Grant County
PUBLIC UTILITY DISTRICT

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March 29, 2016

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

Re: Priest Rapids Hydroelectric Project No. 2114-236 Evaluation of Total Dissolved Gas Related to the Operation of the Priest Rapids Fish Bypass

Dear Secretary Bose,

Attached please find Public Utility District No. 2 of Grant County, Washington's (Grant PUD's) Evaluation of Total Dissolved Gas Related to the Operation of the Priest Rapids Fish Bypass consistent with the requirement and associated obligations and mandates of the Washington State Department of Ecology (WDOE) 401 water quality certification (WQC). Section 6.4.6(b) of the 401 WQC required Grant PUD to conduct a field study to quantify the total dissolved gas (TDG) associated with the Priest Rapids Fish Bypass (PRFB), which was installed in the spillway of Priest Rapids Dam. Article 401(a)(18) of the Federal Energy Regulatory Commission (FERC) required FERC approval of the study plan prior to implementation.

In addition, on February 1, 2008 the National Marine Fisheries Service (NMFS) issued a Biological Opinion regarding the effect of FERC's action issuing a license for the Project on endangered species subject to NMFS jurisdiction. The Biological Opinion's Reasonable and Prudent Alternatives (RPAs) and terms and conditions were also directly incorporated in the FERC license to operate the Project on April 17, 2008. These terms and conditions required Grant PUD to investigate top-spill fish passage options at Priest Rapids Dam, which, through modeling, testing, and construction, Grant PUD built the Priest Rapids PRFB, which began operation during fish-spill season of 2014.

The evaluation of TDG related to the operation of the PRFB was conducted in accordance with the study plan titled, *Study Plan for Evaluating Total Dissolved Gas Exchange Related to Operation of the Priest Rapids Fish Bypass*, which was developed in consultation with the WDOE and the Priest Rapids Coordinating Committee (PRCC). The study plan was submitted to the Federal Energy Regulatory Commission (FERC) on March 30, 2011 and approved by FERC on June, 3 2011. On December 29, 2015, Grant PUD requested an extension of time to submit this report from WDOE from December 31, 2015 to March 31, 2016. On January 6, 2016, WDOE approved Grant PUD's request for extension of time.

The following final report summarizes the TDG evaluation conducted downstream of Priest Rapids Dam with varying Project operations during August 1-19 of 2014.

On February 11, 2016, the Evaluation of Total Dissolved Gas Related to the Operation of the Priest Rapids Fish Bypass report was distributed for review and comment to WDOE and the PRCC, which includes representatives from NMFS, Colville Confederated Tribes, Yakama Nation, Washington Department of Fish and Wildlife, Columbia River Intertribal Fish Commission, and the Wanapum. Grant PUD received no comments. This report was submitted to WDOE on March 29, 2016.

If you have questions, please contact me at 509-753-1468 or at rhendr1@gcpud.org.

Sincerely,

Ross Hendrick
License Compliance Manager

Cc: PRCC

Priest Rapids Hydroelectric Project (P-2114)

EVALUATION OF TOTAL DISSOLVED GAS RELATED TO THE OPERATION OF THE PRIEST RAPIDS FISH BYPASS

FINAL REPORT

License Article 401(a)(18)

By Carson Keeler

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

February 2016

Executive Summary

The evaluation of total dissolved gas (TDG) related to the operation of the Priest Rapids Fish Bypass (PRFB) was conducted in accordance with the study plan titled, *Study Plan for Evaluating Total Dissolved Gas Exchange Related to Operation of the Priest Rapids Fish Bypass* (Hendrick and Keeler 2011), 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 March 30, 2011 and approved on June, 3 2011.

As stated in the study plan, the primary objective of the field study was to quantify TDG associated with the operation of the Priest Rapids Fish Bypass (PRFB) during a series of controlled operating conditions. To complete this objective, a TDG sensor array arranged in a lateral transecting pattern was placed approximately 2000 feet downstream of Priest Rapids Dam to monitor TDG levels.

In order to quantify TDG production associated with the operation of the PRFB, TDG data was collected during the following powerhouse loading conditions between August 6 and 8, 2014:

1). **Test 1 –** Powerhouse flow <10 kcfs and the PRFB operating at full capacity; and
2). **Test 2 –** Powerhouse flow <60 kcfs and the PRFB operating at full capacity; and
3). **Test 3 –** Powerhouse flow <120 kcfs and the PRFB operating at full capacity; and
4). **Test 4 –** Powerhouse flow <140 kcfs and the PRFB operating at full capacity.

Every attempt was made to hold project operations steady for at least three consecutive hours during the targeted testing noted above 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 Priest Rapids Dam. The field testing began with installation of the TDG array transect on August 1, 2014 and continued until August 19, 2014 with the removal of the transect. The four powerhouse condition tests were conducted between August 6 and August 8 of 2014. The actual operational conditions varied slightly from the targeted discharges due to river conditions. The field study was continued for 11 additional days to collect additional information to help with the TDG exchange evaluation. In addition to the targeted tests there were other incidental test periods during the study period which inadvertently meet the testing requirements for further evaluation of the PRFB operation. Actual operational conditions, including information describing the incidental tests are provided in Section 2.4 and Appendix A of this final report.

The overall average TDG percent saturation (%SAT) noted at the TDG array transect during the testing periods were never above 116 %SAT, and the TDG %SAT were never above 112 %SAT at the Priest Rapids tailrace FSM station (next downstream TDG compliance point). Furthermore, and most significant, the PRFB was able to meet TDG compliance at both the TDG array transect (2000 feet downstream from Priest Rapids Dam) and the Priest Rapids tailrace FSM station (next downstream compliance point at Vernita Bridge) throughout the complete testing periods during all operational conditions. For more detailed information/explanations of the TDG exchange associated with the operation of the PRFB, see Appendix A of this final report.

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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).

In addition, on February 1, 2008 the National Marine Fisheries Service (NMFS) issued a Biological Opinion regarding the effect of FERC's action issuing a license for the Project on endangered species subject to NMFS jurisdiction. The Biological Opinion's Reasonable and Prudent Alternatives (RPAs) and terms and conditions were also directly incorporated in the FERC license to operate the Project on April 17, 2008. These terms and conditions required Grant PUD to investigate top-spill fish passage options at Priest Rapids Dam, which, through modeling, testing, and construction, Grant PUD built the Priest Rapids Fish Bypass (PRFB), which was operational during fish-spill season of 2014.

Section 6.4.6 of the 401 WQC (WDOE 2007) required Grant PUD to conduct a field study to quantify the total dissolved gas (TDG) associated with the PRFB channel chute downstream of Priest Rapids Dam. Article 401(a)(18) of the license (FERC 2008) required FERC approval of the study plan prior to implementation.

The evaluation of TDG related to the operation of the PRFB was conducted in accordance with the study plan titled, *Study Plan for Evaluating Total Dissolved Gas Exchange Related to Operation of the Priest Rapids Fish Bypass* (Hendrick and Keeler 2011), which was developed in consultation with the WDOE and the Priest Rapids Coordinating Committee (PRCC). The study plan was submitted to the Federal Energy Regulatory Commission (FERC) on March 30, 2011 and approved on June, 3 2011.

The following final report summarizes the TDG evaluation conducted downstream of Priest Rapids Dam with varying Project operations during August 1-19 of 2014.

1.1 Background

The terms and conditions of the 2008 Biological Opinion required Grant PUD to investigate alternative top-spill designs for a fish-bypass facility at Priest Rapids Dam in consultation with National Marine Fisheries Society (NMFS) and the PRCC (NMFS 2008). Following completion of the Downstream Passage Alternatives Study (Jacobs et al. 2003), a process was initiated to develop a new fish passage facility for Priest Rapids Dam. In 2006 a prototype surface spill passage route (top-spill bulkhead located at spillways nineteen and twenty) was constructed to help evaluate fish behavior and survival under controlled operating conditions to address unknown aspects of fish passage at Priest Rapids Dam. Evaluations were undertaken in 2006, 2007 (Timko et al. 2007), 2008 (Sullivan et al. 2008), 2009 (Timko et al. 2009), and 2010 (Timko et al 2010) under consultation with the PRCC. Based on the above referenced studies of the prototype surface spill (top-spill bulkhead), construction of the PRFB began in 2011, which permanently modified spillbays twenty through twenty-two to create a surface spill fish-passage route at Priest Rapids Dam. The construction of the PRFB was completed in April of 2014. The study plan was initiated on August 1, 2014 with the installation of the TDG array approximately 2000 feet downstream of Priest Rapids Dam.

1.1 Regulatory Framework

Washington state water quality standards are established by WDOE for TDG during the non-fish and fish-spill seasons (see Washington Administrative Code (WAC) 173-201A-200(1)(f)). The current standard for TDG (in percent saturation (%SAT)) during the non-fish spill season (September 1 through March 31) is 110 percent for any hourly measurement. The current standard for TDG (in %SAT) during the fish-spill season (April 1 through August 31) is 115 percent in the forebay and 120 percent in the tailrace, based on the average of the twelve highest consecutive hourly readings in a twenty-four hour period. A one-hour, 125 percent maximum standard for TDG also applies throughout the Project. The PRFB was designed to minimize TDG uptake, and in accordance with Section 6.4.6 of the 401 WQC and this final report, Grant PUD tested TDG conditions associated with the operation of the PRFB to verify that TDG standards can be met during its operation.

The study plan titled, *Study Plan for Evaluating Total Dissolved Gas Exchange Related to Operation of the Priest Rapids Fish Bypass* (Hendrick and Keeler 2011) was designed to satisfy the requirements of Sections 6.4.6 of the 401 WQC for operation of the Project by collecting TDG data above and below Priest Rapids Dam during various operating conditions associated with the operation of the PRFB. The TDG data collected during the study period 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 and Appendix A for more information).

1.2 Site Description

Priest Rapids Dam is located at river mile (RM) 397.1 near Desert Aire, Washington (Figures 1 and 2). The Priest Rapids powerhouse has a generator nameplate capacity of 955 MW. The total length of Priest Rapids Dam is 10,103 feet. The normal pool operating range is between 481.5 and 488.0 feet above mean sea level. The powerhouse contains ten turbine units which operate at a design head of 78 feet and have a current discharge of 174 thousand cubic feet per second (kcfs). The spillway has a total design capacity of 1,400 kcfs and includes 19 tainter gates with deflectors in each spillbay and a PRFB designed to provide improved TDG exchange and fish passage at the east end of the spillway (operational during fish-spill season 2014). Priest Rapids Reservoir extends eighteen miles upstream to the tailwater of Wanapum Dam and has a surface area of approximately 7,725 acres.

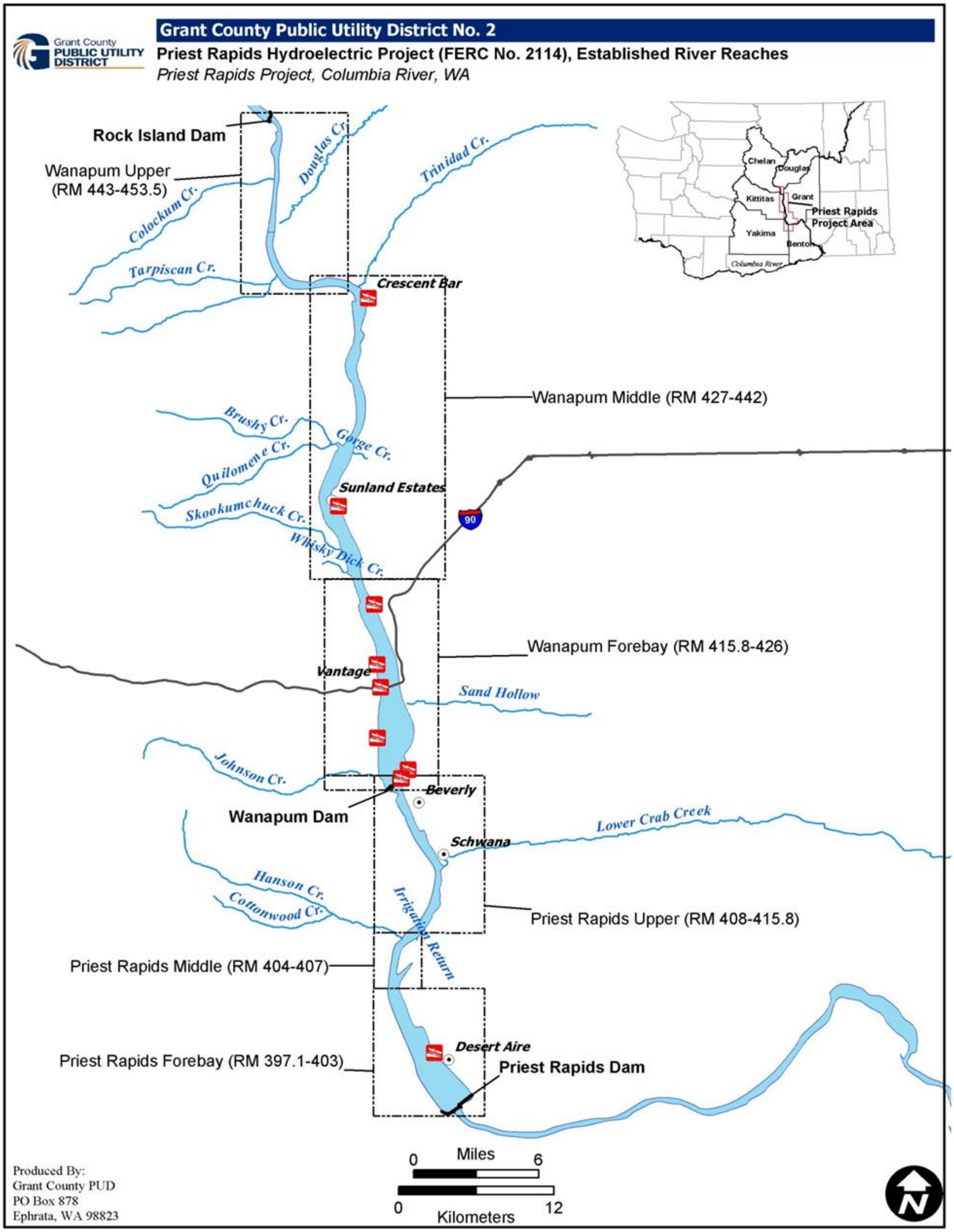

Figure 1 The Priest Rapids Hydroelectric Project and established river reaches presented by river mile (RM), mid-Columbia River, WA.

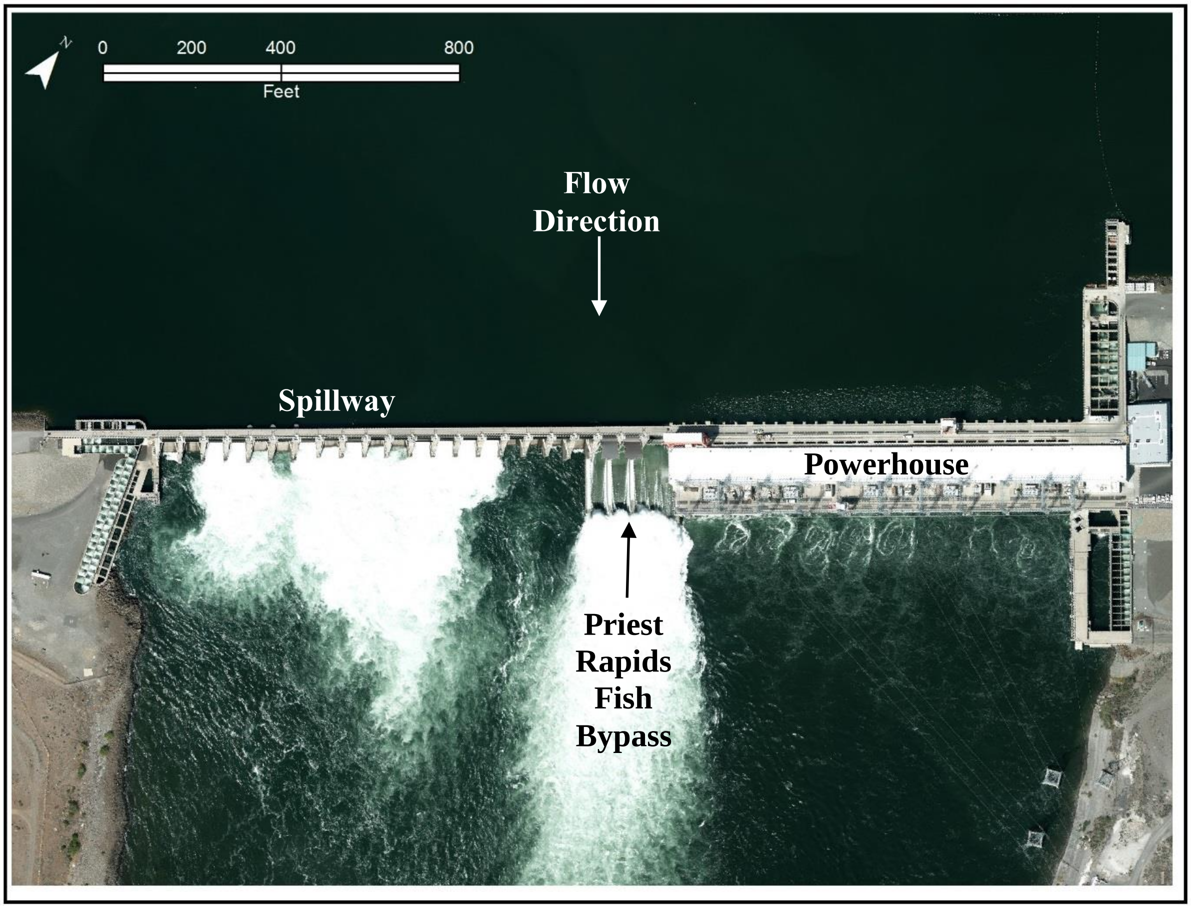

Figure 2 **Aerial photograph of Priest Rapids Dam, mid-Columbia River, WA.**

1.3 Objectives

Per section 6.4.6 of the 401 WQC for the Project, the primary objective of this TDG exchange study was to quantify TDG associated with the operation of the PRFB during a series of controlled operating conditions. To complete this objective, a TDG sensor array arranged in a lateral transecting pattern was placed approximately 2000 feet downstream of Priest Rapids Dam to monitor changes in TDG levels compared to TDG levels recorded upstream in the Priest Rapids Dam forebay with the PRFB passing up to 27 kcfs of water with varying tailwater elevations.

2.0 Methods

The following sections provide a summary of the data collection methods that were used during the PRFB TDG study, including descriptions of TDG sensors, calibration and quality assurance methods, location of the TDG sensor array, and proposed operational conditions. The project test operations began on August 1, 2014, with the installation of the in-field TDG sampling instruments in the Priest Rapids Dam tailrace and continued until August 19 with the final removal of all test instruments. The PRFB was operated between 20-30 kcfs for the entire study period. For a more detailed description of the methods used for this study, see the study plan developed for this PRFB TDG study (Hendrick and Keeler 2011).

The PRFB TDG study utilized an array of remote instruments capable of logging time histories of TDG pressures at numerous locations up and downstream of Priest Rapids Dam. Hach Corporation Hydrolab Mini-Sondes and Data-Sondes were used to record data. A total of 15 TDG instruments, three existing real-time fixed site monitoring stations (FSM stations) and twelve logging instruments were used to monitor TDG (in millimeters of mercury (mmHg)), temperature (degrees Celsius (°C)), and depth (meters (m)) at eight stations or locations. Instruments were paired at the same depth for several of the deeper stations to avoid data loss. In addition TDG percent saturation (%SAT) was calculated using ambient air pressure and TDG pressure. Measurements were made on 15-minute intervals for the duration of the study period (August 1-19, 2014).

Project operations data including total river flow (kcfs), powerhouse discharge (kcfs), spillway discharge (kcfs), PRFB discharge (kcfs), forebay elevation (msl feet), and tailwater (msl feet) elevation were also collected on 15-minute intervals.

Atmospheric conditions of air temperature, barometric pressure (not corrected to sea level) were collected at the Priest Rapids Dam weather station to determine potential atmospheric influences on TDG levels. Barometric pressure/air pressure data was also collected by Grant PUD at just above the water surface near their forebay and tailwater fixed TDG monitors. 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 1):

- PRDF – Priest Rapids 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. Two additional logging instruments, PRDA and PRDB, were placed at this location for the duration of the study. This data provided information on incoming/background TDG levels for comparison to TDG levels downstream of Priest Rapids Dam during the PRFB test operations.
- T1 - A five-station/ten-instrument TDG transect located approximately 2000 feet downstream of Priest Rapids Dam. Stations were distributed as evenly as possible across the river. The paired instruments were attached together with the sensors positioned at 3 ft up from bottom. A composite TDG value was collected from this transect to determine TDG values produced by the PRFB compared to forebay TDG pressures. The location of this transect was selected because of its position in the river where it narrows having uniform flows laterally, and minimal back eddies to confound the data analysis.
- PRDT – Priest Rapids Dam tailrace FSM station, an existing real-time TDG monitor attached to a pier-nose (mid-channel) of Vernita Bridge, located approximately nine river miles downstream. Data collected at this location was used comparatively with TDG pressures as measured at the T1 transect, and to verify the PRFB's ability to meet downstream TDG water quality standards (120 %SAT).
- PASCO – This is an existing FSM station located at RM 329, 68 river miles below the Priest Rapids Dam (owned and operated by the U.S. Army Corps of Engineers), and

serves as the next downstream reservoir forebay TDG compliance point for Priest Rapids Dam. Data collected from this real-time TDG monitor was used to evaluate TDG levels for compliance with the forebay TDG water quality standard (115 %SAT).

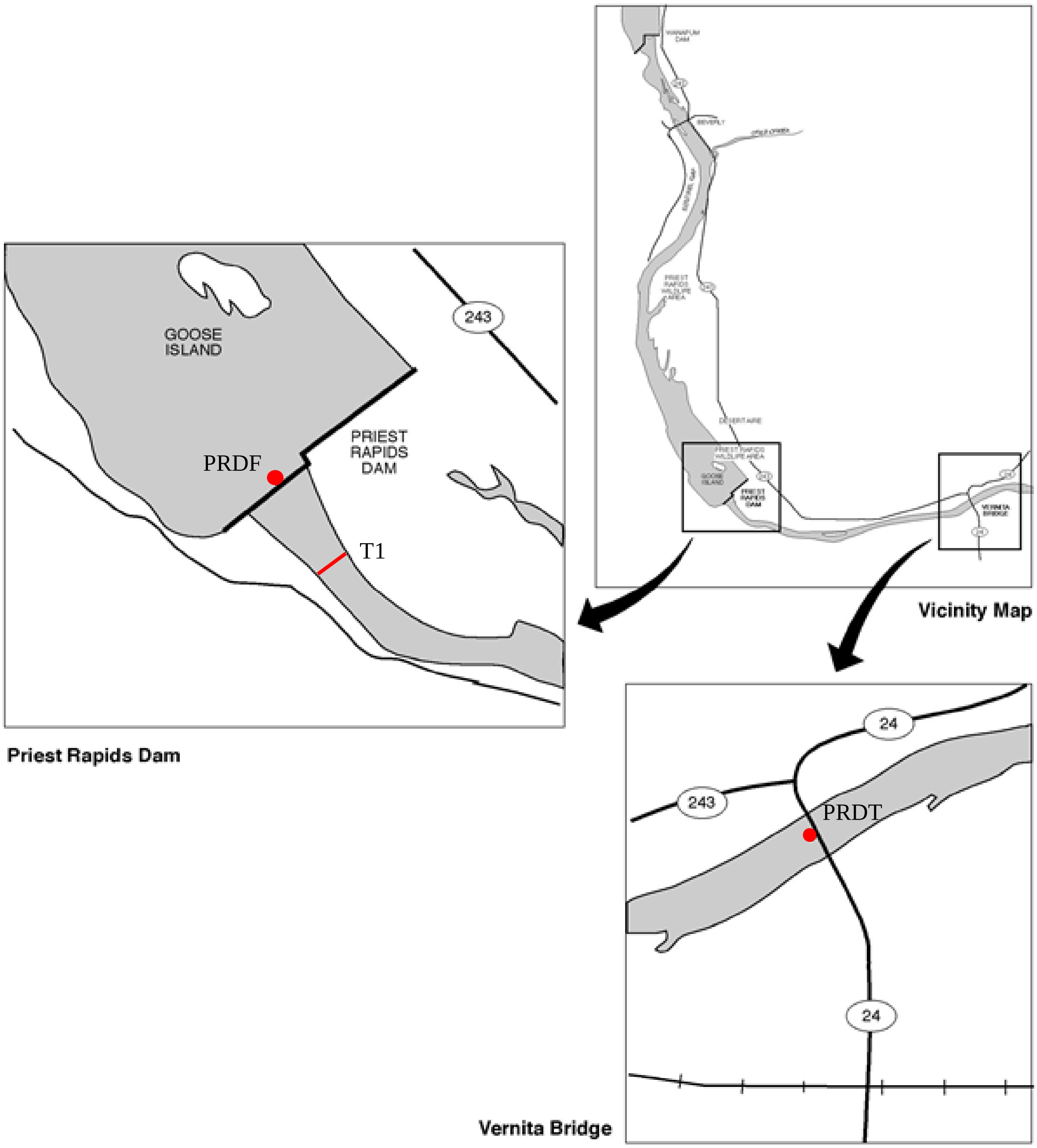

Figure 3 TDG monitoring stations: Priest Rapids forebay (PRDF), total dissolved gas array transect (T1), and the Priest Rapids tailrace (PRDT).

2.2 Water Quality Monitoring Instruments

Logging and/or reporting instruments were used exclusively for the water quality monitoring during the evaluation at Priest Rapids Dam. The 12 instruments used for this study were wireless and capable of remote logging. All of the monitoring instruments used for this study measured and recorded date, time, temperature (˚C), depth (m), TDG (mm Hg), and instrument battery voltage (v) for the entire deployment period (August 1-19, 2014).

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 July 31, 2014. Post deployment checks on calibration were completed the day after retrieval (August 20, 2014) 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.

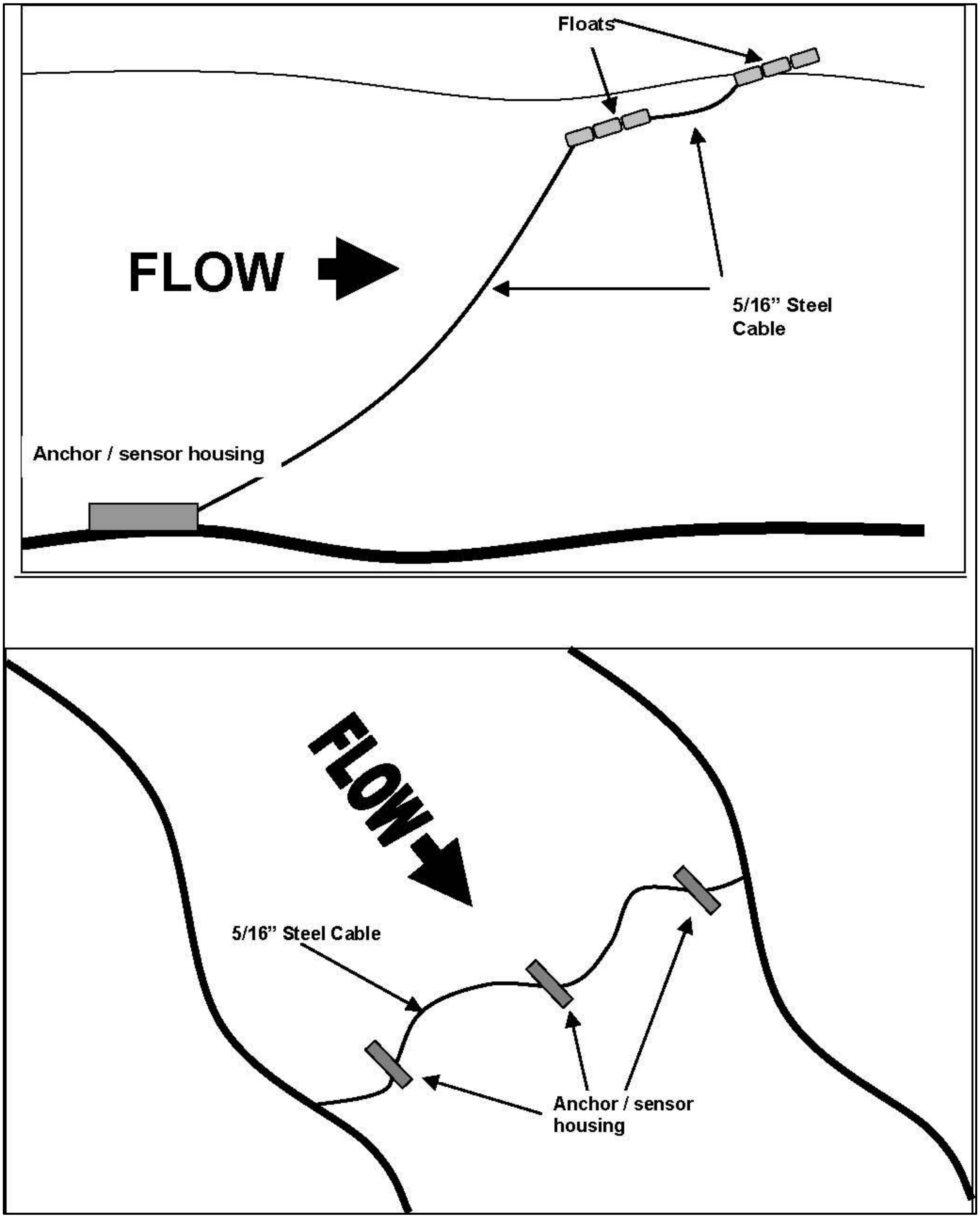

Figure 4 **Schematic of TDG sensor array transects used 2000 feet downstream of Priest Rapids Dam, mid-Columbia River, WA.**

2.4 Operational Conditions

In order to evaluate the TDG exchange associated with the operation of the PRFB during controlled operational conditions, the PRFB was operated up to its capacity of 27 kcfs with four powerhouse loading targets; no flow, 60 kcfs, 100-120 kcfs, and greater than 140 kcfs. Table 1 below presents the proposed operating conditions along with the actual operating conditions performed during the specific targeted tests.

Table 1 Proposed vs. Actual operating conditions for the total dissolved gas exchange study at Priest Rapids Dam, August 2014.

	Proposed			Actual[2]			
Test #	PRFB Flow[1]	Powerhouse Flow[1]	Total Flow[1]	PRFB Flow[1]	Powerhouse Flow[1]	Total Flow[1]	Date Completed
1	≥27	0	≥27	28.4	9.8	39.4	8/7-8/8/14
2	≥27	60	≤87	28.7	56.7	86.5	8/7/14
3	≥27	100-120	127-147	23.9	110.4	135.7	8/6/14
4a[3]	≥27	>140	≥167	25.1	142.6	169.2	8/6/14
4b[3]	≥27	>140	≥167	24.6	157.5	183.6	8/7/14

Notes:
[1]Flow values shown in thousand cubic feet per second (kcfs).
[2]Values for the actual test conditions were averaged over the ~3 hr. test period.
[3]Test 4 was observed in two different instances that closely matched the original proposed conditions, thus test 4 was broken in to two separate, but similar tests (4a/4b) for the purpose of this analysis.

Proposed conditions were identified in the study plan (Hendrick and Keeler 2011), while the actual conditions were those performed during the TDG evaluation at Priest Rapids Dam and displayed in Table 1 above, were the average values over each test period. For Test 1, the powerhouse flow could not be held at 0 kcfs due to operational and flow constraints and was instead held to 9.8 kcfs; however it is unlikely that this difference impacted the results of the test, since a majority of the flow was still concentrated out of the PRFB. In addition, for Test 3 and 4a/b, where the PRFB flow was less than the proposed flow condition of ≥27 kcfs, the obtainable flow was based off of the elevation of the forebay, and not a decrease in the operation of the PRFB.

Depth, temperature, and TDG values were collected at 15-minute intervals (starting at the top of the hour) from August 1, 2014 at 0900 hours to August 19, 2014 at 0800 hours for the purpose of this TDG evaluation. Project operational data (flow per unit, total powerhouse flow, PRFB flow, etc.) were collected during the entire study period and are included in this TDG evaluation (see Section 3.0 below and Appendix A for more details).

3.0 Results

The following sections describe the results of the TDG evaluations performed at Priest Rapids Dam during August 1-19, 2014 to quantify and summarize the TDG values associated with the operation of the PRFB.

3.1 Targeted Tests Operations

Project operations were held steady for at least three consecutive hours to allow conditions to stabilize during the targeted test periods. Targeted tests 1, 2, 3, and 4a/b had corresponding total discharges of 39.4 kcfs, 86.5 kcfs, 135.7 kcfs, 169.2 kcfs, and 183.6 kcfs, respectively. Figure 5 below notes the total powerhouse discharge (kcfs), PRFB discharge (kcfs), and tailwater elevation (ft msl) during the targeted test periods (T1, T2, T3, and T4a/b). Total powerhouse (turbine) flow during the targeted test periods ranged from 8.3-161.0 kcfs, with PRFB flow ranging from 20.7-32.9 kcfs during the same timeframe. Finally, tailwater elevations ranged from 401.2-413.6 ft. (ft msl) during the same targeted test periods.

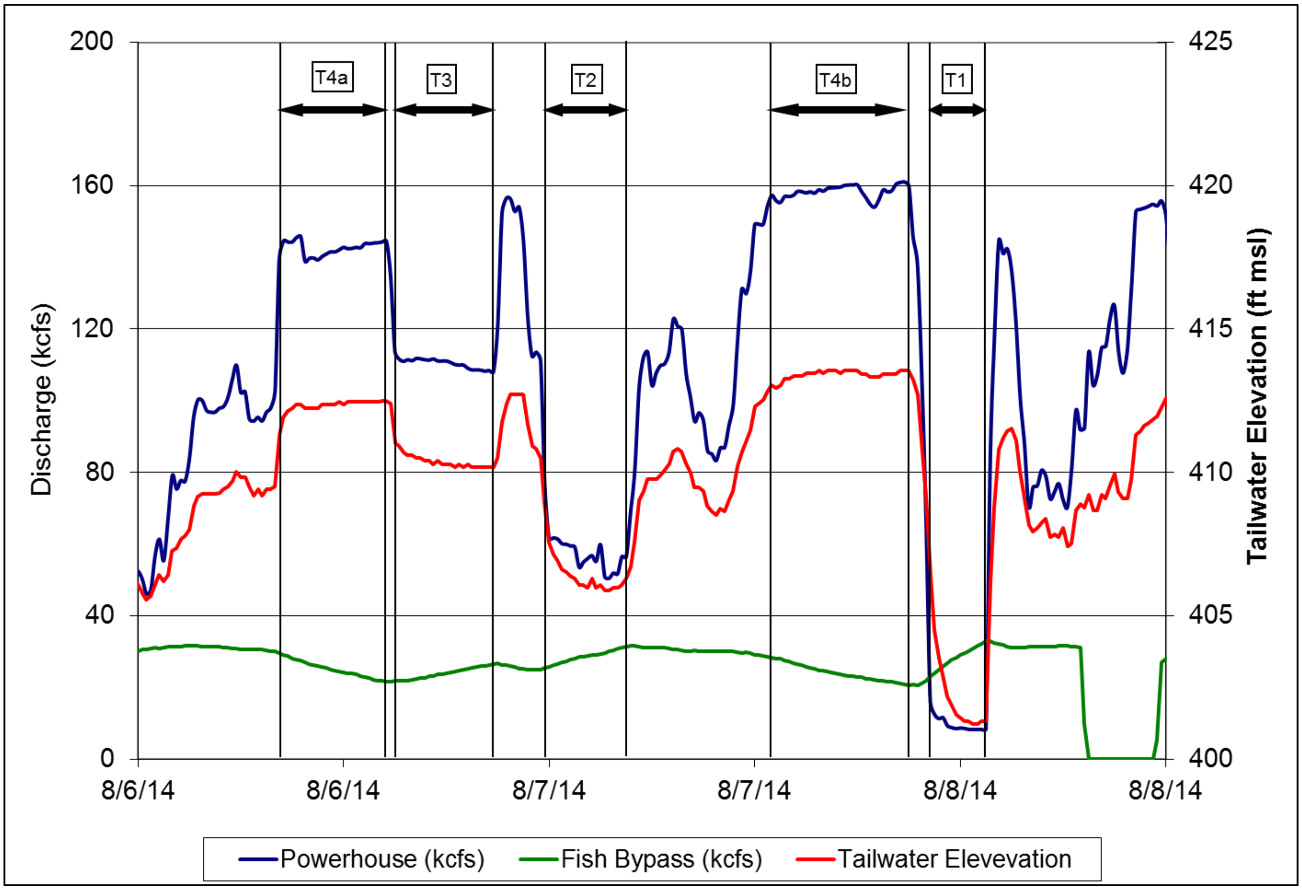

Figure 5 **Total powerhouse discharge (kcfs), PRFB discharge (kcfs), and tailwater elevation (ft msl) collected during the targeted tests at Priest Rapids Dam in August 2014, mid-Columbia River, WA.**

3.2 Targeted Test Total Dissolved Gas Percent Saturation

Figure 6 below displays the targeted test periods (T1, T2, T3, and T4a/b) with corresponding powerhouse discharge and TDG %SAT at the Priest Rapids forebay (XPRDF), the TDG array transect (XT1), and the Priest Rapids tailrace (PRDT) locations.

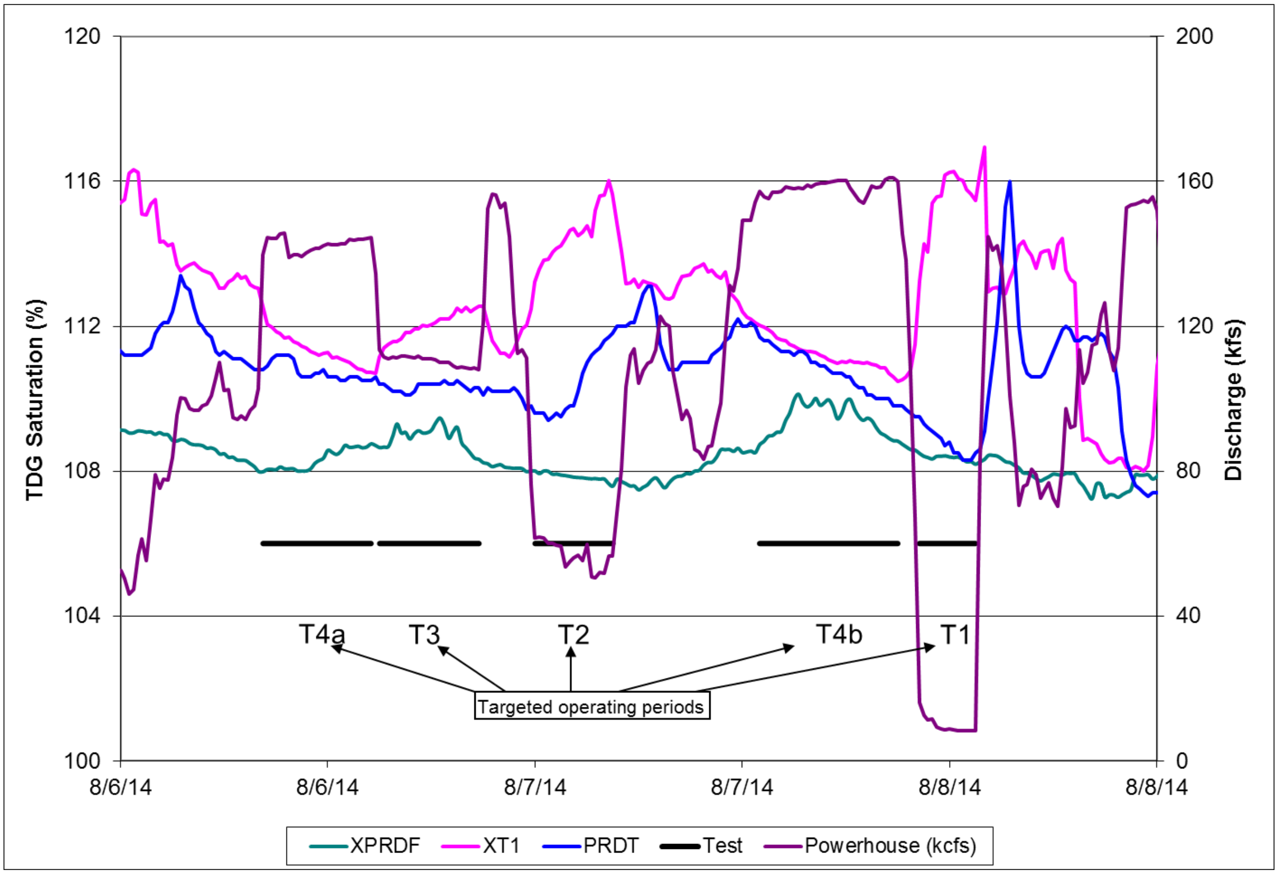

Figure 6 **Average total dissolved gas percent saturation (%SAT) for transect (XT1) stations, Priest Rapids Dam tailrace fixed-site monitoring station (PRDT) and forebay (XPRDF) station with total project discharge during the targeted test periods, August 2014, mid-Columbia River, WA.**

The difference in TDG %SAT between the Priest Rapids forebay FSM station and the TDG array transect for the targeted testing periods were 7.7 %SAT for Test 1, 7.1 %SAT for Test 2, 3.3 %SAT for Test 3, and 2.8 %SAT for Test 4, for an overall mean difference of 5.2 %SAT. The difference in TDG %SAT between the Priest Rapids forebay FSM station and the Priest Rapids tailrace FSM station for the same testing periods were 4.2 %SAT for Test 1, 4.2 %SAT for Test 2, 1.2 %SAT for Test 3, and 2.1 %SAT for Test 4, for an overall mean difference of 2.9 %SAT. Although the difference in TDG %SAT were as high as 7.7% during the targeted testing periods, the overall average TDG %SAT noted at the TDG array transect during the testing periods were never above 116 %SAT, and the TDG %SAT were never above 112 %SAT at the Priest Rapids tailrace FSM station (next downstream TDG compliance point). Additionally, the PRFB was able to meet TDG compliance at both the TDG array transect (2000 feet downstream from Priest Rapids Dam) and the Priest Rapids tailrace FSM station (next downstream compliance point at Vernita Bridge) throughout the complete testing periods during all operational conditions. Table 2 below displays the summary values of the collected data for each of the targeted test periods along with the difference (delta) in TDG %SAT from the Priest Rapids forebay (PRDF) FSM station to the TDG array transect (T1) and from the Priest Rapids forebay (PRDF) FSM station to the Priest Rapids tailrace (PRDT) FSM station.

Table 2 Priest Rapids Fish Bypass average data for each of the test periods.

Test	Powerhouse[1]	Forebay Elevation[2]	Tailwater Elevation[2]	PRDF[3]	T1[3]	PRDT[3]	Delta %SAT T1-PRDF	Delta %SAT PRDT-PRDF
T1	9.7	486.7	402.3[4]	108.4	116.1	112.5	7.7	4.2
T2	56.7	486.8	406.3	107.9	115.0	112.0	7.1	4.2
T3	110.4	485.3	410.4	108.9	112.3	110.1	3.3	1.2
T4a	142.6	485.7	412.3	108.3	111.1	110.4	2.8	2.1
T4b	157.5	485.6	413.3	109.4	111.1	109.7	1.7	0.4

Notes:
[1] Average discharge (flow) in thousand cubic feet per second (kcfs).
[2] Average elevation data in feet mean sea level (ft msl).
[3] Average total dissolved gas (TDG) in percent saturation (%SAT).
[4.] It should be noted that the PRFB was designed and modeled to operate between 405.2-415.0 ft. and wouldn't typically be operated during such low tailwater elevations.

During periods of high powerhouse operation (Test 4 (>140 kcfs) and Test 3 (>100-120 kcfs)) the highest TDG was associated with the furthest right-bank stations on the TDG sensor array. The opposite occurred as the powerhouse discharge decreased (Test 2 (~60 kcfs) and Test 1 (~10 kcfs)) with the higher TDG saturations recorded toward the left-bank side of the TDG sensor array. This phenomenon indicates limited lateral mixing between the powerhouse and PRFB releases by the time it gets to the TDG sensor array location 2000 feet downstream of Priest Rapids Dam. The PRFB releases characterized by higher TDG are diverted further to the right-bank side of the tailrace as powerhouse operation increases. This resulted in significant lateral gradients (up to 10% TDG) from bank-to-bank at times during the complete testing periods. The opposite lateral pattern occurred as the powerhouse operation decreased for Test 2 and Test 1.

The displacement of the higher TDG waters towards the left-bank at times of lower powerhouse operations is related to multiple processes acting together and occurring with the Project operation and downstream hydrodynamics of the Priest Rapids tailrace. One such occurrence is that if powerhouse operation is lower, there is less mixing of powerhouse water and the overall pattern is dominated by the higher TDG waters from the static PRFB release. Additionally, river bottom elevations tend to be deeper directly downstream of the powerhouse than downstream of the PRFB/spillway. These contrasts are known to exist as far as 2000 feet below Priest Rapids Dam or near the area of the TDG array transect location (Schneider and Carroll 2002). This would tend to lessen any desorption of gases as the aerated PRFB flows move towards the left-bank deeper water. The opposite would be expected if the flows become dominated by higher powerhouse operation and the aerated PRFB releases pass over the shallow and often turbulent reach downstream of the PRFB/spillway. A second likelihood in the increased TDG %SAT values associated with test(s) T1 and T2 is that the lower tailrace elevations associated with the low powerhouse operation during these testing periods resulted in a plunging jet coming from the PRFB operation. The plunging jet from the PRFB operation transported entrained air to deeper depths downstream of the powerhouse. The PRFB was designed and modeled to function/operate between 405.2 – 415.0 ft. msl for optimal fish passage and minimal TDG uptake (Oakwood Consulting 2015). Based on the tailwater exceedance curve, the elevation of the tailwater was below 402.0 ft. only 0.52% of the time during the ten year period of 1999-2009. Figure 7 below displays the tailwater exceendance curve for Priest Rapids Dam used for the design and modeling of the PRFB.

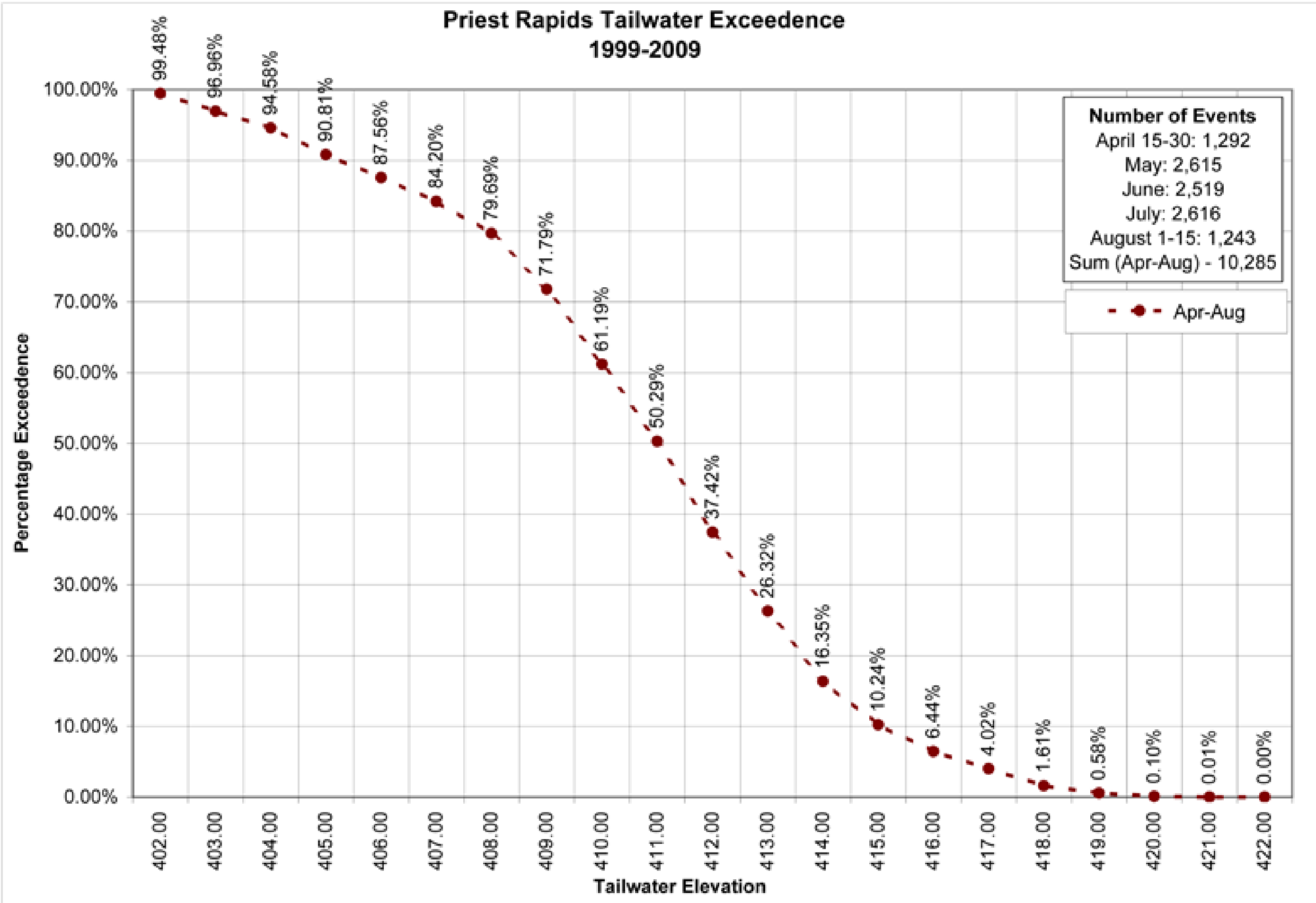

Figure 7 Priest Rapids Dam Fish Bypass (PRFB) tailwater exceedance curve (Oakwood Consulting 2015).

For more detailed information/explanations of the TDG exchange associated with the operation of the PRFB, including additional information related to the relationships between TDG and powerhouse flows and tailwater elevation, see Appendix A of this final report.

3.3 Incidental Tests

The field study was extended for 11 additional days in order to record any incidental times when operational requirements were inadvertently met and the resulting data could possibly be used for further evaluation to quantify TDG associated with the operation of the PRFB. After further analysis of the operational data it was determined that there were 21 additional occasions during the study period when consistent operating conditions were met for a minimum of three consecutive hours.

The operational discharges for the 21 incidental tests varied from a mean of 18.6 kcfs up to 145.5 kcfs. The trend for the incidental tests, as with the targeted test, was that the higher the percentage of PRFB flow of the total flow resulted in higher downstream TDG levels or that the lower powerhouse operations resulted in the highest downstream TDG saturations.

The difference in TDG %SAT between the Priest Rapids forebay and the TDG array transect during the incidental test period ranged from 1.9 %SAT to 9.1 %SAT for an overall mean difference of 4.5 %SAT. The difference in TDG %SAT between the Priest Rapids forebay and the Priest Rapids tailrace FSM stations during the incidental test period ranged from 0.61 %SAT to 8.3 %SAT for an overall mean difference of 2.7 %SAT. Although the difference between the Priest Rapids forebay and the TDG array transect/Priest Rapids tailrace FSM station ranged as high as 9.1 %SAT during the incidental testing periods, at no point did the overall %SAT reach an exceedance point of 120 %SAT. In fact, the %SAT at the TDG array transect ranged from 112.4-116.7 %SAT, while the %SAT at the Priest Rapids tailrace FSM station ranged from 110.5-115.8 %SAT. Lastly, and most important, the PRFB was able to meet TDG compliance at both the TDG array transect (2000 feet downstream from Priest Rapids Dam) and the Priest Rapids tailrace FSM station (next downstream compliance point at Vernita Bridge) throughout the complete testing periods during all operational conditions.

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 percent saturation (%SAT) between the Priest Rapids forebay FSM station and the TDG array transect for the testing periods were 7.7 %SAT for Test 1, 7.1 %SAT for Test 2, 3.3 %SAT for Test 3, and 2.8 %SAT for Test 4, for an overall mean difference of 5.2 %SAT. The difference in TDG %SAT between the Priest Rapids forebay FSM station and the Priest Rapids tailrace FSM station for the same testing periods were 4.2 %SAT for Test 1, 4.2 %SAT for Test 2, 1.2 %SAT for Test 3, and 2.1 %SAT for Test 4, for an overall mean difference of 2.9 %SAT.

Although the difference in %SAT were as high as 7.7% during the targeted test periods, the overall %SAT noted at the TDG array transect during the testing periods was below 116 %SAT for all the test periods, and the TDG %SAT were below 112 %SAT at the Priest Rapids tailrace FSM station (next downstream TDG compliance point) during the targeted test periods. Further, the PRFB was able to meet TDG compliance at both the TDG array transect (2000 feet downstream from Priest Rapids Dam) and the Priest Rapids tailrace FSM station (next downstream compliance point at Vernita Bridge) throughout the complete testing periods during all operational conditions.

For more detailed information/explanations of the TDG exchange associated with the operation of the PRFB, see Appendix A of this final report.

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Appendix A
Priest Rapids Fish Bypass TDG Evaluation Report

1.0 Introduction

The following sections provide details related to the Priest Rapids Fish Bypass (PRFB) total dissolved gas (TDG) study conducted during August of 2014. The objective of this study was to evaluate TDG across the river channel with varying tailwater and turbine operations with the PRFB operating at full capacity (~27 kcfs). Below is a summary of the details contained in this appendix:

- Information on the type of instruments that were deployed, including GPS locations, depths of deployment, and quality assurance/quality control (QA/QC) documentation;
- Details on discharge/flow, water levels, water temperatures and barometric pressures associated with field testing of the study; and,
- 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 three sensors from the analyses due to sensor loss;
    - Determination of the cross-section area weighted arithmetic mean TDG across the entire TDG array transect and its comparison to upstream and downstream TDG values under varying operational conditions.

2.0 Data Collection Methods, QA/QC and Operational Conditions

The following provides a summary of the data collection methods that were used during the study, including descriptions of TDG sensors, calibration and quality assurance methods, location of the TDG array transect, and the proposed operational conditions. The study operations began on August 1, 2014, with the installation of the in-field TDG sampling instruments in the Priest Rapids Dam tailwaters and continued until August 19 with the final removal of all instruments. The PRFB operation was held between 20-30 kcfs for the entire study period.

This study utilized an array of remote instruments capable of logging time histories of TDG pressures at numerous locations up and downstream of Priest Rapids Dam. Hach Corporation Hydrolab Mini-Sondes and Data-Sondes were used to record the data. A total of 15 TDG instruments, three existing real-time fixed-site monitoring stations (FSM stations) and twelve remote logging instruments were used to monitor TDG (in millimeters of mercury (mmHg)), temperature (degrees Celsius (°C)), and depth (meters (m)) at eight stations or locations. Instruments were paired at the same depth for several of the deeper stations to avoid data loss. In addition TDG percent saturation (%SAT) was calculated using ambient air pressure and TDG pressure. Measurements were made on 15-minute intervals for the duration of the study period (August 1-19, 2014).

Project operation data including total river flow (thousand cubic feet per second (kcfs)), powerhouse discharge (kcfs), spillway discharge (kcfs), PRFB discharge (kcfs), forebay and tailwater elevation (msl feet) was also collected on 15-minute intervals.

Atmospheric conditions of air temperature, barometric pressure (not corrected to sea level) were collected at the Priest Rapids Dam weather station to determine potential atmospheric influences on TDG levels. Barometric pressure/air pressure data was also collected by the Grant PUD at just above the water surface near their forebay and tailwater FSM stations. 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):

- PRDF – Priest Rapids 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. Two additional logging instruments, PRDA and PRDB, were placed at this location for the duration of the study. This data provided information on incoming/background TDG levels for comparison to TDG levels downstream of Priest Rapids Dam during the PRFB test operations.
- T1 - A five-station/ten-instrument TDG transect located approximately 2000 feet downstream of Priest Rapids Dam. Stations were distributed as evenly as possible across the river. The paired instruments were attached together with the sensors positioned at 3 ft up from bottom. A composite TDG value was collected from this transect to determine TDG values produced by the PRFB. The location of this transect was selected because of its position in the river where it narrows having uniform flows laterally, and minimal back eddies to confound the data analysis.
- PRDT – Priest Rapids Dam tailrace FSM station, an existing real-time TDG monitor attached to a pier-nose (mid-channel) of Vernita Bridge, located approximately nine river miles downstream. Data collected at this location was used comparatively with TDG pressures as measured at the T1 transect, and to verify the PRFB's ability to meet downstream TDG water quality standards (120 %SAT).

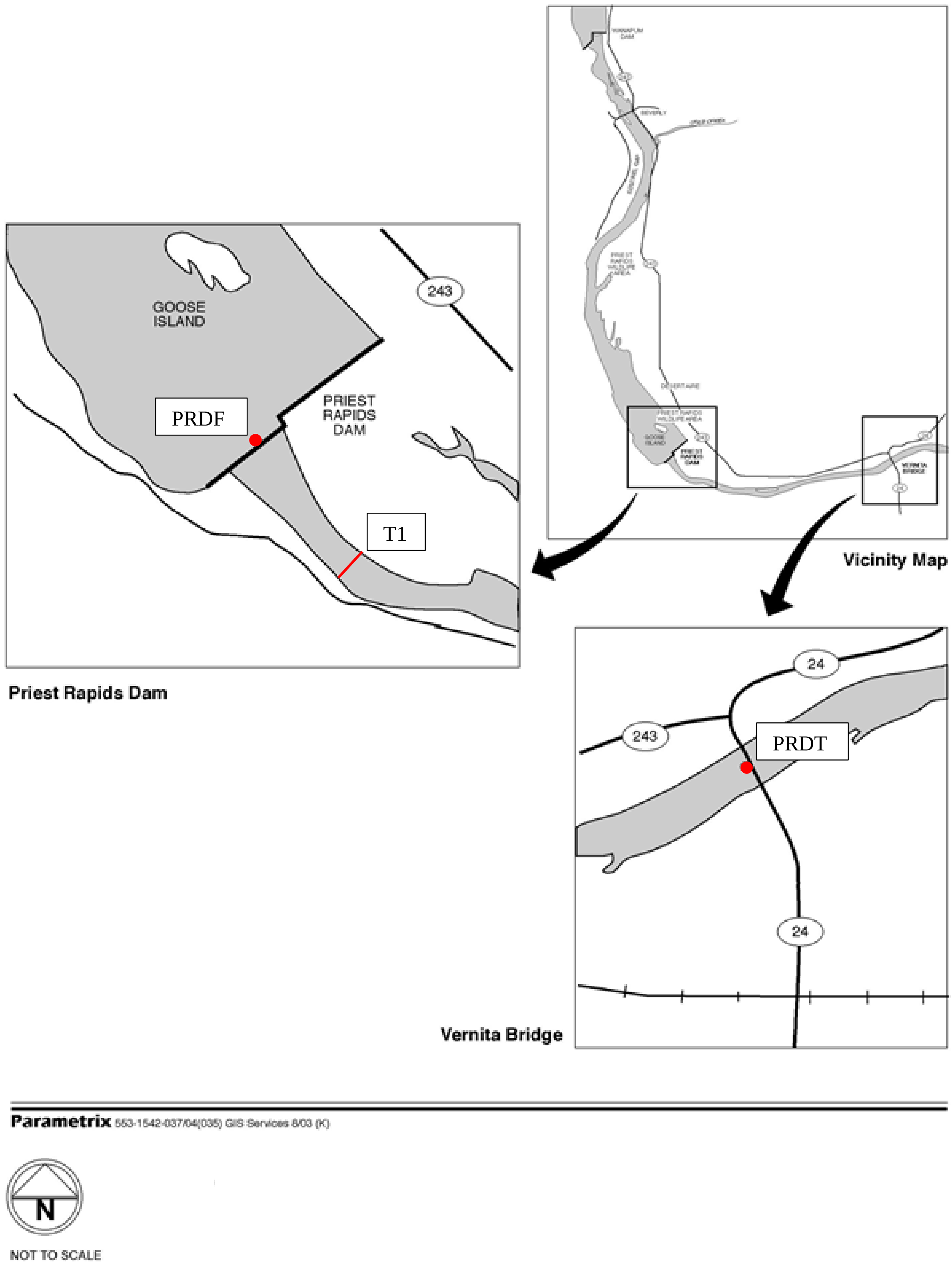

Figure A-1 TDG monitoring stations: Priest Rapids forebay (PRDF), transect array (T1), and tailrace (PRDT).

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 (Hendrick and Keeler, 2011). The instruments were programmed to record measurements of TDG pressure (mmHg), 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 July 31, 2014, per manufacturer's specifications.

All instruments for the field study were deployed on August 1st, 2014. Ten were distributed laterally across the T1 transect at five stations. The T1 transect was approximately 1300 ft in length and 2000 ft downstream of the dam. Starting on the left-bank downstream of Priest Rapids Dam, 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. Each station had 2 instruments deployed on the same cable. The paired instruments were attached together at the same depth, three feet off the bottom of the river, to perform as replicates. Adding an "A" or "B" to the label, T1P4A or T1P4B was used to identify replicate instruments. Two instruments, named PRDFA and PRDFB, were deployed adjacent to PRDF next to the intake of turbine unit ten. PRDFA was placed at a depth of 15 feet and PRDFB was positioned at 30 feet.

The deployment information for each station and instrument is given in Table A-1. This includes station label, instrument or data status, instrument type, serial number, retrieval date and time, position as Latitude and Longitude (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/retrieval boat.

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

Station	Inst/Data Status	Type	SN	Retrieval Date and Time	Station Lat, Long (DD)	Station Depth (ft)	Dist from Left Bank (ft)
PRDFA	OK	MS5	44947	8/19 0900	46.64457° -119.91014°	15	N/A
PRDFB	OK	MS5	44948	8/19 0900	46.64457° -119.91014°	30	N/A
T1P1A	Not retrieved	DS4a	37621	N/A	46.63902° -119.90289°	15	100
T1P1B	Not retrieved	DS4a	39850	N/A	46.63902° -119.90289°	15	100
T1P2A	OK	DS4a	39855	8/19 0730	46.63861° -119.90367°	18	330
T1P2B	Com Failure	MS5	44549	8/19 0730	46.63861° -119.90367°	18	330
T1P3A	OK	MS4	36394	8/19 0745	46.63853° -119.90456°	25	540
T1P3B	Lost	DS4a	37260	8/19 0745	46.63853° -119.90456°	25	540
T1P4A	OK	DS4a	39849	8/19 0755	46.63857° -119.90580°	20	810
T1P4B	OK	MS4	36392	8/19 0755	46.63857° -119.90580°	20	810
T1P5A	OK	MS4	36900	8/19 0705	46.63791° -119.90659°	12	1090
T1P5B	OK	DS4a	32403	8/19 0705	46.63791° -119.90659°	12	1090

Instrument deployment methods varied depending on the location, water condition, and depth. In general, instruments were set using a normal anchor and buoy system for deployment. Anchor and housing weighed approximately 200 pounds and were attached to a series of surface floats via 5/16 inch 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 3 feet up from the anchors. The initial instrument depths were ten feet or greater for all stations.

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. Calibration checks and adjustments were performed on all instruments within one day prior to initial deployment. Post deployment checks on calibration were completed as needed for evaluation of instrument drift and accuracy on the day following retrieval. Post deployment checks included general servicing, personnel checked for and, as necessary, fixed problems (probes clogging, leaking membranes, instruments out of calibration, battery failures etc.) and recalibrated the instrument(s) as needed.

During the pre-deployment calibrations all instruments were set to read within +/-1 mmHg of the atmospheric pressure. The instruments were also corrected to read +/- 1 mmHg of the air pressure plus 200 mmHg 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.

Table A-2 Instrument calibration, pre-deployment, 07/31/2014, and post-retrieval calibration check, 08/20/2014.

Station	Model	SN	Pre Test BP (ΔmmHg)	Pre Test Span BP+200 (ΔmmHg)	Post Test BP Check (ΔmmHg)	Post Test Span BP+200 (ΔmmHg)
PRDFA	MS5	44947	0	1	1	1
PRDFB	MS5	44948	0	1	-2	2
T1P1A	DS4	37621	0	0	(lost)	(lost)
T1P1B	DS4	39850	0	-1	(lost)	(lost)
T1P2A	DS4	39855	0	-1	0	0
T1P2B	MS5	44549	0	0	(no com)	(no com)
T1P3A	MS4	36394	0	-1	0	0
T1P3B	DS4	37260	0	0	(lost)	(lost)
T1P4A	DS4	39849	0	0	0	0
T1P4B	MS4	36392	0	0	0	0
T1P5A	MS4	36900	0	1	0	0
T15B	DS4	32403	0	0	1	1

The tensionometers used for measuring TDG pressures employ semi-permeable membranes connected to pressure transducers with associated electronics to directly measure in-situ TDG 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. No instrument membranes failures occurred during the testing.

2.4 Data Completeness, Quality, and Consistency with Conditions

There were adequate datasets resulting from all but station T1P1 for the study. The T1P1 station cabling became fouled with the bottom of the river during testing and was not retrieved. The T1P3B instrument twisted off of the main anchor line and was lost during testing. The instrument from T1P2B was damaged during deployment and would not communicate following retrieval.

Instrument calibration post checks revealed only minor differences with the known standard pressures, +/- 2 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

In order to evaluate the TDG exchange associated with the operation of the PRFB at varying tailwater elevations the PRFB was operated up to its designed capacity (~27 kcfs) with four powerhouse loading targets: no flow, 60 kcfs, 100-120 kcfs, and greater than 140 kcfs. Table A-3 presents the specific targeted operating conditions.

Table A-3 Targeted operating conditions for the total dissolved gas exchange study.

Operating Condition	Test Condition Label	Turbine Flow (kcfs)	PRFB Flow (kcfs)	Data collection interval (minutes)	Minimum duration (hrs)
1	T1	0	27	15	3
2	T2	60	27	15	3
3	T3	100-120	27	15	3
4	T4	>140	27	15	3

Every attempt was made to hold operations steady for at least three consecutive hours during the targeted testing to allow conditions to stabilize in the tailrace. This was to achieve equilibrium in flow conditions/patterns, tailwater elevations, and a resulting equilibrium in TDG characteristics downstream of Priest Rapids Dam to the PRDT FSM station. The field testing began on August 1st and continued until August 19, 2014. The four targeted tests were conducted August 6-8, 2014. The actual conditions varied slightly from the targeted discharges due to river conditions.

The field study was continued for 11 additional days. In addition to the targeted tests there were other incidental test periods during the study period which inadvertently meet the testing requirements for further evaluation of the PRFB operation.

2.6 Data Collection Schedule

The study began in the field with the installation of all monitoring instruments completed at 1200 hr on August 1, 2014. The study ran for a total of 19 days and was completed on August 19 at

0900 hr with the final retrieval of all instruments except those at T1P1. Powerhouse operation was variable as required for power production for the entire study period.

Retrieval of the test instruments was completed on August 19, 2014. The station T1P1 was not retrieved due to fouling with the bottom. The field crew made further attempts on September 15, 2014, but failed to extract the equipment for T1P1. The T1P3B instrument was stripped from the main deployment cable likely due to the high flows and turbulence characteristic of the tailrace during the test period. The T1P2B instrument failed to communicate for data download following the test. Eight of the original 12 test instruments functioned properly through the entire test period meeting the manufacturers specifications for accuracy at standard pressure based on recommended calibration procedures. No TDG membrane failure occurred during the testing.

Data was reviewed for completeness, quality and consistency. There were no data gaps (time or parameters) identified for the instruments. The project operations logs were reviewed for completeness. The water quality data (TDG and temperature) was merged with operations data according to date and time. All data including operations information is 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, ≤1 %SAT, were tolerated with the data quality and the accuracy taken into account in data 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, paired with the TDG data from each monitoring location.

3.1 Hydrology and Project Operations

Operations data including total river flow, powerhouse discharge, spillway discharge, PRFB discharge, forebay and tailwater elevation were collected as part of the study on 15-minute intervals for the duration of the study period. The operations data were merged with the field study data sets for TDG and water temperature.

Mean daily discharge at Priest Rapids Dam ranged from 92 kcfs up to 148 kcfs during the testing period. The PRFB was operated at, or near, the maximum from 16-30 mean daily kcfs during the testing period (see Figure A-2).

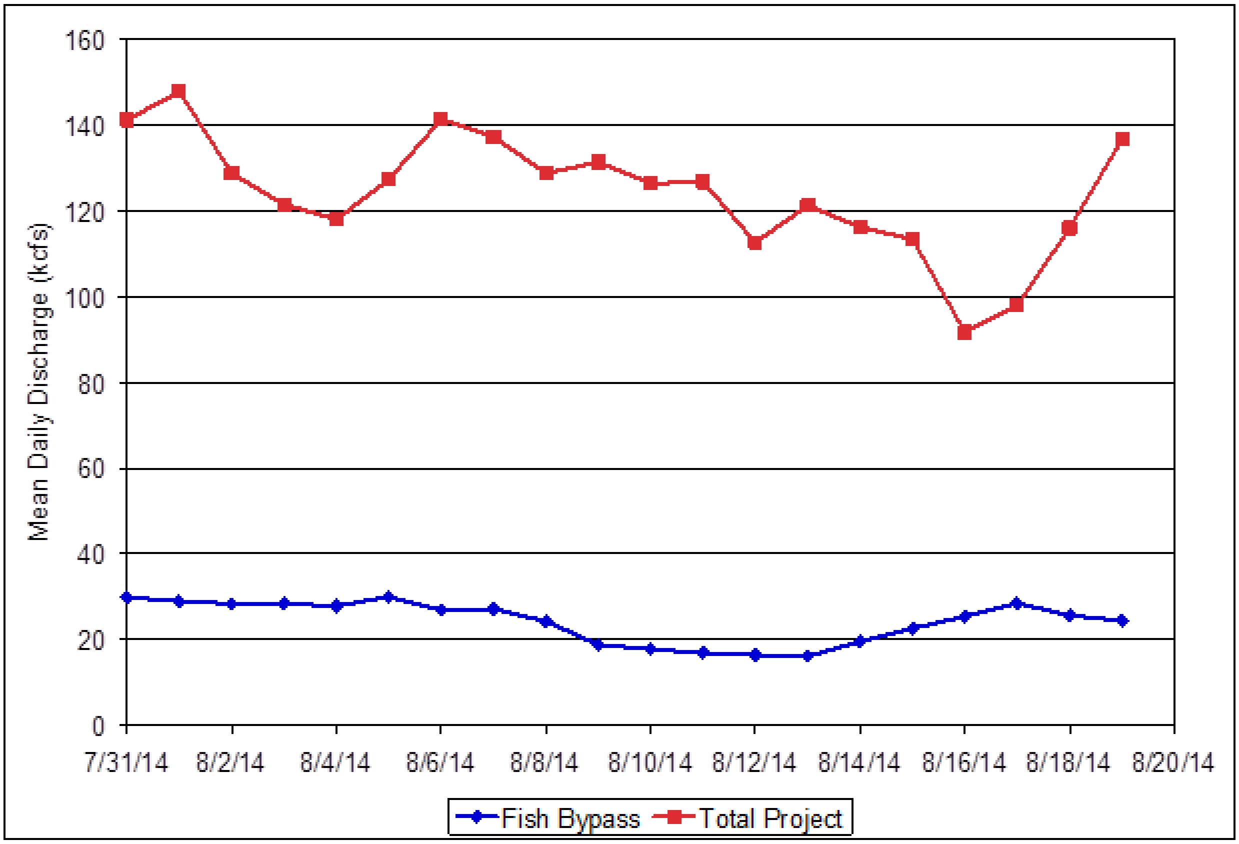

Figure A-2 Mean daily discharge at Priest Rapids Dam during the field testing.

Figure A-3 shows detailed 15-minute interval time histories of the operations/discharge data during the study. This short interval project data was highly variable depending on total river flows, power requirements, and testing needs. The powerhouse operation varied from 8 up to 160 kcfs over the test period and in combination with the PRFB operation was used to acquire the targeted operating conditions for testing. The PRFB was operated fairly consistent with all three bays totaling from 22 up to 32 kcfs for the first 8 days of the field study. The PRFB was shut down completely on 3 occasions between August 8 and 10 for a few hours each time. Following the PRFB shutdown on Aug 10 the PRFB was more varied with only two of the three bays operating until August 14. The operation went back to using the 3 bays until the end of the field study on August 19. Non fish bypass spill occurred for five hours early on August 10th up to a maximum of 29 kcfs distributed over 12 of the 19 regular spill bays. The fish ladder operation was a constant at 1.2 kcfs for the duration of the test period.

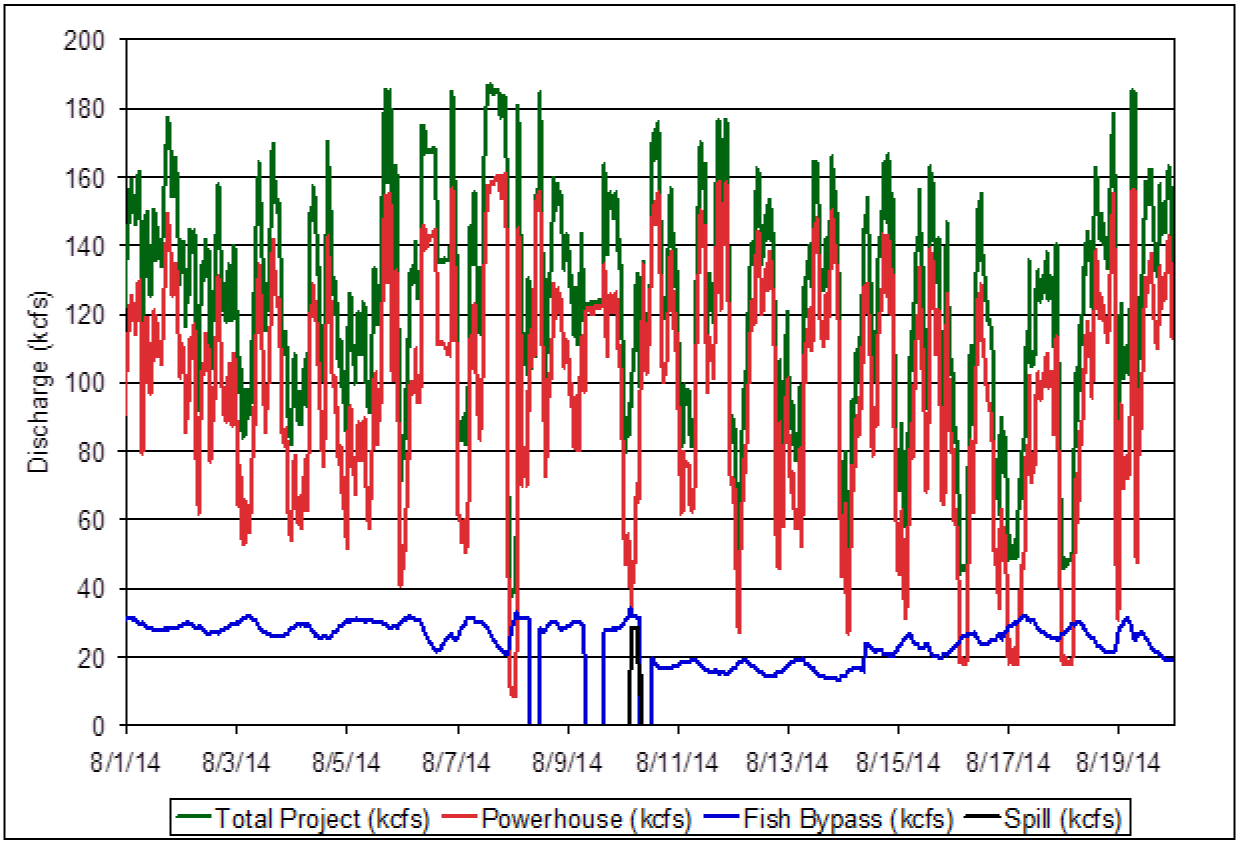

Figure A-3 Columbia River 15-minute interval discharge at Priest Rapids Dam during the field testing.

The Priest Rapids Dam forebay and tailwater surface elevations (msl feet) 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 4 ft from 484 ft to 488 ft msl with a mean daily average of 486.3 ft for the duration of the testing. Tailwater elevations varied over 12 feet with project flow changes from a minimum of 401 ft to a maximum of 413 ft msl and averaged 409.1 ft msl for the test period. The mid points of the targeted operations periods T1, T2, T3, and T4 are depicted on the tailwater elevation plot (see Figure A-4).

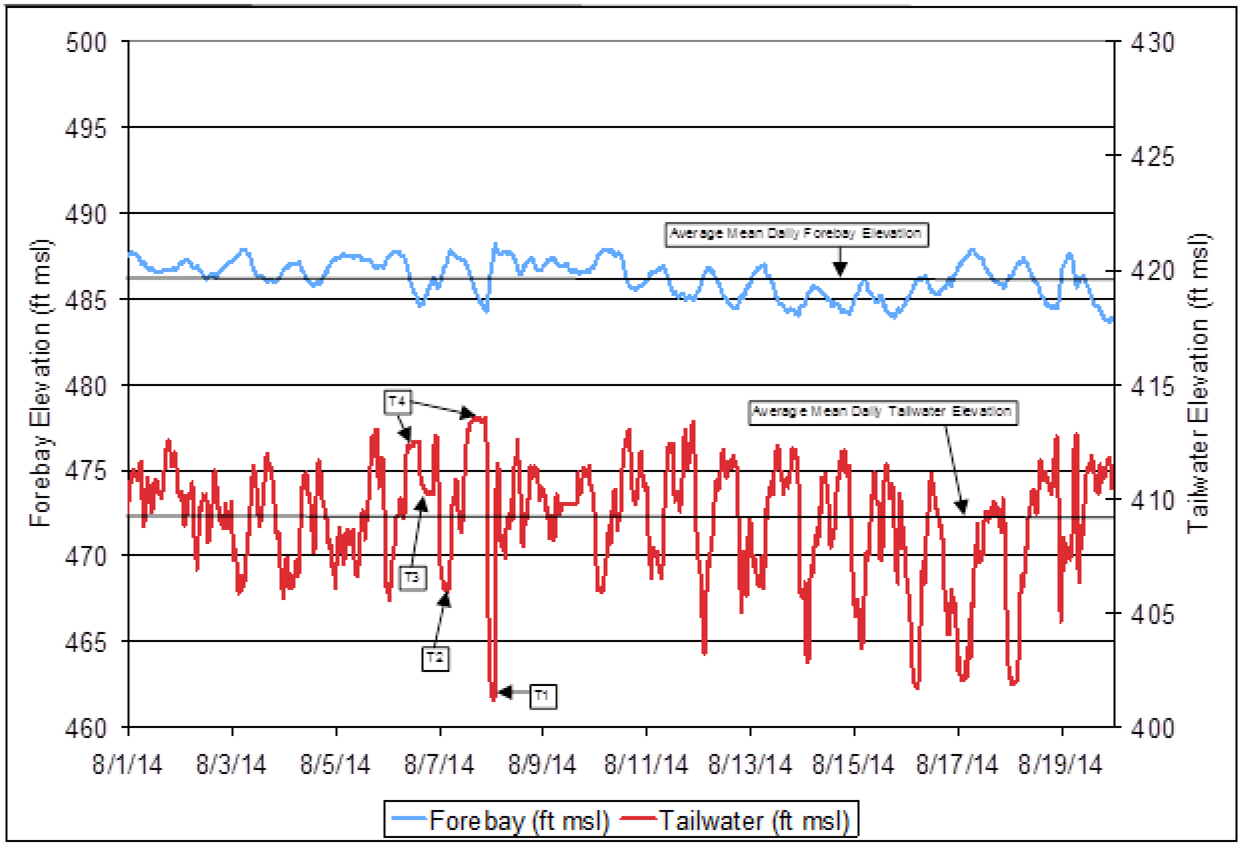

Figure A-4 Priest Rapids Dam forebay and tailwater 15-minute interval elevations during the field testing. Target operation periods T1 through T4 are shown on the tailwater elevation plot.

Priest Rapids tailwater elevation is generally controlled by the total river flow or project releases. The relationship depicted in Figure A-5 during the field test period for a major portion of the operational range can be expressed as linear, with an equation of $y = 0.076x + 399.72$ and $R^2 = 0.93$.

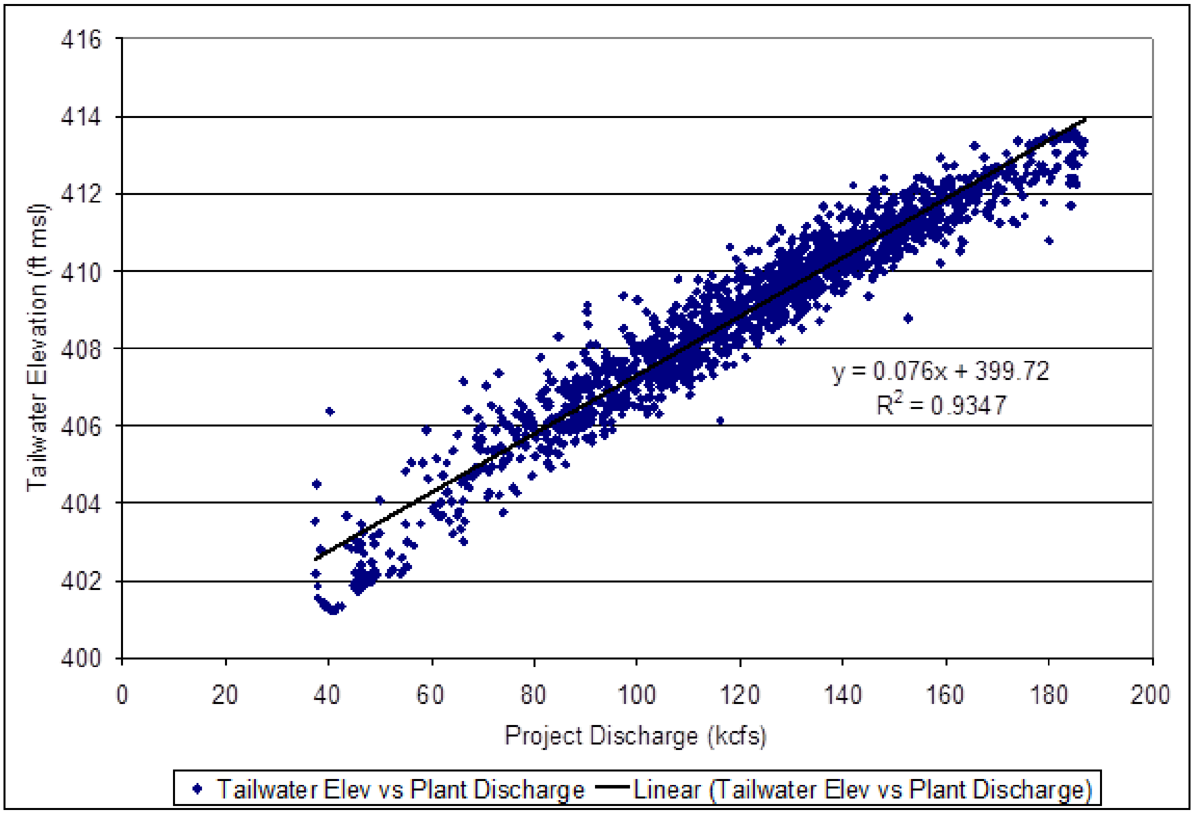

Figure A-5 Relationship between tailwater elevation and project discharge (R^2 = 0.93).

3.2 Total Dissolved Gas

The TDG exchange characteristics at a hydraulic structure are closely coupled to the system hydrodynamics coupled with the downstream bathymetry. As the flow conditions are altered by structural or operational means, the TDG exchange is also modified. Because of the high air entrainment and the transport of air to depth, a rapid and substantial absorption of atmospheric gases takes place in the stilling basin below the spillway and in this case downstream of the PRFB. These flow conditions result in maximum TDG pressures experienced below the dam.

There is little opportunity for entrained air to be introduced into the confined flow path through a turbine, except during turbine startup or shutdown when air may be aspirated into the turbine. In most cases, there is no appreciable change in TDG pressure as generation flows pass through a dam. Since turbine discharges do not entrain air, it has generally been assumed that generation discharges pass forebay TDG pressures to the downstream pool and do not directly contribute to higher TDG exchange. This was documented at Priest Rapids Dam (Schneider and Carroll 2002) where monitoring directly in the draft tube releases determined TDG saturations to be unchanged from forebay concentrations.

Powerhouse discharge may either be entrained into spillway flows in the stilling basin or mixed with spillway releases in the river channel downstream from the region of aerated flow. The development of the mixing zone between the two flows can be responsible for the redistribution of TDG pressure in the receiving tailwater channel. In many cases, the lateral mixing of powerhouse and spillway releases is complete by the time the combined release water arrives at the next dam. However the mixing may be incomplete laterally for significant distances downstream of a dam. When the spillway is adjacent to the powerhouse as in the case of Priest Rapids Dam, a portion of this entrainment flow can be supplied directly from powerhouse releases, and this entrained flow is exposed to air bubbles causing some degree of exchange of dissolved gas.

The fate of releases varies from project to project and often depends upon operating conditions. A rapid and substantial desorption of supersaturated dissolved gas takes place in the tailwater channel immediately downstream of the stilling basin. As the entrained air bubbles are transported downstream, they rise above the compensation depth in the shallow tailwater channel. While above the compensation depth, the air bubbles strip dissolved gas from the water column. The entrained air content decreases as the flow moves downstream as the air bubbles rise and escape to the atmosphere. The desorption of dissolved gas appears to stop quickly due to the loss of entrained air within a few hundred feet of the stilling basin. The longitudinal/temporal and lateral gradients in TDG downstream of the aerated flow regime may be a slow process but is tied to the development of mixing zones and factors such as dilution, temperature change, surface exchange, and chemical/biological processes.

The depth of the tailwater channel appears to be a key parameter in determining TDG levels entering the downstream pool. If a large volume of air is entrained for a sufficient time period, the TDG saturation will approach equilibrium conditions dictated primarily by the depth of flow. Thus, mass exchange in the tailwater channel can have a significant influence on TDG levels delivered downstream during high spill discharges.

The general topographic features of the Columbia River below Priest Rapids Dam are important in defining the flow distribution at downstream river cross-sections, mixing zone development, and the time of travel within the study reach. The open river flow conditions influences the tailwater elevation, development of the mixing zone between powerhouse and spillway flows, time of travel between the dam and TDG sampling stations, and the extent of energy and mass exchange at the air/water interface. The shallow basalt shelf located below the Priest Rapids spillway can promote lateral mixing and surface exchange. The velocity of the releases can also be seen to accelerate below the dam as the channel narrows and depth of flow decreases. These channel features can potentially promote lateral mixing of project releases and the dilution of the higher TDG pressures generated from spill with powerhouse water.

Time histories describing lateral and longitudinal gradients for both TDG and water temperature for the data collected during the 2014 PRFB field testing are presented in the following sections. The data review is divided spatially into forebay data (PRDF), tailwater data (PRDT), and transect data (T1).

3.2.1 Priest Rapids Dam Forebay TDG and Temperature

The Priest Rapids Dam forebay data consisted of three instruments, the existing forebay fixed monitor (PRDF), and two additional instruments at the same location but one (PRDF-A) at 15 ft depth and the second (PRDF-B) at 30 ft depth. The A and B instruments were added for the field testing. All three were deployed off the upstream face of the dam near the turbine unit 10 intake. This forebay data represents the incoming or background TDG for comparison to the downstream TDG during the PRFB test operations.

The three instruments produced similar trends in data for both water temperature and TDG (Figure A-6). However the PRDF data averaged 1.5% %SAT less than the A and B instruments and presented uncharacteristic erratic changes in the recorded TDG indicating a potential problem with the membrane condition. The A and B instrument data was then used in calculating average temperature and TDG saturation for the Priest Rapids Dam forebay waters. This average forebay, XPRDF, saturation and temperature were then used as the representative upstream data during the testing (Figure A-7). The average temperature time history data shows a slight increase over the test period starting with an average of 19.5 °C then increasing to 20.5 °C. The daily cycles in temperature from normal solar warming were generally between 0.5 and 1.0 °C. Note that the TDG pressure change associated with 1 °C temperature based on Charles' Law is approximately 15 mmHg or about 2% saturation change at standard pressure and temperature. The average forebay TDG varied during the field study with a range of 7% saturation from 106 up to 113 % (Figure A-7). The TDG time histories were characterized by daily cycles of approximately 2% which can be associated with daily solar warming cycles and surface exchange characteristics.

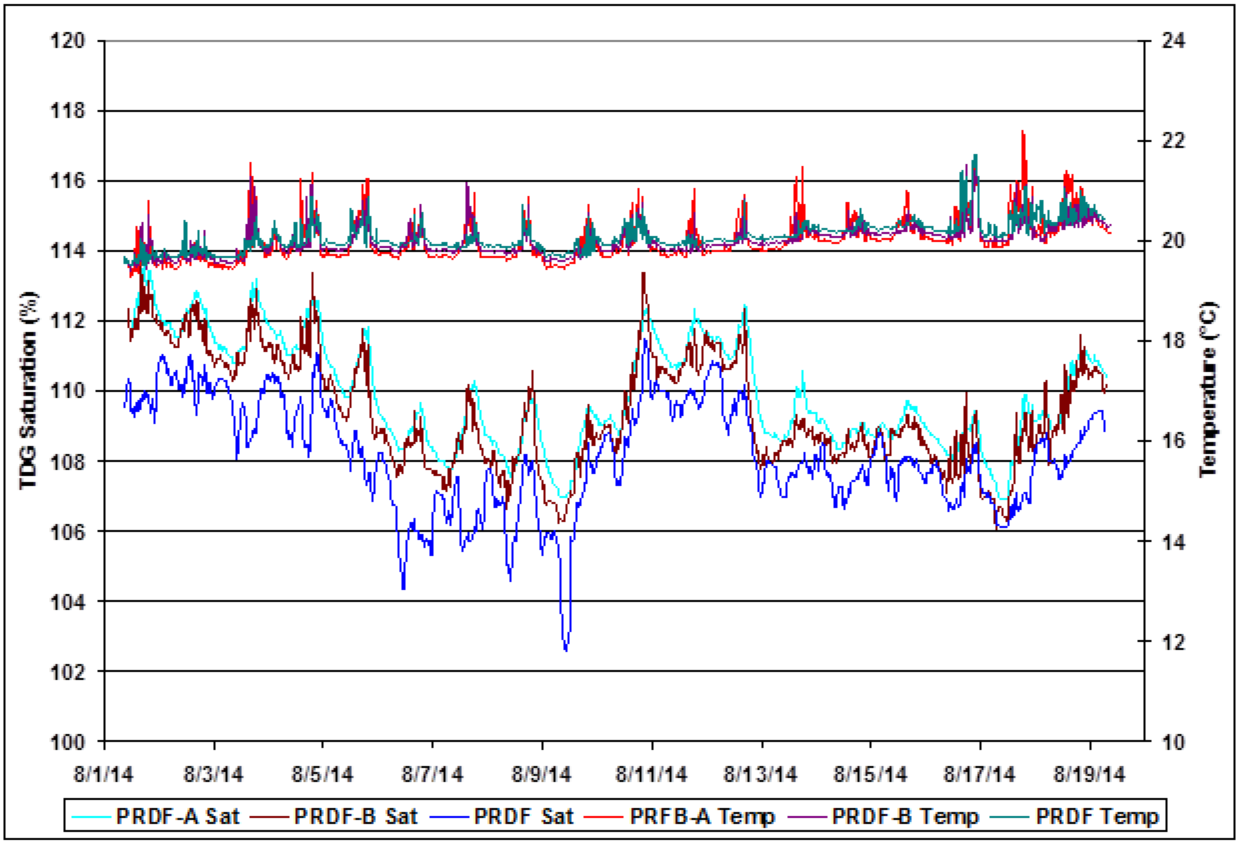

Figure A-6 Priest Rapids Dam forebay TDG and water temperature during the 2014 field study.

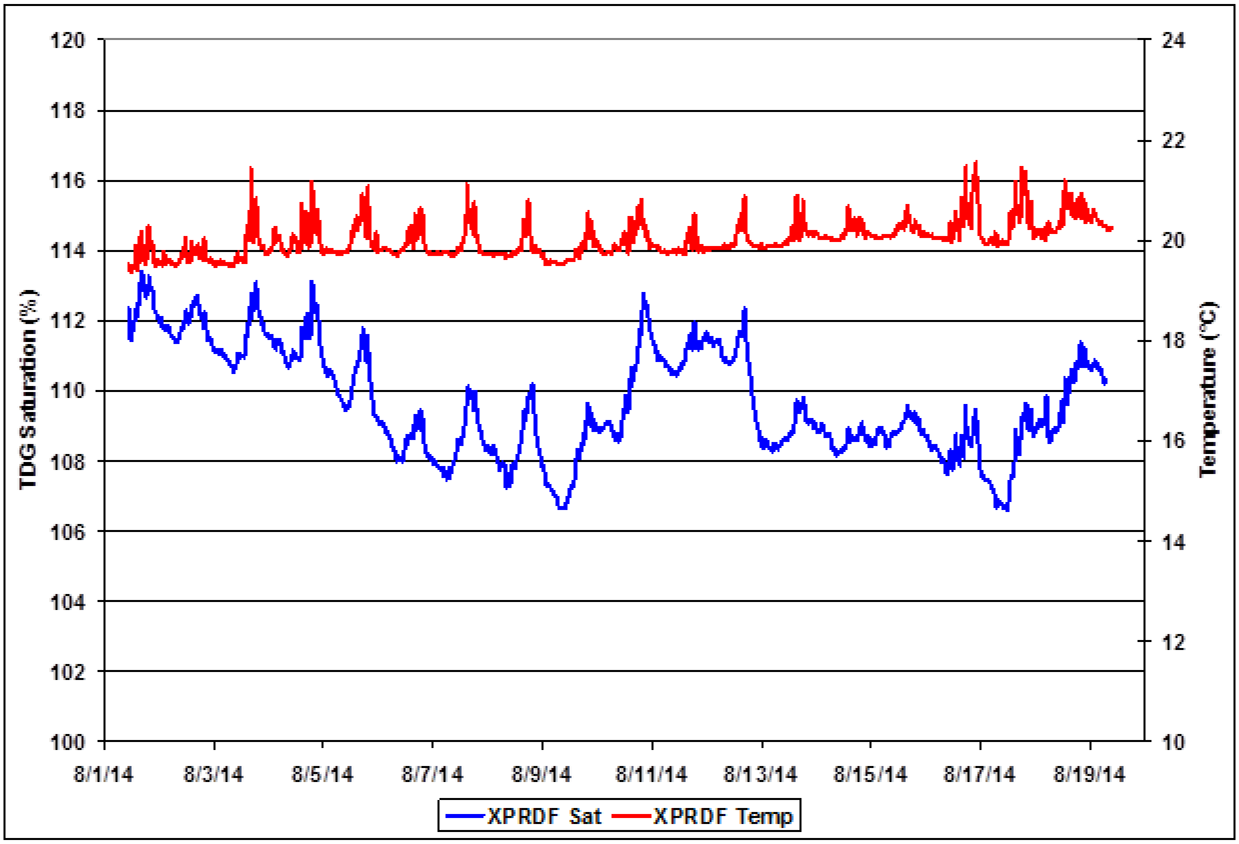

Figure A-7 Average forebay TDG and water temperature during the 2014 PRFB field study.

3.2.2 Priest Rapids Dam Tailwater TDG and Temperature

Figure A-8 depicts both the TDG and water temperature logged by the downstream tailwater stations, PRDT and PASCO. The thermal time histories indicated an approximate 0.8 °C warming from PRDT down to station PASCO. The average temperature was 20.0 and 20.8 °C for PRDT and PASCO respectively. Also note the 1°C warming over the course of the 19 day study for both stations. Daily cycles were generally near 0.2 °C for both stations. Station PRDT was characterized with TDG saturations generally in the 110% to 115% range fluctuating consistently with project operations. The PRDT TDG fluctuations were somewhat variable responding to project operational changes, upstream conditions, and the daily solar influence on water temperature. The downstream station, PASCO exhibited TDG fluctuating in the 105% to 110% range with daily TDG cycles of 2-3 % saturation during the field testing. The average decrease in TDG Saturation was 3.5 % from PRDT downstream to the PASCO station. Likely due to the long distance downstream of PRD, 68 river miles, there was no apparent response to project operation noted in the PASCO station TDG during the study.

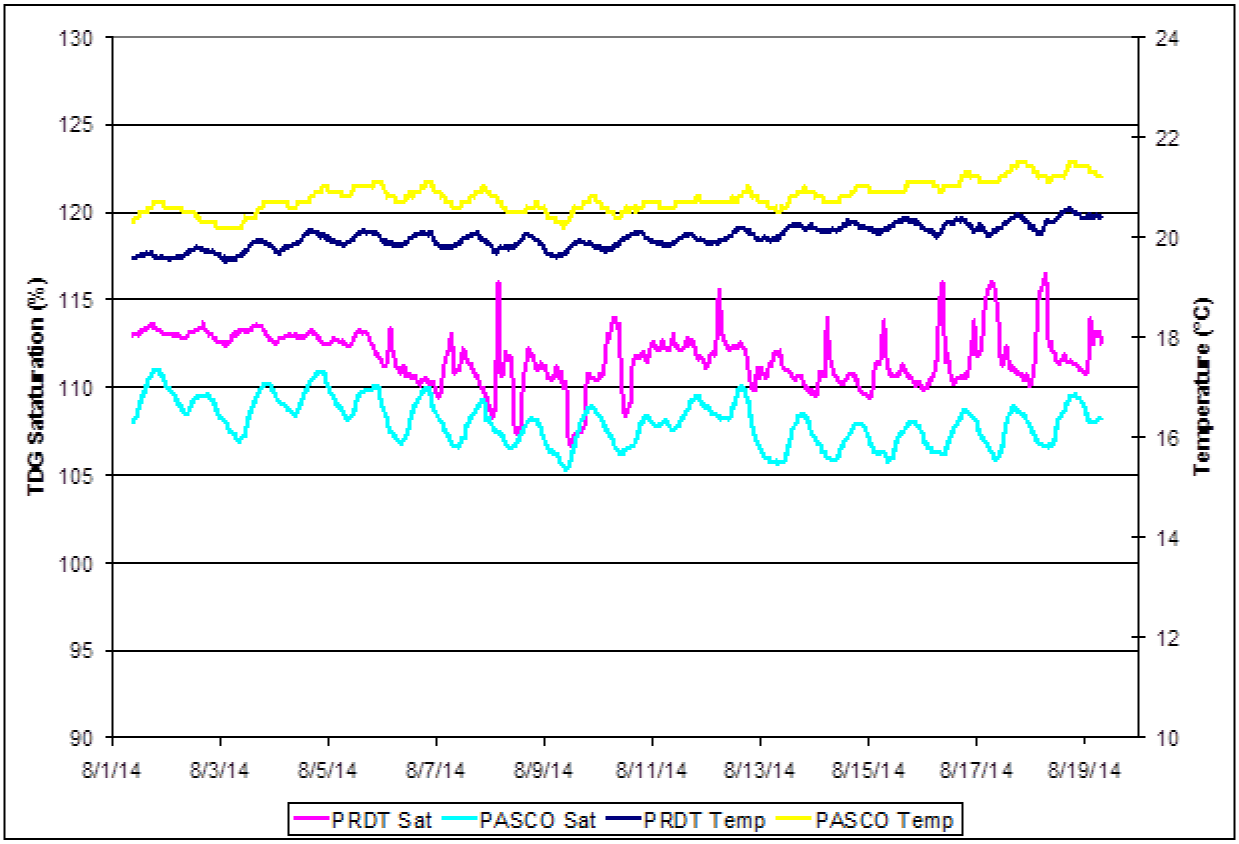

Figure A-8 Priest Rapids Dam tailrace fixed-site monitoring station (FSM station) and the next downstream FSM station (PASCO) TDG and water temperature during the 2014 PRFB field study.

3.2.3 Priest Rapids Dam Transect T1 TDG and Water Temperature

Data collected at the downstream transect, T1, for the complete study period is presented in Figure A-9, and includes the six instrument time histories. Two of the stations, P4 and P5 each having replicate instruments located near river bottom and stations P2 and P3 are represented by one instrument near the bottom in each case. No data was acquired from the P1 station due to lost instruments.

The TDG saturation at T1 stations fluctuated from 105 up to 123% saturation during the PRFB testing period. The lateral gradients in TDG across the river at transect T1 ranged from a couple of percent up to more than ten percent at various times. The transect position for the highest and lowest TDG responses varied from the P2 and P5 stations. Depending on the test conditions the lateral gradient reversed directions for the highest to lowest TDG levels. The left bank station P2 actually recorded the highest TDG with saturation greater than 120 % occurring on more than 9 occasions during the testing. This appeared to relate to the project operation and generally coincided with minimal powerhouse releases. The powerhouse operation was less than 40 kcfs for each of the 9 occasions. The P3 and P4 stations generally fell in between the two extreme stations.

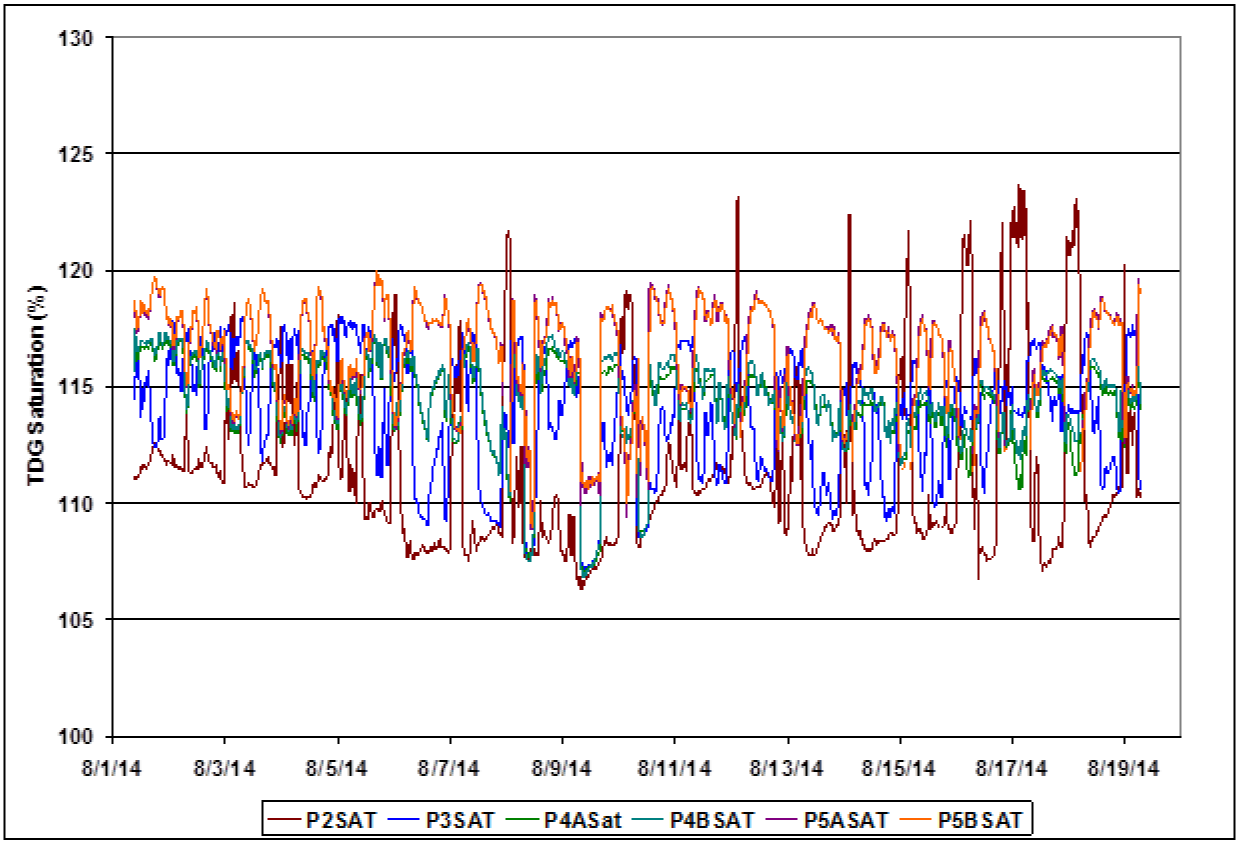

Figure A-9 TDG saturation for all Transect 1 stations during 2014 PRFB field study.

Figure A-10 depicts the T1 data over a shorter time period (August 6-8, 2014) allowing a more detailed observation of the time histories for all instruments and includes all targeted operations testing periods. During periods of high powerhouse operation, tests T4 (>140 kcfs) and T3 (>100-120 kcfs) the highest TDG is associated with the P4 and P5 stations (furthest right-bank stations). The opposite occurred as the powerhouse discharge decreases (T2 at 60 kcfs and T1 at 10 kcfs) the higher TDG saturations are recorded toward the left-bank at the P3 and P2 stations. This indicates limited lateral mixing between the powerhouse and PRFB releases by the time it gets to the T1 transect location. The PRFB releases characterized by higher TDG appear to be diverted further to the right-bank side of the tailwater cross section as powerhouse operation increases. This resulted in significant lateral gradients, up to 10 %SAT from bank to bank at times. The opposite lateral pattern occurred as the powerhouse operation decreased for T2 and T1 targeted tests.

The actual displacement of the higher TDG waters towards the left-bank at times of low powerhouse operation may be related to multiple processes acting together and occurring with the project operation and downstream hydrodynamics. One being that if powerhouse operation is lower there is less dilution water available for mixing and the overall pattern is dominated by the higher TDG waters from the static fish bypass release. Also note that river bottom elevations tend to be deeper directly downstream of the Priest Rapids powerhouse than downstream of the spillway. This comparison may extend as far as 2000 ft or near the area of the T1 transect stations (Schneider and Carroll, 2002). This would tend to lessen any desorption of gases as the aerated bypass flows move into the left bank deeper water. The opposite would be expected if the flows become dominated by higher powerhouse operation and the aerated bypass releases then pass over the shallow and often turbulent reach downstream of the spillway. A second possibility is that lower tailwater elevations associated with the low powerhouse operation may result in a plunging jet coming from the bypass operation, and the bypass design may not handle the lower tailwater elevations. A plunging jet from the fish bypass could potentially transport considerable entrained air to deeper depths present downstream of the powerhouse.

As mentioned earlier, there appears to be no effect on the TDG saturation as the water is passed through the powerhouse. TDG saturation at the P2 left bank station directly downstream of much of the powerhouse releases was the same as that for the forebay station. Note that during the lowest powerhouse operation, near 10 kcfs for T1, the tailwater elevations receded to less than the bottom elevation at P5. This resulted in no P5 data for the T1 test.

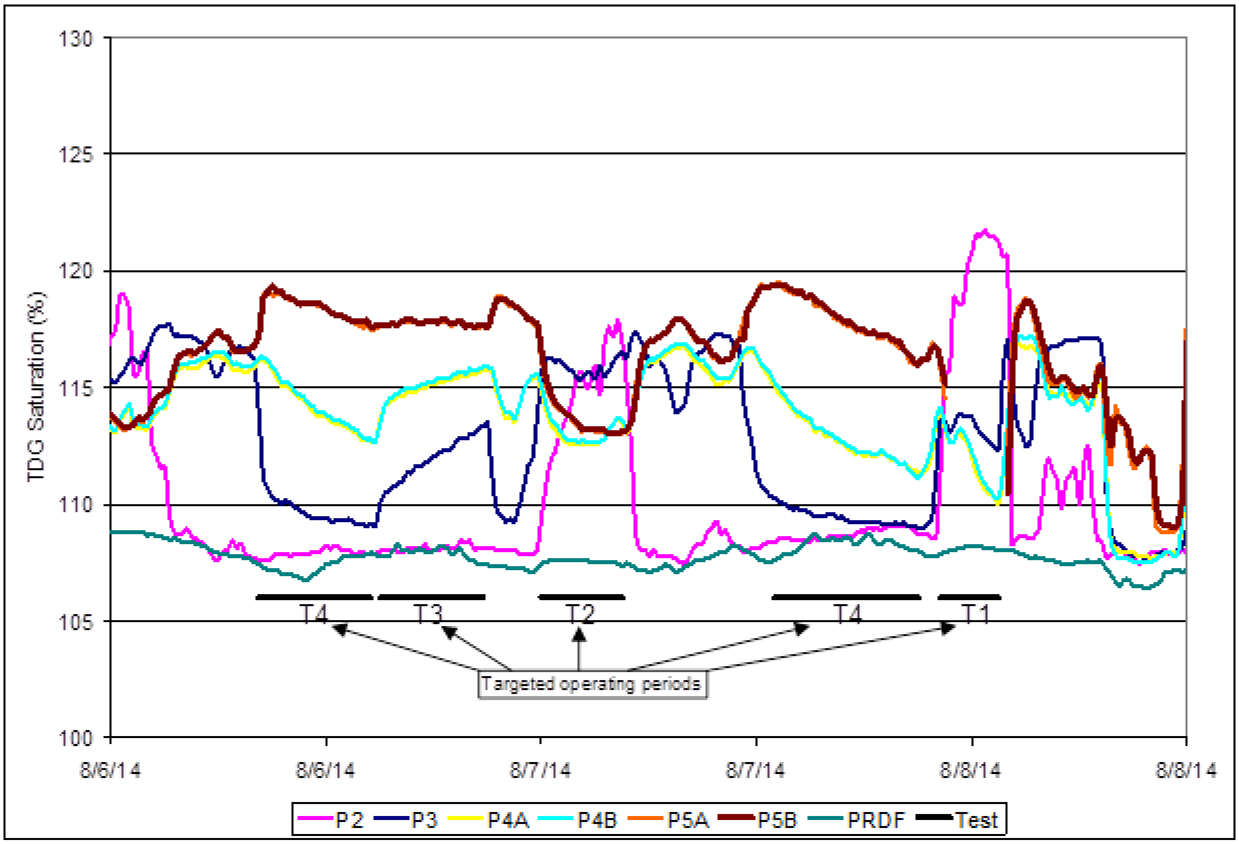

Figure A-8 **TDG saturation for all the sampling stations on Transect T1 from August 6-8, 2014 with targeted operation periods.**

Figure A-11 depicts the average forebay and T1 TDG time histories as well as that for the downstream FSM station, PRDT. Each of the T1 station averages are calculated based on the available instrument data. The average T1 TDG is calculated by weighting each station value based on the cross sectional area represented by that station as a percentage of the entire transect cross section. The depicted instantaneous increase in TDG downstream of the project appears to be in the order of 2-9% with the fish bypass operating. In general, the T1 transect and PRDT TDG data were similar in pattern with the differences generally in the 1 to 3% range. This would imply an approximate 2% saturation decrease over the 9 miles of travel from Priest Rapids Dam down to the Vernita Bridge.

On three occasions, early on the 8th and 9th and again on the 10th of August, when the bypass was shutdown the downstream TDG remained within 1% of the forebay saturations. This would agree with earlier findings that the PRD powerhouse operations have negligible impact on the TDG saturation of the upstream waters.

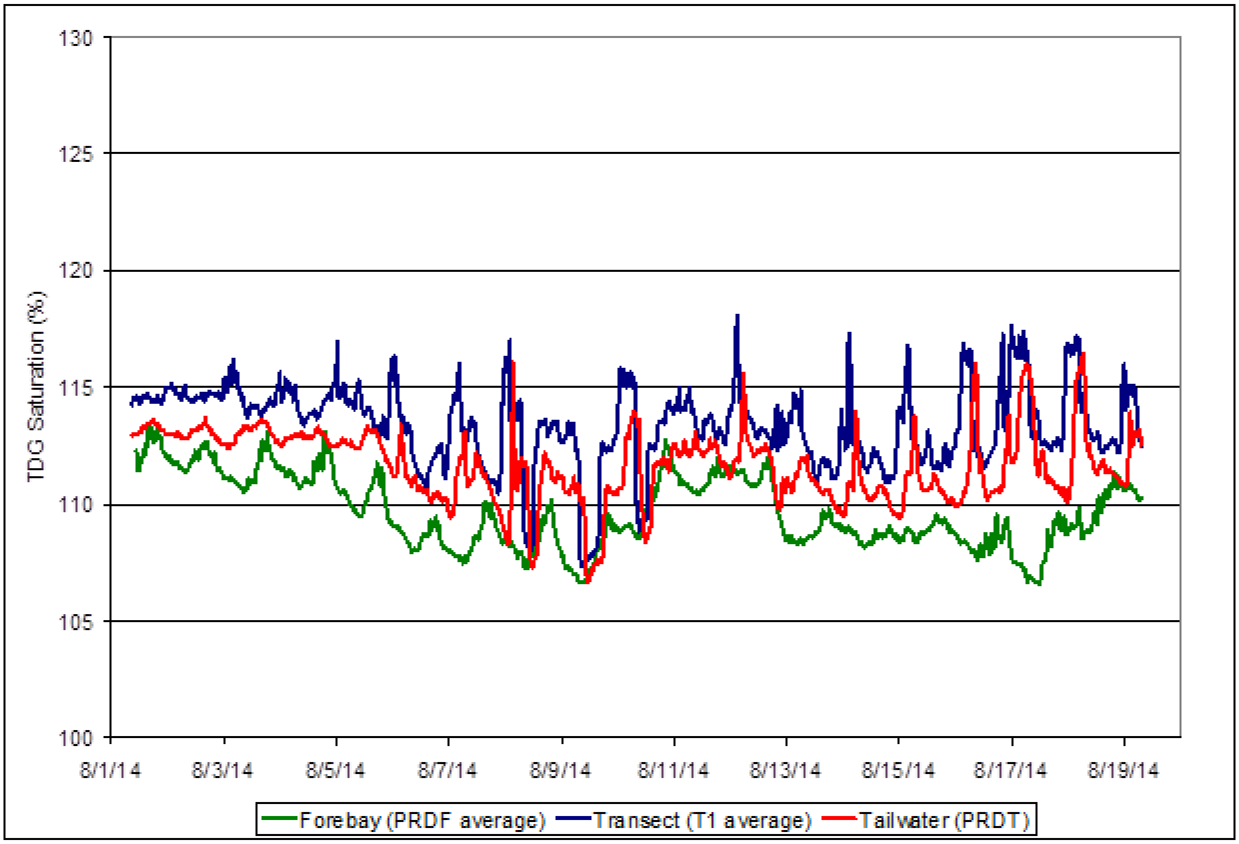

Figure A-9 Priest Rapids forebay fixed-site monitoring station (PRDF) and transect T1 average TDG and the Priest Rapids tailrace fixed-site monitoring station (PRDT).

The T1 temperature data for the study period is presented in Figure A-12. There were no significant lateral thermal gradients indicated. In general the lateral thermal gradient and the daily solar warming were both less than 0.3 °C. The significant decreases in P5 temperature coincide with periods of low flow when the P5 instruments were exposed to colder air temperatures.

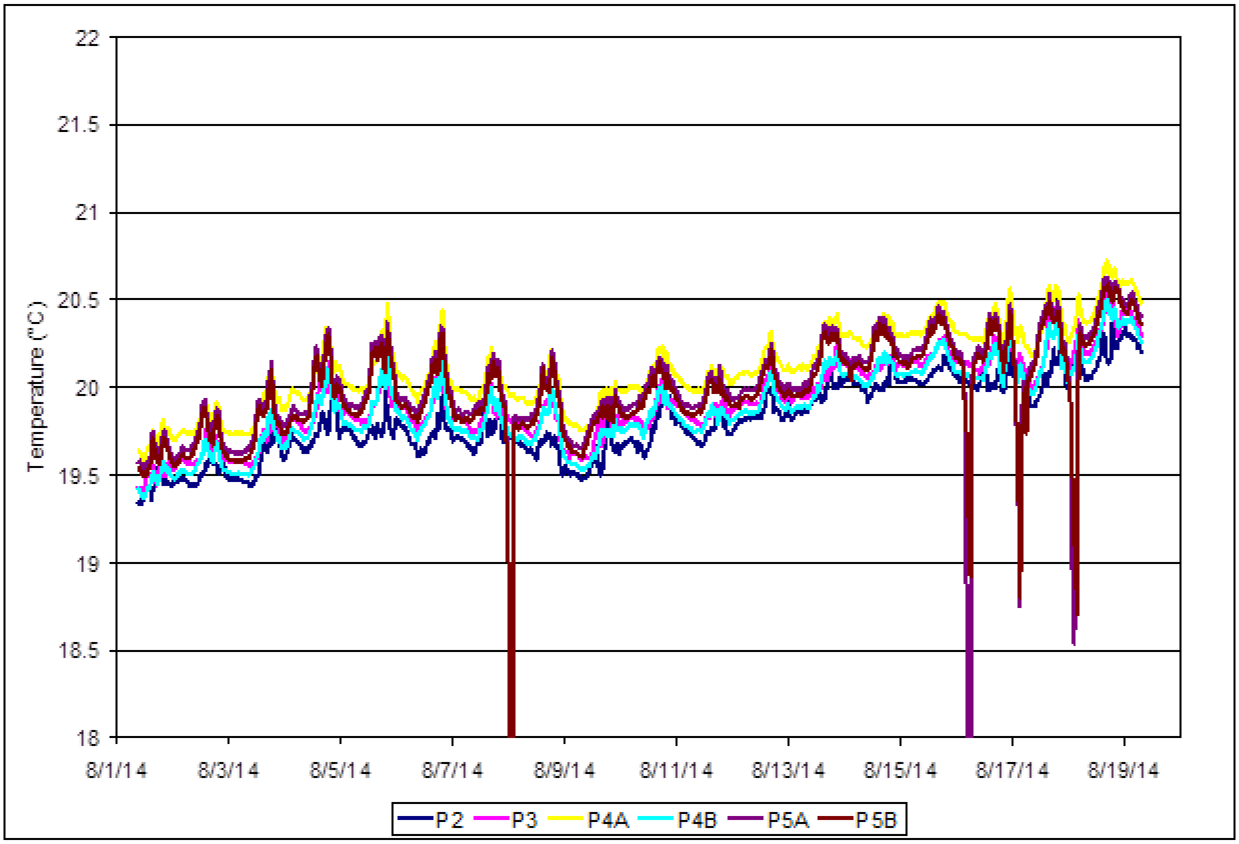

Figure A-10 Transect T1 water temperature during the 2014 PRFB field study.

3.2.4 Comparison of PRD upstream vs. downstream TDG saturations

A limited comparison of the tailwater TDG 15-minute interval time history data at station PRDT to the transect T1 results was presented in Section 3.2.3, Figure A-11 showing the time series data that indicated the two data sets to be similar in pattern with the differences typically less than 5% saturation 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 average T1 data, which allows for the additional time of travel to the PRDT monitor. The time of travel from T1 to PRDT may vary considerably but in general a 3-hour lag fits based on the previous plots. Figure A-13 compares the two downstream locations applying a 3-hour lag in the T1 TDG data. Even though the difference is small the resulting average difference between T1 (3-hr lag) and PRDT from the detailed time history data during the field testing operation is 1.7 % saturation, with a standard deviation of +/- 0.85 % saturation. The two stations are good indicators of each other with a minimal difference considering the normal precision of the equipment and field sampling error.

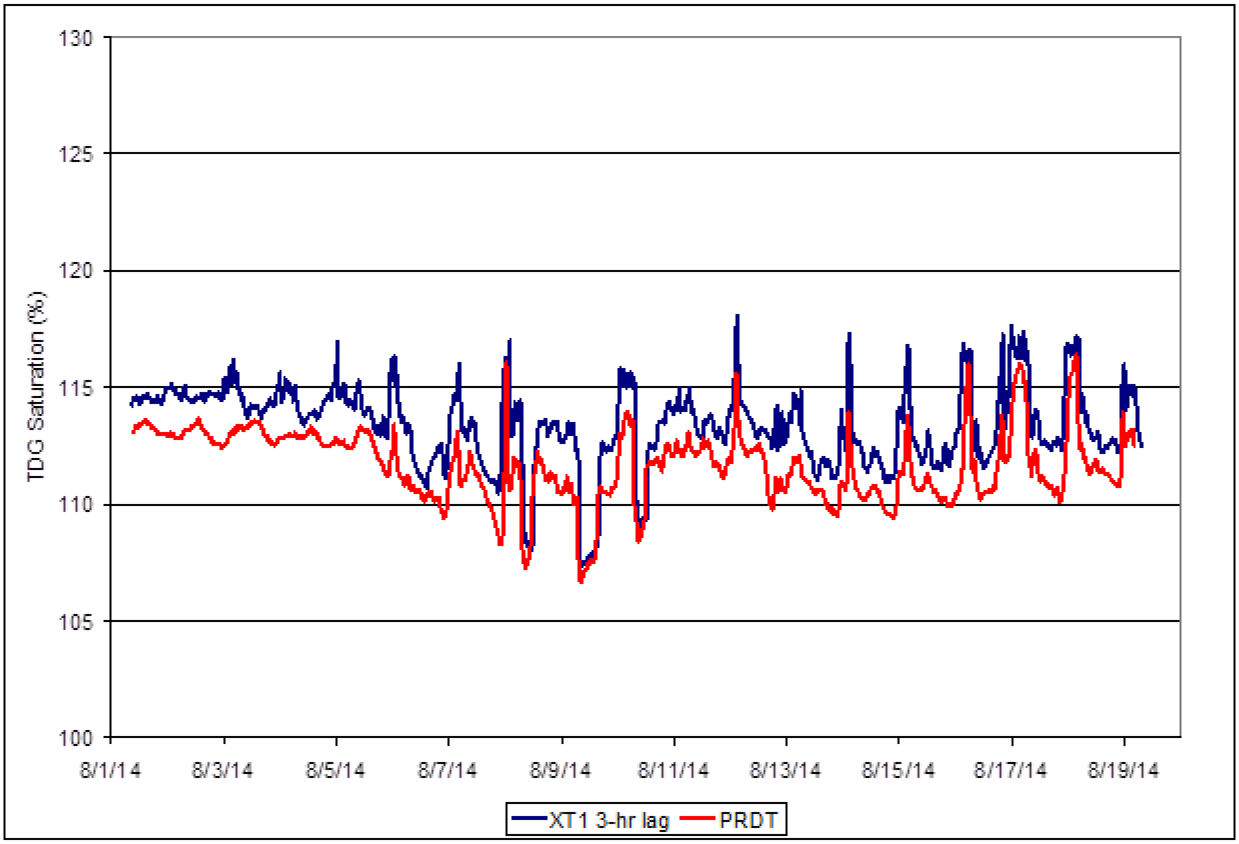

Figure A-11 Comparison of average T1 (3-hr lag) and PRDT TDG levels recorded during the 2014 PRFB field study.

The linear regression of the T1 (3-hr lagged data) vs. PRDT shown in Figure 14 has nearly a one to one relationship with an R^2 of 0.76. This supports the good agreement between the two downstream stations even though they are separated by 9 river miles.

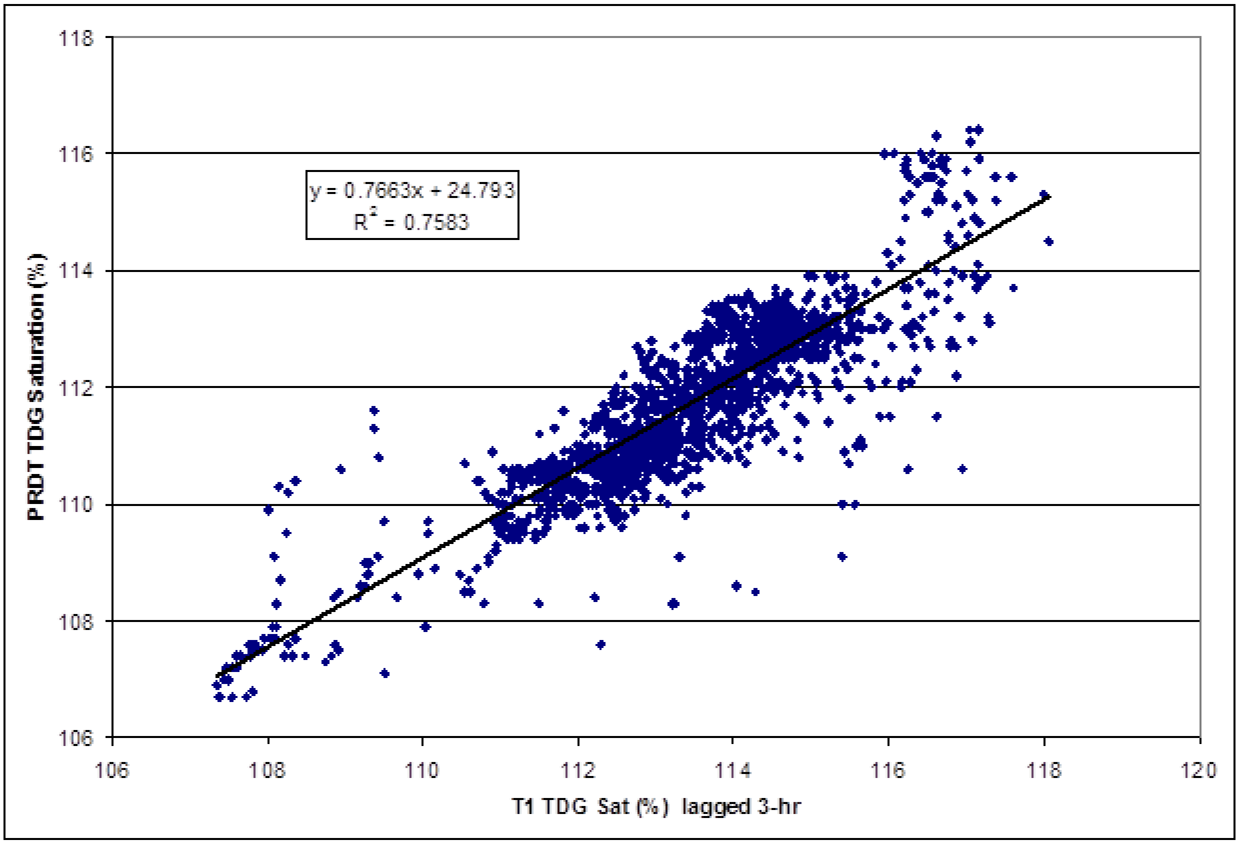

Figure A-12 Comparison of T1 (3-hr lag) vs. PRDT TDG levels recorded during the 2014 PRFB field study.

3.3 Operational tests/Target Operations

In order to isolate TDG exchange associated with the operation of the PRFB at varying tailwater elevations, the bypass was to be operated up to its capacity of 27 kcfs and with four powerhouse loading targets; T1-no flow, T2-60 kcfs, T3-100 to120 kcfs, and T4-greater than 140 kcfs. The purpose for varying the powerhouse loading was to vary the tailwater elevation and capture any differences associated with the characteristic of the bypass jet leaving the chute. In order to acquire equilibrium conditions in downstream hydrodynamics and associated TDG the operations were held steady for at least three hours. The targeted conditions were attempted at least one time each during the period of August 6th to August 8th (Figure 15) and approximate operations were achieved. The actual operations were as follows; T1 – 9.8 kcfs, T2-56.7 kcfs, T3 – 110.4 kcfs, T4a – 142.6 kcfs, and T4b – 157.5 kcfs. A replicate test of the T4 conditions was completed giving a total of 5 test periods during the field study meeting the time requirements for controlled operating conditions.

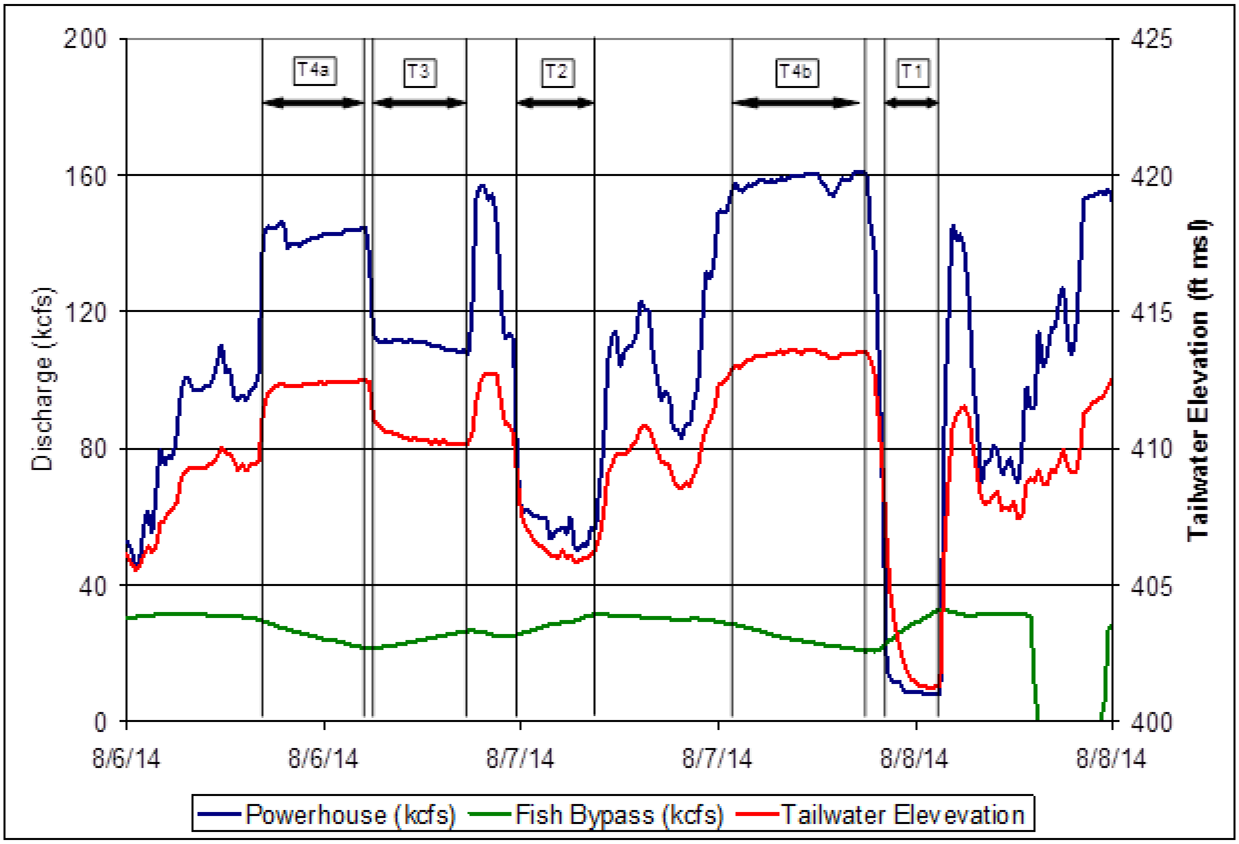

Figure A-13 Targeted test operation periods shown with powerhouse discharge and tailwater elevation, 2014 PRFB field study.

Figure 16 shows the targeted test periods with powerhouse discharge and resulting downstream TDG percent saturation. The T4 test was repeated during the field study and is shown as T4a and T4b. Targeted test 1, 2, 3, 4a and 4b had corresponding average discharges of 9.8, 56.7, 110.4, 142.6 and 157.5 kcfs respectively. The corresponding TDG can be identified on the plot as well. This type of data review was used in determining equilibrated TDG conditions to associate with the individual tests.

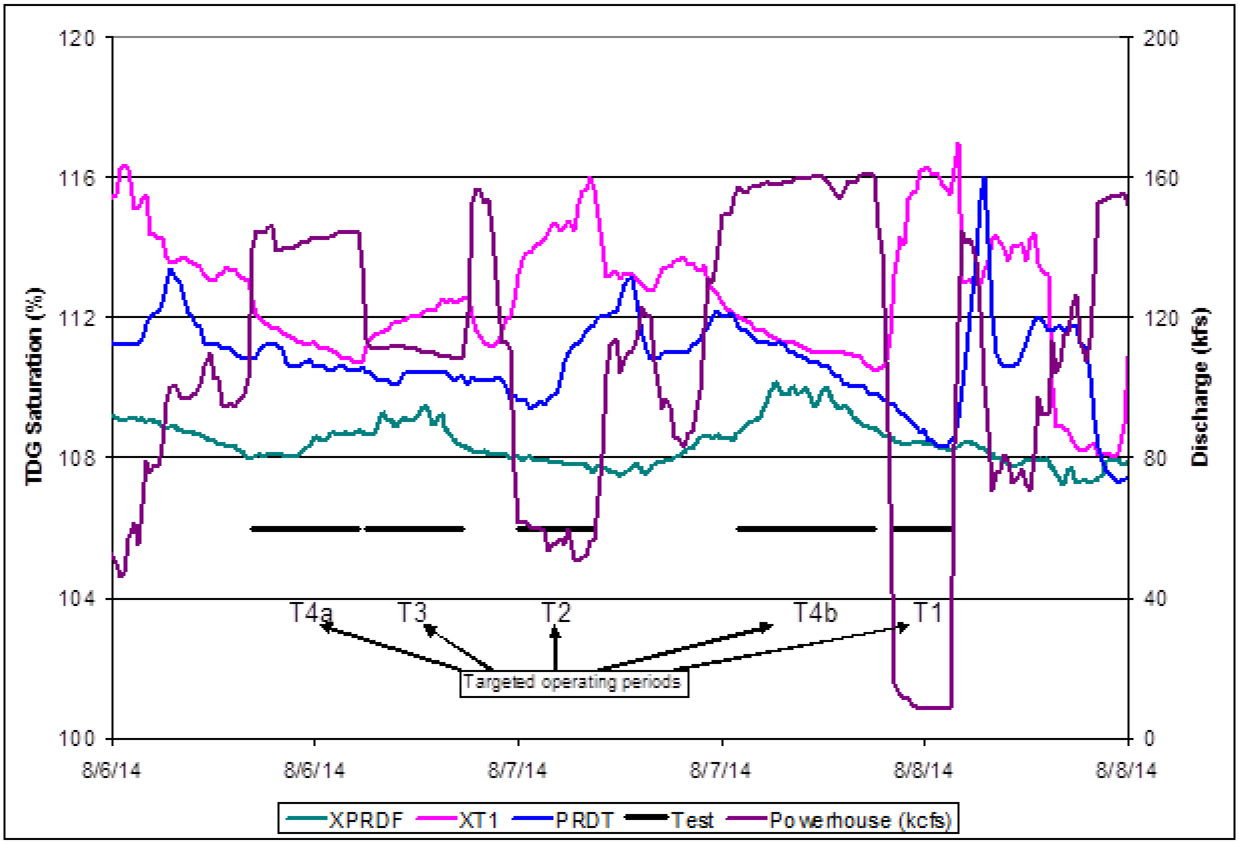

Figure A-14 Mean TDG saturation for transect T1 stations, Priest Rapids Dam tailrace (PRDT) and forebay (XPRDF) stations with total project discharge.

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. A time lag to equilibrated conditions was determined for the downstream stations using visual observations of station responses to the operational changes. The time lag determined for the T1 transect stations was 2 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 1.5 hours of data or six readings per instrument. The PRDT monitor data representing each test was observed to occur from approximately 5 hours following test initiation and continued for the same length of time as for the T1 station responses.

Detailed review of the operating conditions revealed 21 additional periods where project discharge was held adequately constant to allow for steady state conditions in the downstream quality or flow patterns to develop. Figure 17 is an expansion of Figure 16 and covers the entire study period showing the time of occurrence of each test including the targeted test periods plus the 21 additional incidental tests. Based on the time of each controlled test this resulted in a range of 1.5 to 7.5 hours of data collection at 15 minute intervals for use in calculating the test statistic or average by station.

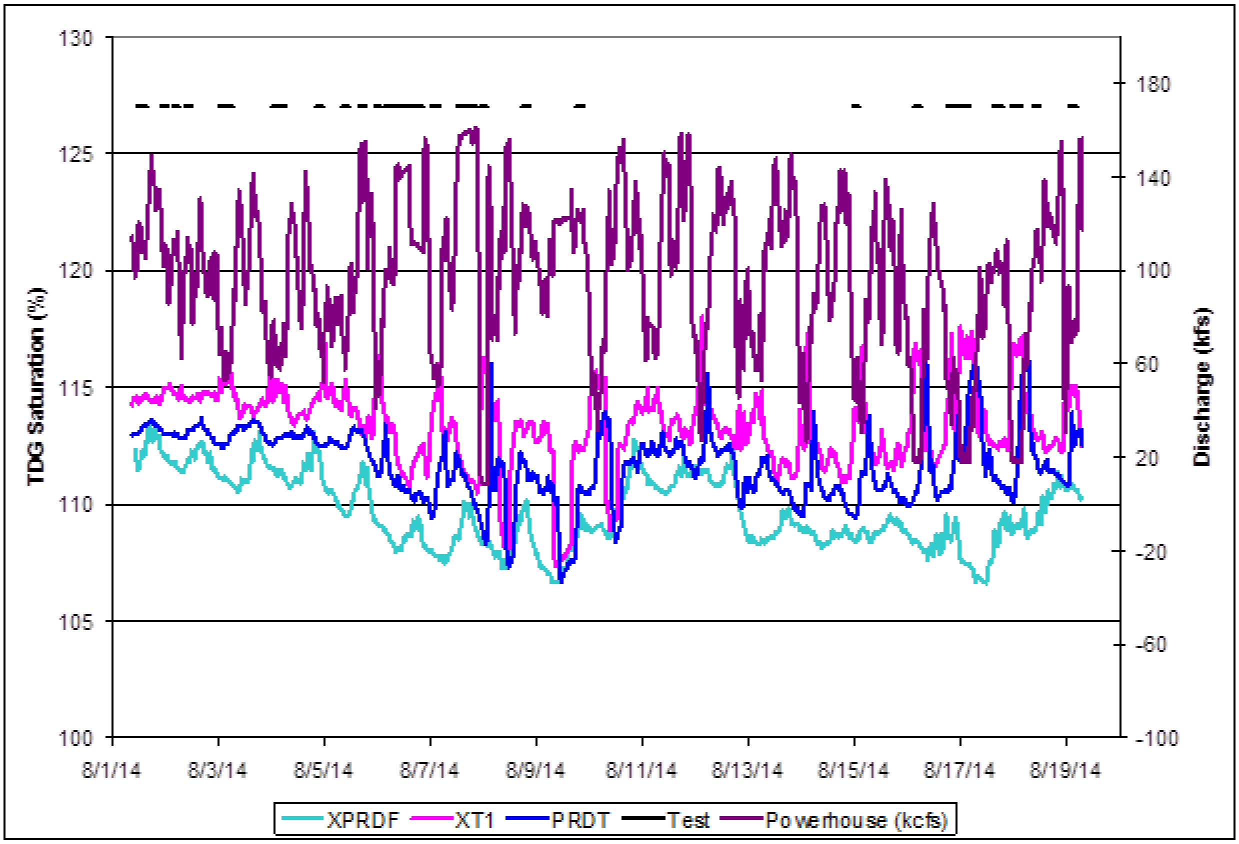

Figure A-15 Mean TDG saturation for transect T1, Priest Rapids tailrace (PRDT) and forebay (PRDG) with powerhouse discharge and depicting the 26 test periods for the complete study period.

A complete listing of descriptive statistics is given in Table A-4 for each of the 26 tests identified between August 1 and August 19, 2014. The constant project discharges for the 21 incidental tests varied from a mean of 18.6 kcfs up to 145.5 kcfs. The trend for the incidental tests as with the targeted test was that the high percentage of bypass flows resulted in higher downstream TDG levels or the lower powerhouse operations resulted in the highest downstream TDG saturations. Incidental tests I15, I17, and I19 all had mean powerhouse releases of 20 kcfs or less and had the highest downstream TDG levels at over 116%. The tests with highest average release, >140 kcfs, were I9, T4a, and T4b experienced the lowest TDG % saturation at 113.1, 111.1, and 111.1 respectively.

Table A-4 Priest Rapids Fish Bypass average data for each of the test periods.

Test Label[1]	Powerhouse (kcfs)	Forebay Elevation (ft msl)	Tailwater Elevation (ft msl)	PRDF (%Sat)	T1 (%Sat)	PRDT (%Sat)	Delta TDG T1-FB	Delta TDG TW-FB
I1	112.12	486.60	410.36	112.04	114.62	113.49	2.58	1.45
I2	107.46	486.99	410.25	112.08	115.01	112.96	2.92	0.87
I3	110.49	487.01	410.25	111.70	114.60	112.87	2.90	1.17
I4	107.10	486.39	409.87	111.88	114.46	113.36	2.58	1.48
I5	59.18	487.69	406.37	111.03	115.48	113.16	4.45	2.13
I6	63.46	487.01	406.48	111.38	114.82	112.96	3.44	1.58
I7	72.73	487.05	407.53	111.92	115.08	112.69	3.16	0.77
I8	67.85	487.46	407.18	109.58	114.49	113.23	4.92	3.66
I9	145.46	486.96	412.44	111.24	113.09	111.85	1.85	0.61
I10	50.99	487.42	406.07	109.14	115.45	112.28	6.31	3.14
I11	98.85	487.60	409.40	108.54	113.17	110.92	4.63	2.37
T4a	142.56	485.74	412.31	108.32	111.10	110.38	2.78	2.06
T3	110.44	485.29	410.38	108.94	112.25	110.09	3.31	1.16
T2	56.73	486.82	406.32	107.85	114.98	112.04	7.13	4.19
T4b	157.47	485.56	413.32	109.35	111.08	109.77	1.72	0.42
T1	9.77	486.73	402.28	108.36	116.06	112.54	7.70	4.18
I12	123.93	487.11	411.19	109.72	113.43	111.20	3.71	1.48
I13	123.08	486.61	411.18	109.05	112.38	110.51	3.33	1.46
I14	50.94	485.05	405.44	108.49	114.19	111.56	5.69	3.07
I15	18.89	485.95	401.99	108.34	116.32	115.04	7.98	6.70
I16	49.44	486.02	405.22	108.88	115.04	112.39	6.16	3.51
I17	20.25	487.14	402.40	107.51	116.61	115.79	9.10	8.28
I18	102.73	486.11	409.54	108.60	112.55	110.57	3.94	1.97
I19	18.64	486.51	402.23	108.98	116.68	115.82	7.70	6.84
I20	109.21	486.35	409.96	109.13	112.84	111.72	3.72	2.59
I21	73.96	487.39	407.54	110.71	114.79	112.95	4.07	2.24

[1]Label I indicates an incidental test number and the label T indicates a targeted test (targeted test data is shaded).

The entire average test TDG data for the PRDF and PRDT stations, and transect T1 is presented in Figure 18. The targeted tests are Test Number 12-16. The mean difference between PRDF and T1 TDG for all of the tests was an increase of 4.5 +/- 2.1% saturation. The mean difference between PRDF and PRDT during this same period was 2.6 +/- 2.0% saturation. As mentioned earlier this indicates a decrease of 2.0 +/-0.8% in overall TDG from the transect T1 to nine miles downstream to the PRDT station.

An inverses relationship (R^2=0.97) between tailwater elevation and TDG at the T1 transect for the targeted tests is depicted in Figure A-18. The same relationship for the downstream monitor station PRDT had an R^2=0.92. The trend was for TDG saturation at the T1 transect to decrease by 5% from 116% down to 111% as tailwater elevation goes up from 402 to 413 ft msl. The shift at the tailwater station was approximately 3%, or 113% down to 110% TDG, over the same range in elevation.

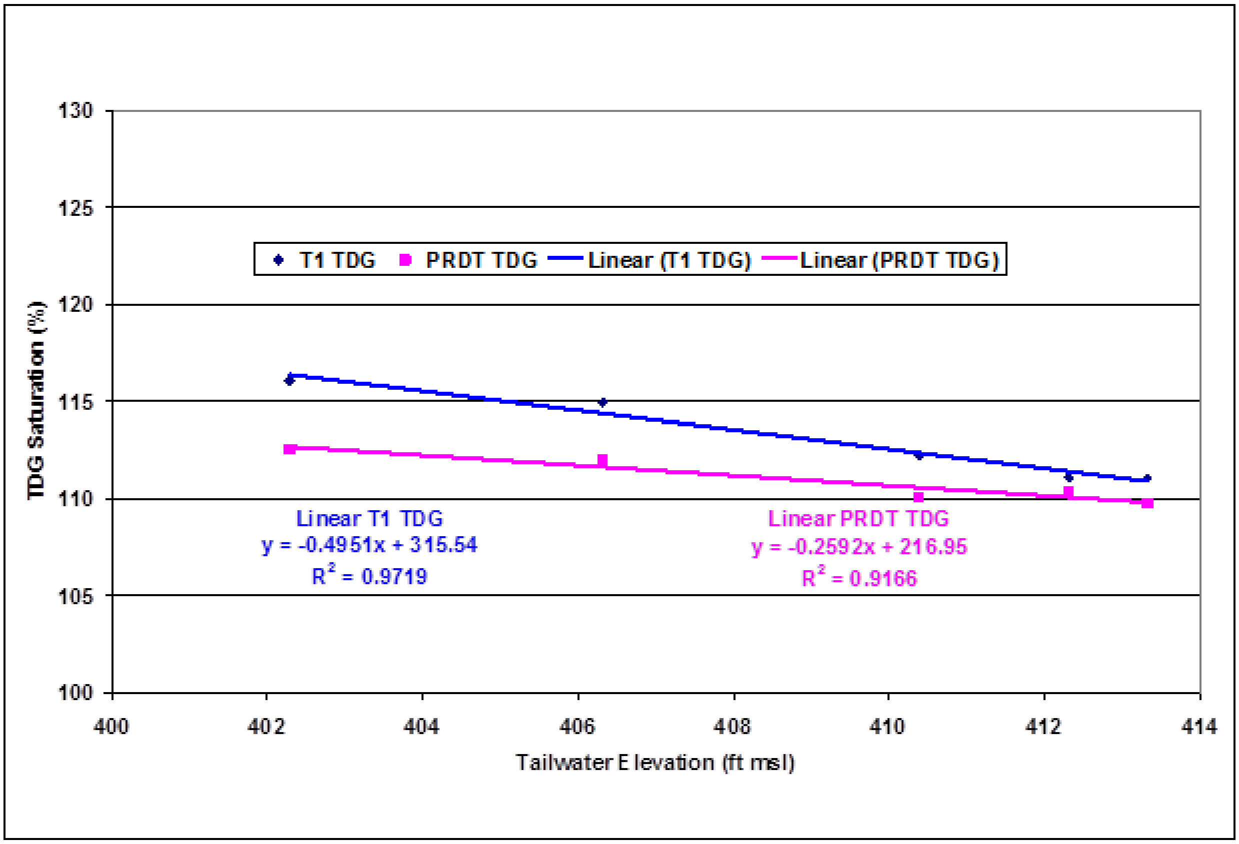

Figure A-18 Relationship between both transect T1 TDG and the Priest Rapids tailrace fixed-site monitoring station (PRDT) TDG and tailrace elevation for the 5 targeted test periods.

The trend is very similar to that shown in Figure A-18 when the average data for all 26 identified tests is used in the analysis (Figure A-19). The R^2 value, 0.73, for the T1 transect responses is a little less but the inverse response is nearly identical with an overall 5% decrease in TDG saturation over the 11 ft tailwater elevation change. The same similarities exist with all 26 of the PRDT monitor responses with tailwater elevation change, and approximate 3% TDG decrease with the increasing tailwater elevation.

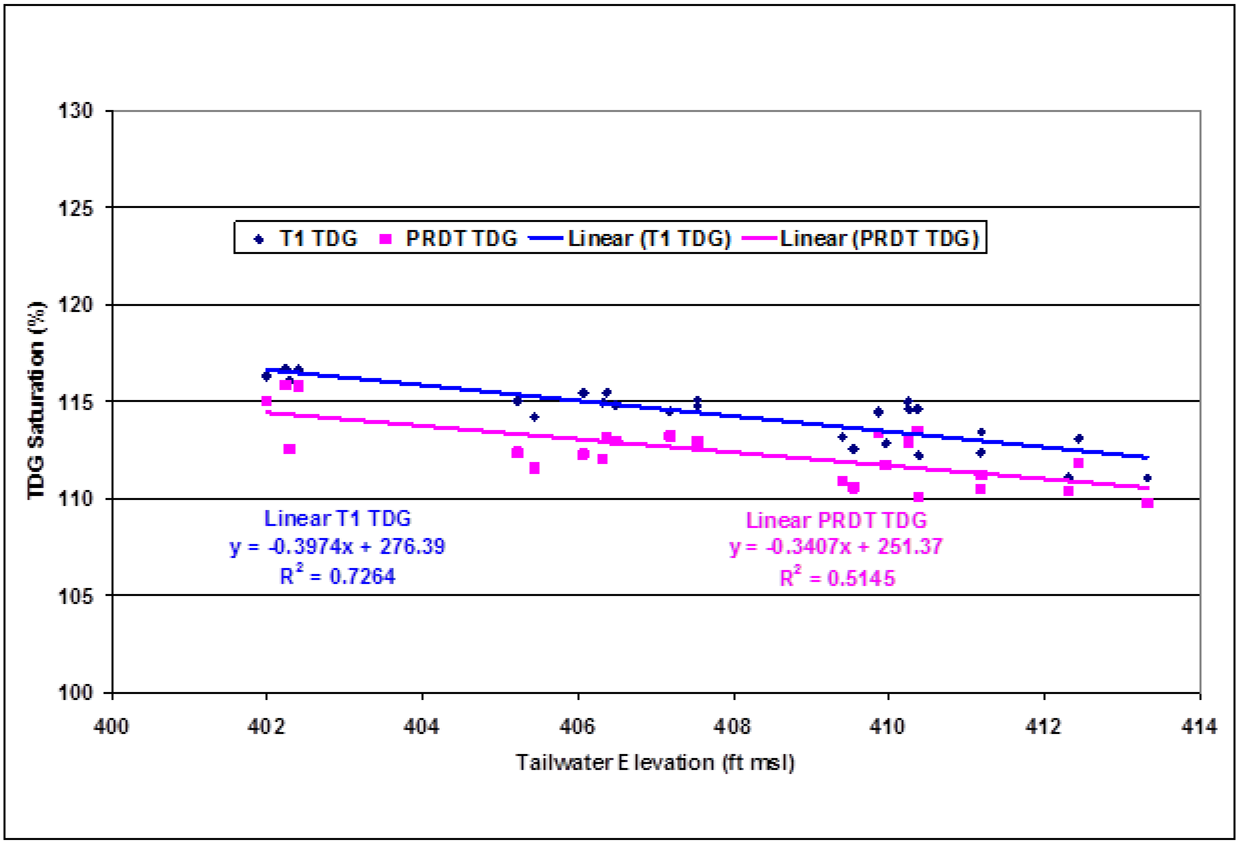

Figure A-16 Relationship between both transect T1 TDG and the Priest Rapids tailrace fixed-site monitoring station (PRDT) TDG and tailwater elevation for all 26 identified tests.

As would be expected the relationship between project powerhouse discharge and resulting TDG levels at the T1 transect downstream was very similar to that for tailwater elevation. The targeted tests as shown in Figure A-20 resulted in an inverse linear relationship between T1 TDG and powerhouse discharge with a high R2 of 0.98. The highest downstream TDG, >116%, resulting from the lowest powerhouse operation, 10 kcfs. The lower downstream saturations near 111% occurred with the higher powerhouse operation of approximately 160 kcfs. The trend demonstrated by linear relationship of the downstream monitor, PRDT, TDG and powerhouse operation is very similar to that for the T1 Transect. The total range of operation for the targeted tests resulted in a 3% shift in PRDT TDG saturation. A similar but weaker relationship (R^2 0.75) resulted from the test data when comparing the powerhouse discharge and the T1 TDG saturation when using all 26 of the test data sets (Figure A-21).

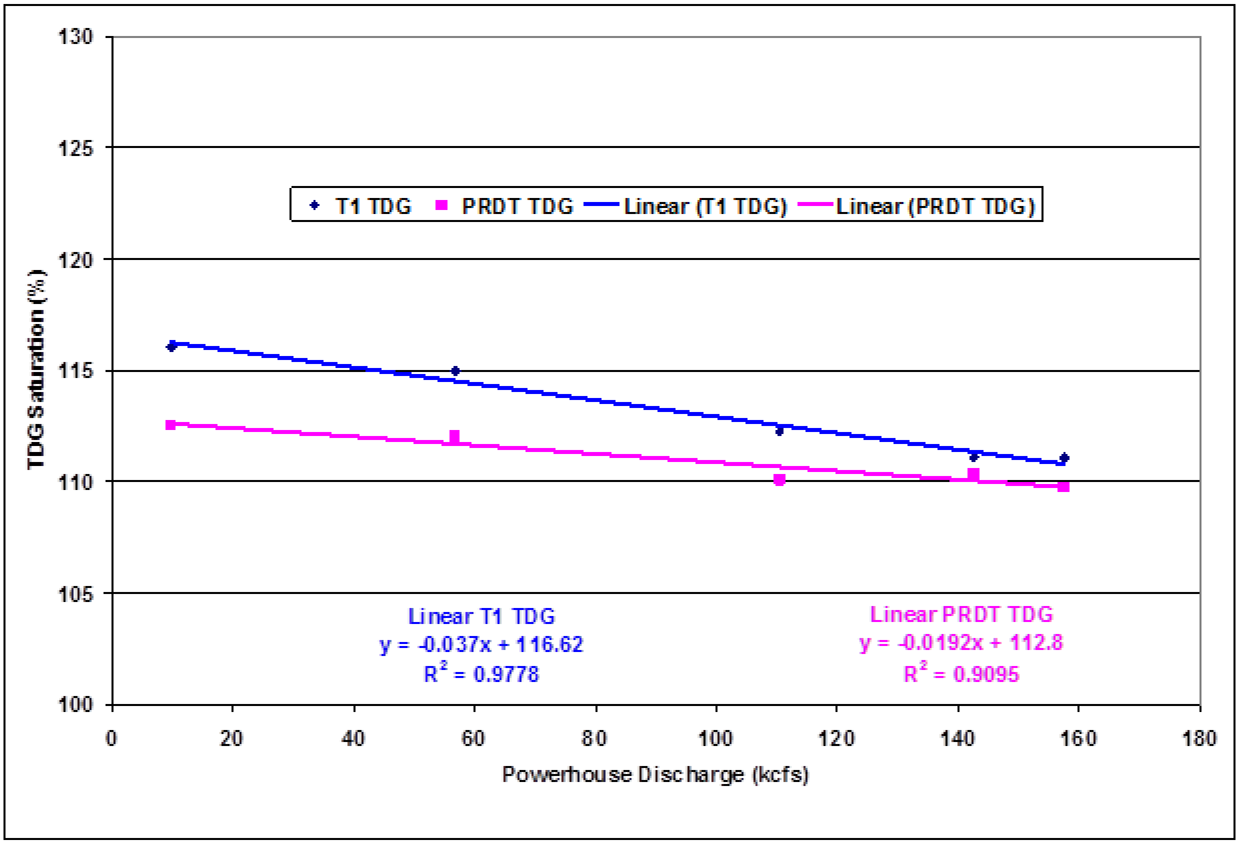

Figure A-17 Relationship between both transect T1 TDG and the Priest Rapids tailrace fixed-site monitoring station (PRDT) TDG and powerhouse operation for the 5 targeted test periods.

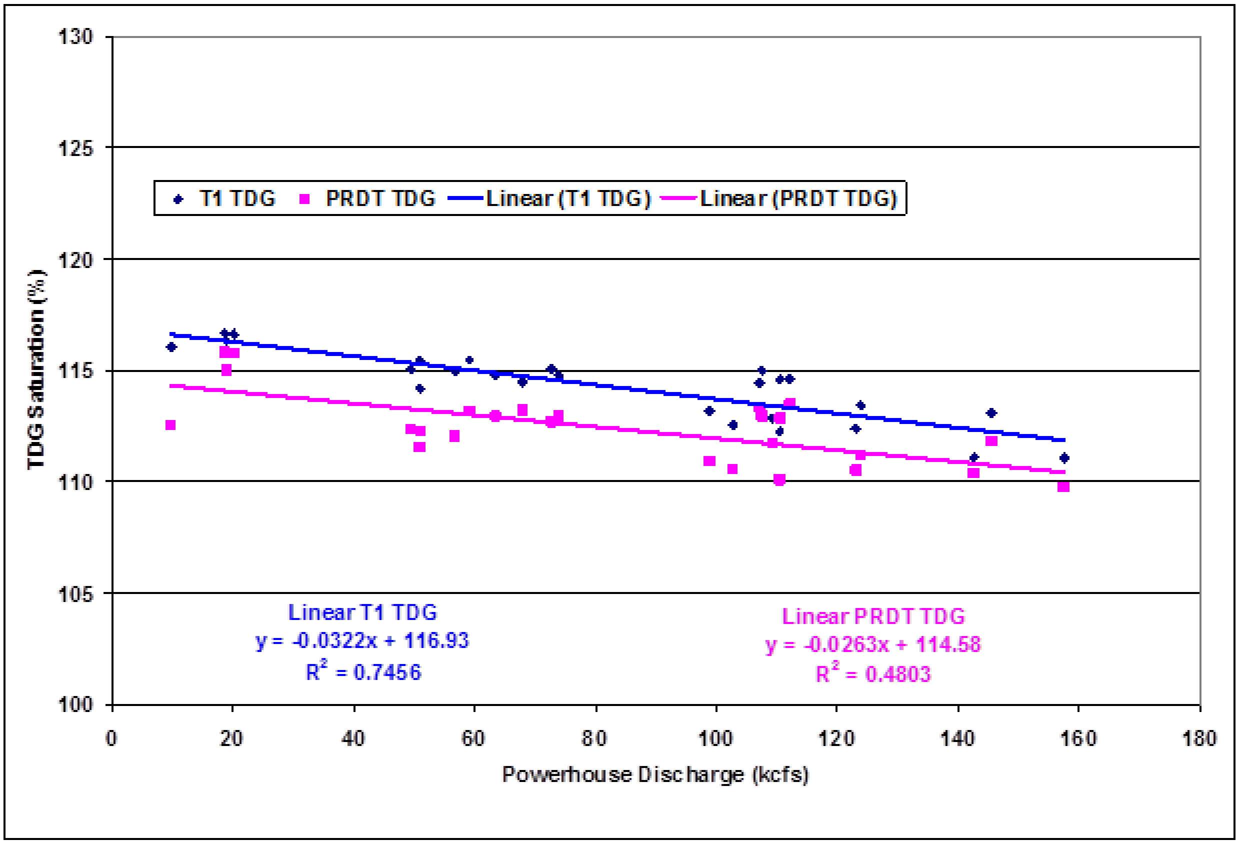

Figure A-18 Relationship between both transect T1 TDG and the Priest Rapids tailrace fixed-site monitoring station (PRDT) TDG and powerhouse operations for the 26 identified tests.

Figure A-22 describes an inverse linear relationship with the delta or increase in TDG resulting from the five targeted test data sets. The resulting increases in TDG from PRD fish bypass operation would decrease to approximately 2% and 0.5% saturation at T1 and PRDT respectively with increases in the forebay levels from 107.8% up to 109.4%.

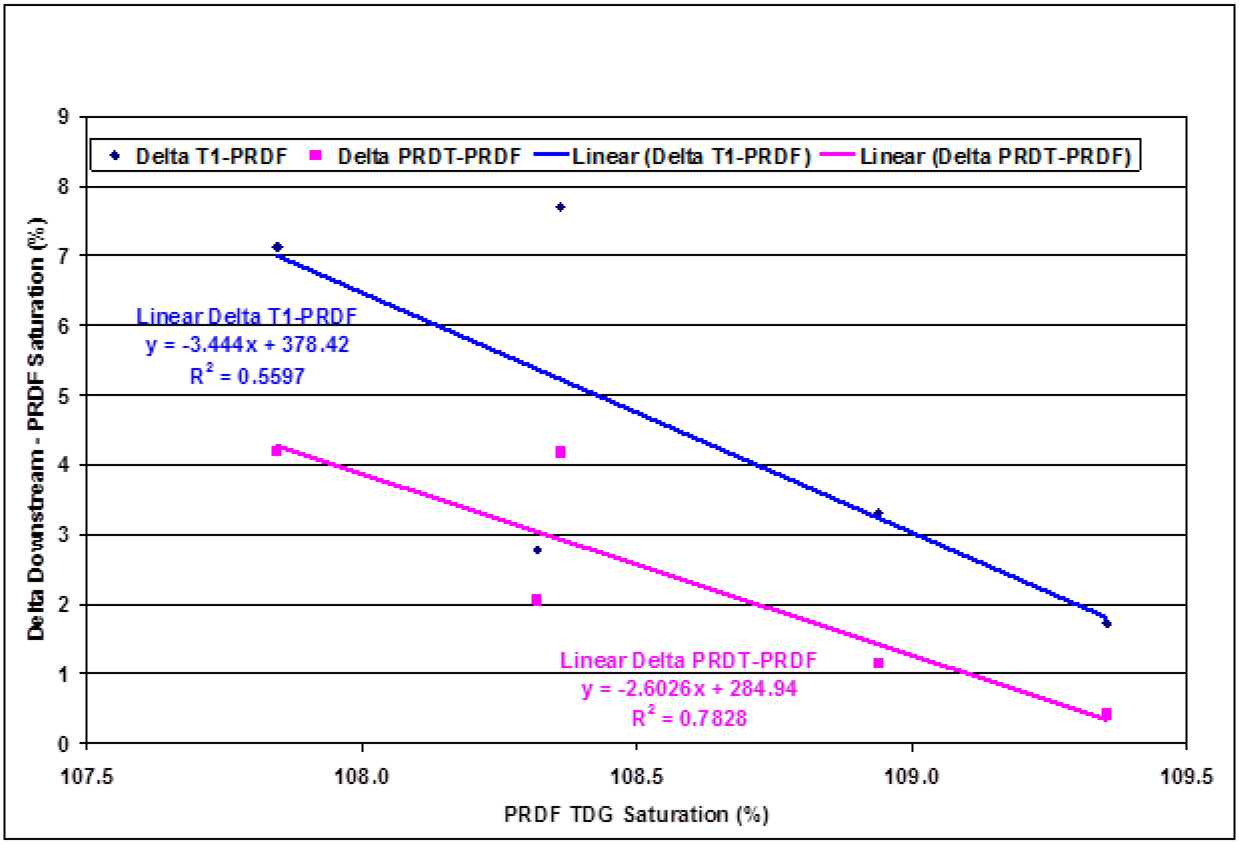

Figure A-19 Targeted test data relationship between resulting increase in TDG at both transect T1 and the Priest Rapids tailrace fixed-site monitoring (PRDT)) and the Priest Rapids forebay fixed-site monitoring station (PRDF).

We get a similar inverse relationship when using all 26 of the identified test data sets (Figure A-23). An increase from 107.5 % up to 112% in the upstream TDG saturation coincides with approximately 4% TDG decreases in the delta TDG occurring at T1 and PRDT. This would imply the supersaturation in TDG achievable from fish bypass operation to have a ceiling or maximum achievable level based on the physics of the PRDF jet and downstream bathymetry.

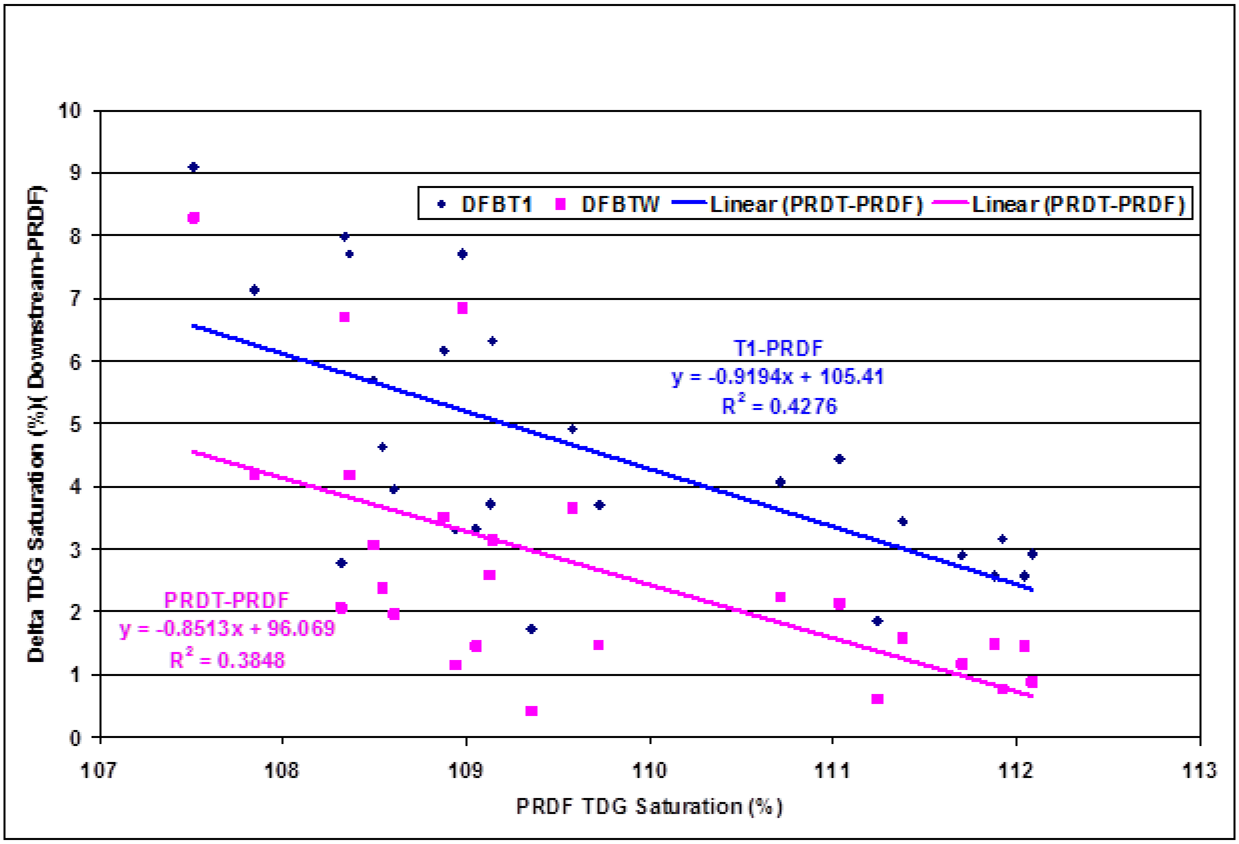

Figure A-20 Relationship between the resulting increase in TDG at both the transect T1 and the Priest Rapids tailrace fixed-site monitoring station (PRDT) and the Priest Rapids forebay fixed-site monitoring station (PRDF) for all 26 test periods.

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Schneider, M. L. and Carroll, J. H., 2002. Total Dissolved Gas Exchange at Priest Rapids Dam, July 21-August 4, 2002. Report submitted to Public Utility District No. 2 of Grant County, Ephrata, Washington.