Adaptive Management Team
Total Dissolved Gas in the Columbia and Snake Rivers

Evaluation of the 115 percent Total Dissolved Gas Forebay Requirement

Washington State Department of Ecology and
State of Oregon Department of Environmental Quality

Draft
September 4, 2008

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DEQ
State of Oregon
Department of Environmental Quality

DEPARTMENT OF
ECOLOGY
State of Washington

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Executive Summary

The Oregon Department of Environmental Quality (ODEQ) and the Washington Department of Ecology (Ecology) are required to make a recommendation on the need for the 115 percent forebay total dissolved gas (TDG) requirement to regulate spill during fish passage spill on the Columbia River and Lower Snake River dams. This document provides technical decision-making information on total dissolved gas issues, an overview of the regulatory history and requirements as described in the Columbia River and Lower Snake River Total Dissolved Gas Total Maximum Daily Loads, and summarizes and evaluates the technical information presented at the total dissolved gas Adaptive Management Team (AMT) meetings.

A weight of evidence approach will be used as the criteria for making decisions. A weight of evidence approach is typically used in scientific forums as an informational and decision-making tool. It provides a framework to inform ODEQ and the Ecology regarding the need for the 115 percent forebay total dissolved gas monitoring requirement to regulate fish passage spill. Most importantly, a weight of evidence approach includes the input of Adaptive Management Team members that have specific technical expertise and data to contribute.

Policy and management issues, such as setting fish passage spill volumes, fish transport options, and bypass routes are not addressed in this paper. This paper only addresses the 115 percent forebay TDG requirement. This paper focuses only on the Lower Snake River and Lower Columbia River dams and does not specifically address the PUD-owned dams on the Middle Columbia River.

This document will be presented to the Adaptive Management Team for a 30-day AMT comment period. Once comments are received and reviewed, the Oregon Department of Environmental Quality and the Washington Department of Ecology will incorporate all appropriate technical comments, and develop a final recommendation on the need for the 115 percent forebay total dissolved gas monitoring requirement to regulate fish passage spill.

ODEQ and Ecology are not soliciting new information with this 30-day AMT comment period. The 30-day comment period is an opportunity for AMT members to verify that the information presented during the AMT meetings are accurately represented in this paper.

Background

Oregon TDG requirements for the Columbia River

The State of Oregon total dissolved gas water quality standard, found in OAR 340-041-0031 (2), states:

> Except when stream flow exceeds the ten-year, seven-day average flood, the concentration of total dissolved gas relative to atmospheric pressure at the point of sample collection may not exceed 110 percent of saturation. However, in hatchery-receiving waters and other waters of less than two feet in depth, the concentration of total dissolved gas relative to atmospheric pressure at the point of sample collection may not exceed 105 percent of saturation.

The Oregon Department of Environmental Quality (ODEQ), with approval from the Environmental Quality Commission (EQC), issues "waivers" to the U.S. Army Corps of Engineers (USACE) to allow for TDG levels above the state standard of 110 percent. According to OAR 340-041-0104 (3) the EQC may modify the total dissolved gas standard in the Columbia River for the purpose of allowing increased spill for salmonid migration. The Commission must find that:

a) Failure to act would result in greater harm to salmonid stock survival through in-river migration than would occur by increased spill;

b) The modified total dissolved gas criteria associated with the increased spill provides a reasonable balance of the risk of impairment due to elevated total dissolved gas to both resident biological communities and other migrating fish and to migrating adult and juvenile salmonids when compared to other options for in-river migration of salmon;

c) Adequate data will exist to determine compliance with the standards; and

d) Biological monitoring is occurring to document that the migratory salmonid and resident biological communities are being protected.

e) The Commission will give public notice and notify all known interested parties and will make provision for opportunity to be heard and comment on the evidence presented by others, except that the Director may modify the total dissolved gas criteria for emergencies for a period not exceeding 48 hours;

f) The Commission may, at its discretion, consider alternative modes of migration.

Oregon first issued a TDG waiver in 1994. The waivers allow for total dissolved gas levels of:

- 120 percent of saturation in the tailrace.
- 115 percent of saturation in the forebay.
- TDG may not exceed 125 percent of saturation for more than two hours in every 24 hours in the forebay and tailrace.

ODEQ measures the TDG average as the highest 12 hours in one calendar day. Biological monitoring is required during voluntary spill to determine the incidence of GBT to juvenile salmonids.

Washington TDG requirements for the Columbia and Snake Rivers

The Washington Department of Ecology (Ecology) last modified the TDG requirements in the water quality standards in 2006. The standards, found in WAC 173-201A 200(1)(f), state that 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 115 percent as measured in the forebays of the next downstream dams and must not exceed an average of 120 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).
- A maximum TDG one hour average of 125 percent must not be exceeded during spillage for fish passage.

When reviewing the appropriateness of revising a water quality standard, Ecology must carefully consider whether the criteria will adequately protect the designated uses for that water. Designated uses are those water uses (e.g., fishing, boating, aquatic life, water supply, etc.) that are designated in water quality standards for protection in a water body. All designated uses and even the most sensitive use must be fully protected. Sometimes the most sensitive use is not an ESA listed threatened or endangered species. If Ecology adopts criteria, which are less stringent for pollutants such as TDG than those published by EPA, Ecology must justify the less restrictive criteria.

Under section 303(c) of the Act, EPA is required to review and to approve or disapprove state-adopted water quality standards. This review involves a determination of whether:

- the State has adopted criteria that protect the designated water uses.
- the State has followed its legal procedures revising or adopting standards.

EPA would review any changes Ecology makes to its water quality standards to ensure that the standards meet the requirements of the Clean Water Act. EPA would disapprove the water quality standards and may promulgate federal standards under section 303(c)(4) of the Clean Water Act if state-adopted standards are not consistent with the factors listed above.

TMDL Overview

The water quality standards for Oregon and Washington for the total dissolved gas (TDG) criterion are identical: 110 percent 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 flood flow. The flows are identified in the Columbia River and Snake River TDG Total Maximum Daily Loads (TMDLs).

A TMDL, as identified in the federal Clean Water Act, determines the quantity (load) of a pollutant that can enter a water body and still meet water quality standards. The TDG TMDLs for the Columbia River and Lower Snake River are available for review at:
Oregon: http://www.deq.state.or.us/wq/TMDLs/columbia.htm#tdg
Washington: Lower Columbia TDG TMDL: http://www.ecy.wa.gov/biblio/0203004.html
Mid Columbia TDG TMDL: http://www.ecy.wa.gov/biblio/0403002.html
Snake River TDG TMDL: http://www.ecy.wa.gov/biblio/0303020.html

The TMDLs address TDG in the mainstem Columbia and Snake Rivers. The states of Oregon and Washington listed multiple reaches of the Columbia and Snake rivers on their federal Clean Water Act 303(d) lists due to TDG levels exceeding the states' water quality standards.

Elevated TDG levels are caused by water flowing over the spillways (spill events) at hydroelectric dams on the Columbia and Snake rivers. Water plunging from a spillway entrains air causing increases in TDG. High TDG can cause Gas Bubble Trauma (GBT) in fish, which can cause chronic or acutely lethal effects, depending on TDG levels. GBT mortality is caused by the formation of gas bubbles in the cardiovascular system. These bubbles block the flow of blood and respiratory gas exchange by the aquatic species.

Spills events can be voluntary or involuntary and are caused by several conditions. "Voluntary" spills are provided to meet juvenile fish passage goals. Voluntary spill is also referred to as fish passage spill. "Involuntary" spills are caused by lack of powerhouse capacity for river flows, from turbine maintenance or breakdown, lack of power load demand, or high river flows.

Biological Opinion for the Federal Columbia River Power System

As required by the Endangered Species Act, the Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) requires that the action agencies (U.S. Army Corps of Engineers, Bonneville Power Administration, and the U.S. Bureau of Reclamation) meet specific hydro system 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 current 2008 Endangered Species Act Section 7(a)(2) Consultation Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation, dated May 5, 2008, states that the voluntary spill program is not to exceed established TDG levels by the state water quality agencies, Table 1. The Biological Opinion does not recommend or identify a numeric TDG threshold for state water quality agencies to include in their TDG standard or waiver for voluntary spill purposes, but rather relies on ODEQ and Ecology to make that determination.

***Table 1. 2008 Biological Opinion Reasonable and Prudent Alternative Action Description for Total Dissolved Gas.**

RPA No.	Action Description	Implementation Plans, Annual Progress Reporting and Comprehensive RPA Evaluations
Hydropower Strategy 3—Implement Spill and Juvenile Transportation Improvements at Columbia River and Snake River Dams		
29	**Spill Operations to Improve Juvenile Passage** The Corps and BPA will provide spill to improve juvenile fish passage while avoiding high TDG supersaturation levels or adult fallback problems. Specific spill levels will be provided for juvenile fish passage at each project, not to exceed established TDG levels (either 110 percent TDG standard, or as modified by state water quality waivers, currently up to 115 percent TDG in the dam forebay and up to 120 percent TDG in the project tailwater, or if spill to these levels would compromise the likelihood of meeting performance standards (see RPA Table, RM&E Strategy 2). The dates and levels for spill may be modified through the implementation planning process and adaptive management decisions. The initial levels and dates for spill operations are identified in Table 2 [in the BiOp]. Future Water Management Plans will contain the annual work plans for these operations and spill programs, and will be coordinated through the TMT. The Corps and BPA will continue to evaluate and optimize spill passage survival to meet both the hydro system performance standards and the requirements of the Clean Water Act (CWA).	**<u>Implementation Plans</u>** • The initial spill operation for juveniles is described in the proposed RPA. The spill operation will be updated annually and reported in the FPP. **<u>Annual Progress Report</u>** • Spill operations are reported annually. **<u>2013 and 2016 Comprehensive RPA Evaluation Reports</u>** • This information is the same as will be reported for each mainstem dam in hydro actions 14-21.

***Reasonable and Prudent Alternative Table, pg 32 of 98, https://pcts.nmfs.noaa.gov/pls/pcts-pub/pcts_upload.summary_list_BiOp?p_id=27149**

The provisions of both the Clean Water Act and the Endangered Species Act (ESA) must be met. Notwithstanding that, it is not the purpose of the Clean Water Act to assume functions properly undertaken based on the Endangered Species Act. On the contrary, the Endangered Species Act contains provisions that encourage EPA to consult with NMFS prior to approval of a TMDL that affects ESA-listed species. This ensures that the TMDL is consistent with species recovery goals. The BiOp issued relating to the Endangered Species Act requires attainment of certain fish passage performance standards. One way of meeting these is through spilling water over hydroelectric dam spillways (fish passage spill). This action results in elevated TDG. Control of

TDG is the purpose of the Columbia and Snake rivers TMDLs. The Clean Water Act does not suggest trade-offs of fish passage for TDG. Rather, it requires attainment of water quality standards. This is one of the significant challenges posed by the TDG TMDLs.

TMDL Implementation

Meeting the load allocations in the TDG TMDLs falls into two phases. Phase I short-term actions involve improving water quality while ensuring that salmonid passage is fully protected in accordance with the BiOp. Phase II long-term actions will involve structural and operational changes to dams to achieve the water quality standard for TDG.

The short-term actions in Phase I focus on meeting the fish passage performance standards as outlined in the BiOp through spills that generate gas no greater than the "waiver" levels of the water quality TDG standards. Water quality standards are measured at existing fixed monitoring stations managed by the U.S. Army of Engineers and U.S. Geological Survey. 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 BiOp are met.

Short-term compliance and the effectiveness of operational implementation actions are monitored at existing fixed monitoring station sites. The current TDG fixed monitoring station system consists of tailrace and forebay monitoring stations at each mainstem lower Snake and Columbia River dam. While most of these stations do a credible job of reporting meaningful data, some stations produce questionable data.

The Phase II long-term actions will be determined after evaluating the success of the short-term actions. The second phase will also move toward further structural modifications and reductions in fish passage spill after the BiOp-specified performance standards are met and adequate survival is provided for non-listed species. Actions taken in the previous phase will be reviewed for their effectiveness, both in improving TDG levels and for protecting salmonid passage. The BiOp survival goals may be met through fish passage actions other than spilling water. The final goal is meeting the Oregon and Washington water quality standard for TDG as measured at the end of the aerated zone below each dam. As part of Phase II, a detailed implementation plan or equivalent will be developed by the designated action agencies.

Long-term compliance with load allocations for dam spills will be at the downstream end of the aerated zone below each spillway in the tailrace. The TDG TMDLs specify distances for the compliance location at each dam. As a result, the load allocation must be met at each dam individually at a specified compliance location, with allowance made for degassing in the tailrace below the spillway.

Need for Adaptive Management

ODEQ was directed to evaluate the need for the 115 percent forebay TDG monitoring requirement during fish passage spill by the Oregon Environmental Quality Commission (EQC) on June 21, 2007. At this EQC meeting, the 2008 and 2009 TDG waiver was approved with the condition that the AMT evaluate the need for the 115 percent TDG forebay limit during fish passage spill as stated:

> 3(vi) The Department may approve changes in the location of forebay and tailrace monitors, use of forebay monitors, and may approve changes to the method for calculating total dissolved gas. Before approving any changes, the Department must consult with the Adaptive Management Team or the federal Columbia River Power System (FCRPS) Water Quality Team or both. The Department is directed to begin this process for consultation immediately and to evaluate and, if appropriate, approve such changes as soon as possible.

Additionally, the TDG waiver outlined the adaptive management process, as per the TDG TMDLs:

> The process for reviewing the implementation status of the 2002 Lower Columbia River Total Dissolved Gas TMDL will begin no later than January 1, 2011. The Washington State Department of Ecology will convene an advisory group comprising representatives of Oregon Department of Environmental Quality, 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. After 2010, the location of total dissolved gas monitors will be consistent with the adaptive management implementation strategy for the 2002 Lower Columbia River Total Dissolved Gas TMDL, may no longer require forebay monitors, and may only require tailrace monitors as TMDL implementation transitions from short-term to long-term strategies.

On June 27, 2007, Ecology received a letter from Save Our Wild Salmon (SOWS) regarding total dissolved gas and the Adaptive Management Team. SOWS stated their concern regarding the use of forebay monitors, specifically “monitoring for the forebays at the dams on the river are not working to protect water quality and salmon as they should.” SOWS requested that Ecology convene the Adaptive Management Team as soon as possible.

The geographic scope of the AMT is the mainstem Columbia River as specified by the 2002 and 2004 TDG TMDLs (Bonneville, The Dallas, John Day, McNary, Priest Rapids, Wanapum, Rock Island, Rocky Reach, Wells, Chief Joseph, and Grand Coulee dams), and the lower Snake River in Washington as specified by the 2003 TDG TMDL (Ice Harbor, Lower Monumental Little Goose, and Lower Granite dams), Figure 1.

Figure 1. The Columbia River Basin. This paper addresses the eight Lower Columbia River and Snake River dams: Lower Granite (LGR), Little Goose (LGS), Lower Monumental (LMN), Ice Harbor (IHR), McNary (MCN), John Day (JDA), The Dalles (TDA), and is Bonneville (BON).

The AMT is a technical group. Policy and management issues, such as setting fish passage spill volumes, fish transport options, and bypass routes are not addressed at the AMT. These topics are discussed at the FCRPS Implementation Team, Technical Management Team or other forums, with representation from Oregon and Washington departments of fish and wildlife.

The Adaptive Management Team

The AMT consisted of 11 member organizations, including the states of Oregon and Washington represented by their respective water quality agencies. The AMT membership was limited to 11 member organizations to expedite technical review and decision making while still allowing for input from the multiple viewpoints.

The role of the AMT members was to share and provide technical information to the group and advise Washington and Oregon on TDG. The role of Washington and Oregon was to make decisions using the technical input and follow state and federal laws and regulations. The Washington Department of Fish and Wildlife (WDFW) and Oregon Department of Fish and Wildlife (ODFW) advised Ecology and ODEQ on the adaptive management process.

The AMT held meetings about monthly from November 2007 through September 2008. At the meetings, different facets and impacts of the 115 percent forebay requirement were discussed. Complete meeting summaries, agendas, presentations, and papers are all available on the AMT website: http://www.ecy.wa.gov/programs/wq/tmdl/ColumbiaRvr/ColumbiaTDG.html.

AMT members:

- State of Washington (Ecology co-chair)
- State of Oregon (ODEQ co-chair)
- NOAA Fisheries
- U.S. Army Corps of Engineers (USACE)
- Save our Wild Salmon
- Confederated Tribes of the Colville Reservation
- Columbia River Inter Tribal Fish Commission
- Grant County Public Utility District (PUD)
- U. S. Environmental Protection Agency (EPA)
- NW River Partners
- U.S. Fish and Wildlife Service (USFWS)

All AMT meetings were open to the public. Regular attendees, in addition to the 11 AMT members, included Bonneville Power Administration (BPA), D. Rohr and Associates, and Douglass PUD.

Issue for the Adaptive Management Team

The technical issue evaluated by the AMT and described in this document is the need for the 115 percent forebay TDG requirement during fish passage spill.

A determination that there is no longer a need for the 115 percent forebay TDG requirement during fish passage spill would result in removing the requirement from the states' water quality standards and waiver, and managing fish passage spill to the tailrace TDG limit of 120 percent. Currently, fish passage spill is managed to both the forebay and tailrace TDG limits, and would continue to be managed to these limits if the 115 percent forebay TDG limit is determined to be necessary.

Forebay Gauge History

Currently, there is no one single entity researching the validity (representativeness) of the forebay monitors. However, several past studies evaluated the application and use of the forebay monitors as it relates to fish passage spill.

In 2000, National Marine Fisheries Service (NMFS) addressed concerns regarding forebay monitor validity by including language in their Biological Opinion Reasonable and Prudent Alternatives (RPA) 132 to complete a systematic review and evaluation of the TDG fixed monitoring stations in the forebays. The study was conducted during the 2003 and 2004 fish passage spill season at McNary Dam and the four Lower Snake River projects: Ice Harbor Dam, Lower Monumental Dam, Little Goose Dam, and Lower Granite Dam.

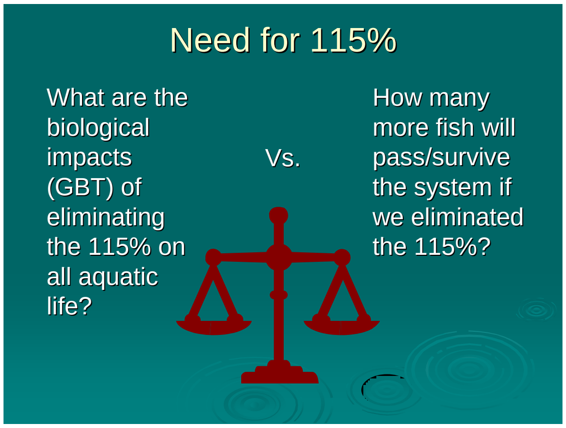
Each of the study project forebay stations experienced "thermally-induced TDG pressure spikes during the test periods." The study resulted in two recommendations. The first was to permanently relocate each forebay gauge to an area just upstream of the project in a location not affected by down-welling surface waters, such as the navigation lock guide wall. Additionally, the study recommended each instrument be positioned at a depth of 12-15 meters to avoid thermal responses in the TDG pressure readings. The findings and full report are available on-line:

> BiOp Measure 132 Final Report, December, 2004: "Total Dissolved Gas Forebay Fixed Monitoring Station Review and Evaluation for Lower Snake River Projects and McNary Dam, 2003-2004,"
> http://www.nwd-wc.usace.army.mil/tmt/wq/studies/rpa132_20041230.pdf

In 2001, the USGS identified validity issues with the Camas-Washougal forebay gauge. Specifically, the USGS found that daily variations of TDG were "probably due to the production of oxygen by aquatic plants and to water-temperature variations on warm, sunny days" (Water-Resources Investigations Report 01-4273, page 11 and figure 13 on page 12, http://or.water.usgs.gov/pubs_dir/WRIR01-4273/index.html). This USGS report led to a 2004 follow-up isotope study of TDG at Camas-Washougal. This data was never published, but the data indicated that the increased afternoon dissolved oxygen at Camas-Washougal forebay gauge was due to photosynthesis rather than Bonneville Dam spill (email communication with Dwight Tanner, USGS, June 24, 2008).

On September 29, 2006, the Fish Passage Center (FPC) sent a memo to the Fish Passage Advisory Committee regarding Spring Spill 2006 (FPC document 136-06.pdf). In that memo, FPC evaluated the "efficacy of forebay monitoring" and discussed the question of "did the USACE's relocation in 2004 and 2005 lead to more accurate monitoring?" in the forebay. The FPC memo concluded that the forebay monitors "do not represent the measurements of TDG in mixed waters as was originally intended." Although the forebay monitors were relocated and lowered deeper into the water column in 2004 and 2005, questions regarding their validity still exist.

Information the AMT Considered



In evaluating the need for the 115 percent TDG forebay limit during fish passage spill season, the AMT considered how removal of the 115 percent TDG forebay limit would affect fish and other aquatic life. ODEQ and Ecology framed the technical evaluation by asking the AMT the following two questions:

Question 1: What are the biological impacts (gas bubble trauma) of eliminating the 115 percent TDG forebay limit on all aquatic life?

Question 2: How many more fish will pass and survive the system if we eliminated the 115 percent limit?

Removing the 115 percent forebay TDG limit has the potential to increase spill volumes at the Columbia and Snake River dams. Increased spill volumes may result from managing fish passage spill only to the 120 percent tailrace TDG limit. Additional spill has the potential to increase fish passage and survival past each dam. However, increasing fish passage spill may also increase the TDG and may increase the incidence of gas bubble trauma in aquatic species.

The AMT presented the following data and analytical results to the states to evaluate the need for the 115 percent TDG forebay limit:

- Analysis of Spill Volumes with and without the 115 percent TDG limit.
- Importance of spill in Juvenile Hydro-system Survivals Smolt to Adult Returns (SARs).
- Comparable Survivability Study (CSS).
- Comprehensive Passage Model (COMPASS).
- Adult Passage and Survival.
- Smolt Monitoring Program Results on Gas Bubble Trauma Incidence.
- NOAA Resident Fish Review.
- Ecology TDG Literature Review.
- Don Weitkamp TDG Literature Review.

All presentations and reports were open for comment. Comments were shared with presenters giving them a chance to respond. All presentation, comments and responses are available on the TDG AMT website:

http://www.ecy.wa.gov/programs/wq/tmdl/ColumbiaRvr/ColumbiaTDG.html

ODEQ and Ecology used all the information presented at the AMT to form the technical basis of their decision.

Spill Volume Considerations

Setting or limiting fish passage spill volumes are considered a management issue for discussion at the Federal Columbia River Power System (FCRPS) forum or other forums. Spill management will not be set or negotiated at the AMT, but will be discussed in the context of TDG and impacts to aquatic species.

Fish passage spill volumes are determined by several factors:

- Spill Operations (as defined by the BiOp).
- Spill Caps (as defined by TDG water quality limits in the forebay and tailrace set by state water quality agencies).
- Involuntary Spill (when the river flow exceeds the hydraulic capacity of the dam).

- Minimum Generation (the amount of flow necessary to generate the minimum amount of electricity to keep the regional electrical grid stable, and the remainder is used for fish passage).
- Over Generation Spill (spill that must occur when the amount of flow in the river system would otherwise produce more energy, if passed through turbines, than there are accessible energy markets available).
- Other fish passage spill determinations may exist, such as physical limitations due to erosion in tailrace basins or navigational concerns.

Spill Volume Analysis: With and Without the 115 Percent TDG Limit

The Fish Passage Center (FPC), USACE, and Bonneville Power Administration (BPA) each conducted an analysis of how much more fish passage spill volume would be possible if the 115 percent was eliminated. The amount of spill varies greatly depending on the fish passage spill volume factors being implemented (described previously) and how much water is in the river. The amount of water in the river varies by year, season, and day. The variations in volume are caused by amount of snow pack, rainfall, water withdrawal, and upstream dam operations.

The three entities analyzed the potential changes in spill volume using different approaches and assumptions. The differences observed among the analyses were due to the flow years used, the assumptions of spill operations, treatment of excess generation spill, and other limitations on spill. The FPC analysis considered past years' empirical data for flow, spill, and TDG data and projected what spill would have occurred if the 115% forebay requirement was removed in four different spill scenarios. The COE and BPA analysis assumed that the 2008 Biological Opinion spill levels were implemented. Their analyses used one spill scenario. The BPA analysis included overgeneration spill and conducted simulations for the 70-year flow record.

One must be careful when directly comparing the spill volumes analyses due to the differences assumed in each analysis. The following table summarizes the assumptions made for spill program amounts implemented in each of the analyses:

Table 2. Spill Volume Analysis Summary

Author	Report Title	Years Analyzed	Simulation	Data Set
FPC	*Volume Changes with Use of Tailrace Monitors*	**Low - Moderate water years**: 2003, 2005, 2007 **High water year**: 2006	**Base Scenario:** Actual Spill (accounting for excess generation spill) **Scenario B**: Spill that would have occurred if all projects spilled to the 120% cap on days when spill was restricted by the 115% downstream forebay (but not the 120% tailrace) **Scenario C**: Spill that would have occurred in that year if all projects spilled to the 120% cap (limited by planned operations) **Scenario D**: Spill that would have occurred in that year if all projects spilled to the 120% cap (not limited by planned operations).	Empirical data set for each year and model estimated changes in spill volumes. [pg 2, document (303)]
USACE	*Report on the SYSTDG Modeling for AMT: With and without 115 percent TDG standard*	**Low water year**: 2007 **Moderate water year:** 2002 **High water year**: 1999	Hourly average of spill volume and spill cap with and without the 115% TDG Forebay Limit for each project and each year.	Hourly time-step model; the flow assumptions from each year and 2008 FCRPS BiOp spill operations. [pg 10, document (710)]
BPA	*HYDSIM Use in Analysis of Removing 115 percent TDG Forebay Gauge Requirements BPA Report to the Adaptive Management Team*	70 years, averaged (1929 - 1999)	70-year average spill with and without the 115% TDG Forebay Limit for each project.	Monthly time-step model; USACE hourly calculated spill caps averaged into monthly spill cap using the 2008 FCRPS BiOp spill operations, applied to 70 years of historical runoff data to generate monthly average flow and spill volumes at each dam. Overgeneration spill included. [pg 10, document (710)]

FPC Analysis

The FPC's analysis, *Spill Volume Changes with Use of Tailrace Monitors*, is available on the AMT website. BPA and USACE provided comments on the FPC analysis, and FPC responded to the comments. These documents are available on the AMT website.

The FPC analyzed the low to moderate water years of 2003, 2005, and 2007 and the high water year of 2006. The FPC ran scenarios with differences in planned operations ranging from the base case (what was actually implemented in that year) to what would occur if there was no spill management except for the 120% TDG requirement (meaning projects were not managed to s specific spill program but spilled the full volume of water to the 120 % TDG). The Scenarios were defined as:

Scenario B: Spill that would have occurred if all projects spilled to the 120% cap on days when spill was restricted by the 115% downstream forebay (but not the 120% tailrace)

Scenario C: Spill that would have occurred in that year if all projects spilled to the 120% cap (limited by planned operations).

Scenario D: Spill that would have occurred in that year if all projects spilled to the 120% cap (not limited by planned operations).

Depending on the year and the scenario used, removing the 115 percent forebay requirement would allow an additional 0.5 to 58.1 million acre feet of spill on the lower Columbia and Snake Rivers, Table 3.

Table 3. FPC additional spill volumes (MAF) under the three modeled scenarios, compared to the Base Case volume (involuntary spill removed). FPC analysis, Table 3. (FB = Forebay) FB Restricted = Scenario B; 120% Limited = Scenario C; 120% = Scenario D.

Water Year	FB Restricted	120% Limited	120%
2003	2.27	13.01	41.57
2005	0.52	11.06	43.06
2006	2.80	9.56	52.53
2007	1.45	5.98	58.07

According to the FPC analysis, the 115 percent forebay requirement affected all dams but had the largest impact on spill at Little Goose and Lower Monument dams on the Snake River.

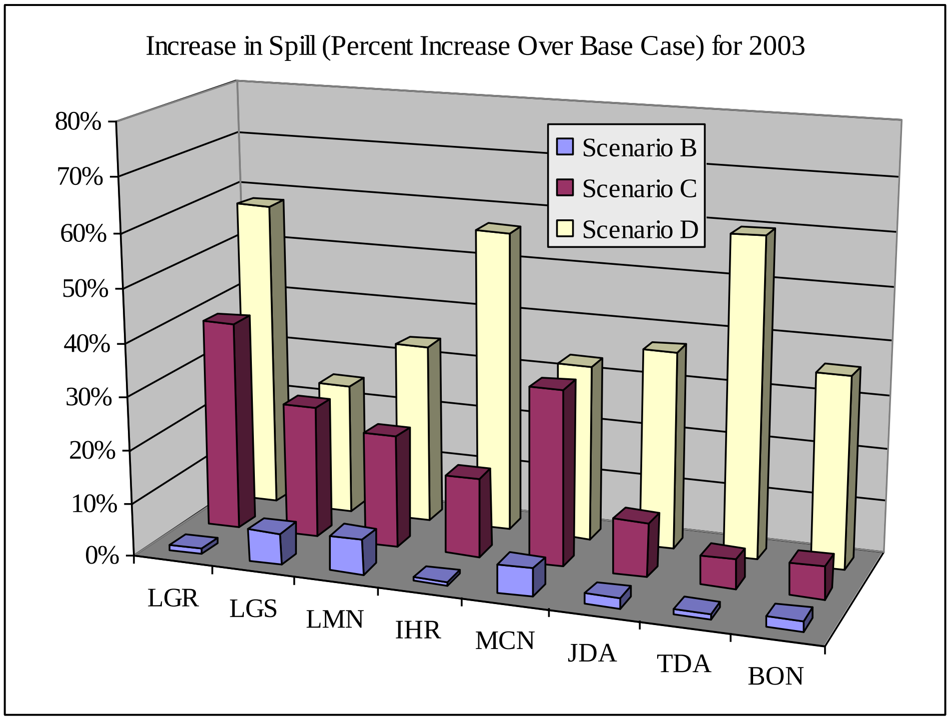


Figure 2. FPC Calculation of Increased Spill in 2003 (percent increase over base case). LGR is Lower Granite, LGS is Little Goose, LMN is Lower Monumental, IHR is Ice Harbor, MCN is McNary, JDA is John Day, TDA is The Dalles, and BON is Bonneville.

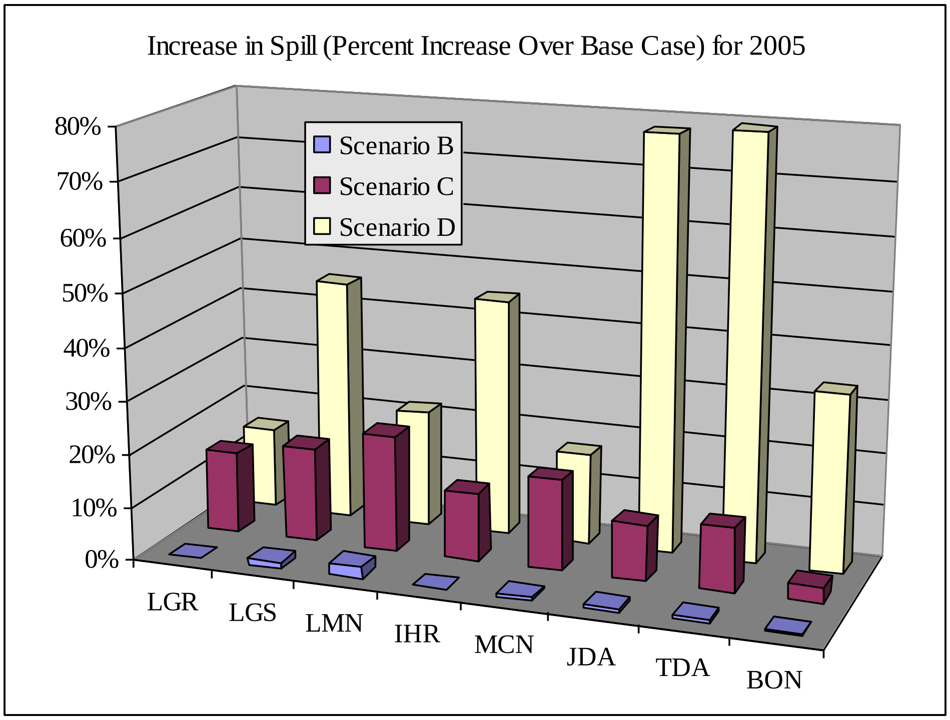


Figure 3. FPC Calculation of Increased Spill in 2005

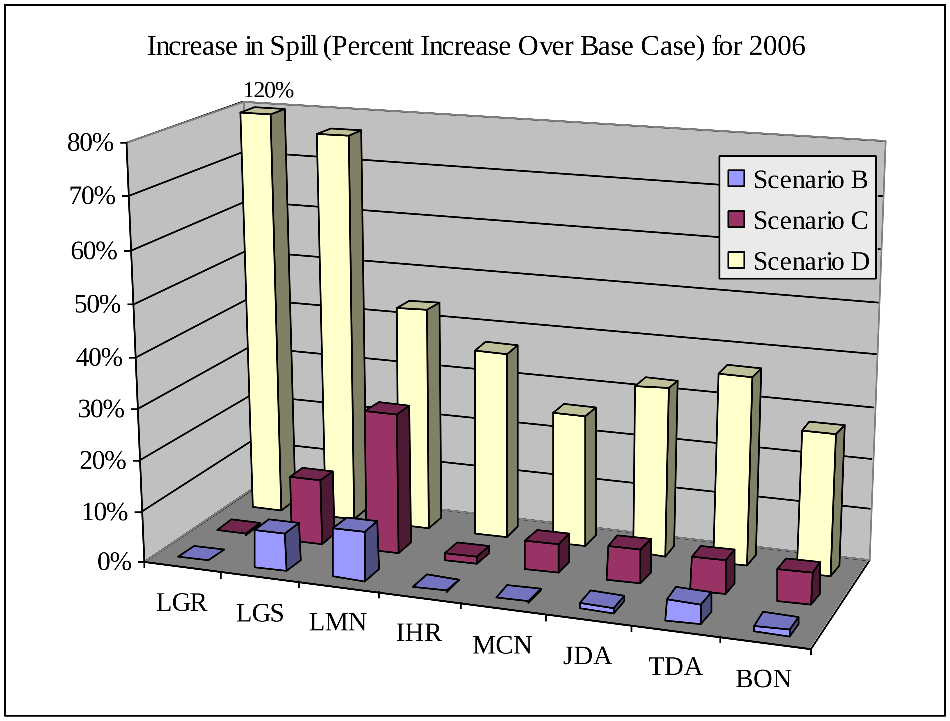


Figure 4. FPC Calculation of Increased Spill in 2006

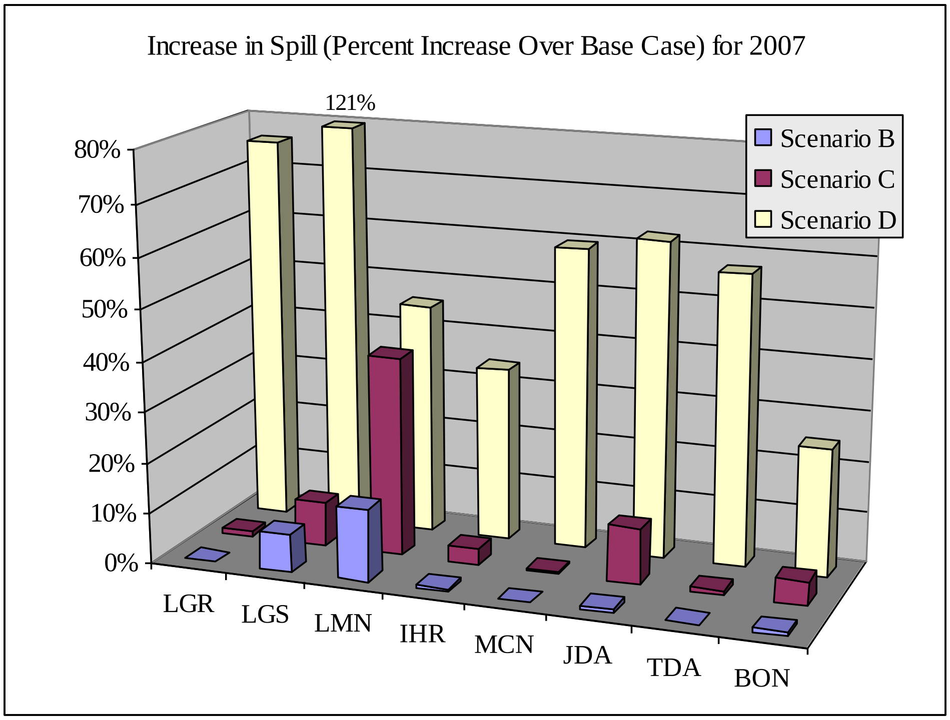


Figure 5. FPC Calculation of Increased Spill in 2007

The FPC analysis also evaluated populations of Chinook and steelhead passing in spill under different scenarios. The percentage of fish passing via spill varied by dam, by year, and by type of fish. The largest changes (more than a five percent increase in a fish type passing in spill comparing the base case with the most conservative spill scenario) were at Little Goose, Lower Monumental, and McNary Dams. Comparing the base case with the least conservative spill scenario sometimes doubled the number of fish passing in spill.

USACE Analysis (SYSTDG)

The USACE's analysis, *Report on the SYSTDG Modeling for AMT: With and without 115 percent TDG standard*, 2008 is available on the AMT website. No comments were received on this analysis.

The USACE analyzed the high water year of 1999, the moderate water year of 2002, and the low water year of 2007. The analysis used assumptions from 1999, 2002 and 2007 operations and spill operations from the March 17, 2008 Columbia and Snake River FCRPS BiOp. See the report for details.

In the USACE analysis, multiple factors controlled spill on the Lower Columbia and Snake Rivers:

- BiOp spill operations (76 percent of the time).
- The 120/115 percent spill caps (12 percent of the time).
- Involuntary spill (8 percent of the time).

- Minimum generation (4 percent of the time).

According to the analysis:

- For the 1999 high water year, eliminating the 115 percent TDG requirement would result in an additional 5.9 Million Acre Feet (MAF) spill (a 4.0 percent increase).
- For the 2002 medium water year, eliminating the 115 percent TDG requirement would result in an additional 2.3 MAF spill (a 1.8 percent increase).
- For the 2007 low water year, eliminating the 115 percent TDG requirement would result in an additional 2.5 MAF spill (a 2.2 percent increase).

Most of the additional spill would come from Lower Monumental and Bonneville dams. In high water years, some would also come from John Day, The Dalles, and Little Goose dams. See Figures 6 through 9 and Table 4 for details.

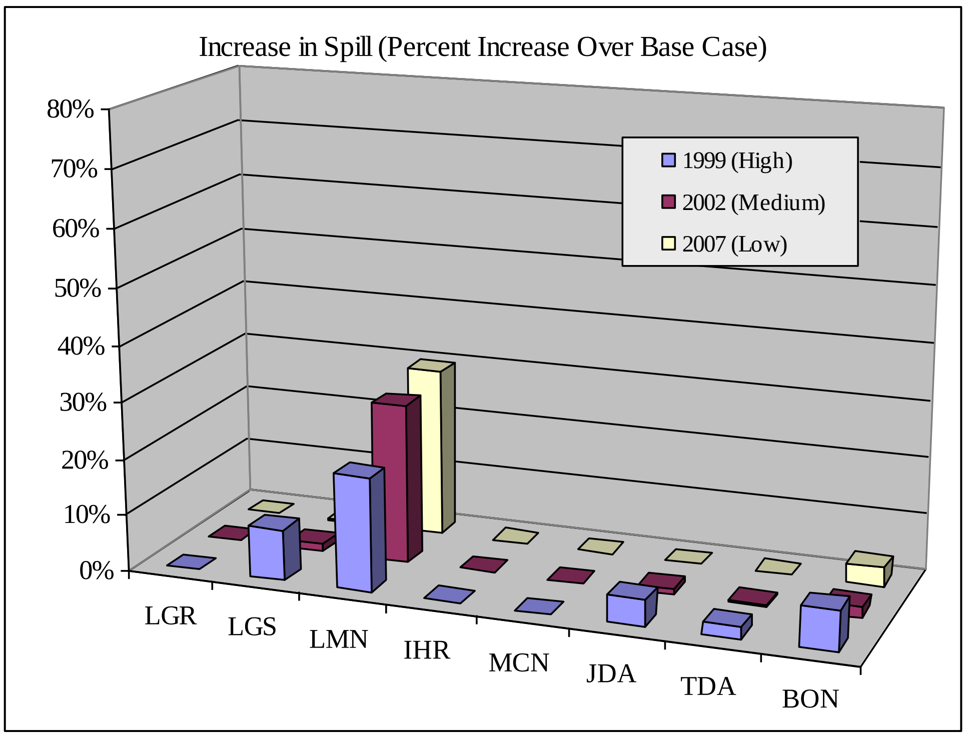


Figure 6. SYSTDG Analysis of Spill Volumes. SYSTDG analyzed how much spill would occur under the base case of the 115 percent/120 percent requirement and determined how much more spill would occur under a 120 percent-only scenario.

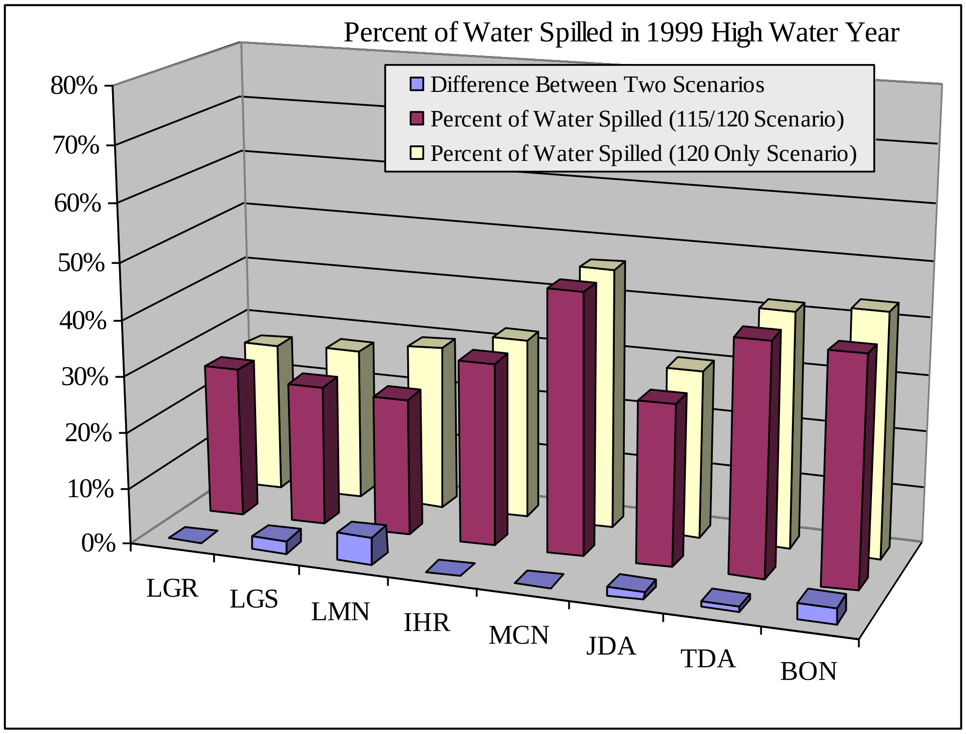


Figure 7. Percent of Water Spilled in 1999 High Water Year. SYSTDG analyzed the amount of water spilled at the dam compared to the total outflow at the dam. SYSTDG did this analysis under the base case 115 percent/120 percent scenario and the 120 percent-only scenario. The "Difference" is the 120 percent-only scenario subtracted from the 115 percent/120 percent scenario**.**

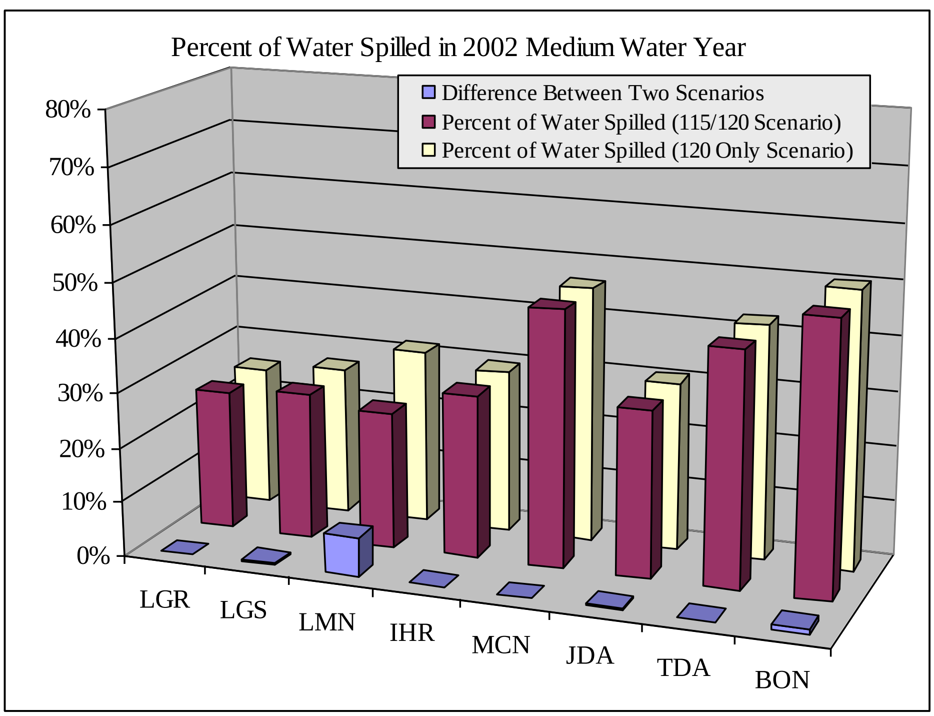


Figure 8. Percent of Water Spilled in 2002 Medium Water Year.

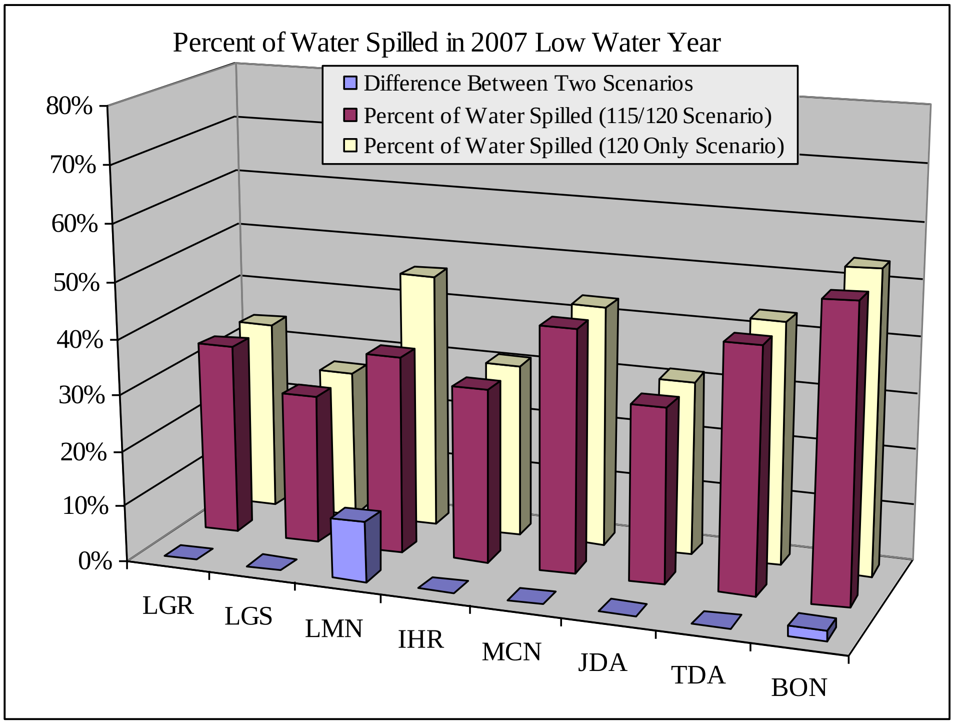


Figure 9. Percent of Water Spilled in 2007 Low Water Year.

Table 4. Percent of Water Spilled in 1999, 2002, and 2007 for all eight dams combined, tabulated with USACE spill data by Ecology using Tables 11, 12, 13 of SYSTDG Report.

	1999 (High)	2002 (Medium)	2007 (Low)
115% / 120% Scenario	36.2%	38.7%	40.7%
120%-Only Scenario	37.6%	39.4%	41.5%
Difference Between Two Scenarios	1.4%	0.7%	0.9%

BPA Analysis (HYDSIM)

The BPA analysis, *HYDSIM Use in Analysis of Removing 115 percent TDG Forebay Gauge Requirements BPA Report to the Adaptive Management Team – May 2008* is available on the AMT website. No comments were received on this analysis.

The BPA analysis used spill caps provided by the USACE analysis. The spill caps were applied to 70 years of historical runoff data to generate month average flow and spill volumes at each dam. Overgeneration spill that occurs in excess of the planned spill program (the 2008 Biological Opinion) is included in the BPA base case.

According to BPA's analysis, eliminating the 115 percent requirement would result in more spill at Lower Monumental (13 percent increase), Bonneville (2.9 percent increase), and, to a much lesser extent, Little Goose (1.1 percent) and The Dalles (0.5 percent increase) dams. The increase in spill at these dams, and the resulting loss of power generation, means the other dams could generate more power and would have less overgeneration spill. Thus eliminating the 115 percent requirement would result in slightly less spill at Lower Granite, Ice Harbor, McNary, and John Day by 0.1 percent - 0.2 percent. See Figure 10 for details.

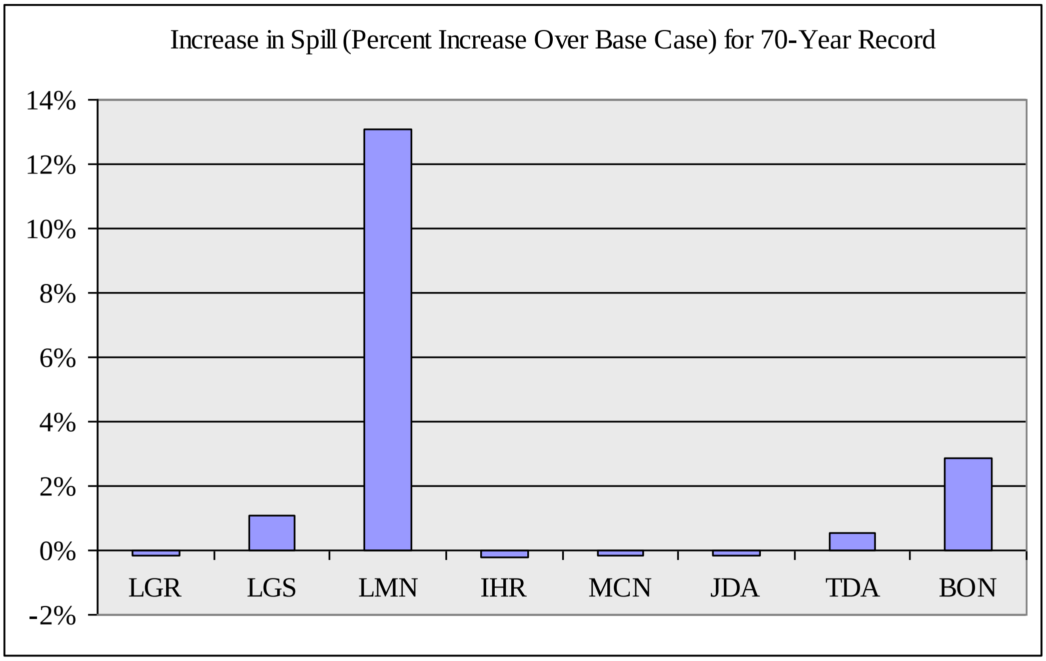


Figure 10. BPA Calculation of Spill Changes

Synthesis of FPC, USACE, and BPA Analyses of Spill Volumes

The three analyses reached similar conclusions on where the elimination of the 115 percent requirement would have the most significant difference.

Table 5. Dams Affected by 115 percent Requirement

Analysis	Dams most affected by eliminating 115% requirement
FPC	Little Goose and Lower Monumental
BPA	Lower Monumental and Bonneville
USACE	Lower Monumental and Bonneville

The three analyses reached variable conclusions on the total amount of additional spill that would occur if the 115 percent requirement was eliminated.

Table 6. Addition Spill Amount

Analysis	Additional Spill Amount (per year, an average for all eight Lower Columbia and Snake River dams combined)
FPC	1% - 60% depending on the year and scenario
USACE	1.8% - 4.0% depending on the year
BPA	1.3% average over 70 water years

One must be careful when directly comparing the spill volumes analyses. While the three analyses presented are addressing the same topic, the assumptions made in each analysis vary. The differences between the FPC, USACE and BPA analyses were the assumptions each analysis made on inclusion of 2008 BiOp spill operations, the treatment and inclusion of overgeneration spill, the years analyzed, and other limitations on spill programs. Since each analysis treated these important factors differently, the changes in spill volumes with and without the 115% TDG forebay limit range in value.

Fish Passage and Survivability Impacts

The FPC, U.S. Fish and Wildlife Service (USFWS), National Oceanic and Atmospheric Administration (NOAA), and the Columbia River Inter-Tribal Fish Commission (CRITFC) each conducted an analysis on how anadromous fish passage and survivability would be impacted if the 115 percent TDG limit was removed. The FPC provided an analysis of the importance of spill in juvenile hydro-system survivals and Smolt to Adult Returns (SARs) using empirical data and a multiple regression analysis. USFWS presented modeling results from the Comparative Survival Study (CSS) on fish passage and juvenile salmonid survivability. NOAA presented results from their Comprehensive Passage (COMPASS) model. Adult passage and survival impacts were summarized by CRITFC. These analyses addressed the eight Lower Columbia and Lower Snake River dams. The following table summarizes the assumptions made for each of the analyses:

Table 7. Fish Passage and Survival Impacts Analysis Summary

Author	Report Title	Years Analyzed	Simulation	Data Set
FPC	*Importance of spill in Juvenile Hydro-system survivals and SARs*	1998 - 2005	Statistical analysis for smolt reach survival analyses for yearling spring / summer Chinook, steelhead and fall Chinook; Relation between juvenile survival and adult return rates with and without the 115% TDG forebay limit.	Empirical data set for each year and species.
USFWS presen-tation	*Comparative Survival Study (CSS) Chapter 2*	1998 - 2006	Statistical analysis for yearling Chinook and steelhead migrants' survival.	Modeled data set for each species for two reaches: Lower Granite to McNary and McNary to Bonneville, using weekly released cohort PIT-tagged fish, with median estimated fish travel time and survival rate. Analysis included temperature, turbidity, flow, water travel time, average percent spill and seasonality for each year and reach modeled.

NOAA	*Explanation of COMPASS Analysis of TDG Alternatives*	70 years, averaged (1929 - 1999)	Statistical analysis of survival and Lower Granite to Lower Granite smolt-to-adult-return for Snake River spring / summer Chinook and steelhead, Upper Columbia spring Chinook and steelhead, and Mid Columbia steelhead with and without the 115% TDG forebay limit.	Daily time step model. HYDSIM monthly modeled mean 70 year water record translated into daily time step for average flow and spill input. Model includes transport, FCRPS survival but not post Bonneville effects for the period starting April to end of June.
CRITFC	*Review of Adult Passage through Different Dam Passage Routes*	2008 ACOE Steelhead Kelt fish passage	Statistical analysis of four downstream adult passage routes: screen bypass system, spill, turbines, and surface bypass.	Empirical data set and literature.

FPC Analysis of Juvenile Hydro-system Survivals and SARs

The FPC's analysis, *Importance of spill in Juvenile Hydro-system survivals and SARs*, is available on the AMT website. BPA provided comments on the FPC analysis, and FPC responded to the comments. These documents are available on the AMT website.

The FPC presented statistical analysis for smolt reach survival analyses for yearling spring / summer Chinook, steelhead and fall Chinook, and a relation between juvenile survival and adult return rates for data collected between 1998 and 2005. The study showed a relationship between increased spill and increased reach survival for juvenile migrants. The analyses accounted for the effect of ocean conditions on adult survival and showed a relationship between juvenile reach survival and adult returns.

According to the FPC analysis, the increased benefit of spill occurs when average spill proportions increase above 40 percent for spring / summer Chinook and steelhead, Figure 11 and 12. This is likely due to fish passing via spill would increase as average spill proportions exceed 40 percent.

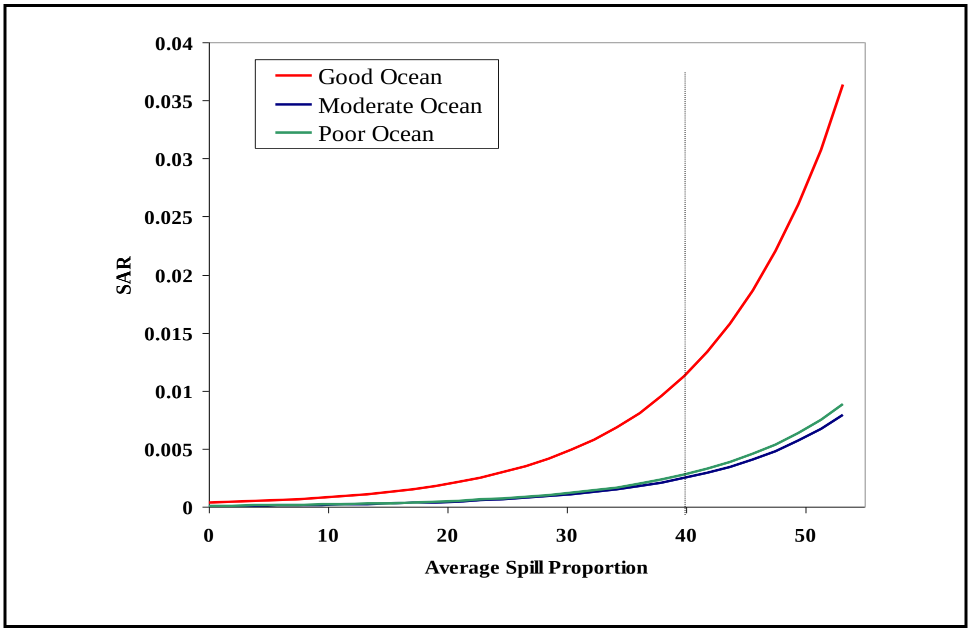


Figure 11. FPC Predicted response to increasing spill volumes of SARs for spring/summer Chinook salmon under good, moderate and poor ocean productivity levels.

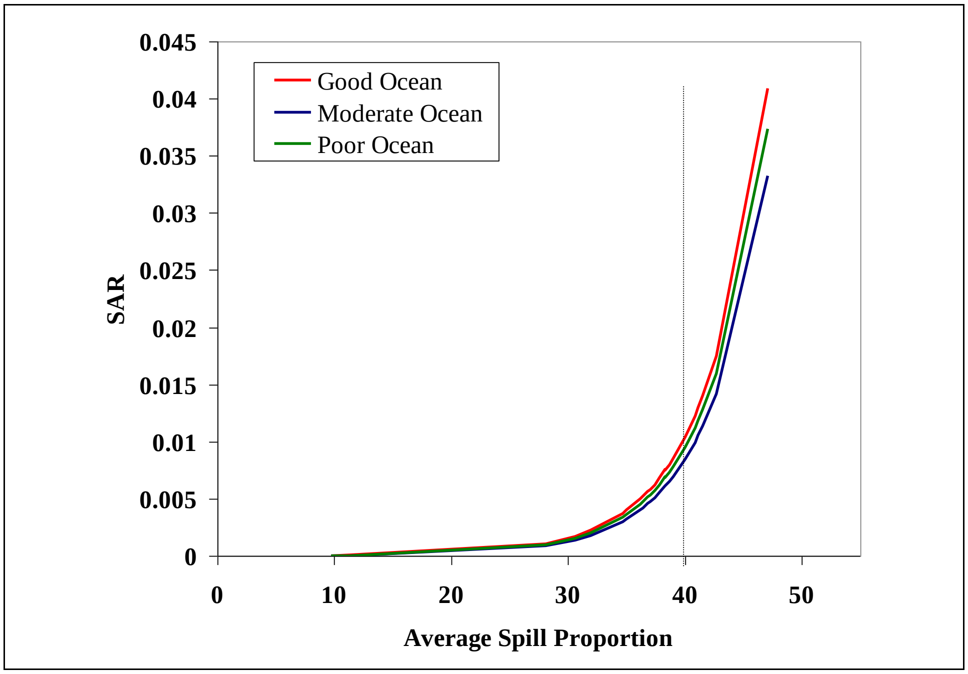


Figure 12. FPC Predicted response to increasing spill volumes of SARs for steelhead under good, moderate and poor ocean productivity levels.

The FPC analysis identified a positive relationship between juvenile reach survival and average spill, Figure 13.

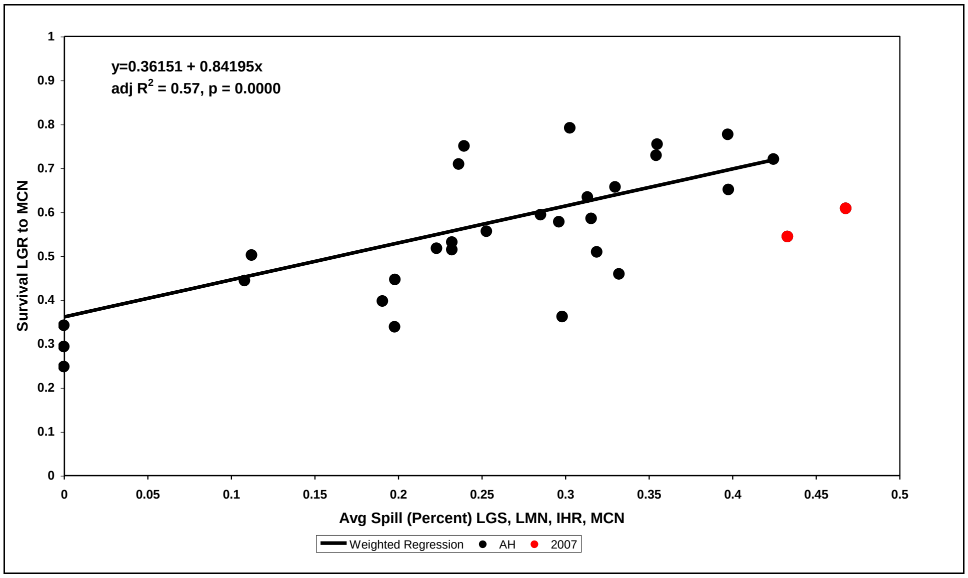


Figure 13. FPC x-y Plot of Sub yearling Chinook Survival versus Average Spill

A similar approach showed that an increase in water travel time had a negative relationship with reach survival demonstrating that as water travel time decreases (i.e. flows increase) survival increases, Figure 14.

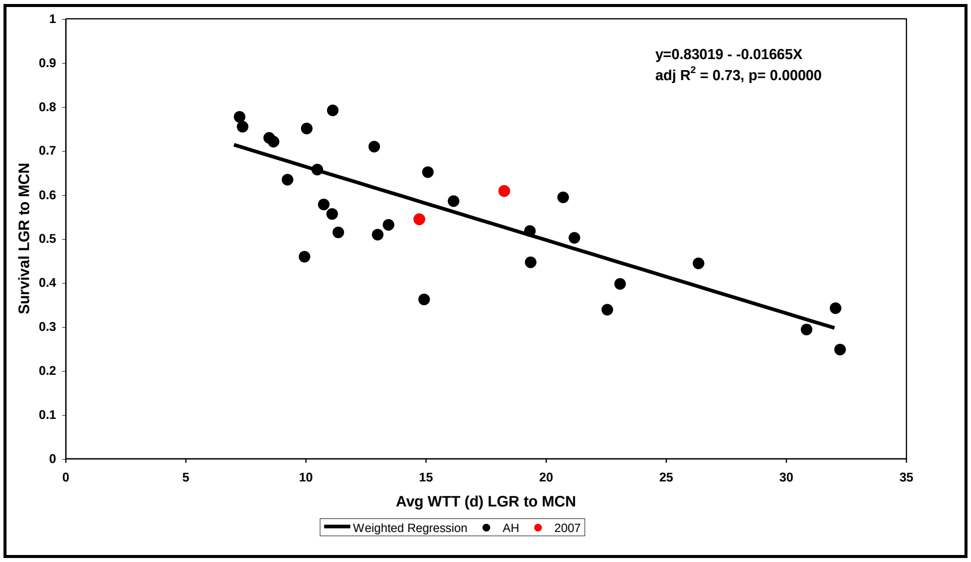


Figure 14. FPC x-y Plot of Hatchery Sub-yearling Chinook Survival versus Water Travel Time

CSS Study Presented by USFWS

The *Comparative Survival Study (CSS) Chapter 2* presented by USFWS is available on the AMT website, along with comments on the analysis. BPA and Northwest River Partners provided comments on the CSS. Most of the comments received at the AMT were developed during the

2007 regional CSS review. USFWS and FPC responded to the comments received during the AMT process. These comments are available on the AMT website. The CSS is a joint project of FPC, USFWS, Idaho Department of Fish and Game, ODFW, WDFW, and CRITFC.

The CSS used the 1998 to 2006 data set to show that juvenile travel times, instantaneous mortality rates, and survival rates through the hydro system are strongly influenced by managed river conditions including flow, water travel time, and spill levels, Figure 15. The report found that fish travel time is a function of water travel time, average percent spill, and Julian day. USFWS further identified that improvements in in-river survival and travel times could be achieved through management actions that reduce water travel time or increase the average percent spilled. The effectiveness of these actions would likely change over the migration season.

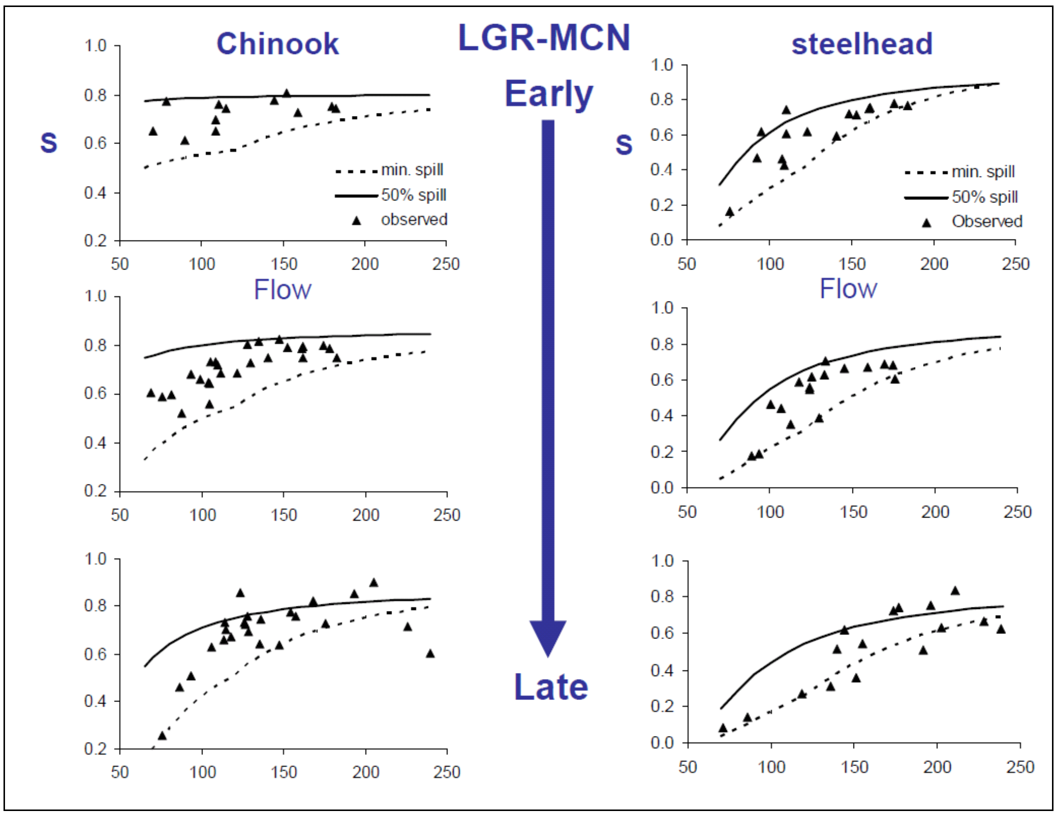


Figure 15. USFWS plots of flow versus survival (S).

The conclusion presented was that if spill were increased fish travel times would be shorter (both species, both reaches) instantaneous mortality rates would be lower (steelhead, Lower Granite-McNary) juvenile survival rates would be higher (both species, both reaches).

NOAA COMPASS Study

The NOAA analysis, *Explanation of COMPASS Analysis of TDG Alternatives*, is available on the AMT website. ODFW provided comments on COMPASS, and BPA and NOAA responded to those comments. The Independent Scientific Advisory Board's review of COMPASS was also received. These documents are available on the AMT website.

The NOAA analysis incorporated results from three modeling efforts. USACE's SYSTDG model provided spill cap volumes. The SYSTDG model is run on an hourly time step and assumed 2008 FCRPS BiOp operations. The hourly time step was converted to a monthly average in order to be incorporated into BPA's HYDSIM model. The HYDSIM model incorporated over-generation conditions and the 2008 electrical load capacity to a model simulation of over 70 years of monthly historical runoff averages. The HYDSIM model derived monthly average flow volumes were then converted to daily input for NOAA's COMPASS model. COMPASS calculated daily flows for the period of April to end of June and incorporated fish transport. The COMPASS model ran using the 2008 FCRPS BiOp operations. See the report for details.

COMPASS estimates the downstream passage survival of juvenile salmonids. Survival values were rounded up to one decimal space for relative difference, and to three decimal spaces for absolute difference, which resulted in several calculations of a zero survival difference between the current TDG management scenario and eliminating the 115 percent TDG forebay limit. However, NOAA states that if model results were carried out to the maximum precision then there would be a small positive difference between alternatives. Differences in survival presented at the AMT Table 8 and Table 9.

Table 8. COMPASS Relative Percent Differences of Steelhead Reach Survivals.

Steelhead Reach Survivals		Snake River	Columbia River
120		66.0%	67.1%
120*115		65.9%	67.0%
absolute difference	70 year Average	0.1%	0.1%
Relative change from 115*120		0.2%	0.2%
120	Low Flows	49.8%	56.2%
120*115	n=23	49.7%	56.2%
absolute difference	<209.1 KCFS	0.1%	0.0%
Relative change from 115*120		0.2%	0.0%
120	Mid-Range Flows	70.3%	69.9%
120*115	n=24	70.2%	69.9%
absolute difference	209.2-263.4 KCFS	0.1%	0.0%
Relative change from 115*120		0.1%	0.00%
120	High Flows	81.0%	76.3%
120*115	n=23	81.0%	76.2%
absolute difference	>263.5 KCFS	0.0%	0.1%
Relative change from 115*120		0.0%	0.1%

Table 9. COMPASS Relative Percent Differences of Spring Chinook Reach Survivals.

Spring Chinook Reach Survivals		Snake River	Columbia River
120		85.5%	71.3%
120*115		85.3%	71.3%
absolute difference	70 year Average	0.2%	0.0%
Relative change from 115*120		0.23%	0.00%
120	Low Flows	81.8%	68.8%
120*115	n=23	81.7%	68.8%
absolute difference	<209.1 KCFS	0.1%	0.0%
Relative change from 115*120		0.12%	0.00%
120	Mid-Range Flows	86.7%	71.7%
120*115	n=24	86.5%	71.7%
absolute difference	209.2-263.4 KCFS	0.2%	0.0%
Relative change from 115*120		0.23%	0.00%
120	High Flows	88.0%	73.4%
120*115	n=23	87.9%	73.4%
absolute difference	>263.5 KCFS	0.1%	0.0%
Relative change from 115*120		0.11%	0.00%

COMPASS analysis concluded that "elimination of the forebay monitors, with resulting increasing spill rates, would provide a small, but positive effect on survival and adult returns of listed stocks", except for Snake River Steelhead. COMPASS model results showed a drop in estimated survival and SAR for Snake River Steelhead, Table 10. The NOAA analysis states that negative effects estimated for Snake River Steelhead could be reduced through "management actions, such as limiting spill, to increase collection for transportation at Lower Granite Dam." Transport is considered a management option by the AMT and is not considered in this technical evaluation.

Table 10. Summary of COMPASS Results for Smolt to Adult Returns (SARs)

Species	Measurement	115% and 120%	120% Only	Relative Change
Snake River Spring / Summer Chinook	Whole population Lower Granite-Lower Granite SAR	0.915%	0.922%	0.8%
Snake River Steelhead	Whole population Lower Granite-Lower Granite SAR	1.803%	1.783%	-1.1%
Upper Columbia River Chinook	Whole population Lower Granite-Lower Granite SAR (surrogate for Rocky Reach Dam to Rocky Reach Dam SAR)	0.768%	0.768%	0.0%
Upper Columbia River Steelhead	Whole population Lower Granite-Lower Granite SAR (surrogate for Rocky Reach Dam to Rocky Reach Dam SAR)	0.716%	0.716%	0.0%
Mid-Columbia Steelhead	In River Survival	52.4-90.3%	52.5-90.3%	0.0-0.2%

CRITFC Adult Passage Analysis

The CRITFC analysis, *Review of Adult Passage through Different Dam Passage Routes*, is available on the AMT website. USACE and BPA provided comments on the CRITFC analysis. Their comments are available on the AMT website. No response to comments was received from CRITFC.

Adult survival is important because of their imminent likelihood to spawn. The CRITFC study states that “the downstream route of adult passage is an important factor that contributes to survival and ultimate escapement to spawning areas and spawning success, reproductive fitness and genetic integrity.” The study evaluates four downstream passage routes available to adults. They include the screen bypass system, spill, turbines, and surface bypass.

CRITFC evaluated each of the four adult downstream passage routes. The CRITFC analysis states that the screen bypass system exposes juvenile and adult salmon to increased water temperatures. These fish are held at temperatures that are significantly warmer than that found in the ambient river. Spill has been associated with increased fish passage efficiency, Table 11, and has been demonstrated to reduce travel and passage times. Turbine passage has an increased mortality because of the blade to fish size ratio. The CRITFC study identified surface bypass structures as an “emerging, promising adult downstream passage route” that provides for reduced adult passage delays. The CRITFC review “indicates that spill and surface bypass and probably a combination of both provide the safest downstream passage route for adult migrants, whether they are fallbacks or steelhead kelts heading seaward.” Fallbacks occur when adult salmon heading upriver go back downstream through or over a dam.

Table 11. Steelhead kelt fish passage efficiencies through Lower Columbia dams with and without spill (data from Corps 2008).

Dam	Percent Spill	Percent Fish Passage Efficiency
Bonneville	37%	84%
Bonneville	0%	68%
The Dalles	30%	99%

Synthesis of FPC, USFWS, NOAA and CRITFC Analyses

It is difficult to assess the precise impacts on fish passage and survival that would result from removing the 115% TDG limit forebay requirement. The analyses and data presented were based on both empirical and simulated data. The assumptions contained in the simulation analyses often ranged widely among studies.

The FPC analysis noted that increased spill would result in increased juvenile reach and adult survival, and that smolt survival had a strong relation to reach survival and spill.

The CSS report found that higher levels of spill during smolt migration years 1998 – 2006 were associated with:

- Reductions in fish travel time (faster migration rates) for both yearling Chinook and steelhead.
- Reductions in instantaneous mortality rates of steelhead.
- Increased survival rates for both yearling Chinook and steelhead.

The COMPASS model analysis found that most species experienced a small, positive effect on in-river survival (<1%) if the 115 percent TDG limit was removed due to increased spill.

The CRITFC study review of four adult passage routes indicated that spill and surface bypass, and probably a combination of both, provide the safest downstream passage route for adult migrants when also evaluating turbine and screen bypass systems. CRITFC states that this route combination is an important factor in adult passage that contributes to survival and escapement to spawning areas and spawning success.

Gas Bubble Trauma Impacts

The USACE analyzed how much TDG would increase if the 115 percent requirement was removed. Four AMT studies provide gas bubble trauma (GBT) summary information on the possible impacts of eliminating the 115 percent requirement. The three TDG literature reviews presented at AMT synthesized hundreds of previous field and laboratory studies. Each review had a slightly different focus. The FPC's report on the Smolt Monitoring Program examined GBT in salmon in the Columbia River. This report is highlighted separately due to its high relevance to the 115 percent requirement.

USACE SYSTDG TDG Simulations

The USACE's analysis, *Report on the SYSTDG Modeling for AMT: With and without 115 percent TDG standard*, analyzed the expected change in TDG in the forebays. The USACE analyzed the high water year of 1999, the moderate water year of 2002, and the low water year of 2007. In each case, the high 12-hour average TDG level is reported.

The simulations summarized the TDG levels for each water year, for each project, with and without the 115 percent TDG standard over the entire spill season (water year), from April through August.

Table 12 and Figure 16 summarize the TDG change in the forebays between the two scenarios, with and without the 115 percent forebay TDG limit. The values highlighted in gray show an increase in the high 12 hour average TDG levels if the 115 percent limit was removed.

Table 12: TDG in the forebays with and without the 115 percent limit.

Forebay High 12 Hour Average % TDG Levels

Water Years: Low = 2007; Medium = 2002; High = 1999

		Seasonal **Average** of the High 12 Hour Average TDG		
Year	**Project**	**With 115%**	**Without 115%**	**Difference**
2007	LWG forebay	101.9	101.9	0.0
2002	LWG forebay	101.7	101.7	0.0
1999	LWG forebay	106.1	106.1	0.0
2007	LGS forebay	106.8	106.8	0.0
2002	LGS forebay	106.1	106.1	0.0
1999	LGS forebay	109.2	109.2	0.0
2007	LMN forebay	109.8	109.8	0.0
2002	LMN forebay	110.7	110.7	0.0
1999	LMN forebay	113.3	113.7	0.5
2007	IHR forebay	110.8	111.7	0.9
2002	IHR forebay	110.8	111.3	0.5
1999	IHR forebay	112.2	115.2	3.0
2007	MCN forebay	109.5	109.5	0.0
2002	MCN forebay	109.0	109.0	0.0
1999	MCN forebay	109.4	109.4	0.0
2007	JDA forebay	107.6	107.6	0.0
2002	JDA forebay	106.9	106.9	0.0
1999	JDA forebay	108.1	108.1	0.0
2007	TDA forebay	109.8	109.8	0.0
2002	TDA forebay	108.8	108.8	0.0
1999	TDA forebay	110.4	110.6	0.2
2007	BON forebay	111.2	111.2	0.0
2002	BON forebay	110.1	110.1	0.0
1999	BON forebay	112.2	112.4	0.2
2007	Camas Forebay	113.3	113.8	0.5
2002	Camas Forebay	113.0	113.0	0.0
1999	Camas Forebay	113.9	115.2	1.3

Average % TDG Difference :	**0.3**

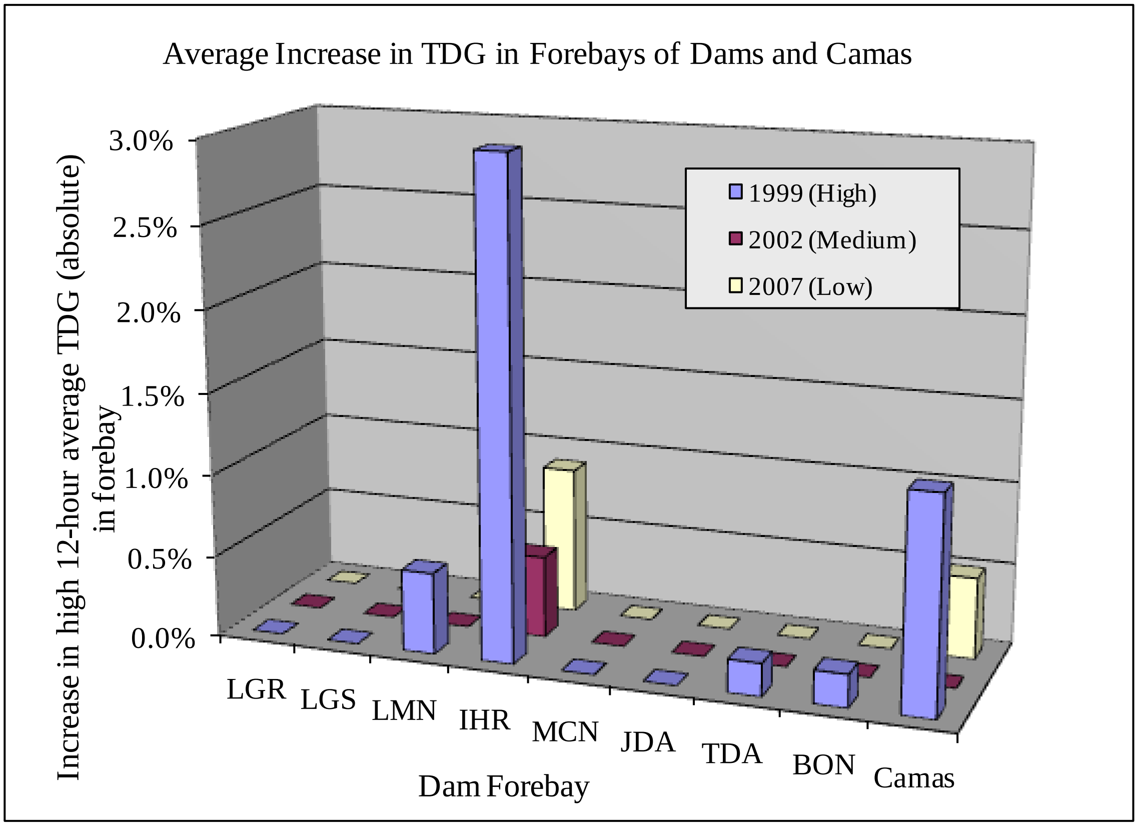


Figure 16. The average absolute increase in percent TDG in the forebays if the 115 percent forebay requirement was removed.

Table 13 and Figure 17 summarize the TDG change in the tailraces between the two scenarios, with and without the 115 percent forebay TDG limit. The values highlighted in gray show an increase and the black highlighted values show a decrease in the high 12 hour average TDG levels if the 115 percent limit was removed.

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Table 13: TDG in the tailraces with and without the 115 percent limit.

Tailrace High 12 Hour Average % TDG Levels

Water Years: Low = 2007; Medium = 2002; High = 1999

		Seasonal **Average** of the High 12 Hour Average TDG		
Year	**Project**	**With 115%**	**Without 115%**	**Difference**
2007	LWG Tailrace	108.5	108.5	0.0
2002	LWG Tailrace	108.8	108.8	0.0
1999	LWG Tailrace	112.2	112.2	0.0
2007	LGS Tailrace	113.8	113.8	0.0
2002	LGS Tailrace	114.6	114.6	0.0
1999	LGS Tailrace	116.0	116.2	0.1
2007	LMN Tailrace	113.2	114.1	0.9
2002	LMN Tailrace	113.1	113.1	0.0
1999	LMN Tailrace	114.4	115.2	0.8
2007	IHR Tailrace	113.4	113.4	0.0
2002	IHR Tailrace	113.9	113.9	0.0
1999	IHR Tailrace	115.1	115.1	0.0
2007	MCN Tailrace	114.7	114.7	0.0
2002	MCN Tailrace	116.0	116.0	0.0
1999	MCN Tailrace	116.5	116.5	0.0
2007	JDA Tailrace	117.5	117.5	0.0
2002	JDA Tailrace	118.2	118.2	0.0
1999	JDA Tailrace	118.9	119.2	0.3
2007	TDA Tailrace	115.1	115.1	0.0
2002	TDA Tailrace	115.0	115.0	0.0
1999	TDA Tailrace	115.7	115.2	**-0.5**
2007	BON Tailrace	117.1	117.6	0.5
2002	BON Tailrace	117.7	117.7	0.0
1999	BON Tailrace	119.6	120.8	1.2

Average % TDG Difference :	**0.1**

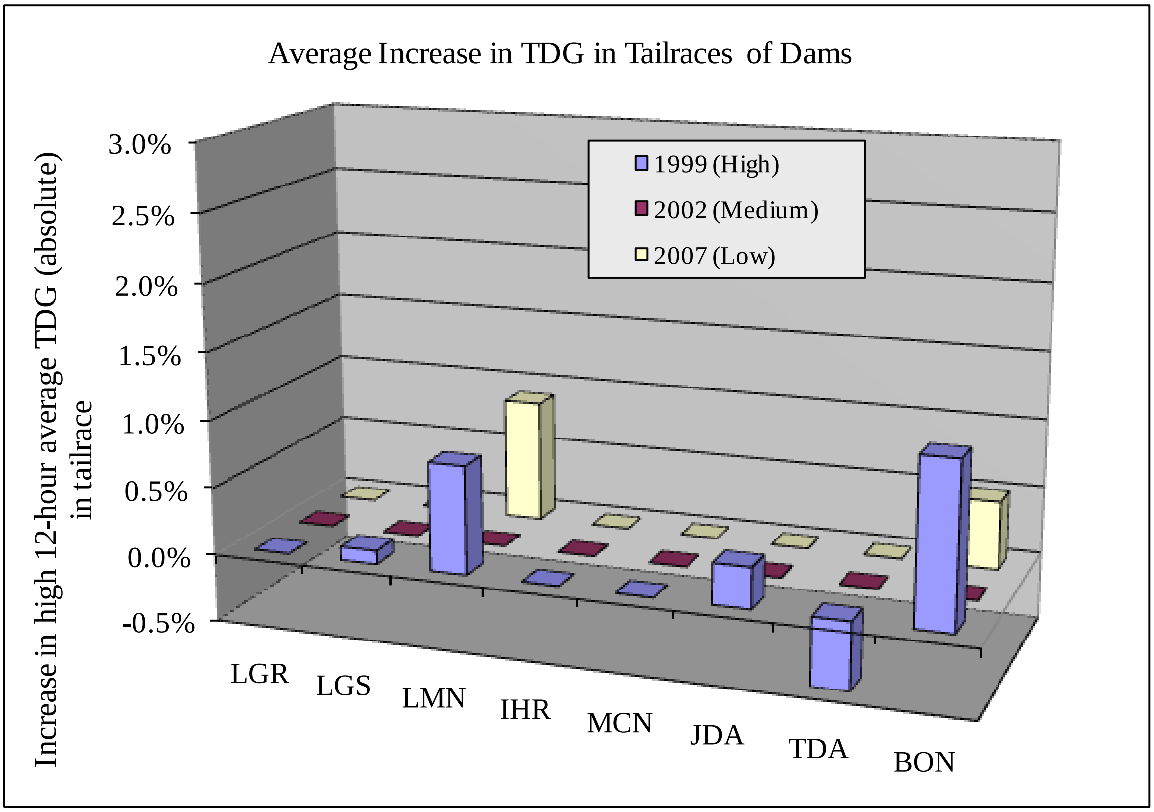

Figure 17. The average absolute increase in percent TDG in the tailraces if the 115 percent forebay requirement was removed.

It is expected that TDG in the forebay would not go above 120 percent because the tailraces are limited to 120 percent. The USACE analysis shows that eliminating the 115 percent requirement would increase TDG by an average of 0.3 percent in the forebays and 0.1 percent in the tailraces. The maximum single day increase in forebay TDG values was predicted at Ice Harbor (downstream of Lower Monumental dam), a difference of 4.1 percent TDG in 2007. The analysis also found situations where TDG appeared to decrease when the 115 percent requirement was eliminated, but these are believed to be modeling artifacts.

Ecology Literature Review

The Department of Ecology completed a literature review to assess the appropriate water quality criteria for TDG. The review, *Evaluation of Total Dissolved Gas Criteria (TDG) Biological Effects Research*, 2008 is available on the AMT website. No comments were received at the AMT regarding the Ecology literature review.

The review showed that, at shallow depths (less than one meter), increasing the TDG from 115 percent would have a detrimental effect on aquatic life. However, with depth compensation, aquatic life at 2 meters or deeper would not be affected if TDG is increased to 120 percent.

Impacts on aquatic life (in shallow water less than one meter)
A number of papers summarized in the literature review studied the impact of TDG on aquatic life at shallow depths. While some studies did not find any effects at 120 percent TDG, the weight of all the evidence clearly points to detrimental effects on aquatic life at shallow depths when TDG approaches 120 percent. There were fewer effects on aquatic life at 115 percent TDG. The detrimental effects ranged from behavior changes to high levels of mortality after a few days. A summary of the findings presented in Table 14 are as follows; see Table 14 for details:

At 110 percent TDG or less, reported symptoms in shallow water included:

- Sub- lethal impacts.
- Mortality in insects and larval striped bass.
- No symptoms present

At 115 percent TDG, reported symptoms in shallow water included:

- Sub-lethal impacts (tadpoles floating).
- Mortality in fish such as 20% in 8 days and 56% in 35 days.
- No symptoms present.

As TDG increases to 120 percent, reported symptoms in shallow water included:

- Sublethal impacts (frogs, sturgeon larvae).
- Increased mortality in fish such as 20% in one day, 50% in 3 or 4 days, 20% in 6 days, 42% in 9 days, 10% in 11 days, 32% in 12 days, 50% in 22 days, and 20% in 23 days.
- Some mortality in other aquatic life (daphnia).
- No symptoms present.

It is important to note that high mortalities are not found in the Columbia River when TDG reaches these levels, presumably due to depth compensation. It is also important to include a significant margin of safety since high mortality is a very undesirable outcome.

Table 14. Summary of TDG Impacts from Ecology Literature Review

Author	Species	Percent TDG	Depth	Impact
Anticliffe et al (2003)	Juvenile rainbow trout	118%	0.1-0.25 m	3% had bubbles.
Anticliffe et al (2002)	Juvenile rainbow trout	116%	0.25 m	42% mortality after 9 days.
Bently et al (1981)	Pike minnow	117.2%	0.25 m	32% mortality after 12 days (also observed behavior changes).
Bouck et al (1976)	Various (salmonids and bass)	120%	1 m	No mortality after 12 days for bass. 50% mortality in 4 days for adult salmon.

Author	Species	Percent TDG	Depth	Impact
Clay et al (1976)	Adult menhaden	110%	Very shallow (assumed)	Erratic swimming and death in 24 hours
Colt et al (1985)	Juvenile catfish	115%	Shallow (assumed)	56% mortality in 35 days
Colt et al (1984a, 1984b, and 1987)	Bullfrogs and African clawed frog	116.5%	Shallow (assumed)	All frogs had bubbles in cardiovascular system and other impacts
		120%	Shallow (assumed)	Behavior changes
		114%	Shallow (assumed)	Tadpoles float to surface
Cornacchia et al (1984)	Larval striped bass	106%	0.1 m	23% increase in mortality after 3 days
Counihan et al (1998)	White sturgeon larvae	118%	0.25 m	No mortalities, but did have behavior changes
Dawley et al (1975)	Juvenile rainbow trout, Coho, whitefish, and steelhead	120%	Shallow	50% mortality in 2.5-6 days depending on the species. (At 2.5 meters there were fewer deaths even with higher TDG.)
Dawley et al (1975)	Juvenile Chinook	116%	0.25 m	10% mortality in 11 days
Dawley et al (1976)	Juvenile Chinook and steelhead	120%	0.25 m	50% mortality in 22 days (Chinook). 50% mortality in 30 hours (steelhead).
Gale et al (2004)	Adult Chinook	114 and 118%	0.5m	Some symptoms, including death. No effect on other some symptoms.
McInerny (1990)	Largemouth bass, bluegill and white bass	115-120%	up to 5-11 m	18-28% gas bubble signs depending on species
Mesa et al (2000)	Juvenile Chinook and steelhead	113%-120%	0.27 m	60% fin bubble in 22 days and 20% mortality in 1.7-5 days at 120%. No mortalities in 22 days at 113%.
Mesa et al (1995)	Juvenile Chinook	120%	0.28 m	50% mortality in 60 hours. No mortalities in 22 days at 112%, but numerous other symptoms.
Mesa et al (1996)	Juvenile Chinook	120%	0.28 m	43% mortality in 75 hours. At 110%, numerous other symptoms.

Author	Species	Percent TDG	Depth	Impact
Nebeker et al (1976)	Various insects	120%	0.25 m	Daphnia: 50% mortality in 93 hours (compared to 10% mortality in 170 hours at 110%). Crayfish: No deaths for 30 days. Larval Stoneflies: No deaths.
Nebeker et al (1980)	Juvenile cutthroat trout	113-120%	0.6 m	Cutthroat trout: At 113%, 20% mortality in 185 hours and at 120%, 20% mortality was 20 hours (juveniles). At 118%, 20% mortality in 142 hours and at 121%, 20% mortality was 34 hours (adults).
	Juvenile speckled dace	119%	0.25 m	Speckled dace: At 119%, 20% mortality was 550 hours.
Nebeker et al (1976)	Adult sockeye	110-120%	0.7 m	At 110%, no signs. At 115%, first mortality in 21 days. At 120%, first mortality in 3 days.
Nebecker et al (1978)	Steelhead	126.7%	0.08 m	Eggs and embryos showed no signs of trauma for 20 days.
Newcolm (1974)	Juvenile steelhead	110%	0.23 m	46% had gas bubble signs. Blood chemistry changes at 105%.
Parametrix (2002)	Resident fish and macro-invertebrates	105-109% with spikes to 115%	0.5 and 3 m	Little signs of GBD.
Parametrix (2003)	Macro-invertebrates and resident fish	113-118%	3 m or less	Mayflies: 9% had GBD at 118%. Bristle worms: 0.05% had GBD at 113% at 3 m deep. Resident fish in 3 m or less showed signs of GBD.
Richter et al (2006)	Resident fish	120%	Unknown	No gas bubbles found in 20 species.
Schisler (1999)	Juvenile rainbow trout	105%	Shallow	Affected symptoms of whirling disease.
Weitcamp (1977)	Juvenile Chinook	120-128%	Up to 4 m	When fish had access to deeper water, no mortalities within 20 days.
Weitcamp et al (2003a)	Resident fish	<120%	<2 m	Only one fish found with gas bubbles.

Depth Distribution:
A number of papers summarized in the literature review studied the depth compensation of fish in the Columbia River (see Table 15). While it is important to consider mean and average depth, the number of fish in the top one meter is particularly critical. Fish depth distribution varies between day and night. The mean depth was always deeper than one meter, and usually deeper than two meters. The amount of time spent at depths shallower than one meter was usually (but not always) less than the amount of time where significant detrimental effects were found.

Table 15. Summary of Depth Distribution from Ecology Literature Review

Author	Species	Fish Observation	Depth
Abernathy et al (1997)	Juvenile Chinook and rainbow trout	Some observed	<1 m
		70% of fish	<3 m
Beeman et al (1997)	Juvenile steelhead	All fish	1.1-4.3 m
Beeman et al (2003)	Resident fish	Suckers (all)	0.3-16 m
		Some observed (all species)	<1 m
		Median (all species)	>= 2 m
Beeman et al (2006)	Juvenile steelhead	Mean	2-2.3 m
	Juvenile chinook	Mean	1.5-3.2
Dawley (1986)	Juvenile Chinook	8-22%	<3 m
Dawley et al (1975)	Juvenile Chinook	46%	<1.8 m
	Juvenile steelhead	29%	<1.8 m
Johnson et al (2007)	Adult chinook	4-12%	Shallow enough to be potentially affected by TDG
Johnson et al (2005)	Adult Chinook	1.3 hours (maximum time)	<1 m
		19 hours (maximum time)	<2 m
		Mean	>2 m
		3-9% of the time	<1m
Johnson et al (2005)	Adult steelhead	10% (Lower Monumental reservoir) 23% (Bonneville tailrace) 1.3% (McNary tailrace) 2.3% (Dalles reservoir)	<1 m
Johnson et al (2008)	Adult Chinook	28% (Dalles) 10% (Bonneville pool)	<2 m
		4.1 hours (maximum time)	<1 m
	Adult steelhead	14% (Lower Monumental reservoir) 2.9% (Dalles reservoir) 21% (Bonneville tailrace) 0.5% (Ice Harbor tailrace)	<1 m
		Some fish spent several days	<1 m
Parametrix (1999)	Brown trout	14%	<1 m

Author	Species	Fish Observation	Depth
[studied the Clark Fork River]		Mean	3 m
Parametrix (1999) [studied the Clark Fork River]	Brown trout	20%	<1 m
	Rainbow trout	53%	<1 m
	Cutthroat trout	40%	<1 m
	Bull trout	Median	1.5-2 m
	Pikeminnow	1%	<1 m
Parametrix (2000) [studied the Clark Fork River]	Brown trout	Median	1.7-5.5 m
	Bull trout	Range	0.9-3.8 m
	Cutthroat trout	Average	1.6 m
		Median hours depth	0.3-2.5 m
	Rainbow	Range	0.3-5.9 m
Smith (1974)	Juvenile Chinook and steelhead	28-46% (Lower Monumental reservoir)	<2m
Weitcamp et al (2003b) [studied Clark Fork River and Lake Pend Oreille]	Resident fish	Half the time (all species)	<2 m
		Median (rainbow trout)	1.3 m

The Ecology literature review also found that:

- Fish cannot quickly avoid high TDG, but some species seem to have some ability to avoid it.
- Fish can be negatively affected by TDG without showing evidence of gas bubbles.
- Susceptibility to gas bubble harm increases with activity, stress, and disease.
- Salmon usually migrate close to the shore where the TDG levels are usually less than in the thalweg (Johnson et al, 2007 and Schrank et al, 1998).
- Depth distribution of aquatic organisms and shallow water exposure is not well-known. There are recent studies on salmonids in the Columbia River, but there is little information on free-floating and surface dwelling organisms such as larvae of fish, crustaceans, and mollusks.

NOAA Fisheries Resident Fish Literature Review

Dr. Mark Schneider conducted a literature review of resident fish for NOAA Fisheries. The review, *Washington and Oregon State – Adaptive Management Team Resident Fish Literature Review*, 2008 is available on the AMT website. USACE provided comments on Dr. Schneider's literature review, and Dr. Schneider provided a response to these comments. These documents are available on the AMT website.

This review concluded that there were negligible adverse effects from 120 percent TDG on resident fish and aquatic invertebrates. Further, with a 10 percent depth compensation for each meter below the surface, a limit of 120 percent at the surface would mean all aquatic life below one meter would have a depth compensated TDG of 110 percent. The report noted that the Columbia River has extensive amounts of deep water habitat available to aquatic life. It also concluded that salmon, resident fish, and invertebrates are similarly affected by TDG supersaturation.

In order to conclude from the report that removing the 115 percent requirement would be acceptable, two assumptions need to be made:

- "Negligible" adverse effects are acceptable (or are mitigated by the benefits).
- The availability of deep water in the Columbia River will provide adequate protection even though not all aquatic life lives in that deep water.

Parametrix Literature Review

Don Weitkamp, Parametrix, conducted a literature review of TDG literature since 1980 on behalf of Avista Utilities, Tacoma Power, and Chelan, Douglas, and Grant County PUDs. The *Total Dissolved Gas Supersaturation Biological Effects, Review of Literature 1980-2007*, 2008 is available on the AMT website. Douglas County PUD commented on Dr. Weitkamp's literature review. Dr. Weitkamp did not respond to these comments. The comments are available on the AMT website.

The literature review found:

- TDG supersaturation results in little or no GBT at levels up to 120 percent of saturation when compensating depths (two meters or more) are available.
- Fish have the capacity to rapidly recover from GBT when they reach compensating depths or TDG supersaturation is decreased.
- Most instances of GBT have reported low incidence and severity; however, there have been a few cases of substantial mortalities reported. The reported mortalities and severe cases of GBT are generally attributed to either TDG supersaturation in situations where available depths are shallow (~1 m or less) or the TDG levels are exceptionally high (>130%).
- Field investigations have not demonstrated population effects resulting from TDG supersaturation.
- Generally the biological effects of TDG supersaturation appear to be influenced by the depth distribution of the fish or invertebrates resulting from their natural behavior, and there is limited evidence suggesting active avoidance of high TDG levels.

Similar to the NOAA Fisheries review, in order to conclude from the Parametrix report that removing the 115 percent requirement would therefore be acceptable, two assumptions need to be made:

- Negligible adverse effects are acceptable (or are mitigated by the benefits).
- The availability of deep water in the Columbia River will provide adequate protection even though not all aquatic life lives in that deep water.

GBT Monitoring Program

The Fish Passage Center (FPC) summarized data from its Smolt Monitoring Program for GBT monitoring in salmon in the Columbia River from 1995 to 2007. This information is available on the AMT website, along with comments on the analysis.

FPC identified relatively low occurrences of fin GBT. The highest was 8 percent, which occurred when TDG exceeded 130 percent. The threshold for spill curtailment is a GBT incidence of 15 percent in the sampled population. However, during certain situations, such as the end of an abnormally slow steelhead migration in 2007, as high as 39 percent of the fish at Little Goose dam had signs of GBT. It is important to note that signs of GBT do not directly translate to mortality.

For salmon experiencing TDG of 116-120 percent in the tailwater of the upstream dam, GBT was found in 1.0 percent of the fish (compared to 0.6 percent of the fish when TDG was 111-115 percent). See Figure 18 for details.

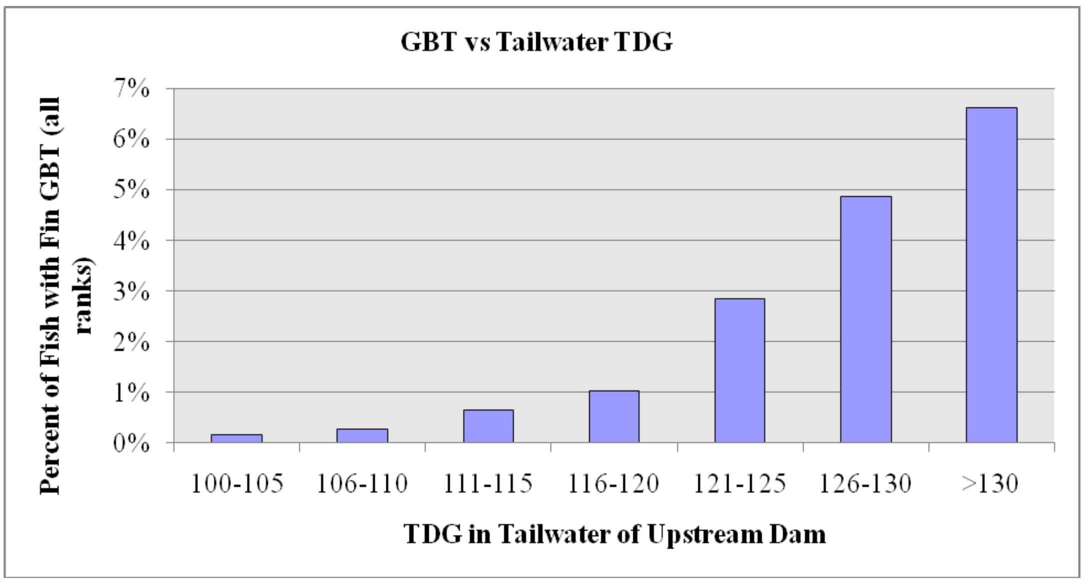

Figure 18. Total GBT at Varying TDG Levels in the Tailrace

For salmon experiencing TDG of 116-120 percent in the forebay of the dam, GBT was found in 1.4 percent of the fish (compared to 0.4 percent of the fish when TDG was 111-115 percent). See Figure 19 for details.

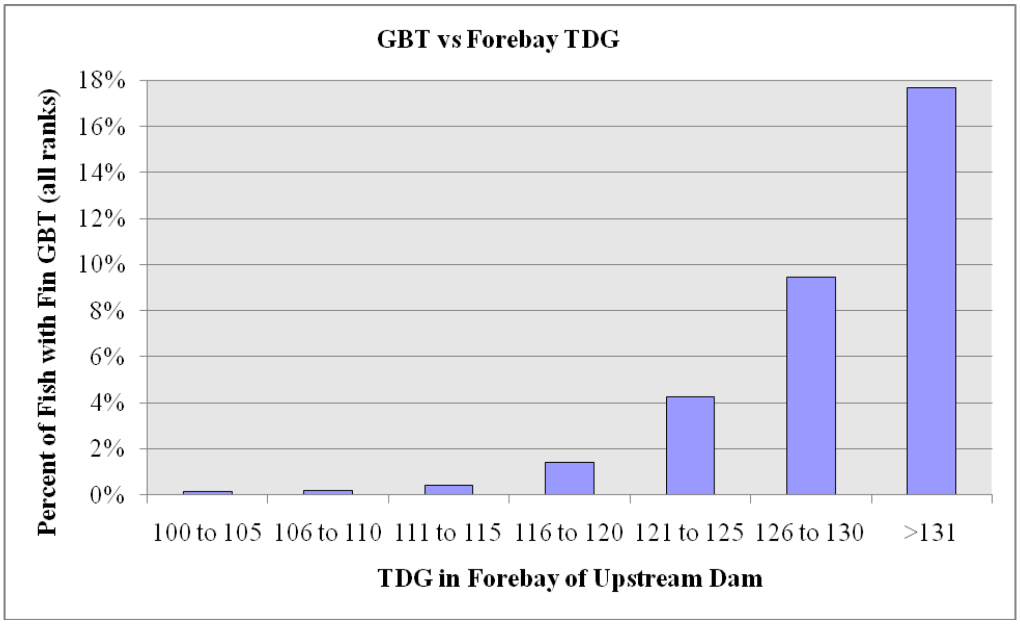

Figure 19. Total GBT at Varying TDG Levels in the Forebay

Synthesis of Ecology, NOAA Fisheries, and Parametrix Literature Reviews and GBT Monitoring Program

It is expected that TDG in the forebay would not go above 120 percent because the tailraces are limited to 120 percent. The USACE analysis showed that eliminating the 115 percent requirement would increase TDG an average of 0.3 percent in the forebays and 0.1 percent in the tailraces. The Ecology, NOAA and Parametrix literature reviews agree that a one meter or more depth compensation would protect aquatic species if TDG levels were at or below 120 percent. The three literature reviews and the GBT monitoring program results identify a minor increase in the incidence of GBT if the 115 percent requirement is removed. The NOAA Fisheries and Parametrix literature reviews both argue that any negative effect would be negligible. Results from the GBT monitoring program predict a less than one percent increase in GBT signs even if TDG increases from 111-115 percent to 116-120 percent. The Ecology literature review identifies an impact to aquatic species in shallow waters less than one meter deep that should not be considered negligible. The Ecology review found that there is a detrimental effect on aquatic life at less than one meter depths and that some aquatic life may be residing in shallow depths for long enough to suffer the detrimental effects of GBT.

Chronic, long-term effects of exposure to high TDG are difficult to fully study. Some studies have been done on various aspects of chronic exposures, but few studies have been completed on high TDG exposures greater than one month.

Agencies' Decisions

This section will be completed after receiving comments from AMT….