State, Federal and Tribal Fishery Agencies Joint Technical Staff Memo

To:        Rob Lothrop (Columbia River Inter-Tribal Fish Commission)
            Sharon Kiefer (Idaho Department of Fish and Wildlife
            Tony Nigro (Oregon Department of Fish and Wildlife)
            Bill Tweit (Washington Department of Fish and Wildlife)
            Howard Schaller (US Fish and Wildlife Service)

From:     Bob Heinith (Columbia River Inter-Tribal Fish Commission)
            Russ Kiefer (Idaho Department of Fish and Wildlife)
            Ron Boyce (Oregon Department of Fish and Wildlife)
            Cindy LeFleur (Washington Department of Fish and Wildlife)
            David Wills (US Fish and Wildlife Service)

Date:  January 31, 2007

Subject:  Technical Comments on the U.S. Army Corps of Engineer’s application for a waiver to Oregon’s total dissolved gas standard

Contained within this memorandum are our technical comments on the U.S. Army Corps of Engineers’ application for a waiver to Oregon’s total dissolved gas standard for the purpose of voluntarily spilling water at the four lower Columbia River dams to assist in the passage of out migrating threatened and endangered salmonids (salmon and trout) and other anadromous species such as Pacific lamprey. The spilling of water introduces air into the spilled water and results in total dissolved gas saturation in excess of Oregon’s total dissolved gas water quality standard, 110 percent relative to atmospheric pressure.

The applicant requests continuing the current total dissolved gas waiver limits of 120 percent total dissolved gas (TDG) in the tailrace and 115 percent TDG in the forebay. The applicant requests waiver compliance to be measured by fixed monitoring stations located in the
tailwater downstream of the aerated zone below the spillway at each mainstem dam, and in the forebay of the next project downstream.

As in past years we support the applicants’ request for a five-year waiver of the total dissolved gas standard to assist fish passage past the Columbia River hydroelectric projects via non-turbine and screen bypass routes. However, DEQ should carefully consider the technical information presented here in their consideration of how and where the total dissolved gas is measured. We believe that lack of accuracy and reliability of TDG monitoring in the forebays of hydroelectric projects and at the Camas/Washougal station downstream of Bonneville Dam may unnecessarily restrict the ability to provide spill in a manner consistent with the original objectives for the waiver. Data collected and studies since that time strongly suggest that it is nearly impossible to obtain valid measurements at the forebay monitoring locations that represent upstream spill total dissolved gas levels or are representative of a mixed water column due to monitor placement problems and confounding effects of environmental conditions (see DeHart, November 16, 2006 Comments on Corps of Engineers 2006 Draft Water Quality Plan. Attachment 1)

The dissolved gas criteria associated with the waiver were to assure that mortality to salmonids and other species occurring from dissolved gas was substantially less than that due to passage through turbines and screen bypass systems at hydroelectric projects. Over the years, the Biological Monitoring Program, which is part of the DEQ waiver requirements for monitoring, has collected data confirming that managing spill to tailrace total dissolved gas levels of 120% in a controlled spill program provides greater protection to the designated and existing beneficial aquatic uses of the river than was anticipated with the original waiver request in 1995.

1. Outline of the Issue

Supersaturation occurs when a solution contains more of the dissolved material than could be dissolved by the solvent under normal circumstances. Dissolved gas supersaturation in the Columbia and Snake rivers routinely occurs during the spring and summer freshet as a result of water spilling over dams (voluntarily or involuntarily). Total Dissolved Gas (TDG) is the measure of the sum total of all gas partial pressures (including water vapor) in water. TDG can be reported as an absolute overall dissolved gas pressure or relative to atmospheric pressure. Gas bubbles can form in the blood and tissues of aquatic organisms when water becomes supersaturated with gas. This results in “Gas Bubble Trauma” (GBT) in the affected organisms. GBT can, in turn if severe enough, cause rapid acute mortality as well as increase long-term mortality in aquatic organisms.

The original waiver criteria for TDG were established in 1994. This was the first time a waiver had been requested from the water quality agencies for variation from the national standard with the intent of providing survival benefits to migrating juvenile salmonids through additional spill passage. A literature review of past experiments (Spill and 1995 Risk Management (WDFW et al., 1995) had suggested that spill to the 125% TDG level might still have provided benefits to the designated and existing fish uses, but to err on the conservative side, a target of 115% TDG in the mixed waters of the forebay and 120% TDG in the tailrace was adopted. These criteria have been in-place since 1994 along with a biological monitoring program to assess the impacts of the controlled spill program.
The goal of the spill program is to provide benefits to migrating juvenile salmonids and other fish as they pass over dams, while not imposing harm from exposure to dissolved gas that outweighs the benefits of spill. The project forebay TDG monitors were originally intended to represent a mixed cross section in the river just upstream of the dam. The tailwater instruments are located immediately downstream of the projects, often in spillway releases downstream of aerated flow, and prior to complete mixing with powerhouse releases. The ability to adequately monitor TDG is extremely important and the question of whether, or not the forebay monitors reflect the actual picture of the potential harm that could occur from TDG has been an uncertainty from the beginning of the monitoring program. While the tailwater instruments are also affected to some degree during periods of non-spill by the same processes that cause errors in forebay readings, the physical process of spilling water sufficiently mixes the water column such that the tailwater monitors adequately represent the mixed water column measurement of TDG due to spill.

In 1994, the Oregon Department of Environmental Quality (DEQ) and the Washington Department of Ecology (DOE) granted variances from the 110% TDG standard for the first time. The waiver allowed TDG to reach 120%, which was defined as the 12 highest hourly readings measured at monitoring sites about a mile downstream of the dams. The maximum instantaneous allowable TDG specified was 125%. At Bonneville Dam the location designated was at Hamilton Island, approximately 1.5 miles downstream of the dam. The monitoring locations were not permanent monitoring sites and data were collected using a manually deployed probe that took readings from 2-4 times in a 24-hour period.

In March of 1995, the National Marine Fisheries Service reissued (NMFS 1995) its 1994-1998 Biological Opinion (BIOP) (NMFS 1994), which included several directives relative to the concentrations and monitoring of total dissolved gas levels that were different from the 1994 program. This BIOP originally developed the 115/120% TDG standard for monitoring that continues to be implemented today. The BIOP states that “until it can be determined how tailrace monitoring stations relate to the river reaches between monitoring sites and how TDG data collected at these sites relate to fish experience, forebay monitoring data will be used for in-season management”… “Spill will be reduced as necessary when the 12 hour average TDG concentration exceeds 115% of saturation (or as limited by state water quality standard modifications) at the forebay monitor of any Snake or lower Columbia river dam or at the Camas/Washougal station below Bonneville Dam or another suitable location to measure accurately chronic exposure levels. Spill will also be reduced when 12-hour average TDG level exceeds 120% of saturation (or as limited by state water quality modifications) at the tailrace monitor at any Snake or lower Columbia river dams.”

It was in this document that the Camas/Washougal site was established to represent a downstream forebay location below Bonneville Dam. The forebay sites were established as a measure of TDG in mixed waters and to represent the long-term exposure levels of migrants throughout the migration corridor. NMFS (NOAA Fisheries) expresses most concern for

---

1 Since the original TDG wavier for fish was issued by DEQ, it has been determined by the region’s fishery agencies and tribes that forebay monitors measure a host of variables, including but not limited to solar influence, temperature, and biological processes, thus, they are not representative of spill affects at upstream dams. These local process can bias forebay TDG readings.
migrating juvenile salmonids that are delayed in forebay locations for several hours to days at elevated gas levels. The use of a 12-hour average, rather than a 24-hour average, was chosen to provide a conservative measure of total dissolved gas.

Since 1995, the annual monitoring of TDG has been according to the guidelines established in the 1994-1998 Biological Opinion. However, as stated previously, the use of the forebay and Camas/Washougal sites have been problematic since the beginning of the program. In 2000, NOAA Fisheries addressed the concern regarding forebay monitors and included in their Biological Opinion a reasonable and prudent alternative (RPA 132), which states “The Action Agencies shall develop a plan to conduct a systematic review and evaluation of the TDG fixed monitoring stations in the forebays of all the mainstem Columbia and Snake river dams (including the Camas/Washougal monitor)…The Action Agencies shall conduct the evaluation and make changes to the location of the fixed monitoring sites, as warranted, and in coordination with the Water Quality Team.” The COE conducted several tests at project forebay FMS stations in the lower Snake and Columbia rivers and found that several stations experienced thermally induced TDG pressure spikes during the test periods indicating down welling of warm surface waters, resulting in non-representative spiking of TDG (Carroll, 2004).

Based on a study conducted for RPA 132, the COE recommended the relocation of several monitors to address the impact that the daily spike in temperature had on TDG readings. The monitors were relocated upstream of the dam face and the transducers were placed deeper in the water column where daily spikes in temperature were supposed to be minimized. However, based on the three separate analyses that were conducted by the Fish Passage Center (September 29, 2006 memo to Fish Passage Advisory Committee) (Attachment 2), it was concluded that forebay monitors still do not accurately reflect the TDG of mixed waters and continue to be impacted by localized processes. Measures (relocation) taken under RPA 132 to assure that the forebay monitors were representative of mixed water at several of the projects did not achieve that objective.

2. **Spill Restriction Based on the Forebay Monitoring Requirement**

Spill amounts were included in the 2000 Biological Opinion and reiterated in the 2004 Biological Opinion that were part of a suite of measures designed to meet viability standards under the Endangered Species Act. The following table shows the spill amounts that were modeled for the 2000 BIOP spill measures compared to pre-season spill amounts estimated for 2006 (2006 Water Management Plan) and for 2007 (Draft 2007 Water Quality Plan) using the 115% forebay and 120% tailrace criteria, and to spill amounts that would be provided based on a 120% tailrace criteria using 2006 flow data if the 120% tailrace reading was the point of compliance (FPC memo to FPAC, September 29, 2006). From the table it can be seen that the pre-season estimates of spill amounts in 2006 and 2007 were less than that assumed in the 2000 BIOP especially for Snake River projects. Spill amounts would approach the assumed BIOP amounts if spill was managed based on tailrace 120% TDG criteria.
Table 1. Spill amounts (kcfs) assumed in modeling for 2000 BIOP, estimated spill amounts for 2006 and 2007 to meet 115% forebay/120% tailrace TDG criteria, and estimated spill amount to meet 120% tailrace criteria using 2006 flow data.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LGR</td>
<td>60</td>
<td>42</td>
<td>40</td>
<td>54</td>
</tr>
<tr>
<td>LGO</td>
<td>45</td>
<td>32</td>
<td>20</td>
<td>51</td>
</tr>
<tr>
<td>LMN</td>
<td>40</td>
<td>40</td>
<td>25</td>
<td>39</td>
</tr>
<tr>
<td>IHR</td>
<td>105N/45D</td>
<td>105</td>
<td>95</td>
<td>76</td>
</tr>
<tr>
<td>MCN</td>
<td>135 (120-150 range)</td>
<td>155</td>
<td>170</td>
<td>179</td>
</tr>
<tr>
<td>JDA</td>
<td>85 Kcfs or 60% (70-100)</td>
<td>95</td>
<td>110</td>
<td>133</td>
</tr>
<tr>
<td>TDA</td>
<td>230 or 64%</td>
<td>91</td>
<td>110</td>
<td>147</td>
</tr>
<tr>
<td>BVL</td>
<td>135 (120-150)</td>
<td>100</td>
<td>115</td>
<td>101</td>
</tr>
</tbody>
</table>

Over the past several years, (Table 2) there have been several instances where TDG levels were exceeded at the forebay monitors, while the upstream tailrace monitors were in compliance. During spring 2002-06 at Snake River projects and McNary, exceedences of forebay criteria constituted a high proportion of total exceedences and proportion of days where the forebay monitor was in exceedence but the upstream tailrace monitor was not (Table 2). This table includes all days when monitors were exceeded and does not distinguish between controlled and uncontrolled spill. In addition, there were times when actions were taken to decrease spill when possible if forebay monitors exceeded the 115%, while tailrace monitors below the upstream project did not exceed 120%.
Table 2. Total number of exceedences per year and proportion of total where forebay exceeded 115% and tailrace did not exceed 120%.

<table>
<thead>
<tr>
<th>Project Forebay</th>
<th>Total Number of Exceedences in Spring Spill Season (Apr 3-June 20 Snake R.; Apr 20-June 30 Columbia R.)</th>
<th>Number of Days that Forebay was in Exceedence but Upstream Tailrace was Not</th>
<th>Proportion of Total Exceedences where the Forebay was in Exceedence while Tailrace was Not</th>
</tr>
</thead>
</table>

* Data for 2001 and/or 2005 missing for sites where no exceedences were recorded during spring spill season.
3. Biological Rationale

A. TDG and Fish Physiology

The potential for adverse effects of dissolved gas to Columbia River aquatic species may seem complex but is fairly easy to understand. The gases of concern are those comprising the atmosphere on earth, i.e., 80% nitrogen, 20% oxygen and a few trace gases. The presence of dissolved gases is measured by the pressure they exert, measured in mm Hg. The measured pressures are compared to atmospheric pressures. If there is more gas in the water due to spill at hydroelectric projects or due to many other causes than the gas pressure (atmospheric) at the surface of the water, then it is referred to as supersaturated and the percentage above the atmospheric pressure is calculated.

Several environmental factors affect the solubility of the composite gases of air. If there are changes in these factors it alters the pressures exerted by those gases, thus, can affect the degree of saturation. Increasing water temperature, falling barometric pressure, and biological activity (respiration) cause an increase in the partial pressures of the individual dissolved gases. Decreasing water temperature, photosynthesis, and a rising barometer have the opposite effect. Wind, although it does not affect gas physics, can decrease the amount of gases in river water by stripping it at the surface. When evaluating the gas level due to one factor, e.g., spill, the other factors must be considered.

Table 3 shows the dramatic influence environmental factors, e.g., water temperature, dissolved oxygen, barometric pressure, wind, photosynthesis, and biological respiration may have on the TDG measurements recorded in a monitoring program. Of great significance to management of voluntary spill is the length of time that elapses from the instant of spill and the TDG measurement. The table portrays the labile nature of TDG measurements. The table information represents changes in measurements that occurred in the 25 mile transit from Bonneville Dam to the Camas/Washougal monitor. The table shows that monitors located miles downstream of the spill site could on a calm warm afternoon during the spill season yield a TDG measurement that has a 5-6% error due to environmental factors. Management to the forebay monitor readings of TDG would result in a reduction of spill, while the tailrace of the upstream project was in compliance.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Change</th>
<th>Units</th>
<th>TDG Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Temperature</td>
<td>Increase</td>
<td>1 °C</td>
<td>~3.0 °</td>
</tr>
<tr>
<td>Barometer</td>
<td>Increase</td>
<td>7-8 mm Hg</td>
<td>~1.0%</td>
</tr>
<tr>
<td>Photosynthetic</td>
<td>Increase</td>
<td>1 mg/l</td>
<td>~2.0%</td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>Decrease</td>
<td>18 mph</td>
<td>~5.3%</td>
</tr>
</tbody>
</table>
Aquatic organisms living in a supersaturated river, depending on dissolved oxygen for their metabolic oxygen will tend to come into an equilibrium state with the level of dissolved gases surrounding them. As long as the organism remains in a physical environment that maintains the dissolved gas within it tissue to be equal to the dissolved gases in the water, no gas bubbles can form. For example, as long as the organism remains at adequate depth, benefiting from the hydrostatic pressure, the gases in its tissues will remain at equilibrium. However, if the organism ascends or sounds the gas balance will reflect the pressure change. Ascent will place the organism tissues in an unsteady, supersaturated state. The tissue gases tend to return to a gaseous phase as bubbles and blisters referred to as GBT. Sounding will increase the solubility of the gases and serve to protect the organism.

Dissolved gas affects all aquatic biota similarly, whether salmonids, resident fish or invertebrates. The biological effect is a function of dose response as moderated by hydrostatic pressure, that is, depth. Each meter of depth equates to 10% of depth compensation. This means that the organisms’ depth determines the biological effect of exposure to water supersaturated with atmospheric gas. If the Corps’ Fixed Monitoring Station records a gas level of 120% supersaturation, it is referring to a gas level relative to water surface pressure. This same gas content at 1 m is only 110% supersaturated due to the compensatory influence of hydrostatic pressure. At 2 m it is in equilibrium, i.e., it is no longer supersaturated. The same is true of fish or invertebrate tissue levels of gas. If the fish or invertebrate tissues are equilibrated with the ambient level of dissolved gas and the water total dissolved gas is 120% relative the surface, the organisms cannot develop GBT if they are at 2 meters or more in depth. In short, GBT is the result of uncompensated hyperbaric pressure of TDG (see Figure 1). It is the same for all fish, salmonid or resident species, as well as invertebrates. Beeman and Maule (2006) found that juvenile salmon and steelhead hydrostatic compensation resulting from migration at depth in the water column was sufficient to protect them from gas bubble disease during the controlled fish spill program.

The dose response effect is a function of the difference in gas pressure in the water compared to organism tissue level. If a fish is at equilibrium with water at surface atmospheric pressure (100%) the fish gas physiology is stable. If the fish moves into water with a level of supersaturation the greater the supersaturation the more rapid will be gas uptake by the fish or other aquatic organism. The greater the differential between water TDG and tissue TDG the more rapid will be the tissue uptake of gases. At this point one needs to consider depth compensation, which is the effect of pressure on the potential for development of GBT (Figure 1). A fish with tissue gas levels equal to 130% supersaturation at the surface will not show GBT as long as it stays below 2m from the surface where its tissue will only be 110% supersaturated.
B. Biological Monitoring

Juvenile Salmonids

Since 1995, the biological monitoring program has recorded annually the effects of the FCRPS biological opinion spill program and effects of TDG on incidence of GBT. The data observed over the years through the biological monitoring has consistently shown very low incidence of GBT when gas levels are at the 120% tailrace criteria. When fish are exposed to gas levels greater than 120%, there is an increasing trend in incidence and severity of these signs (Figure 2). For all fish examined through the Smolt Monitoring Program for signs of GBT when tailrace TDG levels were 120% or less the incidence of any fin signs observed in that population was 0.5%. This demonstrates a minimal effect of biological opinion spill levels over the last 11 years with TDG levels managed to 120% in the project tailrace. The percentage of fish with severity of GBT symptoms begins to increase above 120% and then dramatically increases above 125%.

The 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) and the NMFS’ 2000 Biological Opinion for the Federal Columbia River Power System (NMFS 2000) found that dissolved gas levels of 120% saturation 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% saturation Backman et al. 2002a.2

---

2 These researchers found that Gas Bubble Trauma was not detected in most of in-river migrants sampled from 1996-1999. This included fish sampled during two very high flow years where spill was at uncontrolled levels through the Federal Columbia River Power System.
Adult Salmon

Adult salmonids were monitored for signs of GBT through the 1999 spill season. Few signs of GBT were observed at TDG levels within the waivers. Additionally, juveniles are more susceptible to GBT, and if they are being monitored adequately the adults will also be protected (L. Marsh, Oregon Department of Environmental Quality, memorandum to the Environmental Quality Commission, March 27, 2000). Physical handling of adults adds extra stress.

Backman and Evans (2002b) found that in samples of 4,667 adult chinook salmon, fish were rarely observed with gas bubble trauma, despite sampling large numbers when total dissolved gas exceeded 130% saturation. Specifically, Backman and Evans (2002b) found no statistically significant relation between total dissolved gas and gas bubble trauma for chinook salmon. For adult sockeye and steelhead, Backman and Evans (2002b) found that most gas bubble trauma symptoms were minor (>5% fin occlusion) with severe bubbles (>26% fin occlusion) being observed only when total dissolved gas exceeded 126%.

Resident Fish and Invertebrates

The requested TDG variance is expected to have minimal impacts on resident fish or macro invertebrates in the Columbia River. The NMFS monitored resident fishes and aquatic invertebrates in the Columbia River downstream from Bonneville Dam for signs of GBT in 1993, 1994, 1995, and 1996. Organisms sampled included northern pikeminnow, bass, perch, catfish, crappie, sturgeon, shad, suckers, chub, sculpins, sticklebacks, minnows, crayfish and other crustaceans, clams, snails, and insects. Sampling in 1993 revealed a very low incidence of GBT in prickly sculpin (0.6%; 1 of 174 fish); peamouth chub, (0.4%; 1 of 238 fish); and threespine stickleback (0.2%; 2 of 906 fish). No signs of GBD were seen in the three species of invertebrates (crayfish, Asian clam, and dragonfly larvae) that were examined (Toner and Dawley, 1995). In 1994, no signs of GBT were observed in any of the 4,955 resident fish or 3,928 invertebrates that were examined (Toner et al., 1995). During 1995, signs of GBT were noted in five species of resident fish, but never exceeded 1% of those fish examined (Dawley and Schrank, 1995).

In 1997, resident fish were collected and examined for the TDG biological monitoring program in the Columbia River. Fish that were examined included peamouth, largescale sucker, mountain whitefish, northern pikeminnow, stickleback, redside shiner, sculpin, sandroller, pumpkinseed, and carp. A total of 214 individual fish of these resident species were examined for external signs of GBD. No signs of GBT were seen on any of those fish.

In 1998, only largescale suckers and mountain whitefish were examined. No signs of GBT were observed in these fish. In 1999, largescale sucker, northern pikeminnow, stickleback and sculpin were examined. Again, no signs of GBT were observed.

In addition, many of these resident species occupy shallow near shore areas that are out of the main current of the Columbia River. Such areas typically have lower total dissolved gas concentrations than those in the main current. Toner et al. (1995) indicated that the lower TDG levels in the shallow backwater and shoreline areas may be due to the lack of exchange with
higher TDG water in the main river. Faster dissipation of gas from shallow water was also thought to occur because of its higher surface area to volume ratio.

Ryan et al. (2000) found only 3.9% of the almost 40,000 non-salmonid resident fish sampled (27 species) in the mid-Columbia and lower Snake rivers, Washington, showed signs of GBT during spring spill periods in 1994-1997, with TDG reaching above 135%. They concluded that GBT signs were rare in non-salmonid resident fish when TDG levels were less than 120%. Signs of GBT were rare with the invertebrate samples taken.

In work conducted with resident fish behavior relative to TDG supersaturation in the Lower Clark Fork River in Idaho, Weitkamp et al. (2003a) concluded that the fish behavior of the resident fish greatly influenced the degree of supersaturation the fish actually experience. In further work on the Lower Clark Fork River, Weitkamp et al. (2003b) found that the occurrence and severity of GBT was greatly lower than expected for the TDG levels measured (120-150%). Their conclusion was "... the majority of fish are spending sufficient time at depths that avoid or mediate both the incidence and severity of GBT when TDG supersaturation is in the range of 120-130% of saturation."

![Figure 2](G:\STAFF\DOCUMENT\2007 Documents\2007 Files\16-07.doc)

**Figure 2.** Percentage of all fish examined for GBT at Little Goose, Lower Monumental, McNary and Bonneville dams from 1995 to 2005 that showed GBT symptoms in fins by severity rank and TDG exposure based on upstream tailwater monitor and fish travel time from that site. Fin ranks are: rank 1 – less than 5% fin area covered with bubbles, rank 2 – 5 to 25%, rank 3 – 26 to 50% and rank 4 – greater than 50%.
C. Fish benefits from maintaining spill at the 120% tailrace level.

Spill is a key measure in NOAA Fisheries Biological Opinions to mitigate for the construction and operation of the Federal Columbia River Power System. Several efforts have been undertaken to provide the benefit of spill in terms of fish survival, however it is impossible to adequately determine the direct and indirect effects of spill on survival with existing tools and data. Most biological models rely on monthly time-steps and average fish numbers that make it extremely difficult to capture the effects of changing daily spill management and other conditions affecting fish survival. In addition, the current state of knowledge of the benefit of spill beyond project passage and delayed effects is continually developing. The benefits of spill include the following:

- Spill provides a non-turbine, non-bypass route of passage past a hydroelectric project that has a higher associated juvenile survival benefit than turbine and screened system passage routes (NOAA 2000a). In addition, recent data suggests there may be some delayed effects of hydrosystem passage especially with bypass routes that are not manifested in juvenile survival. These effects show in smolt to adult survival rates and are due to passage through the hydrosystem. Passage through multiple bypass systems seems to exacerbate the issue reinforcing the positive benefits of spill.
- Since fish transportation does not provide a positive benefit for all species, the agencies and tribes recommend a spread-the-risk management strategy to allow 50% of the fish to migrate in-river primarily through spill and/or other surface passage routes. The effectiveness of the hydro projects at collecting fish and low current spillway passage efficiency makes it difficult to achieve this objective and in most years significantly more than the 50% of fish are transported. In the interim, spill is the primary means to achieve the spread-the- risk management strategy.
- Spill decreases forebay residence time, decreases migration rate (or travel time) and increases survival. Decreasing travel time has been shown to decrease exposure time to in-river predation. Also, survival to adult is increased when travel time is decreased and fish arrive at the estuary during the "optimal" biological window (Marmorek et al. 2004; Williams et al.).
- Turbulence in tailraces from spill disperses predators and improves survival through this area.

While it is impossible to quantify and represent the total benefit of spill, it is possible to estimate improvements that can be made in increasing spillway passage the route of passage that has been shown to provide the highest survival of any passage route at Columbia and Snake River dams. To illustrate this, we compared the number of fish that would be passed via spillways when spill is implemented under the Court Order spill as was done in 2005 and 2006 where spill was managed to 115/120% TDG criteria to that if the Court Order spill was managed only to the 120% tailrace TDG.

The daily fish collections from the smolt monitoring program, the actual spill that occurred in 2006 and the estimates of the spill passage efficiency (SPE) from the NOAA National Marine Fisheries Service COMPASS model (for Snake River Spring Chinook and Steelhead) were used to obtain daily population estimates. Two different spill levels were
applied to the daily population estimates at each project where smolt monitoring data was available from 2006. The first spill level represents the amount of spill that would have occurred in 2006 managing to the 115/120% TDG levels (after involuntary and excess hydraulic capacity were removed, see Attachment 2, September 29, 2006 Spring Spill 2006 memo for a full description of how these numbers were derived) and the second spill level represent an estimated spill that would have occurred if spill were only managed to the 120% tailrace criteria. Again, the SPE used in this portion of the analysis was from the NOAA Fisheries COMPASS model.

As can be seen in the following table, managing spill to a 115% forebay/120% tailrace TDG criteria can result in substantially fewer fish passing over the spillway at many projects as compared to managing spill based on 120% tailrace TDG criteria. The greatest effect would occur at Little Goose Dam with over 18% fewer yearling chinook passing in spill.

Table 4. Estimated percent increase in numbers of fish passing in spill when Court ordered spill is managed to the 120% tailrace TDG.

<table>
<thead>
<tr>
<th>Project†‡</th>
<th>Number of Fish Passing Through Spill (under 2006 operations to 115/120% with over-generation and excess hydraulic capacity spill removed)</th>
<th>Number of Fish Passing Through Spill (using spill cap of 120% TDG at tailrace as estimated in Spring 2006 memo)</th>
<th>Percent Change (c)</th>
</tr>
</thead>
</table>
| Lower Granite | Yearling Chinook: 1,996,987  
      Steelhead: 5,623,601                                                                                                           | Yearling Chinook: 1,996,987  
      Steelhead: 5,623,601                                                                                                           | 0.00  
      0.00 |
| Little Goose | Yearling Chinook: 1,233,733  
      Steelhead: 1,242,498                                                                                                           | Yearling Chinook: 1,459,566  
      Steelhead: 1,409,044                                                                                                           | 18.30  
      13.40 |
| Lower Monumental | Yearling Chinook: 2,443,704  
      Steelhead: 2,287,001                                                                                                           | Yearling Chinook: 2,824,271  
      Steelhead: 2,563,396                                                                                                           | 15.57  
      12.09 |
| McNary       | Yearling Chinook: 1,159,564  
      Steelhead: 292,327                                                                                                              | Yearling Chinook: 1,163,128  
      Steelhead: 292,916                                                                                                              | 0.31  
      0.20 |
| Bonneville   | Yearling Chinook: 1,673,950  
      Steelhead: 164,399                                                                                                               | Yearling Chinook: 1,796,918  
      Steelhead: 171,120                                                                                                               | 7.35  
      4.09 |

* Ice Harbor and The Dalles are not Smolt Monitoring Program sampling sites and, therefore, fish abundance data were not available for this analysis  
† John Day not included in this analysis due to difficulties in estimating spill relative to the court order (see attached Spring Spill 2006 Memo for details)

From the table it is apparent that at some projects there could be significant gain in the number of fish passing over the spillway if TDG management is based on tailrace monitoring. Comparable data for 2006 is not available at John Day due to unreliable fish passage data due to unplanned powerhouse unit outages. However, it should be noted that based on TDG monitoring that spill at all lower Columbia River projects is often constrained by forebay TDG monitoring.
and it is highly likely that similar increases in spillway passage would be observed at these projects if spill was managed based only on tailrace monitoring.

The current spill program, limited by forebay monitors, is unable to achieve a spread the risk management strategy with regard to the transportation program for Snake River migrants and in-river migrants. Reductions in the spill program caused by the forebay monitors impacts the ability to keep migrants from being collected and transported. Currently the majority of both Snake River Spring Chinook and Steelhead are transported rather than allowed to migrate in river. Due to concerns with screened bypass systems the default operation is to transport fish that are collected and not return them to the river. The best available scientific information indicates that spillway passage is more likely to increase adult return rates as compared to bypass passage. For example: The 2005 NMFS technical memorandum on the effects of the federal Columbia River power system on salmonid populations contained the following pertinent information. In figures 53 & 54 on pages 112 & 113 this report shows the relative SARs between smolts migrating uncollected (primarily through spill) at collector projects and those bypassed. Smolts with only one bypass history had an average SAR 25% less than those migrating uncollected, and in almost half of these comparisons the difference was significant. Therefore the only way to insure a spread the risk strategy for transported migrants versus in-river occurs, is to pass fish over the spillways and through surface spill routes such as the Removable Spillway weirs. Table 5 indicates the recent percentages of juveniles transported. By using the tailrace monitors to govern the spill program closer to 50% of the migrants will be left to migrate in river. Modeling indicates in years when spill is provided at the collector projects ~5-15% more juveniles would be left to migrate in river than transported. The increase in percent of in river migrants varies from year to year given the different flow years and the shape of the run-off and how it impacts TDG readings.

Table 5. Estimated proportion of fish transported from 1999-2006.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yearling Chinook</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>.61 (H)</strong></td>
<td>.58 (W)</td>
<td>0.92</td>
<td>0.87</td>
<td>0.629</td>
<td>0.683</td>
<td>0.98</td>
<td>0.71</td>
<td>.777 (H)</td>
</tr>
<tr>
<td><strong>Steelhead</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>.76 (H)</strong></td>
<td>.79 (W)</td>
<td>0.94</td>
<td>0.964</td>
<td>0.67</td>
<td>0.677</td>
<td>0.986</td>
<td>0.81</td>
<td>0.825</td>
</tr>
<tr>
<td><strong>Subyearling Chinook</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>.56 (H)</strong></td>
<td>.52 (W)</td>
<td>0.809</td>
<td>0.972</td>
<td>0.895</td>
<td>0.929</td>
<td>0.962</td>
<td>0.93</td>
<td>0.87</td>
</tr>
</tbody>
</table>

*Spill at the collector projects, (Lower Granite, Little Goose, Lower Monumental, McNary) was not provided in these years.

**Court Ordered Spill Operation

4. Summary

In conclusion, it must be acknowledged that there are problems with managing spill based on forebay monitoring due location of monitors and confounding effects of other environmental variables, therefore, we recommend managing fish spill and total dissolved gas based on 120% TDG measured in dam tailraces as the sole criterion. The fishery agencies and
tribes’ “Spill and 1995 Risk Management” assessment originally established a range of 120-125% TDG as the transition zone where the effects of TDG would be increasing, but still very low. This has been reaffirmed by 1) the updated Risk Assessment for the Spill Program in the NOAA 2000 FCRPS Biological Opinion, 2) 12 years of physical and biological monitoring, 3) an independent scientific assessment and, 4) studies in the peer-reviewed literature. Nearly 200,000 salmonids have been evaluated for signs of GBT and less than 2% of those fish were observed with the most minor signs of GBT (less than 5% of a fin covered with bubbles) when spill levels were managed to 120% in the tailraces of dams. This is far less than the biological criteria established for the voluntary spill program of 15% of fish affected with minor signs. This shows that managing spill to 120% TDG criteria in the tailraces is conservative, and best protects the sensitive fishery existing and designated use of the Columbia River.

References


WDFW (Washington Department of Fish and Wildlife), ODFW (Oregon Department of Fish and Wildlife), IDFG (Idaho Department of Fish and Game), and CRITFC (Columbia River Inter-Tribal Fish Commission). 1995. Spill and 1995 risk management.


November 16, 2006

Mr. Rudd Turner
U.S. Army Corps of Engineers, Northwestern Division
P.O. Box 2870  attn: CENWD-PDD-A
1125 NW Couch St.
Portland OR 97208-2870

Dear Mr. Turner,

Thank you for the opportunity to review and comment on the draft report, Water Quality Plan for Dissolved Gas and Water Temperature in the Mainstem Columbia and Snake Rivers. We are providing these comments given the very short deadline that the COE has provided, however, we may have additional comments at a later date. In general, there has been concern raised over the last several years regarding the implementation of the Biological Opinion and Court Ordered Summer Spill Program under the existing 115/120% total dissolved gas guidelines and the configuration of the physical monitoring stations. The 2000 Biological Opinion addressed the concerns by developing RPA 132, which required the Action Agencies to develop a plan to conduct a systematic review and evaluation of the TDG fixed monitoring system in the forebays of all the mainstem Columbia and Snake river dams. The COE undertook the study and relocated some forebay monitors based on temperature related considerations.

The Fish Passage Advisory Committee asked the Fish Passage Center to conduct a review of the 2006 spring spill program and to review the appropriateness of the forebay monitoring system (FPC memo to FPAC dated September 29, 2006) relative to present water quality waiver requirements. Based on this review, the FPC concludes that the forebay monitors may not be adequately representing the total dissolved gas resulting from spill at upstream projects. Downstream forebay monitors, as presently configured, are not indicative of the readings in a well-mixed water column due to the local influence of temperature, barometric pressure and biological processes.

We believe that the COE should present the issues in the Water Quality Plan and discuss how TDG may be better monitored including, the possibility of setting the waiver criteria to 120% TDG at both the forebay and tailrace monitors based on the gas bubble trauma (GBT) monitoring program data collected over the past twelve years. These data show that the incidence of GBT is much less than 1% of fish sampled and the severity of the signs of GBT are mostly of the least severe Rank 1, where less that 5% of a fin is affected. The COE might also include the possibility of routinely monitoring the concentration of oxygen in the water column to distinguish the partial pressure of gas added to TDG from local biological processes.
The following are the Fish Passage Center’s specific preliminary comments:

1. Page 18, para 4 - Total Dissolved Gas (TDG) is the measure of the sum total of all gas partial pressures (including water vapor) in water. It is important to note both the relation of TDG with barometric pressure and temperature particularly at the forebay monitor locations, and the oxygen gas added to the water column by primary productivity. While oxygen can contribute significantly to the overall TDG concentration, it is not regarded as a problem for aquatic organisms since oxygen can be removed from tissues via metabolic activity.

2. Page 21, TDG Fixed Stations – Function and Location – The COE should include a discussion of the limitations of measuring only TDG in the complex situation where fixed monitors are located. In the tailrace fixed monitoring stations it is likely that the TDG measured represents the additional gas added to the water column due to spill, however, at the forebay sites the representation of the additional spill gas is confounded by other gases and physical changes. At the very least the COE should explore the possibility of measuring oxygen at these locations and consider only the partial pressures due to nitrogen increases when assessing against a 115% criterion.

3. Page 22-23. All of the language relative to RPA 132 has been stricken from the text. The COE concludes that the forebay monitor relocation has addressed the issue of misrepresenting the TDG due to spill, and that the only remaining issue that remains is the Camas/Washougal Monitor. While the use of the Camas/Washougal station remains an issue, the issue of the forebay monitors adequately representing TDG associated with upstream spill has not been adequately resolved for the agencies and tribes. The Fish Passage Advisory Committee requested that the Fish Passage Center conduct a review of the impact of the forebay monitors on the implementation of the Biological Opinion spill program. That review was provided in a memo to FPAC dated September 29, 2006 (attached). As a result of that review considerable questions remain concerning the adequacy of the forebay monitors. This section should be rewritten to express regional concern.

4. Page 75. The COE presents their perspective on current water temperature and the relation to historic temperatures. The COE clearly labels the discussion as their perspective and that is appropriate, however, it would be helpful to include alternatives to the COE’s perspective since this document talks about input from other entities.

5. Page 83. Section 13.1.3.4 – The reference to some regional interests suggesting that releases that approach 120% would make more sense in the COE included the years when Dworshak was operated to 120% and the results obtained from GBT monitoring that took place below the dam. The discussion would also benefit by including an explanation (i.e. the flexibility to augment flows with higher levels of flow augmentation from Dworshak Dam) when presenting regional interests’ suggestions. Additionally, this section should incorporate a discussion of possible modifications to Dworshak Dam that would help alleviate TDG concerns under spill conditions. For instance, are there possible spillway modifications that would decrease TDG.
6. Page 91. The paragraph relative to the merits of transportation should reflect current knowledge regarding the benefits of transportation to the overall survival of wild spring Chinook to return as adults. The results of the Comparative Survival Study shows no benefit of transportation to wild spring Chinook and only marginal benefit to hatchery spring Chinook relative to migrating in-river. Benefits of transportation may be better for hatchery and wild steelhead. The statement in the document regarding the negative impacts to the runs if transportation cannot be implemented need to be revised.

7. Page 96, third paragraph. The last sentence states that “These drawdown scenarios would be expected to decrease the amount of time that water is exposed to solar radiation, however because of the reduced volume of water, the peaks in temperature would be expected to be higher and the water in that stretch of the river would be expected to warm and cool much faster during the daily cycle.” The later part of this sentence is misleading and likely untrue. There is much more to consider when discussing peak temperatures. Of particular importance is the surface area of the water body, also the width to depth ratio of a particular stretch of water - wide and shallow stretches would heat and cool faster than a narrow and deep section.

8. Page 96. When discussing the drawdown of reservoirs the COE should also include discussion of an intermediate drawdown of JDA to MOP (approx. five feet lower than MIP).

9. Page 106, third paragraph. As an effect of changing flood control rule curves, the second sentence states “…if more water were used to flush fish out during the spring, decreased power production would result in the summer and fall.” Changing flood control rule curves should not impact summer water. The intent of changing of flood control rule curves would be to reduce winter and early spring power drafts, so reservoirs do not have to work as hard to get to their April 10th elevations. This would reduce power production in the winter and early spring months- not during the summer.

10. Page 106, third paragraph. Pushing more water out in the spring as a result of altered flood control does not necessarily mean more TDG. Changes in flood control would likely benefit juveniles the most during medium and low water years. It is unlikely that during these types of water years, even with more spring water, projects would be in a forced spill situation.

11. Page 124. The paragraph under 15.4.2 is the exact same paragraph that is under 15.3.2 on page 122.

Sincerely,

Michele DeHart
Fish Passage Center Manager
MEMORANDUM

TO: FPAC

FROM: Michele DeHart

DATE: September 29, 2006

RE: Spring Spill 2006

The Fish Passage Advisory Committee requested that the Fish Passage Center conduct an evaluation of the spill that occurred this past spring in the Federal Columbia River Power System (FCRPS). The FCRPS spring spill program was provided in response to the 9th Circuit Court’s Order for spill and, therefore, the analysis conducted was in the context of the Court Order. In general, the Court’s Order was implemented appropriately, but conservatively, within the present guidelines for total dissolved gas (TDG) management. The question arises as to whether the original criteria established in 1995 for total dissolved gas management remain appropriate given the additional knowledge gained since that time.

There were several key points that came from this analysis:

1. The actual spill that occurred (when excess hydraulic capacity and spill in excess of market capacity, or spill due to turbine unit outages, were removed) was considerably less than what could have occurred under the Court’s Order (about 4.1 MAF) if TDG were managed to the tailrace monitor.
2. The amount of spill varied from project to project; with a few key projects having the greatest limitation on spill (Lower Monumental, The Dalles, Bonneville and Little Goose) based on the downstream forebay monitor readings.
3. The reason why the spill was significantly less at some projects lies partly due to the real time management of spill to total dissolved gas measurements at the tailrace, but is most significantly related to the management of spill to downstream forebay TDG levels.
4. The use of downstream forebay monitors for measuring dissolved gas relative to spill needs to be addressed. Downstream forebay monitors, as presently configured, are not
indicative of the readings in a well-mixed water column due to the local influence of
temperature, barometric pressure and biological processes.

5. In season management of total dissolved gas during periods of overgeneration spill must
be managed with consideration of biological objectives, rather than to dissolved gas
objectives alone.

Assessment of Spill for Spring 2006

Appendix A contains graphic representations of the actual spill that occurred in the spring
of 2006 relative to the Court’s Order. From the graphs it can be seen that spill occurred in three
distinct time periods, first when flows were manageable, second when flows exceeded hydraulic
capacity of the projects and third, when flows were manageable at most project’s but spill was
high due to a lack of market for the electricity. When flows were less than powerhouse capacity,
spill was managed to the waiver requirements of 120% total dissolved gas in the tailrace and
115% total dissolved gas in the next downstream forebay monitor. At some projects spill
exceeded the Court Order due to project limitations e.g. Lower Granite had a limited hydraulic
capacity throughout the season due to a turbine unit outage and spill exceeded the Court Order
most of the time. In the later part of May, flows peaked in the Snake River and all the projects
exceeded the Court Order. Subsequent to this period, extremely high volumes of spill occurred
during nighttime hours due to excess market capacity spill and management actions that limited
spill during daytime hours to meet water quality waivers.

In order to develop an assessment of spill relative to the Court order the volume of spill
was calculated in several ways. The first was to determine the maximum amount of spill that
could have occurred if the Court Order were fully implemented without any total dissolved gas
restrictions, or in the case of projects that are to spill to the gas caps, spill was calculated to the
tailrace value of 120% (a). Then the actual volume of spill that occurred was calculated (b). This
volume did not include any involuntary spill, or spill that was in excess of the court order. This
excess spill occurred due to project capacity limits (flow in excess of hydraulic capacity or
limited hydraulic capacity due to unit outages) or due to overgeneration or lack of market spill.
The difference between what actually occurred and what could have occurred under the Court’s
order without gas restrictions was determined (c). The next calculations considered what could
have been spilled if the Court ordered spill program were only managed to the tailrace 120%,
rather than to both the tailrace and the downstream forebay monitors (d). The difference
between the Court Ordered spill and what could have occurred if tailrace monitors were used is
calculated as the potential difference (e). John Day Dam was excluded from the analysis this
year. The T1 line outage at John Day Dam reduced hydraulic capacity resulting in tailrace
egress conditions that were not particularly good for fish passage. To address this line outage,
the Salmon Managers requested that John Day Dam operate as close to 40% spill around the
clock, as possible, to address fish passage concerns. Consequently, it is impossible to evaluate
the spill that occurred relative to the Court’s Order.

From the following table it is estimated that spring spill during 2006 was approximately
4.4 MAF less that what was expected under the Court’s Order if TDG was not a constraint. This
was primarily a result of in-season management to the downstream forebay total dissolved gas
monitors. This was an appropriate management of the system under the present dissolved gas
waiver criteria established by the States’ water quality agencies. However, from the second part
of this exercise it can be observed that if the tailrace monitor were used for in-season
management (rather than both the forebay and tailrace) then the volume of spill (4.1 MAF) would have been substantially greater than would have occurred under the present management due to higher gas cap spill levels (Table 2). This would have provided additional survival benefits to migrating salmonids by increasing the number of fish that passed a project via spill. Biological monitoring when TDG is managed to 120% in the tailrace continues to show little impact to populations at this TDG concentration. Consequently, since the forebay monitors are limiting the fish mitigation measure, then it must be explored if the present TDG management criteria are appropriate.

<table>
<thead>
<tr>
<th>Site</th>
<th>Volume Court Order Spill (Kaf) (a)</th>
<th>Volume Actual 2006 Spill (not including involuntary spill or spill greater than court order) (Kaf) (b)</th>
<th>Difference (c)</th>
<th>Volume Spill at 120% TDG @TW Limited by 2006 Court Order (d)</th>
<th>Potential difference if managed to 120% TR (Kaf) (e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Granite</td>
<td>3134</td>
<td>3134</td>
<td>0</td>
<td>3134</td>
<td>0</td>
</tr>
<tr>
<td>Little Goose</td>
<td>5810</td>
<td>5141</td>
<td>669</td>
<td>5774</td>
<td>36</td>
</tr>
<tr>
<td>Lower Monumental</td>
<td>6268</td>
<td>4687</td>
<td>1581</td>
<td>6111</td>
<td>157</td>
</tr>
<tr>
<td>Ice Harbor</td>
<td>8165</td>
<td>8012</td>
<td>153</td>
<td>8165</td>
<td>0</td>
</tr>
<tr>
<td>McNary</td>
<td>15661</td>
<td>15374</td>
<td>287</td>
<td>15632</td>
<td>29</td>
</tr>
<tr>
<td>John Day**</td>
<td>18341</td>
<td>17993</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Dalles</td>
<td>18016</td>
<td>16965</td>
<td>1051</td>
<td>17936</td>
<td>80</td>
</tr>
<tr>
<td>Bonneville</td>
<td>14281</td>
<td>13585</td>
<td>696</td>
<td>14281</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>4437</td>
<td></td>
<td></td>
<td></td>
<td>302</td>
</tr>
</tbody>
</table>

** John Day not included in total Kaf calculation.

Table 1. Volume calculation for spill in 2006 that would have occurred if the Court Order were fully implemented (i.e. no TDG restriction) (a), that volume that did occur voluntarily (b), and the volume that could have occurred if the Court order were managed using tailrace monitors only (d).

<table>
<thead>
<tr>
<th>Project</th>
<th>Spill (Kcfs) if Gas Cap Managed to Project Tailrace Monitor (120%)</th>
<th>Spill (Kcfs) if Gas Cap Managed to Downstream Forebay Monitor (115%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Granite</td>
<td>54.1</td>
<td>53.1</td>
</tr>
<tr>
<td>Little Goose</td>
<td>50.7</td>
<td>30.2</td>
</tr>
<tr>
<td>Lower Monumental</td>
<td>39.0</td>
<td>29.5</td>
</tr>
<tr>
<td>Ice Harbor</td>
<td>76.2</td>
<td>63.5</td>
</tr>
<tr>
<td>McNary</td>
<td>179.2</td>
<td>161.1</td>
</tr>
<tr>
<td>John Day</td>
<td>133.5</td>
<td>131.0</td>
</tr>
<tr>
<td>The Dalles</td>
<td>147.0</td>
<td>122.2</td>
</tr>
<tr>
<td>Bonneville</td>
<td>101.3</td>
<td>113.3</td>
</tr>
</tbody>
</table>

Table 2. Gas cap estimates generated based on regressions between spill volumes and tailrace TDG or in the next downstream forebay for the Spring 2006 data.

Spill, TDG Supersaturation, and Monitoring
Supersaturation occurs when a solution contains more of the dissolved material than could be dissolved by the solvent under normal circumstances. Dissolved gas supersaturation in the Columbia and Snake rivers routinely occurs during the spring and summer freshet as a result of water spilling over dams. Total Dissolved Gas (TDG) is the measure of the sum total of all gas partial pressures (including water vapor) in water. TDG can be reported as an absolute overall dissolved gas pressure or relative to atmospheric pressure. Gas bubbles can form in the blood and tissues of aquatic organisms when water becomes supersaturated with gas. This results in “Gas Bubble Disease” in the affected organisms. Gas Bubble Disease can, in turn, cause rapid acute mortality as well as increase long-term mortality in aquatic organisms.

The original waiver criteria for TDG were established in 1994. This was the first time a waiver had been requested from the water quality agencies for variation from the national standard with the intent of providing survival benefits to migrating juvenile salmonids through additional spill passage. A literature review of past experiments (Spill and 1995 Risk Management) had suggested that 125% TDG levels might still have provided the benefits of spill, but to err on the conservative side a target of 115% in the mixed waters of the forebay and 120% total dissolved gas in the tailrace was adopted. These criteria have been in-place since 1994 along with a biological monitoring program to assess the impacts of the controlled spill program.

For all spills, the highest TDG levels, and therefore the area most likely to exceed standards, are directly below the spillway. In this area, the plunging and air entrainment of the spill (aerated zone) generates high levels of TDG, but then quickly degasses while the water remains turbulent and full of bubbles. However, as this water moves from the stilling basin into the tailrace, degassing slows and the TDG levels stabilize. In the pools, gas exchange rates increase as wind speeds rise, which produces degassing, particularly if breaking waves result. At the next downstream project water should be well mixed and TDG levels much reduced.

However, if wind speeds are still and TDG concentrations are not being increased because of spill, the percent saturation of TDG can increase if the water temperature increases or barometric pressure drops, or if primary productivity (periods of algal growth) occurs. It is important to note that the gas added to the water column by primary productivity is oxygen, and while it contributes to the overall TDG concentration, it is not regarded as a problem for aquatic organisms since oxygen can be removed from tissues via metabolic activity.

**Efficacy of forebay monitoring**

The goal of the spill program is to provide benefits to migrating juvenile salmonids, while not imposing harm from exposure to dissolved gas that outweighs the benefits of spill. The project forebay TDG monitors were originally intended to represent a mixed cross section in the river just upstream of the dam. The tailwater instruments are located nearer the projects, often in spillway releases downstream of aerated flow, and prior to complete mixing with powerhouse releases. The ability to adequately monitor TDG is extremely important and the question of whether, or not, the forebay monitors reflect the actual picture of the potential harm that could occur from TDG has been a question from the beginning of the monitoring program. While the tailwater instruments are also affected to some degree during periods of non-spill by the same processes that cause the forebay monitors to measure TDG levels above 100%, the physical process of spilling water sufficiently mixes the water column such that the tailwater monitors adequately represent the mixed water column measurement of TDG due to spill.
In 2000 NOAA Fisheries addressed the concern regarding forebay monitors and included in their Biological Opinion a reasonable and prudent alternative (RPA 132), which states “The Action Agencies shall develop a plan to conduct a systematic review and evaluation of the TDG fixed monitoring stations in the forebays of all the mainstem Columbia and Snake river dams (including the Camas/Washougal monitor)…The Action Agencies shall conduct the evaluation and make changes to the location of the fixed monitoring sites, as warranted, and in coordination with the Water Quality Team.” All of the project forebay FMS stations were problematic in that each experienced thermally induced TDG pressure spikes during the test periods indicating downwelling of warm surface waters, resulting in non-representative spiking of TDG (Carroll, 2004).

In October 2004 the COE presented the results of the RPA 132 study (Carroll 2004) conducted relative to the forebay monitors and the recommendation for relocating these monitors. In RPA 132 the COE used temperature to define surface water and the potential for monitors to measure surface rather than mixed water. Routine spikes in daily water temperature were strongly associated with the daily spikes in TDG. The COE recommended the relocation of several monitors to address the daily spike in temperature. The monitors were relocated upstream of the dam face and the transducers were placed deeper in the water column where daily spikes in temperature were minimized (Appendix B).

**Did the COE’s Relocation Lead to More Accurate Monitoring?**

In order to assess whether the relocation of TDG monitors addressed the problem associated with forebay monitoring identified in RPA 132, an analysis of the data collected before and after relocation was developed. The analysis addressed the variation in TDG due to processes other than spill (i.e. primary productivity, barometric pressure and temperature). The data used for the analysis were the TDG measurements that were taken during periods when spill was not occurring in the hydrosystem. In these data the variation in TDG observed would be a function of daily variations in temperature, barometric pressure and in biological processes. To investigate the variation in total dissolved gas (TDG) levels when no spill occurred, the corresponding TDG, flow, and spill data were collected for each of the following forebay monitors: Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, Bonneville, and Camas/Washougal. To minimize the effects of any spill that might have occurred, the analysis focused on three time relatively spill free periods and removed any TDG data that could have potentially been affected by spill. The data were evaluated for removal from the data set based on the lag time (water transit time) between projects and review of the potential for any data point being affected by spill at upstream projects, as well as TDG monitor malfunctions.

The first no-spill time period was during the weeks prior to the implementation of voluntary spill in 2001-2006. The target dates for the Lower Snake projects were generally March 1 – April 2. However, TDG data at Little Goose and Lower Monumental were not logged until after March 1. In this case, the first date for each year that data were available at these sites was used. Voluntary spring spill at the Lower Columbia projects begins in April. Therefore, the dates used for the Lower Columbia projects were the first date for which data was available prior to the initiation of spill. This analysis allowed for the evaluation of whether relocating forebay monitors in 2004 (at John Day) and 2005 (at Little Goose, Lower Monumental, Ice Harbor, and McNary) had an effect on TDG variation, as it was intended.
Beginning in 2003, Bonneville began spilling water to facilitate adult passage (training spill) at this project. This training spill was initiated prior to the implementation of voluntary spring spill and involved spilling a small amount of water (less than 5 kcfs) for a period of approximately 12 hours during the daytime. To investigate the effect of this spill level on TDG at Camas/Washougal, a regression analysis on spill at Bonneville and TDG at Camas/Washougal was conducted. This regression indicated that 5 kcfs might increase the TDG levels at Camas/Washougal by approximately 1%. Therefore, in order to compensate for increased TDG at Camas/Washougal due to training spill, the measured TDG levels were reduced by 1% for use in the analyses.

Second, the 2001 spring and summer voluntary spill seasons (April 3 – August 31, 2001 for both Lower Snake Projects and Lower Columbia Projects) were studied. In 2001, voluntary spill did not occur at the Snake River projects and only occurred for a few days in the Lower Columbia due to extremely low water levels and flows. This analysis addressed variation in TDG throughout an entire spill season, over the range of possible temperatures, when no spill was occurring upstream of the monitors. (Spill at Priest Rapids Dam was accounted for in the analysis and the days when spill at Priest could have affected the forebay reading at McNary were removed).

Finally, the 2005 spring spill season for the Lower Snake Projects (April 3 – June 20, 2005) was reviewed. In the spring of 2005, voluntary spill did not occur at most of the Lower Snake projects due to low water levels and flows. This analysis allowed the investigation in the variation in TDG levels in the spring when no spill was occurring. Adjustments were made to account for the time periods during which spill did occur at the lower Snake projects to remove these data from the data sets.

For each of the forebay monitors listed above, the following data were used in these analyses: 1) hourly measures of TDG, 2) hourly measures of flow, and 3) hourly measures of spill. Spill data were taken from the project directly upstream of the monitor of interest. For each forebay monitor, the mean, minimum, and maximum TDG levels for time periods when spill was not occurring at the project(s) above the monitor was estimated. The hourly spill data were used to corroborate that no spill was occurring above each forebay monitor. In instances where spill was occurring above the forebay monitor, hourly flow data were used to estimate water travel times for each spill event through the use of regression. An average water travel time was estimated for each spill event. Total dissolved gas measures that were recorded after a period of spill, based on the average water travel time for that spill event, were eliminated from the analysis. This enabled the elimination of any TDG levels that may have been influenced by spill occurring above the monitor of interest from each of the analyses. Furthermore, the TDG measurements considered were between 95% and 130%.
1. Pre-Spill Season (2001-2006)

The TDG levels prior to the beginning of the spill season were assessed at all projects using available data (Table 3). The table lists the mean TDG value over the period as well as the minimum and maximum values. From the table it can be seen that TDG averaged above 100% with maximum hourly values well in excess of 100%. These data show that all forebay monitors in the system are affected to some degree by processes other than spill, e.g. temperature and primary productivity.

Additionally, the table shows that at projects where forebay monitors were relocated to address RPA 132 (see bold line in table), there was no discernable response to the relocation of the monitor. At all locations, after monitor relocation, the effect of local processes on forebay TDG readings appeared about the same as before relocation.

<table>
<thead>
<tr>
<th>Forebay Monitor</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Granite</td>
<td>Mean TDG 102.9</td>
<td>101.1</td>
<td>101.4</td>
<td>101.6</td>
<td>103.5</td>
<td>102.3</td>
</tr>
<tr>
<td></td>
<td>Min. TDG 99.6</td>
<td>98.1</td>
<td>98.3</td>
<td>98.5</td>
<td>98.9</td>
<td>98.7</td>
</tr>
<tr>
<td></td>
<td>Max. TDG 105.9</td>
<td>103.6</td>
<td>105.8</td>
<td>104.8</td>
<td>108.8</td>
<td>104.9</td>
</tr>
<tr>
<td>Little Goose</td>
<td>Mean TDG 104.2</td>
<td>101.4</td>
<td>101.1</td>
<td>102.2</td>
<td>102.7</td>
<td>103.3</td>
</tr>
<tr>
<td></td>
<td>Min. TDG 102.3</td>
<td>100.5</td>
<td>99.2</td>
<td>99.5</td>
<td>99.5</td>
<td>100.8</td>
</tr>
<tr>
<td></td>
<td>Max. TDG 108.1</td>
<td>103.6</td>
<td>103.3</td>
<td>106.4</td>
<td>105.2</td>
<td>105.3</td>
</tr>
<tr>
<td>Lower Monumental</td>
<td>Mean TDG 104.4</td>
<td>101.7</td>
<td>100.9</td>
<td>102.9</td>
<td>102.2</td>
<td>103.4</td>
</tr>
<tr>
<td></td>
<td>Min. TDG 102.3</td>
<td>100.4</td>
<td>98.5</td>
<td>100.7</td>
<td>100.2</td>
<td>102.1</td>
</tr>
<tr>
<td></td>
<td>Max. TDG 108.5</td>
<td>103.5</td>
<td>103.4</td>
<td>107.3</td>
<td>105.8</td>
<td>105.1</td>
</tr>
<tr>
<td>Ice Harbor</td>
<td>Mean TDG 103.2</td>
<td>101.8</td>
<td>101.4</td>
<td>103.0</td>
<td>104.9</td>
<td>101.8</td>
</tr>
<tr>
<td></td>
<td>Min. TDG 100.7</td>
<td>99.2</td>
<td>98.7</td>
<td>100.4</td>
<td>99.4</td>
<td>99.7</td>
</tr>
<tr>
<td></td>
<td>Max. TDG 107.8</td>
<td>104.4</td>
<td>104.8</td>
<td>106.9</td>
<td>109.7</td>
<td>105.1</td>
</tr>
<tr>
<td>McNary Oregon</td>
<td>Mean TDG 104.3</td>
<td>102.1</td>
<td>101.8</td>
<td>104.2</td>
<td>104.6</td>
<td>103.0</td>
</tr>
<tr>
<td></td>
<td>Min. TDG 101.1</td>
<td>99.1</td>
<td>98.1</td>
<td>100.1</td>
<td>101.0</td>
<td>99.9</td>
</tr>
<tr>
<td></td>
<td>Max. TDG 110.5</td>
<td>110.1</td>
<td>110.1</td>
<td>111.9</td>
<td>110.0</td>
<td>108.4</td>
</tr>
<tr>
<td>McNary Washington</td>
<td>Mean TDG 103.9</td>
<td>102.2</td>
<td>102.2</td>
<td>104.1</td>
<td>104.3</td>
<td>102.9</td>
</tr>
<tr>
<td></td>
<td>Min. TDG 101.2</td>
<td>99.0</td>
<td>99.2</td>
<td>100.0</td>
<td>101.1</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>Max. TDG 109.9</td>
<td>107.5</td>
<td>105.8</td>
<td>108.4</td>
<td>108.7</td>
<td>106.8</td>
</tr>
<tr>
<td>John Day</td>
<td>Mean TDG 103.3</td>
<td>103.5</td>
<td>102.9</td>
<td>105.1</td>
<td>104.4</td>
<td>103.9</td>
</tr>
<tr>
<td></td>
<td>Min. TDG 100.8</td>
<td>100.7</td>
<td>100.3</td>
<td>102.5</td>
<td>101.7</td>
<td>100.9</td>
</tr>
<tr>
<td></td>
<td>Max. TDG 106.5</td>
<td>107.2</td>
<td>107.8</td>
<td>109.5</td>
<td>106.9</td>
<td>107.1</td>
</tr>
<tr>
<td>The Dalles</td>
<td>Mean TDG 102.6</td>
<td>103.2</td>
<td>102.3</td>
<td>103.8</td>
<td>104.0</td>
<td>103.8</td>
</tr>
<tr>
<td></td>
<td>Min. TDG 100.3</td>
<td>100.8</td>
<td>100.1</td>
<td>100.8</td>
<td>101.6</td>
<td>101.2</td>
</tr>
<tr>
<td></td>
<td>Max. TDG 105.5</td>
<td>110.9</td>
<td>104.9</td>
<td>108.1</td>
<td>108.2</td>
<td>107.0</td>
</tr>
<tr>
<td>Bonneville</td>
<td>Mean TDG 103.7</td>
<td>102.8</td>
<td>102.0</td>
<td>103.7</td>
<td>104.5</td>
<td>103.2</td>
</tr>
<tr>
<td></td>
<td>Min. TDG 100.8</td>
<td>100.5</td>
<td>99.7</td>
<td>101.2</td>
<td>101.3</td>
<td>100.7</td>
</tr>
<tr>
<td></td>
<td>Max. TDG 106.1</td>
<td>106.0</td>
<td>106.2</td>
<td>106.7</td>
<td>107.2</td>
<td>107.7</td>
</tr>
<tr>
<td>Camas/ Washougal</td>
<td>Mean TDG 104.1</td>
<td>103.0</td>
<td>101.5</td>
<td>103.4</td>
<td>103.4</td>
<td>102.9</td>
</tr>
<tr>
<td></td>
<td>Min. TDG 100.3</td>
<td>100.0</td>
<td>99.0</td>
<td>99.5</td>
<td>100.6</td>
<td>100.3</td>
</tr>
<tr>
<td></td>
<td>Max. TDG 107.5</td>
<td>108.5</td>
<td>105.0</td>
<td>107.9</td>
<td>108.6</td>
<td>108.0</td>
</tr>
</tbody>
</table>

Table 3. Mean, minimum and maximum TDG values estimated for each project based on hourly TDG data available for the season prior to the initiation of spill. Italicized data indicate the years where some above-project spill occurred and some TDG measures were eliminated when estimating mean, min, and max TDG. An estimated water travel time was used to determine which TDG measurements to eliminate from the estimation of mean, min, and max TDG at each project.
2. 2001 Spill Season

The 2001 drought year presented a data set where most of the time spill did not affect the forebay monitors. During the 2001 spill season (April 3 to August 31, 2001), all projects had a mean TDG above 100% after removal of any data from the data set that may have been affected by spill (spill did occur in the Mid Columbia). The mean TDG level ranged from 101.3% at John Day to 104.1% at McNary dam (Oregon side) (Table 4). The lowest minimum TDG was 95% at the John Day monitor. Finally, the highest maximum TDG was 111% at the Lower Granite monitor.

<table>
<thead>
<tr>
<th>Forebay Monitor</th>
<th>Mean Seasonal TDG</th>
<th>Min Hourly TDG</th>
<th>Max Hourly TDG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Granite</td>
<td>102.9</td>
<td>97.7</td>
<td>111.0</td>
</tr>
<tr>
<td>Little Goose</td>
<td>101.2</td>
<td>95.8</td>
<td>110.2</td>
</tr>
<tr>
<td>Lower Monumental</td>
<td>102.4</td>
<td>97.1</td>
<td>110.6</td>
</tr>
<tr>
<td>Ice Harbor</td>
<td>101.9</td>
<td>95.4</td>
<td>110.1</td>
</tr>
<tr>
<td>McNary - Oregon</td>
<td>104.1</td>
<td>101.7</td>
<td>110.1</td>
</tr>
<tr>
<td>McNary - Washington</td>
<td>103.1</td>
<td>99.0</td>
<td>105.7</td>
</tr>
<tr>
<td>John Day</td>
<td>101.3</td>
<td>95.0</td>
<td>107.3</td>
</tr>
<tr>
<td>The Dalles</td>
<td>101.2</td>
<td>95.1</td>
<td>107.2</td>
</tr>
<tr>
<td>Bonneville</td>
<td>102.1</td>
<td>97.9</td>
<td>107.1</td>
</tr>
<tr>
<td>Camas/Washougal</td>
<td>103.4</td>
<td>97.9</td>
<td>110.4</td>
</tr>
</tbody>
</table>

Table 4. Mean, minimum and maximum TDG values estimated for each project based on hourly TDG data available for 2001. Italicized data indicate the years where some above-project spill occurred and some TDG measures were eliminated when estimating mean, min, and max TDG. An estimated water travel time was used to determine which TDG measurements to eliminate from the estimation of mean, min, and max TDG at each project.

3. 2005 Spring Spill Season

Planned spill did not occur in the Snake River above Ice Harbor Dam during the spring. During the 2005 spring spill season (April 3 to June 20, 2005), all Lower Snake River projects had a mean TDG above 100% (Table 5). The mean TDG for the Lower Snake River projects ranged from 102.8% at the Lower Granite forebay monitor to 103.5% at the Ice Harbor forebay monitor. The lowest minimum TDG was 98.9% at the Lower Granite monitor. The highest maximum TDG was 108.8% at the Lower Monumental monitor.

<table>
<thead>
<tr>
<th>Forebay Monitor</th>
<th>Mean TDG</th>
<th>Min TDG</th>
<th>Max TDG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Granite</td>
<td>102.8</td>
<td>98.9</td>
<td>108.3</td>
</tr>
<tr>
<td>Little Goose</td>
<td>103.0</td>
<td>99.7</td>
<td>106.7</td>
</tr>
<tr>
<td>Lower Monumental</td>
<td>103.0</td>
<td>100.0</td>
<td>108.8</td>
</tr>
<tr>
<td>Ice Harbor</td>
<td>103.4</td>
<td>101.3</td>
<td>106.4</td>
</tr>
</tbody>
</table>

Table 5. Mean, minimum and maximum TDG values estimated for each project based on hourly TDG data available for 2005. Italicized data indicate the years where some above-project spill occurred and some TDG measures were eliminated when estimating mean, min, and max TDG. An estimated water travel time was used to determine which TDG measurements to eliminate from the estimation of mean, min, and max TDG at each project.
Based on the three separate analyses that were conducted, it is safe to say that, in conclusion, forebay monitors do not accurately reflect the TDG of mixed waters and continue to be impacted by localized processes. Measures (relocation) taken under RPA 132 to assure that the forebay monitors were representative of mixed water at several of the projects did not achieve that objective.

**Oxygen relationship**

While the role of dissolved oxygen from primary productivity is acknowledged in affecting the overall TDG concentration, in RPA 132 the COE did not specifically address the impact of primary productivity on the total dissolved gas levels. Primary productivity can increase dissolved oxygen levels, which would result in a higher TDG percent saturation reading. It is possible that the forebay monitors are often affected by oxygen production due to primary productivity as well as diel temperature variations. Dissolved oxygen readings are not routinely collected, therefore, limited dissolved oxygen data exists in the record to assess the impact of dissolved oxygen on the overall total dissolved gas readings for the time period used in the previous analysis. However, there are some periods where simultaneous hourly data are available for total dissolved gas, dissolved oxygen and temperature at the dam forebay monitors. These data were available for certain periods prior to the initiation of the spill program at the lower Snake River projects for 2001 to 2004. Those limited data were analyzed to determine the potential relation between dissolved oxygen, total dissolved gas and temperature (Table 6).

A series of correlation coefficients were estimated for the available data. From the table it can be seen that about half of the correlation coefficients showed a stronger relation between dissolved oxygen and total dissolved gas, than for temperature and total dissolved gas. While the studies conducted under RPA 132 only addressed temperature, the data here suggest that at times dissolved oxygen may be as important in affecting the forebay monitor reading as temperature. The impact of dissolved oxygen from primary productivity may explain why the monitor relocation in response to RPA 132 did not achieve its objective.

<table>
<thead>
<tr>
<th>Project</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>LGR</td>
<td>TEMP</td>
<td>-0.34</td>
<td>-0.11</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>DO</td>
<td>0.48</td>
<td>0.11</td>
<td>-0.02</td>
</tr>
<tr>
<td>LGO</td>
<td>TEMP</td>
<td>-0.31</td>
<td>-0.02</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>DO</td>
<td>0.83</td>
<td>0.21</td>
<td>0.20</td>
</tr>
<tr>
<td>LMN</td>
<td>TEMP</td>
<td>0.53</td>
<td>0.28</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>DO</td>
<td>0.18</td>
<td>0.19</td>
<td>0.12</td>
</tr>
<tr>
<td>IHR</td>
<td>TEMP</td>
<td>-0.41</td>
<td>-0.02</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>DO</td>
<td>0.85</td>
<td>0.19</td>
<td>-0.57</td>
</tr>
</tbody>
</table>

*Table 6. Correlation coefficients (r²) between hourly temperature readings (TEMP) and TDG and between hourly dissolved oxygen (DO) readings and TDG at the Snake River projects.*

While these data are limited, they do suggest a mechanism that may be contributing to the continued inability of forebay monitors to adequately represent the TDG of the mixed water column in the forebay of a dam.

**Biological Monitoring**
Since 1995, the biological monitoring program has recorded annually the effects of the FCRPS biological opinion spill program. The data observed over the years through the biological monitoring has consistently shown very low incidence of GBT when gas levels are at the 120% tailrace criteria. When fish are exposed to gas levels greater than 120%, there is an increasing trend in incidence and severity of these signs (Figure 1). For all fish examined through the Smolt Monitoring Program for signs of GBT when tailrace TDG levels were 120% or less the incidence of any fin signs observed in that population was 0.5%. This demonstrates the minimal effect of biological opinion spill levels with TDG levels managed to 120% in the project tailrace. That percentage of fish affected with GBT begins to increase above 120% and then dramatically increases above 125%.

![Figure 1. Percentage of all Fish Examined for GBT at Little Goose, Lower Monumental, McNary and Bonneville dams from 1995 to 2005 that showed fin any GBT as well as the percent by TDG category based on upstream tailwater monitor and fish travel time from that site. Fin ranks are: rank 1 – less than 5% fin area covered with bubbles, rank 2 – 5 to 25%, rank 3 – 26 to 50% and rank 4 – greater than 50%.](image)

**2006 Spill**

An issue surfaced during the 2006 spring spill season with regard to the management of spill solely to physical TDG criteria. During the spring freshet the TDG levels exceeded the water quality standards and the incidence of GBT in fish exceeded the criteria at some projects (Appendix C). However, since this was uncontrolled spill, no recourse was possible. However, later in the season the incidence of GBT again increased at the Snake River projects as a result of project operations for the management of excess market spill after the spring peak flows had
occurred. This occurred during mid-June of 2006. At the time the Action Agencies’
management of spill attempted to meet water quality standards during daytime hours, which
resulted in spill levels well in excess of the Court’s order during nighttime hours. The
management resulted in periods when TDG levels may have been significantly higher that if
attempts were made to manage spill to a lower overall daily average. A more logical
management approach would have been to attempt as best as possible to evenly distribute spill
over the 24-hour period. While the instantaneous gas would have exceeded the waiver criteria,
the daily average TDG would have been lower for the day. The overall lower TDG values may
have had less impact on fish. This type of management should be implemented in future years.

Conclusions

Spill in 2006 was implemented according to the Court’s Order and the current dissolved
gas waiver criteria. However, it appears that there is sufficient information to conclude that
changes should be considered to the waiver criteria regarding the use of forebay monitors as a
point of compliance for dissolved gas. These monitors do not represent the measurements of
TDG in mixed waters as was originally intended. Further, it appears that efforts to relocate
monitors have not addressed the impacts to measurements caused by localized variations in
temperature, barometric pressure and primary productivity.

Consequently, spill that occurred in the spring of 2006 offered less mitigation to
migrating salmonids (4.1 MAF) than what could have occurred if spill only met the 120% TDG
tailrace objective, after excess hydraulic capacity and excess market spill were removed from the
equation. The bias towards a higher TDG reading at the forebay monitors results in an
unnecessary limitation of protection measures for fish passage. The alternative of using the
tailrace monitor allows for better implementation of the intent of the Court’s Order.

Biological monitoring conducted over several years’ supports the minimal impact to
migrating salmonids of total dissolved gas levels at 120% or less. So few fish have been
detected over 12 years of monitoring when spill is 120% at the tailrace location of an upstream
project that it is safe to assume minimal impact. Management to the 120% tailrace criteria
assures the safety of fish in a planned spill program, while at the same time better allowing for
the achievement of the biological objectives of the program.

References:

Bouck, G.R., A.V. Nebeker, and D.G. Stevens, 1976. Mortality, saltwater adaptation and
reproduction of fish exposed to gas supersaturated water. U.S. Environmental Protection
Agency, Office of Research and Development, EPA-600/3-76-050, Washington, D.C.

Carroll, J.H. 2004. TDG Forebay Fixed Monitoring Station Review and Evaluation for Lower
Snake River Projects and McNary Dam US Army Corps of Engineers. Contract Number:
DACW68-03-D-0003.

Biological Opinion.

Washington Department of Fish and Wildlife, Oregon Department of Fish and Wildlife, Idaho Department of Fish and Game, and Columbia River Inter-Tribal Fish Commission. 1995. Spill and 1995 Risk Management.
Appendix A
John Day (Spill vs. Court Order)

John Day (Forebay and Tailrace TDG)

John Day (Flow vs. Hydraulic Capacity)
APPENDIX B
Fixed Monitoring System Station Codes – See attached table.

<table>
<thead>
<tr>
<th>Year</th>
<th>Status or Action</th>
</tr>
</thead>
</table>
| 2000 | - All stations remain as they were in 1999  
      | - JDAW – a second, redundant monitor added |
| 2001 | - All stations remain as they were in 1999  
      | - Walla Walla District installed temperature monitor in DWQ pool  
      | - Pasco & Anatone kept as winter monitors  
      | - Portland District added a 2nd Camas gauge |
| 2002 | - WQT recommended Camas remain, add a new station at Corbett  
      | - SKAW terminated in favor of new Corbett station  
      | - WRNO remained in service  
      | - Added data logger at west end of TDA powerhouse, east end station remained official mgmt gauge  
      | - Added JDA scroll case temperature monitor. JDA forebay remained as mgmt gauge  
      | - WQT agreed to evaluate all FMS for performance at the end of 2002 |
| 2003 | - Continued exploratory monitoring at Corbett  
      | - WRNO & TDDO declared inconsistent with other tailrace monitors  
      | - A monitor in the BON tailrace replaced WRNO  
      | - No change in BON forebay monitor  
      | - Relocation of forebay monitors under consideration for TDA, JDA, MCQW & MCQO  
      | - FB monitor relocation reviewed for IHR, LMN, LGS, & LGR. A multi-year plan to review and analyze includes review and analysis of existing data from the forebay fixed monitors for representativeness and anomalies in total dissolved gas and temperature. |
| 2004 | - CMWM remained a spill mgmt site  
      | - no change  
      | - BON tailrace monitor installed on Bradford Island |
|      | - No Change - WRNO, BON (forebay), TDA, TDDO, JDAW, MCN, Pasco, IDSW, LMNW, LGSW, LGNW |
|      | TDDO is inconsistent with other tailwater sites. Continue use of site to manage spill. Recommend additional investigations of more suitable location  
<pre><code>  | - JDA relocates to upstream end of nav. lock, 15 m deep. |
</code></pre>
<table>
<thead>
<tr>
<th>Year</th>
<th>Details</th>
</tr>
</thead>
</table>
| 2004 continued | - MCNW and MCNO – transition year. Evaluate alternate sites, include Re-locate to upstream end of Washington nav lock guide wall, 15 m deep, & at the Oregon BRZ (Oregon side)  
- Transition year for IHR, LMN, LGS, LGW. Evaluate & locate Monitors were set at 5 m |
| 2005 | - No Change CWMW, BON, TDA, TDDO, JDA-2, JDAW, MCPW, Pasco, IDSW, LMNW, LGSW, LGNW  
- Winter only (TDG and Temp) - WRNO  
- BON tailrace moved to CCIW. Use CCIW data to manage BON spill  
- MCPO, MCPW- Washington side monitor moved to end of nav lock guide wall, 15 m deep. MCPO no change, add a monitor on a float at the BRZ  
- Redeploy monitor to depth of 15 m. at IHR-2, LMN-2, LGS-2, LGR-2 |
| 2006 | -No Change CMWM, TDA, JDA-2, MCPW-2, IDSW, LMN-2, LGS-2, LGNW  
-WRNO installed 3/1/06, removed at end of May 2006 after chum emergence  
- Site became year-round tailrace TDG monitor – CCIW, TDDO, IDSW, LMNW, LGSW  
- Site monitoring discontinued during fall and winter – BON, MCQW-2, IHR-2, LGW-2. Operational during spill season  
- MCQO permanently retired |

Note: See page 3 for fixed monitoring system station code and name

Summary Notes:
2003 - BON tailrace monitor added at Turtle Rock  
- Multi-year plan to relocate Snake River forebay monitors developed

2004 – forebay monitor relocations to JDA, MCN, IHR, LMN, & LGR. Moved monitors to 5 m depth on nav lock walls

2005 – Redeployed MCPW, IHR-2, LMN-2, LGS-2, LGR-2 to 15 m depth on nav lock wall  
- BON tailrace moved to CCIW  
- WRNO used during the chum incubation and emergence period (March- May)
## 2005 Dissolved Gas Monitoring Network

### Station Code and Name

<table>
<thead>
<tr>
<th>STATION CODE</th>
<th>STATION NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIIW</td>
<td>US/Cas Boundary</td>
</tr>
<tr>
<td>HGHW</td>
<td>Below Hungry Horse</td>
</tr>
<tr>
<td>FDRW</td>
<td>Grand Coulee Forebay</td>
</tr>
<tr>
<td>GCGW</td>
<td>Grand Coulee Tailwater</td>
</tr>
<tr>
<td>ALFI</td>
<td>Albeni Falls Forebay</td>
</tr>
<tr>
<td>ALFWR</td>
<td>Albeni Falls Tailwater</td>
</tr>
<tr>
<td>LBQM</td>
<td>Libby Tailwater</td>
</tr>
<tr>
<td>CHER</td>
<td>Chief Joseph Forebay</td>
</tr>
<tr>
<td>CH2W</td>
<td>Chief Joseph Tailwater</td>
</tr>
<tr>
<td>WEL</td>
<td>Wells Forebay</td>
</tr>
<tr>
<td>WELW</td>
<td>Wells Tailwater</td>
</tr>
<tr>
<td>RRH</td>
<td>Rocky Reach Forebay</td>
</tr>
<tr>
<td>RR3W</td>
<td>Rocky Reach Tailwater</td>
</tr>
<tr>
<td>RIS</td>
<td>Rock Island Forebay</td>
</tr>
<tr>
<td>RIGW</td>
<td>Rock Island Tailwater</td>
</tr>
<tr>
<td>WAN</td>
<td>Wanapum Forebay</td>
</tr>
<tr>
<td>WANW</td>
<td>Wanapum Tailwater</td>
</tr>
<tr>
<td>PRD</td>
<td>Priest Rapids Forebay</td>
</tr>
<tr>
<td>PR3W</td>
<td>Priest Rapids Tailwater</td>
</tr>
<tr>
<td>PAOW</td>
<td>Columbia R. Above Snake</td>
</tr>
<tr>
<td>DWQI</td>
<td>Dwosslak Tailwater</td>
</tr>
<tr>
<td>PEKI</td>
<td>Peck/Clearwater</td>
</tr>
<tr>
<td>LEWI</td>
<td>Lewiston/Clearwater</td>
</tr>
<tr>
<td>ANQW</td>
<td>Upper Snake at Anahote</td>
</tr>
<tr>
<td>LWG-2</td>
<td>Lower Granite Forebay</td>
</tr>
<tr>
<td>LGNW</td>
<td>Lower Granite Tailwater</td>
</tr>
<tr>
<td>LG8-2</td>
<td>Little Goose Forebay</td>
</tr>
<tr>
<td>LGSW</td>
<td>Little Goose Tailwater</td>
</tr>
<tr>
<td>LMN-2</td>
<td>Lower Monum. Forebay</td>
</tr>
<tr>
<td>LMNW</td>
<td>Lower Monum. Tailwater</td>
</tr>
<tr>
<td>JHR-2</td>
<td>Ice Harbor Forebay</td>
</tr>
<tr>
<td>IDSW</td>
<td>Ice Harbor Tailwater</td>
</tr>
<tr>
<td>MCQW-2</td>
<td>McNary Forebay – WA</td>
</tr>
<tr>
<td>MCQO</td>
<td>McNary Forebay – OR</td>
</tr>
<tr>
<td>MCPW</td>
<td>McNary Tailwater</td>
</tr>
<tr>
<td>IDA-2</td>
<td>John Day Forebay</td>
</tr>
<tr>
<td>JHAW</td>
<td>John Day Tailwater</td>
</tr>
<tr>
<td>TDA</td>
<td>The Dalles Forebay</td>
</tr>
<tr>
<td>TEDO</td>
<td>The Dalles Tailwater</td>
</tr>
<tr>
<td>BCN</td>
<td>Bonneville Forebay</td>
</tr>
<tr>
<td>CCTW</td>
<td>Bonneville Tailwater</td>
</tr>
<tr>
<td>WNO</td>
<td>Warrensville</td>
</tr>
<tr>
<td>CWMW</td>
<td>Camas/Washougal</td>
</tr>
</tbody>
</table>
**Figure 1.** Percent signs of GBT observed in samples of juvenile salmon at Little Goose Dam and the upstream tailwater reading of total dissolved gas.

**Figure 2.** Percent signs of GBT observed in samples of juvenile salmon at Lower Monumental Dam and the upstream tailwater reading of total dissolved gas.
Figure 3. Percent signs of GBT observed in samples of juvenile salmon at Bonneville Dam and the upstream tailwater reading of total dissolved gas.