APPENDIX E

SYSTDG STATISTICAL EVALUATION

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Introduction

SYSTDG is a decision support tool used to estimate total dissolved gas (TDG) pressures resulting from project operations on the Columbia, Snake, and Clearwater Rivers. In an effort to quantify the uncertainty of SYSTDG estimates and improve modeling accuracy and reliability, a statistical evaluation of the predictive errors was performed on observed TDG levels during the 2006 fish passage season on the Columbia and Snake Rivers. This evaluation was conducted by comparing SYSTDG-calculated total dissolved gas pressures to observed TDG pressures measured by the fixed monitoring stations (FMS) located in the forebays and tailwaters of Corps operated dams within the Columbia Basin. The dams of interest included Bonneville Dam, The Dalles Dam, John Day Dam, McNary Dam, Ice Harbor Dam, Lower Monumental Dam, Little Goose Dam, Lower Granite Dam and Dworshak Dam.

Approach

SYSTDG simulations were run for the entire 2006 spill season for one project and river reach at a time so that predictive errors could be calculated independently for each dam and river reach. Predictive errors were calculated by subtracting the observed TDG pressures from calculated forebay or tailwater fixed monitoring station TDG pressures on an hourly basis. The tailwater FMS comparison was dependent upon the location of the sampling station relative to the mixing zone of project releases. In most cases, the tailwater fixed monitoring stations are located in either spillway flows undiluted from powerhouse flows or in mixed river waters. The predictive errors were calculated only during active spillway operations at each project at the tailwater FMS. The TDG pressures transported to the forebay of the next downstream dam were used to determine the predictive error during the period from April 1-August 31 for the Snake River and Lower Columbia River Projects. In each simulation the observed temperatures and total pressures were used as boundary conditions for the simulation. Where forebay and tailwater temperatures were different by over 0.3^{o} C, the observed forebay TDG pressure was approximated by linearly interpolating between total pressure observations where temperatures were within 0.3^{o} Celsius. 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 fixed monitoring stations is the lagged response of TDG pressures to the change in spill operation. Depending upon the location of the tailwater FMS, it may take up to 5 hours for a TDG response, from a given operation at a dam, to show up at the monitoring station. A mistake in the timing of comparing a calculated and observed response at a tailwater FMS can result in a large predictive error. The operational records used in these simulations were averaged on an hourly basis. Any operational change occurring within the hour was prorated by the cumulative discharge to determine the average hourly value. This hourly average operation falls between actual operating conditions introducing an erroneous result. In some cases, the spill pattern as established in the 2006 fish passage plan or auxiliary spill patterns designed for low flow summer spill were not implemented at the dam. The model predictions are dependent upon the number of spillway bays that were active for any spill operation. The presence of local TDG gradients near a FMS introduced by thermal patterns or project operations can bias the observed TDG pressure and introduce a prominent source of error when comparing to model estimates. Thermally induced errors are common at forebay fixed monitoring stations where a 1° C increase in temperature above bulk river conditions can result in a 2-3 percent increase in the TDG saturation. Sampling errors at tailwater stations have been identified at many of the projects in the study area and will be noted in greater detail in the following discussion of study findings. The challenge in reviewing the properties of the predictive errors is to determine the source of this error, whether it be biased observed conditions or misrepresentation of conditions from a modeling standpoint.

Background

The Columbia River flows in 2006 were above average during the fish passage season resulting in longer periods of forced spill and greater frequencies of TDG saturation in exceedance of the state water quality standards. The monthly average flow in the Columbia River at The Dalles Dam during the 2006 season was compared to flow conditions from 1975-2006 in Figure E1. The flows in April of 2006 were high compared to typical flow conditions as only three years experienced a high monthly average flows. The average flow in May of 2006 was well above average falling in the upper quartile of monthly flows observed since 1975. The monthly flows in June, July and August of 2006 were slightly above the 32 year average for these months.

On the Lower Columbia River, McNary Dam spilled considerably higher rates of water during the 2006 fish passage season when compared to the other dams. The higher spill rates at McNary were the result of the smaller powerhouse capacity and the higher voluntary spill capacity as limited by TDG water quality standards. A statistical summary of the hourly project operations in the Lower Columbia River are shown in Table E1 for the period of April 1- August 31. The average spill at McNary was 124.4 kcfs compared to 101.3 at Bonneville Dam, 91.3 at The Dalles Dam, and 92.8 kcfs at John Day Dams. McNary Dam spilled almost 49 percent of the Columbia River flows during the fish passage season compared to only 35.3 percent at John Day Dam. The highest hourly spill of 252.3 kcfs occurred at The Dalles Dam while at McNary Dam over 5 percent of the hourly spillway discharges exceeded 200 kcfs. It is curious that the average total river flow was 11 kcfs less at The Dalles Dam compared to McNary Dam. The average Columbia River Flow at McNary was just 3.6 kcfs less than observed at Bonneville Dam despite the added inflows from the John Day River, Deshutes River, Hood River, and White Salmon River.

Table E1. Statistical Summary of Hourly Project Flows from April 1-August 31, 2006 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	3672	3672
Avg		258.6	101.3	244.2	91.3	248.7	87.7	255	124.4	157.7	35.7
Stdev		91	35.1	91.4	44.6	92.8	52.2	87.6	52.5	52.3	36.8
Max		408.1	180	408.5	252.3	405.8	240.9	410.7	234.4	296.9	158.5
Min		113.2	0	79.9	0	71.9	0	79.3	0	36.2	0
Qsp/Qtot			39.2		38.4		35.3		48.8		22.6
	1%	117.5	2.2	93.5	0	84	0	97	0	43.7	0
	5%	119.3	64.3	102.7	36.2	101.9	22.1	124.9	46.2	73.7	0
	25%	168.9	75.5	155.3	58.3	159.6	44.9	168.8	83.3	121.3	11
	50%	274.6	95.7	256.2	96	262.3	75	271.1	120	158.9	22.4
	75%	338.6	129.3	328.9	117.1	335.1	132.4	340.2	166.2	190	50
	95%	386.3	160.1	371	156.7	376.8	170.3	376.5	207.8	252.3	112.2
	99%	399.2	174.1	390.7	250.1	396.4	210	395.1	228.4	277.9	128.9

*Units kcfs except for Qspill/Qtot entry.

The Snake River contributed about one-third of the flow to the Lower Columbia River during the period from April 1- August 31, 2006. Ice Harbor spilled about 50.5 percent of the Snake River flow during this period compared to 29.2, 29.1, and 38.4 percent for Lower Monumental, Little Goose, and Lower Granite Dams, respectively as listed in Table E2. The spill at Ice Harbor Dam was governed by forced spill conditions and biological testing of the raised spillway weir (RSW). The largest hourly spill of 110 kcfs occurred at Ice Harbor Dam during the 2006 spill season. The spill volume at Lower Granite Dam was considerably larger than at Little Goose and Lower Monumental 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 restricted to a maximum of 4.6 kcfs as constrained by the Idaho State water quality standard for TDG of 110 percent.

The total dissolved gas saturation was monitored in the forebay and tailwater of each Lower Columbia River Dam throughout the spill season of 2006. The average TDG saturation in the forebay of each dam was nearly identical ranging from a high of 110.9 at Bonneville to a low of 109.1 at John Day Dam. The average TDG saturation at CWMW located about 22 miles downstream of Bonneville Dam in mixed water, was slightly higher at 113.1 percent as listed in Table E3. The frequency of hourly observations greater than 115 percent at forebay stations ranged from 32.7 percent at CWMW to a low of 11.2 percent in the forebay of John Day Dam. The TDG saturation rarely exceeded 120 percent at these forebay fixed monitoring stations. The average TDG saturation at the tailwater stations ranged from 119.2 percent at Bonneville to 115.2 percent at The Dalles Dam. 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 34.9 percent below Bonneville Dam to only 3.7 percent at The Dalles Dam. With the exception of The Dalles Dam, the frequency of the tailwater station exceeding the 120 percent criteria was greater than the frequency of the next forebay station exceeding 115 percent. These summary TDG statistics were based on hourly observations and not daily statistics composed of the highest 12 hourly observations as referenced by the state water quality standards.

Table E2. Statistical Summary of Hourly Project Flows from April 1-August 31, 2006 on the Columbia River

Project	Ice Harbor		Lower Monumental		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	84.59	42.75	83.33	24.26	82.18	23.91	83.32	32.03	9.03	0.84
Stdev	50.37	28.01	49.61	17.04	47.92	17.63	48.13	22.01	3.47	1.49
Max	222.3	129.9	227.3	109.1	204.4	106.2	205.7	130.7	15.2	4.8
Min	15.7	0	15.1	0	17.6	0	20.3	0	1.6	0
Qsp/Qtot		50.5		29.2		29.1		38.4		9.3
1%	18.87	0	17.77	0	18.4	0	21.5	0	1.6	0
5%	23.6	12.9	23.8	10.7	24.4	7.4	25	13.06	4.1	0
25%	30.9	19.4	31.3	16.4	35.2	10.9	33.38	18	6.15	0
50%	84.15	36.25	81.3	17.9	80	20.3	76.65	20.2	9.9	0
75%	127.4	59.9	125.53	24.8	122.43	29.4	124.8	42.85	11.2	1.6
95%	167.05	94.8	161.95	65.3	160.59	65.85	160	75.1	14.8	4.4
99%	193.93	110.03	192.49	95	183.55	79.8	184.72	105	15	4.6

*Units kcfs except for Qspill/Qtotal entry.

The total dissolved gas saturation was monitored in the forebay and tailwater of each Lower Snake River Dam throughout the spill season of 2006. The average TDG saturation in the forebay of each Snake River Dam increased in a downstream direction as listed in Table E4. The average forebay TDG saturation at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams were 103.7, 110.4, 112.6, and 113.0 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 31.6 percent at Lower Monumental Dam. Unlike the projects in the Lower Columbia River, the TDG saturation in the forebay of Ice Harbor, Lower Monumental, and Little Goose

Dams exceeded 120 percent saturation on a frequency of 5.4, 8.7, and 4.6 percent of the time during the 2006 spill season. The average TDG saturation at the tailwater stations ranged from 117.0 percent at Lower Monumental Dam to 114.3 percent at Little Goose Dam. The frequency of hourly TDG observations exceeding 120 percent at the tailwater monitoring stations ranged from 15.7 percent below Lower Granite Dam to only 8.3 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. The TDG saturation exceeded 125 and 130 percent at the tailwater station below Lower Granite Dam 6.2 and 2.9 percent of the time.

Table E3. Statistical Summary of Hourly Project Flows from April 1-August 31, 2006 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	3663	2520	3668	3668	3601	3668	3634	3667	3658	3656
Avg	113.1	115.4	119.2	110.9	115.2	110.3	117.2	109.1	117	110.4
Stdev	3.3	3.3	2.71	4.97	3.37	4.27	3.7	4.7	3.16	4.37
Max	120.5	122.1	127.5	121.1	123.1	123.6	135.4	118.1	124.1	119.8
Min	103.3	104.2	111.9	101.3	104.1	102.2	104.1	100.5	103.8	100.4
100	100	100	100	100	100	100	100	100	100	100
105	98.5	98.8	100	82.4	99.2	88.2	99	72.6	98.8	85.9
110	82.6	94.4	100	58.8	95.5	52.9	96.1	46.2	98.5	55.9
115	32.7	63.2	98.6	28.3	55	16.4	76.2	11.2	76.7	17.4
120	0.3	3.6	34.9	0.9	3.7	0.4	18.9	0	17.7	0
125	0	0	1.8	0	0	0	0.6	0	0	0
130	0	0	0	0	0	0	0.5	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 mean, minimum, maximum, standard deviation, and confidence limits and are listed in the four tables below. Table E5 and E7 describe the predictive errors statistics in mm Hg of pressure while Table E6 and E8 describe the predictive errors in percent saturation. The predictive error statistics expressed in terms of percent saturation shown in Tables E6 and E8 were derived by dividing the seasonal average barometric pressure at each FMS into the predictive error of the total dissolved gas pressure and expressed as a percentage.

Camas/Washougal (CWMW)

A hind cast of Bonneville operations was 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 2006. (Note: Camas/Washougal is referred to the tidal reach abbreviated TID within SYSTDG). The predictive error of the hourly total dissolved gas pressure was determined throughout the interval involving 3569 observations. A total of 103 TDG pressure records at CWMW were either missing or removed from this analysis during this study period. The calculated TDG pressures under-estimated observed conditions by an average of 1.3 mm Hg (average predictive error +1.3 mm Hg) and the standard deviation of the predictive error was 6.9 mm Hg as listed in Table E5. The size of the predictive error in 2006 at CWMW was slightly less than determined in 2005 despite the wide range of project operations (standard deviation of the predictive error was 10.5 mm Hg in 2005). The 50 percent confidence interval for the predictive error ranged from +4.5 to -3.0 mm Hg of pressure and the 80 confidence interval ranged from +9.9 to -4.7 mm Hg. The seasonal time history of observed and calculated TDG pressures at the CWMW gage is shown in Figure E2. There is little difference in the seasonal values of the observed and calculated TDG pressures at the CWMW gage resulting from spillway operations. The calculated and observed conditions are shown throughout the month of June in Figure E3. A strong daily cycle is evident in these records caused in part by the thermal exchange that is evident throughout this shallow open river reach. The nighttime high percent spill events at Bonneville Dam that were scheduled during the summer months coincided with the peak daily heating cycling resulting in a daily range of TDG pressures of as much as 80 mm Hg at the CWMW gage. The contribution of TDG loading from the Bonneville 2nd powerhouse corner collector outfall becomes more important during the lower total river flow conditions in July. In summary, the predictive error was generally small at the CWMW station with 50 percent of the errors less than +/-0.6 percent saturation and 80 percent of the errors less than +/-1.3 percent saturation as listed in Table E6.

Table E4. Statistical Summary of Hourly Project Flows from April 1-August 31, 2006 on the Columbia 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	3670	3670	3666	3617	3670	3566	3657	3670	3663
Avg	115.4	113	117	112.6	114.3	110.4	115.5	103.7	102.3
Stdev	4.03	3.73	3.2	5.3	3.97	4.51	5.55	2.33	3.37
Max	126.3	124.9	128.8	130.6	141.4	125.7	145.9	110	115.4
Min	102.1	102.2	97.3	102.1	100.8	101.3	100.6	98.1	80
100	100	100	100	100	100	100	100	97.8	79.5
105	98.8	97.7	98.7	96.1	98.8	93.4	98.8	33.3	18.7
110	92.1	81	97.6	65.5	94.1	45.9	90.1	0.1	0.4
115	55	29.5	79.1	31.6	37.1	14.4	45	0	0.1
120	11.7	4.2	14.4	8.7	8.3	5.4	15.7	0	0
125	0.9	0	0.6	2.1	1.4	0.7	6.2	0	0
130	0	0	0	0.1	0.1	0	2.9	0	0

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 2006, in an effort to determine the predictive error of SYSTDG estimations in Bonneville Dam tailwater. The official tailwater compliance station below Bonneville Dam is located in the spillway exit channel at station CCIW. However, the long term FMS at WRNO, which is located about 6 miles downstream from the dam in waters that are approaching well-mixed conditions, was inactive from July 13 to August 30 during the 2006 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 over-estimated observed conditions by an average of 3.8 mm Hg (average predictive error -3.8 mm Hg) and the standard deviation of the predictive error was 11.7 mm Hg as listed in Table E7. The 50 confidence interval of the predictive error ranged from +0.8 to -9.1 mm Hg of pressure and the 80 confidence interval ranged from +8.2 to -11.8 mm Hg of pressure. The standard error of TDG pressure at the WRNO station during the 2006 season was significantly less than determined in 2005 (11.7 to 15.1 mm Hg). The seasonal time history of observed and calculated TDG pressures at the WRNO gage is shown in Figure E4. The seasonal TDG values at Warrendale are closely correlated to the spillway operations at Bonneville Dam and are a function of the TDG levels produced at upstream dams and discharged through the turbines at Bonneville Dam. The calculated and observed TDG pressures at WRNO are shown throughout the month of June in Figure E5. The TDG saturation rarely exceeded 120 percent at WRNO during the 2006 fish passage season because of the influence of the dilution of spillway flows by powerhouse flows. Those occurrences of TDG saturation greater than 120 percent at WRNO were generally associated with high TDG levels in the forebay of Bonneville Dam. The sources of TDG pressure observed at the WRNO gage include both spillway and Bonneville 2nd Powerhouse corner collector releases.

Table E5. Statistical summary of the predictive errors of the observed and calculated total dissolved gas pressures at forebay fixed monitoring station, April 1-August 31, 2006.									
Parameters		Predictive Error at Forebay FMS* (mmHg)							
Station		LGSA	LMNA	IHRA	MCNA	JDY	TDA	BON	CWMW
Number of Observations		3464	3516	3569	3438	3573	3550	3569	3569
Average		0	-14.1	-11.8	-4.3	4.3	-1.3	-1.5	1.3
Standard Deviation		18.3	19.7	10.6	11	9.2	7.4	6.7	6.9
Maximum		57.4	35	16.4	40.7	34.6	22.7	22.6	32.3
Minimum		-53.2	-64.5	-44.8	-41.1	-16.8	-33.5	-20	-26.5
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	-32.2	-47.8	-31.2	-21	-9	-12.7	-11.8	-8.2
	10%	-18	-38.3	-24.4	-15	-5.3	-9.1	-8.3	-4.7
	25%	-11.6	-30.3	-19.9	-11.3	-2.4	-6.7	-6.1	-3
	50%	0.4	-10.9	-9	-4.6	3	-1.7	-1.7	0.5
	75%	10.3	1.2	-3.8	2.1	10.3	4.4	2.7	4.5
	90%	22.4	9.2	-0.2	9.5	16.7	8.4	7.3	9.9
	95%	33.9	14.6	1.9	13	21.2	10.8	10	14.8
*Predictive error is the observed minus calculated TDG pressure where negative values reflect an overestimation and positive values reflect an underestimation.									

Table E6. Statistical summary of the predictive errors of the observed and calculated total dissolved gas saturation at forebay fixed monitoring station, April 1-August 31, 2006.									
		Predictive Error at Forebay FMS* (Saturation %)							
Station		LGSA	LMNA	IHRA	MCNA	JDY	TDA	BON	CWMW
Number of Observations		3464	3516	3569	3438	3573	3550	3569	3569
Average		0.3	-1.7	-1.3	-0.3	0.9	-0.2	-0.2	0.17
Standard Deviation		2.5	2.6	1.3	1.5	1.2	1	0.9	0.91
Maximum		8	5	2.4	5.9	5	3.1	3	4.29
Minimum		-6.8	-8.4	-5.6	-5	-1.8	-4.4	-2.7	-3.46
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	-4.1	-6.1	-3.8	-2.5	-0.8	-1.7	-1.6	-1.09
	10%	-2.1	-4.9	-2.9	-1.7	-0.3	-1.2	-1.1	-0.61
	25%	-1.2	-3.8	-2.3	-1.2	0.1	-0.9	-0.8	-0.38
	50%	0.4	-1.3	-0.9	-0.3	0.8	-0.2	-0.2	0.05
	75%	1.7	0.4	-0.3	0.6	1.8	0.6	0.3	0.59
	90%	3.4	1.4	0.2	1.5	2.6	1.1	1	1.3
	95%	4.9	2.1	0.5	2.1	3.2	1.4	1.3	1.93
*Predictive error is the observed minus calculated TDG saturation where negative values reflect an overestimation and positive values reflect an underestimation.									

Bonneville Dam Spillway Exit Channel (CCIW)

A hind cast of Bonneville operations was simulated using the SYSTDG model of the river reach from the Bonneville Dam to the fixed monitoring station located at Camas/Washougal in an effort to determine the predictive error of SYSTDG simulations in the Bonneville Dam spillway exit channel on the bank of Cascade Island (CCIW) from 1 April through 31 August 2006. These TDG properties reflect conditions in spillway releases undiluted from powerhouse flows. The calculated TDG pressures under-estimated observed conditions by an average of

1.3 mm Hg (average predictive error +1.3 mm Hg) and the standard deviation of the predictive error was 6.9 mm Hg as listed in Table E5 under the label of CCIW. The 50 confidence interval for the predictive error ranged from -3.0 to 4.5 mm Hg of pressure and the 80 confidence interval ranged from -4.7 to 9.9 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the CCIW gage are shown in Figure E6. Calculated TDG pressures representing spill were generally higher than the observed conditions at the CCIW gage during June as seen in Figure E7. 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 estimation of TDG levels exiting the spillway channel therefore reflect average conditions that typically exceeded the near shore TDG levels sampled at station CCIW.

Table E7. Statistical summary of the predictive errors of the observed and calculated total dissolved gas pressures at tailwater fixed monitoring stations.

Parameters		Predictive Error at Tailwater FMS* (mm Hg)									
		DWQI	LGNW	LGSW	LMNW	IDSW	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Observations		1032	3551	3573	3570	3576	3564	3516	3507	3574	2422
Average		15.8	7.1	-1	-14.7	-9.5	2.4	-3.9	0.3	-2	-3.8
Standard Deviation		12.3	15.4	13.2	22.3	10.3	10.1	9.8	6.8	14.4	11.7
Maximum		65	81.2	138.8	67.5	38.1	99.6	87.5	34.5	51.6	55.3
Minimum		-195.6	-50.3	-68.2	-84.9	-45.4	-40.7	-84.4	-42.8	-53	-72.9
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	5.2	-12.4	-20.9	-51.3	-27.6	-14.8	-18.2	-10.3	-27.7	-18.6
	10%	7.3	-8	-14.4	-40.6	-21.3	-6.1	-11.8	-5.3	-17.9	-11.8
	25%	10.5	-4.1	-9.5	-30	-16.4	-2.6	-9.2	-3.3	-12.6	-9.1
	50%	17	4.5	0.2	-14.3	-8.1	2.2	-4.7	0.8	-1.1	-4.8
	75%	21.6	16.9	6.7	2.2	-2.7	8	1.2	4.4	9	0.8
	90%	25.6	28	12.7	13.8	2	13.3	8.4	7.5	13.5	8.2
	95%	28	30.9	16.4	19.6	6.4	18.9	12.3	9.7	17	14.9

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

The Bonneville spill pattern applied during the 2006 fish passage season was altered from the 2005 patterns for spill discharges of 100 kcfs and less. The minimum gate setting of 2 ft was applied during these lower spill discharges resulting in fewer than 18 active spill bays for spill of 90 kcfs or less. These inactive bays were generally located in bays 5-15. Alternative spill patterns sensitive to tailwater elevations were identified for spill discharges ranging from 50 to 100 kcfs as described in the 2006 Fish Passage Implementation Plan dated March 31, 2006. In general, the spill was shifted into bays near the shore (bays 1-3, and 16-18) for higher tailwater elevations. Spill patterns were identified for tailwater elevations ranging from 10 to 25 ft. The implementation of these new spill patterns was limited to the month of April because of the excessive and restrictive TDG pressures observed at the CCIW station.

The TDG pressures generated with the new spill patterns were significantly higher than the old pattern for a comparable spill because of the higher unit discharge over bays with flow deflectors at an elevation of 7 ft. The TDG pressure at the CCIW station as a function of the total spill discharge is shown in Figure E8. The variability of TDG pressure for spill of 100 kcfs and less was considerably greater than for high spill conditions. TDG saturations greater than 125 percent saturation were generated for spills of less than 80 kcfs. The spillway capacity as limited by generation of water with a TDG saturation of 120 percent is shown to range from 80 to 140 kcfs in this figure.

Table E8. Statistical summary of the predictive errors of the observed and calculated total dissolved gas saturations at tailwater fixed monitoring stations.

Parameters		Predictive Error at Tailwater FMS* (Saturation %)									
		DWQI	LGNW	LGSW	LMNW	IDSW	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Observations		1032	3551	3573	3570	3576	3564	3516	3507	3574	2422
Average		2.1	1	-0.1	-2	-1.3	0.3	-0.6	-0.3	-0.5	-0.9
Standard Deviation		1.7	2.1	1.8	3	1.4	1.3	1.4	0.9	1.9	1.5
Maximum		8.9	11	18.6	9	5.1	13.2	11.5	4.3	6.6	6.8
Minimum		-26.7	-6.8	-9.1	-11.4	-6	-5.3	-11.3	-5.9	-7.2	-9.9
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	0.7	-1.7	-2.8	-6.8	-3.7	-1.9	-3	-1.7	-4	-2.7
	10%	1	-1.1	-1.9	-5.4	-2.9	-0.8	-1.6	-1.1	-2.6	-1.9
	25%	1.4	-0.6	-1.3	-4	-2.2	-0.3	-1.3	-0.8	-1.9	-1.6
	50%	2.3	0.6	0	-1.9	-1.1	0.3	-0.7	-0.2	-0.4	-0.9
	75%	2.9	2.3	0.9	0.3	-0.3	1	0.1	0.3	1	-0.2
	90%	3.5	3.8	1.7	1.9	0.3	1.8	1.1	0.7	1.6	0.7
	95%	3.8	4.2	2.2	2.6	0.8	2.5	1.6	1	2	1.5

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

The fixed monitoring station CCIW contained data that changed abruptly (20-30 mm Hg) over the course of one hour during constant project operations. An example of this type of TDG response is shown in Figure E9 (label a) where on June 9th during a spill of 148 kcfs a 23 mm Hg drop in TDG pressure was recorded. An unexplained gain in TDG pressure of exactly the same degree (label b) was observed on June 10th . The operating conditions involving spill discharge and pattern remained unchanged throughout this entire period. The calculated TDG pressures would have closely reflected the observed conditions during this period if a fixed gain of 23 mm Hg would have been applied to the observed data during this period. The spurious dropout was also observed on June 11th (label c) for a single hour again during the same spill magnitude and pattern of as scheduled on the previous two days. Although it is difficult to conclusively discount these observations, it is likely that these TDG levels were not representative of the cross sectional average conditions. These spurious events significantly contribute to the larger predictive errors at the CCIW station.

Bonneville Dam Forebay (BON)

SYSTDG was used to simulate the TDG production and transport from The Dalles Dam to Bonneville Dam from 1 April through 31 August in an effort to determine the predictive error of TDG pressure estimations in Bonneville Dam forebay. The strong winds that frequent this river reach have been associated with synoptic degassing events that reduce the TDG levels arriving at Bonneville Dam. The calculated TDG pressures over-estimated observed conditions by an average of 1.5 mm Hg (average predictive error -1.5 mm Hg) and the standard deviation of the predictive error was 6.7 mm Hg as listed in Table E5. The 50 confidence interval for the predictive error ranged from +2.7 to -6.1 mm Hg of pressure and the 80 confidence interval ranged from +7.3 to -8.3 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the BON gage are shown in Figure E10 The seasonal patterns of TDG pressures in the forebay of Bonneville are a series of events where the TDG pressures rapidly decline followed by a general recovery of higher TDG pressures. These events are correlated with strong wind events followed by weak or moderate wind conditions. The calculated and observed TDG pressures at BON are shown throughout the month of June in Figure E11. The high percent of spill at The Dalles Dam during the nighttime hours in the first half of June result in rapid changes in the forebay TDG pressures at Bonneville Dam. The average travel time in the Bonneville pool during June was 1.2 days. The TDG pressures in the forebay of Bonneville are a complex interaction of the TDG loading released from The Dalles Dam, thermal cycling, and wind induced degassing. The weak wind events on July 7-8 were generally responsible for the increasing TDG pressures in the forebay of Bonneville Dam (Figure E12). Currently, the wind field observed from The Dalles municipal airport is applied uniformly throughout this river reach to estimate the rate of degassing.

The Dalles Dam Tailwater (TDDO)

SYSTDG was used to simulate the TDG production and dissipation from The Dalles Dam to Bonneville Dam forebay from 1 April through 31 August in an effort to determine the predictive error of SYSTDG estimates in The Dalles Dam tailwater during spill events. The Dalles tailwater gage is located about 3 miles downstream from the dam in waters that approach well-mixed conditions. The flow-weighted average TDG conditions were simulated for The Dalles Dam during the spill season and compared to the observed conditions at the tailwater TDG gage TDDO. The calculated TDG pressures were lagged 3 hours, due to the travel time, in making this comparison. The calculated TDG pressures under-estimated observed conditions by an average of 0.3 mm Hg (average predictive error -0.3 mm Hg) and the standard deviation of the predictive error was 6.8 mm Hg as listed in Table E7. The 50 percent confidence interval of predictive error ranged from +4.4 to -3.3 mm Hg of pressure and the 80 percent confidence interval ranged from +7.5 to -5.3 mm Hg of pressure. Over 50 percent of the predictive errors at the tailwater FMS (TDDO) were less then +/- 0.8 percent of saturation during the study period while 80 percent of the estimates were within

+/- 1.1 percent of saturation as listed in Table E8. The seasonal time history of observed and calculated TDG pressures at the TDDO gage are shown in Figure E13. The TDG saturation at the tailwater station TDDO rarely exceeded the TDG standard of 120 percent because of the influence of the TDG content in powerhouse releases. The larger variances in TDG response at TDDO during the first half of the spill season were due to the on-off scheduling of spill at John Day Dam. The amount of TDG added by The Dalles Dam spill was moderated by the policy to spill about 40 percent of the instantaneous total river flow. The calculated and observed TDG pressures at TDDO are shown throughout the month of June in Figure E14. The tailwater station at The Dalles Dam is influenced by both powerhouse and spillway flows. This is the only tailwater station besides DWQI below Dworshak Dam operated by the Corps of Engineers that is located in mixed waters and used for management purposes for state water quality standards. The estimated TDG pressures contained in spillway flows undiluted from powerhouse flow consistently exceeded 120 percent of saturation as shown in Figure E15. The estimated TDG pressure in spill undiluted from powerhouse flow is shown by the blue line labeled “SP CAL”. The TDG exchange in spillway flows at The Dalles has been found to be highly correlated with the tailwater depth of flow and weakly dependent on the spill discharge or pattern. This relationship was demonstrated during the high spill discharge on June 11 where the TDG content in spill was estimated to decrease during this event when compared to smaller spills the previous day. The net increase in the average TDG saturation in the Columbia River caused by the operation of The Dalles Dam can be seen in Figure E15 by comparing the TDG saturation in the forebay (green symbols) and the tailwater (blue symbols). The standard error of TDG pressure in the tailwater of The Dalles Dam was the smallest of all the nine Corps of Engineers Dams reviewed in this section. The size of the predictive error in the tailwater of The Dalles was equal to the predictive error in the forebay of Bonneville Dam. The uncertainty in estimating the transport, dispersion, and dissipation of the TDG pressures released from The Dalles Dam did not result in a larger variance in the predictive error in the forebay of Bonneville Dam.

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. The daily cycling of spill at John Day Dam during the first half of the spill season coupled with the short travel time in this river reach (0.4–2.4 days) provided a means of evaluating the ability of SYSTDG to handle a distinct volume of water with TDG pressure as a marker. The calculated TDG pressures over-estimated observed conditions by an average of 1.3 mm Hg (average predictive error –1.3 mm Hg) and the standard deviation of the predictive error was 7.4 mm Hg as listed in Table E5. The 50 percent confidence interval of the predictive error ranged from 6.7 to -4.4 mm Hg of pressure and the 80 percent confidence interval ranged from +8.4 to -9.1 mm Hg of pressure. The standard error of estimate in the forebay of The Dalles Dam was only slightly greater than the standard error determined in the forebay of Bonneville Dam (7.4 versus 6.7 mm Hg). The seasonal time history of observed and calculated TDG pressures at the TDA gage are shown in Figure E16. The TDG saturation exceeded 115 percent for much of the months of April, May, and June. The daily variability in TDG pressures observed in the forebay of The Dalles Dam are in response to the on-off cycling of spill at John Day Dam. The spill policy called for sixty percent spill at night and no spill during the day but forced spill conditions prevented the cessation of daytime spill. This daily variation was greatly diminished when a continuous spill policy of 30 percent of total river flow was implemented at John Day Dam during the second half of the spill season (June 21-August 31). The calculated and observed TDG pressures at TDA are shown throughout the month of June in Figure E17. The daily cycling in TDG pressures in the forebay at TDA were closely reproduced by the SYSTDG estimates indicating the ability to simulate the transport and mixing of waters with a distinct TDG marker.

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 2006. The large spillway coupled with a spill pattern that transitions from a peaked to a uniform distribution and the entrainment of powerhouse releases into spillway flows throughout the tailwater channel presents a challenge in describing the TDG loading properties unique to John Day Dam. The calculated TDG pressures over-estimated observed conditions by an average of 3.9 mm Hg (average predictive error –3.9 mm Hg) and the standard deviation of the predictive error was 9.8 mm Hg as listed in Table E7. The 50 percent confidence interval of the predictive error ranged from +1.2 to -9.2 mm Hg of pressure and the 80 percent confidence interval ranged from +8.4 to -11.8 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the JHAW gage are shown in Figure E18. The daily variation in TDG pressures routinely ranged over 50 mm Hg during the on-off cycling of spill at John Day Dam (Figure E18). The broad range in the spillway capacity as limited by the tailwater TDG criteria of 120 percent can be seen in the summary of spillway operation in June shown in Figure E19. On June 14 the daytime spill of 150 kcfs using a uniform spill pattern resulted in a TDG pressure at JHAW of about 910 mm Hg or just under 120 percent of saturation. During the nighttime hours on June 28-29 a spill of 84.5 kcfs using the non-uniform or peaked spill pattern resulted in a TDG saturation of 912 mm Hg. The higher unit discharge associated with the non-uniform spill pattern generated higher TDG levels than the uniform pattern for a comparable spill discharge. A large contribution to the variance of the predictive error at JHAW occurred in August when spill ranged from 25 to 70 kcfs. The TDG response during the small spill events less than 30 kcfs did not reach steady conditions and tended to respond inconsistently as shown in Figure E20. The mixing zone may be encroaching upon the tailwater fixed monitoring stations for these very low flow conditions in August.

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 4.8 to 11.2 days. Calculated forebay TDG pressures were subtracted from the observed John Day forebay fixed monitoring station data to produce an hourly predictive error. The calculated TDG pressures under-estimated observed conditions by an average of 4.3 mm Hg (average predictive error +4.3 mm Hg) and the standard deviation of the predictive error was 9.2 mm Hg as listed in Table E5. The 50 percent confidence interval for the predictive error ranged from +10.3 to -2.4 mm Hg of pressure and the 80 percent confidence interval ranged from +16.7 to -5.3 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the JDY gage are shown in Figure E21. The duration that forebay TDG saturation was greater than 115 percent at John Day Dam was much smaller than at Bonneville and The Dalles Dams. 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 the highest in the Lower Columbia River but resulted in the lowest forebay TDG levels. The average forebay saturation at John Day Dam was 109.1 percent compared to 110.4 at McNary Dam and 110.3 at The Dalles Dam. The rapid increase and decrease in TDG pressures in the forebay of John Day Dam were typically related to wind events and elevated forced spill events at McNary Dam. 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 June in Figure E22. The weekly trends in TDG pressure in the forebay of John Day Dam were generally reproduced but the details of the daily patterns were not captured as closely as other forebay stations. The forebay TDG pressures at McNary Dam are generally greater than the forebay TDG pressures at John Day Dam. This suggests that a net reduction in TDG pressures occurs in the John Day pool. The net reduction in TDG pressures in John Day pool is greatest during August when the travel time is as much as 4 times longer than during the peak river flows in May and June.

McNary Dam Tailwater (MCPW)
The frequency of spillway flows greater than 120 kcfs was significantly higher at McNary Dam than the other three lower Columbia River Dams during the 2006 fish passage season. The SYSTDG model was used to simulate the TDG exchange associated with spillway releases from McNary Dam throughout the 2006-spill season as shown in Figure E23. The applied spill pattern varied

throughout the year because of mechanical problems with raising selected spill gates. The calculated TDG pressures under-estimated observed conditions by an average of 2.4 mm Hg (average predictive error +2.4 mm Hg) and the standard deviation of the predictive error was 10.1 mm Hg as listed in Table E7. The accuracy of TDG predictions in the tailwater of McNary Dam in 2006 were similar to conditions in 2005 (standard error of estimate was 11.0 mm Hg in 2005). The 50 percent confidence interval for the predictive error ranged from 8.0 to –2.6 mm Hg of pressure and the 80 percent confidence interval ranged from 13.3 to -6.1 mm Hg of pressure. The observed and calculated TDG pressures in the tailwater of McNary Dam are shown throughout the month of June in Figure E24 where the spill policy changed from forced spill to voluntary spill. The TDG estimates tended to under-estimate the TDG exchange when spill discharges exceeded 200 kcfs during the month of June. The calculated and observed TDG pressures at the tailwater station MCPW generally tracked together as shown in Figure E25 and were an exponential function of total spillway discharge. The tendency to under-estimate the observed conditions for spill discharges greater than 200 kcfs and less than 60 kcfs is also indicated in this figure.

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 and Ice Harbor Dam on the Snake River. The spill policy at Priest Rapids Dam during 2006 called for considerably lower spill rates during voluntary spill flows than in previous years. However, the TDG loading introduced into McNary pool was moderated by the degassing throughout the open river reach in the Hanford area. The spill operations at Ice Harbor Dam were cycled periodically throughout most of the 2006 spill season to accommodate biological testing. This operation introduced pulses or slugs of water with high TDG levels into McNary pool. The forebay fixed monitoring station on the Oregon side of McNary Dam was discontinued during the 2006 season. Thermally induced pressure responses were not a common problem during the 2006 sampling season at station MCNA.

SYSTDG was used to simulate the TDG properties in the Columbia River from Priest Rapids Dam to McNary Dam and on the Snake River from Ice Harbor Dam to the mouth of the Snake River. The calculated TDG pressures over-estimated observed conditions by an average of 4.3 mm Hg (average predictive error –4.3 mm Hg) and the standard deviation of the predictive error was 11.0 mm Hg as listed in Table E5. The standard error was significantly smaller in 2006 than determined in 2005 (11.0 versus 14.5 mm Hg). The 50 percent confidence interval for the predictive error ranged from 2.1 to -11.3 mm Hg of pressure and the 80 percent confidence interval ranged from 9.5 to -15.0 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 E26. The over-estimation of TDG pressures in the forebay of McNary Dam during the high flows in June were related to over-estimating the TDG production at Priest Rapids Dam. The calculated and observed TDG pressures in the forebay of McNary Dam are shown in Figure E27 for the month of June. The variation in McNary forebay TDG pressure in June ranged from 840-900 mm Hg. The daily variation in the predicted TDG pressure was highly correlated with the observed conditions but the estimated TDG magnitude was greater throughout the entire month. The predictive errors in the forebay of McNary Dam were the highest of all the forebay stations on the Lower Columbia River. The primary source for these errors was higher TDG loading originating from the Mid-Columbia River.

Ice Harbor Dam Tailwater (IDSW)

The spill policy at Ice Harbor Dam was varied throughout the 2006 fish passage season to accommodate biological testing of the raised spillway weir (RSW). The spill pattern ranged from a bulk spill pattern involving the RSW with training flow to the standard spill pattern using all ten spill bays. The percent of river spill also varied significantly throughout the fish passage season. The TDG production equation developed for Ice Harbor was based on the TDG exchange observed during standard spill pattern operations prior to the 2004 spill season. The TDG exchange at Ice Harbor Dam was simulated from 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 TDG pressures over-estimated observed conditions by an average of 9.5 mm Hg (average predictive error –9.5 mm Hg) and the standard deviation of the predictive error was 10.3 mm Hg as listed in Table E7. The 50 percent confidence interval of the predictive error ranged from -2.7 to -16.4 mm Hg of pressure and the 80 percent confidence interval ranged from +2.0 to -21.3 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the IDSW gage are shown in Figure E28. The calculated values tend to compare favorably to observed conditions throughout most of the year. The predictive error tended to be larger during the spill activities during late July and August. The standard deviation of the predictive error at Ice Harbor Dam tailwater in 2006 was similar to conditions observed at McNary and John Day Dams. The daily variation in TDG pressures for observed and calculated conditions can be seen in Figure E29 for the month of May. The observed and predicted TDG pressures were similar throughout this period as the daily TDG response cycled with total river flows. The depth of flow in the tailwater channel remains an important determinant of TDG exchange at Ice Harbor Dam. The 95 kcfs spill on May 11 resulted in significantly smaller TDG pressures than a comparable spill on May 20 during higher tailwater conditions. The spillway operations at Ice Harbor can result in a net reduction in the TDG loading exiting the Snake River when forebay TDG levels are high. On June 12-14 the Ice Harbor forebay TDG pressures were greater than 900 mm Hg while the TDG saturation at the tailwater fixed monitoring station ranged from 875 to 895 as shown in Figure E30. A net reduction in TDG during spill at Ice Harbor Dam was also realized during the last week in June.

Ice Harbor Dam Forebay (IHRA)
A simulation was run from Lower Monumental Dam to the forebay of Ice Harbor Dam from 15 April through 31 August to determine the predictive error of SYSTDG estimations in the forebay of Ice Harbor Dam. Calculated forebay TDG pressures were subtracted from the observed TDG pressures at the forebay fixed monitoring station at Ice Harbor Dam (IHRA) to determine the hourly predictive error. The calculated TDG pressures over-estimated observed conditions by an average of 11.8 mm Hg (average predictive error –11.8 mm Hg) and the standard deviation of the predictive error was 10.6 mm Hg as listed in Table E5. The 50 percent confidence interval for the predictive error ranged from -3.8 to -19.9 mm Hg of pressure and an 80 percent confidence interval ranged from -0.2 to -24.4 mm Hg of pressure. The variance of the predictive error at Ice Harbor Dam forebay was similar to conditions found in the forebay of McNary Dam on the Columbia River. The biased estimate of forebay conditions at Ice Harbor Dam was attributed to conditions during the low flow and voluntary spill conditions in July and
August as seen in the seasonal time history of observed and calculated TDG pressures at the IHRA gage as shown in Figure E31. The elevated TDG pressures in the forebay at Ice Harbor were associated with the forced spill on the Snake River during the May and June and were closely reproduced by SYSTDG. The observed and calculated TDG pressures in the forebay of Ice Harbor are shown in Figure E32 throughout June. The forebay station at IHRA located on the upstream navigation lock guide wall didn’t experience the frequent pressure response to thermal cycling that was evident at the old forebay station IHR located on the face of Ice Harbor Dam. The close reproduction of the passage of higher TDG waters from Ice Harbor pool demonstrates both the transport and dissipation properties of SYSTDG for this river reach. The over-estimation of TDG pressures in the forebay of Ice Harbor Dam are likely the result from too much generation of TDG pressure during summer spill events.

Lower Monumental Dam Tailwater (LMNW)
The predominant spill pattern applied at Lower Monumental Dam during the 2006 fish passage season was a bulk spill pattern involving only 2 or 3 spill bays. The TDG production equation developed during the 2004 TDG field study was applied during this spill season. This study identified powerhouse entrainment discharge as being an important component of the TDG exchange during bulk spill releases. In many cases, the entire powerhouse release is entrained into the aerated spill release significantly increasing the TDG loading at Lower Monumental Dam. The SYSTDG model was applied to simulate the TDG levels produced from spill operations at Lower Monumental Dam from 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 TDG pressures over-estimated observed conditions by an average of 14.7 mm Hg (average predictive error –14.7 mm Hg) and the standard deviation of the predictive error was 22.3 mm Hg as listed in Table E7. The 50 percent confidence interval for the predictive error ranged from 2.2 to -30.0 mm Hg of

pressure. The 90 percent confidence interval for the predictive error ranged from 13.8 to -40.6 mm Hg of pressure. The accuracy of TDG predictions at Lower Monumental Dam in 2006 were poorer when compared with estimates in 2005 where the average error was -3.8 mm Hg and the standard error was 13.1 mm Hg. The daily variation of TDG pressures at the tailwater FMS below Lower Monumental Dam are shown in Figure E33. There was a tendency for calculations to overestimate the TDG exchange associated with small spillway releases. In these instances the TDG exchange measured at the tailwater fixed monitoring station was more closely approximated by estimates of average cross sectional conditions. The hourly observed and calculated TDG pressures at the tailwater FMS (LMNW) are shown in Figure E34 for the month of May. This figure shows a general agreement between the observed and calculated TDG response at LMNW for both forced and voluntary spill conditions in May. The TDG production equation generated during the 2004 spill season did not include forces spill discharges greater than 45 kcfs. The observations during the 2006 season should be used to update this TDG exchange relationship for Lower Monumental Dam.

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 E35. The seasonal variability of TDG pressures in Lower Monumental forebay were similar to conditions discussed at the Ice Harbor forebay where the forecasted TDG pressures were accurately predicted during the period from April through June. The predicted forebay TDG pressures began to diverge from observed conditions in July and through August. The relatively large increase in TDG levels observed during the forced spill events in May suggests the influence of the entrainment of powerhouse flows plays an important role in the TDG loadings in the Snake River in Lower Monumental pool. The calculated TDG pressures over-estimated observed conditions by an average of 14.1 mm Hg (average predictive error –14.1 mm Hg) and the standard deviation of the predictive error was 19.7 mm Hg as listed in Table E5. The 50 percent confidence interval for the predictive error ranged from 1.2 to -30.3 mm Hg of pressure and the 80 confidence interval ranged from +9.2 to -38.3 mm Hg of pressure. The daily variation of TDG pressures for the month of May at the forebay FMS above Lower Monumental Dam are shown in Figure E36. The estimated forebay TDG saturation was closely reproduced during the transition form voluntary to involuntary spill at Little Goose Dam with the timing and magnitude of the peak TDG pressure in the Lower Monumental forebay of 960 mm Hg being closely predicted. The extensive summer time spill at Little Goose Dam at low total river flows and low tailwater elevations were scheduled throughout the summer of the 2006 spill season. The dissipation of this TDG load during passage through the Little Goose pool or the estimated production at Little Goose Dam was misrepresented to a sizable degree.

Little Goose Dam Tailwater (LGSW)

The spill policy at Little Goose Dam called for spilling 30 percent of the river both day and night. The spill pattern was modified during the 2006 fish passage season by alternating between a bulk pattern and a uniform pattern. The bulk pattern passed the majority of flow through bays 2 and 3. The uniform flow distributed spill over bays 2-7 with a minimum unit discharge of about 5500 cfs. The bulk pattern was used throughout the summer months. A minimal discharge through spill bay 1 without a flow deflector was maintained throughout much of the spill season while spill bay 8 was not used at all. 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 E37. The calculated TDG pressures over-estimated observed conditions by an average of 1.0 mm Hg (average predictive error -1.0 mm Hg) and the standard deviation of the predictive error was 13.2 mm Hg as listed in Table E7. The 50 percent confidence interval ranged from +6.7 to -9.5 mm Hg of pressure and the 80 percent confidence interval ranged from +12.7 to -14.4 mm Hg of pressure. The interaction of powerhouse and spillway releases at Little Goose Dam is heightened because of the depth of the stilling basin and surface oriented spillway discharge oriented adjacent to the powerhouse. The interpretation of the observed TDG response at the tailwater fixed monitoring station is closely related to the near field circulation patterns. The calculated and observed tailwater TDG pressures below Little Goose Dam during the month of May are shown in Figure E38. The TDG pressures at the tailwater FMS were observed to vary by as much as 50 mm Hg during constant spill discharges during the first half of May. The TDG response during the higher forced spill events during the end of the month were closely released to the magnitude of spill or unit spill bay discharge. The observed TDG pressures below Little Goose Dam at LGSW were influenced by the TDG content in the forebay during low spill discharges but not during the high spill. The observed and estimated TDG pressures at Little Goose Dam in the forebay and tailwater FMS are shown in Figure 39 for the month of June. The spill of 20 kcfs on June 12-13 resulted in TDG levels of 870 to 886 mm Hg which were above the estimated TDG content in spill (dark blue line labeled Sp cal). A flow weighted average of the corrected forebay TDG pressures and the calculated spillway TDG saturation closely reproduced the observed TDG pressures at the tailwater FMS. The same spill magnitude was also scheduled on June 16-17 when forebay TDG pressures were flat ranging from 810-820 mm Hg or less than the estimated TDG content in spill of 870 mm Hg. Again the flow weighted average TDG pressure between powerhouse and spillway flows taking into account the entrainment of powerhouse flows, closely approximated the observed TDG pressure at LGSW. The increasing trend in TDG pressures during June 16-17 can be attributed to a slight increase in the percent of river spilled. The high rates of spill in June appear to be related to a lack of load since powerhouse discharges are well below capacity during these events. These pulsed spill events generated TDG pressures well above 120 percent of saturation and also correspond with the occurrence of the highest incidence of signs of gas bubble trauma (18 percent) at Little Goose Dam. The generation of TDG levels above 120 percent could have been minimized or eliminated by distributing spill more uniformly over a day.

Little Goose Dam Forebay (LGSA)

SYSTDG was used to hind cast the TDG pressures in Little Goose pool in response to operations at Lower Granite Dam from 1 April 31 August. The elevated TDG levels in the forebay of Little Goose Dam are a consequence of the TDG uptake associated with spill at Lower Granite Dam, the thermal exchange during transport through the pool, and the surface exchange of dissolved gasses with the atmosphere. The predicted TDG pressure response in the Little Goose forebay were uncharacteristically uneven when compared to the observed conditions as shown in Figure E40 during the spring and early summer months. The peak TDG events arriving at Little Goose Dam were over estimated by 20-40 mm Hg while the estimation of TDG pressure in late June and early July were under-predicted. The likely cause for the over-prediction of forebay TDG pressures was the over prediction of TDG production during spill at Lower Granite Dam. In particular, the estimation of the entrainment of powerhouse flows into the spillway could account for this level of predictive error. The entrainment coefficient for Lower Granite Dam was equal to unity as determined in the 2002 TDG exchange study conducted at Lower Granite Dam. A second component that contributes to larger predictive errors in the forebay of Little Goose Dam was the reliability of the observed data. During June 9-13 the observed data appears to be about 60 mm Hg less than actual conditions because of an instantaneous drop and increase in TDG pressures. On April 28 an abrupt increase in TDG saturation of 20 mm Hg was registered which was exactly the size of the prediction error on this date. The average calculated TDG pressure was similar to observed conditions with an average predictive error of 0.0 mm Hg and the standard deviation of the predictive error was 18.3 mm Hg as listed in Table E5. The 50 percent confidence interval ranged from +10.3 to -11.6 mm Hg of pressure and the 80 percent confidence interval ranged from +22.4 to -18.0 mm Hg of pressure. The calculated and observed tailwater TDG pressures in the forebay of Little Goose Dam during the month of June are shown in Figure E41. The observed and calculated TDG pressures were generally within 10 mm Hg during the first half of June with the calculated conditions consistently under-estimating observed pressures. The rise in TDG pressures the second half of June was not captured by the model. The increasing TDG pressures was likely attributed to the general reduction in the percent of river spilled, calm wind conditions, and rapid warming of water temperatures.

Lower Granite Dam Tailwater (LGNW)

The spill policy at Lower Granite Dam during the 2006 fish passage season called for a continuous spill of 20 kcfs during the spring and 18 kcfs during the summer. The standard spill pattern called for spill through the RSW in bay 1 with the remaining training spill distributed uniformly through the remaining bays. A biological testing program involving the standard and bulk spill patterns was scheduled during the summer time. The spill patterns were scheduled in random blocks throughout 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 E42. The calculated TDG pressures under-estimated observed conditions by an average of 7.1 mm Hg (average predictive error +7.1 mm Hg) and the standard deviation of the predictive error was 15.4 mm Hg as listed in Table E7. The 50 percent confidence interval for the predictive error ranged from 16.9 to -4.1 mm Hg of pressure and the 80 percent confidence interval ranged from +28.0 to -8.0 mm Hg of pressure. The calculated TDG saturation was closely approximated during the higher spillway releases during the period from April through June. The magnitude of spill at Lower Granite Dam exceeded 100 kcfs resulting to TDG saturation greater than 130 percent saturation for several days as shown in Figure E43. The tailwater TDG pressure was closely predicted during the month of May where spill ranged from 20 kcfs to 130 kcfs and the TDG pressures ranged from 820 to 990 mm Hg. The calculated TDG saturation was smaller than the observed conditions during the months of July and August as shown in Figure E44. The simulated conditions assumed the standard pattern was used throughout the month resulting in the general under-estimation of TDG pressures during the bulk spill event. The actual spill pattern information was used to forecast TDG conditions throughout the year and the resultant predictions at LGNW for the month of August are shown in Figure E45. The sensitivity of TDG pressures to spill pattern changes are demonstrated in this figure where the flow weighted average of project releases closely predict observed conditions during the standard pattern and higher TDG levels were predicted during the bulk spill events.

Dworshak Dam Tailwater (DWQI)

The TDG pressures in the tailwater channel below Dworshak Dam were simulated during the 2006 spill season as shown in Figure E46. The calculated TDG pressures under-estimated observed conditions by an average of 15.8 mm Hg (average predictive error +15.8 mm Hg) and the standard deviation of the predictive error was 12.3 mm Hg as listed in Table E7. The 50 percent confidence interval for the predictive error ranged from +21.6 to +10.5 mm Hg of pressure and the 80 confidence interval ranged from +25.6 to 7.3 mm Hg of pressure. Dworshak Dam does not have a forebay TDG station and the TDG pressures observed at the tailwater station during powerhouse only operations were used to estimate the TDG pressures released by the powerhouse during concurrent powerhouse and spillway/regulating releases. The 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 periodic scheduling of the minimum powerhouse releases as shown in Figure E46 resulted in TDG pressures ranging from 760-810 mm Hg as observed at the tailwater fixed monitoring station (DWQI). The estimates of TDG pressures at the tailwater fixed monitoring station DWQI are assumed to reflect well-mixed conditions and are therefore dependent upon the TDG levels of powerhouse and spillway/regulating outlet conditions. The TDG pressures associated with spill were estimated to be as high as 940 mm Hg during a spill of 4 kcfs as shown in Figure E47. The TDG data collected during 2005 and 2006 were used to update the TDG production equation for Dworshak as shown in Figure E48. These analyses resulted in an increase in the forecasted TDG pressures for small spill events by as much as 10 percent saturation for a spill discharge of 1 kcfs. The updated TDG production equation was used to simulate the TDG levels below Dworshak during the 2006 season as shown in Figure E49. The updated model more closely predicted the observed conditions during the April and July spill events especially during the smaller spill events.

Comparison of 2005 and 2006 Simulations

The performance of the SYSTDG decision support system as measured by the hourly predictive error statistics at fixed monitoring stations during the 2006 spill season was in some cases better and worse than the performance observed during the 2005 fish passage season. The wide range of operating conditions in 2006 involving the spill discharge and applied spill patterns posed a greater challenge for predicting TDG pressure than in previous years. 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 errors of estimates were larger at tailwater stations than at forebay stations because of the temporal and spatial variability in TDG exchange. A more meaningful estimate of the predictive error at tailwater stations would involve additional filtering of the data to eliminate the transitional data during operational changes. The standard deviation of the predictive errors in 2005 ranged from 7.1 to 36.3 mm Hg at fixed monitoring stations. In 2006, the standard deviation of the predictive errors at fixed monitoring stations ranged from 6.8 to 22.3 mm Hg. Significant improvements were achieved in estimating the TDG exchange and transport at Lower Granite and at the Warrendale gage below Bonneville Dam. The standard deviation of the predictive error at the tailwater station below Lower Granite Dam (LGNW) was reduced from 36.3 mm Hg in 2005 to only 15.4 mm Hg during the 2006 season. The degree of improvement at the Warrendale gage as measured by the standard deviation of the predictive error fell from 15.1 mm Hg in 2005 to 11.7 mm Hg in 2006. There were several stations where the predictive errors were considerably greater in 2006 compared to 2005. The standard deviation of the predictive error in the forebay of Lower Monumental Dam increased from 8.5 mm Hg in 2005 to 19.7 mm Hg in 2006. The source for the more than doubling of the standard deviation of the predictive error was associated with the spill operations during July and August from Little Goose Dam. The estimation of Snake River degassing determined in 2005 was based on significantly short travel times that observed in 2006. The standard deviation of the predictive error at the tailwater station CCIW below Bonneville Dam during the normal spill operations in 2005 was only 7.6 mm Hg as compared to 14.4 mm Hg in 2006.

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 2006 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 2006 were dominated by forced spill operations for much of the months of May and June. The operational policy involving spilling water on the Snake and Lower Columbia Rivers during the summer months was conducted for the second time in 2006 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 2006 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 forebay station comparisons generated smaller predictive errors (Tables E5 and E6) than the tailwater station comparisons (Tables E7 and E8). The average predictive errors at forebay stations were less than 1 percent of saturation with the exception of Ice Harbor and Lower Monumental Dams. The overestimation of forebay TDG pressures at Ice Harbor Dam was attributed to misrepresenting dissipation of TDG levels during the long travel times through Ice Harbor pool in the late summer months. The larger estimation errors in the forebay of Lower Monumental Dam were largely attributed to estimates misrepresenting TDG production at Little Goose Dam during August. The correlation between strong winds and declining TDG pressure at forebay stations was evident during the 2006 spill season and was an important determinant of calculated forebay TDG levels. In several reaches, the inclusion of alternative weather station data for wind may improve the model results.

The larger predictive errors determined at the tailwater FMS were likely associated with the TDG heterogeneities generated in spillway flows and monitored at many tailwater FMS, the timing and duration required to establish steady-state TDG levels at monitoring stations, and the application of accurate spill pattern operations. The standard deviation of predictive error at the tailwater stations ranged from 6.8 mm Hg at The Dalles Dam tailwater station TDDO to 22.3 mm Hg at Lower Monumental tailwater station (LMNW). The large errors observed during the month of August at the Lower Monumental Dam tailwater were associated the incorrect designation of the applied spill pattern. The development of the TDG production relationship at Lower Monumental Dam was based on the detailed TDG exchange study conducted in 2004 where spill didn't exceed 50 kcfs.

Bonneville Dam operations during the 2006 season incorporated a new spill pattern during high tailwater conditions. These new spill patterns generated TDG levels much higher than the standard spill patterns that resulted in a much small spill cap. The SYSTDG model under estimated the TDG response for the new spill patterns. The standard deviations of the predictive errors at FMS downstream of Bonneville Dam were small compared to other projects. The standard deviation of the predictive error in the spillway exit channel was 14.4 mm Hg compared to 6.9 mm Hg downstream at the Camas/Washougal gage. The non-uniformity of TDG levels in the spillway exit channel and occasional spurious response in the measure TDG pressure are responsible for the size of the prediction error.

The spill policy at The Dalles Dam in 2006 called for 40 percent of the river to pass through the spillway. On several occasions much high spill rates were implemented due to the lack of load. The estimated TDG content in spill undiluted by powerhouse flow were generally greater than 120 percent and as high as 130 percent. The standard deviation of the predictive error at FMS downstream of The Dalles Dam ranged from 6.8 mm Hg at the tailwater station TDDO to 6.7 mm Hg in the forebay of Bonneville Dam. The tailwater stage elevation and not the spill pattern or discharge is the primary determinant of TDG exchange at The Dalles Dam.

The spill operations at John Day Dam followed a normal pattern throughout the 2006 fish passage season. The standard deviation of the predictive error at FMS's downstream of John Day Dam ranged from 9.8 mm Hg at the tailwater station JHAW to 7.4 mm Hg in the forebay of The Dalles Dam.

The operations at McNary Dam involved spill throughout the entire summer for the second consecutive year. McNary Dam spilled more water than any project on the Columbia River in 2006 but had fewer occurrences of TDG saturation greater than 120 percent when compared to the tailwater response at John Day or Bonneville Dams. The standard deviation of the predictive error at FMS downstream of McNary Dam ranged from 10.1 mm Hg at the tailwater station MCPW to 9.1 mm Hg in the forebay of John Day Dam.

Ice Harbor Dam continues to have the smallest TDG uptake for a comparable spill discharge at any project on the Columbia or Snake Rivers. The combination of spillway flow deflectors with a shallow tailwater channel are thought to account for this property. The operation of the spillway at Ice Harbor Dam in 2006 involved biological testing of the RSW. The standard deviation of the predictive error at FMS downstream of Ice Harbor Dam ranged from 10.3 mm Hg at the tailwater station IDSW to 11.0 mm Hg in the forebay of McNary Dam.

The predictive errors of TDG pressures in the tailwater of Lower Monumental dam were the highest of any of the projects evaluated during the 2006 fish passage season. The larger errors were attributed to the new range of operating conditions encountered during the year. The standard deviation of the predictive error at FMS downstream of Lower Monumental Dam ranged from 22.3 mm Hg at the tailwater station LMNW to 11.8 mm Hg in the forebay of Ice Harbor Dam.

The spillway operations at Little Goose Dam involved a new spill pattern including spill through bay 1 without a flow deflector. The volume of water passed over bay 1 was limited and the previous TDG production model was found to provide reasonable prediction of TDG pressures at the tailwater fixed monitoring station. The standard deviation of the predictive error at FMS downstream of Little Goose Dam ranged from 13.2 mm Hg at the tailwater station LGSW to 14.1 mm Hg in the forebay of Lower Monumental Dam. The summertime estimates of forebay TDG pressures at Lower Monumental Dam contributed to the higher variance in the predictive errors.

The spillway operations at Lower Granite Dam featured the prominent use of the raised weir crest and continuous spill using the standard and bulk spill patterns during the summer months. The standard deviation of the predictive error at FMS downstream of Lower Granite Dam ranged from 7.1 mm Hg at the tailwater station LGNW to 18.3 mm Hg in the forebay of Little Goose Dam.

Spillway releases scheduled at Dworshak Dam during the 2006 spill season were required to meet rule curve criteria in April and provide temperature management flows in July. The TDG production relationship was updated to afford more accurate estimates at small spill rates. The standard deviation of the predictive error at FMS downstream of Dworshak Dam was 12.3 mm Hg.

Recommendations

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

The documentation of model parameters and programming tools needed to maintain the database and workbook should be updated.

The data quality control and assurance tools should be put into practice. A data screening program has been developed to help identify erroneous data.

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 high spill rates scheduled across the region during 2006 should extend the range of the TDG production models at many projects.

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.

The surface exchange coefficients should be adjusted to reduce the predictive error bias as determined at forebay stations. These coefficients and applied weather data was likely a major source of error during July and August on the Snake River. In some cases, the application of wind magnitude and direction data from alternative stations should be examined to see if predictions could be improved.

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

The management of forced spill should be evaluated in terms of where and when to spill water. The SYSTDG model could be used to evaluate alternative spillway flows on main stem TDG levels. In some cases, it may be advantageous to shift spill/generation between projects to add fish guidance and manage TDG levels in regions containing high fish densities. The schedule of spilling water during light load conditions should be evaluated. In most cases, the elevation of spill rates over 24 hours will generate smaller TDG levels than scheduling several hours of very high spill conditions as was the practice in 2006.

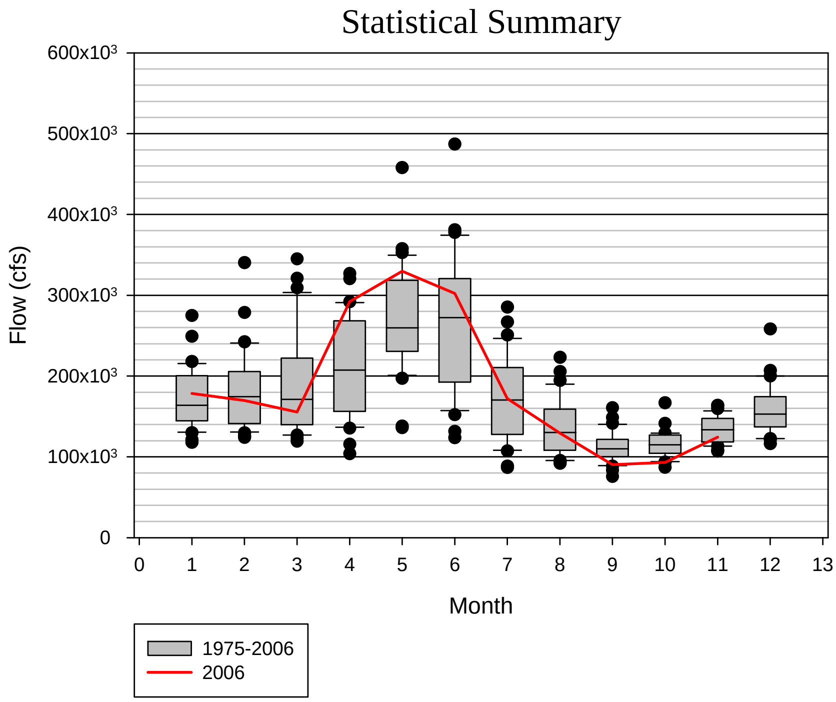

Figure E1. Statistical Summary of Columbia River Monthly Average Flows at The Dalles Dam for 1975-2006 (2006 – Red, 1997-2006 summary gray box 25, 50, 75th percentiles, whiskers 5-95th percentiles).

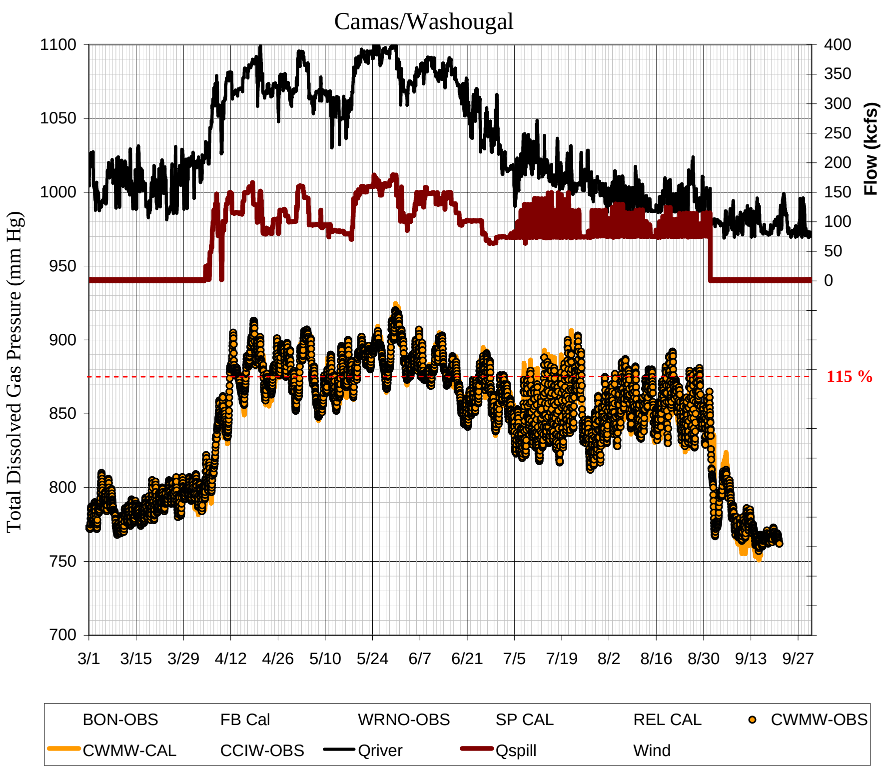

Figure E2. Observed and Calculated Total Dissolved Gas Saturation in the Columbia River at the Camas/Washougal fixed monitoring station downstream of Bonneville Dam, March-September 2006

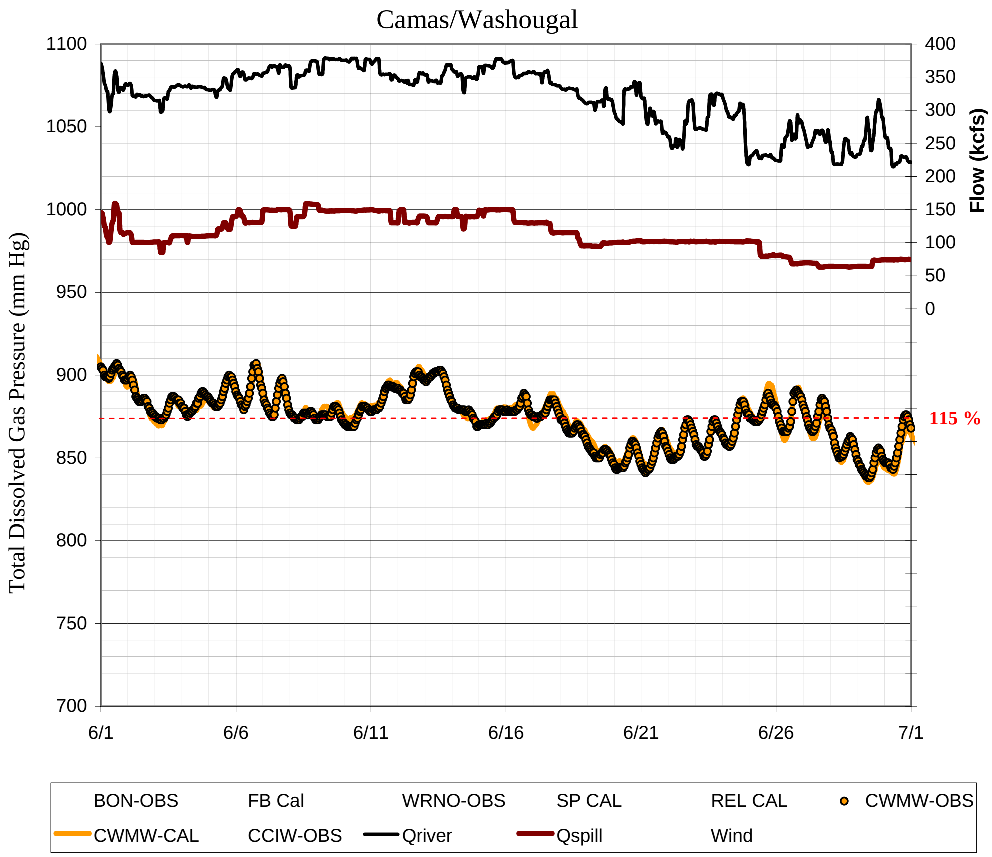

Figure E3. Observed and Calculated Total Dissolved Gas Saturation in the Columbia River at the Camas/Washougal fixed monitoring station downstream of Bonneville Dam, June 2006

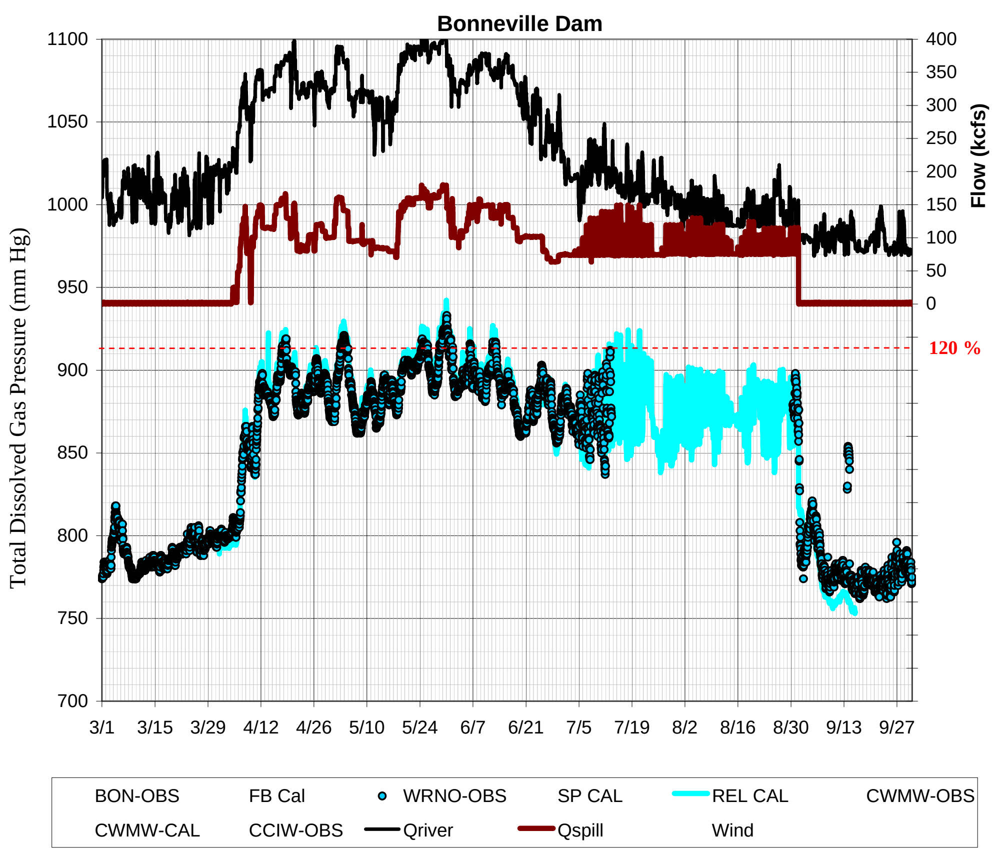

Figure E4. Observed and Calculated Total Dissolved Gas Saturation in the Columbia River at the Warrendale fixed monitoring station downstream of Bonneville Dam, March-September 2006

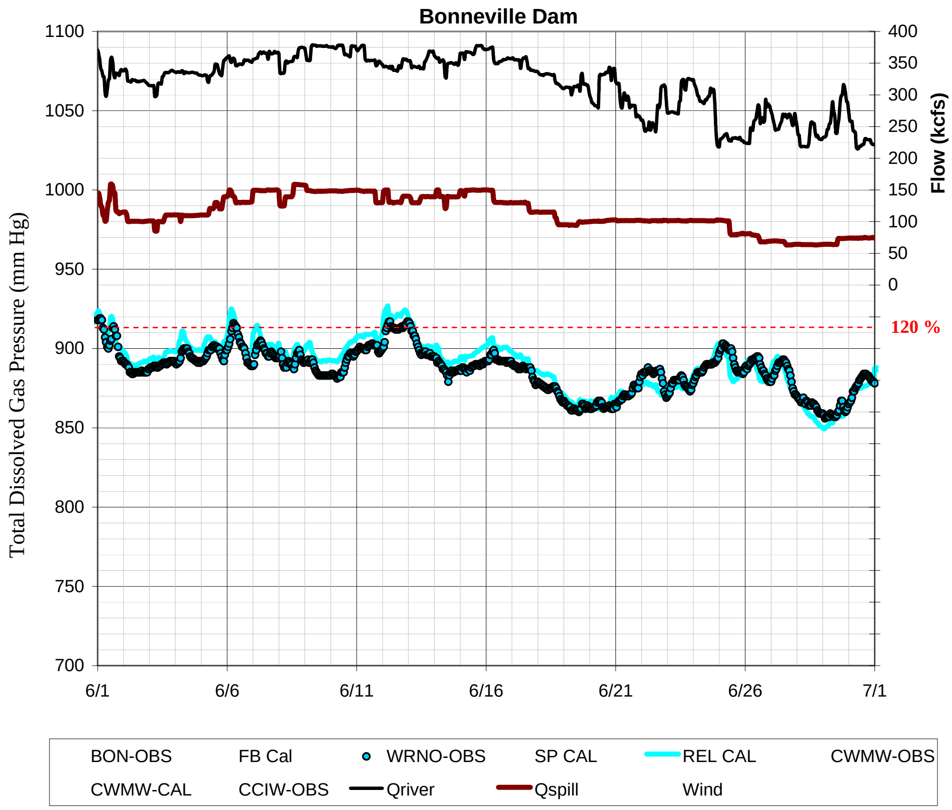

Figure E5. Observed and Calculated Total Dissolved Gas Saturation in the Columbia River at the Warrendale fixed monitoring station downstream of Bonneville Dam, June 2006

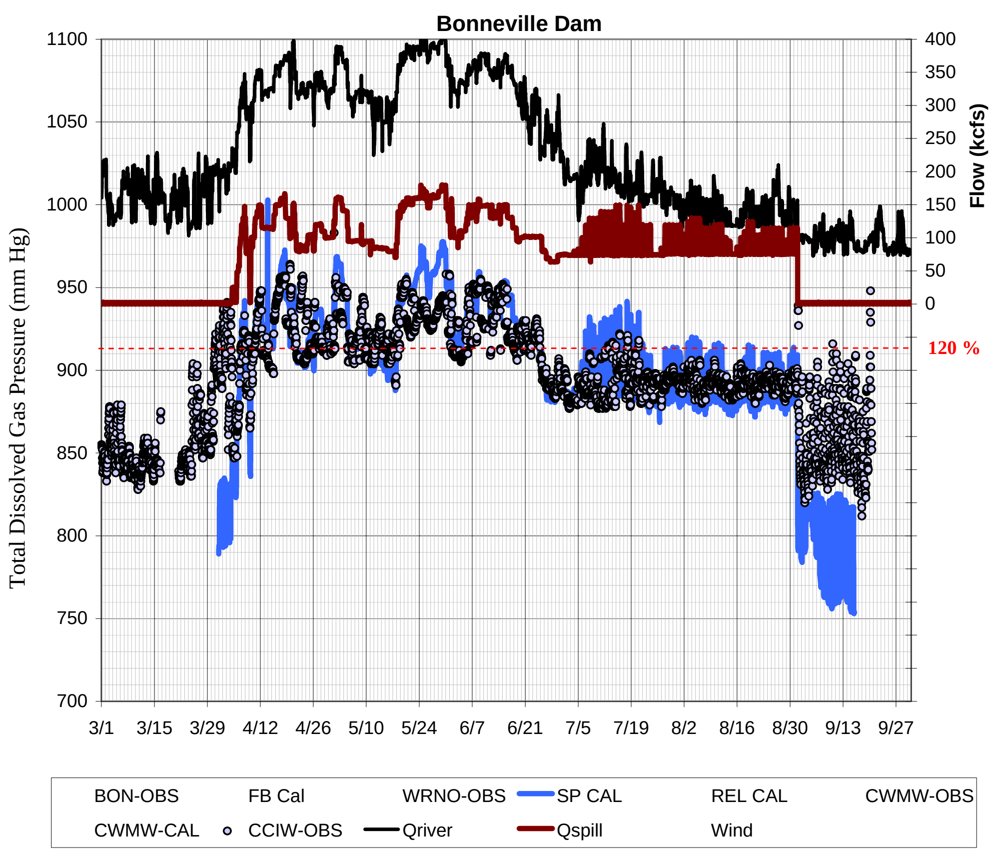

Figure E6. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam, March-September 2006

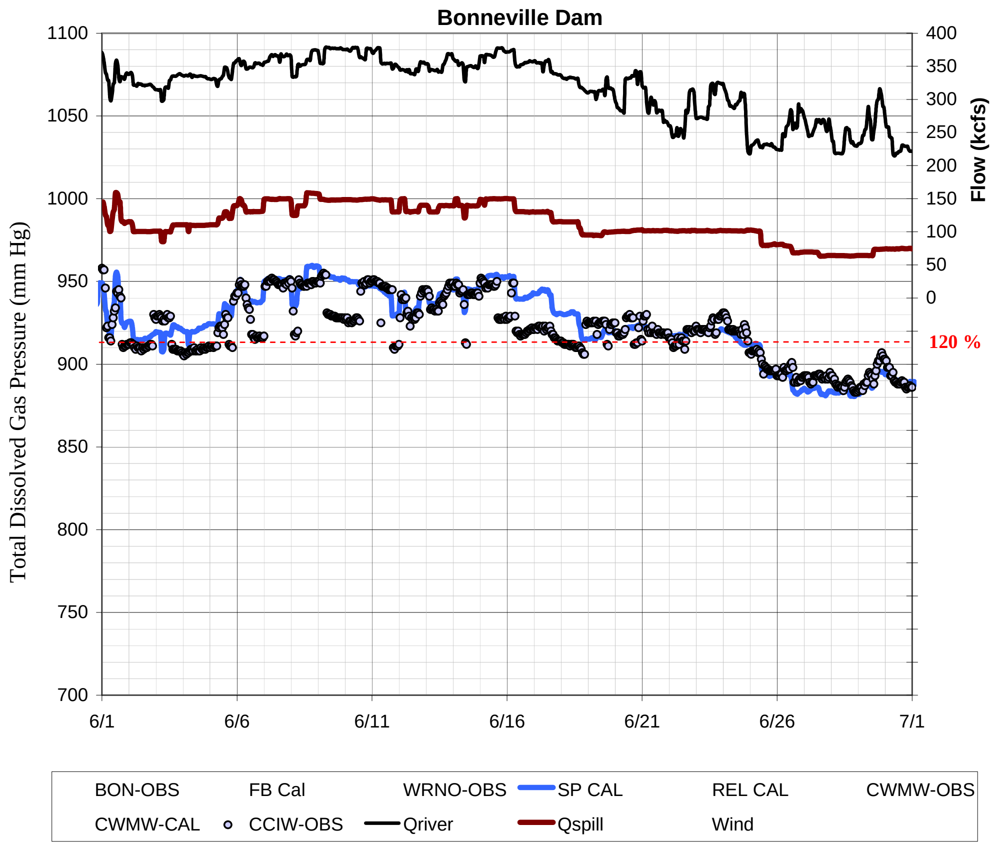

Figure E7. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam, June 2006

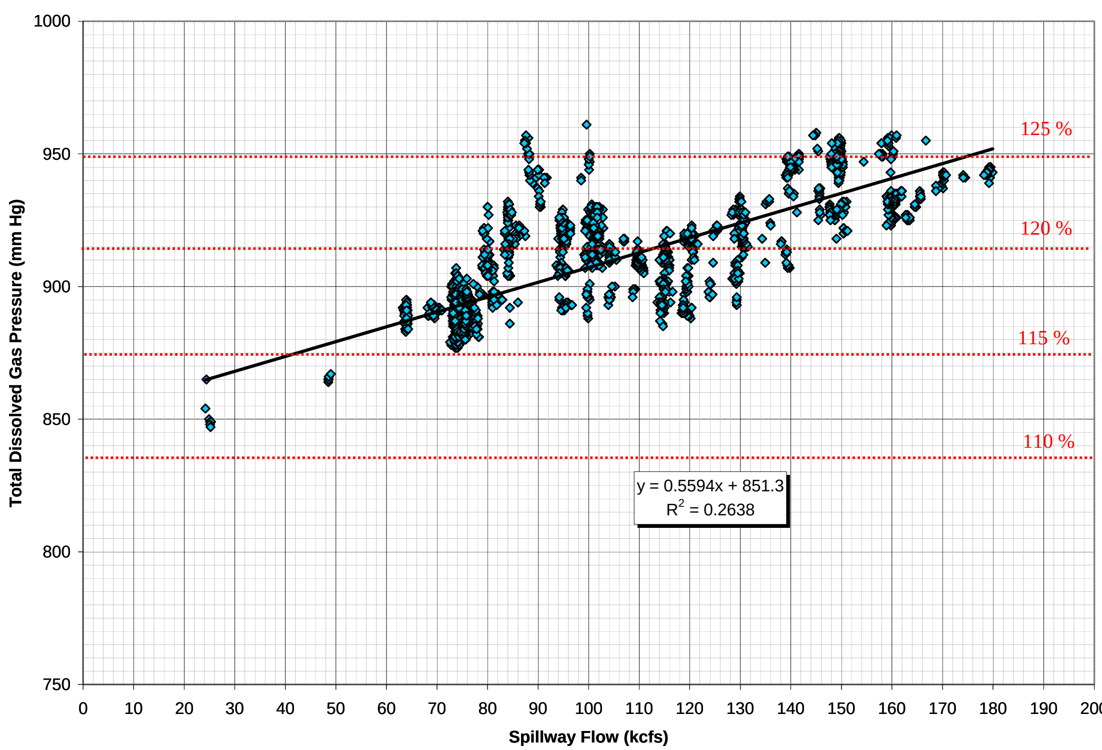

Figure E8. Total Dissolved Gas Pressure at Station CCIW versus Spillway flow during the 2006 Fish Passage Season.

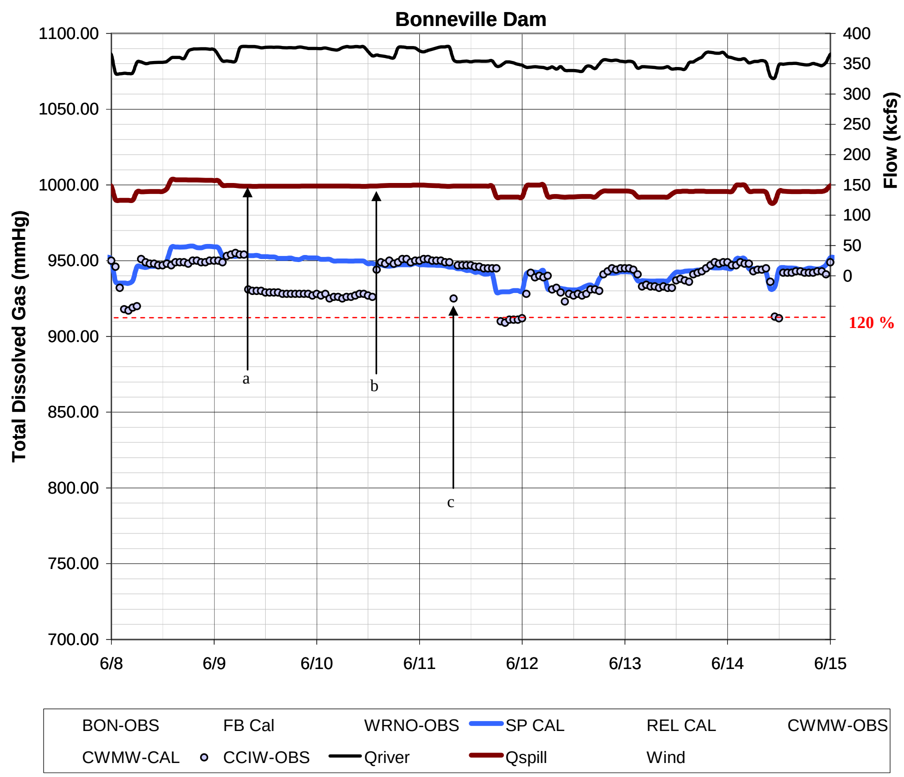

Figure E9. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam, June 8-14, 2006

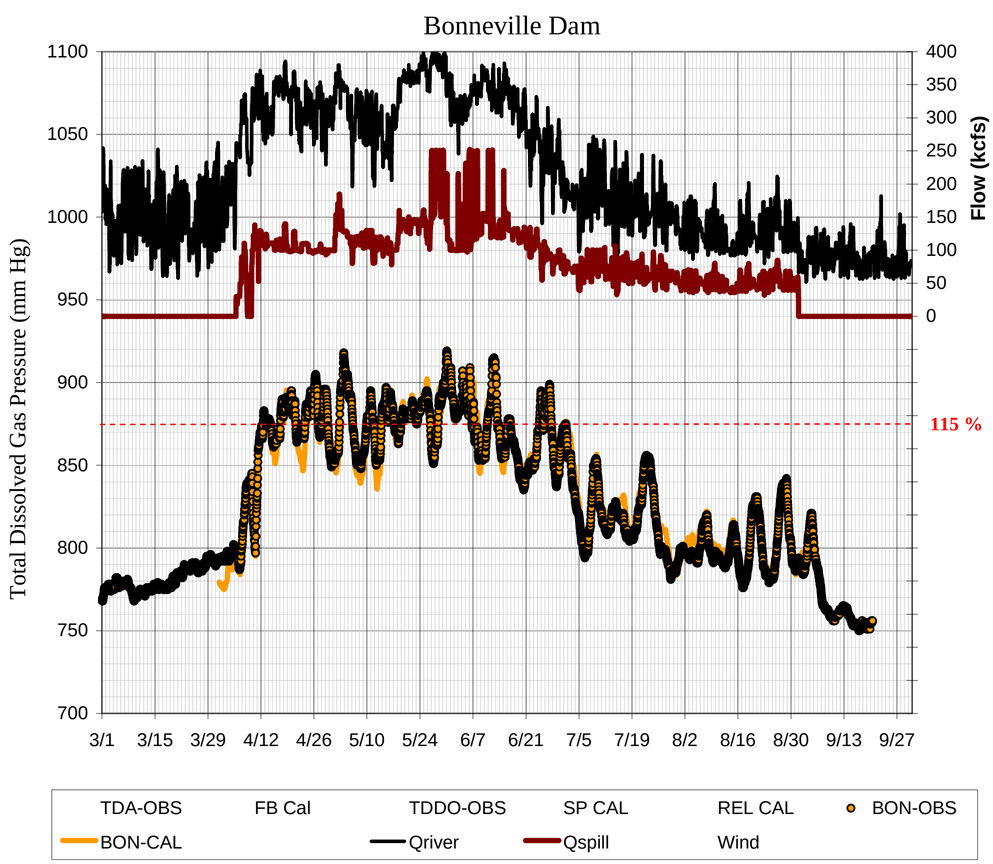

Figure E10. The Dalles Dam Operations with Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of Bonneville Dam, March-September 2006

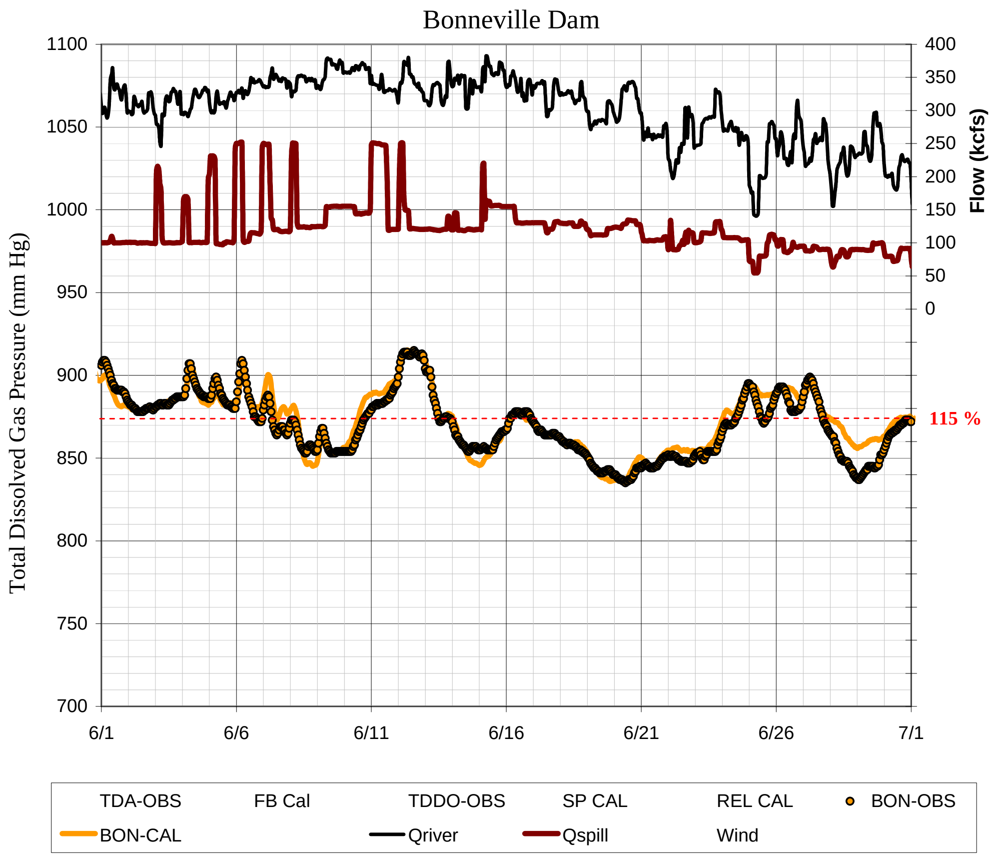

Figure E11. The Dalles Dam Operations with Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of Bonneville Dam, June 2006

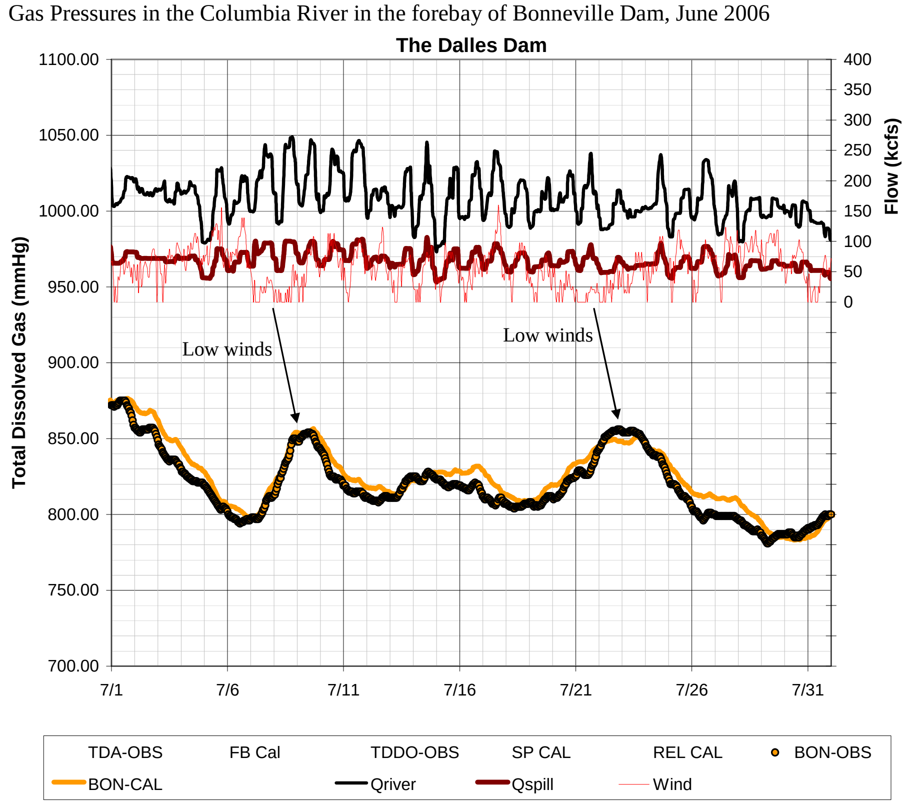

Figure E12. The Dalles Dam Operations with Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of Bonneville Dam, July 2006

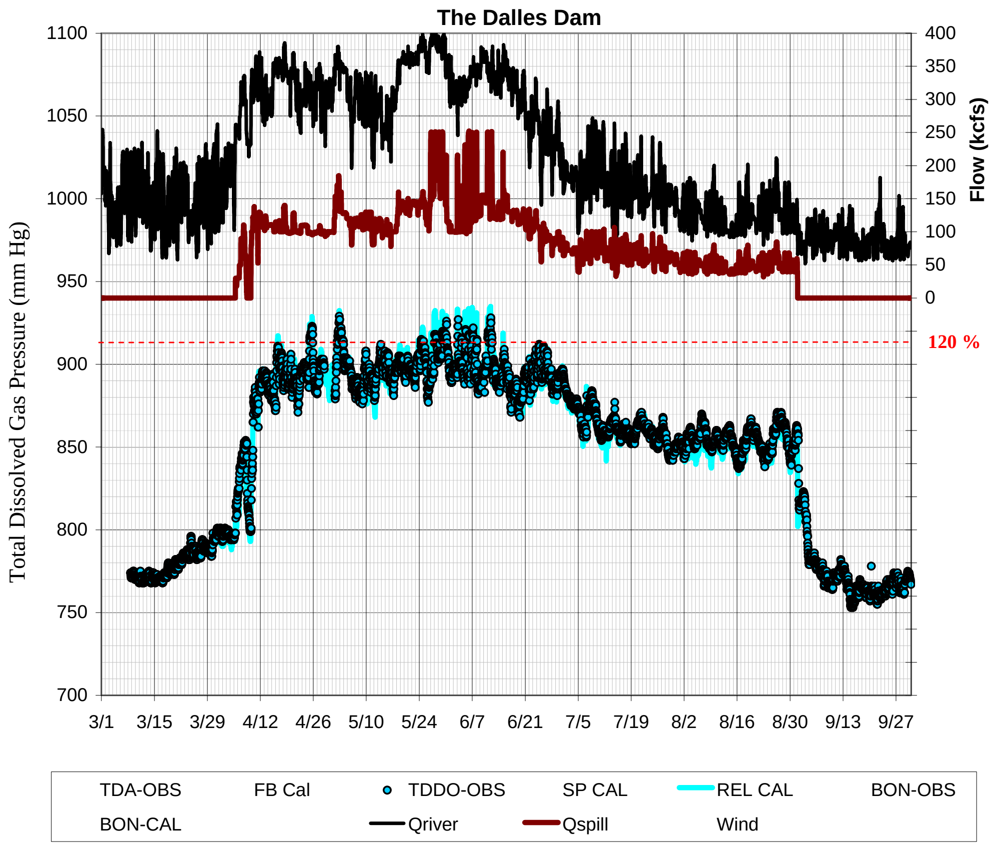

Figure E13. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel of The Dalles Dam, March-September 2006

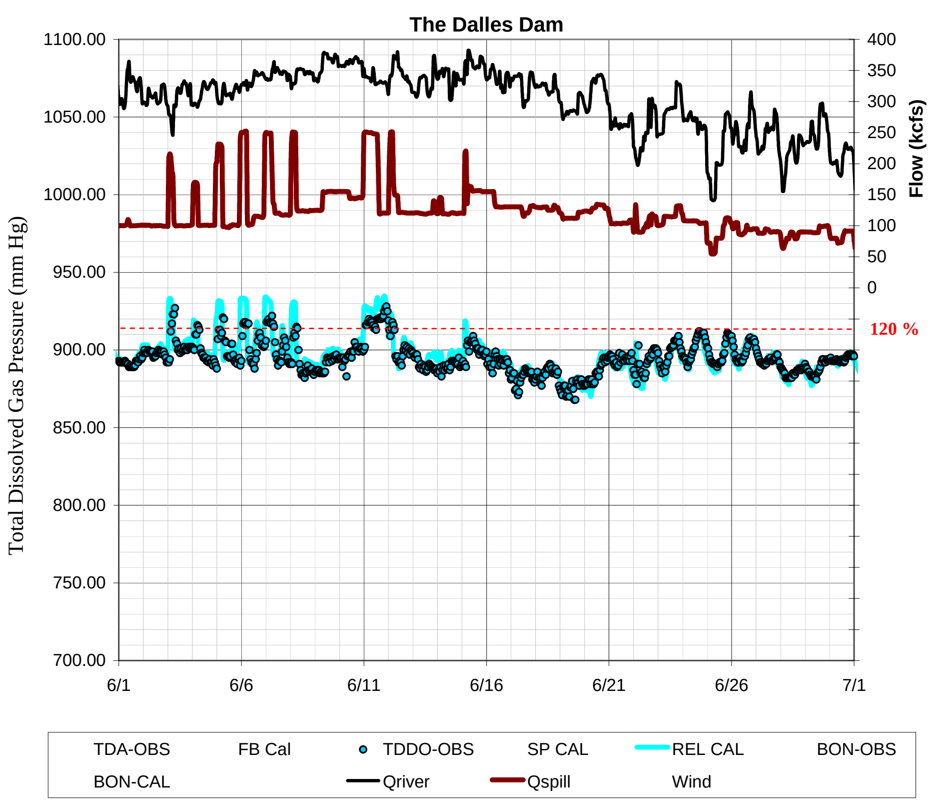

Figure E14. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel of The Dalles Dam, June 2006

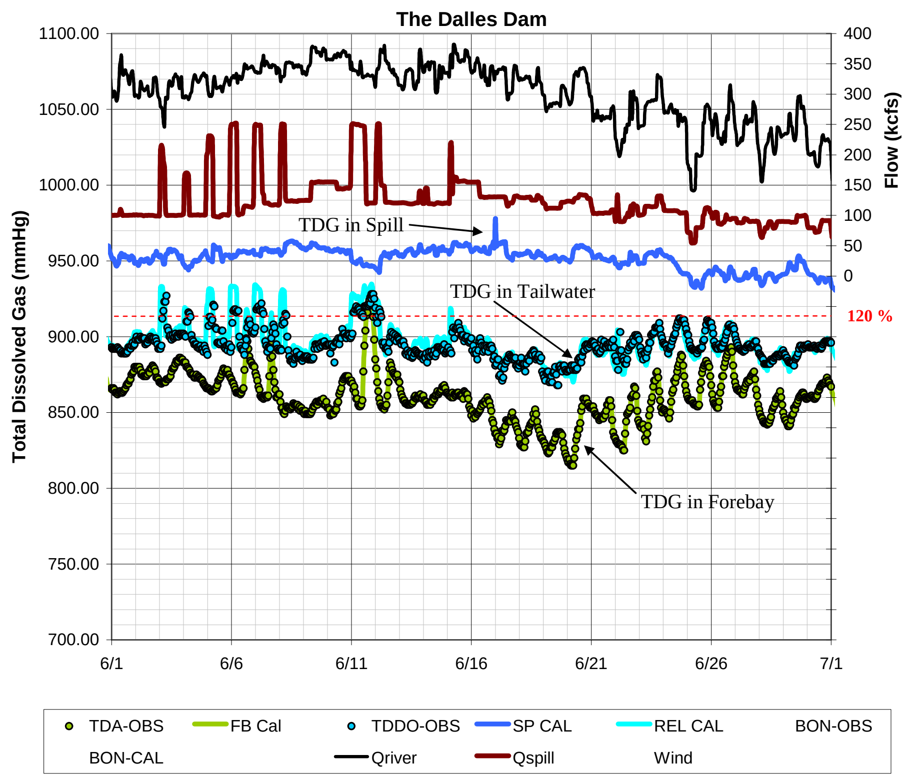

Figure E15. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel of The Dalles Dam, June 2006

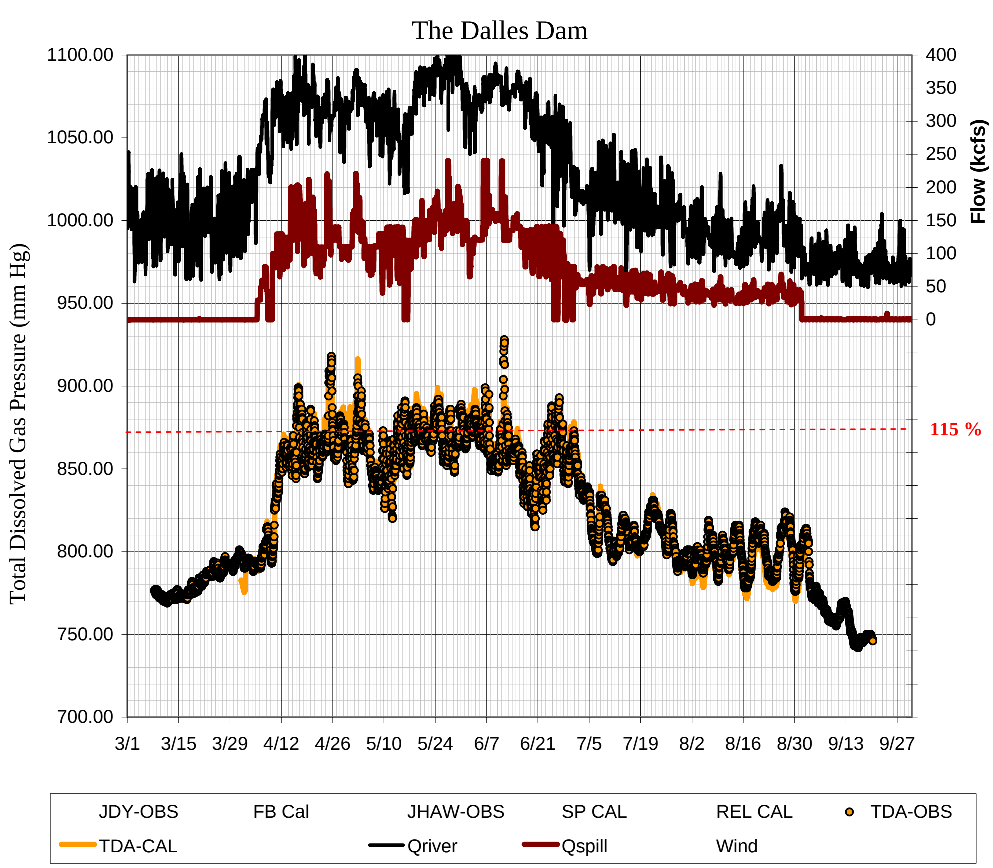

Figure E16. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of The Dalles Dam, March-September 2006

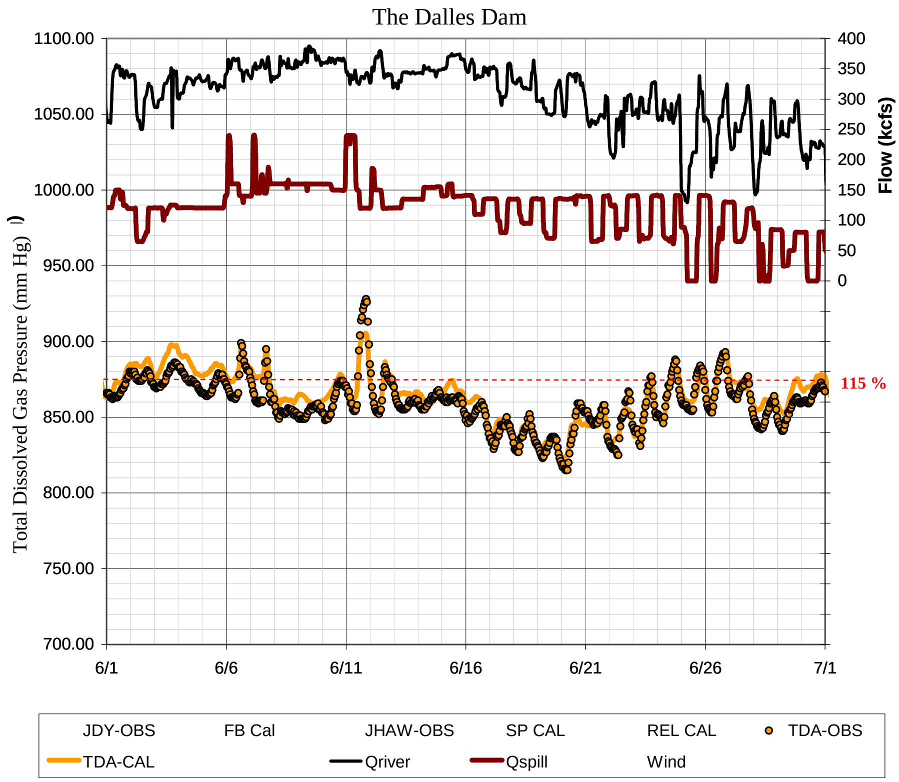

Figure E17. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of The Dalles Dam, June 2006

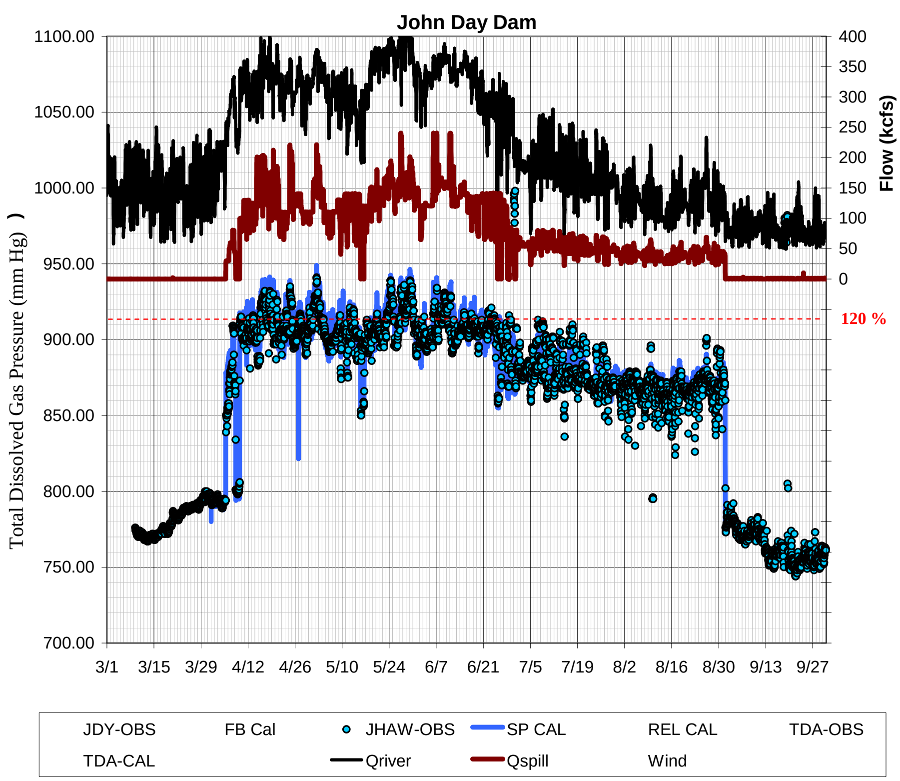

Figure E18. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, March-September 2006

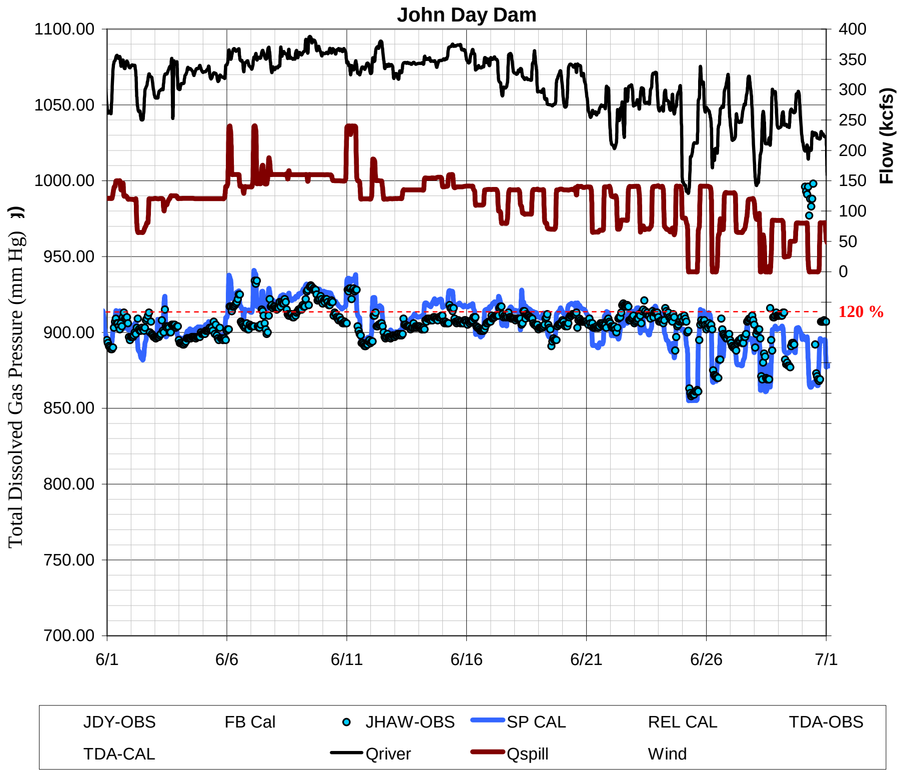

Figure E19. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, June 2006

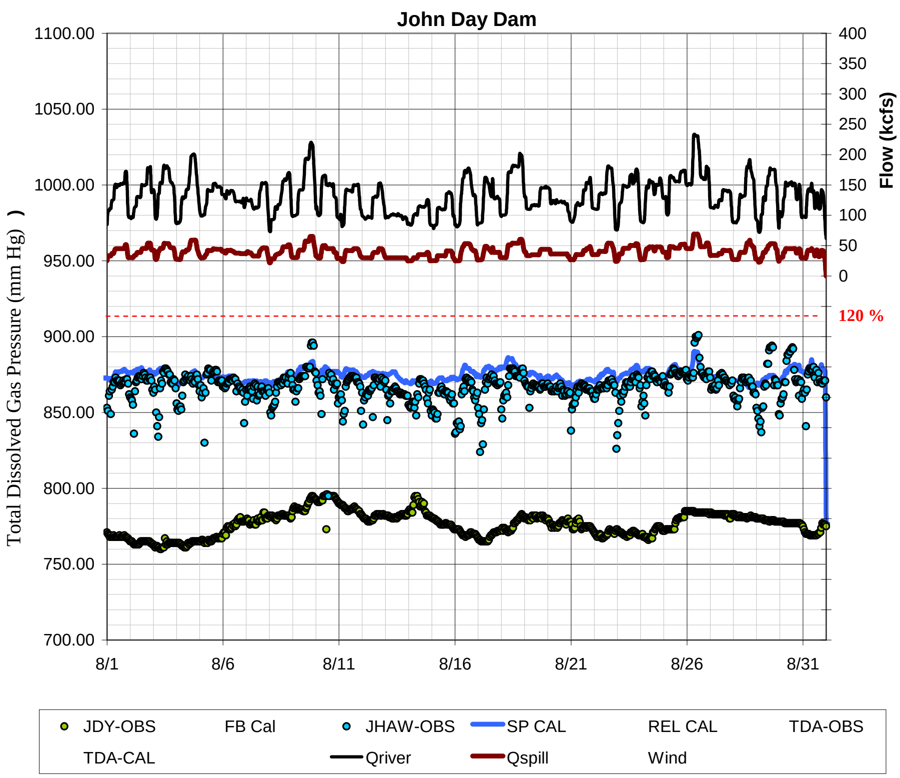

Figure E20. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, August 2006

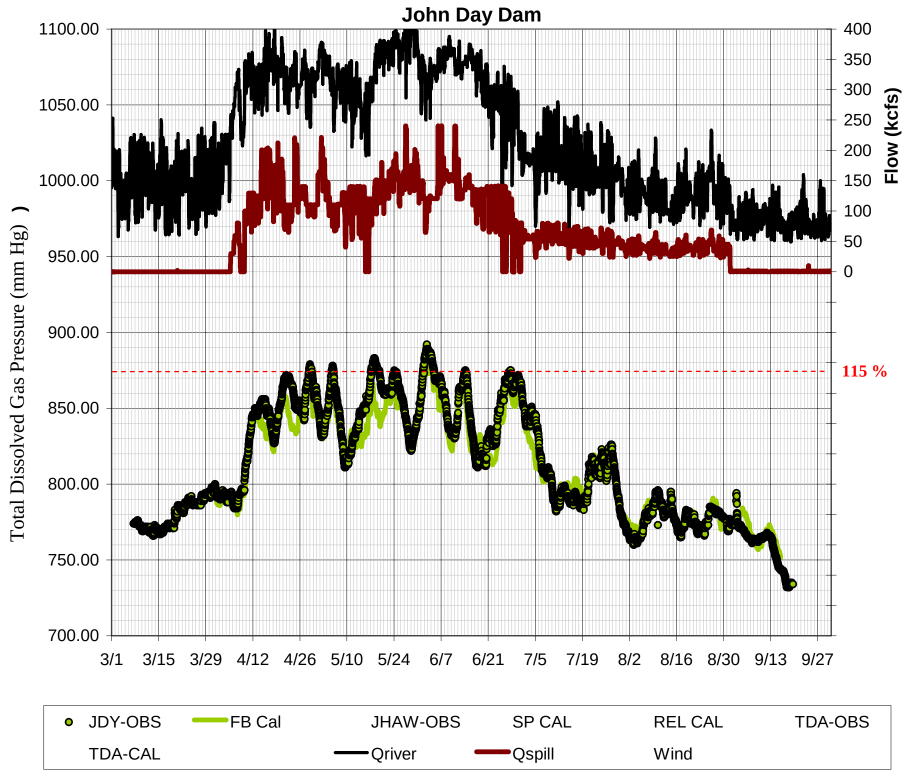

Figure E21. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of John Dam, March-September 2006

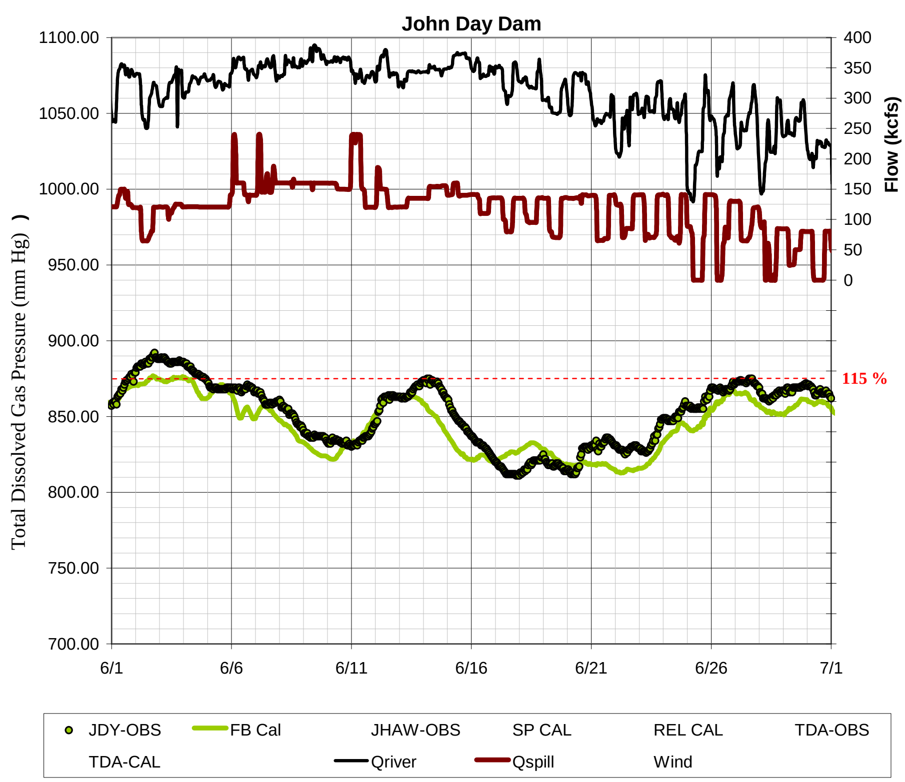

Figure E22. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of John Dam, June 2006

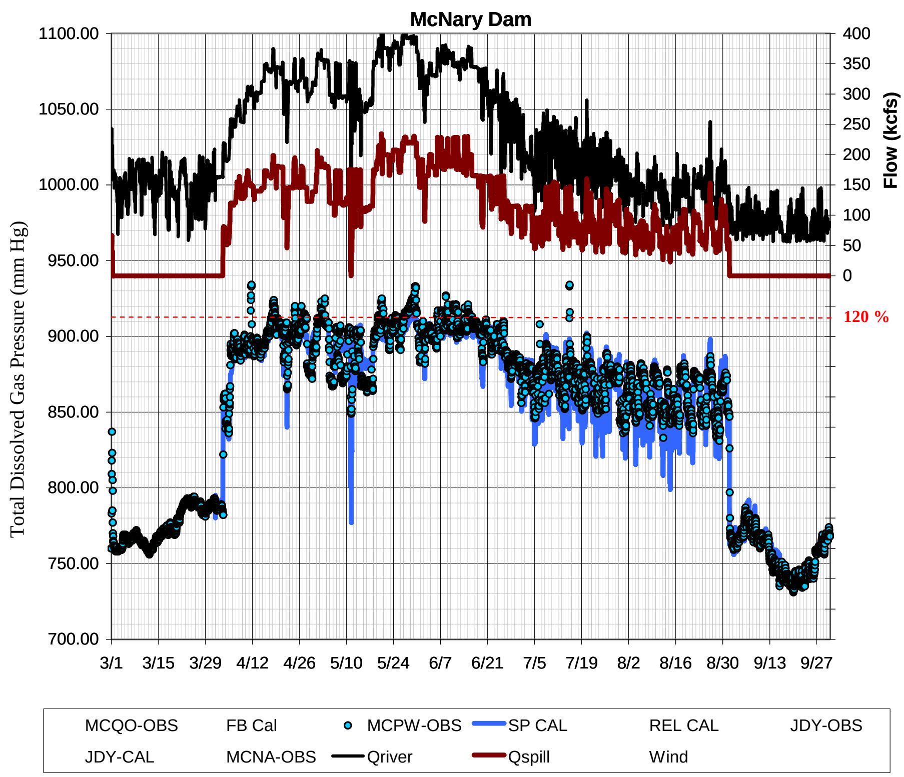

Figure E23. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater of McNary Dam, March-September 2006

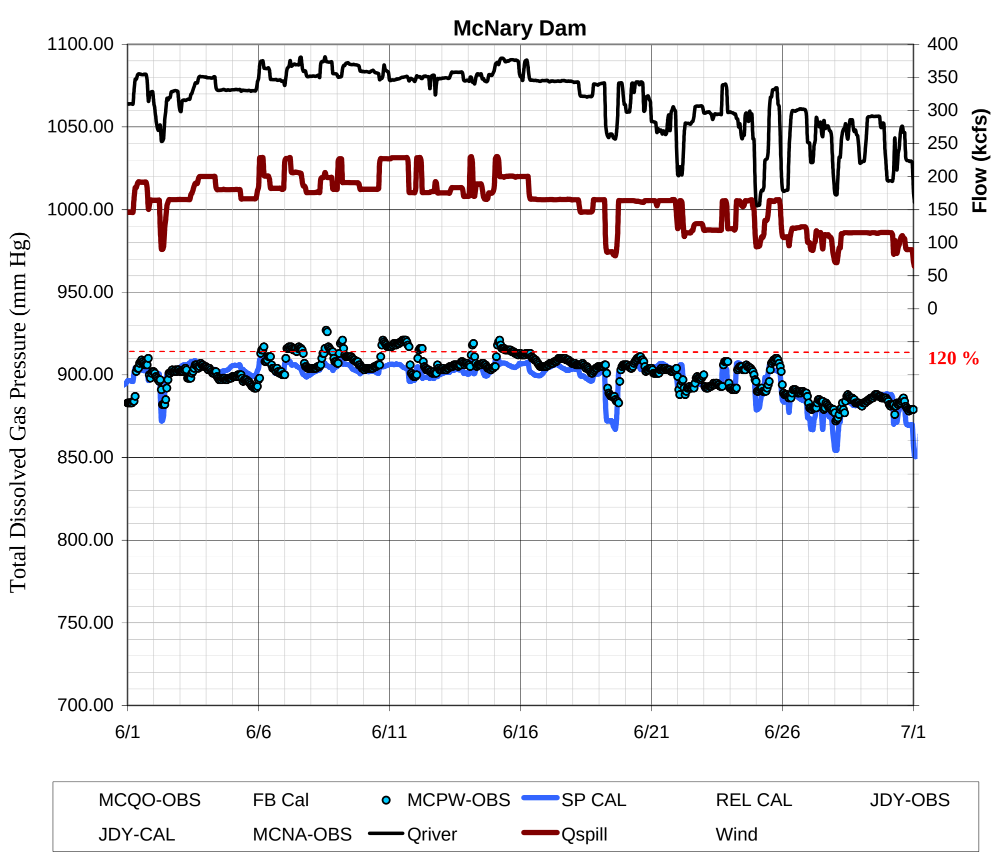

Figure E24. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater of McNary Dam, June 2006

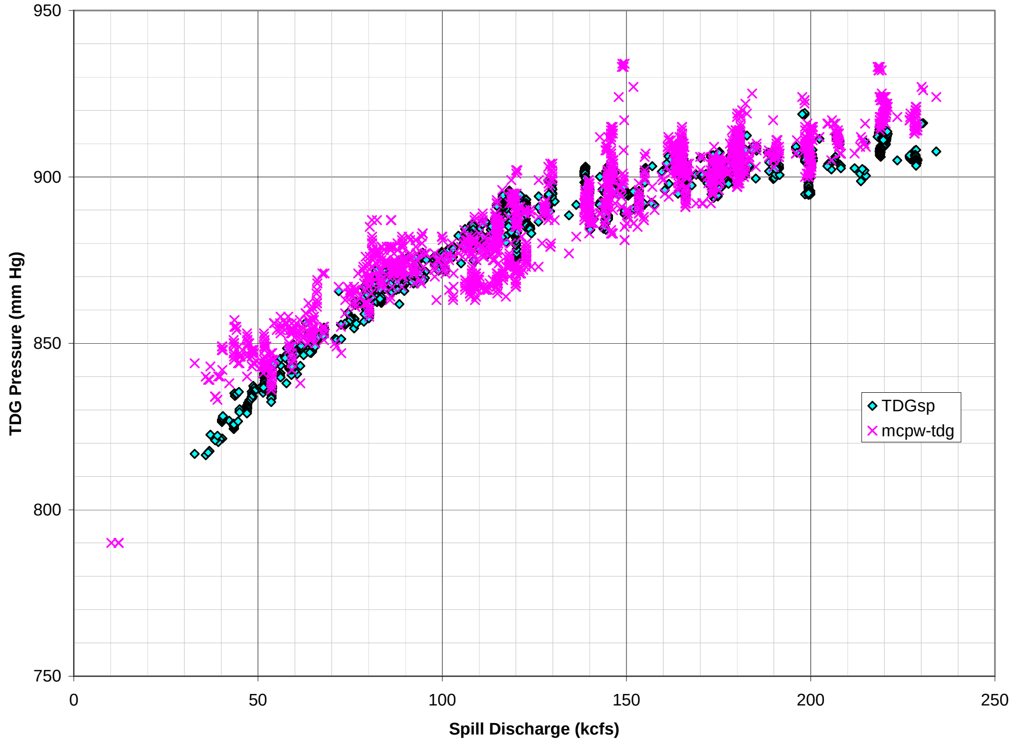

Figure E25. Calculated and Observed Total Dissolved Gas Pressure versus spillway discharge at McNary Dam, 2006 mcpw-tdg observed, TDGsp-calculated)

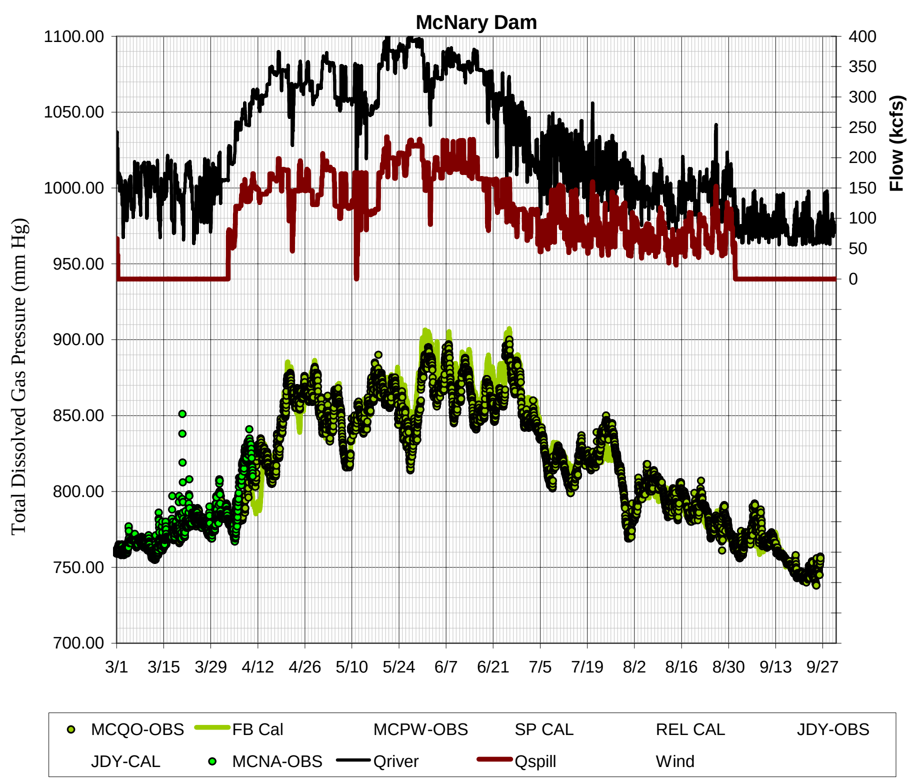

Figure E26. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of McNary Dam, March-September 2006

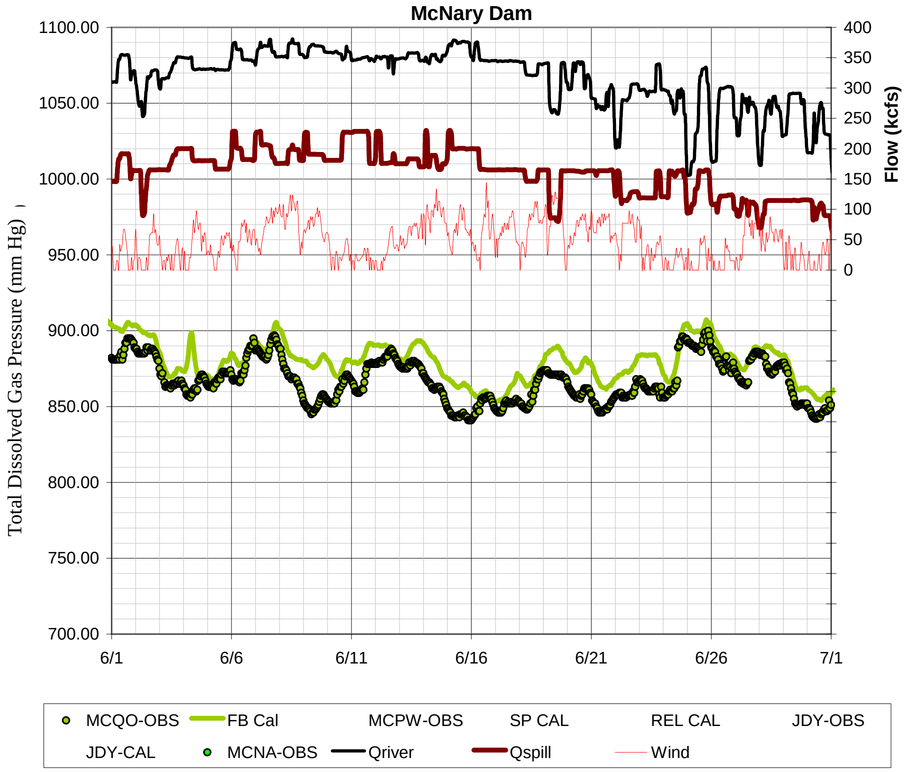

Figure E27. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of McNary Dam, May 2006

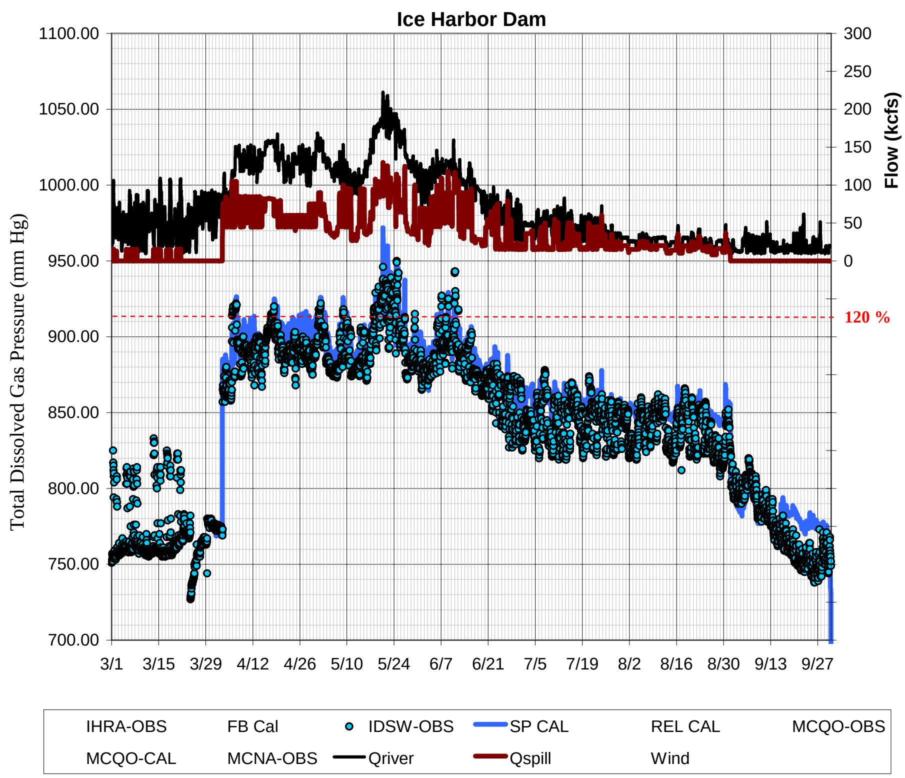

Figure E28. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater downstream from Ice Harbor Dam, March-September 2006

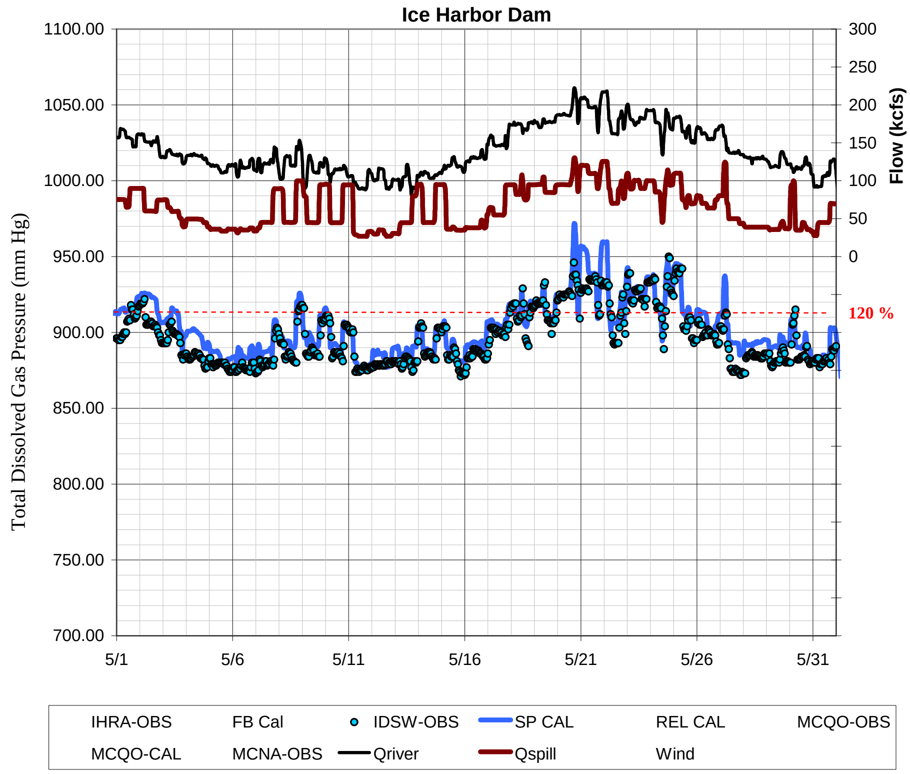

Figure E29. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater downstream from Ice Harbor Dam, May 2006

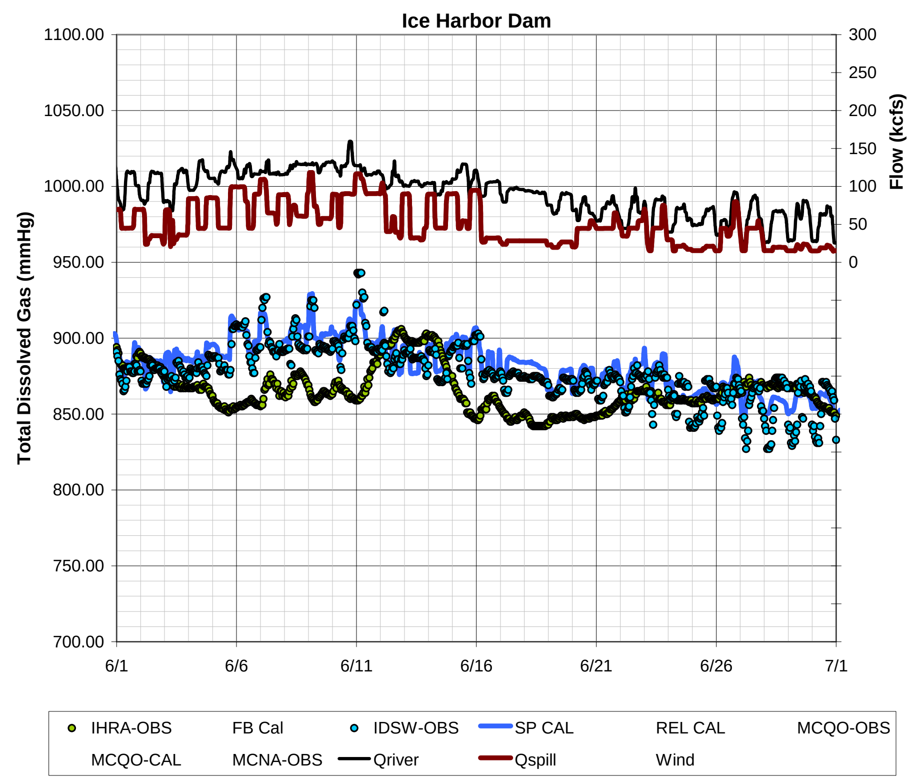

Figure E30. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater downstream from Ice Harbor Dam, June 2006

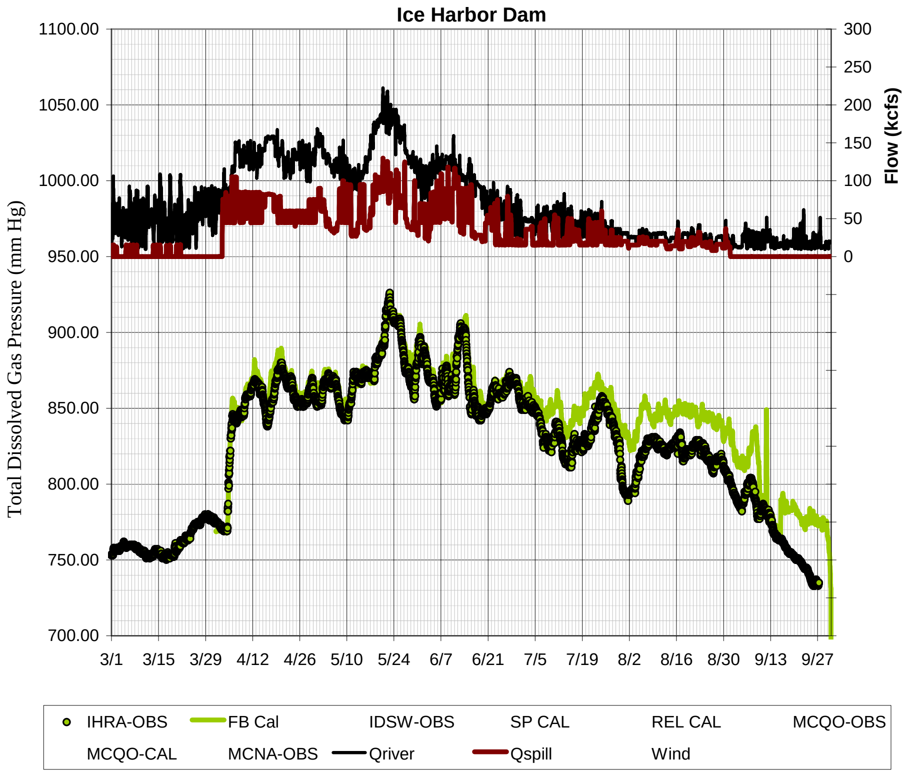

Figure E31. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Ice Harbor Dam, March-September 2006

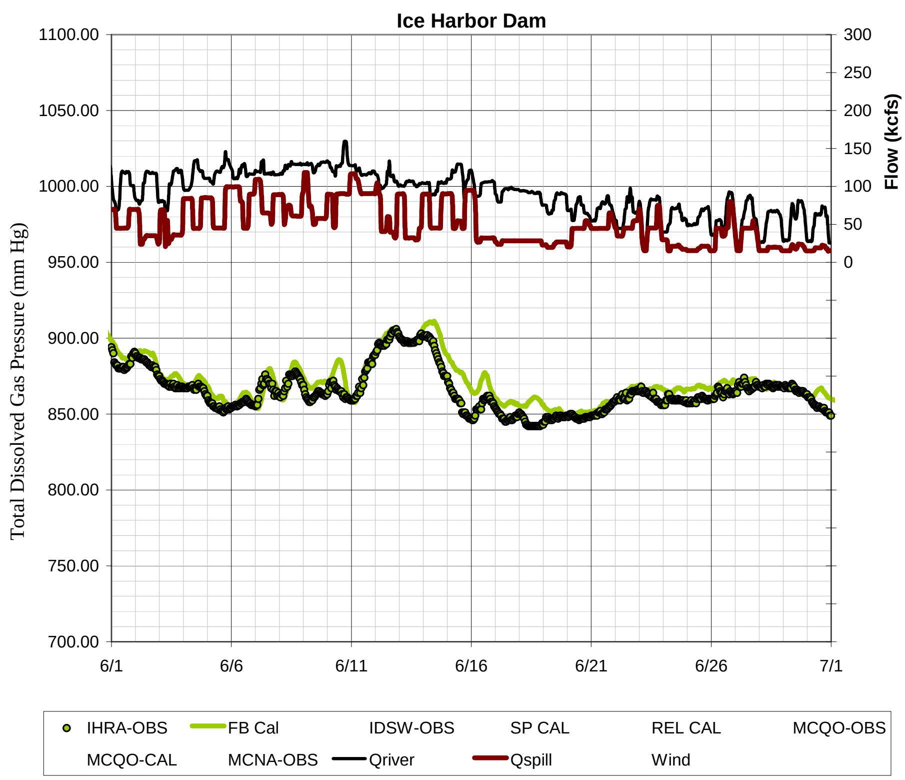

Figure E32. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Ice Harbor Dam, June 2006

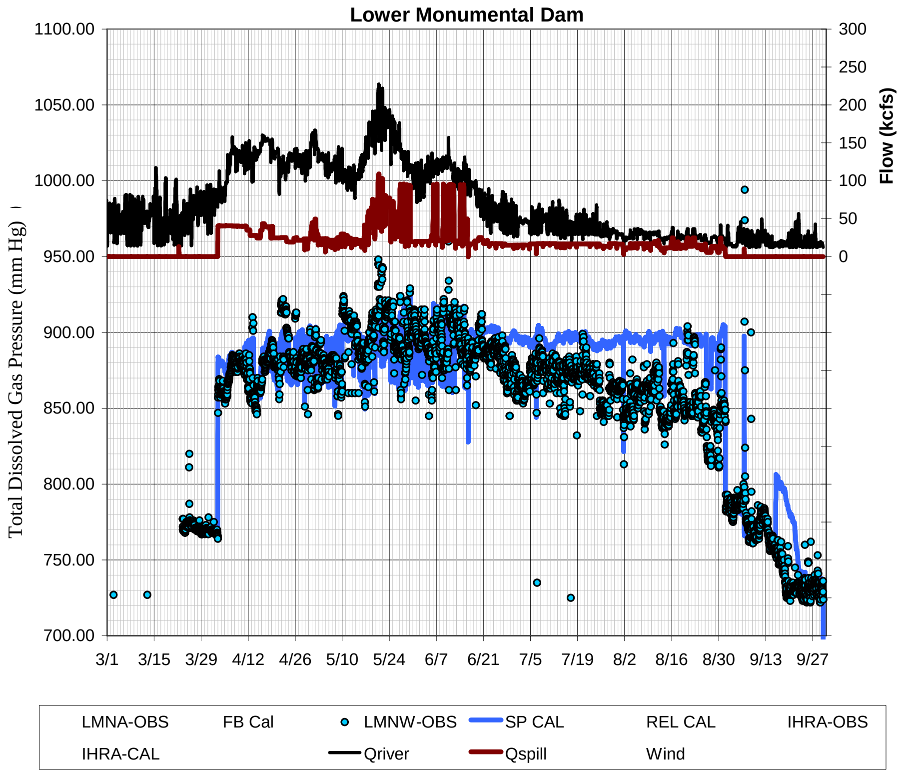

Figure E33. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Monumental Dam, March-September 2006

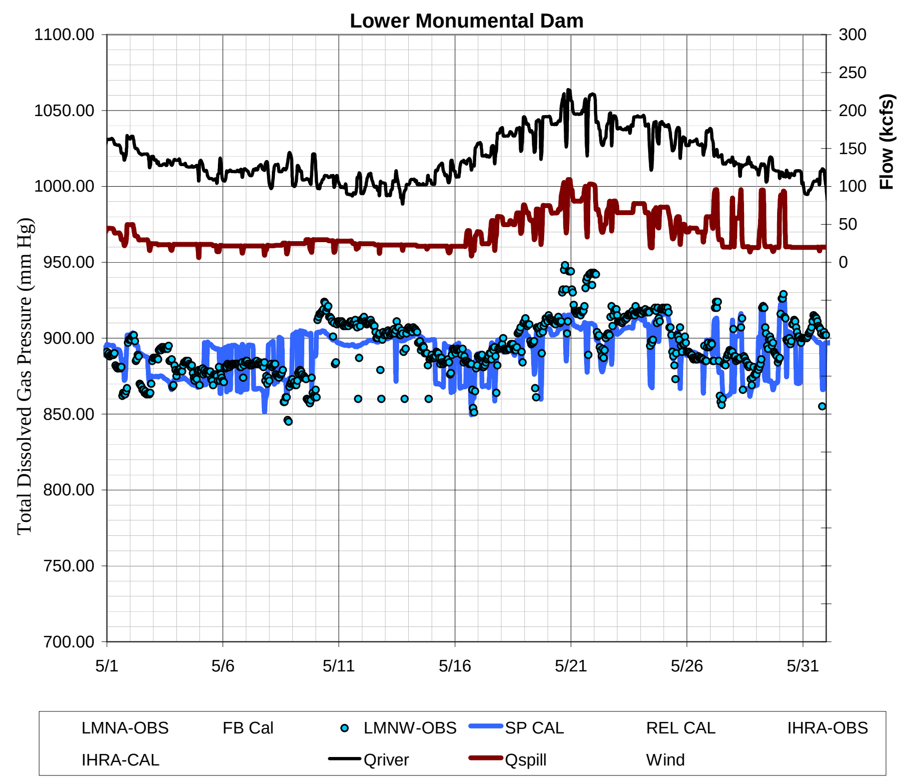

Figure E34. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Monumental Dam, May 2006

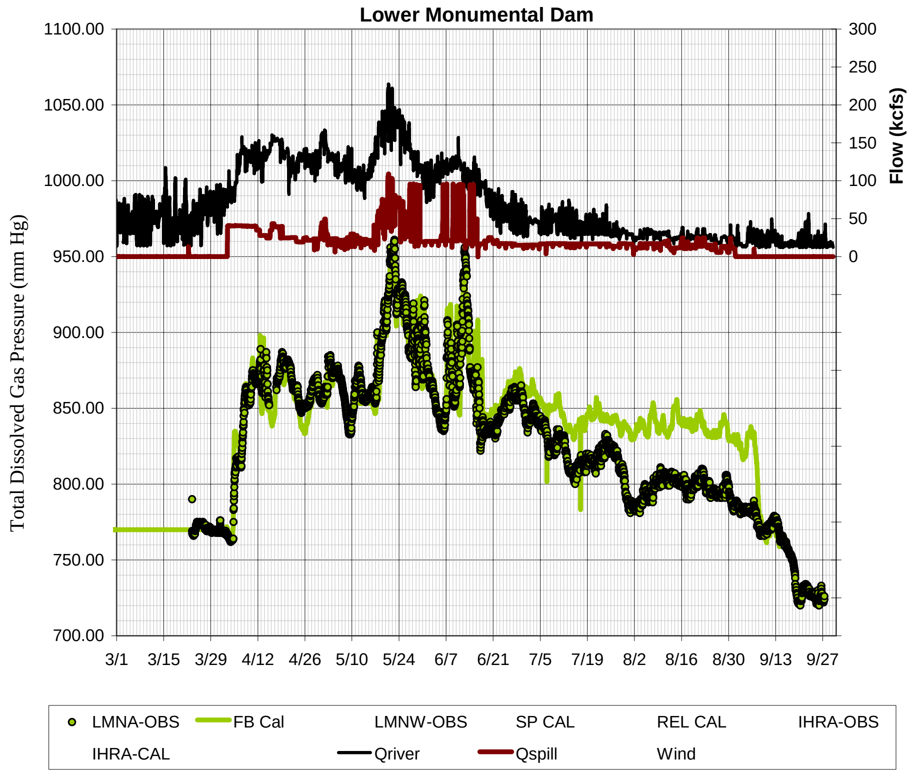

Figure E35. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Lower Monumental Dam, March-September 2006

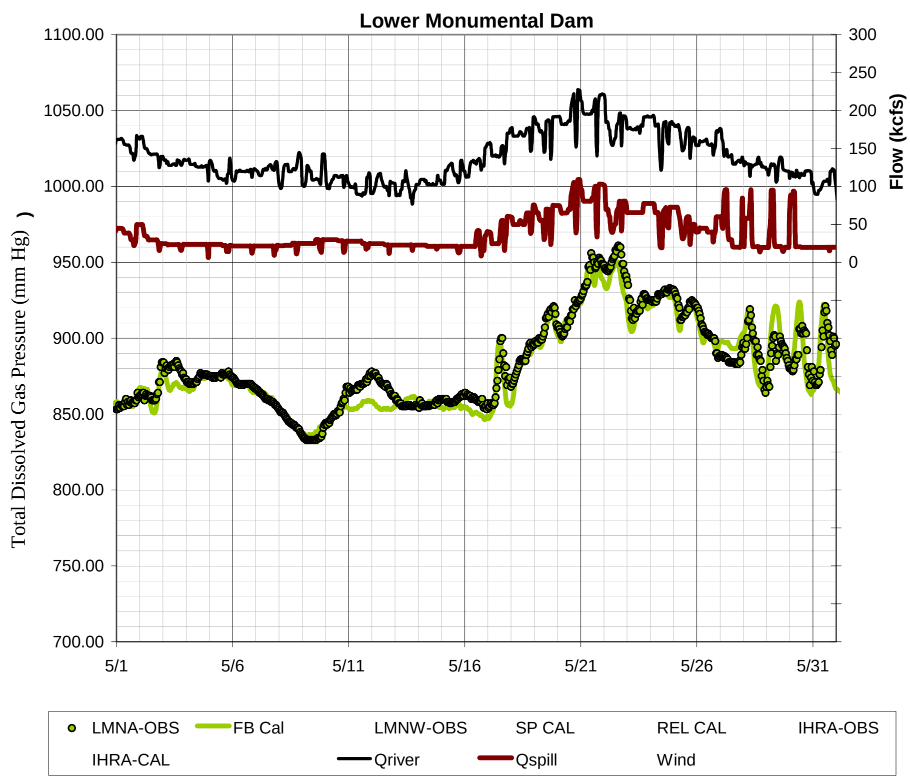

Figure E36. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Lower Monumental Dam, May 2006

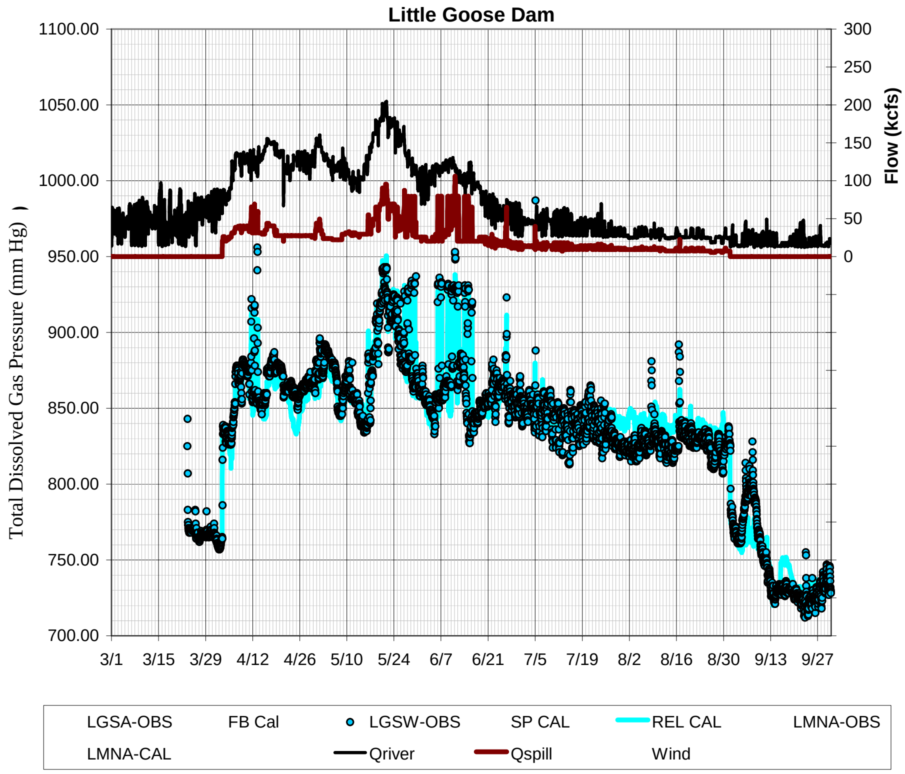

Figure E37. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Little Goose Dam, March-September 2006

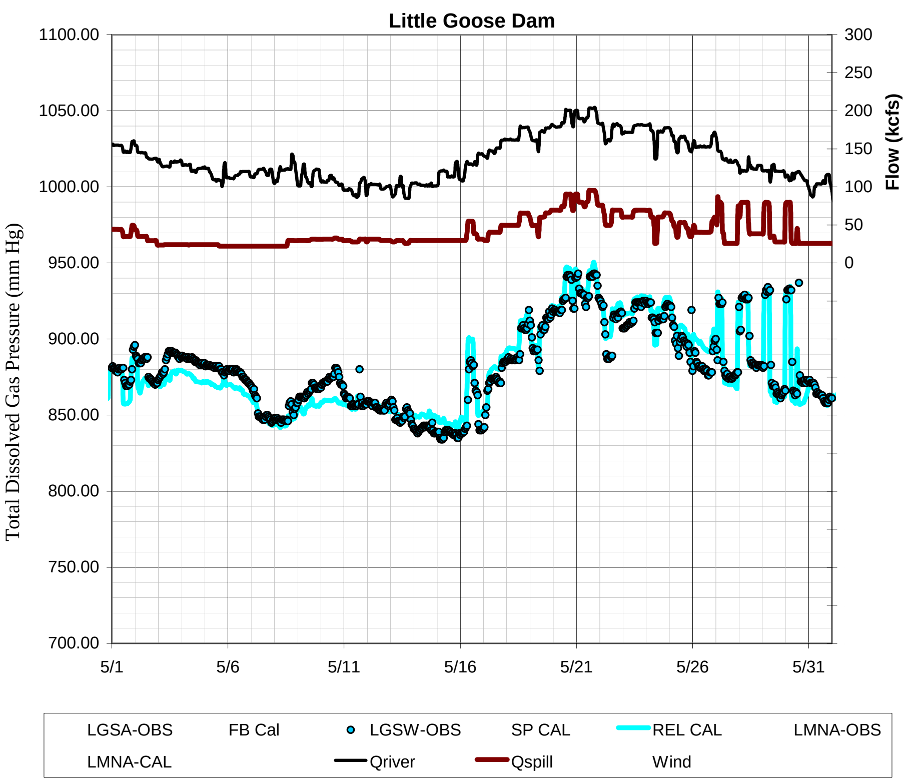

Figure E38. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Little Goose Dam, May 2006

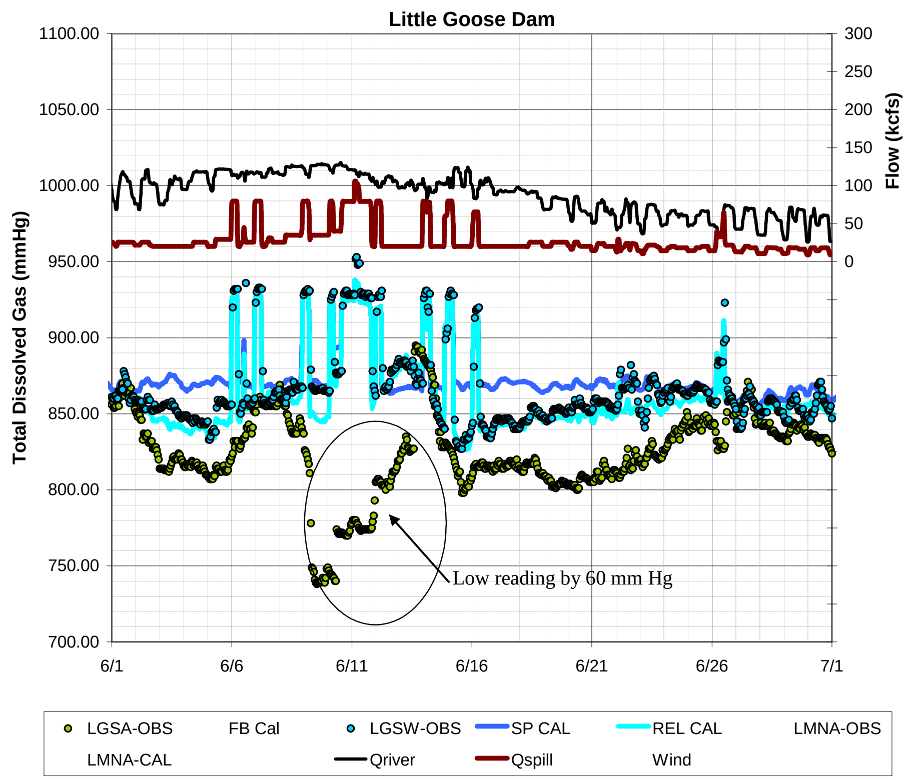

Figure E39. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel at Little Goose Dam, June 2006

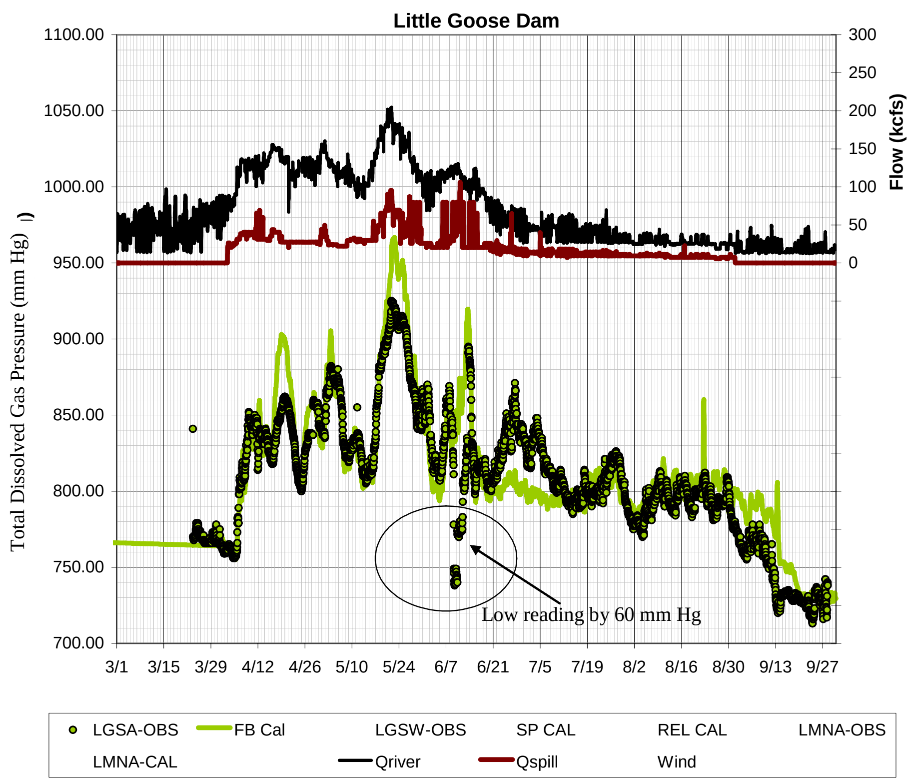

Figure E40. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Little Goose Dam, March-September 2006

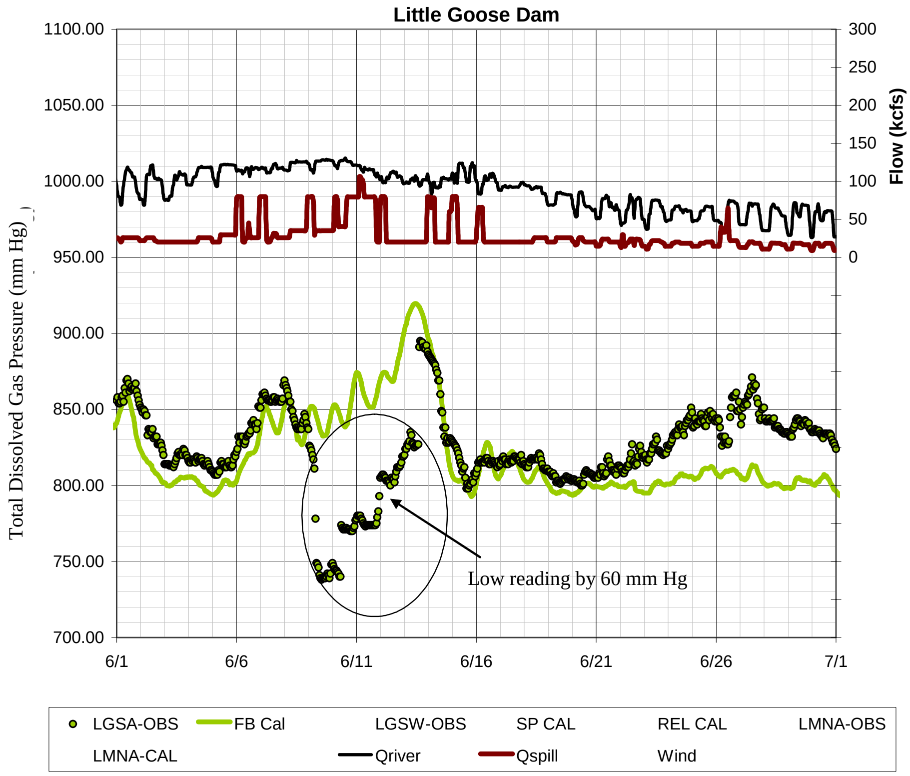

Figure E41. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Little Goose Dam, June 2006

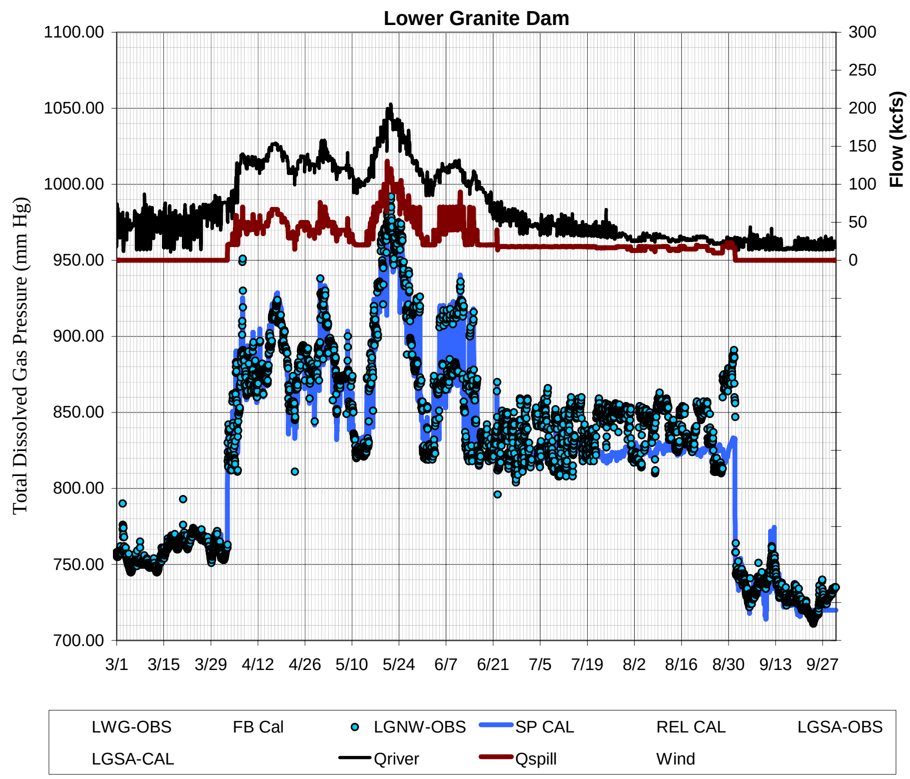

Figure E42. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, March-September 2006

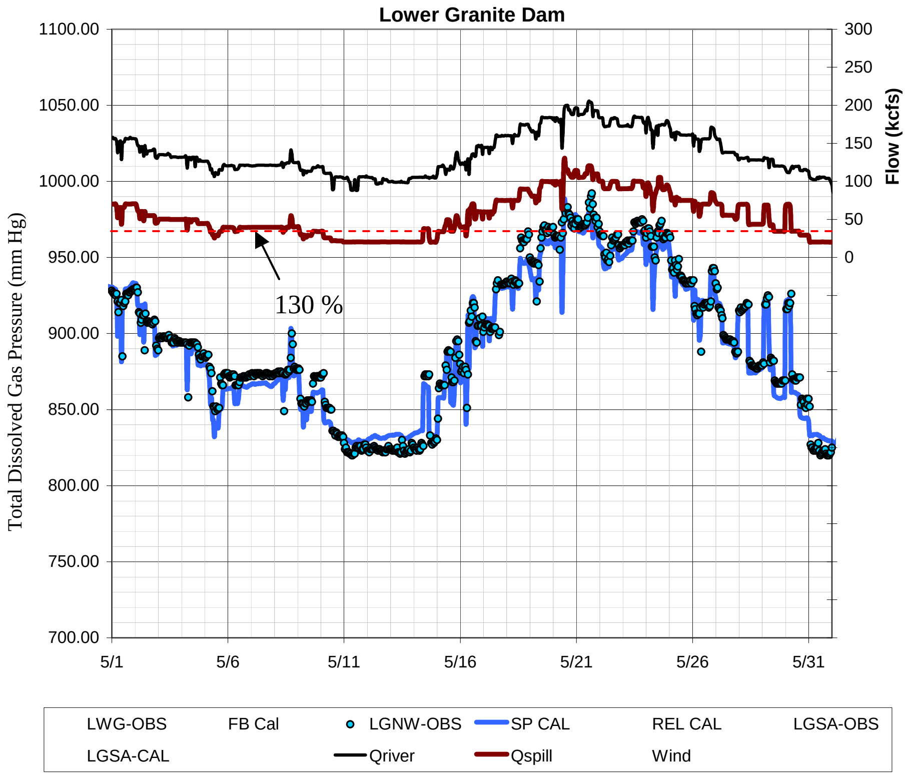

Figure E43. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, May 2006

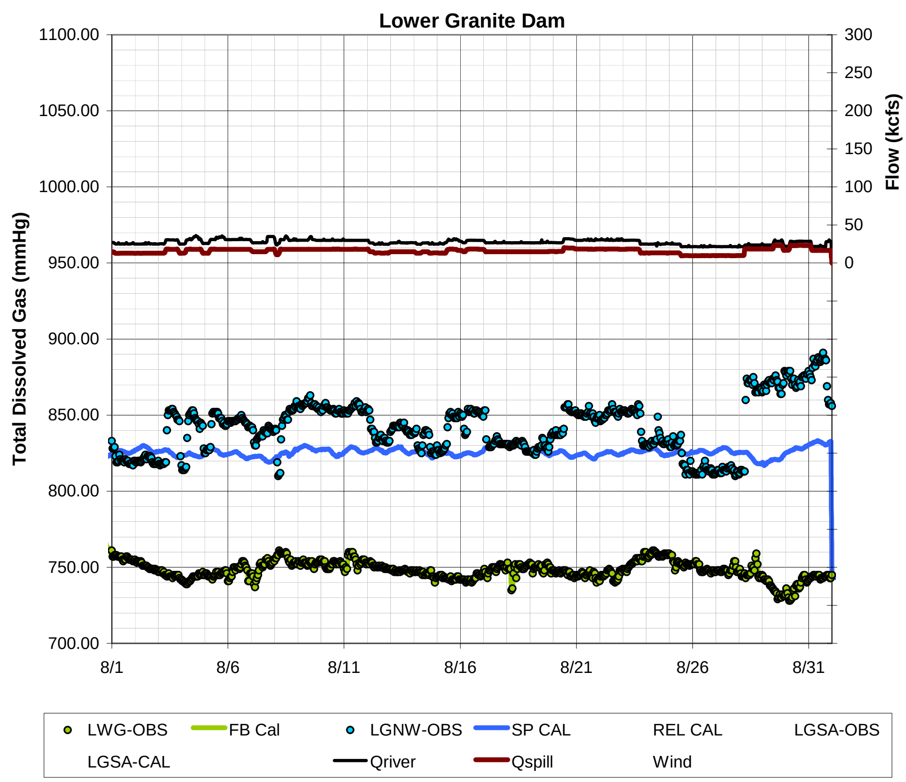

Figure E44. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, August 2006

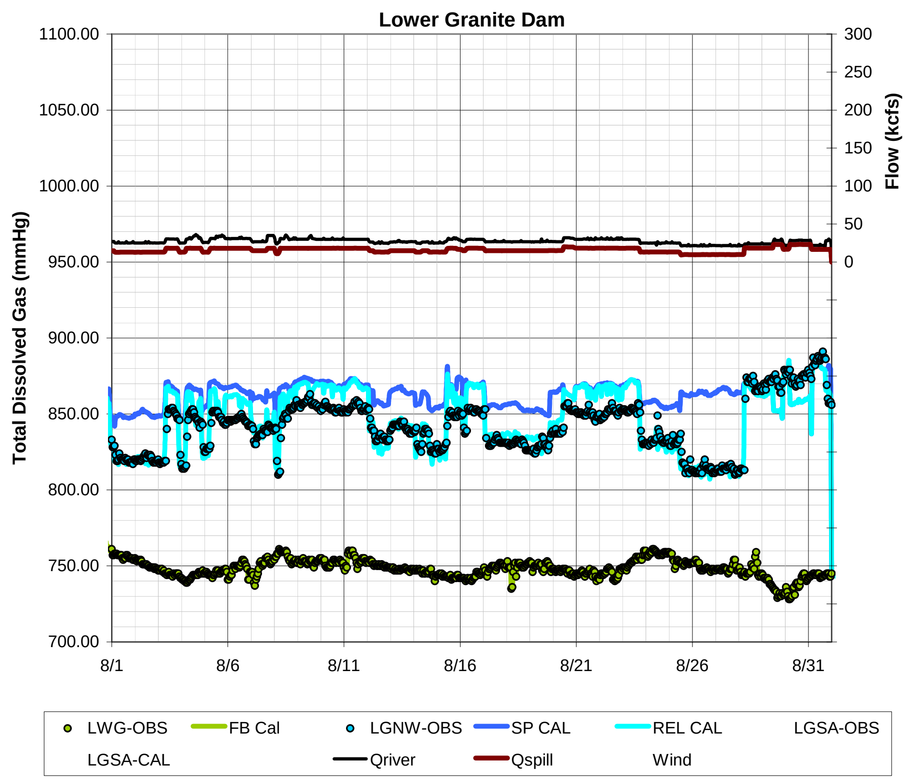

Figure E45. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, August 2006

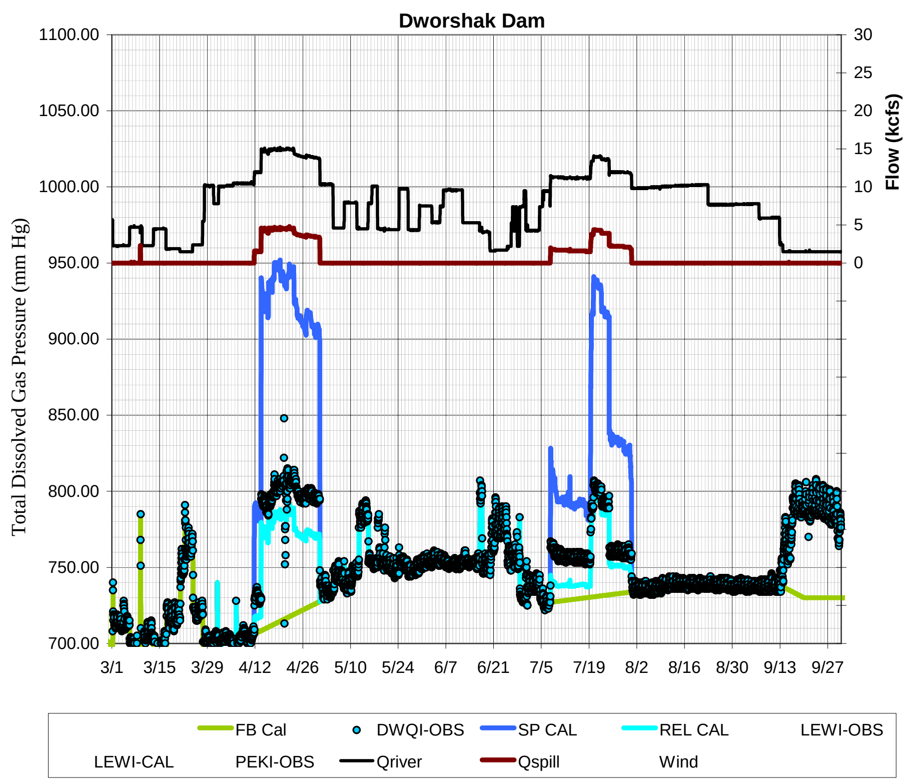

Figure E46. Observed and Calculated Total Dissolved Gas Pressures in the Clearwater River in the tailwater channel downstream from Dworshak Dam, March-September 2006

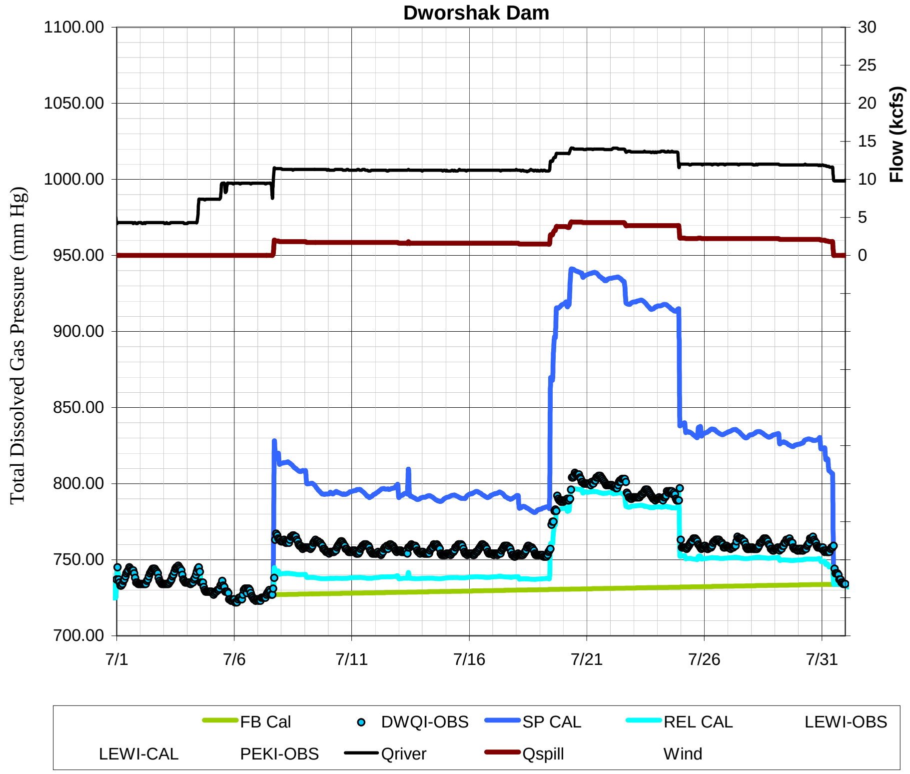

Figure E47. Observed and Calculated Total Dissolved Gas Pressures in the Clearwater River in the tailwater channel downstream from Dworshak Dam, July 2006

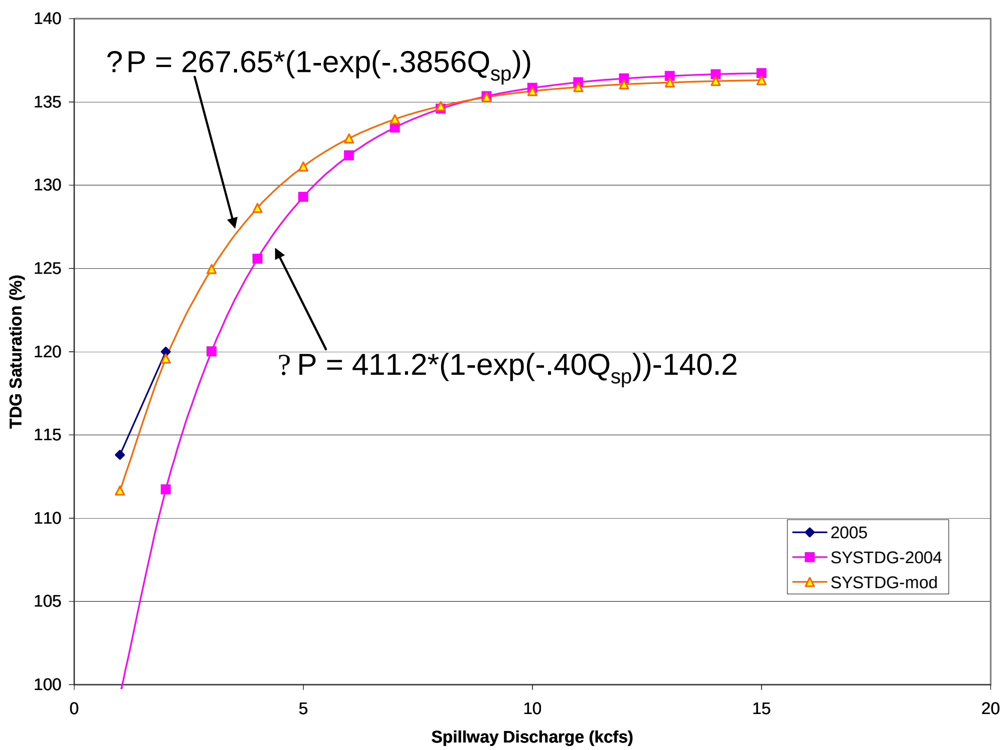

Figure E48 Total Dissolved gas production as a function of spill at Dworshak Dam (old and new production relationships)

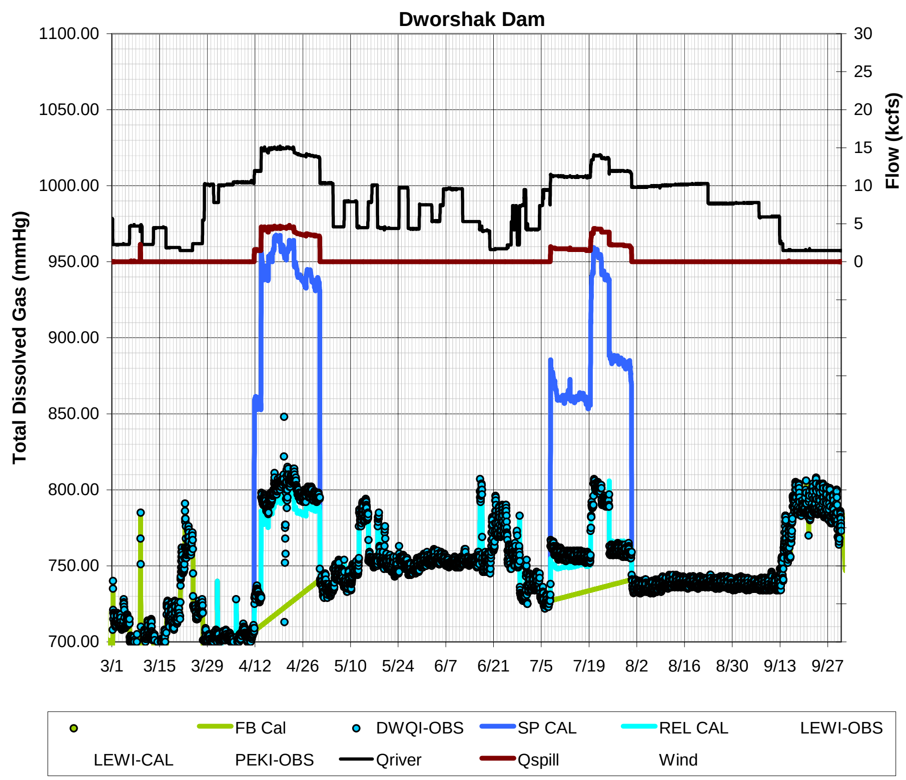

Figure E49. Observed and Calculated Total Dissolved Gas Pressures in the Clearwater River in the tailwater channel downstream from Dworshak Dam, March-September 2006 (updated TDG production model)