September 21, 2008

History of the Total Dissolved Gas Monitoring System

Prepared by Laura Hamilton, Corps of Engineers, NWD

Initial Water Quality Monitoring:

In 1974, the Corps began to investigate the issue of dissolved gas in the water and the constituent of concern was percent nitrogen. The data were biweekly forebay samples for the Columbia River below Chief Joseph to Bonneville and on the Lower Snake from Lower Granite to Ice Harbor. There were two tailwater sites: McNary and Bonneville. The main approach to addressing dissolved gases (N2) was to use a forecasting model called WRE-Nitrogen Entrainment Model, which used the transport equations from the Stream Water Quality Model to predict how much dissolved nitrogen is in the water. The model results were compared against the actual biweekly readings.

The voluntary spill programs began first at the John Day dam in 1977 and usually occur from May through June and during this time percent nitrogen data was collected. Percent nitrogen data used to manage spill was obtained by lowering a tensiometer and a potable YSI oxygen/water temperature meter into the forebay and tailwater from either a cable or a boat. The 1977 TDG samples were taken during May and June in the forebay and tailwater of John Day and McNary with at least three samples in each forebay and tailwater, usually more. This approach was used through 1979 and the sample locations changed from year to year. In 1979 sampling switched from % nitrogen to % total dissolved gas, dissolved oxygen and temperature. In 1980, samples were taken only in the forebay and tailwater of The Dalles based on the idea that they were reflective of John Day. In 1981, spill began at Lower Monumental dam. The time and amount of water to be spilled was based on the numbers of fish detected with the sonar and the dam biologist's judgment. By 1983, there were total dissolved gas gages in the forebays of Ice Harbor, McNary, John Day and The Dalles.

First Continuous Monitoring System:

In 1985, a continuous monitoring system for TDG was installed in 10 locations which included the forebays of the Columbia and Snake River projects and the Bonneville tailwater (WRNO). The monitoring system collected data from April 15 through September 8th. The instruments were connected to Common Sensing tensiometer and Sutron Data Collection Platforms (DCP) and sent data to the CROHMS database. This was hourly data; however because there was not enough room for this hourly data to be stored in CROHMS, the data was compressed, which resulted in most of the data being stored in three to four hour intervals.

In 1989, there was a 10-year agreement established between Bonneville Power Administration, state and federal fish agencies and environmental organizations that called for daily spill at John Day, Lower Monumental, Ice Harbor, and The Dalles dams. The US Army Corps of Engineers did not sign onto the agreement but agreed to implement the actions it described. As a result, the comprehensive monitoring system was installed in 1990 - 1991 composed of the 10 forebay gages and a few tailwater gages (McNary, Lower Monumental, Little Goose, Lower Granite, four Ice Harbor tailwater monitoring stations, Kalama (KLAW) and Wauna Mill (WANO)).

The 10 year agreement stayed in effect for 3 years, until 1991 when Snake River sockeye salmon was declared endangered under the Endangered Species Act (ESA). As a result, the Corps went into consultation with NOAA Fisheries to protect listed salmon. Through the subsequent years, more fish were listed as endangered. In 1992, the spring/summer Chinook and fall Chinook were listed.

Existing Continuous TDG Monitoring System:
As a result of the ESA listings, the Corps began spilling for fish passage at the four Corps projects on the Lower Columbia (MCN, TDA, JDA, BON) and Snake Rivers (LWG; LGS; LMN, IHR) during 1993 but at low levels for a short period of time. For instance, The Dalles spilled 10% of the average daily project discharge between 2000 and 0400 hours from May 1 through June 6. From June 7 through August 23, spill 5% of the project discharge. The Corps also began the Dissolved Gas Abatement Study (DGAS) in 1994 to obtain information that would encourage discussions on the best way to address spill issues and the study was completed by 2001.

The Camas/Washougal, Skamania and Kalama TDG gages were installed in 1993. In 1994, spill continued at the four Corps projects on the Lower Columbia (MCN, TDA, JDA, BON) and Snake Rivers (LWG; LGS; LMN, IHR) with an additional small spill amount at McNary in July to help disperse fish and lower predation. In 1995, the NOAA Fisheries Biological Opinion was issued which called for spill at the eight aforementioned Lower Columbia and Lower Snake projects during the spring and in the summer spill occurred at Ice Harbor, John Day, The Dalles and Bonneville projects. As a result, in 1994-1995 the Corps further developed the TDG monitoring system to include tailwater gages for the Corps eight projects along with the existing forebay gages. The new 8200 model of the Sutron Data Collection Platform (DCP) was connected to new instruments that Common Sensing, Inc. (CSI) assembled. The DCPs collected water quality data from 3 sensors (water temperature, atmospheric barometric pressure, and total dissolved gas pressure) or 5 sensors (water temperature, atmospheric barometric pressure, total dissolved gas pressure, dissolved oxygen, and nitrogen and argon gas pressures). In 1998, chum and steelhead were listed. By 2000, twelve different species of fish were listed.

Representativeness of TDG gages:
In 1996-1997, as part of the DGAS field data collection effort, an array of three to five logging water quality instruments were deployed on a transect at each existing Fixed Monitoring Station (FMS) site. Parameters logged include total dissolved gas, temperature and dissolved oxygen. Data collected by these logging instruments were compared to that collected by the adjacent FMSs to determine whether each FMS collected data that was representative of the in-river maximum, mean and/or near TDG levels. The conclusion of the study was that all of the gages were representative of these parameters except McNary tailwater (MCPW); Little Goose tailwater (LGSW), John Day tailwater (JHAW) and Lower Granite tailwater (LGNW) .

The 2000 Biological Opinion RPA 132 recommended a TDG study on the forebay gages be preformed to address representativeness issues. Previous TDG research studies that were conducted and review of hourly TDG historical data identified thermal spikes that occur at certain forebay gages. As a result of RPA 132, there was a study of the five forebay gages (Lower Granite, Little Goose, Lower Monumental, Ice Harbor and McNary) to provide more representative measures of TDG saturation. Thermally; induced pressure spikes caused by daily heating and cooling of the surface level in the forebay of the dams were observed. To address this issue, the forebay FMS were repositioned away from the vertical face of the dam to the upstream lock guide wall and at a greater depth (15 meters) for the 2005 fish passage season. The idea to move the five forebay gages on the Snake River and McNary was discussed at the Dec. 9, 2003 Regional Water Quality Team meeting where it was agreed that the forebay fixed monitoring stations would be relocated in 2005. At the Jan 24, 2005 Water Quality Team meeting various agencies approved of the relocation. In 2003 and 2004 both existing and alternative forebay gages operated in parallel and the information was used in the gage relocation decision. The gages that were relocated include McNary Dam and the four Lower Snake River projects and as Table 1 list, the names of the forebay gages were changed to reflect their new location. The Lower Granite gage remained in the same location (on the lock guidewall) but was lowered to the 15m depth.

History of the Camas/Washougal Monitoring System

The Camas/Washougal, Skamania and Kalama TDG gages were installed in 1993. In 1996-1997, as part of the DGAS field data collection effort, an array of three to five logging water quality instruments were deployed on a transect at each existing FMS site including Camas/Washougal. Parameters logged include total dissolved gas, temperature and dissolved oxygen. Data collected by these logging instruments were compared to the adjacent FMS data to determine whether each FMS data was representative of the in-river maximum, mean and/or near TDG levels. The study found that TDG saturation associated with spillway releases ranged from 123 to 137% during spills of 40 to 250kcfs. The conclusion of the study was that Camas/Washougal was representative. The other gages were representative of these parameters too except McNary tailwater (MCPW); Little Goose tailwater (LGSW), John Day tailwater (JHAW) and Lower Granite tailwater (LGNW). The 1998 TDG report, page 25, states that the Corps is considering moving these gages.

Camas/Washougal Study

In spite of the DGAS study showing that Camas/Washougal was representative, there remained questions about the how much TDG variability in TDG saturation occurs at the Camas/Washougal gage so the NMFS regional forum WQT members requested further evaluation of the gage. During June 8-22, 2001, Dr. Mike Schneider, ERDC, and Joe Carroll, Corps contractor, performed a study for alternative TDG monitoring station locations that would be more representative than Camas/Washougal. The study included a total of 25 gage locations spanning from the forebay of Bonneville, River mile 145.7 to just downstream of the CWMS FMS at river mile 121.6. They were placed as a TDG transect and their locations were:

1. The first transect of three gages was positioned in the Bonneville spillway channel at 1500-1800 ft downstream of the structure and their names were SWP1, SWP2, SWP3.
2. The second TDG transect of three gages was at river mile 140.7, approximately 0.5 miles upstream of Warrendale (WRNO) and Skamania. The gages names were TWP1, TWP2, TWPS.
3. The third transect consist of six instruments that were deployed lateral from the Camas/Washougal FMS at river mile 121.6 positioned approximately 100 m apart. There names were CWP1, CWP2, CWP3, CWP4, CWP5, CWP6. This transect of stations captured the temporal and spatial variability in total dissolved gas pressure, temperature and dissolved oxygen.
4. The vertical profile of three instruments, referenced as CWP6B (for bottom), CWP6M (mid-depth), and CWP6S (surface) were located adjacent to the CWMW FMS at the Camas marina. The depths for the vertical profile were near surface at one meter, mid-depth at 3.5 m and bottom at 8m.
5. An auxiliary instrument called R46 was positioned 0.4 miles downstream of the CWMW transect in deep water.
6. Three auxiliary instruments were positioned upstream of the CWMW transect. The G49 gage was located at river mile 122.5 positioned 0.9 miles upstream of CWMW transect in 8m of water. The NM gage was located at river mile 123.5 about 1.9 miles upstream from the CWMW FMS and in shallow water near the north shore. The Corbett gage was located at river mile 127, 5.4 miles upstream of the CWMW FMS at Corbett Landing, near the south shore. This instrument was positioned near the primary Columbia River channel.
7. The four existing FMS were included in the study and they were Bonneville forebay (BON river mile 145.5); Skamania (SKAW) at the end of the dock in an embayment along the Washington side; Warrendale (WRNO) on the Oregon side at river mile 140.2; and Camas/Washougal (CWMW) 26 miles downstream from Bonneville dam at river mile 121.6.

A portable weather station was deployed at powerhouse No. 1 and barometric pressure, air temperature and wind speed and direction were recorded.

<u>Conclusions from the Camas study:</u>
The following are the conclusions of the study:

- The study found that one of the more remarkable trends apparent in the TDG data during the testing was the daily cycling in water temperature, DO concentration and TDG saturation.
- The wide viability in TDG saturation at the Camas/Washougal FMS can be attributed to a wide variety of sources such as spill, generation, upstream TDG levels, natural barometric pressure cycle, and biological and temperature cycles.
- Considering the dynamics of these naturally occurring processes then we would expect frequent and sometimes significant variation in the TDG pressures and/or saturation of the Columbia River water below Bonneville Dam.

- Since a high degree of variability in TDG occurs in both the shallow water or littoral zones and the deeper mid river zones with only minimal spatial differences, then only limited benefits (in meeting the objectives of a TDG FMS) could be expected from relocating the Camas/Washougal Fixed Monitoring Station.
- The share based location of WRNO and SKAW stations nearly always result in measures not representative of spillway flows. Due to the lack of mixing the TDG saturation is often ambiguous being highly dependent on project operations. Because of this, the tailwater FMS stations are inconsistent with most other tailwater FMS stations in the Columbia River Basin. Since neither Warrendale and Skamania meet the requirements for a tailwater downstream mixed river TDG FMS station location, alternative sampling locations such as at the exit of the spillway channel would provide a more consistent and meaningful measure of TDG pressures generated by Bonneville Dam.
- There was no significant sampling bias with the Camas/ Washougal.
- The prominent findings from this study found that Camas/Washougal was representative of the TDG levels in the Columbia River because there were only minimal spatial differences in TDG.

In the October 10, 2002 WQ Team meeting Mike Schneider presented the report called "Lower Columbia River TDG Fixed Monitoring Station Review of the 2000 Biological Opinion, Action 132." It provided recommendations which included the statement that Camas-Washougal (CWMW) potential marginal benefits in relocation of this permanent FMS to the provisional site at Corbett. It was recommended continuing the CWMW site with additional exploratory monitoring for the Corbett site with consideration of replacing CWMW as the downstream site.

General Overview of TDG Exchange research studies

The Engineering Research and Development Center (ERDC) of the US Army Corps of Engineers performed 28 TDG exchange research studies on forebay and tailwater gages on the Lower Columbia and Snake Rivers. The Corps spend millions of dollars over a ten year period (1996 to 2006) studying the impacts of projects operations on total dissolved gas loading, exchange processes and representativeness of the gages. Table 1 provides a list of the 28 studies, locations, dates and descriptions.

Each of these TDG research studies had multiple transects, with each transect containing multiple (2 to 8) gages that were installed to measure the TDG levels at different points across the river. Consistently, these research studies showed variability in TDG levels from gage to gage in the transect. The variability of TDG levels were found to be minimal with the forebays transect gages but more pronounced in the tailwater transect gages. These results reflect with the fact that high TDG levels are generated from the spillway and forebay TDG levels are carried through the powerhouse so that TDG levels can be different at different points of the tailrace.

The Table 2 provides a general overview of the history of the gages, their installation dates, dates of removal and the year that spill began at each dam.

Table 1
TDG Water Quality Research Studies by CEWES (ERDC)

Project	Date of Field Study	Memorandum Title and Date
Bonneville	16-Feb-96	CEWES-HS-L Memorandum dated 18 April 1996; subject: Data Documentation and Preliminary Analysis: Field Study at Columbia and Snake River Spillways, Part II
	18-19 Feb 1997	CEWES-CS-L Memorandum dated 10 July 1996; subject: Near-Field Study of TDG in Bonneville Spillway Tailwater
	1-5 Feb 1999	CEWES-CS-L Memorandum dated 18 August 1999; subject: Near-Field Study of TDG in Bonneville Spillway Tailwater
	1 April-September 7, 2002	CEWES-CS-L Memorandum dated September 2003, Total Dissolved Gas Exchange at Bonneville Dam, 2002 Spill Season
	18-22 Feb, 2004	CEWES-CS-L Memorandum dated September 2003, Estimated Total Dissolved Gas Exchange of the Bonneville 2nd Powerhouse Corner Collector Bypass Outfall
The Dalles	28-29 Mar 1995	CEWES-HS-L Memorandum dated May 11, 1995; subject: Data Documentation and Preliminary Analysis: Field Study at Columbia and Snake River Spillways
	28-29 Aug 1996	CEWES-CS-L Memorandum dated 16 December 1996; subject: Near-Field Study of Total Dissolved Gas in The Dalles Spillway Tailwater
John Day	16-Feb-96	CEWES-HS-L Memorandum dated 18 April 1996; subject: Data Documentation and Preliminary Analysis: Field Study at Columbia and Snake River Spillways, Part II
	10-12 Feb 1998	CEWES-CR-F Memorandum dated 23 October, 1998; subject: TDG Exchange During Spillway Releases at John Day Dam, Near-Field Study, February 10-12, 1998
	February 12-20, 2000	CEWES-CR-F Memorandum dated 18 December, 2000, Total Dissolved Gas Exchange during Spillway Releases at John Day Dam, February12-19, 2000
McNary	11-13 Feb 1997	CEWES-CR-F Memorandum dated 22 August 1997; subject: Near-Field Study of Total Dissolved Gas in the McNary Spillway Tailwater
Ice Harbor	23-24 Mar 1995	CEWES-HS-L Memorandum dated May 11, 1995; subject: Data Documentation and Preliminary Analysis: Field Study at Columbia and Snake River Spillways
	May 1-2, 1996	CEWES-HS-L Memorandum dated 13 June 1996; subject: Total Dissolved Gas Data Documentation and Preliminary Analysis: Near-Field Study of the Ice Harbor Tailwater
	June 27-28, 1996	CEWES-CS-L Memorandum dated 27 January 1997; subject: Documentation and Analysis of the Near-Field Ice Harbor Tailwater Study, June 27-28, 1996
	March 5-9, 1998	CEWES-CR-F Memorandum dated 27 November 1998; subject: Documentation and Analysis of the Ice Harbor Near-Field Tailwater Study, March 1998, Post-Deflector Installation
Little Goose	17-21 Mar 1995	CEWES-HS-L Memorandum dated May 11, 1995; subject: Data Documentation and Preliminary Analysis: Field Study at Columbia and Snake River Spillways
	20-22 Feb 1998	CEWES-CR-F Memorandum, dated 10 December 1998; subject: Total Dissolved Gas Exchange during Spillway Releases at Little Goose Dam, February 20-22, 1998
	May 14-July 17, 2007	CEWES-CR-F Memorandum, draft; subject: Total Dissolved Gas Exchange during Spillway Releases at Little Goose Dam, 2007
Lower Monumental	13-14 Feb 1996	CEWES-HS-L Memorandum dated 18 April 1996; subject: Data Documentation and Preliminary Analysis: Field Study at Columbia and Snake River Spillways, Part II
	21-22 Aug 1996	CEWES-HS-L Memorandum dated 6 December 1996; subject: Near-Field Study of TDG in the Lower Monumental Tailwater
	April 1 – July 19, 2004	CEWES-HS-L Memorandum dated 20 February 2006; subject: Total Dissolved Gas Exchange at Lower Monumental Dam, 2004 Spill Season
Lower Granite	14-15 Mar 1995	CEWES-HS-L Memorandum dated May 11, 1995; subject: Data Documentation and Preliminary Analysis: Field Study at Columbia and Snake River Spillways
Lower Granite	4 Arpil-20 July, 2002	CEWES-HS-L Memorandum dated October 15, 2003, Total Dissolved Gas Exchange at Lower Granite Dam, 2002 Spill Season
Columbia River at Camas/Washougal	June 8 – 22, 2001	CEWES-HS-L dated May 25, 2003, Water Quality Study of TDG, Temperature, and Dissolved Oxygen Spatial and Temporal Variations Downstream of Bonneville Dam, June 8-
Libby Dam	June 25 – July 10 2002	CEWES-CR-F Memorandum dated June 20, 2003, Total Dissolved Gas Exchange at Libby Dam, Montana June-July 2002
Albeni Falls Dam	May 6 – June 30, 2003	CEWES-HS-L Memorandum dated April 2007, Total Dissolved Gas Exchange at Albeni Falls Dam, 2003
Chief Joseph Dam	June 6-11, 1999	CEWES-HS-L Memorandum dated November 3, 1999, Total Dissolved Gas Field Investigations at Chief Joseph Dam, 6-11 June 1999
Chief Joseph Dam	April 22-23, 2007	CEWES-HS-L Memorandum Draft, 2007 TDG Field Investigation of Spillway Flow Deflectors at Chief Joseph Dam

Table 2
History of TDG Gages

Gage name	ID	Status	Date of First monitoring date in database	Date of continual hourly monitoring	Data of Removal	Year Spill Began at Project
Lower Granite Forebay	lwg	in	3/7/1985	4/16/1990	---	1991
Lower Granite Tailwater	lgnw	in	---	4/10/1995	---	1991
Little Goose Forebay	lgs	REMOVED	4/4/1985	9/26/1990	10/5/2004	1991
Little Goose Forebay	lgsa	in	---	3/25/2005	---	1991
Little Goose Tailwater	lgsw	in	---	4/10/1995	---	1991
Lower Monumental Forebay	lmna	in	---	3/28/2005	---	1981
Lower Monumental Tailwater	lmnw	in	---	3/31/1995	---	1981
Lower Monumental Forebay	lmn	REMOVED	4/3/1986	4/16/1990	9/16/2004	1981
Ice Harbor Tailwater	idsw	in	---	5/4/1994	---	1989
Ice Harbor Forebay	ihr	REMOVED	4/23/1985	5/8/1990	3/31/2005	1989
Ice Harbor Forebay	ihra	in	---	3/31/2005	---	1989
McNary Forebay - Washington Side	mcna	in	---	3/31/2005	---	1977
McNary Tailwater	mcpw	in	---	4/26/1995	---	1977
McNary Forebay - Oregon Side	mcqo	in	4/2/1985	4/24/1990	---	1977
McNary Forebay - Washington Side	mcqw	REMOVED	4/2/1985	11/4/1990	3/31/2005	1977
John Day Forebay	jda	REMOVED	3/4/1985	1/15/1991	9/16/2003	1977
John Day Forebay	jdy	in	---	3/24/2004	---	1977
John Day Tailwater	jhaw	in	---	3/15/1995	---	1977
The Dalles Forebay	tda	in	4/22/1985	1/15/1991	---	1989
The Dalles Tailwater	tddo	in		6/21/1996	---	1989
The Dalles Tailwater	tdto	REMOVED	4/21/1995	6/21/1996	7/6/1996	1989
Skamania		REMOVED	5/11/1994	4/15/1993		1998
Bonneville Forebay	bon	in	4/2/1986	1/15/1991	---	1998
Cascade Island	cciw	in	---	4/6/2004	---	1998
Kalama	klaw	REMOVED	6/21/1993	6/21/1993	1998	1998
Camas/Washougal	cwmw	in	---	6/21/1993	---	1998
Warrendale	wrno	in	5/23/1985	4/16/1990	---	1998
Wauna Mill	wano	REMOVED	7/4/1993	7/4/1993	9/16/1998	1998