APPENDIX G

SYSTDG STATISTICAL EVALUATION

April – August 2008

Introduction

SYSTDG (System Total Dissolved Gas) is a decision support spreadsheet model used to estimate total dissolved gas (TDG) pressures resulting from main stem dam operations on the Columbia, Snake, and Clearwater Rivers. A statistical evaluation of the predictive errors was performed on observed TDG levels during the 2008 fish passage season on the Columbia and Snake Rivers in an effort to quantify the uncertainty of SYSTDG estimates and improve modeling accuracy and reliability. This evaluation was conducted by comparing SYSTDG-calculated TDG pressures to observed TDG pressures measured on the fixed monitoring stations (FMS) located in the forebays and tailwaters of Corps hydro-power 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 2008 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. The difference between the hourly observed and calculated TDG pressure or saturation was the definition used for the predictive error where negative errors reflect over-estimation of observed conditions and positive values reflect an under-estimation of observed conditions. 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 FMS are located in either spillway flows undiluted from powerhouse flows or in mixed river waters. The summary of predictive error was limited to a period of 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 1-August 31 for the Lower Snake River and Lower Columbia River projects. In each reach simulation the observed temperatures and total pressures in the forebays were used as boundary conditions for the simulation. Where forebay and tailwater temperatures were different by over 0.3^{o} C, the observed forebay TDG pressure was approximated by linearly interpolating between total pressure observations where temperatures were within 0.3^{o} C. A detailed description of model input parameters and coefficients can be found in the SYSTDG user's 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 FMS 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. An error in pairing a spill operation with the corresponding TDG 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 patterns as established in the 2008 fish passage plan or auxiliary spill patterns were not implemented as scheduled 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 FMS where a 1° C increase in temperature above bulk river conditions can result in a 2-3 percent increase in the TDG saturation. Sampling errors at tailwater stations have been identified at a number 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 modeling errors is to determine the source of this error, and whether the error represents an estimate bias or misrepresentation of conditions from a modeling framework.

Background

The Columbia River flows in 2008 were well below normal in April and well above normal during the month of June resulting in frequent periods of forced spill and events where the TDG saturation exceeded of the state water quality standards when compared to normal flow conditions. The monthly average flow in the Columbia River at The Dalles Dam during the 2008 season was compared to flow conditions from 1975-2008 in Figure G1. The average Columbia River flow in April of 2008 was well below normal falling in the lower quartile of flows since 1975. The Columbia River flows rapidly increased in May and during June the average flows were ranked the sixth highest flow since 1975. The monthly flows in July and August of 2008 were slightly above average and below average, respectively.

On the Lower Columbia River, the highest percentage of total river flow spilled from April 1 through August 31 of about 47.8 percent, occurred at McNary Dam. The higher spill rate at McNary Dam resulted from the limited hydraulic capacity of the powerhouse and commitment to spill during the summer months. A statistical summary of the hourly project operations in the Lower Columbia River are shown in Table G1 for the period of April 1- August 31. The average spill at McNary was 110.7 kcfs compared to 107.9 kcfs at Bonneville Dam, 86.5 kcfs at The Dalles Dam, and 73.9 kcfs at John Day Dams. The highest hourly spill of 250.9 kcfs occurred at McNary Dam. The spill policy at Priest Rapids Dam during 2008 resulted in much lower spill volumes and TDG saturation levels entering the McNary Pool compared to the TDG levels from the Snake River.

Table G1. Statistical Summary of Hourly Project Flows from April 1-August 31, 2008 on the Columbia River											
Project		**Bonneville**		**The Dalles**		**John Day**		**McNary**		**Priest Rapids**	
		Qtotal (kcfs)*	Qspill (kcfs)	Qtotal (kcfs)	Qspill (kcfs)	Qtotal (kcfs)	Qspill (kcfs)	Qtotal (kcfs)	Qspill (kcfs)	Qtotal (kcfs)	Qspill (kcfs)
N		3672	3672	3672	3672	3672	3672	3672	3672	3671	3671
Avg		238.7	107.9	222.4	86.5	229.1	73.9	231.4	110.7	141.6	27.2
Stdev		101.9	50.2	103.0	47.7	106.5	45.5	99.9	65.3	60.7	27.8
Max		437.7	245.3	423.0	250.3	451.4	240.6	425.7	250.9	292.7	149.3
Min		106.1	0.0	60.6	0.0	49.5	0.0	57.8	0.0	0.0	0.0
Qsp/Qtot			45.2		38.9		32.2		47.8		19.2
	1%	115.2	0.0	86.2	0.0	78.4	0.0	92.7	0.0	43.5	0.0
	5%	118.2	2.4	98.1	0.0	99.4	0.0	106.9	0.0	57.6	0.0
	25%	151.6	76.8	132.4	51.1	139.3	39.2	142.3	63.6	90.5	1.1
	50%	197.5	98.5	190.6	76.1	195.7	66.3	198.0	88.7	132.6	21.6
	75%	330.3	129.0	314.4	129.0	326.7	111.3	334.2	165.0	186.9	33.8
	95%	416.3	201.0	399.7	162.6	411.7	140.0	397.0	225.1	249.0	89.9
	99%	422.5	225.3	412.4	189.0	428.0	190.1	411.4	244.1	269.2	111.5
*Units kcfs except for Qspill/Qtotal entry.											

The Snake River contributed about one-third of the flow to the Lower Columbia River during the period from April 1- August 31, 2008. Ice Harbor spilled about 58.6 percent of the Snake River flow during this period compared to 33.2, 34.0, and 41.4 percent for Lower Monumental, Little Goose, and Lower Granite Dams, respectively as listed in Table G2. The higher spill rate at Ice Harbor Dam was governed by the higher spillway capacity as limited by the TDG levels at the tailwater FMS and the biological testing of the removable spillway weir (RSW). The largest hourly spill of 170.3 kcfs occurred at Ice Harbor Dam during the 2008 spill season. The spill volume at Lower Granite Dam was considerably larger than at Little Goose Dam despite the presence of the RSW. The lower spill rates at Little Goose and Lower Monumental Dams were partially attributed to lower spill caps dictated by TDG levels in the forebay of the downstream project. The spill at Dworshak Dam was above average during the 2008 spill season and was scheduled nearly continuous during the summer months. Flow in excess of powerhouse capacity at Dworshak Dam was passed either by the regulating outlets or over the spillway. The highest spill rate at Dworshak Dam was 7.4 kcfs.

Table G2. Statistical Summary of Hourly Project Flows from April 1-August 31, 2008 on the Columbia River											
Project		**Ice Harbor**		**Lower**		**Little Goose**		**Lower Granite**		**Dworshak**	
		Qtotal (kcfs)*	Qspill (kcfs)	Qtotal (kcfs)	Qspill (kcfs)	Qtotal (kcfs)	Qspill (kcfs)	Qtotal (kcfs)	Qspill (kcfs)	Qtotal (kcfs)	Qspill (kcfs)
N		3672	3672	3672	3672	3672	3672	3672	3672	3672	3672
Avg		79.7	46.7	75.9	25.2	76.1	25.9	78.4	32.4	10.8	2.1
Stdev		45.1	28.4	44.1	16.3	41.6	19.4	42.9	25.3	4.1	2.1
Max		238.0	170.3	236.9	122.1	220.1	130.1	214.9	143.6	16.9	7.4
Min		10.2	0.0	12.2	0.0	11.8	0.0	14.4	0.0	1.0	0.0
Qsp/Qtot			58.6		33.2		34.0		41.4		19.4
	1%	25.7	0.0	26.0	0.0	24.4	0.0	30.8	0.0	1.1	0.0
	5%	31.0	16.0	29.4	14.8	26.3	7.4	32.4	18.2	1.6	0.0
	25%	40.4	25.0	38.1	17.4	42.6	12.8	45.1	18.4	9.5	0.0
	50%	65.0	40.1	61.2	19.8	61.7	20.1	62.7	20.2	11.7	2.2
	75%	117.2	60.1	112.0	25.9	111.5	34.9	116.9	35.9	14.1	4.2
	95%	160.1	109.2	155.4	68.7	150.7	70.8	154.9	83.8	15.1	5.4
	99%	199.8	129.8	200.2	88.6	187.0	95.4	195.4	125.0	16.5	6.5
*Units kcfs except for Qspill/Qtot entry.											

The total dissolved gas saturation was monitored in the forebay and tailwater of each Lower Columbia River Dam throughout the spill season of 2008. The average hourly TDG saturation in the forebay of each dam ranged from a high of 110.6 at Bonneville Dam to a low of 108.0 percent at John Day Dam (Table G3). The average TDG saturation at Camas/Washougal station (CWMW) located about 22 miles downstream of Bonneville Dam in mixed water and grouped with other forebay stations, was slightly higher at 113.8 percent as listed in Table G3. The frequency of hourly observations greater than 115 percent at forebay stations ranged from 36.9 percent at CWMW to a low of 5.6 percent in the forebay of The Dalles Dam. The TDG saturation exceeded 120 percent only at CWMW and BON fixed monitoring stations.

The average TDG saturation at the tailwater stations ranged from 118.3 percent at Bonneville to 114.5 percent at The Dalles Dam (Table G3). The tailwater station at The Dalles Dam reflects the contributions from both powerhouse and spillway flows unlike the other three projects where the tailwater station monitors the TDG content in spillway flows undiluted from powerhouse flows. The frequency of hourly TDG observations exceeding 120 percent at the tailwater monitoring stations ranged from 31.2 percent below Bonneville Dam to only 1.3 percent at The Dalles Dam. The likelihood of the tailwater station exceeding the 120 percent criteria was less than the frequency of the next forebay station exceeding 115 percent at all the Lower Columbia River projects during the 2008 fish passage season except at McNary Dam. These summary TDG statistics were based on hourly observations and not daily statistics composed of the highest 12 hourly observations or a moving 12 hour average as referenced by the state water quality standards in Oregon and Washington.

Table G3. Statistical Summary of Hourly Total Dissolved Gas Saturation at Fixed Monitoring Stations from April 1-August 31, 2008 on the Columbia River										
	Bonneville				**The Dalles**		**John Day**		**McNary**	
Station	**CWMW**	**WRNO**	**CCIW**	**BON**	**TDDO**	**TDA**	**JHAW**	**JDY**	**MCPW**	**MCNA**
	FB (%)	TW (%)	TW (%)	FB (%)	TW (%)	FB (%)	TW (%)	FB (%)	TW (%)	FB (%)
N	3651	761	3646	3670	3672	3670	3601	3671	3645	3672
Avg	113.8	112.9	118.3	110.6	114.5	109.6	115.2	108.0	115.7	109.7
Stdev	3.4	3.9	3.5	4.1	3.6	3.6	4.2	4.4	4.3	4.3
Max	121.6	118.0	130.0	122.0	125.0	119.4	126.1	119.3	124.2	119.8
Min	103.5	103.6	108.4	101.0	100.3	101.3	101.8	99.0	99.9	100.7
100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.7	100.0	100.0
105	98.8	97.2	100.0	91.4	95.7	88.2	94.4	66.4	93.9	85.5
110	88.2	71.6	100.0	56.7	93.1	48.8	90.5	31.8	93.6	45.2
115	36.9	47.2	76.8	14.4	51.0	5.6	56.7	7.8	60.4	13.2
120	2.4	0.0	31.2	0.3	1.3	0.0	4.7	0.0	15.9	0.0
125	0.0	0.0	0.6	0.0	0.0	0.0	0.5	0.0	0.0	0.0
130	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The total dissolved gas saturation was monitored in the forebay and tailwater of each Lower Snake River dam throughout the spill season of 2008. The average hourly TDG saturation in the forebay of each Snake River dam increased in a downstream direction as listed in Table G4. The average forebay TDG saturation at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams were 102.6, 110.1, 112.2, and 113.5 percent, respectively. The frequency of exceeding 115 percent saturation in the forebay of the Snake River Dams ranged from 0 percent at Lower Granite Dam to a maximum of 33.8 percent at Ice Harbor Dam. The frequency of hourly TDG saturation exceeding 115 percent was also very high at Lower Monumental Dam at 32.2 percent during the 2008 fish passage season.

The average TDG saturation at the tailwater stations ranged from 116.6 percent at Lower Monumental Dam to 113.5 percent at Little Goose and Lower Granite Dams. The frequency of hourly TDG observations exceeding 120 percent at the tailwater monitoring stations ranged from a high of 21.6 percent below Lower Granite Dam to 10.6 percent at Little Goose Dam. The frequency of the forebay station exceeding the 115 percent criteria was greater than the frequency of the upstream tailwater station exceeding 120 percent which implies that forebay stations more frequently constrain spill operations on the Snake River than tailwater stations.

Table G4. Statistical Summary of Hourly Total Dissolved Gas Saturation at Fixed Monitoring Stations from April 1-August 31, 2008 on the Snake and Clearwater River									
Project	**Ice Harbor**		**Lower Monumental**		**Little Goose**		**Lower Granite**		**Dworshak**
Station	**IDSW**	**IHRA**	**LMNW**	**LMNA**	**LGSW**	**LGSA**	**LGNW**	**LWG**	**DWQI**
	TW (%)	**FB (%)**	**TW (%)**	**FB (%)**	**TW (%)**	**FB (%)**	**TW (%)**	**FB (%)**	**TW (%)**
N	**3660**	**3638**	**3648**	**3672**	**3667**	**3671**	**3672**	**3660**	**3671**
Avg	**115.8**	**113.5**	**116.6**	**112.2**	**113.5**	**110.1**	**113.5**	**102.6**	**103.5**
Stdev	**4.1**	**4.4**	**3.6**	**6.2**	**5.0**	**5.5**	**6.4**	**2.0**	**5.2**
Max	**135.1**	**124.8**	**128.6**	**130.9**	**129.5**	**126.5**	**134.8**	**108.6**	**115.0**
Min	**101.1**	**101.0**	**99.6**	**99.0**	**99.6**	**99.5**	**100.0**	**98.2**	**92.3**
100	**100.0**	**100.0**	**99.7**	**98.9**	**99.4**	**99.4**	**100.0**	**94.9**	**71.1**
105	**98.0**	**95.9**	**98.1**	**92.0**	**98.0**	**91.4**	**98.1**	**17.0**	**49.4**
110	**97.8**	**81.9**	**98.0**	**58.7**	**77.6**	**35.2**	**70.8**	**0.0**	**4.8**
115	**51.0**	**33.8**	**74.9**	**32.2**	**34.5**	**21.1**	**25.8**	**0.0**	**0.0**
120	**13.4**	**5.8**	**13.5**	**11.7**	**10.6**	**7.8**	**21.6**	**0.0**	**0.0**
125	**1.9**	**0.0**	**1.5**	**3.4**	**2.2**	**0.9**	**7.8**	**0.0**	**0.0**
130	**0.4**	**0.0**	**0.0**	**0.4**	**0.0**	**0.0**	**2.2**	**0.0**	**0.0**

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 the descriptive statistics of mean, minimum, maximum, standard deviation, and the confidence limits for the following percentiles: 5, 10, 25, 50, 75, 90, and 95 percent. Table G5 and G7 describe the predictive errors statistics in mm Hg of pressure while Table G6 and G8 describe the predictive errors in percent saturation. The prediction error was calculated by subtracting the calculated TDG level from the observed value ($TDG_{error}=TDG_{obs}-TDG_{cal}$). A prediction error with a negative sign indicates the calculated value was larger than the observed value.

Camas/Washougal (CWMW)
A hind cast of Bonneville operations were simulated using the SYSTDG model for the river reach from Bonneville Dam to the fixed monitoring station located at Camas/Washougal (CWMW) from 1 April through 31 August 2008. The predictive error of the hourly total dissolved gas pressure was determined throughout the interval involving 3627 observations. The calculated TDG pressures under-estimated observed conditions by an average of 6.6 mm Hg (average predictive error +6.6mm Hg) and the standard deviation of the predictive error was 10.4 mm Hg as listed in Table G5. The size of the predictive error in 2008 at CWMW was slightly greater than determined in 2007 due to the wider range in project operations (standard deviation of the predictive error was 9.5 mm Hg in 2007). The low flow and tailwater conditions during the month of August resulted in the largest errors in TDG saturation at the CWMW gauge. The influence of the Bonneville 2nd powerhouse corner collector outfall was likely the source for the under prediction of the TDG loading at Bonneville Dam. The 50 percent

confidence interval for the predictive error ranged from +13.2 to -1.2 mm Hg of pressure and the 80 confidence interval ranged from +20.8 to -5.0 mm Hg. The seasonal time history of observed and calculated TDG pressures at the CWMW gage is shown in Figure G2. There were instances where the TDG saturation at the CWMW exceeded the TDG criteria of 115% of saturation in each of the months of spill. The excursions during the first two months of the year were often related with elevated background TDG levels. The excursions during the summer months were associated mainly with spill to capacity directives during the nighttime hours.

For most of the study period, there were small differences in the observed and calculated TDG pressures at the CWMW gage resulting from spillway operations as shown throughout the month of May in Figure G3. A strong daily TDG variation was evident in these records caused in part by the thermal exchange that is evident throughout this shallow open river reach even during May. The contribution of TDG loading from the Bonneville 2nd powerhouse corner collector (B2CC) outfall becomes more important during the lower total river flow conditions in July and August. The estimated TDG saturation generally underestimated the observed conditions during the late summer month even with the more prominent TDG contributions from the B2CC. In summary, the predictive error was generally relatively small at the CWMW station with 50 percent of the predictive error in TDG pressure ranging from -0.2 to 1.7% and 80 percent of the errors in TDG pressure ranging from -0.7 to 2.7% as listed in Table G6. The influence of thermal cycling in the Columbia River is more prominent in the reach below Bonneville Dam than in upstream reaches and can significantly impact the daily TDG metrics used to determine compliance with state water quality standards.

Table G5. Statistical summary of the predictive errors of the observed and calculated total dissolved gas pressures at forebay fixed monitoring station, April 1-August 31, 2008.									
Parameters		**Predictive Error at Forebay FMS* (mmHg)**							
Station		**LGSA**	**LMNA**	**IHRA**	**MCNA**	**JDY**	**TDA**	**BON**	**CWMW**
Number of		3522	3638	3638	3672	3672	3670	3646	3627
Average		-5.5	0.8	-1.4	-0.5	6.8	-6.1	4.1	6.6
Standard Deviation		16.2	12.3	9.8	11.0	12.8	12.2	7.4	10.4
Maximum		34.0	39.6	29.4	33.8	72.5	45.0	38.7	44.9
Minimum		-68.3	-33.2	-35.5	-61.9	-13.1	-70.5	-11.4	-17.5
TDG Predictive Error for Percentile Occurrence (mm Hg)	**5%**	-37.5	-18.6	-18.3	-17.4	-8.0	-27.8	-6.8	-7.2
	10%	-29.4	-14.7	-14.6	-12.6	-6.0	-23.4	-5.0	-5.0
	25%	-12.3	-7.9	-7.8	-6.1	-2.5	-13.7	-1.4	-1.2
	50%	-3.0	0.2	-0.4	-0.3	4.0	-3.1	3.2	4.6
	75%	4.3	8.6	5.7	6.0	13.0	1.9	8.5	13.2
	90%	13.0	16.4	9.8	12.8	22.4	6.4	14.5	20.8
	95%	18.0	22.3	12.6	16.5	30.8	10.6	17.4	25.9
*Predictive error is the observed minus calculated TDG pressure 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 1 April through 31 August 2008, in an effort to determine the prediction error of SYSTDG simulations 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 from January 1 to April 30 during part of the 2008 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 away from the channel bank. 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 4.3 mm Hg (average predictive error +4.3 mm Hg) and the standard deviation of the predictive error was 10.2 mm Hg as listed in Table G7. The 50 confidence interval of the predictive error ranged from -0.1 to 10.1 mm Hg of pressure and the 80 confidence interval ranged from -5.2 to 14.1 mm Hg of pressure. The standard error of TDG pressure at the WRNO station during the 2008 season was slightly larger than determined in 2007 (10.2 to 8.9 mm Hg). The seasonal time history of observed and calculated TDG pressures at the WRNO gage is shown in Figure G4. The daily TDG values at Warrendale are a function of both the TDG levels associated with spillway operations at Bonneville Dam and the TDG levels produced at upstream dams and discharged through both powerhouses at Bonneville Dam. The calculated and observed TDG pressures at WRNO are shown throughout the month of April in Figure G5. The TDG saturation never exceeded 120 percent at WRNO during the 2008 fish passage season because of the influence of the dilution of spillway flows by powerhouse flows and limited sampling period. However, the TDG levels exceeded 115 percent over 47.2 percent of the time as compared to 36.9 percent observed at CWMW.

Table G6. Statistical summary of the predictive errors of the observed and calculated total dissolved gas saturation at forebay fixed monitoring station, April 1-August 31, 2008.

		Predictive Error at Forebay FMS* (Saturation %)							
Station		**LGSA**	**LMNA**	**IHRA**	**MCNA**	**JDY**	**TDA**	**BON**	**CWMW**
Number of		3522	3637	3637	3671	3671	3670	3646	3627
Average		-0.4	0.5	0.1	0.2	1.2	-0.8	0.5	0.9
Standard Deviation		2.2	1.7	1.3	1.5	1.7	1.6	1.0	1.4
Maximum		4.9	5.7	4.2	4.8	10.0	5.9	5.1	5.9
Minimum		-8.8	-4.2	-4.3	-8.0	-6.6	-9.2	-1.5	-2.3
Predictive Error for Percentile Occurrence (mm	**5%**	-4.7	-2.2	-2.1	-2.0	-0.7	-3.7	-0.9	-0.9
	10%	-3.6	-1.6	-1.6	-1.4	-0.4	-3.1	-0.7	-0.7
	25%	-1.3	-0.7	-0.7	-0.5	0.1	-1.8	-0.2	-0.2
	50%	-0.1	0.4	0.3	0.2	0.9	-0.4	0.4	0.6
	75%	0.9	1.5	1.1	1.1	2.1	0.2	1.1	1.7
	90%	2.1	2.6	1.7	2.0	3.3	0.8	1.9	2.7
	95%	2.7	3.4	2.0	2.5	4.4	1.4	2.3	3.4

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

<u>Bonneville Dam Spillway Exit Channel (CCIW)</u>

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 spillway exit channel on the bank of Cascade Island (CCIW) from 1 April through 31 August 2008. There were substantial differences between the calculated and observed TDG pressures in the spillway exit channel. These TDG estimates reflect conditions in spillway releases undiluted from powerhouse flows and average conditions exiting the spillway channel. The high TDG levels prior to spill in April were associated with the TDG loading of the adult fish ladders discharging into the spillway exit channel. The calculated mean error of TDG pressures was equal to 0.2 and the standard deviation of the predictive error was 18.0 mm Hg as listed in Table G7 under the label of CCIW. The 50 confidence interval for the predictive error ranged from 1.2 to 9.9 mm Hg of pressure and the 80 confidence interval ranged from -35.8 to 15.1 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the CCIW gage are shown in Figure G6. It should be noted that the calculated TDG pressures over-estimated the observed values during the higher spillway discharges in the summer. The estimates of TDG saturation in the Bonneville exit channel were based on the cross sectional average TDG pressures as determined during the 2002 TDG exchange study conducted at Bonneville (Schneider, 2003). This study determined that for spill discharges higher than 120 kcfs, TDG pressures observed near the CCIW station underestimated the cross sectional average TDG saturation in the spillway exit channel. The sample bias is considerable at CCIW and estimated average TDG saturation can fall as much as 50 mm Hg above the observed conditions. 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 during nighttime spill in the summer. A detailed summary of calculated and observed TDG pressures in spill at the CCIW gage during May 2008 is shown in Figure G7.

Table G7. Statistical summary of the predictive errors of the observed and calculated total dissolved gas pressures at tailwater fixed monitoring stations, April 1-August 31, 2008.

Parameters		Predictive Error at Tailwater FMS* (mm Hg)									
		DWQI	**LGNW**	**LGSW**	**LMNW**	**IDSW**	**MCPW**	**JHAW**	**TDDO**	**CCIW**	**WRNO**
Number of		2013	3149	2561	2794	2149	1816	1462	3672	2658	741
Average		-7.3	5.2	3.8	4.2	-2.4	-0.5	0.6	-0.6	0.2	4.3
Standard Deviation		14.3	11.3	9.4	14.7	6.8	7.8	11.9	9.9	18.0	10.2
Maximum		72.5	45.9	48.6	60.1	20.2	30.0	34.8	47.3	39.1	36.6
Minimum		-74.5	-23.0	-47.4	-41.0	-26.2	-26.3	-24.3	-55.8	-64.5	-60.7
TDG Predictive Error for Percentile Occurrence (mm Hg)	**5%**	-23.1	-11.4	-10.3	-15.7	-14.2	-12.9	-15.8	-16.5	-40.6	-9.1
	10%	-20.1	-8.9	-5.1	-11.2	-10.7	-10.8	-13.7	-10.4	-35.8	-5.2
	25%	-15.7	-1.7	-0.4	-4.7	-6.2	-6.0	-10.3	-5.0	1.2	-0.1
	50%	-11.0	4.6	4.0	1.8	-2.3	-0.2	-0.4	0.0	5.3	4.9
	75%	1.5	10.1	8.8	9.3	1.4	4.7	11.1	4.5	9.9	10.1
	90%	14.9	19.0	13.8	26.5	6.1	9.7	16.5	9.1	15.1	14.1
	95%	16.9	27.6	17.9	35.8	9.6	11.8	20.0	12.5	20.2	17.2

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

The observed and calculated TDG pressure in the spillway exit channel during the 2008 spill season as a function of spill discharge are shown in Figure G8. The observed TDG pressure reached a maximum level for a spill of 130 kcfs and did not increase during the higher spillway flows. The calculated TDG response in the exit channel is a linear relationship with spill discharge and is also influenced by the tailwater channel depth of flow. The tailwater spill capacity as limited by TDG saturation of 120 percent was observed to fall below levels seen in previous years at Bonneville Dam because of the high total river flow and associated tailwater elevation during much of the 2008 spill season. The estimates of TDG pressure at the Camas/Washougal FMS during August of 2008 were unexpectedly larger than seen in previous years. The low tailwater elevations may have resulted in higher TDG generation associated with the Bonneville second powerhouse corner collector outfall. The low tailwater elevations generate a prominent plunging flow that entrains air into the constructed plunge pool with a minimum elevation of -70 ft.

Table G8. Statistical summary of the predictive errors of the observed and calculated total dissolved gas saturations at tailwater fixed monitoring stations, April 1-August 31, 2008.											
Parameters		**Predictive Error at Tailwater FMS* (Saturation %)**									
		DWQI	**LGNW**	**LGSW**	**LMNW**	**IDSW**	**MCPW**	**JHAW**	**TDDO**	**CCIW**	**WRNO**
Number of Observations		2013	3149	2561	2794	2149	1816	1462	3672	2658	741
Average		-1.0	0.7	0.5	0.6	-0.3	-0.1	0.1	-0.3	-0.2	0.2
Standard Deviation		2.0	1.5	1.3	2.0	0.9	1.0	1.6	1.3	2.4	1.3
Maximum		9.9	6.2	6.5	7.9	2.7	4.0	4.6	5.9	4.9	4.4
Minimum		-10.3	-3.1	-6.3	-5.5	-3.5	-3.5	-3.2	-7.3	-8.8	-8.1
TDG Predictive Error for Percentile Occurrence (mm Hg)	**5%**	-3.1	-1.5	-1.4	-2.1	-1.9	-1.7	-2.1	-2.4	-5.6	-1.6
	10%	-2.7	-1.2	-0.7	-1.5	-1.4	-1.4	-1.8	-1.6	-5.0	-1.1
	25%	-2.1	-0.2	-0.1	-0.6	-0.8	-0.8	-1.4	-0.9	-0.1	-0.4
	50%	-1.5	0.6	0.5	0.2	-0.3	0.0	-0.1	-0.2	0.5	0.3
	75%	0.2	1.4	1.2	1.2	0.2	0.6	1.5	0.4	1.1	0.9
	90%	2.0	2.6	1.9	3.5	0.8	1.3	2.2	1.0	1.8	1.4
	95%	2.3	3.7	2.4	4.8	1.3	1.6	2.6	1.5	2.4	1.9
*Predictive error is the observed minus calculated TDG saturation where negative values reflect an overestimation and positive values reflect an underestimation.											

Bonneville Dam Forebay (BON)

Estimates of TDG pressures in the forebay of Bonneville Dam have been one of the more reliable locations in the study area. 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 slightly under-estimated observed conditions by an average of 4.1 mm Hg (average predictive error +0.5 percent saturation) and the standard deviation of the predictive error was 7.4 mm Hg as listed in Table G5. The 50 confidence interval for the predictive error ranged from -1.4 to 8.5 mm Hg of pressure and the 80 confidence interval ranged from -5.0 to 14.5 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the BON gage are shown in Figure G9. 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. Currently, the wind field observed from The Dalles municipal airport is applied uniformly throughout this river reach to estimate the rate of degassing.
The calculated and observed TDG pressures at BON are shown throughout the month of May in Figure G10. The tendency for lower TDG conditions during the summer months at Bonneville Dam are related to the longer travel time from The Dalles Dam and the change in spill policy at John Day Dam in mid July.

The Dalles Dam Tailwater (TDDO)

The SYSTDG estimates of TDG pressure at the The Dalles tailwater FMS (TDDO) during the 2008 spill season were typically dependable within +/- 1.5% saturation. 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 4 hours, due to the travel time, in making this comparison. The calculated TDG pressures over-estimated observed conditions by an average of -0.6 mm Hg and the standard deviation of the predictive error was 9.9 mm Hg as listed in Table G7. The 50 percent

confidence interval of predictive error ranged from -5.0 to 4.5 mm Hg of pressure and the 80 percent confidence interval ranged from -10.4 to
9.1
mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the TDDO gage are shown in Figure G11. The TDG saturation at the tailwater station TDDO infrequently exceeded the TDG standard of 120 percent because of the influence of the TDG content in powerhouse releases. 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 June in Figure G12. The tailwater station at The Dalles Dam is influenced by both powerhouse and spillway flows. The estimated TDG pressures contained in spillway flows undiluted from powerhouse flow (dark blue SP Cal) consistently exceeded 120 percent of saturation as shown in Figure G13. The TDG estimate in spill at The Dalles Dam has been found to be a simple linear function of the effective tailwater depth of flow. The tailwater elevation is directly related to both The Dalles Dam total discharge and the pool elevation established by Bonneville Dam. The TDG exchange at The Dalles Dam has not been found to be sensitive to spill within or outside of the spillway training wall located between bays 6 and 7. The calculated and observed TDG pressure at the The Dalles tailwater FMS as shown in Figure G14. The wide range of TDG values for a given spill discharge reflects the wide range of forebay TDG levels contributed by the powerhouse.

The Dalles Dam Forebay (TDA)

A simulation was conducted from the John Day Dam to The Dalles Dam forebay from 1 April through 31 August to determine the predictive error of SYSTDG simulations in The Dalles Dam forebay during spill events at John Day Dam. This simulation was based on historic operation of the spillway and was not based on the addition of the temporary spillway weirs (TSW) on spill bays 15 and 16. The nighttime spill at John Day Dam lasted only a short time during the spring due to higher than normal river flows. The calculated average TDG pressures were generally larger than observed by an average of -6.1 mm Hg and the standard deviation of the predictive error was 11.9 mm Hg as listed in Table G5. The 50 percent confidence interval of the predictive error ranged from -13.7 to 1.9 mm Hg of pressure and the 80 percent confidence interval ranged from -23.4 to 6.4 mm Hg of pressure. The standard error of estimate in the forebay of The Dalles Dam was considerably greater than the standard error determined in the forebay of Bonneville Dam (12.2 versus 7.4 mm Hg). The seasonal time history of observed and calculated TDG pressures at the TDA gage are shown in Figure G15. The TDG saturation exceeded 115 percent about 5 percent of the time during the fish passage season. The calculated and observed TDG pressures at TDA are shown throughout the month of May in Figure G16. The SYSTDG model over-predicted the TDG pressures arriving at The Dalles Dam particularly during high spill events at John Day Dam. A powerhouse entrainment coefficient used by SYSTDG was increased to 0.75 based on the observed conditions throughout the month of April. However, this parameterization of entrainment flow over predicted the TDG loading at John Day Dam during the higher flows and spillway discharge during May and June. An entrainment coefficient of 0.35 is recommended for characterizing the TDG loading at John Day Dam based on a review of TDG data collected in the Columbia River downstream of John Day Dam during the 2008 spill season.

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 1 April through 31 August 2008. The structural configuration and spill pattern at John Day Dam was changed during the 2008 spill season incorporating two spill bays with temporary spillway weirs (TSW). The spill pattern called for higher discharges through these two spill bays. The relationship between TDG generation and spillway discharge at John Day Dam changed significantly during the 2008 compared to previous years. The TDG generation model maintained the same functional form but the spill pattern was altered resulting in a pattern where TDG pressures continuously increased as a function of spillway discharge. The pattern prior to 2008 consisted of an operating range where TDG was inversely related to spill discharge because the TDG generation decreased as the spill pattern transitioned from a bulk to a uniform pattern. There was a tendency for the SYSTDG model to underestimate the TDG pressure at the John Day Dam tailwater FMS during lower spill discharges. This under-estimation of TDG pressure may have resulted from the increasingly non-uniform spill pattern caused by the TSW's.
The calculated average TDG pressures reliably estimated the observed condition as evidenced by an average error of 0.6 mm Hg and the standard deviation of the predictive error was 11.9 mm Hg as listed in Table G7. The 50 percent confidence interval of the predictive error ranged from -10.3 to 11.1 mm Hg of pressure and the 80 percent confidence interval ranged from -13.7 to 16.5 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the JHAW gage are shown in Figure G17. The broad range in the night time river flow resulted in abrupt changes in the level of spill seen in the summary of spillway operations in May shown in Figure G18. The observed TDG pressure at the tailwater FMS below John Day Dam was directly related to spill discharge as shown in Figure G19. The short duration spill at 240 kcfs was repeated numerous times at John Day Dam during the 2008 spill season and maintained the general linear trend between TDG production and tailwater TDG saturation. The SYSTDG model faithfully predicted the TDG magnitude of this high discharge event.

John Day Dam Forebay (JDY)
The TDG pressures were simulated from McNary Dam to the John Day forebay from 1 April through 31 August in an effort to determine the predictive error of SYSTDG estimations in the John Day forebay during the fish passage season. The John Day pool is the longest river reach simulated and the travel time ranged from 3.0 to 10.0 days during the 2008 fish passage season. 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 6.8 mm Hg and the standard deviation of the predictive error was 12.8 mm Hg as listed in Table G5. The 50 percent confidence interval for the predictive error ranged from -2.5 to 13.0 mm Hg of pressure and the 80 percent confidence interval ranged from -6.0 to 22.4 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the JDY gage are shown in Figure G20. The duration that

forebay TDG saturation was greater than 115 percent at John Day Dam was much smaller than at Bonneville Dam. The lower forebay TDG levels at John Day Dam can be attributed to the long travel time and rate of off-gassing in John Day pool. The percent of river spilled at McNary Dam was among the highest in the Lower Columbia River but resulted in the lowest forebay TDG levels at John Day Dam. The rapid change in TDG pressures in the forebay of John Day Dam was 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 uncertainty in estimating 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 May in Figure G21. The peak observed TDG saturation at JDY on May 28 was grossly under-estimated by the SYSTDG model in this case. The under estimation of TDG pressures in the John Day Forebay during the 2008 fish passage season may also be related to the estimation of TDG exchange at McNary Dam with the temporary spillway weirs (TSW) in operation influencing both the entrainment of powerhouse flows and local generation of TDG saturation. The prediction of in-pool degassing in the John Day pool can be improved by applying a different weather station wind field and exchange coefficients. The weather data at The Dalles municipal airport was applied to the John Day pool in 2008. In the future, weather data from the Hermiston area should be used to estimate the off-gassing processes in the John Day pool.

<u>McNary Dam Tailwater (MCPW)</u>

The operation of two TSW's at McNary Dam and a revised spill pattern during the 2008 fish passage season resulted in a small change in TDG generation from previous conditions as monitored at the tailwater fixed monitoring station. The SYSTDG model was used to simulate the TDG exchange associated with spillway releases from McNary Dam throughout the 2008 spill season as shown in Figure G22. The 2008 spill pattern called for bulked releases at spillbays with the TSW in bays 19 and 20. The rated flow over the TSW was a function of the forebay elevation and was generally in excess of 10 kcfs. The calculated TDG pressures at station MCPW contained a minimal bias as evidenced by the mean error of only -0.5 mm Hg and a standard deviation of the predictive error was 7.8 mm Hg as listed in Table G7. The 50 percent confidence interval for the predictive error ranged from -6.0 to 4.7 mm Hg of pressure and the 80 percent confidence interval ranged from -10.8 to 9.7 mm Hg of pressure. The observed and calculated TDG pressures in the tailwater of McNary Dam are shown throughout the month of May in Figure G23. The TDG estimates tended to slightly under-estimate the TDG exchange when spill discharges dropped below 100 kcfs as shown in Figure G24. The inverse relationship between spill and TDG saturation at the tailwater FMS for spill flows less than 90 kcfs is probably caused by the greater influence of TDG generated from the high unit spillway releases at the TSW's during lower spill events. The spillway capacity as limited by a tailwater TDG criterion of 120 percent had a mean value of about 200 kcfs during the 2008 spill season.

McNary Dam Forebay (MCNA)

The TDG response at the McNary forebay was estimated by simulating the contributions from Priest Rapids Dam on the Columbia River at Pasco and Ice Harbor Dam on the Snake River. The spill policy at Priest Rapids Dam during 2008 called for considerably lower spill rates during voluntary spill flows than in previous years. In addition, the TDG loading introduced into McNary pool was further moderated by the degassing throughout the open river reach in the Hanford area. The spill policy at Ice Harbor Dam was cycled periodically throughout most of the 2008 spill season to accommodate biological testing. This operation introduced pulses or slugs of water with high TDG levels into McNary pool. The calculated mean error of TDG pressures in the forebay of McNary Dam of -0.5 mm Hg and the standard deviation of the predictive error was 11.0 mm Hg as listed in Table G5. The standard error was slightly larger in 2008 than determined in 2007 (11.0 versus 9.7 versus mm Hg). The 50 percent confidence interval for the predictive error ranged from -6.1 to 6.0 mm Hg of pressure and the 80 percent confidence interval ranged from -12.6 to 12.8 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 G25. The calculated and observed TDG pressures in the forebay of McNary Dam are shown in Figure G26 for the month of May.

Ice Harbor Dam Tailwater (IDSW)

The model of TDG production at Ice Harbor Dam resulted in the best agreement between observed and calculated TDG pressures. The spill policy at Ice Harbor Dam was varied throughout the 2008 fish passage season to accommodate biological testing of the removable spillway weir (RSW). Ice Harbor Dam spilled the highest percentage of total river flow of 58 percent of any project in the study area. The maximum spill discharge at Ice Harbor Dam in 2008 was 170 kcfs resulting in a tailwater TDG saturation of 135 percent which was the highest TDG saturation observed in the study area. The high rates of spill were related to the flow rates associated with the spring freshet on the Snake River in the third week of May. 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 exchange at Ice Harbor Dam was simulated from 1 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 mean predictive error of TDG pressure was -2.4 mm Hg and the standard deviation of the predictive error was 6.8 mm Hg as listed in Table G7. The 50 percent confidence interval of the predictive error ranged from -6.2 to 1.4 mm Hg of pressure and the 80 percent confidence interval ranged from -10.7 to 6.1 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the IDSW gage are shown in Figure G27. The calculated values tend to compare favorably to observed conditions throughout most of the year when spill rates are above 30 kcfs. The predictive error tended to be larger during the spill activities during late July and August. The daily variation in TDG pressures for observed and calculated conditions can be seen in Figure G28 for the month of May. The influence of tailwater elevation on TDG exchange can be noted in the range of TDG pressures as a function of spill discharge shown in Figure

G29. The range in TDG pressures of 885 to 915 mm Hg for a spill discharge of 90 kcfs is chiefly attributed to the variation in tailwater elevation. Ice Harbor Dam continues to have the smallest TDG uptake for a comparable spill discharge of any project on the Columbia or Snake Rivers. The spill capacity as limited by the 120 percent TDG saturation criterion was as high as 90 kcfs. The combination of spillway flow deflectors with a shallow tailwater channel are thought to account for this efficient TDG exchange property.

Ice Harbor Dam Forebay (IHRA)

A simulation was run from Lower Monumental Dam to the forebay of Ice Harbor Dam from 1 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 slightly over-estimated observed conditions by an average of -1.4 mm Hg and the standard deviation of the predictive error was 9.8 mm Hg as listed in Table G5. The 50 percent confidence interval for the predictive error ranged from -7.8 to 5.7 mm Hg of pressure and an 80 percent confidence interval ranged from -14.6 to 9.8 mm Hg of pressure. The estimates of forebay conditions at Ice Harbor Dam tended to closely approximate observed conditions during the spring and early summer and began to diverge during the late summer as shown in Figure G30. The observed and calculated TDG pressures in the forebay of Ice Harbor are shown in Figure G31 throughout May. The variation in TDG saturation in the forebay of Ice Harbor Dam is related to the variation in percent of river spilled at Lower Monumental Dam and the influence of wind/wave generated degassing events. The forebay TDG levels at Ice Harbor Dam did experience excursions above the TDG standard of 115% during April through July. The frequency of hourly TDG supersaturation above 115 percent at the Ice Harbor forebay station was the highest of the four Snake River projects. The spill policy at Lower Monumental Dam (bulk spill pattern) resulted in the hourly TDG saturation in the Ice Harbor forebay to exceed 115% over 33.8 percent of the time.

Lower Monumental Dam Tailwater (LMNW)

The SYSTDG model for Lower Monumental Dam tailwater produced the highest standard error of projects modeled on the Snake River. The estimates typically under-estimated the TDG saturation observed at the tailwater FMS. The complexities in the TDG exchange characteristics include the application of multiple spill patterns and the entrainment of powerhouse flows into spillway flows. The scheduling of a bulk spill pattern resulted in higher TDG pressures when compared with the standard spill pattern. The SYSTDG model was applied to simulate the TDG levels produced from spill operations at Lower Monumental Dam from 1 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 mean TDG pressures under-estimated observed conditions by an average of 4.2 mm Hg and the standard deviation of the predictive error was 14.7 mm Hg as listed in Table G7. The 50 percent confidence interval for the predictive error ranged from -4.7 to 9.3 mm Hg of pressure. The 90 percent confidence interval for the predictive error ranged from -11.2 to 26.5 mm Hg of pressure. The daily variation of TDG pressures at the tailwater FMS below Lower Monumental Dam are shown in Figure G32. There was a tendency for calculations to under-estimate the TDG exchange associated with high spillway releases. The hourly observed and calculated TDG pressures at the tailwater FMS (LMNW) are shown in Figure G33 for the month of May. This figure shows a general agreement between the observed and calculated TDG response at LMNW for voluntary spillway flows the first half of May, before forced spillway flows began (due to freshet). The different TDG production for alternative spill patterns can be seen during the first two and one-half weeks in May where the TDG pressure increases about 50 mm Hg as the spill pattern is switched from a uniform pattern to a bulk spill pattern. The observed and calculated TDG pressure in the tailwater of Lower Monumental Dam is shown in Figure G34 for spill events with a duration of 3 hours or longer. The TDG production model consists of the product of the effective depth of flow and the exponential function of unit spillway discharge. The large variance in TDG pressure was under-estimated by the model shown in Figure G34. An alternative TDG production formulation was developed consisting of the power function of tailwater depth of flow and the specific spillway discharge. The observed and calculated TDG pressure associated with the power function formulation is shown in Figure G35. This model captures the wider range in TDG production during voluntary spill conditions as well as reproducing the higher TDG pressures generated during the forced spillway flows.

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 1 April through 31 August as shown in Figure G36. The TDG saturation in the forebay of Lower Monumental Dam during May exceeded the TDG saturation observed in the tailwater of Little Goose Dam. The local maximum TDG saturation in the tailwater of Little Goose Dam likely occurred away from the tailwater fixed monitoring station during this period of spill exceeding 100 kcfs. The high forebay TDG pressure at Little Goose Dam may have also contributed to these high TDG levels transported through Lower Monumental pool and exceeding 125 percent of saturation. On average the calculated TDG pressures closely matched observed conditions as evidenced by the mean error of 0.8 mm Hg. However the standard deviation of the predictive error was 12.3 mm Hg as listed in Table G5. The 50 percent confidence interval for the predictive error ranged from -7.9 to 8.6 mm Hg of pressure and the 80 confidence interval ranged from -14.7 to 16.4 mm Hg of pressure. The under-estimation of TDG pressure during the summer is likely attributed to under-prediction of TDG generation at Little Goose Dam. The peak forebay TDG saturation was under-estimated by the model by 20-30 mm Hg at Little Goose Dam during the 2008 spill season. The daily variation of TDG pressures for the month of May at the forebay FMS above Lower Monumental Dam are shown in Figure G37.

Little Goose Dam Tailwater (LGSW)

The 2008 spill patterns at Little Goose Dam consisted of three distinct spill patterns. The bulk spill pattern generated significantly higher TDG levels when compared to the uniform pattern. The TDG saturation at Little Goose Dam tailwater is approximated best as a function of forebay TDG levels and TDG levels estimated in spill. At higher spill discharges the TDG saturation in the tailwater approaches the TDG saturation generated in aerated spill. A TDG simulation was conducted from Little Goose Dam to Lower Monumental Dam from 1 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 bulk project releases were subtracted from the tailwater fixed monitoring station (LGSW) TDG data to estimate the predictive error by the model as shown in Figure G38. The calculated TDG pressures under-estimated observed conditions by an average of 3.8 mm Hg and the standard deviation of the predictive error was 9.4 mm Hg as listed in Table G7. The 50 percent confidence interval ranged from -0.4 to 8.8 mm Hg of pressure and the 80 percent confidence interval ranged from -5.1 to 13.8 mm Hg of pressure.

The entrainment of powerhouse flows into spillway releases at Little Goose Dam is amplified because of the large depth of the stilling basin and skimming spillway discharge jet located adjacent to the powerhouse. The interpretation of the observed TDG response at the tailwater FMS is closely related to the near field circulation patterns and prominent interaction of powerhouse and spillway flows. The calculated and observed tailwater TDG pressures below Little Goose Dam during the month of May are shown in Figure G39. The spillway discharge ranged from 15 to 130 kcfs during the month of May with the maximum TDG pressures of ranging from 820 to 960 mm Hg.

The observed and calculated TDG saturation at the tailwater FMS as a function of the spillway discharge for 2008 is shown in Figure G40. The TDG production relationship is slightly under estimated at high spillway discharges. The observed and calculated TDG pressures increase at a decreasing rate with increasing spillway discharge.

<u>Little Goose Dam Forebay (LGSA)</u>
SYSTDG was used to hind cast the TDG pressures in Little Goose pool in response to operations at Lower Granite Dam from 1 April 31 August. The elevated TDG levels in the forebay of Little Goose Dam as shown in Figure G41 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 of dissolved gasses with the atmosphere. The average calculated TDG pressure was generally greater than observed conditions with an average predictive error of -5.5 mm Hg and the standard deviation of the predictive error was 16.2 mm Hg as listed in Table G5. The 50 percent confidence interval ranged from -12.3 to 4.3 mm Hg of pressure and the 80 percent confidence interval ranged from -29.4 to 13.0 mm Hg of pressure. The standard error of TDG pressures in the forebay of Little Goose Dam was the largest of all the forebay stations in the study area. The calculated and observed tailwater TDG pressures in the forebay of Little Goose Dam during the month of May are shown in Figure G42. The peak TDG events were overestimated upon arriving at the forebay of Little Goose Dam having undergone a significant reduction in TDG pressure in route.

<u>Lower Granite Dam Tailwater (LGNW)</u>
The spillway operations at Lower Granite Dam during 2008 resulted in tailwater TDG saturations exceeding 125 percent of saturation over 7.8 percent of the time, the highest

of any project in the study area. The high TDG generation at Lower Granite Dam during the 2008 spill season was caused in part by the limited powerhouse capacity of 70 kcfs during the high flows in May and early June. The voluntary spill policy at Lower Granite Dam during the 2008 fish passage season called for a continuous spill of 20 kcfs during the spring and 18 kcfs during the summer. The TDG levels associated with spillway releases from Lower Granite Dam were simulated from the 1 April through 31 August as shown in Figure G43. The calculated TDG pressures under-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 11.3 mm Hg as listed in Table G7. The 50 percent confidence interval for the predictive error ranged from -1.7 to 10.1 mm Hg of pressure and the 80 percent confidence interval ranged from -8.9 to 19.0 mm Hg of pressure. The TDG saturation during the month of May is shown in Figure G44 at the Lower Granite Dam tailwater FMS LGNW. The predicted TDG pressure closely tracked the observed TDG pressure below Lower Granite Dam during the 2008 spill season. The peak spillway discharge of 144 kcfs caused a TDG saturation of about 135 percent. The peak TDG saturation generated at Lower Granite Dam experienced a significant reduction traveling in Little Goose pool unlike the conditions transported through Lower Monumental pool. The spillway operations at Lower Granite Dam featured the prominent use of the removable spillway weir and training spill uniformly distributed over spill bays 2-8. Lower Granite Dam generated TDG saturations exceeding 130 percent at much smaller spill discharges than at Ice Harbor Dam as shown in Figure G45. A non-linear relationship was apparent between tailwater TDG pressure and spill discharge at Lower Granite Dam with estimates slightly over-predicting the TDG production during high spill events.

Dworshak Dam Tailwater (DWQI)

Spillway and regulating releases were the rule at Dworshak Dam during the 2008 spill season. The TDG saturation observed at the tailwater FMS did not exceed 115 percent of saturation and exceeded 110 percent only 4.8 percent of the time. There was a tendency for regulating releases to generate slightly higher TDG pressures than comparable spillway flow. The mixing zone between powerhouse flow and spill is well developed at the tailwater FMS in the North Fork of the Clearwater River. The TDG content in RO flow of 2.2 kcfs was estimated to exceed 120% prior to mixing with powerhouse release. The TDG pressures in the tailwater channel below Dworshak Dam were simulated during the 2008 spill season as shown in Figure G46. The calculated TDG pressures over-estimated observed conditions by an average of 7.3 mm Hg (average predictive error -7.3 mm Hg) and the standard deviation of the predictive error was 14.3 mm Hg as listed in Table G7. The 50 percent confidence interval for the predictive error ranged from -15.7 to 1.5 mm Hg of pressure and the 80 confidence interval ranged from -20.1 to 14.9 mm Hg of pressure. The predictive error for TDG pressures in the tailwater of Dworshak Dam were the highest of all the projects included in this analyses. 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 estimation of the forebay TDG pressure is probably a significant component of the predictive error since powerhouse releases constitute most of the TDG load observed at the tailwater station. 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 observed and calculated TDG pressures in the tailwater of Dworshak Dam are shown in Figure G47 for the month of June. The frequent change in operations and spill discharge cause a corresponding change in TDG pressure in the Clearwater River. The estimated TDG pressure associated with the peak spillway discharge of 7.2 kcfs was predicted to reach about 134% of saturation which is close to the highest TDG level observed in this study area. The observed and calculated TDG pressures in the tailwater of Dworshak Dam are shown in Figure G48 as a function of spillway discharge. The lack of a consistent trend between spillway discharge and TDG pressure is caused by the influence of the TDG content in powerhouse flows and variation in percent of river spilled at Dworshak Dam.

Comparison of 2007 and 2008 Simulations

The performance of the SYSTDG decision support system as measured by the hourly predictive error statistics at fixed monitoring stations during the 2008 spill season was in some cases better and worse than the performance observed during the 2007 fish passage season. The wide range of both voluntary and forced spill operations in 2008 was in contrast to lower river flow rates during the 2007 spill season. The movement of TSW operation at McNary Dam in 2008 involved a structural modification to spillway releases which likely influenced both TDG exchange and entrainment of powerhouse flows. 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. In general the standard error of estimates between tailwater stations and forebay stations were nearly the same for conditions modeled in 2008. The data at the tailwater station were filtered by duration of spill in this year's analysis to generate a more meaningful estimate of the predictive error at tailwater stations. The standard deviation of the predictive errors in 2007 ranged from 5.2 to 18.1 mm Hg at fixed monitoring stations. In 2008, the standard deviation of the predictive errors at fixed monitoring stations ranged from 6.8 to 16.2 mm Hg. Significant improvements in predicting TDG pressures at tailwater stations were achieved at Little Goose and McNary Dams. The standard deviation of the predictive error at the tailwater station below Little Goose Dam (LGSW) was reduced from 16.4 mm Hg in 2007 to 9.4 mm Hg during the 2008 season. The degree of improvement at the McNary tailwater gauge MCPW as measured by the standard deviation of the predictive error fell from 17.8 mm Hg in 2007 to 7.8 mm Hg in 2008. There were several stations where the predictive errors were considerably greater in 2008 compared to 2007. The standard deviation of the predictive error in the tailwater of Bonneville Dam increased from 9.4 mm Hg in 2007 to 18.0 mm Hg in 2008. The source of the larger standard deviation of the predictive error was associated with the sampling bias at CCIW and was not indicative of a TDG loading error. The prediction errors at Dworshak tailwater station DWQI almost tripled from 5.2 mm Hg in 2007 to 14.3 mm Hg in 2008. The mixing of powerhouse flows with variable TDG levels with spillway releases was likely the cause for the increase in the hourly prediction errors at the tailwater fixed monitoring station.

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 2008 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 in 2008 were characterized by forced spill conditions during much of May and June and by voluntary spill operations throughout the remainder of the year. The operational policy involving spilling water on the Snake and Lower Columbia Rivers during the summer months was continued in 2008 with TDG levels generally within the state water quality standards for TDG during the fish passage season. The spill patterns were modified at a number of projects in 2008 season to evaluate benefits to fish guidance. These unique operations resulted in conditions outside of the normal operating range under which the SYSTDG model was developed. The predictive error was computed by subtracting the hourly estimates of TDG pressure from observed conditions.

In general, the predictive errors at the forebay station (Tables G5 and G6) were similar to errors estimated at tailwater stations (Tables G7 and G8). The average predictive errors at forebay stations were less than 1 percent of saturation with the exception of John Day Dam. The overestimation of forebay TDG pressures at John Day Dam was attributed to misrepresenting either the production of TDG conditions at McNary Dam or the dissipation rate during transport to John Day Dam. The correlation between strong winds and declining TDG pressure at forebay stations was again evident during the 2008 spill season. In several reaches, the considerations of alternative weather station data for wind may improve the estimation of TDG off-gassing during passage through a given river reach.

The largest average predictive error determined at a tailwater FMS was observed below Dworshak Dam. The lack of a forebay FMS at Dworshak contributed to the biased estimates of TDG pressure in the tailwater at Dworshak Dam. The errors in predicting TDG saturation below a spillway are 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 spill pattern operations. The standard deviation of predictive error at the tailwater stations ranged from 6.8 mm Hg at Ice Harbor Dam tailwater station (IHRW) to 18.0 mm Hg at the Bonneville tailwater station (CCIW). The large standard errors below Bonneville Dam result from biased observed values at higher spill rates.

The TDG production characteristics observed at Bonneville Dam tailwater station (CCIW) during the 2008 spill season were highly non-linear with little change in TDG saturation for spill rates above 130 kcfs. The SYSTDG model over estimated the TDG response at the CCIW station during higher spillway flows. The model estimates were based on the average cross sectional response observed in the spillway exit channel during sampling in 2002. The sampling bias underestimating the TDG loading at CCIW during higher flows during the 2002 study is likely to be present under existing conditions because the spill pattern has not changed for flows above 100 kcfs since 2002. The higher production of TDG saturation predicted by the model was consistent with TDG levels observed downstream in the Columbia River. The tailwater spill capacity as limited by TDG saturation of 120 percent was observed to fall below levels seen in previous years at Bonneville Dam because of the high total river flow and associated tailwater elevation during much of the 2008 spill season. The estimates of TDG pressure at the Camas/Washougal FMS during August of 2008 were unexpectedly larger than seen in previous years. The low tailwater elevations may have resulted in higher TDG generation associated with the Bonneville second powerhouse corner collector outfall.

The TDG predictions at The Dalles Dam and throughout the Bonneville pool proved to be one of the more reliable reaches in the study area. The standard error observed at the Dalles tailwater station was estimated to be 9.9 mm Hg while the corresponding standard error in the forebay of Bonneville Dam was only 7.4 mm Hg. The cause for the poorer estimates of tailwater TDG levels compared to downstream estimates in the forebay of Bonneville Dam were likely associated with the greater occurrence of abrupt changes in TDG pressure caused by operation changes at the tailwater station. It is important to recognize that the tailwater FMS below The Dalles Dam resides in mixed waters influenced by both powerhouse and spillway flows when interpreting the overall system impact on TDG loading in the Lower Columbia River. It should be noted that the estimated TDG content in spill water undiluted from powerhouse flows remained well above 120% for the duration of the fish passage season. The higher river flows during 2008 resulted in spill at The Dalles Dam exceeding 126 kcfs requiring spill bays outside of the spillwall (bays 1-6) being active about 25 percent of the time. There was no indication that the TDG generation properties at The Dalles Dam changed noticeably during these spill patterns.

The structural configuration and spill pattern at John Day Dam was changed during the 2008 spill season incorporating two spill bays with TSW's. The spill pattern called for higher discharges through these two spill bays. The relationship between TDG generation and spillway discharge at John Day Dam changed significantly during the 2008 compared to previous years. The TDG generation model maintained the same functional form but the spill pattern was altered resulting in a pattern where TDG pressures continuously increased as a function of spillway discharge. The pattern prior to 2008 consisted of a range of spill discharge where the TDG generation decreased as the spill pattern transitioned from a bulk to a uniform pattern. There was a tendency for the SYSTDG model to underestimate the TDG pressure at the tailwater FMS during lower spill discharges. This under-estimation of TDG pressure may have resulted from the increasingly non-uniform spill pattern caused by the TSW's. The SYSTDG model over-predicted the TDG pressures arriving at The Dalles Dam particularly during high spill events at John Day Dam. An entrainment coefficient used by SYSTDG was increased to 0.75 based on the observed conditions throughout the month of April. However, this parameterization of entrainment flow over predicted the TDG loading at John Day Dam during the higher flows and spillway discharge during May and June. An entrainment coefficient of 0.35 is recommended for characterizing the TDG loading at John Day Dam based on a review of TDG data collected in the Columbia River downstream of John Day Dam during the 2008 spill season.

The operations at McNary Dam involved spilling water through a couple of TSW's throughout the entire fish passage season. The location of these structures changed in 2008 being located in spill bays 19 and 20. The spillway capacity as limited by the tailwater TDG saturation of 120 percent was observed to be slightly higher at about 180 kcfs during 2008 when compared to conditions in 2006. The TDG levels at the tailwater station increased in magnitude when spill levels dropped below 80-90 kcfs. This property was likely related to the mixing zone from the TSW releases reaching the north shore during lower spillway discharges. McNary Dam spilled more water than any project except Bonneville Dam on the Columbia River in 2008. The TDG estimates in the forebay of John Day Dam were systematically underestimated during the 2008 spill season. The mean and standard error in the forebay of John Day Dam were 6.8 and 12.8 mm Hg, respectively. The time of travel in John Day pool is the longest of any of the reaches modeled in this investigation. This long duration can amplify errors associated with wind driven degassing. The prediction of in-pool degassing in the John Day pool can be improved by applying a different weather stations wind field and exchange coefficients. The weather data at The Dalles municipal airport was applied to the John Day pool in 2008. In the future, weather data from the Hermiston area should be used to estimate the off-gassing processes in the John Day pool.

The SYSTDG model of Ice Harbor TDG generation as observed at the tailwater FMS had the smallest standard error of any of the projects studied. Ice Harbor Dam continues to have the smallest TDG uptake for a comparable spill discharge of any project on the Columbia or Snake Rivers. Ice Harbor Dam spilled the highest percentage of total river flow of 58 percent of any project in the study area. The spill capacity as limited by the 120 percent TDG saturation criterion was as high as 90 kcfs. The combination of spillway flow deflectors with a shallow tailwater channel are thought to account for this efficient TDG exchange property. The operation of the spillway at Ice Harbor Dam in 2008 involved biological testing of the RSW where day to day changes in total spill discharge were often large. The maximum spill discharge at Ice Harbor Dam in 2008 was 170 kcfs resulting in a tailwater TDG saturation of 135 percent which was the highest TDG saturation observed in the study area.

The TDG production model for Lower Monumental Dam produced the highest standard error on the Snake River that typically under-estimated the TDG saturation observed at the tailwater FMS. The complexity in the TDG exchange characteristics includes the application of multiple spill patterns and the entrainment of powerhouse flows into spillway flows. The scheduling of a bulk spill pattern resulted in higher TDG pressures when compared with the standard spill pattern. An alternative TDG production formulation was developed consisting of the power function of tailwater depth of flow and the specific spillway discharge. The observed TDG saturation at the tailwater FMS was found to be a function of the forebay TDG saturation for small total river flows. The frequency of hourly TDG supersaturation above 115 percent at the Ice Harbor forebay station was the highest of the four Snake River projects. The spill policy at Lower

Monumental Dam resulted in the TDG saturation in the Ice Harbor forebay to exceed 115% over 33.8 percent of the time.

The TDG saturation in the forebay of Lower Monumental Dam during May exceeded the TDG saturation observed in the tailwater of Little Goose Dam. The local maximum TDG saturation in the tailwater of Little Goose Dam likely occurred away from the tailwater fixed monitoring station during this period of spill exceeding 100 kcfs. The high forebay TDG pressure may have also contributed to these high TDG levels in Lower Monumental pool exceeding 125 percent of saturation. The 2008 spill patterns at Little Goose Dam consisted of three distinct spill patterns. The bulk spill pattern generated significantly higher TDG levels when compared to the uniform pattern. The TDG saturation at Little Goose Dam is approximated best as a function of forebay TDG levels and TDG levels estimated in spill. At higher spill discharges the TDG saturation in the tailwater approaches the TDG saturation generated in aerated spill. There was a tendency during spill greater than 80 kcfs to under-estimate both the TDG saturation observed in the tailwater and residual TDG saturation transported to Lower Monumental Dam.

The spillway operations at Lower Granite Dam during 2008 resulted in tailwater TDG saturations exceeding 125 percent of saturation over 7.8 percent of the time, the highest of any project in the study area. The peak TDG saturation experienced a significant reduction traveling in Lower Monumental pool unlike the conditions transported through Little Goose pool. The peak TDG events were overestimated upon arriving at the forebay of Little Goose Dam. The spillway operations at Lower Granite Dam featured the prominent use of the removable spillway weir and training spill using a uniform spill pattern. Lower Granite Dam generated TDG saturations exceeding 130 percent at much smaller spill discharges than at Ice Harbor Dam.

Spillway and regulating releases were the rule at Dworshak Dam during the 2008 spill season. The TDG saturation observed at the tailwater FMS did not exceed 115 percent of saturation and exceeded 110 percent only 4.8 percent of the time. There was a tendency for regulating releases to generated slightly higher TDG pressures than comparable spill way flow. The mixing zone between powerhouse flow and spill is well developed at the tailwater FMS in the North Fork of the Clearwater River. The TDG content in RO flow of 2.2 kcfs was estimated to exceed 120% prior to mixing with powerhouse release.

Recommendations

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

The TDG budgets in Little Goose and Lower Monumental pools during high forced spill conditions will require additional field sampling to supplement data from the FMS. It is not possible to determine with significant confidence if the predictive errors in these pools is attributed to the rate of off-gassing or rate of TDG production. These events generate TDG levels that are known to cause gas bubble trauma in juvenile salmonid and steelhead.

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 inclusion of removable spillway weirs (RSW) or repositioning of temporary spillway weirs (TSW) is expected to continue on a regular basis.

The SYSTDG decision support system will continue to improve the ability to handle alternative spill patterns into predictions of TDG loading in the Columbia River basin.

As additional weather stations provide real time data, continue to update the SYSTDG model to utilize these data.

The identification of consistent sampling bias at tailwater fixed monitoring stations should be documented and incorporated into management activities.

The uncertainty of TDG predictions should be factored into a risk based management policy for spill.

Figures Appendix G

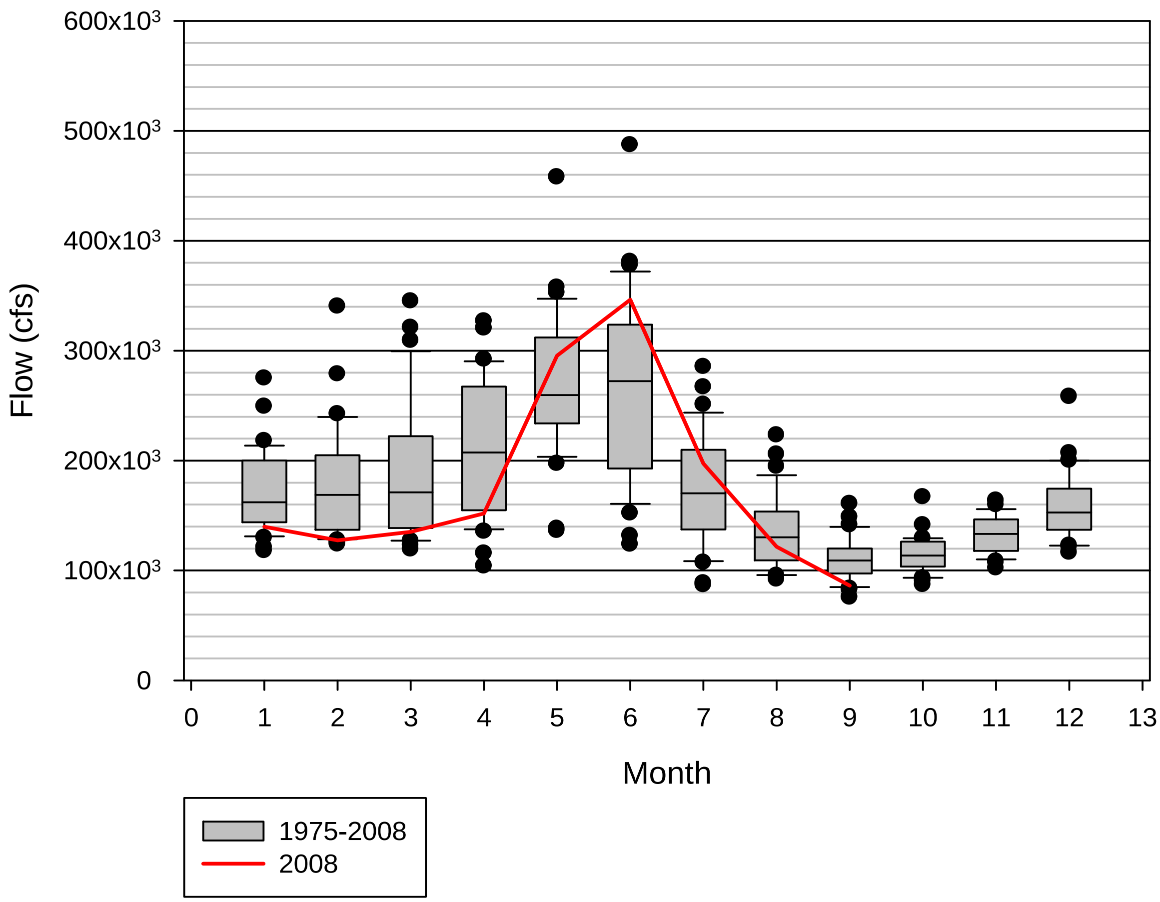

Figure G1. Statistical Summary of Columbia River Monthly Average Flows at The Dalles Dam for 1975-2008
(2008 – Red, 1975-2008 summary gray box 25, 50, 75th percentiles, whiskers 5-95th percentiles).

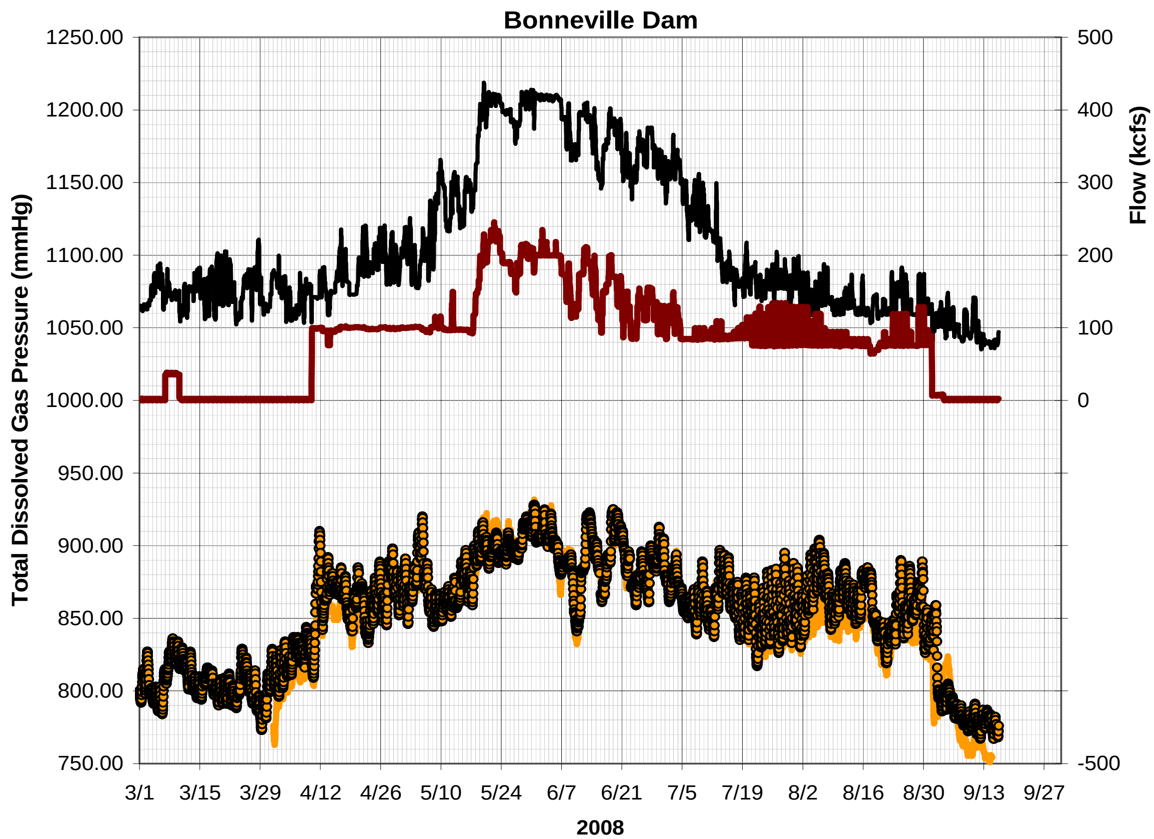

Figure G2. Observed and Calculated Total Dissolved Gas Saturation in the Columbia River at the Camas/Washougal fixed monitoring station downstream of Bonneville Dam, March-September 2008

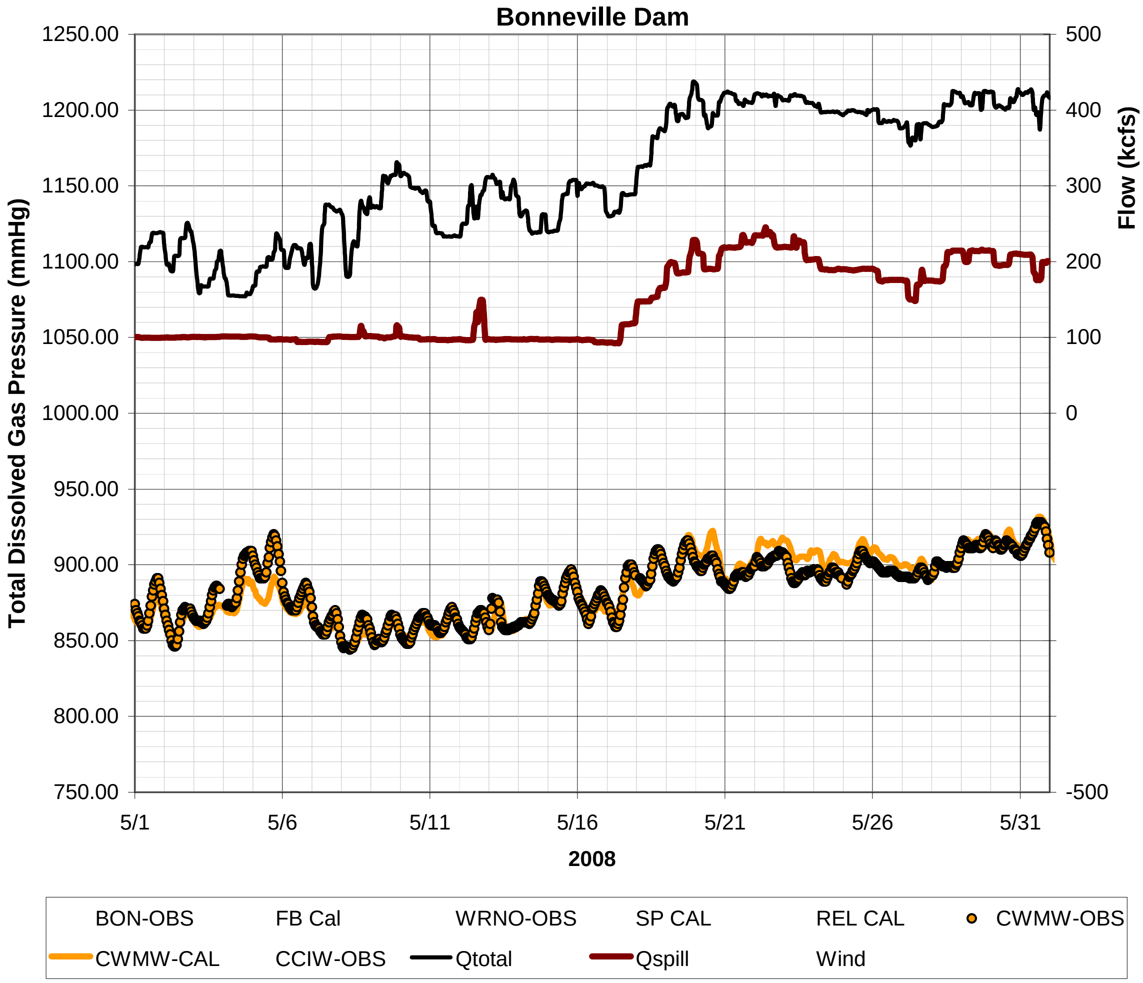

Figure G3. Observed and Calculated Total Dissolved Gas Saturation in the Columbia River at the Camas/Washougal fixed monitoring station downstream of Bonneville Dam, May 2008

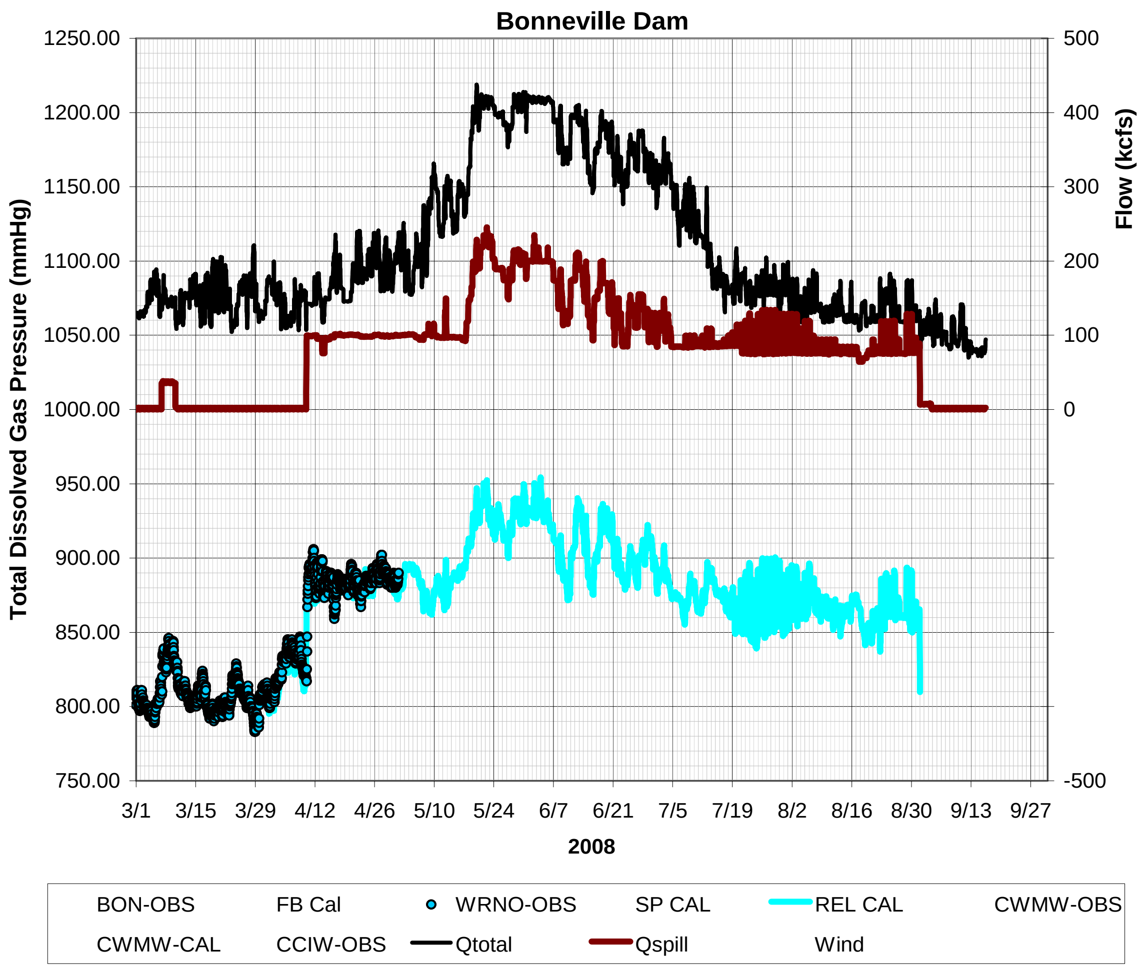

Figure G4. Observed and Calculated Total Dissolved Gas Saturation in the Columbia River at the Warrendale fixed monitoring station downstream of Bonneville Dam, March-September 2008

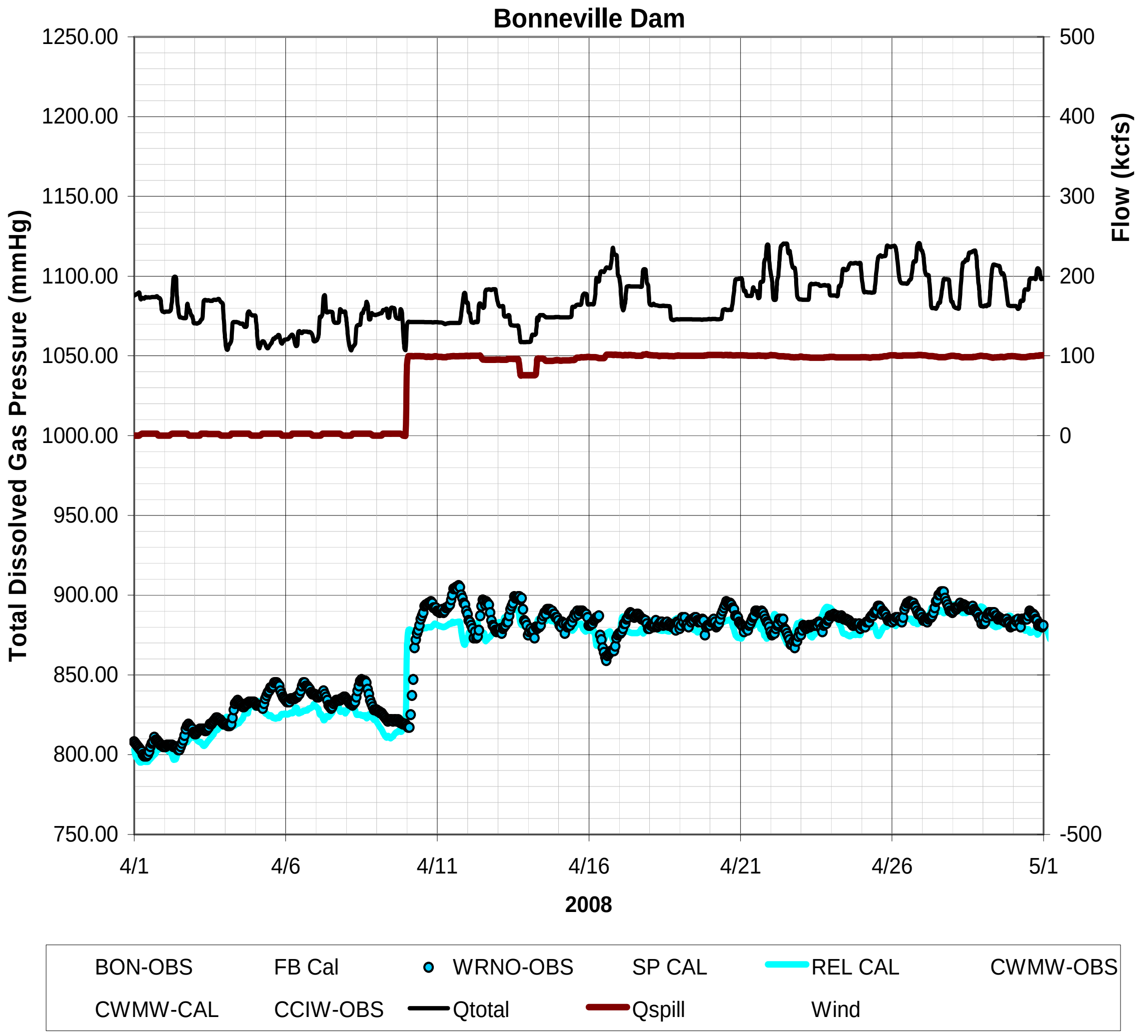

Figure G5. Observed and Calculated Total Dissolved Gas Saturation in the Columbia River at the Warrendale fixed monitoring station downstream of Bonneville Dam, April 2008

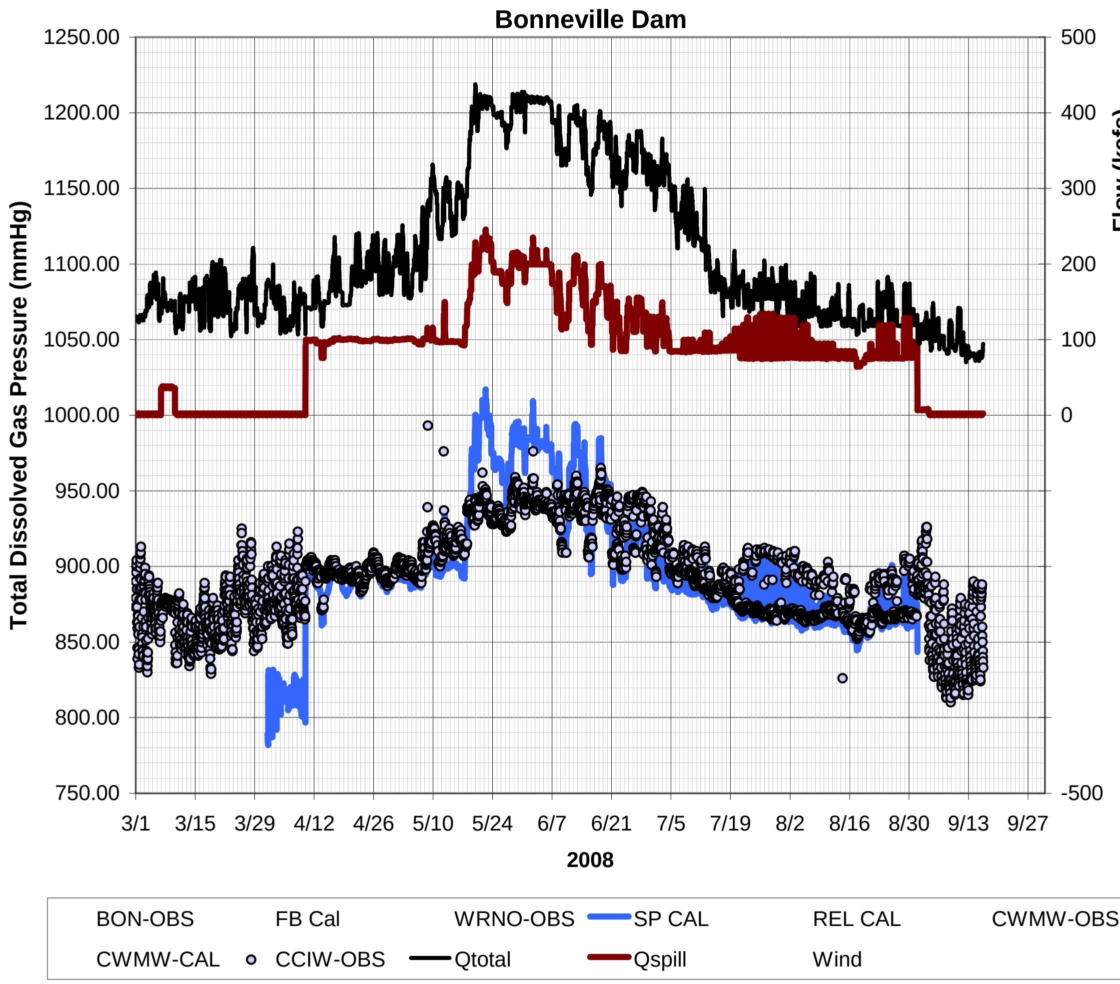

Figure G6. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam, March-September 2008

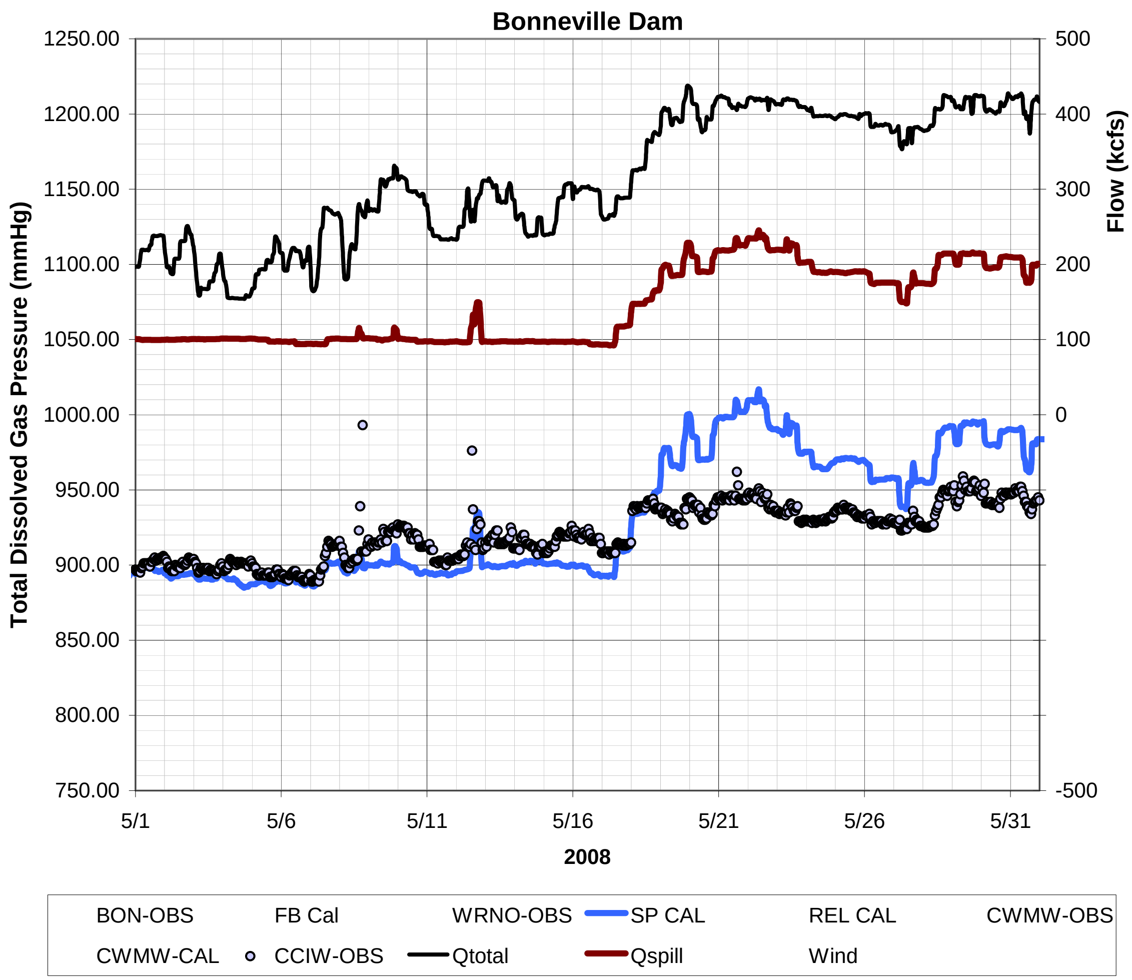

Figure G7. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam, May 2008

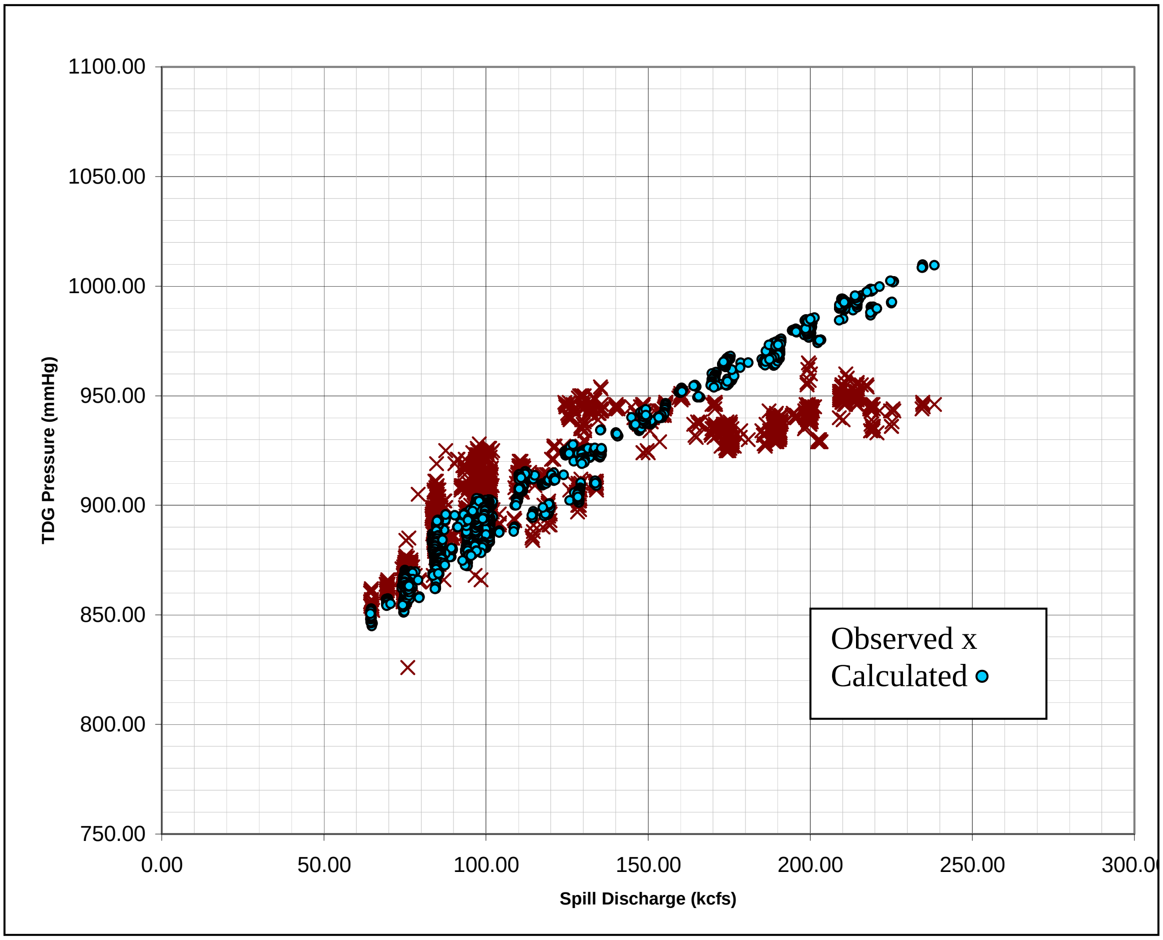

Figure G8. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam as a Function of Spill Discharge, 2008

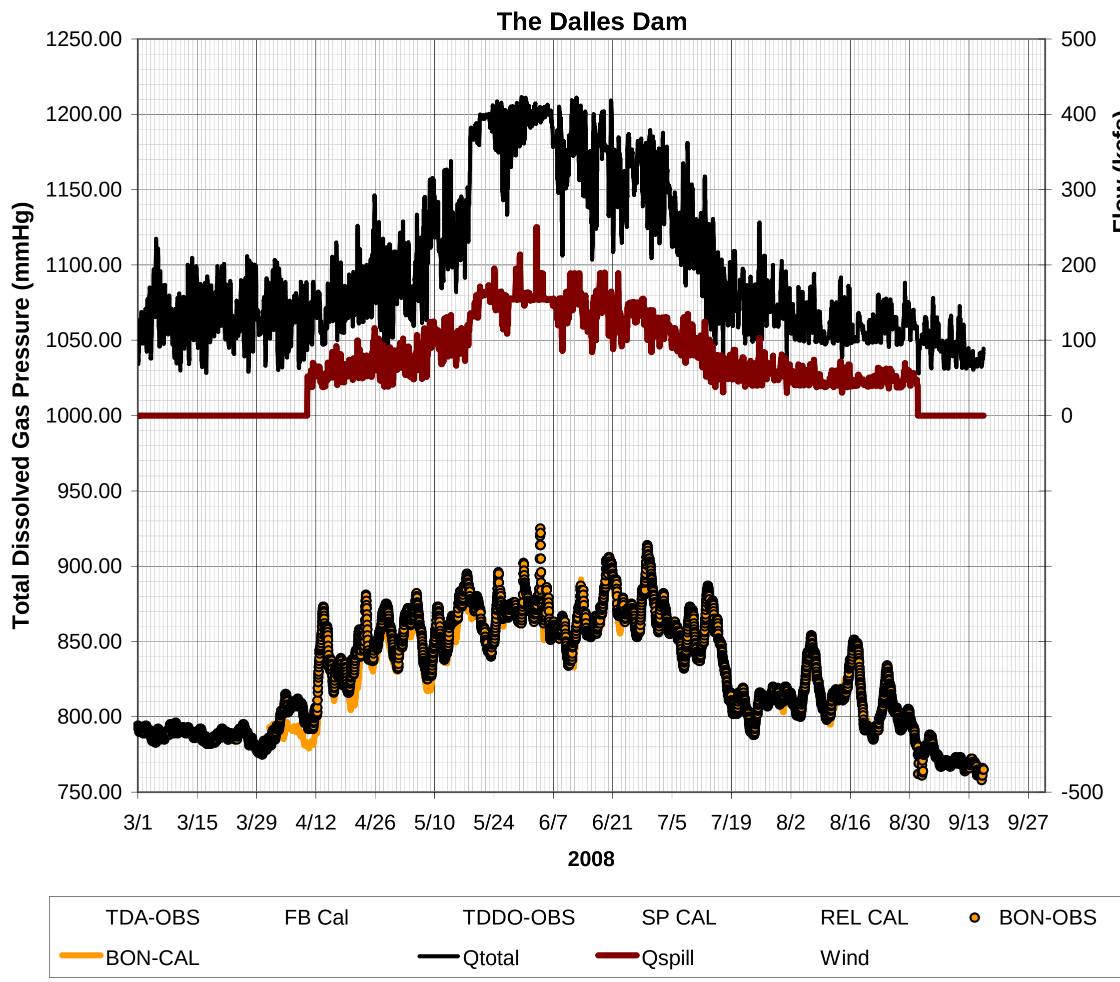

Figure G9. The Dalles Dam Operations with Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of Bonneville Dam, March-September 2008

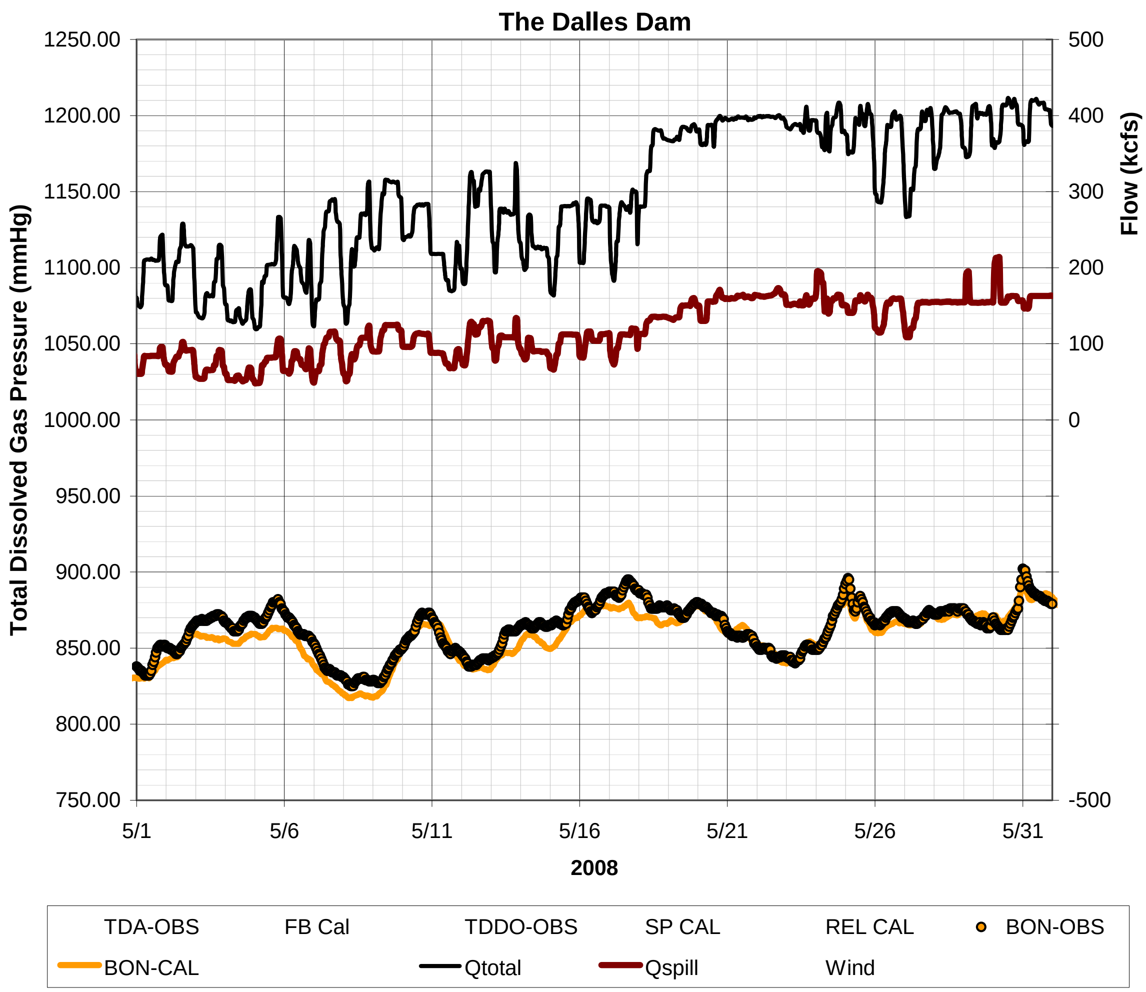

Figure G10. The Dalles Dam Operations with Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of Bonneville Dam, May 2008

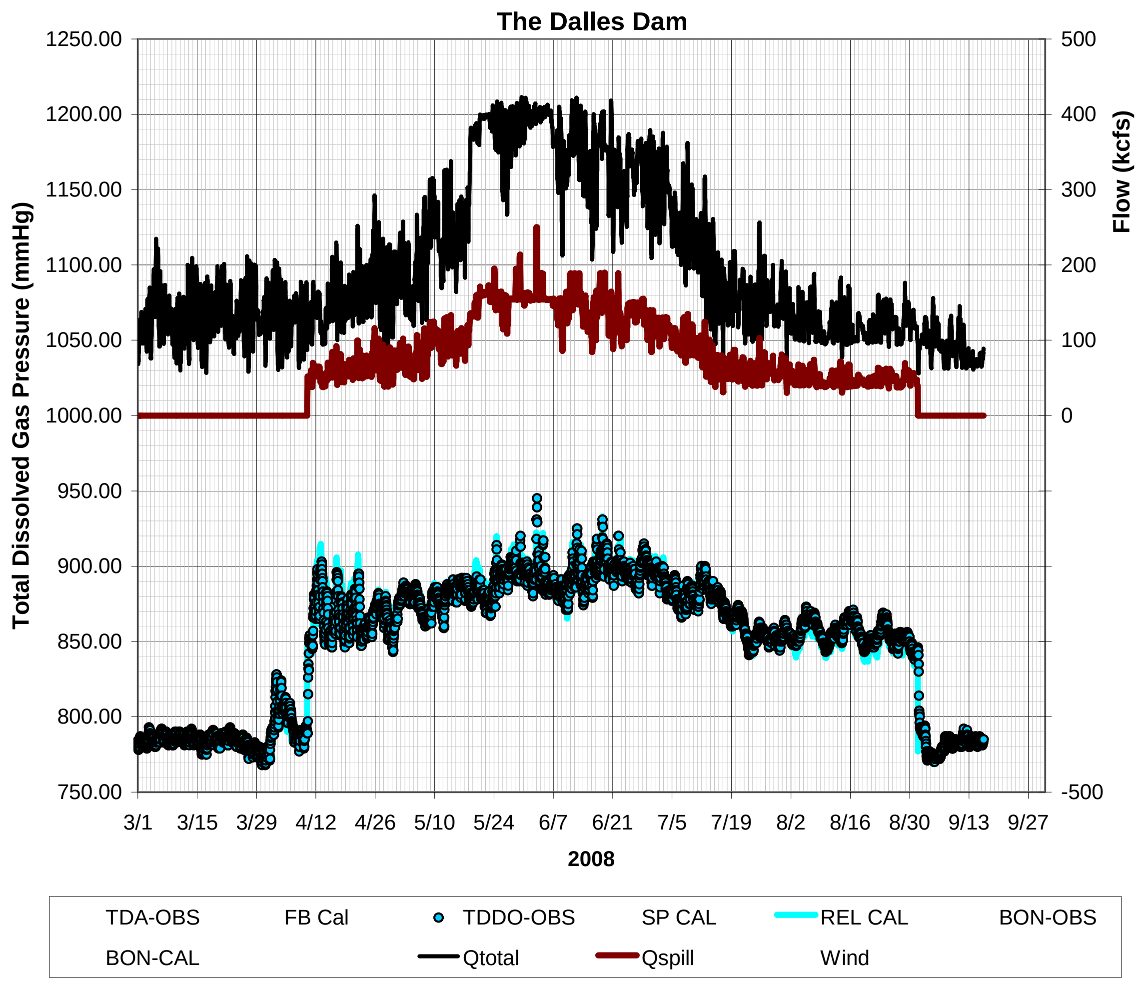

Figure G11. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel of The Dalles Dam, March-September 2008

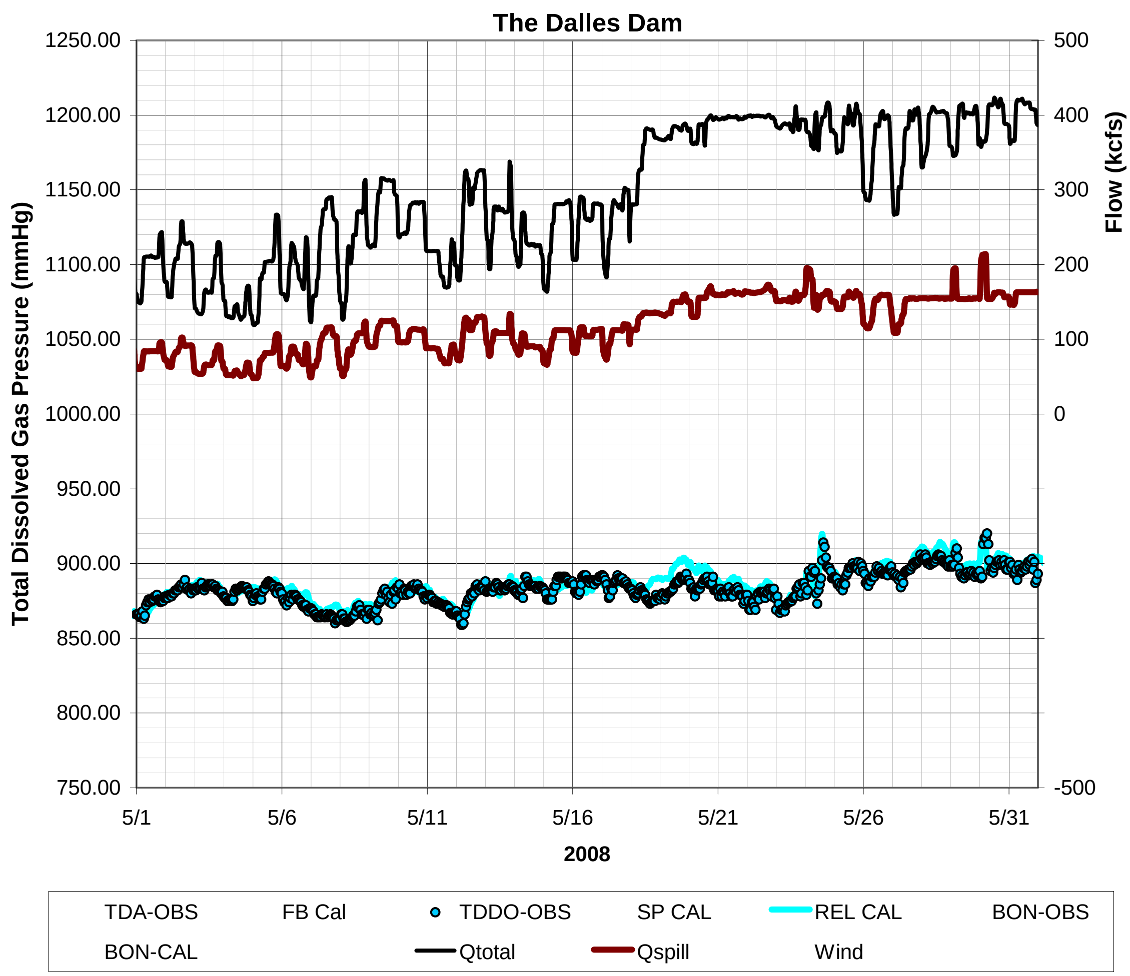

Figure G12. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel of The Dalles Dam, May 2008

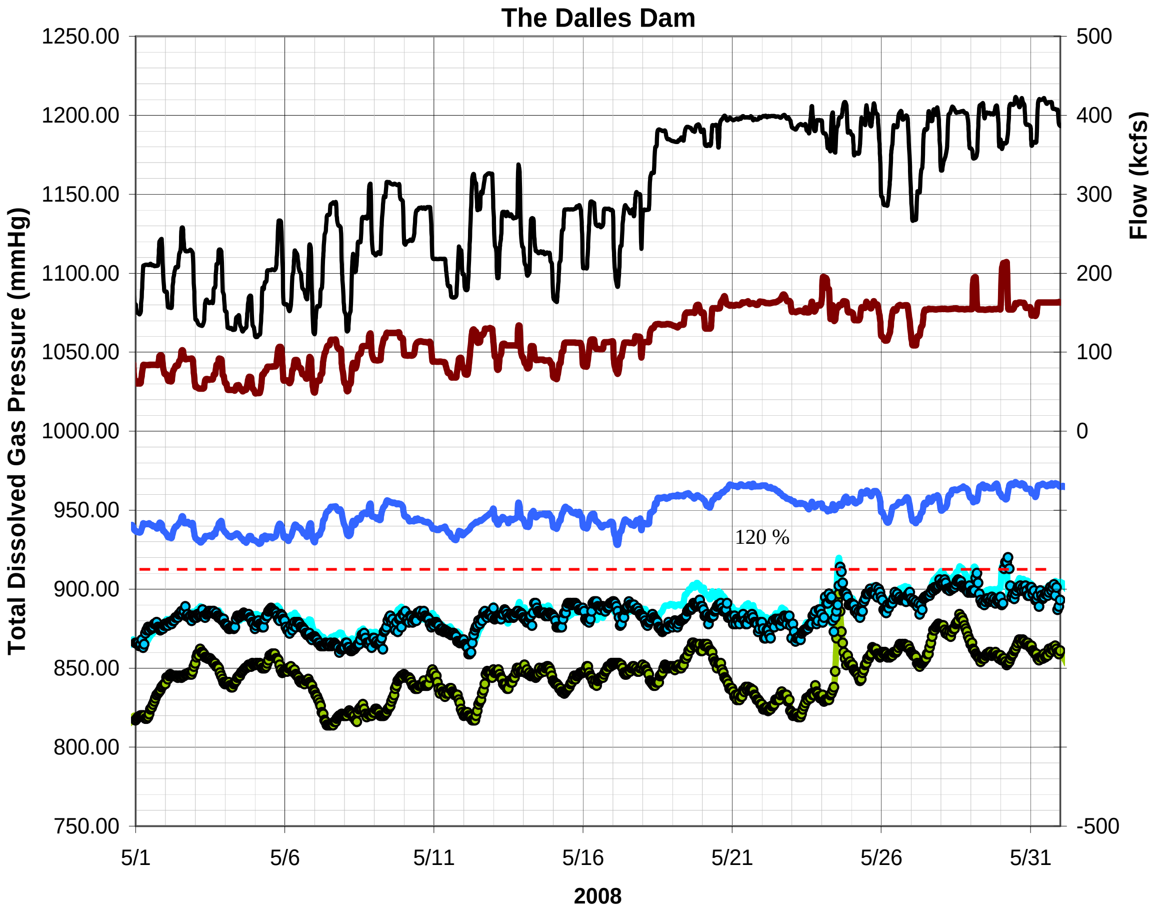

Figure G13. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel of The Dalles Dam, June 2008

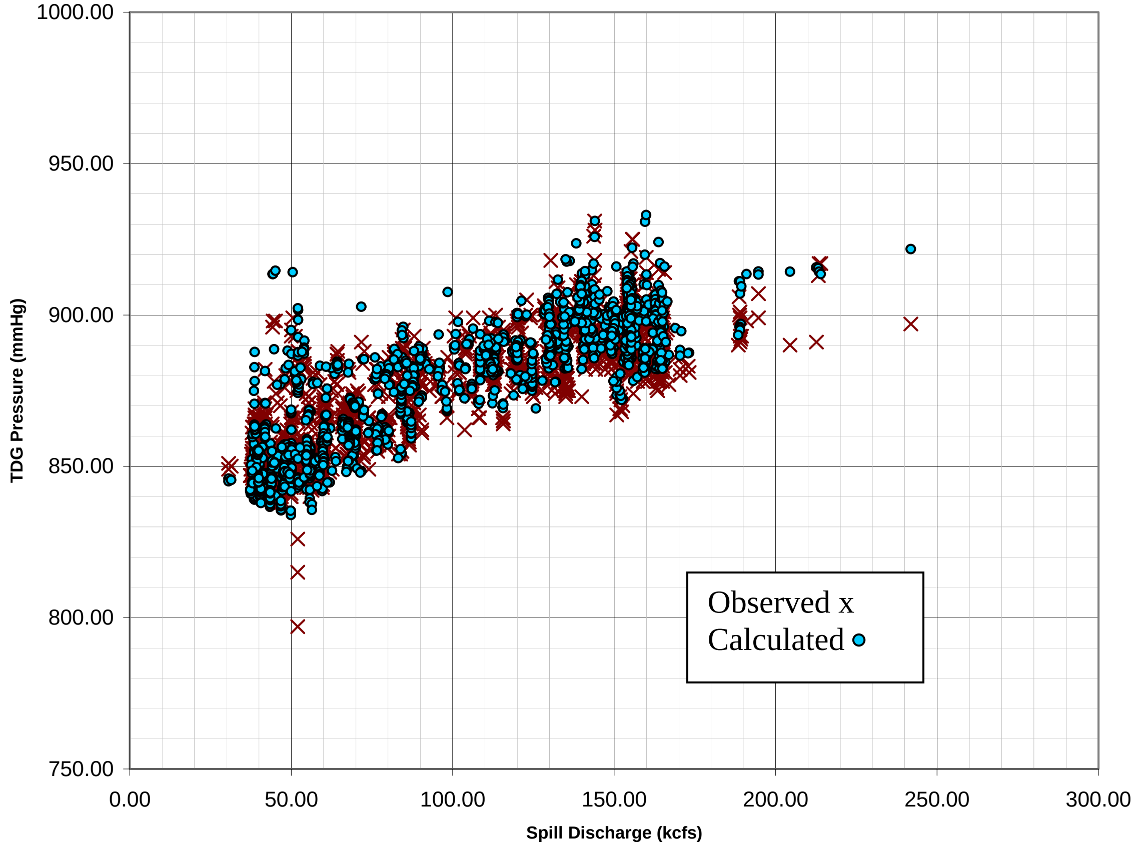

Figure G14. Observed and Calculated Total Dissolved Gas Pressure in the Columbia River below The Dalles Dam as a Function of Spillway Discharge, 2008

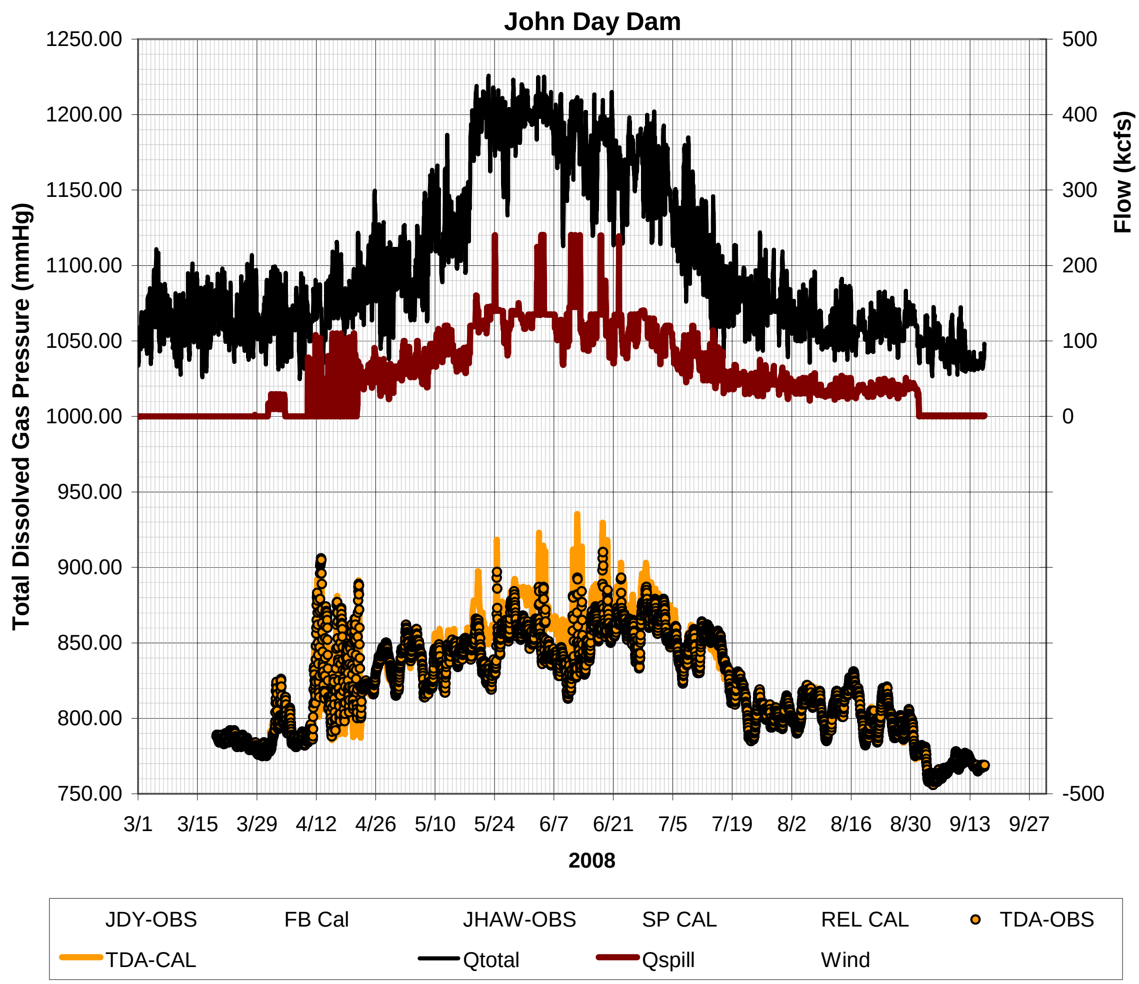

Figure G15. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of The Dalles Dam, March-September 2008

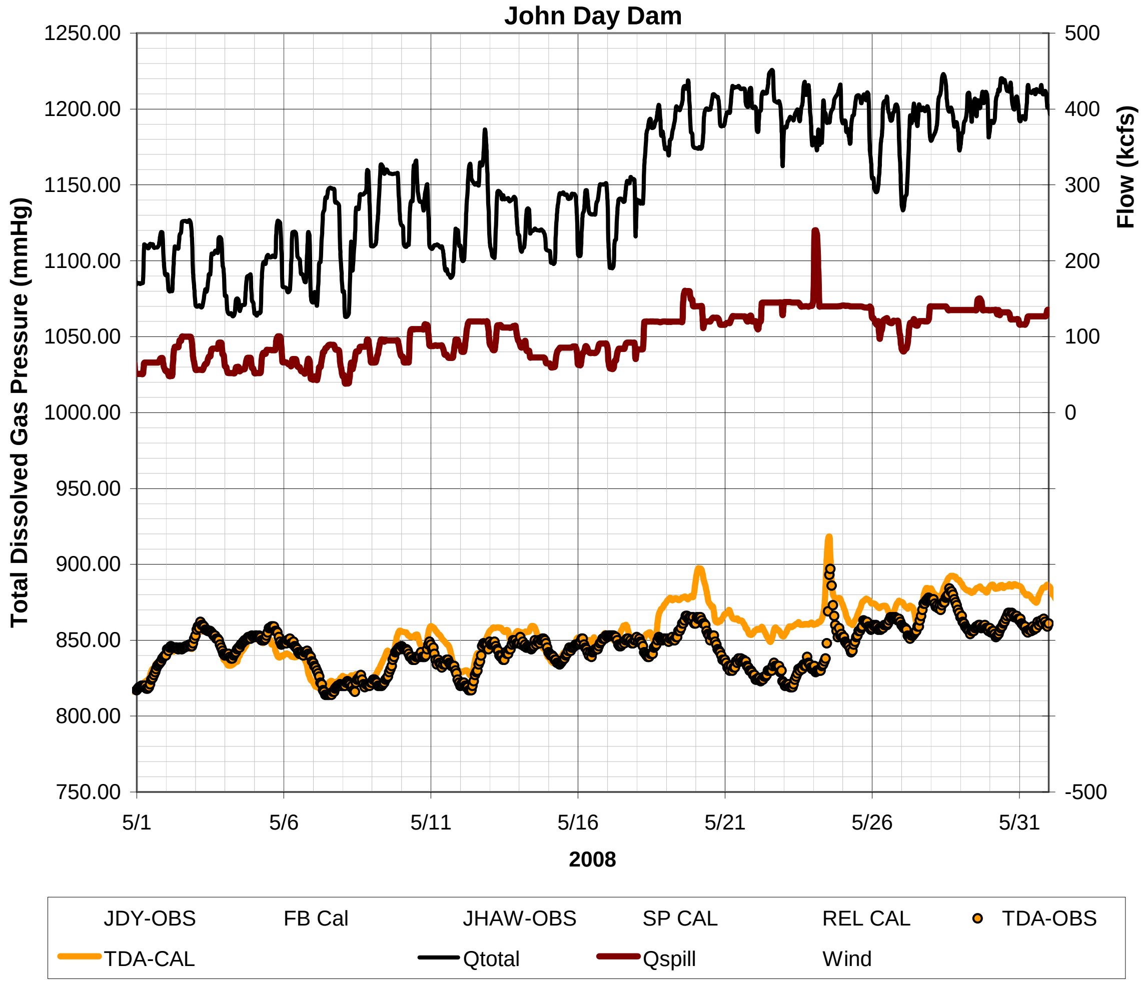

Figure G16. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of The Dalles Dam, May 2008

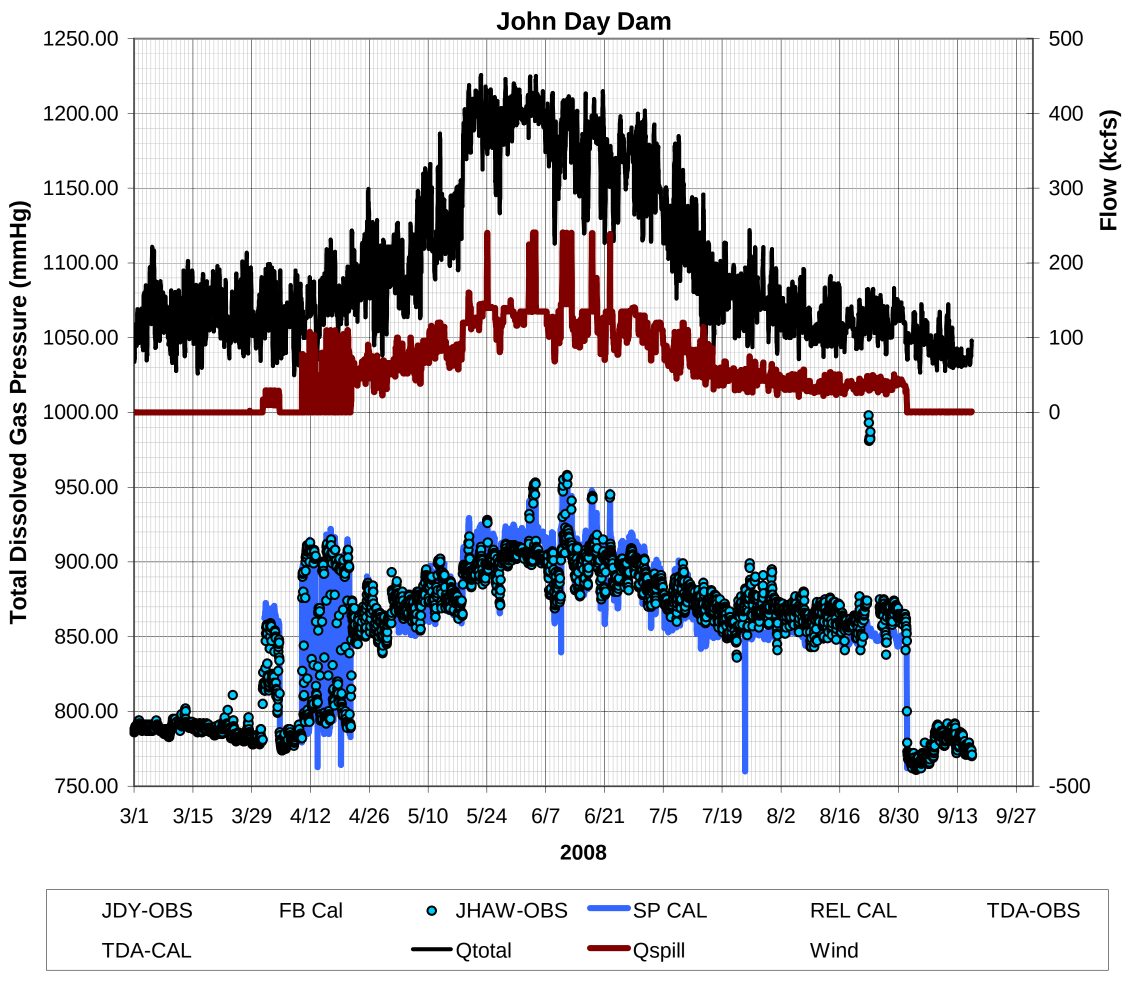

Figure G17. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, March-September 2008

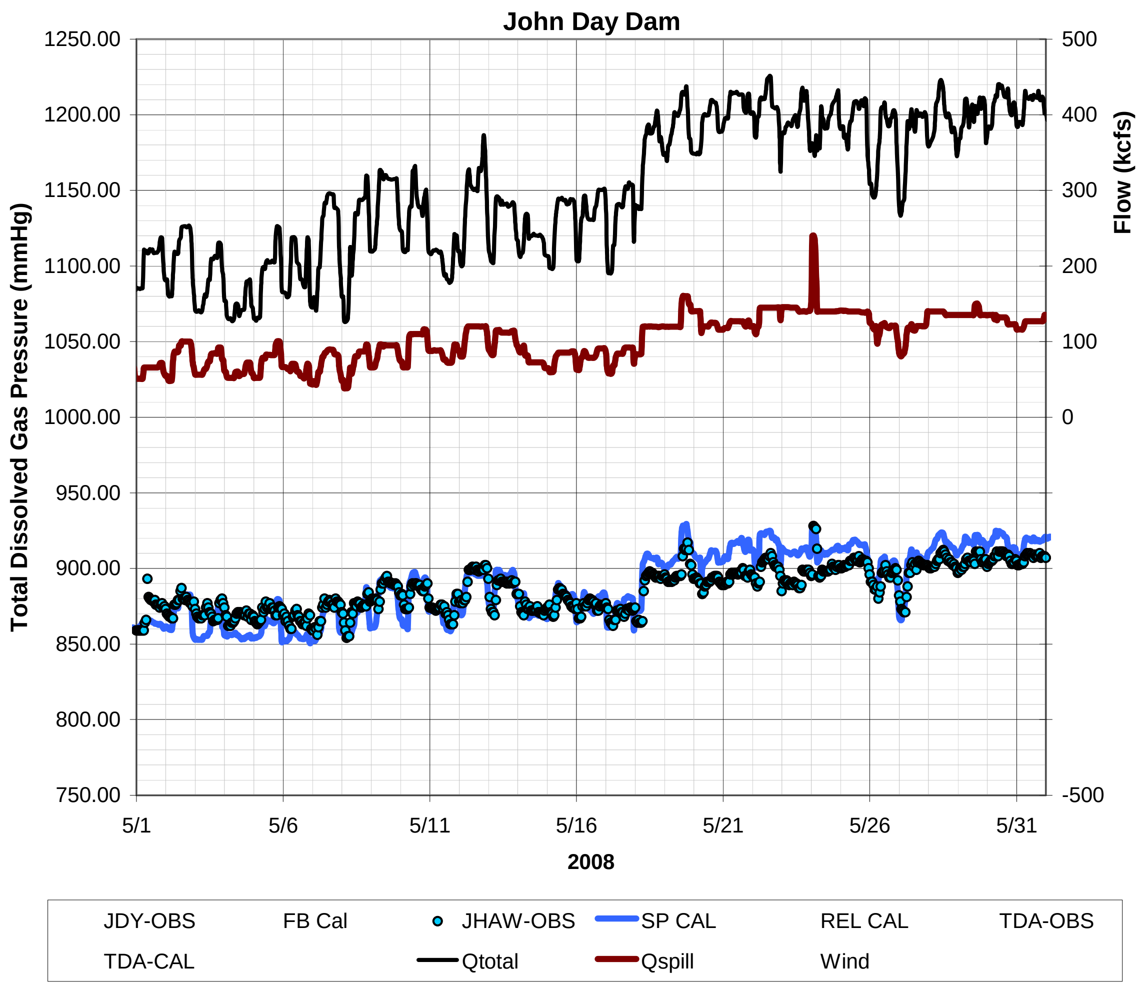

Figure G18. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, May 2008

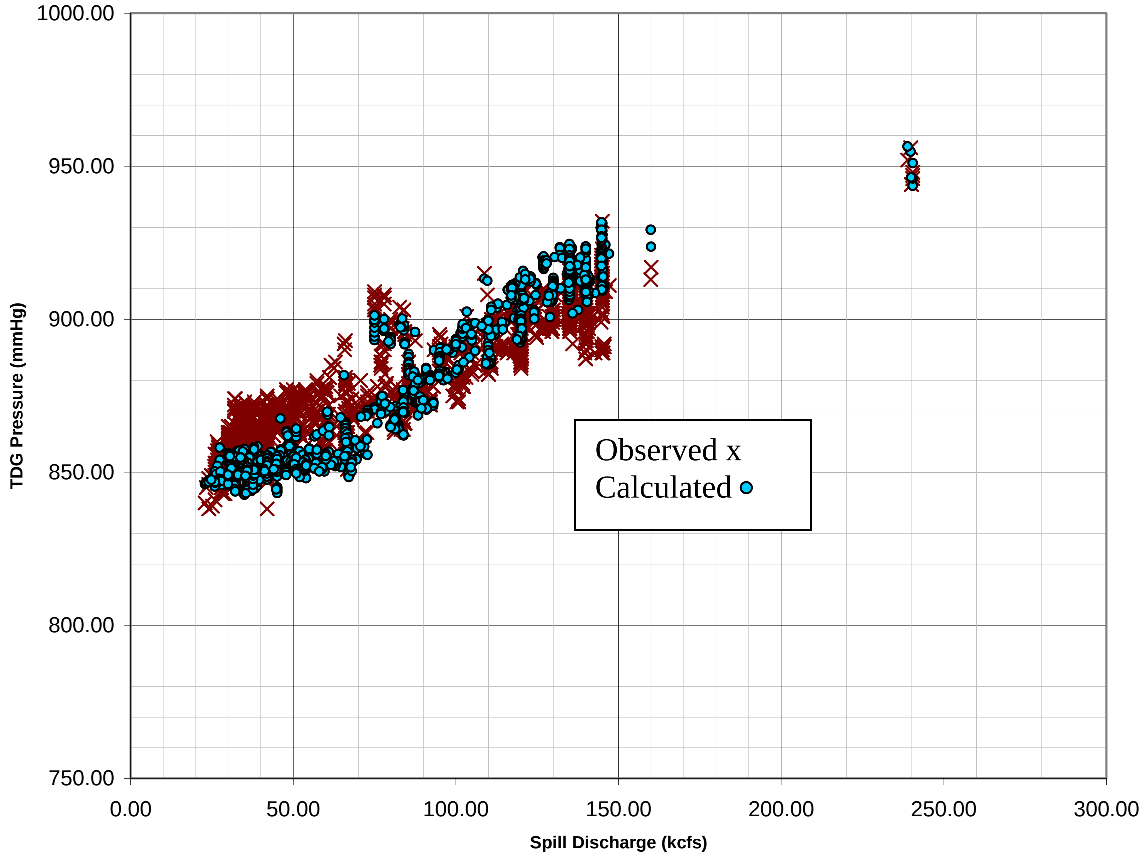

Figure G19. Observed and Calculated Total Dissolved Gas Pressure in the Columbia River below John Day Dam as a Function of Spillway Discharge, 2008

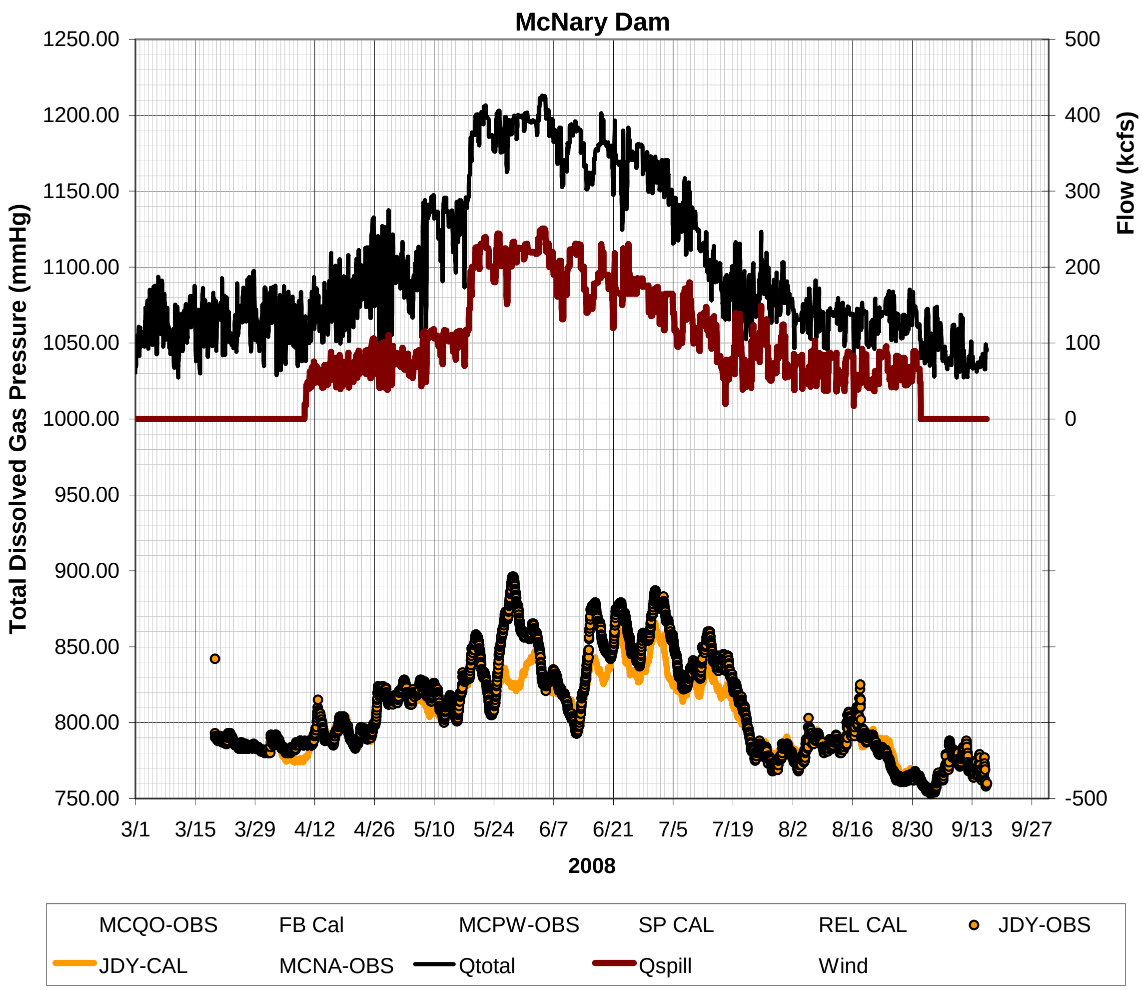

Figure G20. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of John Dam, March-September 2008

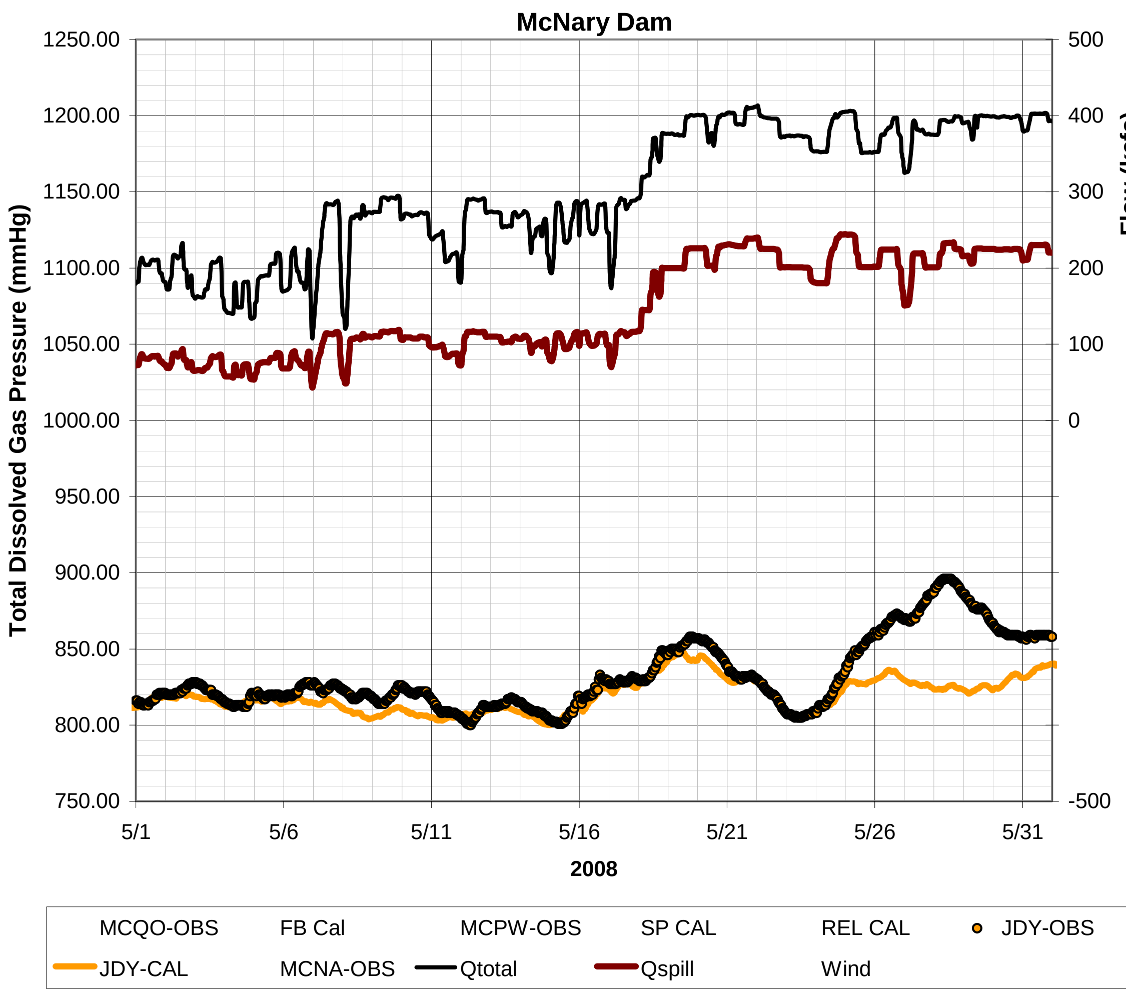

Figure G21. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of John Dam, May 2008

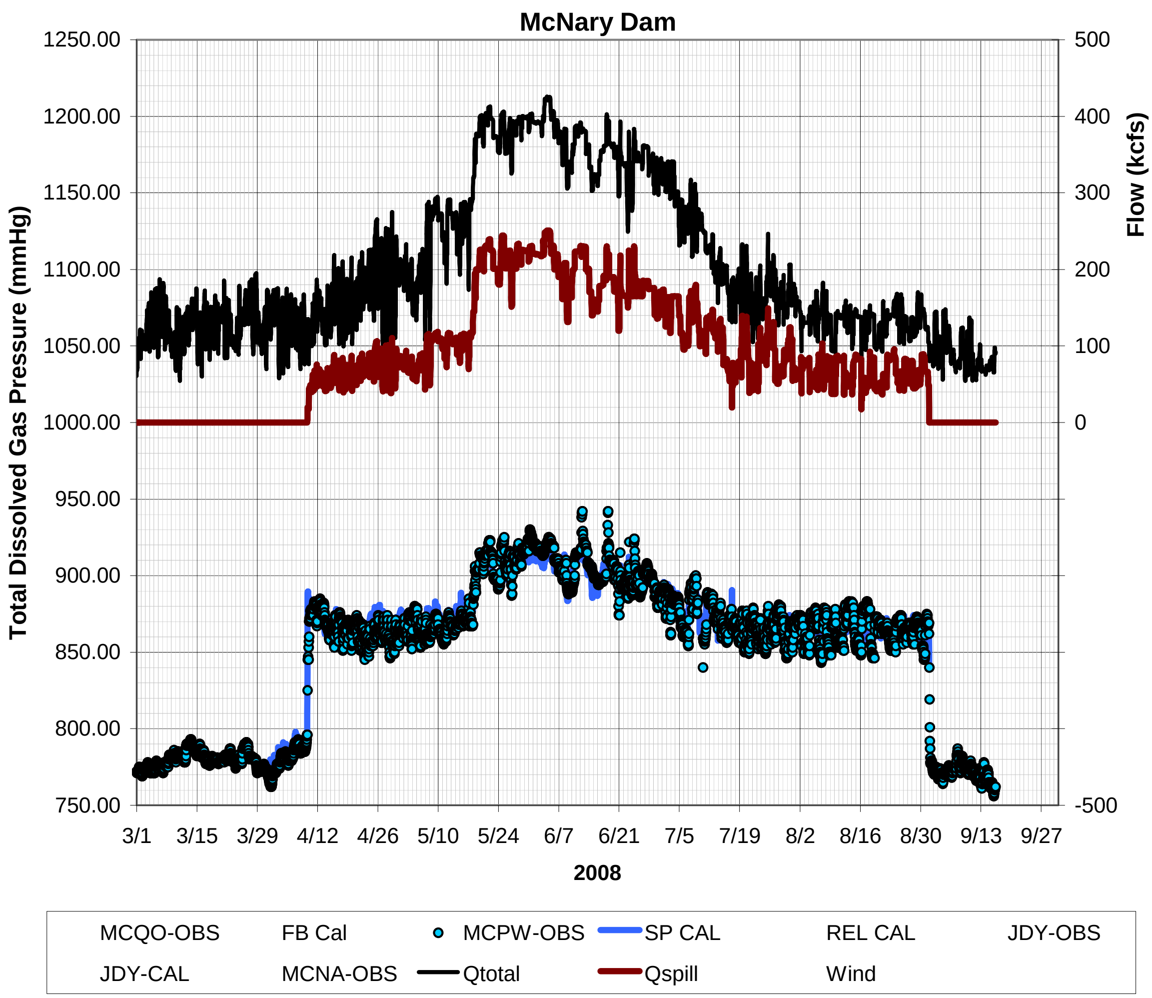

Figure G22. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater of McNary Dam, March-September 2008

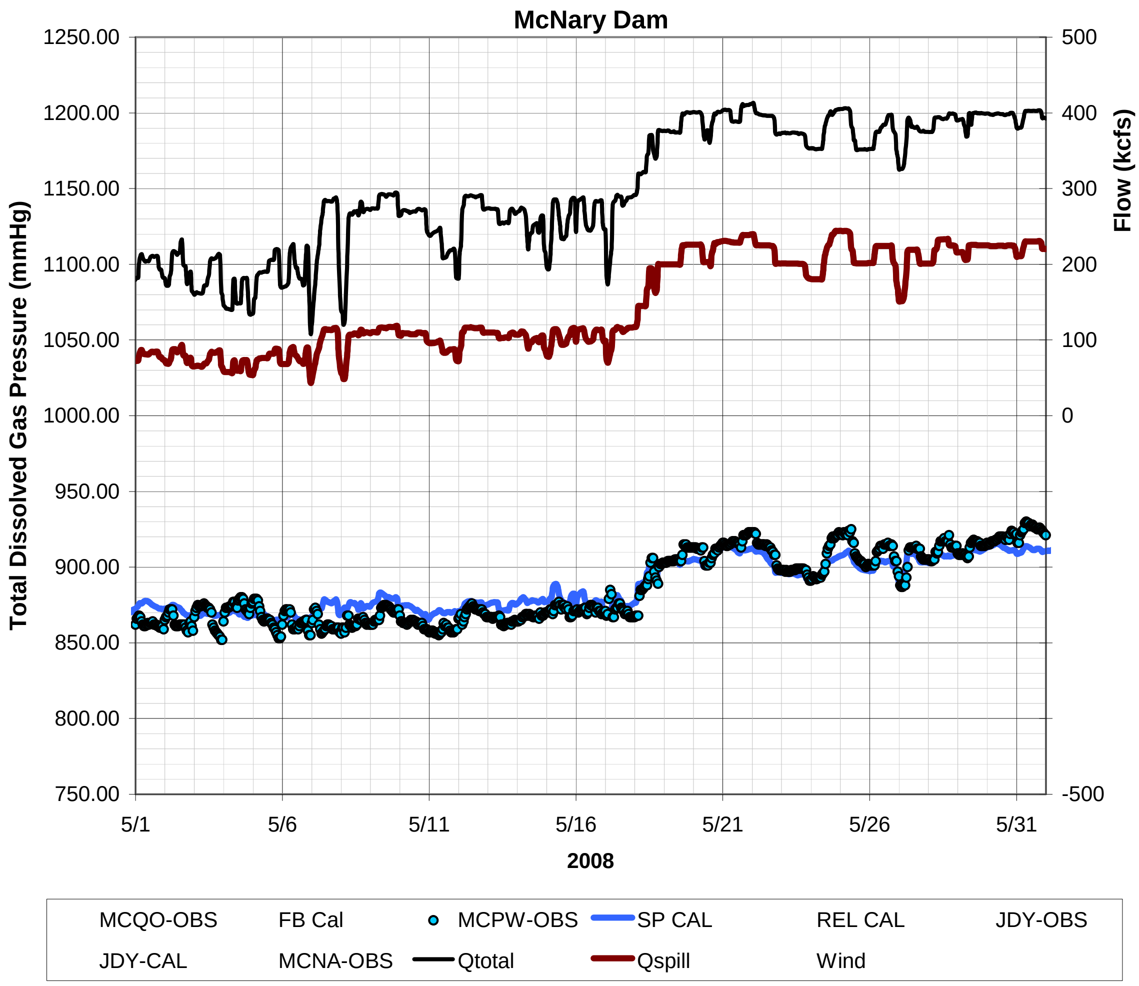

Figure G23. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater of McNary Dam, June 2008

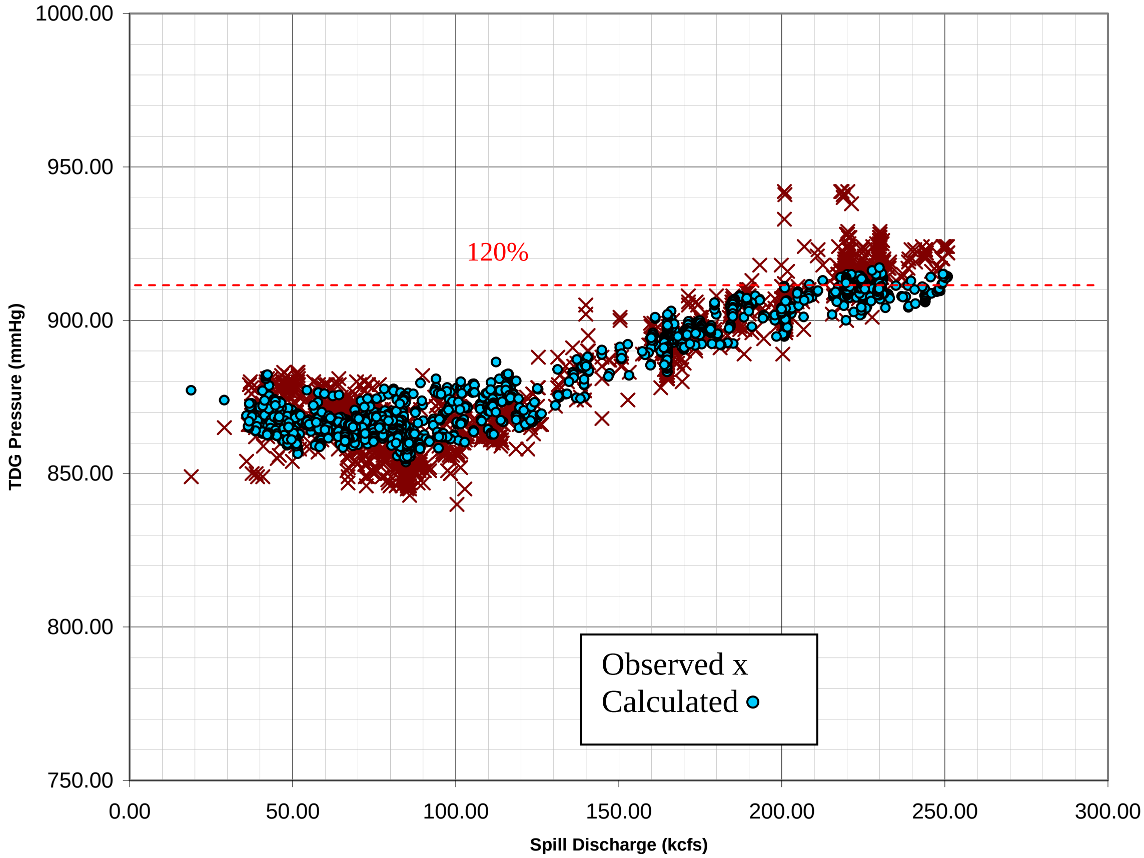

Figure G24. Observed and Calculated Total Dissolved Gas Pressure in the Columbia River below McNary Dam as a Function of Spillway Discharge, 2008

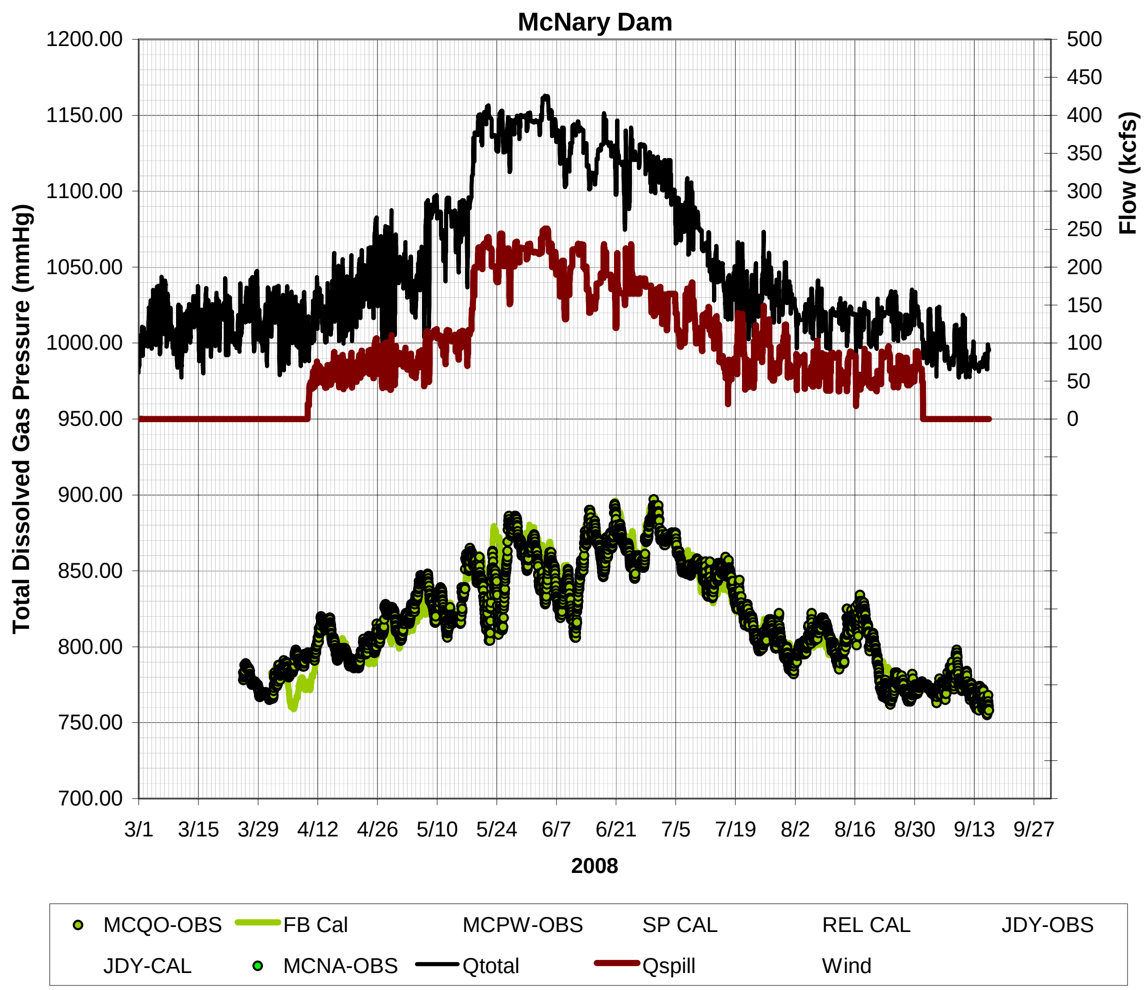

Figure G25. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of McNary Dam, March-September 2008

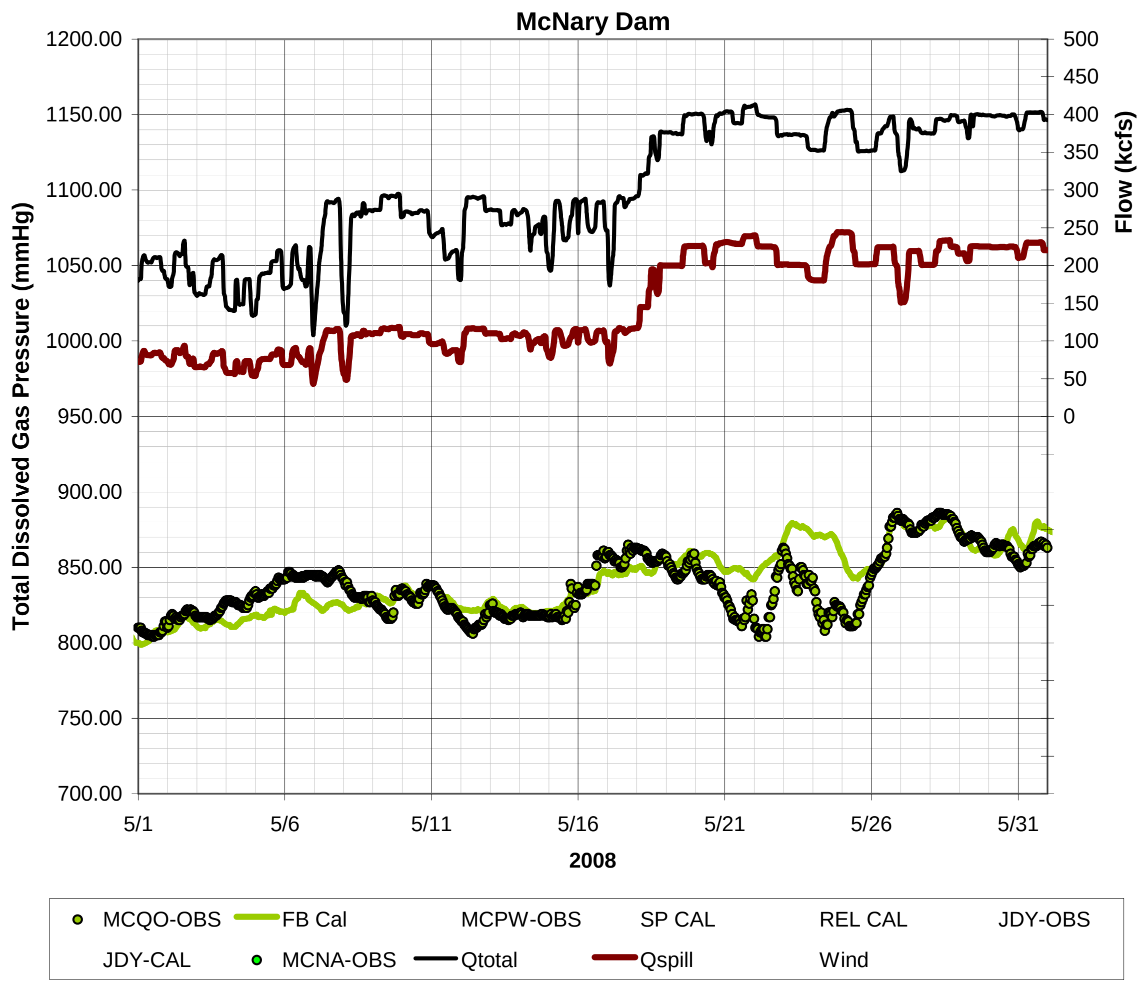

Figure G26. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of McNary Dam, May 2008

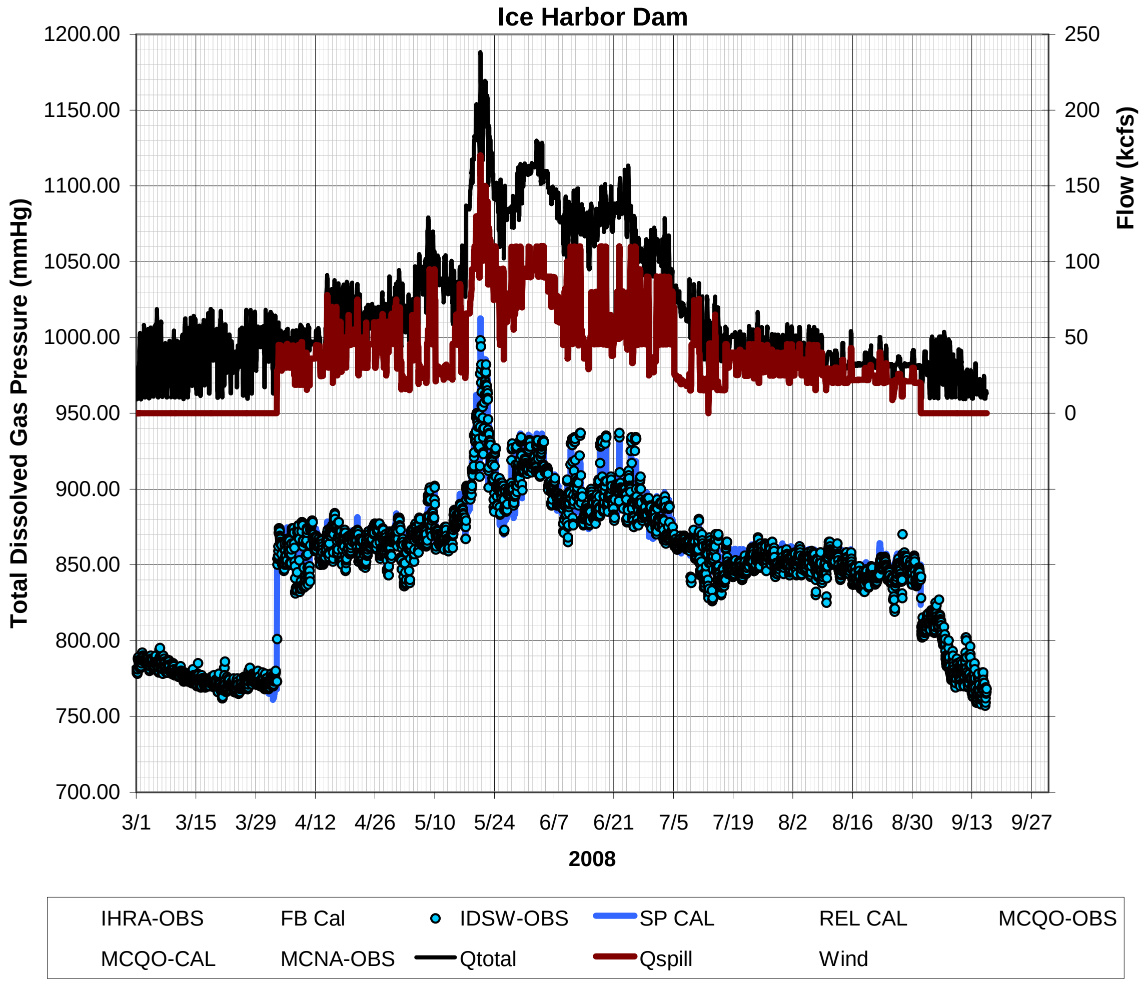

Figure G27. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater downstream from Ice Harbor Dam, March-September 2008

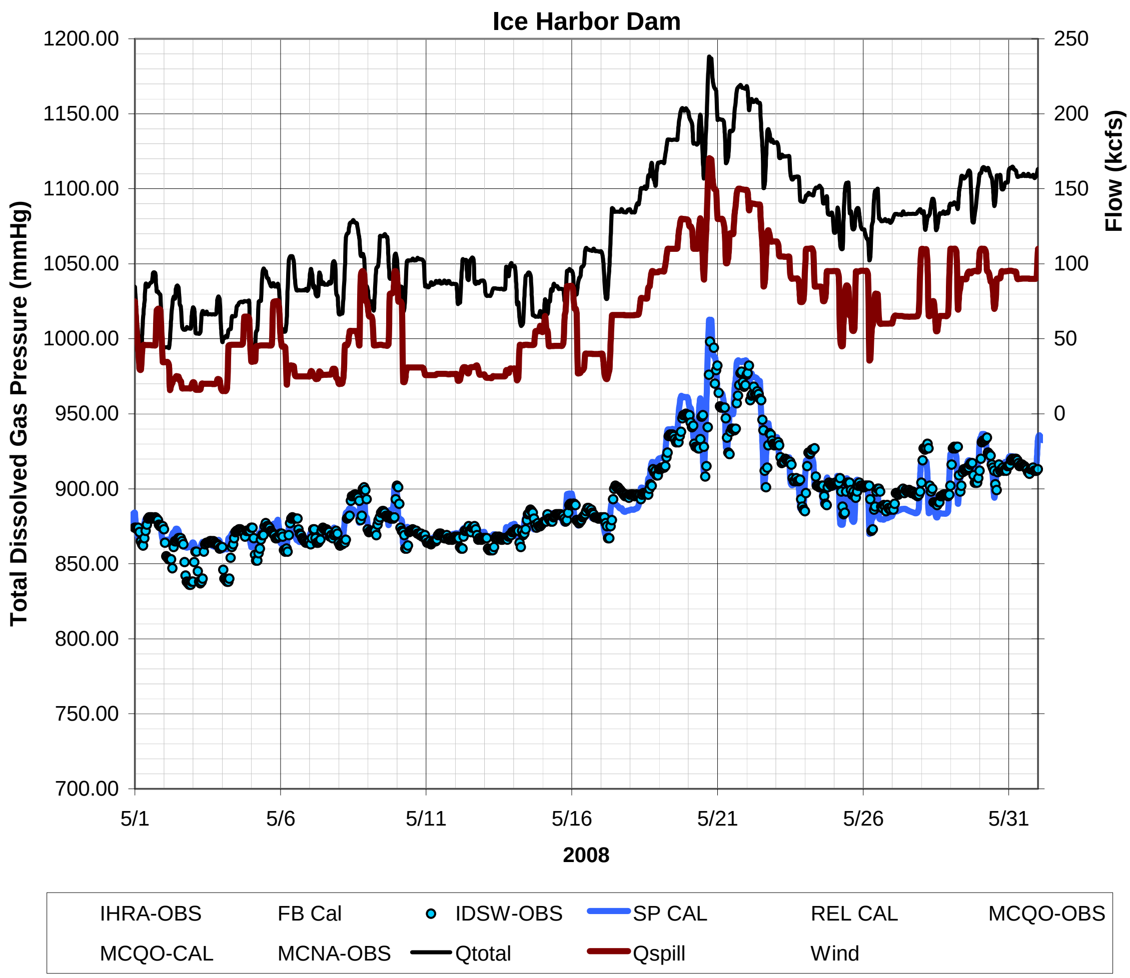

Figure G28. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater downstream from Ice Harbor Dam, May 2008

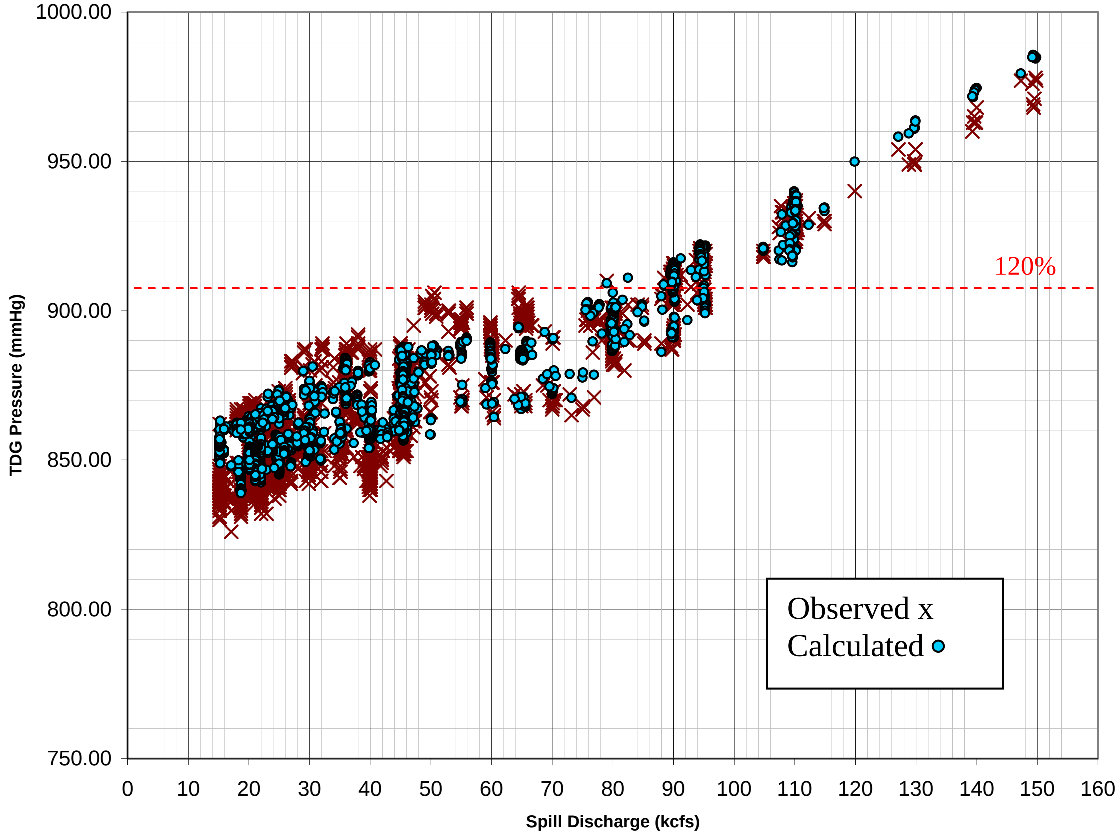

Figure G29. Observed and Calculated Total Dissolved Gas Pressure in the Snake River below Ice Harbor Dam as a Function of Spillway Discharge, 2008

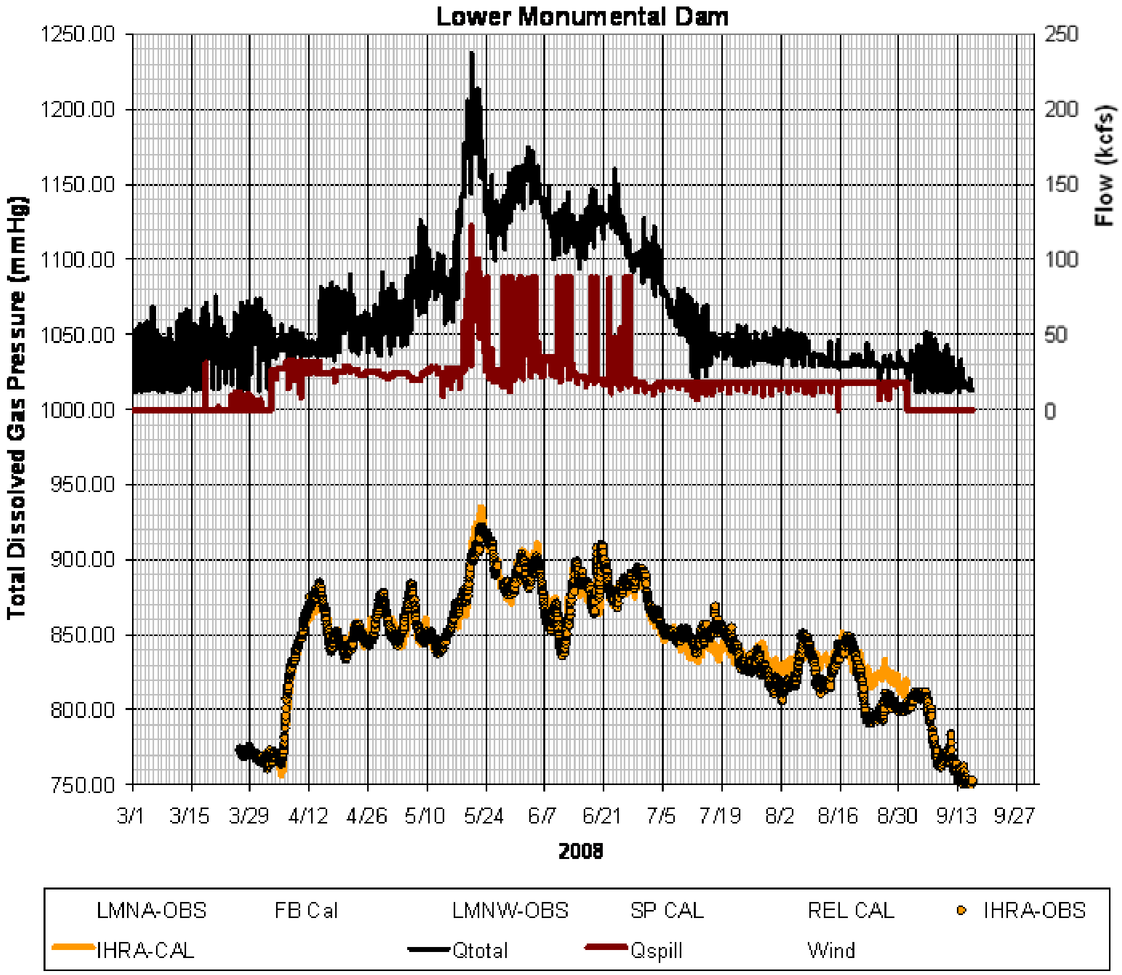

Figure G30. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Ice Harbor Dam, March-September 2008

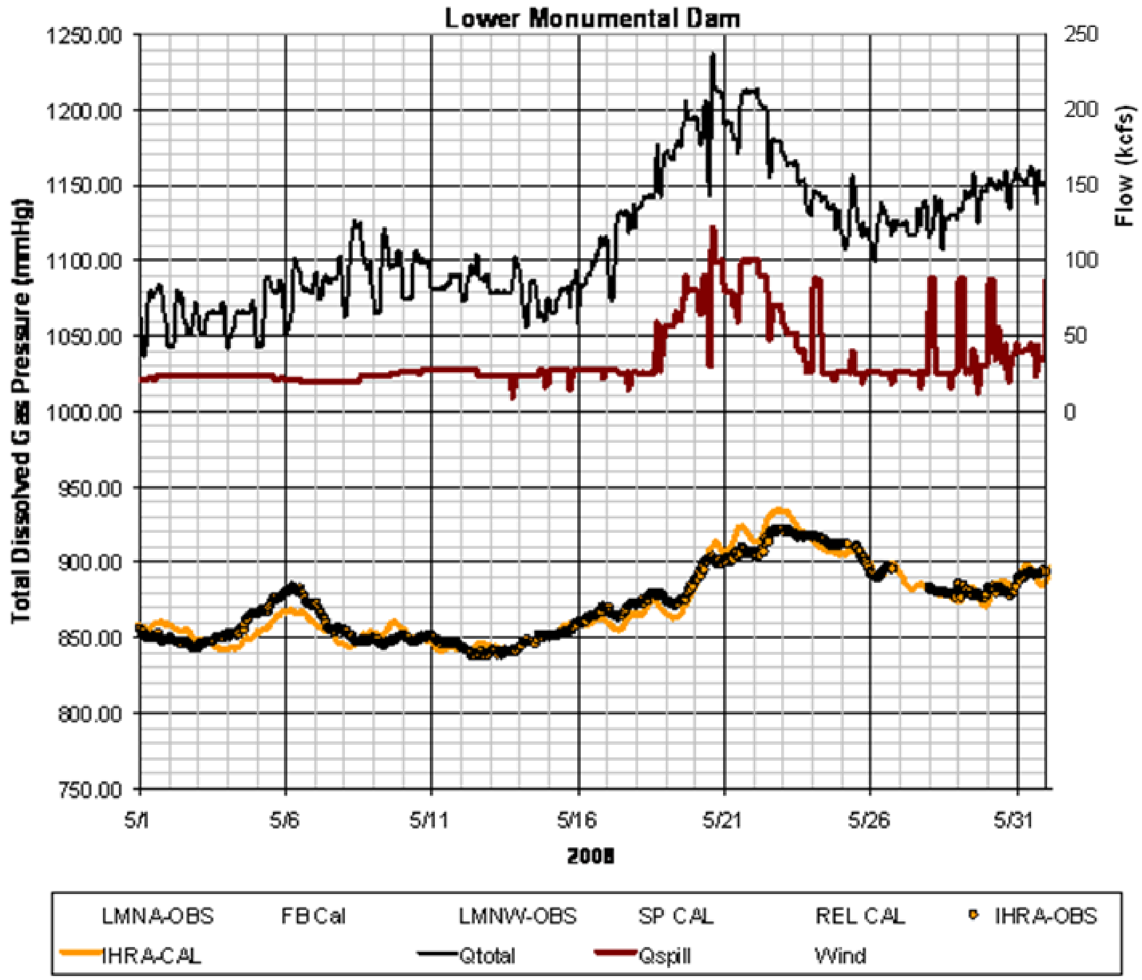

Figure G31. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Ice Harbor Dam, May 2008

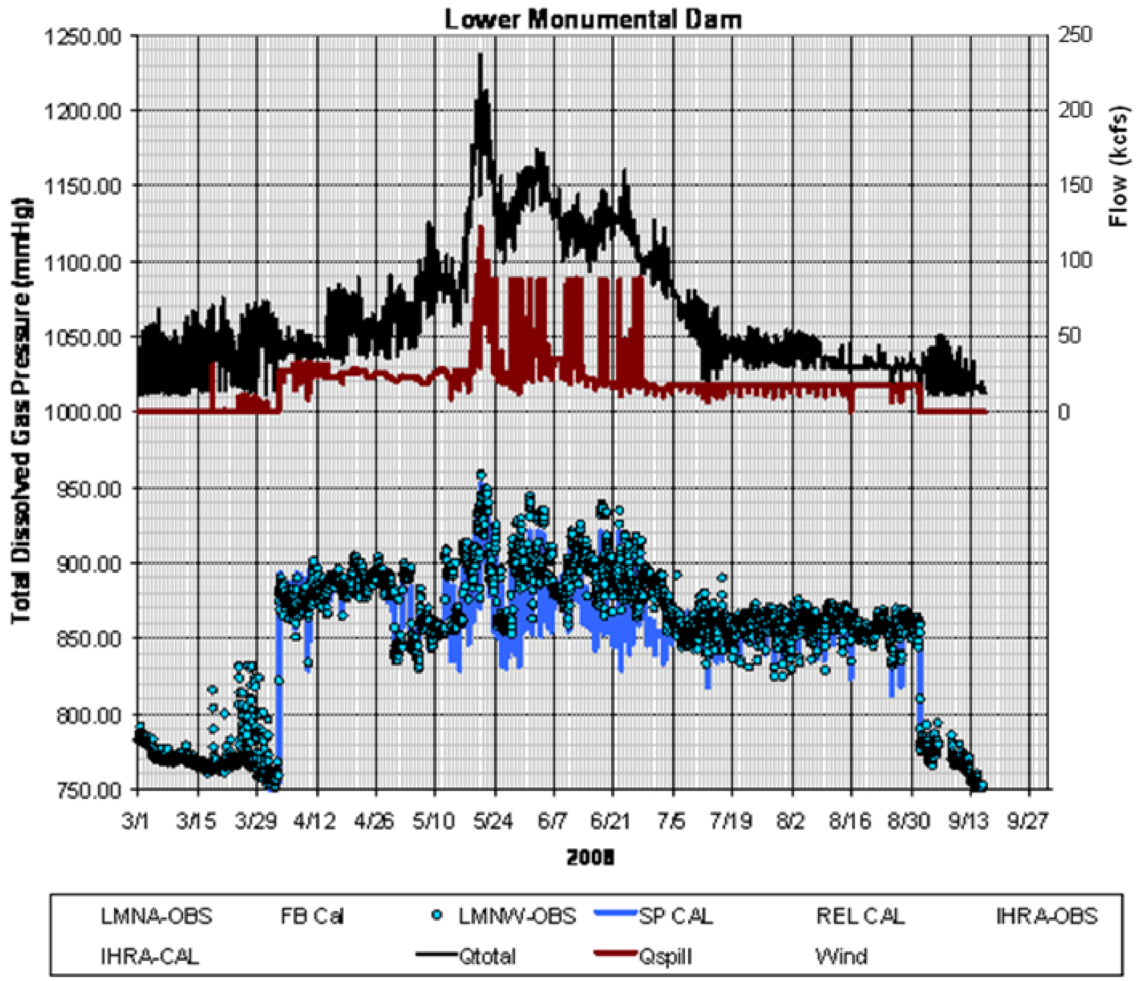

Figure G32. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Monumental Dam, March-September 2008

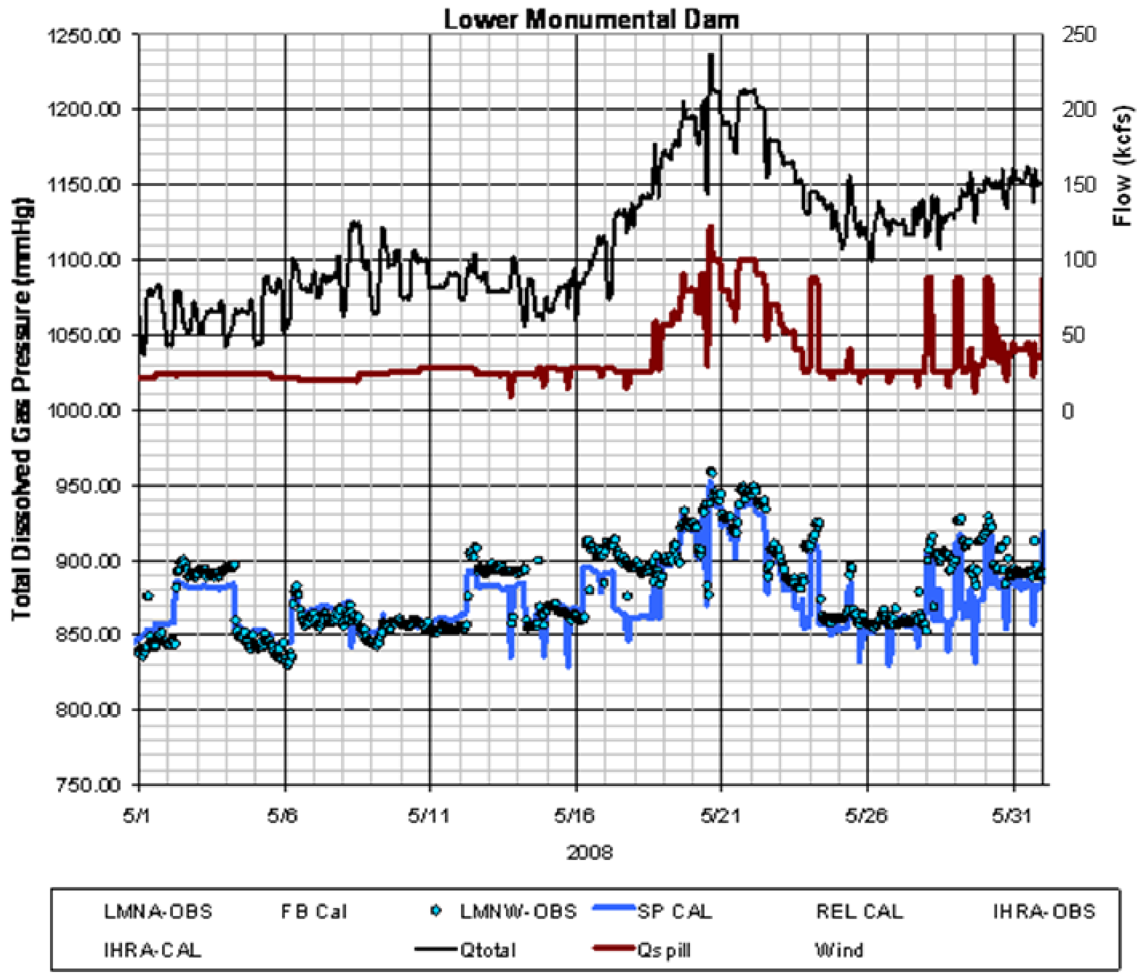

Figure G33. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Monumental Dam, May 2008

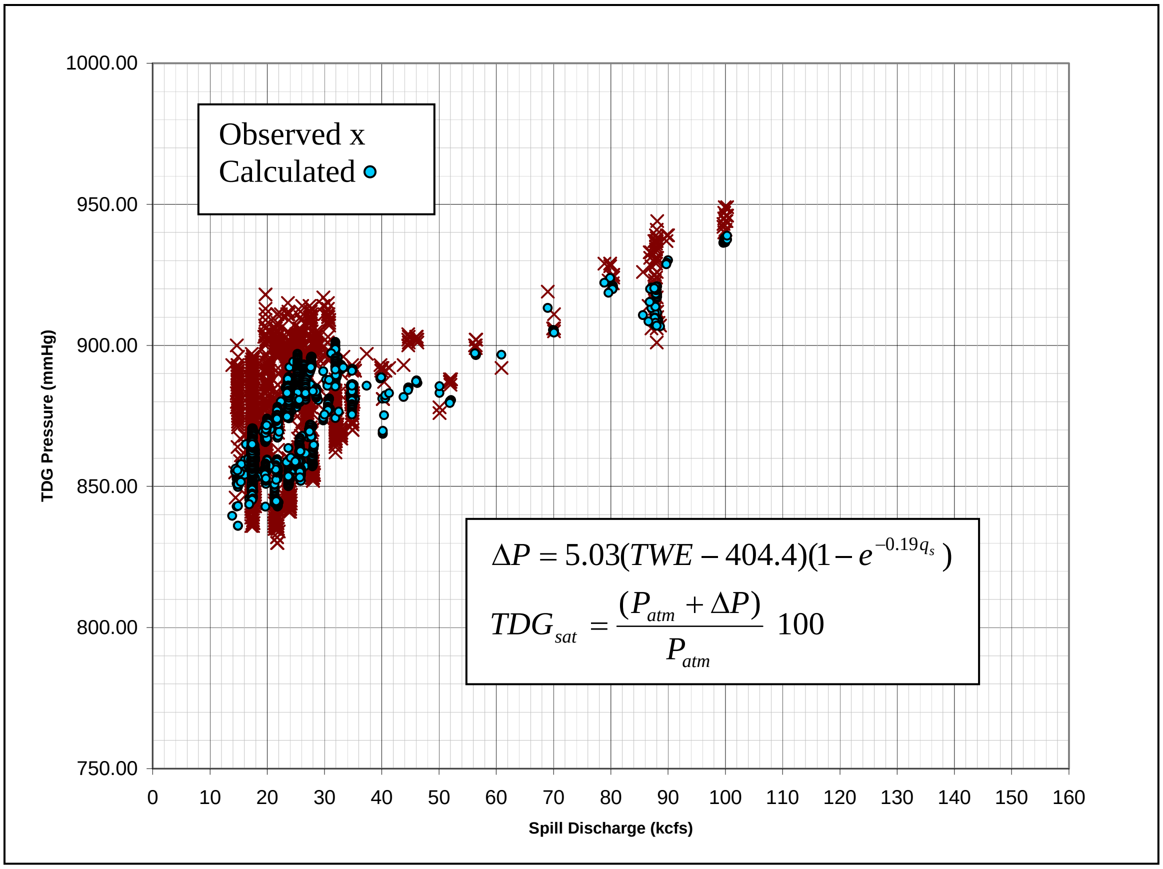

Figure G34. Observed and Calculated Total Dissolved Gas Pressure in the Snake River below Lower Monumental Dam as a Function of Spillway Discharge, 2008

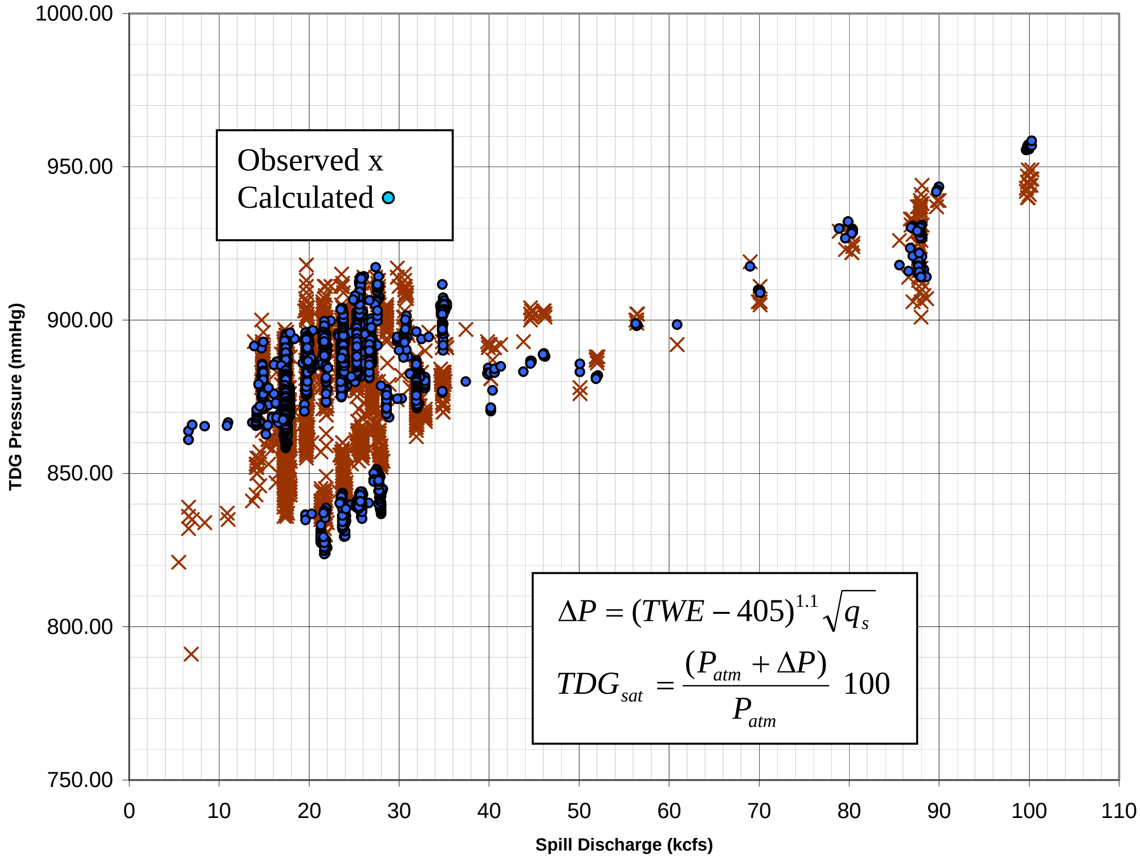

Figure G35. Observed and Calculated Total Dissolved Gas Pressure in the Snake River below Lower Monumental Dam as a Function of Spillway Discharge, 2008

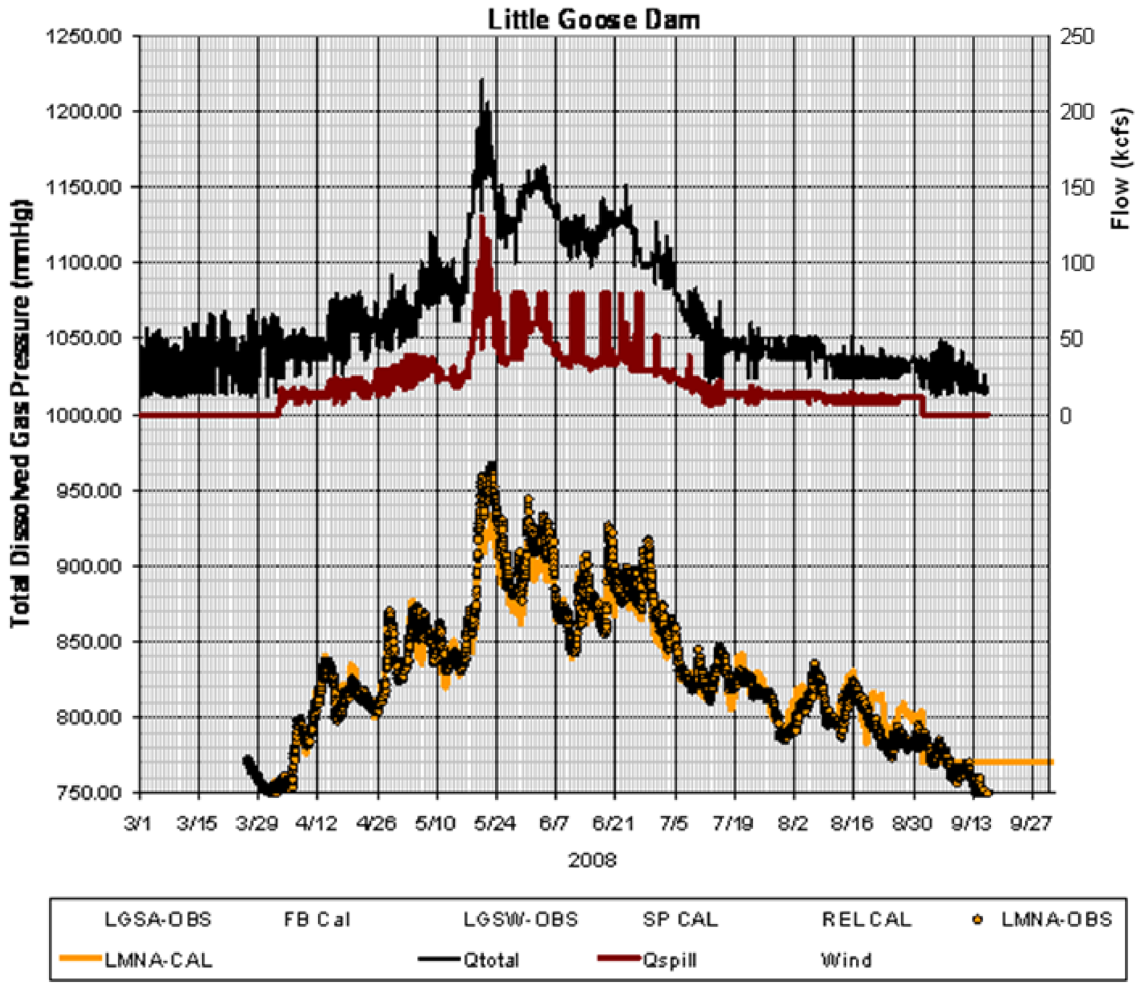

Figure G36. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Lower Monumental Dam, March-September 2008

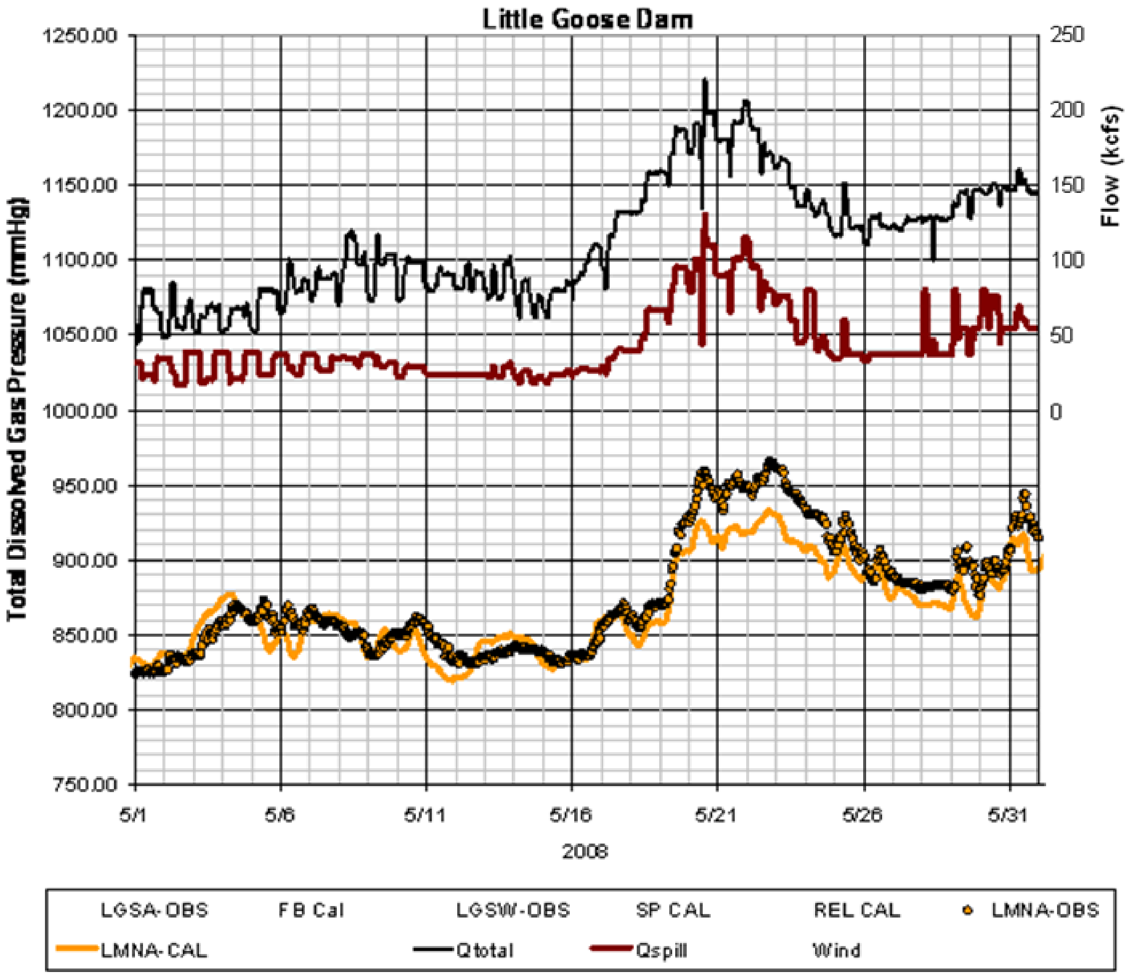

Figure G37. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Lower Monumental Dam, May 2008

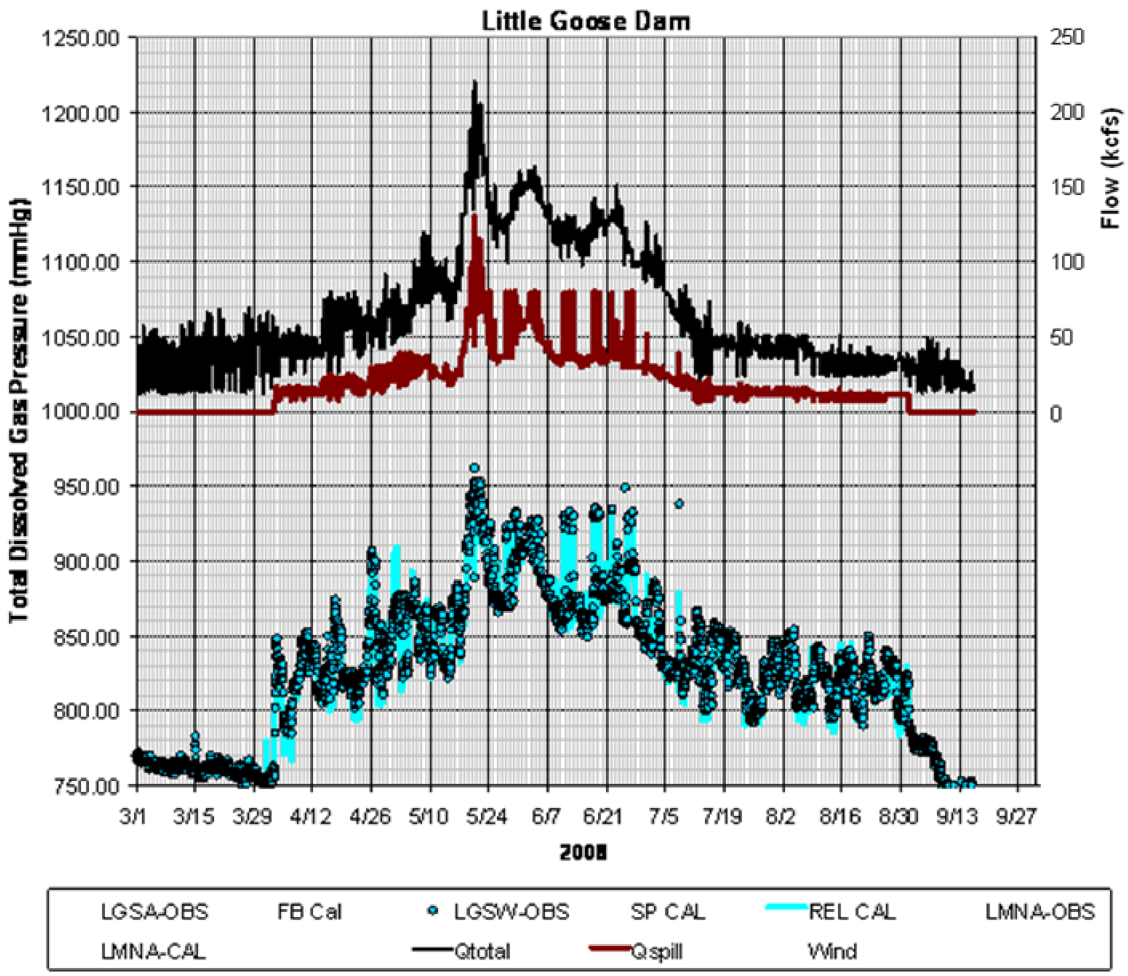

Figure G38. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Little Goose Dam, March-September 2008

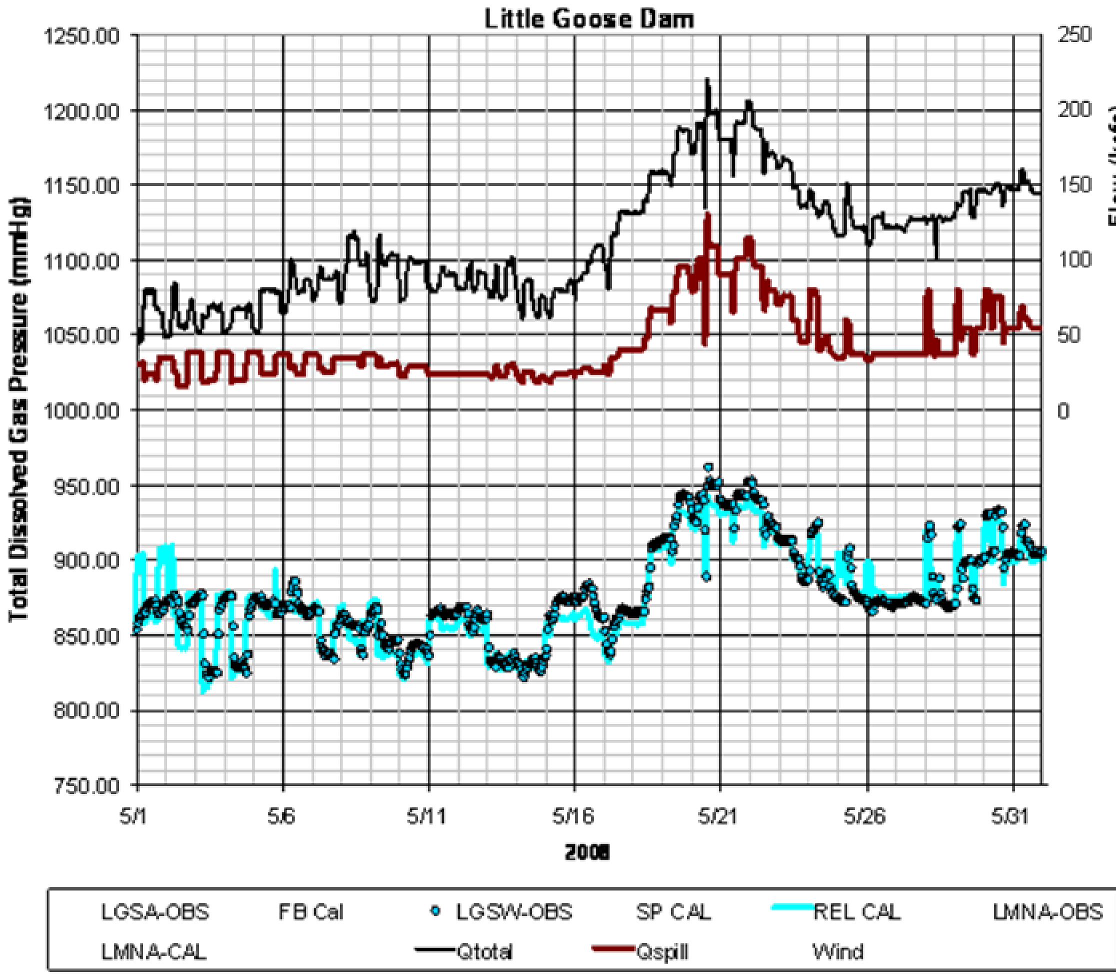

Figure G39. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Little Goose Dam, May 2008

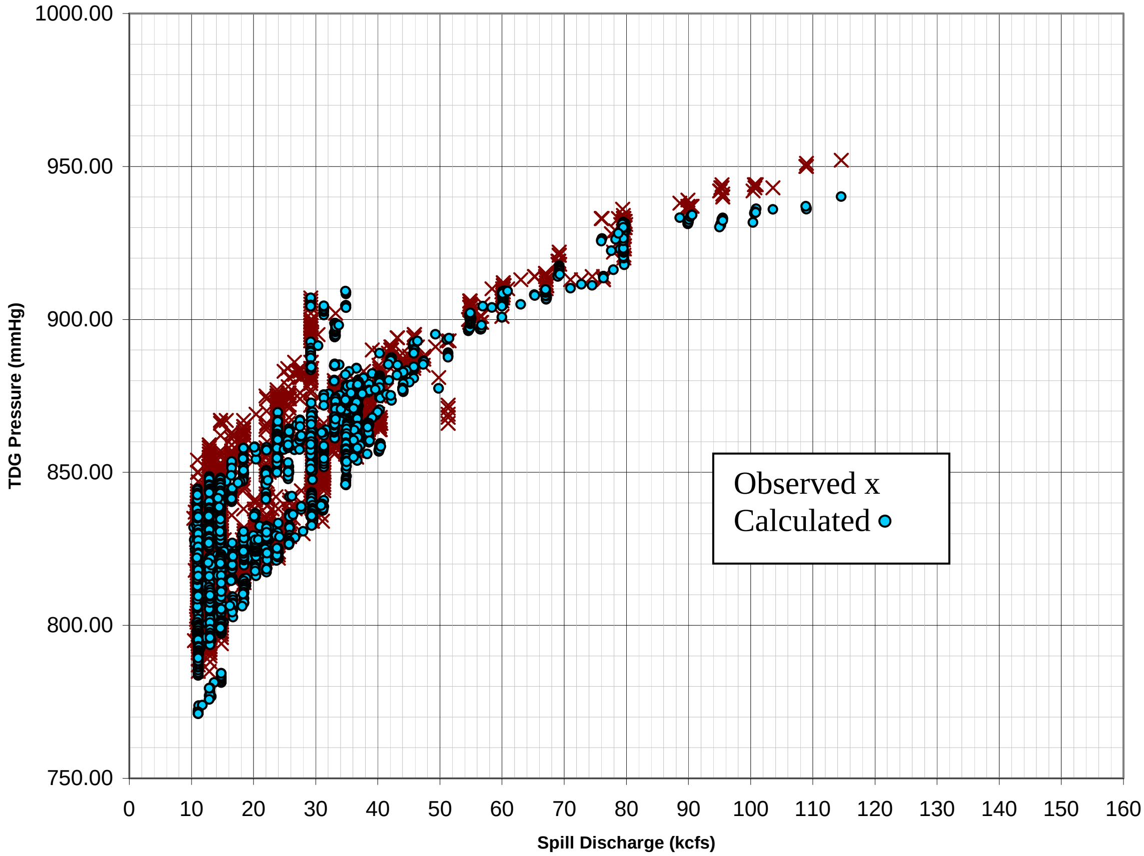

Figure G40. Observed and Calculated Total Dissolved Gas Pressures as a Function of Spillway Discharge in the Snake River at the tailwater channel downstream from Little Goose Dam, 2008

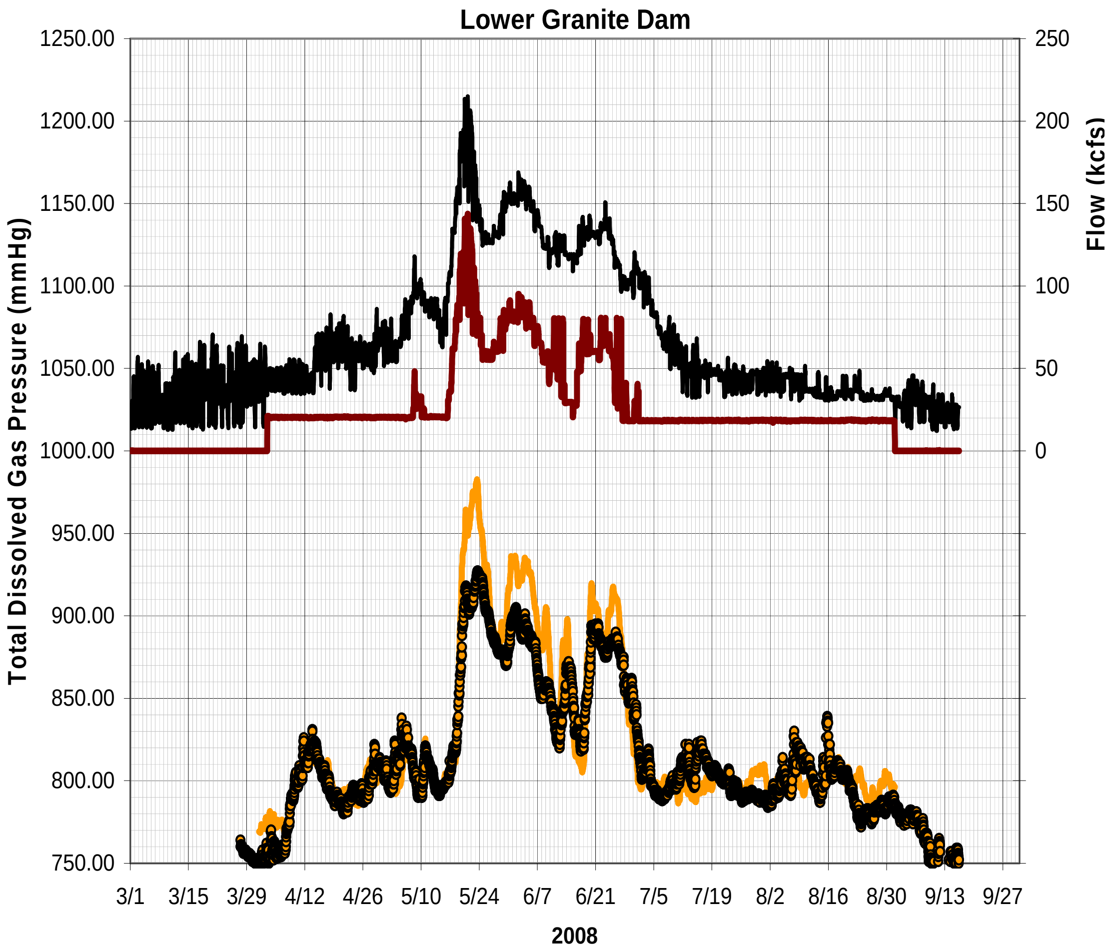

Figure G41. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Little Goose Dam, March-September 2008

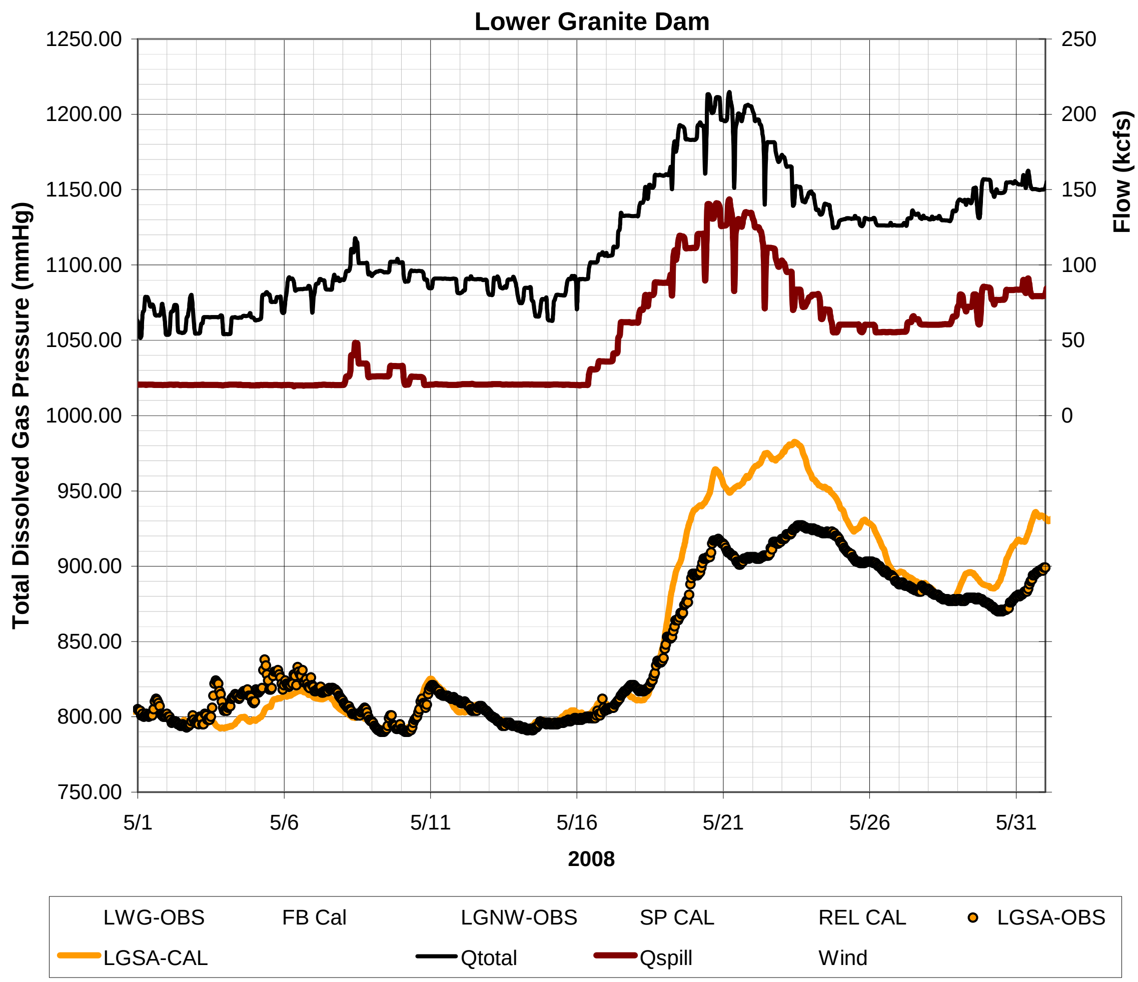

Figure G42. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Little Goose Dam, May 2008

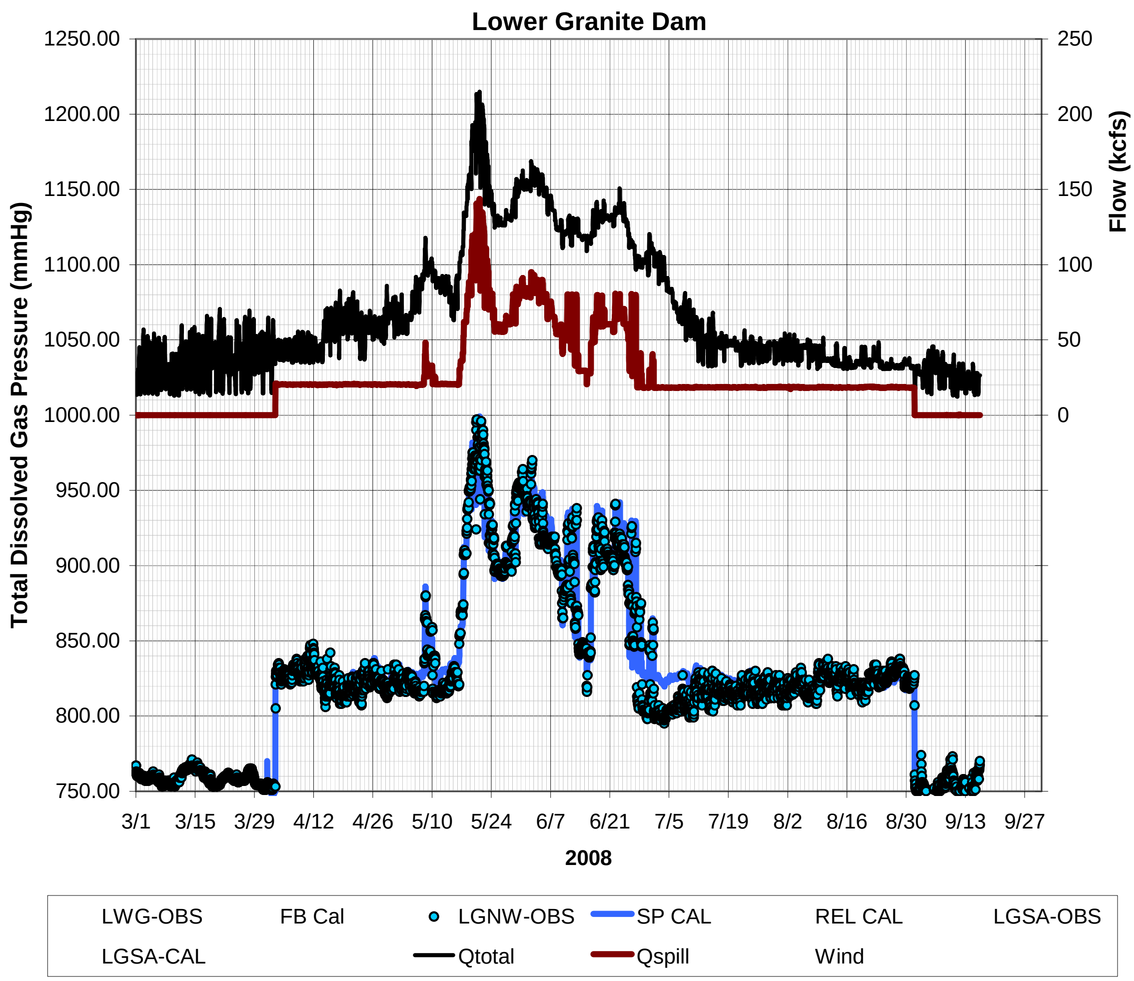

Figure G43. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, March-September 2008

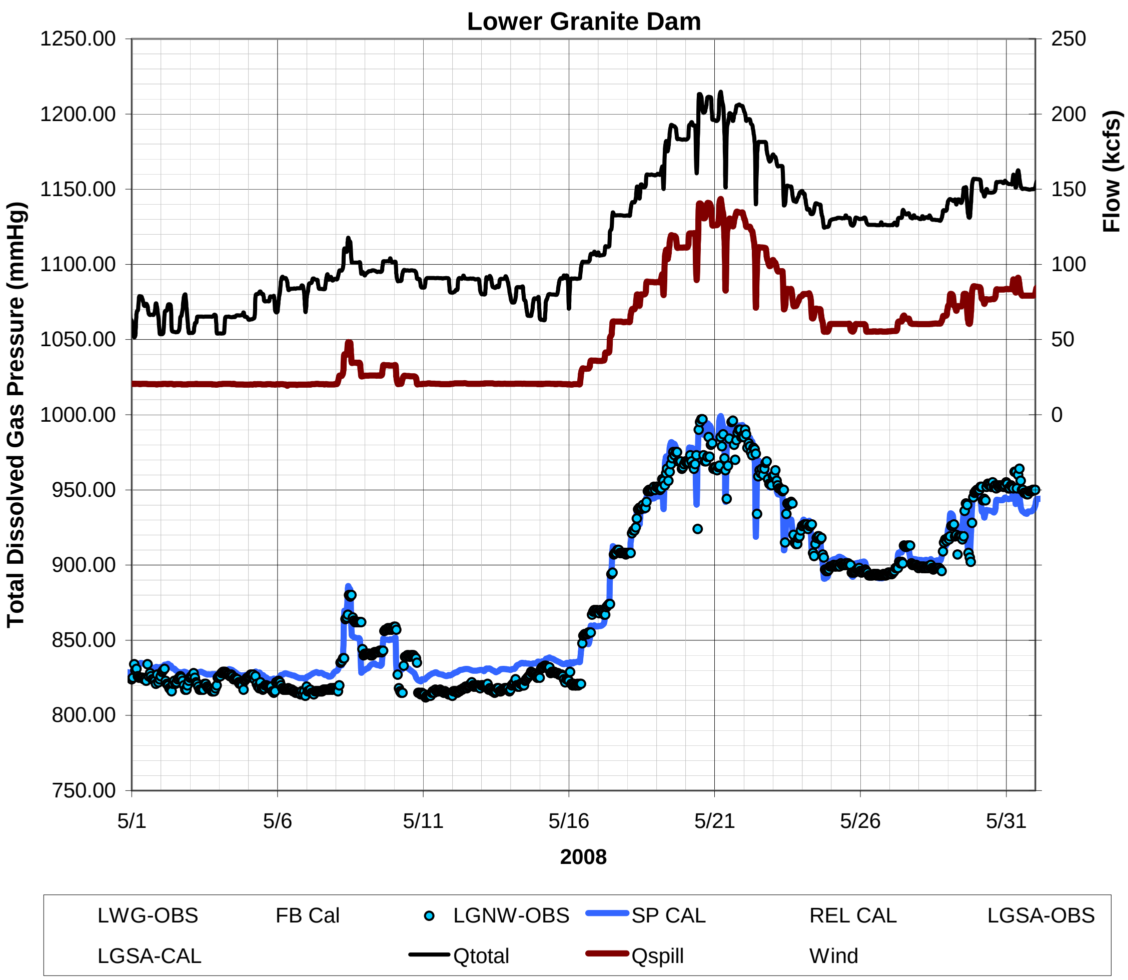

Figure G44. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, May 2008

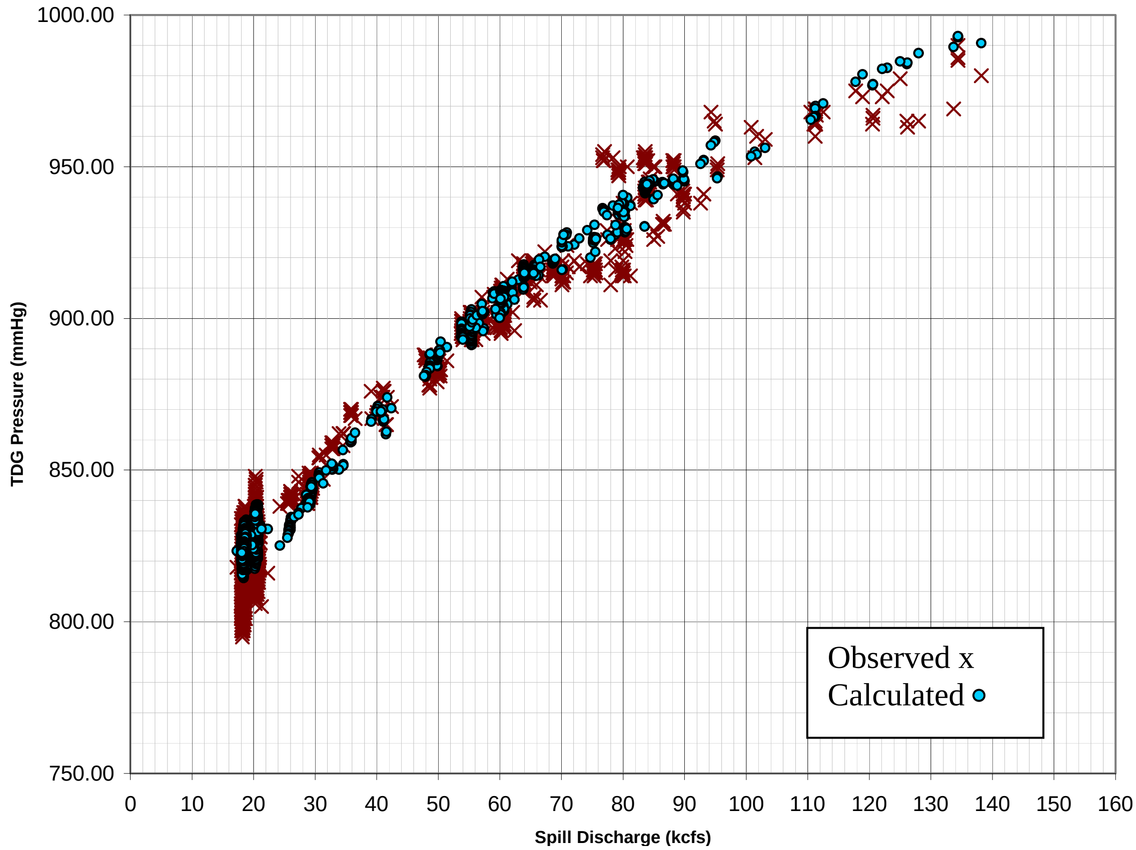

Figure G45. Observed and Calculated Total Dissolved Gas Pressure in the Snake River below Lower Granite Dam as a Function of Spillway Discharge, 2008

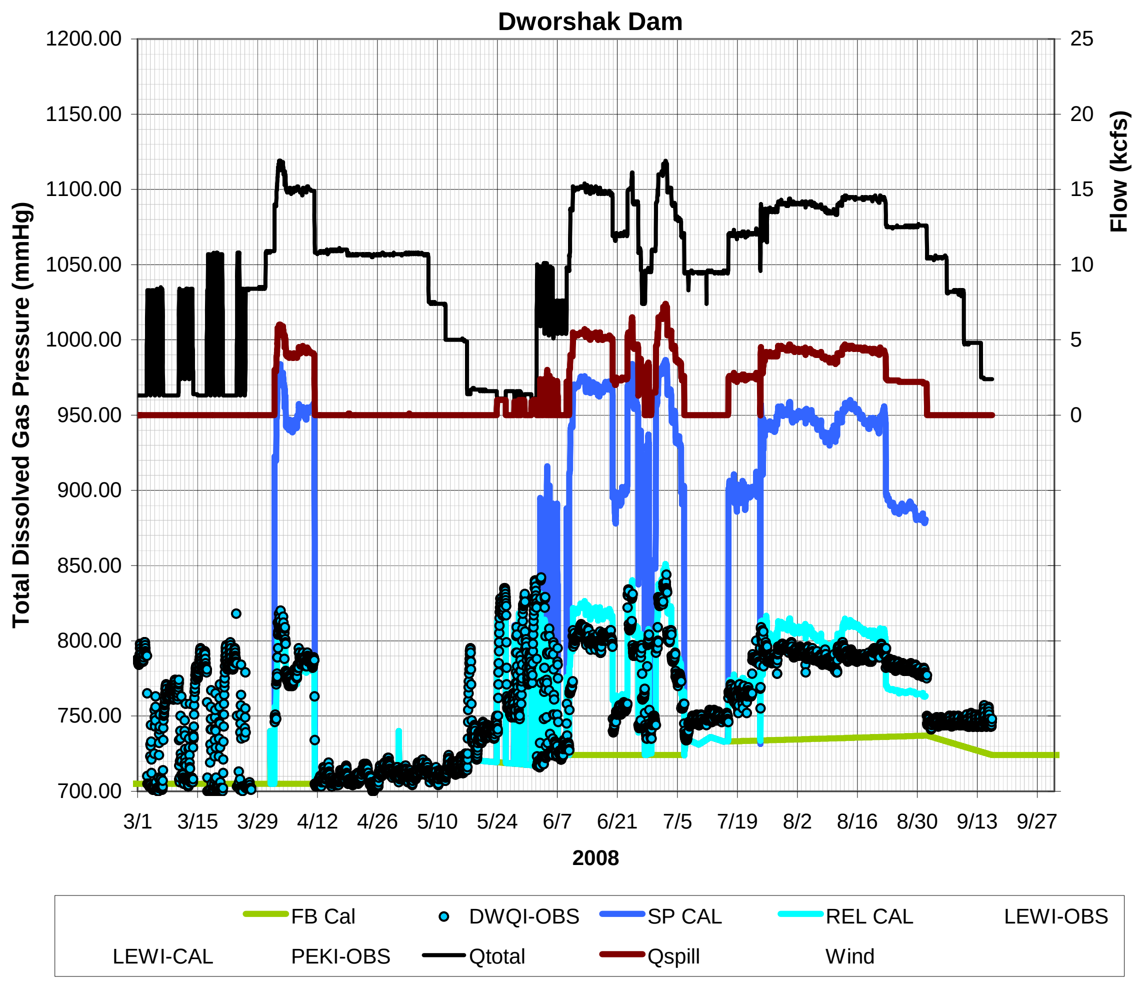

Figure G46. Observed and Calculated Total Dissolved Gas Pressures in the Clearwater River in the tailwater channel downstream from Dworshak Dam, March-September 2008

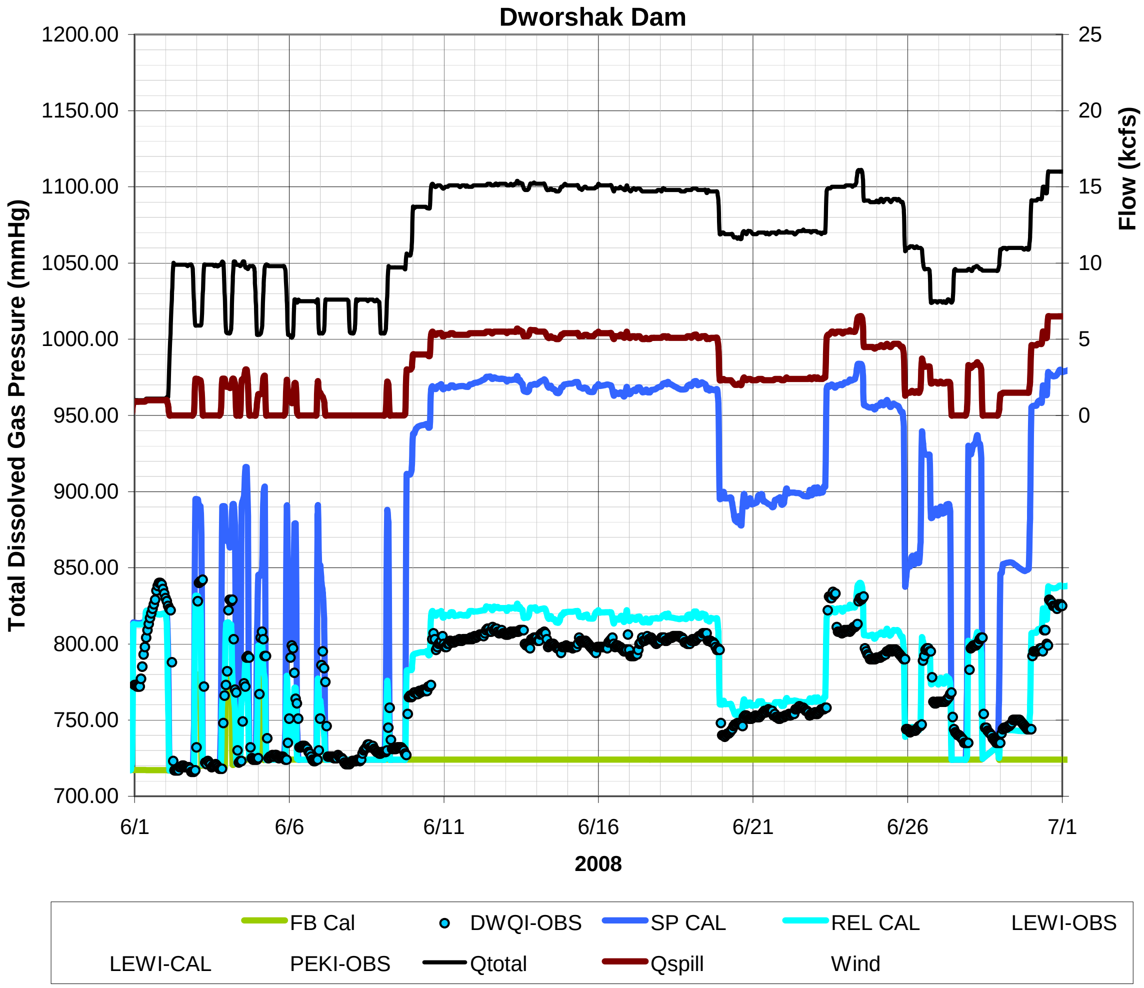

Figure G47. Observed and Calculated Total Dissolved Gas Pressures in the Clearwater River in the tailwater channel downstream from Dworshak Dam, June 2008

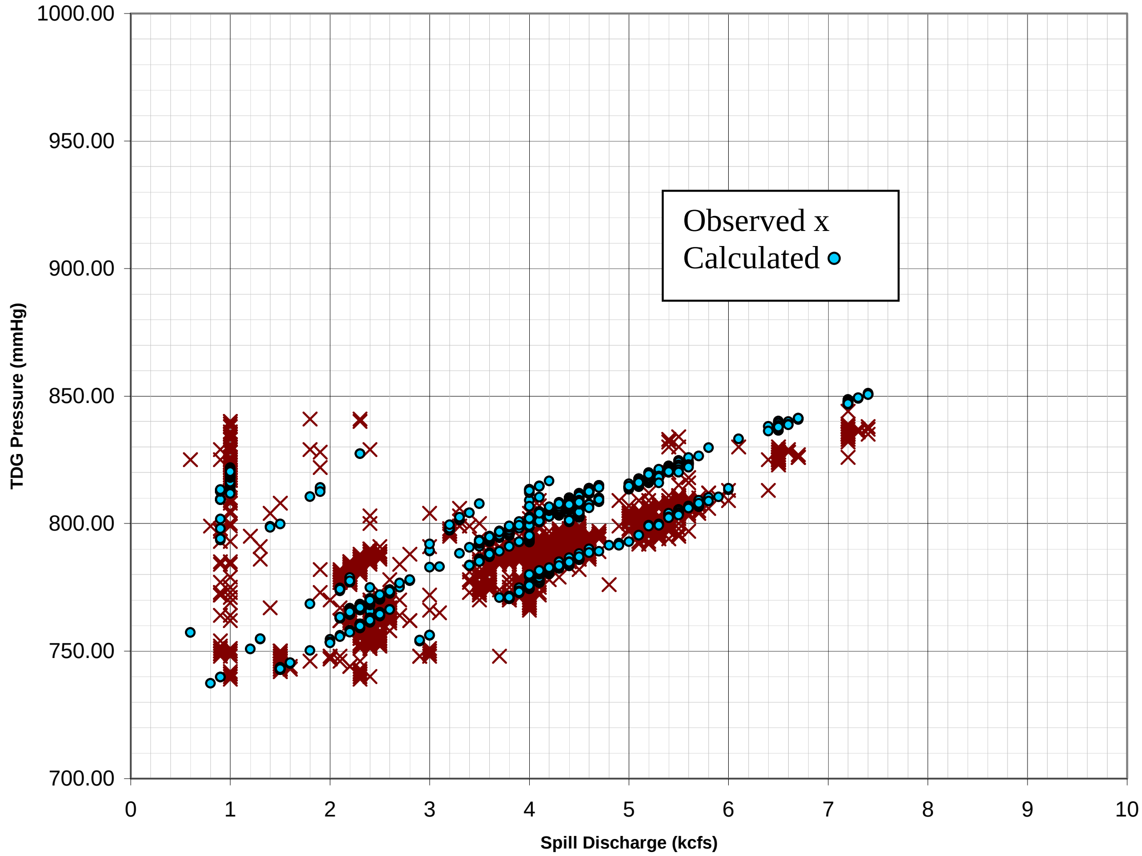

Figure G48. Observed and Calculated Total Dissolved Gas Pressure in the Clearwater River below Dworshak Dam as a Function of Spillway Discharge, 2008