Appendix G

SYSTDG Statistical Evalutation
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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 2007 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 2007 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 2007 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, and whether the error represents an estimate bias or misrepresentation of conditions from a modeling standpoint.

Background

The Columbia River flows in 2007 were slightly below average during the fish passage season resulting in infrequent periods of forced spill and fewer events where the TDG saturation exceeded of the state water quality standards when compared to conditions in 2006. The monthly average flow in the Columbia River at The Dalles Dam during the 2007 season was compared to flow conditions from 1975-2007 in Figure G1. The flow in April of 2007 was slightly above average flows. The average flow in May of 2007 was the highest monthly flow of the year but fell slightly below the average of conditions since 1975. The monthly flows in June, July and August of 2007 were below the 32 year average for these months.

On the Lower Columbia River, the highest percentage of total river flow spilled of about 43 percent, occurred at Bonneville and McNary Dams. The higher spill rates at McNary and Bonneville Dams were the result of higher commitments to spill during the summer months. A statistical summary of the hourly project operations in the Lower Columbia River are shown in Table G1 for the period of April 1- August 31. The average spill at McNary was 89.2 kcfs compared to 90.8 at Bonneville Dam, 72.9 at The Dalles Dam, and 51.8 kcfs at John Day Dams. The actual percent spill rates at The Dalles and John Day Dams were slightly below the policy defined in the fish passage plan of 40 and 30 percent respectively, due to spills limited by TDG constraints at downstream forebay stations. The highest hourly spill of 173.9 kcfs occurred at John Day Dam. The average Columbia River Flow at McNary was just 0.7 kcfs less than observed at Bonneville Dam despite the added inflows from the John Day River, Deshutes River, Hood River, and White Salmon River. The spill policy at Priest Rapids Dam during 2007 resulted in much lower spill volumes and TDG saturation levels entering the McNary Pool.

Table G1. Statistical Summary of Hourly Project Flows from April 1-August 31, 2007 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	3671	3671	3672	3672	3671	3672
Avg		208.7	90.8	195.4	72.9	199.4	51.8	208	89.2	151.7	22
Stdev		52.4	23.6	58	28.1	57.8	48.9	51.6	23.8	36.5	21.6
Max		324.2	159.9	374.8	132.3	348	173.9	376.2	149.6	264.4	131
Min		115.6	0	64.9	0	70.2	0	89.8	17.8	3671	3672
Qsp/Qtot			43.5		37.3		26		42.9		14.5
	1%	118.6	62.4	99.8	0	100.6	0	125.2	42.1	37.8	0
	5%	132	74.6	110.6	40.1	114	0	139.8	55.4	77.9	0
	25%	165	76.5	148.5	53.6	153.1	0	167.1	76.1	101.6	0.6
	50%	210.5	95.4	200.1	76.5	204.7	42.2	211.2	91.8	132	13.2
	75%	251.1	99	240.1	94	245.2	83.7	251.5	107.1	157.8	19
	95%	278.4	106.9	269.6	106.6	271.8	131.9	273.5	116.2	175.5	23.5
	99%	289.6	130.8	282.6	111.8	286.2	144.9	289.4	123.3	189.3	27.2
*Units kcfs except for Qspill/Qtotal entry.											

The Snake River contributed about one-fifth of the flow to the Lower Columbia River during the period from April 1- August 31, 2007. Ice Harbor spilled about 57.6 percent of the Snake River flow during this period compared to 40.2, 30.6, and 38.0 percent for Lower Monumental, Little Goose, and Lower Granite Dams, respectively as listed in Table G2. The higher spill rate at Ice Harbor Dam was governed by the higher spillway capacity as limited by the TDG levels at the tailwater FMS and the biological testing of the raised spillway weir (RSW). The largest hourly spill of 95.6 kcfs occurred at Ice Harbor Dam during the 2007 spill season. The spill volume at Lower Granite Dam was considerably larger than at Little Goose Dam despite the presence of the RSW. The lower spill rates at Little Goose and Lower Monumental Dams were partially attributed to lower spill caps dictated by TDG levels in the forebay of the downstream project. The spill at Dworshak Dam was very limited during the 2007 spill season and occurred in July for temperature management purposes.

Table G2. Statistical Summary of Hourly Project Flows from April 1-August 31, 2007 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	3671	3671
Avg		45.5	26.2	44.8	18	44.8	13.7	45.8	17.4	7.3	0.1
Stdev		22.5	15.7	21.9	6	21.2	6.6	21.5	3.9	2.8	0.6
Max		119.3	95.6	118.4	40.6	117.2	40.9	110.4	20.3	12.1	2.6
Min		9.7	0	14.8	0	16.5	0	13.2	0	2.2	0
Qsp/Qtot			57.6		40.2		30.6		38		1.4
	1%	20.7	8.4	20.8	7.2	20	5.6	22.1	9.8	2.3	0
	5%	23.3	12.1	23.7	10.1	24.2	7.4	23.7	11.3	4.3	0
	25%	26.4	15.2	27.3	13.6	25.1	7.4	28.6	16.3	5.3	0
	50%	39.7	20	37.4	17.2	37.6	11.2	37.2	19.6	7.9	0
	75%	56.2	38.1	55.3	22.6	55.2	16.7	55.3	19.9	9.8	0
	95%	80.4	45.6	79.6	24.7	79	25.5	82.2	20	10	0
	99%	91.8	54.9	91.1	26.5	89.5	25.7	90.9	20.1	11.8	2.2
*Units kcfs except for Qspill/Qtot entry.											

The total dissolved gas saturation was monitored in the forebay and tailwater of each Lower Columbia River Dam throughout the spill season of 2007. The average TDG saturation in the forebay of each dam was similar ranging from a high of 109.5 at McNary Dam to a low of 104.3 percent 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 112.1 percent as listed in Table G3. The frequency of hourly observations greater than 115 percent at forebay stations ranged from 12.0 percent at CWMW to a low of 0.1 percent in the forebay of John Day Dam. The TDG saturation never exceeded 120 percent at these forebay fixed monitoring stations. The average TDG saturation at the tailwater stations ranged from 116.4 percent at Bonneville to 113.6 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 3.1 percent below Bonneville Dam to only 0.0 percent at McNary Dam. The frequency of the tailwater station exceeding the 120 percent criteria was less than the frequency of the next forebay station exceeding 115 percent at all four lower Columbia River projects during the 2007 fish passage season. These summary TDG statistics were based on hourly observations and not daily statistics composed of the highest 12 hourly observations or a moving 12 hour average as referenced by the state water quality standards in Oregon and Washington.

Table G3. Statistical Summary of Hourly Total Dissolved Gas Saturation at Fixed Monitoring Stations from April 1-August 31, 2007 on the Columbia River										
Station	Bonneville				The Dalles		John Day		McNary	
	CWMW	WRNO	CCIW	BON	TDDO	TDA	JHAW	JDY	MCPW	MCNA
	FB (%)	TW (%)	TW (%)	FB (%)	TW (%)	FB (%)	TW (%)	FB (%)	TW (%)	FB (%)
N	3660	1458	3672	3672	3672	3649	3671	3671	3672	3670
Avg	112.1	113.3	116.4	109.2	113.6	108.6	114	104.3	115.4	109.5
Stdev	2.5	2.7	2.1	3.1	2.3	3.3	4	17.1	1.7	3
Max	119.2	117.9	121.1	117.2	120.1	118.4	121.4	115.1	122	118.3
Min	104.4	104.7	107.4	102.5	103.5	102.6	104.5	0	110.9	102.1
100	100	100	100	100	100	100	100	97.4	100	100
105	99.7	99.7	100	89.9	99.5	88.7	99.4	72.4	100	91.8
110	81.9	84.9	99.6	43	94.8	31.4	80.1	15.6	100	45
115	12	26.1	65.8	1.5	24.6	4.3	43.5	0.1	57.2	3.9
120	0	0	3.1	0	0.1	0	1.4	0	0	0
125	0	0	0	0	0	0	0	0	0	0
130	0	0	0	0	0	0	0	0	0	0

The total dissolved gas saturation was monitored in the forebay and tailwater of each Lower Snake River Dam throughout the spill season of 2007. The average TDG saturation in the forebay of each Snake River Dam increased in a downstream direction as listed in Table G4. The average forebay TDG saturation at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams were 101.9, 107.6, 108.7, and 111.5 percent, respectively. The frequency of exceeding 115 percent saturation in the forebay of the Snake River Dams ranged from 0 percent at Lower Granite Dam to a maximum of 17.1 percent at Ice Harbor Dam. The average TDG saturation at the tailwater stations ranged from 114.5 percent at Lower Monumental Dam to 110.5 percent at Little Goose Dam. The frequency of hourly TDG observations exceeding 120 percent at the tailwater monitoring stations ranged from 2.9 percent below Lower Monumental Dam to 0.0 percent at Lower Granite Dam. The frequency of the forebay station exceeding the 115 percent criteria was greater than the frequency of the upstream tailwater station exceeding 120 percent which implies that forebay stations more frequently constrain spill operations on the Snake River than tailwater stations.

Table G4. Statistical Summary of Hourly Total Dissolved Gas Saturation at Fixed Monitoring Stations from April 1-August 31, 2007 on the Snake and Clearwater River									
Project	**Ice Harbor**		**Lower Monumental**		**Little Goose**		**Lower Granite**		**Dworshak**
Station	**IDSW**	**IHRA**	**LMNW**	**LMNA**	**LGSW**	**LGSA**	**LGNW**	**LWG**	**DWQI**
	TW	FB	TW	FB	TW	FB	TW	FB	TW
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
N	3672	3672	3662	3664	3672	3672	3672	3572	3667
Avg	112.7	111.5	114.5	108.7	110.5	107.6	111.1	101.9	99.3
Stdev	2.3	3.4	3.4	3.8	3.7	2.5	2.1	1.5	1.9
Max	120.3	118.3	124.2	118.8	121.8	115.6	116.6	105.7	107.4
Min	102.9	101.9	101.9	101.1	104.5	102	100.7	97.9	94
100	100	100	100	100	100	100	100	90.3	31
105	99.5	96.9	98.7	83.7	99.6	84	98.7	2.8	0.2
110	88.6	71.6	94.7	37.7	43.9	14.7	73.5	0	0
115	19.7	17.1	36.3	5.1	17.3	0.1	7	0	0
120	0.1	0	2.9	0	0.2	0	0	0	0
125	0	0	0.4	0	0	0	0	0	0
130	0	0	0.4	0	0	0	0	0	0

Results

The following section presents a brief description of each simulation and a summary of the statistical analyses generated from each comparison. The statistical analyses of the predictive error for the FMS stations includes the descriptive statistics of mean, minimum, maximum, standard deviation, and the confidence limits for the following percentiles: 5, 10, 25, 50, 75, 90, and 95 percent. Table G5 and G7 describe the predictive errors statistics in mm Hg of pressure while Table G6 and G8 describe the predictive errors in percent saturation. The prediction error was calculated by subtracting the calculated TDG level from the observed value. A prediction error with a negative sign indicates the calculated value was larger than the observed value.

Camas/Washougal (CWMW)

A hind cast of Bonneville operations 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 2007. (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 3636 observations. The calculated TDG pressures under-estimated observed conditions by an average of 1.6 mm Hg (average predictive error +1.6 mm Hg) and the standard deviation of the predictive error was 9.5 mm Hg as listed in Table G5. The size of the predictive error in 2007 at CWMW was slightly greater than determined in 2006 despite the narrower range of project operations (standard deviation of the predictive error was 6.9 mm Hg in 2006). The 50 percent confidence interval for the predictive error ranged from +5.1 to -4.6 mm Hg of pressure and the 80 confidence interval ranged from +15.6 to -7.5 mm Hg. The seasonal time history of observed and calculated TDG pressures at the CWMW gage is shown in Figure G2. There were instances where the TDG saturation at the CWMW exceeded the TDG criteria of 115% of saturation in each of the months of spill. The excursions during the first two months of the year were often related with elevated background TDG levels. The excursions during the summer months were associated mainly with spill to capacity directives during the nighttime hours.

There were little differences in the seasonal values of the observed and calculated TDG pressures at the CWMW gage resulting from spillway operations as shown throughout the month of June in Figure G3. A strong daily cycle was evident in these records caused in part by the thermal exchange that is evident throughout this shallow open river reach even during the spring months with spill was held relatively constant. 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 (B2CC) outfall becomes more important during the lower total river flow conditions in July and August. The estimated TDG saturation generally underestimated the observed conditions during the late summer month even with the more prominent TDG contributions from the B2CC. In summary, the predictive error was generally relatively small at the CWMW station with 50 percent of the errors less than +/-0.7 percent saturation and 80 percent of the errors less than +/-2.1 percent saturation as listed in Table G6. The influence of thermal cycling in the Columbia River is more prominent in the reach below Bonneville Dam than in upstream reaches and can significantly impact the daily TDG metrics used to determine compliance with state water quality standards.

Table G5. Statistical summary of the predictive errors of the observed and calculated total dissolved gas pressures at forebay fixed monitoring station

Parameters		Predictive Error at Forebay FMS* (mmHg)							
Station		LGSA	LMNA	IHRA	MCNA	JDY	TDA	BON	CWMW
Number of Observations		3646	3638	3646	3646	3554	3625	3672	3636
Average		1.5	-17.6	-0.8	4	5.1	2.8	-0.8	1.6
Standard Deviation		18.1	14.9	9.9	9.7	10.6	7.8	7.3	9.5
Maximum		54.8	17.5	31.9	74.8	38.3	37.3	36.4	37.3
Minimum		-48.2	-51.1	-35	-18.2	-16.9	-19.6	-25.6	-25.9
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	-33	-38.5	-17	-7.9	-9.7	-9.5	-10.9	-9.6
	10%	-25.5	-36.3	-12.7	-5.6	-7.6	-6.9	-8.7	-7.5
	25%	-8.4	-30.4	-7.5	-1.9	-3.6	-2.6	-5.2	-4.6
	50%	2.5	-19.8	-1.1	3.1	4.5	2.4	-1.1	-0.7
	75%	13.4	-4	6.7	8.3	11.9	7.7	3.7	5.1
	90%	23.5	1.8	11.7	13.6	19.8	12.7	7.5	15.6
	95%	29.3	5.2	14.5	17.6	25.2	15.9	9.5	22.8

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

Bonneville Dam Tailwater (WRNO)
A hind cast of Bonneville operations was conducted using the SYSTDG model of the river reach from the Bonneville Dam to the fixed monitoring station located at Camas/Washougal from 1 April through 31 August 2007, in an effort to determine the prediction 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 January 1 to May 31 during the 2007 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 6.1 mm Hg (average predictive error -6.1 mm Hg) and the standard deviation of the predictive error was 8.9 mm Hg as listed in Table G7. The 50 confidence interval of the predictive error ranged from -0.6 to -11.4 mm Hg of pressure and the 80 confidence interval ranged from +5.2 to -16.9 mm Hg of pressure. The standard error of TDG pressure at the WRNO station during the 2007 season was significantly less than determined in 2006 (8.9 to 11.7 mm Hg). The seasonal time history of observed and calculated TDG pressures at the WRNO gage is shown in Figure G4. The daily TDG values at Warrendale are a function of both the TDG levels associated with spillway operations at Bonneville Dam and the TDG levels produced at upstream dams and discharged through both powerhouses at Bonneville Dam. The calculated and observed TDG pressures at WRNO are shown throughout the month of May in Figure G5. The TDG saturation never exceeded 120 percent at WRNO during the 2007 fish passage season because of the influence of the dilution of spillway flows by powerhouse flows. However, the TDG levels exceeded 115 percent over 26 percent of the time or over twice the frequency observed at CWMW (12 percent) indicating a significant amount of degassing taking place between these two stations.

Table G6. Statistical summary of the predictive errors of the observed and calculated total dissolved gas saturation at forebay fixed monitoring station, April 1-August 31, 2007.

		Predictive Error at Forebay FMS* (Saturation %)							
Station		LGSA	LMNA	IHRA	MCNA	JDY	TDA	BON	CWMW
Number of Observations		3646	3638	3646	3646	3554	3625	3672	3636
Average		0.5	-2	0.2	0.8	1.1	0.4	-0.1	0.2
Standard Deviation		2.4	2	1.3	1.3	1.4	1	1	1.3
Maximum		7.7	2.7	4.7	10.3	5.5	5	4.7	4.9
Minimum		-6.1	-6.5	-4.4	-2.2	-1.8	-2.6	-3.3	-3.4
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	-4.1	-4.9	-1.9	-0.8	-0.9	-1.3	-1.4	-1.3
	10%	-3.1	-4.5	-1.4	-0.5	-0.6	-0.9	-1.1	-1
	25%	-0.8	-3.8	-0.7	0	-0.1	-0.3	-0.7	-0.6
	50%	0.7	-2.3	0.2	0.7	0.9	0.3	-0.1	-0.1
	75%	2.1	-0.2	1.3	1.4	1.9	1	0.5	0.7
	90%	3.5	0.6	1.9	2.1	2.9	1.7	1	2.1
	95%	4.3	1	2.3	2.6	3.7	2.1	1.3	3

*Predictive error is the observed minus calculated TDG saturation where negative values reflect an overestimation and positive values reflect an underestimation. TDG supersaturation can be computed from pressures by dividing by the local average atmospheric pressure (730-760 mm Hg) and expressed as a percentage.

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 2007. These TDG properties reflect conditions in spillway releases undiluted from powerhouse flows. The calculated mean error of TDG pressures was equal to 0.0 and the standard deviation of the predictive error was 9.4 mm Hg as listed in Table G3 under the label of CCIW. The 50 confidence interval for the predictive error ranged from -3.0 to 4.2 mm Hg of pressure and the 80 confidence interval ranged from -8.0 to 6.6 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the CCIW gage are shown in Figure G6. It should be noted that the calculated TDG pressures over estimated the observed values during the higher spillway discharges in the summer. The estimates of TDG saturation in the Bonneville exit channel were based on the cross sectional average TDG pressures as determined during the 2002 TDG exchange study conducted at Bonneville (Schneider, 2003). This study determined that for spill discharges higher than 120 kcfs, TDG pressures observed near the CCIW station underestimated the cross sectional average TDG saturation in the spillway exit channel. The estimation of TDG levels exiting the spillway channel therefore reflect average conditions that typically exceeded the near shore TDG levels sampled at station CCIW during nighttime spill in the summer. Calculated TDG pressures representing spill were nearly identical to the observed conditions at the CCIW gage during June as seen in Figure G7.

Table G7. Statistical summary of the predictive errors of the observed and calculated total dissolved gas pressures at tailwater fixed monitoring stations.

Parameters		Predictive Error at Tailwater FMS* (mm Hg)									
		DWQI	LGNW	LGSW	LMNW	IDSW	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Observations		248	3324	3622	3341	3447	3672	2468	3648	3672	1462
Average		-1.5	3.2	-11	-4.6	-10.4	7.9	-7.4	-0.3	0	-6.1
Standard Deviation		5.2	13.4	16.4	13.9	12.5	17.8	11.4	13	9.4	8.9
Maximum		15.6	42.8	56	66.2	29.2	103.8	27.7	39.1	57.8	17.5
Minimum		-36.8	-76.9	-92.9	-113.9	-89.4	-36.8	-87.3	-51.7	-58.8	-56.3
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	-8.7	-14.6	-36.2	-25.7	-30.5	-12	-26	-24.5	-16.2	-20.2
	10%	-7.5	-12.1	-32.3	-21.5	-28.1	-9.1	-20.6	-19.2	-8	-16.9
	25%	-5.3	-6	-24.1	-14.1	-21.3	-4.6	-13.2	-8.3	-3	-11.4
	50%	-1.3	1.1	-11.3	-5.3	-8.1	2.6	-7.2	3	1.4	-6.1
	75%	2.1	8.6	2.8	5.1	-0.1	19.1	-0.8	7.9	4.2	-0.6
	90%	4.2	26.4	10.4	12.8	4.3	31.7	6.5	12.9	6.6	5.2
	95%	5.9	32.4	13.3	17.7	6.9	36.7	11.1	18	9.6	8.3

*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 2007 fish passage season was altered from the 2006 patterns for spill discharges of 100 kcfs and less. A minimum gate opening 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. In general, the new spill pattern was slightly bulked in the outer bays for spill discharges less than 100 kcfs. A single spill pattern was established for each spill discharge unlike the 2006 patterns. The gate openings were generally limited to a maximum opening of 3.5 ft for spill discharges less than 100 kcfs. Strong return currents are generated when a spill bay is not in operation resulting in circulation patterns that are not favorable for juvenile egress.

The highest TDG pressure observed at CCIW during the 2007 monitoring season of 960 mm Hg occurred outside of the fish passage season. The elevated TDG pressures shown in Figure G6 in September when no spill was schedule has been linked to the fish ladders. A separate field investigation of these supersaturated conditions in the fish ladders was initiated by the Portland District. Preliminary results indicate the supplemental supply of flow to the ladders is resulting in these elevated TDG conditions.

Table G8. 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		248	3324	3622	3341	3447	3672	2468	3648	3672	1462
Average		-0.2	0.4	-1.5	-0.6	-1.4	1.1	-1	-0.4	-0.2	-1.1
Standard Deviation		0.7	1.8	2.2	1.9	1.7	2.4	1.5	1.8	1.2	1.1
Maximum		2.1	5.7	7.5	8.9	3.9	13.9	3.6	4.8	7.5	2.2
Minimum		-5.1	-10.3	-12.4	-15.1	-11.7	-4.9	-11.4	-7.1	-7.9	-7.4
TDG Predictive Error for Percentile Occurrence (mm Hg)	5%	-1.2	-2	-4.9	-3.4	-4.1	-1.6	-3.4	-3.7	-2.8	-2.7
	10%	-1	-1.6	-4.3	-2.9	-3.7	-1.2	-2.7	-2.9	-2.4	-1.9
	25%	-0.7	-0.8	-3.2	-1.9	-2.8	-0.6	-1.8	-1.5	-1.8	-1.6
	50%	-0.2	0.1	-1.5	-0.7	-1.1	0.3	-0.9	0.1	-1.1	-0.9
	75%	0.3	1.2	0.4	0.7	0	2.5	-0.1	0.8	-0.4	-0.2
	90%	0.6	3.6	1.4	1.7	0.6	4.2	0.9	1.4	0.4	0.7
	95%	0.8	4.4	1.8	2.4	0.9	4.9	1.5	2	0.7	1.5

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

Bonneville Dam Forebay (BON)

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 critical time period for compliance at the Bonneville forebay station occurs during the peak spring flows when the travel time is short (1-1.5 days) in the Bonneville pool and background TDG level are peaking. The strong winds that frequent this river reach have been associated with synoptic degassing events that reduce the TDG levels arriving at Bonneville Dam. The calculated TDG pressures slightly over-estimated observed conditions by an average of 0.8 mm Hg (average predictive error -0.8 mm Hg) and the standard deviation of the predictive error was 7.3 mm Hg as listed in Table G5. The 50 confidence interval for the predictive error ranged from +3.7 to -5.2 mm Hg of pressure and the 80 confidence interval ranged from +7.5 to -8.7 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the BON gage are shown in Figure G8. The TDG pressures in the forebay of Bonneville are a complex

interaction of the TDG loading released from The Dalles Dam, thermal cycling, and wind induced degassing. Currently, the wind field observed from The Dalles municipal airport is applied uniformly throughout this river reach to estimate the rate of degassing.
The calculated and observed TDG pressures at BON are shown throughout the month of June in Figure G9. The tendency for lower TDG conditions during the summer months at Bonneville Dam are related to the longer travel time from The Dalles Dam and the change in spill policy at John Day Dam.

The Dalles Dam Tailwater (TDDO)
SYSTDG was used to simulate the TDG production and transport 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 13.0 mm Hg as listed in Table G7. The 50 percent confidence interval of predictive error ranged from +7.9 to -8.3 mm Hg of pressure and the 80 percent confidence interval ranged from +12.9 to -19.2 mm Hg of pressure. Over 50 percent of the predictive errors at the tailwater FMS (TDDO) were less then +/- 1.5 percent of saturation during the study period while 80 percent of the estimates were within +/- 2.9 percent of saturation as listed in Table G8. The seasonal time history of observed and calculated TDG pressures at the TDDO gage are shown in Figure G10. The TDG saturation at the tailwater station TDDO never 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 G11. The tailwater station at The Dalles Dam is influenced by both powerhouse and spillway flows. The estimated TDG pressures contained in spillway flows undiluted from powerhouse flow consistently exceeded 120 percent of saturation as shown in Figure G12. The estimated TDG pressure in spill undiluted from powerhouse flow is shown by the darker gray line labeled “SP CAL”. The standard error of TDG pressure in the tailwater of The Dalles Dam was considerable larger in 2007 when compared to 2006 (standard deviation error 2007-13.0 mm Hg versus 2006-6.8 mm Hg). The larger error in 2007 at TDDO were likely caused by the large daily variance in TDG levels passed by the powerhouse and mixing and dispersion with spillway flows during transport to the tailwater station.

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 (0.5–1.0 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 under-estimated observed conditions by an average of 2.8 mm Hg (average predictive error 2.8 mm Hg) and the standard deviation of the predictive error was 7.8 mm Hg as listed in Table G5. The 50 percent confidence interval of the predictive error ranged from 7.7 to -2.6 mm Hg of pressure and the 80 percent confidence interval ranged from +12.7 to -6.9 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 (7.8 versus 7.3 mm Hg). The seasonal time history of observed and calculated TDG pressures at the TDA gage are shown in Figure G13. The TDG saturation exceeded 115 percent on a couple of occasions during 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 spilling 60 percent of the river at John Day Dam. 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 G14. The daily cycling in TDG pressures in the forebay at TDA were well represented by model estimates. There was a tendency to under-estimate the peak daily TDG saturation arriving at The Dalles forebay. The source of this prediction error is likely related to in-pool dispersion and TDG production at John Day dam since the daily minimums were closely reproduced during this time period.

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 2007. 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 7.4 mm Hg (average predictive error –7.4 mm Hg) and the standard deviation of the predictive error was 11.4 mm Hg as listed in Table G7.   The 50 percent confidence interval of the predictive error ranged from -.8 to -13.2 mm Hg of pressure and the 80 percent confidence interval ranged from +6.5 to -20.6 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the JHAW gage are shown in Figure G15. The daily variation in TDG pressures routinely ranged over 50 mm Hg during the on-off cycling of spill at John Day Dam (Figure G18).   The broad range in the night time river flows result in abrupt changes in the level of spill seen in the summary of spillway operation in June shown in Figure G16. The large spillway at John Day Dam and change from uniform to bulk pattern for spill just above 100 kcfs resulted in only small changes in TDG saturation during these abrupt changes in spillway flow. The TDG produced during a spill of 130 kcfs on June 2-3 resulted in about the same TDG saturation at the tailwater fixed monitoring station as the 95 kcfs spill on June 3-4.

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 4.5 to 10.0 days during the 2007 fish passage season. Calculated forebay TDG pressures were subtracted from the observed John Day forebay fixed monitoring station data to produce an hourly predictive error. The calculated TDG pressures under-estimated observed conditions by an average of 5.1 mm Hg (average predictive error +5.1 mm Hg) and the standard deviation of the predictive error was 10.6 mm Hg as listed in Table G5. The 50 percent confidence interval for the predictive error ranged from +11.9 to -3.6 mm Hg of pressure and the 80 percent confidence interval ranged from +19.8 to -7.6 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the JDY gage are shown in Figure G17. 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 among the highest in the Lower Columbia River but resulted in the lowest forebay TDG levels. The rapid change in TDG pressures in the forebay of John Day Dam was typically related to wind events. The predictive errors were larger in the John Day forebay when compared to most other projects because of the uncertainty in the TDG production relationship at McNary Dam and the uncertainty in estimating the in-pool TDG exchange during the long time of travel between dams. The observed and calculated TDG pressures in the forebay of John Day Dam are shown throughout the month of June in Figure G18. Both the timing and peak observed TDG saturation at JDY on June 3 were under-estimated by the SYSTDG model in this case. The under estimation of TDG pressures in the John Day Forebay during the 2007 fish passage season may also be related to the estimation of TDG exchange at McNary Dam with the temporary spillway weirs (TSW) in operation influencing both the entrainment of powerhouse flows and local generation of TDG saturation.

McNary Dam Tailwater (MCPW)

The operation of two TSW's at McNary Dam and a revised spill pattern during the 2007 fish passage season resulted in a substantial change in TDG generation from previous conditions as monitored at the tailwater fixed monitoring station. The SYSTDG model was used to simulate the TDG exchange associated with spillway releases from McNary Dam throughout the 2007 spill season as shown in Figure G19. The 2007 spill pattern called for bulked releases at spillbays with the TSW in bays 20 and 22. The rated flow over the TSW was a function of the forebay elevation and was generally in excess of 10 kcfs. The calculated TDG pressures at station MCPW under-estimated observed conditions by an average of 7.9 mm Hg (average predictive error +7.9 mm Hg) and the standard deviation of the predictive error was 17.8 mm Hg as listed in Table G7. The accuracy of TDG predictions in the tailwater of McNary Dam in 2007 were considerably poorer than conditions in 2006 (standard error of estimate was 10.1 mm Hg in 2006). The 50 percent confidence interval for the predictive error ranged from 19.1 to –4.6 mm

Hg of pressure and the 80 percent confidence interval ranged from 31.7 to -9.1 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 G20. The TDG estimates tended to under-estimate the TDG exchange when spill discharges dropped below 100 kcfs during the month of June. The TDG saturation was closely predicted on June 22-23 when the spill discharge was over 100 kcfs. However, the TDG saturation increased abruptly corresponding with the lowering of spill to 80 kcfs on June 24. The inverse relationship between spill and TDG saturation at the tailwater fixed monitoring station is probably caused by the greater influence of TDG generated from the high unit spillway releases at the TSW's during lower spill events. The observed and calculated TDG pressure at MCPW as a function of total spill discharge is shown in Figure G21 during the 2007 spill season. The estimates are consistent with observations for spill flows over 80 kcfs. However, the observed TDG saturation increases in general when spill is lowered below 80 kcfs which is a property not captured by model estimates. The calculated and observed TDG pressures at the tailwater station MCPW as a function of spill discharge for 2006 is shown in Figure G22. The 2006 data exhibits a logarithmic increase as a function of total spillway discharge.

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 2007 called for considerably lower spill rates during voluntary spill flows than in previous years. In addition, the TDG loading introduced into McNary pool was further moderated by the degassing throughout the open river reach in the Hanford area. The spill policy at Ice Harbor Dam was cycled periodically throughout most of the 2007 spill season to accommodate biological testing. This operation introduced pulses or slugs of water with high TDG levels into McNary pool. The calculated TDG pressures under-estimated observed conditions by an average of 4.0 mm Hg (average predictive error 4.0 mm Hg) and the standard deviation of the predictive error was 9.7 mm Hg as listed in Table G5. The standard error was significantly smaller in 2007 than determined in 2006 (9.7 versus 11.0 mm Hg). The 50 percent confidence interval for the predictive error ranged from 8.4 to -1.9 mm Hg of pressure and the 80 percent confidence interval ranged from 13.6 to -5.6 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 G23. The calculated and observed TDG pressures in the forebay of McNary Dam are shown in Figure G24 for the month of June. The variation in McNary forebay TDG pressure in June ranged from 790-870 mm Hg. The daily variation in the predicted TDG pressure was highly correlated with the observed conditions but the estimated TDG magnitude was less than observed throughout the entire month. The abrupt change in the forebay TDG pressure can be related to thermal events as shown in Figure G25. The abrupt increase in forebay TDG pressure on June 14 and 20^{th} on the order of 20-25 mm Hg was associated with an increase in temperature of 0.5-1.0 ^{o}C.

Ice Harbor Dam Tailwater (IDSW)

The spill policy at Ice Harbor Dam was varied throughout the 2007 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 10.4 mm Hg (average predictive error –10.4 mm Hg) and the standard deviation of the predictive error was 12.5 mm Hg as listed in Table G7. The 50 percent confidence interval of the predictive error ranged from -0.1 to -21.3 mm Hg of pressure and the 80 percent confidence interval ranged from +4.3 to -28.1 mm Hg of pressure. The seasonal time history of observed and calculated TDG pressures at the IDSW gage are shown in Figure G26. The calculated values tend to compare favorably to observed conditions throughout most of the year when spill rates are above 20 kcfs. 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 2007 was similar to conditions observed at The Dalles and John Day Dams. The daily variation in TDG pressures for observed and calculated conditions can be seen in Figure G27 for the month of May. The observed and predicted TDG pressures were similar throughout this period for spill greater than 20 kcfs. The TDG levels associated with spill discharges less than 20 kcfs may be influenced by dilution from powerhouse flows as observed at the tailwater fixed monitoring stations.

Ice Harbor Dam Forebay (IHRA)

A simulation was run from Lower Monumental Dam to the forebay of Ice Harbor Dam from 1 April through 31 August to determine the predictive error of SYSTDG estimations in the forebay of Ice Harbor Dam. Calculated forebay TDG pressures were subtracted from the observed TDG pressures at the forebay fixed monitoring station at Ice Harbor Dam (IHRA) to determine the hourly predictive error. The calculated TDG pressures slightly over-estimated observed conditions by an average of 0.8 mm Hg (average predictive error –0.8 mm Hg) and the standard deviation of the predictive error was 9.9 mm Hg as listed in Table G5. The 50 percent confidence interval for the predictive error ranged from 6.7 to -7.5 mm Hg of pressure and an 80 percent confidence interval ranged from 11.7 to -12.7 mm Hg of pressure. The variance of the predictive error at Ice Harbor Dam forebay was similar to conditions found in the forebay of John Day and McNary Dams on the Columbia River. The estimates of forebay conditions at Ice Harbor Dam tended to be generally higher than observed conditions during the summer and lower than observed during the spring as shown in Figure G28. The observed and calculated TDG pressures in the forebay of Ice Harbor are shown in Figure G29 throughout June. The variation in TDG saturation in the forebay of Ice Harbor Dam is related to the variation in percent of river spilled at Lower Monumental Dam and the influence of wind/wave generated degassing events. The forebay TDG levels at Ice Harbor Dam did experience excursions above the TDG standard of 115% during the first three months of the study period.

Lower Monumental Dam Tailwater (LMNW)

The predominant spill pattern applied at Lower Monumental Dam during the 2007 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 mean TDG pressures over-estimated observed conditions by an average of 4.6 mm Hg (average predictive error –4.6 mm Hg) and the standard deviation of the predictive error was 13.9 mm Hg as listed in Table G7. The 50 percent confidence interval for the predictive error ranged from 5.1 to -14.1 mm Hg of pressure. The 90 percent confidence interval for the predictive error ranged from 12.8 to -21.5 mm Hg of pressure. The accuracy of TDG predictions at Lower Monumental Dam in 2007 were improved when compared with estimates in 2006 where the average error was -14.7 mm Hg and the standard error was 22.3 mm Hg. The daily variation of TDG pressures at the tailwater FMS below Lower Monumental Dam are shown in Figure G30. There was a tendency for calculations to under-estimate the TDG exchange associated with high spillway releases. The hourly observed and calculated TDG pressures at the tailwater FMS (LMNW) are shown in Figure G31 for the month of May. This figure shows a general agreement between the observed and calculated TDG response at LMNW for voluntary spillway flows less than 25 kcfs.

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 G32. The predicted forebay TDG pressures began to diverge from observed conditions in June and through August. The calculated TDG pressures over-estimated observed conditions by an average of 17.6 mm Hg (average predictive error –17.6 mm Hg) and the standard deviation of the predictive error was 14.9 mm Hg as listed in Table G5. The 50 percent confidence interval for the predictive error ranged from -4.0 to -30.4 mm Hg of pressure and the 80 confidence interval ranged from +1.8 to -36.3 mm Hg of pressure. The over-estimation of TDG pressure during the summer is likely attributed to over-prediction of TDG generation at Little Goose Dam. The daily variation of TDG pressures for the month of May at the forebay FMS above Lower Monumental Dam are shown in Figure G33. The estimated forebay TDG saturation was closely reproduced during this period of highest spill at Little Goose Dam during the 2007 spill season. However, the consistent over-estimation of TDG during the summer months at the forebay station at Lower Monumental Dam was the largest of the projects evaluated in this study.

Little Goose Dam Tailwater (LGSW)
The spill policy at Little Goose Dam resulted in the least amount of spill of the four Snake River projects. Over half the time the spill at Little Goose Dam was less than 11.2 kcfs during the 2007 spill season. 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 G34. The calculated TDG pressures over-estimated observed conditions by an average of 11.0 mm Hg (average predictive error -11.0 mm Hg) and the standard deviation of the predictive error was 16.4 mm Hg as listed in Table G7. The 50 percent confidence interval ranged from +2.8 to -24.1 mm Hg of pressure and the 80 percent confidence interval ranged from +10.4 to -32.3 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 jet 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 and prominent interaction of powerhouse and spillway flows. The calculated and observed tailwater TDG pressures below Little Goose Dam during the month of May are shown in Figure G35. The spillway discharge ranged from 10 to 30 kcfs during the month of May with the maximum TDG pressures of about 890 mm Hg corresponding with 30 kcfs spill on May 7 and 8th. It should be noted that the powerhouse discharge was reduced during these spill event contributing to the rise in TDG pressure at the tailwater fixed monitoring station. A spill approaching 30 kcfs on May 18 generated a TDG pressure of only 870 mm Hg at LGSW in part because of the high powerhouse releases.

The observed and calculated TDG saturation at the tailwater FMS as a function of the spillway discharge for 2007 is shown in Figure G36. The TDG production relationship with spill discharge exhibits two major trends. The upper grouping of data is associated with events during April and May where the observed and calculated conditions are similar. The lower grouping of data defined by the area “A” are not closely predicted by the model and represent the conditions in the summer months. The change in spill pattern on June 1 to a more uniform pattern was the likely cause for lower TDG production response.

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 as shown in Figure G37 are a consequence of the TDG uptake associated with spill at Lower Granite Dam, the thermal exchange during transport through the pool, and the surface exchange of dissolved gasses with the

atmosphere. The average calculated TDG pressure was similar to observed conditions with an average predictive error of 1.5 mm Hg and the standard deviation of the predictive error was 18.1 mm Hg as listed in Table G5. The 50 percent confidence interval ranged from +13.4 to -8.4 mm Hg of pressure and the 80 percent confidence interval ranged from +23.5 to -25.5 mm Hg of pressure. The calculated and observed tailwater TDG pressures in the forebay of Little Goose Dam during the month of May are shown in Figure G38. The observed and calculated TDG pressures were generally within 10 mm Hg during May. The large predictive error in the Little Goose forebay is associated with the consistent under-estimation of conditions in June and over-estimation in August.

Lower Granite Dam Tailwater (LGNW)

The spill policy at Lower Granite Dam during the 2007 fish passage season called for a continuous spill of 20 kcfs during the spring and 18 kcfs during the summer. The minimum generation requirements resulted in spill rates falling below the summer target levels during late July and August. 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 G39. The calculated TDG pressures under-estimated observed conditions by an average of 3.2 mm Hg (average predictive error +3.2 mm Hg) and the standard deviation of the predictive error was 13.4 mm Hg as listed in Table G7. The 50 percent confidence interval for the predictive error ranged from 8.6 to -6.0 mm Hg of pressure and the 80 percent confidence interval ranged from +26.4 to -12.1 mm Hg of pressure. The TDG saturation during the month of May is shown in Figure G40 at the Lower Granite Dam tailwater FMS LGNW. The spill discharge was held constant throughout the month and the TDG saturation ranged from 805 to 835 mm Hg. The highest TDG observations are associated with lower powerhouse releases suggesting the tailwater station is influenced by both powerhouse and spillway TDG content. The line labeled REL-Cal determined from a flow weighted estimate of both powerhouse and spillway flows is highly correlated but smaller than the TDG response at LGNW. The sensitivity of TDG pressures to spill pattern changes are illustrated by conditions in June where the bulk pattern resulted in significantly higher TDG pressures than the standard pattern. The under-estimation of TDG production at Lower Granite Dam was also apparent in estimates of TDG in the forebay of Little Goose Dam.

Dworshak Dam Tailwater (DWQI)

The TDG pressures in the tailwater channel below Dworshak Dam were simulated during the 2007 spill season as shown in Figure G41. 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 5.2 mm Hg as listed in Table G7. The 50 percent confidence interval for the predictive error ranged from +2.1 to -5.3 mm Hg of pressure and the 80 confidence interval ranged from +4.2 to -7.5 mm Hg of pressure. Dworshak Dam does not have a forebay TDG station and the TDG pressures observed at the tailwater station during powerhouse only operations were used to estimate the TDG pressures released by the powerhouse during concurrent powerhouse and spillway/regulating releases. The 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 uptake of TDG during turbine operation was generally larger than observed during the spill of 2.2 kcfs during July. The periodic scheduling of the minimum powerhouse releases as shown in Figure G41 resulted in TDG pressures ranging from 750-800 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 (SP-CAL) were estimated to be as high as 890 mm Hg during a spill of 2.2 kcfs as shown in Figure G42.

Comparison of 2006 and 2007 Simulations

The performance of the SYSTDG decision support system as measured by the hourly predictive error statistics at fixed monitoring stations during the 2007 spill season was in some cases better and worse than the performance observed during the 2006 fish passage season. The wide range of both voluntary and forced spill operations in 2006 was in contrast to lower river flow rates and new spill patterns applied at Bonneville, McNary, Little Goose, and Lower Granite Dams during the 2007 spill season. The addition of TSW operation at McNary Dam in 2007 involved a structural modification to spillway releases which likely influenced both TDG exchange and entrainment of powerhouse flows. The standard deviation of the predictive error is the most descriptive metric of how accurate the calculated TDG pressures were to the observed TDG pressures. In general the standard error of estimates 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 or comparing the daily TDG metrics for compliance with Oregon and Washington State standards. The standard deviation of the predictive errors in 2006 ranged from 6.7 to 22.3 mm Hg at fixed monitoring stations. In 2007, the standard deviation of the predictive errors at fixed monitoring stations ranged from 5.2 to 18.1 mm Hg. Significant improvements were achieved in estimating the TDG exchange and transport below Lower Monumental and Bonneville Dams. The standard deviation of the predictive error at the tailwater station below Lower Monumental Dam (LGNW) was reduced from 22.3 mm Hg in 2006 to 13.9 mm Hg during the 2007 season. The degree of improvement at the CCIW gage as measured by the standard deviation of the predictive error fell from 14.4 mm Hg in 2006 to 9.4 mm Hg in 2007. There were several stations where the predictive errors were considerably greater in 2007 compared to 2006. The standard deviation of the predictive error in the tailwater of McNary Dam increased from 10.1 mm Hg in 2006 to 17.8 mm Hg in 2007. The source the larger standard deviation of the predictive error was associated with the TSW operation and associated spill patterns. The prediction errors at The Dalles tailwater station doubled from 6.8 mm Hg in 2006 to 13.0 mm Hg in 2007. The mixing of powerhouse flows with highly variable TDG levels with spillway releases was likely the cause for the increase in the hourly prediction errors at the tailwater fixed monitoring station.

Conclusions

The decision support spreadsheet SYSTDG was used to simulate the production, transport, and dissipation of TDG pressures in the Columbia River basin during the 2007 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 2007 were dominated by voluntary spill operations throughout most of the year. The operational policy involving spilling water on the Snake and Lower Columbia Rivers during the summer months was continued in 2007 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 2007 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 G5 and G6) than the tailwater station comparisons (Tables G7 and G8). The average predictive errors at forebay stations were less than 1 percent of saturation (7.6 mm Hg) with the exception of John Day and Lower Monumental Dams. The overestimation of forebay TDG pressures at John Day Dam was attributed to misrepresenting the production of TDG conditions at McNary Dam. The larger estimation errors in the forebay of Lower Monumental Dam were largely attributed to estimates misrepresenting TDG production at Little Goose Dam during the use of the uniform spill pattern during the summer. The correlation between strong winds and declining TDG pressure at forebay stations was evident during the 2007 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 0.7 percent saturation (5.2 mm Hg) at Dworshak Dam tailwater station DWQI to 2.4 percent saturation (17.8 mm Hg) at McNary tailwater station (MCPW). The large errors observed during the month of August at the Little Goose Dam tailwater were associated with the incorrect designation of the applied spill pattern.

Bonneville Dam operations during the 2007 season incorporated a new spill pattern for flows less than 100 kcfs. These new spill patterns generated more moderate TDG levels than the bulk spill pattern used in 2006. The SYSTDG model over estimates the TDG response at the CCIW station during higher spillway flows. These estimates were based on the average cross sectional response observed in the spillway exit channel during sampling in 2002. The sampling bias evident at CCIW for higher flows is likely to be present under existing conditions because the spill pattern has not changed for flows above 100 kcfs since 2002.

The spill policy at The Dalles Dam in 2007 called for 40 percent of the river to pass through the spillway. On several occasions this spill policy could not be met because of TDG saturation in the forebay of Bonneville Dam exceeding the TDG criteria of 115 percent. The estimated TDG content in spill releases undiluted by powerhouse flow were generally greater than 120 percent and as high as 126 percent. 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 2007 fish passage season with daytime spill at 60 percent of river flow in the spring and a continuous 30 percent of river spilled during the summer. The predictions of forebay TDG levels at The Dalles Dam in 2007 were improved through the revision of estimates of powerhouse entrainment at John Day Dam as a percentage of spillway discharge.

The operations at McNary Dam involved spilling water through a couple of TSW's throughout the entire fish passage season. The TDG levels at the tailwater station increased in magnitude when spill levels dropped below 80 kcfs. This property was likely related the mixing zone from the TSW releases reaching the north shore during lower spillway discharges. McNary Dam spilled more water than any project except Bonneville Dam on the Columbia River in 2007 but had no incidences of TDG levels exceeding the tailwater 120 percent criteria or the 115 percent criteria at John Day Dam.

Ice Harbor Dam continues to have the smallest TDG uptake for a comparable spill discharge of any project on the Columbia or Snake Rivers. The 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 2007 involved biological testing of the RSW where day to day changes in total spill discharge were often large. However, the variation in the generation of TDG supersaturation was modest in comparison to spill discharge.

The frequency of hourly TDG supersaturation above 115 percent at the tailwater station below Lower Monumental Dam was the highest of the four Snake River projects. The spill policy at Lower Monumental Dam resulted in the TDG saturation in the Ice Harbor forebay to exceed 115% over 17.1 percent of the time. The predictive of TDG pressures in the Lower Monumental pool were improved in 2007 over previous years. The bulk spill pattern at Lower Monumental Dam contributes to the larger addition to TDG loading of the Snake River when compared to other projects.

The 2007 spill patterns at Little Goose Dam included both a bulk and uniform pattern. The bulk spill generated significantly higher TDG levels when compared to the uniform pattern. The small rates of spill coupled with the uniform spill pattern during the summer resulted in small changes to the TDG loading in the Snake River. In several instances, spill operation at Little Goose Dam lowered the TDG levels in the Snake River.

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 bulk spill pattern resulted in higher TDG levels when compared with the standard pattern. Both spill patterns resulted in tailwater TDG levels below the spillway capacity as limited by the 120 percent criteria.

Project releases through the regulating outlet were limited at Dworshak Dam during the 2007 spill season were scheduled to support temperature management activities in the Snake River during July. The mixing zone between powerhouse flow and spill is well developed at the tailwater FMS in the North Fork of the Clearwater River. The TDG content in RO flow of 2.2 kcfs was estimated to exceed 120% prior to mixing with powerhouse release.

The reliability of the SYSTDG model continues to improve as a wider range of operations, structural configurations, and environment events are sampled at fixed monitoring stations and in site specifics TDG exchange studies using an array of remotely logging sensors. In some cases, the TDG response at a singular point of sample does not reflect past trends of TDG exchange at a project. Without additional data, it is impossible to determine if the observed TDG response is representative of spillway flows or a consequence of a localized processes resulting in a biased sample.

Recommendations

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

The description of TDG exchange at all projects within the study area should be updated to reflect the current spill patterns and structural configurations.

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

The objective of tailwater fixed monitoring stations is to accurately reflect aggregate TDG exchange in spillway releases. As major changes to spillway structures and spill patterns are implemented, site specific field studies should be conducted to quantify the TDG exchange and degree of sampling bias at these monitoring locations.

Continue to update and document of model parameters and programming tools needed to maintain the database and workbook.

The inclusion of a daily TDG metrics involving the highest 12 consecutive hourly observations in a day as required by the State of Washington should be incorporated into the workbook.

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

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

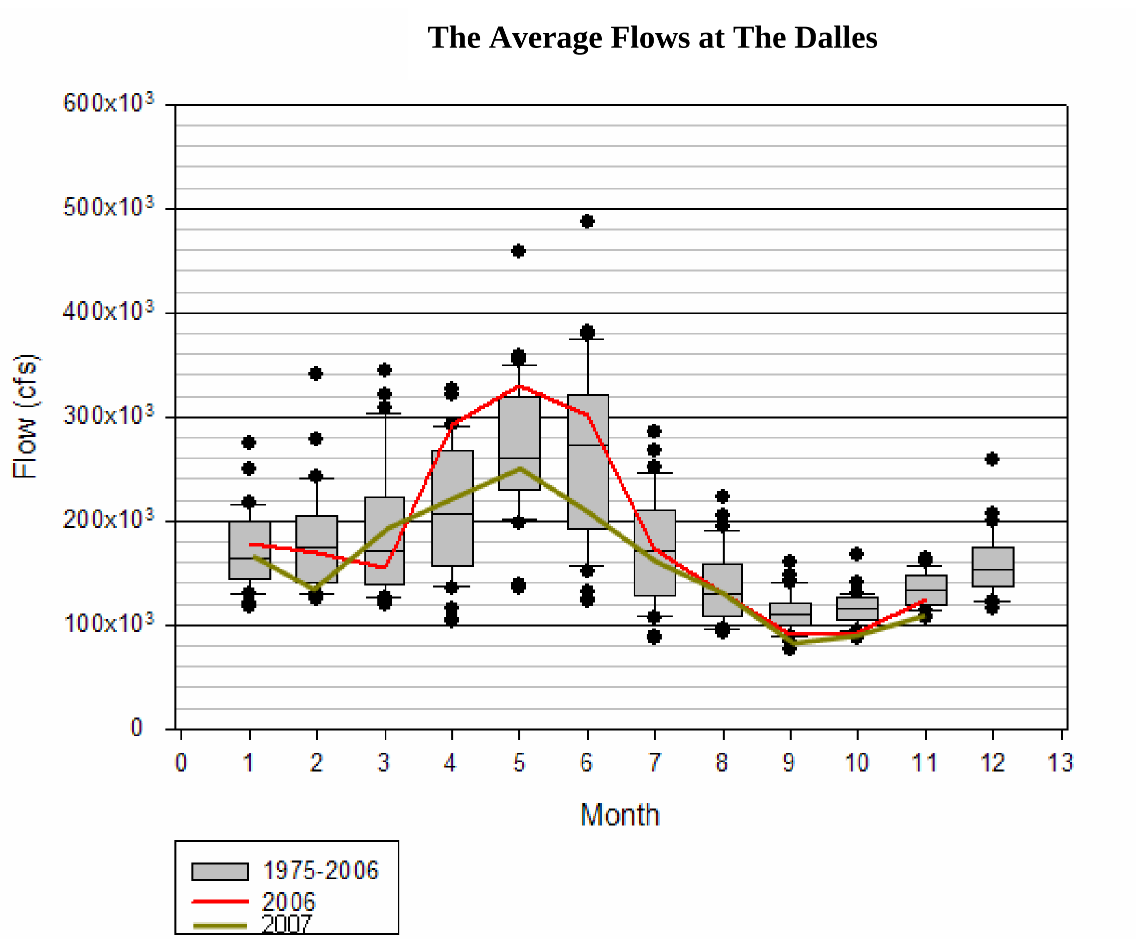

Figure G1. Statistical Summary of Columbia River Monthly Average Flows at The Dalles Dam for 1975-2007 (2007 – Red, 1997-2007 summary gray box 25, 50, 75th percentiles, whiskers 5-95th percentiles).

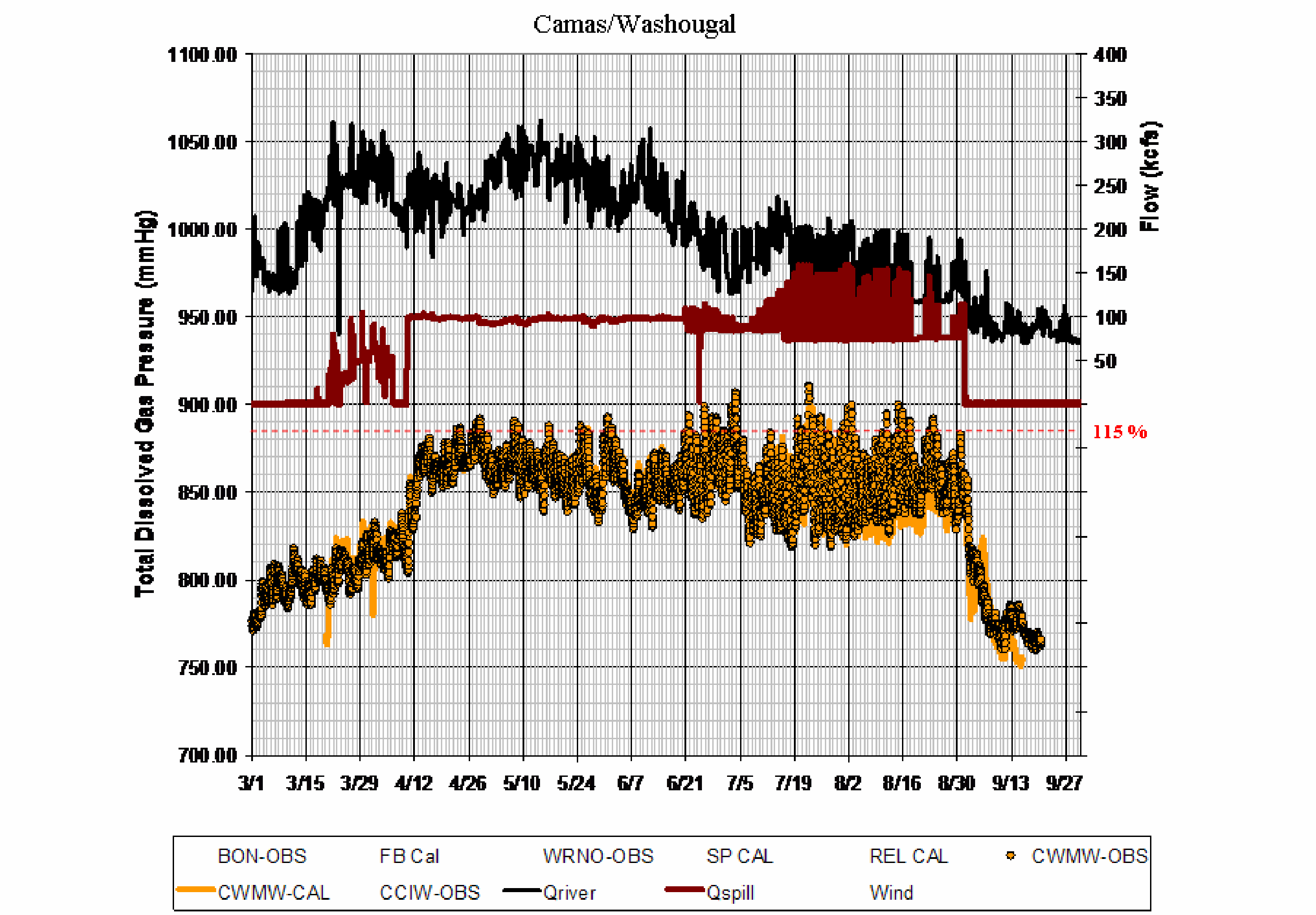

Figure G2. Observed and Calculated Total Dissolved Gas Saturation in the Columbia River at the Camas/Washougal fixed monitoring station downstream of Bonneville Dam, March-September 2007

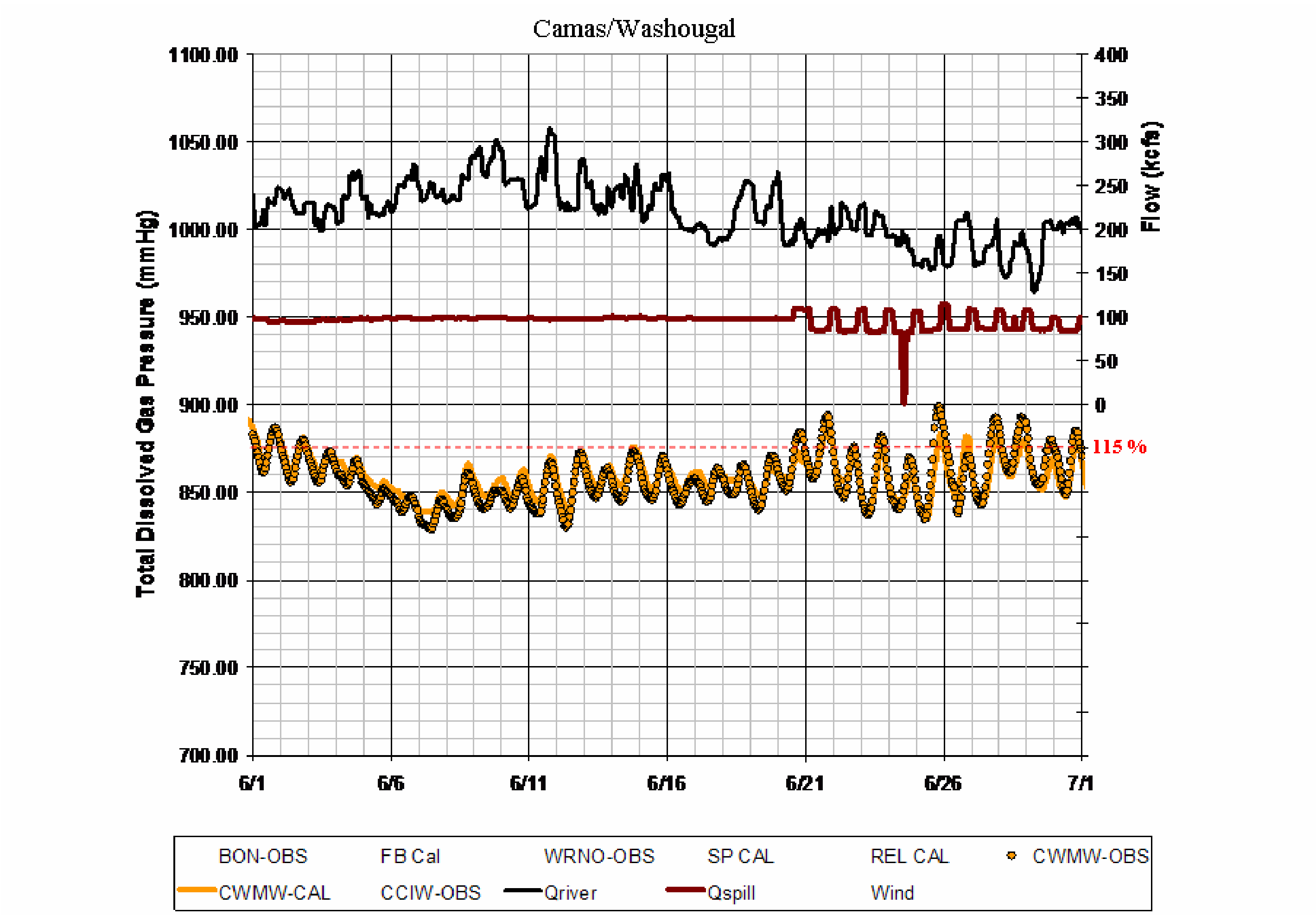

Figure G3. Observed and Calculated Total Dissolved Gas Saturation in the Columbia River at the Camas/Washougal fixed monitoring station downstream of Bonneville Dam, June 2007

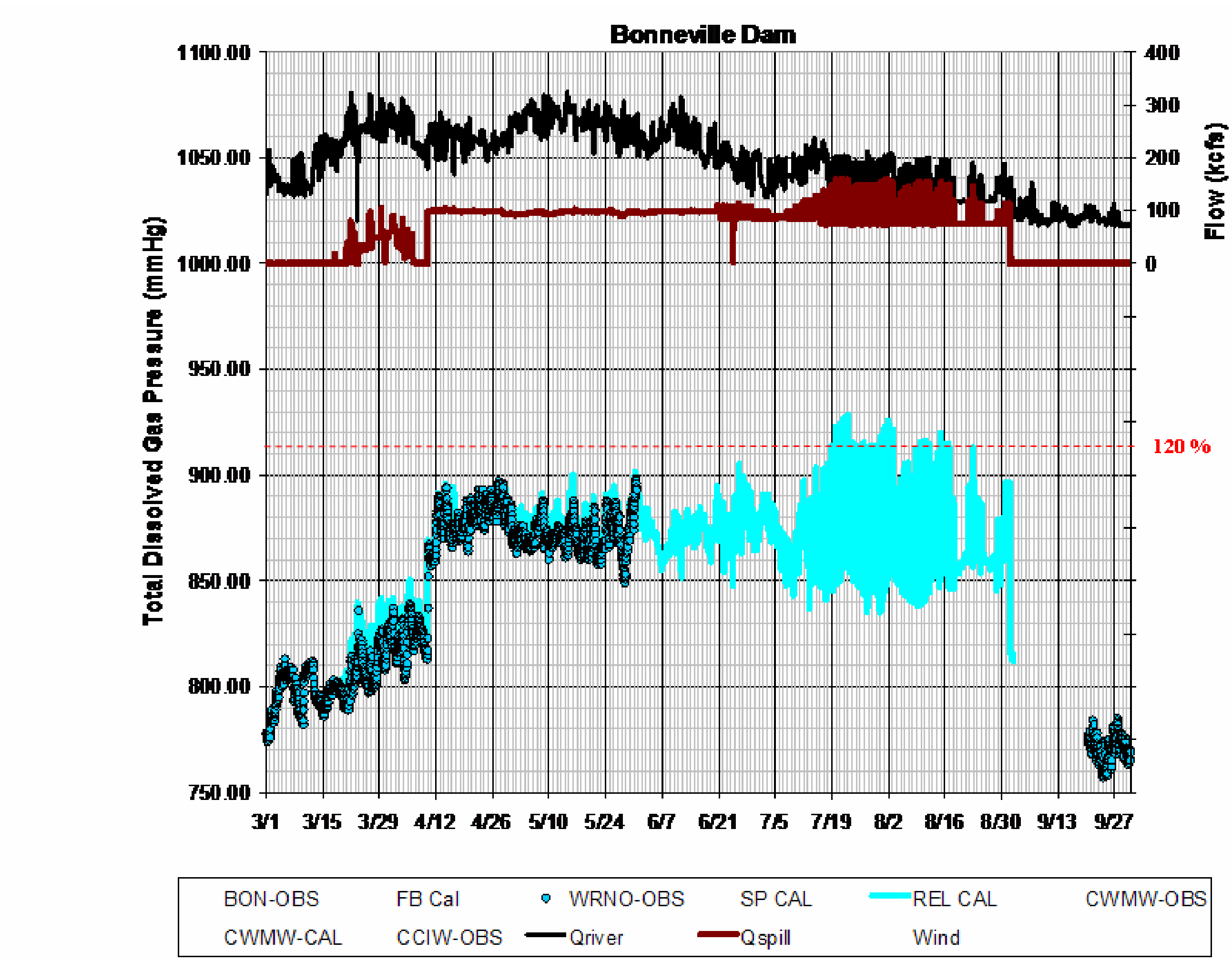

Figure G4. Observed and Calculated Total Dissolved Gas Saturation in the Columbia River at the Warrendale fixed monitoring station downstream of Bonneville Dam, March-September 2007

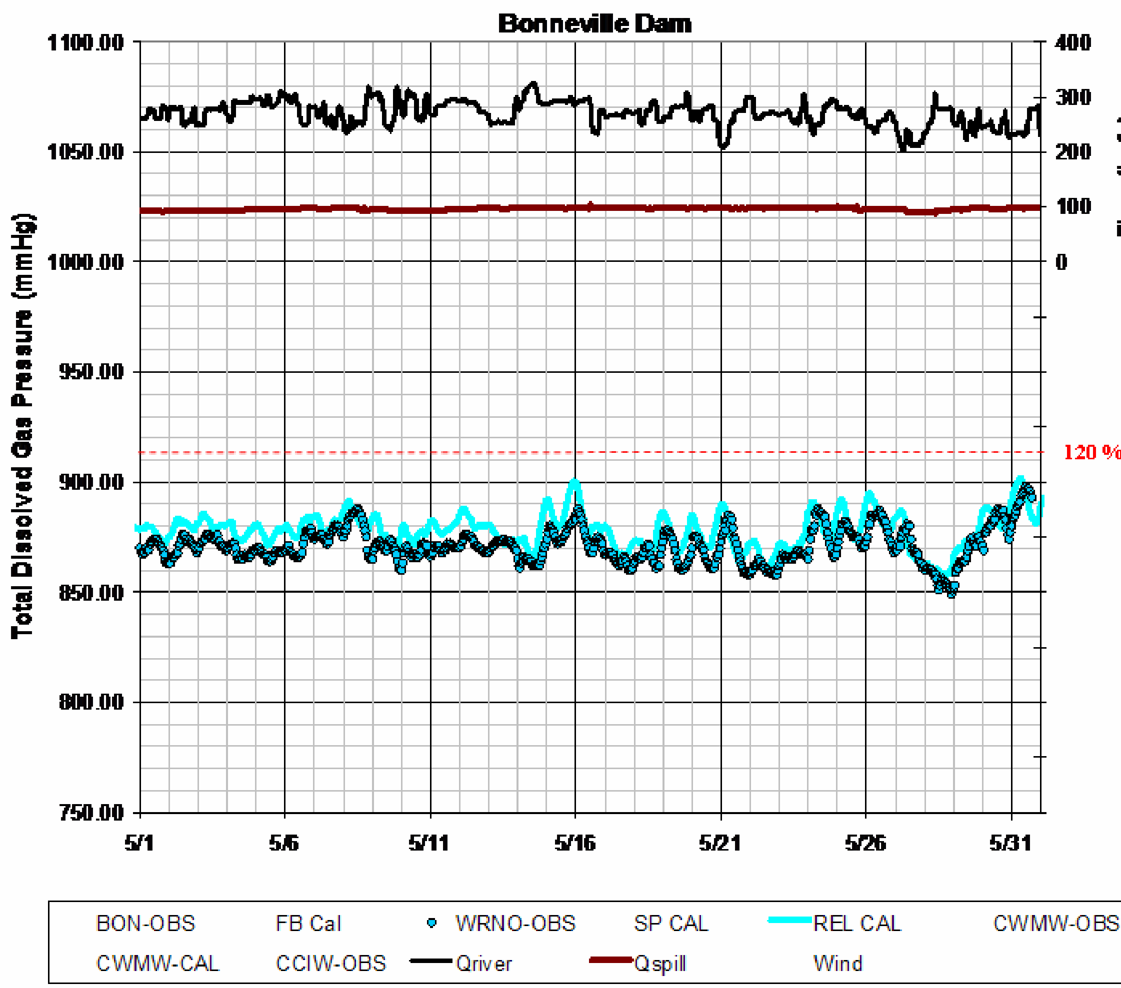

Figure G5. Observed and Calculated Total Dissolved Gas Saturation in the Columbia River at the Warrendale fixed monitoring station downstream of Bonneville Dam, May 2007

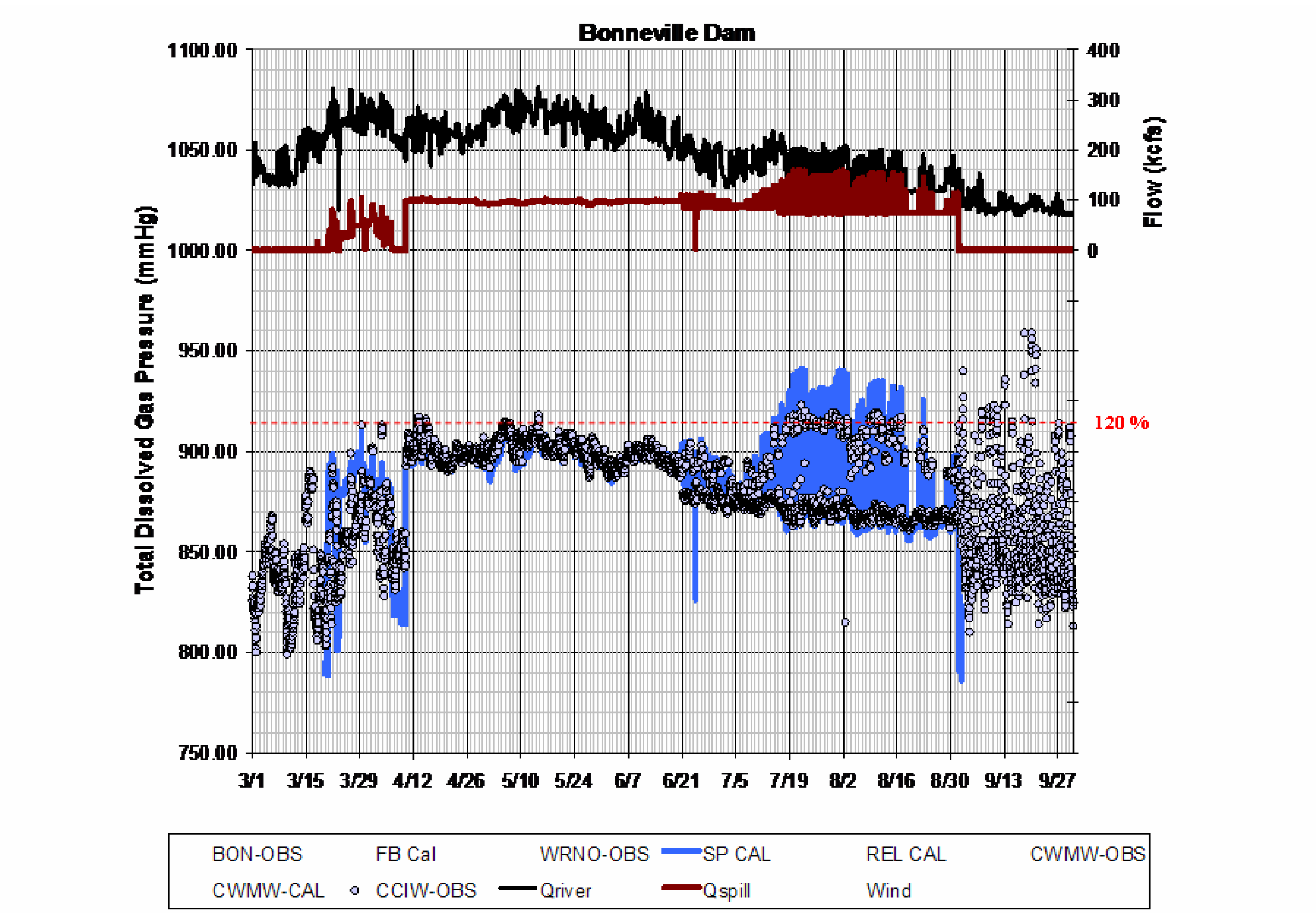

Figure G6. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam, March-September 2007

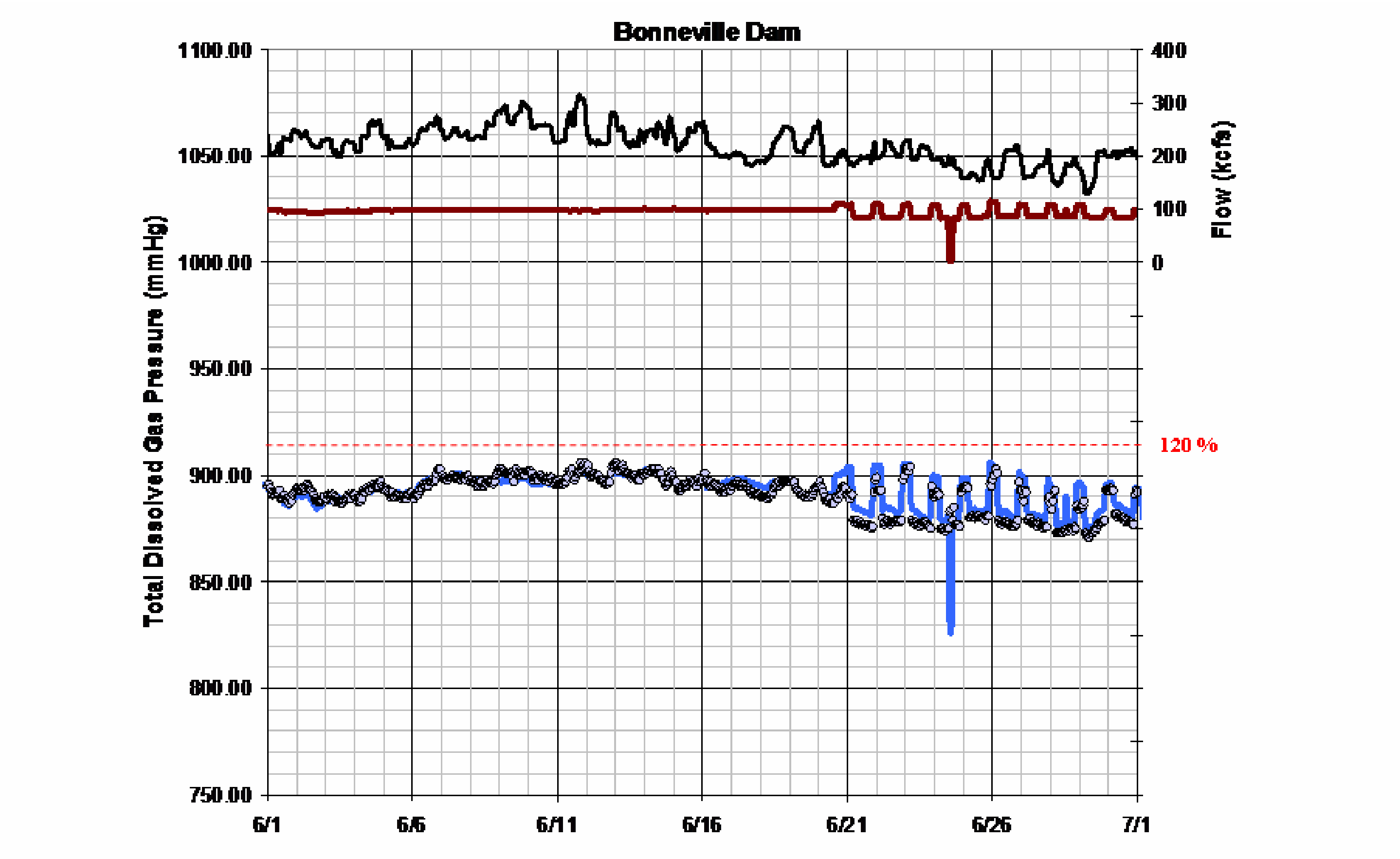

Figure G7. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River at the Cascade Island fixed monitoring station downstream of Bonneville Dam, June 2007

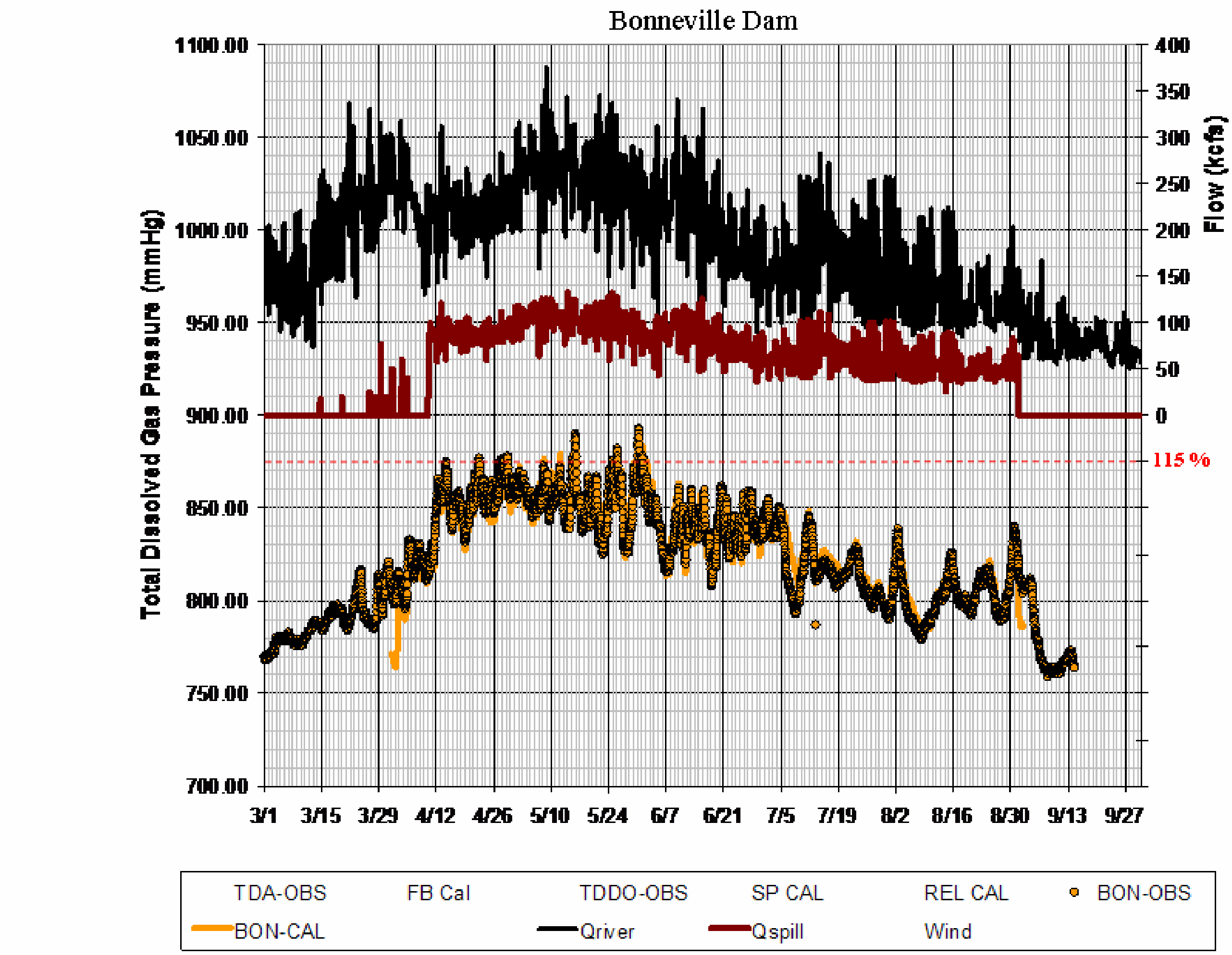

Figure G8. The Dalles Dam Operations with Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of Bonneville Dam, March-September 2007

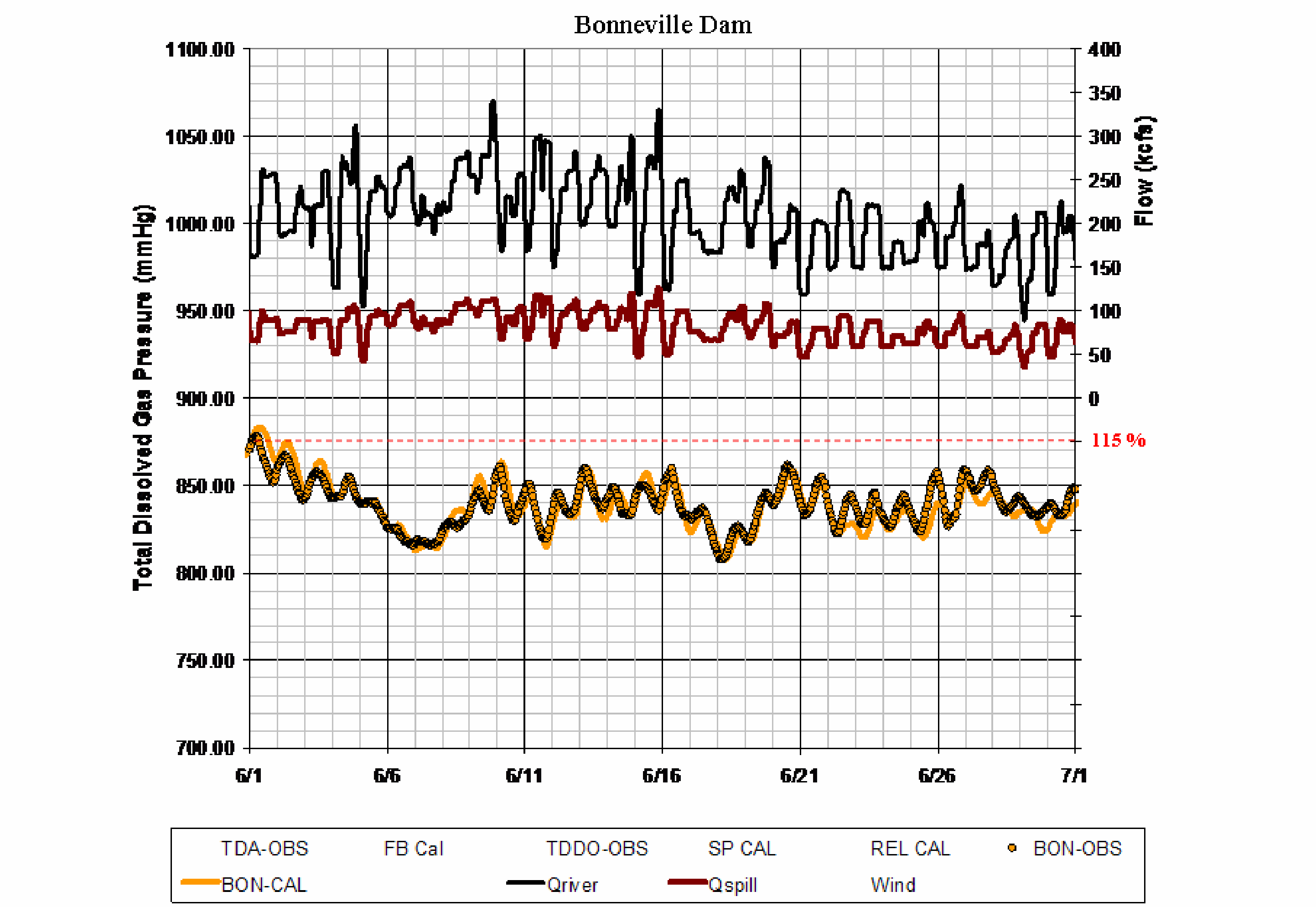

Figure G9. The Dalles Dam Operations with Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of Bonneville Dam, June 2007

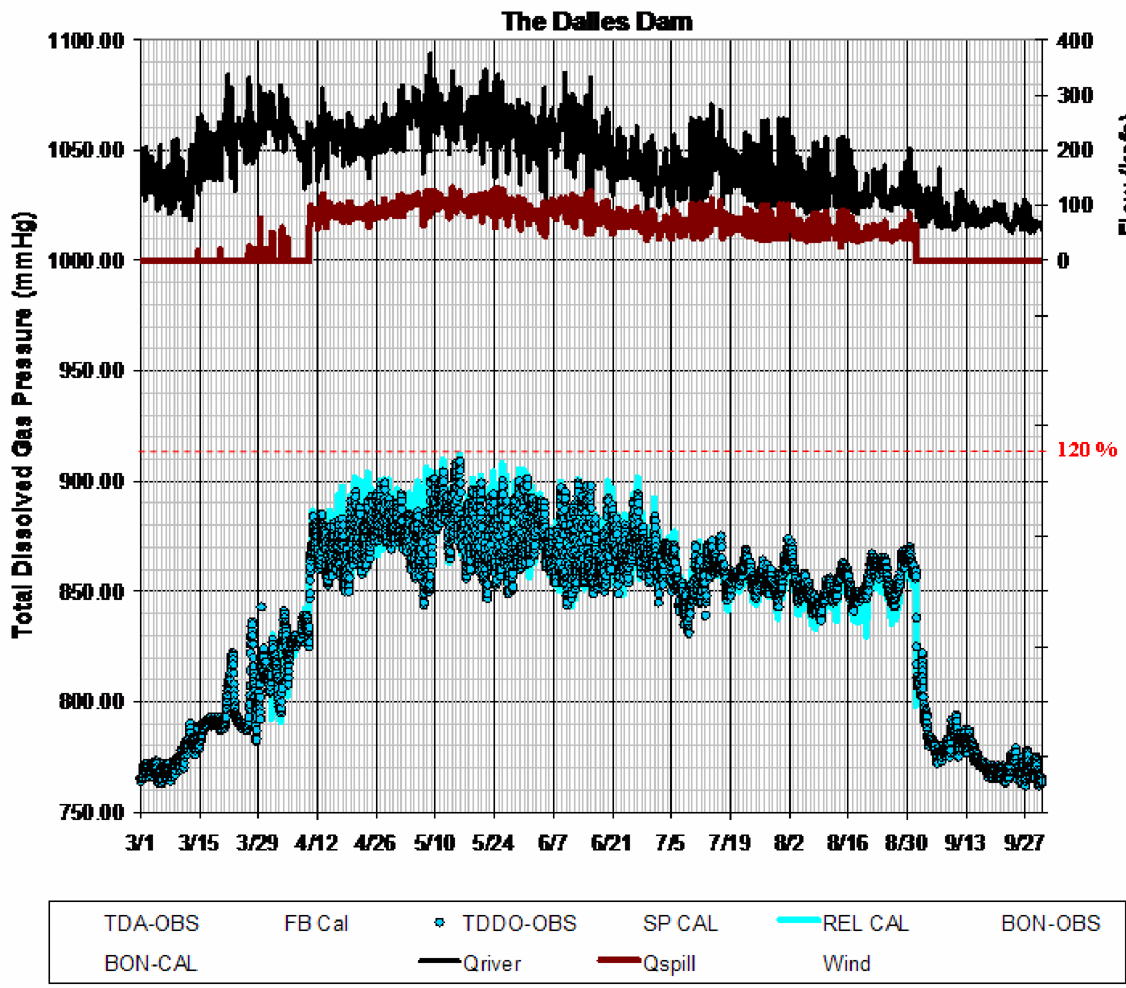

Figure G10. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel of The Dalles Dam, March-September 2007

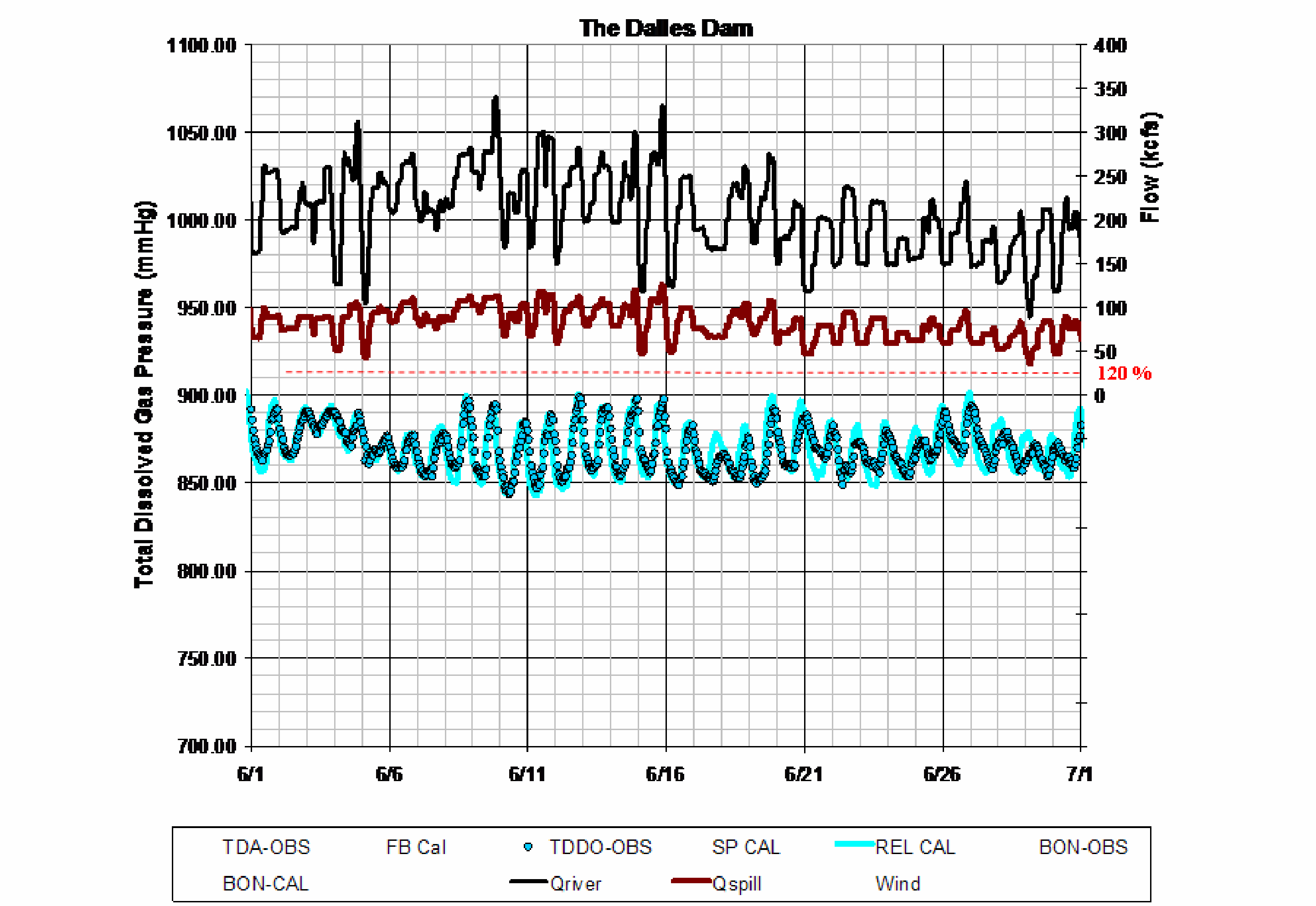

Figure G11. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel of The Dalles Dam, June 2007

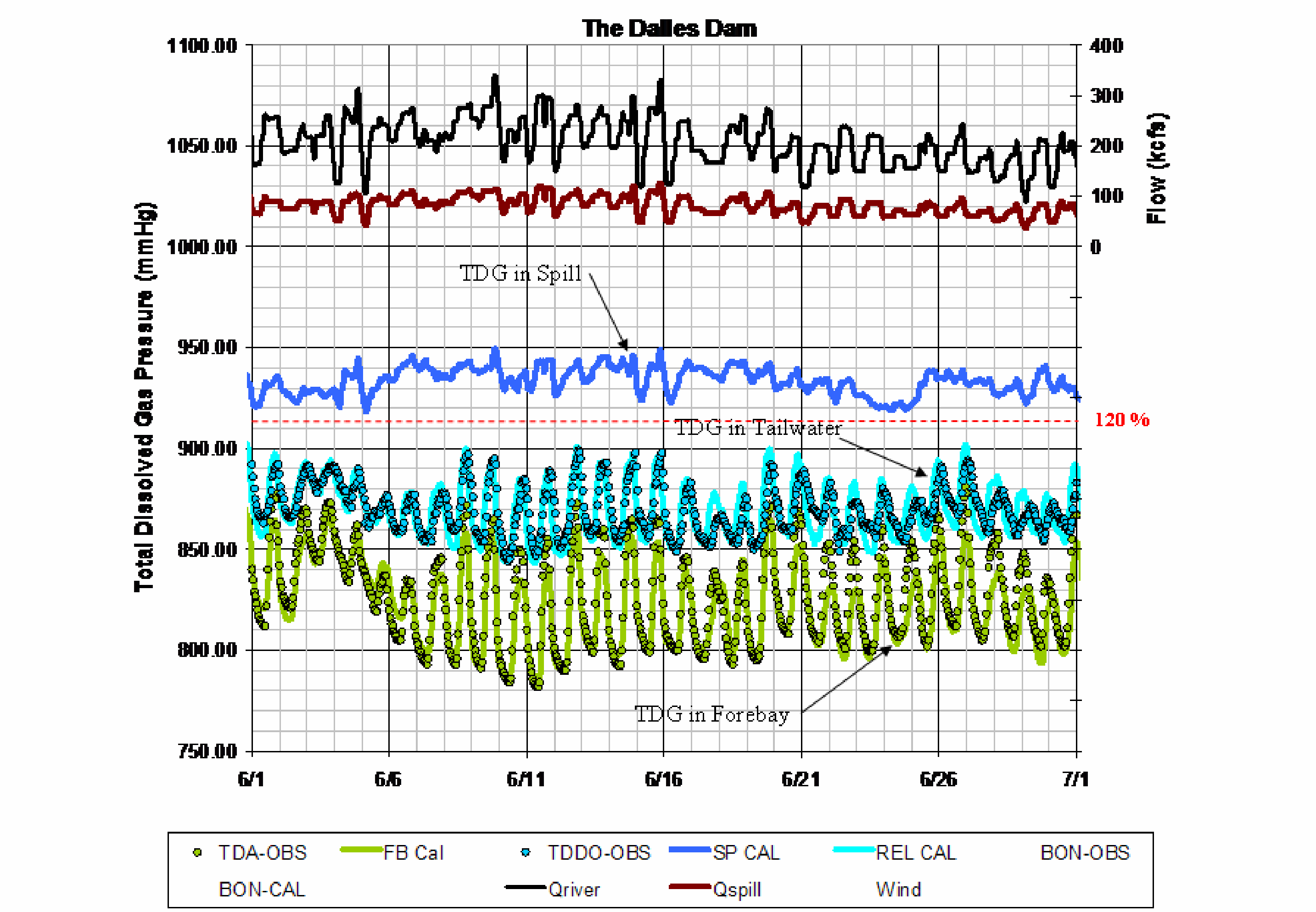

Figure G12. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel of The Dalles Dam, June 2007

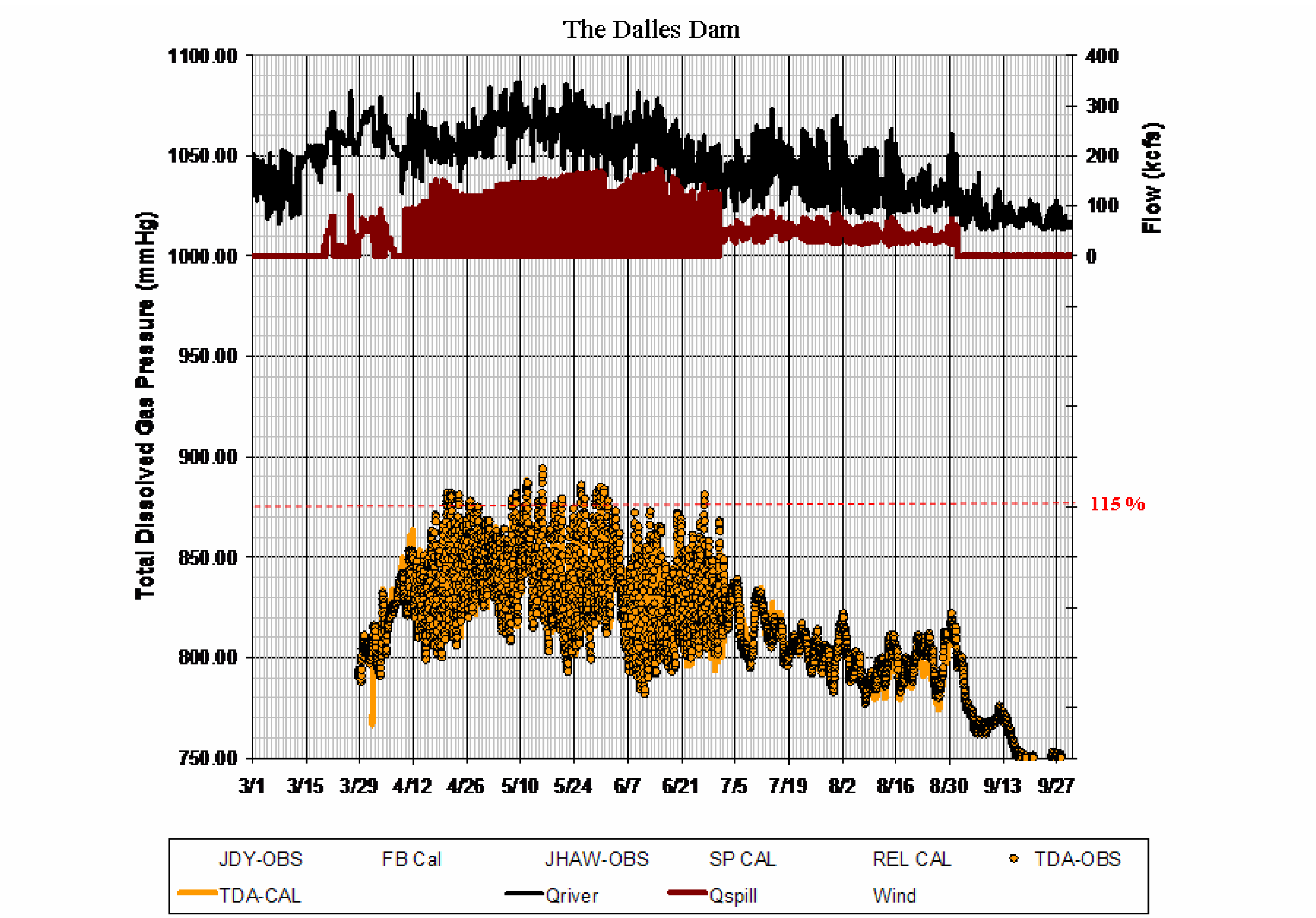

Figure G13. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of The Dalles Dam, March-September 2007

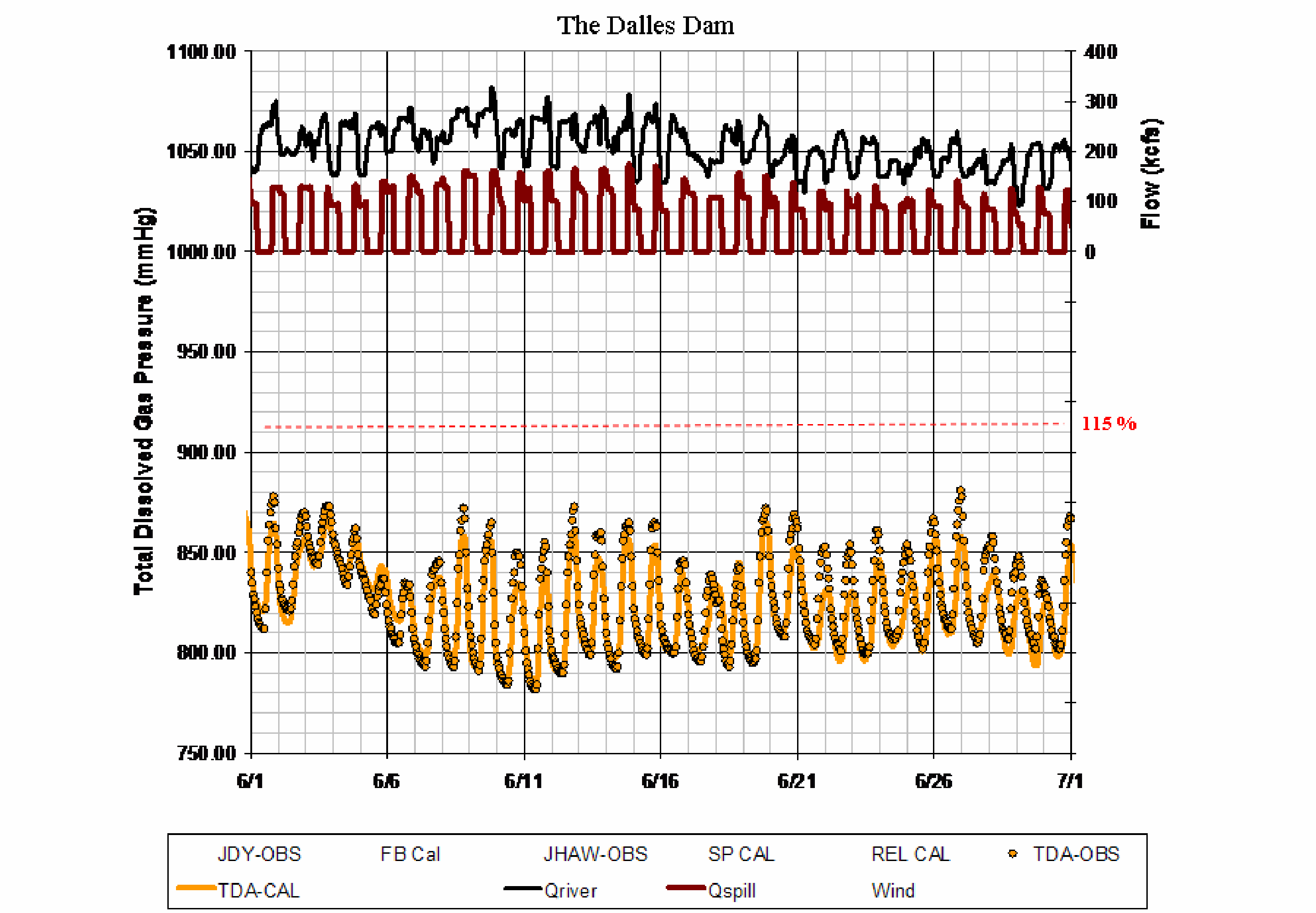

Figure G14. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of The Dalles Dam, June 2007

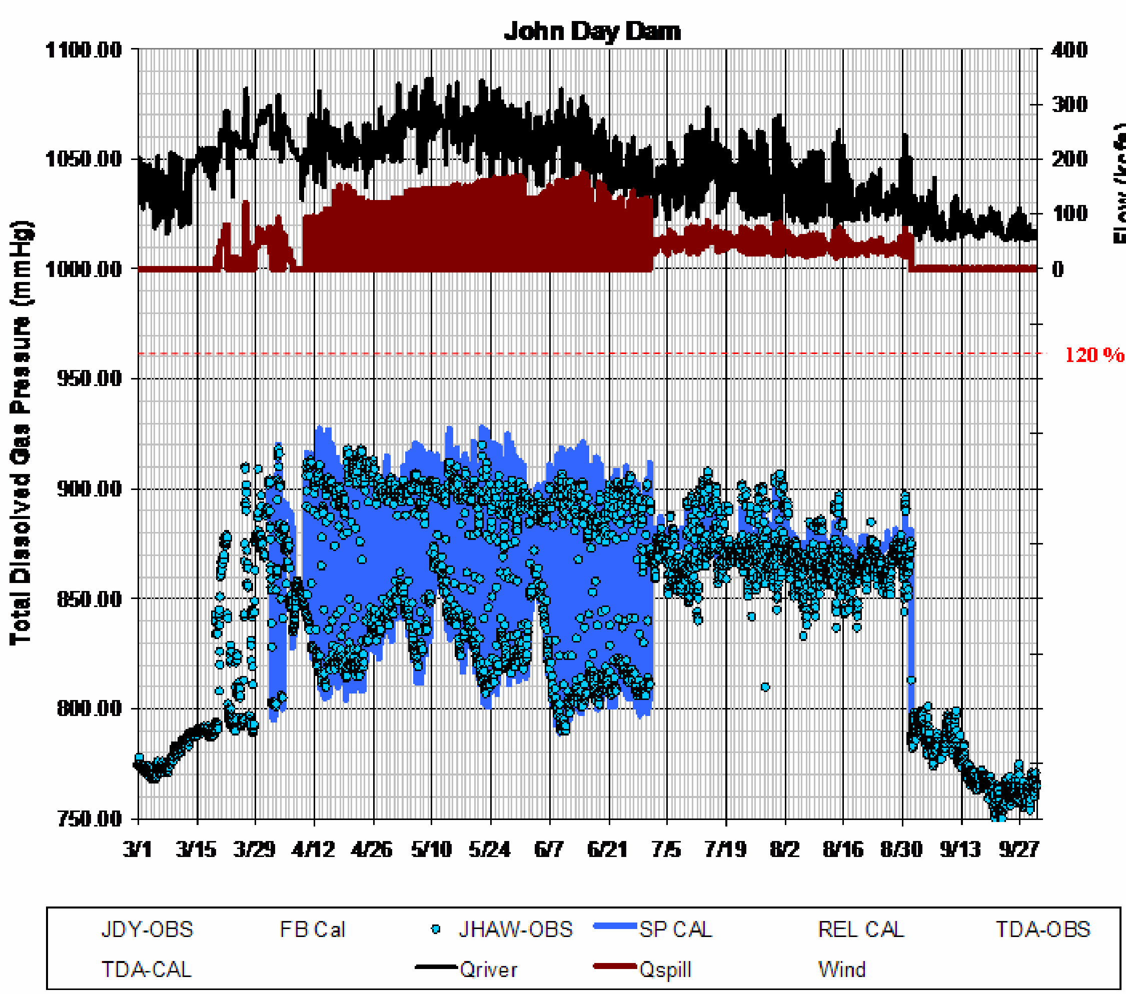

Figure G15. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, March-September 2007

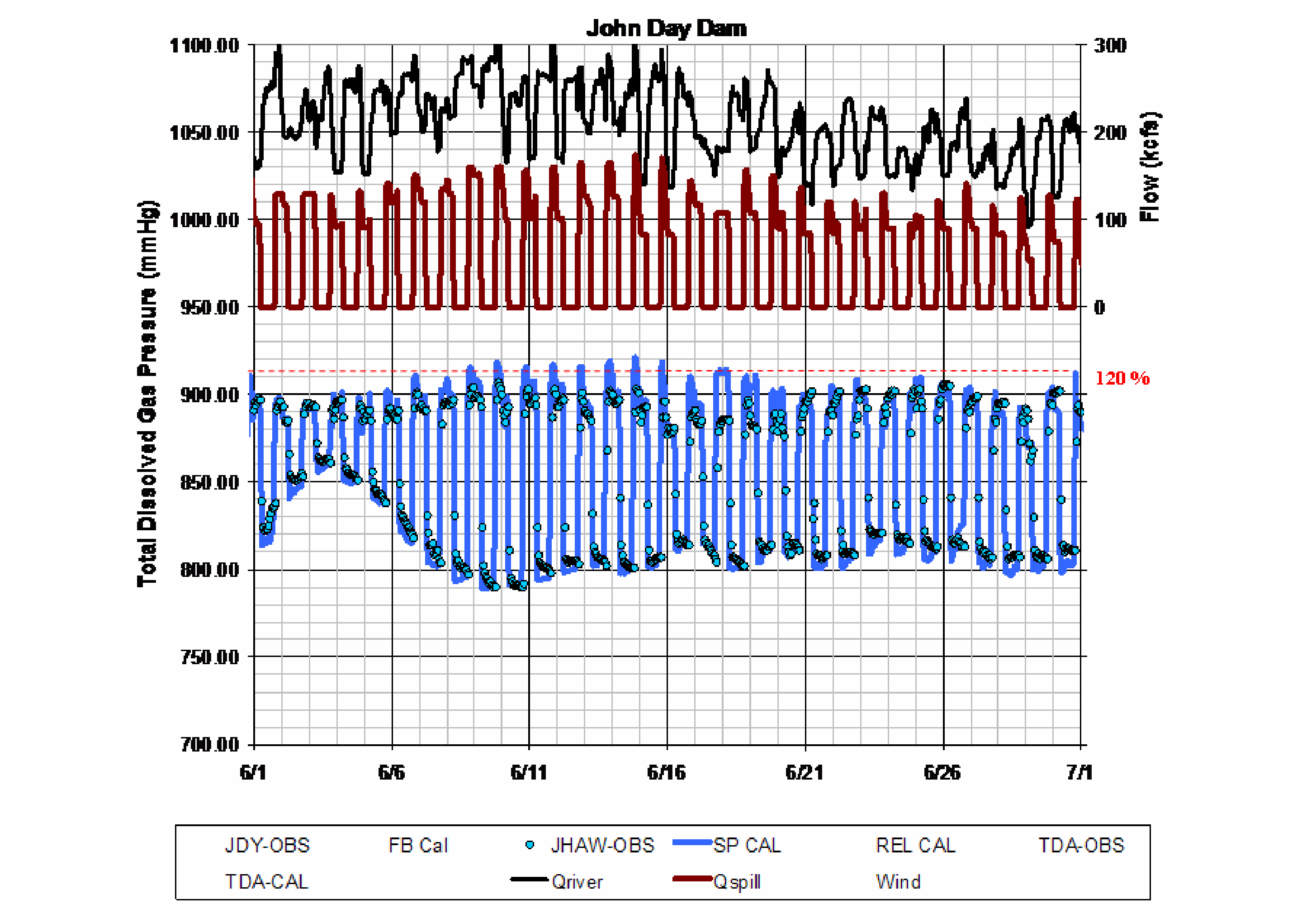

Figure G16. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater channel downstream from John Day Dam, June 2007

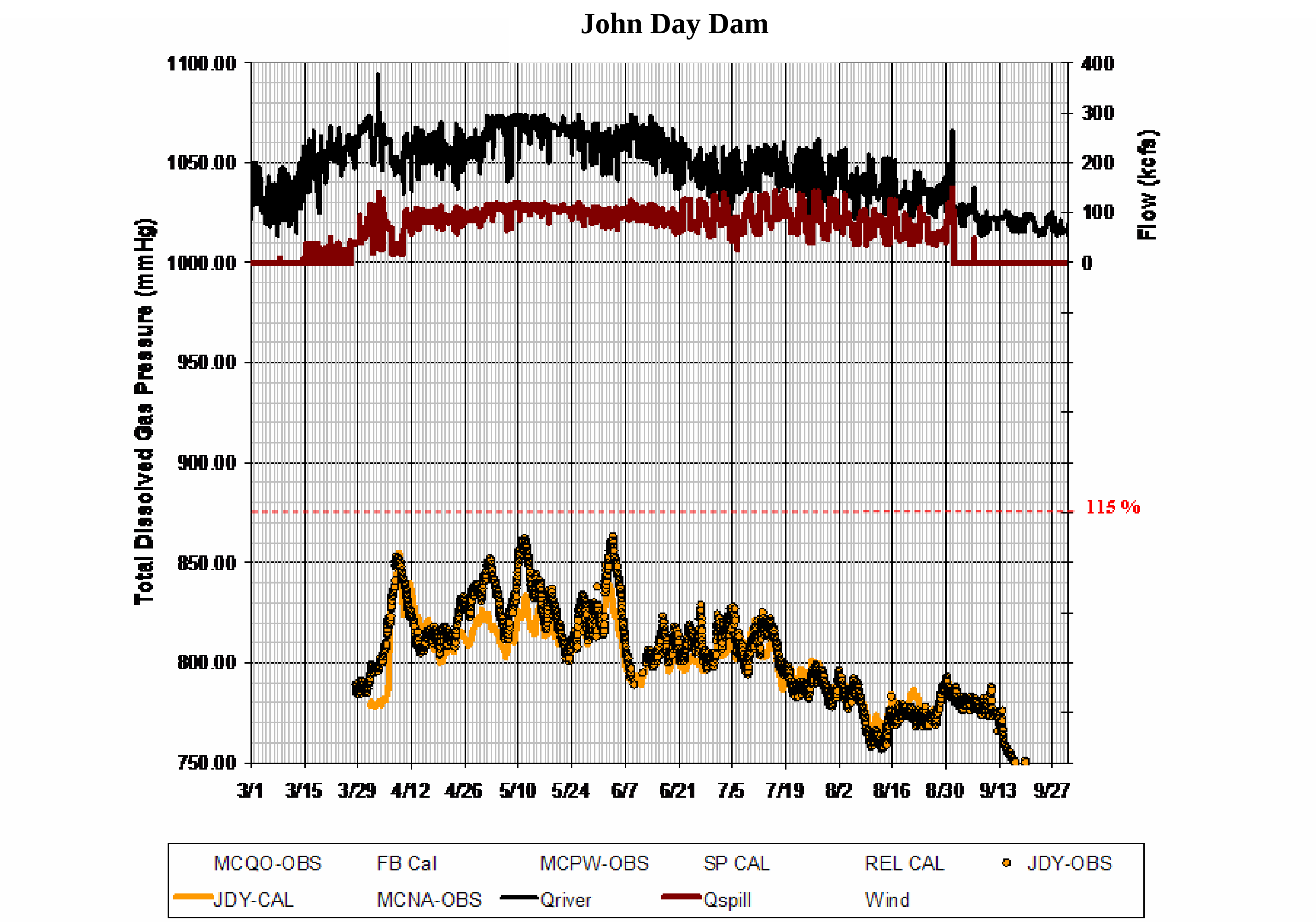

Figure G17. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of John Dam, March-September 2007

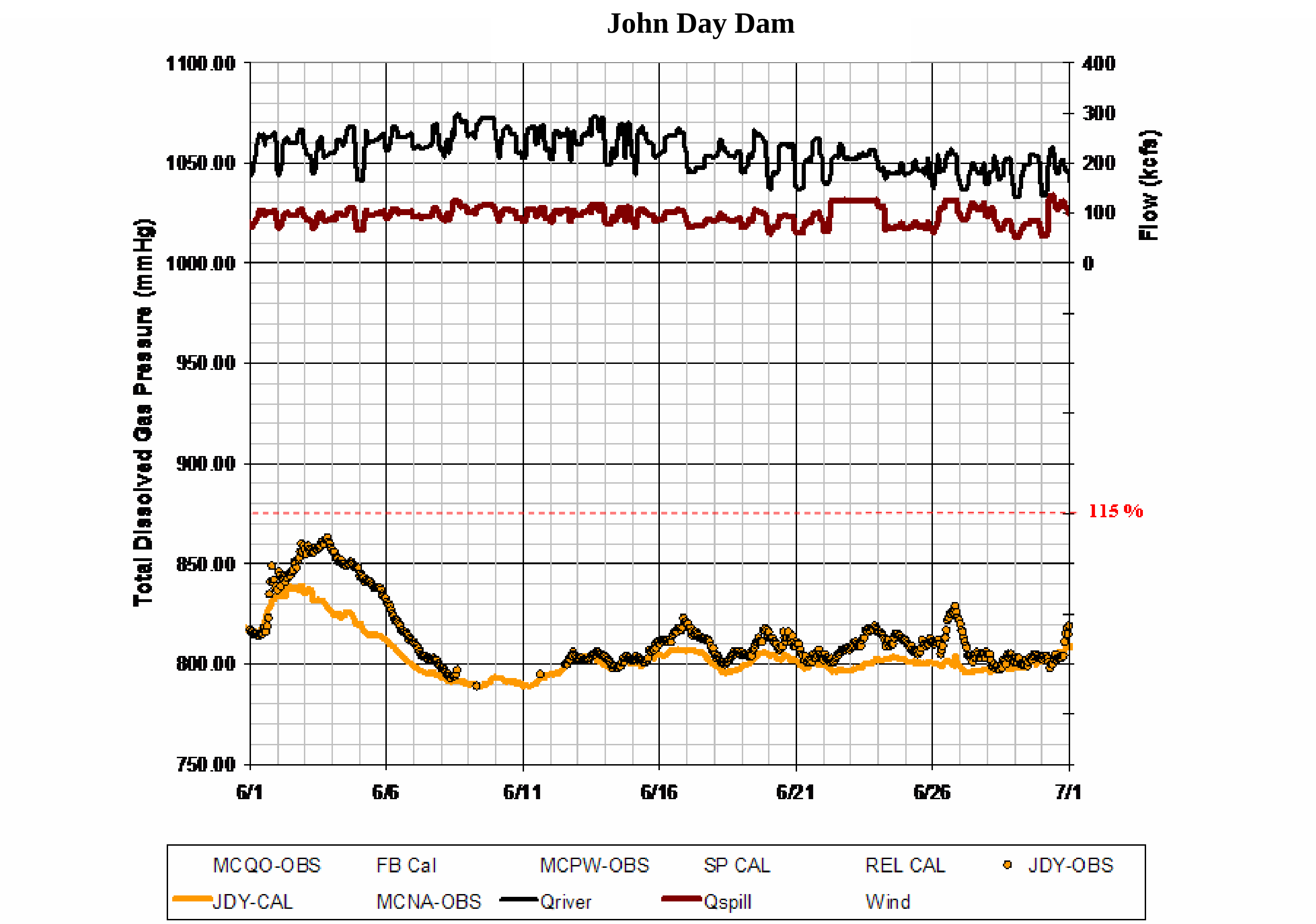

Figure G18. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of John Dam, June 2007

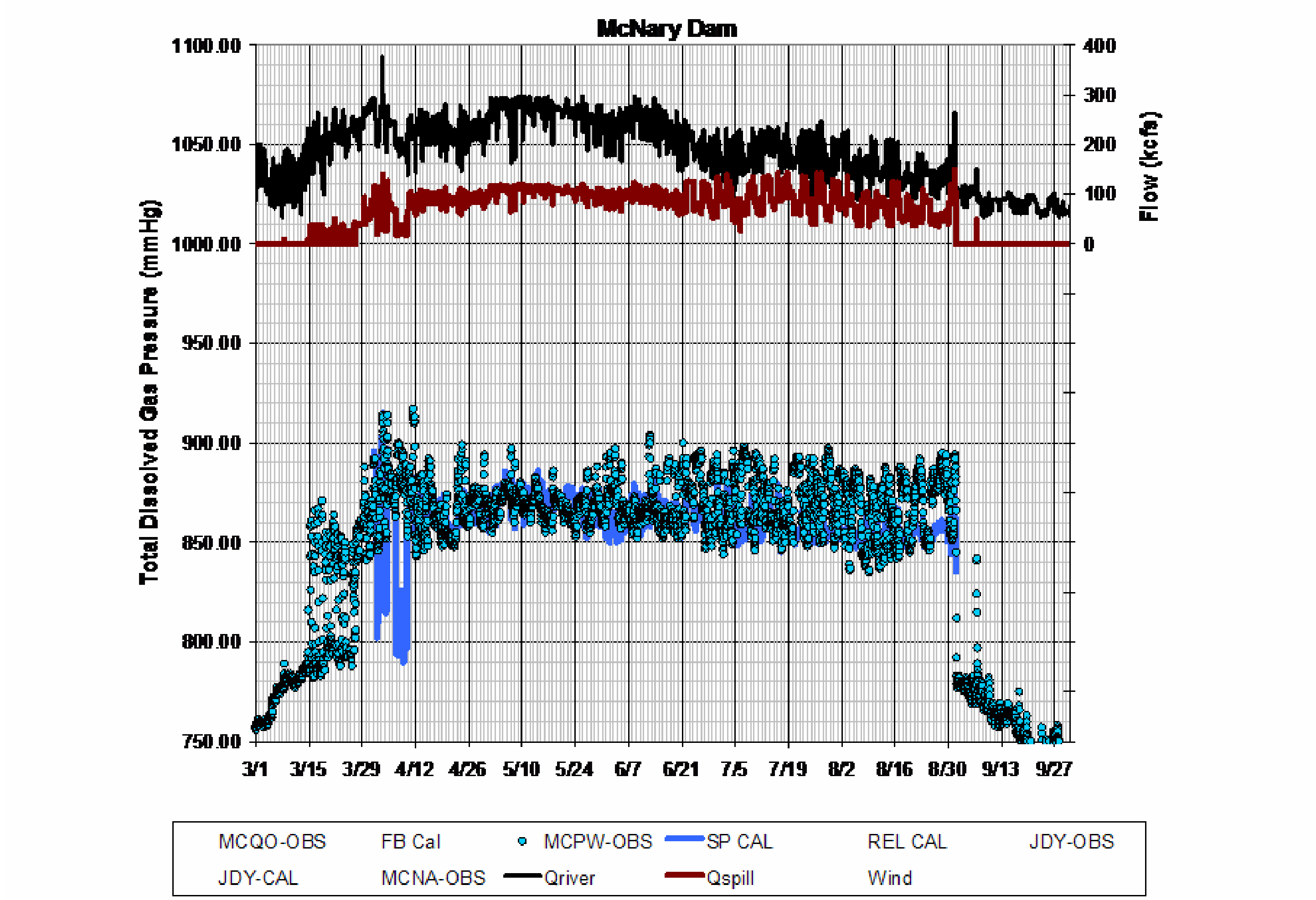

Figure G19. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater of McNary Dam, March-September 2007

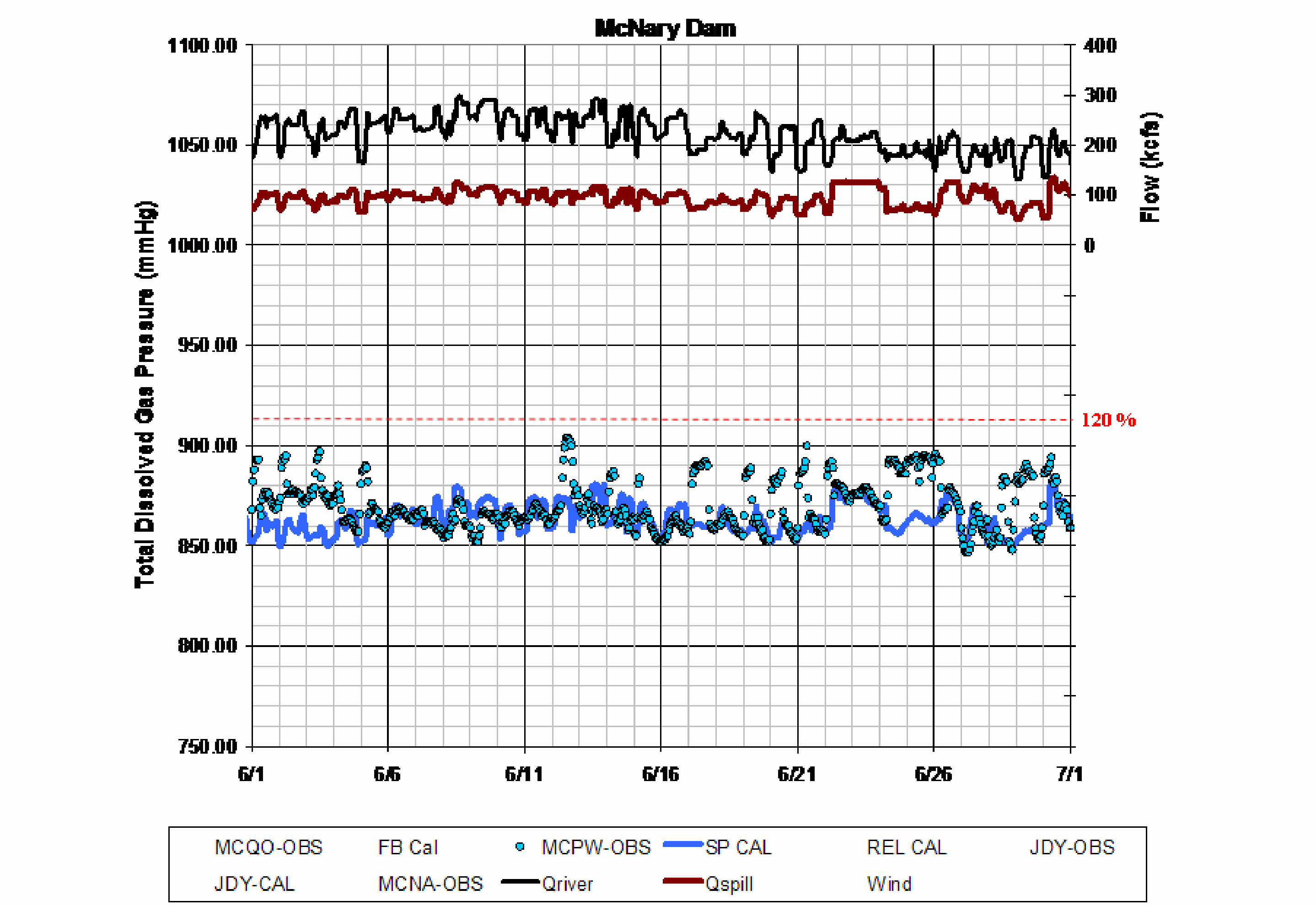

Figure G20. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the tailwater of McNary Dam, June 2007

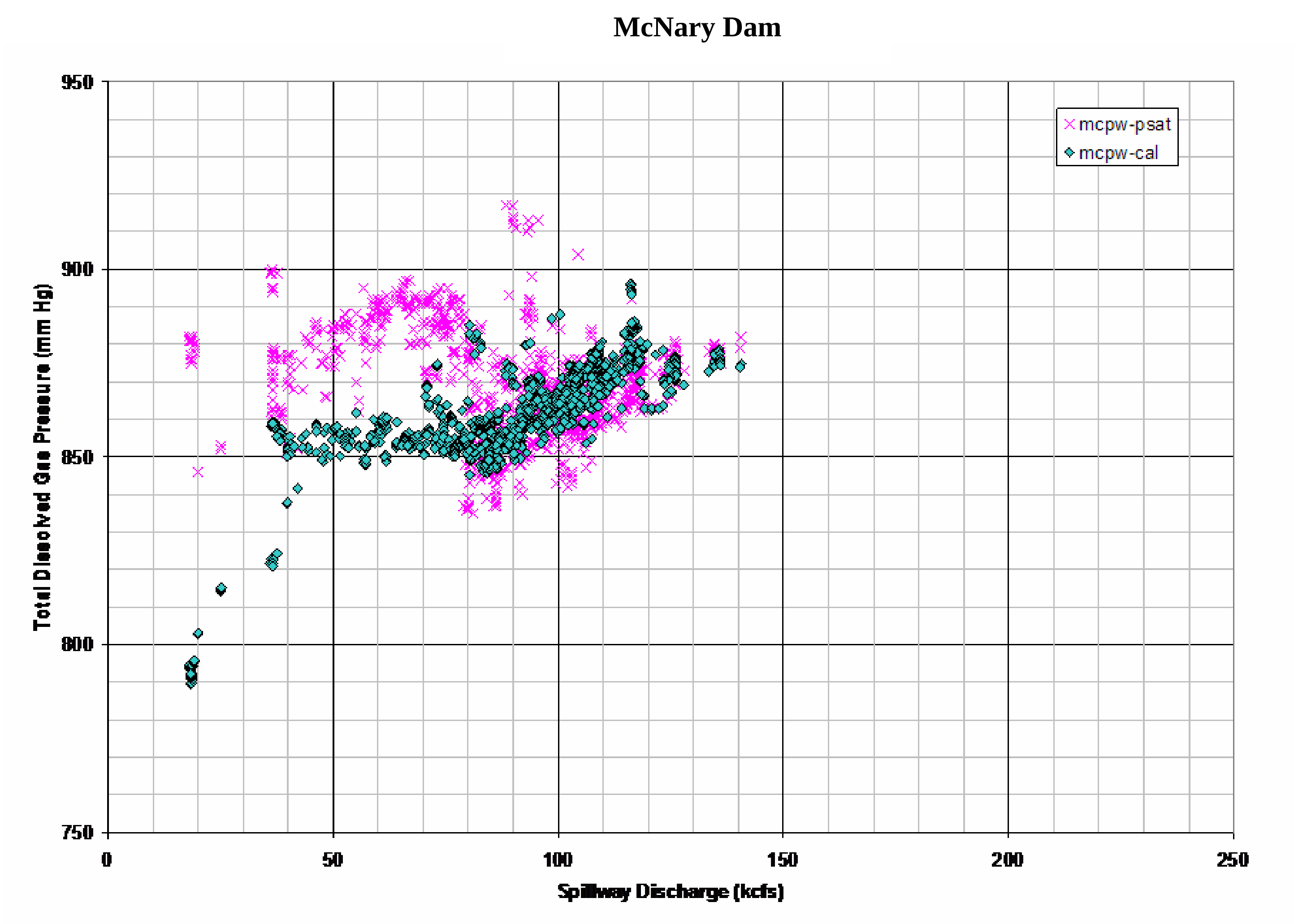

Figure G21. Calculated and Observed Total Dissolved Gas Pressure versus spillway discharge at McNary Dam, 2007 (mcpw-tdg observed, mcpw-cal calculated)

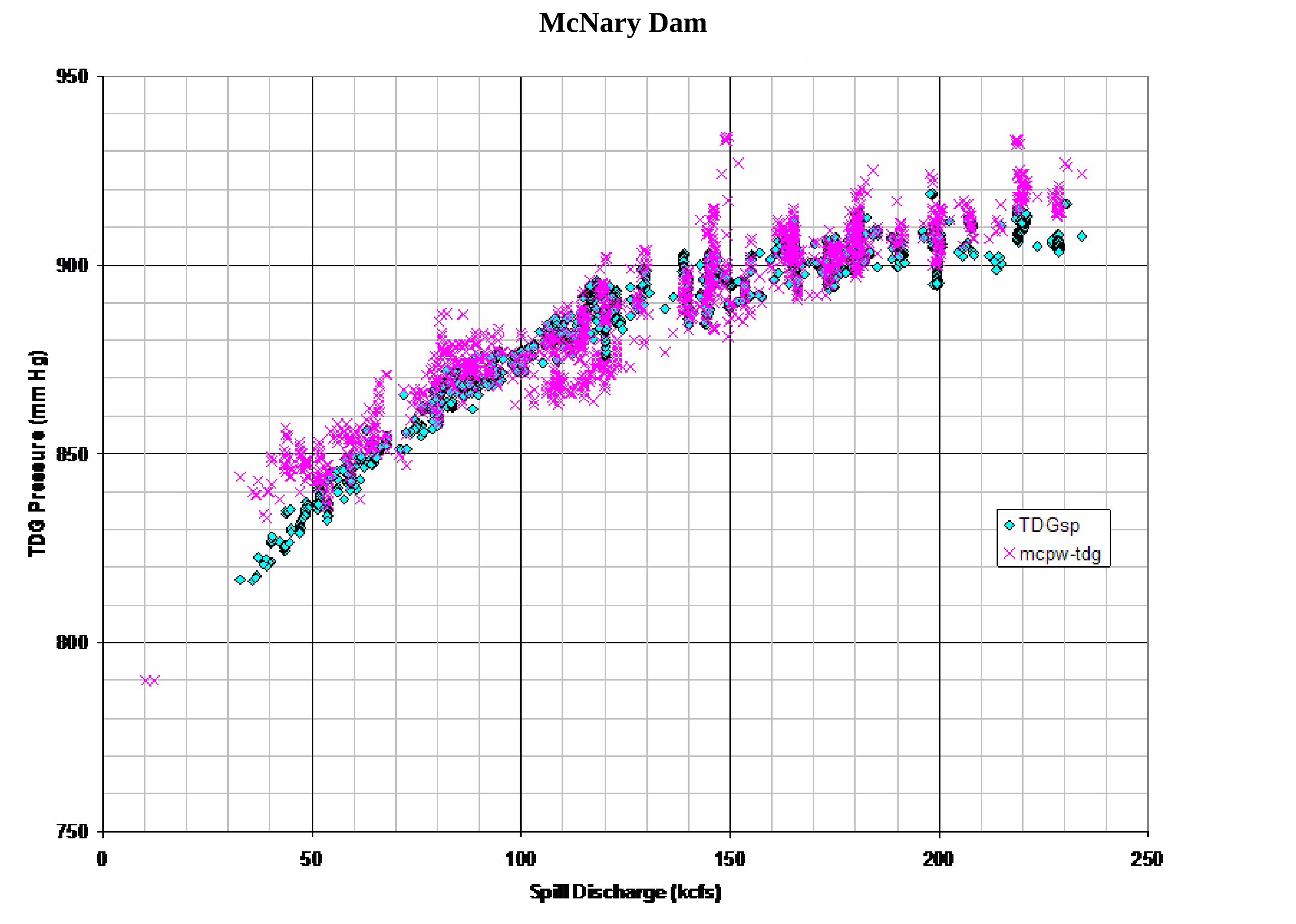

Figure G22. Calculated and Observed Total Dissolved Gas Pressure versus spillway discharge at McNary Dam, 2006 (mcpw-tdg observed, TDGsp-calculated)

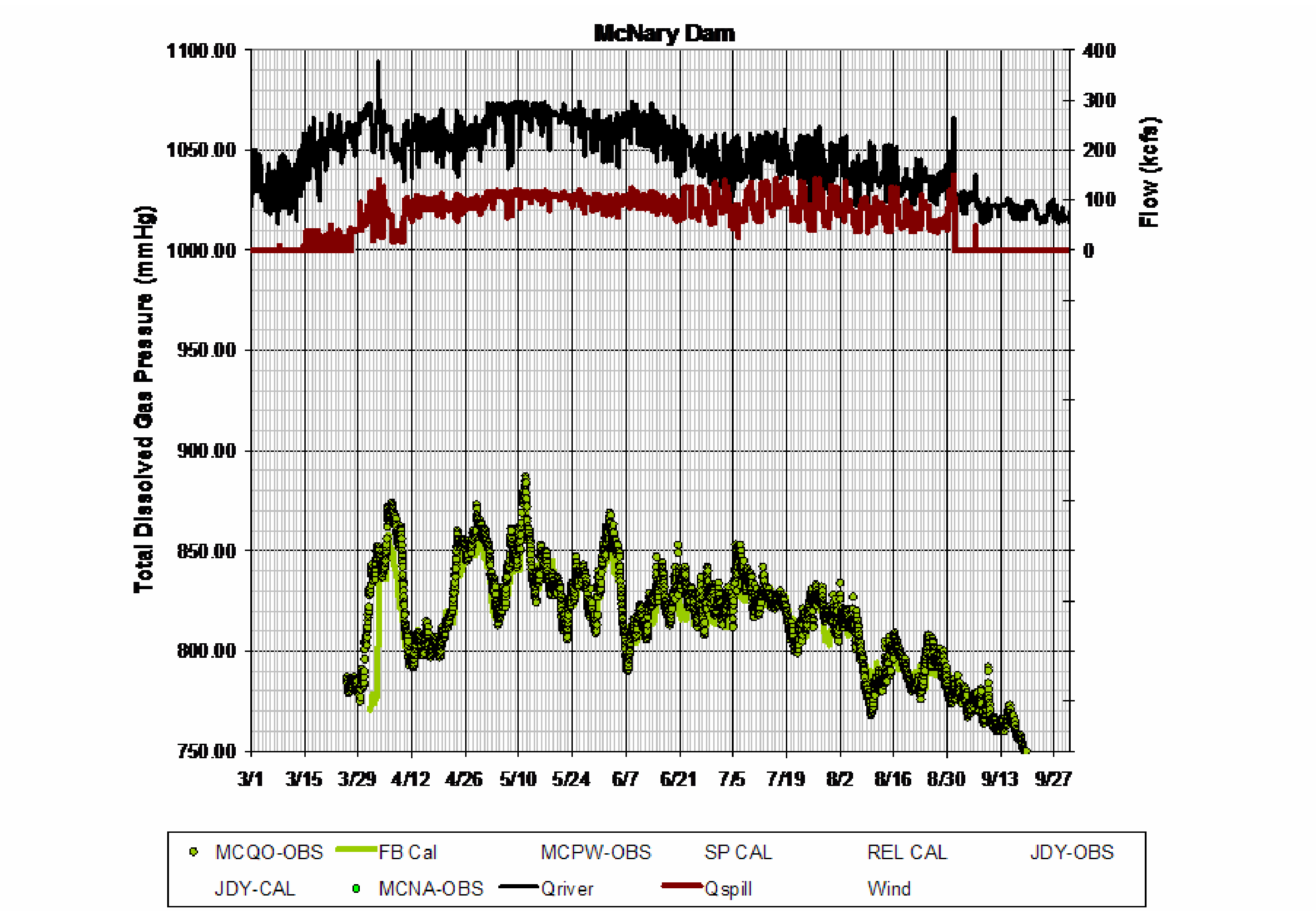

Figure G23. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of McNary Dam, March-September 2007

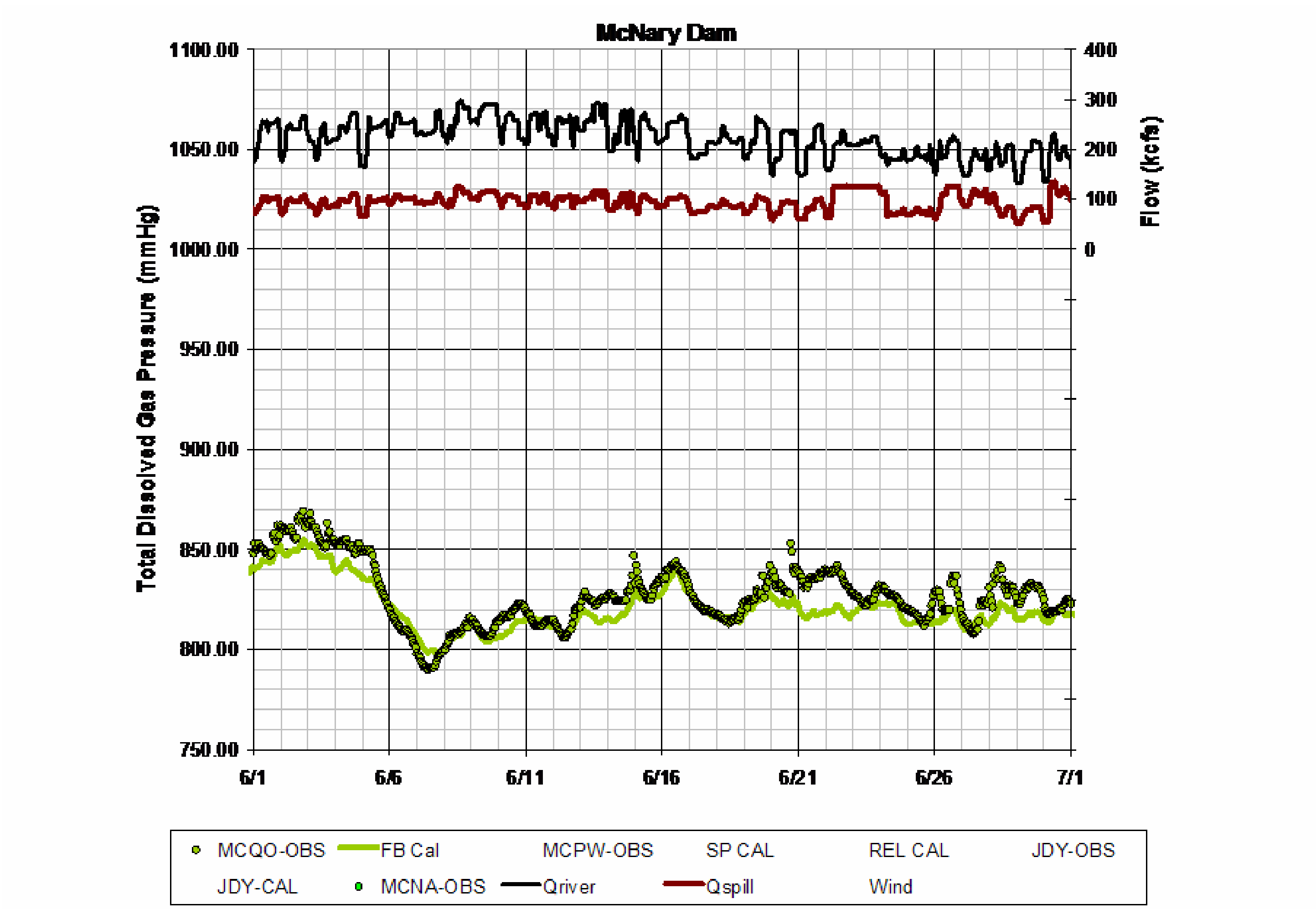

Figure G24. Observed and Calculated Total Dissolved Gas Pressures in the Columbia River in the forebay of McNary Dam, June 2007

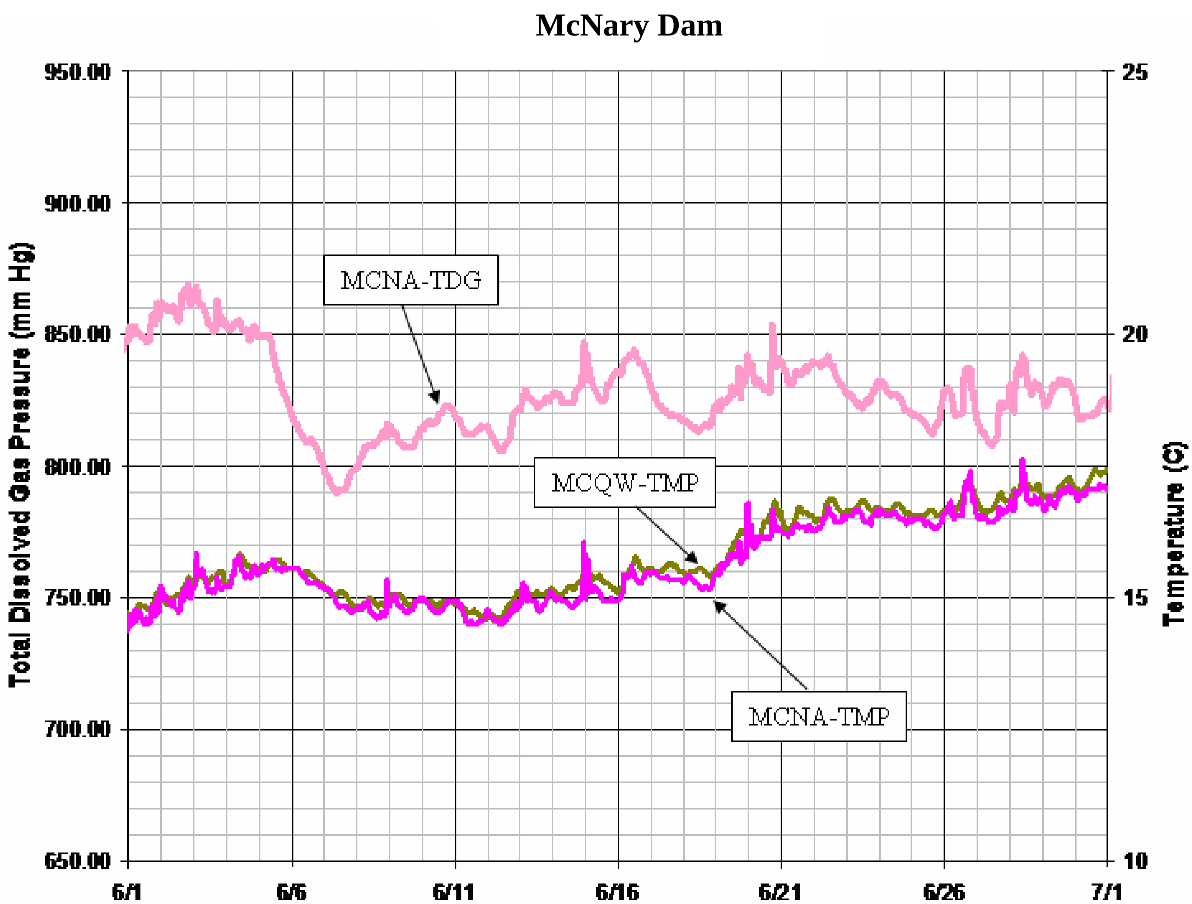

Figure G25. Observed Total Dissolved Gas Pressure and Temperature in the Columbia River in the forebay and tailwater of McNary Dam, June 2007 (MCNA-forebay, MCQW-tailwater)

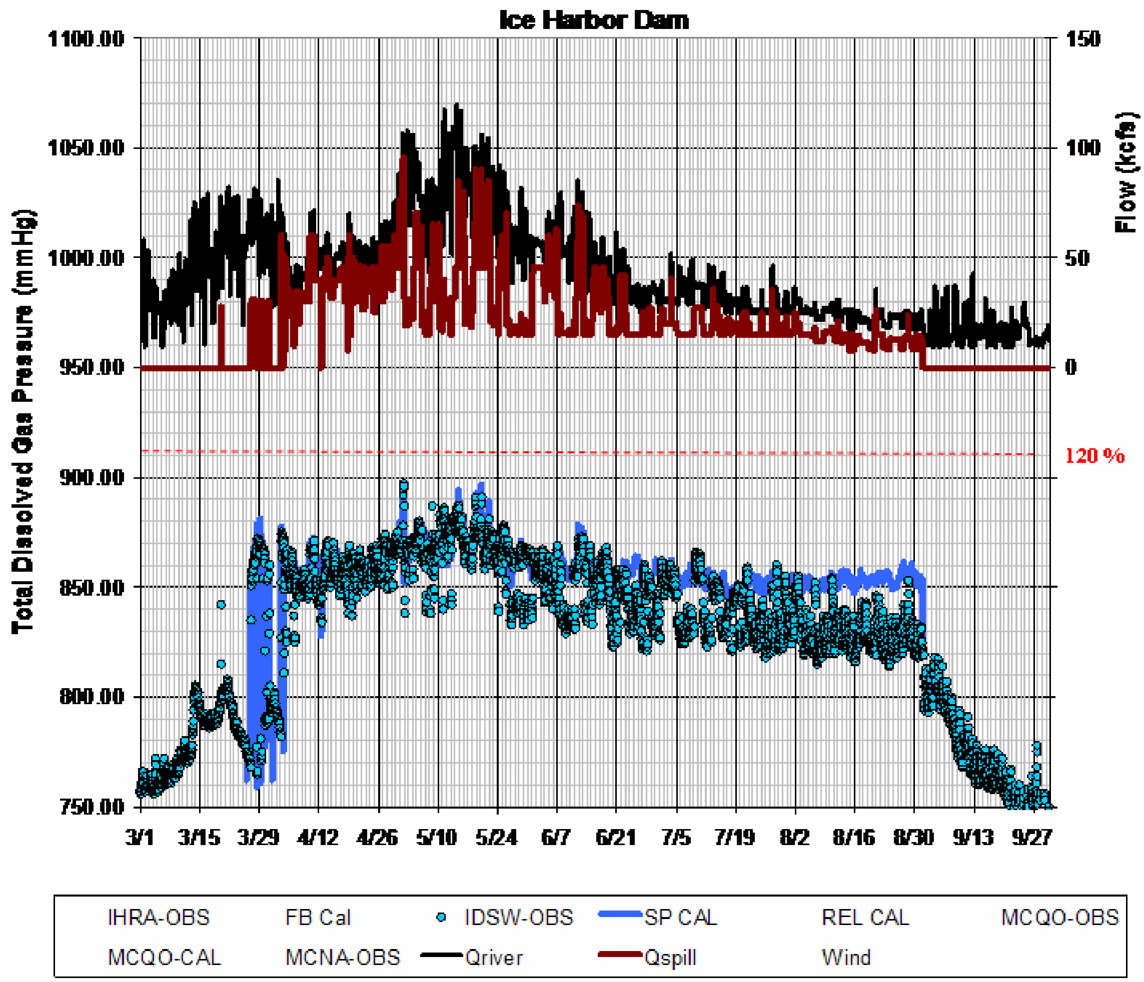

Figure G26. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater downstream from Ice Harbor Dam, March-September 2007

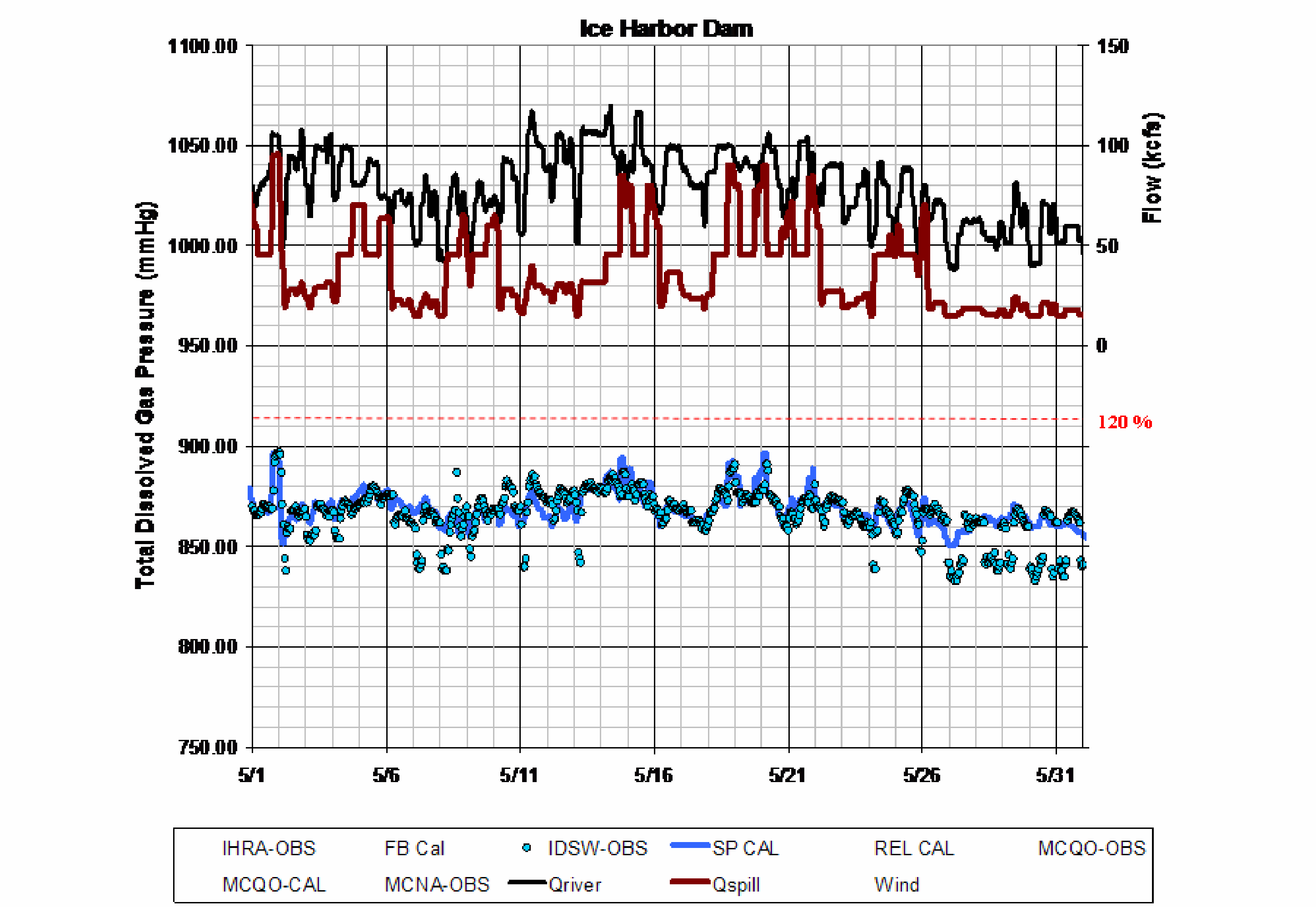

Figure G27. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater downstream from Ice Harbor Dam, May 2007

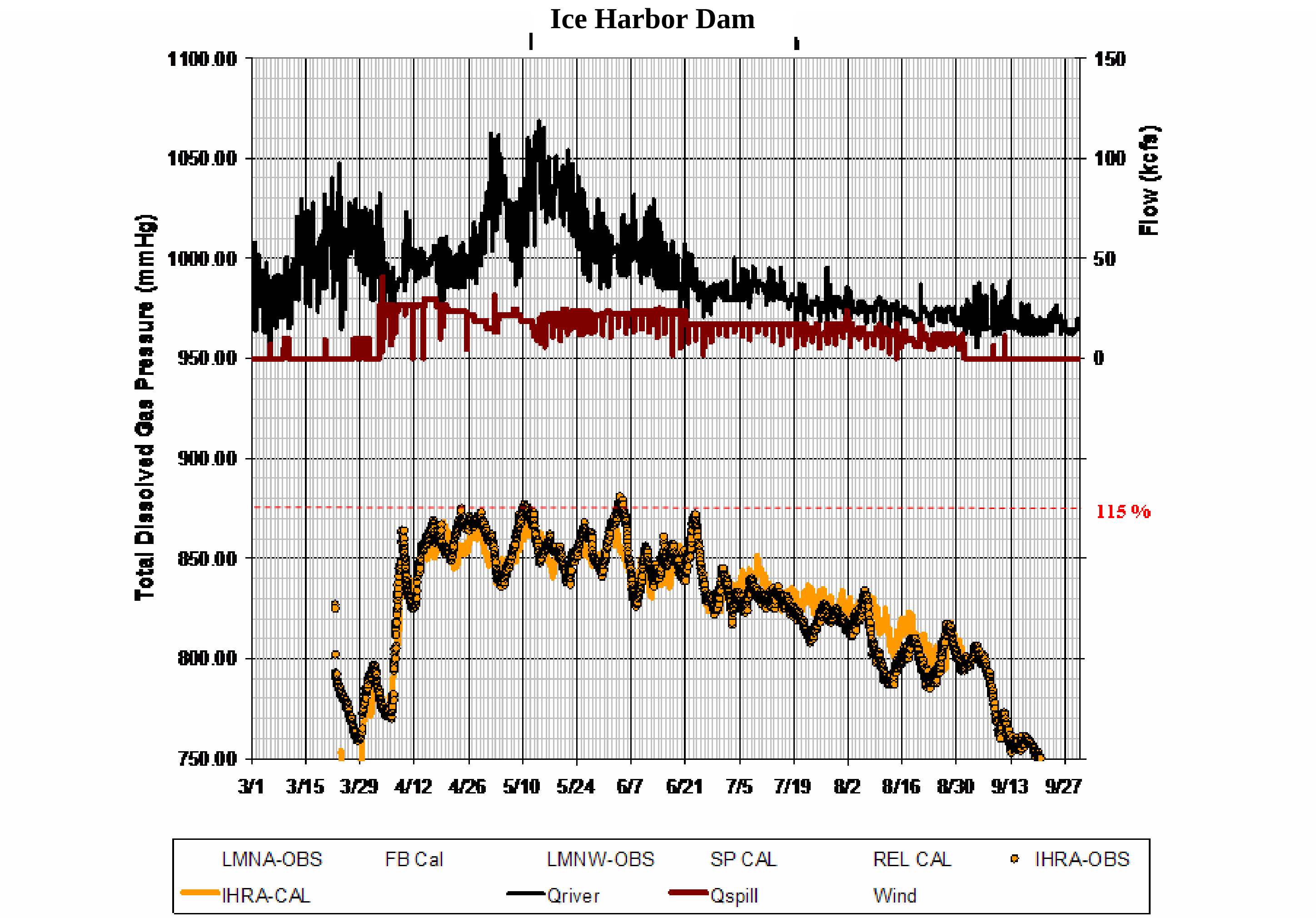

Figure G28. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Ice Harbor Dam, March-September 2007

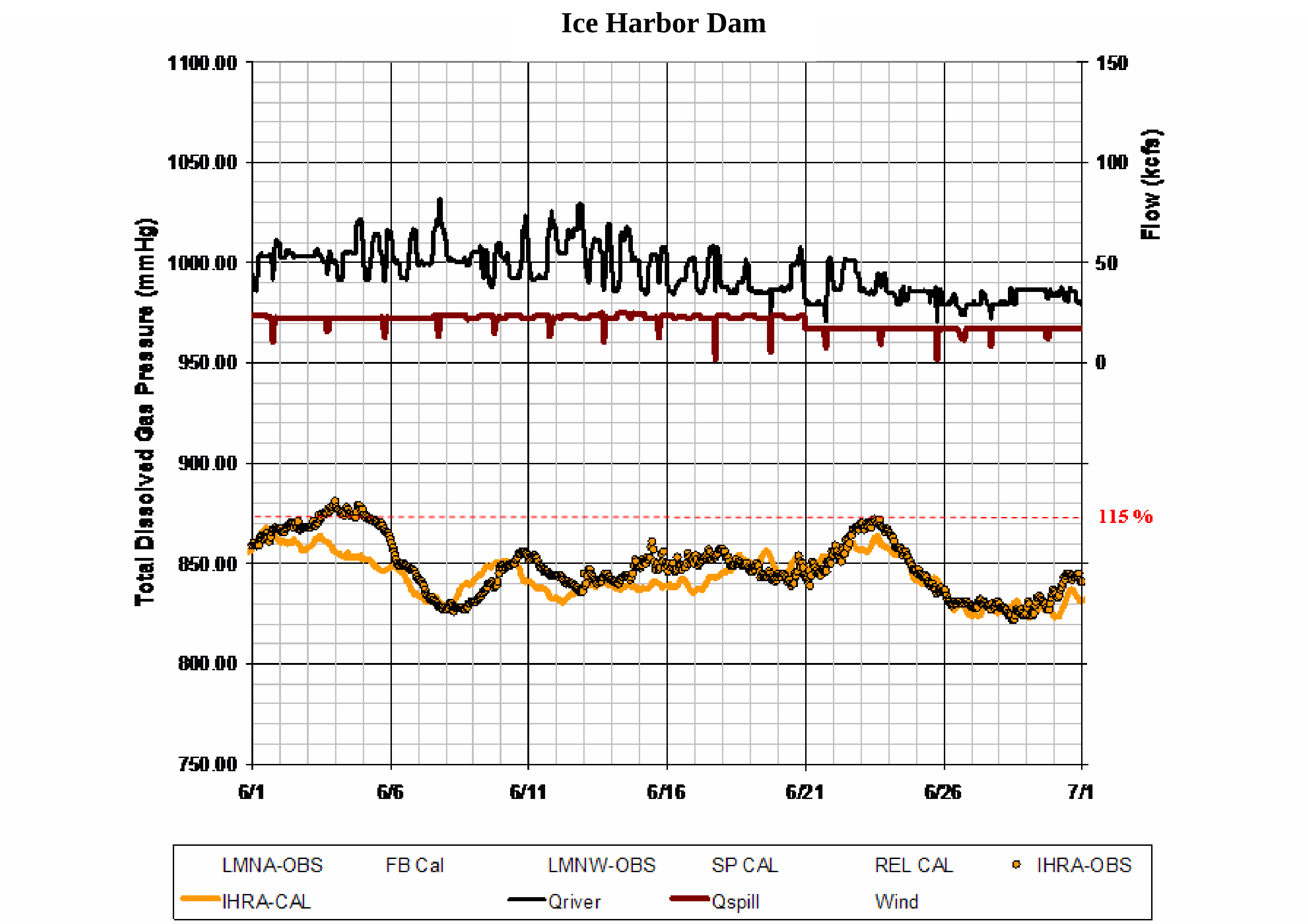

Figure G29. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Ice Harbor Dam, June 2007

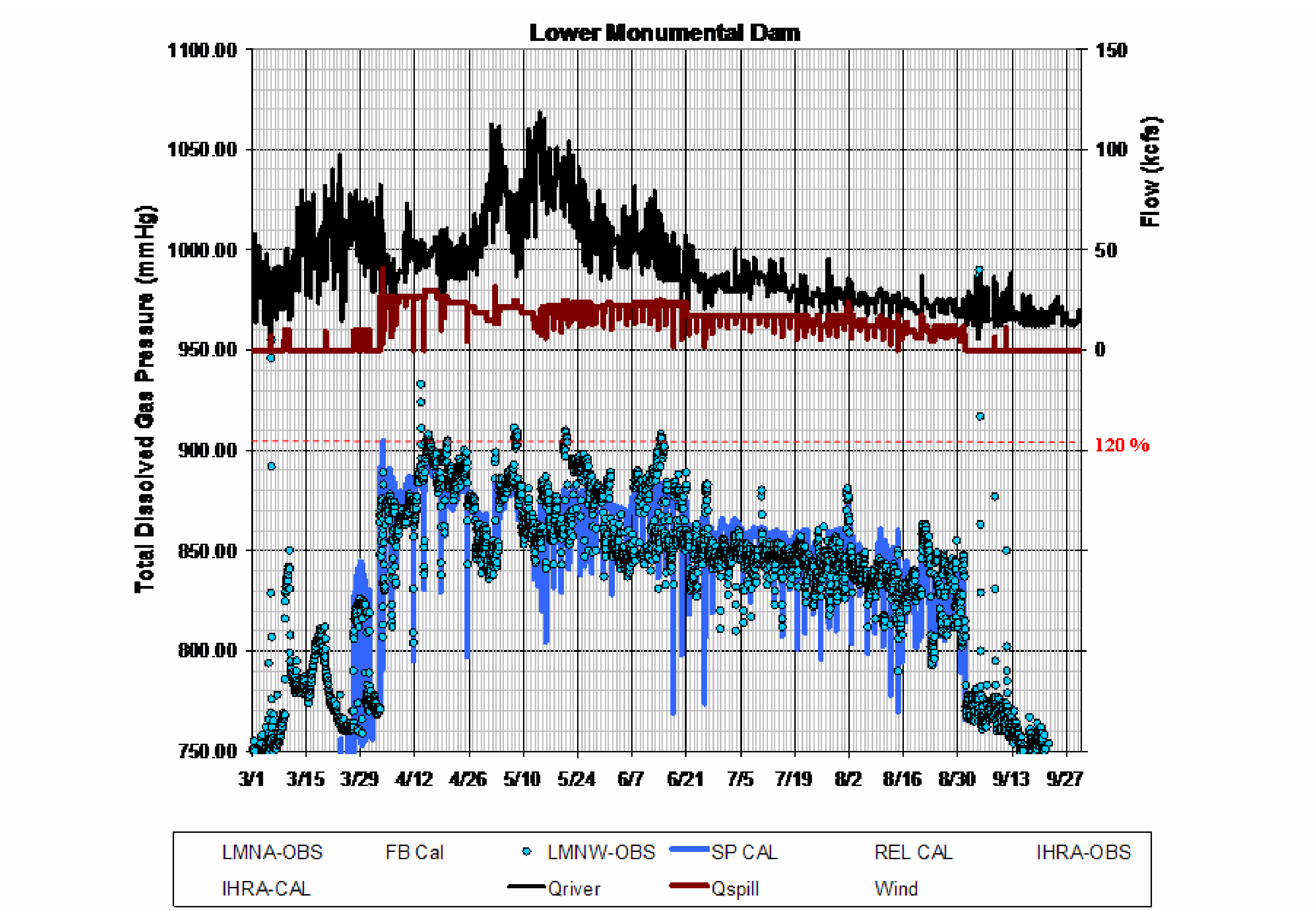

Figure G30. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Monumental Dam, March-September 2007

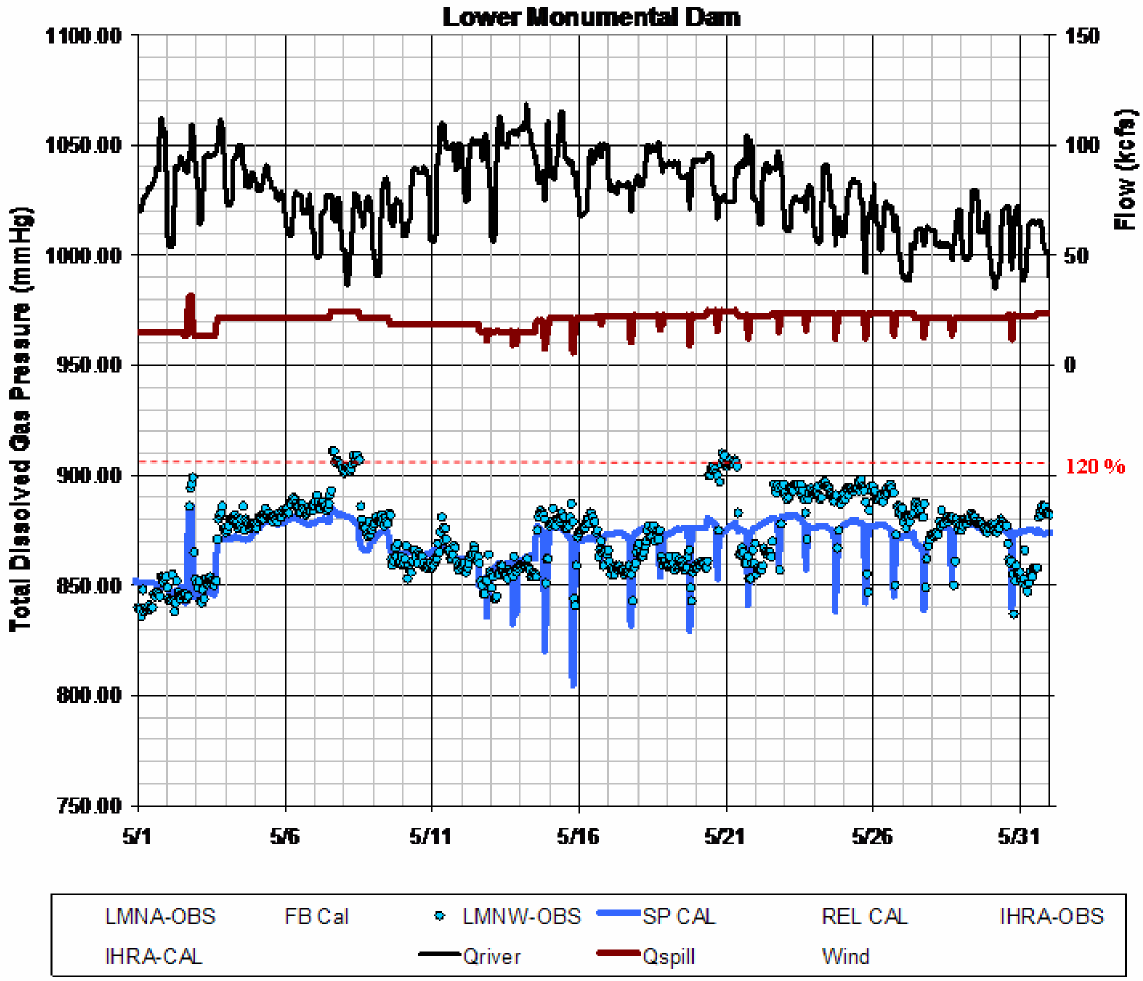

Figure G31. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Monumental Dam, May 2007

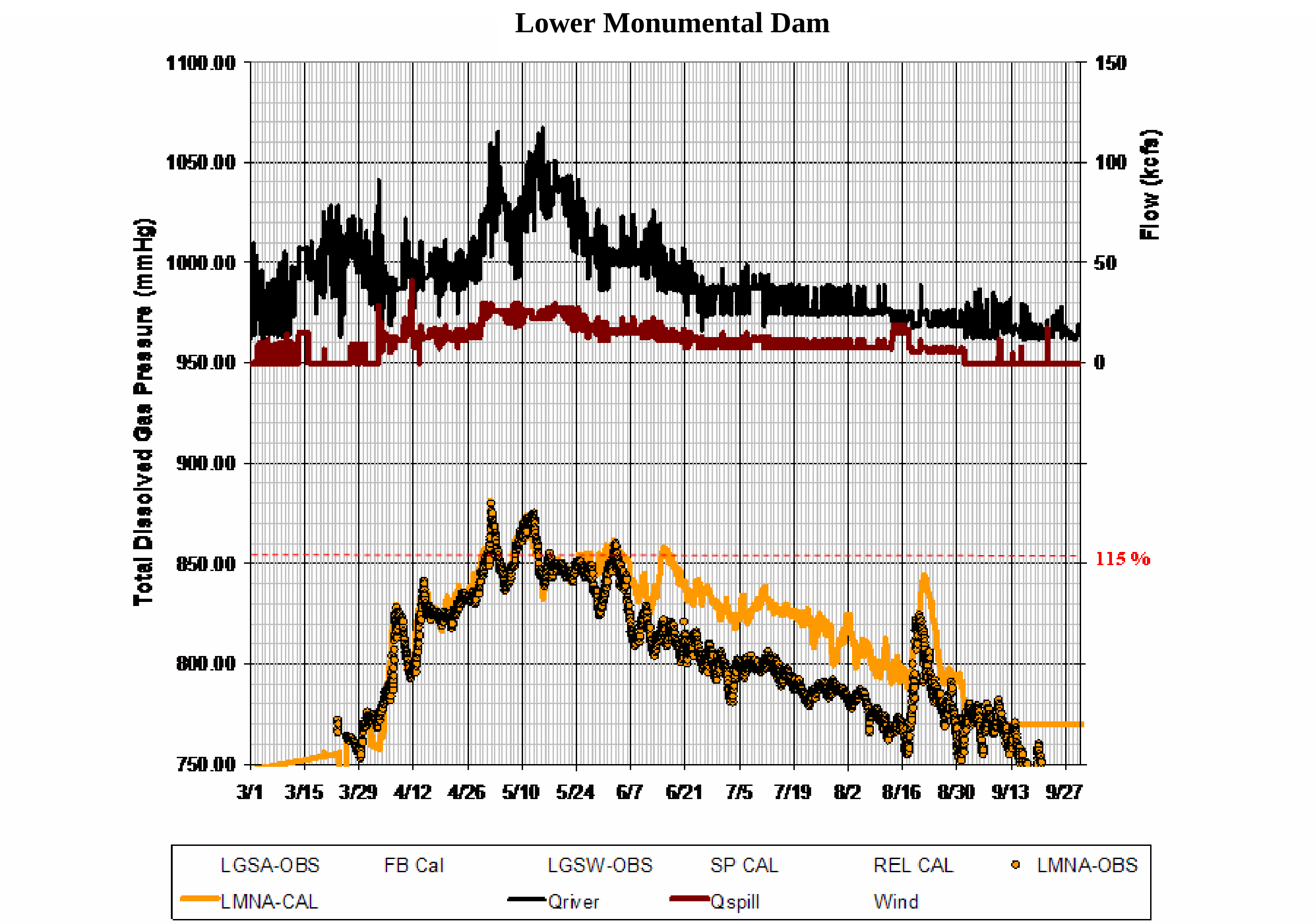

Figure G32. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Lower Monumental Dam, March-September 2007

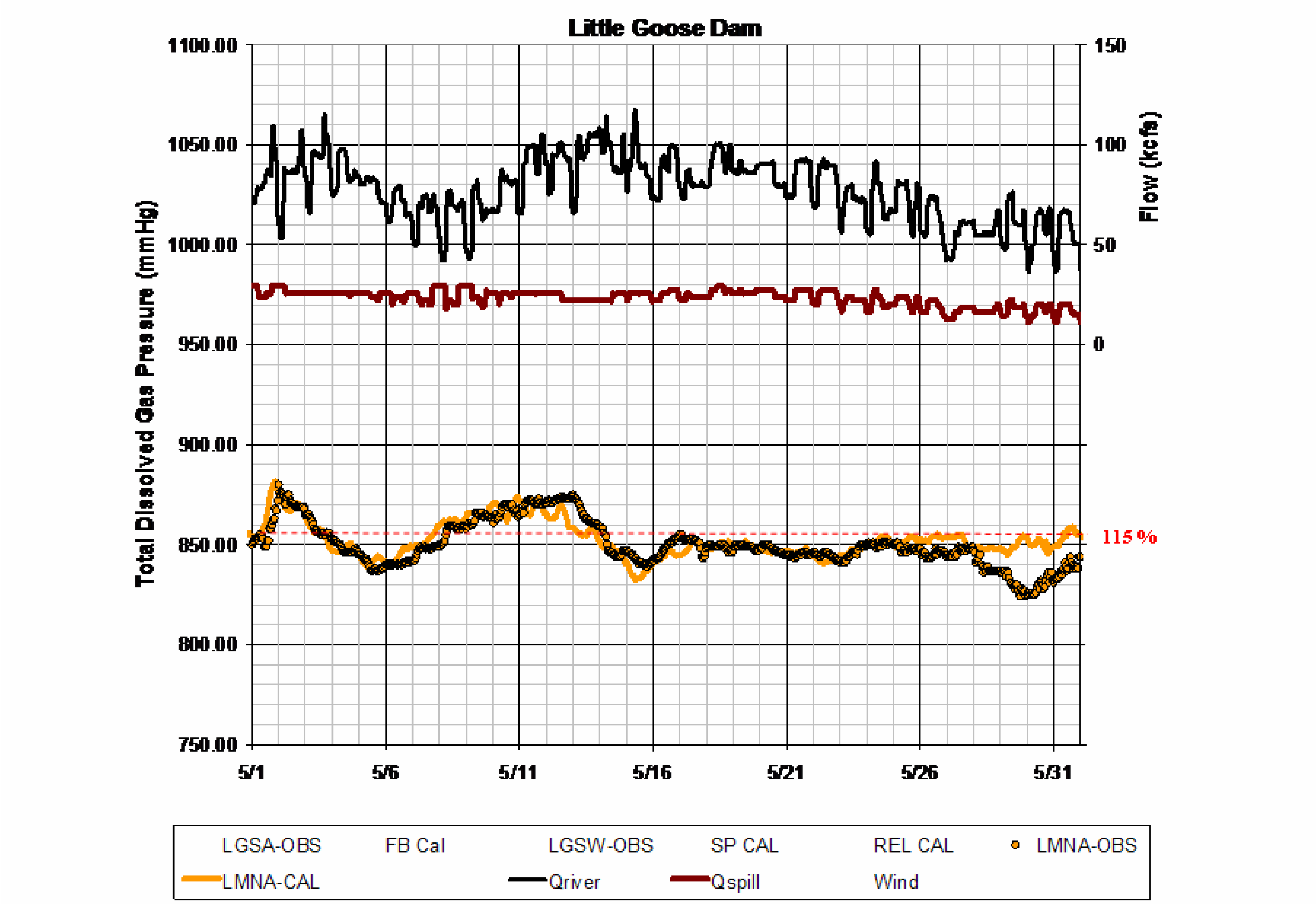

Figure G33. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Lower Monumental Dam, May 2007

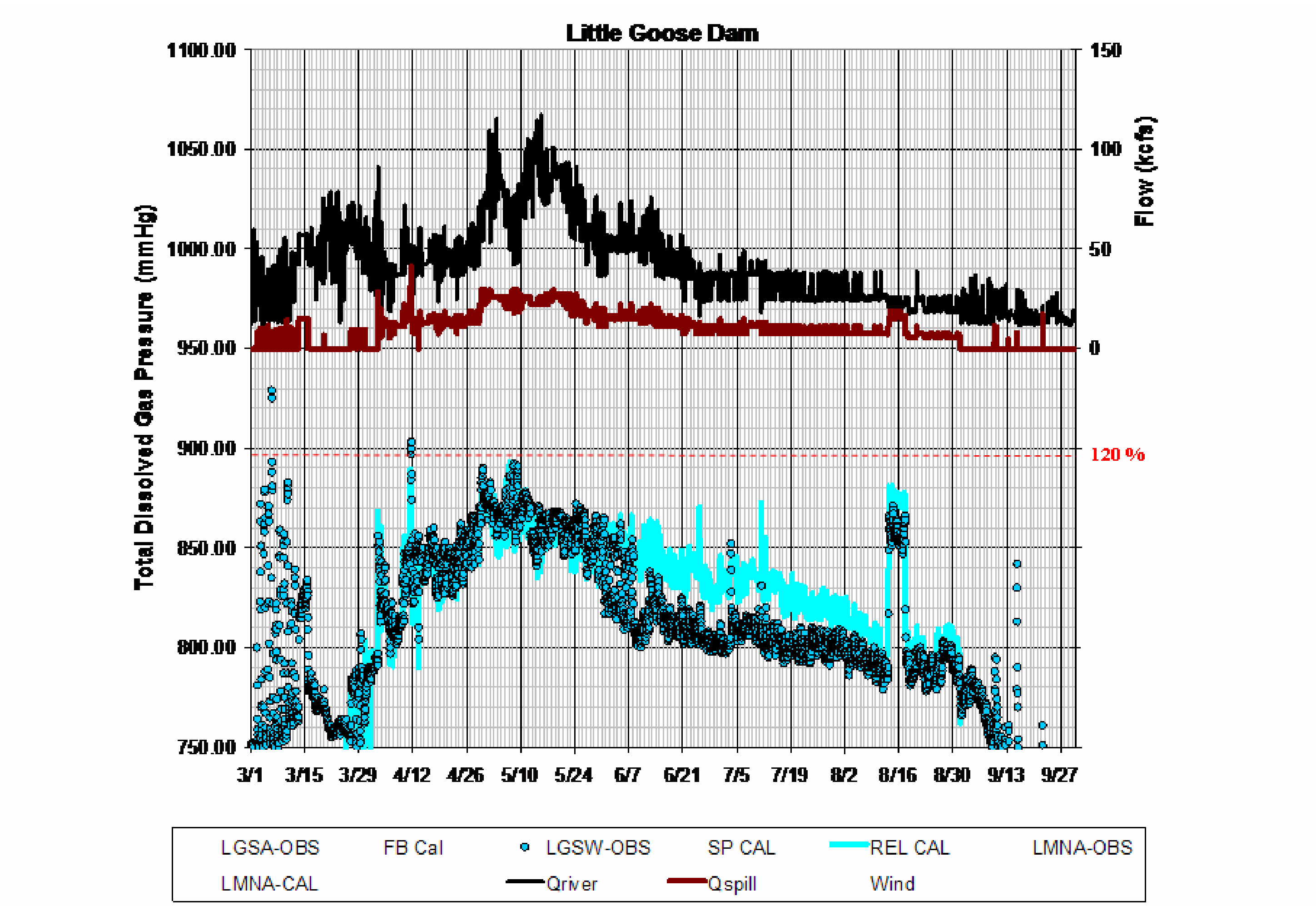

Figure G34. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Little Goose Dam, March-September 2007

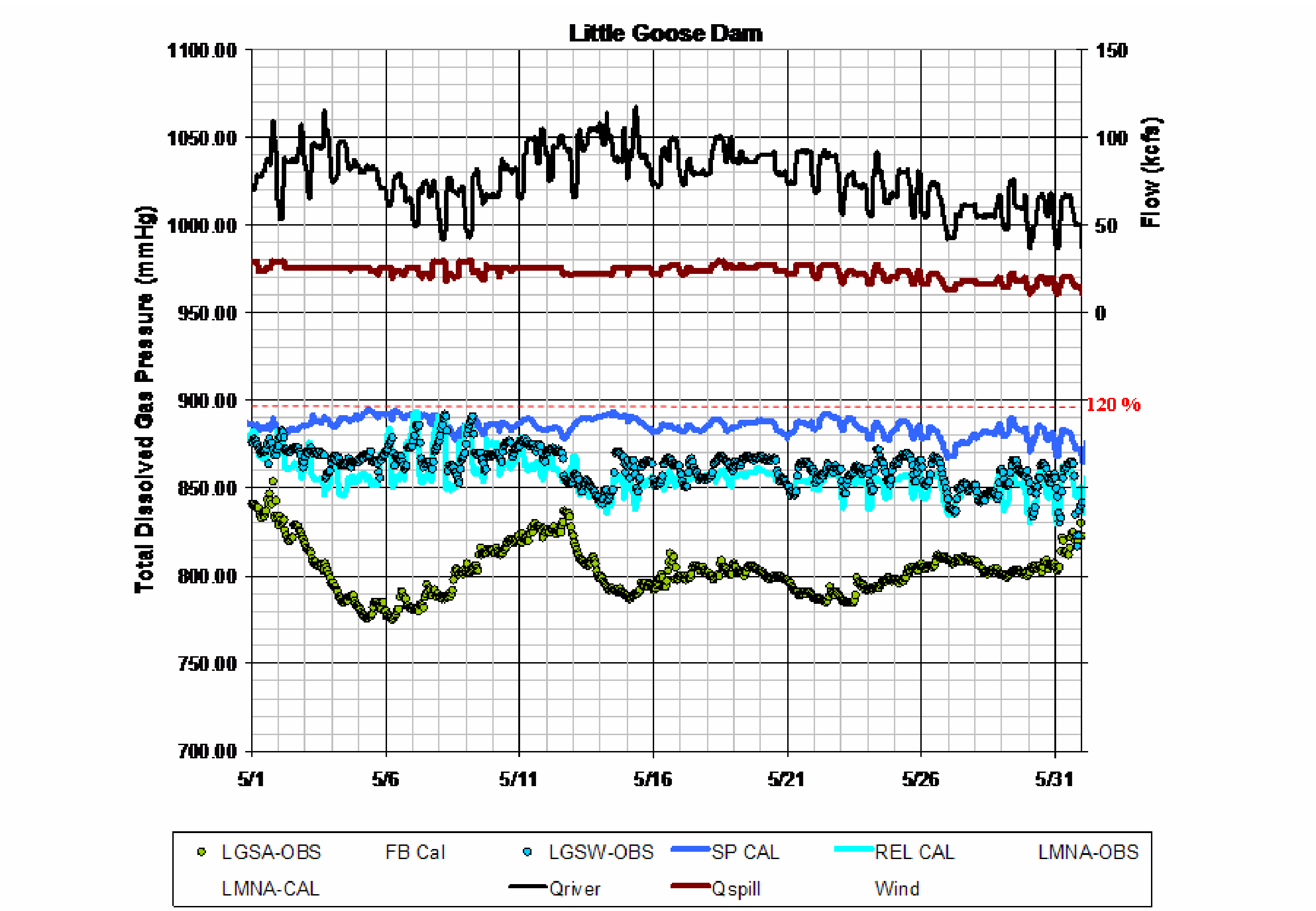

Figure G35. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Little Goose Dam, April 2007

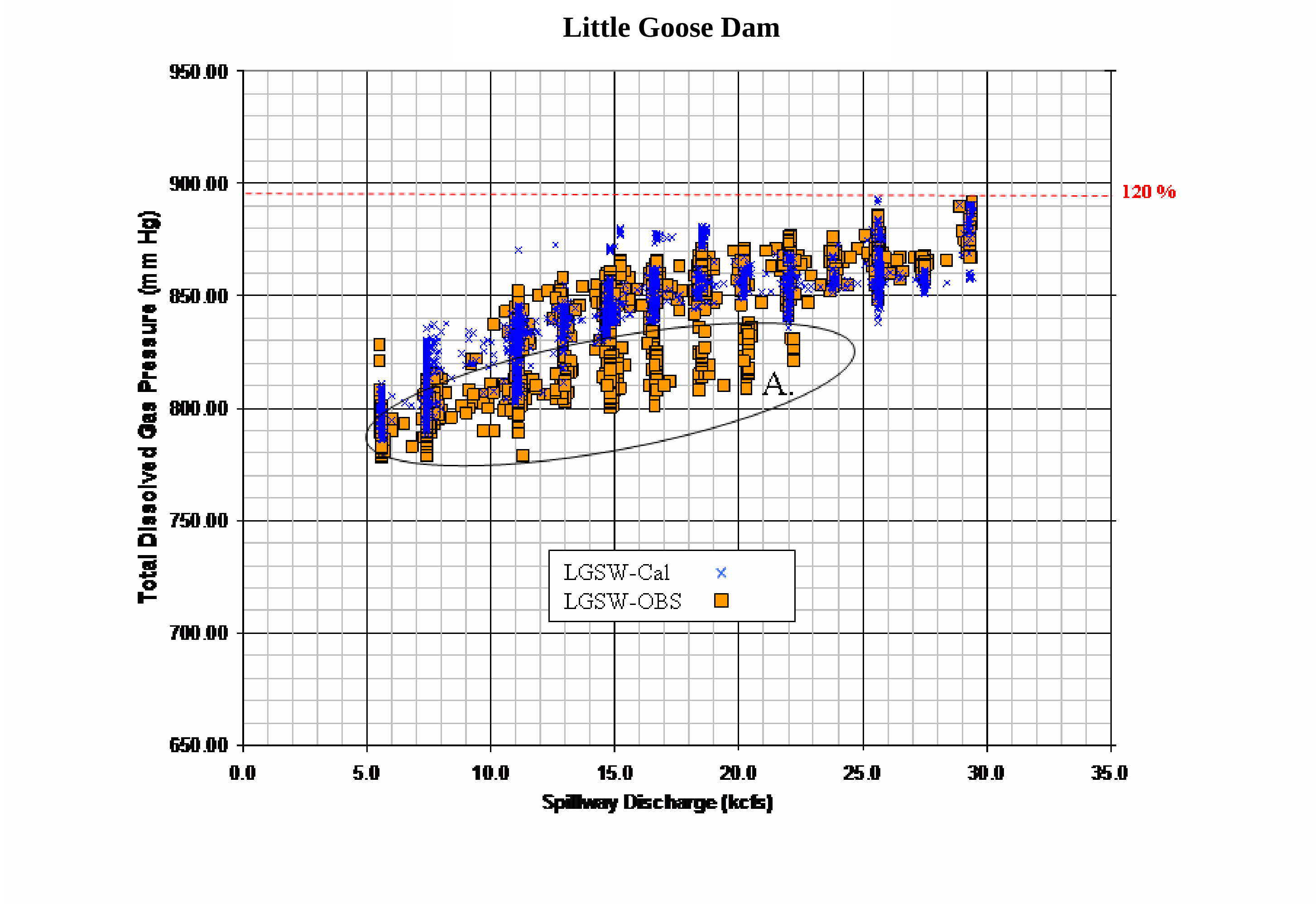

Figure G36. Observed and Calculated Total Dissolved Gas Pressures as a Function of Spillway Discharge in the Snake River at the tailwater channel downstream from Little Goose Dam, 2007

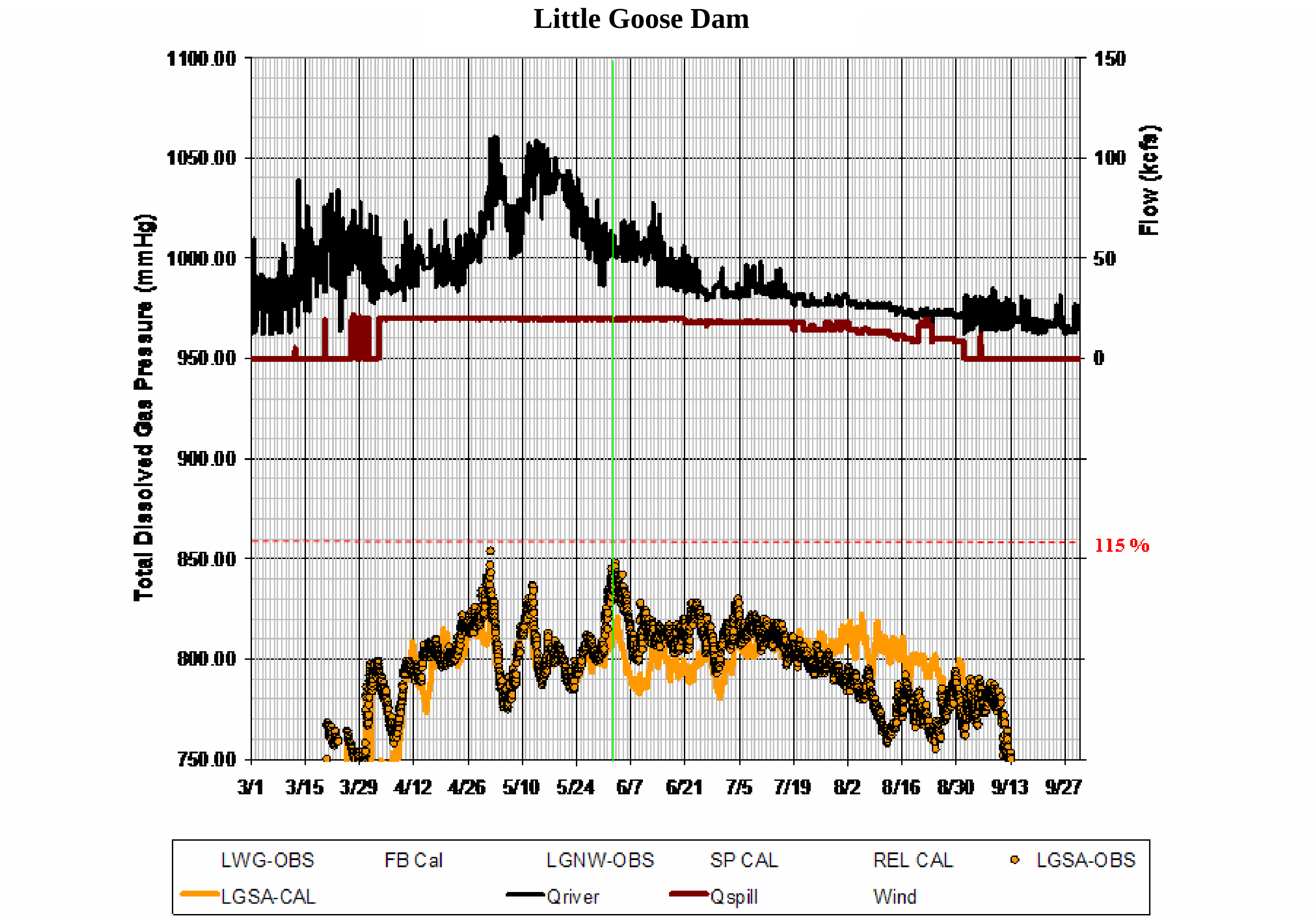

Figure G37. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Little Goose Dam, March-September 2007

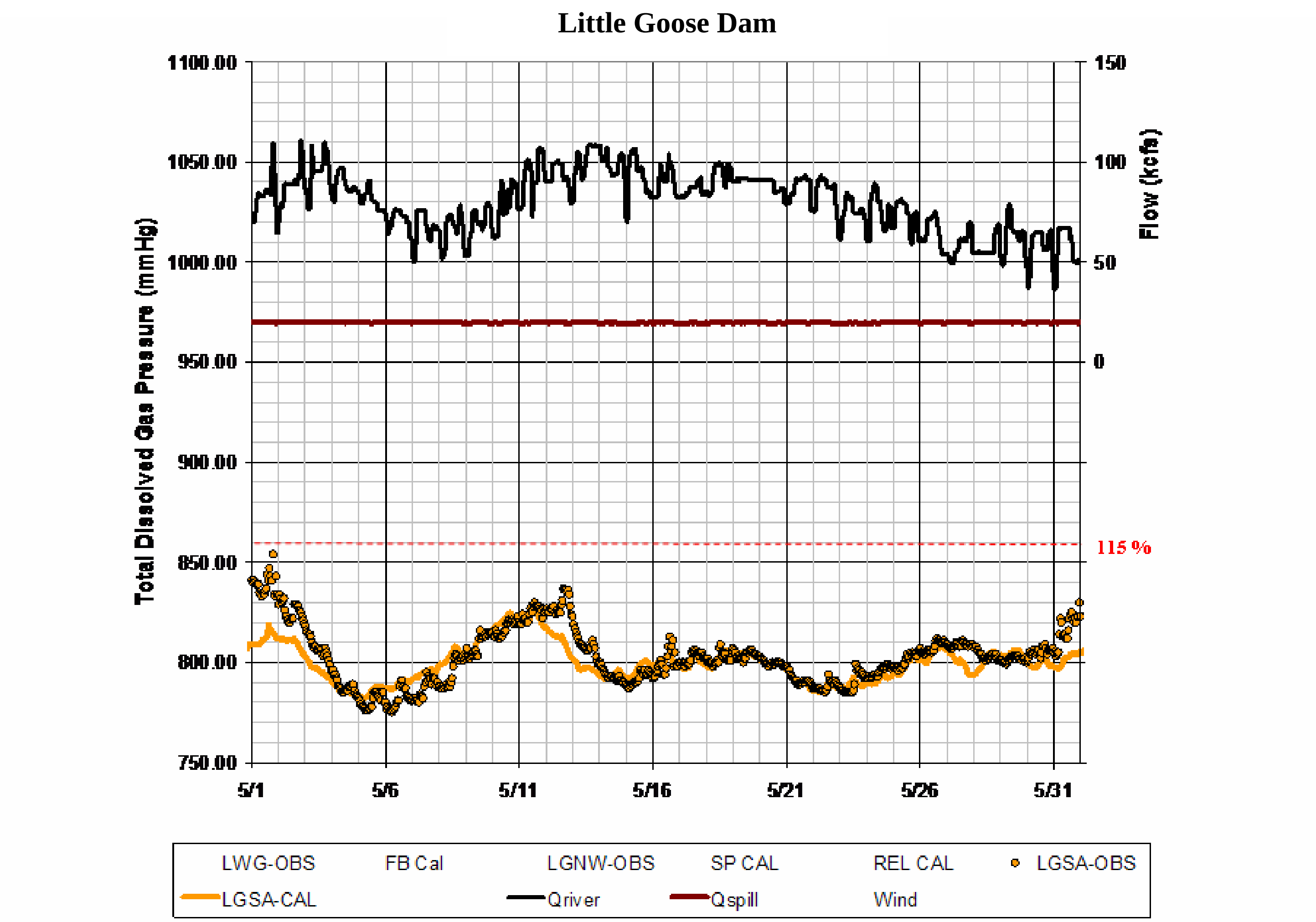

Figure G38. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the forebay of Little Goose Dam, May 2007

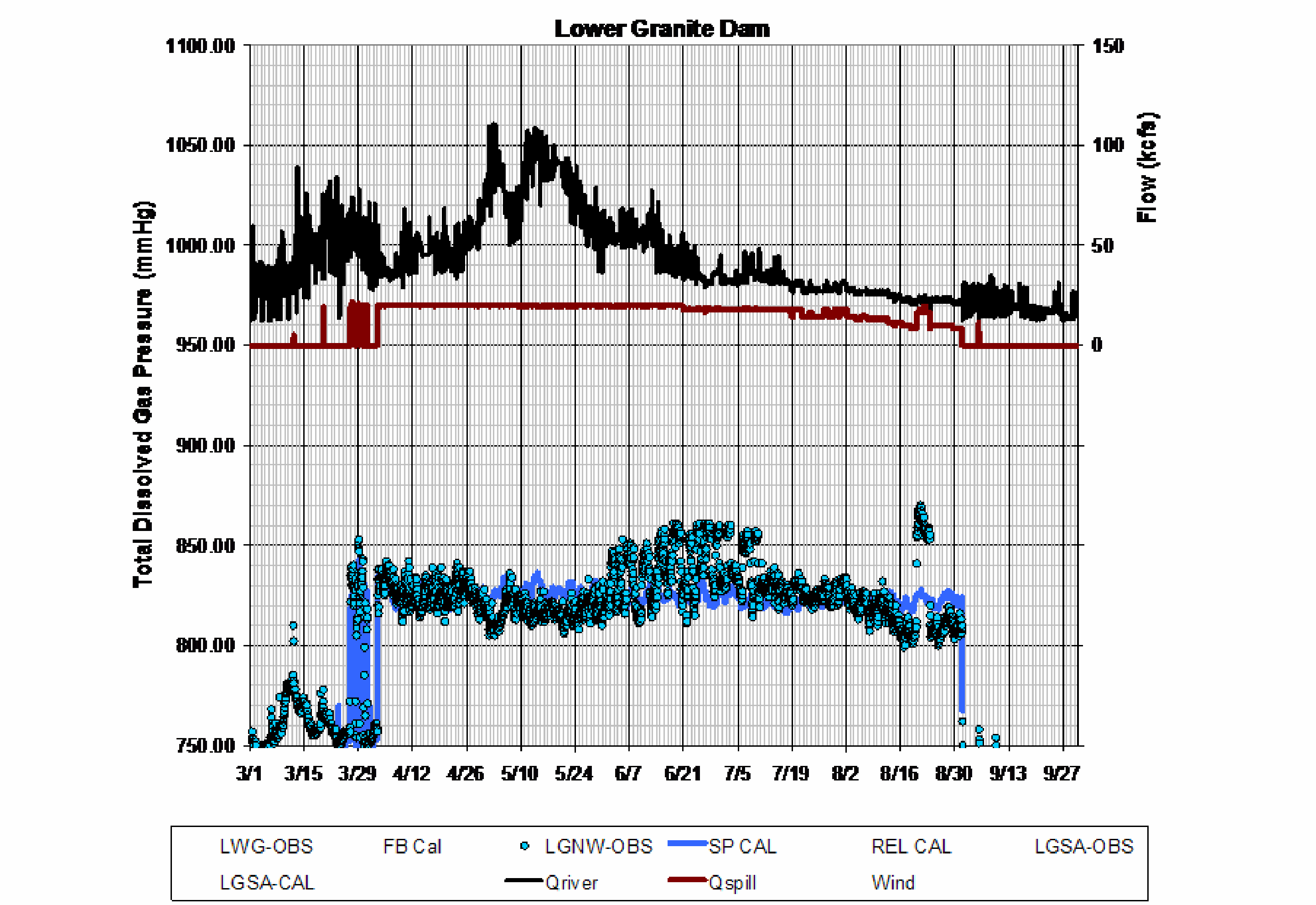

Figure G39. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, March-September 2007

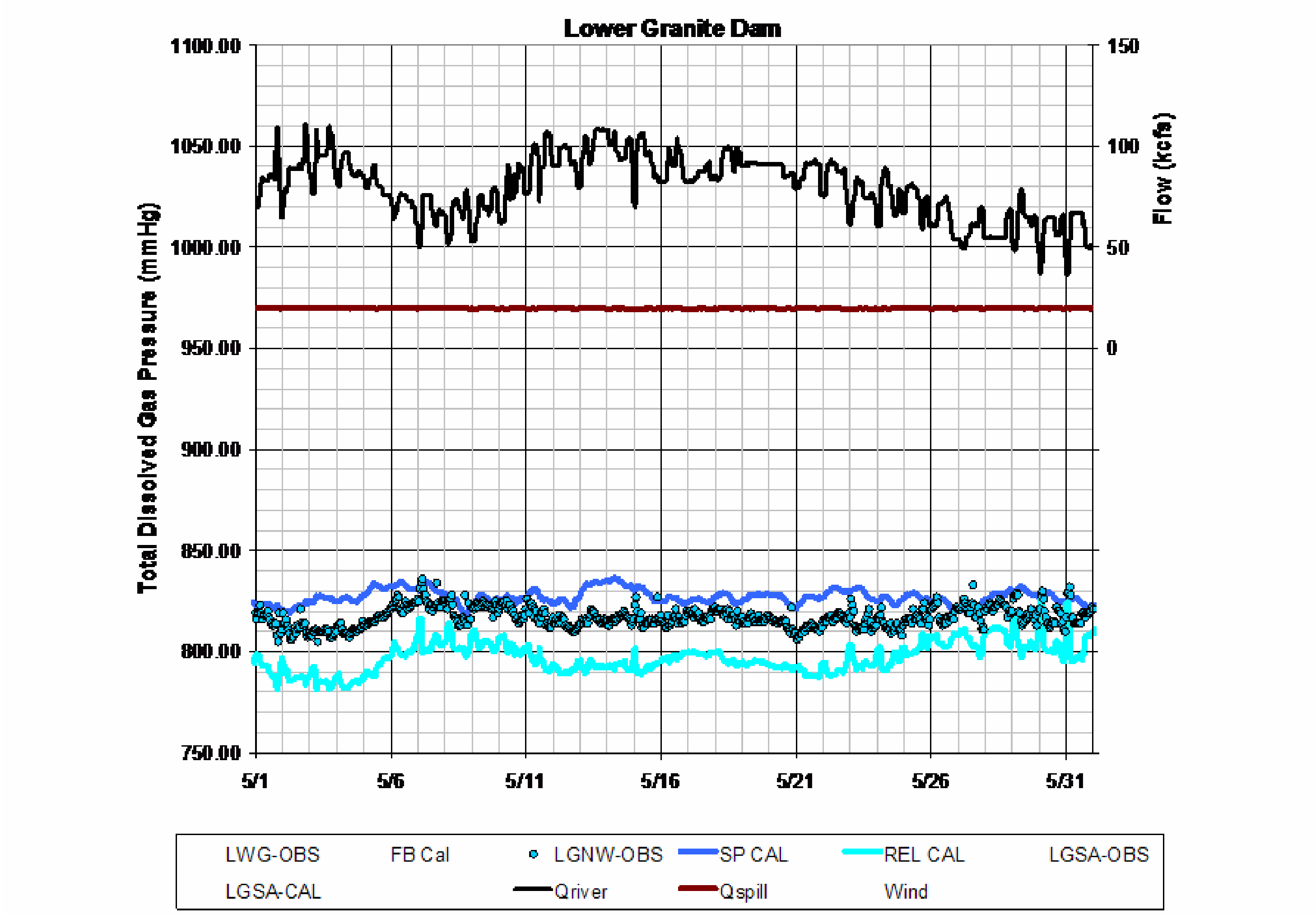

Figure G40. Observed and Calculated Total Dissolved Gas Pressures in the Snake River in the tailwater channel downstream from Lower Granite Dam, May 2007

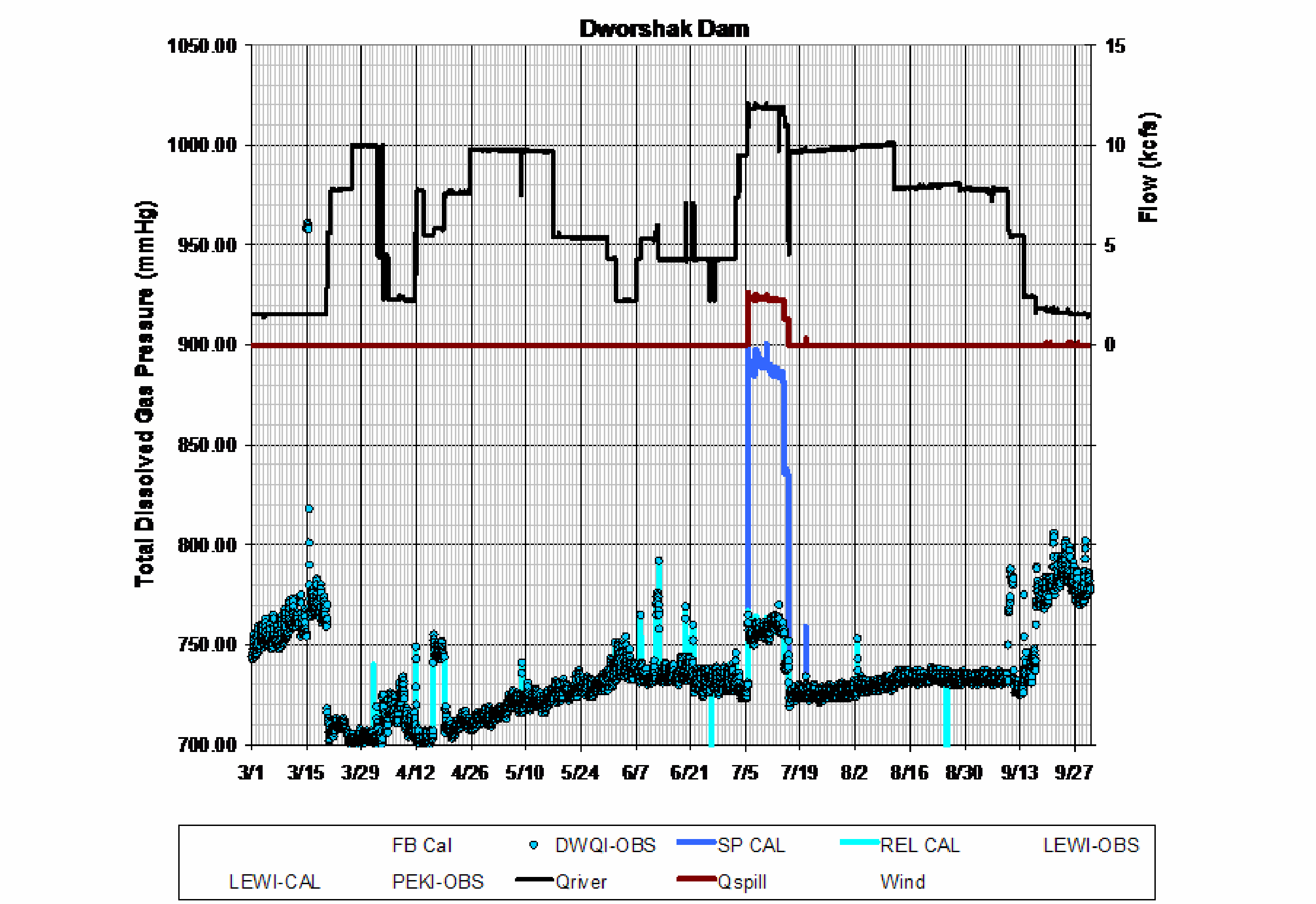

Figure G41. Observed and Calculated Total Dissolved Gas Pressures in the Clearwater River in the tailwater channel downstream from Dworshak Dam, March-September 2007

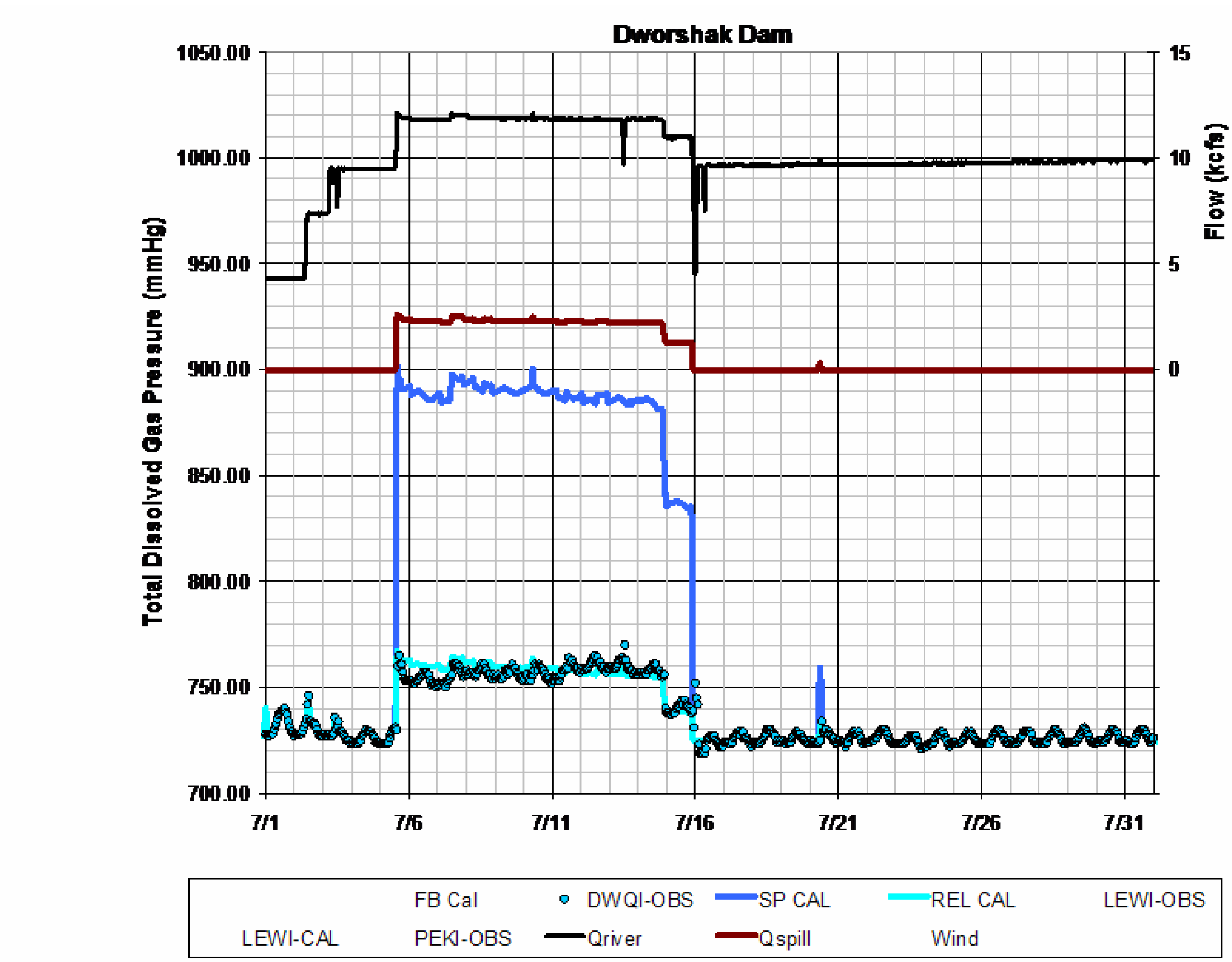

Figure G42. Observed and Calculated Total Dissolved Gas Pressures in the Clearwater River in the tailwater channel downstream from Dworshak Dam, July 2007