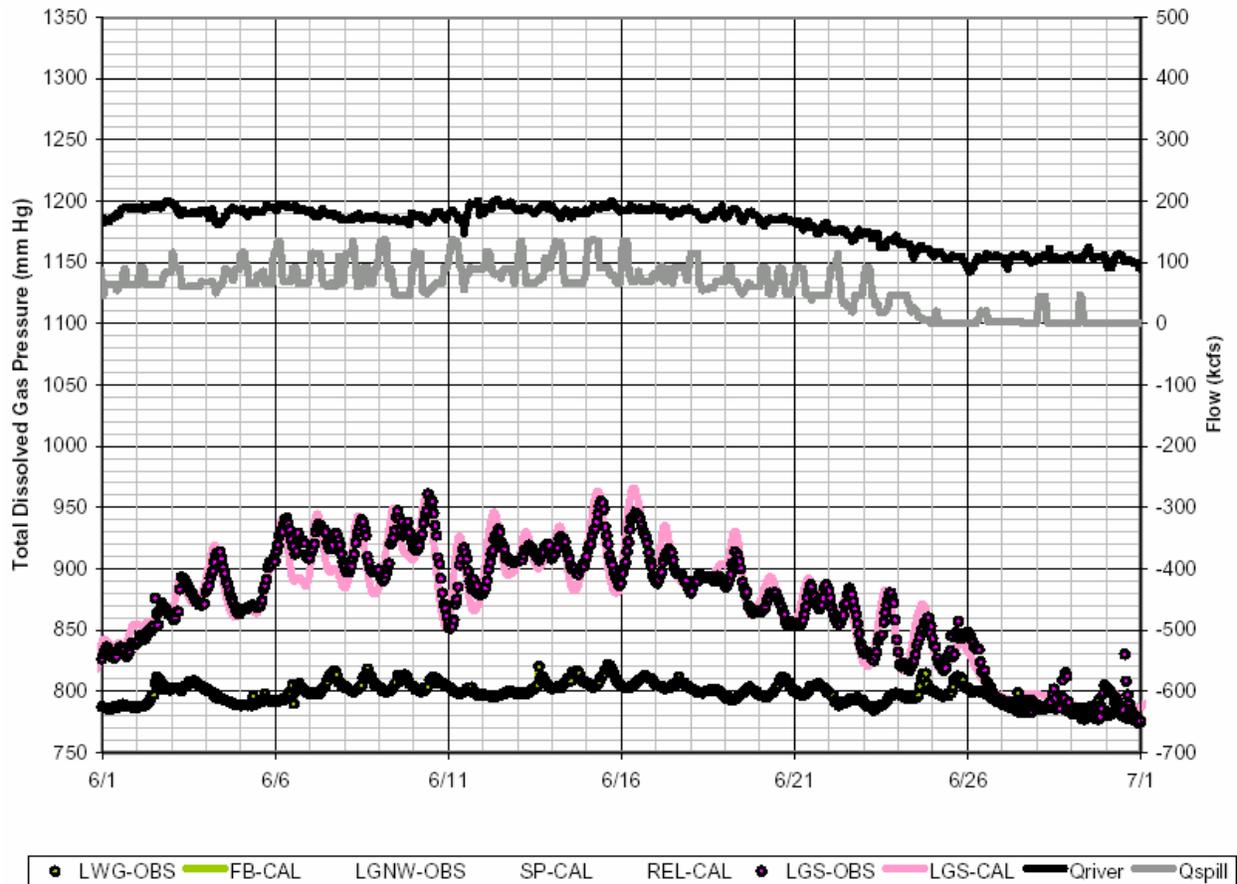


Figure 11. Observed and Estimated TDG Pressure in the Forebay of Lower Granite and Little Goose Dams, June 1997 (Powerhouse Entrainment=0.75 Q_s).

2. Little Goose Dam

TDG Exchange

A near-field TDG exchange investigation was conducted at Little Goose during February 20-22, 1998, as described in Schneider and Wilhelms (1998a). The study consisted of sampling TDG pressures below the spillway during spillway discharges ranging from 20 to 60 kcfs with and without powerhouse flows. Two spill patterns were investigated during this study: adult and juvenile. The study findings indicated that the TDG production was directly related to the unit spillway discharge, spill pattern, and powerhouse flow. The resultant average TDG saturation in Little Goose project flows ranged from 110 to 127% during the study for unit spillway discharges ranging from 2.5 to 10 kcfs/bay. The operation of all eight bays (adult pattern) was found to increase the TDG exchange when compared to the juvenile pattern (only bays with flow deflectors) at similar unit spillway flows by as much as 5% saturation. The presence of ambient TDG pressures associated with powerhouse releases was not observed downstream of the highly aerated flow regime associated with Little Goose spill, implying considerable lateral interaction of project releases. In the case of the adult spill pattern at a discharge of 40 and 60 kcfs, the

addition of a powerhouse flow of 60 kcfs with forebay TDG saturation of 101% did not change the average TDG saturation below Little Goose of 123 and 126%, respectively.

Regression

The TDG exchange at Little Goose was further explored through the evaluation of data from the FMS. This evaluation provided a wider range of operating conditions in terms of spillway discharge and tailwater elevation than observed during the near-field test. The regression equation was based on data collected during the 1997 spill season for spills using the juvenile spill pattern (spill was limited to the six internal spillway bays). The filtered data resulted in a total of 190 independent observations as listed in Table 5. The delta TDG pressure ranged from 79.6 to 218.8 mm Hg for these events. The unit spillway discharge ranged from 1.8 to 21.6 kcfs/bay, and the tailwater depth ranged from 36.3 to 42.1 feet.

Table 5. Statistical Summary of Regression Variables

	Delta Pressure ΔP (mm/Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	190	190	190
Minimum	79.6	1.8	36.3
Maximum	218.8	21.6	42.1
Average	158.4	9.5	39.0
Standard Deviation	29.0	3.5	1.3

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-17

The TDG production during spillway releases using the juvenile spill pattern from Little Goose, as defined by $\Delta P = P_{tw} - P_{bar}$, was found to be proportional to the product of tailwater depth and an exponential function of an exponential function of the unit spillway discharge as shown in Equation 14. Both of the coefficients determined by the nonlinear regression analysis were significant to the 99% confidence interval as shown in Table 6. This formulation explained much of the variability in the data with an r-squared of 0.84 and a standard error of 11.65 mm Hg. Several data points were responsible for the poorer correlation coefficient for this data set compared to the other projects.

$$\Delta P = 5.566 D_{tw} (1 - e^{-0.150 q_s}) \quad \text{Equation 14}$$

Where:

$$\begin{aligned} \Delta P &= P_{tw} - P_{bar} \\ P_{tw} &= \text{TDG pressure at the tailwater FMS (mm Hg)} \\ P_{bar} &= \text{Barometric pressure at the tailwater FMS (mm Hg)} \\ q_s &= \text{Flow-weighted unit spillway bay discharge (kcfs/bay)} \\ D_{tw} &= \text{Tailrace channel depth (feet) } (E_{tw} - E_{ch}) \\ E_{tw} &= \text{Elevation of the tailwater (fmsl)} \\ E_{ch} &= \text{Average elevation of the tailrace channel (500 fmsl)} \end{aligned}$$

Table 6. Statistical Summary of Nonlinear Regression at Little Goose, Juvenile Spill Pattern, 1997 Spill Season

$\Delta P_{tw} = c_1 * D_{tw} * (1 - \exp(c_2 * q_s))$ Number of observations n=190 $r^2 = 0.84$ Std. Error=11.65 mm Hg				
Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
c_1	5.566	0.0996	55.91	<0.0001
c_2	-0.150	0.0060	24.91	<0.0001

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-18

The unit spillway discharge was plotted against the observed and calculated tailwater delta TDG pressure in Figure 12. The exponential relationship between the TDG pressure and specific discharge is evident in this figure as the TDG pressure approached an upper limit as the specific discharge becomes large. Much of the variability in the TDG pressure for a constant unit discharge can be accounted for by the variation in the tailrace channel depth. The degree of TDG exchange will approach a threshold value only for a constant tailwater depth using this formulation. Since the tailwater depth will continue to increase for higher river flows during forced spill conditions, the limit for TDG exchange will also continue to increase.

Most of the variability in the TDG production can be accounted for by the unit spillway discharge. The specific discharge is a surrogate measure for the velocity, momentum, and exposure time of aerated flow associated with spillway discharge. The three-dimensional response surface for Equation 14 is shown in Figure 13 along with the filtered observed FMS data. The TDG pressure increases for a constant unit spillway discharge as the tailrace channel depth increases. However, the influence of the tailwater depth is small as evidenced by the small slope in the response surface for a constant unit discharge. The tailrace channel depth is a function of the total river flow and the pool elevation of the lower reservoir. This relationship couples the operation of the powerhouse at Little Goose and the storage management in Lower Monumental pool to the TDG production in spillway releases from the Little Goose spillway.

The response function as defined in Equation 14 was used to create a hindcast of the TDG production observed during the 1997 spill season. The hourly project operation and TDG saturation at the Little Goose FMS's (LGS-forebay, LGSW-tailwater) for the month of May 1997 are shown in Figure 14 along with the estimates of tailwater TDG saturation (TDGest) based on Equation 14. In general, the estimated TDG saturation was generally within 1 percentage point of the observed tailwater TDG saturation during the juvenile spill events. The scheduling of the adult spill pattern is indicated by the positive discharge through bay 8 (Qs8). In general, the tailwater TDG pressure dropped below 120% only during juvenile spill events of 40 kcfs or less.

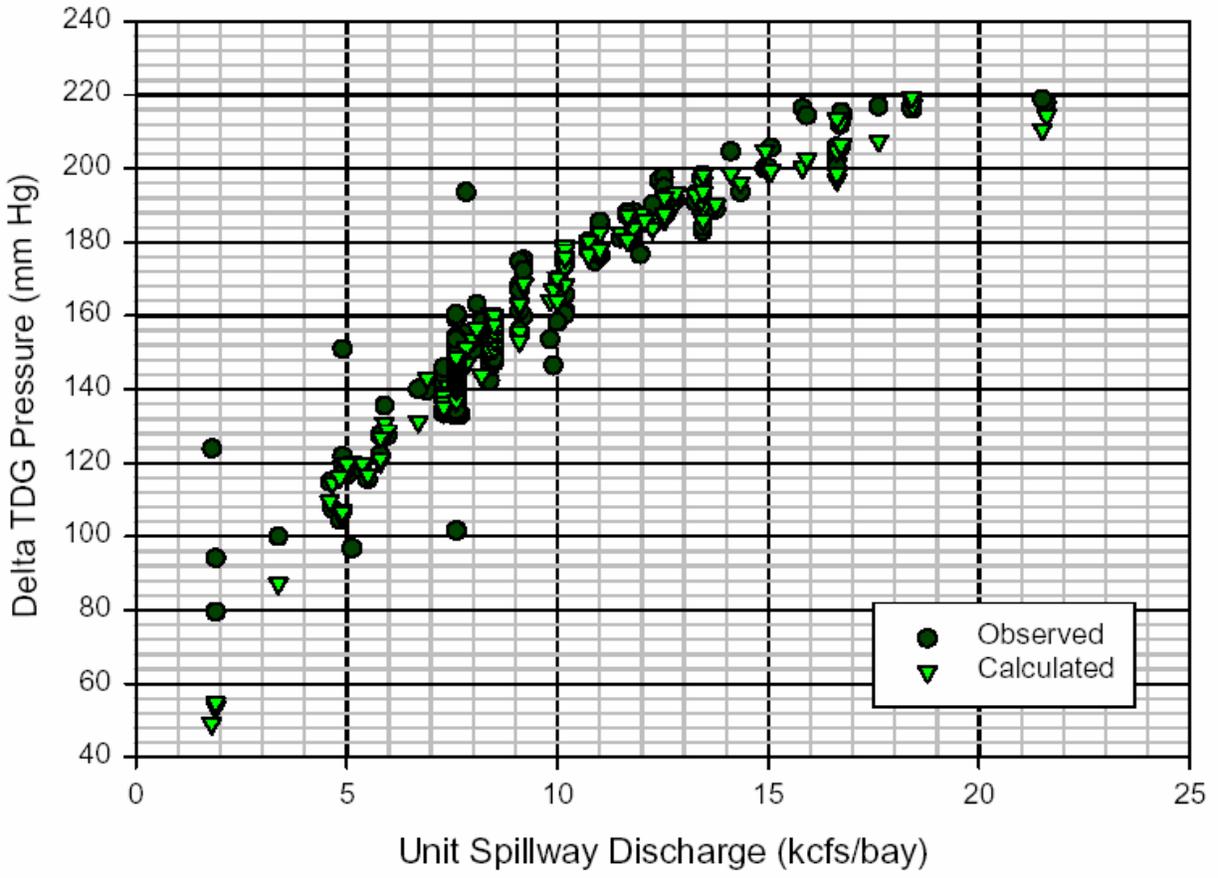


Figure 12. Unit Spillway Discharge versus TDG Pressure above Barometric Pressure at Little Goose Dam, Juvenile Spill Pattern, 1997.

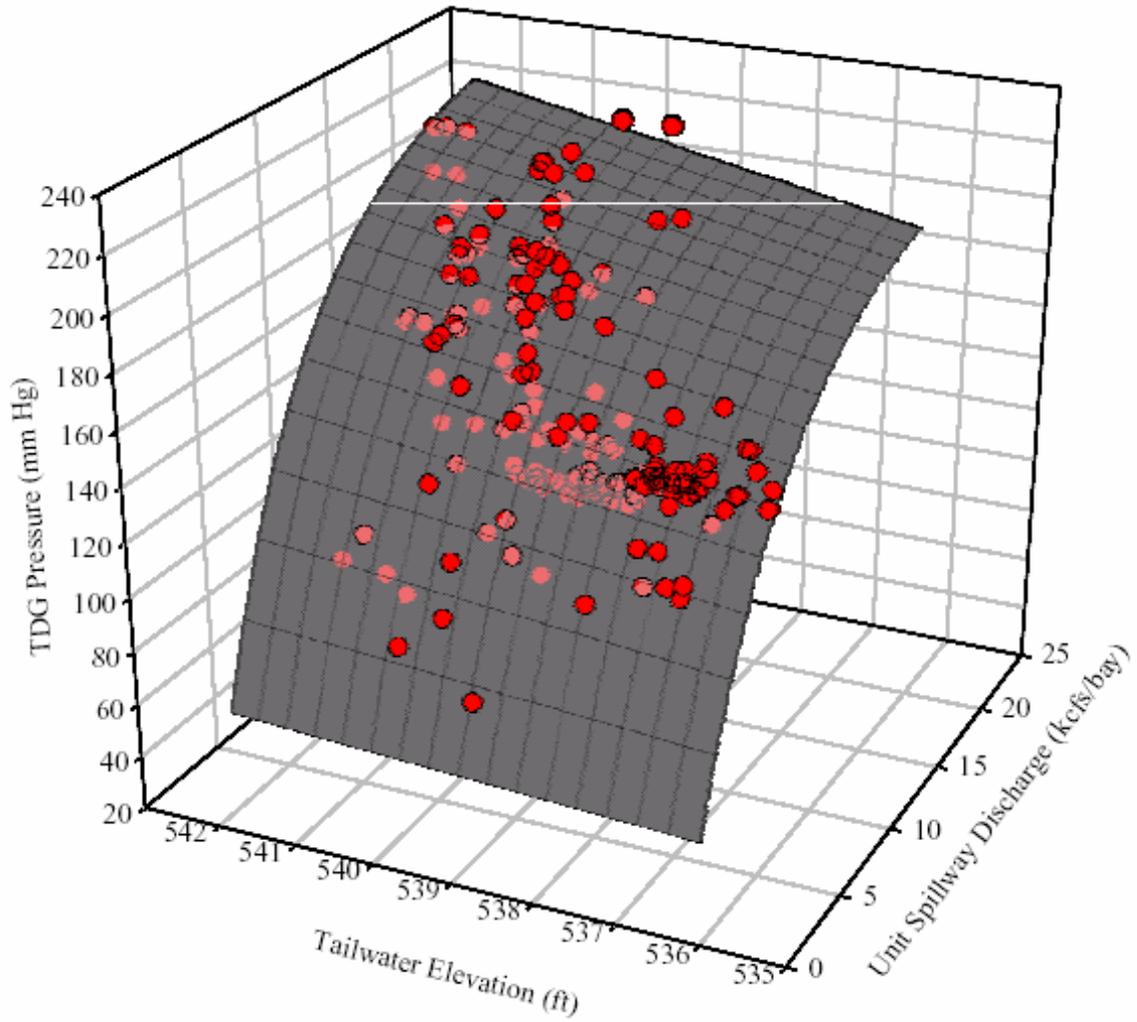


Figure 13. Unit Spillway Discharge, Tailwater Elevation, and TDG Pressure Above Barometric Pressure at Little Goose Dam, 1997.

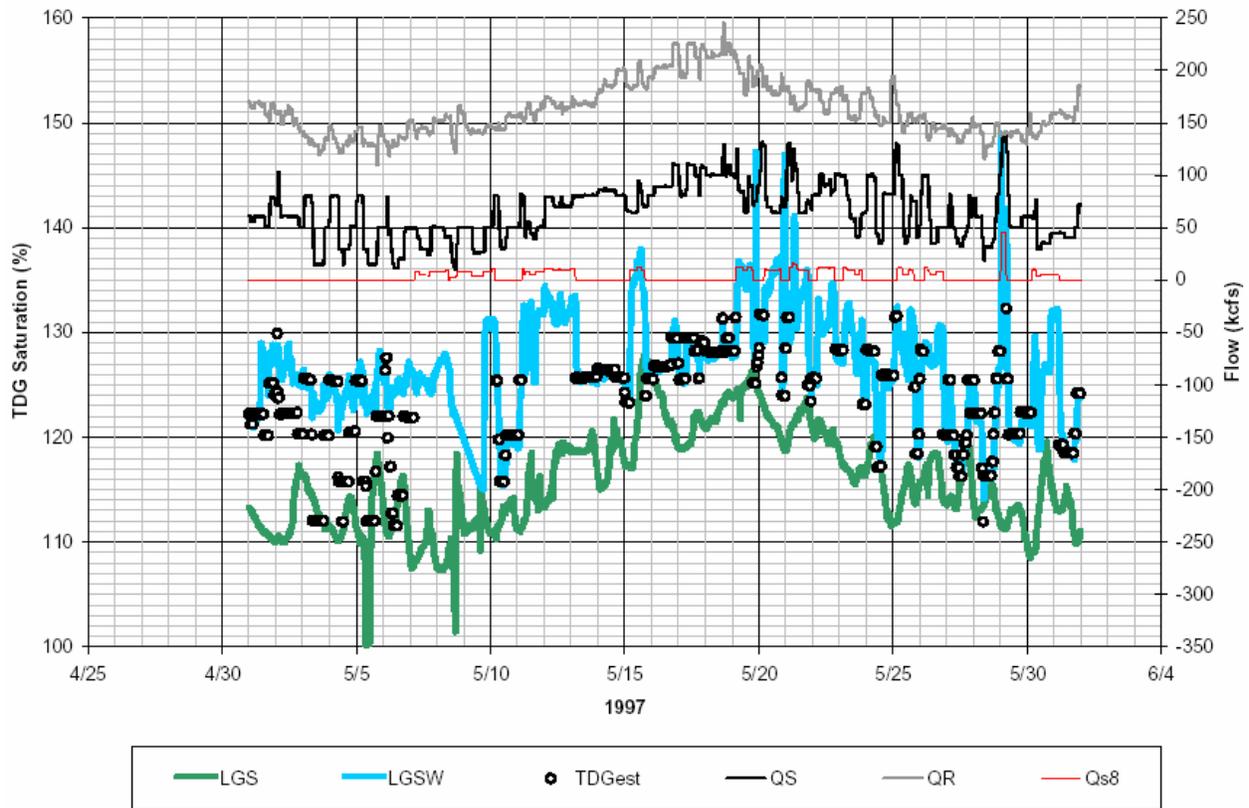


Figure 14. Observed and Estimated TDG Saturation at the Tailwater Fixed Monitoring Station at Little Goose Dam, 1997.
 (LGS=Observed Forebay TDG, LGSW=Observed Tailwater TDG, LGSWest =Calculated Tailwater, TDG,QR=Hourly Total River Flow, QS=Hourly Spillway Flow)

The tailwater TDG saturation exceeded 130% during juvenile spill releases approaching 100 kcfs. Large differences between the observed and calculated TDG saturations were observed prior to May 10. These differences were most likely due to instrument malfunction during this period.

The operations of all spillway bays in the adult spill pattern with a constant operation of three hours were identified during the 1997 spill season for Little Goose. This data filtering resulted in a total of only 35 independent hourly observations. The delta TDG pressure was found to range from 65.6 to 276.6 mm Hg as listed in Table 7. The range in unit spillway discharge was from 1.9 to 13.2 kcfs/bay, and the tailwater depth ranged from 38.5 to 41.7 feet.

Table 7. Statistical Summary of Regression Variables

	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	35	35	35
Minimum	65.6	1.9	38.5
Maximum	276.6	13.2	41.7
Average	222.4	7.9	40.2
Standard Deviation	42.0	2.8	0.8

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-19

The functional relationship for the TDG production of the adult spill pattern (all eight bays) was similar to the equation determined for spillway bays with flow deflectors at Little Goose as shown in Equation 15. All of the coefficients determined by the nonlinear regression analysis were significant to the 99% confidence interval as shown in Table 8. This formulation contained a much higher standard error (19.5 mm Hg) than found in other production relationships with an r-squared of 0.79. The observed and calculated delta TDG pressures were plotted against the unit spillway discharge at Little Goose in Figure 15.

$$\Delta P = 6.488 D_{tw} (1 - e^{-0.280 q_s}) \quad \text{Equation 15}$$

Table 8. Statistical Summary of Nonlinear Regression at Little Goose, Adult Spill Pattern, 1997 Spill Season

$\Delta P_{tw} = c_1 * D_{tw} * (1 - \exp(c_2 * q_s))$ Number of observations n=35 $r^2 = 0.79$ Std. Error = 19.51 mm Hg				
Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
c_1	6.488	0.2197	29.5268	<0.0001
c_2	0.2796	0.0319	8.7538	<0.0001

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-19

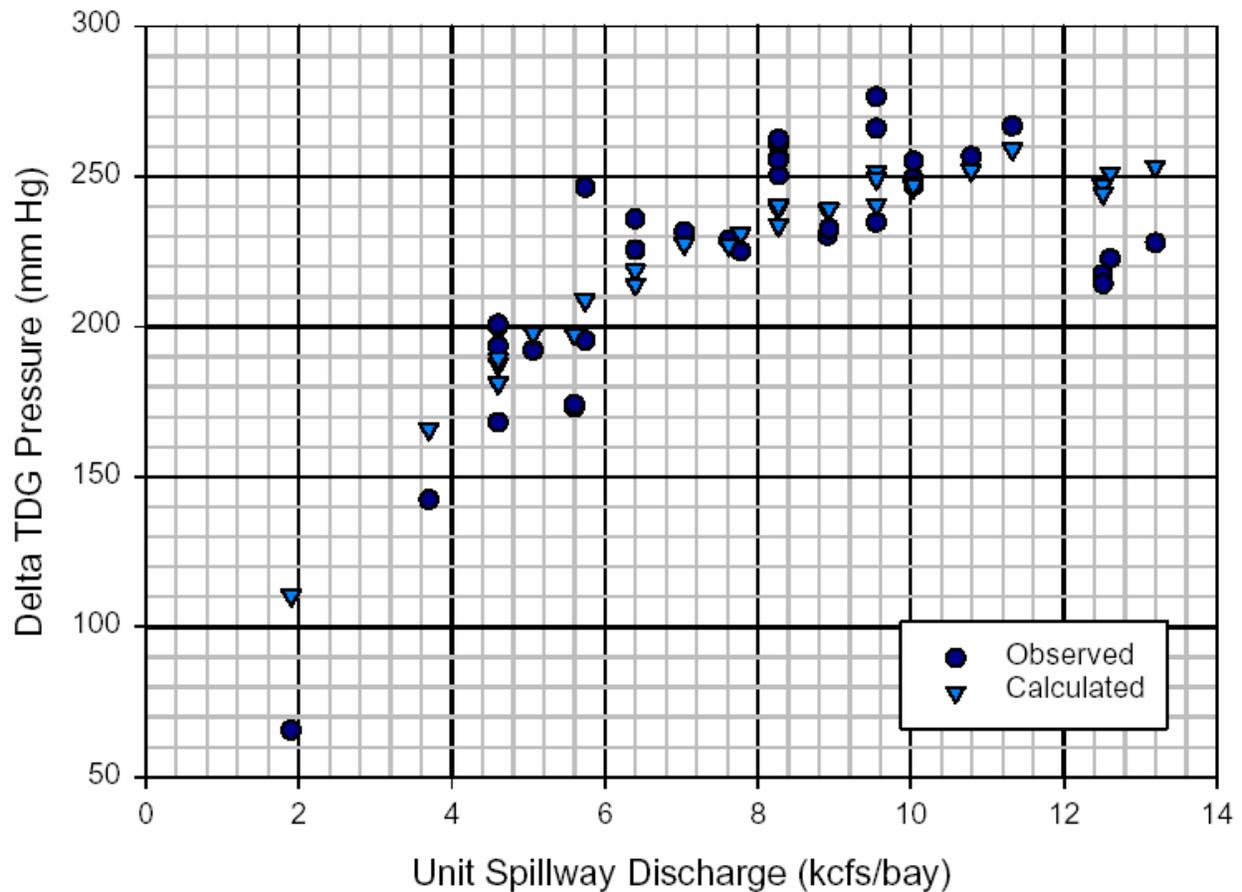


Figure 15. Unit Spillway Discharge versus TDG Pressure Above Barometric Pressure at Little Goose Dam, Adult Spill Pattern, 1997.

Entrainment of Powerhouse Discharge

The determination of the fate of powerhouse flow was documented during the TDG exchange study conducted at Little Goose (Schneider and Wilhelms, 1998a). The entrainment of powerhouse flows into the bubbly flow in the stilling basin is significant below Little Goose and has been estimated to be a function of the spillway discharge. The effective spillway flow (actual+entrainment) has been greater than 200% of the rated spillway release. The effective spillway discharge at Little Goose can be estimated as $Q_e=1.0Q_s$ provided that the powerhouse flows exceed the entrainment discharge.

This functional form for the entrainment discharge was applied to observed data during the 1997 spill season at Little Goose. The average TDG pressure generated by Little Goose operations was estimated by using a flow-weighted average of powerhouse and spillway flows. The TDG content of spillway flows was determined from Equation 15 and while the TDG pressure associated with powerhouse releases was set to the observed forebay TDG pressure. A simple hydrologic routing of project releases was performed to estimate the TDG pressure arriving at Lower Monumental. No entrainment of powerhouse flows was assumed for the first scenario. The results from this analysis are shown in Figure 16 where the observed hourly TDG pressure

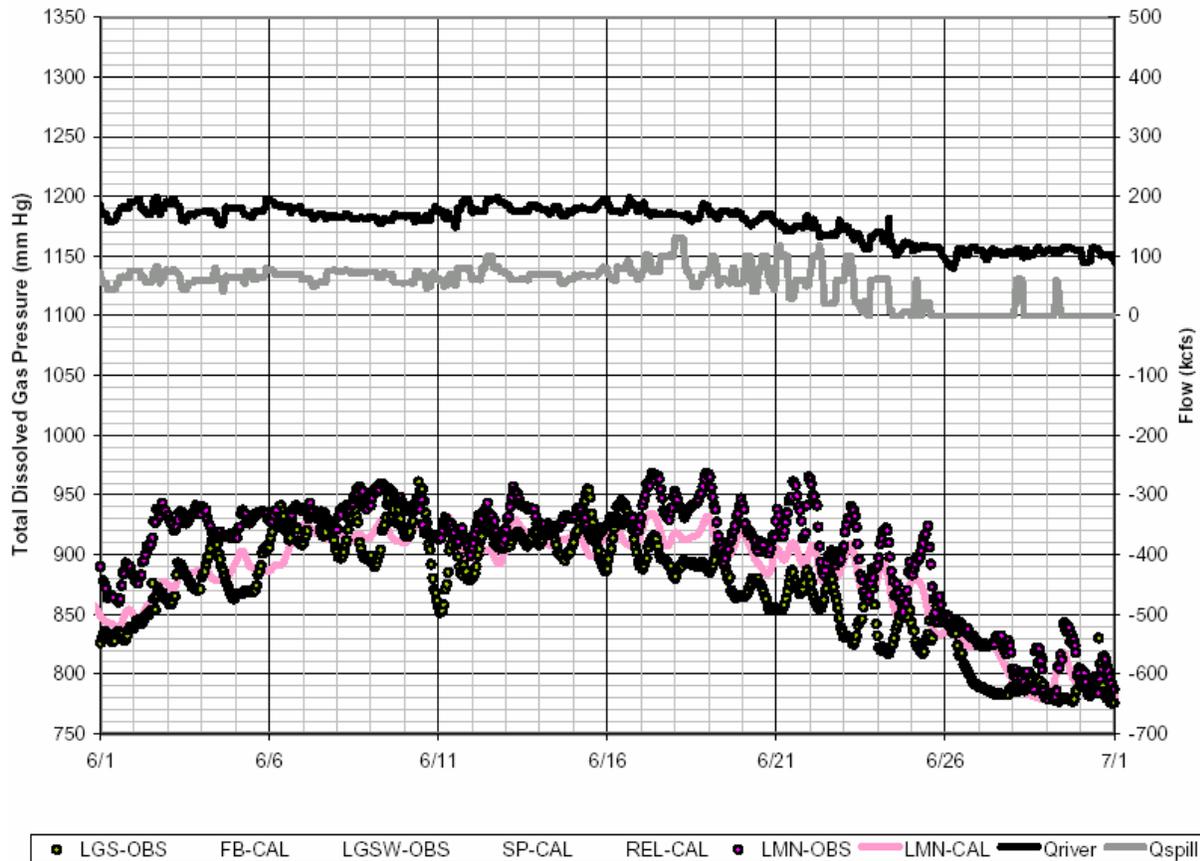


Figure 16. Project Operations and Observed and Calculated TDG Pressures in the Forebay of Lower Monumental Dam, June 1997 (No entrainment of Little Goose Dam Powerhouse Flows).

in the forebay of Lower Monumental (LMN-obs) is shown as shaded circles while the estimated TDG pressure in the forebay of Lower Monumental (LMN-cal) is shown as a light pink line (the lower gray line in black-and-white copies). The difference between the estimated and observed TDG pressure was as large as 50 mm Hg and was consistently less than observed conditions throughout the month of June.

The simulation of TDG exchange and transport was repeated using a simple linear relationship between spillway discharge and the estimated entrainment of powerhouse flow. The entrainment of powerhouse flow was assumed to equal to the spillway discharge as limited by available powerhouse releases. The entrained powerhouse flows were assumed to be exposed to the same conditions as spillway releases and to experience comparable TDG uptake. The results from the simulation with entrainment are shown in Figure 17. The calculated TDG pressure much more closely approximates the observed TDG pressures in the forebay of Lower Monumental. This evaluation agrees closely with the finding from the near-field TDG study, which indicated a significant component of powerhouse releases is exposed to aerated flow conditions and TDG exchange processes.

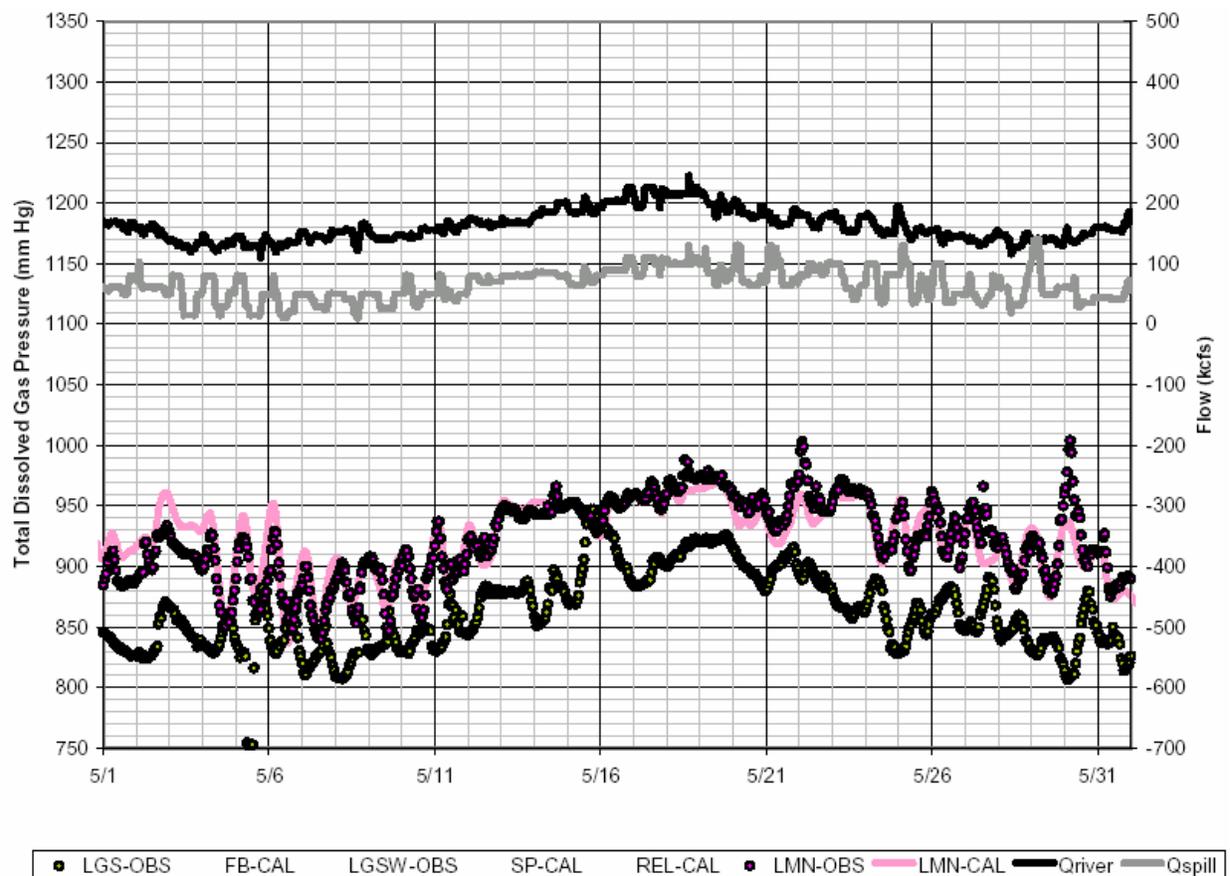


Figure 17. Project Operations and Observed and Calculated TDG Pressures in the Forebay of Lower Monumental Dam, June 1997 (Entrainment of Little Goose Dam Powerhouse Flows=Spillway Discharge).

3. Lower Monumental Dam

TDG Exchange

A TDG exchange field investigation was conducted at Lower Monumental during August 21-22, 1996, with the study summarized in Schneider and Wilhelms (1996). The study consisted of sampling TDG pressures below the spillway during spillway discharges ranging from 10 to 50 kcfs. Two different spill patterns were investigated during this study--adult and juvenile spill patterns. The study findings indicated that the TDG production was directly related to the unit spillway discharge. The TDG saturation ranged from 105 to 121% during the study for unit spillway discharges ranging from 1.3 to 8.4 kcfs/bay. The influence of the operation of spillway bays without flow deflectors was found to increase the TDG exchange for comparable unit spill discharges by as much as 9% saturation. The relatively small total river flows and associated range in tailwater elevations resulted in test spill conditions corresponding with tailwater elevations ranging from 438.6 to 439.9 fmsl.

An evaluation of data from the tailwater FMS during 1997 provided an opportunity to study the TDG exchange of spillway flows at Lower Monumental under a wider range of operating conditions. The spillway events were identified by the applied spill pattern and separate evaluations were conducted for these types of events. The data associated with spill over bays with flow deflectors with a constant operation of three hours were identified. This data filtering resulted in a total of 68 independent hourly observations. The delta TDG pressure was found to range from 101.9 to 238.7 mm Hg as listed in Table 9. The range in unit spillway discharge was from 2.1 to 24.1 kcfs/bay, and the tailwater depth ranged from 42.7 to 48.1 feet.

Table 9. Statistical Summary of Regression Variables

	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	68	68	68
Minimum	101.9	2.1	42.7
Maximum	238.7	24.1	48.1
Average	205.1	13.3	44.6
Standard Deviation	25.6	4.8	1.1

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-21

Regression

The functional relationship between TDG production and project operation at Lower Monumental was similar to Little Goose. The TDG pressure in excess of the local barometric pressure, as defined by $\Delta P = P_{tw} - P_{bar}$, was found to be proportional to the product of tailwater depth and an exponential function of the specific discharge as shown in Equation 16. All of the coefficients determined by the nonlinear regression analysis were significant to the 99% confidence interval as shown in Table 10. This formulation explained much of the variability in the estimated dependent variable with an r-squared of 0.96 and a standard error of 5.4 mm Hg.

$$\Delta P = 5.056 D_{tw} (1 - e^{-0.210 q_s}) \quad \text{Equation 16}$$

Where:

$$\begin{aligned} \Delta P &= P_{tw} - P_{bar} \\ P_{tw} &= \text{TDG pressure at the tailwater FMS (mm Hg)} \\ P_{bar} &= \text{Barometric pressure at the tailwater FMS (mm Hg)} \\ q_s &= \text{Flow-weighted unit spillway bay discharge (kcfs/bay)} \\ D_{tw} &= \text{Tailrace channel depth (feet) (E}_{tw} - E_{ch}) \\ E_{tw} &= \text{Elevation of the tailwater (fmsl)} \\ E_{ch} &= \text{Average elevation of the tailrace channel (500 fmsl)} \end{aligned}$$

Table 10. Statistical Summary of Nonlinear Regression at Lower Monumental, Juvenile Spill Pattern, 1997 Spill Season

$\Delta P_{tw} = c_1 * D_{tw} * (1 - \exp(c_2 * q_s))$					
Number of observations n=68 $r^2 = 0.96$ Std. Error = 5.4 mm Hg					
Coefficient		Estimate from Regression	Standard Error	t-statistic	Probability
Deflected	c_1	5.056	0.0306	165.3989	<0.0001
bays	c_2	-0.21	0.0060	35.8829	<0.0001

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-22

The unit spillway discharge was plotted against the observed and calculated tailwater TDG pressure above the local barometric pressure as shown in Figure 18. The exponential relationship between the TDG pressure and specific discharge is evident in this figure as the TDG pressure approached an upper limit as the specific discharge becomes large. Much of the variability in the TDG pressure for a constant unit discharge can be accounted for by the variation in the tailrace channel depth.

Most of the variability in the TDG production can be accounted for by the specific discharge. The specific discharge is a surrogate measure for the velocity, momentum, and exposure time of aerated flow associated with spillway discharge. The three-dimensional response surface for Equation 16 is shown in Figure 19 along with the observed data. The TDG pressure increases for a constant unit spillway discharge as the tailrace channel depth increases. However, the influence of the tailwater depth is small as evidenced by the small slope in the response surface for a constant unit discharge. The tailrace channel depth is a function of the total river flow and the pool elevation of the lower reservoir. This relationship couples the operation of the powerhouse at Lower Monumental and the storage management in Ice Harbor pool to the TDG production in spillway releases from the Lower Monumental spillway.

The response function as defined in Equation 16 was used to create a hindcast of the TDG production observed during the 1997 spill season. The hourly project operation and TDG saturation at the Lower Monumental FMS's (LMN-forebay, LMNW-tailwater) for the month of May 1997 are shown in Figure 20 along with the estimates of TDG saturation based on Equation 16. In general, the estimated tailwater TDG saturation (LMNW-cal) was generally within 1 percentage point of the observed tailwater TDG saturation. Spillway releases greater than 40 kcfs generally produced tailwater TDG saturation greater than 120% during this period. Forced spillway releases of 120 kcfs generated tailwater TDG saturation in excess of 132%. The usage of the adult spill pattern in Figure 20 is indicated by the operation of spillway bay 1 (QS1-red).

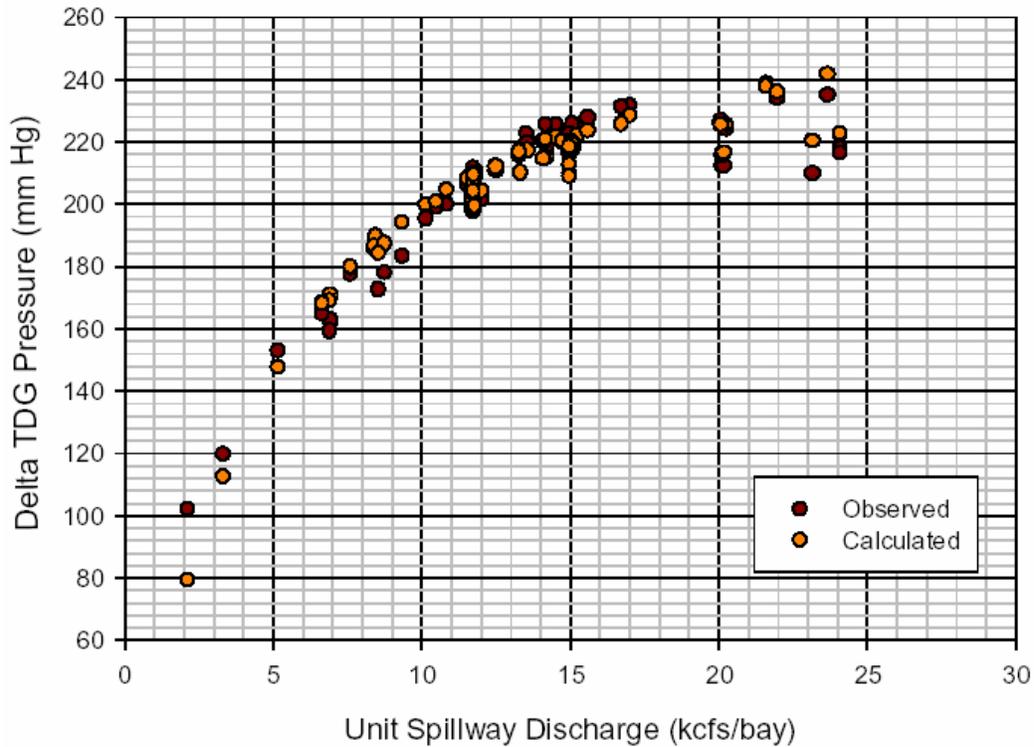


Figure 18. Unit Spillway Discharge versus TDG Pressure Above Barometric Pressure at Lower Monumental Dam, Juvenile Spill Pattern, 1997.

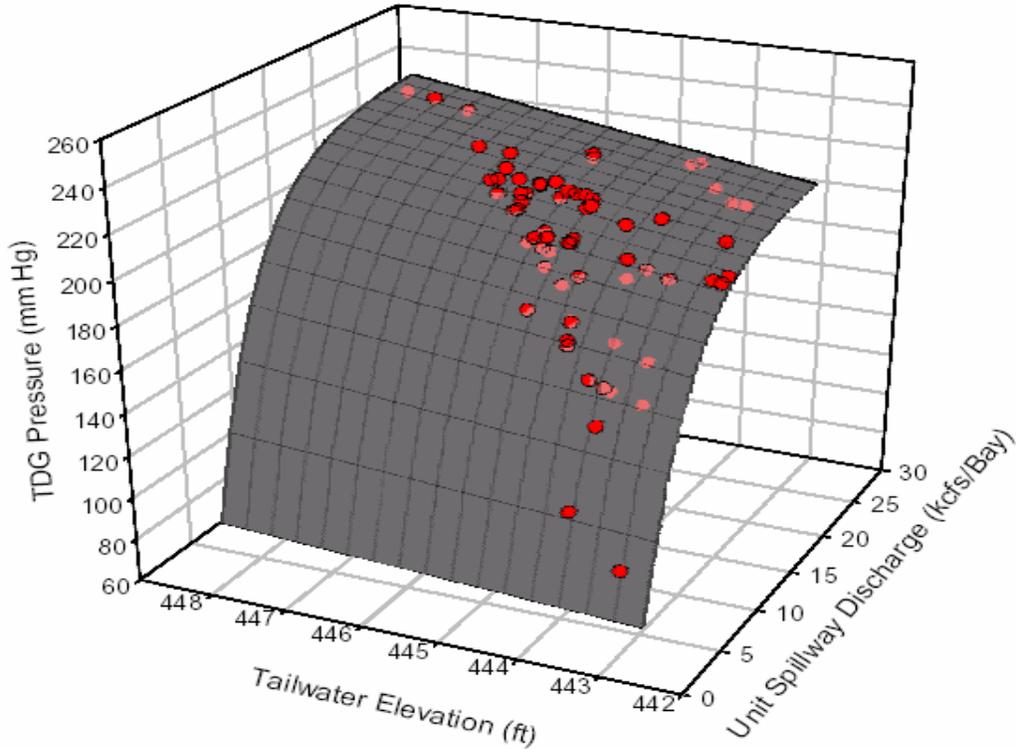


Figure 19. Unit Spillway Discharge, Tailwater Elevation, and TDG Pressure Above Barometric Pressure at Lower Monumental Dam, 1997.

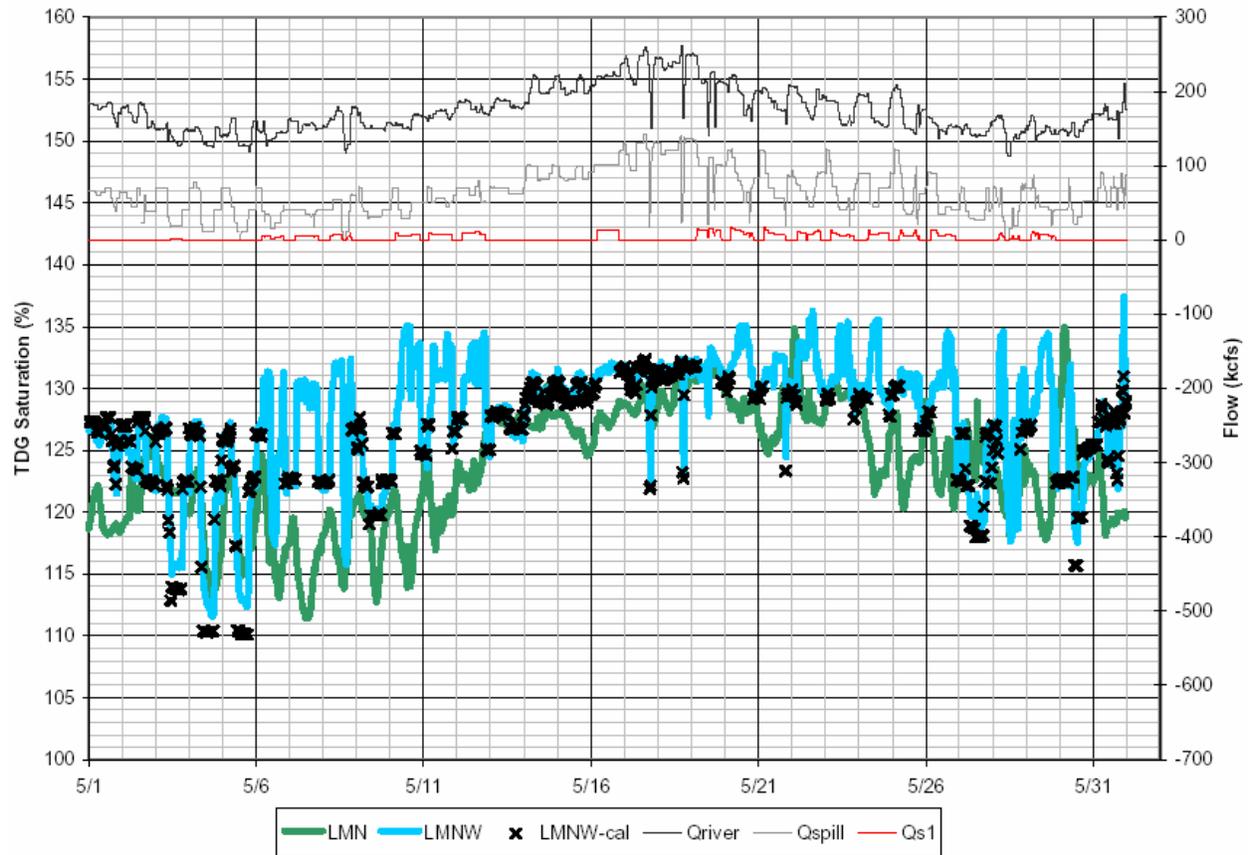


Figure 20. Observed and Estimated TDG Saturation at the Tailwater Fixed Monitoring Station at Lower Monumental Dam, May 1997.

(LMN=Observed Forebay TDG, LMNW=Observed Tailwater TDG, LMNW-cal =Calculated Tailwater TDG, QR=Hourly Total River Flow, QS=Hourly Spillway Flow)

The operations of all spillway bays in the adult spill pattern with a constant operation of three hours were identified during the 1997 spill season. This data filtering resulted in a total of only 34 independent hourly observations. The delta TDG pressure was found to range from 134.5 to 267.5 mm Hg as listed in Table 11. The range in unit spillway discharge was from 2.2 to 12.5 kcfs/bay, and the tailwater depth ranged from 43.5 to 46.6 feet.

Table 11. Statistical Summary of Regression Variables

	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	34	34	34
Minimum	134.5	2.2	43.5
Maximum	267.5	12.5	46.6
Average	237.1	7.5	45.1
Standard Deviation	23.8	2.5	0.8

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-23

The functional relationship for the TDG production of the adult spill pattern (Equation 17) was similar to the equation determined for spillway bays with flow deflectors at Lower Monumental. All of the coefficients determined by the nonlinear regression analysis were significant to the 99% confidence interval as shown in Table 12. This formulation contained a much higher standard error (15.9 mm Hg) than found in other production relationships with an r-squared of 0.57. The observed and calculated delta TDG pressures were plotted against the unit spillway discharge in Figure 21.

$$\Delta P = 5.427 D_{tw} (1 - e^{-0.580 q_s}) \quad \text{Equation 17}$$

Table 12. Statistical Summary of Nonlinear Regression at Lower Monumental, Adult Spill Pattern, 1997 Spill Season

$\Delta P_{tw} = c_1 * D_{tw} * (1 - \exp(c_2 * q_s))$ Number of observations n=34 $r^2 = 0.57$ Std. Error = 15.9 mm Hg				
Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
Deflectored bays	c_1 5.427	0.0853	63.5939	<0.0001
	c_2 -0.58	0.0769	7.5959	<0.0001

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-24

Entrainment of Powerhouse Discharge

Estimates of the entrainment of powerhouse flows into spillway discharge were not available from this near-field study because of the limited amount of powerhouse discharge. Visual observations of surface flow patterns below the powerhouse suggested that all powerhouse releases (14.5-19.2 kcfs) were being directed into the stilling basin. Since direct determination of the entrainment of powerhouse flows into the highly aerated conditions below Little Goose were not practical, it was assumed that the entrainment characteristics of Lower Monumental were similar to Ice Harbor. The estimates of the entrainment of powerhouse flows were estimated to average 30 kcfs and to be independent of the total spillway discharge.

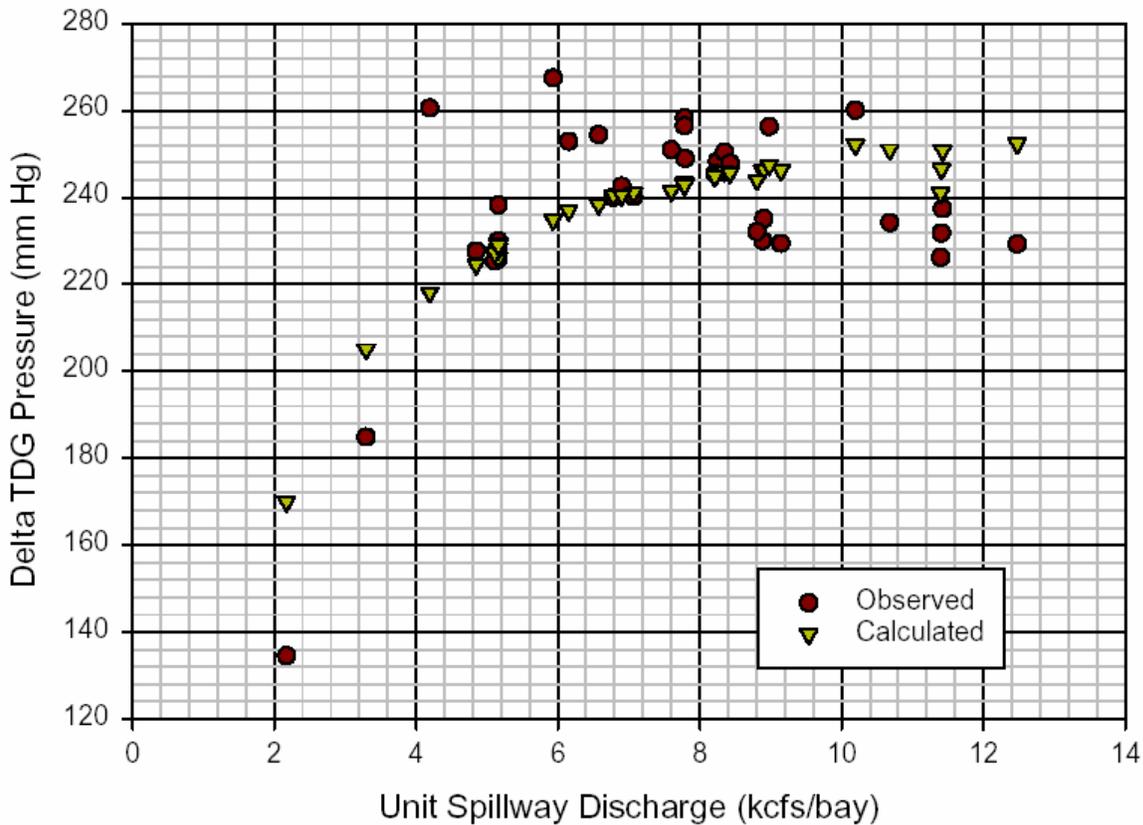


Figure 21. Unit Spillway Discharge versus TDG Pressure Above Barometric Pressure at Lower Monumental Dam, Adult Spill Pattern, 1997.

4. Ice Harbor Dam

TDG Exchange

The installation of spillway flow deflectors at Ice Harbor was completed in a staged schedule over 3 years. “Type II” flow deflectors were installed in spillway bays 2 through 9 at elevation 338 fmsl at Ice Harbor. The first four deflectors were completed during the winter of 1996-97 followed by four more deflectors in the fall of 1997. The end bay deflectors were completed during the winter of 1998-99.

The flow deflectors significantly changed the TDG exchange properties and spill management from Ice Harbor. A detailed post flow deflector near-field study of TDG exchange below Ice Harbor was conducted during March 5-9, 1998, as described by Wilhelms and Schneider (1998). The study consisted of sampling TDG pressures below the stilling basin during spillway discharges ranging from 15 to 75 kcfs with and without powerhouse flows. Several different spill patterns were investigated during this study: uniform bays 2 through 9 and standard spill pattern. The study findings indicated that the TDG production was directly related to the unit

spillway discharge. The TDG saturation was found to be an exponential function of unit spillway discharge with 110% saturation associated with a unit spillway discharge of 3 kcfs/bay and 115% saturation generated for a unit spillway discharge of 8 kcfs/bay for the uniform spill pattern.

The data did support the additional influence of the tailwater depth of flow on the TDG exchange characteristics. The addition of flow deflectors significantly reduced the absorption of TDG in the stilling basin, reducing the peak TDG pressures just downstream of the stilling basin end sill from 170 to 135% saturation.

The evaluation of data from the tailwater FMS during 1998 provided the opportunity to study the TDG exchange of spillway flows under a wider range of operating conditions. The spillway operation at Ice Harbor was found to generate significantly lower TDG pressures during lower total river flow conditions in comparison to the other Snake River projects. The unit spillway discharge was plotted against the tailwater TDG saturation in Figure 22 for the filtered data during the 1998 spill season at Ice Harbor. Two distinct linearly related groupings of points, corresponding roughly with low and high total river flow conditions, can be seen in this figure. The lower limit of this data cluster corresponds with lower total river flows and low tailwater stage. The corresponding spill capacity for a 120% tailwater waiver standard can be as high as 100 kcfs based on the lower limit in this data cluster. The upper limit of this data cluster corresponds with the highest total river flows experienced during 1998. The spill capacity for a TDG saturation of 120% in spillway releases into the tailrace channel could be as low as 70 kcfs. During the forced spill conditions at Ice Harbor (15 kcfs/bay discharges), the TDG pressures generated at Ice Harbor were significantly higher (10 to 20 mm Hg) than at upstream projects on the Snake River.

A second interesting feature of the relationship between unit spillway discharge and tailwater TDG saturation is the large variance in TDG saturation with unit spillway discharges of 4.5 and 9.0 kcfs/bay. These two spill levels correspond with the daytime and nighttime spillway capacities scheduled during much of the voluntary spring spill season. The data corresponding with a unit discharge of 9.0 kcfs/bay ± 0.2 kcfs/bay were extracted from the body of the data and plotted against the tailwater stage, initial forebay saturation, and water temperature. The tailwater stage was found to be highly correlated with this subset of data for a constant unit spillway discharge. A linear regression between TDG saturation and tailwater stage resulted in a correlation coefficient of 0.76 and a slope of 0.8% saturation per foot. This relationship suggests an 8% increase in TDG saturation should result from a 10-foot increase in depth of the tailrace channel.

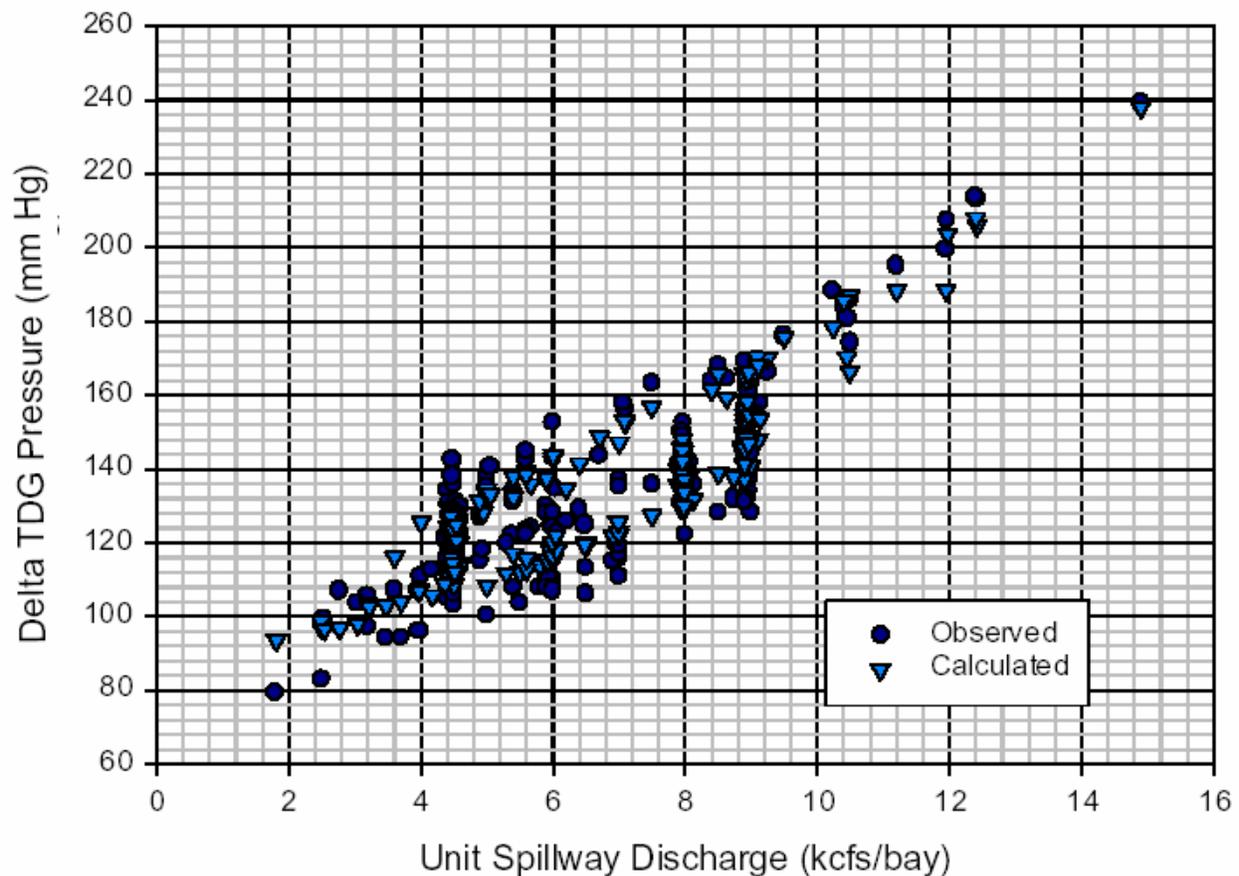


Figure 22. Unit Spillway Discharge versus TDG Pressure Above Barometric Pressure at Ice Harbor Dam, 1998.

Regression

A nonlinear regression was performed on the data from the 1998 spill season. The dependent variable was TDG pressure above the barometric pressure at the tailwater FMS. The two independent variables were tailwater depth and average unit spillway discharge. To prevent the incorporation of redundant data pairs during the same extended operation, only data with a constant operation for 3 hours were included in the analysis, resulting in a sample set of 233 observations. The tailwater depth ranged from 19.4 feet to 34.5 feet, which corresponded with total river flows from 29.7 kcfs to 243 kcfs as listed in Table 13. The unit spillway discharge ranged from 1.8 to 14.9 kcfs/bay and the delta pressure ranged from 79.3 to 239.0 mm Hg.

Table 13. Statistical Summary of Regression Variables

	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	234	234	234
Minimum	79.3	1.8	19.4
Maximum	239.0	14.9	34.5
Average	132.9	6.5	25.6
Standard Deviation	23.5	2.3	3.0

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-26

The change in TDG pressure, as defined by $\Delta P = P_{tw} - P_{bar}$, below Ice Harbor during spillway operations was found to be proportional to the product of tailwater depth and the specific discharge as shown in Equation 18. The regression equation was based on data collected during the 1998 spill season. All of the coefficients determined by the nonlinear regression analysis were significant to the 99% confidence interval as shown in Table 14. This formulation explained much of the variability in the estimated dependent variable with an r-squared of 0.90 and a standard error of 7.63 mm Hg. The constant coefficient of 84.57 forces a minimum TDG saturation of 112% at an atmospheric pressure of 755 mm Hg.

$$\Delta P = 0.014 D_{tw}^{2.097} q_s^{0.772} + 84.57 \quad \text{Equation 18}$$

Where:

$$\begin{aligned} \Delta P &= P_{tw} - P_{bar} \\ P_{tw} &= \text{TDG pressure at the tailwater FMS (mm Hg)} \\ P_{bar} &= \text{Barometric pressure at the tailwater FMS (mm Hg)} \\ q_s &= \text{Flow-weighted unit spillway bay discharge (kcfs/bay)} \\ D_{tw} &= \text{Tailrace channel depth (feet) (} E_{tw} - E_{ch} \text{)} \\ E_{tw} &= \text{Elevation of the tailwater (fmsl)} \\ E_{ch} &= \text{Average elevation of the tailrace channel (500 fmsl)} \end{aligned}$$

This relationship implies that both the depth of flow and specific discharge are important factors in determining the level of TDG exchanged during spillway releases. The response surface for TDG pressure above atmospheric pressure as a function of both unit discharge and tailwater stage is shown in Figure 23. The depth of the channel will influence the pressure time history of entrained air with larger depths resulting in a greater potential for the exchange of TDG. The specific discharge or discharge per spillway bay reflects the amount of energy available during spillway releases, which will establish the turbulence and the potential to entrain air in the stilling basin. The level of forebay TDG saturation was not an important parameter. Water temperature was not a significant variable in the exchange relationship at Ice Harbor.

Table 14. Statistical Summary of Nonlinear Regression at Ice Harbor, 1998 Spill Season

$\Delta P = c_1 * D_{tw}^{c_2} q_s^{c_3} + c_4$ Number of observations n=233 $r^2 = 0.90$ Std. Error=7.63 mm Hg				
Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
c_1	0.0140	0.0471	1.98	<0.0486
c_2	2.097	0.0652	11.66	<0.0001
c_3	0.772	0.1356	11.99	<0.0001
c_4	84.57	3.62	24.04	<0.0001

Source: U.S. Army Corps of Engineers DGAS Study, Appendix G, p. G-27

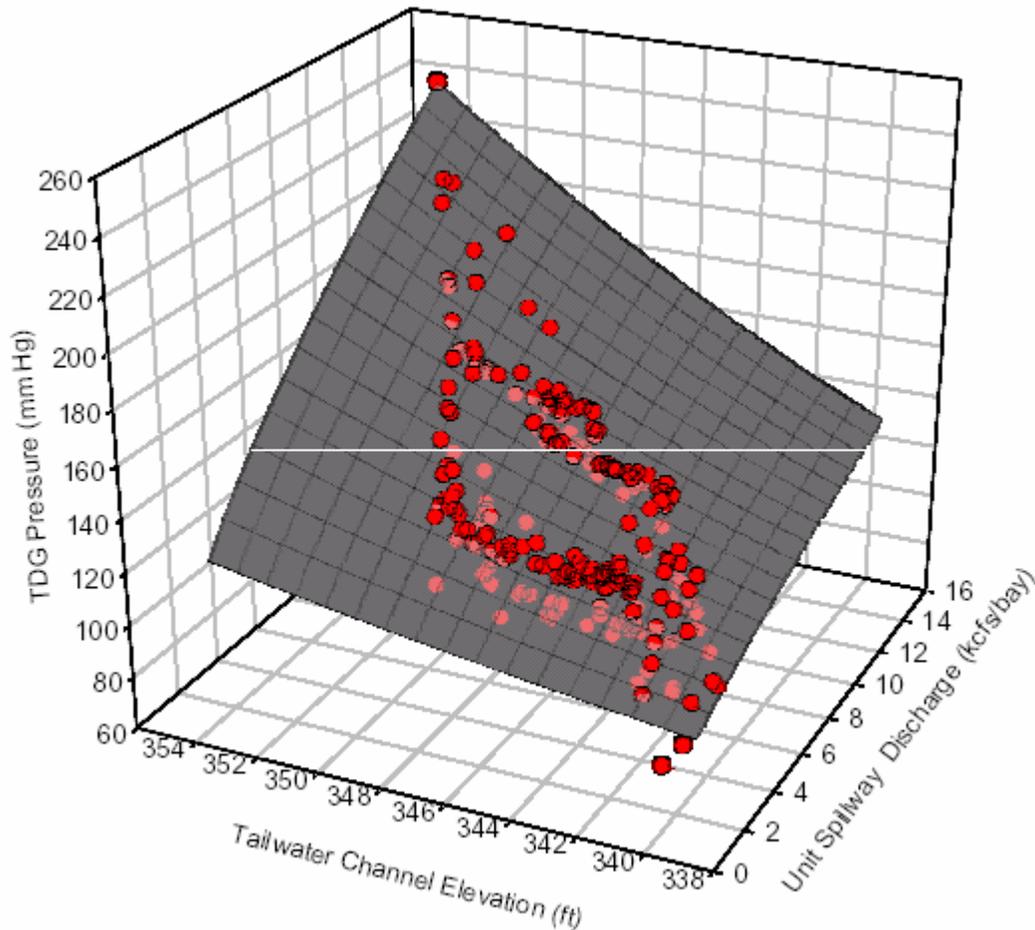


Figure 23. Unit Spillway Discharge, Tailwater Elevation, and TDG Pressure Above Barometric Pressure at Ice Harbor Dam, 1998.

Equation 18 was highly significant in explaining the variance in the TDG pressure at the tailwater FMS. The regression model was used to create a hindcast of the observed tailwater TDG saturation below Ice Harbor for the 1998 spill season. The results are shown in Figure 24 for the month of May 1998. The calculated TDG saturation closely tracked the diurnal variation in tailwater TDG saturation during May with a tendency to slightly overestimate the observed conditions during the beginning of the month. Even with this robust relationship, caution and judgment must be applied when using this equation outside the ranges of discharge and tailwater depth from which it was derived. The average, absolute, and root mean square error in TDG saturation computed using all of the observed data with spillway discharge during the months of April through July of 1998 were -0.3, 1.3, and 2.1%, respectively. The calculation of the error of estimate of the tailwater TDG pressure did not take into account the lagged time of response between operational changes and arrival of water at the tailwater FMS.

The management of project operations with regard to TDG must take into account the level of spillway discharge, spill pattern, and tailwater stage. The spill capacity resulting in 120% TDG saturation below Ice Harbor will be a direct function of both the total river flow, which is the determinant of tailwater stage, and unit spillway discharge.

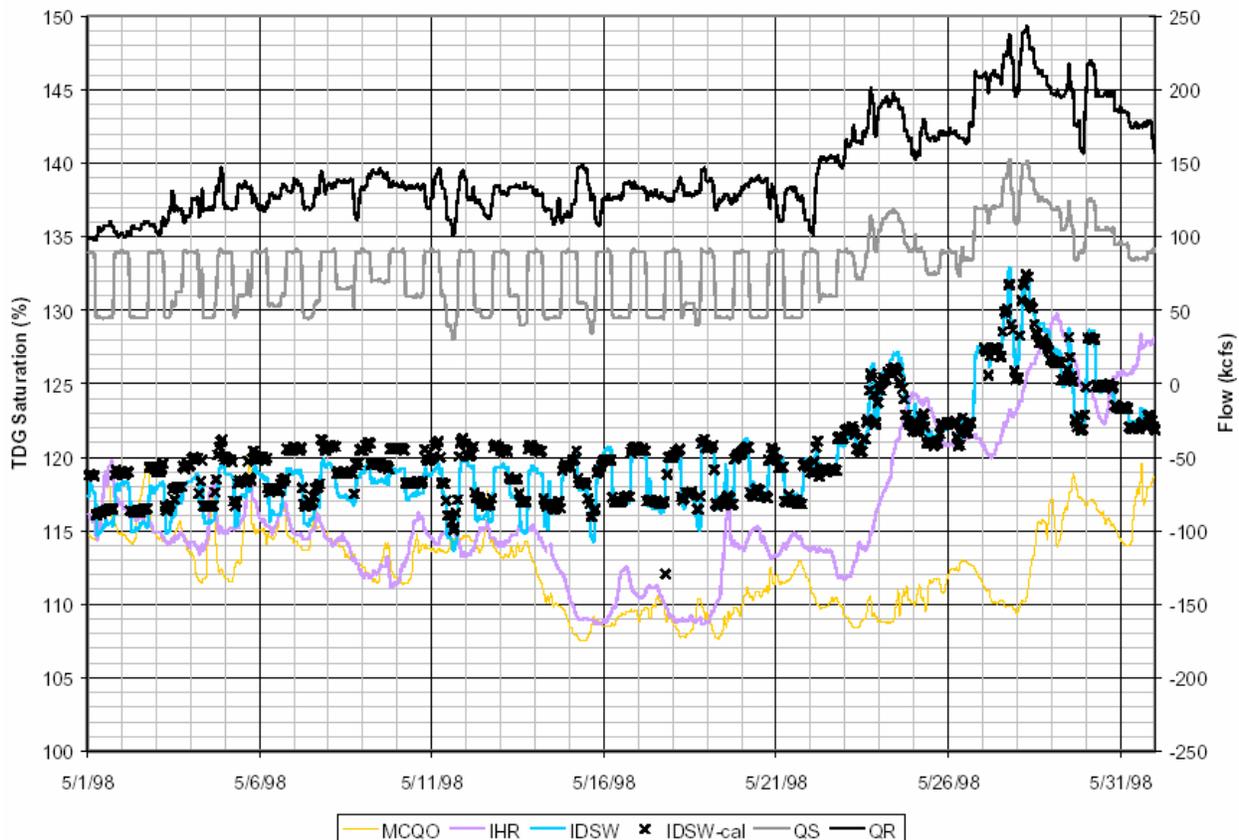


Figure 24. Observed and Estimated TDG Saturation at the Tailwater Fixed Monitoring Station at Ice Harbor Dam, May 1998.

(IHR=Observed Forebay TDG, IDSW=Observed Tailwater TDG, IDSW-cal =Calculated Tailwater TDG, QR=Hourly Total River Flow, QS=Hourly Spillway Flow)

Entrainment of Powerhouse Discharge

The entrainment of powerhouse flows into the highly aerated flow conditions below Ice Harbor was estimated from data collected during the 1998 spillway TDG exchange study. The powerhouse entrainment discharge was estimated for each flow condition by applying a simple mass balance statement of powerhouse and spillway project flows. The estimates of the entrainment of powerhouse flows were found to range from 26.4 to 38.5 kcfs and average about 30 kcfs. The powerhouse entrainment discharge was not found to vary as a function of the total spillway discharge.

Loading Capacity

Linkage of TDG Loading to the Criteria

As discussed above, the fundamental process that elevates TDG is gas transfer between the air and water at the boundary of entrained bubbles, driven by differential gas pressures. For any given spill volume and tailwater depth, the excess pressure over ambient barometric pressure, ΔP , can be predicted. The mass loading of air that is associated with any given ΔP will depend on water temperature. However this mass loading is of less importance than ΔP , since it is ΔP that drives whether gas bubble trauma will occur. For these reasons, using excess pressure rather than mass loading to express loading capacity is appropriate for this TMDL, and is supported by the Clean Water Act's allowance for the use of "other appropriate measures" in the development of TMDLs.

To determine the TMDL loading capacity, ΔP can be directly related to the TDG water quality criteria, as describe in Equation 6:

$$S_{idg} = \frac{(P_{atm} + \Delta P)}{P_{atm}} * 100$$

The equation can be rearranged to establish a ΔP loading capacity (ΔP_{lc}):

$$\Delta P_{lc} = P_{atm} * (S_{idg} / 100)$$

To choose a critical barometric pressure P_{atm} for establishing a loading capacity, the 95th percentile low pressure was determined. Data from the FMS sites on the Snake River from 1995 through 2002 were evaluated, and the 95th percentile low barometric pressure ranges from 736 mm Hg at the Lower Granite forebay to 746 mm Hg in the Ice Harbor tailrace. Therefore, loading capacities for the Lower Snake River are set to the ΔP values shown in Table 15.

The use of critical barometric pressure to set a value of ΔP to meet the criterion of 110% saturation is appropriate because of the need to meet the criteria throughout the river as conditions change downstream of the dams and away from compliance locations. However, the TDG criteria for fish passage are very specific for their location of application and are silent about the required levels away from the compliance locations. Therefore, loading capacities for fish passage will be set in terms of percent saturation, and are equal to the criteria.

Table 15. Lower Snake River TDG Loading Capacities

Location	Loading Capacity
Fish passage – Forebays of Ice Harbor, Lower Monumental, and Little Goose Dams ¹	115% Saturation ²
Fish passage – Tailrace of Ice Harbor, Lower Monumental, Little Goose, and Lower Granite Dams ¹	120% Saturation ²
Fish passage – Tailrace of Ice Harbor, Lower Monumental, Little Goose, and Lower Granite Dams ¹	125% Saturation ³
Non-fish passage - All other locations	74 mm Hg above saturation ⁴

¹when authorized by Ecology after approval of a gas abatement plan

²average of 12 highest hourly readings in a 24-hour period

³maximum hourly reading

⁴maximum instantaneous

Load and Wasteload Allocations

For the purpose of this TMDL, load allocations will be provided because no NPDES permits will be issued to the dams to regulate TDG caused by spills². This approach is also reasonable for several reasons:

- Spills entrain air to reach a polluted state, much like a high-energy release of water might erode a stream bank.
- Dams are essentially very large instream structures that will require modifications to achieve compliance with water quality standards. Even after modification, dams may be forced to pass through high incoming levels of TDG from upstream sources.
- The level of improvement expected from any specific structural or operational modification is uncertain, and therefore a series of modifications may be needed to achieve the desired outcome, with effectiveness monitoring to assess results.

Wasteload allocations in this TMDL are zero, because there are no NPDES-permitted point sources that contribute to elevated TDG in the Lower Snake River.

A possible source of TDG to the Lower Snake River is Palouse Falls, located on the Palouse River several miles upstream of the Lower Monumental pool. Research has shown that natural water falls may increase TDG, such as several studies have shown for Kootenai Falls in Montana. TDG and flow data were analyzed to determine the potential effect of Palouse Falls on the Lower Snake River. Back-calculations of TDG in the Palouse River suggest that TDG levels over 110% are possible during high-flow events. However, the analysis also suggests that the potential increase in TDG from the Palouse River is negligible, because flows in the Palouse River are usually a small fraction of Snake River flows (commonly 2-4% during high flows and rarely over 5%). Detailed monitoring and modeling would be required to determine the influence of Palouse Falls with certainty. However, the current analysis is sufficient to determine that additional data collection, analysis, and a load allocation for the Palouse River are unnecessary for this TMDL.

Table 16 shows the load allocations for forebays and tailraces of each of the four dams on the Lower Snake River. Because of the unique nature of TDG, load allocations are not directly expressed in terms of mass loading. Like loading capacity, allocations are in terms of percent saturation for fish passage and in terms of ΔP at all other times and locations. Load allocations are equal to loading capacity at each dam's forebay and tailrace and at the upstream boundary.

The load allocation for Ice Harbor Dam is based on the allocation at the upstream boundary of the Lower Columbia River TDG TMDL (Pickett and Harding, 2002). The Lower Columbia TDG TMDL allows the effects of spills for fish passage during Phase 1 of the implementation strategy. Ice Harbor Dam load allocation for spills for fish passage are subject to Ecology

² The courts have determined the characterization of dams as point sources for which NPDES permits will not be issued for certain parameters (National Wildlife Federation v Gorsuch, D.C. Circuit, November 5, 1982). The current policy of the state of Washington is to not issue NPDES permits for TDG.

approval of gas abatement plans. Ecology will not approve the gas abatement plans if operation of the spills for fish passage will cause TDG to exceed levels that cause a violation of the applicable criteria and load allocation.

Table 16. Load Allocations for TDG in Lower Snake River

Location	Load Allocation
Fish passage – Forebays of Ice Harbor, Lower Monumental, and Little Goose Dams ¹	115% saturation ²
Fish passage – Tailrace of Ice Harbor, Lower Monumental, Little Goose, and Lower Granite Dams ¹	120% saturation ²
Fish passage – Tailrace of Ice Harbor, Lower Monumental, Little Goose, and Lower Granite Dams ¹	125% saturation ³
Non-fish passage – Ice Harbor Dam Tailrace	75 mm Hg above saturation ³
Non-fish passage – All other locations	74 mm Hg above saturation ⁴

¹when authorized by Ecology after approval of a gas abatement plan

²average of 12 hourly readings in a 24-hour period as approved in a gas abatement plan

³maximum hourly reading

⁴maximum instantaneous

Long-term Compliance with Water Quality Standards

Compliance with Standards for All Spills

Federal and state laws and rules require compliance with state water quality standards; therefore, the ultimate goal of this TMDL is to achieve compliance. Special criteria have been established for “voluntary” spills for fish passage, and this TMDL includes allocations for that situation.

For a dam to be covered by the allocations for fish passage, Ecology must designate the fish passage period (beginning and ending dates) based on the recommendations of the National Marine Fisheries Service and other decision-making bodies, and must approve the gas abatement plan for the dam. Spills in support of fish passage (such as for research or performance testing) can also be included by the fish passage load allocations with prior approval from Ecology.

Spills can occur at any time and at any volume due to lack of power demand or powerhouse maintenance or failure. Therefore, this TMDL will be applicable for all spills below 7Q10 river flood flow conditions, regardless of the timing or cause of the spill. (*Seasonal Variation* later in this report discusses 7Q10 flows.)

Operational versus Structural Solutions

The four Lower Snake River dams, as currently designed, are incapable of meeting the water quality standards for all spill flow levels below 7Q10 flood conditions. Therefore, compliance with this TMDL will require structural changes. The Dissolved Gas Abatement Study (DGAS)

report outlines a variety of alternatives for operational and structural changes, which move in the direction of compliance under all spill levels. However, the effectiveness of these changes can only be estimated, and must be assessed after implementation. Also, implementation of structural solutions is dependent on Congressional appropriations. Therefore long-term compliance with this TMDL will take a significant length of time and must take into account a certain level of inherent uncertainty.

Compliance Areas

In this TMDL, the geographic area where the TMDL is in effect is termed the “compliance area”. Monitoring for TMDL compliance will occur at locations within or near the compliance area, as described in the Summary Implementation Strategy and in future implementation and monitoring plans.

The pools behind each dam and the reach from Ice Harbor dam to the Columbia River will each have compliance areas defined, for a total of five compliance areas in this TMDL. From Lower Granite to Ice Harbor dams, the compliance areas will extend from the tailrace of the upstream dam to the forebay of the downstream dam. The compliance area of the Lower Granite pool will extend from the Idaho border to the forebay of the dam. The compliance area downstream of Ice Harbor Dam extends from the tailrace to the confluence of the Columbia River.

Load allocations for non-fish passage conditions must be met at all locations throughout each compliance area. Load allocations for fish passage are specified for each tailrace and forebay, and must be met at the fixed monitoring station locations established at the upstream and downstream boundaries of the compliance areas.

The tailrace compliance area boundaries for the dams were chosen from several options, illustrated in Figure 25:

1. By a strict interpretation of state water quality standards without any consideration of applying the mixing zone provisions of the water quality standards, the tailrace compliance area would be the entire river from the dam downstream. This includes the area of maximum TDG immediately below the spillway. However, this area is difficult to identify and monitor in real time, and does not take into account the rapid degassing in the aerated zone.
2. If mixing zone provisions were applied to the aerated zone (the area of bubble entrainment and dissipation), then the tailrace compliance area would begin at the end of the aerated zone. This location would be easier to identify for regulatory purposes.
3. The area of compliance could begin at the tailwater FMS sites, but mixing zone provisions would need to be applied to the entire river, including powerhouse flow. The locations of the tailwater FMS sites are clearly identified. However, they are inconsistent with respect to the amount of mixing they represent between water gassed by the spill and water unchanged from the forebay.

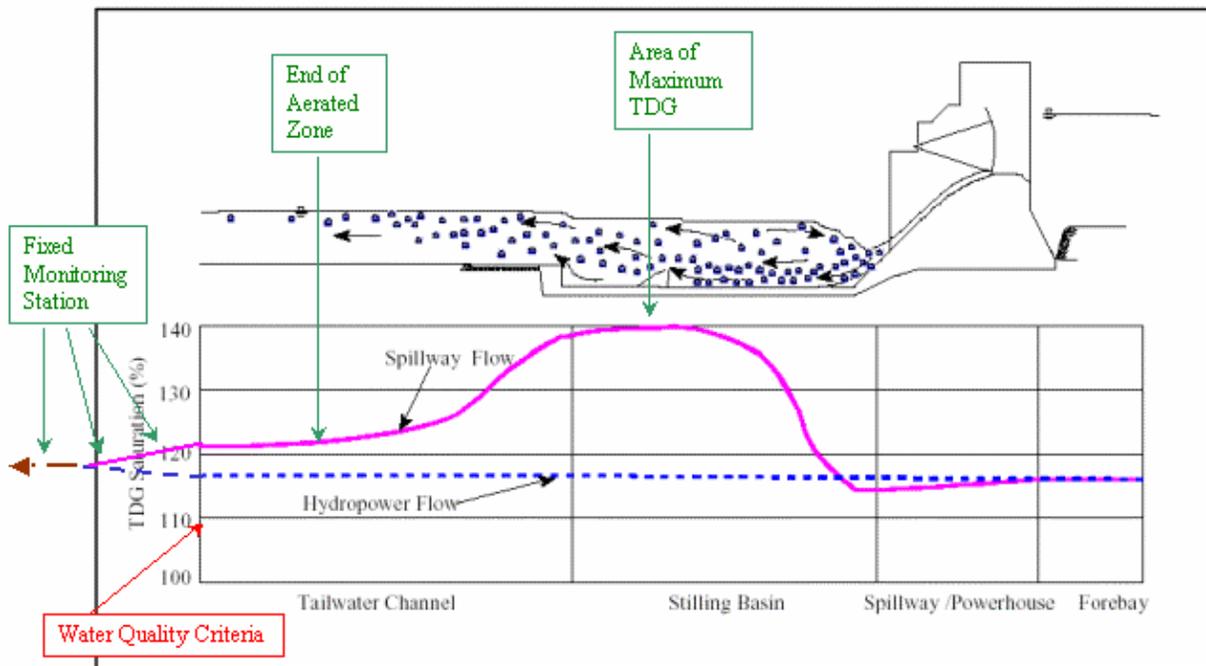


Figure 25. Key Features of Potential Tailwater Compliance Area Boundaries.

The boundary of the tailwater compliance area in this TMDL will be based on application of the mixing zone to the aerated zone immediately below the spillways of the dams. The Washington State water quality standards provide an allowance for a mixing zone, and compliance with standards is required at the boundary of the mixing zone. There are several reasons that use of a mixing zone is appropriate in this situation:

- TDG levels rise immediately below the spillway, but then degas for some distance downstream. The tailrace compliance area boundaries were determined from U.S. Army Corps of Engineers research which identified the location where degassing was mostly complete. This is a local area of impact with very dynamic conditions.
- Because the area below the spillway is very dynamic, TDG levels are difficult to accurately assess.
- Extensive fisheries research has shown that most anadromous fish are able to pass through this area below the spillway quickly without ill effects.
- Because of the turbulent flow associated with the spill above the compensation depth (the depth where hydrostatic pressure equals ΔP), little or no resident fish habitat is available in this area. The zone below the compensation depth is by definition in compliance with standards.
- Provision of a mixing zone and deviation from the size requirements are appropriate because of the public interest in ensuring that water quality standards are applied appropriately to the dam projects.

The upstream boundaries of compliance areas are shown in Table 17. The tailrace compliance area for each tailrace load allocation will begin at the end of the aeration zone in the tailrace of each dam, at the location specified in Table 17. Each dam will be responsible for managing its own spill to remain in compliance with the standards, but will not be responsible for high TDG levels produced upstream and passed through the powerhouse.

The load allocation for the upstream boundary applies at the Idaho border, and will be addressed by the State of Idaho under EPA oversight.

Table 17. TMDL Compliance Area Boundaries

Project	Location
Upstream boundary	Lower Granite pool below Idaho border
Lower Granite Dam tailrace	1500 feet below end of spillway ¹
Little Goose Dam tailrace	1500 feet below end of spillway ²
Lower Monumental Dam tailrace	1200 feet below end of spillway ³
Ice Harbor Dam tailrace	1300 feet below end of spillway ⁴

¹Pickett, 2002

²Schneider and Wilhelms, 1998a

³Schneider and Wilhelms, 1996

⁴Wilhelms and Schneider, 1998

Monitoring of Compliance

For monitoring of long-term compliance in the spills, it will be necessary to monitor throughout the load allocation compliance areas, and especially at the boundaries. However, it is not expected that this requirement will be met through a permanent remote monitoring setup. Compliance will be determined by a combination of periodic synoptic surveys, especially after structural changes have been completed, and continuous monitoring using a statistical relationship between the continuous monitor and conditions at the compliance location. This allows long-term monitoring to be managed separately from monitoring for short-term operational needs.

For short-term compliance with all allocations, the FMS stations can continue to be used, or new FMS stations can be established. This will allow operational management that is linked to easily accessible data, based on overall environmental management needs and the realities imposed by structural characteristics. Thus, short-term compliance can remain adaptive and flexible, while long-term compliance remains fixed to firm goals.

No monitoring station currently exists to assess compliance at the upstream boundary other than the forebay station at Lower Granite. Existing information should be reviewed to determine the best method to assess compliance with Washington's TDG standards at the state line, which could then be included in the Detailed Implementation Plan.

Compliance with fish passage allocations will be assessed at the FMS stations. Ideally these stations will be sited to assess the location where the highest time-averaged TDG values can be found.

Compliance with allocations in the pools under non-fish passage conditions will be assessed both by comparison of FMS tailrace and downstream forebay monitoring, and by detailed synoptic surveys. Detailed monitoring may be appropriate following changes in temperature management procedures that alter typical temperature increases, such as through implementation of a temperature TMDL or Endangered Species Act requirements.

Margin of Safety

The margin of safety for this TMDL is implicit in the TMDL analysis through the use of conservative assumptions. A detailed analysis of how the margin of safety is included is provided below.

Critical Conditions

No specific high- or low-flow critical conditions exist for this TMDL. Spills that generate high gas levels can occur in any season, and load allocations are applicable to spills at all flow levels below the 7Q10 flood flow. The worst-case situation is typically during maximum river flow during the spring freshet. However, the load allocations apply equally under all flow conditions.

Barometric pressure was established at levels equivalent to critical conditions. Other parameters, such as low wind speeds combined with increasing water temperatures, can affect compliance with load allocations. Several conservative assumptions provide a margin of safety to the TMDL, in addition to the low probability of these critical conditions occurring at the same time.

To evaluate the interaction of wind and water temperatures, the potential temperature increase in each pool was evaluated. For each dam the time of travel was estimated from the application of EPA's RBM-10 model (USEPA, 2001) for a 30-year period. The 90th percentile travel time (in days) was determined for each month. FMS data were then evaluated to determine the maximum temperature increase for each day during the travel time for the appropriate month. The load allocation for each pool equals the increase in TDG caused by the median temperature increase during the spill season.

However, it is possible that windy conditions in the TMDL cause sufficient degassing to offset increases in TDG from water temperature increases. Average daily wind speed was evaluated and plotted against temperature increases, and the potential degassing effect was evaluated from several of the equations used in TDG modeling as summarized in Appendix B of Cole and Wells (2001). This analysis indicates that increasing temperature generally occurs during periods of low wind with low rates of degassing. However, the U.S. Army Corps of Engineers provided an analysis of conditions below Lower Granite Dam during 2002 (as part of their comments on this TMDL) which indicates that degassing occurs over a wide range of conditions. The inclusion of load allocations for both the tailrace of each dam and the forebay of the downstream dam should provide a margin of safety that will offset the potential for water temperature increases to push TDG saturation above the criteria.

Given the clear mathematical relationship between spill quantities, the load allocations (ΔP), and TDG percent saturation, compliance with load allocations will be met by specifying operational and structural goals for spills that prevent the load allocation from being exceeded. In general, the long-term goal of meeting water quality standards must be met with structural modifications to the dam projects. In the short-term, operational methods will be used to protect beneficial uses to the fullest extent and meet standards whenever possible.

Criteria versus Site-specific Conditions

Probably few river systems have been as extensively studied for the effects of TDG than the Columbia/Snake system. Research has been conducted for over 40 years on TDG and aquatic life. Federal, state, and tribal fishery agencies all support a more lenient standard than currently in state regulation. Review of EPA guidance also suggests the criterion could be applied with an averaging period, rather than as an instantaneous value. Therefore, the current standards include an implicit margin of safety when applied to this river system.

Data Quality and Quantity

A margin of safety is usually identified in a TMDL to recognize uncertainty in the data used to produce the TMDL. Due to the monitoring requirements imposed by the Washington State Department of Ecology as a part of the fish passage program over the past seven years, there is a large record of hourly data of TDG levels, barometric pressure, water temperature, tailwater elevation, forebay elevation, total river flow, and spill quantity. Fairly rigorous standardized data quality procedures are provided for these data. These data are available on the Technical Management Team homepage, hosted by the Northwest Division of the U.S. Army Corps of Engineers, at <http://www.nwd-wc.usace.army.mil/TMT/welcome.html>.

Further, the Corps has undertaken an extensive Dissolved Gas Abatement Study (DGAS) over the past five years. The study included near-field TDG monitoring and the development of a mathematical model to describe the production, dissipation, and behavior of TDG in the Columbia system for the federal projects. The data collection also followed standardized data quality procedures. The production of TDG at the four dams that are the identified sources in this TMDL are, therefore, well understood.

As a result of this monitoring, there are abundant data of good quality for constructing this TMDL. Therefore, the margin of safety required for data and modeling variability in this TMDL is relatively small.

Seasonal Variation

In the Lower Snake River, exceedances (violations) of the TDG standard occur during the months of March through August, which cover both the fish out-migration season and the high-flow season in conjunction with spring runoff. One of the determinants of TDG levels is total river flow. When river levels are particularly high, TDG levels rise more rapidly if there is any water spilled over the spillway. During low-flow periods, there is generally not a TDG problem, other than spill for fish passage, as long as all water is passed through the powerhouses.

Occasionally turbine units will be out of service for maintenance, either scheduled or on an emergency basis. This may require water to be spilled involuntarily, because there are insufficient turbines available to handle the water in the river. Involuntary spill can also occur due to lack of demand from Bonneville Power Administration power purchasing or from the sequencing of water releases from upstream storage reservoirs.

Clearly, there is little control over emergency outages. Maintenance is generally scheduled (1) to coincide with low electricity demand periods, and (2) when river flows are such that they will not cause TDG exceedances.

In summary, spills can occur at any time, although they are most likely in the spring and early summer. This TMDL will apply during the entire year, with separate allocations for fish passage conditions (which generally occur in spring and early summer) and for non-fish passage conditions (which could include involuntary spill outside the snowmelt runoff season).

7Q10 Flows

As discussed above, Washington's water quality standards only apply when river flows are below the 7Q10 flood flows. The Snake River 7Q10 flow was calculated from flows measured and reported by the U.S. Geological Survey (Snake River below Ice Harbor Dam, Station No. 13353000). Methodology followed the guidelines of the U.S. Water Resources Council (1981).

Annual peak 7-day average flows were calculated (using the October-September Water Year from 1975 through 2000), and then the 10-year return flow was determined by the Log-Pearson Type 3 method. The skew coefficient used in the analysis was calculated from the data; the generalized and weighted skew was not determined or used, but the error introduced by this shortcut was probably small to nil.

The 7Q10 flood flow calculated for the Snake River is 214 kcfs. This applies throughout the TMDL area, because no tributaries enter the Snake River large enough to alter peak flows. Flows in the Palouse River were subtracted to determine the 7Q10 flood flow above the Palouse River, and the same result was obtained. An earlier calculation of 7Q10 by the Corps was slightly higher because flows for years prior to the construction of Dworshak Dam were included in the calculation. Dworshak has likely reduced peak flood flows due to its operation for flood storage.

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Summary Implementation Strategy

Overview

The goal of this total dissolved gas (TDG) TMDL for the Lower Snake River is to meet Washington's water quality standards for TDG. The goal of water quality standards is to protect beneficial uses of the river. While these include such beneficial uses as hydropower generation, irrigation, drinking water, and water contact recreation, the most sensitive use is anadromous salmonids. These species are particularly vulnerable, as they navigate past the dams both as downstream migrating juveniles and as upstream returning adults.

The four dams on the river – Lower Granite, Little Goose, Lower Monumental, and Ice Harbor – pass water by spilling over the spillway, by generating electricity through the turbines, and to a much lesser extent by passing water through special fish facilities such as adult ladders and juvenile fish passageways. TDG is generated by spilling water over the spillway. Absent considerations for fish survival, spills are considered “involuntary” since they occur due to lack of powerhouse capacity. Involuntary spills can be caused by flood flows, lack of electric load for powerhouse generation, or turbines being off-line due to maintenance or repair. However, fish survival needs necessitate spills to improve juvenile fish passage.

Up to a point, the danger to fish from exposure to high TDG is overshadowed by the dangers to fish of going through the turbines. In response, the National Marine Fisheries Service (NOAA Fisheries) performed a comparison risk analysis that forms the basis for modifications to Washington's water quality standard for TDG.

In December 2000, NOAA Fisheries released a Biological Opinion under the federal Endangered Species Act for 12 listed species in the Columbia and Snake rivers. A significant component of this Biological Opinion is the provision of spilled water at the Lower Snake River hydropower facilities to facilitate fish passage. In addition, spill for juvenile fish passage is beneficial for non-ESA listed species. Clearly, if spilled water is the cause of elevated TDG levels but is required for fish passage, care needs to be taken not to implement gas abatement measures that may benefit water quality, while damaging the beneficial uses, such as juvenile migration, that the federal Clean Water Act was designed to protect.

This implementation strategy therefore must take into account both requirements: to reduce high TDG generated at the dams by spilling water, and to provide the levels of spill under the Biological Opinion to facilitate fish passage. Additional provision for spill is sometimes necessary for non-listed species.

Gas reduction at the four Lower Snake River dams has been the subject of intensive research over the past six years. Federal fish agencies, tribes, the U.S. Environmental Protection Agency, Bonneville Power Administration, state fish and wildlife departments, and the U.S. Army Corps of Engineers are organized into work groups to address the TDG problems. The result of this is a much enhanced understanding of the generation and dynamics of TDG production. In addition,

implementation actions designed to reduce TDG generation have already been undertaken (e.g., the installation of flow deflectors or “flip lips” at Ice Harbor Dam). Further actions are planned, but funding is often dependent on Congressional approval and is linked to basin priorities for the Snake River.

Implementation Plan Development

The operation of the Columbia River hydropower system is carried out through multiple agencies and governed by several regulatory authorities. The following is a list of these parties:

- The U.S. Army Corps of Engineers operates the dams and provides engineering, contracting and construction authorities (based on funding from Congress) for structural changes at these dams. The Corps provides flood control oversight and responds to the energy, environmental, transportation, and recreational needs of the public. The Corps is required to achieve a balance between these requirements where they conflict.
- NOAA Fisheries and the U.S. Fish and Wildlife Service oversee the protection of endangered species, four of which are anadromous salmonids found in the Lower Snake River. Several forums have been established to oversee implementation of the Biological Opinion requirements for these species. These forums include the Water Quality Team that focuses on temperature and TDG management, the Technical Management Team that makes decisions regarding hydropower operations, the System Configuration Team that makes decisions on structural modifications, and an implementation or policy team to which policy issues that cannot be resolved in the other forums are elevated.
- Tribes have treaty rights to the salmon in the Snake River and are involved on many levels of fish management and environmental protection.
- The Bonneville Power Administration oversees power production and distribution. Revenues help fund fish and environmental mitigation for the impact of the dams.
- The Washington Department of Fish & Wildlife works within the forums detailed above, as well as protects and enhances non-listed salmon, resident fish, and wildlife.
- The U.S. Environmental Protection Agency is part of the caucus of federal agencies involved in operation and management of the federal Columbia River hydropower system. Its specific role is to ensure consistency with federal environmental laws and regulations. The agency will ultimately take action on this TMDL under Section 303(d) of the federal Clean Water Act.
- The Washington State Department of Ecology will oversee implementation of this TDG TMDL. They will work collaboratively with the U.S. Army Corps of Engineers, Bonneville Power Administration, tribal, and other state and federal agencies through existing forums. Tools available include interagency agreements, administrative orders, and gas abatement approvals required by surface water quality standards. Review of gas abatement

requirements will be done primarily through the Corps' Water Quality Plan for the Columbia and Snake Rivers. Other forums such as the ESA Fish Facility and Design Review Work Groups, the Technical Management Team, Water Quality Team, and the Structural Configuration Team will also be involved as needed.

- Other agencies are involved in different aspects of river management that can have a bearing on TDG generation. The most prominent include the Northwest Power Planning Council, data gatherers such as the Fish Passage Center and U.S. Geological Survey, and the states of Idaho and Oregon.

Meeting the load allocations in this TMDL will fall into two phases. Phase I will involve improving water quality, while ensuring that salmonid passage is fully protected in accordance with the 2000 Biological Opinion. Phase II will involve structural and operational changes to dams to achieve the water quality standard for TDG.

The short-term actions in Phase I will focus on meeting the fish passage performance standards as outlined in the 2000 Biological Opinion through spills that generate gas no greater than the "waiver" levels of the water quality TDG standards (Washington special conditions). Water quality standards for TDG are evaluated at existing fixed monitoring stations managed by the U.S. Army Corps of Engineers. This phase will also include short-term structural modifications at the dams to achieve TDG reductions during periods of spill, while ensuring that the fish passage requirements of the 2000 Biological Opinion are met. A Detailed Implementation Plan (DIP) or equivalent will be developed that further refines the measures to be considered in Phase II. The DIP is planned to be issued one year after EPA approval of the TMDL. The DIP will explain the progress towards meeting the load allocations, any revisions to the monitoring strategy, and present any new information that could affect how the TMDL is implemented.

Phase II will evaluate success from the short-term actions. The second phase will also move toward further structural modifications and reductions in fish passage spill if the Biological Opinion specified performance standards are being met and adequate survival is provided for non-listed species.

Biological monitoring has been required by the state of Washington in order to assess gas bubble trauma to fish as a result of spill. Based on six years of data, the results show little trauma to migrating juvenile salmon at TDG levels allowed by the states in their modified water quality standards.

Implementation Activities

As the operator of the four Lower Snake River dams, the U.S. Army Corps of Engineers published its Final Draft Technical Report and Appendices of the Phase II Dissolved Gas Abatement Study (DGAS) in April 2001. This study was undertaken as part of the Columbia River Fish Mitigation Program. This study has been the result of an ongoing collaborative effort between federal and state fisheries agencies, dam operators, tribes, and environmental agencies toward reducing TDG in the river in balance with enhancing spill opportunities for juvenile salmon.

As described above, this implementation strategy is to be carried out in two phases.

Short Term – Phase I

This phase is already underway, as a result of actions taken by the Corps, and will continue through 2010. As detailed above, the emphasis in this phase will be taking those actions that will result in reductions of TDG, while ensuring the fish passage requirements of the 2000 Biological Opinion are met. The Biological Opinion envisions spill for fish passage under modified water quality standards of Washington, as have been provided for the past six years. Included in this program will be the near-term actions that have been identified in the Biological Opinion. Maintenance of required spill at the modified standards to allow for fish passage will be as measured at the fixed monitoring stations both in the forebay and the tailrace of each dam.

This phase will also address the first stages of reducing gas during spills due to high-flow events, turbine outages, and during lack of demand for electrical power. This is outlined in the Corps report, “Final Draft Dissolved Gas Abatement Report,” April 2001.

Table 18 includes specific mainstem Snake River structural implementation actions (from the NOAA Fisheries 2000 Federal Columbia River Power System Biological Opinion) that have been completed or will be completed during this phase, and are directly related to achievement of the water quality standard.

Table 18. Short-term Implementation Activities

2000 Biological Opinion Action Item Description	Completion Date	Action Item #
Ice Harbor Deflectors	Done	134
Survival-Based Spill Caps at All Dams	Ongoing	68, 82
Lower Monumental Endbay Deflectors	Done	134
Little Goose Endbay Deflectors	2005	134
Divider Walls at Appropriate Dams	Under Evaluation	135

Several operational implementation actions are available to minimize involuntary spill that are already in use, or can be evaluated during Phase I and implemented if practical. These include:

- Scheduling routine turbine maintenance and repair during low-power load and river flow periods.
- Preventive maintenance of turbines to prevent breakdown.
- System management of water release from upstream storage reservoirs to minimize involuntary spills at dams in the TMDL area.
- Optimizing power purchasing to allow maximum use of powerhouse capacity and minimization of involuntary spill.

Specific implementation methods for these actions will be provided in a Detailed Implementation Plan (DIP), or equivalent. The gas abatement plan provided by the Corps to Ecology and Ecology's conditions of approval will provide details for the DIP. Ecology and the Corps are working together to coordinate gas abatement plans and the DIP with the Water Quality Plan, which is being developed by the Corps to meet (among other things) dissolved gas standards in the Snake River.

Table 19 contains additional short-term implementation actions that are indirectly related to achievement of the water quality standard. Implementation of these measures, though, is likely to improve salmonid passage and help achieve the performance standards of the Biological Opinion. Carrying out these actions will enable a decreased reliance on spilling water for fish passage in the near-term period. Voluntary spill levels for fish passage with their associated TDG will be reduced as these actions are implemented, and will result in achieving the survival performance standards contained in the 2000 Biological Opinion.

Table 19. Additional Short-term Implementation Activities

2000 Biological Opinion Action Item Description	Completion Date	Action Item #
Lower Granite Removable Spillway Weir	Done	80
Lower Monumental Bypass Outfall Relocation	2004 or 2005	76

Long Term – Phase II

This phase will begin in 2011 and proceed through 2020. Actions taken in the previous phase will be reviewed for their efficacy, both in improving TDG levels and for protecting salmonid passage. The Biological Opinion survival goals are being met through fish passage actions other than spilling water. Reductions in gas entrainment through spill will be realized so that the required final goal of meeting the water quality standard for TDG can be met as measured at the end of the aerated zone below each dam.

Table 20 details those long-term actions that will protect fish passage while moving the system toward attainment of the water quality standard for TDG.

The U.S. Army Corps of Engineers DGAS study identified a number of structural measures designed to abate TDG. Several of these measures should be evaluated for their efficacy in abating gas and ensuring that they provide safe and effective fish passage. If necessary, those measures found to be effective and safe should be identified for funding and implementation.

Table 20. Fish Passage Actions That Support TDG Water Quality Goals

2000 Biological Opinion Action Item Description	Completion Date	Action Item #
Removable Spillway Weirs at Lower Monumental, Little Goose, and Ice Harbor	Under Evaluation	75, 77
Lower Monumental Extended Screens	Under Evaluation	78
Spill Effectiveness Studies	Ongoing	83
Predator Removal and Abatement	Ongoing	100-103
Improved Operation and Maintenance	Ongoing	58,59,63,144, 145,146
Implement Turbine Survival Program Results	Under Evaluation	88, 90, 91, 92

Compliance with TDG Criteria

Structural work has already been carried out to reduce high levels of TDG at the four Lower Snake River dams. The track record for Congressional funding for these projects is good, and there is reason to believe that further funding of projects will continue. Funding to improve fish passage facilities also has a good track record, and there is reason to believe that this will continue to be funded both through Congress and energy revenues.

Meeting the TDG criteria at all times will be a challenge. Funding for the more expensive structural modifications of the second phase is entirely dependent on Congressional will, national and regional priorities, and budgetary availability of funds. High river flows cannot always be passed through the dams without violating the 110% criterion during time periods when the spills for fish passage are not in effect.

Ecology has regulatory authority over the four federal dam projects. Washington's regulatory authority comes through the *Federal Clean Water Act*, the *Revised Code of Washington's Pollution Control Act 98-48* and the *Washington Administrative Code's Water Quality Standards 173-201A*.

The Washington State Department of Ecology is responsible for ensuring that water quality standards are met. Ecology is confident that the collaborative relationship with the dam operators toward reducing gas will continue and be enhanced through this TMDL. The U.S. Army Corps of Engineers has agreed to continue working through the Endangered Species Act forums established to oversee and carry out the requirements of the Biological Opinion.

Special dissolved gas conditions exist in the Washington State Water Quality Standards for the Snake River. Higher gas levels are allowed in these standards in order to pass juvenile salmonids in spill and avoid the turbines in the Snake River. However, the dam owner must

provide assurances that they are taking steps to reduce dissolved gasses in order to get an ‘approval’ for this special condition from Ecology. The Corps must submit a gas abatement plan to Ecology for approval. Ecology’s approval will include certain conditions. Monitoring, compliance schedules and reporting is required. This standard can be found in Washington State Water Quality Standards (old) 173-201A(060)(4); (new)173-201A-200(1)(f).

Adaptive Management

The process for reviewing the status of implementation of this TMDL will follow the timing and process for the review of the federal Biological Opinion in 2010. The Washington State Department of Ecology will convene an advisory group comprising representatives of tribes and federal and state agencies to evaluate appropriate points of compliance for this TMDL. Based on these findings, further studies may be needed, and structural and operational gas abatement activities will be redirected or accelerated if needed.

Monitoring Strategy

Short-term compliance and the effectiveness of operational implementation actions will be monitored at existing fixed monitoring station sites for both fish passage and non-fish passage allocations. The current fixed monitoring station TDG monitoring system consists of tailrace and forebay monitoring stations at each mainstem Lower Snake River dam and at key locations in some tributaries. While these stations do a credible job of reporting meaningful data, some at times may not be achieving desired sampling objectives (representing spill or average forebay conditions).

This system is now undergoing a thorough review by the NOAA Fisheries Water Quality Team. Screening criteria have been developed and are used to evaluate all existing monitoring stations. Stations that do not conform to these criteria will be relocated to more appropriate locations. This screening process will include consideration of how well the station represents TDG and water temperature in a given river reach, and how sensitive the station is to non-spill factors that affect TDG, such as temperature and aquatic plant respiration.

Ideally monitoring will assess the location where the highest time-averaged TDG values can be found, but during Phase I of implementation the Water Quality Team will continue to choose these sites based on balancing Endangered Species Act and Clean Water Act objectives. During Phase II the goal will be to “tighten up” the monitoring locations and TDG objectives to allow compliance with load allocation at all locations in the compliance area. Based on detailed synoptic surveys, either the fixed monitoring stations can be moved to a location likely to measure maximum TDG levels, or methods can be developed to back-calculate maximum TDG levels from forebay levels, powerhouse flows, spill volumes.

Monitoring of long-term compliance with load allocations and the effect of structural changes will include an evaluation of previous and future near-field transect studies at the compliance location (the end of the aerated zone below each dam). Load allocation compliance monitoring will occur following major structural changes or immediately following the end of Phase I and

Phase II. Also, statistical relationships may be developed between TDG levels at the continuous monitoring location and the compliance location that allow real-time and long-term trend evaluation of compliance.

Prior to the initiation of a load allocation monitoring survey, a quality assurance project plan, or equivalent, must be approved by the Washington State Department of Ecology. The project plan should address the safety and stability of the site to support monitoring equipment and activities when subject to the strong hydraulics below the dams. Due to these factors, it is possible that an alternate site may be needed. If so, some correlation to the load allocation compliance point will be necessary.

Potential Funding Sources

A discussion on funding is warranted, given the expensive nature of some of the suggested structural actions. Known funding sources include power generation revenues through Bonneville Power Administration, as directed by the Northwest Power Planning Council and System Configuration Team and the U.S. Congress.

Summary of Public Involvement

The state of Washington developed and implemented the Public Involvement and Outreach strategy for this TMDL project in partnership with the Columbia and Snake Rivers Mainstem TMDL Coordination Team. Team members included U.S. Environmental Protection Agency, Idaho Department of Environmental Quality, Oregon Department of Environmental Quality, Washington State Department of Ecology, Western Governors Association, Columbia Basin Tribes, and the Columbia River Inter-Tribal Fish Commission.

The public review draft of the Lower Snake River Total Dissolved Gas TMDL was released for public comment on February 24, 2003. A public comment period of 40 days was established by public notice issued concurrently with the release of the draft TMDL. The public notice scheduled a public hearing, and a closing date for the receipt of written comments (April 4, 2003). The announcement appeared in the State Register on March 5, 2003. A copy of the public notice is included in the appendix.

A public hearing was held on Tuesday, March 25, 2003 in Kennewick, Washington, at the Washington State Department of Ecology Field Office, 1315 W. Fourth Avenue. No public testimony was offered at this hearing. Sign-in sheets are included in the appendix.

Individual outreach meetings were held with the appropriate watershed advisory groups and with primary stakeholders, which included:

- Nez Perce Tribe
- Umatilla Tribe
- U.S. Army Corps of Engineers (Portland, Walla Walla, and Seattle Districts, and Pacific Northwest Division)
- Bonneville Power Administration
- National Marine Fisheries Service (NOAA Fisheries)

In addition, meetings and presentations were held with the NOAA Fisheries Water Quality Team that includes federal and state agencies, public utility districts, tribes, and Bonneville Power.

The TMDL team held public meetings to receive input and comments from all interested participants. These meetings included public workshops to accept informal comments for each regional phase of the TMDL project, and a public hearing for the formal public comment period.

The TMDL team used public outreach tools such as letters, focus sheets, and other printed materials; websites with short narratives and graphics, downloadable documents and relevant links; news releases and articles; and field visits.

Public Involvement Actions

- U.S. Environmental Protection Agency website

- Washington State Department of Ecology website
- Focus sheets
- News releases
- E water news – Washington State University Water Research Center newsletter article
- Monthly coordination team meetings – EPA, Idaho Department of Environmental Quality, Oregon Department of Environmental Quality, Washington State Department of Ecology, Western Governors Association, Columbia Basin Tribes, Columbia River Inter-Tribal Fish Commission (CRITFC)
- Monthly updates and discussions with the NOAA Fisheries Water Quality Team
- Presentations to the NOAA Fisheries Implementation Team
- Columbia River Tribal TMDL workshop on November 17 - 18, 2000
- Public meetings in Spokane, Washington and Portland, Oregon on July 23 - 24, 2001
- Presentations to CRITFC Tribal Water Quality Conference on September 26 - 28, 2001
- Public meetings in Lewiston, Idaho and Pasco, Washington on October 29 - 30, 2001
- Meetings with U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, and Bonneville Power Administration
- Meetings with CRITFC, Umatilla, and Nez Perce tribes
- Public comment period February 25 through April 4, 2003; Public hearing in Kennewick, Washington, on March 25, 2003.

The comment period and hearing were announced through the following avenues: published in the State Register, display advertisement in the Columbia Basin Bulletin, news release, and mailed to those on the Columbia/Snake Rivers TMDL mailing list.

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Appendix

Response to Public Comments

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Focus on Lower Snake River

Public Hearing Planned for the Lower Snake River TDG TMDL and Implementation Plan

Background

Why is Elevated TDG a Problem?

Federal Law Requires Cleanup of Polluted Waters

Public Comment Period

Sign-in Sheet for Public Hearing

Introduction

The public review draft of the lower Snake River Total Dissolved Gas TMDL was released for public comment on February 25, 2003. A public comment period of 40 days was established by public notice issued concurrently with the release of the draft TMDL. The Public Notice scheduled a public hearing, and a closing date for the receipt of written comments. The announcement appeared in the State Register on March 5, 2003. A copy of the public notice is attached near the end of this appendix.

Public Hearings

1. A public hearing was held in Kennewick, Washington on Tuesday, March 25, 2003 at the Washington State Department of Ecology Field Office, 1315 W. Fourth Avenue.
6:30 p.m. Question and Answer Session
8:00 p.m. Public Hearing

No public testimony was offered at this hearing. A copy of the sign-in sheet is the last page of this appendix.

Written Comments

Written comments were received from the following:

- Steven Hays, Fish and Wildlife Consultant, Chelan County Public Utility District No. 1
- James T. Irish, Water Quality Manager, Federal Hydro Projects, Department of Energy, Bonneville Power Administration
- Helen Rueda, Watershed Restoration Unit, Office of Water, United States Environmental Protection Agency, Region X
- Mark J. Schneider, Water Quality Advisor, United States Department of Commerce, National Marine Fisheries Service
- David Ponganis, United States Army Corps of Engineers¹
- Rick Emmert, United States Army Corps of Engineers¹
- Rick Klinge, Fisheries Biologist, Public Utility District No. 1 of Douglas County.²
- Don Sampson, Executive Director, Columbia River Inter-Tribal Fish Commission

¹ Comments received via e-mail on April 3, 2003.

² Comments received via e-mail on March 26, 2003.

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Response to Comments

The following response to comments is organized under the same headings as are found in the draft TMDL. A general section for comments that are overarching precedes them.

General Comments

Comment: How are activities involving pollution trading between projects recognized by this TMDL?

Response: *Most pollution trading projects currently in place deal with the cumulative effects of nutrients in water bodies such as lakes or rivers. The TDG problem is not a cumulative situation and requires a solution that does not allow TDG exceedances above the criteria at any location on the river outside of the mixing zone. (An assumption here is that the sources of TDG have implemented all technology-based requirements for TDG reduction.) Pollution trading does not directly apply due to the nature of TDG generation during spills. Typical spills supersaturate the water with gas then release the gas during travel through the aeration zone. The level of TDG in a parcel of water after passing through a spillway is independent of the level of TDG in the parcel prior to the spill. Each dam is responsible for the TDG effects during spill events at the dam.*

In the Lower Snake, planning to minimize adverse spills at the four dams will continue within the Corps. In future TDG TMDLs, there may be situations where TDG is cumulative or where trading can occur as part of the interim implementation period. For example, trading may be able to occur between spill at one dam and power generation at another. These possibilities will be addressed at the appropriate time.

Comment: A methodology measuring progress towards achieving the TDG standard has not been outlined in this document.

Response: *Progress will be measured in two principal ways (described in “Monitoring of Compliance” and “Monitoring Strategy” in the TMDL). The FMS monitoring network will be used to evaluate real-time data. As long as the FMS is reporting TDG levels above the standards, the TMDL objectives have not been achieved. But long term trends could be evaluated to determine progress towards the objectives. Second, as major structural modifications are implemented; near-field monitoring could be conducted under varying spill conditions to determine the effectiveness of TMDL implementation at the compliance location. It is likely that these studies will be performed after major work or at the end of each implementation phase. Specific methodology will be developed in a Quality Assurance Project Plan prior to studies that assess progress.*

Comment: Fish passage and the survival and productivity of salmon and other anadromous fish populations must not suffer by taking measures to control total dissolved gas, such as forcing fish through turbines, which may reduce total dissolved gas in the river. These conflicts should be identified and fully described in the main portion of the final report. How the TMDL meets treaty obligations, the CWA and the ESA must be identified and fully described in the final report.

Response: *The section “Coordination with Endangered Species Act” addresses this issue at a level of detail appropriate for this TMDL.*

Comment: The TMDL describes structures that separate powerhouse flow from spillways. The COE is studying the addition of extended divider walls at the project to enhance this capability. Currently, the lower Snake projects do have divider walls, however, they are not of great length and thus do not fully

separate spillway flow from powerhouse flow. However, with the additional of endbay deflectors at several of the projects and operations that insure skimming flow, the mixing or entrainment of powerhouse flow can be greatly reduced. Has this issue been evaluated in the modeling to determine the load allocations in the TMDL?

Response: *There is a section on “Entrainment of Powerhouse Discharge” for each dam that discusses this issue. The approach taken in the draft TMDL did not provide incentives for separation of powerhouse flows from spill. In the final TMDL, the inclusion of allocations for the downstream forebay should make separation of powerhouse flows more desirable, which is a net benefit to the environment.*

Comment: Further, this section describes that without wind degassing rates the change of TDG levels in the pool are very low. However, wind levels can be excessive in the Lower Snake and lead to degassing rates that are not very low. How is this issue dealt with in the TMDL? From our read of the TMDL, this issue is ignored since the TMDL made a potential erroneous assumption that wind rates are not very high and thus leads to little degassing. Just because wind may be hard to model accurately does not mean it should be ignored in the analysis.

Response: *Wind data was analyzed extensively for the TMDL, but the effects of wind on degassing rate are difficult to quantify. Initial analysis suggested that the effect of wind on degassing might be small at times when water temperatures are increasing and causing gas pressure increases. However, additional information provided by the Corps of Engineers suggests that conditions that would produce gas pressure increases without being offset by degassing from wind or pressure differentials would be much rarer than indicated by the analysis for the draft TMDL. Therefore, the final TMDL accounts for the effect of wind degassing and water temperature increases in a different way: by including allocations for the downstream forebay of each dam.*

Comment: While CRITFC agrees that the current fixed monitoring sites may not be ideal, the biological monitoring that is done in conjunction with sites has shown them to provide adequate data to be used in the monitoring. Further, the Water Quality team has been reviewing the fixed monitoring sites to insure that the locations do represent in- river conditions. This is important to note that the sites should be representative of the river as a whole and not just the highest point of TDG in which a salmon may spend very limited time. It is more important to determine what the TDG levels are for the areas where salmon’s rate of exposure is extensive of the longest. This should also include the salmon’s ability to achieve depth compensation in that area.

Response: *The TMDL supports the use of the fixed monitoring stations for on-going evaluation of compliance. The issues of the exposure of biota to TDG levels and how that might affect criteria, is a subject for a review of the standards. The 110 percent criteria don’t allow much flexibility about evaluating anything but maximum levels. The use of the mixing zone provisions in the standards to exclude the aerated zone from the compliance area is the one area of flexibility available. The fish passage waiver levels allow for time-averaging of data, but don’t specify exact locations other than “tailwater” or “forebay” and are silent on spatial averaging. Ecology assumes that the tailwater monitoring should reflect conditions of unmixed spill below the aerated zone, but also recognized that by agreement with other agencies the existing fixed monitoring stations will continue to be the points of compliance.*

List of Figures

No comments received.

List of Tables

No comments received.

Acronyms and Abbreviations

No comments received.

Abstract

Comment: Page vii - first sentence in paragraph 2 notes that spill events elevate TDG levels far above standards. Perhaps this should be "far above criteria reference levels" or be qualified as "when standards apply, that is below 7Q10." Load allocations apply year-round with seasonal variations but page xi notes that the TMDL only applies below 7Q10. For the latter, do they really mean that the standard only applies below 7Q10 but the load allocation applies year-round.

Response: *The abstract has been slightly revised for clarity. The standard includes the provision that criteria don't apply above the 7Q10 flood flow. The TMDL is written to ensure compliance with standards, so the allocations apply year-round but only for flows below 7Q10 flood flow levels.*

Comment: Page vii – “Measurements of TDG levels in the pool at the upstream boundary of the TMDL area occasionally exceed standards, but the cause of these high values is unclear.” The cause of these spikes is well known and is related to temporary thermal stratification in the forebay of Snake River dams. These events can result in local TDG saturations above 110 percent saturation.

Response: *The language quoted is no longer in the TMDL. The effect of solar heating (which causes stratification) is noted.*

Acknowledgements

No comments received.

Executive Summary

Comment: The TMDL discounts the effect of wind on degassing. However, several locations in the Lower Columbia and likely the Snake River are greatly affected by wind to the point that dam operations must be changed due to wind conditions. While we understand that it is difficult to model wind, some attempt should be made for an explanation that quantifies, in a probabilistic sense, the degree of effect wind does or does not have. Does wind affect TDG by 1 percent or 10 percent?

Response: *Quantification of the effect of wind takes a large body of data, which has not generally been available from previous work or attainable with the resources available. While it is clear that high winds can have a substantial gassing effect, it is difficult to determine the effect on gas levels of the moderate winds that occur most of the time.*

Comment: Page x. Monitoring Plan. We strongly recommend keeping the long-term, fixed monitoring sites as the locations used to determine in-season compliance. A long-term database of both physical

TDG measurements and biological data tied to these measurements has been established and maintained. It would seem logical to continue to use these locations.

***Response:** The TMDL does recognize the value of the fixed monitoring sites for long-term and real-time monitoring of compliance. However, the fixed monitoring sites have been established for a variety of reasons, not the least of which is accessibility. Some of them have been sited for reasons besides monitoring a representative site in the river. We believe monitoring at the edge of the aerated zone will be necessary to determine compliance with the TMDL with a reasonable level of assurance. However, this monitoring will likely occur infrequently as a special study.*

Comment: Page xii. The TMDL discusses the ability of funding for structural projects required to reduce total dissolved gas production from the dams, and assumes that funding will be forthcoming from the Corps of Engineers under Columbia River Fish Mitigation Program (CRFMP) in which Congress appropriates annual funds from the Energy and Water Appropriations legislation. While there has been past funding available for these types of projects, future funding is far less certain. In 2002 and 2003, the CRFMP funding suffered serious cuts by Congress. Due to budgetary constraints, the Corps and NMFS are prioritizing projects to reduce dissolved gas levels to the current temporary dissolved gas waiver levels. These include projects such as installation of spillway deflectors at Chief Joseph dam in the upper Columbia River, which obtained separate line item funding for design in the 2004 Energy and Water Bill, but still lacks funding commitment for installation. Other projects not associated with meeting total dissolved gas standards below temporary waiver limits are being given a higher priority by the Corps and NMFS. While the draft report states that the costs of future structural configurations to meet the TMDL may be borne by BPA, BPA financial mismanagement and future power obligations make this highly unlikely. The bottom line is that future funding for structural remedies at Snake River dams to meet the TMDL standards is highly uncertain. The Final Report should acknowledge these difficulties and suggest potential remedies or funding sources. The final report should also explore the possibility that excess involuntary spill can be reduced by generation and grounding that generation or using improved transmission facilities planned for the Lower Snake hydroprojects.

***Response:** Flow deflectors at Ice Harbor and at John Day along with other projects, have all been successfully funded. Flow rates that are below the 7Q10 but that exceed the turbine capacity can still be a problem for meeting the load allocations, particularly if the spills for fish passage allocations are not in effect. For this reason, the reasonable assurance section has been retitled in the implementation strategy to avoid a misperception that we are certain that current standards will be always met. Reasonable assurance is a concept intended to evaluate the extent to which point sources must lower their pollutant loading if nonpoint sources of pollution are not likely to achieve reduction targets. There are no point sources subject to this TMDL so reasonable assurance is irrelevant.*

Comment: Page xi. The monitoring plan is divided into short-term and long-term compliance, and the relationship of and timeline for these periods should be described here as well as in the implementation plan.

***Response:** We believe the TMDL describes this adequately.*

Comment: While CRITFC has strongly recommended that CRFMP projects which address meeting long-term CWA standards for total dissolved gas and temperature be given priority over other CRFMP projects, the federal hydro operating agencies, including the Corps, have largely disregarded these recommendations. CRITFC has also requested that EPA and the state water quality agencies use their authorities to assure that priority be given to these actions, but the water quality agencies have not consistently responded to these requests. It is vital that the final Report clearly outline to the federal agencies that funding of structural measures to meet CWA standards be given priority status, and that the mechanism to force compliance with these actions is definitive.

Response: *No Executive Branch action can force a legislative body to appropriate money. We have indicated to the action agencies that we expect that they will vigorously pursue funding, and are looking at ways to give weight to this message so that the likelihood of funding is improved. However, there is no “mechanism to force compliance” available.*

Comment: Page x – Clarify the methodology of identifying the loading capacity, pollutant allocation, and factor of safety. It seems like an in-pool temperature increase is a source of elevated TDG pressure and should be identified as such. The complication is that this in-pool source occurs simultaneously with in-pool degassing. Most of the time the in-pool sinks is much greater than the in-pool thermal source when viewed in the terms of average river conditions. Is the net in-pool process considered in the margin of safety?

Page x - Under Pollutant Allocations, paragraph 2 notes that winds produce very little degassing during conditions of high temperature increase. The TMDL does not include the effects of degassing in the pool allocations. It is unclear if TDG levels are exceeding the standards under these conditions. In any case, it makes sense in the margin of safety if not a significant effect.

Response: *The requested information is provided in the body of the text, but is more detailed than appropriate for the Executive Summary. The approach to water temperature increases in the pool has changed in the final TMDL. See the responses in the Load and Wasteload Allocations section.*

Comment: Page xi - In the Seasonal Variation section (or on page 65), is there a way to illustrate with a diagram or chart how the TMDL load allocations apply year-round but the TMDL (or should it be standard?) only applies for flows below the 7Q10 flood flows?

Response: *The concept is fairly simple, and we don't believe a diagram or chart will help.*

Comment: Page xii; Public Participation: There is a blank line in this section.

Response: Corrected.

Introduction

Comment: The draft report identifies that high levels of total dissolved gas have deleterious effects on fish and other aquatic life. This statement should be quantified and qualified. Significant exposure to high levels of total dissolved gas can impact fish if they cannot achieve depth compensation.

Response: *Certainly elevated total dissolved gas levels have a deleterious effect on fish if they cannot achieve depth compensation. However, even if depth is available, it is not clear that fish take advantage of it. This is only the introductory statement of the TMDL. Greater detail of the effects of elevated total dissolved gas on fish is contained in the body of the document.*

Compliance with Clean Water Act

No comments received.

Coordination with Endangered Species Act

Comment: CRITFC finds that the draft report raises serious conflicts between meeting the provisions of the Clean Water Act (CWA), meeting the requirements of the Endangered Species Act and meeting legal obligations to the treaty tribes. These requirements are not described, nor are means to resolve the conflicts offered. For example, as detailed in their anadromous fish recovery plan, *Wy-Kan-Ush-Mi Wa-Kish-Wit*, the treaty tribes have more aggressive salmon recovery goals for the Snake River than NMFS.

Response: *The draft TMDL takes great care to explain the potential conflicts between the provisions of the Clean Water Act and the Endangered Species Act. The National Marine Fisheries Service and the U.S. Fish and Wildlife Service were intimately involved in designing the Implementation component of the TMDL expressly to avoid these conflicts. The fact is that there is an entire section dedicated to the Endangered Species Act in a TMDL required under the Clean Water Act. Means to resolve potential conflicts are offered in the implementation plan through the phased approach.*

Comment: We have concerns that the draft report fails to reconcile meeting the needs of tribal treaty obligations, ESA requirements, and full protection of the beneficial use, i.e., anadromous fish passage, under the Clean Water Act. It is critical that this is fully addressed in the Final Report.

Response: *The draft TMDL expressly seeks to reconcile actions under both acts. This issue is well covered in the final report.*

Comment: The TMDL describes the short-term and long-term allocations but fails to describe what the timelines are for the allocations. Current operations at the projects are subject to regulation at these points. To date, when the projects operate within the waiver limits, little to no harmful biological impacts from total dissolved gas have been discerned for in the juvenile or adult salmon. Since the TDG standard was set to protect ESA and resident fish populations, it is prudent to continue to operate the projects in this manner. Changing the load allocation point to a new point protection for these species could undermine the beneficial use that the TMDL was designed to protect. CRITFC supports studies in the tailrace to determine and study the best possible operations and structural changes to reduce TDG production, but in-season management should be left at the current fixed monitoring sites.

Other than sluiceway/surface bypass development, including removable spillway weirs, no other fish passage technologies are apparent for the short or long-term. Even these technologies require attendant spill to move salmon to the systems and to provide good tailrace egress conditions for juveniles to avoid predators. Permitting increased levels of total dissolved gas in the Columbia River in order to implement spill at the Corps dams will better protect the salmon beneficial use than forcing them through turbines and screened bypass systems (Strong 1998; CRITFC 2000a; CRITFC 2000b). Juvenile salmon mortality through turbines has been estimated between 4 percent and 19 percent (Whitney et al. 1997; Gilbreath et al. 1993). Adult salmon mortality through turbines has been estimated from 22 percent -51 percent (Wagner and Ingram 1973; Buchanan and Moring 1986; Liscom and Sturehrenberg 1985). Recent radio-telemetry studies for steelhead kelts have indicated that no kelts survived downstream passage during non-spill periods (Evans, 2002 personal comm.). Juvenile and adult salmon that are subjected to screen system passage are exposed to and held at temperatures that are significantly warmer than that found in the ambient river (Hoffarth 2000). Temperatures in bypass systems have been found to exceed water quality standards for much of the summer salmon migration (WDFW and ODFW 2000). Further, recent studies indicate that juvenile salmon that must pass through screen bypass systems have a significantly lower smolt-to-adult return rate than juvenile salmon that pass primarily through spill (Bouwes et al. 2002).

Spill will always be required at mainstem dams for fish passage, although sluiceways and surface bypass development may increase fish passage efficiency, therefore, reducing some spill levels. Whether or not these levels will meet CWA standards remains uncertain. What is certain is that involuntary spills will continue, and gas abatement structures that are fish passage friendly must be expedited to reduce dissolved gas generated from dams.

The draft report discusses TDG monitoring from 1995 – 1996. There has been considerable in-river monitoring since then, which should be incorporated in the final report. This includes dam monitoring by the Fish Passage Center (FPC 1997-2001), and monitoring contained in scientific reviews by the NWPPC's Independent Scientific Advisory Board's evaluation of gas abatement (ISAB 98-8 *Review of the U.S. Army Corps of Engineers Dissolved Gas Abatement Program*). These reviews found that dissolved gas levels of 120 percent TGP were conservative and not harmful to salmon in the river. Further, analysis of three years of research from in-river juvenile salmon sampling in the Columbia River indicates that very low incidences of GBT were found in juvenile salmon that were exposed to dissolved gas levels up to 125 percent saturation (Backman et al. 2000). Specifically, Backman et al. (2001) found no statistically significant relation between total dissolved gas and gas bubble trauma for chinook salmon. Most gas bubble trauma symptoms were minor (>5 percent fin occlusion) with severe bubbles (>26 percent fin occlusion) being observed only when total dissolved gas exceeded 126 percent. Chinook salmon were rarely observed with gas bubble trauma, despite sampling large numbers when total dissolved gas exceeded 130 percent saturation (Backman et al. 2001). Based upon this information, CRITFC continues to support a 125 percent total dissolved gas standard in the Lower Columbia River for the short-term to be modified as gas abatement structures are added to dams.

TMDL Should Use the Special Condition Criteria

The primary purpose of the TMDL should be the attainment of the desired biological outcome: support of aquatic life. The TMDL should establish load allocations based on the Special Condition (WAC 173-201A-060), including criteria of 120 percent TDG in project tailraces and 115 at project forebays. The Special Condition criteria have been demonstrated to support and protect aquatic life, thus meeting the requirements of the Clean Water Act. The final review draft wrongly asserts that the TDG criteria in the Special Condition are not to be used as a compliance endpoint because they are “to be viewed as temporary”. The current water quality standards do state that “These Special Conditions for total dissolved gas in the Snake and Columbia rivers are viewed as temporary and are to be reviewed by the year 2003.” However, Ecology's proposed revisions to the water quality standards, which are in the final stages of rule-making, include the following provisions which are permanent, not temporary:

Proposed WAC 173-201A-200(1)(f)

(iii) The TDG criteria may be adjusted to aid fish passage over hydroelectric dams when consistent with a department approved gas abatement plan. This plan must be accompanied by fisheries management and physical and biological monitoring plans. The elevated TDG levels are intended to allow increased fish passage without causing more harm to fish populations than caused by turbine fish passage.

(iv) The following special fish passage exemptions for the Snake and Columbia rivers apply when spilling water at dams is necessary to aid fish passage:

- TDG must not exceed an average of one hundred fifteen percent as measured in the forebays of the next downstream dams.
- TDG must not exceed an average of one hundred twenty percent as measured in the tailraces of each dam; and

- A maximum TDG one hour average of one hundred twenty-five percent must not be exceeded during spillage for fish passage.

The language in the revised water quality standards reflects the fact that the criteria in the Special Condition were reviewed by 2003, as specified in WAC 173-201A-060, and found to adequately protect and support the beneficial use of aquatic life in the Snake and Columbia Rivers. This TMDL can use the Special Condition criteria as endpoints for compliance and Ecology's argument to the contrary is specious. If the Special Condition criteria did not comply with the Clean Water Act, Ecology would not have made them a permanent part of their proposed revised water quality standards.

TMDL Should Include Target Analysis and Focus On Desired Condition

The final review draft should include a more extensive analysis to determine the appropriate target for the TMDL. EPA guidance for establishing TMDLs (Draft Guidance for Water Quality-based Decisions: The TMDL Process (Second Edition)) allows some flexibility in setting targets. The EPA guidance states: "From a broad management perspective, the purpose of target analysis is to define the relationship between designated uses, numeric measure(s) of success, and pollutant loading. The primary goals of target analysis are (1) to clarify whether the ultimate goal of the TMDL is to comply with a numeric water quality criterion, comply with an interpretation of a narrative water quality criterion, or attain a desired condition that supports meeting a specified designated use; (2) to identify the water body's critical conditions; (3) to identify appropriate ways to measure (track) progress toward achieving stated goals; and (4) to tie the measures to pollutant loading." In this TMDL, the target should be attainment of a desired condition that supports meeting a specified designated use rather than compliance with numeric criteria. The applicable water quality standards for TDG contain different numeric criteria developed to attain a desired condition ; the improved survival of salmonid fish. The final review draft mentions the value of spill for fish passage and the results of research showing no significant adverse effects on aquatic life from TDG levels at the higher numeric criteria contained in the Special Condition. The TMDL should be revised to set a target consistent with the Special Condition and with the attainment of greatest benefit to aquatic life beneficial uses, rather than focusing on the most stringent, and likely unattainable, numeric criterion in the water quality standards.

***Response:** The department is well aware of the potential conflicts between protecting water quality and impeding fish passage. That is why we have added load allocations to the final TMDL that are based on meeting the 120 percent/115 percent criteria in effect during spills for fish passage.*

Unlike most river systems, the Columbia and Snake Rivers have in place a process to detect and quantify the effects of TDG generation. This TMDL does not need to rely solely on the numeric criteria for TDG. The numeric criteria are established to be protective for the most difficult or sensitive habitats. The GBT detection process is very important in allowing the special condition criteria during spills for fish. Gas abatement plans that include feedback mechanisms looped to the GBT detection levels will continue to be required. So long as the gas abatement plan is approved, the LA based on the 120 percent at end of aerated zone criteria will be in effect during spills for fish passage.

Ecology has gone to great lengths in the TMDL to describe the potential conflicts and to construct an implementation plan in a phased way so that these potential conflicts can be avoided. Protection of fish through total dissolved gas levels at standards and survival targets as defined in the 2000 Biological Opinion is the appropriate outcome of this exercise.

Comment: It is not enough that the TMDL be written to reflect achievement of biological performance standards for the NMFS' 2000 Biological Opinion. As noted by CRITFC (CRITFC 2000), these standards are inadequate to recovery salmon populations to healthy, harvestable levels described in the *Spirit of the Salmon*. For example, as opposed to the Opinion juvenile survival standard of 95 percent per dam, the *Spirit*

of the Salmon recommends a short-term fish passage efficiency standard of 80 percent and a long-term fish passage efficiency standard of 90 percent. These higher standards, combined with increased, normative flow regimes recommended by the tribes, will require more spill volumes over longer periods at the Lower Snake Dams. Therefore, the final TMDL must be written to reflect actions that will meet these higher productivity levels by identifying and accomplishing higher standards of protecting the beneficial use. It would be very helpful to identify these short-term and long-term compliance goals in the main body of the Final TMDL Report and not solely in the implementation plan.

Response: *We are unable to address the perceived deficiencies of a federally constructed biological opinion in the TMDL under the Clean Water Act. There is no action in the implementation plan that is inconsistent with the 2000 biological opinion. Great care was taken to work closely with the National Marine Fisheries Service and the U.S. Fish and Wildlife Service to craft an implementation plan that achieved the requirements of the Clean Water Act while not detracting from the provisions of the 2000 biological opinion or the Endangered Species Act. Implementation provisions being incorporated into the body of the TMDL is neither appropriate nor legal. A TMDL is a quantitative evaluation of loading capacity and an allocation of loads. Implementation is completely separate from that. The former is an action requiring federal EPA approval; the latter is purely a state action.*

Comment: It is our understanding that the implementation plan is not a legally defensible document but the TMDL is. Staff is concerned with potential legal ramifications that the TMDL poses as currently written. Language needs to be added to the main body of the TMDL to address the potential conflicts between the needs of the CWA and the needs of the 2000 Biological Opinion to meet the requirements under ESA.

Response: *We are unable to alleviate your potential legal concerns with the TMDL. Language already appears in the body of the TMDL addressing the potential conflicts between the Clean Water Act and the Endangered Species Act, and great care has been taken throughout to avoid these potential conflicts.*

Comment: On Page 3 of the draft report, the TMDL is referred to as a, “[p]lanning tool, not a rule of law or other stand-alone enforceable document.” Further the draft report states that it does not take precedence over the federal Endangered Species Act, Indian Treaties, or federal hydropower system enabling legislation. The action of reducing spill to meet the TMDL is in direct conflict with the 2000 Biological Opinion spill program, the CRITFC tribes’ spill program described in the *Spirit of the Salmon* restoration plan and the Northwest Power Planning Council’s 1994 *Strategy for Salmon* restoration plan. These spill programs have been identified as critical components of salmon recovery. The implementation plan outlines how the TMDL is to be achieved, and attempts to reduce the conflict between current ESA operations and the need to meet CWA in the short term.

Response: *The state water quality agencies have fully supported the spill program for fish passage over the last ten years. There is nothing in this TMDL that detracts from that support. The major focus of the short-term phase of the implementation plan is on involuntary spill. We have, however, indicated that decreased reliance on fish passage spill will also be a feature of the short-term, but only in conformance with achievement of the survival standards detailed in the 2000 biological opinion.*

Comment: As previously stated, the relationship between meeting CWA, ESA and tribal treaty responsibilities and protection of the beneficial use needs to be clearly defined in this section.

Response: *In the TMDL we make it clear that the provisions of both the Clean Water Act and the Endangered Species Act must be met.*

Comment: Page 3 – “Therefore, in the short-term, structural gas abatement solutions may result in higher spills rather than lower TDG levels”. The consequence of adding spillway flow deflector to

Columbia and Snake River dams was to reduce the TDG exchange during a given spillway release. The applied consequence of this “gas abatement” structure measure was for more water to be spilled without exceeding the modified TDG criteria. The peak TDG pressures stayed unchanged while the total TDG loading to the system was increased during involuntary spill conditions. This deregulation in the system TDG properties afforded by “gas abatement alternatives” was justified by NMFS as improving fish survival.

The structural measures designed to reduce the TDG exchange in spill have resulted in higher volumes of voluntary spill (increased spill capacities at TDG waiver limits) and increased loading of TDG in the Snake River.

Response: *Agree. The structural and operational improvements allow for more water to be spilled before the gas cap is reached. This increases the mass of gassed water but only up to the gas standard. On the other hand, structural and operational improvements at the dams can, up to a point that varies for each dam, keep gas levels lower during spills that occur for lack of power demand or ability to transmit, lack of hydraulic capacity, or other reasons. Some language has been added to address these comments.*

Applicable Criteria

Comment: Page 5 – The mixing zone definition needs to be added to the Applicable Criteria section.

Response: *This has not been included primarily because of the length and complexity of the citation. Also, the mixing zone definition could be misleading because it refers to receiving water adjacent to an effluent outfall. The concept of the mixing zone is what is used in the compliance strategy for TDG levels caused by discharge of spills through dams. The regulation that applies to mixing zones at traditional point sources and stormwater outfalls is not directly applicable to the TDG from dam situation, although we are applying it in an indirect fashion.*

Comment: Page 6 - The statement in the next-to-last paragraph that “TMDLs must by law ensure compliance with existing permanent standards.....” should be clarified with respect to the statement on page 3 that “A TMDL is a planning tool, not a rule of law or other stand-alone document.”

Response: *A TMDL must be based on the law, but it is in and of itself not enforceable but can be enforced through other means. The word “ensure” has been changed to “address” to reduce any confusion.*

Comment: “But as new, more effective fish passage facilities are completed and evaluated, their contribution to the attainment of hydrosystem performance standards will hopefully allow spill levels for fish passage and associated TDG levels to be reduced, but only as long as the performance standards are met.” This statement seems to suggest that spill maybe a long term alternative required to meet fish guidance performance standards that supercedes the requirements set out in the CWA and is at odds with the statement “This TMDL must be written to reflect ultimate attainment of the TDG water quality standard.”

Response: *This statement is an acknowledgement that some form of spill may continue to occur in order to meet fish passage requirements of the Bi-Op. The TMDL has to be written with the goal to achieve water quality standards. There is no conflict with CWA requirements so long as the water quality standards are met or there continues to be reasonable progress toward meeting the water quality standard. The TMDL will have to be implemented to best protect the beneficial uses, including endangered salmon. Coordination with anadromous fish concerns is vital toward achieving the ultimate*

goal of the Clean Water Act which is to have fishable and swimmable waters. If further study shows that resident populations of aquatic organisms are being protected at the higher gas levels that are approved for juvenile fish passage, higher gas levels may be appropriate for at least portions of this river during time periods when fish passage spills are not in effect. This would have to be written into the water quality standards, which is outside the scope of the TMDL.

Comment: “The results suggest that, in weighing the benefits gained in increased salmon survival...”. The finding regarding the benefits of spill on guidance of juvenile and adult fish at Lower Snake projects has been mixed. Efforts to substantiate the benefits of spill on guidance of salmonids will play a substantial role in spill management planning.

Response: *We agree. Although spill plays the major role in bypassing turbines, entrainment into spillways varies at each dam. Many other factors also play a role in fish survival through each dam.*

Comment: The state water quality agencies should immediately pursue a review of the existing 110 percent TGP standard and the 115 percent-120 percent temporary waiver as they relate to protecting fish passage and the beneficial use under the CWA.

Response: *The provision for additional review of the water quality standard for total dissolved gas is already contained in the long-term phase of implementation. The department is currently fully committed with reviews of other water quality standards. We always welcome suggestions for standards that are in need of review. Inevitably, the number of standards suggested exceeds our resources at any given time. We also encourage other parties to undertake a full scientific review and submit it to us. The Environmental Protection Agency can provide the process and methodology for such a standards review.*

Comment: The final Report should find a means of compliance with the CWA, the ESA and treaty obligations.

Response: *This is already fully covered in this section and in the implementation plan.*

Comment: The Water Quality Standard and TMDL should be based on the greatest net ecological benefit to support aquatic life. The current TDG water quality criterion of 110 percent is based largely on laboratory studies where fish were held in shallow water and exposed to elevated levels of TDG in relation to the atmospheric pressure. Most aquatic life in the Snake River does not typically inhabit the upper three feet of the river’s depth. The water quality standard and the TMDL should be established to provide the greatest net ecological benefit to support the designated uses. Because TDG is a dynamic, natural process, the goal of the TMDL should be as established for thermal TMDLs, a total maximum daily load that “will assure protection and propagation of a balanced, indigenous population of shellfish, fish and wildlife”(40 CFR 130.7(c)(2)). The use of spill to improve survival of migratory anadromous salmonids, especially for ESA listed species, should be given equal weight to meeting water quality criteria that are set with a conservative margin of safety, as is the 110 percent TDG criterion. The salmonids, resident fish species, benthic organisms and other aquatic life forms in the Snake River all spend most of their time at water depths where TDG saturation levels are less than 100 percent relative to the ambient hydrostatic pressure, even though the TDG pressure exceeds 110 percent relative to the atmospheric pressure at the water’s surface. As stated in the draft TMDL (page 69), biological monitoring to assess gas bubble trauma to fish has shown little trauma to migrating juvenile salmon at TDG levels of 120 percent (modified water quality standards). This TMDL should provide equal consideration to developing the data to support a permanent, site-specific criterion for TDG for the Snake River that supports the designated uses to achieve the greatest net ecological benefit.

TMDL Should Seek Biological Outcome – Not Focus Only On Numerical Criteria

Chelan PUD disagrees with Ecology’s philosophy that the primary purpose of the TMDL is the ultimate attainment of the total dissolved gas (TDG) water quality criterion of 110 percent. Ecology equates compliance with the Clean Water Act (CWA) as being mechanistic compliance with the most stringent water quality numerical criterion for TDG (110 percent) in Washington’s water quality standards. Instead, Ecology’s goal should be to improve biological outcomes for fish in a manner that achieves overall compliance with the CWA and related state and federal law, including the requirement that existing beneficial uses be maintained and protected. Ecology is well aware that mechanical application of the 110 percent criteria is not always the best approach to protecting salmon and, in fact, could be unlawful in certain situations under the Endangered Species Act (ESA). Biological performance standards under the ESA require spill as a means of improving survival of salmonid fish. Washington’s TDG standard contains a Special Condition that recognizes and supports this use of spill. However, Ecology asserts that the TMDL must be written to reflect the ultimate attainment of the 110 percent TDG water quality criterion, without sufficient regard to fish survival requirements mandated by other laws. The final review draft inappropriately, and perhaps unlawfully, relegates fish passage requirements and fish survival to merely being “facilitated under an implementation plan”.

A key purpose of the Clean Water Act is to protect and support beneficial uses. The only beneficial use that is sensitive to total dissolved gas is aquatic life, primarily salmonid fish. Ecology acknowledges that extensive research has demonstrated that the 110 percent criterion is unnecessarily stringent, and “in weighing the benefit gained in increased salmon survival by spills for fish passage against the benefit to the beneficial use from strict adherence to the standard, it would be reasonable to find flexibility in application of the standards.” In this case of clear conflict, where meeting a numerical criterion for water quality would limit other actions that provide significant benefit to the beneficial use, such as fish passage spill, meeting the numerical criterion should not be the ultimate objective of the TMDL. The TMDL may define loadings of TDG that meet specific numeric criteria, but the summary implementation strategy should seek to balance conflicting management actions to achieve protection and support of the beneficial use, not focus strictly on meeting the numerical criteria.

Response: *We have provided load allocations based on meeting the fish passage criteria of 120 percent in the tailrace and 115 percent TDG in the forebays as well as the 110 percent criterion.*

Total maximum daily loads present recommended allocations that are implemented through other mechanisms. They are not a rule making activity. Setting new rules for adjusted water quality standards to take into account site-specific needs on the Snake are beyond the scope of this TMDL. Data needs toward a site-specific gas standard on the Snake will happen outside the scope of this TMDL. The provision to review the water quality standard for total dissolved gas is already contained in the long-term phase of implementation.

Comment: The state water quality agencies must commit to an effort to review the adequacy of the existing total dissolved gas standard for the mainstem Snake River with respect to protecting the beneficial use, and this effort should parallel implementation plan efforts.

Response: *This has been provided for in the long-term phase of implementation. However, a change in water quality standards is a different exercise than a TMDL.*

Background

No comments received.

Sources of Total Dissolved Gas

No comments received.

Spill for Fish Passage

Comment: The bottom line for the treaty tribes is protection of the beneficial use, i.e. salmon and other anadromous fish passage through the Federal Snake River Hydrosystem. Based on numerous biological studies, many of which the draft report fails to discuss, we have serious concerns that the existing standard of 110 percent TGP and the existing variances of 120 percent TGP in the dam tailraces and 115 percent TGP in the downstream dam forebays limits protection of the beneficial use. The federal government should do everything possible to meet their obligations under the CWA, but not at the expense of the beneficial use that the CWA is supposed to be protecting.

Response: *Anadromous fish passage is one of a number of beneficial uses to be protected on the Snake River. The criterion of 110 percent of saturation is designed to protect salmonid and resident fish species from gas bubble trauma. A standard change is a different exercise. We have provided for this in the implementation component of the TMDL in the long-term.*

Involuntary Spill

No comments received.

Water Quality and Resource Impairments

No comments received.

TDG Generation from Spills

Comment: Page 10 – “if conditions are still...” The degassing process is still active but at a lesser rate than if the wind is generating conditions promoting yet high rates of exchange.

Response: *This phrase is no longer in the TMDL. The TMDL is now addressing the wind and degassing issue differently.*

Comment: Page. 11; First paragraph: “?but the loss rate is controlled by conditions?”

Response: *Corrected.*

TDG Impacts on Aquatic Life

Comment: The information provided about total dissolved gas and different levels of total dissolved gas impacts are all derived from laboratory work, which does not adequately represent natural systems. Laboratory studies are very conservative because fish cannot achieve depth compensations. Only data acquired from river studies, as noted above, should be incorporated into the final Report.

It is not clear to us what the water quality agencies’ criterion were for developing the two levels of compliance- one hour maximum and the average highest 12 hours? With the current amount of data it

seems prudent to determine if these limits are still appropriate. The chronic and acute levels outlined in the waivers should also be further reviewed to determine if the levels are adequate or overly conservative. Restraints from the existing 110 percent TGP and 115 percent-120 percent temporary TGP standards are the major constraints to meeting juvenile passage goals to protect the beneficial use. These levels need to be reviewed as a key component of any short or long-term implementation plan. A review of the acute and chronic levels to determine if more flexibility is available is critical. This could lead to more spill to increase passage of a larger percentage of juveniles and adults.

Response: *A review is already provided in the long-term phase of the implementation plan. The criteria for determining the temporal criteria for the total dissolved gas variances are based on applications we receive from the federal agencies.*

Monitoring of TDG

Comment: Page 13 – “For the purpose of TMDL compliance, TMDL needs do not need to...” When would the needs of monitoring for TMDL compliance be at odds with monitoring for biological/habitat concerns?

Response: *Monitoring for ESA needs at the fixed monitoring stations has been established through the Water Quality Team. This process has evaluated a broader range of issues than the more narrow focus of TMDL compliance. In some situations these two processes might result in different conclusions about monitoring needs.*

Technical Analysis

Analysis of TDG generation processes

Comment: The TMDL uses the Corps analysis for much of the technical work. However, the COE analysis was performed in the late 1990's to 2000. Operations have changed considerable during that time. Most notable is the operation of the spillways to reduce powerhouse entrainment. By operating a flat pattern instead of the crowned adult pattern that was used in the analysis and insuring that operations produce skimming flows, the percentage of powerhouse flow entrained can be greatly reduced. However the draft report does not consider this change in operations since it was done after the analysis was completed. This operation change needs to be evaluated to determine what effect it will have on the analysis as a whole and incorporated into the final Report and implementation plan.

Same comment as above applies to Lower Granite. Furthermore with the addition of the removable spillway weir in spillbay 1, the gassing characteristics for Lower Granite have been greatly impacted and changed. This should be mentioned or evaluated.

Same comment as above with regard to powerhouse entrainment.

Same comment as above. Further, a new stilling basin has been added and new end bay deflectors were completed this year. The analysis does not take in to account either of these changes, which will have a significant effect on the gassing characteristics of Lower Monumental. These should be incorporated into the final report and implementation plan.

Response: *The Corps work cited is intended to provide background about historical knowledge of TDG generation processes. We recognize that the understanding of TDG generation processes will improve over time and those processes will change as new operations and structures are implemented. The TMDL*

itself is approved by EPA and by necessity represents a “snapshot” of the best science available at its development. However, the implementation plan belongs to Ecology and can be revised as new developments suggest modifications. This is described in the section “Adaptive Management”.

Comment: Paragraph 6 states, “...[t]he authors of this report support evaluation of...water quality standards.” Does this mean the agencies support this evaluation?

Response: Ecology is willing to support such an effort if desired by stakeholders, but would have to determine the availability of resources to provide specific funding or staff support when a project of this sort is proposed.

Analysis of Current Conditions

Data Quality

Comment: Page 31 and 32, Data Quality section – This section addressed only quantity of data, not quality. I think you can do better.

Response: Reference is made in this section to multiple sources of data quality information, which for succinctness was not repeated in the Report. We could do better, but prefer to allow the reader to reference the original reports which speak for themselves.

Lower Granite Dam

Entrainment of Powerhouse Discharge

Comment: Pages 33&34: Figures 10 and 11 appear to be the same, seems redundant to have them twice in two pages.

Response: They are different, and are discussed separately in the text.

Ice Harbor Dam

Regression

Comment: Page 53; "Even with this robust relationship, caution and judgment must be applied when using this equation outside the ranges of discharge and tail water depth from which it is derived"

Response: Corrected.

Load and Wasteload Allocations

Comment: We do not understand the rationale for not requiring the specific dams, as identified in the draft report, to have NPDES permits. As discussed later in the TMDL, there are only four points of total dissolved gas of concern in the Lower Snake: Lower Granite Dam, Little Goose Dam, and Lower Monumental Dam, and Ice Harbor. Since these are the known sources of total dissolved gas (TDG) we wonder why the TMDL does not require NPDES permits? If a NPDES permit is not required for exceedence of total dissolved gas at the dams, then we do not understand why a temporary TDG waiver for total dissolved gas is required from the

Corps to implement the yearly fish spill program. The waiver is a form of regulation, which would imply that these points of concern would be point sources. The final report should explain this inconsistency.

Page 56 - footnote #2 states that "The courts have determined the characterization of dams as point sources for which NPDES permits will not be issued for certain parameters. The current policy of the state of Washington is to not issue NPDES permits for TDG." It is unclear if this statement interprets dams as causing pollution or discharging pollutants? In either case no permit is required. A citation(s) is lacking and should be added. If this is not the definitive legal thinking on the issue, it should be qualified.

Response: *The D.C. Circuit Court, in a reversal of the district court, ruled that certain dam-induced water quality changes do not constitute the "discharge of a pollutant" as that term was interpreted by EPA in the context of section 502 of the CWA. EPA then would not require that dams, even though labeled point sources, need to be permitted under the NPDES program for most parameters. (National Wildlife Federation v. Gorsuch, D.C. Circuit, November 5, 1982) The current policy of the State of Washington is to not issue NPDES permits for TDG. The state of Washington Water Pollution Control Act applies to all sources of water pollution regardless of NPDES permit status under the federal Clean Water Act.*

Comment: The load allocations presented are inconsistent with the recent Lower Columbia TDG TMDLs. The Lower Columbia TDG TMDL did not allocate a loading to the thermally induced pressure increases. The load allocations for spill are not reasonable or achievable targets.

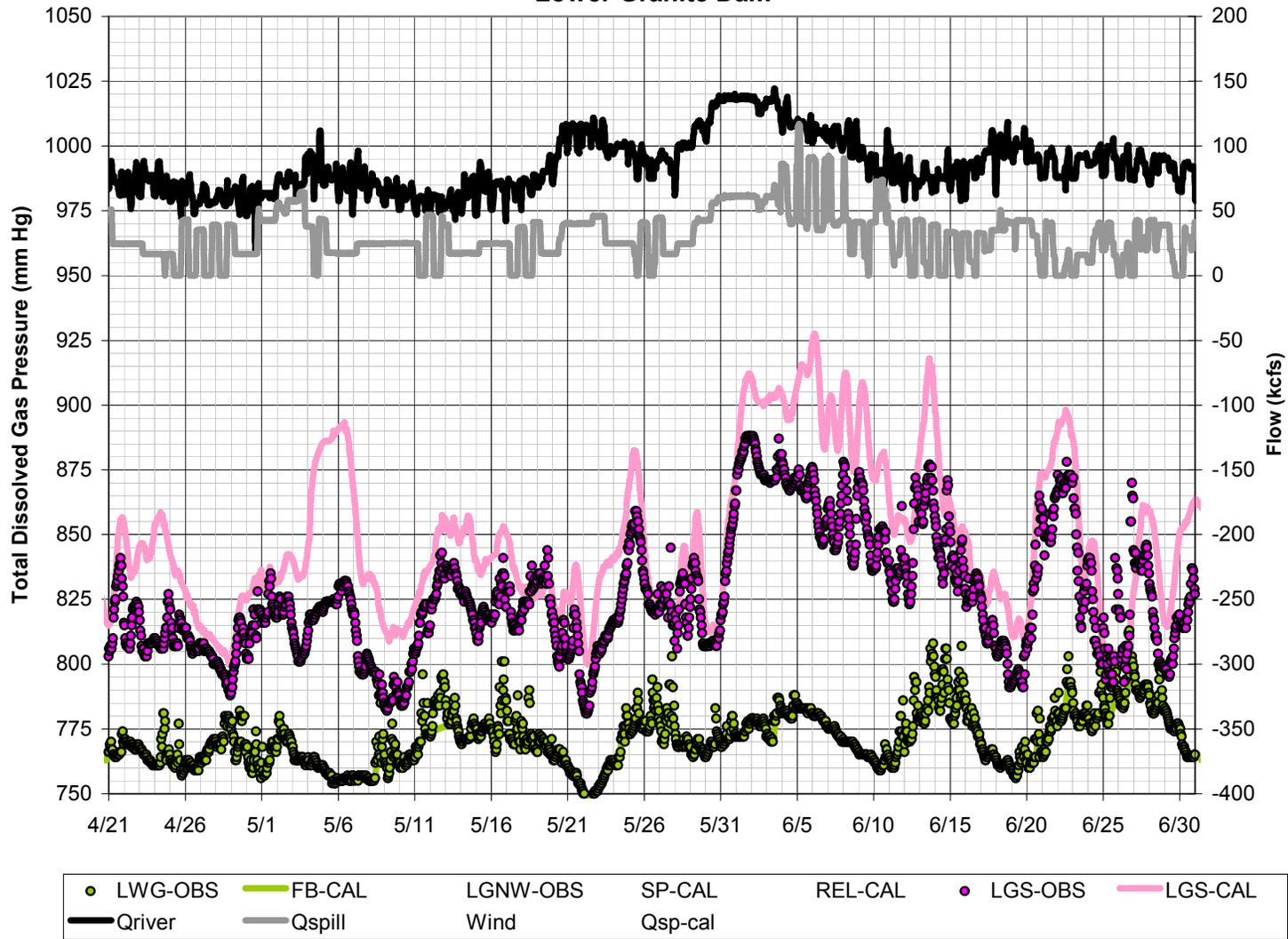
Response: *The reasons that the load allocations are different from the Lower Columbia TDG TMDL are explained in the TMDL. The allocations to the pools for thermally induced pressure increases that were in the draft TMDL have been replaced with allocations to be met in the downstream forebay. The load allocations are based on the technical requirements to meet the water quality standards, so they are technically reasonable. The cost and availability of measures to achieve the targets are to be addressed in the implementation plan.*

Comment: The load allocation for spill is overly protective of the water quality standard of 110 percent because the degassing component in the Snake River has been assumed to be negligent while applying a thermally induced pressure increase. A detailed accounting of TDG pressures in Little Goose pool during the 2002 fish passage season was used to calculate the loss rate of TDG pressure in this river reach.

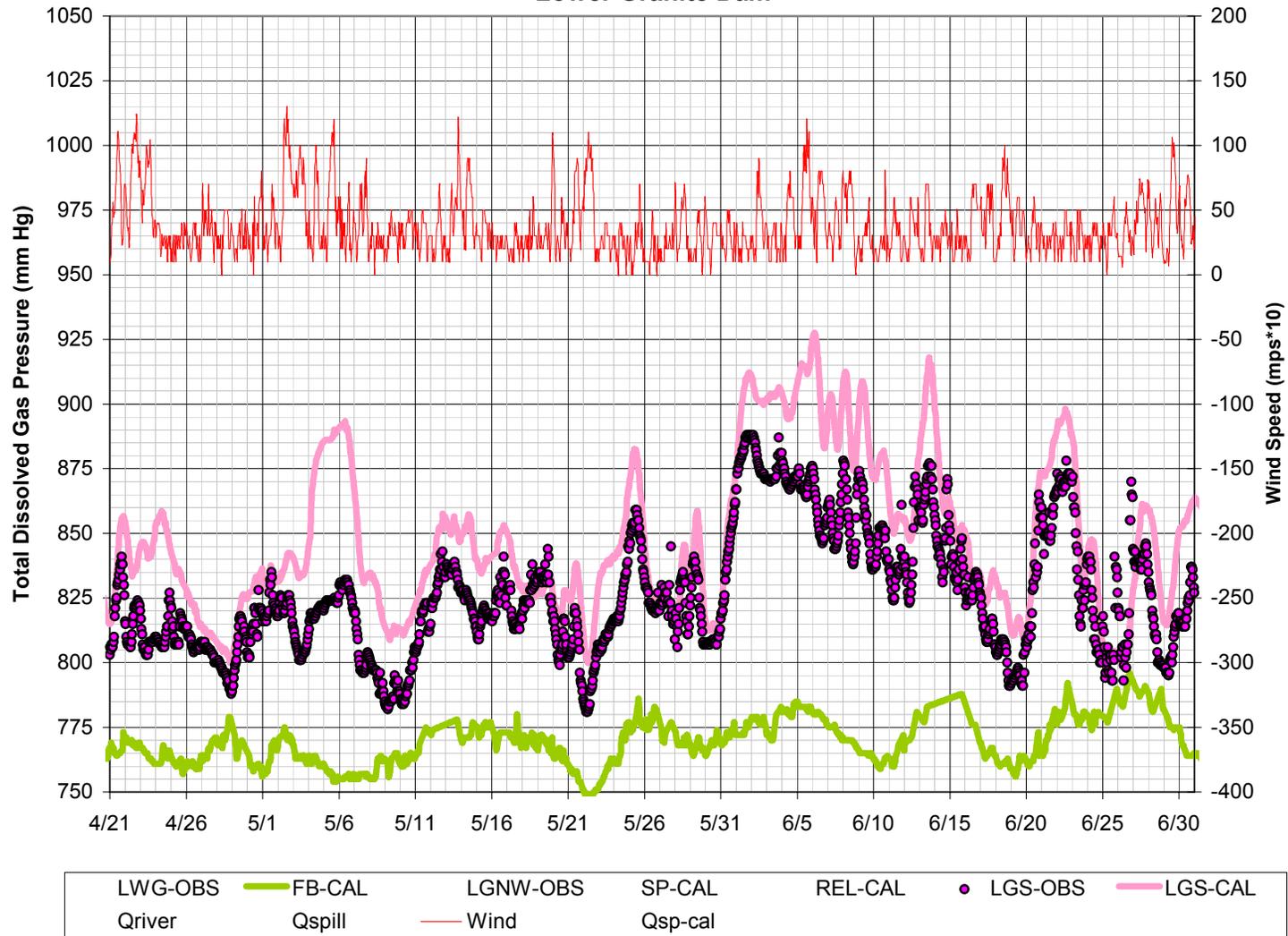
An array of TDG instruments were deployed below Lower Granite Dam during the 2002 spill season. These data were used to quantify the TDG loading produced during spillway flows at Lower Granite Dam. These TDG pressures were routed through the Little Goose pool by using the SYSTDG workbook to evaluate the exchange rates of TDG pressures. The observed (symbols) and calculated TDG pressures (pink line) assuming no loss of mass in transit through the Little Goose pool is shown in Figure 1. The conservative transport of TDG pressures in the Little Goose pool resulted in forebay TDG pressures at Little Goose Dam much larger than observed at the forebay fixed monitoring station. The routed pressures reflect the change in temperatures observed between these projects but for a constant concentration as discharged from Lower Granite Dam. The calculated TDG pressures with no degassing were greater than the observed conditions throughout the fish passage season and exceeded the observed conditions by as much as 60 mm Hg. The hourly wind speed (mps * 10) as observed at the Agrimet station located at Rice Bar on Lake Bryan is shown along with the observed and calculated TDG pressures in Figure 2. The circled periods of high wind shown in Figure 2 correspond with large differences between the observed and calculated (no degassing scenario) TDG pressures in the forebay of Little Goose Dam. The high wind events also correspond with decreasing TDG pressure in the forebay of Lower Granite Dam (green line).

The seasonal simulation of TDG pressure in Lake Bryan was repeated assuming TDG pressure is continuously exchanged at the water surface of the Snake River. The mass exchange was assumed to be a first order process driven by the gradient between the local TDG pressure and the atmospheric pressure. The exchange coefficient was assumed to be a function of the wind speed. The observed and calculated TDG pressure in the forebay of Little Goose Dam assuming degassing at the water surface is shown in Figure 3. The observed and calculated TDG pressure is similar throughout the fish passage season with an average predictive error of -2.5 mm Hg and an rms error of 10.4 mm Hg. The statistical summary of the change in TDG pressure between Lower Granite and Little Goose Dams with and without in-pool degassing is shown in Table 1. The average change in hourly TDG pressure released from Lower Granite Dam to the forebay of Little Goose Dam was 19.4 mm Hg or about 2.6 percent saturation. The loss of TDG pressure was greater than 43.7 mm Hg during 5 percent of the hourly releases from Lower Granite Dam. The loss of TDG pressures was less than 7.2 mm Hg 5 percent of the time. The degassing of TDG pressures in the Snake River was significant during the 2002 spill season. The loss of TDG pressure during transport is a continuous process that occurs with or without strong surface winds. The presence of strong sustained winds can greatly accelerate the exchange of gasses between the Snake River and the atmosphere. In most cases, degassing at the water surface is considerable larger than thermally induced pressure gains. The frequency of moderate to high winds (5 to 10) relative to the time of travel through the pool (typically 2 to 4 days) supports the claim that ignoring the degassing processes in determining the load allocation for TDG in the Snake River will result in an overly restrictive criteria.

Lower Granite Dam



Lower Granite Dam



Lower Granite Dam

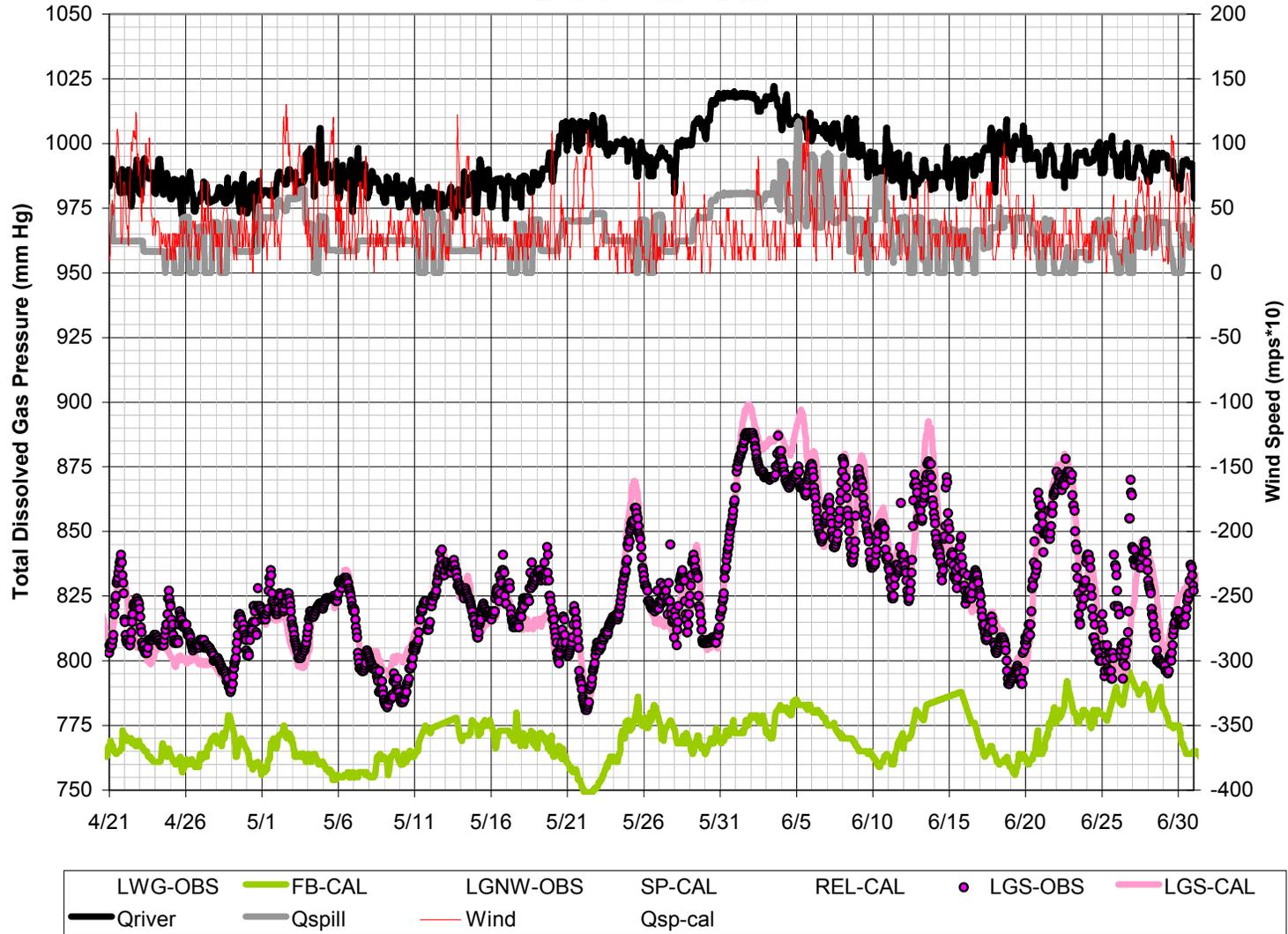


Figure 1. Statistical Summary of the change in the TDG pressure of hourly releases from Lower Granite Dam to Little Goose Dam, April 5-July 8, 2002. (number of observations = 2261)		
Parameter	Change in TDG Pressure (mm Hg)	
Average	-19.4	
Minimum	-68.0	
Maximum	-1.5	
Standard Deviation	11.8	
Percentile	0.05	-43.7
	0.25	-25.0
	0.50	-15.5
	0.75	-11.9
	0.95	-7.2

Peak TDG pressures in the Snake River are typically found in spill waters immediately below the spillway. These peak pressures diminish as water is transported downstream due to dilution with powerhouse releases and continue mass exchange at the water surface. The location of a point of compliance at the downstream end of a river reach will generally reflect mixed river conditions. However, the TDG properties may be significantly moderated by degassing at the water surface and maybe a weak measure of the influence of a particular dam's influence on water quality conditions in the Snake River.

The influence of temperature on the total pressure is a well-defined property defined by the Charles Law (volume of gas varies directly with the absolute temperature). Consider a control volume of water at equilibrium with the atmosphere. If the water temperature increases, the total dissolved gas pressure will increase in direct proportion if the mass concentrations are held constant. This rise in pressure (supersaturation) is in disequilibria with the atmosphere prompting mass exchange at the water surface. Agitation or circulation of the water column will enhance the exchange of mass at the air/water interface lower the TDG pressure in the water. The presence of waves and breaking waves that entrain additional bubbles will further enhance this surface exchange of gasses. The methodology used by WDOE to calculate the near dam load allocation assumes no surface exchange occurs during an extreme (90th Percentile Simulated Event) in-pool temperature increase. It is overly restrictive to assume that surface exchange is zero in the Snake River.

Response: *Based on the analysis provided in this comment, the final TMDL has been modified to take a different approach to address pressure increases due to increasing water temperatures. The allocation for each pool has been removed and instead allocations are provided for the forebays of the downstream dam. Between the likelihood of degassing during passage of the pool and the requirement to meet the downstream forebay allocations, the margin of safety is sufficient to address water temperature increases.*

Comment: Page 57 - I assume the author is aware of the additional meteorological data now available for the Lower Snake such as at <http://mac1.pn.usbr.gov/agrimet/agrimetmap/silwda.html> and others. The statement during the presentation at the public workshop that the wind data had been studied and showed that there wasn't enough wind to bring about any surface chop to aid in degassing is incorrect according to an analysis quantifying the impact of wind generated degassing in sections of the Snake river using SYSTDG. I think his conclusions regarding wind generation exchange from empirical aeration equations developed in other areas of the country. They do not seem sufficiently accurate to use them on the Snake River.

Response: *This comment has been addressed in the TMDL (see above).*

Comment: At what point does the frequency and magnitude of spill discharge and total project TDG loading factor into this TMDL? Could we not have an instance where the TDG saturation in spill is 112 percent (an excursion above the 110 percent standard) during background conditions of 115 percent? In this case, spillway flows are enhancing the TDG conditions in the Snake River. How would this operation be recognized in this TMDL?

Response: *The TMDL requires each spill to meet the standards regardless of upstream concentration. The dynamics of gas generation and powerhouse flows can be complex, so that addressing the specific situation and the nature of an enforcement response is left to the discretion of the department. A reasonable response in the situation described in the comment would be to first examine the operational constraints available to the dam operator in attempting to achieve the 110 percent criterion.*

Comment: Page 56 – “Back-calculation of TDG in the Palouse River suggests that TDG levels over 110 percent are possible during the high flow events.” This approach is not applicable because of the small loading attributed to the Palouse River, the need to account for all other source and sinks, and the accuracy of adequate boundary conditions.

Response: *The approach is limited by the considerations listed, but is still adequate as a screening tool to determine the need for tributary allocations.*

Comment: Page 56 - Last 2 sentences in paragraph 3 suggest that "Detailed monitoring and modeling is needed to determine the influence of Palouse Falls with certainty." but that the current analysis shows that a load allocation for the Palouse River is unnecessary. Since there are costs to monitor and model for a nice-to-have research item, suggest changing "is needed" to "would be required... However, the current TMDL analysis is sufficient to determine that a load allocation and monitoring / modeling for the Palouse River under this TMDL is unnecessary." This would make this consistent with the Executive Summary, page ix, last sentence.

Response: *A revised version of the suggested language has been added.*

Comment: TDG strategy – A reasonable strategy for managing spill in the system relative to the 110 percent standard must take into account the frequent occurrence of forced spill in the Snake River and the existence of TDG levels above 110 percent. This strategy involves not adding to the TDG loading of the Snake River when approach conditions are above 110 percent and not to creating average TDG in the Snake River above 110 percent when approach conditions are at or below 110 percent. There are circumstances where spilling water at levels above 110 percent could result in a net reduction in TDG saturation in the river (when forebay levels also are greater than 110 percent).

Response: *The strategy described in this comment appears to address a fully mixed river. The TMDL discusses the need to meet standards even when not fully mixed. Therefore, for the Lower Snake River dams the standards need to be met below the spill even when not fully mixed (or during 100 percent spill). The only allowance is the exclusion of the aerated zone from the compliance area. The dams addressed in this TMDL are not held responsible for high TDG arriving from upstream, but they also do not get any credit for low upstream TDG. Also, high upstream TDG levels do not provide a license for a dam to exceed the 110 percent criterion. Nonetheless, Ecology recognizes the complexity and on-the-ground realities of dam operation during the compliance period, and can exercise discretion in its choice of enforcement response.*

Comment: Page 56 - Add to the second or third bullets "Even after modification, some very large dams still may be unable to achieve WQS due to incoming levels of TDG from upstream sources."

Response: *A revised version of the suggested language has been added.*

Comment: Page 57 – Table 15 in addition to other concerns with the load allocations, why have a seasonal component to these allocations? This is an unneeded complication to the TMDL.

Response: *Seasonal Allocations are no longer included in the TMDL.*

Long-term Compliance with Water Quality Standards

Compliance with Standards for All Spills

Comment: This section should be eliminated or rewritten. The paragraphs referring to compliance with standards for all spills is inconsistent with previous sections that declare that the TMDL does not take precedence over ESA, or Indian Treaty rights. Proposing the fish spill program must be applicable for this TMDL appears to mean that the TMDL takes precedence over ESA and tribal treaty rights. This inconsistency should be addressed in the Final Report. CRITFC agrees that the specified hydroprojects need to comply with the Clean Water Act but not at the expense of the very same beneficial use that the TMDL is trying to protect.

Further, public interest is not what necessitates the fish spill program. Passage protection of ESA-listed and non-listed anadromous fish migrants is what necessitates the spill program.

Response: *This section is pertinent, and should remain. With the extensive attention paid to fish passage spills, this statement is a reminder that standards must be met for spills due to other causes. Previous sections have stated that the Clean Water Act does not take precedence over the Endangered Species Act. However, neither does the Endangered Species Act take precedence over the Clean Water Act. Both Acts need to be met simultaneously. Ecology believes that protecting fish and other aquatic life is an issue of public interest.*

Comment: Page 59 - It seems reasonable to reconsider the discharge criteria (7Q10 discharge) used in the state standard. The 7Q10 discharge is much greater than the maximum powerhouse capacity of the Snake River powerhouses and the occurrence of involuntary spill is not controlled by the operation of these dams. The expense of alternatives to meet TDG standards throughout this range of flows will be prohibitive.

Response: *The 7Q10 flow exemption for meeting TDG criteria represents the liberalization of the requirement that standards must protect beneficial uses. The mechanism for further liberalization of the situations when the gas criteria need not be met is in the revision of the standards, not the TMDL.*

Compliance Locations

Comment: Page 60 – Figure 27 – This figure is misleading. The change in TDG pressures between the end of the aerated zone and existing fixed monitoring stations is often next to nothing, especially for the Snake River projects.

Response: *This figure is meant to illustrate the use of the mixing zone exemption to establish the upstream boundary of a compliance area. An exact representation of the TDG levels from the aerated*

zone to the fixed monitoring station is not intended. The caption has been revised to help reduce any confusion over this point.

Comment: The objectives of multiple compliance locations should be more clearly presented (some statement regarding acute and chronic exposure, average and extreme pressures). Should compliance locations be established to identify the resulting TDG loading generated from project operations? A point measure of TDG below the spillway by itself is not an adequate measure of a project's impacts on the average Snake River TDG pressures. A point measure of 115 percent in spill water during a 10 kcfs spill release will have a different impact on the Snake River than a 50 kcfs spill at 115 percent if the river is running 100 kcfs in both cases. A clear objective statement will help determine the adequacy of existing and alternative sampling locations. The compliance locations stated in Table 16 should be similar for each dam and should include a range of distances (1500 ft to 1 mile).

Response: *The concept of “compliance locations” has been changed to “compliance areas” in the final TMDL. The objectives are compliance with the load allocations. The criteria do not have acute and chronic levels defined, so inclusion of that concept is not appropriate. The final TMDL defines the average or maximum level to be applied. Also the criteria are based on the percent saturation, but are silent on the impact of mass loading, so mass loading will not be included as a requirement. However, the establishment of forebay allocations will indirectly take mass loading into account.*

Comment: Page 61 – Table 16 – These distances referenced from the CE studies refer to the end of the stilling basin and not the spillway. The extent of the aerated plume will grow with higher discharges. It would be safe to say that the highly aerated flow plays out within 100 ft of the end of the stilling basin.

Response: *The distances have been set to the spillway, based on the values in the reports.*

Comment: TMDL Should Incorporate Powerhouse Flows Into Mixing Zone for Compliance Point. The final review draft contains a basic flaw in the designation of load allocations and compliance points. The allowable load, or loading capacity, of a pollutant is the amount of pollutant that the water body can receive and meet water quality standards. In the case of mainstem Columbia and Snake River hydroelectric projects, the flows from the spillway and powerhouse mix at some point downstream from the project. Unless the powerhouse flow has equal or greater TDG pressure than the spillway flow, the spillway flow will be diluted by powerhouse flow and the resultant TDG pressure will be less than TDG measured at the end of the aerated zone below the spillway. The final review draft appropriately sets the load allocation for a hydroelectric project equal to the loading capacity less background loads, yet incorrectly sets the compliance point at the end of the aerated zone below the spillway, without consideration of the dilution of TDG pressure as the spillway flow mixes with powerhouse flow. Since spillway flows are generally much lower than powerhouse flows, the point of compliance should either be at a location where flows are mixed or the load allocation should be increased according to the degree of dilution that occurs after mixing. As Ecology is aware, there is ample authority under federal and state water quality regulations for the use of mixing zones when determining compliance with numerical water quality criteria. In the case of TDG, an extended mixing zone is appropriate.

Without giving some credit for mixing and dilution, there would be no benefit, in terms of compliance, for reductions in spill volume. In this sense, the compliance point in the final review draft is inconsistent with the proposed implementation activities that include a number of measures to reduce the volume of involuntary spill and spills for fish passage. The compliance point at the end of the aerated zone will not accurately reflect the reduction in load, or benefit, of actions that reduce spill volumes because the compliance point does not include the effect of dilution. If the compliance point remains the same, then the load allocation should be increased proportional to the percentage of river flow coming through the spillway to incorporate dilution.

Response: Ecology must respectfully disagree regarding dilution of flows. As the discussion in the TMDL states, the use of the entire Columbia River for dilution is not appropriate. In addition, each dam cannot control upstream TDG levels, which may be higher than the TDG produced by the spill. The rationale is not clear as to why the commenter believes that not allowing dilution eliminates incentives to reduce spill. Spill volume is the single largest operational factor in TDG production, so compliance in the areas of least dilution would tend to push for smaller volumes than compliance that includes dilution.

Comment: Compliance points of measure are identified as 1000 feet or 1500 feet ie. A point downstream of bubbly flow from the spillway. Also, the table 17 lists divider walls as short term implementation activities. If we install divider walls to reduce the mass of gas being introduced to the river below the dams, we will likely not be able to measure their effects at the compliance points because they are so close to spillway. I would anticipate that the powerhouse flows will take some distance to mix laterally with and dilute spillway water beyond the bubbly flow zone. How do you envision this working? How can we get credit for the divider wall installations? Is there some way to look at the improvement in terms of the reduction in habitat areas affected???

Response: The final TMDL includes points of compliance at the downstream forebays, which should provide a way to “get credit” for the installation of divider walls.

Monitoring of Compliance

No comments received.

Margin of Safety

No comments received.

Critical Conditions

No comments received.

Criteria versus Site-specific Conditions

No comments received.

Data Quality and Quantity

No comments received.

Seasonal Variations

Comment: Page 65 - Should the last sentence of paragraph 2 which describes when spill may occur also mention flow releases / spill for fish as part of the scenario?

Response: No, but the sentence has been revised for clarity.

7Q10 Flows

No comments received.

Summary Implementation Strategy

No comments received.

Overview

Comment: Implementation - The past dissolved gas abatement measures applied at Snake River project should be cataloged (flow deflectors and spill pattern changes). Some recognition of these water quality enhancement measures should be documented in addition to the proposed measures. Lower Granite Dam flow deflectors were added in the year 197x on all eight spillbays. Flow Deflectors at Little Goose Dam were added in the year 197x on 6 interior bays. Spillway flow deflectors at Lower Monumental Dam were added in the year 197x on 6 interior bays. Little Goose and Lower Granite spill pattern were modified to reduce TDG production by limiting spill to bays with flow deflectors (1998-present).

Response: *Comment acknowledged*

Comment: The draft report discusses the beneficial uses of the river outlined by the Oregon and Washington's water quality standard, but none of these uses, except the anadromous fish identified in the draft report are impacted by total dissolved gas. Therefore, what constitutes the best operations for the needs of the anadromous and other resident and aquatic species should take precedence when considering the strategy to meet the total dissolved gas TMDL.

Response: *Limiting total dissolved gas is designed specifically to address the needs of anadromous and resident fish.*

Implementation Plan Development

Comment: Pages 69 and 71, Implementation Plan Development – On these pages references are made to a “Detailed Implementation Plan.” What is meant by a “Detailed Implementation Plan” and how is this different from the title of the document section, i.e., “Summary Implementation Strategy?”

Page 66, The Detailed Implementation Plan referenced on pages 67 and 68 should be defined in the document. How is this different from the Summary Implementation Strategy?

Response: *For the state of Washington, a TMDL is required to contain a Summary Implementation Strategy. The state then has a year in which to provide a Detailed Implementation Plan (DIP). These requirements are laid out in Ecology's Memorandum of Understanding with EPA regarding TMDL development. A description of the DIP has been added to the section.*

Comment: CRITFC strongly supports the Draft report's statement that a review of the standard should take place before the end of the short-term compliance phase. Current data indicates that for the anadromous fish, resident fishes and other aquatic life, the 110 percent TGP standard is overly conservative. A thorough scientific review and any additional research to verify past findings should be conducted to determine the standard. This review would need to determine if the current level is adequately protecting the beneficial uses. A process to determine if a new level TDG or permanent waiver change for the Snake Basin would be a better balance for the requirement of the beneficial uses needs to be undertaken. It is critical that CRITFC

and its member tribes, as resource co-managers, should be full participants in this review and the short and long-term implementation plans.

Response: *The review of the 110 percent TDG standard, resources permitting, will occur in the long-term phase of implementation. Such data and studies as would be needed to support a review of the standard will be collected in the short-term*

Comment: The final report should also include 1) completion of monitoring and other scientific literature relative to the short-term standard, 2) provision for implementing a review of the existing standard in parallel with development of short-term and long-term implementation plans and, 3) inclusion of tribes as co-managers of the resource in development of these actions.

Response: *Amendments to the water quality standard are a different exercise and will be fully developed in the appropriate forum. The Tribes are co-managers of the fishery resource, and we always welcome input on managing water quality improvements.*

Comment: The TMDL discusses the spill program objective which is to generate spill “no greater” than the waiver levels. To what level does “no greater” mean? Currently there is much debate about how close total dissolved gas levels can be to the waiver levels before spill needs to be reduced. Due to the great benefits of spill and the lack of data that would indicate levels of total dissolved gas at 115 percent-120 percent are harmful to anadromous species, it would seem that some flexibility could be used when managing the spill program at the fixed monitoring sites. There is no discussion of this in the draft report. The final report should address this important issue.

Response: *“No greater than,” means “shall not exceed as measured at the fixed monitoring stations.” This TMDL has been written to meet the water quality standard as required by the Clean Water Act.*

Comment: Page 67; Sixth bullet statement: "The agency will ultimately approve this TMDL under section?": though it is likely that EPA will in fact approve this TMDL, this is not a given. A better wording would be "take action on".

Response: *Corrected.*

Comment: Page 68; Second paragraph "Water quality monitoring standards are monitored? by the U.S. Army Corps of Engineers."

Response: *Corrected.*

Implementation Activities

Short Term – Phase I

Comment: Page 71 – Table 18 – How does the relocation of the Lower Monumental bypass outfall influence spill management policy?

Response: *Improved bypass efficiency could reduce the amount of spill needed for fish passage.*

Long Term – Phase II

Comment: The wording that describes the Long Term Phase II section should be clarified in the Final Report. Reductions in spill would only occur if tribal fish passage goals are being met through surface

bypass methods. All structural changes to abate dissolved gas should be implemented and the standard should be reviewed before reductions in the spill program are implemented. It is unacceptable to CRITFC to use turbine or screened bypass operations as a means to reduce fish passage spill.

Response: The section describes any reduction in spills that could occur after first meeting the survival goals of the Biological Opinion.

Reasonable Assurance

See response in the Executive Summary section for comment on pg xii.

Comment: Increases of spill and spill efficiency are critical to promote restoration and enhancement of anadromous fish populations in the Snake Basin that are the foundation of the tribal treaties. The Lower Snake TMDL should promote protection of the beneficial use by assuring safe dam passage thorough appropriate dissolved gas standards, while requiring the Corps and other federal agencies to prioritize structural measures to reduce the creation of total dissolved gas from federal dams in the Lower Snake River. We strongly recommend that the state water quality agencies join the tribes in requiring the Corps and other federal agencies to give top priority to funding of both gas abatement and temperature structures at the Lower Snake dams.

Response: The function of a TMDL is to return waters to water quality standards. To try and change fish passage past dams is not within the range of this TMDL. This should be addressed within a biological opinion under the Endangered Species Act. Indeed, the 2000 biological opinion sets survival standards. This TMDL is consistent with those survival standards. We welcome Tribal support in securing funding for water quality improvements on the Snake River.

Adaptive Management

No comment received.

Monitoring Strategy

Comment: Will this TMDL require 12 month monitoring efforts? It seems that there is language in the TMDL to do so. Also, how similar with the Upper Columbia TMDL look?

Response: The TMDL proposes that existing monitoring at fixed monitoring stations continue until 2010, and then the sites will be reviewed for improved monitoring of the TMDL. The TMDL does not require 12 month monitoring, but over time specific sites may be identified where this is desirable. Some 12 months sites may be appropriate at strategic locations in the basin, but not for all fixed monitoring station sites. The TMDL for the Mid and Upper Columbia River TDG will look similar, except for Wells and Grand Coulee dams. The details of that TMDL have not been worked out yet, and there will be drafts of that document available for review later in 2003.

Potential Funding Sources

Comment: Page 72 – “While most of these stations do a credible job of reporting meaningful data, some have been shown to be questionable.” Some of the stations at times, may not be achieving desired sampling objectives (representing spill or average forebay conditions). The data is not questionable. The application of the data may have certain limitations.

Response: *This language has been revised.*

Comment: Page 73 – Potential Funding Sources - This must be changed to say that “all federal funding is subject to congressional approval. Bonneville Power Administration is not a funding source. All federal project modifications or additions must be approved by congress and funded by congressional funding process.

Response: *The requested change is incorporated.*

Summary of Public Involvement

No comment received.

Public Involvement Actions

No comment received.

References and Bibliography

No comment received.



Focus on **Lower Snake River**

Public hearing planned on the Lower Snake River Total Dissolved Gas TMDL and Implementation Plan

The Washington State Department of Ecology (Ecology) invites you to provide your comments at a public hearing on the proposed Lower Snake River Total Maximum Daily Load (TMDL) and implementation plan for reducing total dissolved gas.

Before the formal public hearing, there will be a brief presentation to learn about the proposed TMDL and implementation plan, followed by an informative question and answer session. This public hearing addresses only the TMDL and the implementation plan that are being submitted to the U.S. Environmental Protection Agency (EPA).

Background

The Lower Snake River Total Dissolved Gas TMDL is based on the federal Clean Water Act, state water quality standards, the Dissolved Gas Abatement Study conducted by the U.S. Army Corps of Engineers, and the National Marine Fisheries Service's 2000 Biological Opinion for the Federal Columbia River Power System. The TMDL/implementation plan identifies strategies for reducing total dissolved gas in the Lower Snake River – from the Idaho border to its confluence with the Columbia River.

Why is elevated total dissolved gas (TDG) a problem?

Super saturation of the water column with dissolved gases may result from either natural or human caused conditions. High concentrations of TDG negatively impact the health and survival of fish and other aquatic life. The primary source of elevated dissolved gas in the Snake River is spill from federal dams – Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

Spill results from river flows exceeding the available capacity of the dam's powerhouse. Spills are also made to assist fish passage. The Snake River's salmonid populations have declined significantly, and inadequate fish passage has been identified as one of the causes. The habitat – the lakes and rivers where fish live – also needs to be healthy for the fish populations to recover. This TMDL attempts to balance fish passage needs with the TDG levels necessary to protect habitat.

Federal law requires cleanup of polluted waters

Federal law requires states to identify sources of pollution in waters that fall short of water quality standards and to determine how much pollution needs to be reduced for the water body to remain healthy. Given this information, Ecology and regional

Presentation and hearing are scheduled for:

Tuesday
March 25, 2003

6:30 PM

1315 W. 4th Ave. (off
Olympia St.)

Ecology Field Office,
Kennewick, WA

Written comments should be mailed to:

Ann Butler
WA Dept. of Ecology
PO Box 47600
Olympia, WA
98504-7600

Or

E-mail
anbu461@ecy.wa.gov

*Call for more
information: (360) 407-
6480*

interests develop strategies for achieving the necessary reduction or elimination of pollution. The result is a water cleanup plan or Total Maximum Daily Load (TMDL), which identifies the allowable pollution levels from various sources. In the Snake River, TDG levels exceed the state of Washington's standards. This TMDL provides target levels and an implementation plan to reduce TDG to acceptable levels.

Public Comment Period:

Ecology will review and consider all relevant comments received during the public comment period. Following this review, the TMDL and implementation plan may be modified. When complete, the TMDL will be sent to EPA for approval. You will be notified of Ecology's final decision if you present either oral or written comments during the comment period. If you do not comment but wish to receive notification of Ecology's final decision, please call or write Ann Butler at the address on the front of this mailing.

The public comment period on the plan is February 24 through April 4, 2003.

Written comments on the proposed Total Maximum Daily Load and/or Implementation Plan must be received by **5 p.m. on April 4, 2003**.

The TMDL/Implementation Plan is also available for examination and copying at Ecology's Headquarters Office at 300 Desmond Drive SE, Lacey, WA 98503, or at Ecology Field Office in Kennewick (see above hearing location). Documents are also available on Ecology's web site at: www.ecy.wa.gov/biblio/0303020.html

If you require this publication in an alternative format, please contact the secretary at (360) 407-6404 (Voice) or (TTY) at 711 or 1-800-833-6388

