APPENDIX N

SYSTDG STATISTICAL EVALUATION
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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, a statistical evaluation of the predictive errors was performed. This evaluation was done so by comparing SYSTDG-calculated total dissolved gas pressures to observed 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 2004 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-June 8 for the Snake River Projects and from April 15 –August 31 for the 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 neighboring values. 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 Biop was 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. Statistical analyses including mean, standard deviation, and confidence limits were generated from these comparisons and are listed in the four tables below. Tables N-1a and N-2a describe the predictive errors in mm Hg of pressure while Tables N-1b and N-2b describe the predictive errors in percent saturation. In order to calculate the predictive errors in percent saturation barometric pressures measured by each fixed monitoring station were averaged during the months of March through September. The predictive error pressures were then divided by associated averaged barometric pressure and multiplied by 100.

Table N-1a. 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)								
		LGS	**LMN**	**IHR**	**MCQW**	**MCQO**	**JDY**	**TDA**	**BON**	**CWMW**
Average		-3.5	-3.8	-2.4	-2.0	-3.8	-1.3	-6.1	-5.2	1.5
Standard Deviation		9.1	6.6	6.8	10.3	15.4	9.4	8.8	5.7	7.9
Maximum		44.1	27.6	26.6	37.6	71.3	29.7	26.5	12.6	27.5
Minimum		-25.2	-32.8	-30.2	-31.8	-42.3	-25.4	-25.5	-20.3	-22.6
TDG Predictive Error for Percentile Occurrence (mm Hg)	**5%**	-15.4	-14.6	-13.0	-19.3	-27.4	-13.5	-17.2	-14.5	-9.9
	10%	-12.7	-10.8	-10.3	-15.0	-23.1	-11.9	-15.5	-12.9	-7.8
	25%	-9.0	-7.1	-6.5	-8.8	-14.3	-7.7	-12.6	-9.4	-3.8
	50%	-5.4	-3.8	-2.6	-2.2	-4.4	-2.6	-8.2	-5.2	0.7
	75%	0.4	-0.6	1.2	5.3	4.5	2.9	-0.1	-1.6	6.3
	90%	7.8	3.6	6.1	10.8	16.1	12.8	6.6	2.1	11.8
	95%	14.5	8.1	9.5	14.7	24.3	17.2	10.4	4.6	15.5

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

Table N-1b. 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* (%)								
		LGS	**LMN**	**IHR**	**MCQW**	**MCQO**	**JDY**	**TDA**	**BON**	**CWMW**
Average		-0.5	-0.5	-0.3	-0.3	-0.5	-0.2	-0.8	-0.7	0.2
Standard Deviation		1.2	0.9	0.9	1.4	2.0	1.2	1.2	0.8	1.0
Maximum		5.9	3.7	3.5	5.0	9.5	3.9	3.5	1.6	3.6
Minimum		-3.4	-4.4	-4.0	-4.2	-5.6	-3.4	-3.4	-2.7	-3.0
TDG Predictive Error for Percentile Occurrence (mm Hg)	**5%**	-2.1	-2.0	-1.7	-2.6	-3.6	-1.8	-2.3	-1.9	-1.3
	10%	-1.7	-1.4	-1.4	-2.0	-3.1	-1.6	-2.0	-1.7	-1.0
	25%	-1.2	-1.0	-0.9	-1.2	-1.9	-1.0	-1.7	-1.2	-0.5
	50%	-0.7	-0.5	-0.3	-0.3	-0.6	-0.3	-1.1	-0.7	0.1
	75%	0.1	-0.1	0.2	0.7	0.6	0.4	0.0	-0.2	0.8
	90%	1.0	0.5	0.8	1.4	2.1	1.7	0.9	0.3	1.5
	95%	1.9	1.1	1.3	1.9	3.2	2.3	1.4	0.6	2.0

*Predictive error is the observed minus calculated TDG saturation 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 of the river reach from the Bonneville Dam to the fixed monitoring station located at Camas/Washougal (CWMW) from 12 April through 31 August 2004. (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 1.5 mm Hg (average predictive error +1.5 mm Hg) and the standard deviation of the predictive error was 7.9 mm Hg. The 50% confidence interval for the predictive error ranged from +6.3 to -3.8 mm Hg of pressure and a 90% confidence interval ranged from +15.5 to -9.9 mm Hg. The seasonal time history of observed and calculated TDG pressures at the CWMW gage is shown in Figure N-1. 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 June in Figure N-2. 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 high percent spill events reinforce the timing of the daily thermal cycling resulting in a daily range of TDG pressures of as much as 80 mm Hg. 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.

Table N-2a. 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	WRNO	CCIW	CCIW-2
Average		-1.3	-11.3	-2.4	-25.7	-4.5	-12.7	-8.7	-0.5	-0.6	0.9	-14.5
Standard Deviation		11.3	15.8	14.7	21.9	19.5	10.0	9.3	8.1	12.6	13.4	14.8
Maximum		83.0	50.2	29.1	69.9	52.6	39.3	18.1	39.0	55.7	56.6	44.3
Minimum		-89.3	-64.2	-38.2	-88.6	-98.9	-41.2	-82.8	-55.4	-61.6	-61.3	-88.1
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	-18.0	-37.9	-32.5	-52.7	-36.0	-25.7	-25.9	-14.1	-15.6	-27.1	-49.7
	10%	-15.8	-32.3	-29.5	-43.3	-26.4	-24.1	-19.4	-10.9	-13.3	-15.1	-32.1
	25%	-8.5	-20.2	-8.5	-38.2	-16.4	-20.0	-11.9	-5.8	-9.3	-2.8	-19.4
	50%	-1.7	-9.2	-0.5	-32.8	-4.6	-13.6	-7.5	0.2	-2.1	2.2	-10.5
	75%	7.7	-2.8	6.6	-15.9	5.8	-6.7	-3.9	5.3	7.9	7.2	-6.4
	90%	11.4	5.3	14.9	7.5	22.2	-1.1	0.7	9.0	16.1	11.4	-2.5
	95%	13.3	10.6	19.8	13.2	30.5	2.6	4.1	11.1	19.9	14.4	1.4

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

Table N-2b. 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	WRNO	CCIW	CCIW-2
Average		-0.2	-1.5	-0.5	-3.4	-0.6	-1.7	-1.1	-0.1	-0.1	0.1	-1.9
Standard Deviation		1.5	2.1	2.5	2.9	2.6	1.3	1.2	1.1	1.7	1.8	1.9
Maximum		11.3	6.8	5.9	9.3	7.0	5.2	2.4	5.1	7.3	7.4	5.8
Minimum		-12.1	-8.6	-8.9	-11.8	-13.1	-5.5	-10.9	-7.3	-8.1	-8.0	-11.5
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	-2.5	-5.1	-4.5	-7.0	-4.8	-3.4	-3.4	-1.9	-2.0	-3.6	-6.5
	10%	-2.1	-4.3	-4.3	-5.8	-3.5	-3.2	-2.6	-1.4	-1.7	-2.0	-4.2
	25%	-1.2	-2.7	-1.8	-5.1	-2.2	-2.6	-1.6	-0.8	-1.2	-0.4	-2.5
	50%	-0.2	-1.2	-0.2	-4.4	-0.6	-1.8	-1.0	0.0	-0.3	0.3	-1.4
	75%	1.1	-0.4	0.7	-2.1	0.8	-0.9	-0.5	0.7	1.0	0.9	-0.8
	90%	1.6	0.7	2.3	1.0	3.0	-0.1	0.1	1.2	2.1	1.5	-0.3
	95%	1.8	1.4	3.4	1.8	4.0	0.3	0.5	1.5	2.6	1.9	0.2

*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 run using the SYSTDG model of the river reach from the Bonneville Dam to the fixed monitoring station located at Camas/Washougal (CWMW) from 12 April through 31 August 2004, in an effort to determine the predictive error of SYSTDG estimations in Bonneville Dam tailwater. The official tailwater compliance station below Bonneville is located at Warrendale (WRNO) located about 6 miles downstream from the dam in waters that are approaching well-mixed conditions. 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 5 hours and compared to the observed TDG pressures at the WRNO gage. The calculated TDG pressures over-estimated observed conditions by an average of 0.6 mm Hg (average predictive error -0.6 mm Hg) and the standard deviation of the predictive error was 12.6 mm Hg. The 50% confidence interval of the predictive error ranged from +7.9 to -9.3 mm Hg of pressure and the 90% confidence interval ranged from +19.9 to -15.6 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 N-3. 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 May in Figure N-4. The daily cycling of TDG pressures were closely reproduced at the WRNO gage where the nighttime and daytime spill events were slightly overestimated during the second half 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)

An auxiliary TDG station (CCIW) was added in the Bonneville spillway exit channel on the banks of Cascade Island. Data observed before 03 June was collected from an instrument deployed in a steel pipe, thirty feet deep and roughly eighty feet from shore. On 03 June, this pipe was found broken and four days later an instrument was redeployed from shore at a depth of approximately 7 feet and only about 20 ft from shore. A change in TDG response was observed once this instrument was relocated and therefore two comparisons were made, one prior to relocation and one after.

The first comparison involved simulating conditions from Bonneville Dam to the Camas/Washougal gage 12 April through 03 June 2004. A component of this simulation was the TDG pressure contribution from spillway releases undiluted from powerhouse flows that could be compared to the response at the CCIW gage. The predictive error computed by subtracting the calculated TDG pressures associated with undiluted spill water from observed TDG pressures collected at CCIW before June 3. The calculated TDG pressures under-estimated observed conditions by an average of 0.9 mm Hg (average predictive error +0.9 mm Hg) and the standard deviation of the predictive error was 13.4 mm Hg as listed in Tables N-2a and N-2b under the label of CCIW. The 50% confidence interval for the predictive error ranged from +7.2 to -2.8 mm Hg of pressure and the 90% confidence interval ranged from +14.4 to -27.1 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the CCIW gage are shown in Figure N-5. Calculated TDG pressures representing spill were higher than the observed conditions at the CCIW gage. For spill discharges higher than 120 kcfs, the presence of much higher TDG pressures away from the shore-based monitor resulted in average conditions greater than the near shore observations at the CCIW gage (Figure N-6). This phenomenon was seen during the detailed field investigation conducted during the 2002 spill season as well (Schneider, 2003).

Bonneville Dam Spillway Exit Channel (CCIW-2)

The change in sampling station locations is clearly shown in Figure N-5 where the observed and calculated TDG pressures are close to each other in April and May and deviate significantly after June 3. For this reason a second comparison at the CCIW gage was calculated from June 7 through August 31, 2004 with results listed under the label CCIW-2 in Tables N-2a and N-2b. The calculated TDG pressures over-estimated observed conditions by an average of 14.5 mm Hg (average predictive error -14.5 mm Hg) and the standard deviation of the predictive error was 14.8 mm Hg. The predictive error 50% confidence interval ranged from –6.4 to -19.4 mm Hg of pressure and a 90% confidence interval ranged from 1.4 to –49.7 mm Hg.. As seen in Figure N-7, the calculated conditions overestimated the observed conditions for spillway flows greater than 75 kcfs. The TDG pressures observed at CCIW during the second deployment were not representative of spill as confirmed by the response downstream at the Warrendale gage. The observed TDG pressures at Warrendale were frequently higher than levels observed at the CCIW gage even with the added dilution of powerhouse releases influencing the observations at WRNO. The high predictive error associated with CCIW data after June 7 resulted from observations biased by the near shore conditions that significantly underestimated the TDG pressures in spill. The response of TDG pressures observed at the second CCIW location reinforces the importance of locating this station in waters sufficiently deep and removed from the littoral zone of the Bonneville exit spillway channel.

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 5.2 mm Hg (average predictive error –5.2 mm Hg) and the standard deviation of the predictive error was 5.7 mm Hg. The 50% confidence interval for the predictive error ranged from -1.6 to -9.4 mm Hg of pressure and the 90%

confidence interval ranged from +4.6 to -14.6 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the BON gage are shown in Figure N-8. 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 N-9. 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 strong wind events on June 22-26 are generally responsible for the decline in TDG pressures in the forebay of Bonneville Dam. 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 12 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 0.5 mm Hg (average predictive error -0.5 mm Hg) and the standard deviation of the predictive error was 8.1 mm Hg. The 50% confidence interval of predictive error ranged from +5.3 to -5.8 mm Hg of pressure and the 90% confidence interval ranged from +11.1 to -14.1 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. The construction of a training wall between spill bays 6 and 7 and the implementation of a bulk spill pattern at The Dalles spillway resulted in new hydraulic conditions throughout the stilling basin and tailwater channel below the project. The TDG exchange properties were not greatly impacted by these structural and operational changes. A detailed study of the TDG exchange properties during the 2004 spill season at The Dalles Dam is under development based on the observations of TDG pressures from an array of stations located near the dam. The seasonal time history of observed and calculated TDG pressures at the TDDO gage are shown in Figure N-10. 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 May in Figure N-11. The calculated TDG pressures tended to be slightly higher than the observed conditions at the TDDO fixed monitoring station. The abrupt increase in TDG pressure on May 6 of about 15 mm Hg (2 percent saturation) was likely caused by the servicing of the TDG instrumentation. The larger predictive error during the early part of May was attributed in part to a sampling bias at the TDDO gage. The performance of SYSTDG in estimating the response at The Dalles tailwater FMS should be improved by incorporating the results from the 2004 TDG exchange study.

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 6.1 mm Hg (average predictive error –6.1 mm Hg) and the standard deviation of the predictive error was 8.8 mm Hg. The 50% confidence interval of the predictive error ranged from -0.1 to -12.6 mm Hg of pressure and the 90% confidence interval ranged from +10.4 to -17.2 mm Hg of pressure as listed in Tables N-1a and N-1b. The seasonal time history of observed and calculated TDG pressures at the TDA gage are shown in Figure N-12. 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 TDDO 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 and July in Figure N-13 and N-14. 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. The 90 percent confidence interval for the prediction error was about 9 mm Hg larger at The Dalles forebay when compared to Bonneville forebay, which suggests room for improving the model predictions.

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 12 April through 31 August 2004. 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 8.7 mm Hg (average predictive error –8.7 mm Hg) and the standard deviation of the predictive error was 9.3 mm Hg. The 50% confidence interval of the predictive error ranged from -3.9 to -11.9 mm Hg of pressure and the 90% confidence interval ranged from +4.1 to -25.9 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the JHAW gage are shown in Figure N-15. The daily variation in TDG pressures routinely ranged over 100 mm Hg during the on-off cycling of spill at John Day Dam (Figure N-15). As seen in Figure N-16, the majority of larger predictive errors were associated with the operational day/night spill cycles that occurred from mid-April through mid-June. The erroneous response of observed TDG levels on June 17 is readily apparent when compared with the calculated response. This event demonstrates the capability of SYSTDG model estimates to be used as a means of screening the response of real-time measurements of TDG pressure. The range in the 50 percent confidence interval for predictive errors below the spillway at John Day Dam was slightly higher (6 mm Hg) than determined below Bonneville Dam as listed in Tables N-2a and N-2b.

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 over-estimated observed conditions by an average of 1.3 mm Hg (average predictive error –1.3 mm Hg) and the standard deviation of the predictive error was 9.4 mm Hg. The 50% confidence interval for the predictive error ranged from –7.7 to 2.9 mm Hg of pressure and the 90% confidence interval ranged from-13.5 to 17.2 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the JDY gage are shown in Figure N-17. 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 stoppage of spill at McNary triggered a significant reduction in TDG pressures in the forebay of John Day Dam. The deviation of calculated and observed TDG pressures in the forebay of John Day Dam after McNary Dam stopped spilling indicates some deficiencies in estimating the in-pool degassing response. The observed and calculated TDG pressures in the forebay of John Day Dam are shown throughout the month of June in Figure N-18. The strong winds starting on June 22 initiated a general reduction in the TDG pressures in the forebay of John Day Dam. The model predictions under-estimate the observed conditions during this long duration wind event. These predictions may be improved by applying wind data closer to the John Day pool. The wind data from The Dalles airport was applied throughout the John Day pool in these simulations.

McNary Dam Tailwater (M CPW)

The SYSTDG model was used to simulate the TDG exchange associated with spillway releases from McNary Dam throughout the 2004-spill season. The 2004 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 over-estimated observed conditions by an average of 12.7 mm Hg (average predictive error –12.7 mm Hg) and the standard deviation of the predictive error was 10.0 mm Hg. The overestimation of observed conditions occurred during spillway releases greater than 160 kcfs as shown in Figure N-19. The daily peak TDG pressures observed at the tailwater FMS tended to increase during the spill season despite the magnitude of the spill discharge. This pattern could be related to the depth of the stilling basin and adjoining tailwater channel. The 50% confidence interval for the predictive error ranged from –20.0 to –6.7 mm Hg of pressure and the 90% confidence interval ranged from -25.7 to 2.6 mm Hg of pressure. The observed and calculated TDG pressures in the tailwater of McNary Dam are shown throughout the month of April in Figure N-20. There was a frequent tendency to over predict the observed TDG response at the tailwater FMS below McNary Dam. This consistent bias in the estimation formulation identifies a need to revisit the TDG exchange formulation for McNary Dam.

McNary Dam Forebay (MCQW)

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 every two days throughout most of the 2004 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 2.0 mm Hg (average predictive error –2.0 mm Hg) and the standard deviation of the predictive error was 10.3 mm Hg. 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 –8.8 to 5.3 mm Hg of pressure and the 90% confidence interval ranged from –19.3 to 14.7 mm Hg of pressure. About one half of the predictive errors were within +/- 1 percent of saturation, which compares favorably with the results from the forebays of John Day and The Dalles Dams. The observed and calculated TDG pressures in the forebay of McNary Dam are shown throughout the months of March-September in Figure N-21. The abrupt increase in the observed TDG pressures shown in Figure N-22 are generally associated with thermally induced TDG pressure events.

McNary Dam Forebay (MCQO)
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 3.8 mm Hg (average predictive error –3.8 mm Hg) and the standard deviation of the predictive error was 15.4 mm Hg. 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 –14.3 to 4.5 mm Hg of pressure and the 90% confidence interval ranged from –27.4 to 24.3 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 N-21. The cloud of observed data points at station MCQO obscures the line representing the calculated values throughout much of this period. The detailed comparisons of observed and calculated TDG pressures in the forebay of McNary Dam are shown for the month of May in Figure N-23. The hourly variability in the observed data at station MCQO is much larger than observed at the projects downstream. The calculated TDG pressure generally follows the observed daily average conditions but does not replicate the higher frequency patterns that are thermally induced in most cases.

Ice Harbor Dam Tailwater (IDSW)
The spillway operation at Ice Harbor Dam cycled every two days between a bulk spill pattern and the standard spill pattern using all ten spill bays for flows greater than 18.2 kcfs. The TDG production equation was developed for the standard spill pattern but was applied for the bulk spill pattern during the 2004 spill season. A simulation was run from Ice Harbor Dam to the confluence with the Columbia River from 12 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 4.5 mm Hg (average predictive error –4.5 mm Hg) and the standard deviation of the predictive error was 19.5 mm Hg. The 50% confidence interval of the predictive error ranged from +5.8 to -16.4 mm Hg of pressure and the 90% confidence interval ranged from +30.5 to -36.0 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the IDSW gage are shown in Figure N-24. The calculated values tend to compare favorably to observed conditions throughout most of the year. The notable exceptions for a small predictive error were during the bulk spill at

peak river flows in late May and early June. The standard deviation of the predictive error was much larger at Ice Harbor than observed on the Columbia River Projects. The larger variation in the predictive error can be attributed to the difficulty in pairing up data due to the time of travel between the dam and the sampling stations, applying the wrong spill pattern, and the response of bulk spill patterns not properly predicted by the formulation developed for the standard pattern. The daily variation in TDG pressures for observed and calculated conditions can be seen in Figure N-25 for the month of June. The observed and predicted levels at the beginning of the month vary by as much as 20 mm Hg but are nearly identical during the second half of the month. The influence of the depth of flow in the tailwater on TDG exchange should be reviewed in light of the response associated with the bulk spill pattern.

Ice Harbor Dam Forebay (IHR)

A simulation was run from Lower Monumental Dam to the forebay of Ice Harbor Dam from 15 April through 09 June 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 (IHR) to determine the hourly predictive error. The calculated TDG pressures over-estimated observed conditions by an average of 2.4 mm Hg (average predictive error –2.4 mm Hg) and the standard deviation of the predictive error was 6.8 mm Hg. The 50% confidence interval for the predictive error ranged from 1.2 to -6.5 mm Hg of pressure and a 90% confidence interval ranged from +9.5 to -13.0 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 IHR gage are shown in Figure N-26. The TDG pressures increase about 50 mm Hg due to the initiation of spill from Lower Granite and Little Goose Dams in mid-April. The forebay TDG pressure increased a second time in May in response to the initiation of spill at Lower Monumental Dam. The percent of spill at Lower Monumental Dam dropped quickly resulting in a decline in TDG pressures reaching Ice Harbor Dam. The detailed reductions in TDG pressures at IHR are shown in Figure N-27. 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 spillway operation at Lower Monumental Dam applied a bulk spill pattern involving only 2 or 3 spill bays during the first spill cycle in April and May of 2004. The standard spill pattern involving 7 of the 8 spill bays was applied during the forced spill conditions at the end of May and early June. All 8 spillbays were not used because of mechanical problems with bay 2. The TDG production equation developed from the standard spill pattern was applied for all spill events during the 2004 spill season. The SYSTDG model was applied to simulate the TDG levels produced from spill operations at Lower Monumental Dam from 12 April though 08 June. 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 25.7 mm Hg (average predictive error –25.7 mm Hg) and the standard deviation of the predictive error was 21.9 mm Hg. The 50% confidence interval for the predictive error ranged from –15.9 to -38.2 mm Hg of pressure or from 2 to 5 percent saturation above observed conditions. The primary source of error occurred during the bulk spill pattern as shown in the seasonal time history of observed and calculated TDG pressures at the Lower Monumental tailwater station as shown in Figure N-28. The calculated TDG response using the standard spill pattern was much closer to observed conditions during spill later in the season. The daily variation of TDG pressures at the tailwater FMS below Lower Monumental Dam are shown in Figure N-29. The predicted hourly trend in TDG pressures during the bulk spill pattern was similar to observed conditions but about 30 mm Hg higher. A detailed TDG exchange investigation was conducted below Lower Monumental Dam using an array of 13 additional TDG sampling stations. The results from this study will be used to update the TDG formulation at Lower Monumental Dam for both the standard and bulk spill patterns. The entrainment of powerhouse flow is a significant component of TDG exchange during the application of the bulk spill pattern. The overestimation of the TDG pressures at the tailwater FMS did not lead to a similar overestimation of TDG pressures arriving at Ice Harbor Dam.

Lower Monumental Dam Forebay (LMN)

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 09 June as shown in Figure N-30. 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 at the end of May suggests the influence of the entrainment of powerhouse flows plays an important role in the TDG loadings in the Snake River. The rise and decline of TDG pressures at the end of June and beginning of July was not caused by spilling water on the Snake River. The likely source of TDG pressures approaching 110% during this period was the rapid heat gain that occurred during this period. If surface mass exchange processes occur at a slower rate than heat absorption, the resultant TDG pressures will rise and can often exceed 110% saturation. The presence of strong winds can often quickly return the TDG levels closer to equilibrium conditions of 100%. 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 6.6 mm Hg. The 50% confidence interval for the predictive error ranged from -0.6 to -7.1 mm Hg of pressure and the 90% confidence interval ranged from +8.1 to -14.6 mm Hg of pressure. The daily variation of TDG pressures at the forebay FMS above Lower Monumental Dam are shown in Figure N-31. A component of the predictive error at station LMN can be attributed to thermally induced pressure spikes observed at the forebay fixed monitoring station. The distinction of higher TDG pressures associated with nighttime spill events at Little Goose Dam is slightly overestimated and may justify increasing the dispersion coefficient used throughout this pool.

Little Goose Dam Tailwater (LGSW)

A TDG simulation was run from Little Goose Dam to Lower Monumental Dam from 12 April through 08 June 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 N-32. The calculated TDG pressures over-estimated observed conditions by an average of 2.4 mm Hg (average predictive error –2.4 mm Hg) and the standard deviation of the predictive error was 14.7 mm Hg. The 50% confidence interval ranged from +6.6 to –8.5 mm Hg of pressure and the 90% confidence interval ranged from +19.8 to -32.5 mm Hg of pressure. The primary source for this large error was the small percent spill events during the height of river flows in the Snake River. The calculated values reflect spillway water undiluted from powerhouse flows. However, in the case of a very small spill relative to total river flow, the mixing zone likely encroaches on water sampled at the tailwater fixed monitoring station thereby influencing the observed conditions. One solution to reporting undiluted spillway levels would be to introduce a dilution coefficient for each dam. This coefficient would trigger the dilution of a small hourly spill with powerhouse releases instead of displaying the undiluted TDG content of this type of event. The calculated and observed tailwater TDG pressures below Little Goose Dam during the month of April are shown in Figure N-33. The peak TDG pressures were closely reproduced in this simulation during the nighttime spill at Little Goose Dam. The artificially low calculated TDG pressures were associated with small reported spillway flows resulting from the hourly averaging of project spill. These events were not real and the associated TDG loading resulting from the simulation of these events were small. This figure demonstrates the insensitivity of the TDG content in spillway releases compared to the initial forebay TDG content. The arrival of much higher TDG levels in the forebay of Little Goose Dam did not result in a comparable increase in the TDG levels downstream of the dam in spillway releases.

Little Goose Dam Forebay (LGS)

SYSTDG was used to hind cast the TDG pressures in Little Goose pool in response to operations at Lower Granite Dam from 15 April through 09 June. The elevated TDG levels in the Forebay of Little Goose Dam are a consequence of spill at Lower Granite Dam and thermal induced pressure spikes, which are not representative of bulk river conditions. The predicted TDG pressure responses to spill are reasonably well predicted as shown in Figure N-34. Both the timing and magnitude of TDG pressures were closely reproduced in this simulation. The calculated TDG pressures over-estimated observed conditions by an average of 3.5 mm Hg (average predictive error -3.5 mm Hg) and the standard deviation of the predictive error was 9.1 mm Hg. The 50% confidence interval ranged from +0.4 to -9.0 mm Hg of pressure and the 90% confidence interval ranged from +14.5 to -15.4 mm Hg of pressure. In some cases the predictive errors can be attributed to thermal heating, driving observed gas levels higher than what was estimated or representative of bulk flow conditions. The calculated and observed tailwater TDG pressures in the forebay of Little Goose Dam during the month of April are shown in Figure N-35. The wind field from Pasco was used to simulate the degassing rate in Little

Goose pool. The application of the wind field from a weather station much closer to this area may help reduce the predictive error in this reach.

Lower Granite Dam Tailwater (LGNW)

The TDG levels associated with spillway releases from Lower Granite Dam were simulated from the 12 April through 08 June as shown in Figure N-36. The calculated TDG pressures over-estimated observed conditions by an average of 11.3 mm Hg (average predictive error –11.3 mm Hg) and the standard deviation of the predictive error was 15.8 mm Hg. The 50% confidence interval for the predictive error ranged from -2.8 to -20.2 mm Hg of pressure and the 90% confidence interval ranged from +10.6 to -37.9 mm Hg of pressure. A large contribution to the size of the predictive error was associated with spill discharges that were less then 20 kcfs and constituted a small percent of the total river flow. The observed and calculated TDG response for April and the May-June spill events are shown in Figure N-37 and 37 respectively. In general, predictive errors were small for spill flows greater than 20 kcfs and much larger for spill less than 20 kcfs shown in Figure N-38. This pattern is likely related to the dilution of spillway flow by powerhouse releases as observed at the tailwater fixed monitoring station. The application of a mixing zone correction where the dilution of spillway waters was estimated to be an exponential function of the percent of river spilled is listed in Equation 1.

$$\frac{P_{mz} - P_{fb}}{P_{sp} - P_{fb}} = (1 - e^{c_1\left(\frac{Q_{sp}}{Q_{total}}\right)^{c2}}) \qquad (1)$$

The determination of the TDG pressure in the mixing zone P_{mz} listed in equation 1 with coefficients C_1=120 and C_2=2.5 was determined at the Lower Granite tailwater station LGNW as shown in Figure N-39. The mixing zone formulation P_{mz} approaches P_{sp} as the fraction of spill becomes larger than 0.20 and approaches P_{fb} as the fraction of spill goes to zero.

Dworshak Dam Tailwater (DWQI)

The TDG pressures in the tailwater channel below Dworshak Dam were simulated during the 2004 spill season as shown in Figure N-40. The calculated TDG pressures over-estimated observed conditions by an average of 1.3 mm Hg (average predictive error -1.3 mm Hg) and the standard deviation of the predictive error was 11.3 mm Hg. The 50% confidence interval for the predictive error ranged from +7.7 to -8.5 mm Hg of pressure and the 90% confidence interval ranged from +13.3 to -18.0 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 N-40 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 730 mm Hg and a TDG pressure of spillway flows modeled as an exponential function of spillway/regulating outlet discharge as shown in Figure N-41. The calculated TDG pressures associated with spillway/regulating outlet releases (SP-CAL) ranged from 790-1000 mm Hg (107-136 percent). The estimated 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.

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 2004 spill season. These estimates of TDG pressure were compared with observed levels from the fixed monitoring stations to evaluate the reliability of these calculations and observed TDG pressures, and to determine the uncertainty of TDG estimates to support spill management policy. The application of spillway operations throughout the basin were generally limited to levels within the Biop guidance to aid fish passage. The degree of spill at the Snake River projects was limited because of the low flow conditions. 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 N-1a and N-1b) than the tailwater station comparisons (Tables N-2a and N-2b). 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. One improvement in calculating the TDG pressures in the tailwater is the use of a mixing zone correction that will influence estimates at small percent river spill conditions (Equation 1). During small percent spill conditions, the mixing zone can encroach upon water sampled at the tailwater FMS and reflect some mixture of powerhouse and spillway releases. At higher percent spill conditions the TDG characteristics reflect TDG levels in spillway releases undiluted from powerhouse flow.

The smallest predictive error was calculated at The Dalles Dam tailwater, while the largest predictive error was associated with the Lower Monumental Dam tailwater as shown in Figure N-42. In the plot shown in Figure N-42, the red box reflects the predictive error of the 25th, 50th, and 75th percentile, the whiskers show the 10 and 90 percentile, and the symbols reflect outliers. 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 Monumental Dam was associated with the application of a new bulk spill pattern that was not well represented by the TDG exchange formulation associated with the standard spill pattern.

The determination of the predictive errors at forebay stations often consisted of a sampling bias component that resulted from a thermally induced pressure response. The relocation of many of the forebay FMS should greatly eliminate this source of error in the future. The potential error of calculated TDG pressures at forebay stations involve a wide range of sources including TDG production at the upstream project, transport, mixing, surface exchange of TDG pressures, and thermally induced pressure coupling. The fates of all atmospheric gasses were treated similarly.

Bonneville Dam forebay simulations produced the smallest predictive error out of all the forebay sites evaluated based on the standard deviation statistic, while McNary forebay simulations produced the largest amount of predictive error. In general, the average forebay TDG estimates were biased on the negative side (over estimation) of observed conditions. In general, over 50 percent of the TDG projections at forebay stations were within +/- 1 percent saturation of the observed conditions.

The description of TDG exchange at all projects within the study area should be updated to reflect the patterns associated with recent data associated with both research studies and routine monitoring activities. In some cases, the contribution from the entrainment of powerhouse flows will constitute a major portion of the TDG loading generated at a project.

The surface exchange coefficients should be adjusted to reduce the predictive error bias as determined at forebay stations. 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.

The sampling biases determined at tailwater fixed monitoring stations should be addressed through relocation of stations and the application of TDG indexing. The tailwater stations located in mixed river environments are infrequently constrained by the tailwater TDG criteria of 120 percent. Detailed TDG exchange studies have clearly established consistent patterns of average and peak TDG pressures in spillway releases that differ from shore based observations from the fixed monitoring stations. In these cases, the average and peak TDG conditions in spillway flows can be implied or indexed to observations from the FMS.

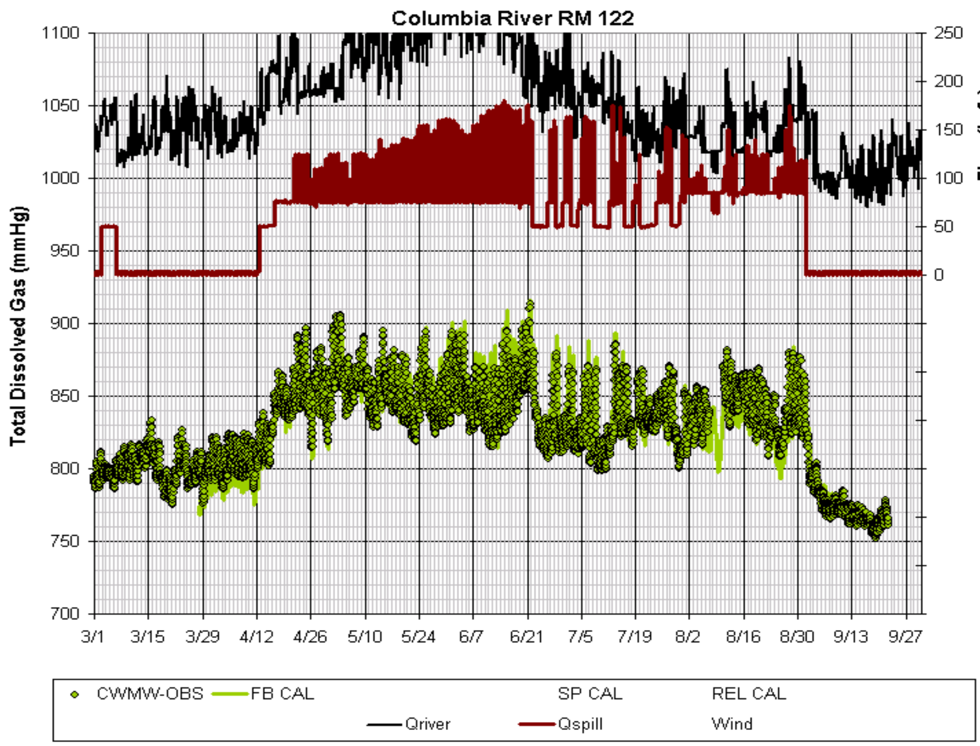

Figure N-1. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Camas/Washougal fixed monitoring station downstream of Bonneville Dam, March-September 2004

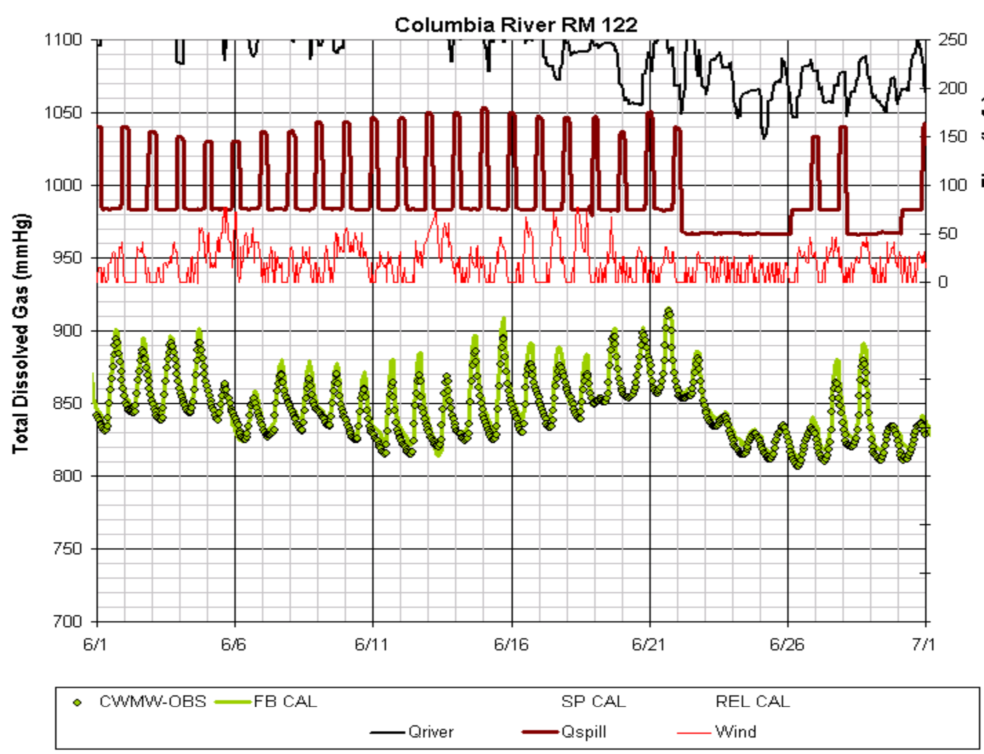

Figure N-2. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Camas/Washougal fixed monitoring station downstream of Bonneville Dam, June 2004

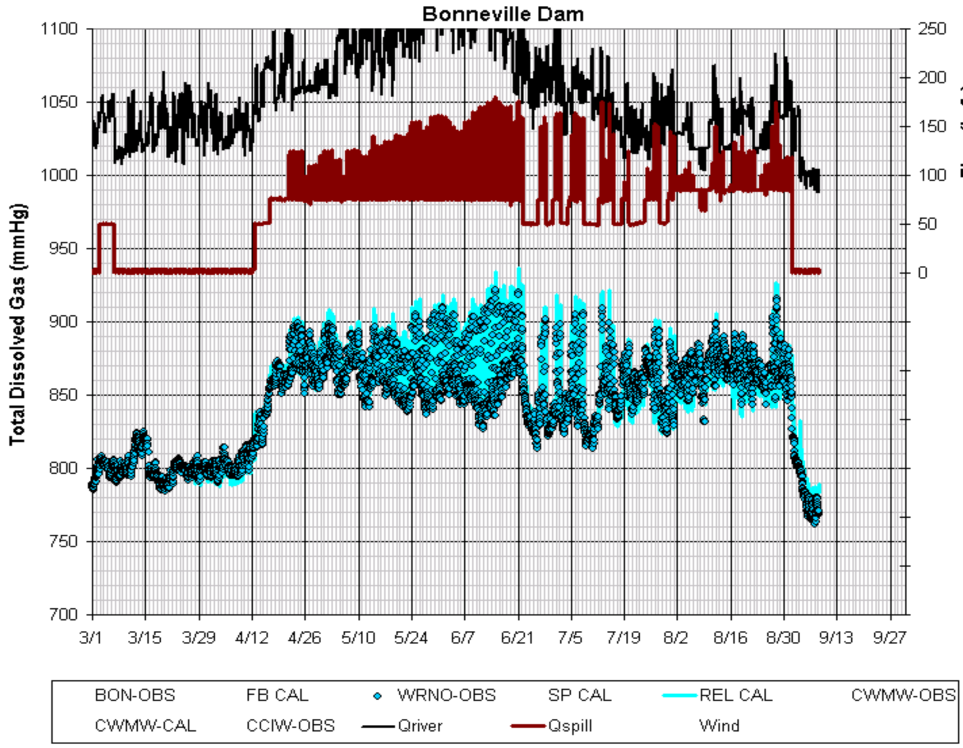

Figure N-3. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Warrendale fixed monitoring station downstream of Bonneville Dam, March-September 2004

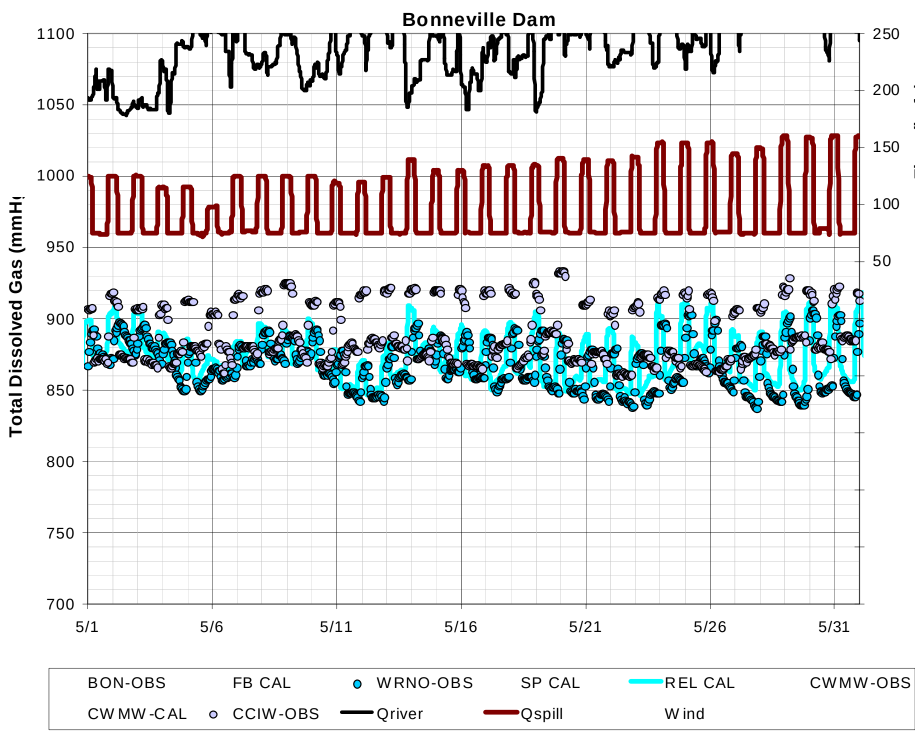

Figure N-4. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Warrendale fixed monitoring station downstream of Bonneville Dam, March-September 2004

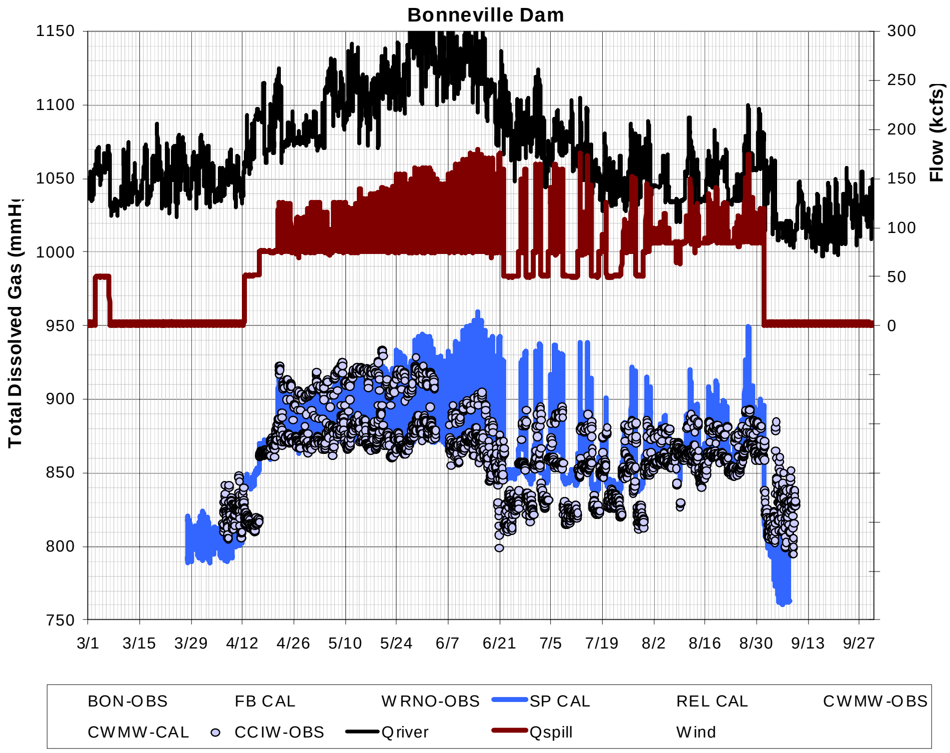

Figure N-5. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam, March-September 2004

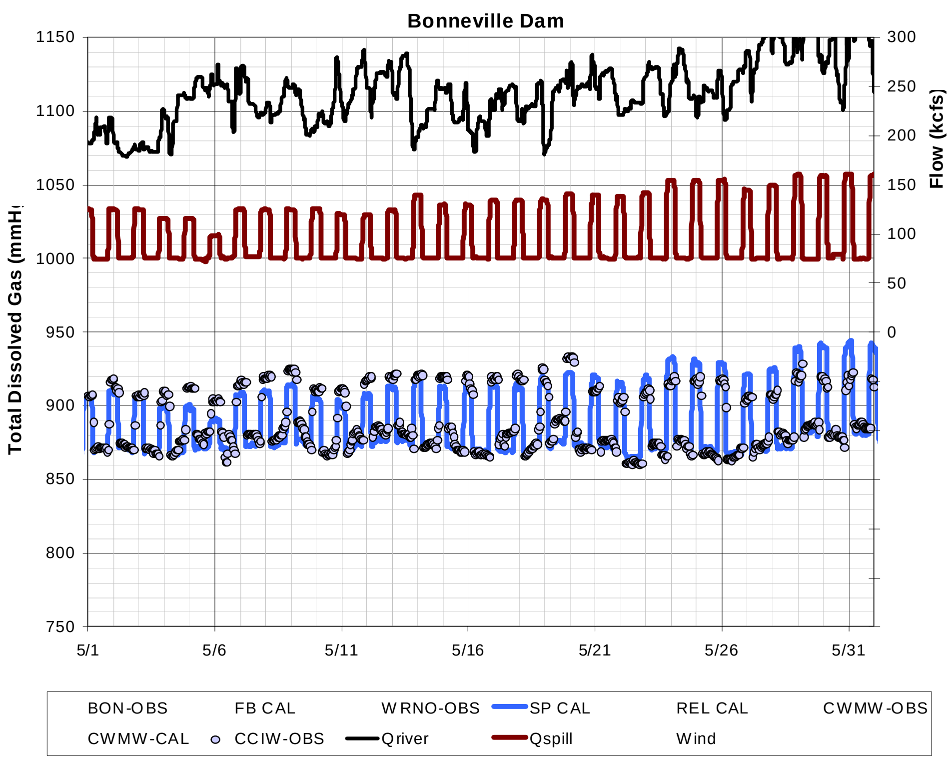

Figure N-6. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam, May 2004

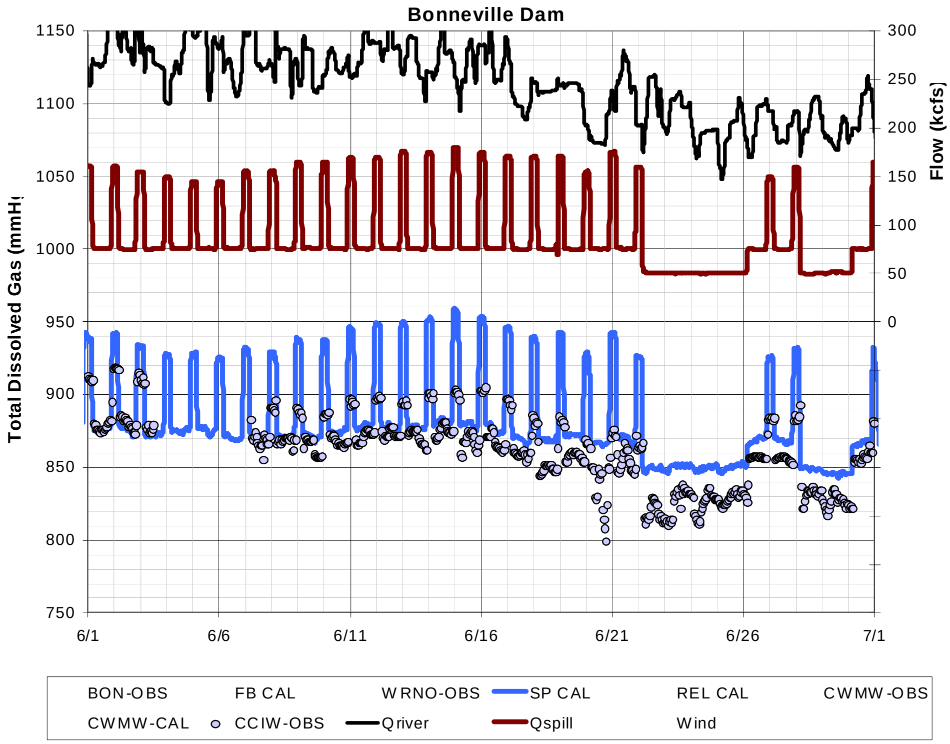

Figure N-7. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam, June 2004

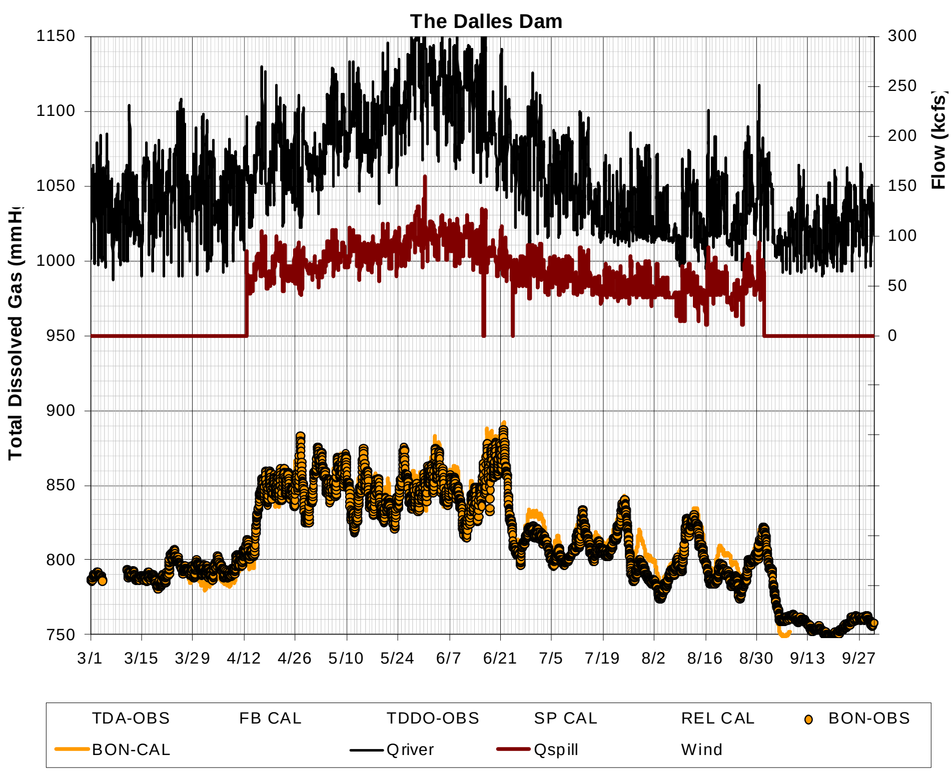

Figure N-8. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of Bonneville Dam, March-September 2004

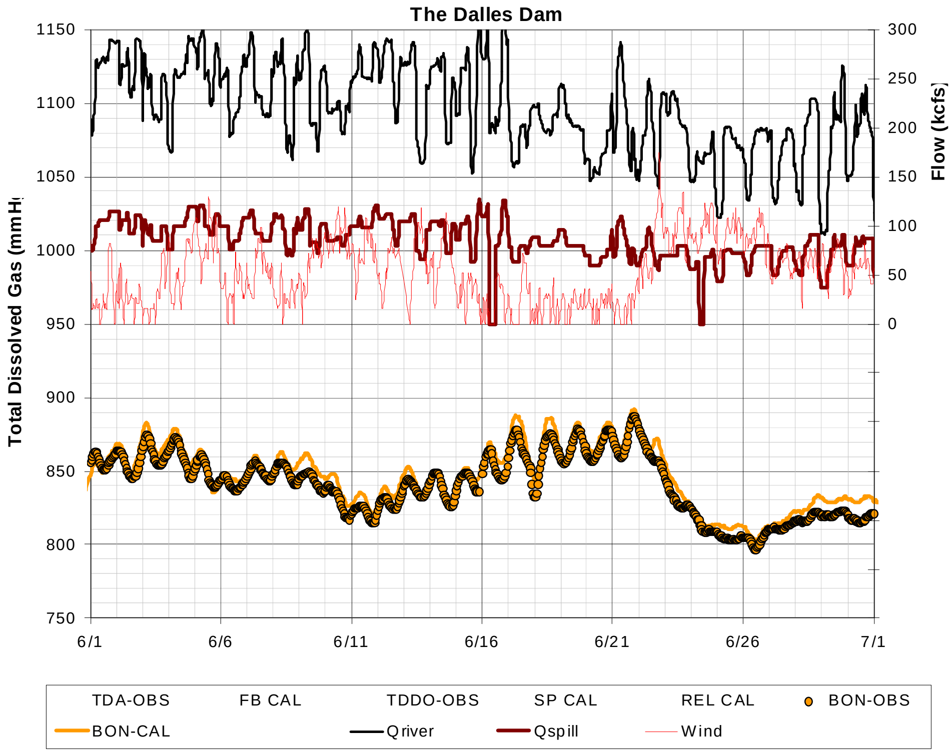

Figure N-9. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of Bonneville Dam, June 2004

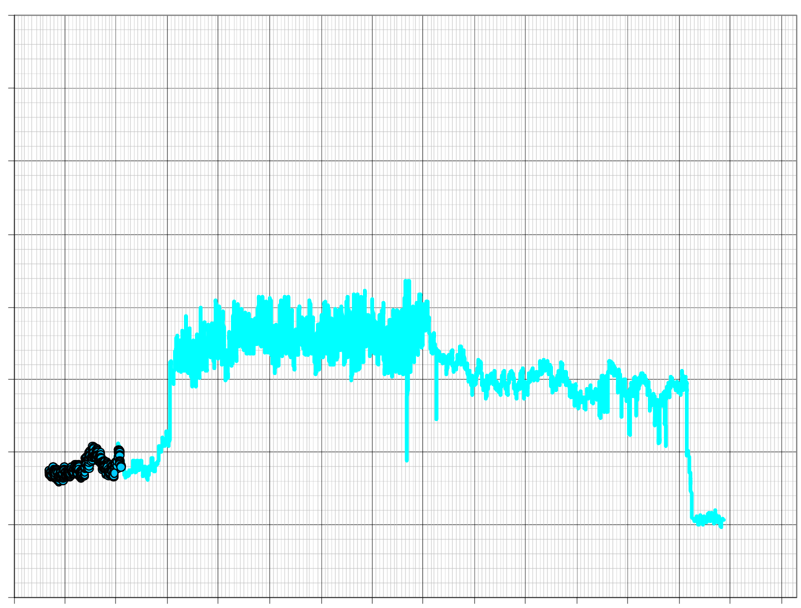

Figure N-10. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from The Dalles Dam, March-September 2004

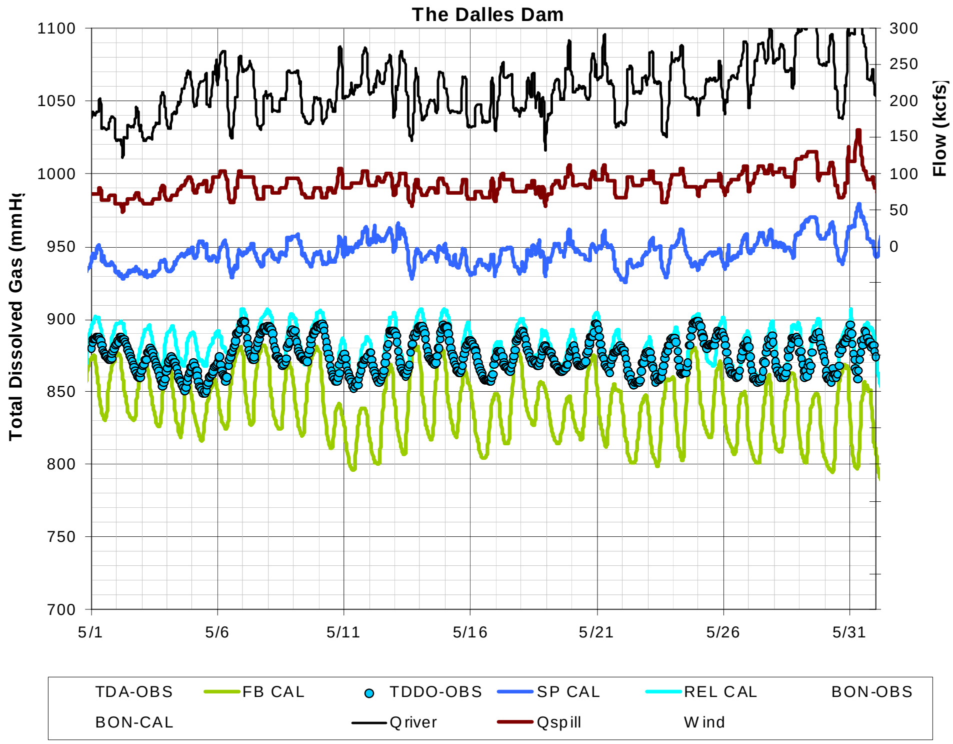

Figure N-11. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from The Dalles Dam, May 2004

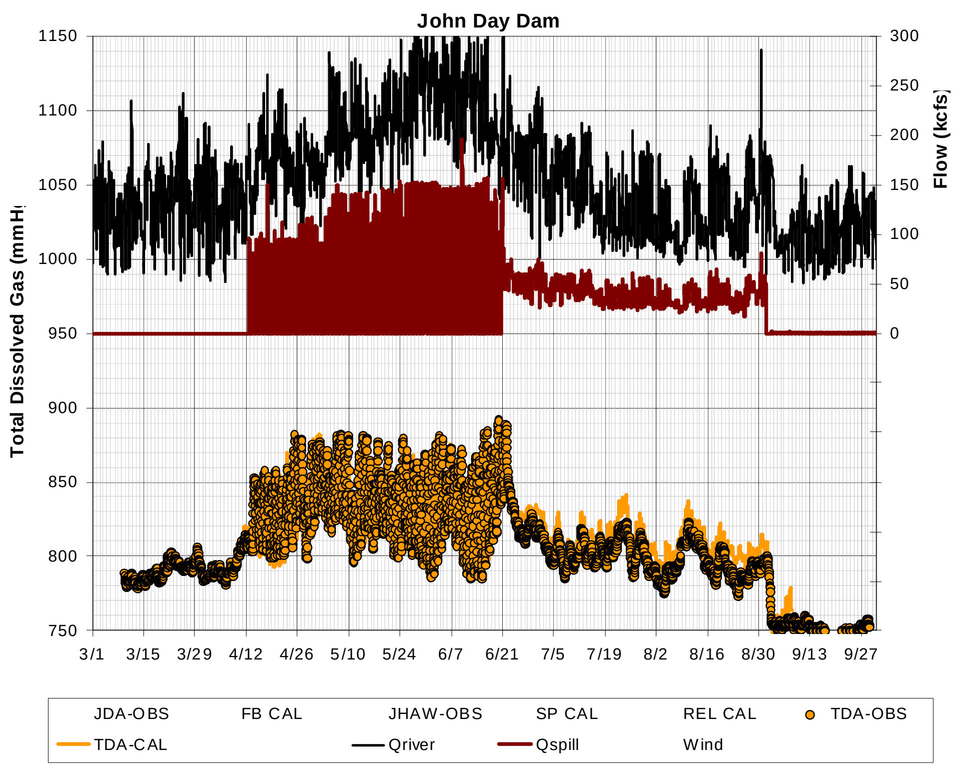

Figure N-12. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of The Dalles Dam, March-September 2004

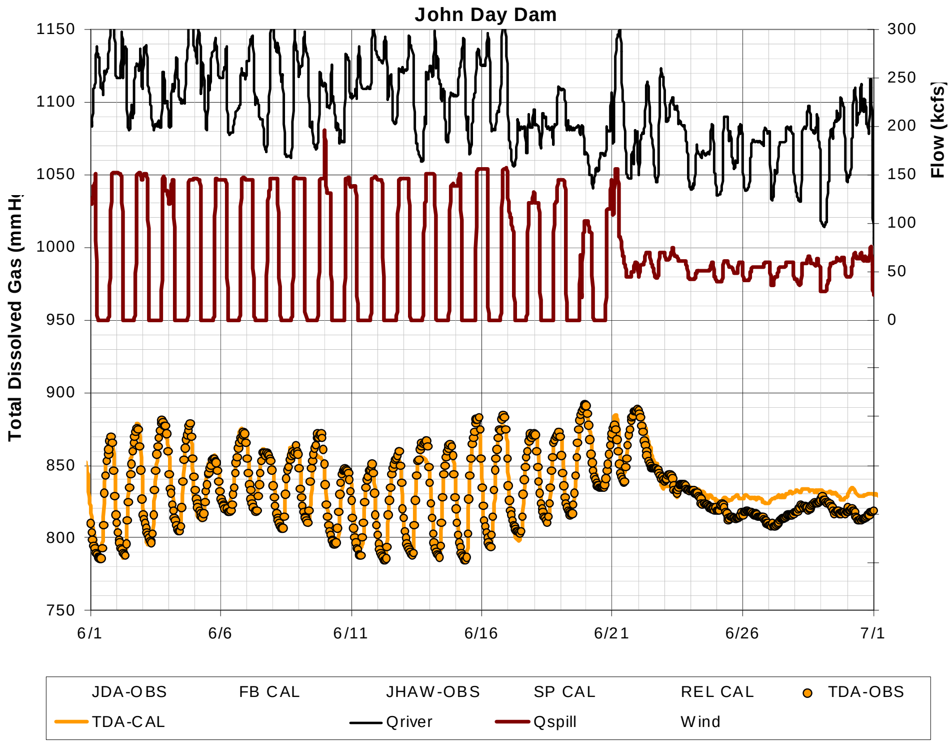

Figure N-13. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of The Dalles Dam, June 2004

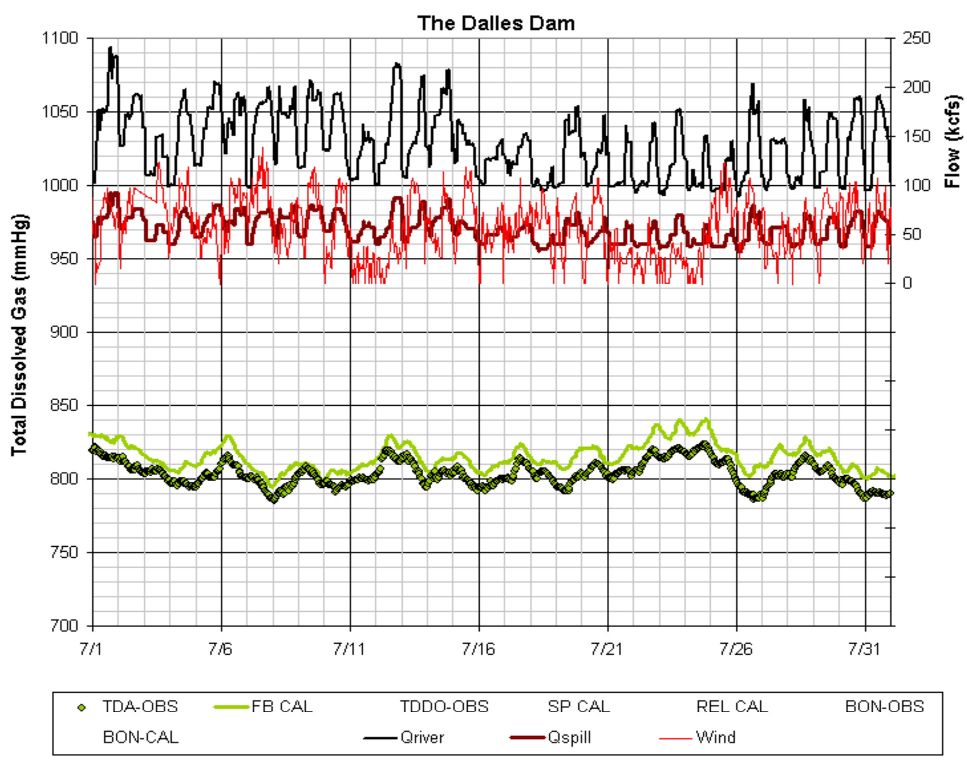

Figure N-14. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of The Dalles Dam, July 2004

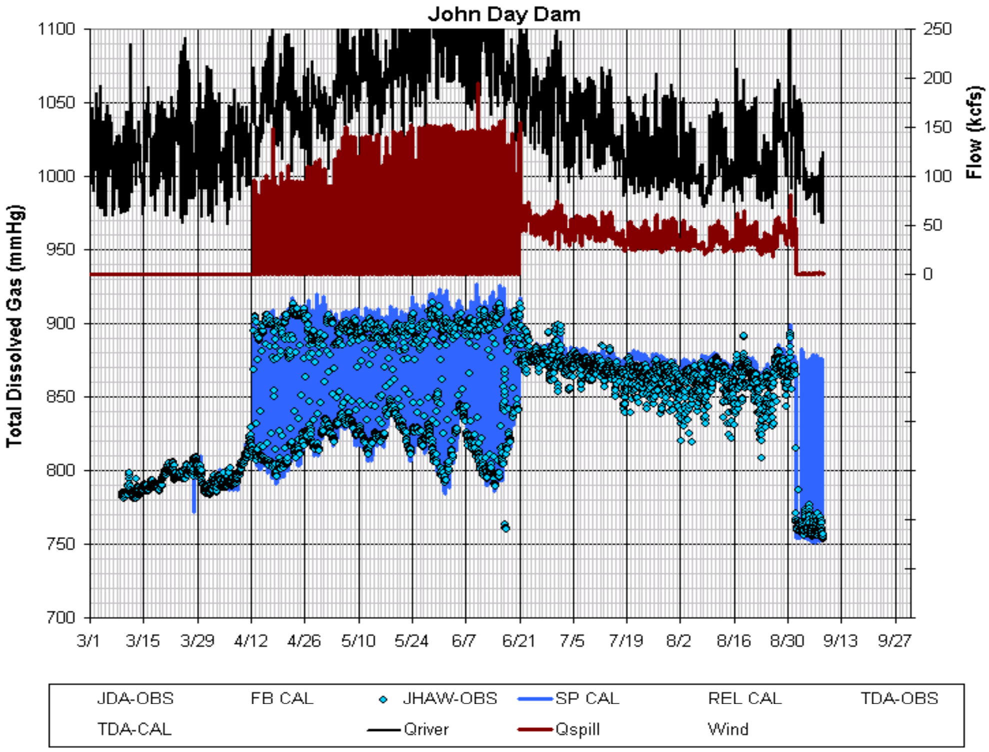

Figure N-15. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, March-September 2004

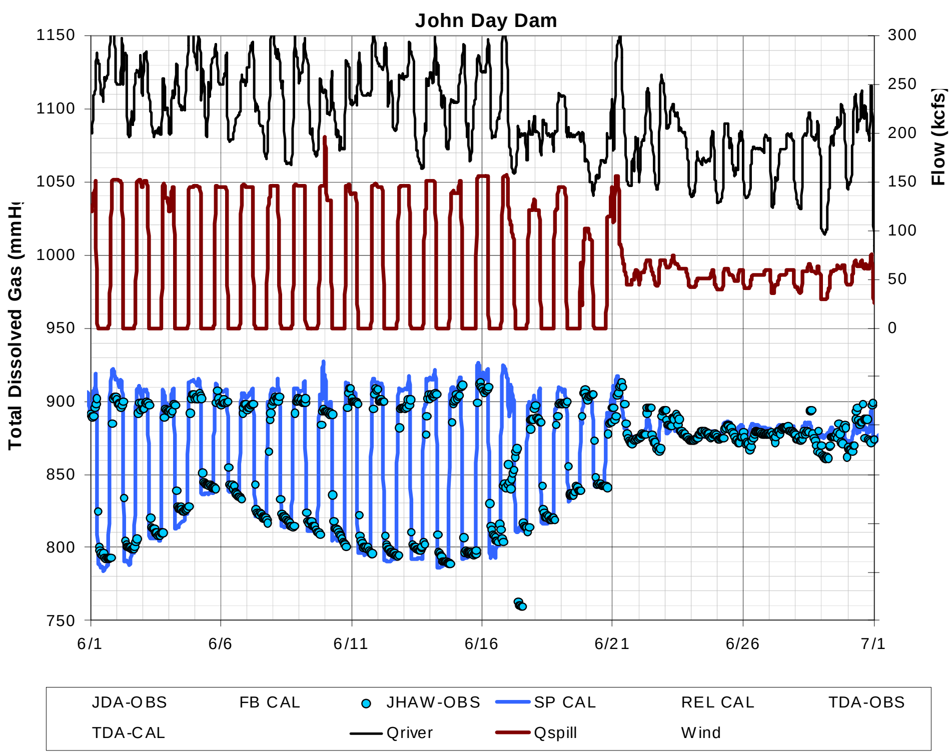

Figure N-16. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, May 2004

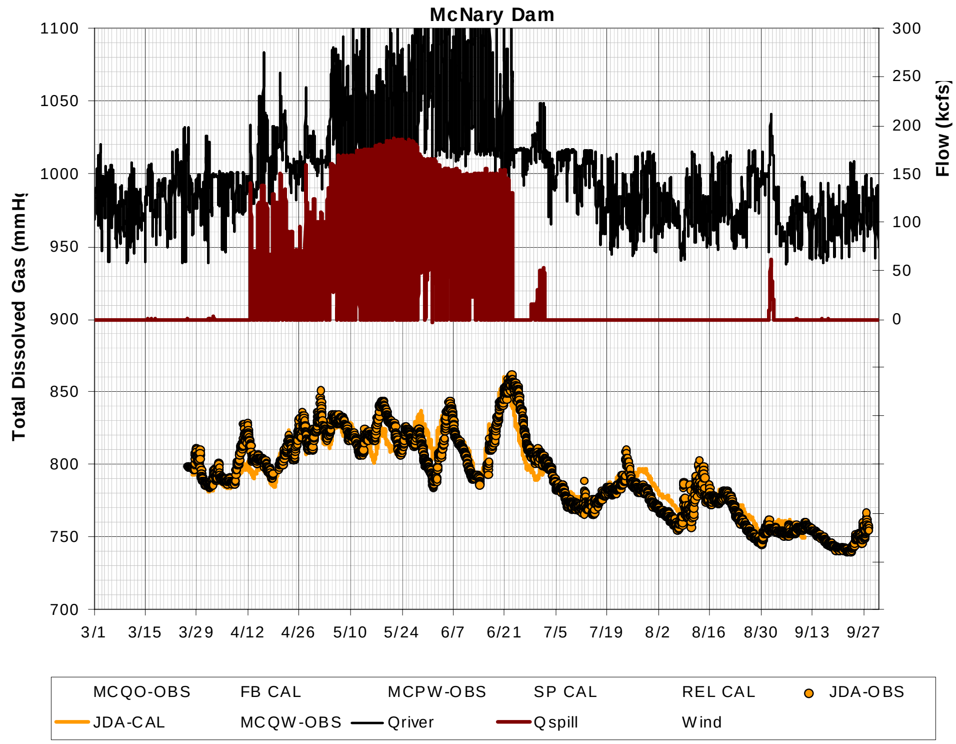

Figure N-17. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of John Day Dam, March-September 2004

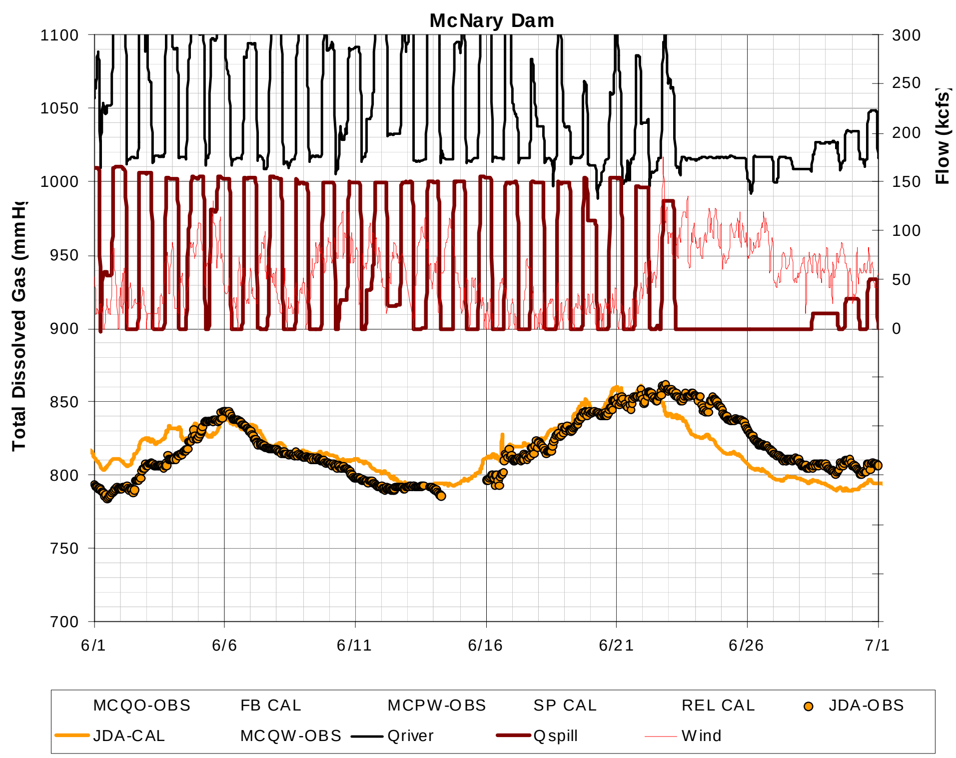

Figure N-18. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of John Day Dam, June 2004

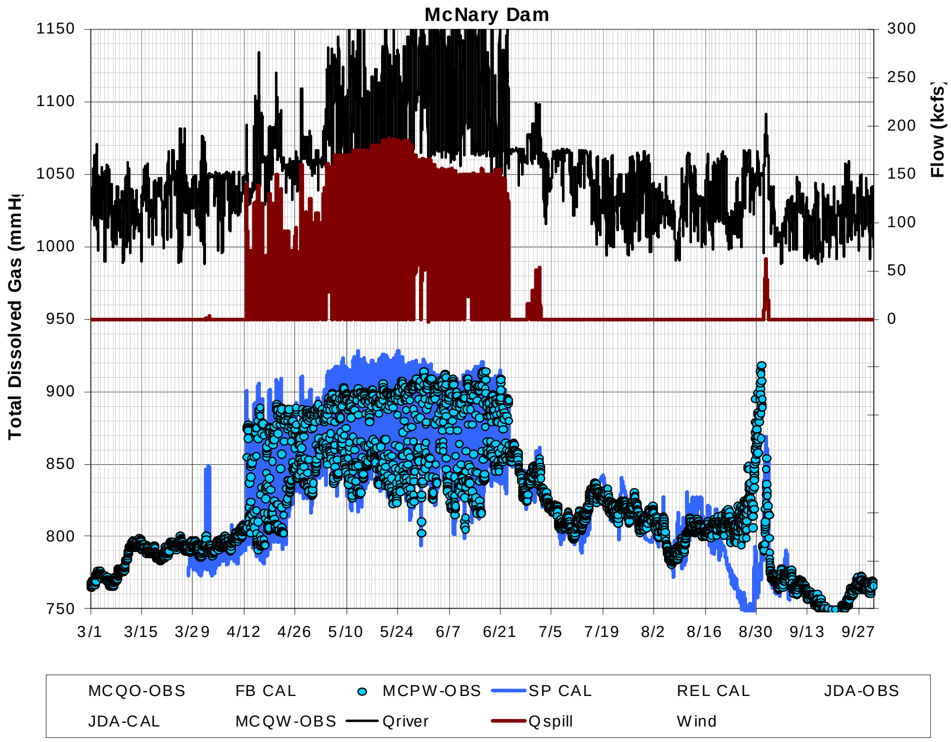

Figure N-19. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from McNary Dam, March-September 2004

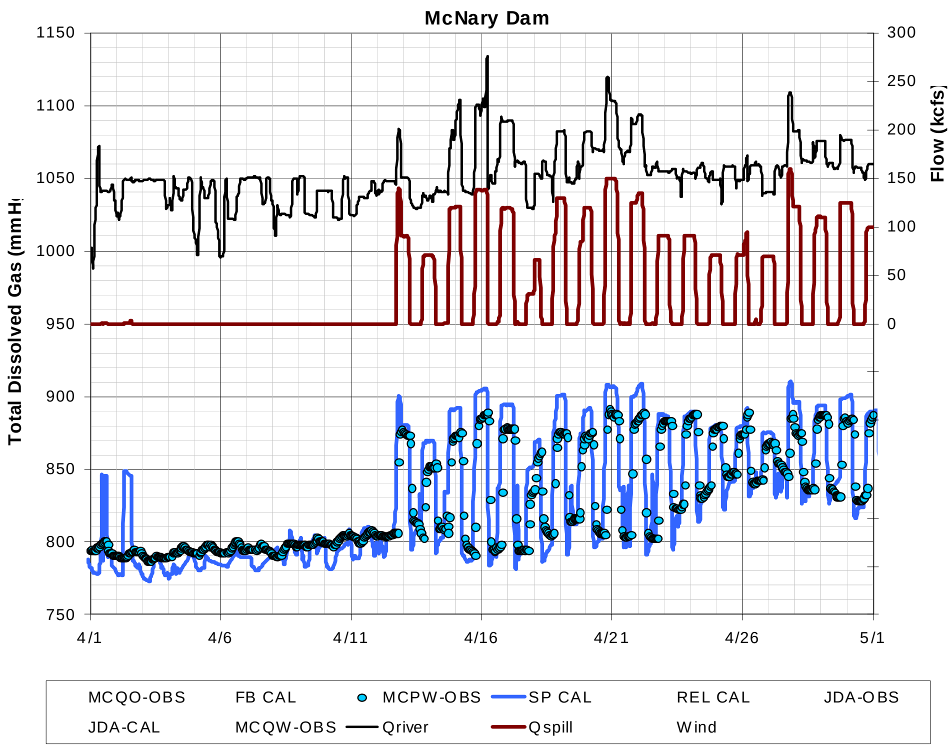

Figure N-20. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from McNary Dam, April 2004

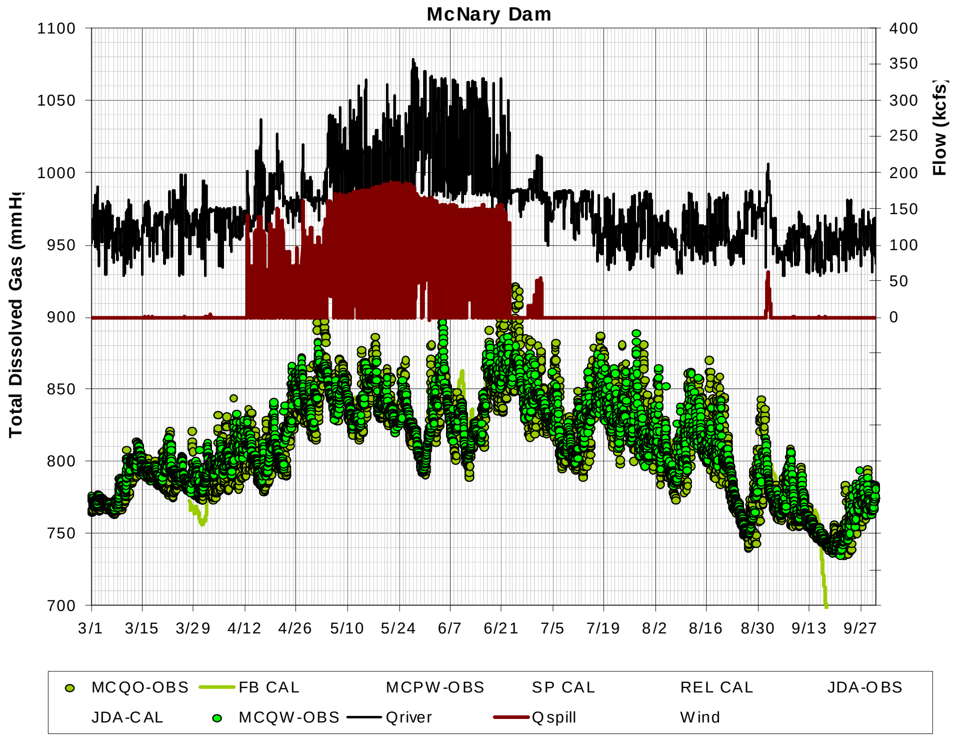

Figure N-21. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of McNary Dam, March-September 2004

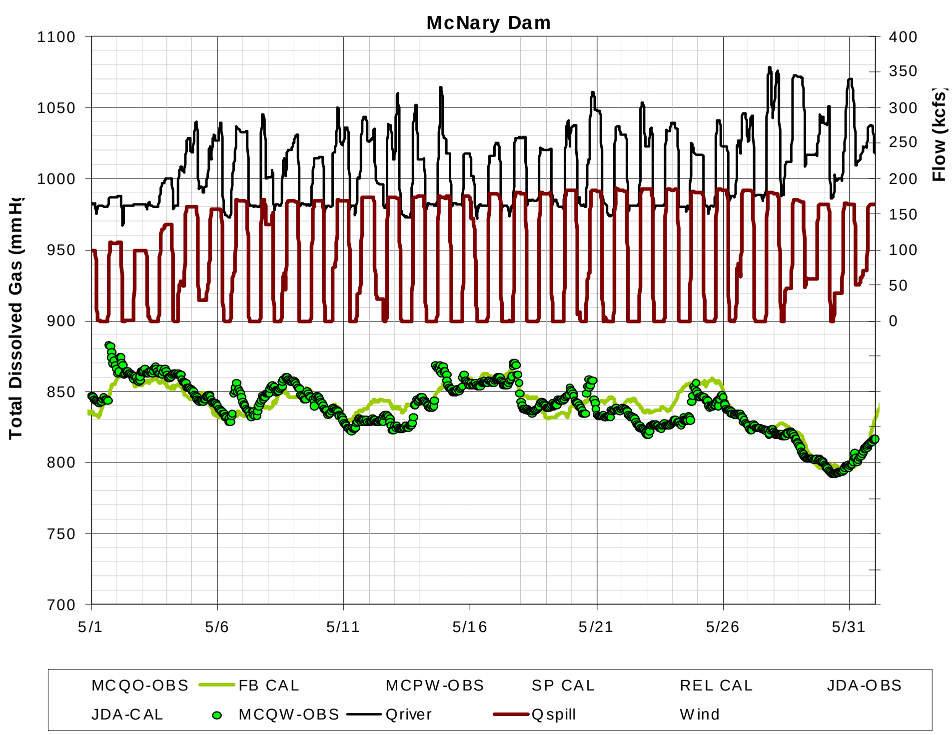

Figure N-22. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of McNary Dam, May 2004

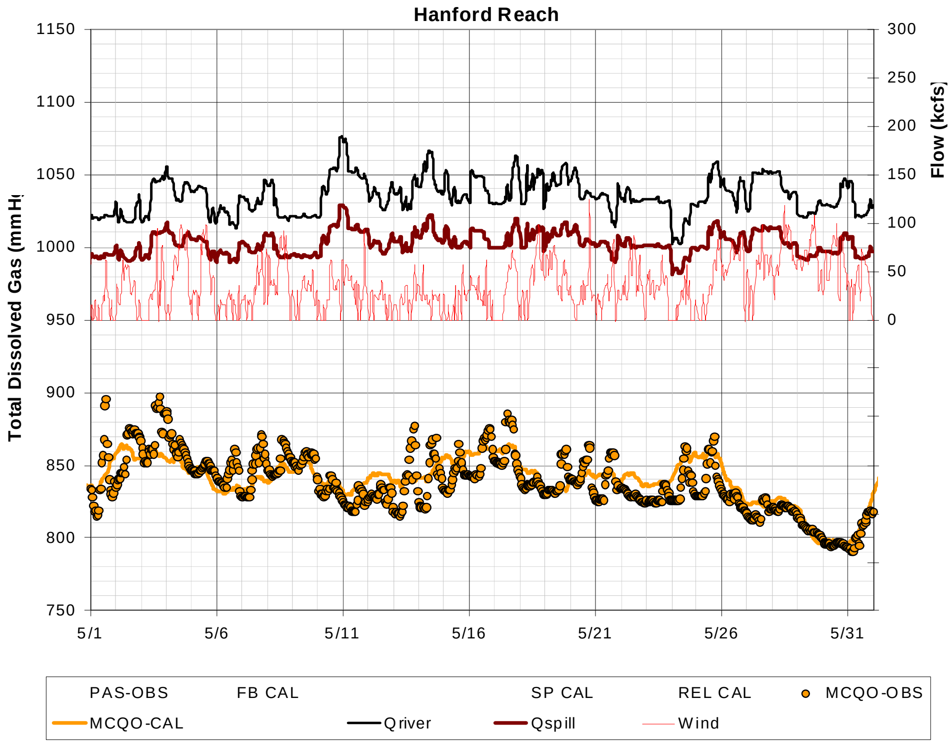

Figure N-23. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of McNary Dam, May 2004

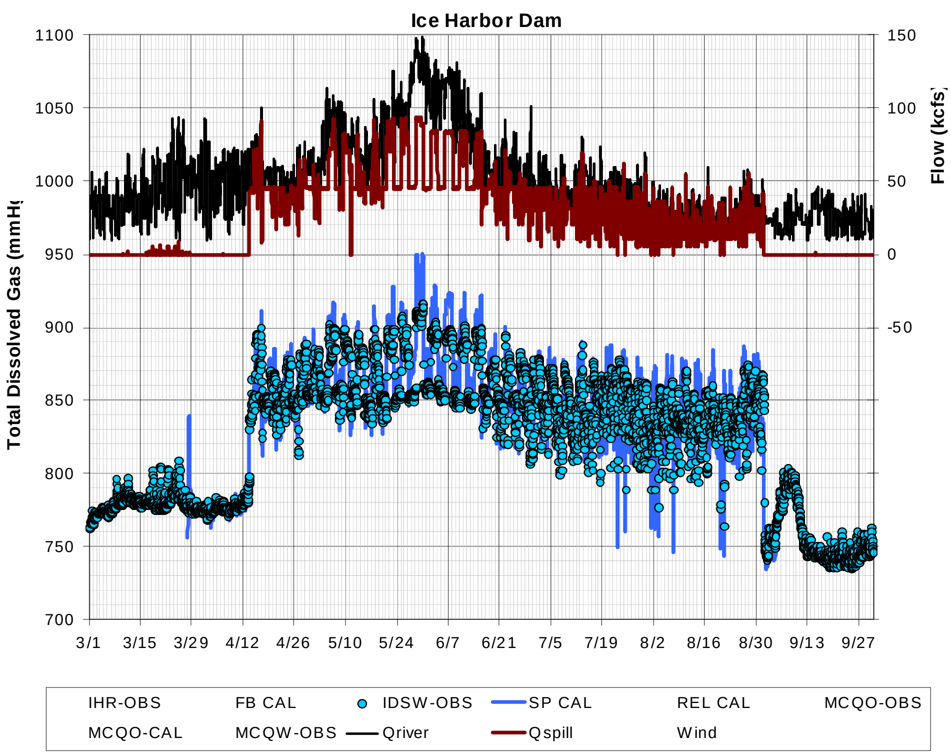

Figure N-24. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Ice Harbor Dam, March-September 2004

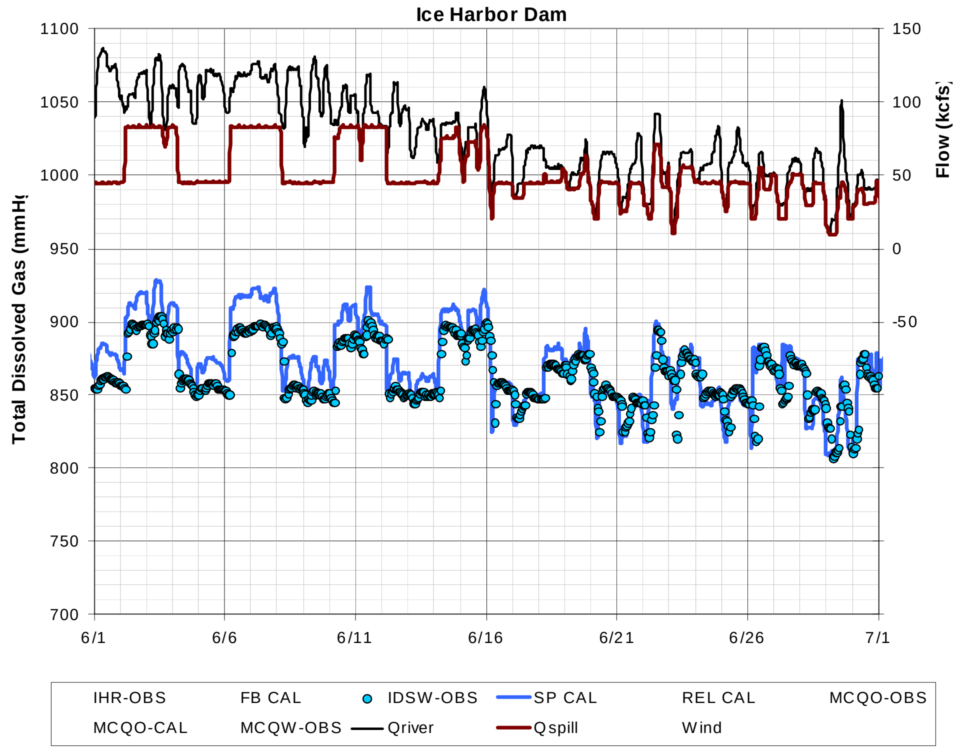

Figure N-25. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Ice Harbor Dam, June 2004

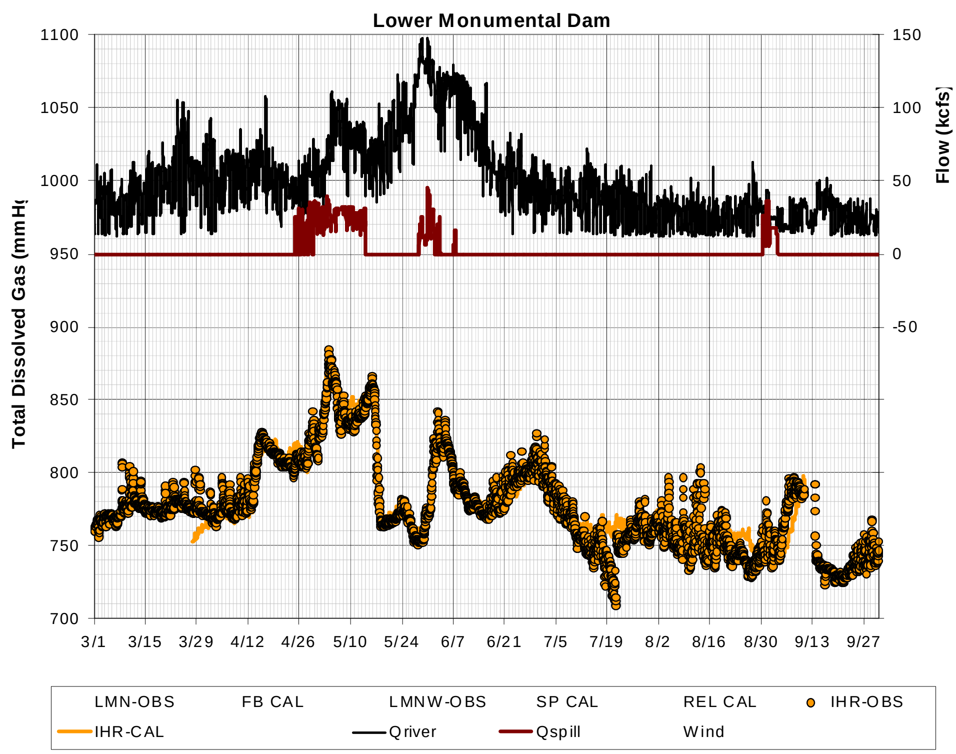

Figure N-26. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Ice Harbor Dam, March-September 2004

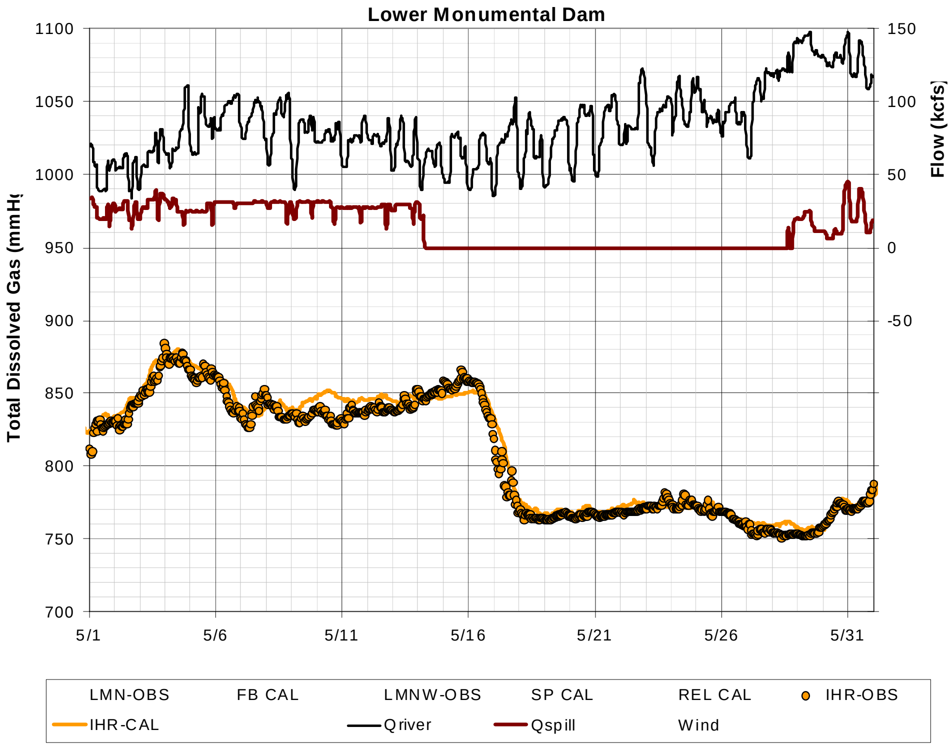

Figure N-27. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Ice Harbor Dam, May 2004

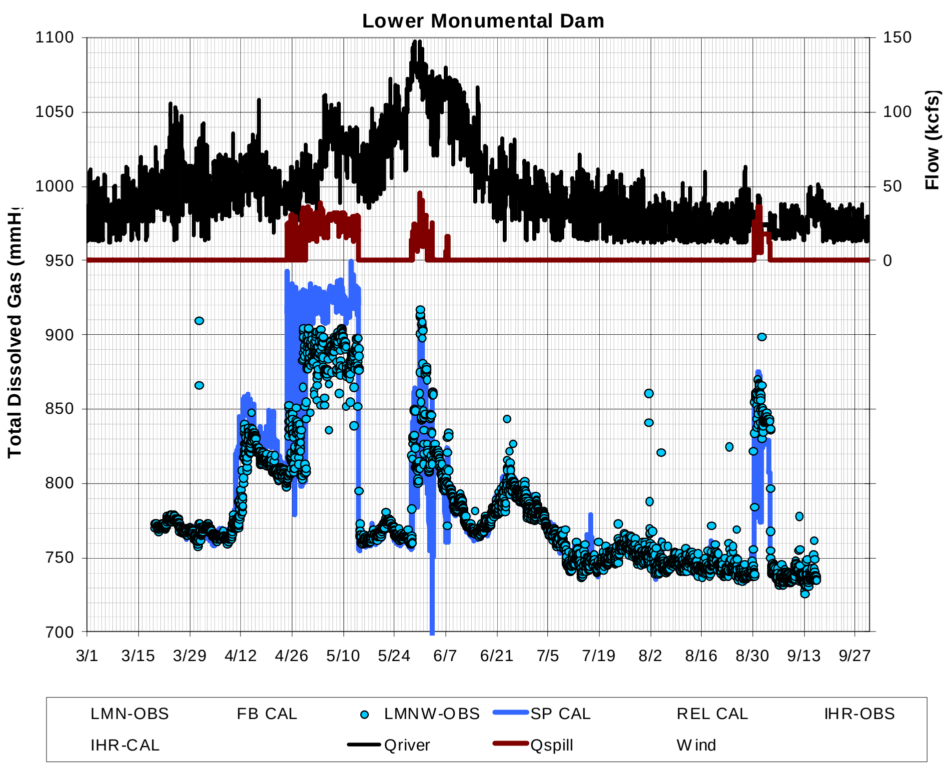

Figure N-28. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Monumental Dam, March-September 2004

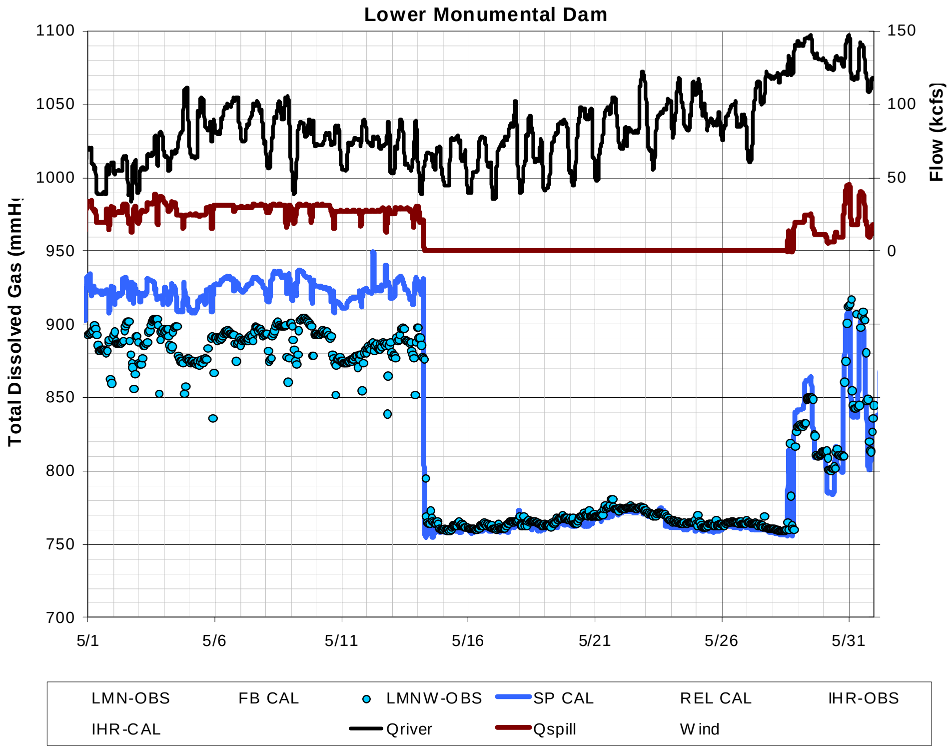

Figure N-29. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Monumental Dam, May 2004

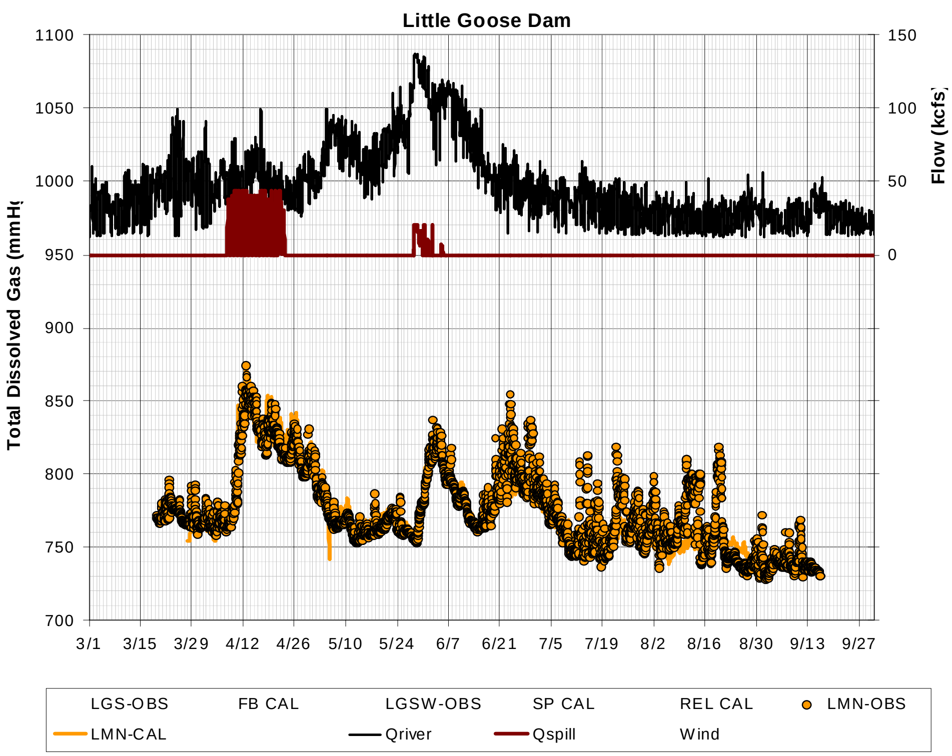

Figure N-30. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Lower Monumental Dam, March-September 2004

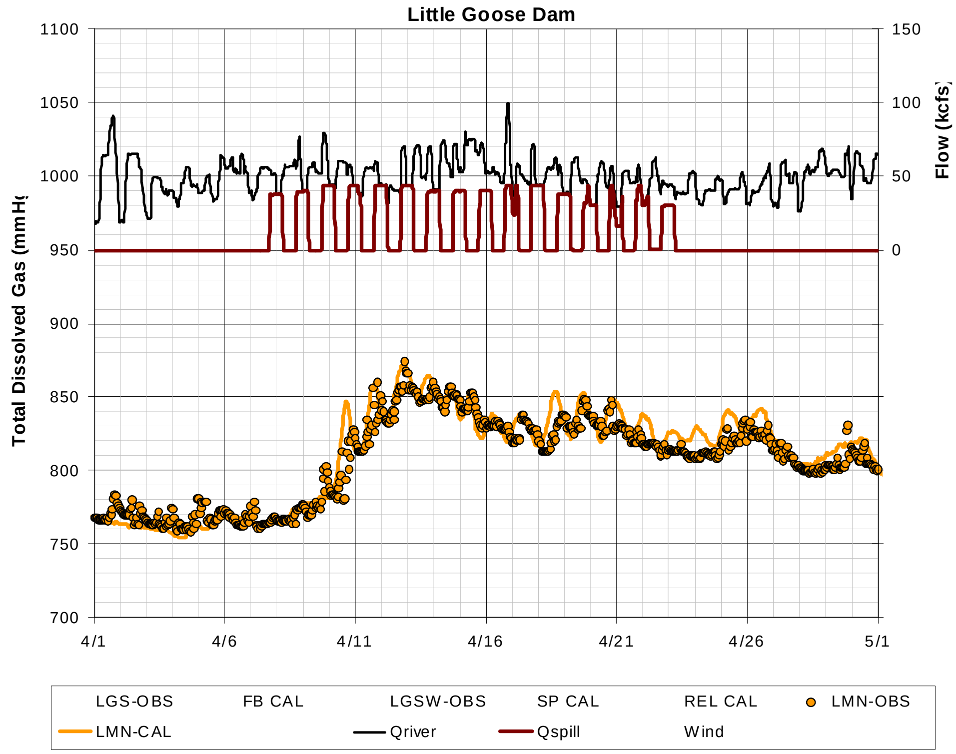

Figure N-31. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Lower Monumental Dam, June 2004

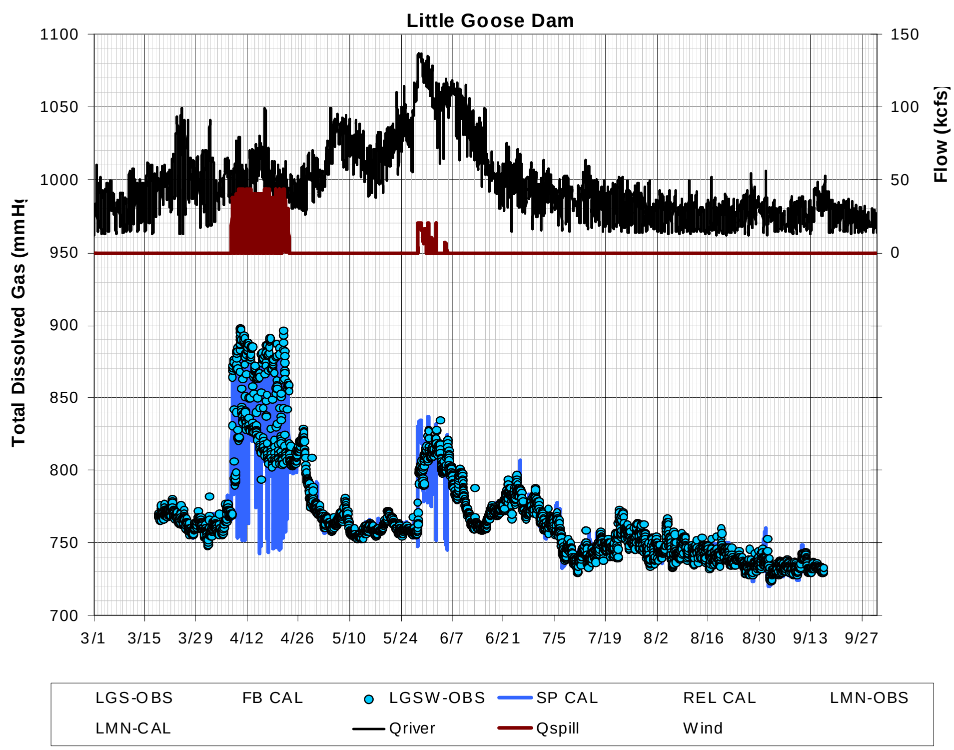

Figure N-32. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Little Goose Dam, March-September 2004

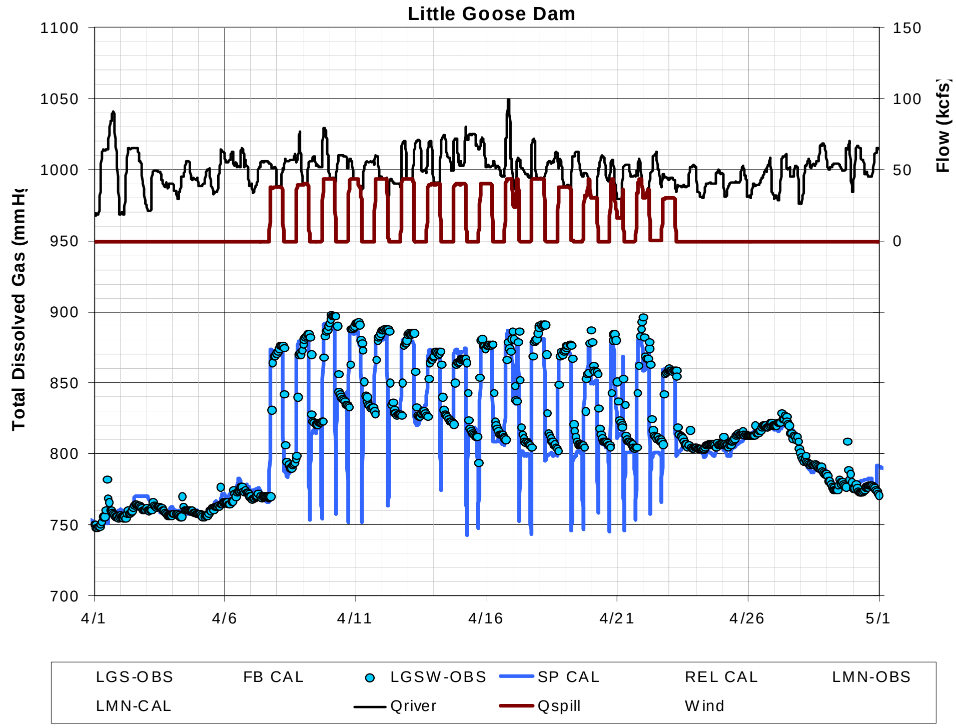

Figure N-33. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Little Goose Dam, April 2004

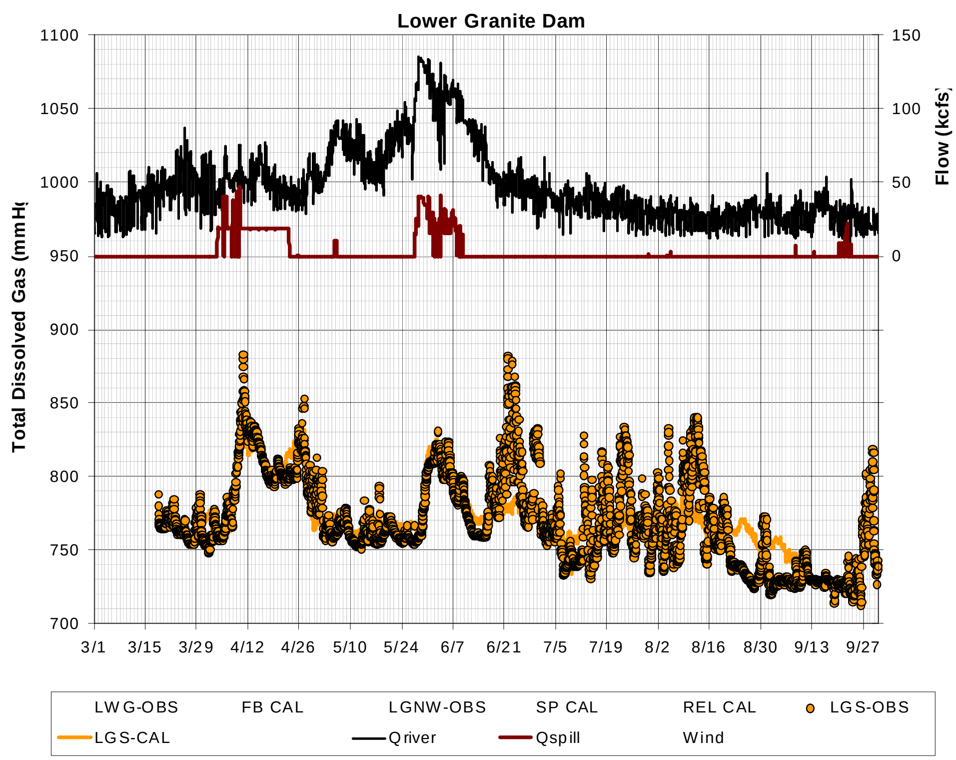

Figure N-34. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Little Goose Dam, March-September 2004

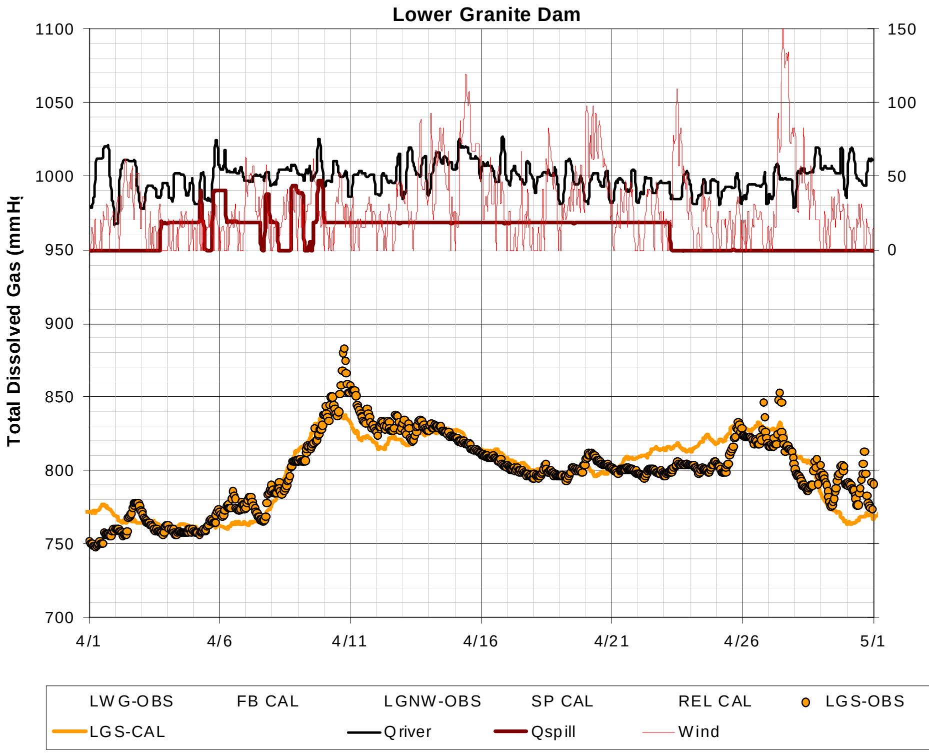

Figure N-35. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Little Goose Dam, April 2004

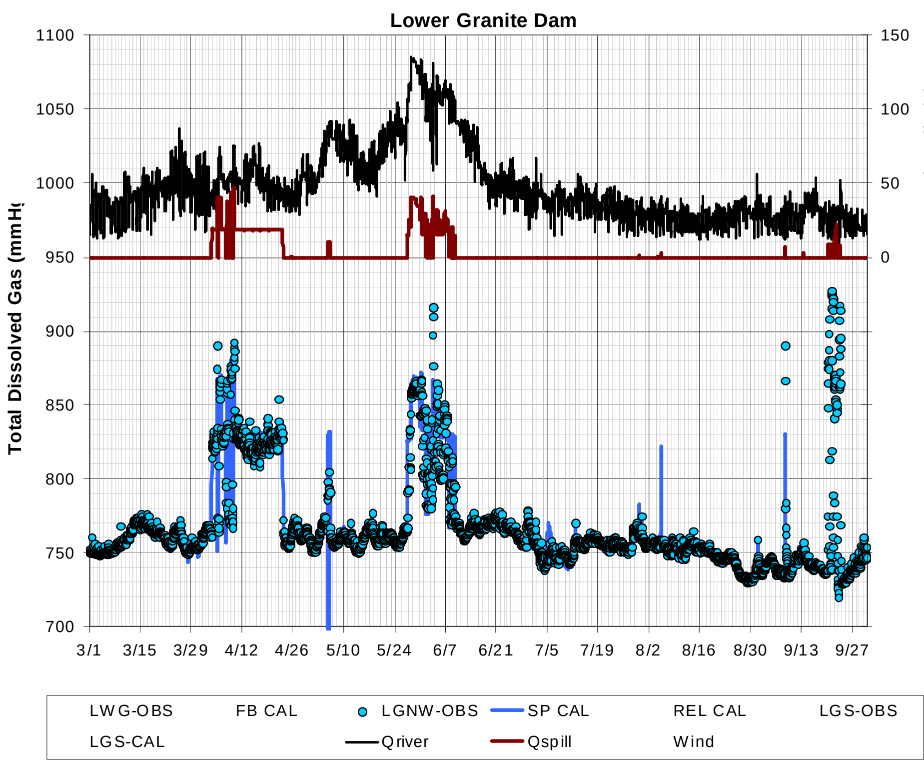

Figure N-36. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, March-September 2004

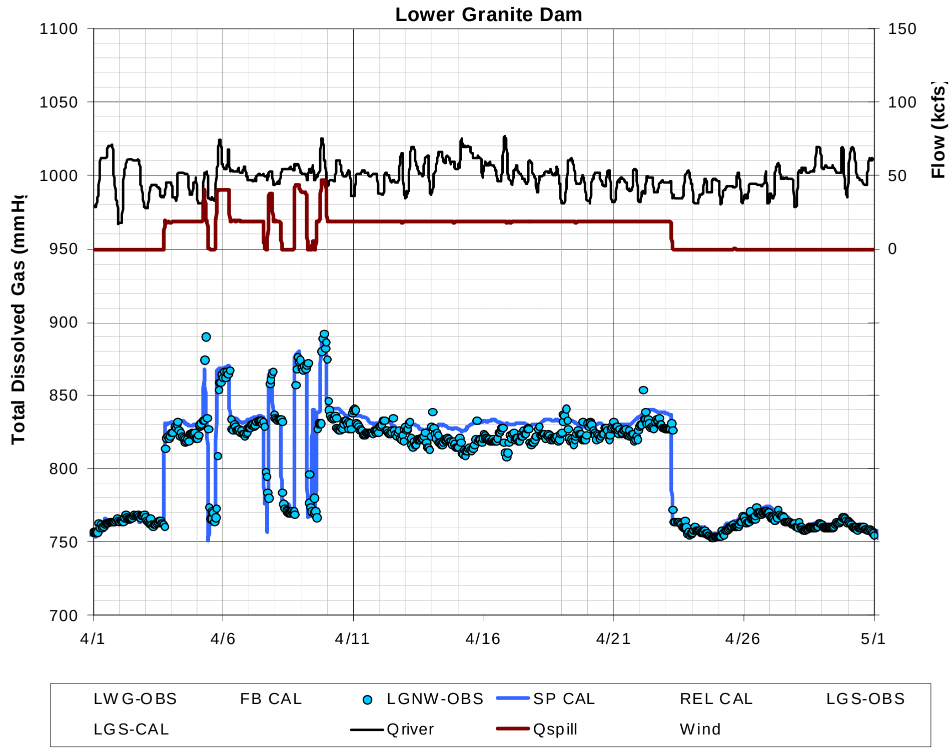

Figure N-37. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, April 2004

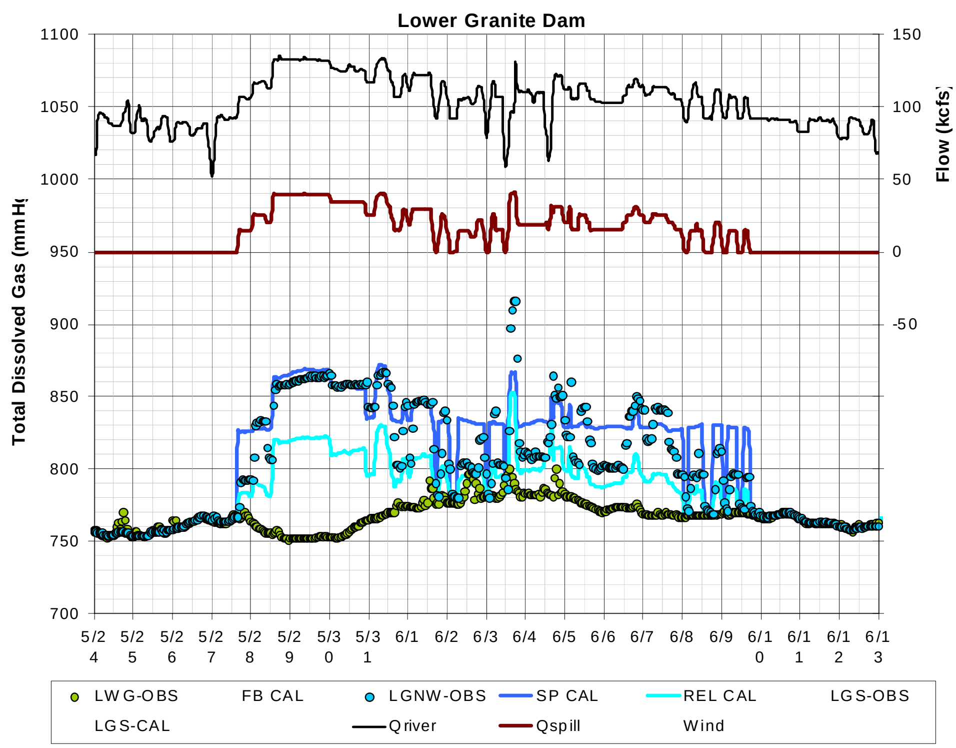

Figure N-38. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, May-June 2004

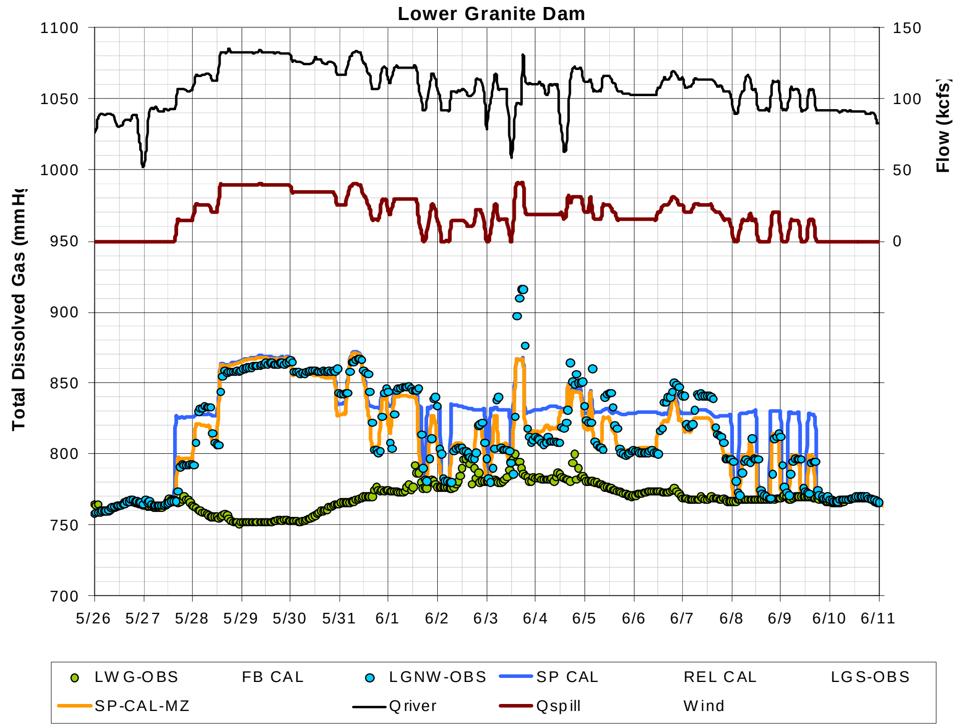

Figure N-39. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam with a Mixing Zone Correction, May-June 2004

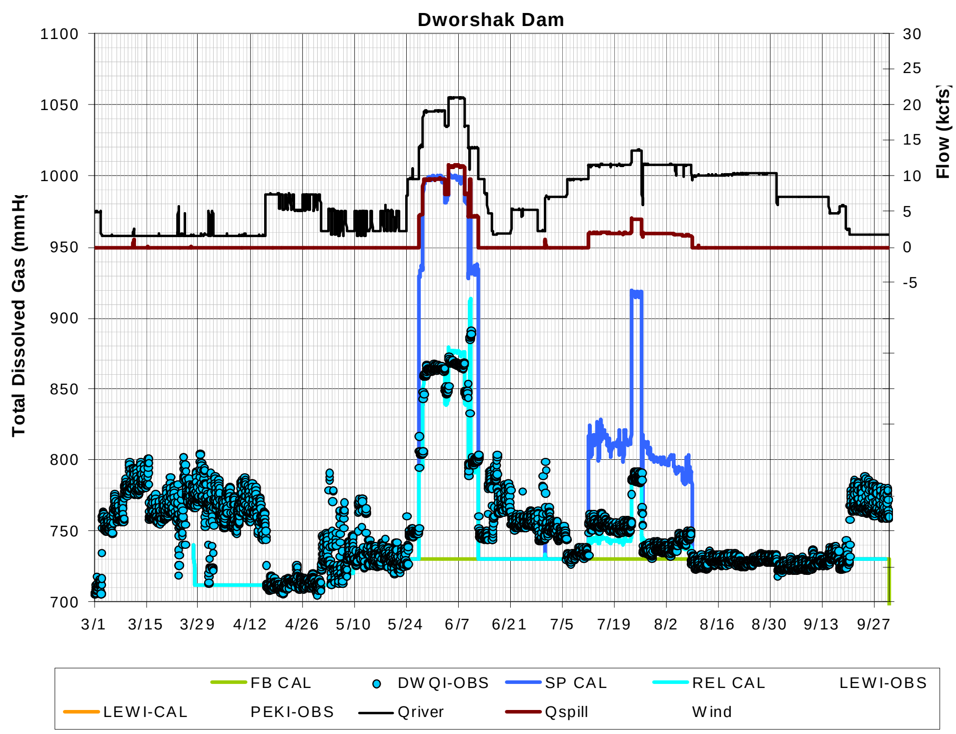

Figure N-40. Observed and Calculated Total Dissolved Gas Pressures in the Clearwater River in the tailwater channel downstream from Dworshak Dam, March-September 2004

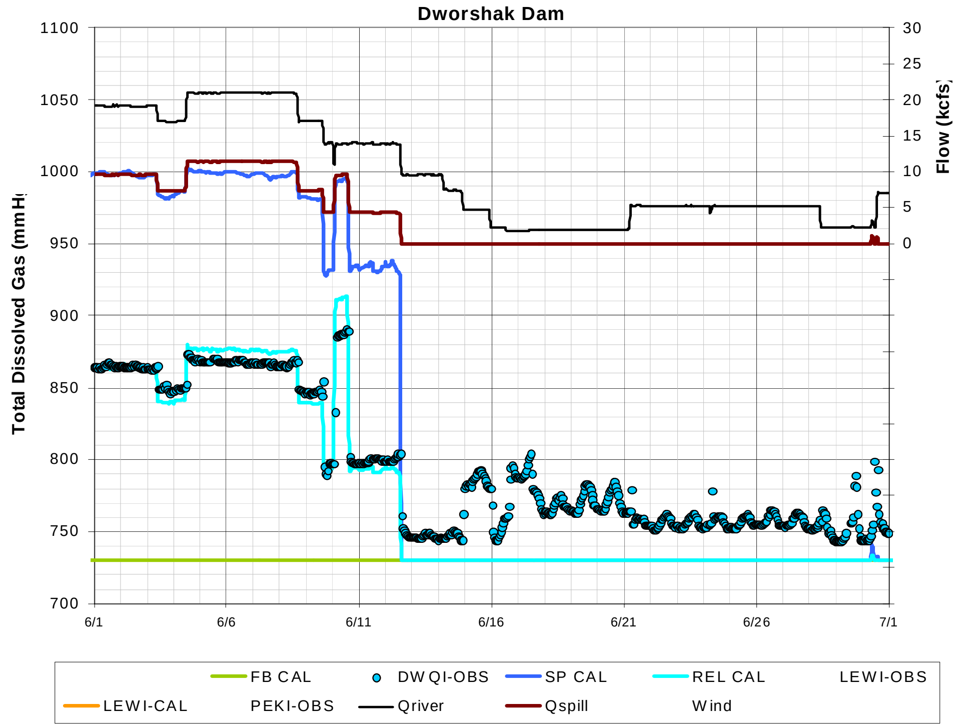

Figure N-41. Observed and Calculated Total Dissolved Gas Pressures in the Clearwater River in the tailwater channel downstream from Dworshak Dam, June 2004

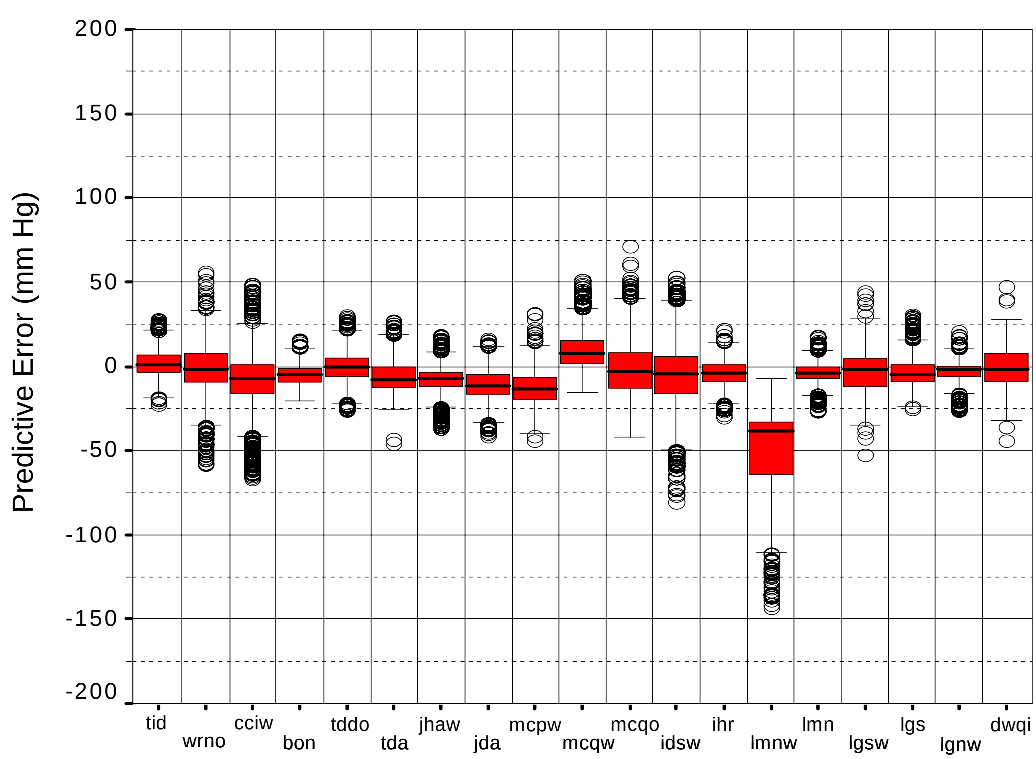

Figure N-42. Summary of SYSTDG Predictive Errors by TDG sampling station, 2004.