APPENDIX G

SYSTDG STATISTICAL EVALUATION

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Section 1 Introduction

SYSTDG (System Total Dissolved Gas) is a decision support spreadsheet model used to estimate total dissolved gas (TDG) percent and pressures resulting from mainstem dam operations on the Columbia, Snake, and Clearwater rivers. A review of project operations and resultant TDG levels was conducted for the 2012 spill season from April 1 through August 31. A statistical evaluation of the predictive errors was performed comparing hourly observed and calculated TDG levels from the SYSTDG model. This was to quantify the predictive error of SYSTDG estimates and improve modeling accuracy and reliability. This evaluation includes Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, Lower Granite, Dworshak, Chief Joseph, and Grand Coulee.

The purposes of this statistical evaluation of SYSTDG include:

1. Evaluate the effectiveness of the SYSTDG model and identify ways to improve it.
2. Address the "Continued development and use of SYSTDG model for estimating TDG production to assist in real-time decision making" per the 2010 Supplemental Biological Opinion, RPA 15.
3. Provide the SYSTDG modelers with an understanding of the predictive error for each gauge for more effective use of the model when setting daily spill caps.

Section 2 Causes of SYSTDG Predictive Error During 2012

SYSTDG simulations were run for one project and river reach at a time, so that predictive errors could be calculated independently for each dam and river reach. The tailwater FMS comparison was dependent upon the location of the FMS relative to the mixing zone of project flows. In most cases, the tailwater FMS are located in spillway flows undiluted from powerhouse flows but some are in mixed river waters. The summary of predictive error was limited to a period of active spillway operations at each project at the tailwater FMS for constant spill operations of 3 hours duration and longer.

Several model inputs are required to conduct these simulations. A detailed description of model input parameters and coefficients can be found in the SYSTDG user's manual (USACE, 2004). The TDG exchange was estimated in each river reach as a function of wind activity. The change in water temperatures during passage through each river reach was also included in estimates of the percent TDG. In each reach simulation the observed temperatures and total pressures in the forebays were used as boundary conditions.

<u>Sources Of Predictive Error</u>

The differences between model estimates and observed TDG pressures (predictive error) at fixed monitoring stations can be attributed to various sources that can be a challenge to identify. Predictive error documented in this statistical evaluation may represent influences of any of the listed sources below and may not reflect negatively on the SYSTDG model accuracy.

1. 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.

2. The spill pattern used during seasonal operations differed from the approved spill patterns in the fish passage plan. These alternative operations can be attributed to equipment malfunction, operator discretion, and dam safety concerns.

3. Limitations in the TDG exchange equation relating project operations and background TDG pressures upstream of the project with changes in TDG pressures observed downstream from the dam.

4. Errors can result from using wrong lag times when attempting to match spill operations from a project and the corresponding TDG measurement downstream. This can be a prominent source of predictive error in the model.

5. The presence of spatial TDG gradients near a FMS introduced either by thermal patterns or project operations can bias the observed TDG pressure and introduce a prominent difference between the estimated and observed TDG pressure. Thermally induced errors may also occur at forebay FMS where a 1°C increase in temperature above bulk river conditions can result in a 2 to 3 percent increase in the TDG.

6. Instrument malfunction can cause observed TDG gauge readings to be erroneous resulting in increased predictive error.

7. Sampling biases can cause observed TDG gauge readings to not be representative of river conditions resulting in increased predictive error.

Section 3 Statistical Analysis Results

The results of the SYSTDG statistical analysis are shown in the following tables and graphs for each modeled river reach and the corresponding FMS. The statistical analyses of the predictive error for the FMS includes the descriptive statistics of average, minimum, maximum, standard deviation, and the predictive error associated with the following percentiles: 5, 10, 25, 50, 75, 90, and 95 percent. Tables G1 and G3 describe the predictive error statistics in mm Hg of pressure while Tables G2 and G4 describe the predictive errors in percent TDG. The predictive error was calculated by subtracting the observed TDG level from the calculated value ($TDG_{error} = TDG_{obs}-TDG_{cal}$). The difference between the hourly observed and calculated TDG pressure or percent TDG was the definition used for the predictive error where negative errors reflect over-estimation of observed conditions and positive errors reflect an under-estimation of observed conditions. For tailwater FMSs, the predictive errors were analyzed only for spill operations of 3 hours and longer in order to exclude transient TDG observations. A

graphical comparison of the calculated and observed TDG pressures for each FMS can be seen in Figures G1 through G22.

Table G1
Statistical Summary of the Predictive Errors Of the Observed and Calculated TDG Pressures in mmHg at forebay FMS

		Predictive Error* at Forebay FMS (mm Hg)									
FMS		**LGSA**	**LMNA**	**IHRA**	**WEL**	**CHJ**	**MCNA**	**JDY**	**TDA**	**BON**	**CWMW**
N		3665	3665	3663	3445	3648	3615	3653	3653	3651	3607
Avg		-4.1	3.8	-5.9	-3.5	2.0	4.0	-10.8	-6.4	4.9	-0.7
SDEV		17.1	10.4	8.7	4.6	8.1	12.3	16.5	11.1	9.7	7.2
Max		53.0	78.0	33.0	33.9	30.8	55.7	56.0	110.0	58.1	99.0
Min		-55.4	-20.0	-51.2	-32.4	-38.9	-25.7	-53.6	-36.9	-17.4	-19.7
TDG Predictive Error for Percentile Occurrence (mm Hg)	5	-32.1	-11.6	-20.4	-10.5	-10.8	-11.4	-38.3	-21.6	-9.3	-10.6
	10	-28.1	-8.6	-16.8	-8.8	-7.3	-8.9	-32.9	-18.7	-6.9	-9.2
	25	-16.9	-3.6	-10.8	-6.1	-3.1	-4.4	-21.9	-13.8	-1.7	-6.2
	50	-2.3	3.0	-5.6	-3.8	1.9	2.3	-10.3	-8.2	4.4	-1.0
	75	9.4	10.5	-0.7	-1.6	7.2	9.5	-0.1	-0.5	10.6	3.7
	90	16.6	16.7	4.5	1.8	11.6	16.9	10.3	9.6	16.2	8.4
	95	20.1	20.9	7.8	4.8	14.1	31.2	17.9	14.2	18.6	12.0

*Predictive error is the observed minus calculated TDG pressure where negative values reflect an over-estimation and positive values reflect an under-estimation

Table G2
Statistical Summary of the Predictive Errors Of the Observed and Calculated Percent TDG at forebay FMS,

		Predictive* Error at Forebay FMS (%)									
FMS		**LGSA**	**LMNA**	**IHRA**	**WEL**	**CHJ**	**MCNA**	**JDY**	**TDA**	**BON**	**CWMW**
N		3665	3665	3663	3445	3648	3615	3653	3653	3651	3652
Avg		-0.2	0.9	-0.5	-0.5	1.1	0.8	-1.0	-0.8	0.6	0.4
Std Dev		2.3	1.4	1.2	0.6	1.1	1.6	2.2	1.4	1.3	4.8
Max		5.4	6.0	3.0	4.6	5.3	8.0	4.5	4.7	7.7	48.1
Min		-7.1	-2.3	-6.4	-4.4	-4.3	-3.1	-6.8	-4.9	-2.4	-2.6
TDG Predictive Error for Percentile Occurrence (mm Hg)	5	-4.0	-1.2	-2.4	-1.4	-0.6	-1.2	-4.7	-2.8	-1.2	-1.4
	10	-3.4	-0.8	-1.9	-1.2	-0.1	-0.9	-4.0	-2.5	-0.9	-1.2
	25	-1.9	-0.1	-1.1	-0.8	0.4	-0.3	-2.5	-1.8	-0.2	-0.8
	50	0.1	0.7	-0.4	-0.5	1.2	0.6	-1.0	-1.1	0.6	-0.1
	75	1.6	1.8	0.2	-0.2	1.7	1.6	0.4	-0.1	1.4	0.5
	90	2.6	2.6	0.9	0.2	2.3	2.6	1.8	1.2	2.1	1.2
	95	3.1	3.2	1.4	0.6	2.8	4.4	2.8	1.9	2.4	1.7

*Predictive error is the observed minus calculated TDG pressure where negative values reflect an over-estimation and positive values reflect an under-estimation

Table G3
Statistical Summary of the Predictive Errors Of the Observed and Calculated TDG Pressures in mmHg at Tailwater FMS,

		Predictive* Error at Tailwater Fixed Monitoring Station (mm Hg)											
FMS		DWQI	LGNW	LGSW	LMNW	IDSW	GCGW	CHQW	MCPW	JHAW	TDDO	CCIW	WRNO
N		1753	2916	2568	2539	2336	894	1854	2103	1792	1986	1793	2303
Avg		-4.2	-19.9	0.6	0.8	1.0	-0.2	-3.8	3.0	-11.1	1.5	3.2	1.2
SDEV		7.2	16.5	12.8	13.0	7.7	9.7	9.2	9.2	9.9	8.7	10.7	8.4
Max		39.1	26.4	101.7	47.3	35.8	29.5	71.0	62.0	31.2	64.4	30.2	41.3
Min		-33.3	-68.0	-63.3	-62.7	-26.7	-64.7	-46.2	-29.5	-40.4	-25.3	-39.6	-21.2
TDG Predictive Error for Percentile Occurrence (mm Hg)	5	-15.1	-50.2	-16.8	-18.7	-11.1	-11.1	-17.0	-10.1	-21.9	-10.2	-15.7	-9.9
	10	-11.9	-43.3	-13.3	-14.1	-8.2	-7.8	-13.1	-7.7	-20.4	-8.2	-11.0	-6.7
	25	-8.6	-30.2	-7.8	-8.1	-3.6	-4.8	-8.7	-3.5	-17.5	-4.1	-3.6	-3.3
	50	-4.8	-16.9	-1.4	0.1	0.8	-1.2	-4.6	2.3	-13.4	0.6	5.8	-0.3
	75	-0.2	-8.9	7.7	10.9	4.7	2.9	1.2	8.0	-6.6	6.2	10.7	3.6
	90	3.9	0.3	16.5	15.4	9.7	10.2	8.0	15.6	-1.2	11.9	13.4	11.9
	95	8.1	4.5	23.8	18.4	15.1	18.8	11.4	19.4	10.6	15.0	16.4	20.3

*Predictive error is the observed minus calculated TDG pressure where negative values reflect an over-estimation and positive values reflect an under-estimation

**These observed and calculated deviations are labeled predictive error in this document, but this characterization does not account for the sampling bias at CCIW.

Table G4
Statistical Summary of the Predictive Errors Of the Observed and Calculated Percent TDG at Tailwater FMS,

		Predictive* Error at Tailwater Fixed Monitoring Station (%)											
FMS		DWQI	LGNW	LGSW	LMNW	IDSW	GCGW	CHQW	MCPW	JHAW	TDDO	CCIW	WRNO
N		1753	2916	2568	2553	2336	894	1854	2103	1792	1986	1793	2303
Avg		-0.6	-2.7	0.1	0.2	0.1	0.0	-0.5	0.4	-1.5	-0.1	0.2	-0.1
SDEV		1.0	2.2	1.7	2.4	1.0	1.4	1.2	1.2	1.3	1.2	1.4	1.2
Max		4.6	3.5	13.5	23.6	4.8	4.1	9.6	8.4	4.2	8.3	3.8	5.5
Min		-4.5	-9.2	-8.4	-8.5	-3.6	-9.0	-6.2	-2.4	-5.4	-3.5	-5.5	-3.3
TDG Predictive Error for Percentile Occurrence (mm Hg)	5	-2.1	-6.8	-2.3	-2.5	-1.5	-1.7	-2.3	-1.4	-2.9	-1.8	-2.3	-1.6
	10	-1.6	-5.8	-1.8	-1.9	-1.1	-1.2	-1.8	-1.0	-2.7	-1.4	-1.7	-1.3
	25	-1.2	-4.1	-1.1	-1.1	-0.5	-0.7	-1.2	-0.5	-2.3	-0.9	-0.7	-0.8
	50	-0.7	-2.3	-0.2	0.0	0.1	-0.2	-0.6	0.3	-1.8	-0.2	0.5	-0.3
	75	0.0	-1.2	1.0	1.5	0.6	0.4	0.2	1.0	-0.9	0.6	1.2	0.2
	90	0.5	0.0	2.2	2.1	1.3	1.4	1.1	2.1	-0.2	1.4	1.6	1.3
	95	1.0	0.6	3.2	2.5	2.0	2.5	1.5	2.6	1.4	1.8	2.0	2.3

*Predictive error is the observed minus calculated TDG pressure where negative values reflect an over-estimation and positive values reflect an under-estimation

Section 4 Highlights of the Statistical Evaluation

A statistical evaluation of SYSTDG's performance was conducted to assess how well the model estimated percent TDG. The predictive errors that SYSTDG computed in 2012 compared favorably with the predictive errors from previous years despite the sustained high Columbia River flows throughout the fish passage season. The TDG production equations applied for unusually high flows in the late summer on the Columbia River accurately predicted the percent TDG levels observed.

1. The calculated TDG pressures in the Bonneville tailwater channel provided reliable estimates of project TDG generation during the outage of the tailwater FMS at Cascade Island (CCIW).

2. The John Day spillway TDG equation performed well for flows less than 120 kcfs and above 170 kcfs. For an intermediate range of flows, SYSTDG over predicted the TDG levels compared to the observed TDG levels at the tailwater FMS.

3. The spillway flows at McNary Dam experienced the widest range of conditions during the 2012 spill season with spillway discharges as high as 350 kcfs. The McNary TDG exchange equation closely approximated the observed conditions over this entire range of operations. However, accuracy of the estimated TDG levels arriving at John Day decreased during the spill season.

4. The performance of SYSTDG in the mid-Columbia River from Wells to Grand Coulee dams was reassessed during 2012 spill season due to additional spill at Chief Joseph in 2011 and 2012. The use of experimental and partial spill patterns at Chief Joseph Dam resulted in elevated TDG levels when compared to a uniform 19 bay spill pattern. The SYSTDG exchange equation was updated during the spill season to account for these frequent changes in spill patterns.
5. An analysis of SYSTDG equations to predict the TDG exchange from Grand Coulee Dam to the Chief Joseph pool was completed. The model performed well during 2012 for a wide range of flow conditions at Grand Coulee Dam and showed a degassing rate of 1 to 3 percent for the reach between Grand Coulee and Chief Joseph. This degassing rate is consistent for all Grand Coulee Dam forebay TDG levels.

Section 5 TDG Monitoring Studies

TDG monitoring studies are periodically scheduled to investigate significant structural or operational changes of the spillway. These studies are designed to support TDG monitoring and management functions; provide updates to TDG gas abatement goals associated with the TDG TMDL and to update the SYSTDG model. During the 2012 spill season, there were no supplemental TDG monitoring studies conducted at Federal projects on the Columbia or Snake Rivers. If funding and appropriate water conditions are available, studies should be conducted below Grand Coulee and Chief Joseph to better refine the TDG production and exchange equations in the model.

Section 6 Improvements Made to SYSTDG in 2012

The 2012 high flows and spill provided the opportunity to collect the information needed to update the TDG production equations in SYSTDG for several projects. The high water year played an important role in achieving the following five improvements to SYSTDG this year:

1. The Grand Coulee Dam TDG production equation was updated for drum gate operations in response to the wide ranges of discharges that occurred during the spill season. The updated TDG exchange equation was based on the 2012 observed data and operations

and is a function of the spill, powerhouse flow, and TDG levels in the powerhouse releases.

2. The Chief Joseph Dam TDG production equation was updated to accommodate the frequent closure of spill bays for maintenance activities.

3. The TDG exchange equation for the summer spill patterns at McNary Dam was updated to more accurately estimate the summertime TDG exchange.

4. The Bonneville Dam TDG production equation was updated to include an adjustment bias that allows improved predictions of the TDG levels commonly observed at the Cascade Island fixed monitoring station.

5. As part of an environmental study of potential system operations related to the Columbia River Treaty, the TDG exchange equations for Priest Rapids, Wanapum, Rock Island, Rocky Reach, and Wells Dams were updated using project operations and TDG data over the 2011 and 2012 spill seasons.

Section 7 SYSTDG Improvements Recommended for 2013

The following improvements and maintenance activities to the SYSTDG model are recommended for 2013.

1. Grand Coulee Dam: The TDG levels of the powerhouse flows should be validated because of consistent differences between the TDG levels in the forebay and tailwater during powerhouse releases.

2. Chief Joseph Dam: The TDG exchange at Chief Joseph Dam as a function of spillway flows and patterns should continue to be investigated. It is recommended that a standard spill patterns be designed that distributes spill uniformly over all 19 bays and implemented in 2013 spill pattern. It is also recommended that the resultant TDG levels from the new standard spill patterns be evaluated.

3. McNary Dam: The spill patterns used to estimate the number of effective spill bays should be expanded to cover high flow spillway discharges.

4. John Day Dam: The influence of bulk spill through the spillway weirs at bays 18 and 19 at John Day Dam, and the performance of the 50 foot flow deflector in bay 20 remain difficult to assess from the single measurement station below the dam. The impact of this spill pattern on the entrainment of powerhouse flows into the stilling basin may contribute to modeling errors at downstream stations. These issues warrant additional field measurements involving transect sampling for dissolved gasses. John Day Dam TDG exchange equation over-estimated the TDG levels for a range of flow during 2012. An updated TDG exchange equation should be developed and implemented in upcoming version of SYSTDG.

5. Bonneville Dam: The B2CC outfall can contribute significantly to the TDG loading below Bonneville Dam during low flow and low tailwater conditions. The TDG exchange at this location during higher flows remains difficult to model and is an area for further model development.

6. Lower Granite Dam: The TDG exchange equation for Lower Granite Dam should be updated to more accurately estimate TDG levels from lower spillway flows and summertime spill patterns.

7. Lower Monumental Dam: The updated Lower Monumental Dam tailwater TDG production equation based on the higher flows observed in 2012 should be established. The equation should equate the difference in TDG pressure as the result of the effective depth of flow, and the square root of the unit spillway flow.

8. Dworshak Dam: The TDG levels in regulating outlets and spillway flows at Dworshak Dam were estimated from well mixed waters conditions at the tailwater fixed monitoring stations DWQI. It is recommended that direct measurements of the TDG levels in spill flows should be collected to confirm the TDG exchange equation.

Section 8 Figures for Appendix G

Figure G1
The Camas Washougal FMS

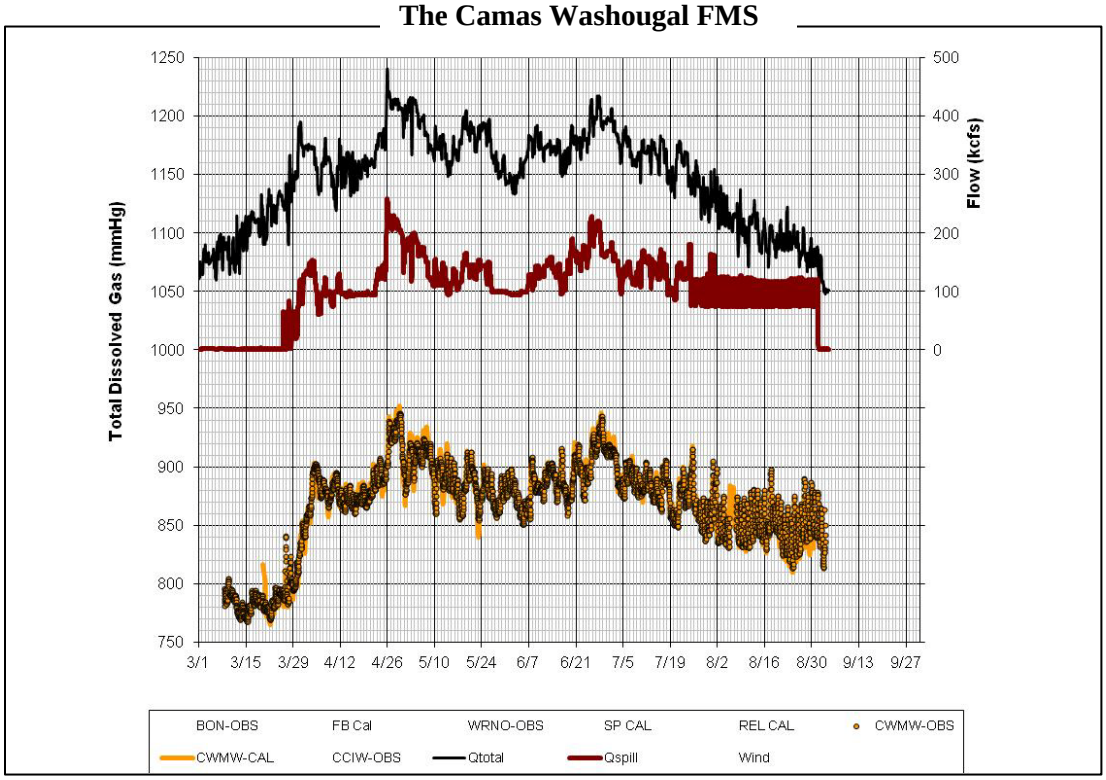

Figure G2
Warrendale FMS

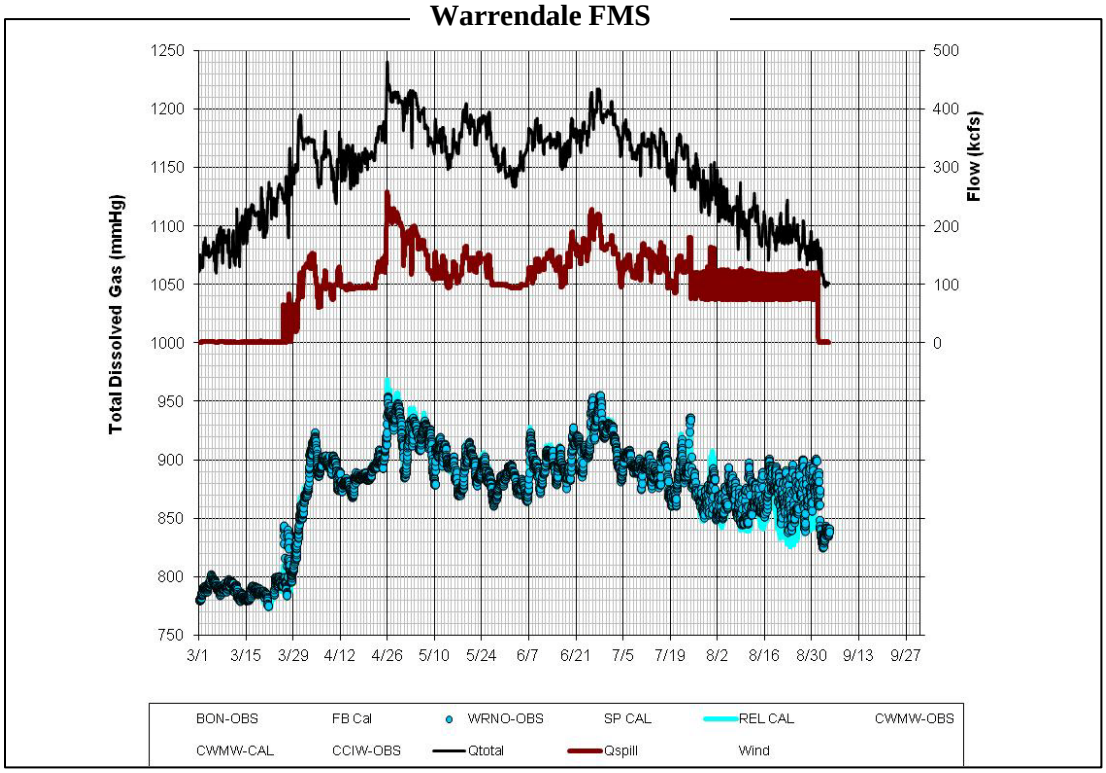

Figure G3
Cascade Island FMS

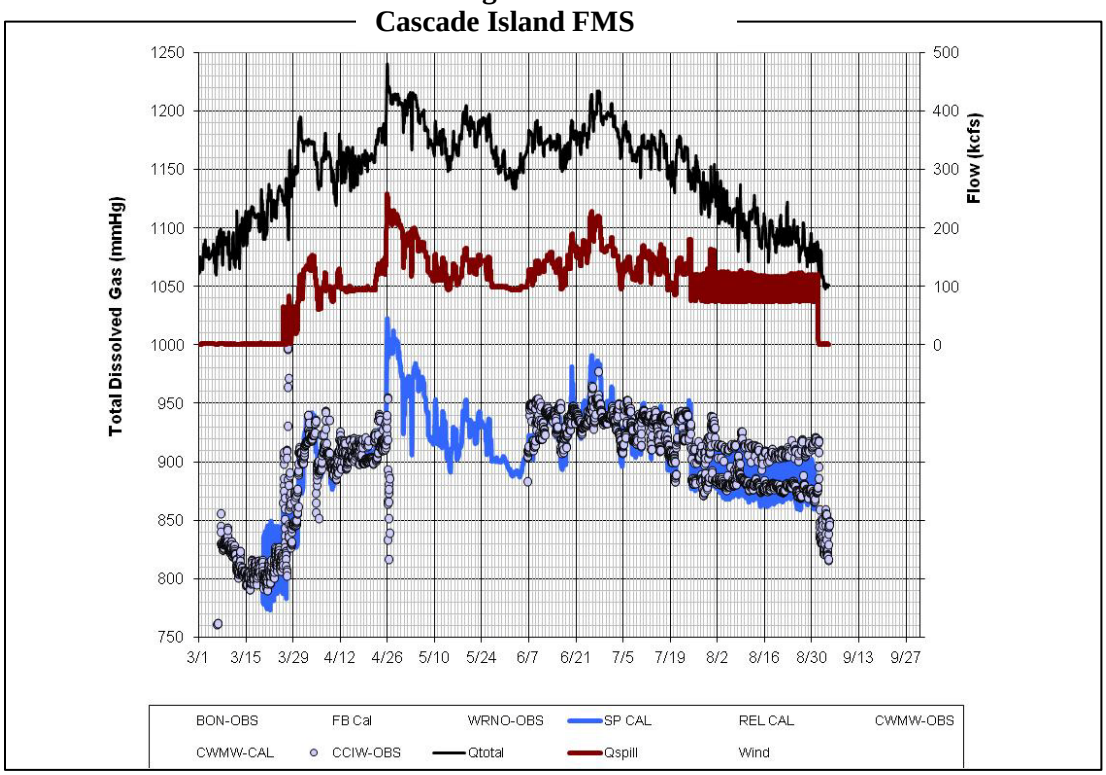

Figure G4
Bonneville Forebay FMS

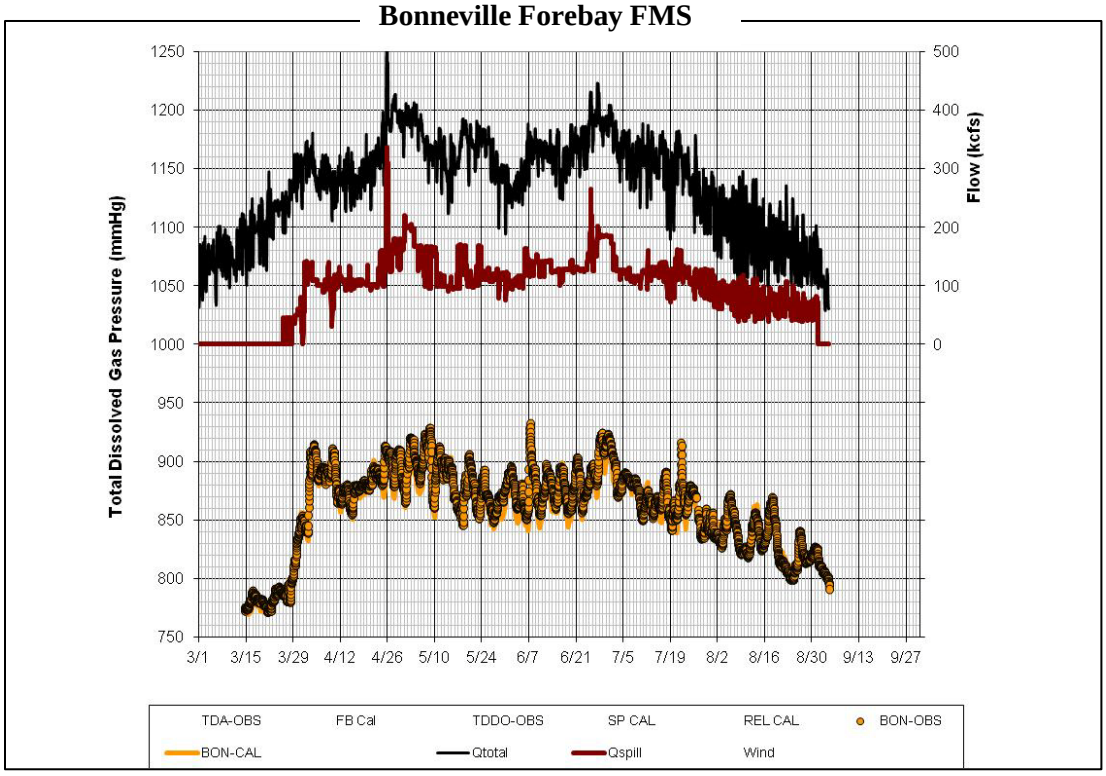

Figure G5
The Dalles Tailwater FMS

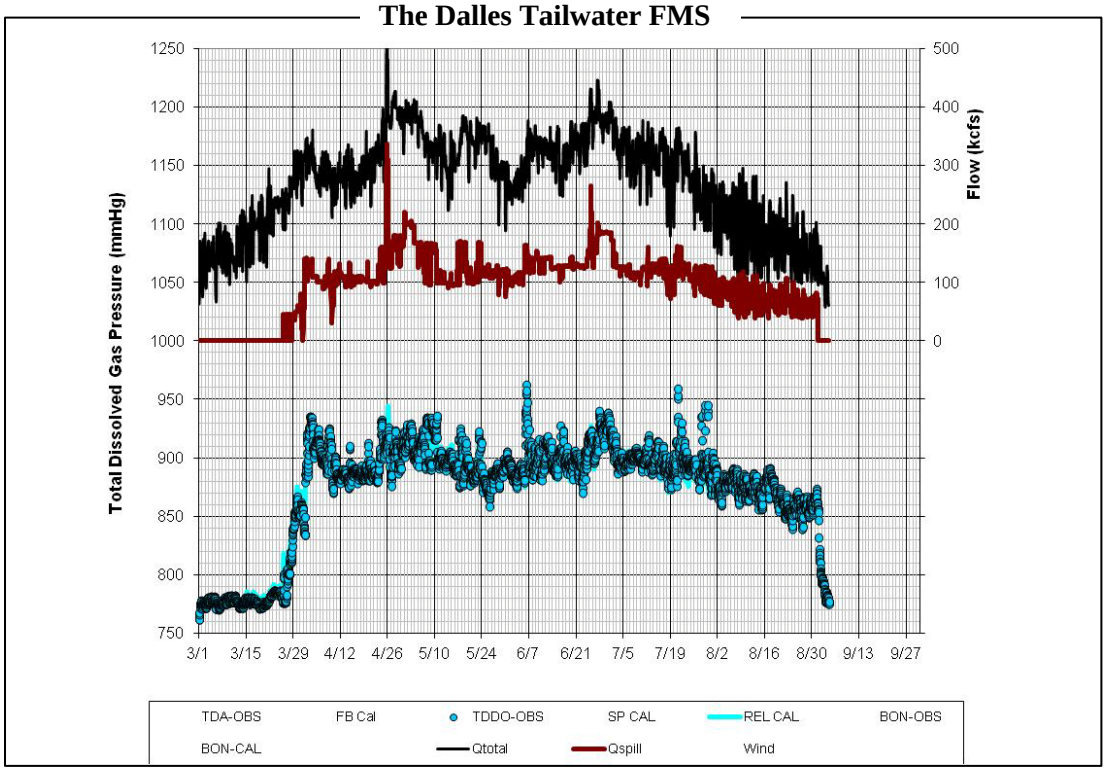

Figure G6
The Dalles Forebay FMS

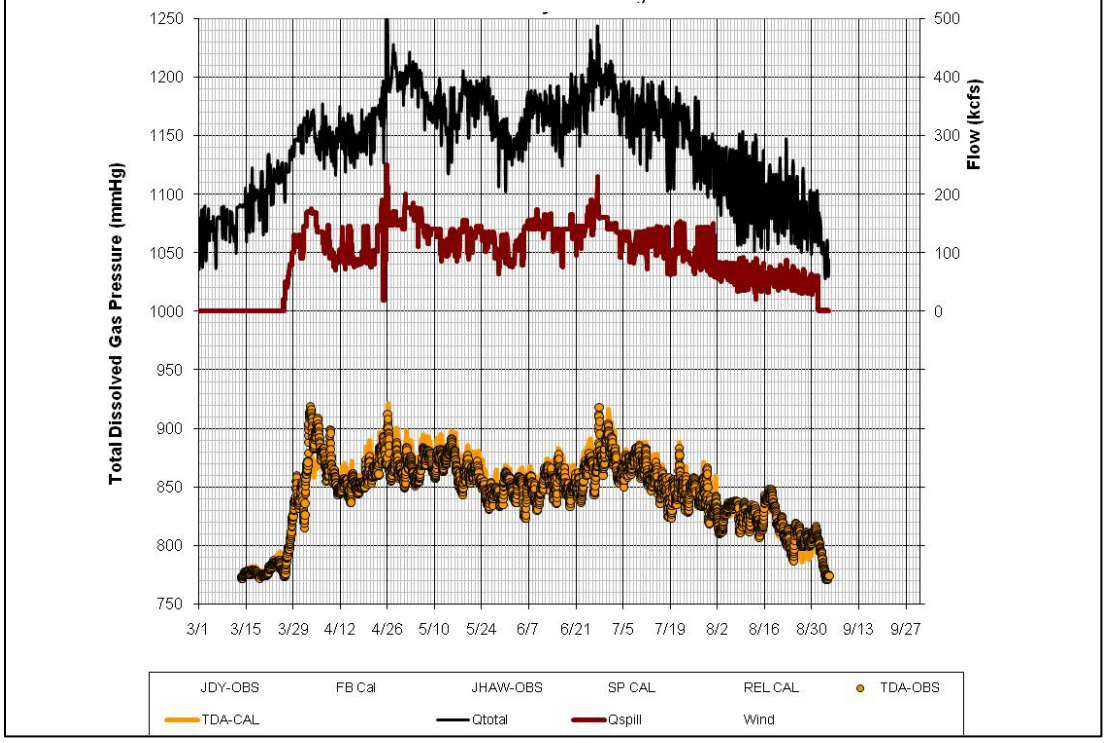

Figure G7
John Day Tailwater FMS

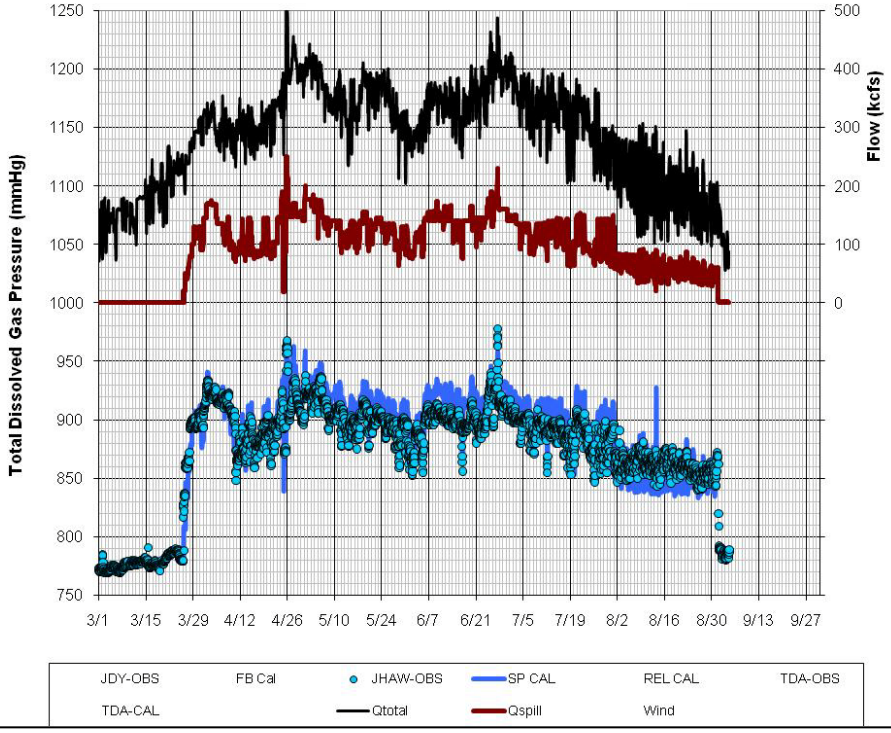

Figure G8
John Day Forebay FMS

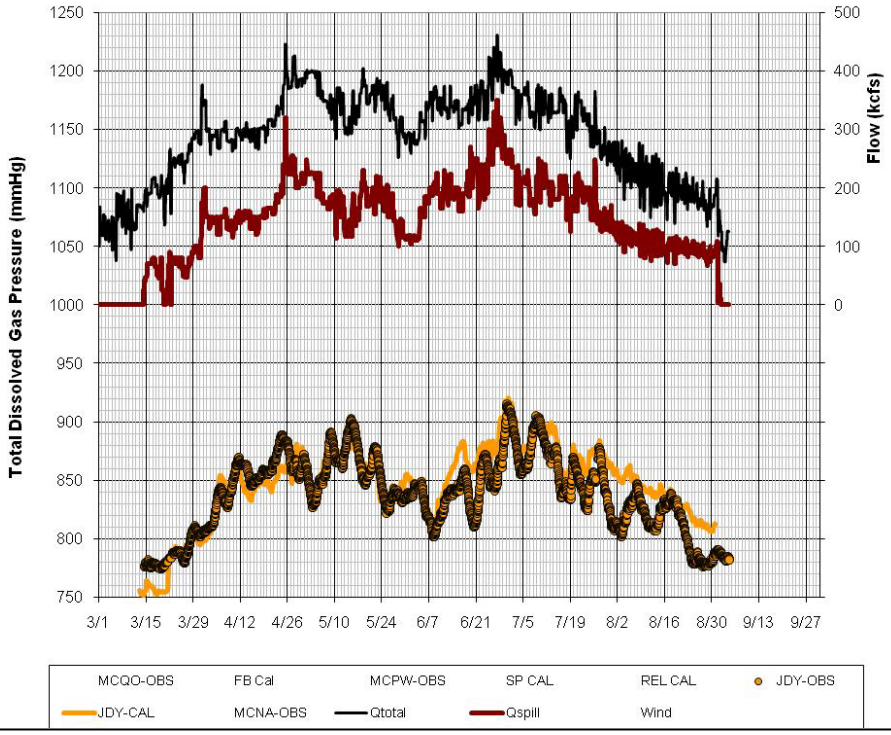

Figure G9
McNary Tailwater FMS

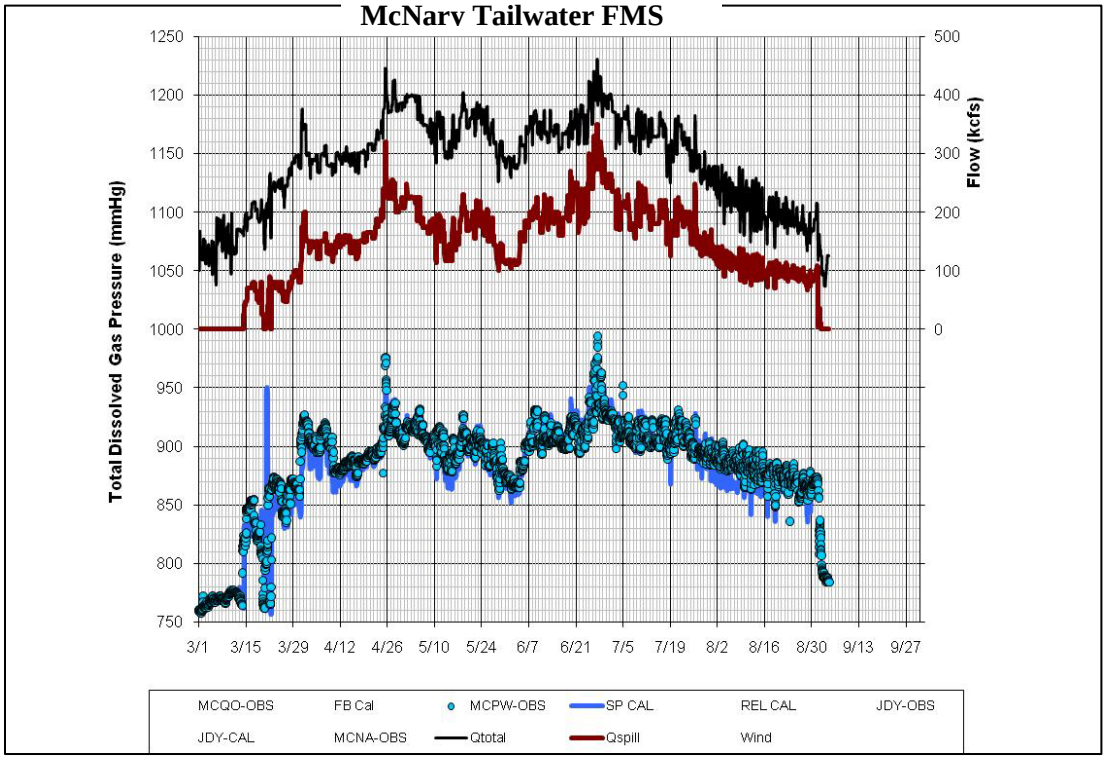

Figure G10
McNary Forebay FMS

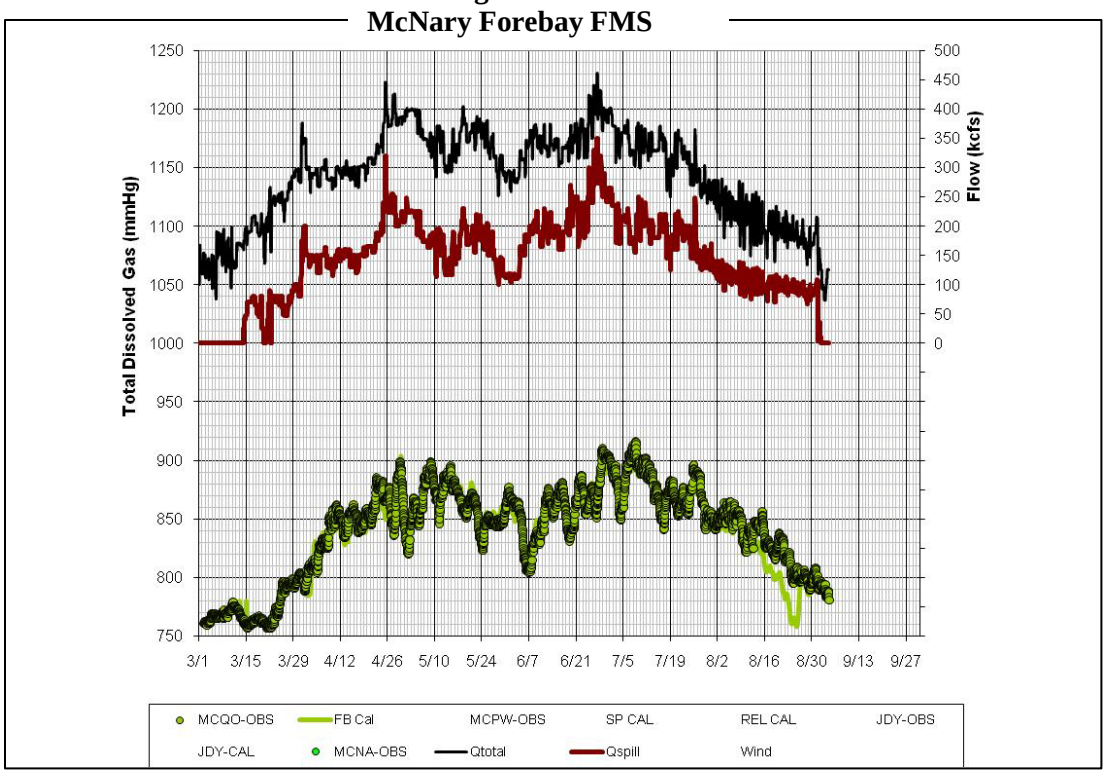

Figure G11
Wells Dam Forebay FMS

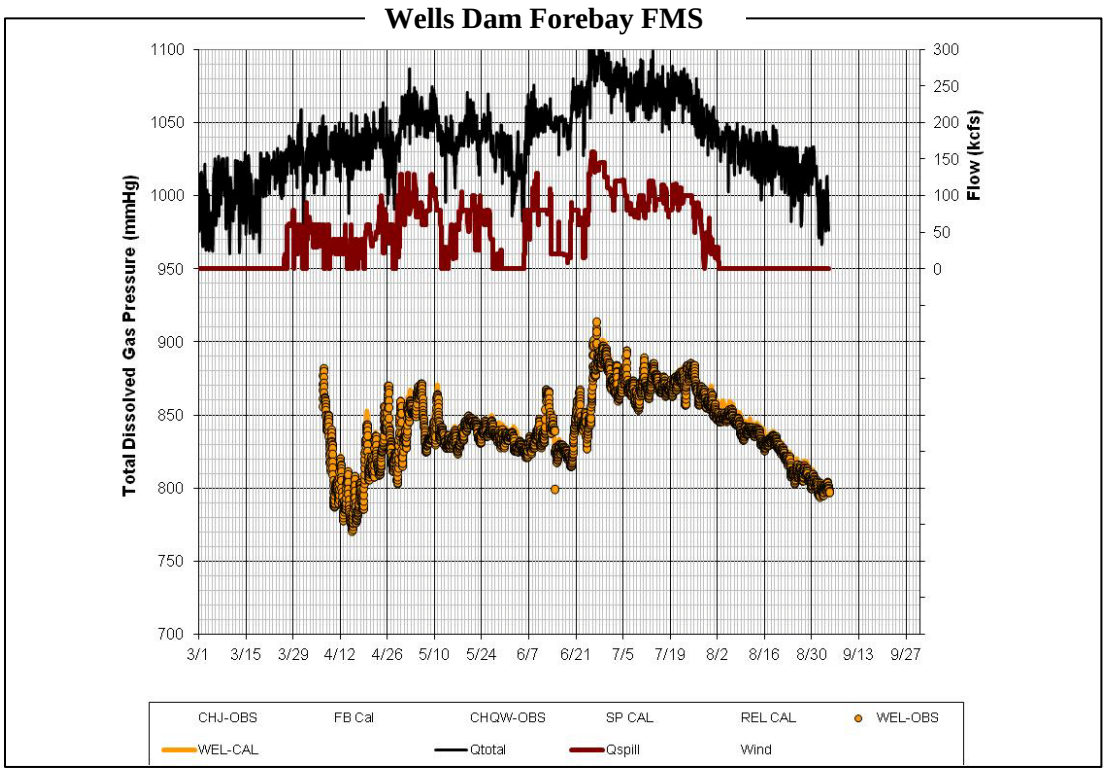

Figure G12
Chief Joseph Dam Tailwater FMS

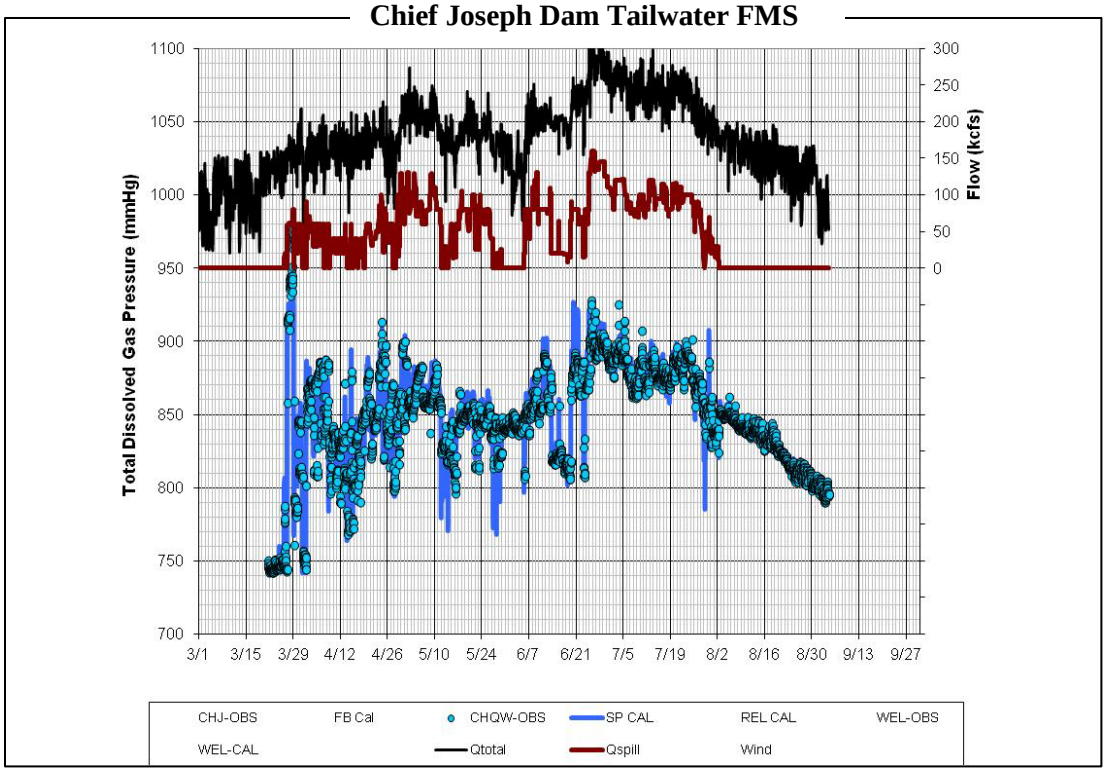

Figure G13
Chief Joseph Dam Forebay FMS

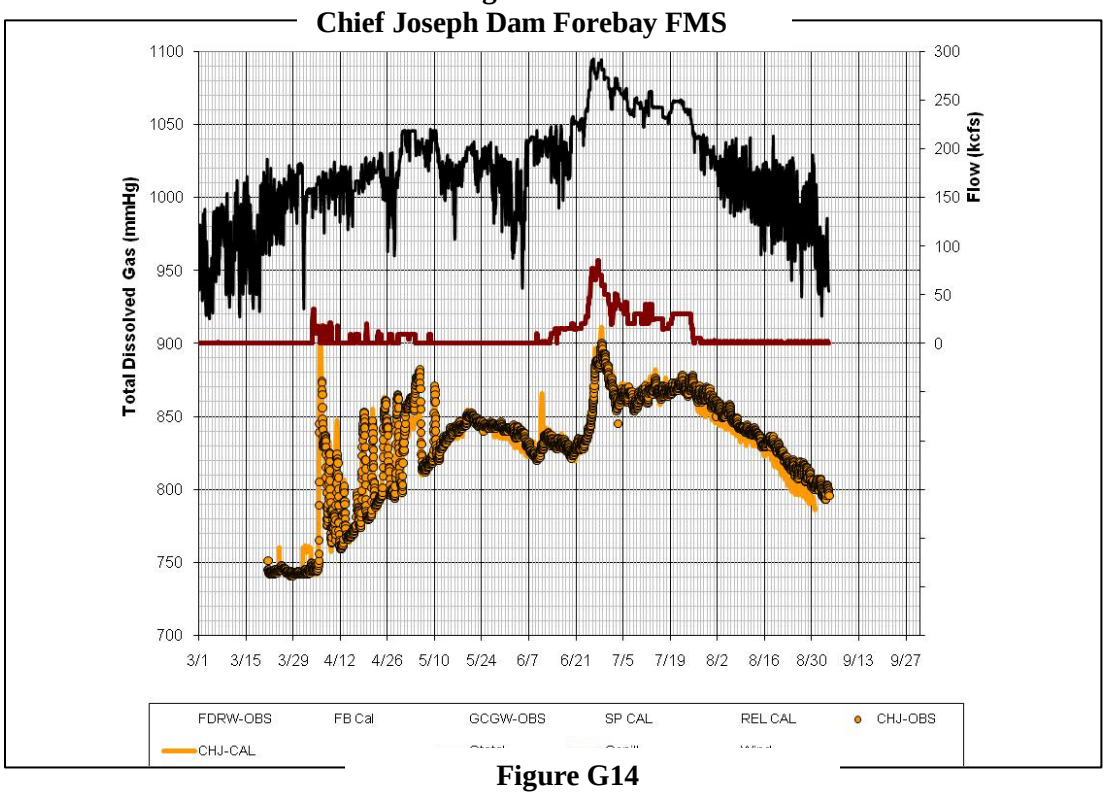

Figure G14
Grand Coulee Dam Tailwater FMS

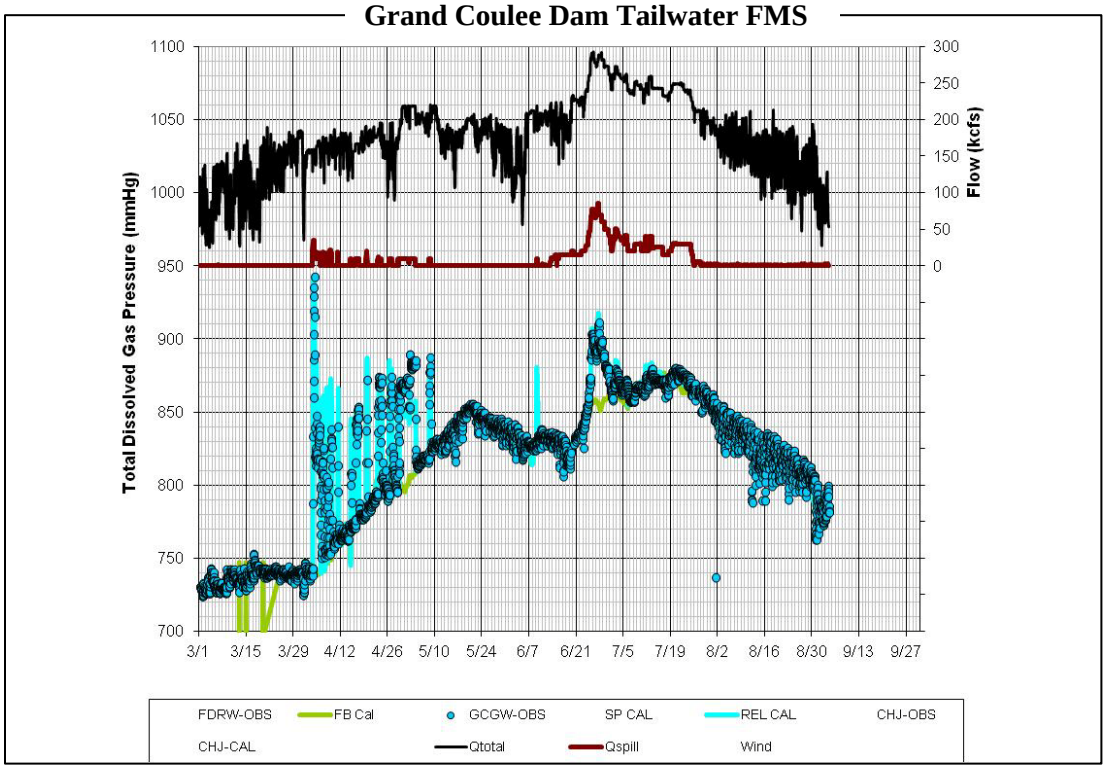

Figure G15
Ice Harbor Dam Tailwater FMS

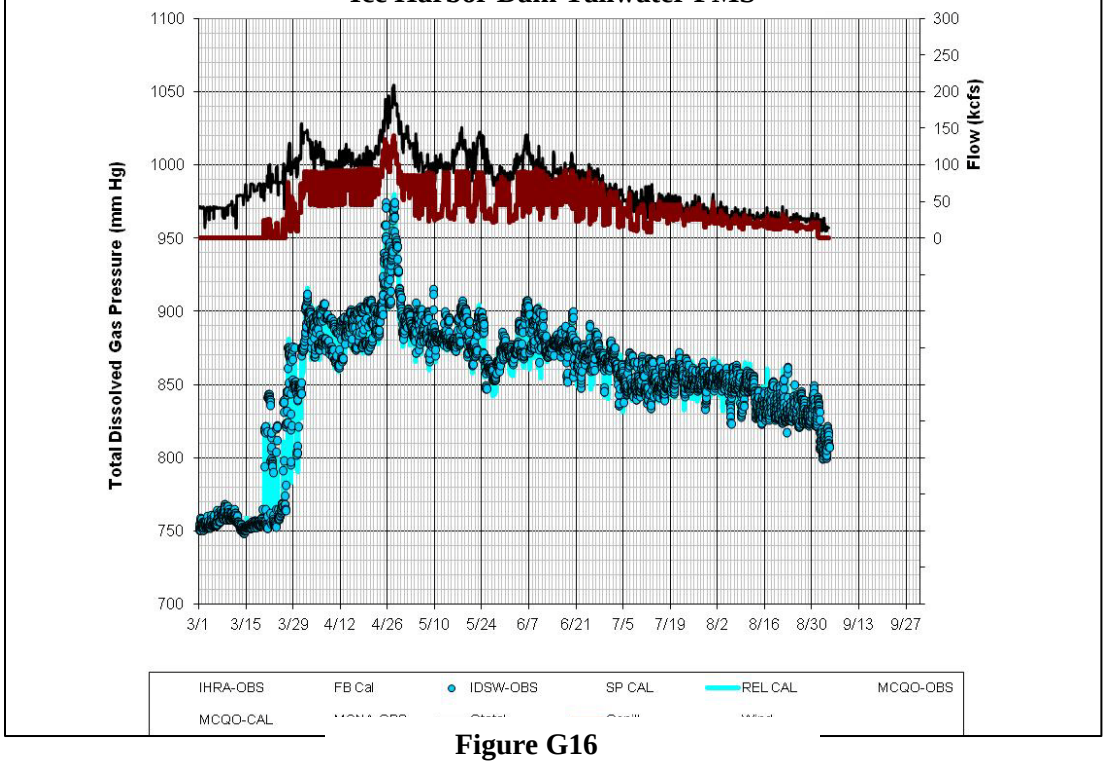

Figure G16
Ice Harbor Dam Forebay FMS

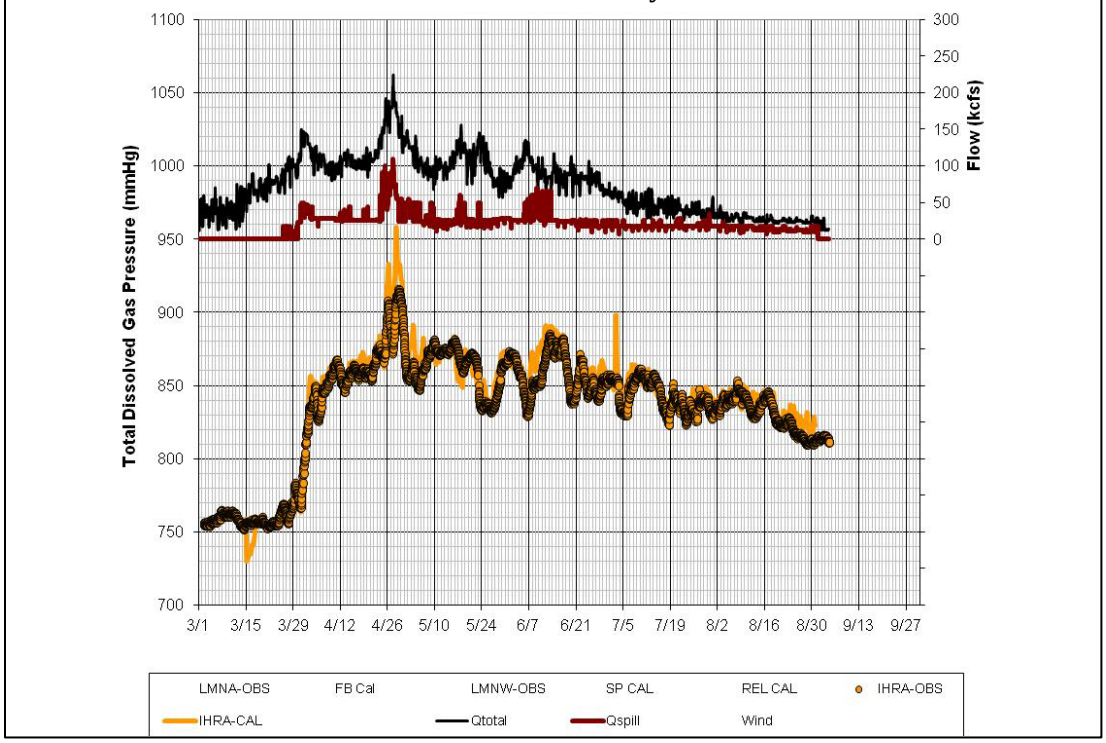

Figure G17
Lower Monumental Dam Tailwater FMS

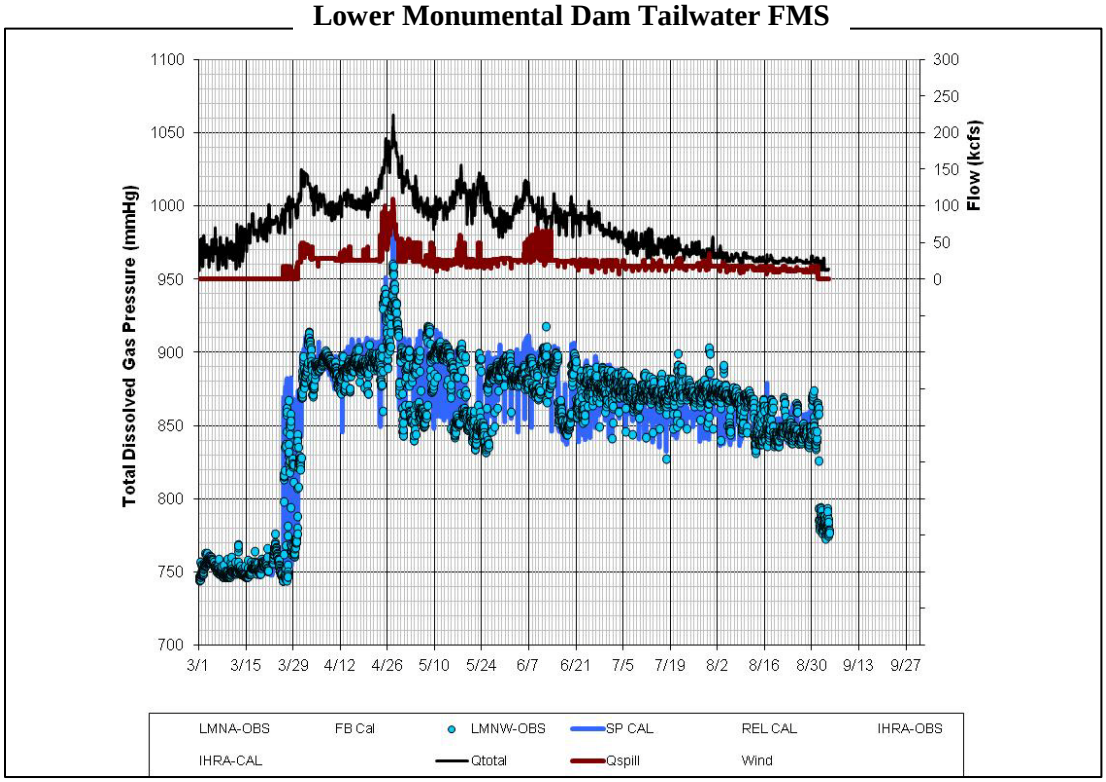

Figure G18
Lower Monumental Dam Forebay FMS

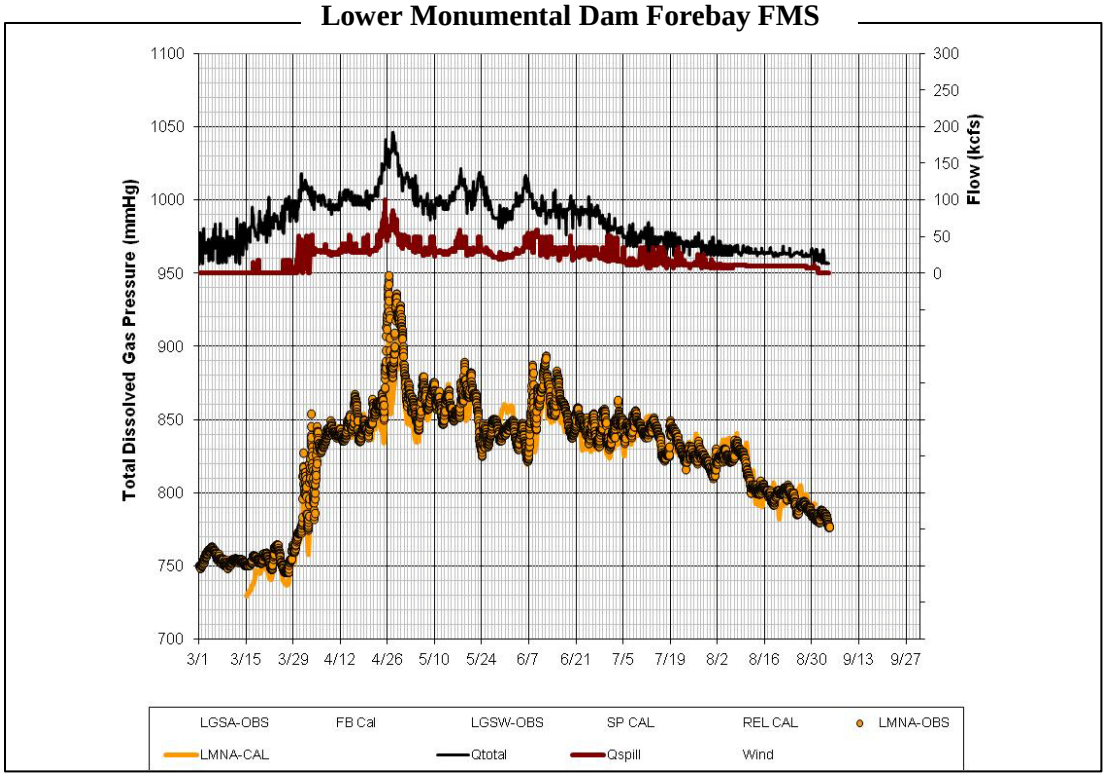

Figure G19
Little Goose Dam Tailwater FMS

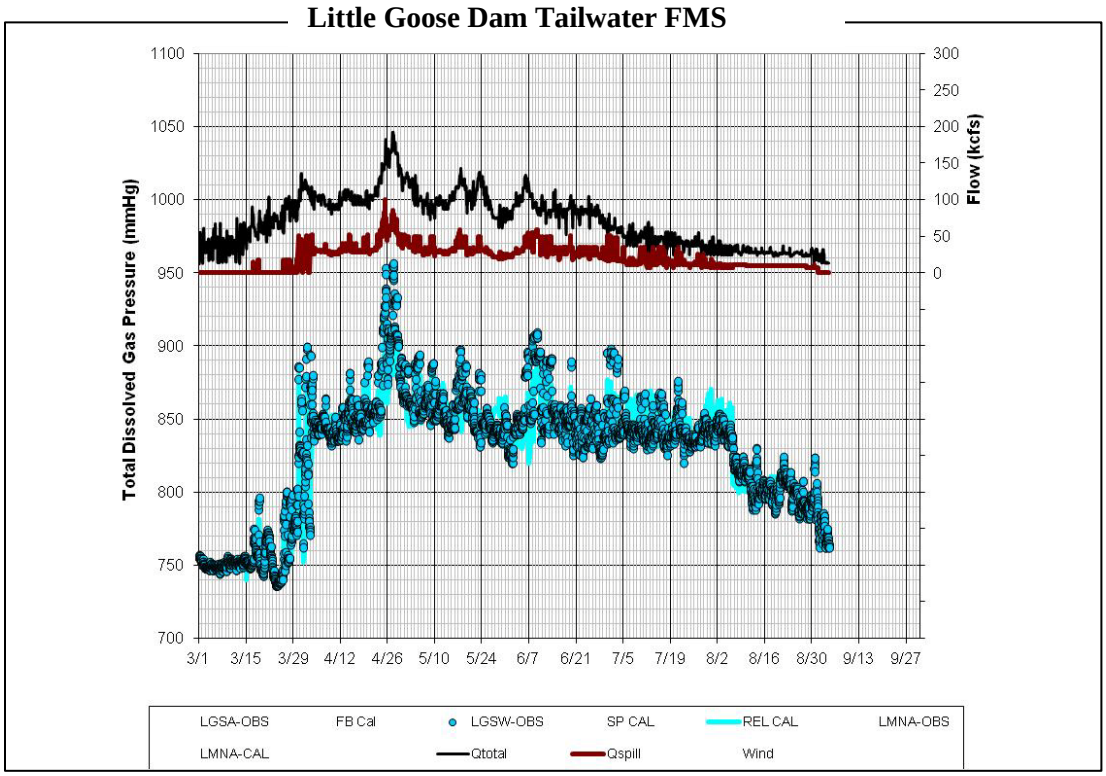

Figure G20
Little Goose Dam Forebay FMS

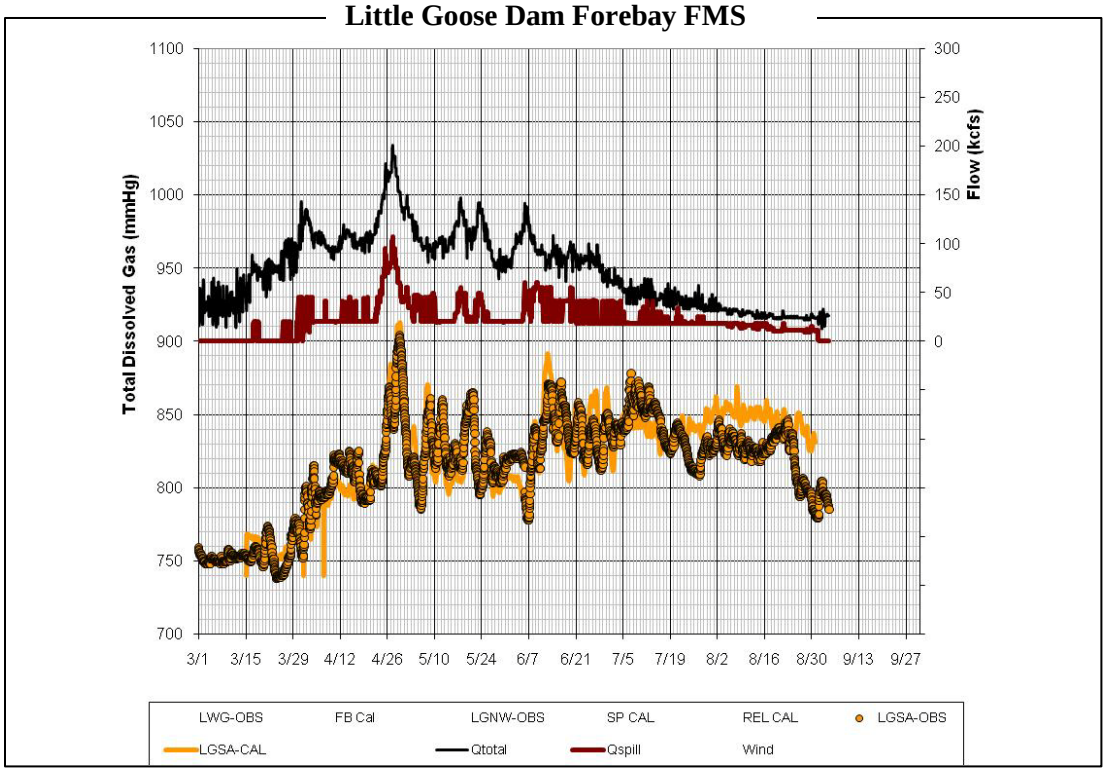

Figure G21
Lower Granite Dam Tailwater FMS

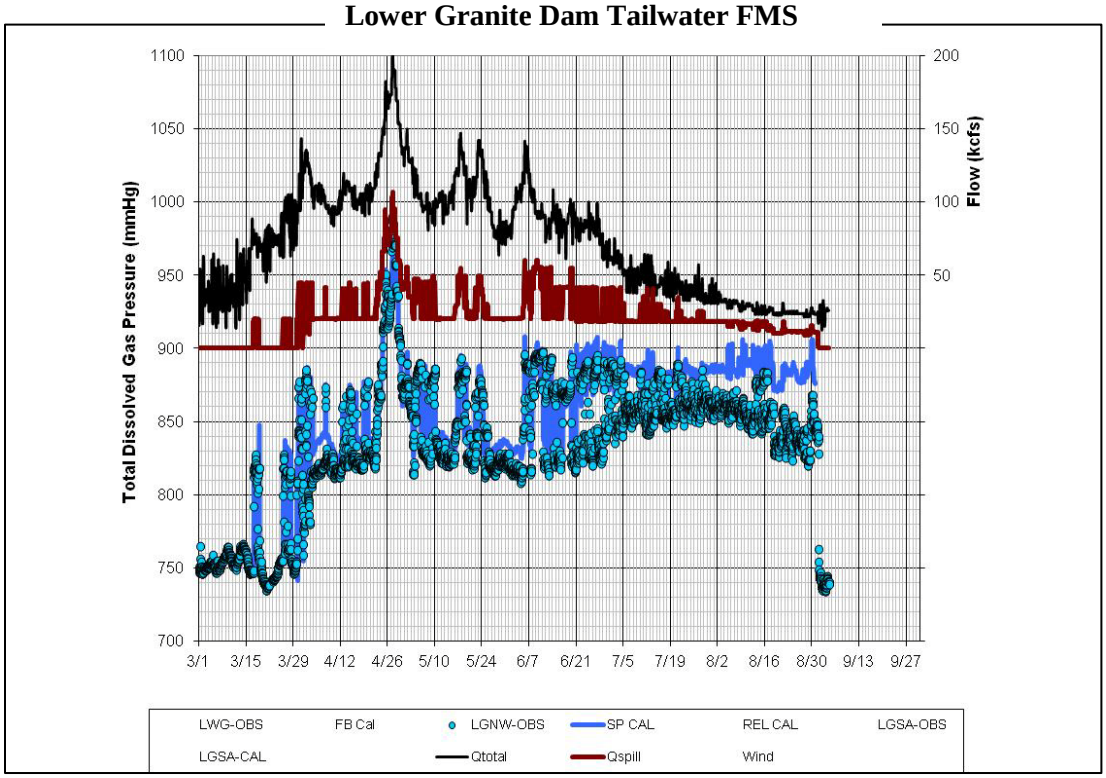
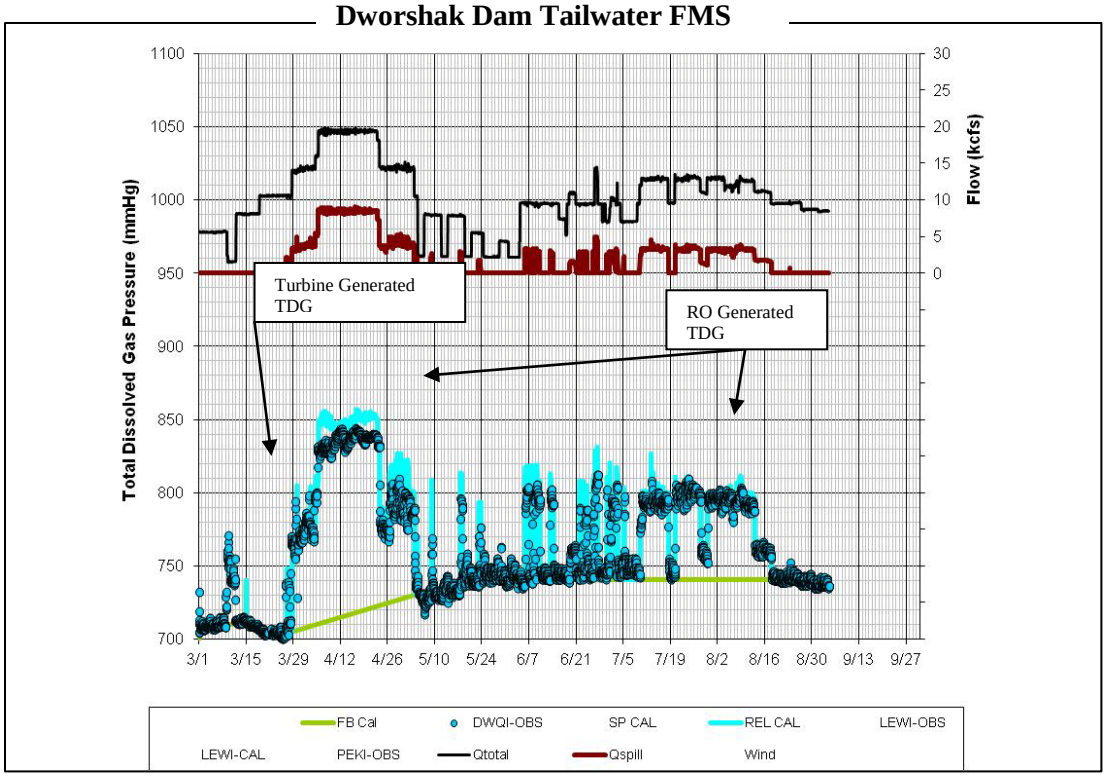
Figure G22
Dworshak Dam Tailwater FMS