Appendix E

SYSTDG Statistical Evaluation
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Prepared by

Mike Schneider
Hydraulic Engineer
US Army Corps of Engineers
Engineer Research and Development Center

Kathryn Barko
Research Scientist
Bowhead Contractor

Introduction

SYSTDG is a decision support tool used to estimate total dissolved gas (TDG) pressures resulting from project operations on the Columbia, Snake, and Clearwater Rivers. In an effort to quantify the uncertainty of SYSTDG estimates and improve modeling accuracy and reliability, a statistical evaluation of the predictive errors was performed. This evaluation was conducted by comparing SYSTDG-calculated total dissolved gas pressures to observe TDG pressures measured by the fixed monitoring stations (FMS) located in the forebays and tailwaters of Corps operated dams within the Columbia Basin. The dams of interest included Bonneville Dam, The Dalles Dam, John Day Dam, McNary Dam, Ice Harbor Dam, Lower Monumental Dam, Little Goose Dam, Lower Granite Dam and Dworshak Dam.

Approach

SYSTDG simulations were run for the entire 2005 spill season for one project and river reach at a time so that predictive errors could be calculated independently for each dam and river reach. Predictive errors were calculated by subtracting the observed TDG pressures from calculated forebay or tailwater fixed monitoring station TDG pressures on an hourly basis. The tailwater FMS comparison was dependent upon the location of the sampling station relative to the mixing zone of project releases. In most cases, the tailwater fixed monitoring stations are located in either spillway flows undiluted from powerhouse flows or in mixed river waters. The predictive errors were calculated only during active spillway operations at each project at the tailwater FMS. The TDG pressures transported to the forebay of the next downstream dam were used to determine the predictive error during the period from April 15-August 31 for the Snake River and Lower Columbia River Projects. In each simulation the observed temperatures and total pressures were used as boundary conditions for the simulation. Where forebay and tailwater temperatures were different by over 0.3 C, the observed forebay TDG pressure was approximated by linearly interpolating between total pressure observations where temperatures within 0.3 degrees Celsius. A detailed description of model input parameters and coefficients can be found in the SYSTDG user manual (USACE, 2004).

The calculated predictive errors consist of components attributed to the numerical modeling of system properties, operational settings, and the sampling errors introduced from the FMS. One common source of error at tailwater fixed monitoring stations is the lagged response of TDG pressures to the change in spill operation. Depending upon the location of the tailwater FMS, it may take up to 5 hours for a TDG response, from a given operation at a dam, to show up at the monitoring station. A mistake in the timing of comparing a calculated and observed response at a tailwater FMS can result in a large predictive error. The operational records used in these simulations were averaged on an hourly basis. Any operational change occurring within the hour was prorated by the cumulative

discharge to determine the average hourly value. This hourly average operation falls between actual operating conditions introducing an erroneous result. In some cases, the spill pattern as established in the 2005 fish passage plan or auxiliary spill patterns designed for low flow summer spill, were not implemented at the dam. The model predictions are dependent upon the number of spillway bays that were active for any spill operation. The presence of local TDG gradients near a FMS introduced by thermal patterns or project operations can bias the observed TDG pressure and introduce a prominent source of error when comparing to model estimates. Thermally induced errors are common at forebay fixed monitoring stations where a 1° C increase in temperature above bulk river conditions can result in a 2-3% increase in the TDG saturation. Sampling errors at tailwater stations have been identified at many of the projects in the study area and will be noted in greater detail in the following discussion of study findings. The challenge in reviewing the properties of the predictive errors is to determine the source of this error, whether it be from a biased observed conditions or misrepresentation of conditions from a modeling standpoint.

Results

The following section presents a brief description of each simulation and a summary of the statistical analyses generated from each comparison. The statistical analyses of the predictive error for the FMS stations includes mean, minimum, maximum, standard deviation, and confidence limits and are listed in the four tables below. Table E1 and E3 describe the predictive errors statistics in mm Hg of pressure while Table E2 and E4 describe the predictive errors in percent saturation. The predictive error statistics expressed in terms of percent saturation shown in Tables E2 and E4 were derived by dividing the seasonal average barometric pressure at each FMS into the predictive error of the total dissolved gas pressure and expressed as a percentage.

Table E1. Statistical summary of the predictive errors of the observed and calculated total dissolved gas pressures at forebay fixed monitoring stations.										
Parameters		Predictive Error at Forebay FMS* (mm Hg)								
		LGSA	LMNA	IHRA	MCNA	MCQO	JDY	TDA	BON	CWMW
Number of Observations		3330	3327	3330	3334	3334	3334	3334	3316	3299
Average		-8.7	-6.3	-3.4	-15.2	-12.1	1.9	-4.2	-2.6	1.9
Standard Deviation		15.6	8.5	9	14.5	17.8	8.1	8.3	7.1	10.5
Maximum		49.8	17.7	20.6	30.9	74.6	29.1	33.7	23.5	36.2
Minimum		-64.6	-55.6	-40.2	-50.7	-74.4	-22.9	-36.4	-23.6	-27.5
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	-40.1	-22.1	-19.7	-34.7	-39.5	-10.4	-15.7	-14.4	-13.6
	10%	-31.4	-16.7	-16.1	-31.4	-35	-8.2	-13.4	-11	-10.5
	25%	-17.1	-9.9	-8.3	-25.4	-25.7	-3.9	-9.3	-7.1	-5.5
	50%	-5	-5.2	-2.3	-18	-12.5	1.3	-4.7	-2.9	0.4
	75%	1.8	-1.4	2.5	-6.7	-0.1	7.6	-0.3	2.1	8.9
	90%	7.9	2.6	6.9	6.2	11.5	12.9	4.7	6.4	16.1
	95%	11.9	5.6	10.1	13.4	18.1	15.7	11.2	9.6	20.5

* Predictive error is the observed minus calculated TDG pressure where negative values reflect an overestimation and positive values reflect an underestimation.

Camas/Washougal (CWMW)

A hind cast of Bonneville operations was run using the SYSTDG model for the river reach from the Bonneville Dam to the fixed monitoring station located at Camas/Washougal (CWMW) from 15 April through 31 August 2005. (Note: Camas/Washougal is called the tidal reach or TID within SYSTDG). The predictive error of the hourly total dissolved gas pressure was determined throughout the interval. The erroneous TDG pressures observed at CWMW were removed from this analysis. The calculated TDG pressures under-estimated observed conditions by an average of 1.9 mm Hg (average predictive error +1.9 mm Hg) and the standard deviation of the predictive error was 10.5 mm Hg as listed in Table E1. The 50% confidence interval for the predictive error ranged from +8.9 to -5.5 mm Hg of pressure and a 90% confidence interval ranged from +16.1 to -10.5 mm Hg. The seasonal time history of observed and calculated TDG pressures at the CWMW gage is shown in Figure E1. There is little difference in the seasonal values of the observed and calculated TDG pressures at the CWMW gage resulting from spillway operations that varied widely throughout the season. The calculated and observed conditions are shown throughout the month of July in Figure E2. A strong daily cycle is evident in these records caused in part by the thermal exchange that is evident throughout this shallow open river reach and the nighttime spill to capacity directive. The nighttime high percent spill events at Bonneville Dam coincide with the timing of the daily thermal cycling resulting in a daily range of TDG pressures of as much

as 80 mm Hg at the CWMW gage. The contribution of TDG loading from the Bonneville 2nd powerhouse corner collector outfall becomes more important during the lower total river flow conditions in July. In summary, the predictive error was generally small at the CWMW station with 50 percent of the errors less than +/-1 percent saturation and 90 percent of the error less than +/-2 percent saturation as listed in Table E2 below.

Table E2. Statistical summary of the predictive errors of the observed and calculated total dissolved gas saturations at forebay fixed monitoring stations.

Parameters		Predictive Error at Forebay FMS* (%)								
		LGSA	LMNA	IHRA	MCNA	MCQO	JDY	TDA	BON	CWMW
Number of Observations		3330	3327	3330	3334	3334	3334	3334	3316	3299
Average		-1.2	-0.8	-0.5	-2	-1.6	0.2	-0.6	-0.3	0.2
Standard Deviation		2.1	1.1	1.2	1.9	2.4	1.1	1.1	0.9	1.4
Maximum		6.7	2.4	2.8	4.1	9.9	3.9	4.4	3.1	4.7
Minimum		-8.7	-7.5	-5.4	-6.8	-9.9	-3	-4.8	-3.1	-3.6
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	-5.4	-3	-2.6	-4.6	-5.2	-1.4	-2.1	-1.9	-1.8
	10%	-4.2	-2.2	-2.1	-4.2	-4.7	-1.1	-1.8	-1.4	-1.4
	25%	-2.3	-1.3	-1.1	-3.4	-3.4	-0.5	-1.2	-0.9	-0.7
	50%	-0.7	-0.7	-0.3	-2.4	-1.7	0.2	-0.6	-0.4	0.1
	75%	0.2	-0.2	0.3	-0.9	0	1	0	0.3	1.2
	90%	1.1	0.3	0.9	0.8	1.5	1.7	0.6	0.8	2.1
	95%	1.6	0.8	1.3	1.8	2.4	2.1	1.5	1.3	2.7

* Predictive error is the observed minus calculated TDG pressure where negative values reflect an overestimation and positive values reflect an underestimation.

Table E3. Statistical summary of the predictive errors of the observed and calculated total dissolved gas pressures at tailwater fixed monitoring stations.

Parameters		Predictive Error at Tailwater FMS* (mm Hg)									
		DWQI	LGNW	LGSW	LMNW	IDSW	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Observations		1013	2141	1895	2143	3319	2912	2428	3332	3299	3300
Average		-5.7	-25.6	15.7	-3.8	-5.6	2.4	-3.1	-1	-12.1	9.4
Standard Deviation		10.9	36.3	11.8	13.1	10.5	11	10.7	7.2	7.6	15.1
Maximum		34.2	26	100	61	36.5	58.8	23.7	20.3	21.4	65.7
Minimum		-54.9	-182.4	-20.9	-55	-54.7	-41.1	-46.9	-41.2	-62.1	-33
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	-24.2	-93.7	0.8	-26.6	-25	-13.7	-23.7	-13.1	-25	-12.5
	10%	-21.5	-85.4	3.6	-24	-22.3	-11.6	-17.5	-10.1	-18.1	-9.7
	25%	-15.2	-31.8	8.7	-12.7	-11.6	-6.9	-8.9	-5.4	-13.9	-2.2
	50%	-2	-16.2	13.7	-0.9	-3.9	2.8	-2.9	-0.2	-11.5	8.3
	75%	2.8	-6	20.4	5.8	1	9.7	4.2	4	-9	21.4
	90%	6.2	2.9	31.5	10.3	6.5	16.5	10.8	7.4	-5.4	29.7
	95%	8.2	8.8	36.7	13.1	10.4	21.1	13.1	9.6	-2.2	33.9

*Predictive error is the observed minus calculated TDG pressure where negative values reflect an overestimation and positive values reflect an underestimation.

Table E4. Statistical summary of the predictive errors of the observed and calculated total dissolved gas saturations at tailwater fixed monitoring stations.											
Parameters		Predictive Error at Tailwater FMS* (%)									
		DWQI	LGNW	LGSW	LMNW	IDSW	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Observations		1017	2141	1895	2143	3319	2912	2428	3332	3299	3300
Average		-0.8	-3.4	2.1	-0.5	-0.7	0.3	-0.4	-0.1	-1.6	1.2
Standard Deviation		1.5	4.9	1.6	1.7	1.4	1.5	1.4	1	1	2
Maximum		4.7	3.5	13.4	8.2	4.8	7.8	3.1	2.7	2.8	8.6
Minimum		-7.5	-24.5	-2.8	-7.4	-7.3	-5.5	-6.2	-5.4	-8.2	-4.3
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	-3.3	-12.6	0.1	-3.6	-3.3	-1.8	-3.1	-1.7	-3.3	-1.6
	10%	-2.9	-11.5	0.5	-3.2	-3	-1.5	-2.3	-1.3	-2.4	-1.3
	25%	-2.1	-4.3	1.2	-1.7	-1.5	-0.9	-1.2	-0.7	-1.8	-0.3
	50%	-0.3	-2.2	1.8	-0.1	-0.5	0.4	-0.4	0	-1.5	1.1
	75%	0.4	-0.8	2.7	0.8	0.1	1.3	0.5	0.5	-1.2	2.8
	90%	0.8	0.4	4.2	1.4	0.9	2.2	1.4	1	-0.7	3.9
	95%	1.1	1.2	4.9	1.8	1.4	2.8	1.7	1.3	-0.3	4.4

*Predictive error is the observed minus calculated TDG saturation where negative values reflect an overestimation and positive values reflect an underestimation.

Bonneville Dam Tailwater (WRNO)

A hind cast of Bonneville operations was conducted using the SYSTDG model of the river reach from the Bonneville Dam to the fixed monitoring station located at Camas/Washougal from 15 April through 31 August 2005, in an effort to determine the predictive error of SYSTDG estimations in Bonneville Dam tailwater. The official tailwater compliance station below Bonneville Dam is located in the spillway exit channel at station CCIW. However, the long term FMS at WRNO, which is located about 6 miles downstream from the dam in waters that are approaching well-mixed conditions, was active throughout the 2005 fish passage season. One short-coming of the Warrendale gage is its location in an eddy or recirculation cell located near the Oregon shore which tends to dampen its response to bulk TDG properties in deeper portions of the river. The calculated flow weighted average TDG pressures released from Bonneville Dam were lagged 4 hours and compared to the observed TDG pressures at the WRNO gage. The calculated TDG pressures under-estimated observed conditions by an average of 9.4 mm Hg (average predictive error +9.4 mm Hg) and the standard deviation of the predictive error was 15.1 mm Hg as listed in Table E3. The 50% confidence interval of the predictive error ranged from +21.4 to -2.2 mm Hg of pressure and the 90% confidence interval ranged from +29.7 to -9.7 mm Hg of pressure. It is interesting to note that the confidence interval for the predictive error was larger at the WRNO station than determined much further downstream at the CWMW gage. The seasonal time history of observed and calculated TDG pressures at the WRNO gage is shown in Figure E3. The seasonal TDG values at Warrendale are closely correlated to the spillway operations at Bonneville Dam and are a function of the TDG levels produced at upstream dams and discharge through the turbines at Bonneville Dam. The calculated and observed TDG pressures at WRNO are shown throughout the

month of June in Figure E4. The daily cycling of TDG pressures were closely reproduced at the WRNO gage where the nighttime and daytime spill events were slightly underestimated during the month of June. The sources of TDG pressure observed at the WRNO gage include both spillway and Bonneville 2nd Powerhouse corner collector releases.

Bonneville Dam Spillway Exit Channel (CCIW)

A hind cast of Bonneville operations was simulated using the SYSTDG model of the river reach from the Bonneville Dam to the fixed monitoring station located at Camas/Washougal in an effort to determine the predictive error of SYSTDG simulations in the Bonneville Dam tailwater, or more specifically the spillway exit channel on the bank of Cascade Island (CCIW) from 15 April through 31 August 2005. The calculated TDG pressures over-estimated observed conditions by an average of 12.1 mm Hg (average predictive error -12.1 mm Hg) and the standard deviation of the predictive error was 7.6 mm Hg as listed in Table E3 under the label of CCIW. The 50% confidence interval for the predictive error ranged from -9.0 to -13.9 mm Hg of pressure and the 90% confidence interval ranged from -5.4 to -18.1 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the CCIW gage are shown in Figure N5. Calculated TDG pressures representing spill were higher than the observed conditions at the CCIW gage during May as seen in Figure N6. For spill discharges higher than 120 kcfs, the presence of much higher TDG pressures away from the shore-based monitor was consistently was seen during the detailed field investigation conducted during the 2002 spill season (Schneider, 2003). The estimation of TDG levels exiting the spillway channel therefore reflect average conditions that typically exceeded the near shore TDG levels sampled at station CCIW. The spillway operations at Bonneville Dam during 2005 were based on an updated rating curve and recalibrated gate operation.

Bonneville Dam Forebay (BON)

SYSTDG was used to simulate the TDG production and transport from The Dalles Dam to Bonneville Dam from 15 April through 31 August in an effort to determine the predictive error of TDG pressure estimations in Bonneville Dam forebay. This predictive error was determined by subtracting the calculated forebay values at Bonneville from the observed forebay fixed monitoring station data (BON). The strong winds that frequent this river reach have been associated with synoptic degassing events that reduce the TDG levels arriving at Bonneville Dam. The calculated TDG pressures over-estimated observed conditions by an average of 2.6 mm Hg (average predictive error -2.6 mm Hg) and the standard deviation of the predictive error was 7.1 mm Hg as listed in Table E1. The 50% confidence interval for the predictive error ranged from +2.1 to -7.1 mm Hg of pressure and the 90% confidence interval ranged from +6.4 to -11.0 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the BON gage are shown in Figure N7. The seasonal patterns of TDG pressures in the forebay of Bonneville are a series of events where the TDG pressures rapidly decline followed by a general recovery of higher TDG pressures. These

events are strongly correlated with strong wind events followed by weak or moderate wind conditions. The calculated and observed TDG pressures at BON are shown throughout the month of June in Figure N8. The TDG pressures in the forebay of Bonneville are a complex interaction of the TDG loading released from The Dalles Dam, thermal cycling, and wind induced degassing. The weak wind events on July 26-27 were generally responsible for the increasing TDG pressures in the forebay of Bonneville Dam (Figure N9). The modest bias in the calculated TDG pressures in the forebay of Bonneville can be addressed by revisiting the wind field applied throughout this reach and the associated TDG degassing formulation. Currently, the wind field observed from The Dalles municipal airport is applied uniformly throughout this river reach.

The Dalles Dam Tailwater (TDDO)

SYSTDG was used to simulate the TDG production and dissipation from The Dalles Dam to Bonneville Dam forebay from 15 April through 31 August in an effort to determine the predictive error of SYSTDG estimates in The Dalles Dam tailwater during spill events. The Dalles tailwater gage is located about 3 miles downstream from the dam in waters that approach well-mixed conditions. The flow-weighted average TDG conditions were simulated for The Dalles Dam during the spill season and compared to the observed conditions at the tailwater TDG gage TDDO. The calculated TDG pressures were lagged 3 hours, due to the travel time, in making this comparison. The calculated TDG pressures over-estimated observed conditions by an average of 1.0 mm Hg (average predictive error -1.0 mm Hg) and the standard deviation of the predictive error was 7.2 mm Hg as listed in Table E3. The 50% confidence interval of predictive error ranged from +4.0 to -5.4 mm Hg of pressure and the 90% confidence interval ranged from +7.4 to -10.1 mm Hg of pressure. Over 50 percent of the predictive errors at the tailwater FMS (TDDO) were less then +/- 1 percent of saturation during the study period while 90 percent of the estimates were within +/- 2 percent of saturation as listed in Table E4. The spill pattern at The Dalles Dam was modified during the 2005 spill season because of safety concerns with the gate hoists. However, the TDG exchange properties were not greatly impacted by these operational changes because of the importance of the depth of aerated flow in the spillway exit channel. The seasonal time history of observed and calculated TDG pressures at the TDDO gage are shown in Figure E10. The larger variances in TDG response at TDDO during the first half of the spill season were due to the on-off scheduling of spill at John Day Dam. The amount of TDG added by The Dalles Dam spill was moderated by the policy to spill about 40 percent of the instantaneous total river flow. The calculated and observed TDG pressures at TDDO are shown throughout the month of August in Figure E11. The tailwater station at The Dalles Dam is influenced by both powerhouse and spillway flows. This is the only tailwater station operated by the Corps of Engineers that is located in mixed waters. The estimated TDG pressures contained in spillway flows undiluted from powerhouse flow consistently exceeded 120 percent of saturation.

The Dalles Dam Forebay (TDA)

A simulation was run from the John Day Dam to The Dalles Dam forebay from 15 April through 31 August to determine the predictive error of SYSTDG estimations in The Dalles Dam forebay during spill events. The daily cycling of spill at John Day Dam during the first half of the spill season coupled with the short travel time in this river reach (0.7–1.7 days) provided a means of evaluating the ability of SYSTDG to handle a distinct volume of water with TDG pressures as a marker. The calculated TDG pressures over-estimated observed conditions by an average of 4.2 mm Hg (average predictive error –4.2 mm Hg) and the standard deviation of the predictive error was 8.3 mm Hg as listed in Table E1. The 50% confidence interval of the predictive error ranged from -0.3 to -9.3 mm Hg of pressure and the 90% confidence interval ranged from +4.7 to -13.4 mm Hg of pressure as listed in Tables E1. The seasonal time history of observed and calculated TDG pressures at the TDA gage are shown in Figure E12. The daily variability in TDG pressures observed in the forebay of The Dalles Dam are in response to the on-off cycling of spill at John Day Dam. This daily variation was greatly diminished when a continuous spill was implemented at John Day Dam during the second half of the spill season. The TDG estimates at JHAW more frequently over predicted observed conditions during the second half of the spill season when spill was continuous at John Day Dam. The calculated and observed TDG pressures at TDA are shown throughout the month of June Figure E13. The daily cycling in TDG pressures in the forebay at TDA were closely reproduced by the SYSTDG estimates indicating the ability to simulate the transport and mixing of waters with a distinct TDG marker. However, the continuous spill resulted in a consistent over prediction of TDG pressures in the forebay of The Dalles Dam. The estimates of TDG loading associated with spillway releases at John Day Dam is the likely source for this error. The entrainment of powerhouse releases into the spillway is a process that is not well understood over a wide range of operating conditions. The heterogeneities in TDG pressures below the spillway of John Day Dam also introduce a challenge in determining representative TDG levels in spillway flows. A third process contributing to the differences between calculated and observed conditions is the degassing of Columbia River water during transport to The Dalles Dam.

John Day Dam Tailwater (JHAW)

SYSTDG was used to simulate the TDG production associated with spillway operations at John Day Dam as measured at the tailwater fixed monitoring station JHAW from 15 April through 31 August 2005. The large spillway coupled with a spill pattern that is discharge dependent and the interaction of powerhouse and spillway flows throughout the tailwater channel presents a challenge in describing the TDG loading properties unique to John Day Dam. A lag of 2 hours was placed on the calculated undiluted spill water and subtracted from the observed John Day tailwater fixed monitoring station data (JHAW). The calculated TDG pressures over-estimated observed conditions by an average of 3.1 mm Hg (average predictive error –3.1 mm Hg) and the standard deviation of the predictive error was 10.7mm Hg as listed in Table E3. The 50% confidence

interval of the predictive error ranged from +4.0 to -5.4 mm Hg of pressure and the 90% confidence interval ranged from +7.4 to -10.1 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the JHAW gage are shown in Figure E14. The daily variation in TDG pressures routinely ranged over 100 mm Hg during the on-off cycling of spill at John Day Dam (Figure E15). The observed data from the tailwater FMS experienced a gradual decline during the period from July 17-26 as shown in Figure E16. The observed and calculated levels agreed closely after the servicing of the instrument in July 26. The simulated TDG pressures provided a clear indication of the erroneous observed TDG pressures during this period and should be incorporated into quality assurance protocol.

John Day Dam Forebay (JDY)

The TDG pressures were simulated from McNary Dam to the John Day forebay from 15 April through 31 August in an effort to determine the predictive error of SYSTDG estimations in the John Day forebay during spill and non-spill events. The John Day pool was the longest river reach simulated and the travel time ranged from 4.8 to 11.2 days. Calculated forebay TDG pressures were subtracted from the observed John Day forebay fixed monitoring station data to produce an hourly predictive error. The calculated TDG pressures under-estimated observed conditions by an average of 1.9 mm Hg (average predictive error +1.9 mm Hg) and the standard deviation of the predictive error was 8.1 mm Hg as listed in Table E1. The 50% confidence interval for the predictive error ranged from +7.6 to -3.9 mm Hg of pressure and the 90% confidence interval ranged from +12.9 to -8.2 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the JDY gage are shown in Figure E17. The initiation of spill at McNary Dam resulted in a modest increase in the TDG pressures at John Day Dam. The rapid increase and decrease in TDG pressures in the forebay of John Day Dam were typically related to wind events. The predictive errors were larger in the John Day forebay when compared to most other projects because of the uncertainty in the TDG production relationship at McNary Dam and the inability to estimate the in-pool TDG exchange during the long time of travel between dams. The observed and calculated TDG pressures in the forebay of John Day Dam are shown throughout the month of August in Figure E18. The forebay TDG pressures at McNary Dam are generally greater than the forebay TDG pressures at John Day Dam. This suggests that a net reduction in TDG pressures occurs in the John Day pool. The strong winds triggering degassing of TDG pressures coupled with the long travel times is the cause for the net reduction of TDG pressures in this river reach.

McNary Dam Tailwater (MCPW)

The SYSTDG model was used to simulate the TDG exchange associated with spillway releases from McNary Dam throughout the 2005-spill season. The 2005 standard spill pattern called for higher discharges from several spill bays located on the north end of the spillway. The applied spill pattern varied throughout the year because of mechanical problems with raising selected spill gates. The

calculated TDG pressures under-estimated observed conditions by an average of 2.4mm Hg (average predictive error +2.4 mm Hg) and the standard deviation of the predictive error was 11.0 mm Hg as listed in Table E3. The overestimation of observed conditions occurred during spillway releases greater than 160 kcfs as shown in Figure E19. The 50% confidence interval for the predictive error ranged from 9.7 to –6.9 mm Hg of pressure and the 90% confidence interval ranged from 16.5 to -11.6 mm Hg of pressure. The observed and calculated TDG pressures in the tailwater of McNary Dam are shown throughout the month of June in Figure E20 where the spill policy changed from nighttime to continuous spill.

McNary Dam Forebay (MCNA)

The TDG response at the McNary forebay is complicated by the influence from both the middle Columbia and Snake Rivers. Priest Rapids Dam generally spills more water based on the percent of total river flow, than any other project on the Columbia River. However, the TDG loading introduced into McNary pool is moderated by the degassing throughout the open river reach in the Hanford area. The spill operations at Ice Harbor Dam were cycled periodically throughout most of the 2005 spill season. This operation introduced pulses or slugs of water with high TDG levels into McNary pool. The thermal stratification in the forebay of McNary Dam further complicates the determination of approaching TDG pressures to McNary Dam. Thermally induced pressure responses were common throughout the year resulting in forebay TDG pressures that were not representative of bulk river conditions. SYSTDG was used to simulate the TDG properties in the Columbia River from Priest Rapids Dam to McNary Dam and on the Snake River from Ice Harbor Dam to the mouth of the Snake River. The calculated TDG pressures over-estimated observed conditions by an average of 15.2 mm Hg (average predictive error –15.2 mm Hg) and the standard deviation of the predictive error was 14.5 mm Hg as listed in Table E1. The observed thermally induced pressure response is a significant source of the reported predictive error in this case. The 50% confidence interval for the predictive error ranged from -6.7 to -25.4 mm Hg of pressure and the 90% confidence interval ranged from 6.2to -31.4 mm Hg of pressure. The observed and calculated TDG pressures in the forebay of McNary Dam are shown throughout the months of March-September in Figure E21. The calculated and observed TDG pressures in the forebay of McNary Dam are shown in Figure E22 for the month of May. The variation in McNary forebay TDG pressure in May was generally small ranging from 815-875 mm Hg. The calculated TDG pressures were similar to the observed conditions but lagged by 1-2 days. The predictive errors in the forebay of McNary Dam were the highest of all the forebay stations. The primary source for these errors was higher TDG loading originating from the Mid-Columbia River.

Ice Harbor Dam Tailwater (IDSW)

The spill policy at Ice Harbor Dam was varied throughout the 2005 fish passage season to accommodate biological testing of the raised spillway weir (RSW). The

spill pattern ranged from a bulk spill pattern involving the RSW with training flow to the standard spill pattern using all ten spill bays. The percent of river spill also varied significantly throughout the fish passage season. The TDG production equation developed for Ice Harbor was based on the TDG exchange observed during standard spill pattern operations prior to the 2004 spill season. The TDG exchange at Ice Harbor Dam was simulated from 15 April through 31 August in an effort to determine the predictive error of SYSTDG estimations in the tailwater of Ice Harbor Dam during spill events. The calculated TDG produced in undiluted spill waters was compared with observed hourly conditions at the tailwater station IDSW. The calculated TDG pressures over-estimated observed conditions by an average of 5.6 mm Hg (average predictive error –5.6 mm Hg) and the standard deviation of the predictive error was 10.5 mm Hg as listed in Table E3. The 50% confidence interval of the predictive error ranged from +1.0 to -11.6 mm Hg of pressure and the 90% confidence interval ranged from +6.5 to -22.3 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the IDSW gage are shown in Figure E23. The calculated values tend to compare favorably to observed conditions throughout most of the year. The predictive error tended to be larger during the spill activities during late July and August. The standard deviation of the predictive error at Ice Harbor Dam was similar to conditions observed at McNary and John Day Dams. The daily variation in TDG pressures for observed and calculated conditions can be seen in Figure E24 for the month of April. The observed and predicted TDG pressures were similar throughout this period as the daily TDG response cycled with total river flows. The fate of powerhouse flows at Ice Harbor Dam relative to estimates of the TDG loading in the Snake River is a challenging modeling task. A site visit during summer spill revealed 100 percent entrainment of powerhouse releases at Ice Harbor powerhouse into the aerated spillway releases for the conditions observed. The depth of flow in the tailwater channel remains an important determinant of TDG exchange at Ice Harbor Dam.

Ice Harbor Dam Forebay (IHRA)

A simulation was run from Lower Monumental Dam to the forebay of Ice Harbor Dam from 15 April through 31 August to determine the predictive error of SYSTDG estimations in the forebay of Ice Harbor Dam. Calculated forebay TDG pressures were subtracted from the observed TDG pressures at the forebay fixed monitoring station at Ice Harbor Dam (IHRA) to determine the hourly predictive error. The calculated TDG pressures over-estimated observed conditions by an average of 3.4 mm Hg (average predictive error –3.4 mm Hg) and the standard deviation of the predictive error was 9.0 mm Hg as listed in Table E1. The 50% confidence interval for the predictive error ranged from 2.5 to -8.3 mm Hg of pressure and a 90% confidence interval ranged from +6.9 to -16.1 mm Hg of pressure. The range of the predictive error at Ice Harbor Dam was smaller than similar properties at dams on the Columbia River. The limited volume and duration of spill at Lower Monumental Dam probably attributed to the relatively small properties of the predictive error in the forebay of Ice Harbor Dam. The seasonal time history of observed and calculated TDG pressures at the IHRA gage

are shown in Figure E25. The elevated TDG pressures in the forebay at Ice Harbor were associated with the forced spill on the Snake River during the May and the summer spill regiment from that ran from mid-June to the end of August. The relatively constant observed and calculated TDG pressures in the forebay of Ice Harbor are shown in Figure E26 throughout July. The forebay station at IHRA located on the upstream navigation lock guide wall didn't experience the frequent pressure response to thermal cycling that was evident at the old forebay station IHR located on the face of Ice Harbor Dam. The close reproduction of the passage of higher TDG waters from Ice Harbor pool demonstrates both the transport and dissipation properties of SYSTDG for this river reach.

Lower Monumental Dam Tailwater (LMNW)

The predominant spill pattern applied at Lower Monumental Dam during the 2005 fish passage season was a bulk spill pattern involving only 2 or 3 spill bays. The TDG production equation developed during the 2004 TDG field study was applied during this spill season. This study identified powerhouse entrainment discharge as being an important component of the TDG exchange during bulk spill releases. In many cases, the entire powerhouse release is entrained into the aerated spill release significantly increasing the TDG loading at Lower Monumental Dam. The SYSTDG model was applied to simulate the TDG levels produced from spill operations at Lower Monumental Dam from 15 April though 31 August. The TDG properties in undiluted spill waters were compared to the observed conditions at the tailwater fixed monitoring station LMNW. The calculated TDG pressures over-estimated observed conditions by an average of 3.8 mm Hg (average predictive error –3.8 mm Hg) and the standard deviation of the predictive error was 13.1 mm Hg as listed in Table E3. The 50% confidence interval for the predictive error ranged from 5.8 to -12.7 mm Hg of pressure. The 90% confidence interval for the predictive error ranged from 10.3 to -24.0 mm Hg of pressure. The accuracy of TDG predictions at Lower Monumental Dam were significantly improved over the previous estimates in 2004 where the average error was –25.7 mm Hg and the standard error was 21.9 mm Hg. The observed TDG levels in the forebay at Ice Harbor Dam were not frequently impacted by thermally induced pressure fluctuations. The daily variation of TDG pressures at the tailwater FMS below Lower Monumental Dam are shown in Figure E27. There was a tendency for calculations to overestimate the TDG exchange associated with small spillway releases. In these instances the TDG exchange measured at the tailwater fixed monitoring station was more closely approximated by estimates of average cross sectional conditions. A site visit to Lower Monumental Dam during the summer months supported the claim that powerhouse releases were being redirected into the aerated spillway flows and that the tailwater fixed monitoring stations reflected average river conditions below Lower Monumental Dam. The hourly observed and calculated TDG pressures at the tailwater FMS (LMNW) are shown in Figure E28 for the month of May. This figure shows a general agreement between the observed and calculated TDG response at LMNW.

Lower Monumental Dam Forebay (LMNA)

The TDG pressure conditions were simulated from the tailwater of Little Goose Dam to the forebay of Lower Monumental Dam during spill events for the period of 15 April through 31 August as shown in Figure E29. The seasonal variability of TDG pressures in Lower Monumental forebay were similar to conditions discussed at the Ice Harbor forebay. The relatively large increase in TDG levels observed during the forced spill events in May suggests the influence of the entrainment of powerhouse flows plays an important role in the TDG loadings in the Snake River in Lower Monumental pool. The calculated TDG pressures over-estimated observed conditions by an average of 6.3 mm Hg (average predictive error –6.3 mm Hg) and the standard deviation of the predictive error was 8.5 mm Hg as listed in Table E1. The 50% confidence interval for the predictive error ranged from -1.4 to -9.9 mm Hg of pressure and the 90% confidence interval ranged from +2.6 to -16.7 mm Hg of pressure. The daily variation of TDG pressures for the month of July at the forebay FMS above Lower Monumental Dam are shown in Figure E30. The extensive summer time spill at Little Goose Dam at low total river flows and low tailwater elevations were not previously experienced prior to the 2005 spill season. Despite the unique summer time spill conditions scheduled at Little Goose Dam, the calculation of TDG pressures arriving at Lower Monumental Dam were of similar accuracy as determined from the SYSTDG simulations of more routine operations in 2004. The simulations of TDG pressures throughout Lower Monumental pool are consistent with a high degree of entrainment of powerhouse into the aerated spill at Little Goose Dam.

Little Goose Dam Tailwater (LGSW)

A TDG simulation was conducted from Little Goose Dam to Lower Monumental Dam from 15 April through 31 August in order to determine the predictive error of SYSTDG estimations in the tailwater of Little Goose Dam during spill events. The TDG levels calculated for undiluted spill waters were subtracted from the tailwater fixed monitoring station (LGSW) TDG data to estimate the predictive error by the model as shown in Figure E31. The calculated TDG pressures under-estimated observed conditions by an average of 15.7 mm Hg (average predictive error +15.7 mm Hg) and the standard deviation of the predictive error was 11.8 mm Hg as listed in Table E3. The 50% confidence interval ranged from +20.4 to +8.7 mm Hg of pressure and the 90% confidence interval ranged from +31.5 +3.6 mm Hg of pressure. The interaction of powerhouse and spillway releases at Little Goose Dam is heightened because of the depth of the stilling basin and surface oriented spillway discharge. The interpretation of the observed TDG response at the tailwater fixed monitoring station is closely related to the near field circulation patterns. The calculated and observed tailwater TDG pressures below Little Goose Dam during the month of July are shown in Figure E32. The summer time spill policy at Little Goose Dam was changed to accommodate fish passage objectives. The hourly TDG response at the tailwater station LGSW was a function of the different daytime and nighttime spill policies. The observed TDG pressures below Little Goose Dam were often bounded by the estimates of the

TDG content in spillway flows and the average cross sectional TDG pressures accounting for the contribution from both spillway and powerhouse releases.

Little Goose Dam Forebay (LGSA)

SYSTDG was used to hind cast the TDG pressures in Little Goose pool in response to operations at Lower Granite Dam from 15 April 31 August. The elevated TDG levels in the forebay of Little Goose Dam are a consequence of the TDG uptake associated with spill at Lower Granite Dam, the thermal exchange during transport through the pool, and the surface exchange with the atmosphere. The predicted TDG pressure responses in the Little Goose forebay were reasonably well predicted as shown in Figure E33 during the spring and early summer months. However, consistent overestimations of TDG pressures in the forebay of Little Goose Dam were observed during the much of July and August. As noted earlier, the summer time spill on the Snake River was unique. The TDG exchange performance used in SYSTDG was based on observations for operating conditions outside of those experienced in 2005. In the case of Lower Granite Dam, the methodology for estimating TDG exchange for small spill discharges at low tailwater and powerhouse flows provided inaccurate estimates of TDG exchange at Lower Granite Dam and downstream in the forebay of Little Goose Dam. The TDG exchange model for Lower Granite Dam will need to be revised to accommodate the range of operating conditions experienced during the summer of 2005. The calculated TDG pressures over-estimated observed conditions by an average of 8.7 mm Hg (average predictive error -8.7 mm Hg) and the standard deviation of the predictive error was 15.6 mm Hg as listed in Table E1. The 50% confidence interval ranged from +1.8 to -17.1 mm Hg of pressure and the 90% confidence interval ranged from +7.9 to -31.4 mm Hg of pressure. The calculated and observed tailwater TDG pressures in the forebay of Little Goose Dam during the month of June are shown in Figure E34. The observed and calculated TDG pressures were generally within 10 mm Hg during June with little bias apparent in the estimates. The declining TDG pressures in the forebay of Little Goose Dam as the summer progressed were in response to the longer travel time and smaller spillway discharge at Lower Granite Dam. The discrepancy between the observed and calculated TDG pressures at LGSA for July is shown in Figure E35.

Lower Granite Dam Tailwater (LGNW)

The TDG levels associated with spillway releases from Lower Granite Dam were simulated from the 15 April through 31 August as shown in Figure E36. The calculated TDG pressures over-estimated observed conditions by an average of 25.6 mm Hg (average predictive error –25.6 mm Hg) and the standard deviation of the predictive error was 36.3 mm Hg as listed in Table E3. The 50% confidence interval for the predictive error ranged from -6.0 to -31.8 mm Hg of pressure and the 90% confidence interval ranged from +2.9 to -85.4 mm Hg of pressure. The calculated TDG saturation was larger than the observed conditions during the month of July and August. The entrainment discharge was assumed to be a constant fraction of the spill discharge. The estimate of entrainment discharge was thought to be the source for the high predictive errors during the

summer at Lower Granite Dam. The observed and calculated TDG response for June and August are shown in Figure E37 and E38. In general, predictive errors were small for spill flows greater than 20 kcfs as observed during June and much larger for spill less than 20 kcfs as scheduled in August. The formulation for the entrainment discharge was modified to diminish for flows less than 25 kcfs. The powerhouse entrainment discharge was estimated to be a fraction of the spillway discharge as determined from the following expression:

$$Q_{ent} = \min \{ (Q_{sp}/25)^{1.5}, 1.0 \} \times Q_{sp}$$

This expression sets the entrainment discharge equal to the spill discharge for spills greater than 25 kcfs. The entrainment discharge becomes less than the spill discharge for flows less than 25 kcfs. This modified entrainment formulation was added to SYSTDG for Lower Granite Dam for the 2005 fish passage season. The calculated and observed TDG pressures for August are shown in Figure E39 for the modified entrainment formulation. The estimated TDG pressures closely approximate the observed conditions throughout the month of August.

Dworshak Dam Tailwater (DWQI)

The TDG pressures in the tailwater channel below Dworshak Dam were simulated during the 2005 spill season as shown in Figure E40. The calculated TDG pressures over-estimated observed conditions by an average of 5.7 mm Hg (average predictive error -5.7 mm Hg) and the standard deviation of the predictive error was 10.9 mm Hg as listed in Table E3. The 50% confidence interval for the predictive error ranged from +2.8 to -15.2 mm Hg of pressure and the 90% confidence interval ranged from +6.2 to -21.5 mm Hg of pressure. Dworshak Dam does not have a forebay TDG station and the TDG pressures observed at the tailwater station during powerhouse only operations were used to estimate the TDG pressures released by the powerhouse during concurrent powerhouse and spillway/regulating releases. The TDG exchange formulation for Dworshak Dam currently does not account for the TDG production associated with turbine releases. Turbine releases at small discharges (Q_{ph}<2 kcfs) can aspirate air to smooth operations resulting in an elevation of TDG pressures below the dam. The periodic scheduling of the minimum powerhouse releases as shown in Figure E40 resulted in TDG pressures ranging from 760-800 mm Hg as observed at the tailwater fixed monitoring station (DWQI). The TDG pressures associated with powerhouse releases greater than 2 kcfs generally ranged from 710-740 mm Hg. The over-flow operation of the selector gates that released warmer upper level water experienced higher TDG pressures than colder under-flow operations. The estimates of TDG pressures at the tailwater fixed monitoring station DWQI are assumed to reflect well-mixed conditions and are therefore dependent upon the TDG levels of both powerhouse and spillway/regulating outlet conditions. The TDG pressures estimated at the tailwater FMS assumed a TDG pressure of powerhouse flows of 720-730 mm Hg and a TDG pressure of spillway flows modeled as an exponential function of spillway/regulating outlet discharge as shown in Figure E41 for the month of May. The calculated TDG pressures were

generally within 10 mm Hg of the observed conditions at DWQI. The current SYSTDG production relationship at Dworshak Dam does not distinguish between regulating outlet or spillway operations.

Comparison of 2004 and 2005 Simulations

The performance of the SYSTDG decision support system as measured by the hourly predictive error statistics at fixed monitoring stations during the 2005 spill season was similar to the performance observed during the 2004 fish passage season. The standard deviation of the predictive error is the most descriptive metric of how accurate the calculated TDG pressures were to the observed TDG pressures. The standard deviation of the predictive errors in 2004 ranged from 5.7 to 21.9 mm Hg at fixed monitoring stations. In 2005, the standard deviation of the predictive errors at fixed monitoring stations ranged from 7.1 to 36.3 mm Hg. Significant improvements were achieved in estimating the TDG exchange and transport at Lower Monumental and Ice Harbor Dams. The standard deviation of the predictive error at the tailwater station below Lower Monumental Dam (LMNW) was reduced from 21.9 mm Hg in 2004 to only 13.1 mm Hg during the 2005 season. The degree of improvement at Ice Harbor Dam as measured by the standard deviation of the predictive error fell from 19.5 mm Hg in 2004 to 10.5 mm Hg in 2005. There were several stations where the predictive errors were considerably greater in 2005 compared to 2004. The standard deviation of the predictive error in the tailwater of Lower Granite Dam increased from 15.8 mm Hg in 2004 to 36.3 mm Hg in 2005. The source for the more than doubling of the standard deviation of the predictive error was associated first-time spill operations during July and August from Lower Granite Dam. The estimation methodology for TDG exchange at Lower Granite based on historic operations was not applicable over the range of operations experienced during the 2005 fish passage season. The standard deviation of the predictive error at the tailwater station below Lower Granite Dam during the normal spill operations in May-July of 2005 was only 13.1 mm Hg or similar to the accuracy achieved during 2004.

The forebay fixed monitoring station locations were changed at McNary, Ice Harbor, Lower Monumental, and Little Goose Dams in 2005. These stations were located away from the vertical dam face and in deeper water to reduce the pressure induced fluctuations associated with surface warming. The new station locations do provide more representative measures of TDG pressure approaching this projects. It was noted in the 2004 performance evaluation that relocation of forebay stations should improve the accuracy of estimates of forebay TDG pressures. In fact, the accuracy of forebay estimates in 2005 declined slightly on the Snake River and at McNary Dam compared to the 2004 estimates. The primary source for the larger predictive errors in 2005 was in the estimates of degassing corresponding with the much longer travel times between projects during the low flow conditions in the summer. The travel times between Lower Granite Dam and Little Goose Dam ranged from 8-12 days in July of 2005 compared to 2-4 days during typical springtime discharges.

Conclusions

The decision support spreadsheet SYSTDG was used to simulate the production, transport, and dissipation of TDG pressures in the Columbia River basin during the 2005 spill season. These estimates of TDG pressure were compared with observed levels from the fixed monitoring stations to evaluate the reliability of these calculations with observed TDG pressures, and to determine the uncertainty of TDG estimates to support spill management policy. The applications of spillway operations throughout the basin were generally limited to levels identified in the 2005 fish passage plan or special summertime spill operations. The operational policy involving spilling water on the Snake and Lower Columbia Rivers during the summer months was conducted for the first time in 2005. These unique operations resulted in conditions outside of the normal operating range under which the SYSTDG model was developed. At some project, revised spill patterns were employed to aid fish passage during low summer time river flows. The predictive error was computed by subtracting the hourly estimates of TDG pressure from observed conditions.

In general, the forebay station comparisons generated smaller predictive errors (Tables E1 and E2) than the tailwater station comparisons (Tables E3 and E4). The average predictive errors at forebay stations were less than 1 percent of saturation with the exception of Little Goose and McNary Dams. The overestimation of forebay TDG pressures at McNary Dam was attributed to misrepresenting TDG levels originating from the Mid-Columbia River. The larger estimation errors in the forebay of Little Goose were largely attributed to estimates misrepresenting TDG production at Lower Granite Dam during August. The location of forebay stations away from the dam and at greater depth, resulted in fewer temperature induced spikes in TDG pressure and smaller predictive errors at these stations. The correlation between strong winds and declining TDG pressure at forebay stations was evident during the 2005 spill season and was an important determinant of calculated TDG levels.

The larger predictive errors determined at the tailwater FMS were likely associated with the TDG heterogeneities generated in spillway flows and monitored at many tailwater FMS, the timing and duration required to establish steady-state TDG levels at monitoring stations, and the application of accurate operating conditions. The standard deviation of predictive error at the tailwater stations ranged from 7.2 mm Hg at The Dalles Dam tailwater station TDDO to 36.3 mm Hg at Lower Granite tailwater station (LGNW). The large errors observed during the month of August at the Lower Granite Dam tailwater were associated with the estimated size of the entrainment discharge.

Of all the tailwater FMS gauges reviewed, The Dalles Dam simulations produced the smallest predictive error based on the standard deviation statistic, while Lower Granite tailwater simulations produced the largest amount of predictive error as

shown in Figure E42. In the plot shown in Figure E42, the box reflects the predictive error of the 25th, 50th, and 75th percentile, the whiskers show the 10th and 90th percentiles, and the circular symbols reflect observations outside of the 10th and 90th percentiles. The small size of the predictive error at The Dalles and Bonneville tailwater station was partially associated with the contribution from powerhouse releases that were determined from observed forebay conditions. The large predictive error below Lower Granite Dam was associated with the high entrainment discharge during low river flows.

Bonneville Dam operations during the 2005 season were based on a revised spillway rating curve. The TDG production relationships developed from field studies were modified to reflect the change in discharge. The standard deviation of the predictive errors at FMS downstream of Bonneville Dam was small compared to other projects. The standard deviation of the predictive error in the spillway exit channel was 7.6 mm Hg compared to 10.5 mm Hg downstream at the Camas/Washougal gage.

The spillway operations at The Dalles Dam during the 2005 season were impacted by the constrained operations of spill bays 3-6. The change in spill discharge was accomplished by gate changes in spill bays 1 and 2 during a constant gate opening through bays 3-6. The standard deviation of the predictive error at FMS downstream of The Dalles Dam ranged from 7.2 mm Hg at the tailwater station TDDO to 7.1 mm Hg in the forebay of Bonneville Dam. The tailwater stage elevation and not the spill pattern or discharge is the primary determinant of TDG exchange at The Dalles Dam.

The spill operations at John Day Dam followed a normal pattern throughout the 2005 fish passage season. The standard deviation of the predictive error at FMS's downstream of John Day Dam ranged from 10.7 mm Hg at the tailwater station JHAW to 8.3 mm Hg in the forebay of The Dalles Dam.

The operations at McNary Dam involved spill throughout the entire summer that was a departure from previous operational policies. The maximum instantaneous spill rate of 195 kcfs scheduled in the Columbia River Basin occurred at McNary Dam during the 2005 spill season. The standard deviation of the predictive error at FMS downstream of McNary Dam ranged from 11.0 mm Hg at the tailwater station MCPW to 8.1 mm Hg in the forebay of John Day Dam.

The operation of the spillway at Ice Harbor Dam involved biological testing of alternative spill patterns and rates involving the raised weir crest. The standard deviation of the predictive error at FMS downstream of Ice Harbor Dam ranged from 10.5 mm Hg at the tailwater station IDSW to 14.5 to 17.8 mm Hg in the forebay of McNary Dam. The new forebay station at McNary Dam (MCNA) experienced significantly lower estimation errors compared to the shallower station at MCQO.

The spillway operations at Lower Monumental Dam involved more extensive spill during the summer months than during the springtime. A provisional spill pattern was applied during the summer time during low flow conditions. The standard deviation of the predictive error at FMS downstream of Lower Monumental Dam ranged from 13.1 mm Hg at the tailwater station LMNW to 9.0 mm Hg in the forebay of Ice Harbor Dam.

The spillway operations at Little Goose Dam involved only about one week of spill prior to a continuous spill policy from June 20 through the end of August. A provisional spill pattern was applied during the summer time during low flow conditions. The standard deviation of the predictive error at FMS downstream of Little Goose Dam ranged from 11.8 mm Hg at the tailwater station LGSW to 8.5 mm Hg in the forebay of Lower Monumental Dam

The spillway operations at Lower Granite Dam featured the prominent use of the raised weir crest and continuous spill during the summer months. The standard deviation of the predictive error at FMS downstream of Lower Granite Dam ranged from 36.3 mm Hg at the tailwater station LGNW to 15.6 mm Hg in the forebay of Little Goose Dam. The predictions of TDG exchange during the summer months became increasingly inaccurate due to the estimation of entrainment of powerhouse flows. A modified description of entrainment was proposed for Lower Granite Dam resulting in an improved description of TDG exchange at Lower Granite Dam during low flow conditions.

Spillway releases were scheduled at Dworshak Dam during the 2005 spill season. A short period of forced spill occurred in May followed by spill to support the drafting of the Dworshak pool during the summer. The standard deviation of the predictive error at FMS downstream of Dworshak Dam was 10.9 mm Hg.

Recommendations

The following improvements to the SYSTDG model are recommended for the next year.

The description of TDG exchange at all projects within the study area should be updated to reflect the current spill patterns and structural configurations. The SYSTDG decision support system will incorporate real-time spill pattern data in the upcoming 2006 fish passage season where this information is available.

The TDG data collected below Dworshak Dam during the 2005 spill season should be used to improve the TDG exchange algorithm.

A modified entrainment algorithm for powerhouse releases is recommended for the Snake River Projects for low river flow environments. The proposed description for entrainment as developed for Lower Granite dam should be extended to other projects for low flow conditions.

The surface exchange coefficients should be adjusted to reduce the predictive error bias as determined at forebay stations. There exists experimental evidence that the exchange coefficient of atmospheric gasses in river systems has a temperature dependency. This formulation should be investigated in selected river reaches. In some cases, the application of wind magnitude and direction data from alternative stations should be examined to see if predictions could be improved.

The uncertainty of TDG predictions should be factored into a risk based management policy. The likelihood of a spill policy exceeding the TDG criteria at downstream FMS stations should be factored into the decision making process.

Complete the development of the data filters that will remove erroneous data.

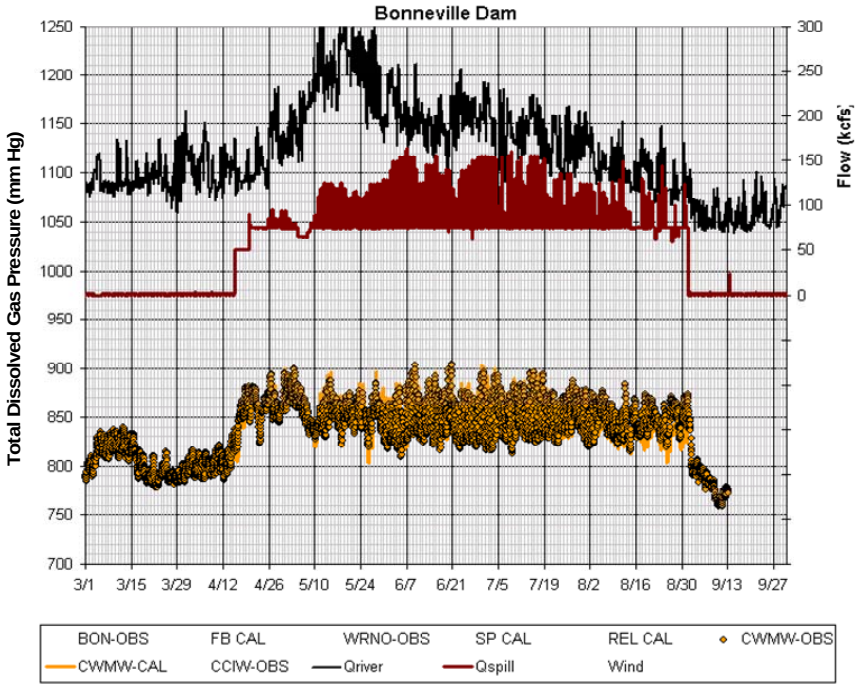

Figure E1. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Camas/Washougal fixed monitoring station downstream of Bonneville Dam, March-September 2005

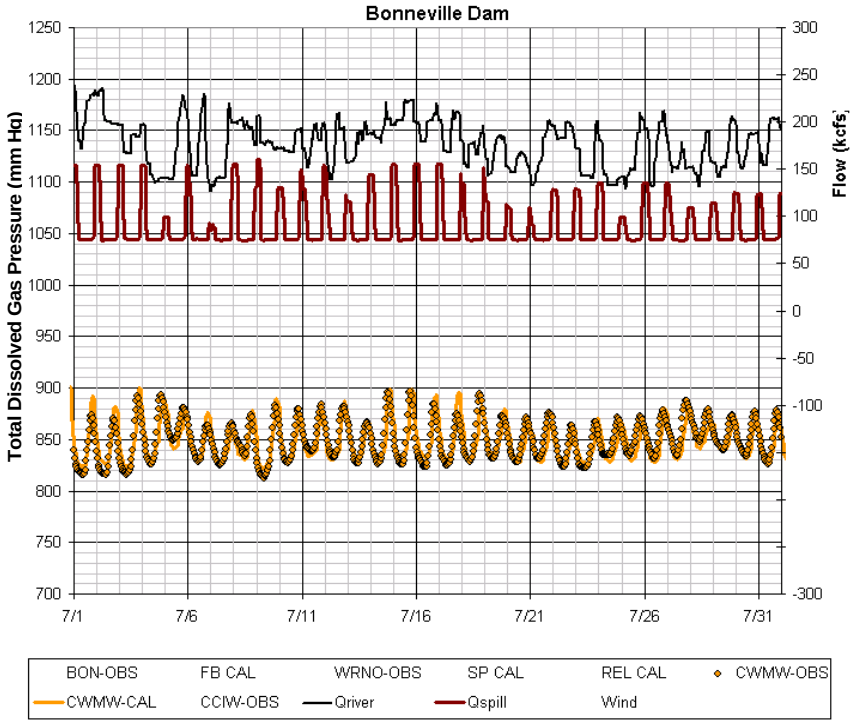

Figure E2. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Camas/Washougal fixed monitoring station downstream of Bonneville Dam, July 2005

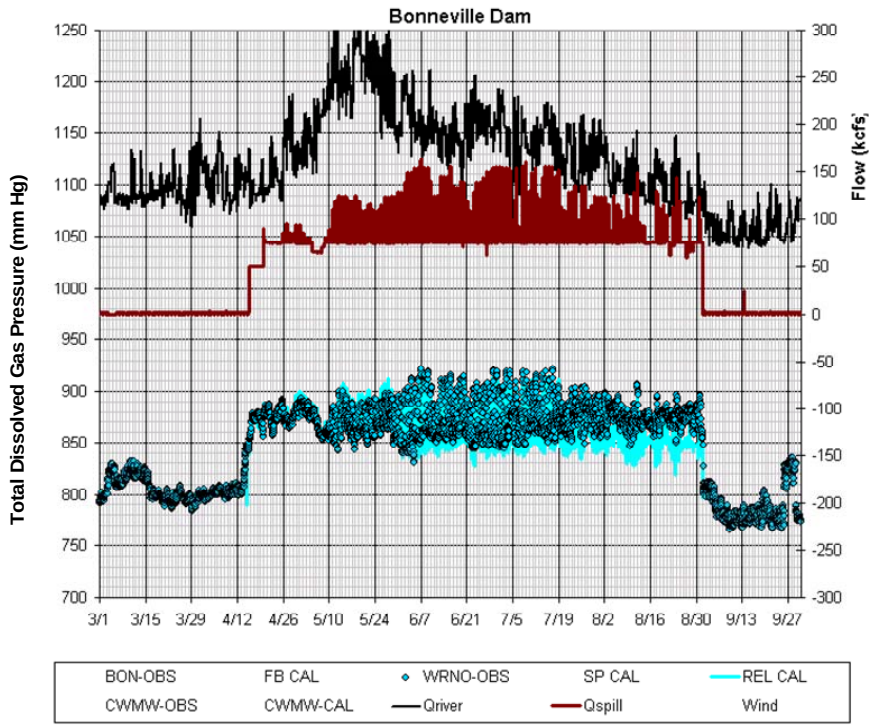

Figure E3. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Warrendale fixed monitoring station downstream of Bonneville Dam, March-September 2005

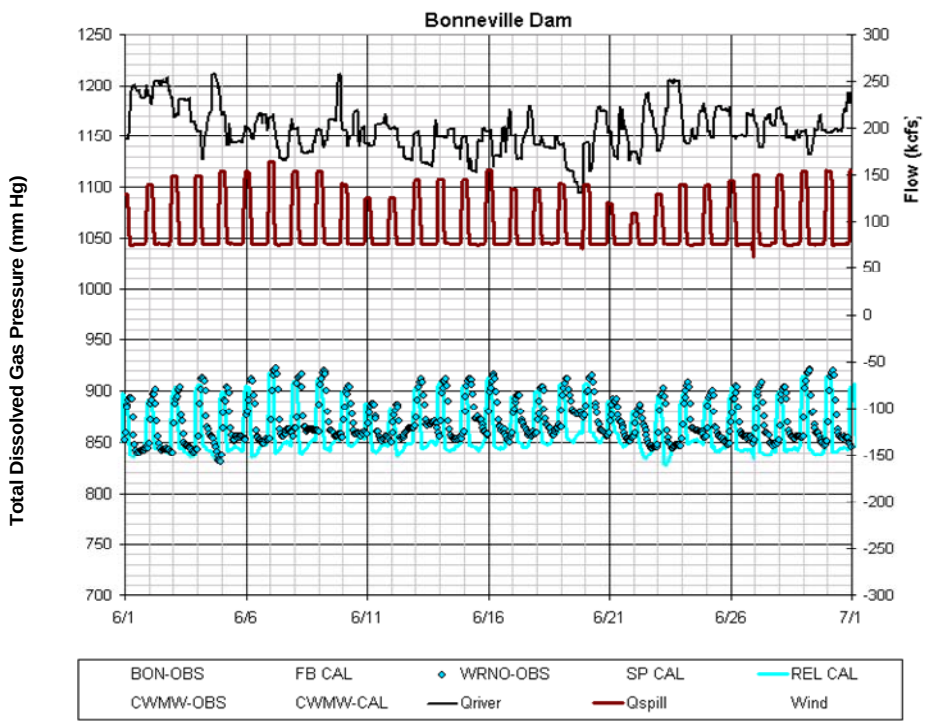

Figure E4. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Warrendale fixed monitoring station downstream of Bonneville Dam, June 2005

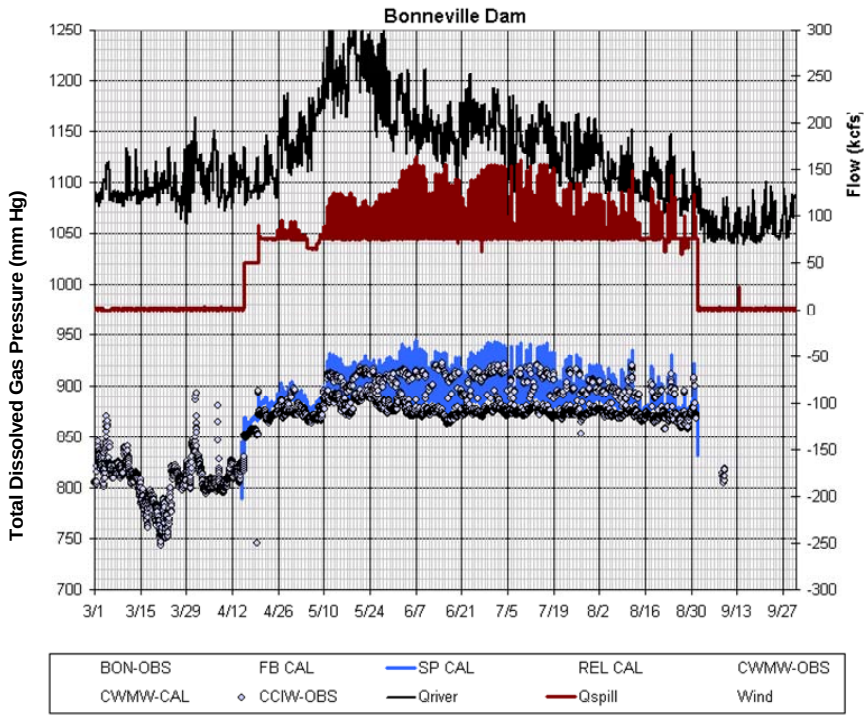

Figure E5. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam, March-September 2005

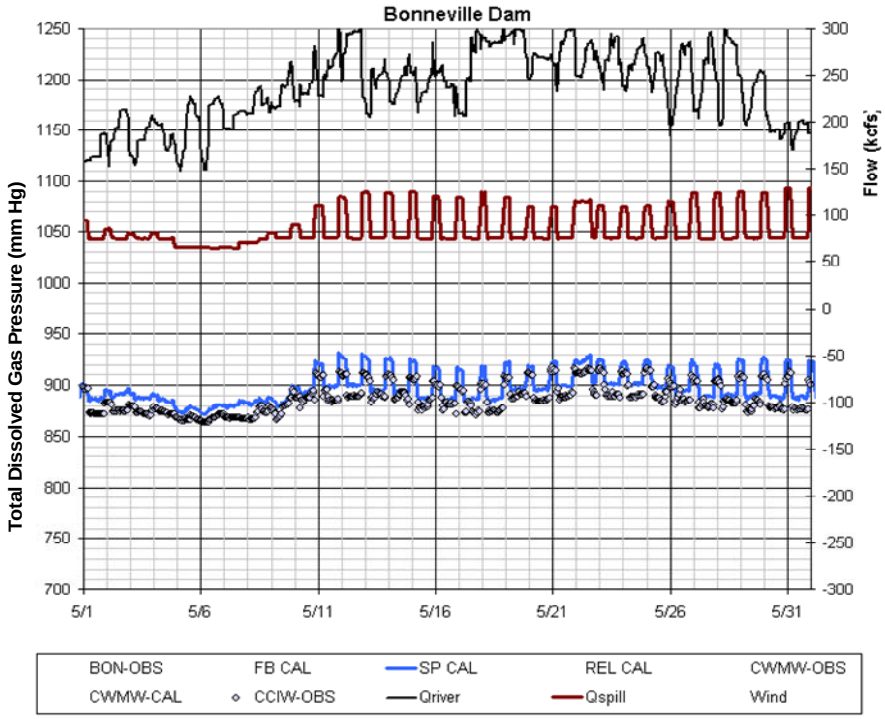

Figure E6. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam, May 2005

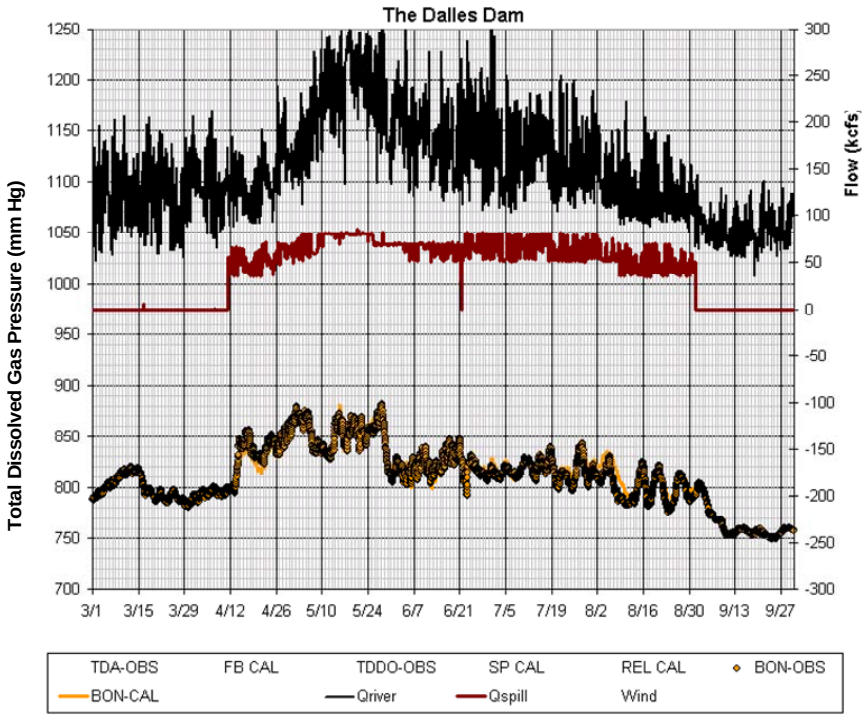

Figure E7. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of Bonneville Dam, March-September 2005

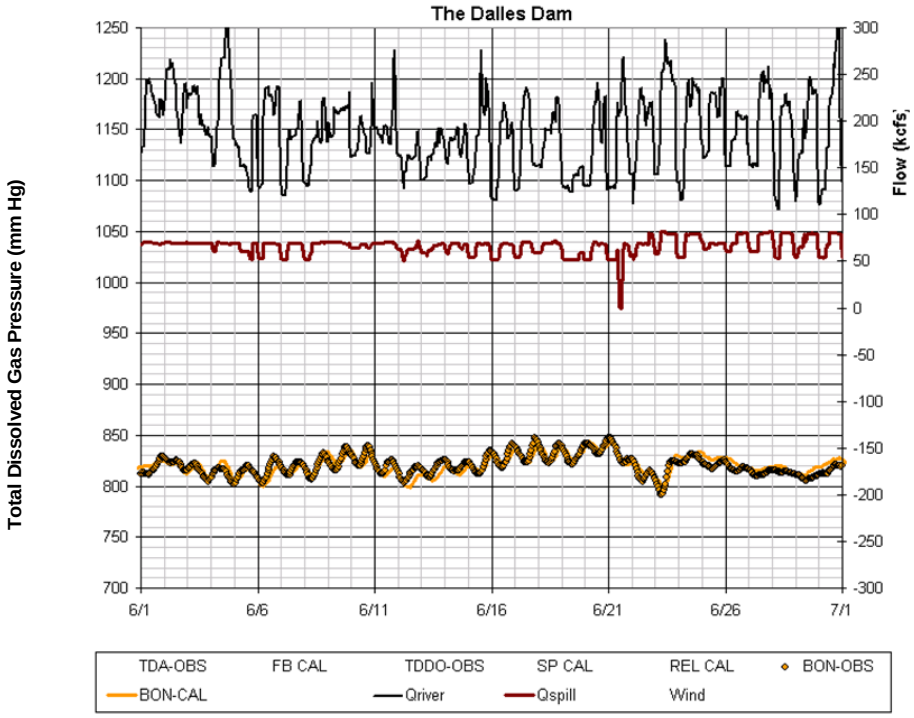

Figure E8. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of Bonneville Dam, June 2005

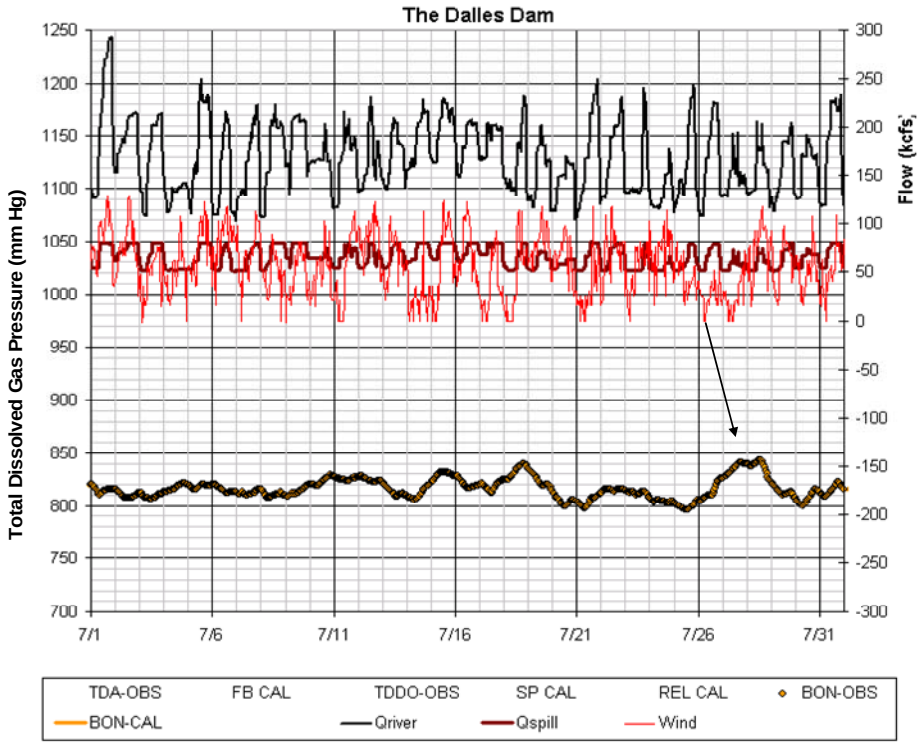

Figure E9. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of Bonneville Dam, July 2005

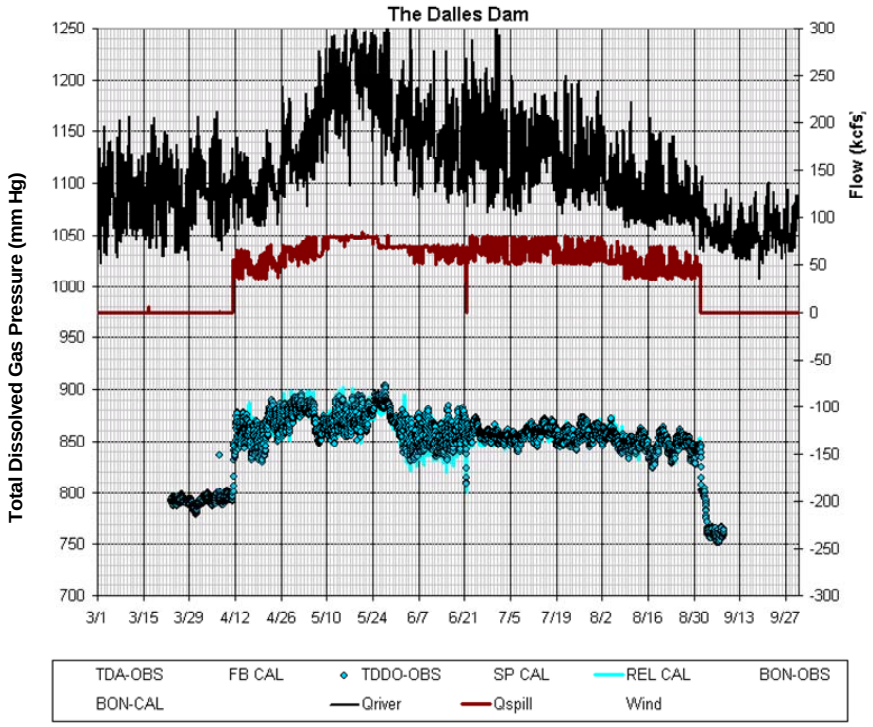

Figure E10. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from The Dalles Dam, March-September 2005

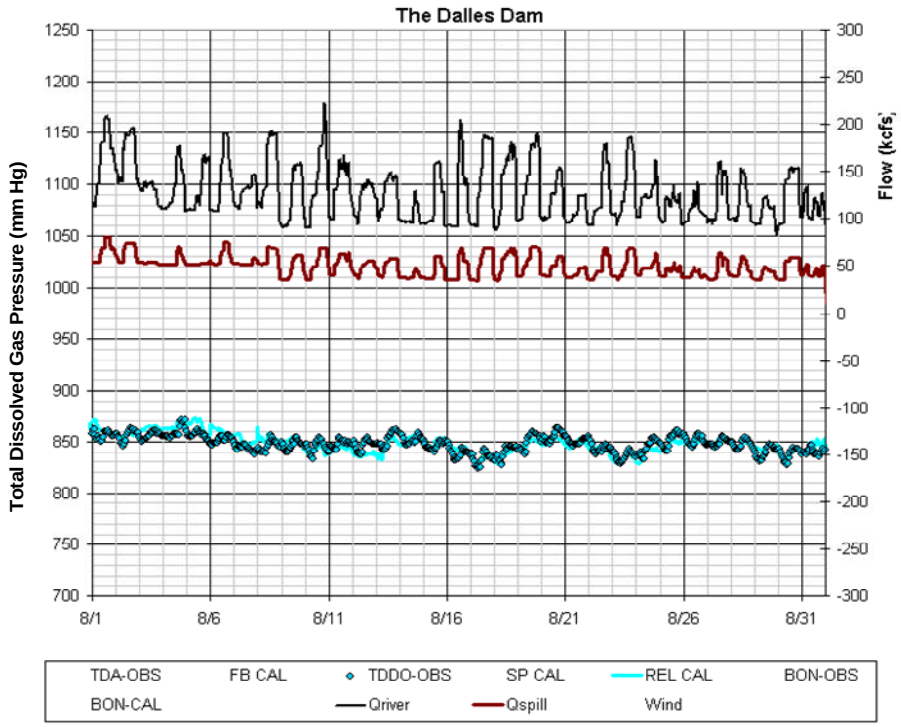

Figure E11. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from The Dalles Dam, August 2005

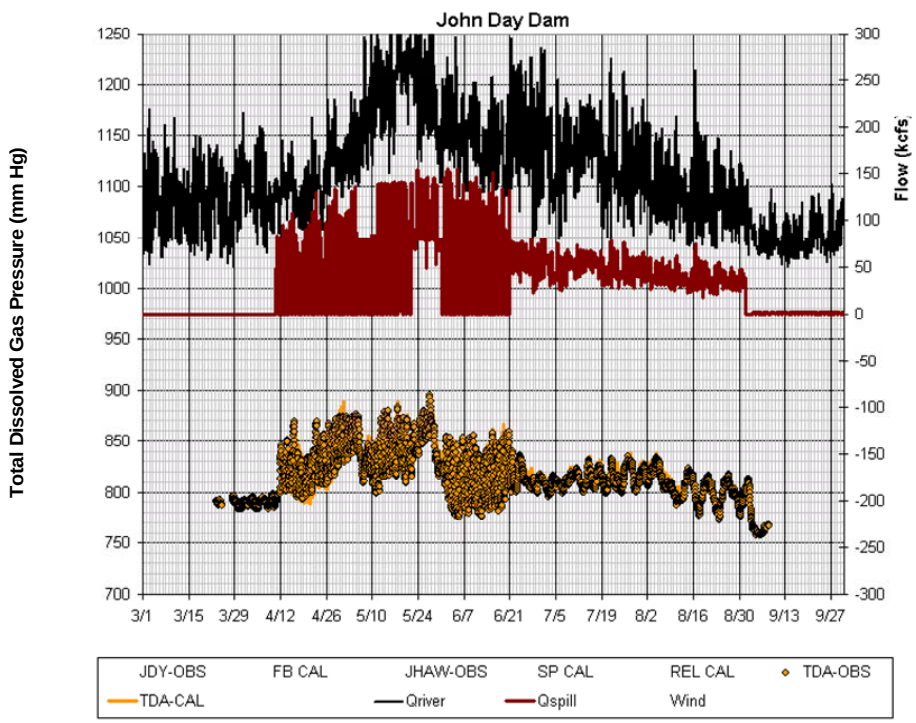

Figure E12. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of The Dalles Dam, March-September 2005

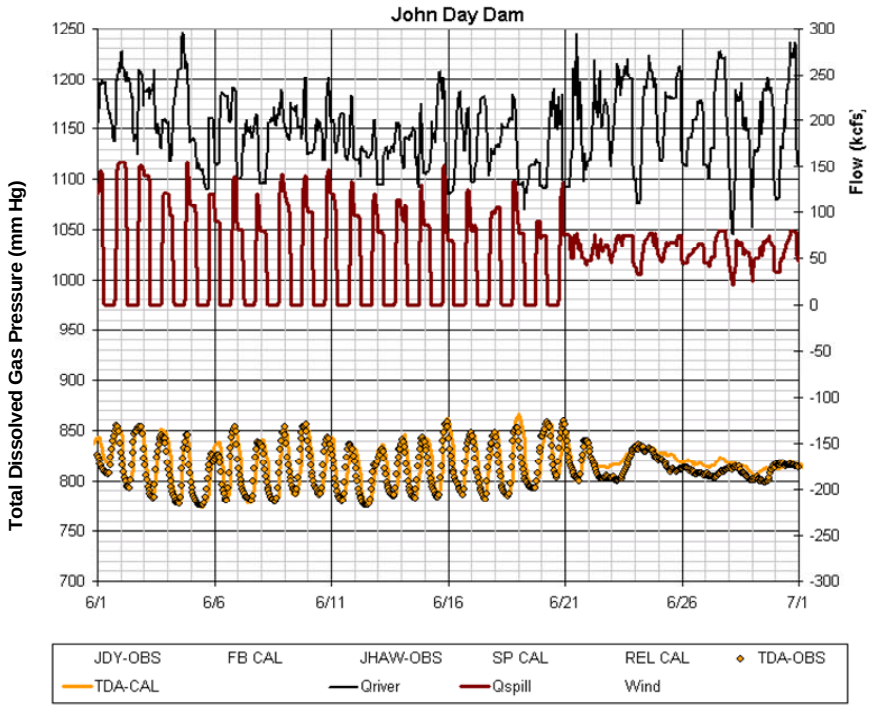

Figure E13. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of The Dalles Dam, June 2005

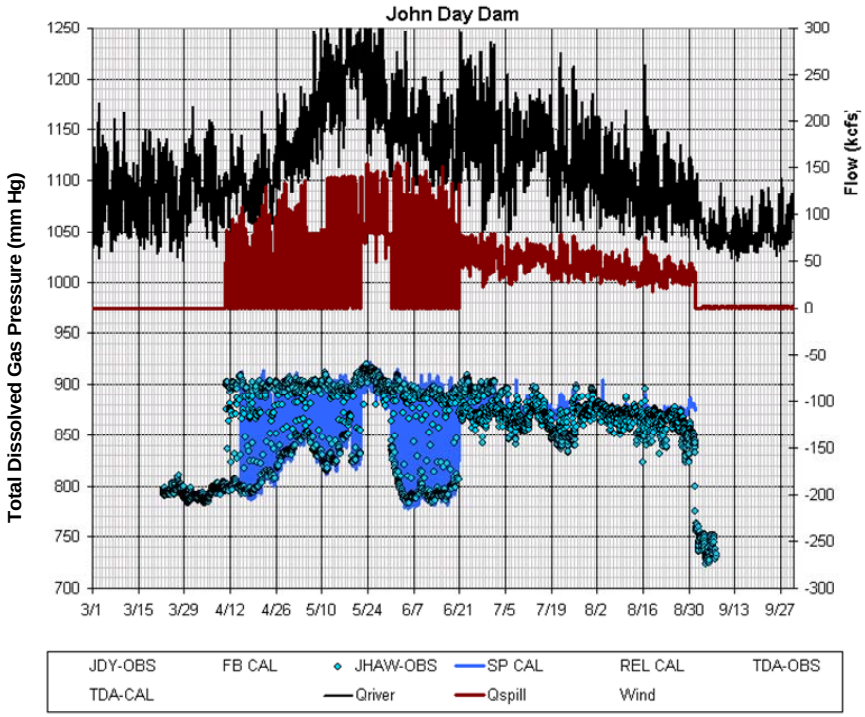

Figure E14. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, March - September, 2005

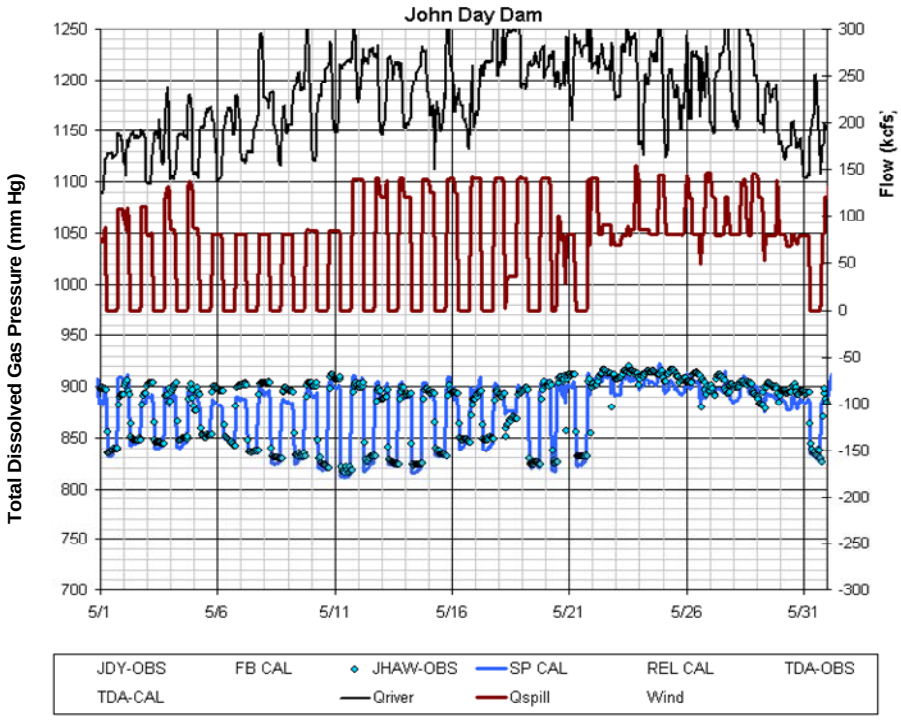

Figure E15. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, May, 2005

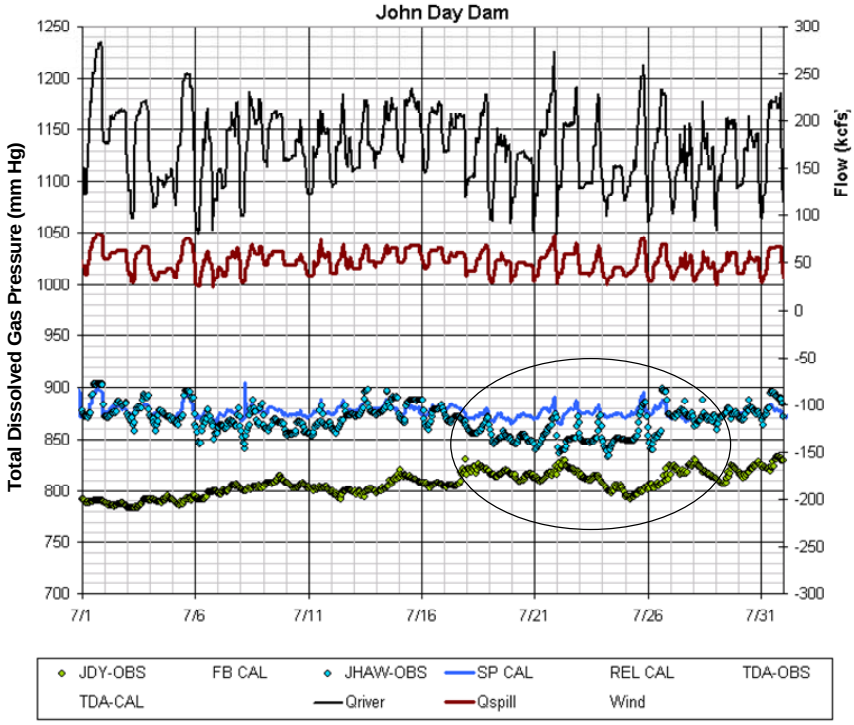

Figure E16. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, July, 2005

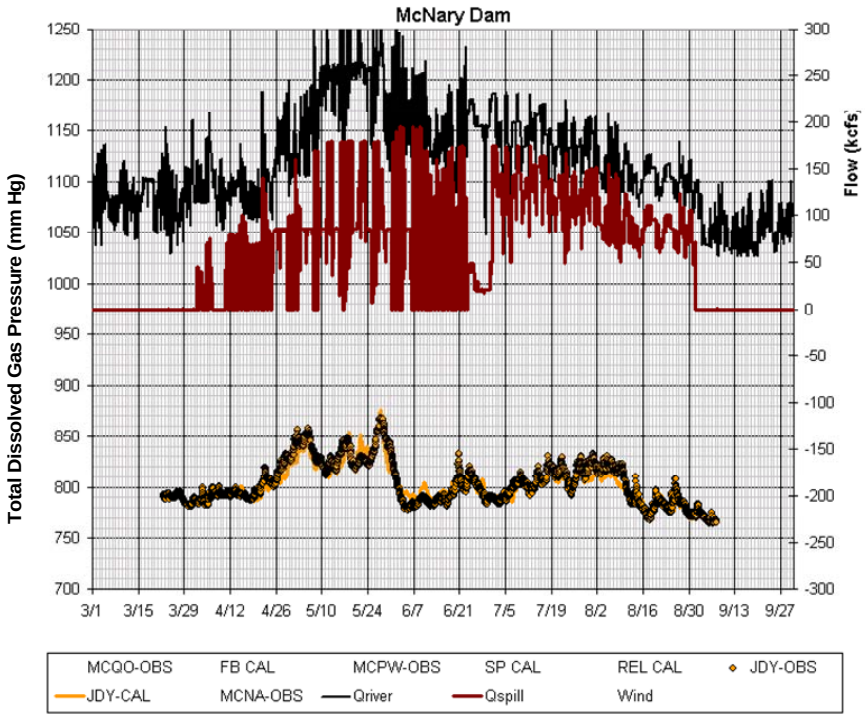

Figure E17. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of John Day Dam, March-September 2005

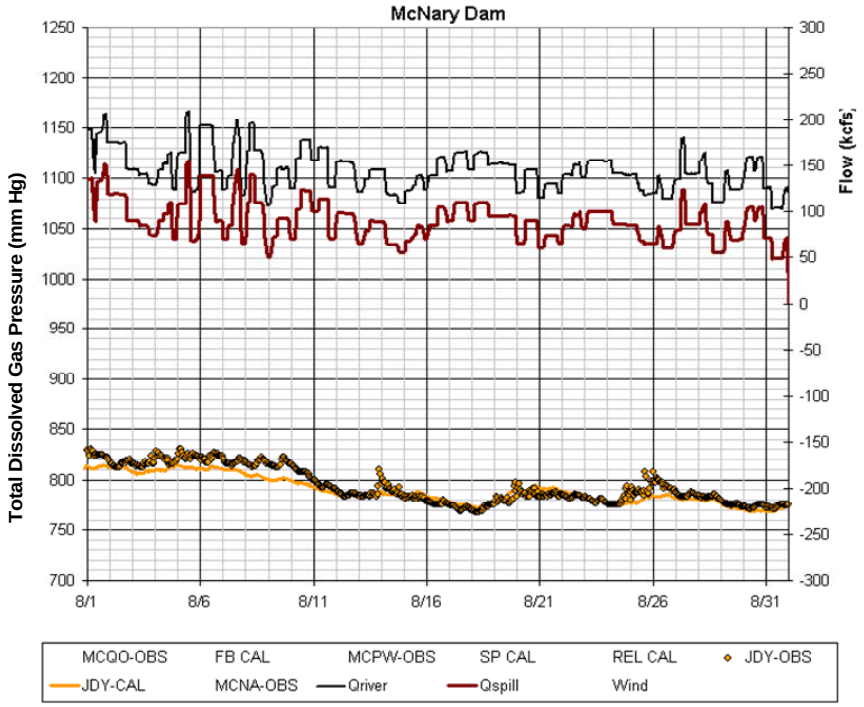

Figure E18. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of John Day Dam, August 2005

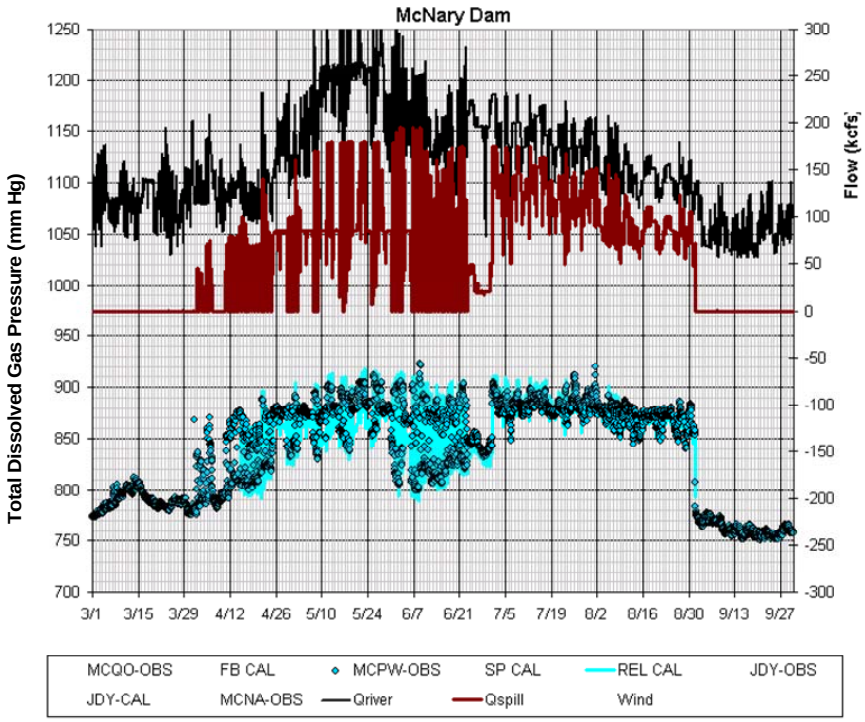

Figure E19. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater of McNary Dam, March-September 2005

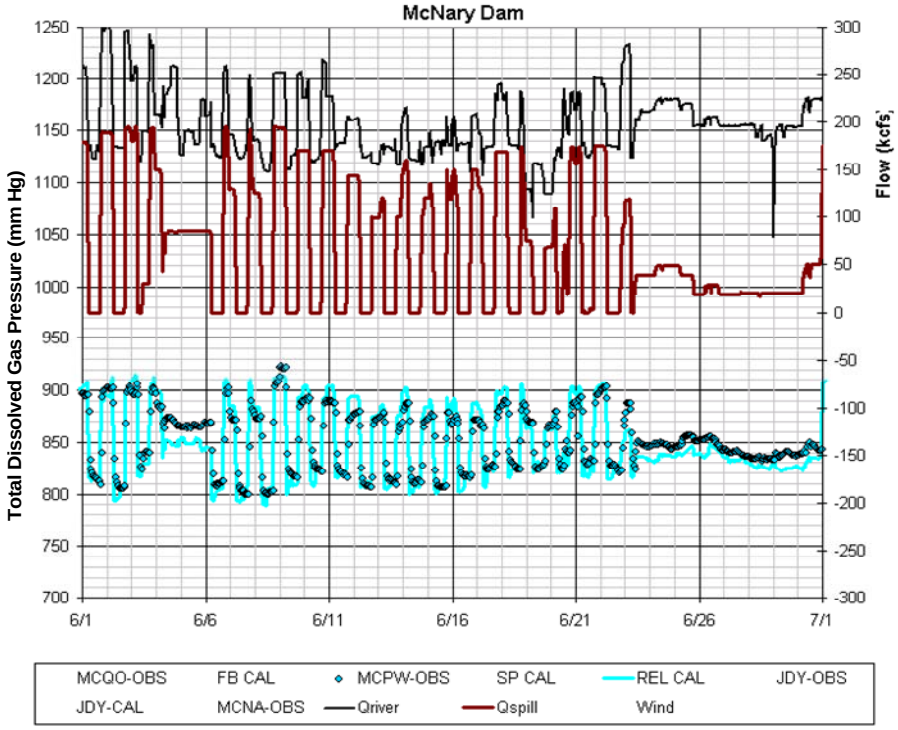

Figure E20. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater of McNary Dam, June 2005

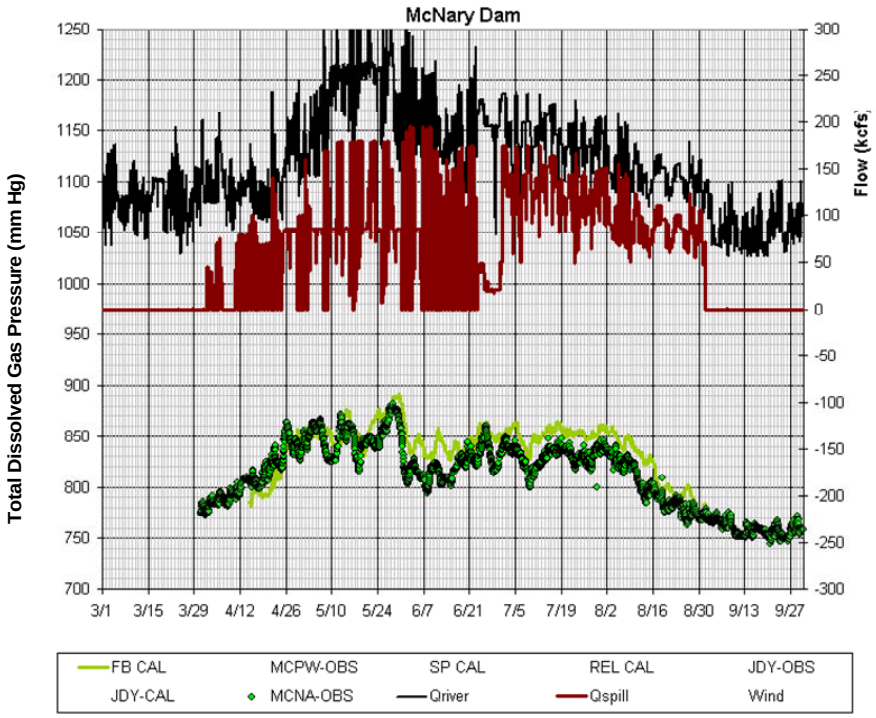

Figure E21. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of McNary Dam, March-September 2005

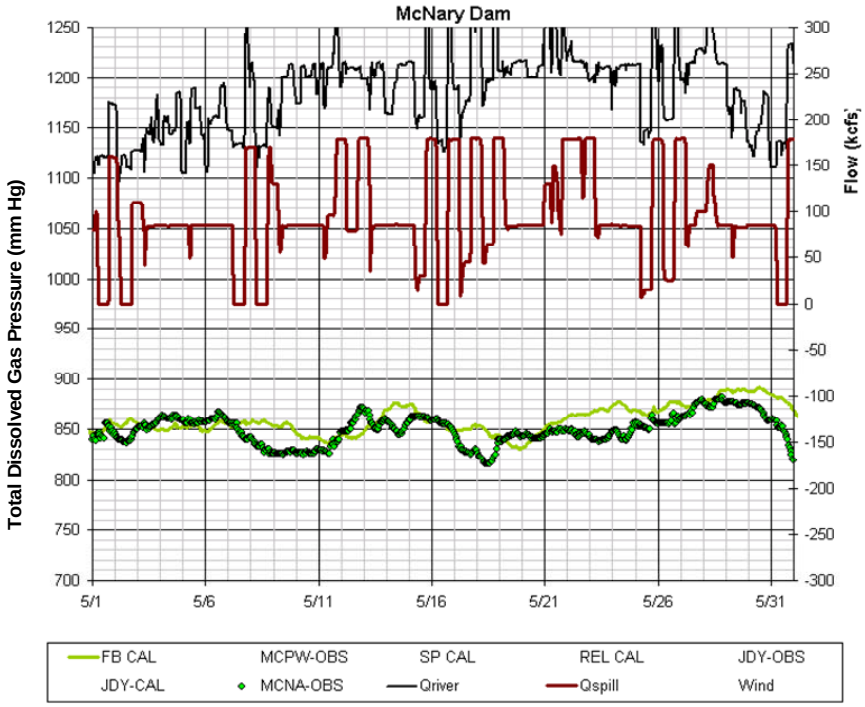

Figure E22. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of McNary Dam, May 2005

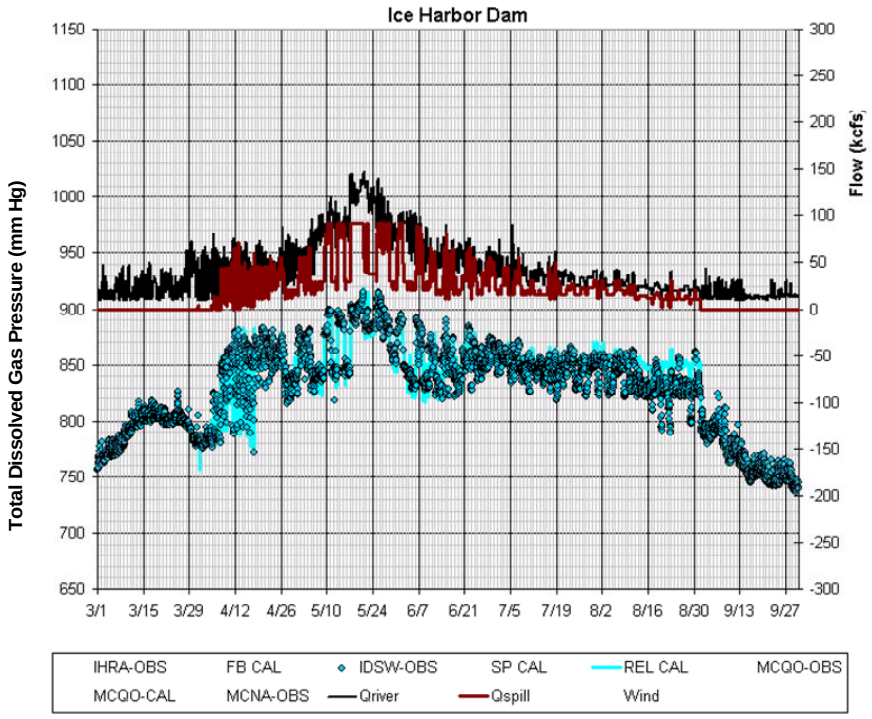

Figure E23. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Ice Harbor Dam, March - September, 2005

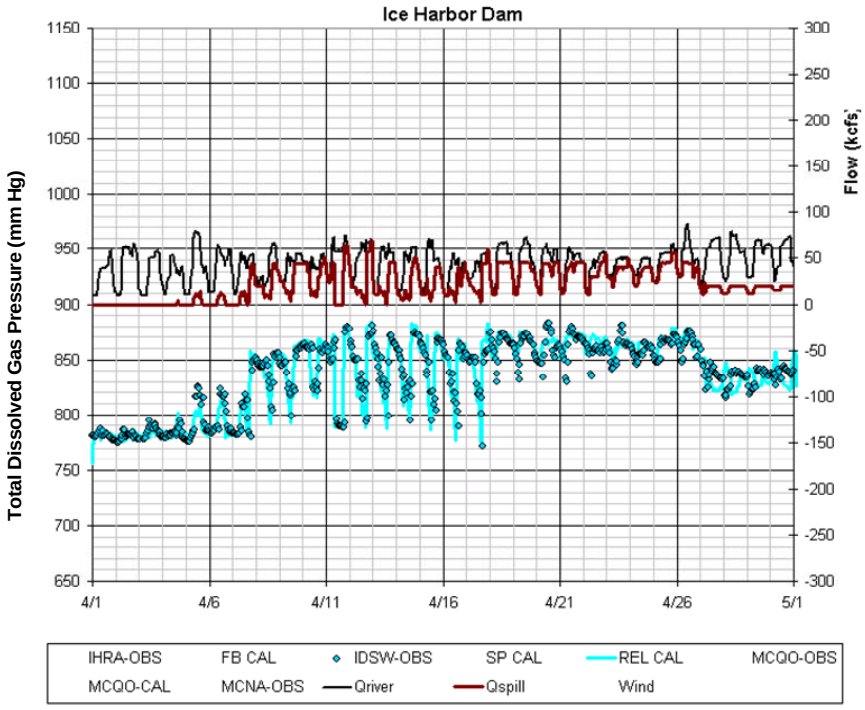

Figure E24. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Ice Harbor Dam, April, 2005

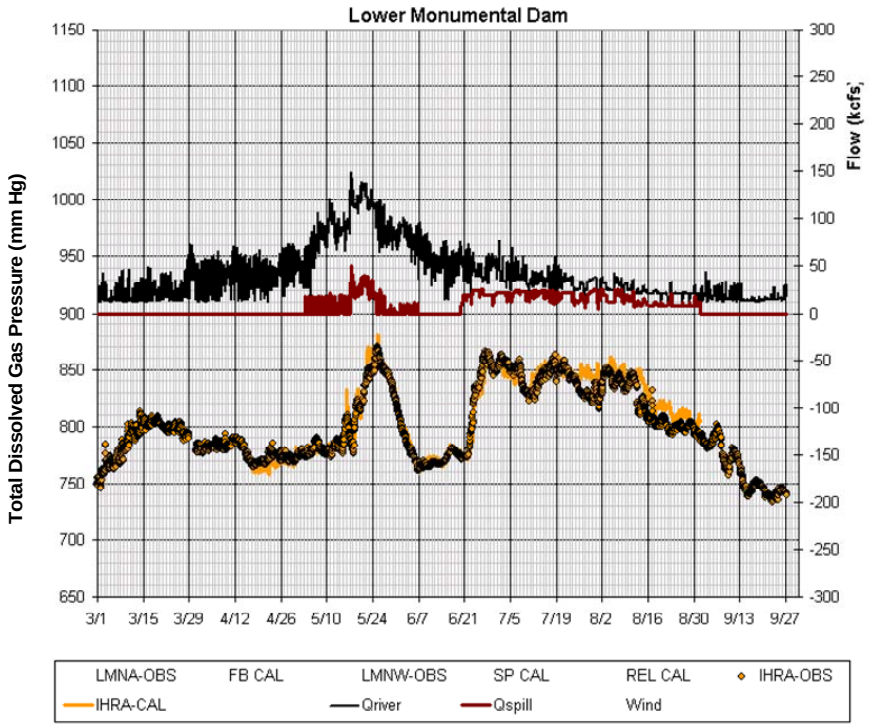

Figure E25. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Ice Harbor Dam, March-September 2005

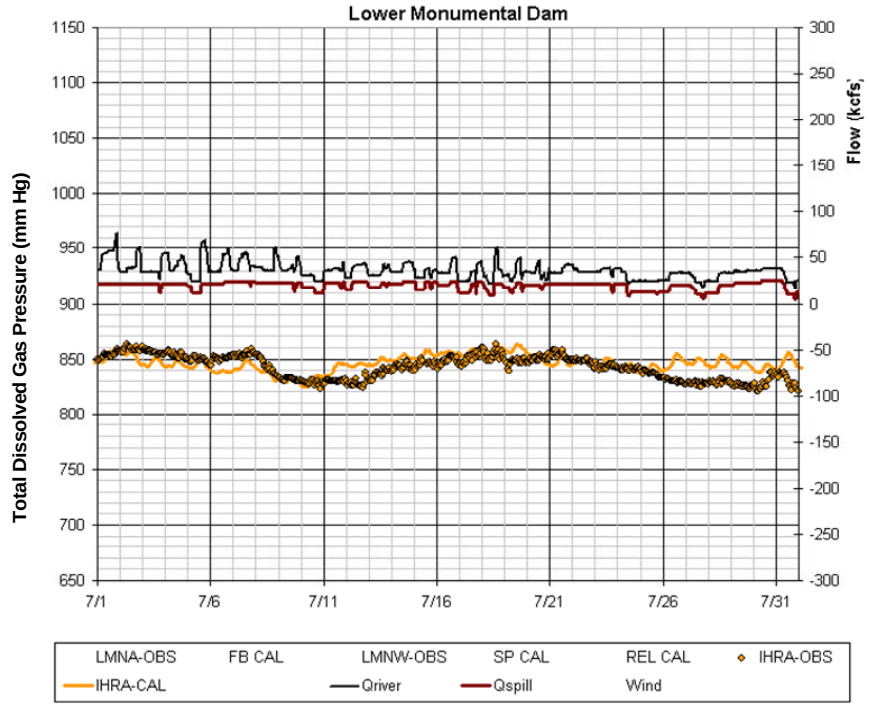

Figure E26. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Ice Harbor Dam, July 2005

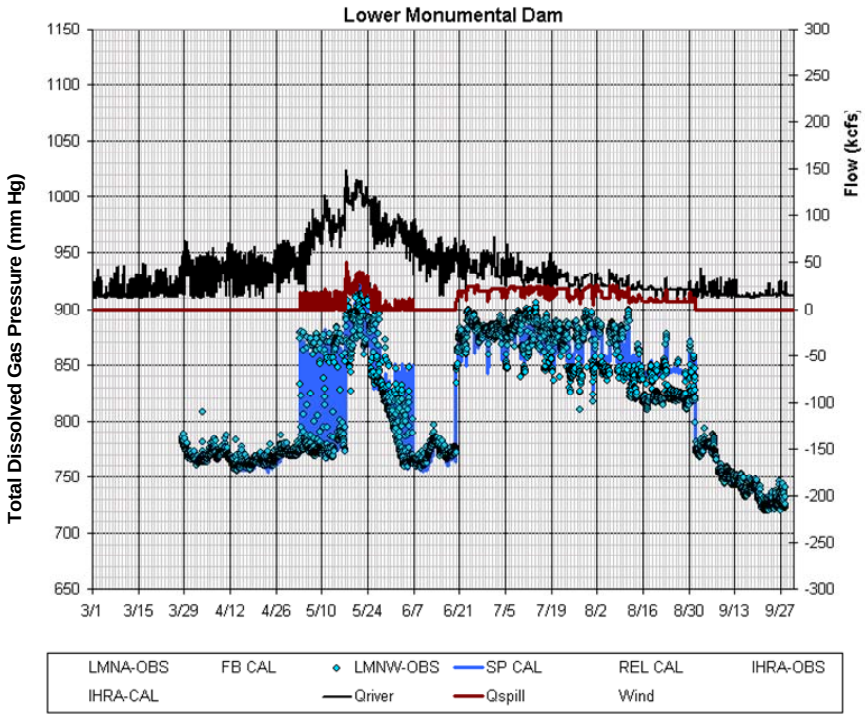

Figure E27. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Monumental Dam, March - September, 2005

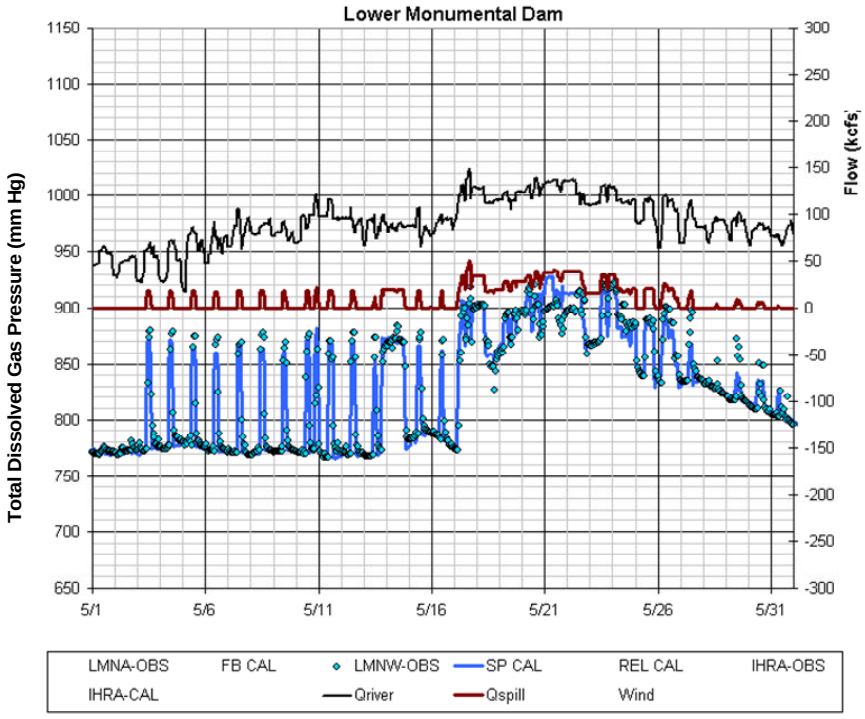

Figure E28. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Monumental Dam, May, 2005

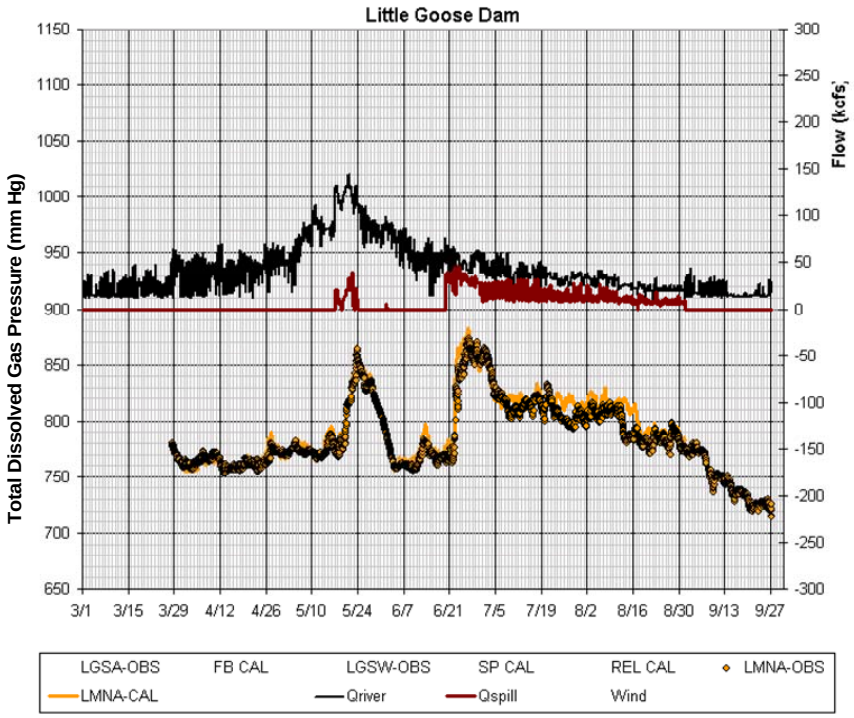

Figure E29. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Lower Monumental Dam, March-September 2005

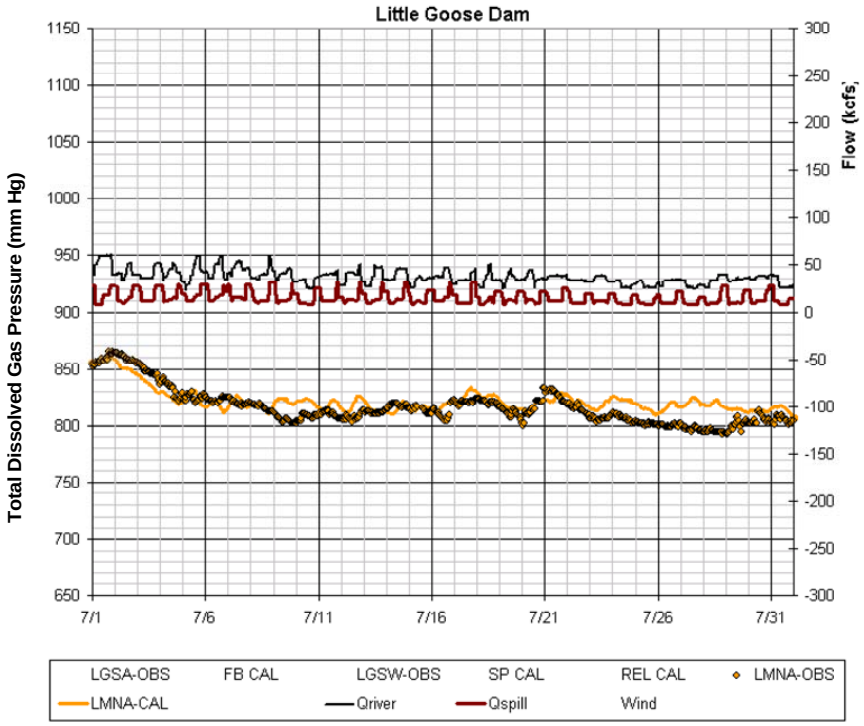

Figure E30. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Lower Monumental Dam, July 2005

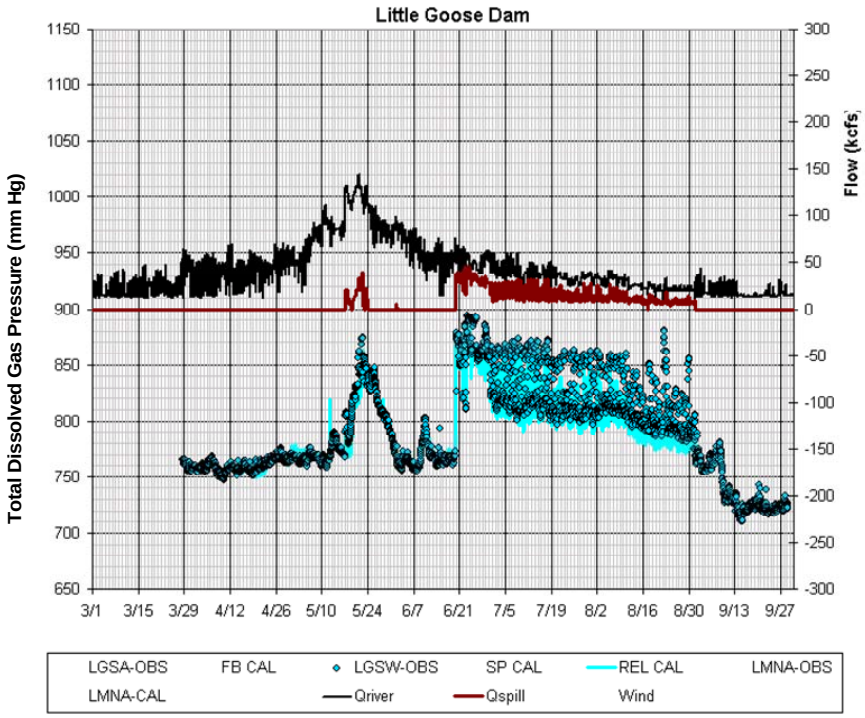

Figure E31. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Little Goose Dam, March - September, 2005

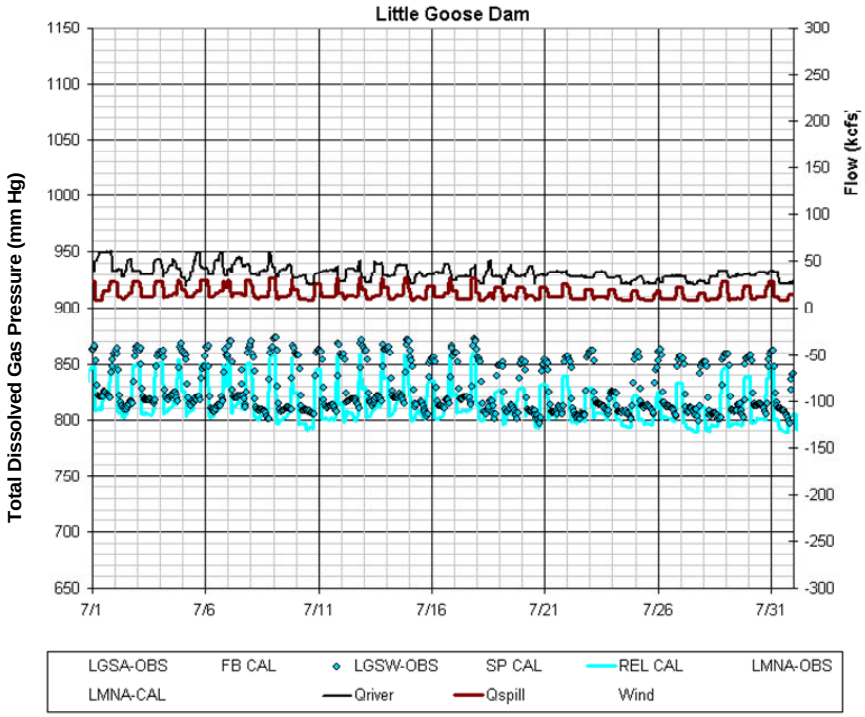

Figure E32. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Little Goose Dam, July, 2005

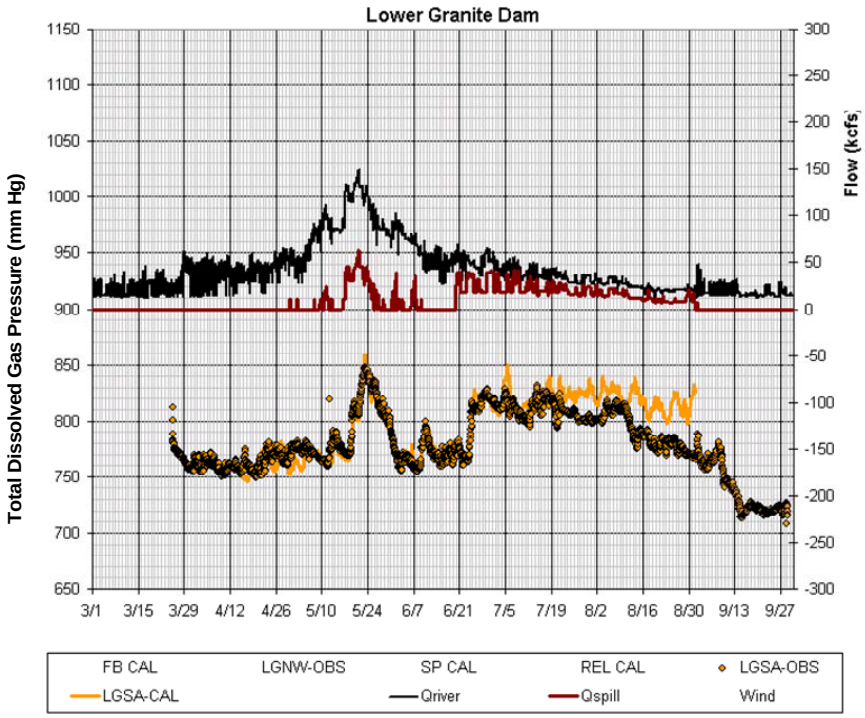

Figure E33. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Little Goose Dam, March-September 2005

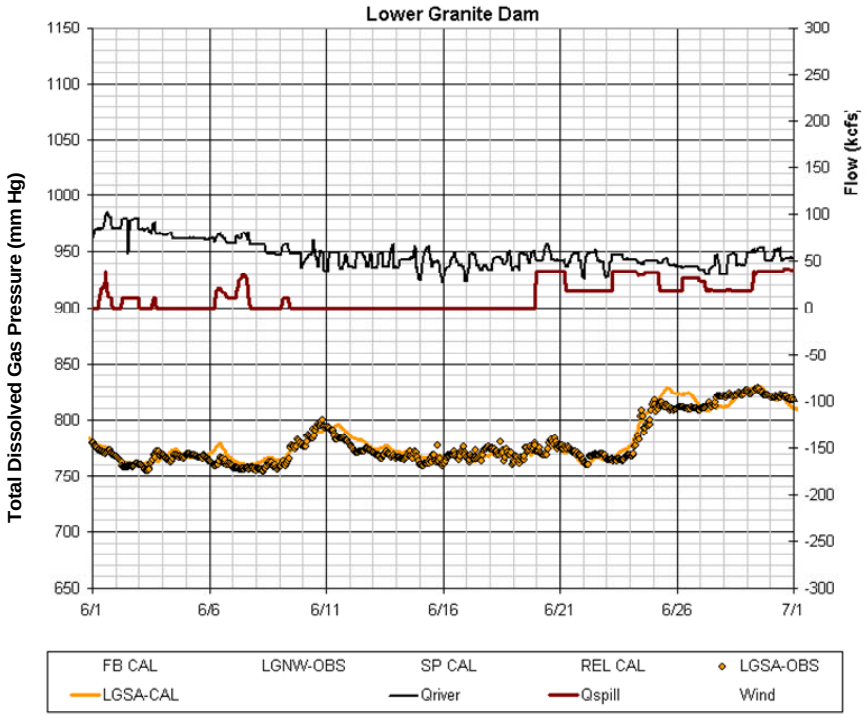

Figure E34. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Little Goose Dam, June 2005

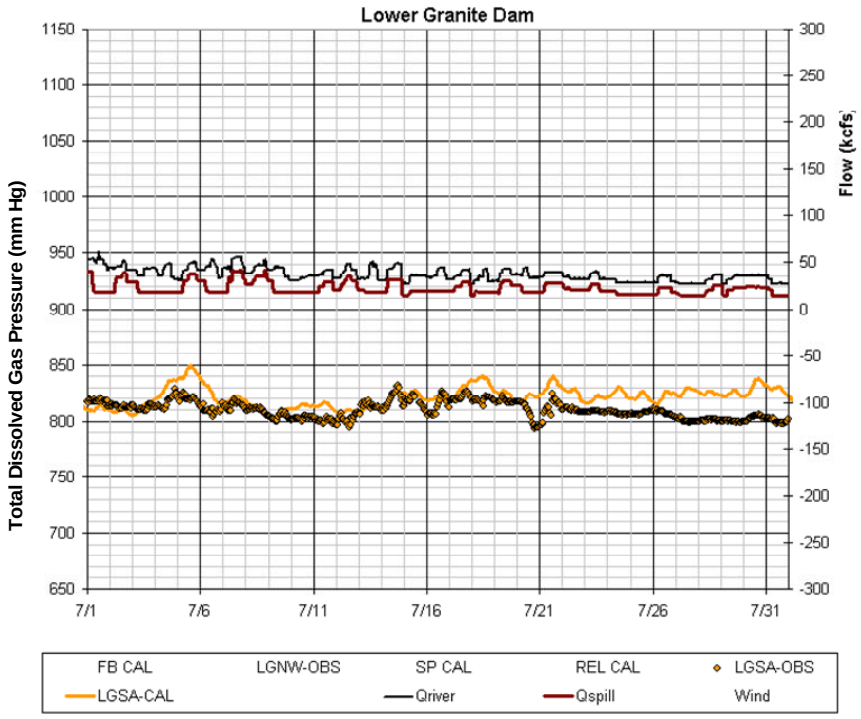

Figure E35. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Little Goose Dam, July 2005

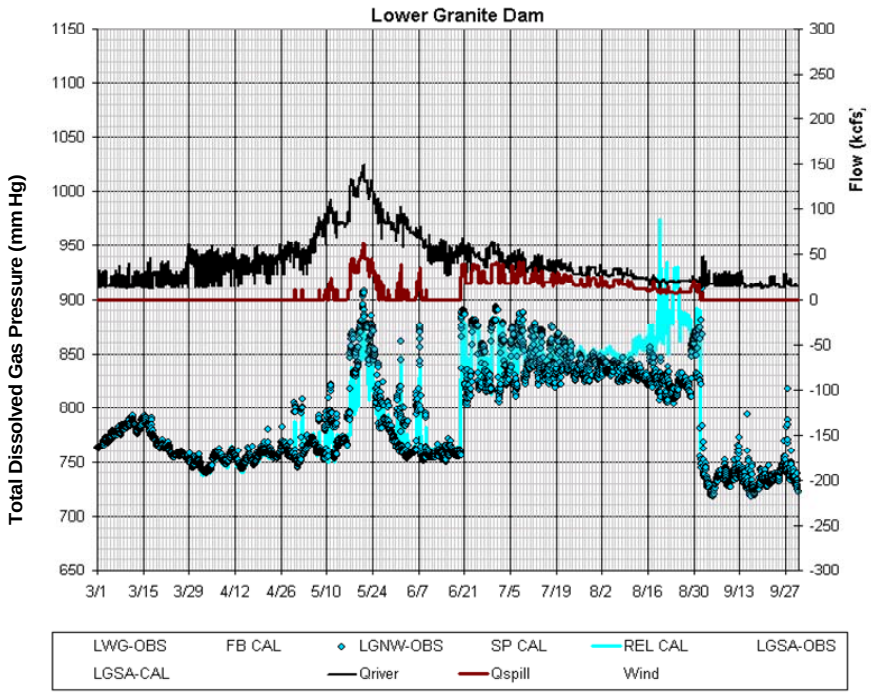

Figure E36. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, March - September, 2005

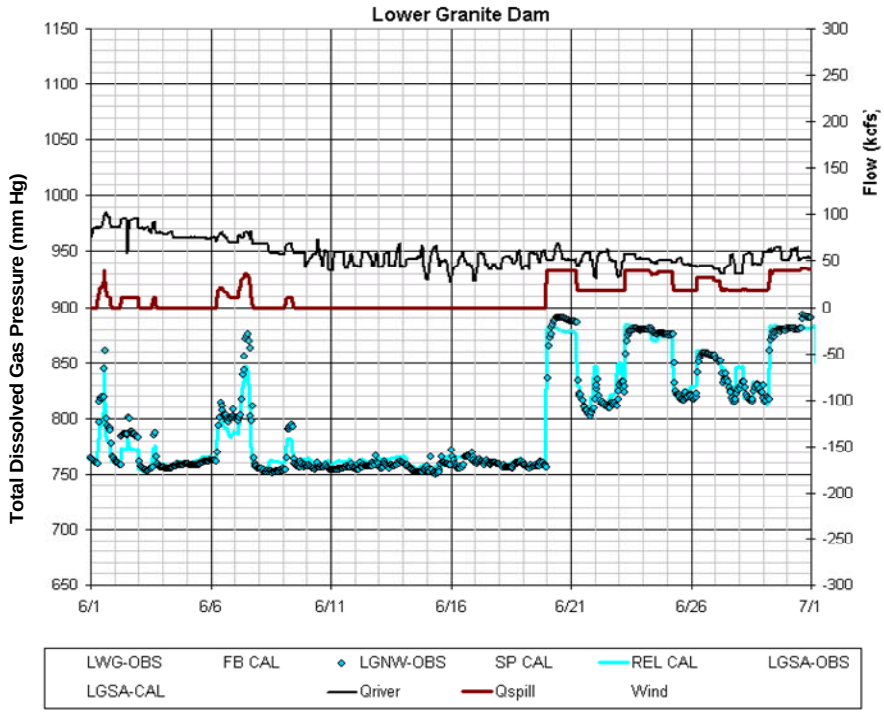

Figure E37. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, June, 2005

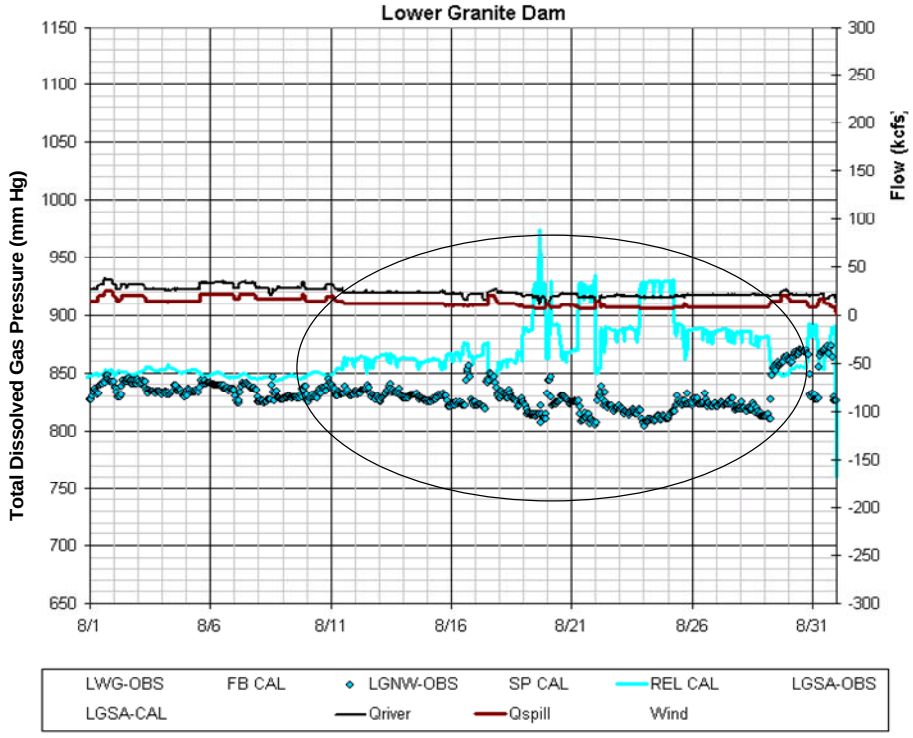

Figure E38. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, August, 2005 (Q_{ent}= Q_{sp})

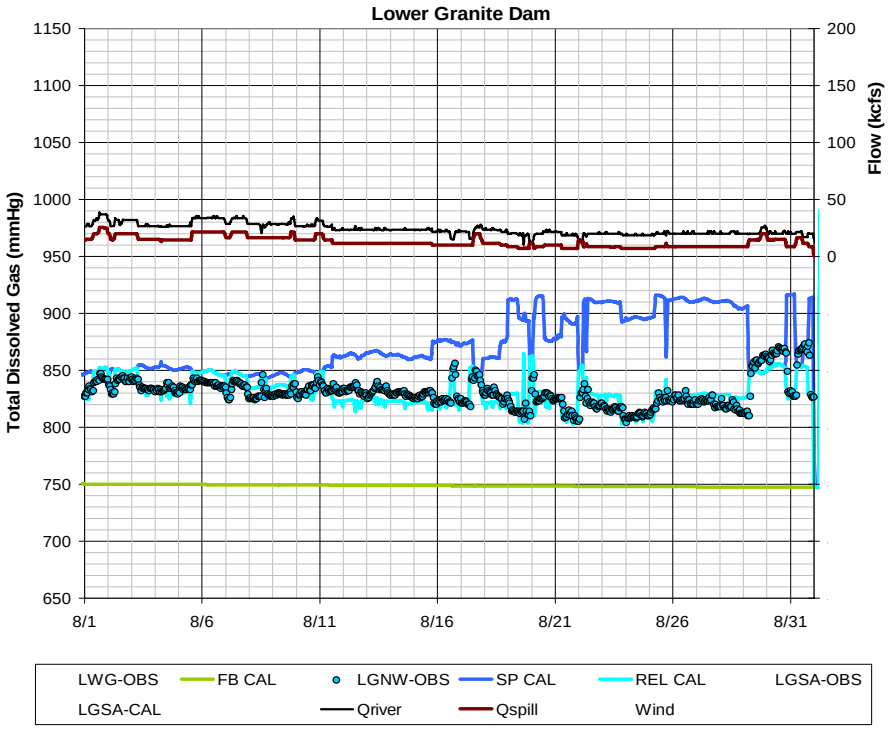

Figure E39. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, August, 2005 (Q_{ent}=min{$(Q_{sp}/25)^{1.5}$,1} x Q_{sp})

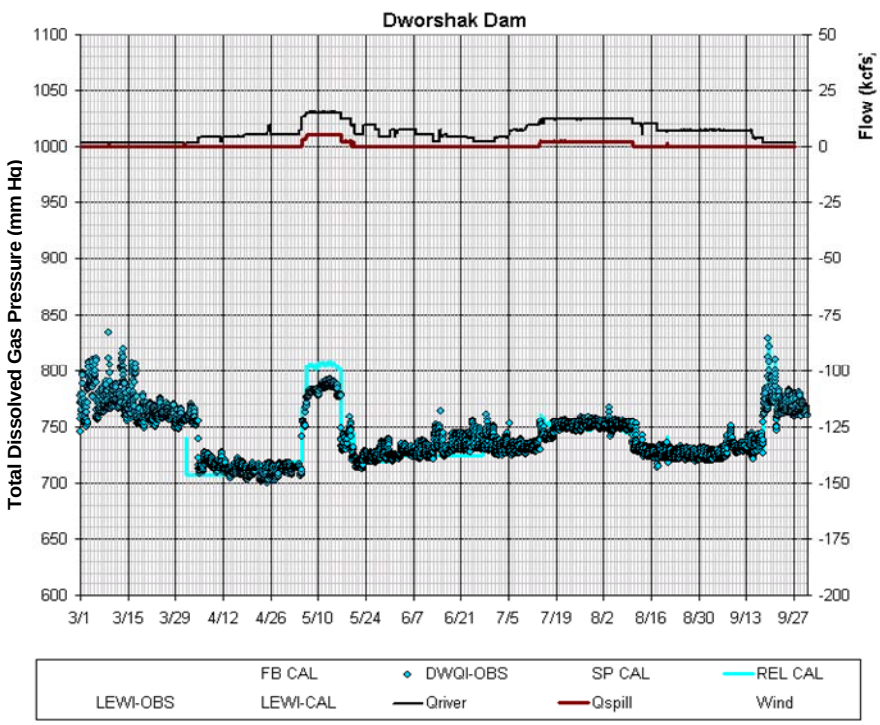

Figure E40. Observed and Calculated Total Dissolved Gas Pressures in the Clearwater River in the tailwater channel downstream from Dworshak Dam, March - September, 2005

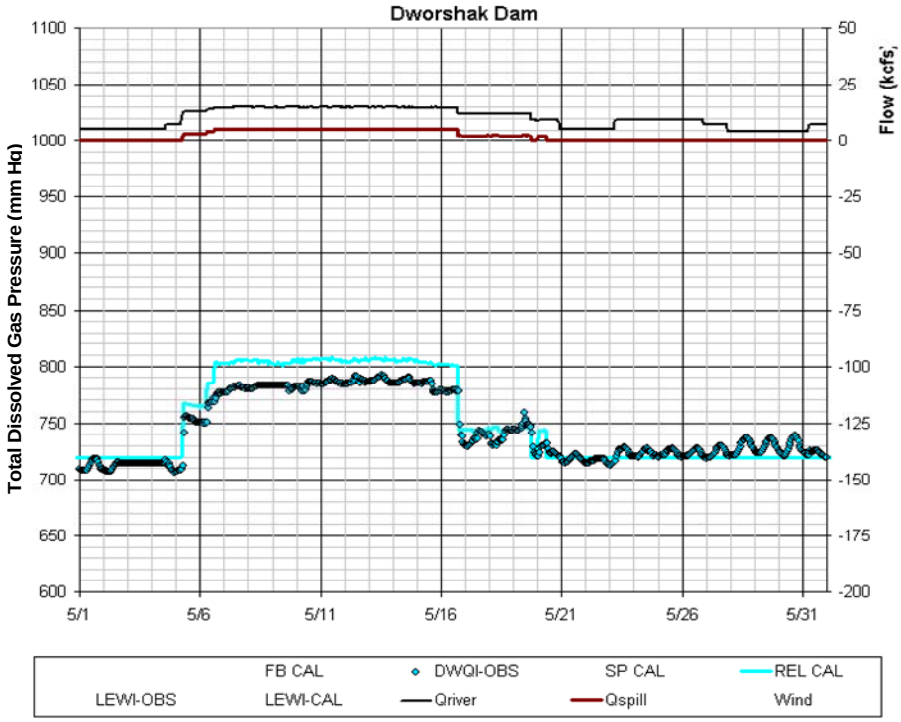

Figure E41. Observed and Calculated Total Dissolved Gas Pressures in the Clearwater River in the tailwater channel downstream from Dworshak Dam, May, 2005

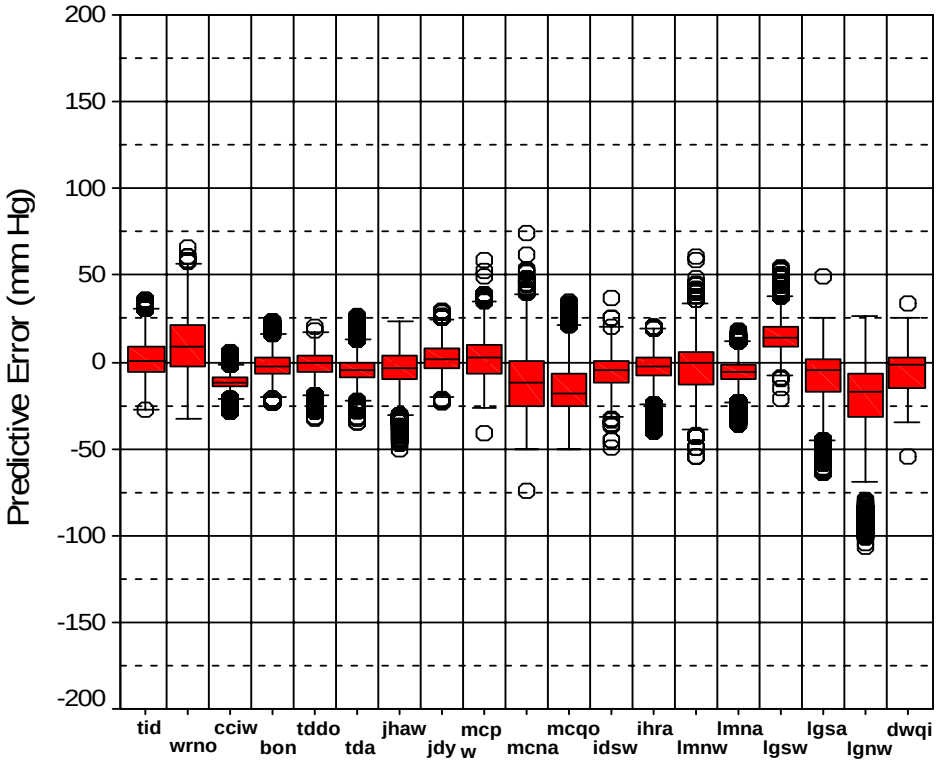

Figure E42. Summary of SYSTDG Predictive Errors by TDG sampling station, 2005.