Appendix G

SYSTDG Statistical Evaluation
April – August 2013

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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 of saturation and pressures resulting from mainstem dam operations on the Columbia, Snake, and Clearwater rivers. A review of project operations and the resultant TDG levels was conducted for the 2013 fish passage 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 dams.

The purposes of this statistical evaluation of SYSTDG include:

1. Evaluate the effectiveness of the SYSTDG model and identify ways to improve it and its use.
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 monitoring gauge for more effective use of the model when reviewing and setting daily spill caps.

Section 2 Statistical Analysis and Results

In order to generate the statistics on the predictive errors, SYSTDG simulations were calculated independently for each dam and river reach from April 1 through August 31. The predictive error was calculated by subtracting the calculated TDG level from the observed value ($TDG_{error} = TDG_{obs} - TDG_{cal}$). The difference between the hourly observed and calculated 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.

The greatest number of hours that could be included in this analysis per project is 3,671 hours if spill occurred all hours from April 1 through August 31. But in most cases, the number of observed hours was lower as all data does not necessarily fit the model within the model conditions and operational ranges. In order to assess how well the model performs, it is necessary to use the hours/days when the operational conditions are typical or "normal". The hours associated with operational conditions that were outside of normal conditions and therefore excluded from this analysis, include:

1. The hours with no spill are not counted for the tailwater gauge.
2. The first three hours of spill while the model is calibrating. Thus tailwater gauge predictive errors were analyzed only for spill operations longer than 3 hours in order to exclude transient TDG observations.

3. The hours when special spill operations were conducted are not included for tailwater gauges. These special spill operations that are not established in the FOP include speed-no-load, doble testing or operating a unit outside of its 1 percent efficiency limits.
4. The hours when the TDG gauge was malfunctioning were not included for either a forebay or tailwater gauge.
5. The hours when there was a transition between outlet tubes verses drumgate spill at Grand Coulee Dam.
6. Any hours associated with project operations when the applicable spill pattern does not cover the flows occurring in the river.

2.1 Statistical Analyses and Results, 2005-2013

A nine-year (2005-2013) summary of the statistical analyses of the SYSTDG model was prepared in order to evaluate how the 2013 statistical analysis compares with the previous years. The nine-year summary results in percent TDG are shown in Tables G1 and G2 and in mmHg pressure in Tables G3 and G4. It would have been preferred to do a ten year analysis, but 2004 was not consistent with the other years, so 2004 was not included.

Table G1
2005-2013 Average Statistical Summary of the Predictive Errors of the Observed and Calculated TDG at Forebay FMS (%TDG)

Fixed Monitoring Stations		LGSA	LMNA	IHRA	WEL*	CHJ*	MCNA	JDY	TDA	BON	CWMW
Number of Obs		3568	3595	3564	3012	2978	3574	3473	3515	3535	3528
Average		0.1	-0.2	-0.2	-0.4	0.3	-0.2	0.4	-0.5	0.1	0.2
Standard Deviation		2.0	1.7	1.4	1.0	1.1	1.7	1.5	1.2	1.0	1.6
Maximum		6.6	4.4	3.9	5.0	6.1	5.9	5.7	4.0	4.6	9.4
Minimum		-6.6	-5.3	-5.2	-4.1	-4.2	-5.4	-4.2	-4.9	-3.1	-3.0
TDG Predictive Error in % TDG	Percentile										
	5%	-3.6	-3.2	-2.6	-2.0	-1.3	-2.8	-1.8	-2.5	-1.4	-1.4
	10%	-2.5	-2.5	-2.0	-1.5	-0.9	-2.2	-1.4	-2.0	-1.1	-1.2
	25%	-1.0	-1.4	-1.1	-1.0	-0.3	-1.4	-0.7	-1.2	-0.5	-0.7
	50%	0.3	-0.2	-0.1	-0.5	0.4	-0.2	0.2	-0.4	0.1	-0.1
	75%	1.4	1.0	0.7	0.1	0.9	0.9	1.3	0.3	0.7	0.8
	90%	2.5	1.9	1.4	0.6	1.4	1.9	2.3	1.0	1.3	1.8
	95%	3.3	2.4	1.8	1.1	1.9	2.7	3.0	1.6	1.7	2.4

* WEL and CHJ includes only 2010-2013

Table G2
2005-2013 Average Statistical Summary of the Predictive Errors of the Observed and Calculated TDG at Tailwater FMS (%TDG)

Fixed Monitoring Stations		DWQI	LGNW	LGSW	LMNW	IDSW	GCGW*	CHQW*	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Obs		1218	3044	2818	2849	2785	640	1020	2589	2203	2875	2711	2224
Average		-0.2	-0.7	0.0	-0.1	-0.4	-1.6	-0.5	0.7	-0.3	-0.4	-0.2	-0.2
Standard Deviation		1.3	2.3	1.6	2.0	1.2	2.2	1.4	1.5	1.5	1.1	1.3	1.3
Maximum		4.9	7.7	10.1	9.5	4.5	6.1	6.3	11.3	5.6	3.9	5.0	5.0
Minimum		-7.8	-9.4	-7.6	-8.7	-5.4	-9.7	-4.9	-4.0	-5.9	-5.7	-6.5	-5.6
TDG Predictive Error in % TDG	Percentile												
	5%	-2.0	-4.4	-2.4	-3.3	-2.4	-4.9	-2.7	-1.5	-2.8	-2.1	-2.9	-2.1
	10%	-1.6	-3.6	-1.7	-2.5	-2.0	-4.2	-2.2	-0.8	-2.2	-1.6	-1.9	-1.6
	25%	-0.9	-1.9	-0.9	-1.3	-1.1	-2.9	-1.2	-0.4	-1.4	-1.0	-0.8	-1.0
	50%	-0.2	-0.6	0.0	0.0	-0.3	-1.4	-0.5	0.5	-0.5	-0.2	-0.2	-0.3
	75%	0.5	0.6	1.0	1.3	0.4	-0.3	0.2	1.6	0.7	0.4	0.5	0.6
	90%	1.2	2.1	1.8	2.3	1.1	0.7	1.2	2.5	1.7	1.0	1.0	1.5
	95%	1.5	2.9	2.4	2.8	1.6	1.5	1.6	3.0	2.2	1.4	1.4	2.2

* GCGW and CHQW includes only 2010-2013

Table G3
2005-2013 Average Statistical Summary of the Predictive Errors of the Observed and Calculated TDG at Forebay FMS (mmHg Pressure)

Fixed Monitoring Stations		LGSA	LMNA	IHRA	WEL	CHJ	MCNA	JDY	TDA	BON	CWMW
Number of Obs		3568	3595	3564	2868	3097	3574	3473	3515	3535	3523
Average		-2.2	-4.8	-3.7	-5.0	-0.4	-3.8	0.1	-3.5	0.9	0.9
Standard Deviation		15.6	12.9	10.3	6.4	9.3	12.2	11.3	9.4	7.5	9.0
Maximum		51.2	51.1	28.3	31.0	45.9	40.7	43.1	38.5	34.8	41.8
Minimum		-55.0	-41.8	-41.3	-29.2	-35.1	-41.5	-29.4	-36.8	-23.1	-23.2
TDG Predictive Error in mm Hg	Percentile										
	5%	-31.3	-26.3	-21.9	-14.8	-16.3	-21.9	-16.3	-18.7	-10.8	-11.0
	10%	-22.8	-21.4	-17.1	-12.1	-12.5	-18.0	-13.2	-15.3	-8.3	-8.8
	25%	-10.7	-13.3	-10.2	-8.6	-6.3	-12.2	-8.0	-9.3	-4.2	-5.4
	50%	-0.9	-4.3	-2.8	-5.1	0.0	-4.3	-0.7	-3.3	0.6	-0.7
	75%	7.6	4.2	3.4	-1.6	6.2	3.6	7.1	2.2	5.6	6.2
	90%	15.8	10.4	8.3	1.4	10.3	11.5	14.8	7.8	10.1	13.3
	95%	21.7	14.7	11.2	4.1	13.4	16.9	19.9	11.8	12.7	18.2

* WEL and CHJ includes only 2010-2013

Table G4
2005-2013 Average Statistical Summary of the Predictive Errors of the Observed and Calculated TDG at Tailwater FMS (mmHg Pressure)

Fixed Monitoring Stations		DWQI	LGNW	LGSW	LMNW	IDSW	GCGW	CHQW	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Obs		1098	3044	2818	2847	2785	640	1020	2589	2203	2875	2743	2224
Average		-5.9	-7.9	0.1	-0.5	-2.7	-11.5	-3.8	4.9	-2.5	-1.2	0.1	0.9
Standard Deviation		10.1	17.7	12.0	14.6	9.2	15.6	10.1	11.4	11.5	8.3	10.2	10.1
Maximum		31.9	53.1	75.3	56.3	33.7	44.5	46.9	84.4	37.8	31.3	39.7	39.7
Minimum		-61.8	-73.8	-56.8	-64.8	-42.3	-70.8	-36.9	-31.8	-44.8	-41.4	-47.6	-40.8
TDG Predictive Error in mmHg	Percentile												
	5%	-19.7	-35.6	-18.0	-24.4	-18.2	-35.8	-20.2	-11.3	-19.8	-13.6	-18.5	-13.8
	10%	-17.6	-30.3	-12.8	-18.4	-14.8	-30.0	-16.2	-7.9	-16.2	-10.1	-12.7	-10.2
	25%	-12.3	-17.6	-6.8	-9.6	-8.6	-20.7	-9.0	-3.1	-10.5	-5.2	-3.8	-5.6
	50%	-6.0	-7.5	0.1	-0.3	-2.0	-10.3	-4.0	4.0	-3.3	0.3	1.3	-0.3
	75%	1.5	2.7	7.1	9.4	3.2	-2.6	1.7	12.3	5.7	4.8	5.6	6.3
	90%	6.7	12.6	13.7	17.0	8.1	5.1	8.9	18.8	12.6	9.1	9.4	13.1
	95%	8.9	17.8	18.1	21.1	11.8	11.0	12.3	22.7	16.7	12.1	12.2	18.6

* GCGW and CHQW includes only 2010-2013

<u>2005-2013 Analyses of the Statistical Results:</u>
The average standard deviation (σ) from both the nine-year statistical analysis and the 2013 statistical analyses for all the TDG gauges was 1.5. The nine-year statistical analysis shows eight TDG gauges that are consistently above the average standard deviation and the 2013 analysis shows a similar trend. Six of the eight TDG gauges consistently have higher than average standard deviations in both the 9-year and the 2013 statistical analyses and they are:

1. Lower Granite tailwater
2. Little Goose tailwater
3. Lower Monumental tailwater
4. Little Goose forebay
5. Lower Monumental forebay
6. McNary forebay

These consistent trends were discussed in previous annual SYSTDG statistical analysis and the causes for these trends have not changed, they are summarized as follows:

- Lower Granite tailwater gauge consistently has a high standard deviation and it is believed to be associated with the TDG production equations in the model. These equations need to be improved, which was recommended in the previous analyses and is recommended in this analysis.
- The TDG production issue at Lower Granite Dam affects both the tailwater gauge and the Little Goose forebay gauges' predictive errors. It is believed that more TDG is being produced at Lower Granite Dam than is accounted for at the Little Goose forebay. Once the Lower Granite Dam TDG production equations are improved, this should also improve the Little Goose forebay and tailwater gauges' predictive error.
- The Lower Monumental tailwater gauge has issues that are believed to be associated with the spill pattern that they use. Large changes in TDG production are observed with small changes in spill rate.
- The McNary forebay gauge has consistently higher predictive errors and it is attributed to the fact that the Pasco gauge is the boundary for McNary forebay gauge, and if the

observed data from Pasco gauge is of poor quality, then predictive error will be elevated. This perspective was confirmed by calculating the monthly standard deviation of the predictive error which showed that June was the only month with a slightly higher than average (1.7 percent) standard deviation. This standard deviation correlates with the fact that the Pasco gauge was malfunctioning from June 16-22 and June 26-30.

2.2 The 2013 Statistical Analysis and Results

The 2013 statistical analysis results in percent TDG are shown in Tables G5 and G6 and in mmHg pressure in Tables G7 and G8. The 2013 SYSTDG statistical analysis of the predictive errors for the gauges includes average, minimum, maximum, standard deviation, and the predictive error associated with the following percentiles: 5, 10, 25, 50, 75, 90, and 95 percent.

Table G5
2013 Average Statistical Summary of the Predictive Errors of the Observed and Calculated TDG at Forebay FMS (%TDG)

Fixed Monitoring Stations		LGSA	LMNA	IHRA	WEL	CHJ	MCNA	JDY	TDA	BON	CWMW
Number of Obs		3598	3580	3216	1398	1486	3444	3261	2867	2963	2983
Average		-2.2	-0.7	0.4	-0.8	0.2	-1.8	-1.7	-0.8	0.1	0.4
Standard Deviation		2.8	1.9	1.4	1.2	0.9	2.2	1.8	1.1	1.2	1.0
Maximum		8.4	3.8	4.5	6.6	8.2	4.0	3.4	2.7	5.6	3.3
Minimum		-12.9	-5.2	-4.3	-3.4	-2.6	-7.9	-5.7	-3.9	-3.5	-2.6
TDG Predictive Error in % TDG	Percentile										
	5%	-7.5	-4.0	-2.2	-2.5	-1.4	-5.1	-4.3	-2.4	-1.7	-1.2
	10%	-6.2	-3.2	-1.4	-2.0	-1.0	-4.7	-3.9	-2.1	-1.3	-0.8
	25%	-3.9	-1.8	-0.6	-1.5	-0.2	-3.9	-3.2	-1.5	-0.6	-0.3
	50%	-1.3	-0.8	0.4	-0.9	0.4	-1.7	-1.9	-0.8	0.2	0.4
	75%	-0.4	0.7	1.5	-0.3	0.9	-0.2	-0.2	-0.1	0.8	1.2
	90%	0.2	1.9	2.2	0.1	1.2	1.1	0.9	0.6	1.4	1.7
	95%	0.9	2.3	2.6	0.4	1.4	1.7	1.4	1.0	1.8	2.1

Note: Predictive error is the observed minus calculated %TDG where negative values reflect an over-estimation and positive values reflect an under-estimation.

Table G6
2013 Average Statistical Summary of the Predictive Errors of the Observed and Calculated TDG at Tailwater FMS (% TDG)

Fixed Monitoring Stations		DWQI	LGNW	LGSW	LMNW	IDSW	GCGW	CHQW	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Obs		274	3164	2589	3222	3495	271	901	3393	3459	2925	2941	2963
Average		-1.6	0.9	-0.9	1.3	0.5	-1.5	-0.9	1.7	-0.4	-0.6	1.1	1.1
Standard Deviation		0.8	2.8	1.6	2.2	1.5	1.5	1.3	1.4	1.2	1.1	1.0	1.8
Maximum		2.4	13.1	8.4	8.2	5.7	7.3	3.6	6.8	10.6	2.6	6.4	9.0
Minimum		-3.8	-6.5	-8.1	-6.5	-5.5	-4.7	-5.6	-3.5	-5.5	-6.1	-7.3	-3.9
TDG Predictive Error in % TDG	Percentile												
	5%	-3.0	-2.6	-4.3	-2.1	-2.2	-3.1	-3.9	-0.6	-2.3	-2.4	-0.4	-1.3
	10%	-2.5	-2.1	-2.4	-1.4	-1.5	-3.0	-3.1	-0.2	-1.9	-1.9	0.1	-0.9
	25%	-1.9	-1.4	-1.5	-0.3	-0.5	-2.7	-1.3	0.4	-1.1	-1.2	0.6	0.0
	50%	-1.5	0.3	-0.8	0.9	0.6	-1.9	-0.7	1.7	-0.4	-0.5	1.2	0.8
	75%	-1.2	2.3	-0.1	3.2	1.5	-0.3	-0.1	3.0	0.3	0.1	1.6	1.9
	90%	-0.8	4.9	0.5	4.3	2.2	0.5	0.5	3.5	1.0	0.8	2.0	3.4
	95%	-0.7	6.9	1.4	4.7	2.7	1.0	0.7	3.8	1.4	1.2	2.2	4.9

Note: Predictive error is the observed minus calculated %TDG where negative values reflect an over-estimation and positive values reflect an under-estimation.

Table G7
2013 Average Statistical Summary of the Predictive Errors of the Observed and Calculated TDG at Forebay FMS (mmHg Pressure)

Fixed Monitoring Stations		LGSA	LMNA	IHRA	WEL	CHJ	MCNA	JDY	TDA	BON	CWMW
Number of Obs		3598	3581	3216	1400	1486	3444	2486	2867	3031	2983
Average		-7.0	-7.5	0.8	-6.2	-2.0	-15.8	-11.8	-5.7	1.1	3.3
Standard Deviation		11.9	14.2	10.8	9.0	6.2	16.0	13.1	8.0	8.8	7.6
Maximum		62.7	169.8	30.9	48.6	56.5	27.1	22.3	20.8	42.9	25.1
Minimum		-60.8	-41.3	-34.9	-25.5	-22.9	-63.8	-39.7	-29.7	-26.8	-19.8
TDG Predictive Error in mmHg	Percentile										
	5%	-32.4	-32.7	-18.6	-18.3	-13.0	-41.0	-33.5	-17.9	-13.0	-9.1
	10%	-18.4	-26.2	-12.8	-14.8	-10.1	-37.5	-29.9	-15.6	-9.8	-6.4
	25%	-10.8	-15.9	-6.7	-10.8	-5.9	-31.0	-22.9	-11.2	-4.6	-2.0
	50%	-6.0	-8.5	0.8	-7.0	-1.3	-15.0	-10.5	-6.0	1.2	3.2
	75%	-1.0	2.8	8.6	-2.1	2.5	-3.9	-2.0	-0.8	6.4	8.9
	90%	3.3	11.5	14.2	0.9	4.6	5.8	4.5	4.6	10.5	13.0
	95%	10.1	14.9	16.8	3.1	7.0	9.6	8.8	7.9	13.4	15.7

Table G8
2013 Average Statistical Summary of the Predictive Errors of the Observed and Calculated TDG at Tailwater FMS (mmHg Pressure)

Fixed Monitoring Stations		DWQI	LGNW	LGSW	LMNW	IDSW	GCGW	CHQW	MCPW	JHAW	TDDO	CCIW	WRNO
Number of Obs		273	3154	2589	3340	3495	271	901	3393	3458	2925	2929	2963
Average		-50.0	-20.1	-7.0	9.1	3.4	-10.7	-6.8	12.9	-3.1	-1.7	9.8	10.8
Standard Deviation		17.4	23.3	11.9	17.1	11.7	11.0	9.9	10.8	8.4	8.0	7.0	13.8
Maximum		-18.2	59.5	62.7	63.5	42.7	53.7	27.3	50.4	36.9	22.3	50.9	69.8
Minimum		-75.2	-80.9	-60.8	-66.6	-55.8	-34.8	-42.1	-26.3	-41.7	-44.5	-38.6	-27.4
TDG Predictive Error in mmHg	Percentile												
	5%	-70.3	-48.6	-32.4	-17.1	-16.4	-22.6	-28.7	-4.3	-17.5	-15.2	-0.9	-7.6
	10%	-69.3	-45.2	-18.4	-12.4	-11.1	-21.8	-23.5	-1.3	-14.1	-11.9	2.4	-4.0
	25%	-65.9	-40.5	-10.8	-2.5	-3.7	-19.8	-9.3	2.8	-8.2	-6.5	6.5	2.2
	50%	-53.4	-26.4	-6.0	6.5	4.6	-14.1	-5.2	12.9	-3.4	-1.3	10.8	8.8
	75%	-30.2	-1.7	-1.0	24.0	11.6	-2.3	-0.6	22.3	2.2	3.3	13.5	17.1
	90%	-22.9	12.5	3.3	32.7	16.9	3.6	3.8	26.7	7.4	8.1	16.5	28.2
	95%	-21.7	20.5	10.1	35.8	20.0	7.2	5.8	28.7	10.3	11.3	18.5	39.5

Discussion of the 2013 Analysis of the Statistical Results:
The 2013 statistical analysis resulted in several significant findings and the following is a discussion of them:

Lower Granite Special Operations: From July 29 through August, Lower Granite had a variety of special operations for approximately 424 hours that produced very high predictive errors. SYSTDG consistently underestimated TDG levels during the special operations with the predictive error ranging from 1 to 14 percent with an average of 7 percent. For real-time operations of the FCRPS, a predictive error of 2.5 percent or higher is too high for decision-making purposes. These high predictive errors are not reflective of a flaw in SYSTDG because the model was operating as it was designed. As a result of this analysis, it was decided that these hours would not be included in the analysis results in Tables G3-G4. Use of SYSTDG is not recommended for determining TDG levels during special operations until after the model is upgraded with TDG production equations that apply to the special operation in question. During this period, there were nine TDG instances at the Lower Granite tailwater or the Little Goose forebay. TDG levels at Lower Granite tailwater exceeded 122 percent for many hours during the speed no load special operations.

The situations with Lower Monumental low flow spill pattern and Lower Granite special operations emphasize the point that SYSTDG was designed to be used for typical spill season conditions from April through August; and when the model is used outside of its design criteria, there will be high predictive error, and simulation results are not as accurate.

Lower Monumental Spill Pattern: From July 31 through August, spill rates at Lower Monumental occasionally dropped below 7.9 kcfs, the lowest gate setting of the Lower Monumental spill pattern. This situation occurred for 254 hours during 2013 spill season. There were some hours when TDG levels rose above 120 percent but the high 12 hour average remained below the state TDG standard of 120 percent so no daily TDG instance

occurred. Because the spill pattern at Lower Monumental does not provide gate settings for low flow conditions often experienced in late summer, the predictive errors in August were high. During this period, the predictive error ranged from a -8 percent (over estimating) and +12 percent (under estimating), with a persistent frequency of over estimating. These high predictive errors are not reflective of a flaw in SYSTDG because the model was operating as it is designed. As a result of this analysis, it was decided that any hours associated with project operations when the spill pattern does not contain low enough settings for extremely low flows, would not be included in the analysis results in Tables G3-G4. During real time operations of the hydrosystem, NWD RCC Water Quality Unit (RCC) deems a predictive error of 2.5 percent or higher as too high for decision-making purposes. Use of SYSTDG is not recommended for determining TDG levels when there is no applicable spill pattern in place. NWD RCC will work with Walla Walla District to develop a spill pattern for low flow gate settings.

Comparison of 2013 Statistical Analysis to Previous Years: The 2013 statistical analysis compared favorably with the 2005-2013 statistical analyses, showing the same trends. The 2013 statistical analysis produced very similar standard deviations for the TDG gauges as the 9 year statistical analysis. The statistical analysis indicated certain TDG gauges and certain projects had very high predictive errors just as the project was transitioning to the spring or summer spill targets. This multi-year comparison emphasized that the SYSTDG improvements recommended in previous annual statistical analysis are still valid.

High Predictive Error at John Day Forebay

The John Day forebay gauge had a seasonal average standard deviation of the predictive error of 1.8 percent in 2013, which was slightly above the 9-year average of 1.5. The main factor that is causing this high predictive error is the estimate of the amount of degassing that occurs in the McNary to John Day reach. The McNary Dam to John Day Dam reach is the longest river reach (76 miles) in the FCRPS and travel time range from 3.8 to 7.9 days in 2013 (average water year). As weather data is not collected at the reservoirs, but at National Weather Service stations, it is not always representative of weather at the reservoir which can introduce some additional predictive error. The weather station being used is further away from John Day, and if it was located closer it would improve the John Day forebay TDG gauge's predictive errors.

High Predictive Error at Bonneville Tailwater Gauge - Warrendale:

The Bonneville tailwater gauge at Warrendale had a seasonal average standard deviation of the predictive error of 1.8 percent in 2013, which was above the 9-year average of 1.3. The seasonal average standard deviation of the predictive error at Warrendale was excellent (standard deviation of 1.2 percent) until approximately July 17. The monthly average standard deviations of the predictive error for April through June were only 1 percent. After July 17, the July monthly average standard deviation of the predictive error was two times higher and August was three time higher than the 9-year seasonal average standard deviation. This spike in the average standard deviation of the predictive error can be attributed to the fact that flow from the Bonneville Powerhouse 2 Corner Collector outfall becomes a prominent source of TDG during low flow conditions. With

low flows, when the Bonneville tailwater elevation drops to 15 feet or less, the B2CC outflow is a distinct plunging trajectory instead of the more horizontal trajectory associated with higher tailwater elevations. This plunging flow then results in higher and persistent TDG production.

Section 3 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 2013 compared favorably with the predictive errors from previous years for most gauges. The following are some of the highlights of the 2013 analysis:

1. The 2013 statistical analysis compared favorably with the 2005-2013 statistical analyses, indicating the same trends for the most of the TDG gauges. This multi-year comparison emphasized that the SYSTDG improvements recommended in previous annual statistical analysis are still valid.

2. The special operations at Lower Granite in August resulted in elevated predictive error at the Lower Granite tailwater gauge. SYSTDG consistently under estimated TDG production during the special operations with the predictive error ranging from 1 to 14 percent with an average of 7 percent. Use of SYSTDG is not recommended during special operations until after the model is upgraded with TDG production equations that apply to the special operation in question.

3. Lower Monumental hourly spill rates in August dropped to 6 kcfs which is below the first setting of the spill pattern of 7.9 kcfs. Because the Lower Monumental spill pattern does not have gate settings for less than 7.9 kcfs spill rates, the predictive errors of the SYSTDG model were significantly higher; ranging from a -8 percent (over estimating) and +12 percent (under estimating), with a persistent pattern of over estimating. This situation illustrates the point that SYSTDG was designed to be used for typical spill season conditions from April through August. When the model is used outside of its design criteria, there will be high predictive error, and the results are not as trustworthy.

Section 4 Causes of SYSTDG Predictive Error

The differences between model estimates and observed percent TDG (predictive error) at fixed monitoring stations (FMS) 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 outflow generation and spill values used in these simulations are averaged on an hourly basis. Any operational change occurring within the hour will not be seen because the instantaneous five-minute flow values were averaged with other five-minute values that can be much higher or lower, resulting in an average

hourly value. Thus hourly average flow is different than actual flow and can introduce erroneous results in the SYSTDG simulation.

2. The spill pattern used during special 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 and production equations for specific operations; background TDG pressures from upstream of the project and 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 gauge 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 gauges 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 occur because the SYSTDG model is designed to simulate the average channel TDG production at the gauge transect. Actual TDG saturation at the gauges is a function of flow rate, spill pattern, wind, and other factors resulting in increased predictive error.

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 production equations. During the 2013 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, TDG field 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 2013

In support of the Columbia River Treaty 2014-2024 Review Study water quality assessments for ecosystem based function; certain improvements were made to the

SYSTDG model. TDG production equations at several projects on the Mid-Columbia River were updated as follows:

1. The TDG production and transport equations for the Wells; Rock Island; Rocky Reach; Wanapum; and Priest Rapids dams were updated based on structural and operational changes in cooperation with the dam owner's input.

2. SYSTDG was converted to pull data directly from the CWMS database instead of using a schedule task, and also from many text files and two Access databases to load the data. This improvement was completed for the most part during 2013, but the task of getting a few pieces of additional data to come into CWMS and revising SYSTDG to pick up the last pieces of data still remains. It is anticipated that this task will be completed in 2014.

3. The feature of adding or changing the various spill patterns was added to SYSTDG in 2012 and updated in 2013.

4. The proposed SYSTDG improvements listed in the 2012 statistical analysis were not incorporated in 2013 due to time and resource constraints.

Section 7 SYSTDG Improvements Recommended for Future Years

7.1 Statistical Analysis recommendations, 2013:

The improvements and maintenance activities to the SYSTDG model that are recommended for future years include those that have been identified in previous year's evaluations along with those identified during the 2013 analysis.

1. Recommend that the Lower Monumental spill pattern should be further developed with gate settings for a spill rates as low as 6 kcfs.

2. Recommend that the improvements to the SYSTDG model recommended in previous annual SYSTDG statistical analyses are implemented as funds and time allows.

3. Recommend the feature of entering spill patterns be added to Chief Joseph Dam input card.

4. Recommend that the Grand Coulee TDG production estimates are updated to better differentiate spill through the outlet tubes compared to the drumgates.

7.2 Recommendations from Previous Statistical Analysis:

The recommendations that have been rolled forward from previous years (2004-2012) are as follows:

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

Chief Joseph Dam: The TDG exchange as a function of spillway flows and patterns should continue to be investigated. It is recommended that standard spill patterns be designed that distributes spill uniformly over all 19 bays and implemented in 2014 spill pattern. It is also recommended that the resultant TDG levels from the new standard spill patterns be evaluated.

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

John Day Dam: The influence of bulk spill through the spillway weirs at bays 18 and 19, and the performance of the 50 foot flow deflector in bay 20, remain difficult to assess from the single TDG gauge 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 flows during 2013. An updated TDG exchange equation should be developed and implemented in upcoming version of SYSTDG.

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

Dworshak Dam: The TDG levels in regulating outlets and spillway flows at Dworshak Dam were estimated from well mixed water 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.

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

Lower Monumental Dam: The updated 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.