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February 20, 2014

Kimberly D. Bose, Secretary
Federal Energy Regulatory Commission
Mail Code: DHAC, PJ-12
888 First Street, N.E.
Washington, D.C. 20426

Re: Priest Rapids Hydroelectric Project No. 2114 – Final Wanapum Dam Advanced Turbine Total Dissolved Gas Evaluation Study Plan Final Report

Dear Secretary Bose,

Attached please find for the Federal Energy Regulatory Commission's (FERC) approval the final report titled, *Evaluation of Total Dissolved Gas Related to the Operation of Advanced Turbines at Wanapum Dam* consistent with the requirements of License Article 401(a)(17) of the Priest Rapids Hydroelectric Project (Project) issued by FERC on April 17, 2008 and Condition 6.4.4(b) of the Washington State Department of Ecology (WDOE) 401 Water Quality Certification (WQC) dated April 3, 2007 and amended March 6, 2008.

The evaluation was conducted in accordance with the study plan titled, *Wanapum Dam Advanced Turbine Total Dissolved Gas Evaluation*, which was developed in consultation with the WDOE and the Priest Rapids Coordinating Committee (PRCC). The study plan was submitted to FERC on September 28, 2012, supplemented on October 2, 2012 and modified and approved by FERC on March 8, 2013. The final report summarizes the total dissolved gas (TDG) evaluation conducted downstream of Wanapum Dam with varying Project operations during the non-spill season (mid-October) of 2013.

Consistent with Section 6.4.4(b) of the WQC, the draft report was provided to WDOE and the PRCC on December 13, 2013 for a 30 day review and comment period. No comments were received.

FERC staff may contact Tom Dresser at 509-754-5088, ext. 2312 or tdresse@gcpud.org with any questions regarding this final report.

Sincerely,

Ross Hendrick
License Compliance Manager

cc: Jeff Grizzel, Grant PUD
Tom Dresser, Grant PUD
NR Records 1.6, Grant PUD
Priest Rapids Coordinating Committee
Priest Rapids Fish Form
Patrick McGuire, WDOE
James Bellatty, WDOE

Priest Rapids Hydroelectric Project (P-2114)

EVALUATION OF TOTAL DISSOLVED GAS RELATED TO THE OPERATION OF ADVANCED TURBINES AT WANAPUM DAM

FINAL REPORT

License Article 401(a)(17)

By Carson Keeler

Public Utility District No. 2 of Grant County, Washington
Priest Rapids Project
FERC Project Number 2114

February 2014

Executive Summary

The evaluation of total dissolved gas (TDG) related to the operation of all ten of the advanced turbines at Wanapum Dam was conducted in accordance with the study plan titled, *Wanapum Dam Advanced Turbine Total Dissolved Gas Evaluation* (Keeler 2012), which was developed in consultation with the Washington Department of Ecology (WDOE) and the Priest Rapids Coordinating Committee (PRCC). The study plan was submitted to the Federal Energy Regulatory Commission (FERC) on September 28, 2012, supplemented on October 2, 2012 and modified and approved by FERC on March 8, 2013.

As stated in the study plan, the primary objective of this evaluation was to assess TDG across the river channel with all ten of the advanced turbines operating at varying conditions to determine whether the operation of all ten of the advanced turbines significantly affects TDG levels during normal Project operations. To complete this objective, a TDG sensor array arranged in a lateral transecting pattern was placed approximately 2000 feet downstream of Wanapum Dam to monitor changes in TDG levels compared to TDG levels recorded upstream at the Wanapum Dam forebay fixed-site monitoring station (FSM station) and downstream at the Wanapum Dam tailrace FSM station.

In order to quantify TDG production associated with the operation of all ten of the advanced turbines, TDG data was collected during the following operational conditions between October 12 and 14, 2013:

1). **Test 1 – Minimum operations** with the turbine gate opening at approximately 60%, under 80 feet of head, which passed an average flow of 9.1 kcfs per turbine unit, equaling an average total powerhouse flow of 93.3 kcfs; and
2). **Test 2 – Average operations** with the turbine gate opening at approximately 77%, under 80 feet of head, which an average flow of 13.1 kcfs per turbine unit, equaling an average total powerhouse flow of 132.5 kcfs; and
3). **Test 3 – Maximum operations** with the turbine gate opening at approximately 95%, under 80 feet of head, which passed an average flow of 19.2 kcfs per turbine unit, equaling an average total powerhouse flow of 193.5 kcfs.

The operational conditions stated above were held steady for at least three consecutive hours to allow conditions to stabilize in the tailrace; depth, temperature, and TDG values were collected at 15-minute intervals (starting at the top of the hour) during the test conditions. The field study period was extended for ten additional days (to October 24, 2013) in order to record any incidental periods when operational requirements were inadvertently met and the resulting data could possibly be used for further evaluation of the advanced turbine operation. After further analysis of the project operation data it was determined that there were ten additional periods during the study period when consistent operating conditions were met for a minimum of three consecutive hours. It is important to note that the ice/trash sluiceway was not operational during the three targeted test periods, but spill through the sluiceway did occur (1.5 - 2.3 kcfs) during all other periods of the TDG evaluation. This sluiceway is operated to provide adult fall back for migrating salmonids, and because of the record fall run of adult Chinook salmon in 2013, Grant PUD was not able to close the sluiceway for the entire study period. Additionally, during these incidental test periods it is important to note that Wanapum Dam was operated as a nine-unit project. A unit was taken offline in order to perform the generator replacement project. For more

information on the additional testing periods identified during the study period see Appendix A of this report.

The difference in TDG %SAT between the Wanapum forebay and the TDG array transect for the targeted test periods (without sluiceway spill) were 0.1 %SAT for Test 1, -0.6 %SAT for Test 2, and 0.4% SAT for Test 3 for an overall mean difference of -0.02%. Given that the sensors used to the collect TDG values for this study have an accuracy ± 0.15 %SAT and sensitivity/resolution of 0.1 %SAT, the differences observed during the targeted tests suggest that the new turbines at Wanapum Dam do not materially increase TDG levels during minimum, average, and maximum operating conditions.

The difference in TDG %SAT between the Wanapum forebay and the TDG array transect for the incidental test periods (with sluiceway spill) ranged from -0.1 %SAT to 2.0 %SAT for an overall mean difference of 0.9 %SAT. Given that the sluiceway was operating during these incident test periods, these incidental test results further suggest that the new turbines at Wanapum Dam do not materially increase TDG levels during regular operation conditions.

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List of Abbreviations

%SAT	percent saturation
bp	ambient atmospheric barometric pressure
FERC	Federal Energy Regulatory Commission
FSM	fixed-site monitoring
GPS	global positioning system
Grant PUD	Public Utility District No. 2 of Grant County
kcfs	thousand cubic feet per second
license	Federal Energy Regulatory Commission License No. 2114
mm Hg	millimeters of mercury
Project	Priest Rapids Hydroelectric Project
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RM	river mile
TDG	total dissolved gas
WAC	Washington Administrative Code
WDOE	Washington Department of Ecology
WFB	Wanapum Fish Bypass
WQC	Water Quality Certification

1.0 Introduction

The Public Utility District No. 2 of Grant County, Washington (Grant PUD) owns and operates the Priest Rapids Hydroelectric Project (Project). The Project is licensed as Project No. 2114 by the Federal Energy Regulatory Commission (FERC) and includes the Wanapum and Priest Rapids developments. A 401 water quality certification (WQC) for the operation of the Project was issued by the Washington Department of Ecology (WDOE) on April 3, 2007 (WDOE 2007), amended on March 6, 2008, and effective on issuance of the FERC license (license) to operate the Project in April of 2008 (FERC 2008).

Sections 6.4.4(b) and 6.4.9 of the 401 WQC (WDOE 2007) required Grant PUD to conduct a field study to evaluate total dissolved gas (TDG) after the installation of the tenth and final Wanapum Dam advanced turbine to determine the effect, if any, the operation of the advanced turbines have on TDG downstream of Wanapum Dam. Article 401(a)(17) of the license (FERC 2008) required FERC approval of the study plan prior to implementation.

The evaluation of TDG related to the operation of all ten of the advanced turbines at Wanapum Dam was conducted in accordance with the study plan titled, *Wanapum Dam Advanced Turbine Total Dissolved Gas Evaluation* (Keeler 2012), which was developed in consultation with the WDOE and the Priest Rapids Coordinating Committee (PRCC). The study plan was submitted to FERC on September 28, 2012, supplemented on October 2, 2012 and modified and approved by FERC on March 8, 2013 (FERC 2013).

The following report summarizes the TDG evaluation conducted downstream of Wanapum Dam with varying Project operations during the non-spill season (October 12-14) of 2013.

1.1 Background

Grant PUD began installation of the first advanced turbine in 2004 and completed the tenth and final turbine in September of 2013. In accordance with Section II of the advanced turbine installation project’s 401 WQC (WDOE 2004), Grant PUD conducted a field study in the winter of 2005 to assess the potential TDG production between an advanced turbine (Turbine 8; W-8) and an existing turbine (Turbine 4; W-4) at Wanapum Dam (Lenz and Dresser 2005). The evaluation was designed to verify that the advanced turbine did not materially increase TDG during normal Project operations. For the field study, WDOE (2004) required a single fixed transect be located approximately 2000 feet downstream of the powerhouse during the non-spill season to collect TDG values associated with turbine operations (both advanced and extant) between the minimum and maximum hydraulic capacities at the cavitation limit and at normal Project operating conditions. Depth, temperature, and TDG were collected every ten-minutes during the sampling period (February 20 – March 5, 2005). Results from this evaluation showed that the advanced turbine did not materially increase TDG during normal Project operations (Lenz and Dresser 2005). The Project’s 401 WQC required Grant PUD to conduct additional testing once all ten units were installed (WDOE 2007).

1.2 Regulatory Framework

The WDOE establishes Washington state water quality standards for TDG during the non-fish and fish-spill seasons (see Washington Administrative Code (WAC) 173-201A-200(1)(f); WDOE 2006). The current standard for TDG (in percent saturation (%SAT)) during the non-fish spill season (September 1 through March 31) is 110 %SAT for any hourly measurement. The current standard for TDG (in %SAT) during the fish-spill season (April 1 through August 31) is

115 %SAT in the forebay and 120 %SAT in the tailrace, based on the average of the 12-highest consecutive hourly readings in a 24-hour period. A one-hour, 125 %SAT maximum standard for TDG also applies throughout the Project.

The study plan titled, *Wanapum Dam Advanced Turbine Total Dissolved Gas Evaluation Study Plan* (Keeler 2012) was designed to satisfy the requirements of Sections 6.4.4(b) and 6.4.9 of the 401 WQC for operation of the Project by collecting TDG data above and below Wanapum Dam during the minimum, average, and maximum operating conditions associated with the operation of all ten of the advanced turbines. The TDG data collected allowed TDG production to be quantified and compared to upstream/incoming TDG and thus allowed for the determination of potential impacts to TDG production (see Section 3.0 for more information).

1.3 Site Description

Wanapum Dam is located at river mile (RM) 415 near Vantage, Washington (Figure 1 and Figure 2). The total length of Wanapum Dam is 8,637 feet, with the axis of the powerhouse being almost parallel with the general direction of river flow and two 'elbows' in its layout. The normal pool operating range is between 560.0 and 571.5 feet above mean sea level. The powerhouse contains ten turbine units which operate at a design head of 80 feet and associated discharge of 178 thousand cubic feet per second (kcfs); the advanced turbines were designed, following installation of new generators, to pass up to 188 kcfs at 80 feet of head. Wanapum Dam also contains a 12-gate spillway to pass excess river flow, right and left-bank fish ladders (for upstream passage) and a Wanapum Fish Bypass (WFB) that passes outmigrating salmonids during the fish-passage season (typical operated between April 1 and August 31).

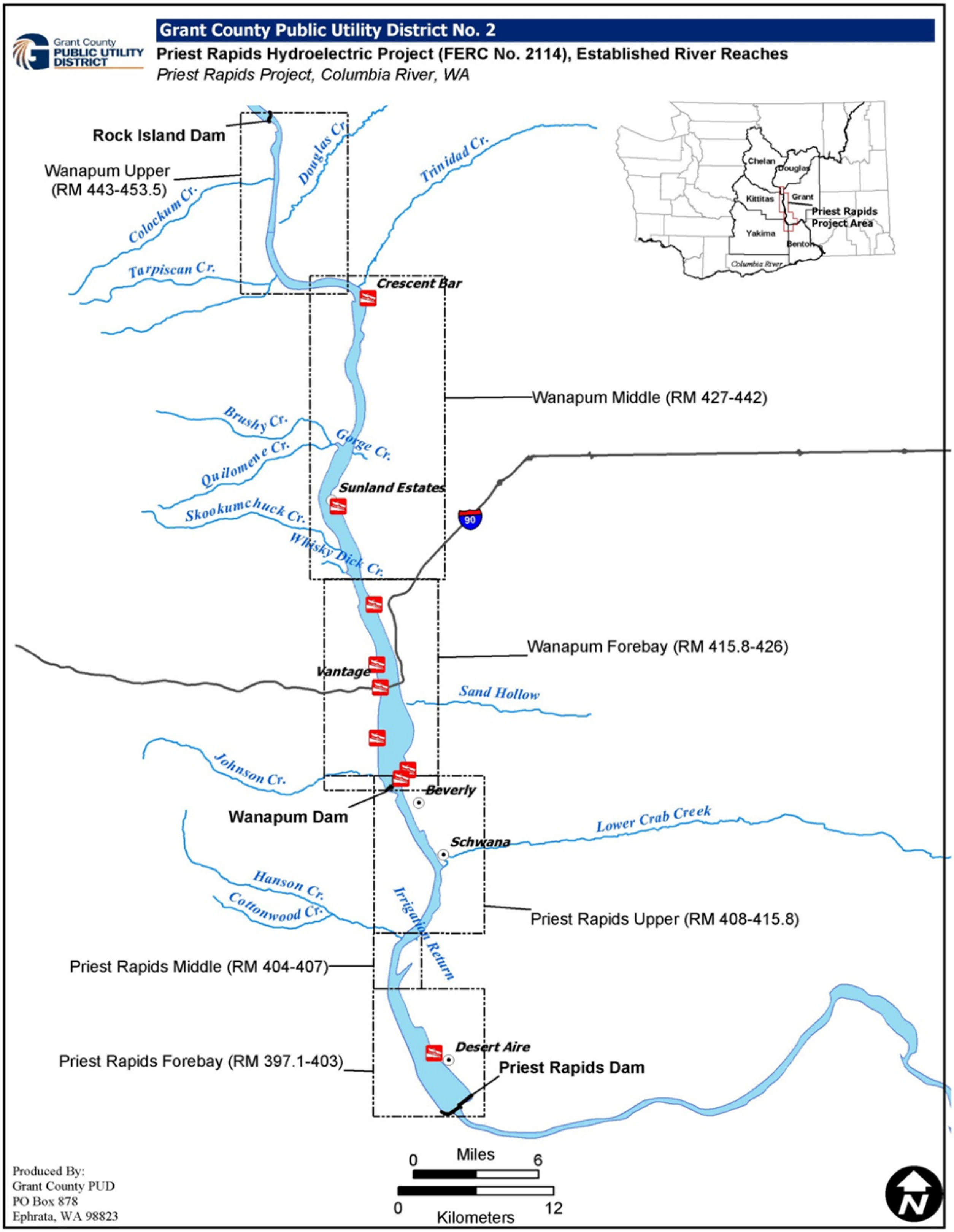

Figure 1 **The Priest Rapids Hydroelectric Project and established river reaches presented by river mile (RM), mid-Columbia River, WA.**

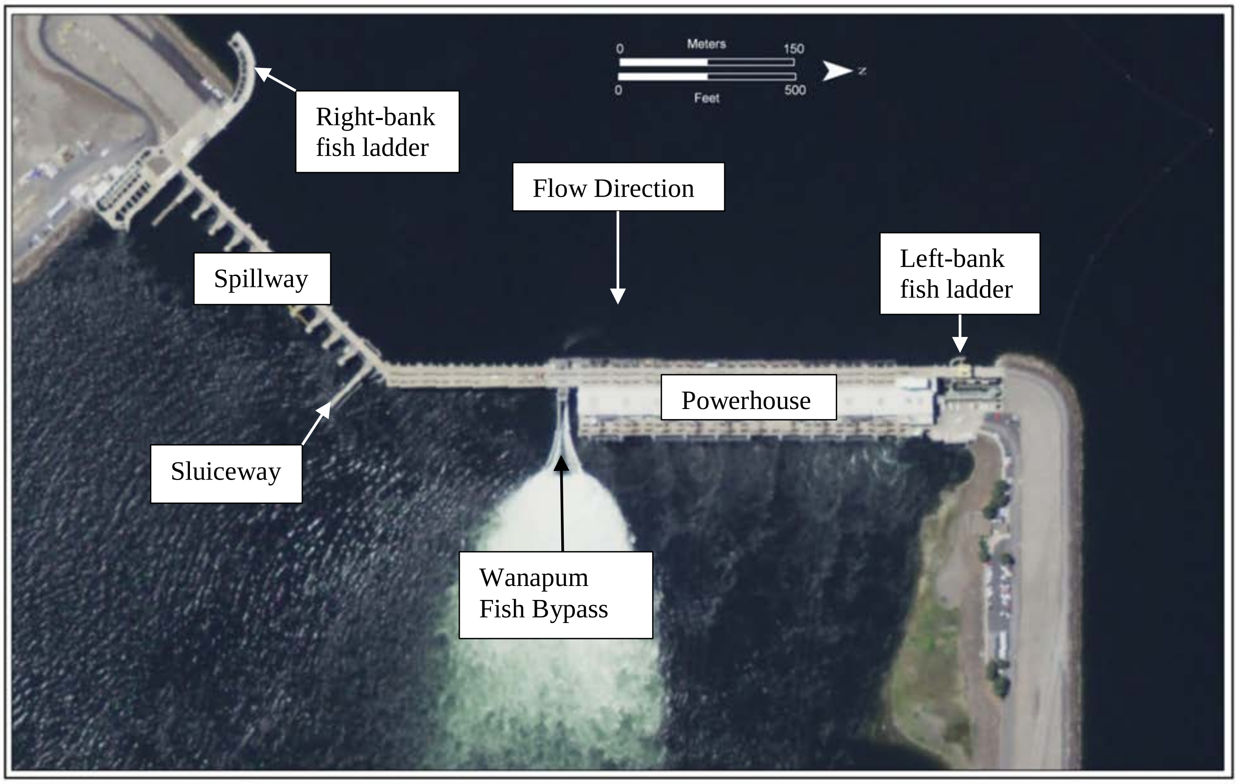

Figure 2 Aerial photograph of Wanapum Dam, mid-Columbia River, WA.

1.4 Objectives

Per Sections 6.4.4(b) and 6.4.9 of the 401 WQC (WDOE 2007), Grant PUD conducted a field study to evaluate TDG across the river channel and at the downstream FSM station of Wanapum Dam during the non-spill season (mid-October, 2013) to evaluate TDG exchange associated with the operation of all ten of the advanced turbines at Wanapum Dam during varying Project operations.

To complete this objective, a TDG sensor array arranged in a lateral transecting pattern was placed approximately 2000 feet downstream of Wanapum Dam to monitor changes in TDG levels compared to TDG levels recorded upstream at the Wanapum Dam forebay FSM station with all ten of the advanced turbines operating at minimum, average, and maximum operating conditions (see Section 2.4 for more details).

2.0 Methods

The following sections describe the methods that were used during the evaluation period, including descriptions of TDG sensors, calibration and quality assurance/quality control (QA/QC) methods, location of the TDG sensor array, and the operational conditions. In addition, TDG %SAT were calculated using ambient air pressure and TDG pressure. Measurements were recorded at 15-minute intervals (starting at the top of the hour) from October 11, 2013 at 0900 hours to October 24, 2013 at 0800 hours for the purpose of this TDG evaluation.

As with past TDG evaluations at Wanapum Dam, this evaluation utilized an array of remote instruments capable of logging time histories of TDG pressures at numerous locations up and downstream of Wanapum Dam. Instruments used during the evaluation were Hydrolab Corporation water quality sondes equipped with, at a minimum, TDG, temperature, and depth sensors. The TDG sensors on these instruments have a stated accuracy of +/- 1.5 millimeters of mercury (mm Hg; ~0.15 %SAT, Hach Company 2006) and a sensitivity/resolution of 1.0 mm Hg (~0.1 %SAT, Hach Company 2006). Additionally, according to Grant PUD's Quality Assurance Project Plan (QAPP; Hendrick 2009), the smallest reference level for decision making is 1.0 %SAT for TDG.

The evaluation concentrated on TDG dynamics in the near-field of Wanapum Dam (within the immediate forebay, tailrace/tailwater, and downstream to the FSM station). Instruments were placed at two depths for some of the deeper stations where vertical gradients in TDG may exist. A total of twelve TDG instruments, two at the existing real-time FSM stations and ten logging instruments at the transect were used to monitor TDG, temperature, and depth at seven stations or locations.

2.1 Monitoring Locations

Water quality data collected during this evaluation included TDG (mm Hg) and %SAT (relative to atmospheric pressure), water temperature (°C), and depth (m). These parameters were collected at the following locations (see also Figure 3):

1). WANF – Wanapum Dam forebay FSM station, an existing real-time FSM station located near turbine unit 10, mid-channel, at an average depth of five meters, depending on forebay elevations. This data provided information on incoming/background TDG levels for comparison to TDG levels downstream of Wanapum Dam during the evaluation period. An additional sensor was placed at this location during the study period (October 11-24, 2013) for the purpose of this study.

2). T1 – A five-station/nine-sensor TDG transect located approximately 2000 feet downstream of Wanapum Dam. Stations were distributed evenly with flow. The station at the far left-bank side of the transect had one instrument at approximately three- meters deep, while the other four internal transect stations had two instruments each attached together at the same depth to perform as replicates. An average composite TDG value were collected from this transect to determine TDG values produced by the advanced turbines compared to forebay TDG levels. The use of the simpler arithmetic average (e.g. compared to flow-weighted average) is justified at this location based on information collected during the WFB TDG study (Hendrick et. al 2009). During the WFB TDG study (Hendrick et. al 2009), minimal vertical or lateral gradients were observed in TDG data collected at this same location, and a strong correlation between the flow weighted average TDG and arithmetic average TDG was found for the entire study period (July 26 to August 24, 2008).

3). WANT – Wanapum Dam tailrace FSM station, an existing real-time FSM station attached to a pier-nose (nearly mid-channel) of Beverly Bridge, located 3.2 RM downstream of Wanapum Dam. Data collected at this location was used to compare TDG values collected at the transect location (T1) and to verify the advanced turbines ability to meet tailrace TDG water quality standards. An additional sensor was placed at this location during the study period (October 11-24, 2013) for the purpose of this study.

4). BPBU – A backup instrument was placed near the Wanapum Dam tailrace boat launch during the study period to log barometric pressure near the water surface.

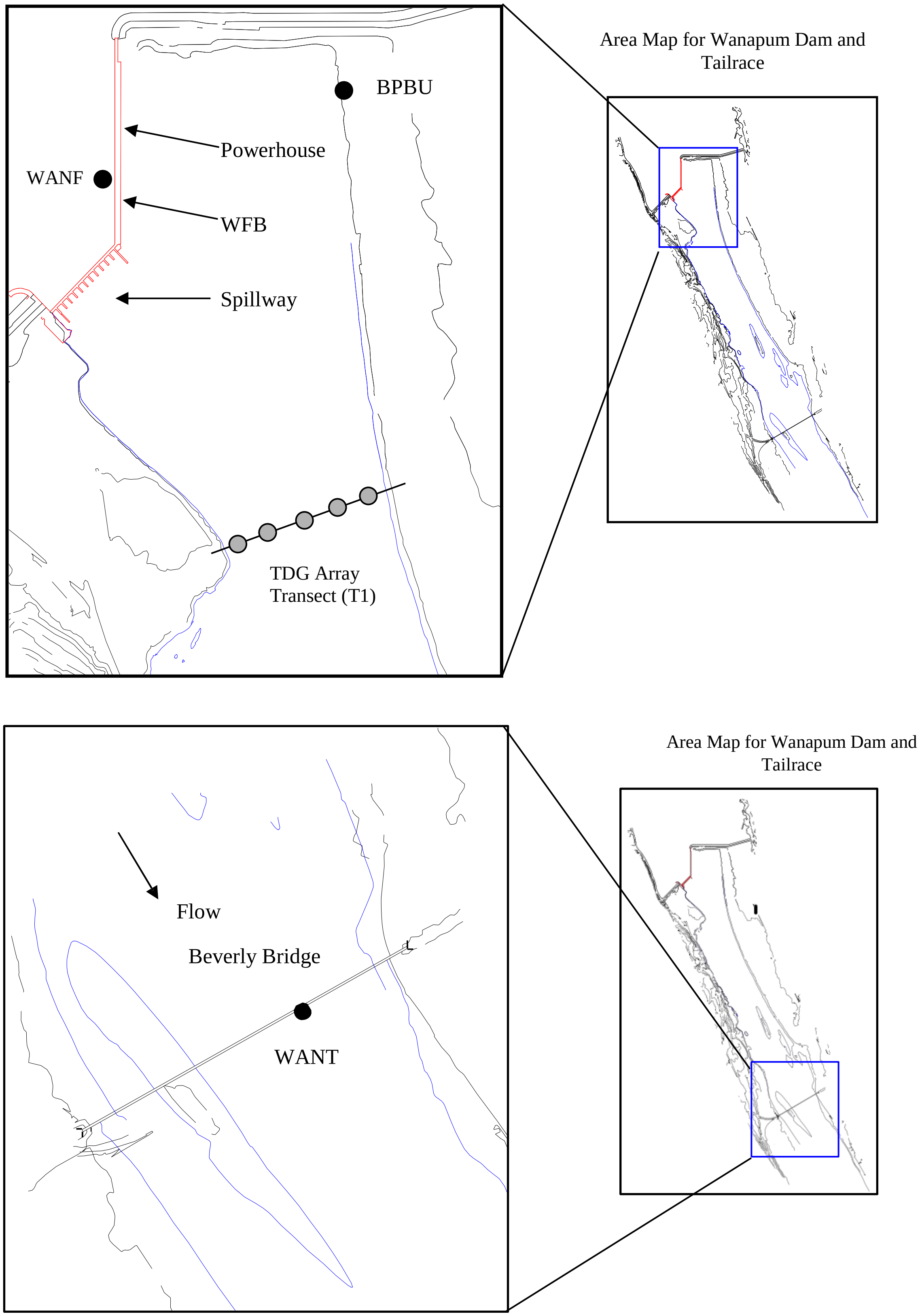

Figure 3 TDG monitoring stations: Wanapum forebay (WANF), barometric pressure backup (BPBU), transect array (T1) and Wanapum tailrace (WANT).

2.2 Water Quality Monitoring Instruments

Logging and/or reporting instruments were used exclusively for the water quality monitoring during the evaluation at Wanapum Dam. The 12 instruments used for this study were wireless and capable of remote logging. All of the monitoring instruments used for this study measure and record date, time, temperature (˚C), depth (m), TDG (mm Hg), and instrument battery voltage (v) for the entire deployment period (October 11-24, 2013).

Programming, calibration, and maintenance procedures of the instruments followed manufacturers' recommendations per instrument manuals (Hach Company 2006) as well as Grant PUD's QAPP (Hendrick 2009). Calibration checks and adjustments were performed on all instruments on October 9, 2013. Post deployment checks on calibration were completed the day after retrieval (October 25, 2013) for evaluation of instrument drift and accuracy (see Appendix A, Table A-2).

2.3 Deployment Methods

Instrument deployment methods for the TDG transect array varied depending on water conditions. In general, instruments were set using normal anchor and buoy cabling for deployment, which included the use of 200 lb. steel housings and anchors attached to a series of surface floats via 5/16 inch diameter steel cable which allowed for the deployment and retrieval of instruments by boat (Figure 4). Surface instruments were deployed inside ABS housings and attached directly to the mainline cable near the floats. All instruments were positioned either near the channel bed or at depths equal to or greater than the compensation depth for TDG, which is the depth in a water column at which the TDG pressure is equal to the hydrostatic pressure. As a rule of thumb, this corresponds to roughly one meter for every ten percent of saturation above 100. The positions of each sampling station or instrument were documented using a standard global positioning system (GPS) instrument onboard the deployment boat.

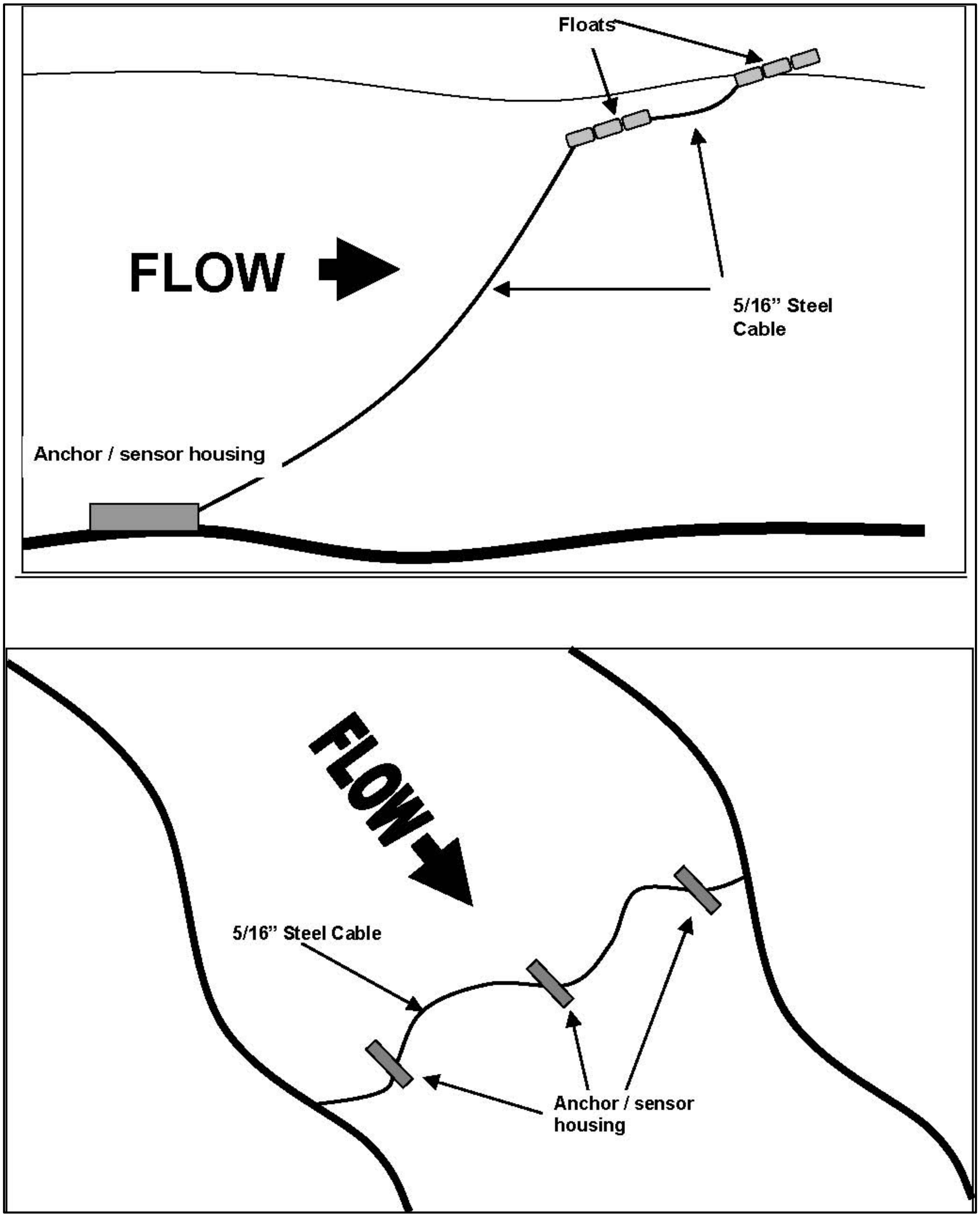

Figure 4 **Schematic of TDG sensor array transects used 2000 feet downstream of Wanapum Dam, mid-Columbia River, WA.**

2.4 Operational Conditions

In order to quantify TDG production associated with operation of all ten of the advanced turbines, TDG data was collected during the operational conditions as displayed in Table 1 below.

Table 1 Proposed vs. Actual operating conditions for the total dissolved gas exchange study at Wanapum Dam, October 2013.

Test	Test Description	Proposed			Actual			Date Completed
		Gate Opening	Turbine Flow	Powerhouse Flow	Gate Opening	Turbine Flow	Powerhouse Flow	
T1	Minimum	60%	9.3	93	60%	9.1	93.3	10/12/2013
T2	Average	77%	13.9	139	77%	13.1	132.5	10/13/2013
T3	Maximum	95%	18.8	180	93%	19.2	193.5	10/14/2013
Note: Flow values shown in kcfs, values for the actual test conditions were averaged over the ~3 hr test period.								

Proposed conditions were defined in the study plan (see Keeler 2012), while the actual conditions were those preformed during the TDG evaluation at Wanapum Dam, and those shown in Table 1 are the average values over each three-hour test periods. For T2, the actual turbine flow was slightly less than predicted for 77% gate opening (13.1 kcfs per unit vs. 13.9 kcfs per unit proposed); however it is unlikely that this difference impacted the results of the test. In addition, for T3 the actual gate opening was 2% less than proposed, but the total flow per unit was, on average, 0.4 kcfs higher than proposed and total average flow was 13.5 higher than proposed.

The difference in the gate opening was due to an over-estimation of the anticipated “maximum” operating condition during the development of the study plan; e.g. the actual maximum operational gate opening is 93%. The additional flow per unit at 93% gate opening was not anticipated, as this was the first time all ten units have been operated at “maximum”; however, the higher flow per unit would, if anything, likely increase any chance for TDG production, and thus any impacts on the TDG test, would have been to increase the “worst-case” scenario of TDG production.

Depth, temperature, and TDG values were collected at 15-minute intervals (starting at the top of the hour) from October 11, 2013 at 0900 hours to October 24, 2013 at 0800 hours for the purpose of this TDG evaluation. Project operational data (flow per unit, total powerhouse flow, percent gate opening, etc.) were collected during the entire study period and are included in this evaluation (see Section 3.0 for more details).

3.0 Results

The following section describes the results of the TDG evaluations performed at Wanapum Dam during mid-October, 2013 to quantify and summarize the TDG values associated with the operation of all ten advanced turbines.

3.1 Targeted Tests

Project operations were held steady for at least three consecutive hours to allow conditions to stabilize during the test. Figure 5 below displays the three targeted test periods (T1, T2, and T3) with corresponding powerhouse discharge and TDG at the WANF, WANT, and transect (T1) locations. Targeted tests 1, 2, and 3 had corresponding discharges of 93.3 kcfs, 132.5 kcfs, and 193.5 kcfs respectively. Note that the remaining TDG values shown on Figure 5 correspond with periods of time when the sluiceway was spilling between 1.5-2 kcfs, and thus likely accounts for the slight differences between upstream and downstream TDG levels during the non-targeted test periods (see Appendix A for additional detail).

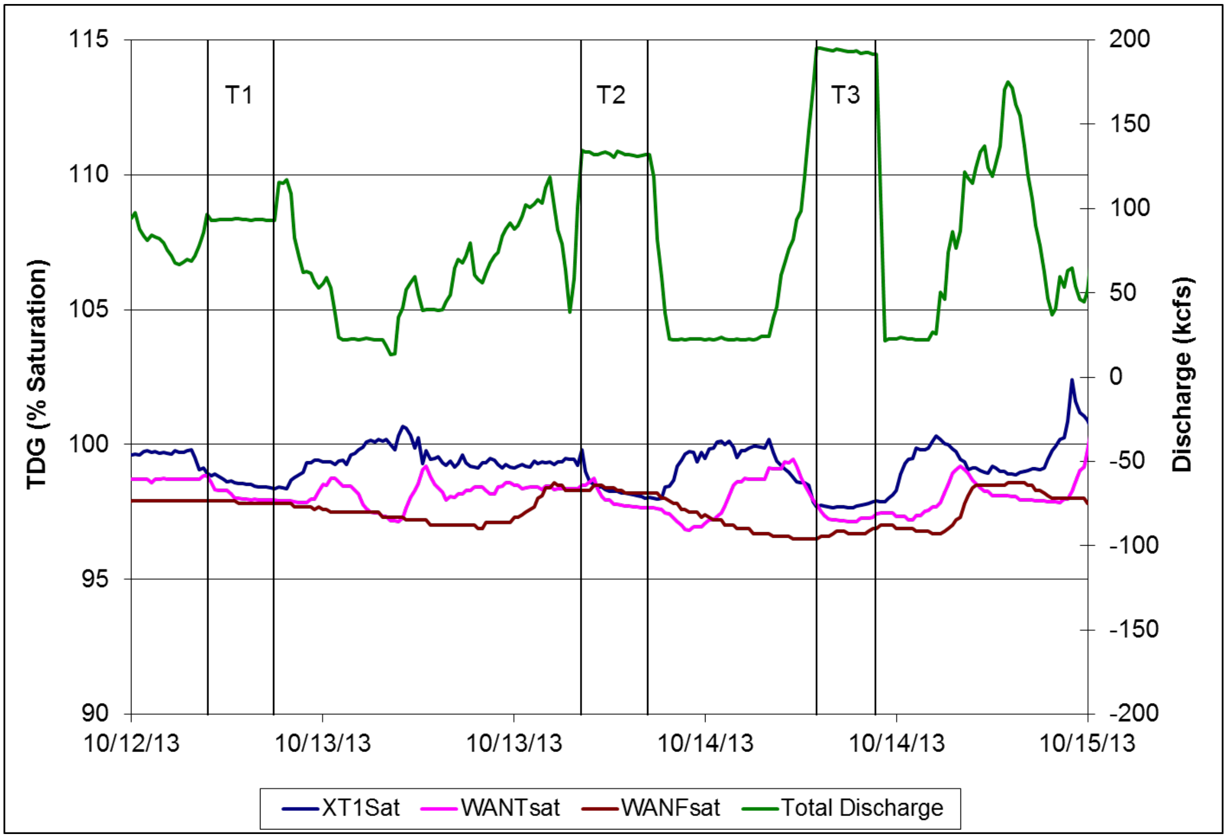

Figure 5 **Average total dissolved gas percent saturation for transect (T1) stations, Wanapum Dam tailrace fixed-site monitoring station (WANT) and forebay (WANF) station with total project discharge.**

Table 2 below displays the summary values of TDG %SAT for each of the three targeted test periods along with the difference in TDG %SAT from forebay (WANF) to transect (T1).

Table 2 **Summary values of total dissolved gas during the targeted test periods.**

Test	Total Discharge (kcfs)	Gate Opening (%)	WANF (%SAT)	T1 (%SAT)	WANT (%SAT)	Delta TDG (T1 – WANF)
T1	93.3	60	98.3	98.4	98.2	0.1
T2	132.5	77	98.7	98.1	97.9	-0.6
T3	193.5	93	97.4	97.8	97.7	0.4

3.2 Incidental Tests

The field study period was extended for ten additional days in order to record any incidental periods when operational requirements were inadvertently met and the resulting data could possibly be used for further evaluation of the advanced turbine operation. After further analysis of the project operation data it was determined that there were ten additional periods during the study period when consistent operating conditions were met for a minimum of three consecutive hours.

The difference in TDG %SAT between the Wanapum forebay and the TDG array transect for the incidental test periods (with sluiceway spill) ranged from -0.1 %SAT to 2.0 %SAT for an overall mean difference of 0.9 %SAT. Given that the sluiceway was operating during these incident test periods, these incidental test results further suggest that the new turbines at Wanapum Dam do not materially increase TDG levels during all operating levels. It is important to note that the ice/trash sluiceway was not operational during the three targeted test periods, but spill from the sluiceway did occur (1.5 - 2.3 kcfs) during all other periods of the TDG evaluation. This sluiceway is operated to provide adult fall back for migrating salmonids and because of the record fall run of adult Chinook salmon in 2013, Grant PUD was not able to close the sluiceway for the entire study period. Additionally, during these incidental test periods it is important to note that Wanapum Dam was operated as a nine-unit project. A unit was taken offline in order to perform the generator replacement project. For more information on the additional testing periods identified during the study period see Appendix A of this report.

4.0 Conclusions

The difference in TDG %SAT between the Wanapum forebay and the TDG array transect (T1) for the targeted test periods (without sluiceway spill) were 0.1 %SAT for Test 1, -0.6 %SAT for Test 2, and 0.4% SAT for Test 3 for an overall mean difference of -0.02%. Given that the sensors used to the collect TDG values for this study have an accuracy ± 0.15 %SAT and sensitivity/resolution of 0.1 %SAT (see Section 2; Hach Company 2006), the differences observed during the targeted tests suggest that the new advanced turbines at Wanapum Dam do not materially increase TDG levels during minimum, average, and maximum operating conditions.

The difference in TDG %SAT between the Wanapum forebay and the TDG array transect (T1) for the incidental test periods (with sluiceway spill) ranged from -0.1 %SAT to 2.0 %SAT for an overall mean difference of 0.9 %SAT (see Appendix A for additional information related to the results of the incidental tests). Given that the sluiceway was operating during these incidental test periods, these incidental test results further suggest that the new advanced turbines at Wanapum Dam do not materially increase TDG levels during regular operation conditions.

Literature Cited

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Appendix A
Wanapum Dam Advanced Turbine TDG Evaluation Data Report

1.0 Introduction

The following sections provide supplementary details related to the Wanapum Dam Advanced Turbine Total Dissolved Gas Evaluation study that was conducted during October 2013. The objective of this study was to evaluate total dissolved gas (TDG) across the river channel downstream of Wanapum Dam with the advanced turbines operating at varying conditions (at minimum/maximum capacity within the cavitation limits and within standard water elevation levels) to determine whether the operation of the advance turbines significantly affects TDG saturation during normal project operations.

Below is a summary of the details contained in this appendix:

- Information on the type of instruments that were deployed, including GPS- determined locations, depths of deployment, and quality assurance/quality control (QA/QC);
- Details on flow rates, water levels, water temperatures and barometric pressures associated field testing of the study;
- Details on the methods and results of data reduction and analysis, including:
    - Discussion of the raw TDG data recorded on each TDG sensor from all the monitoring stations during the study period, including QA/QC results;
    - Elimination of two T1 transect sensors from the analyses due to sensor failure;
    - Determination of the arithmetic mean TDG across the entire T1 transect, and its comparison to upstream and downstream TDG values under varying flow conditions.

2.0 Data Collection Methods, QA/QC and Operational Conditions

The following sections provide a summary of the data collection methods that were used during the study period, including descriptions of TDG sensors, calibration and quality assurance/quality control methods, location of the TDG sensor array, and proposed operational conditions. The study period began on October 10, 2013, with the installation of the in-field TDG sampling instruments approximately 2000 feet downstream of Wanapum Dam. The study period ended on October 24, 2013 with the removal of all test instruments. For a more detailed description of the methods used for this study, see the study plan (Keeler 2012).

This study utilized an array of remote instruments capable of logging time histories of TDG pressures at numerous locations up and downstream of Wanapum Dam. Hach Corporation Hydrolab MiniSondes and DataSondes with TDG sensors, temperature, and depth sensors were used to record data. A total of 12 TDG instruments were used to monitor TDG (millimeter of mercury (mm Hg)), temperature (°C), and depth (m) at seven stations or locations. Instruments were paired at the same depth for all of the deeper stations to avoid data loss and to examine sampling error associated with instruments. In addition TDG percent saturation (%SAT) were calculated using ambient air pressure and TDG pressure. Measurements were made on 15-minute intervals for the duration of the study. Project operations data including total river flow, powerhouse discharge, spillway discharge, Wanapum sluiceway discharge, forebay and tailrace elevations were also collected on 15-minute intervals.

Atmospheric conditions of air temperature, barometric pressure (not corrected to sea level), and wind speed and direction were collected at the Wanapum Dam weather station to determine potential atmospheric influences on TDG levels. Barometric pressure/air pressure data was also collected just above the water surface near the forebay and tailwater fixed-site monitoring stations (FSM stations) owned and operated by the Public Utility District No. 2 of Grant County, Washington (Grant PUD). A temporary logging instrument was maintained at/near the tailwater boat launch during the field-testing period to be used as backup barometric pressure data. The actual barometric pressure for each sample station location was determined from the closest logging barometer operated by Grant PUD.

2.1 Monitoring Locations

Water quality data collected during this study included TDG (in mm Hg and %SAT relative to atmospheric pressure), water temperature, and sample depth. These parameters were collected at the following locations (see also Figure A-1):

- WANF - Wanapum Dam forebay FSM station, an existing real-time TDG monitor located near turbine unit 10, mid-channel, at an average depth of five meters, depending on forebay elevations. A second logging instrument was placed at this location for the purpose of this study. This data provided information on incoming/background TDG levels for comparison to TDG levels downstream of the project during project test operations.
- T1 - A five-station/nine-instrument TDG transect located approximately 2000 feet downstream of Wanapum Dam. Stations were distributed as evenly as possible across the river. The left bank instrument was placed in shallow water at approximately ten feet of depth; the remaining four stations had two paired instruments each. The paired instruments were attached together with the sensors positioned at two feet up from bottom. The location of the transect was selected because of its position in the river where it narrows, developing uniform flowlines that are essentially parallel to the left bank and parallel across the section. There are minimal back eddies at this river section to confound the data analysis based on velocity transects collected at this section previously (see Carroll et al. 2001, Schneider et al. 2001).
- WANT - Wanapum Dam tailrace FSM station, an existing real-time TDG monitor attached to a pier-nose (mid-channel) on Beverly Bridge, located 3.2 river miles downstream of Wanapum Dam. A second logging instrument was placed near the river bottom at this station for the purpose of this study. Data collected at this location was used to compare TDG values collected at the T1 transect and to verify the advanced turbines ability to meet tailrace TDG water quality standards.
- BPBU – A backup instrument was left near the Wanapum Dam tailrace boat launch for the duration of the study to log barometric pressure near the water surface.

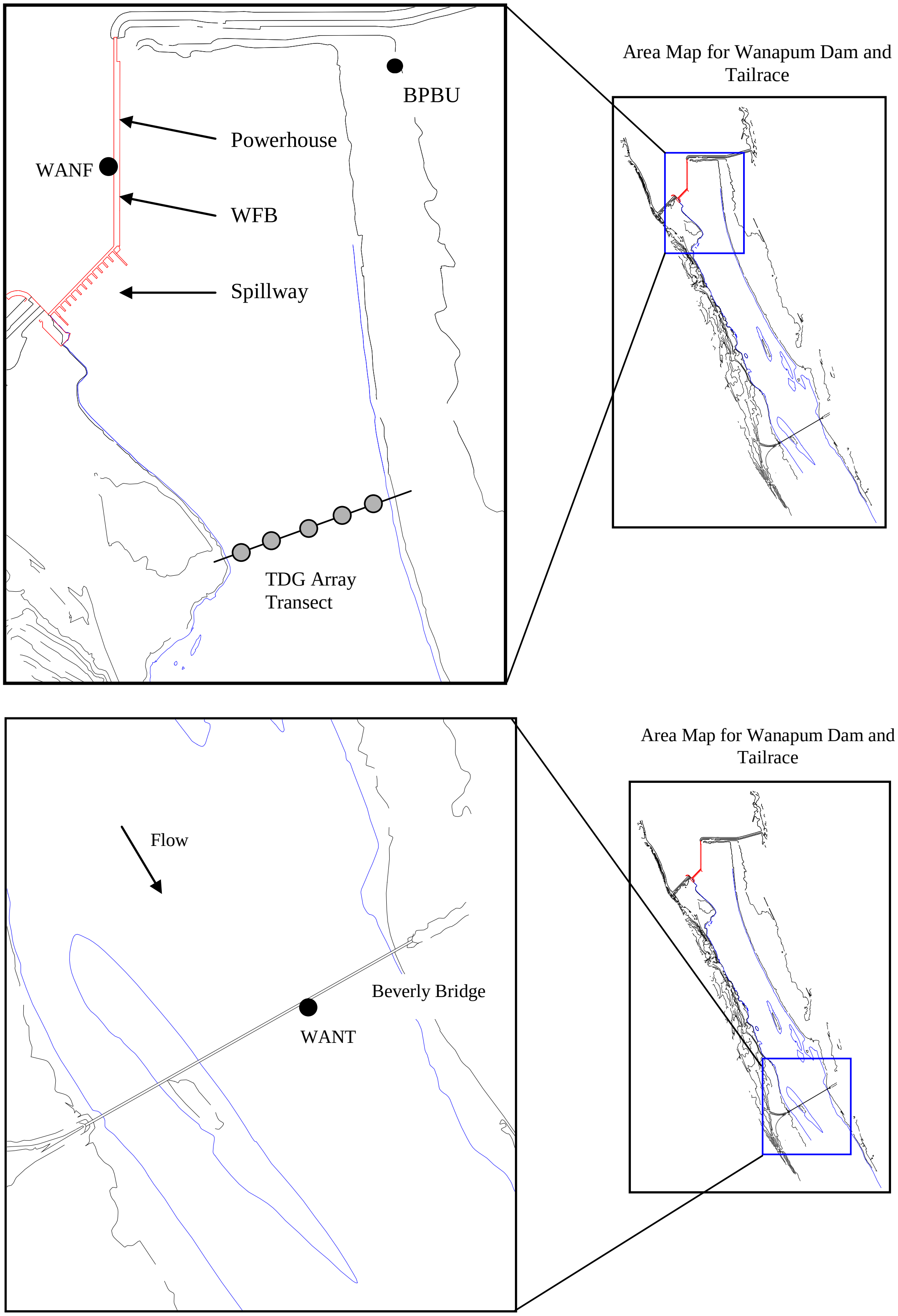

Figure A-1 TDG monitoring stations: Wanapum forebay (WANF), barometric pressure backup (BPBU), transect array (T1) and tailrace (WANT).

2.2 Water Quality Monitoring Instruments and Deployment Methods

A total of twelve TDG monitoring instruments were deployed for this study using rigging methods as described in the study plan developed for this project (Keeler 2012). The instruments were programmed to record measurements of TDG pressure (mm Hg), water temperature (°C), depth (m), and battery voltage on 15-minute intervals for the duration of the study. Pre-deployment instrument calibrations were completed on October 9, 2013, per manufacturer's specifications (Hach Corporation 2006).

Ten instruments were deployed on October 10, 2013. Nine were distributed laterally across the T1 transect as described in the study plan (Keeler 2013). The transect is approximately 1400 feet in length and 2000 feet downstream of Wanapum Dam and consists of five stations arranged laterally across the river channel. Starting on the river left downstream, the stations were given the names of T1P1, T1P2, T1P3, T1P4, and T1P5. The "T1" stands for Transect 1 and the "P" indicates the position across the river. Stations T1P2, T1P3, T1P4, and T1P5 all had two instruments deployed on the same cable. The paired instruments were attached together at the same depth to perform as replicates. Station T1P1 had only one instrument attached to the cable near the river bottom. Adding an "A" or "B" to the label, T1P3A or T1P3B was used to identify replicate instruments. The last station to be deployed on October 10, 2013, labeled WANTBU, was placed adjacent to the Grant PUD's Wanapum Dam tailrace FSM station, on the river bottom at approximately 23 feet of depth.

Deployment of the transect instruments was determined by distance from the right bank. The entire transect from bank to bank was approximately 1400 feet wide, and project discharge ranged from approximately 80 up to 123 kcfs during deployment.

An additional TDG station was established on October 11, 2013. This one named WANFBU was placed adjacent to the Grant PUD's Wanapum Dam forebay FSM station near the intake for turbine unit 10 on the powerhouse at approximately 20 feet of depth. Lastly, a second instrument labeled BPBU was placed near the Wanapum Dam tailrace boat launch at 10' elevation above the tailwater surface to log barometric or air pressure during the test period.

The deployment information for each station and instrument is shown in Table A-1 below. The information displayed includes station, replicate (A or B), instrument type/model, serial number, deployment date, time, way point position (WGS84 decimal degrees), approximate station depth, approximate distance from left bank. The position of each sampling station or instrument was documented using a Garmin GPSMAP 76© onboard the deployment boat.

Table A-1 Station and instrument information during initial deployment.

Station	Hydrolab Model	SN	Date	Time	Latitude Longitude	Depth (ft)	Dist (ft)
WANTWBU	MS5	62950	10/10	1550	46.8335° 119.9419°	24	
WANFBU	DS4a	39850	10/11	0900	46.8748° 119.9717°	20	
T1P1	DS4a	39851	10/10	1415	46.8680° 119.9634°	10	150
T1P2A	MS5	44948	10/10	1525	46.86790° 119.9645°	33	400
T1P2B	DS4a	37261	10/10	1525	46.86790° 119.9645°	33	400
T1P3A	MS5	44927	10/10	1500	46.86760° 119.9656°	29	690
T1P3B	DS4	31405	10/10	1500	46.86760° 119.9656°	29	690
T1P4A	MS5	44945	10/10	1512	46.86706° 119.9668°	26	1000
T1P4B	DS5	39849	10/10	1512	46.86706° 119.9668°	26	1000
T1P5A	DS5	39855	10/10	1440	46.86656° 119.9676°	14	1300
T1P5B	DS4	30948	10/10	1440	46.86656° 119.9676°	14	1300
BPBU	DS4a	37260	10/10	1200	46.876981° 119.9576°		

Instrument deployment methods varied depending on the location, water condition, and depth. In general, instruments were set using a normal anchor and buoy system and/or shore based cabling for deployment. Anchor and housing weighed approximately 200 pounds and were attached to a series of surface floats via 5/16 in diameter steel cable that allows deployment and retrieval of instruments by boat. All instruments were deployed inside ABS housings and attached directly to the mainline cable near the anchors at depths greater than the equivalent of one half-atmosphere pressure (approximately 15 feet) where possible.

2.3 Calibration and Maintenance

Quality control in the field was assured by completing accurate and thorough field notes and other necessary documentation. Programming, calibration, and maintenance procedures of the instruments followed manufacturers' recommendations per instrument manuals (Hach Corporation 2006). Calibration checks and adjustments were performed on all instruments within one day prior to initial deployment. Post deployment checks on calibration were completed for evaluation of instrument drift and accuracy on the day following retrieval (October 25, 2013).

During the pre-deployment calibrations all instruments were set to read within +/-1 mm Hg of the atmospheric pressure. The instruments were also corrected to read +/- 1 mm Hg of the air pressure plus 200 mm Hg for the slope checks. During the post deployment checks all instruments were within +/- 2 mmHg of the atmospheric pressure and no corrections or changes were required. The calibration information for both the pre- and post-deployment checks is included in Table A-2 below.

Table A-2 Instrument calibration, pre-deployment, 10/09/2013, and post-retrieval calibration check, 10/25/2013.

Station	Model	SN	Pre Test BP (ΔmmHg)	Pre Test Span BP+200 (ΔmmHg)	Post Test BP Check (ΔmmHg)	Post Test Span BP+200 (ΔmmHg)
WANTBU	MS5	62950	0	0	0	1
WANFBU	DS4a	39850	0	0	-1	2
T1P1	DS4a	39851	0	0	1	1
T1P2A	MS5	44948	0	0	0	1
T1P2B	DS4a	37261	0	0	0	1
T1P3A	MS5	44927	0	0	0	1
T1P3B	DS4	31405	-1	0	N/A	N/A
T1P4A	MS5	44945	0	0	-1	2
T1P4B	DS5	39849	-1	0	0	1
T1P5A	DS5	39855	0	0	0	1
T1P5B	DS4	30948	-1	0	N/A	N/A
BPBU	DS4a	37260	1	0	0	1
N/A=not applicable. These two instruments had faulty membranes and thus were not given post-deployment checks.						

The tensionometers used for measuring TDG pressures employ semi-permeable membranes connected to pressure transducers with associated electronics to directly measure *in-situ* total dissolved gas pressure in water.

Air calibrations for TDG were performed using a certified mercury column barometer. The TDG sensors were calibrated by comparing the instrument readings (in mmHg) to those of the standard barometer at atmospheric conditions. Response slope or span checks were performed by adding 200 mm Hg of pressure directly to the transducer, and then adjusting the instrument span reading accordingly to properly span the range of interest. The calibration process was repeated as needed to verify and readjust the calibration points.

The condition of the membrane and any condensation trapped inside it can influence readings and result in erroneous data or instrument calibration. An inspection for leaks was performed on the membrane itself before completing the calibration routine. Defective membranes were replaced. Two of the instrument membranes failed as soon as the equipment was placed at depth at the station. This resulted in no data logs from the T1P3B and the T1P5B instruments.

2.4 Data Completeness, Quality, and Consistency with Conditions

The TDG datasets resulting from the study were complete for all stations. The only data losses resulted from the two replicate instruments membrane malfunctions at T1P3B and T1P5B resulting in no actual loss for the stations. There were no power failures for any of the instruments. Grant PUD’s Wanapum forebay FSM station barometric pressure data was used to determine %SAT for the two forebay instruments and the Wanapum Dam tailrace FSM station barometric pressure data was used to calculate all of the downstream or tailwater station TDG %SAT. Instrument calibration post checks revealed only minor differences with the known standard pressures, +/- 1 mm Hg. This would have minimal impact on instrument operation during field- testing. The data quality and consistency is considered good for completion of the evaluation testing.

2.5 Operating Conditions

Every attempt was made to hold project operations steady for at least three consecutive hours to allow conditions to stabilize in the tailrace. This was done to achieve equilibrium in flow conditions/patterns, tailwater elevations, and a resulting equilibrium in TDG characteristics downstream of the project to the Wanapum Dam tailrace FSM station. The project test operations began on October 10, and continued until October 24, 2013. The three individual specified tests were completed by mid-day October 14. The field study was continued for ten additional days in order to document any incidental periods when test requirements were inadvertently met and the resulting data may be used for further evaluation of the advanced turbine operation. There were ten additional periods during the study when relatively constant operating conditions were met for a minimum of three hours. Note that the Wanapum sluiceway operation was shut down completely during the three targeted test periods but spilled between 1.5 - 2.3 kcfs during all other periods of the field study, which likely resulted in minor increases in TDG levels downstream of Wanapum Dam. Additionally, it should be noted that during these additional test periods the project was operated as a nine-unit project, as one unit was taken out of service in order to begin preparation for the generator replacement project. Table A-3 below displays the applicable information on the proposed vs. actual operational conditions during the test periods.

Table A-3 Proposed vs. Actual operating conditions for the total dissolved gas exchange study at Wanapum Dam, October 2013.

		Proposed			Actual			
Test	Test Description	Gate Opening	Turbine Flow	Powerhouse Flow	Gate Opening	Turbine Flow	Powerhouse Flow	Date Completed
T1	Minimum	60%	9.3	93	60%	9.1	93.3	10/12/2013
T2	Average	77%	13.9	139	77%	13.1	132.5	10/13/2013
T3	Maximum	95%	18.8	180	93%	19.2	193.5	10/14/2013

Note: Flow values shown in kcfs, values for the actual test conditions were averaged over the 3 hr test period.

2.6 Data Collection Schedule

The study began in the field with the installation of all monitoring instruments at 1600 hrs on October 10, 2013. The study ran for a total of 14 days and was completed on October 24 at 0800 hr with the final retrieval of all instruments. Powerhouse operation was variable as required for power production for the entire study period.

Retrieval of all test instruments was completed on October 24 with no equipment loss. All 12 of the test instruments functioned properly through all or most of the test period meeting the manufacturers specifications for accuracy at standard pressure based on recommended calibration procedures. However two of the 12 instruments experienced TDG membrane failure early in the testing period.

Data was reviewed for completeness, quality and consistency with conditions. There were no data gaps (time or parameters) identified for the instruments. The FSM station data logs had missing data only during a one-hour period of equipment maintenance on October 16, 2013. The water quality data (TDG and temperature) were merged with operations data according to date and time. All data including operations information was reported at 15-minute intervals (on the hour and quarter hours).

Limited analysis of TDG measures paired at the same stations and depths was reviewed for sample precision. Outliers and data that that were outside of the quality objectives were evaluated to determine the cause of the problem. Slight exceedances of <1 %SAT were tolerated with the data quality and the accuracy taken into account in the data analysis. Exceedances that were traced to membrane failure resulted in the rejection of the data from the dataset. As described in Sections 2.3 and 2.4 two of the TDG membranes for instruments T1P3B and T1P5B failed early in the test resulting in the data being biased to read the hydrostatic pressure from depth. The resulting data logs were not used in the final analysis.

3.0 Data Reduction

The following sections provide additional information related to the QA/QC results from the data collected during the study, and also provides more detail on the hydrology and project operations, operational test results, together with raw and reduced TDG data from each monitoring location.

3.1 Hydrology and Project Operations

The mean daily discharge at Wanapum Dam ranged from 60 kcfs up to 108 kcfs (Figure A-2) during the test period. The project operations data included total river flow, powerhouse discharge, spillway discharge, sluiceway discharge, forebay elevation, and tailwater elevation were collected as part of the normal Wanapum Dam data collection program on 15-minute intervals. The project operations data were then merged with the field study water quality data sets for TDG and water temperature.

Figure A-3 displays detailed 15-minute interval time histories of the operations/discharge data during testing. This close interval project data was highly variable depending on total river flows, power requirements, and testing needs. During the non-targeted test periods the sluiceway was operated fairly constant at approximately 2 kcfs and the total project operation varied from 22 to 195 kcfs. The sluiceway was held to 0 kcfs operation during the targeted testing periods. The fish ladder operation was maintained at 2 kcfs throughout the entire test period. The spillway was not operated during the field testing.

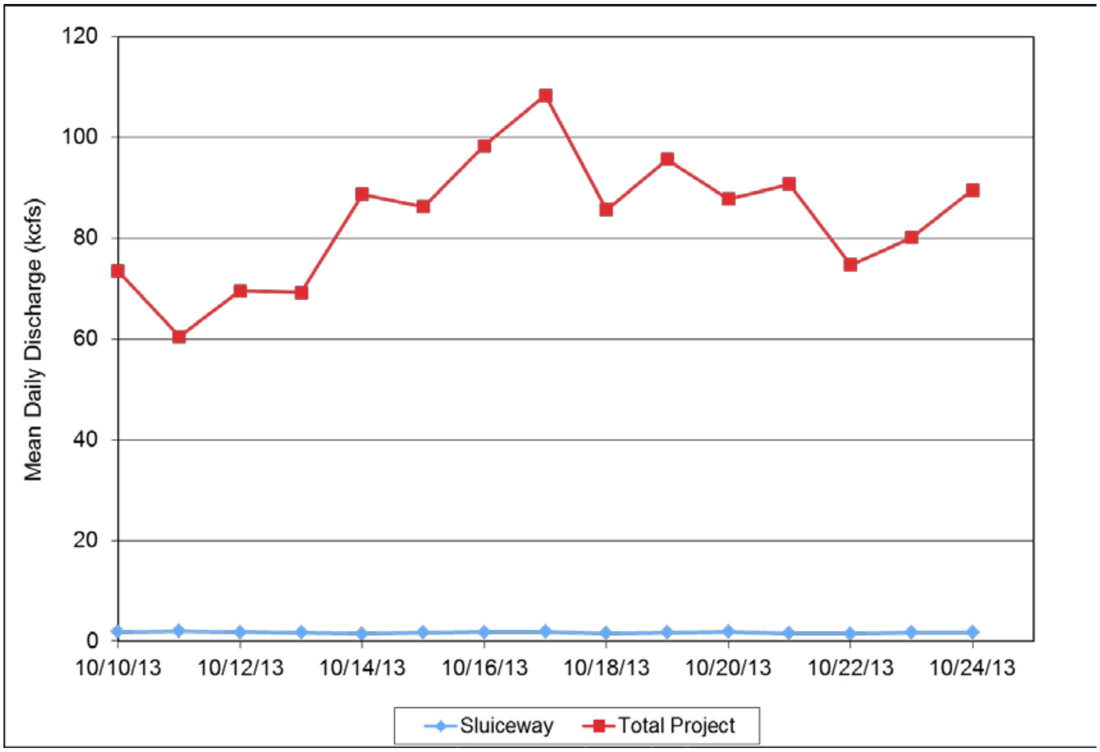

Figure A-2 Columbia River mean daily discharge at Wanapum Dam during the field testing.

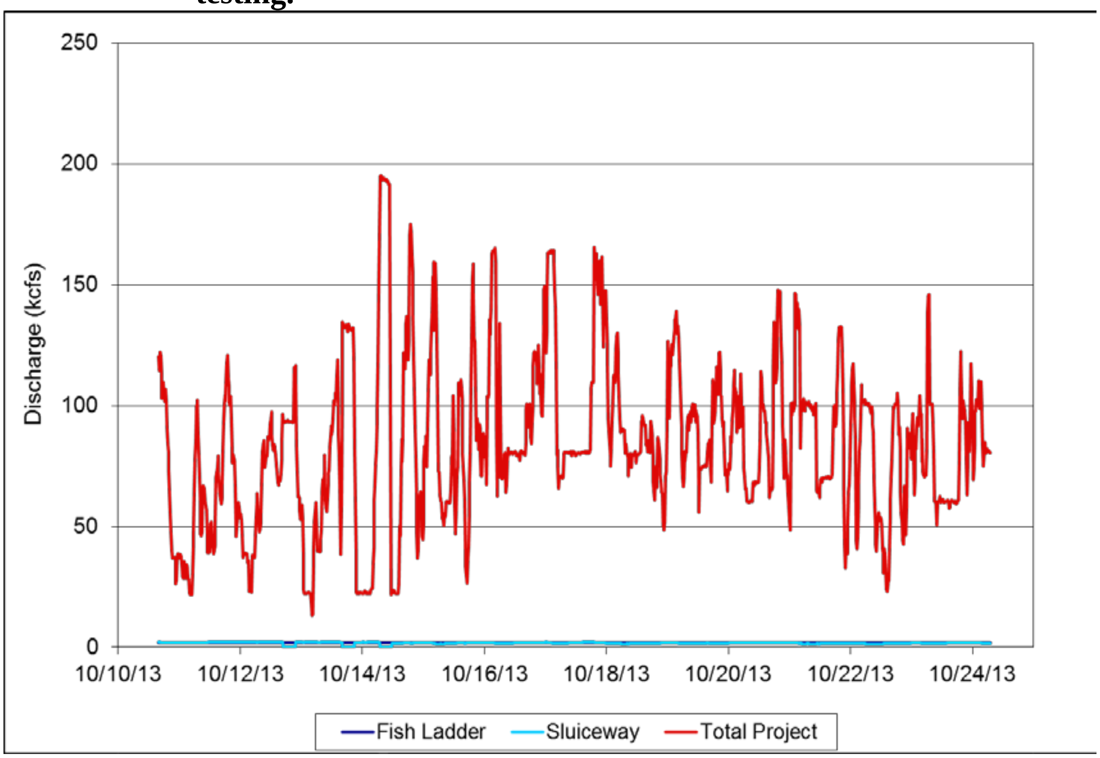

Figure A-3 Columbia River 15-minute interval discharge at Wanapum Dam during the field testing.

The Wanapum Dam forebay and tailwater surface elevations (ft msl) are presented as 15-minute detailed time histories in Figure A-4. Both fluctuated during the study as determined by river flow conditions. Forebay elevations varied over a range of 3.3 ft from 567.9 ft to 571.2 ft msl with a mean daily average of 569.6 ft for the duration of the testing. Tailwater elevations varied over 9.5 feet with project flow changes from a minimum of 484.5 ft to a maximum of 494.0 ft msl and averaged 488.7 ft msl for the test period.

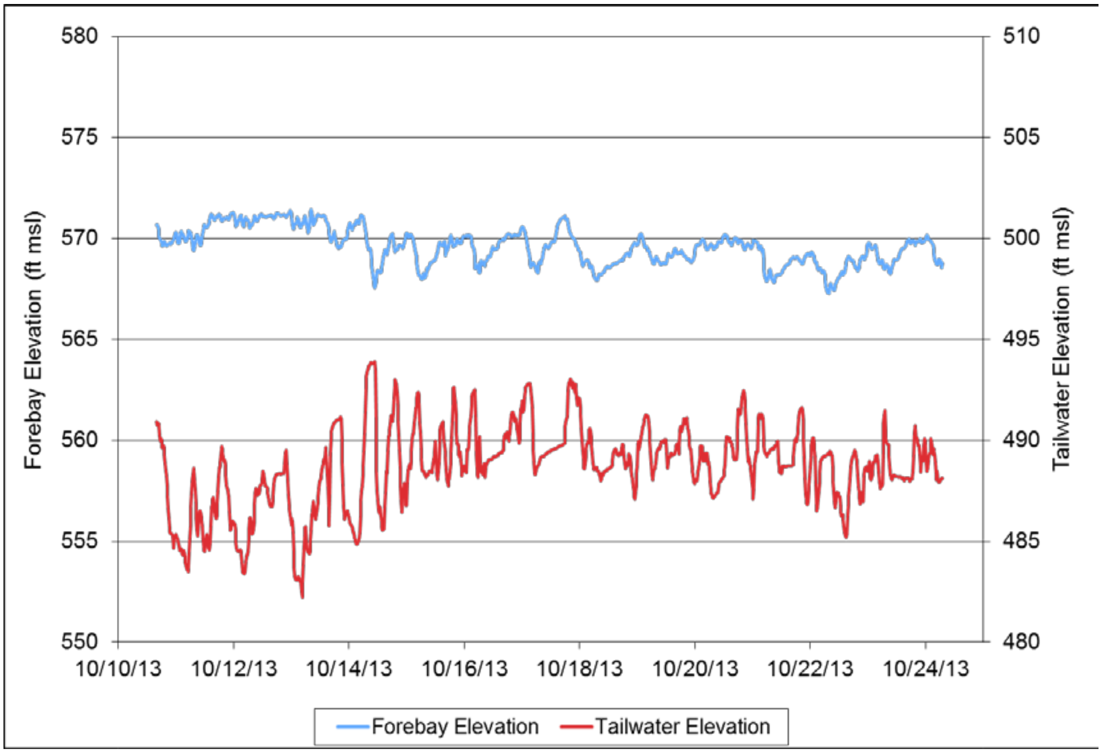

Figure A-4 Forebay and Tailwater 15-minute interval elevations for Wanapum Dam during the field testing.

3.2 Operational Tests/Target Operations

As previously stated, the field study was designed to evaluate TDG downstream of Wanapum Dam during operation of all ten advanced turbines, with the sluiceway operation at zero discharge for as long as possible under the river flow and power production constraints. The initial time required for reaching equilibrium conditions in downstream hydrodynamics and associated TDG was three hours. The three targeted conditions are described in Section 2.4 that also describes the occurrence of ten periods when conditions were constant for a minimum of three hours due to incidental constant project operations. Unlike the targeted test during these incidental test periods the sluiceway was spilling approximately 2 kcfs and unit operation was non-uniform across the powerhouse and consisted of only nine units. A total of 13 test periods (three targeted tests and ten incidental tests) were identified during the study meeting the time requirements for controlled operating conditions.

Average conditions both in project operations and water quality conditions were determined for each identified tests. Average operations were calculated from the beginning to end of each test period. The average TDG for a test was determined from data representing the steady state period for a particular station. For the downstream stations a time lag was determined using visual observations of data time histories and average velocities and travel time as determined from numerical model results for the various river discharges. The time lag determined for the T-1 transect stations were two hours following initiation of a test. The test data collection period extended 30 minutes beyond the end of steady state operating conditions. For a three hour test period this would result in a minimum of one hour of data or four readings per instrument. The Wanapum Dam tailrace FSM station data representing each test was collected from 2.5 hours following test initiation and continued until one hour following the test ending. Based on the time of each controlled test this approach resulted in an approximate range of 3.5 to 8 hours of data collection at 15 minute intervals for use in calculating the test statistic or average by station.

Figure A-5 details the three targeted test periods with powerhouse discharge and resulting downstream TDG %SAT. Targeted test 1, 2, and 3 had corresponding discharges of 93.3 kcfs, 132.5 kcfs, and 193.5 kcfs respectively. The corresponding TDG can be identified on the plot as well. This type of data plots were used extensively in determining equilibrated TDG conditions to associate with the individual tests.

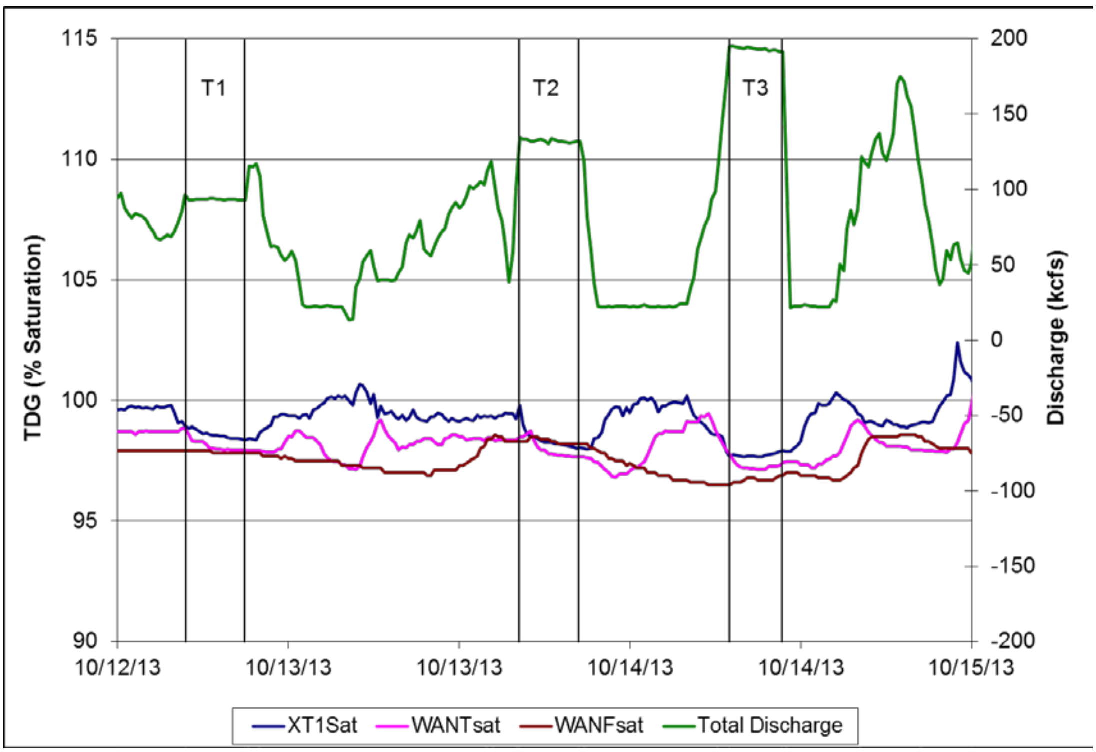

Figure A-5 Mean TDG percent saturation for transect (T1) stations, Wanapum tailrace (WANT) and forebay (WANF) stations with total project discharge.

Figure A-6 is an expansion of Figure A-5 to cover the entire study period and the time of occurrence of each test. A complete listing of descriptive statistics is presented in Table A-4 for each of the 13 tests identified between October 10 and October 24, 2013. The constant project discharges for the 10 incidental tests varied from a mean of 22 kcfs up to 100 kcfs.

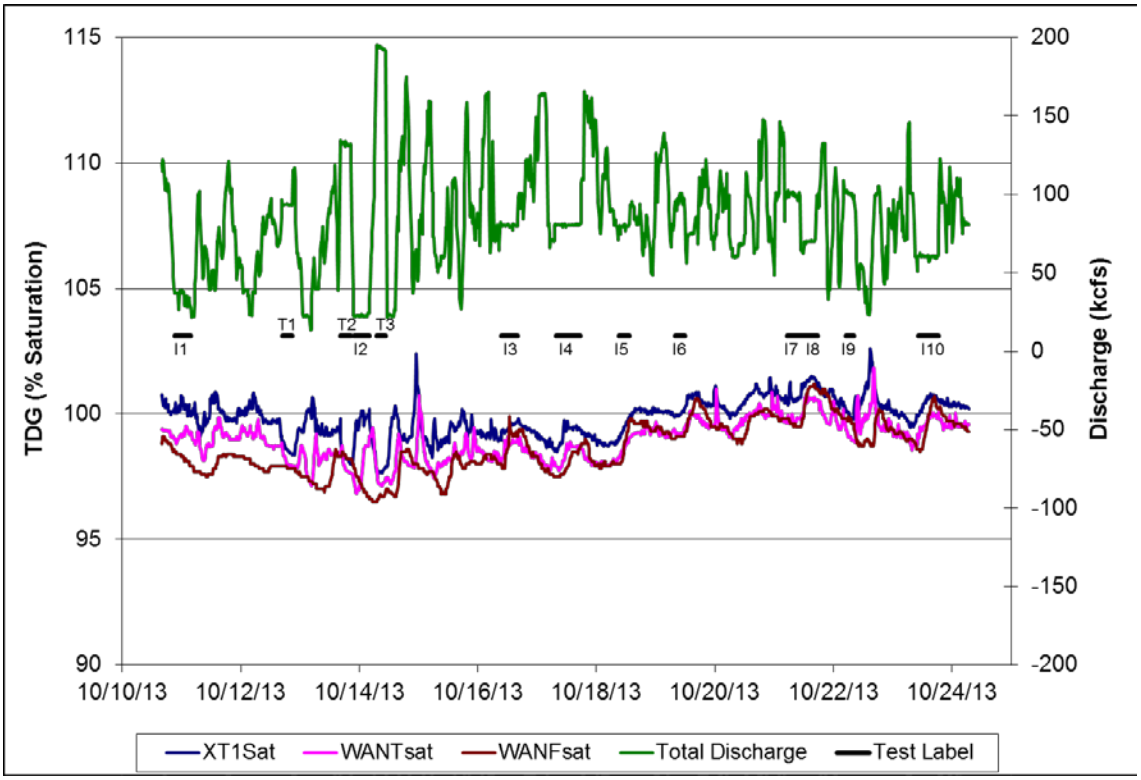

Figure A-6 Mean TDG percent saturation for transect T1, Wanapum tailrace (WANT) and forebay (WANF) with powerhouse discharge for the complete study period.

Table A-4 Summary data for each of the tests.

Test	Total Discharge (kcfs)	WANF (%SAT)	T1 (%SAT)	WANT (%SAT)	Delta TDG T1-WANF
T1	93.3	97.8	98.4	97.9	0.6
T2	132.5	98.3	98.1	97.6	-0.2
T3	193.5	96.7	97.8	97.4	1.1
I1	32.2	98.1	100.2	99.2	2.1
I2	22.6	97.2	100.0	98.5	2.8
I3	80.1	98.8	99.5	98.9	0.7
I4	80.5	98.0	99.3	98.6	1.3
I5	79.5	98.7	99.6	99.0	0.9
I6	96.1	99.1	100.1	99.4	1.0
I7	99.7	99.6	100.5	99.8	0.9
I8	70.1	100.9	101.3	100.6	0.4
I9	100.2	99.7	100.0	99.1	0.3
I10	60.3	99.6	100.5	99.4	0.9

Note: Tests T1 – T3 were the targeted test in accordance with the study plan (Keeler 2012); test I1 – I10 were incidental tests (during which the sluiceway was spilling between 1.5 – 2.3 kcfs).

It is important to note that the ice/trash sluiceway was not operational during the three targeted test periods (T1 – T3), but spill did occur (between 1.5 - 2.3 kcfs) during all other periods of the TDG evaluation, including the incidental test periods (I1 – I10). This sluiceway is operated to provide adult fall back for migrating salmonids and because of the record fall run of adult Chinook salmon in 2013, Grant PUD was not able to close the sluiceway for the entire study period. Additionally during these incidental test periods it is important to note that Wanapum Dam was operated as a nine unit project. A unit was taken offline in order to perform the generator replacement project.

Spikes in TDG occurred on a few occasions at the extreme stations of P5 (far left-bank side) and P1 (far right-bank side) with the highest levels associated with the extreme left-bank station P5 and somewhat at the next station, P4. This apparent gradient went away during periods of no sluiceway operation, indicating minor TDG increases in the left-bank flow downstream from sluiceway operation. Additionally, during incidental tests 1 and 2 the sluiceway flow made up approximately 6% and 9% of the total project flow, respectively. This could be a possible explanation as to the slightly higher TDG deltas seen during incidental tests 1, 2, and 4 in Table A-4.

All of the average test TDG data for the WANF, WANT, and transect T1 is presented in Figure A-7. Values to the left of the black line were collected during the targeted test periods have the sluiceway off and with all ten advanced turbines operating, while the data on the right was collected during the incidental periods were the sluiceway was in operation and the project operated with only nine advanced turbine units. The mean difference between WANF and T1 transect TDG for the targeted tests (T1 – T3) was -0.02 %SAT, while the mean difference for the incidental tests (I1 – I10) was 0.9 %SAT. The mean difference between WANF and WANT during the targeted tests was -0.2 %SAT, while the mean difference between WANF and WANT for the incidental tests periods was 0.3 %SAT.

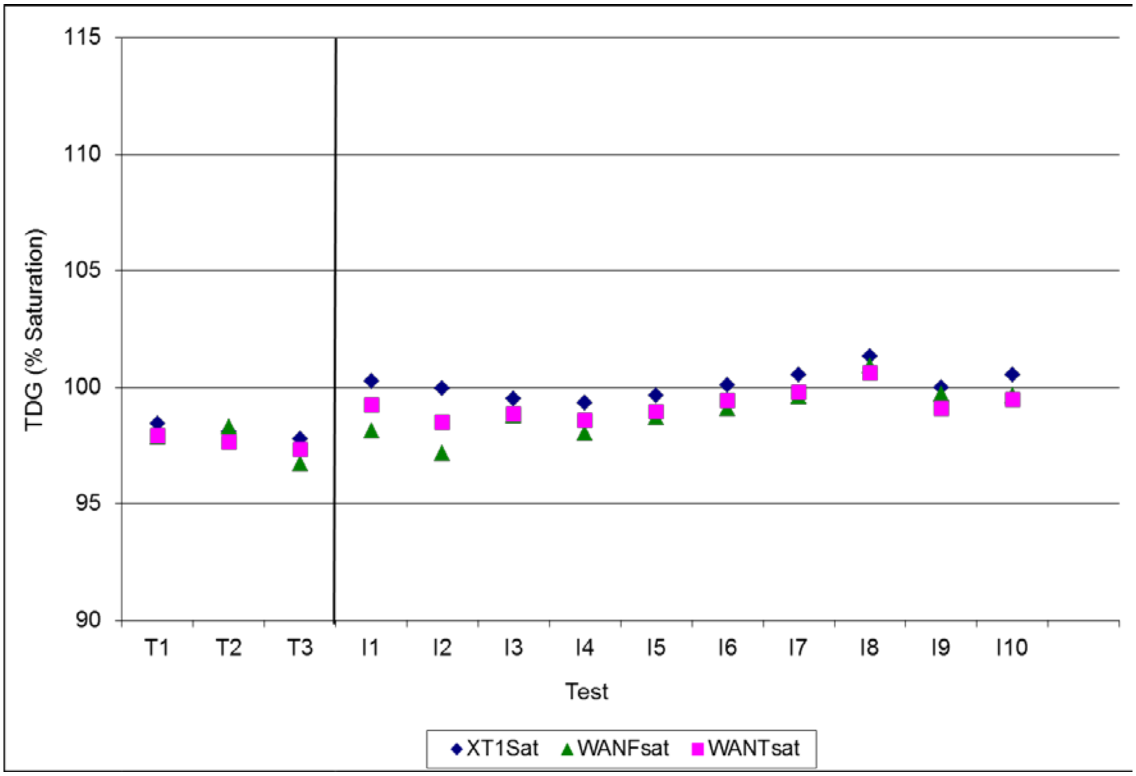

Figure A-7 Average TDG levels recorded at the T1 transect, tailrace (WANT) and forebay (WANF) fixed-site monitoring stations associated with each test condition.

4.0 Total Dissolved Gas Data

Time histories for both TDG and water temperature for the data collected during the study is presented in the following sections. The data is divided spatially into the WANF data, WANT data, and T1 transect data.

4.1 Wanapum Dam Forebay TDG

The Wanapum Dam forebay data consisted of two stations at the same location and depth, the existing forebay FSM station (WANF), and an additional instrument (WANFBU) added for the purpose of this testing period. The forebay data was used as the incoming/background TDG for comparison to the downstream TDG during the testing operations. The two instruments produced similar data for both TDG and water temperature. The time history TDG and temperature data is depicted in Figure A-8. Total dissolved gas varied from 96 %SAT up to 101 %SAT during the entire study period. The TDG time histories were characterized by daily cycles of approximately 2 %SAT. These cycles are likely associated with daily solar warming cycles which were approximately 1°C. The TDG pressure changes associated with 1 degree increase in water based on Charles' Law is approximately 15 mmHg or about a 2 %SAT increase at standard pressure and temperature.

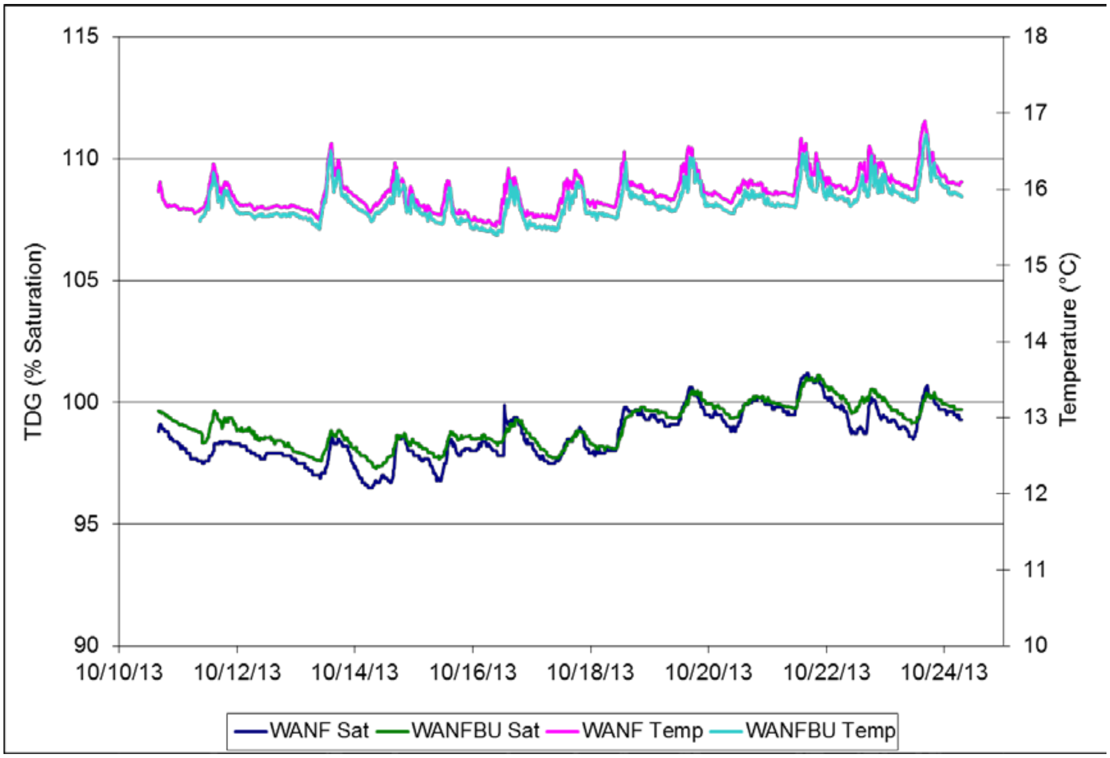

Figure A-8 Wanapum Dam forebay TDG and water temperature during the 2013 study period.

The forebay backup instrument averaged 0.4 % +/- 0.37 % higher than the existing FSM station during its period of operation. The forebay TDG %SAT was collected on the additional instrument added for the purpose of this study. Temperatures ranged from 15.4 to 16.9 °C during the field study. The average temperature difference was 0.1 °C +/-0.08 °C for the two instruments. Note the daily variability for TDG in the forebay measures indicating the influence of fluctuating upstream release gas exchange as well as diel thermal effects from solar warming of at least the surface waters at the depth of the instruments.

4.2 Wanapum Dam Tailwater Total Dissolved Gas

As with the forebay station there was a an additional tailrace monitor added for the purpose of this study (WANTBU). Figure A-9 depicts both the TDG %SAT and water temperature logged by the tailwater instruments. The TDG %SAT values varied from 97 %SAT to 102.3 %SAT during the field testing. The TDG fluctuations were somewhat variable responding to project operational changes, upstream conditions, and the daily solar influence on water temperature.

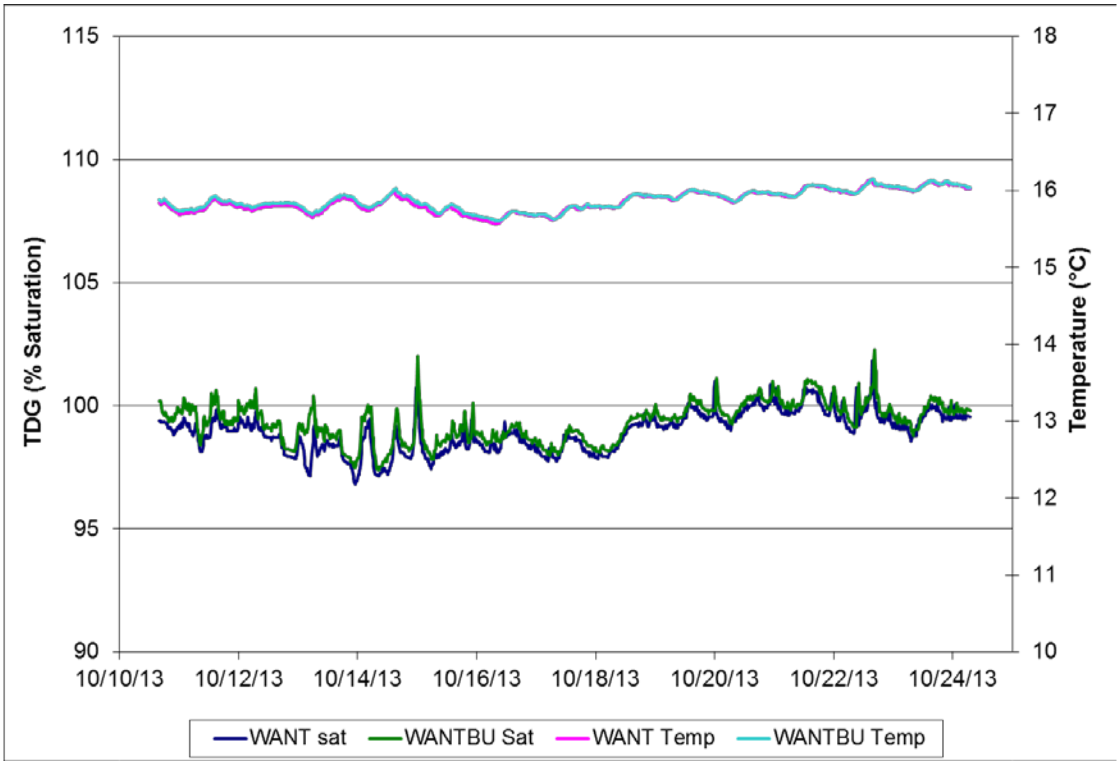

Figure A-9 Wanapum Dam tailwater TDG during the 2013 study period.

The tailwater backup instrument averaged 0.4 % +/- 0.2 % more than the existing FSM station during its period of operation. The average temperature difference was 0.02 °C +/-0.02°C for the two instruments. The tailrace TDG %SAT was collected on the additional instrument added for the purpose of this study.

4.3 Transect T1 TDG

Data collected at the downstream transect, T1, for the complete study period is presented in Figure A-10, and includes the seven-instrument time histories with two of the stations, P2 and P4 each having replicate instruments located near river bottom. Stations P1, P3, and P5 were represented by one instrument near the bottom in each case. Similar to the tailwater station the TDG %SAT at T1 fluctuated from 97 %SAT up to 105 %SAT during the testing period. Spikes in TDG occurred on a few occasions at the extreme stations P5 and P1 with the highest levels normally associated with the left bank station P5 and somewhat at the next station, P4. This apparent gradient went away during periods of no sluiceway operation, indicating minor TDG increases in the left bank flow downstream from sluiceway operation. The difference in TDG for the T1 cross section during the period of sluiceway operation was approximately 3 %SAT.

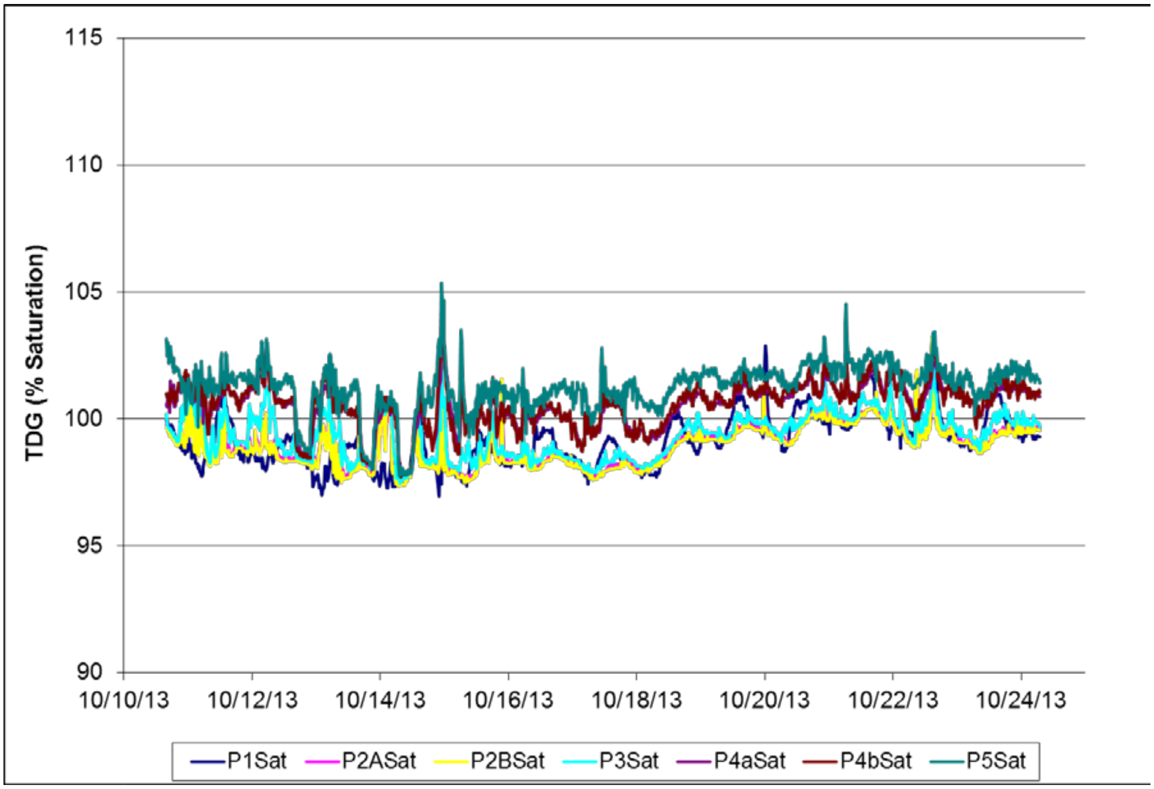

Figure A-10 TDG %SAT for all the sampling stations on transect T1 during the 2013 study period.

The range in TDG %SAT across all instruments on transect T1 during just powerhouse operations was seldom more than 0.3 %SAT indicating minimal to no gradient in TDG %SAT across the river when there were only powerhouse operations, which was the case during the three targeted test operations. Figure A-11 depicts the T1 data over a shorter time period, October 12-15 2013 allowing a more detailed observation of the time histories for all instruments.

Figure A-12 depicts the transect T1 average TDG %SAT time histories as well as that for the downstream FSM station, WANT. In general the TDG %SAT values were similar in pattern with the differences averaging 0.89 %SAT at the same time intervals.

The T1 temperature data for the study period is presented in Figure A-13. In general the lateral thermal gradient and the daily solar warming were both as indicated by the instruments less than 0.5 °C.

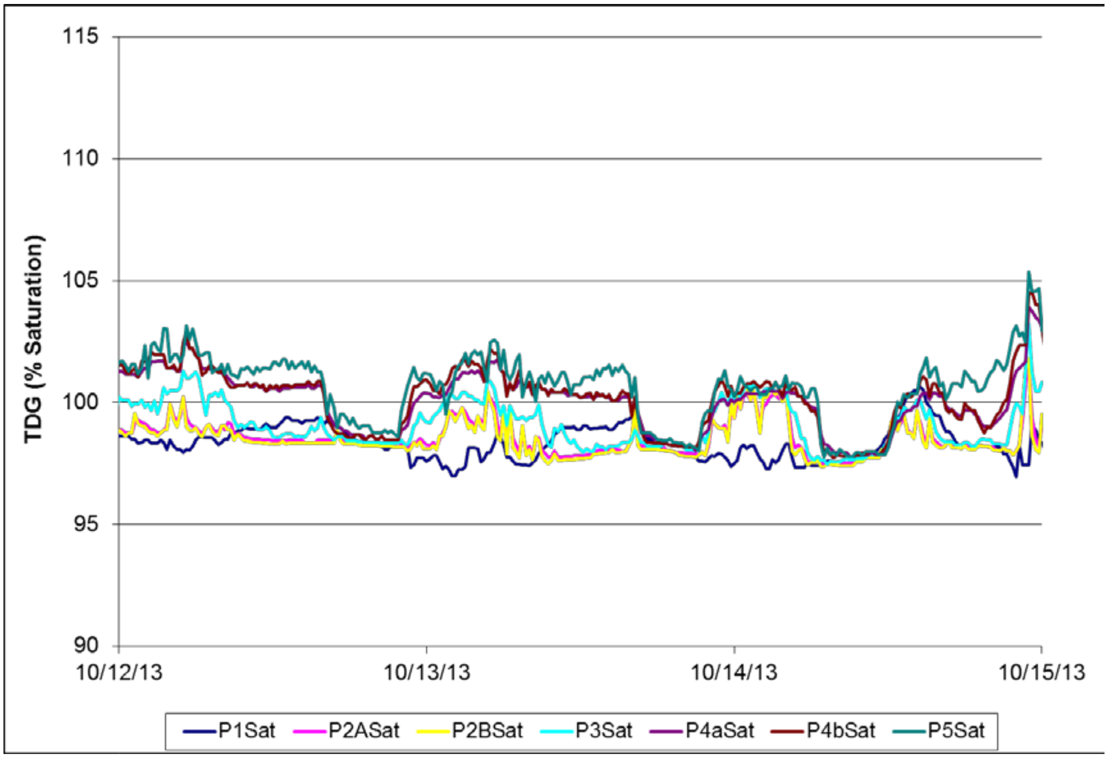

Figure A-11 TDG %SAT for all the sampling stations on transect T1 from October 12 to October 15, 2013.

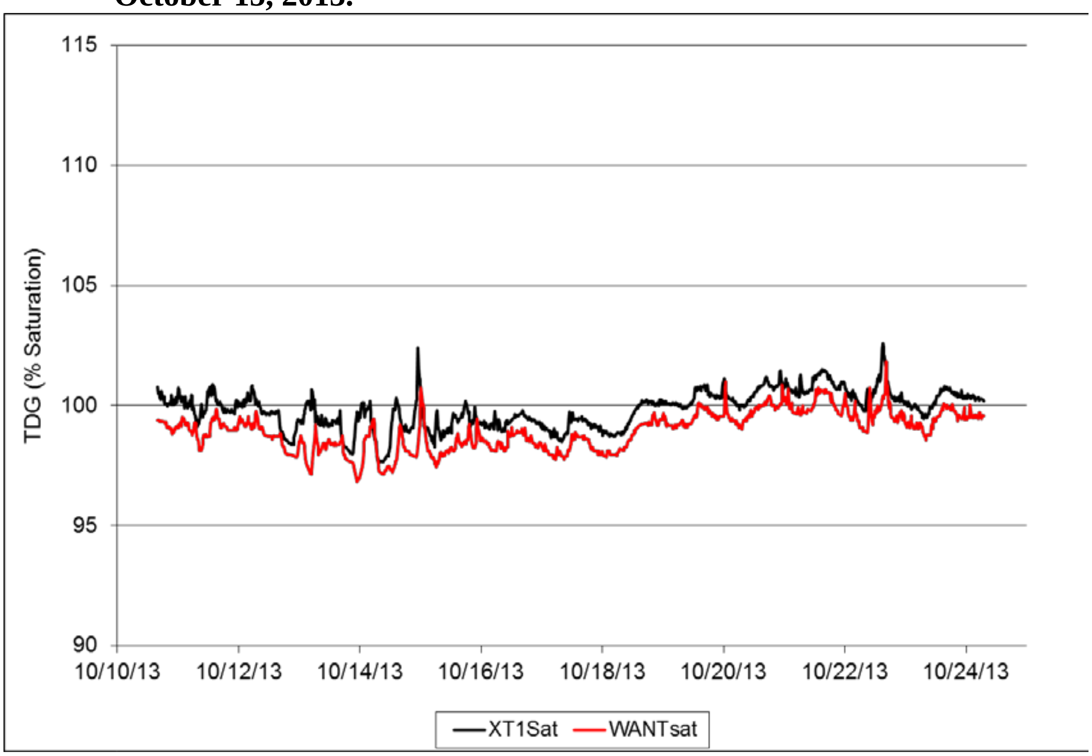

Figure A-12 Transect T1 average TDG %SAT and the Wanapum Dam tailrace FSM station, WANT.

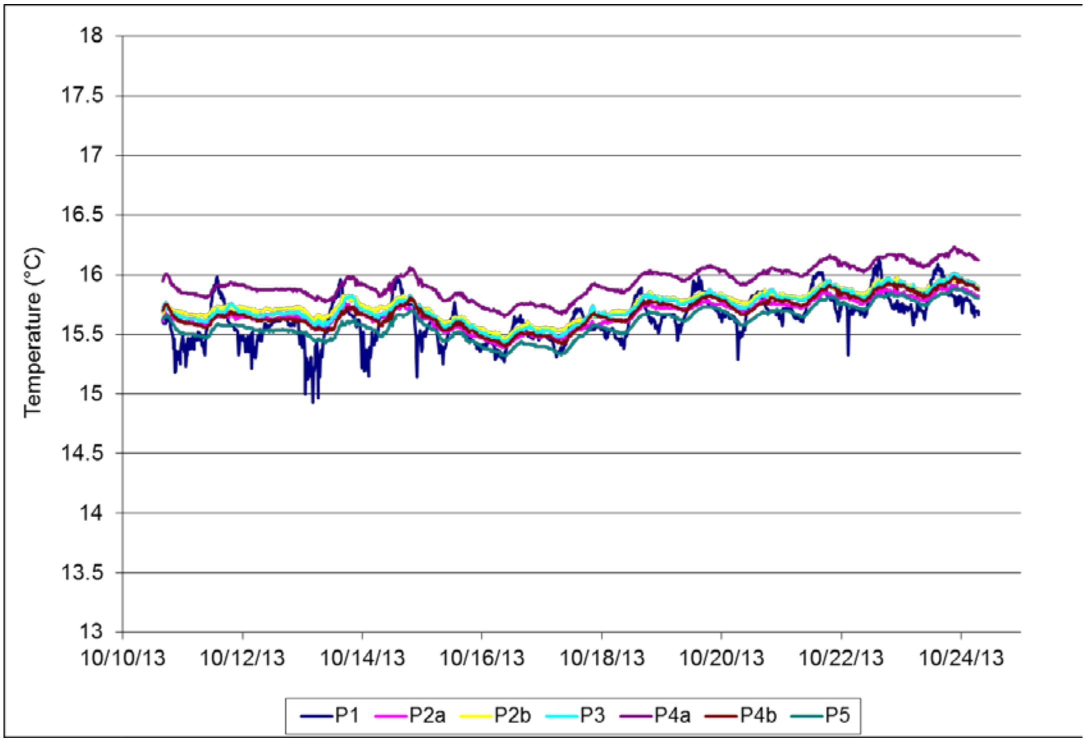

Figure A-13 Transect T1 water temperature data during the study period.

4.4 Comparison of T1 transect vs. WANT TDG values

A limited comparison of the tailwater TDG 15-minute interval time history data at the Wanapum Dam tailrace FSM station (WANT) to the transect T1 results were presented in Section 3.3.3. Figure A-14 shows that the time series data indicated the two data sets to be very similar with the differences typically less than 1%SAT for the same time intervals. This analysis can be extended by using comparable results coming from similar or the same waters by building in a lag for selecting the T1 data, which allows for the additional time of travel to the WANT station. The time of travel from T1 to WANT may vary considerably but in general a 1-hour lag fits with available flow data and from the previous plots. Figure A-14 compares the two downstream locations applying a 1-hour lag in the T1 TDG data. Even though the difference is small the resulting average difference between T1 (1-hr lag) and WANT from the detailed time history data during the field testing operation is 0.63 %SAT, with a standard deviation of +/- 0.21 %SAT. This would indicate that the two stations would be good indicators of each other, as the difference between the two during the period of study was within the precision the equipment and normal field sampling error.

The linear regression of the T1 (1 hr lagged data) vs. WANT shown in Figure A-15 has nearly a one to one relationship with an R^2 of 0.80. This supports the good agreement between the two downstream stations even though they are separated by 3.2 river miles.

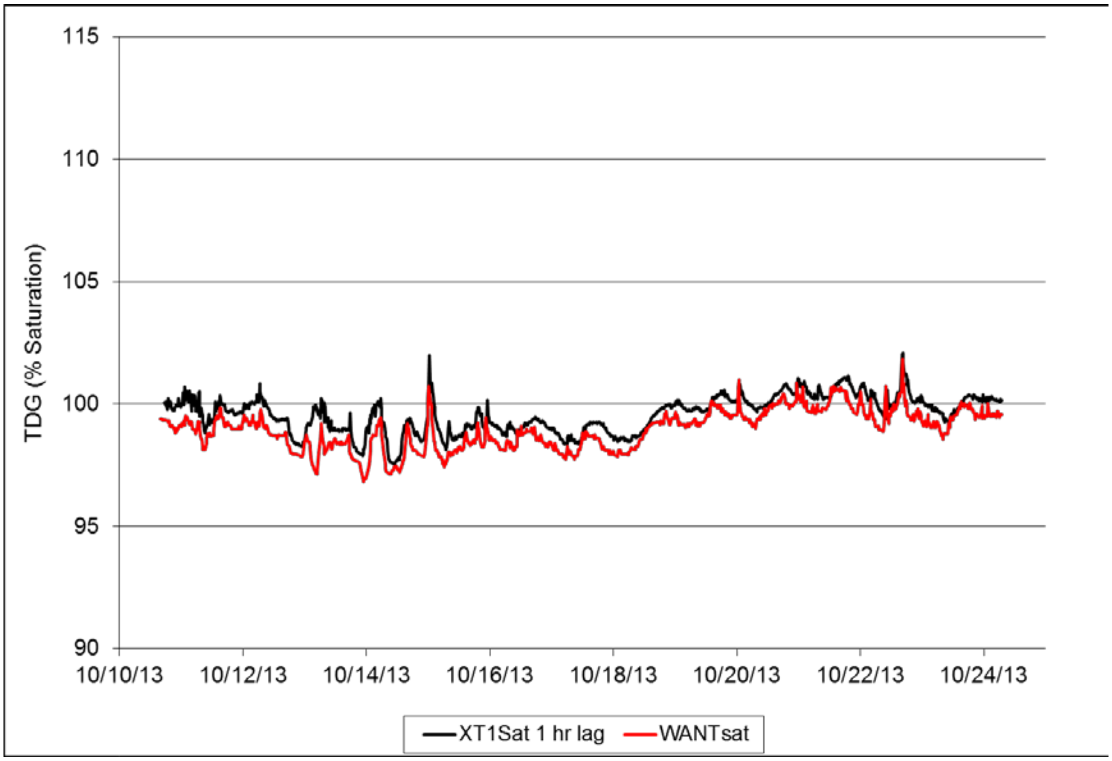

Figure A-14 Comparison of transect T1 (1-hr lag) and Wanapum Dam tailrace (WANT) TDG levels recorded during the field study.

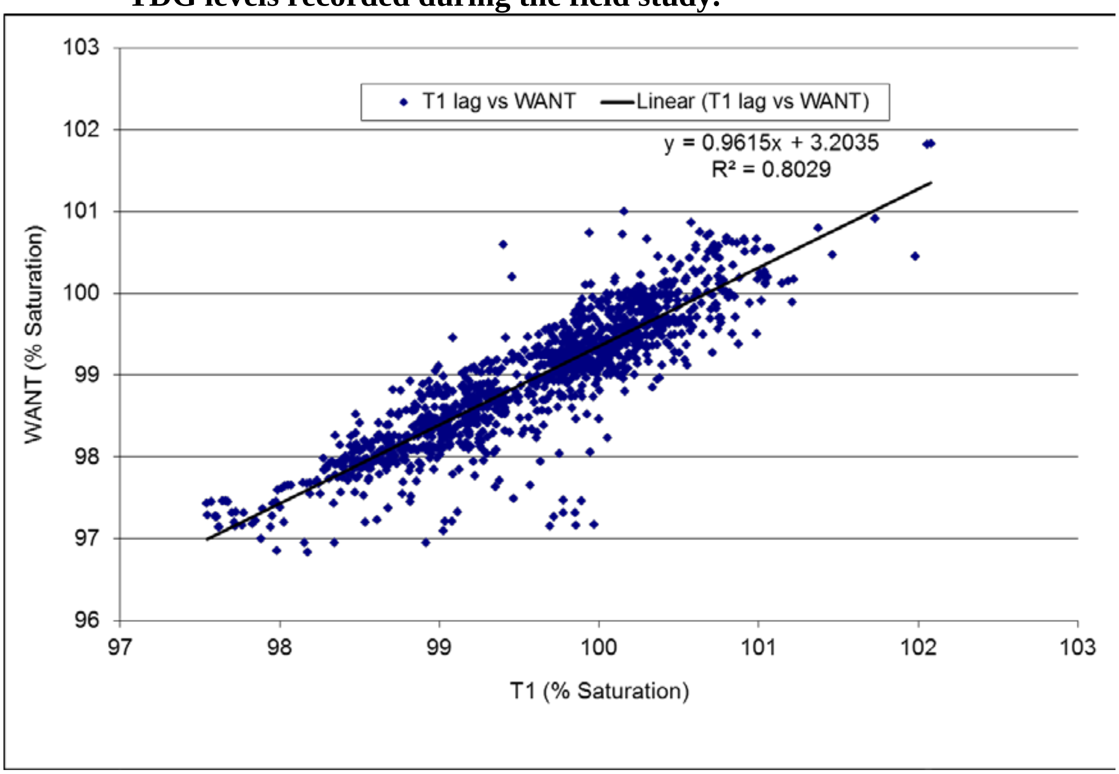

Figure A-15 Comparison of transect T1 (1-hr lag) vs. Wanapum Dam tailrace (WANT) TDG levels recorded during the study period.

Literature Cited

Carroll J. H., Schneider, M., and Lemons, J. 2001. Wanapum Phase III Total Dissolved Gas Spillway Performance Test July 14-16, 1999. Memorandum Report to Public Utility District No. 2 of Grant County. 2001.

Hendrick, R., Carroll, J. H., Hay, D., and Jeske, D. 2008. Study Plan for Evaluating Total Dissolved Gas Exchange Related to Operation of the Wanapum Dam Future Unit Fish Bypass. May 2008. Prepared for Public Utility District No. 2 of Grant County (Grant PUD). May 12, 2008.

Schneider, M., Carroll, J. H., and Lemons, J. 2001. Wanapum Phase 5 Post-Deflector Total Dissolved Gas Full Spillway Performance Test April 26–May 3, 2000. Memorandum Report to Public Utility District No. 2 of Grant County. 2001.