Appendix I

Portland District TDG Report Prepared by the USGS (Includes The Dalles, John Day, and Bonneville Dams)

Prepared in cooperation with the U.S. Army Corps of Engineers

Total Dissolved Gas and Water Temperature in the Lower Columbia River, Oregon and Washington, 2005: Quality-Assurance Data and Comparison to Water-Quality Standards

By Dwight Q. Tanner, Heather M. Bragg, and Matthew W. Johnston

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Conversion Factors

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as
follows: °F=(1.8×°C)+32

Acknowledgments

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Total Dissolved Gas and Water Temperature in the Lower Columbia River, Oregon and Washington, 2005: Quality-Assurance Data and Comparison to Water-Quality Standards

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Significant Findings

When water is released through the spillways of dams, air is entrained in the water, increasing the downstream concentration of dissolved gases. Excess dissolved-gas concentrations can have adverse effects on freshwater aquatic life. The U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, collected dissolved-gas and water-temperature data at eight sites on the lower Columbia River in 2005. Significant findings from the data include:

Variances to the Oregon and Washington water-quality standards for total dissolved gas were exceeded at five of the monitoring sites: Camas (11 days), John Day tailwater (3 days), The Dalles forebay (3 days), Bonneville forebay (3 days), and John Day navigation lock (1 day).

From mid-July to early September, water temperatures were above 20 °C (degrees Celsius) at each of the eight lower Columbia River sites. According to the Oregon temperature standard, the 7-day average maximum temperature of the lower Columbia River should not exceed 20 °C; Washington regulations state that the 1-day maximum should not exceed 20 °C due to human activities.

Most field checks of total-dissolved-gas sensors with a secondary standard were within ± (plus or minus) 1% saturation. Most of the field checks of barometric pressure were within ±1 mm Hg (millimeter of mercury) of a secondary standard, and water temperature field checks were all within ±0.2 °C.

For the eight monitoring sites in water year 2005, an average of 98.2% of the total-dissolved-gas data were received in real time by the USGS satellite downlink and were within 1% saturation of the expected value, based on calibration data, replicate quality-control measurements in the river, and comparison to ambient river conditions at adjacent sites.

Introduction

The U.S. Army Corps of Engineers (USACE) operates several dams in the Columbia River Basin (fig. 1), which encompasses 259,000 square miles of the Pacific Northwest. These dams are multipurpose structures that fill regional needs for flood control, navigation, irrigation, recreation, hydropower production, fish and wildlife habitat, water-quality maintenance, and municipal and industrial water supply. When water is released through the spillways of these dams (instead of being routed through the turbines to generate electricity), ambient air is entrained in the water, increasing the concentration of dissolved gases (known as total dissolved gas [TDG]) downstream from the spillways. TDG conditions above 110% saturation can cause gas-bubble trauma in fish and adversely affect other aquatic organisms (U.S. Environmental Protection Agency, 1986).

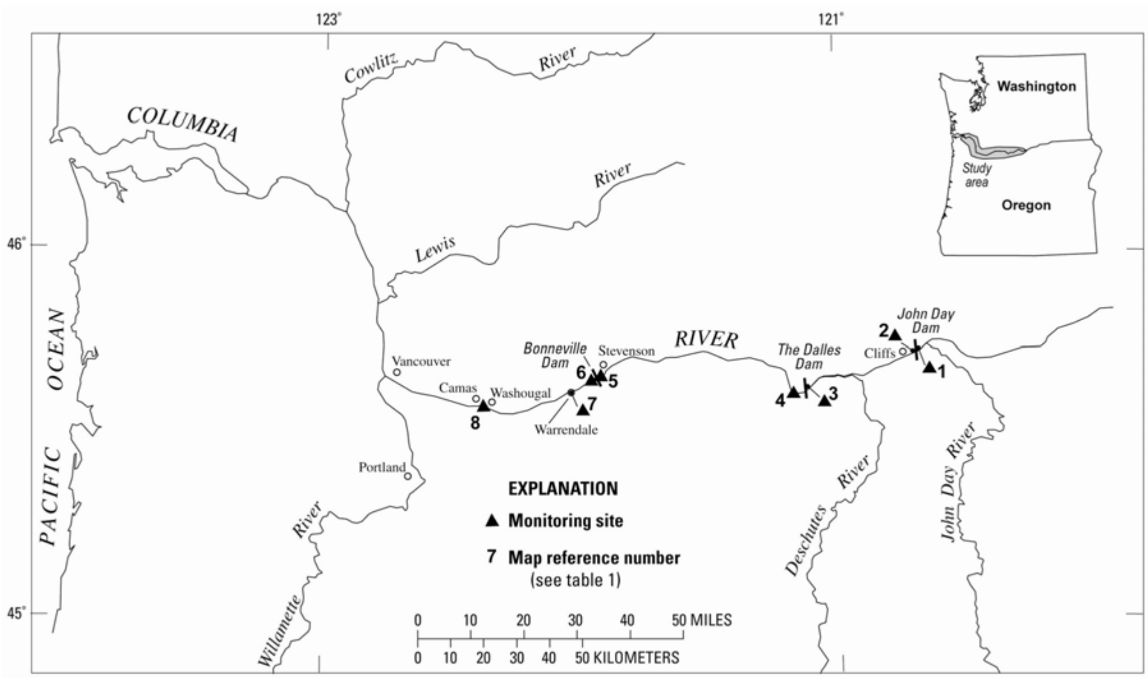

Figure 1. Location of total-dissolved-gas fixed stations, lower Columbia River, Oregon and Washington, water year 2005.

The USACE regulates spill and streamflow to minimize the production of excess TDG downstream from its dams, but there is also a goal of providing for fish passage with spilled water (rather than passage through the turbines). Consequently, the States of Oregon and Washington issue variances to the TDG water-quality standards during the spring and summer. In order to monitor compliance with these variances, the USACE oversees the collection of near real-time TDG and water-temperature data upstream and downstream from Columbia River Basin dams in a network of fixed-station monitors. Data from these sites are available within about 4 hours of current time.

Background

Near real-time TDG and water-temperature data are vital to the USACE for dam operation and for monitoring compliance with environmental regulations. The data are used by water managers to maintain water-quality conditions that facilitate fish passage and survival in the lower Columbia River. The USGS, in cooperation with the Portland District of the USACE, has collected TDG and related data in the lower Columbia River every year, beginning in 1996. Current and historical TDG and water-temperature data can be found on the USGS Oregon Water Science Center Website at *http://oregon.usgs.gov/projs_dir/pn307.tdg/*. Six reports that were published for water years 1996, 2000, 2001, 2002, 2003, and 2004 contain TDG data, quality-assurance data, and descriptions of the methods of data collection (Tanner and others, 1996; Tanner and Johnston, 2001; Tanner and Bragg, 2001; Tanner and others, 2002; Tanner and others, 2003; and Tanner and others, 2004).

To provide suitable data for managing and modeling TDG in the lower Columbia River, hourly data for 2005 were reviewed relative to laboratory and field measurements made during instrument calibrations and daily intersite comparisons. A small fraction of the TDG data were deleted because they were not of suitable quality. The hourly data were stored in a USGS data base (Automated Data Processing System—ADAPS) and in a USACE data base (*http://www.nwd-wc.usace.army.mil/tmt/wcd/tdg/months.html*). The USACE data base also includes hourly discharge and spill data.

Purpose and Scope

The purpose of TDG monitoring in the lower Columbia River is to provide the USACE with (1) real-time data for managing streamflow and spill at its project dams, (2) reviewed TDG data to evaluate conditions relative to water-quality standards, and (3) data for modeling the effect of various management scenarios of streamflow and spill on TDG levels.

This report describes the TDG data and related quality-assurance data from the lower Columbia River at eight sites, from the navigation lock of the John Day Dam (river mile [RM] 215.7) to Camas, Washington (RM 121.7), (fig. 1, table 1). Data for water year 2005 (October 1, 2004, to September 30, 2005) include hourly measurements of TDG pressure, barometric pressure, water temperature, and probe depth. Six of the sites (John Day navigation lock, John Day tailwater, The Dalles forebay, The Dalles tailwater, Cascade Island, and Camas) were operated from February or March to September 2005, which is the usual time of spill from the dams. Two sites (Bonneville forebay and Warrendale) were operated year-round. The site Columbia River at Cascade Island was installed in 2004 to assess TDG levels directly in the tailwater of Bonneville Dam, but the data from that site were not used for management purposes in water year 2005.

Table 1. Total-dissolved-gas fixed stations, lower Columbia River, Oregon and Washington, water year 2005

[Map reference number refers to figure 1; USACE, U.S. Army Corps of Engineers; Columbia River mile locations were determined from U.S. Geological Survey (USGS) 7.5-minute topographic maps; stations in this report are referenced by their abbreviated name or USACE site identifier, °, degree, ’, minute, ”, second]

Map number	USACE site ID	Columbia River mile	USGS station number	USGS station name (and abbreviation)	Latitude	Longitude	Period of record
1	JDY	215.7	454314120413701	Columbia River at John Day navigation lock, Washington (John Day navigation lock)	45° 43’ 14”	120° 41’ 37”	03/22/05-09/07/05
2	JHAW	214.7	454249120423500	Columbia River, right bank, near Cliffs, Washington (John Day tailwater)	45° 42’ 49”	120° 42’ 35”	03/22/05-08/29/05
3	TDA	192.6	453712121071200	Columbia River at The Dalles Dam forebay, Washington (The Dalles forebay)	45° 37’ 12”	121° 07’ 12”	03/28/05-09/08/05
4	TDDO	188.9	14105700	Columbia River at The Dalles, Oregon (The Dalles tailwater)	45° 36’ 27”	121° 10’ 20”	03/23/05-09/08/05
5	BON	146.1	453845121562000	Columbia River at Bonneville Dam forebay, Washington (Bonneville forebay)	45° 38’ 45”	121° 56’ 20”	Year-round
6	CCIW	145.9	453845121564001	Columbia River at Cascade Island, Washington (Cascade Island)	45° 38’ 45”	121° 56’ 40”	02/25/05-09/09/05
7	WRNO	140.4	453630122021400	Columbia River, left bank, near Dodson, Oregon (Warrendale)	45° 36’ 30”	122° 02’ 14”	Year-round
8	CWMW	121.7	453439122223900	Columbia River, right bank, at Washougal, Washington (Camas)	45° 34’ 39”	122° 22’ 39”	02/23/05-09/13/05

Methods of Data Collection

Methods of data collection for TDG, barometric pressure, and water temperature are described in detail in Tanner and Johnston (2001). A summary of these methods follows: Instrumentation at each fixed station consists of a Hydrolab water-quality probe, an electronic barometer, a power supply, and a Sutron Model 8200 data-collection platform

(DCP). The instruments at each site are powered by a 12-volt battery that is charged by a solar panel and/or a 120-volt alternating-current line. At the beginning of the monitoring season in February or March, a new TDG membrane is installed on each Hydrolab. Measurements (including probe depth) are made and logged every hour, and every 4 hours, the DCP transmits the most recent logged data to the Geostationary Operational Environmental Satellite (GOES) system (Jones and others, 1991). The data are automatically decoded and transferred to the USACE data base and to the USGS ADAPS data base. At one site, John Day tailwater, two TDG sensors have been installed on the same Hydrolab to ensure that data are reliably collected at this important site.

The eight fixed-station monitors were calibrated every 2 weeks from March to September, 2005. The Warrendale and Bonneville forebay sites were the only sites in operation from October 2004 through February 2005; during this time, they were calibrated every 3 weeks. The field calibration procedure was as follows: A Hydrolab (which was calibrated several days before the field trip and used as a secondary standard) was deployed alongside of the field Hydrolab for a period of up to 1 hour to obtain check measurements of TDG and water temperature prior to removing the field Hydrolab (which had been deployed for 2 or 3 weeks). The field Hydrolab was then replaced with one that had been calibrated recently at the laboratory and the secondary standard used again to check TDG and temperature measured by the newly deployed Hydrolab in the river. The electronic barometer at the fixed station was calibrated using a portable barometer that had been recently calibrated at the National Weather Service facility in northeast Portland.

During each field calibration, the minimum compensation depth was calculated to determine whether the Hydrolab was positioned at an appropriate depth to measure TDG. This minimum compensation depth, which was calculated according to Colt (1984, page 104), is the depth above which degassing will occur due to decreased hydrostatic pressure. To measure TDG accurately, the Hydrolabs were positioned during each calibration visit at a depth below the calculated minimum compensation depth whenever possible.

The Hydrolab that was brought from the field after 2 to 3 weeks of deployment was then calibrated in the laboratory. The integrity of the TDG membrane was checked, the membrane was air-dried, and the TDG sensor was calibrated at 0, 100, 200, and 300 mm Hg above atmospheric pressure to cover the expected range of TDG in the river (approximately 100, 113, 126, and 139% saturation, respectively).

Summary of Total-Dissolved-Gas Data Completeness and Quality

A summary of USGS TDG data completeness and quality for water year 2005 is shown in table 2. (The USACE satellite downlink was a parallel system, so the amount and quality of USACE data were similar). Data in table 2 were based on the total amount of hourly TDG data that could have been collected during the monitoring season. Any hour without TDG pressure data or barometric pressure data was counted as an hour of missing data for TDG in percent saturation, which is calculated as TDG pressure, in mm Hg, multiplied by 100%, divided by the barometric pressure, in mm Hg. The fourth column in table 2 shows the percentage of data that was received in real time and passed quality-assurance checks. TDG data were considered to meet quality-assurance standards if they were within plus or minus 1% saturation of the expected value, based on calibration data, replicate quality-control measurements in the river, and daily comparisons to ambient river conditions at adjacent sites. At each station, at least 88.9% of the data were received in real time by the USGS downlink and met quality-control checks, with an overall average of 98.2% (table 2).

Table 2. Total-dissolved-gas data completeness and quality, lower Columbia River, Oregon and Washington, WY-2005

[Results are based on values in USGS ADAPS database; TDG, total dissolved gas]

Abbreviated Station Name	Planned Monitoring in Hours	Number of Missing or Deleted Hourly Values	Percentage of Real-Time TDG Data Passing Quality Assurance
John Day navigation lock	4054	8	99.8
John Day tailwater	4054	42	99.0
The Dalles forebay	3933	0	100.0
The Dalles tailwater	4052	1	100.0
Bonneville forebay	8760	20	99.8
Cascade Island	4694	519	88.9
Warrendale	8760	94	98.9
Camas	4738	21	99.6
Average	--	--	98.2

Table 3 is a chronological list of the major portions of data that were either missing from the database (for example, when data telemetry failed) or data that were later deleted from the database because they did not meet quality-assurance standards. Table 3 includes temperature and depth data, which were not considered in table 2, which included only TDG data. The Cascade Island site had the most missing or deleted data. From March 11, 2005 to March 24, 2005, the values measured by the TDG sensor were too low, based on quality-assurance measurements made during the field calibration on March 24. The incorrect values at Cascade Island were caused by a malfunctioning TDG sensor. Water circulation patterns at this site are complex, making it difficult to diagnose instrumentation problems. The malfunctioning instrument was taken out of service on March 24 and was not used for the remainder of the field season. A broken membrane at Cascade Island from August 31 to September 7 (a period of no spill) also caused loss of data at the site.

Table 3. Missing or deleted data, water year 2005

[Site abbreviations: WRNO, Warrendale; CCIW, Cascade Island; TDDO, The Dalles tailwater; BON, Bonneville forebay; JDY, John Day navigation lock; CWMW, Camas; JHAW, John Day tailwater. Date format: month/day/year. Parameter and unit abbreviations: TDG, total dissolved gas; --, no data; mm Hg, millimeters of mercury; BP barometric pressure; WT, water temperature; °C, degrees Celsius]

Date & Time	Site	Parame-ter	Value	Unit	Reason / Notes
1/17/05 07:00	WRNO	TDG	--	mm Hg	Missed transmission
through					
1/17/05 14:00			--		
1/17/05 07:00	WRNO	BP	--	mm Hg	Missed transmission
through					
1/17/05 14:00			--		
1/17/05 07:00	WRNO	WT	--	°C	Missed transmission
through					
1/17/05 14:00			--	°C	
1/17/05 07:00	WRNO	Depth	--	feet	Missed transmission
through					
1/17/05 14:00			--	feet	
3/11/05 13:00	CCIW	TDG	--	mm Hg	Sensor drift caused low values
through					
3/24/05 13:00			--	mm Hg	
4/7/05 10:00	TDDO	TDG		mm Hg	Slow calibration, forgot to delete at site
4/7/05 14:00	BON	BP	0	mm Hg	Accidentally turned off logging during calibration
through					
4/8/05 09:00			0	mm Hg	
4/7/05 17:00	CCIW	TDG	881	mm Hg	Slow calibration, left site before equilibrated
through					
4/8/05 04:00			803	mm Hg	
4/20/05 11:00	JDY	Depth	83.7	feet	Bad sensor
through					
5/3/05 10:00			83.7	feet	
4/19/05 13:00	CCIW	TDG	746	mm Hg	Calibration
4/19/05 13:00	CCIW	WT	18.1	°C	Calibration
4/19/05 13:00	CCIW	Depth	13.5	feet	Calibration

Table 3. Missing or deleted data, water year 2005—continued

[Site abbreviations: WRNO, Warrendale; CCIW, Cascade Island; TDDO, The Dalles tailwater; BON, Bonneville forebay; JDY, John Day navigation lock; CWMW, Camas; JHAW, John Day tailwater. Date format: month/day/year. Parameter and unit abbreviations: TDG, total dissolved gas; --, no data; mm Hg, millimeters of mercury; BP barometric pressure; WT, water temperature; °C, degrees Celsius]

Date & Time	Site	Parameter	Value	Unit	Reason / Notes
5/9/05 04:00 through	JDY	BP	733	mm Hg	Low battery
5/9/05 11:00			621	mm Hg	
5/24/05 17:00 through	CWMW	TDG	--	mm Hg	Missed transmission
5/25/05 08:00			--	mm Hg	
5/24/05 17:00 through	CWMW	BP	--	mm Hg	Missed transmission
5/25/2005 08:00			--	mm Hg	
5/24/05 17:00 through	CWMW	WT	--	°C	Missed transmission
5/25/05 08:00			--	°C	
5/24/05 17:00 through	CWMW	Depth	--	feet	Missed transmission
5/25/05 08:00			--	feet	
7/10/05 21:00 through	JHAW	TDG	857	mm Hg	Sensor drift
7/12/05 14:00			881	mm Hg	
7/10/05 21:00 through	JHAW	TDG2	874	mm Hg	Sensor drift
7/12/05 14:00			898	mm Hg	
7/16/05 6:00 through	JHAW	TDG2	1000	mm Hg	Ruptured membrane
7/26/05 13:00			1020	mm Hg	
7/27/05 12:00	CCIW	TDG	853	mm Hg	Technician error
7/27/05 12:00		Depth	12.8	feet	Technician error
8/17/05 10:00 through	JHAW	TDG2	--	mm Hg	Ruptured membrane
8/23/05 15:00			--	mm Hg	

Table 3. Missing or deleted data, water year 2005—continued

[Site abbreviations: WRNO, Warrendale; CCIW, Cascade Island; TDDO, The Dalles tailwater; BON, Bonneville forebay; JDY, John Day navigation lock; CWMW, Camas; JHAW, John Day tailwater. Date format: month/day/year. Parameter and unit abbreviations: TDG, total dissolved gas; --, no data; mm Hg, millimeters of mercury; BP barometric pressure; WT, water temperature; °C, degrees Celsius]

Date & Time	Site	Parameter	Value	Unit	Reason / Notes
8/24/05 15:00	CCIW	TDG	0	mm Hg	Site calibration
8/24/05 15:00	CCIW	WT	0	°C	Site calibration
8/24/05 15:00	CCIW	Depth	0	feet	Site calibration
8/24/05 16:00	CCIW	TDG	0	mm Hg	Site calibration
8/24/05 16:00	CCIW	Depth	0	feet	Site calibration
8/29/05 02:00	JHAW	TDG	824	mm Hg	Sensor drift
through					
9/7/05 13:00			740	mm Hg	
8/31/05 16:00	CCIW	TDG	1200	mm Hg	Ruptured membrane
through					
9/8/05 12:00			1140	mm Hg	
9/8/05 13:00	CCIW	TDG	0	mm Hg	Site calibration
9/8/05 13:00	CCIW	BP	0	mm Hg	Site calibration
9/8/05 13:00	CCIW	WT	0	°C	Site calibration
9/8/05 13:00	CCIW	Depth	0	feet	Site calibration
9/25/05 0:00	WRNO	TDG	806	mm Hg	Ruptured membrane
through					
9/29/05 11:00			829	mm Hg	

At the Warrendale site, there were 94 hours of missing TDG data (table 2), resulting in 98.9% of the data being received and passing quality assurance criteria. Most of this loss of data occurred in September (table 3), and was due to the rupture or tear of the TDG sensor membrane.

Quality-Assurance Data

Data collection for TDG, barometric pressure, and water temperature involve several quality-assurance procedures, including calibration of instruments in the field and in the laboratory, daily checks of the data, and data review and archive. These methods are explained in detail in Tanner and Johnston (2001), and the results of the quality-assurance data for water year 2005 are presented in this section.

After field deployment of the Hydrolabs for 2 to 3 weeks, the TDG sensors were calibrated in the laboratory. First, the instrument was tested, with the membrane in place, for response to increased pressure and to super-saturation conditions. The membrane was then removed from the sensor and allowed to dry for at least 24 hours. Before replacing the membrane, the TDG sensor was examined independently. The calibration test procedure compared the reading of the TDG sensor to barometric pressure as measured by a calibrated aneroid barometer. Using a certified digital pressure gage as the primary standard, the TDG sensor was calibrated at added pressures of 100, 200, and 300 mm Hg above barometric pressure (approximately 113%, 126%, and 139% saturation, respectively). The accuracy of the TDG sensors was calculated by computing the difference between the expected reading and the TDG sensor reading (expected minus actual) for each of the four test conditions and dividing by the barometric pressure. As shown in figure 2, all of the sensor readings were within 0.5% saturation after 2 to 3 weeks of deployment.

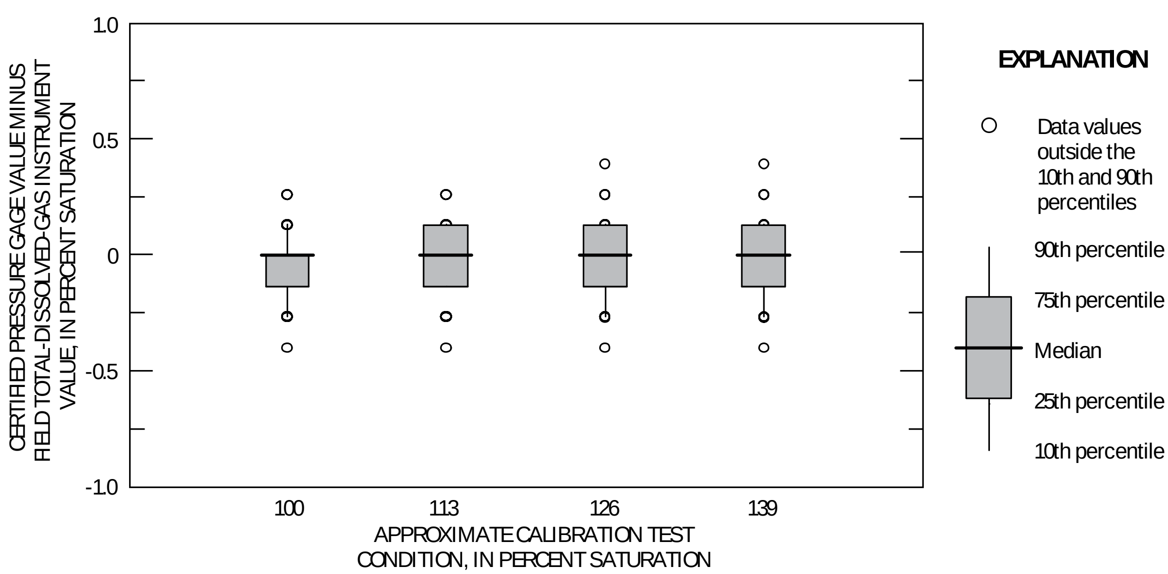

Figure 2. Accuracy of total-dissolved-gas sensors after 2 to 3 weeks of field deployment

The differences in barometric pressure, water temperature, and TDG between the secondary standard instruments and the fixed-station monitors after 2 to 3 weeks of field deployment were measured and recorded as part of the field inspection and calibration procedure. These differences, defined as the secondary standard minus field instrument, were used to compare and quantify the precision between the two independent instruments. For water temperature and TDG, the measurements were made in-situ with the secondary standard (a recently calibrated Hydrolab) positioned alongside the field Hydrolab in the river. An aneroid barometer, calibrated every 6 to 8 weeks, served as the secondary standard for barometric pressure. Figures 3, 4, and 5 illustrate the distribution of quality assurance data for each of the three parameters from all eight field sites.

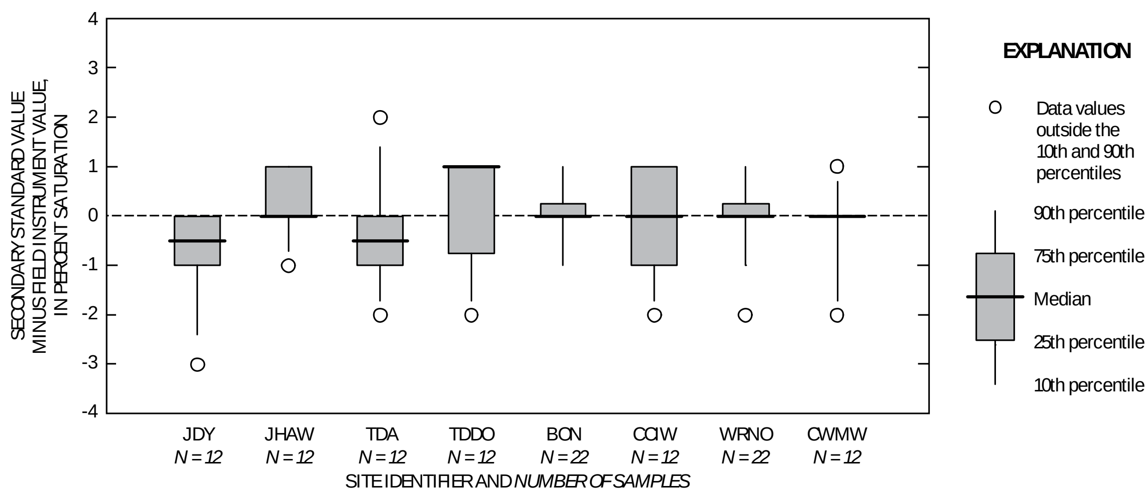

Figure 3. Difference between the secondary standard and the field barometers after 2 to 3 weeks of field deployment

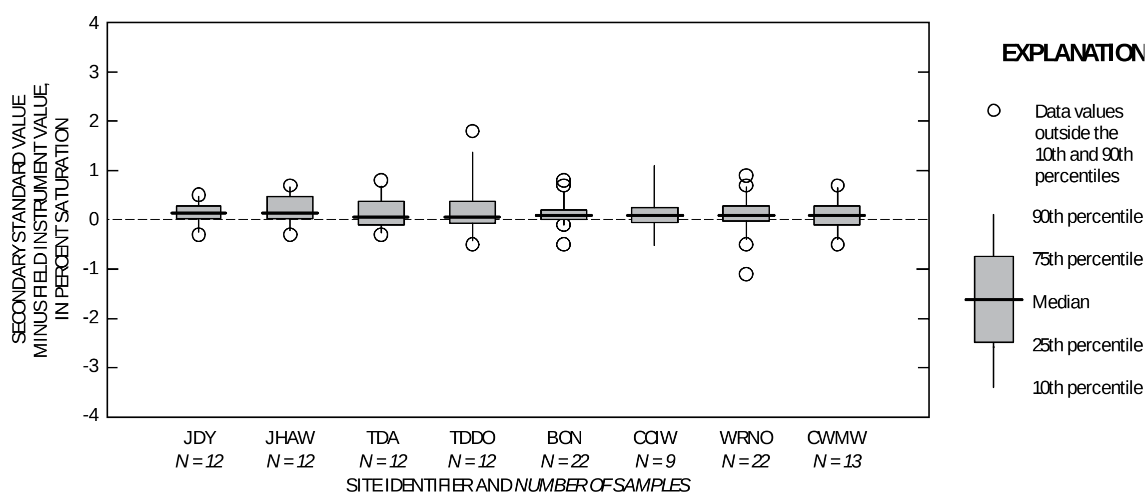

Figure 4. Difference between the secondary standard and the field temperature instruments after 2 to 3 weeks of field deployment

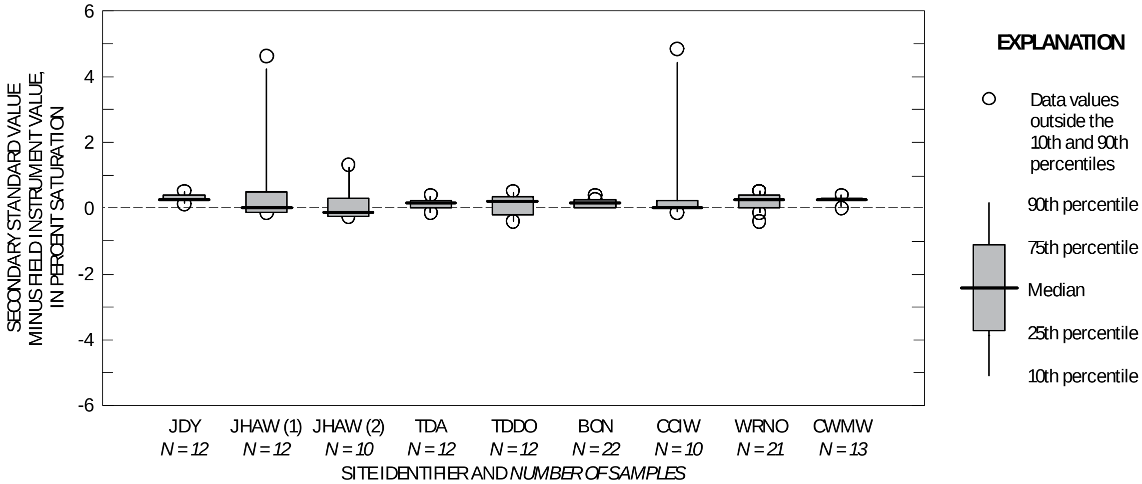

Figure 5. Difference between the secondary standard and the field total-dissolved-gas instruments after 2 to 3 weeks of field deployment

The comparisons of the aneroid barometer and the electronic field barometers are shown in figure 3. Most of the field values are within 1 mm Hg of the standard values, and all but one are within 2 mm Hg. The greatest difference (-3mm Hg) was recorded at John Day navigation lock. The secondary standard temperature sensor and the field temperature sensor results are presented in figure 4. All of the differences are within 0.2 °C (degrees Celsius), and most are within 0.1 °C.

The differences between the secondary standard TDG sensor and the field TDG sensors were calculated following equilibration of the secondary standard unit to the site conditions before removing the field unit. The side-by-side equilibrium was considered complete after a minimum of 30 minutes when the TDG values for each sensor remained constant for 4 to 5 minutes. As shown in figure 5, most of the data demonstrates less than 1% saturation difference between the two TDG sensors.

The three most anomalous TDG data points were the +3.3% and +4.6% saturation at the John Day tailwater primary sensor, JHAW(1), and +4.8% saturation at Cascade Island (figure 5). The outlying data points at John Day tailwater were recorded by different Hydrolab units. Both these TDG sensors passed post-deployment calibration tests. It is possible that a problem has developed at the deployment site (sediment build-up within the instrument housing, for example) that interfered with the sensors. Further instrument tests and site inspections will be conducted before installation of the site in spring 2006. The outlying data point at Cascade Island was the result of a malfunctioning TDG sensor. The unit was removed from service and returned to the manufacturer for repair.

Effects of Spill on Total Dissolved Gas

Spill from each dam increased the level of total dissolved gas downstream. Spill data in this report are from the USACE Website (*http://www.nwd-wc.usace.army.mil/tmt/wcd/tdg/months.html*). Spill from John Day Dam occurred from April 10 to August 31 (fig. 6). As shown in figure 6, data were missing from both TDG sensors for a period in July (deleted due to poor quality). After August 29, the primary sensor failed and the data shown in figure 6 are from the secondary sensor. The spill from

April 10 to June 20 was usually less than 150,000 ft^3/s (cubic feet per second) and usually occurred only between 7:00 p.m. and 7:00 a.m. for fish passage considerations. Figure 6 shows that TDG downstream from John Day Dam increased in response to spill from the dam, with the TDG level usually being less than 120% saturation. From June 21 to August 31, continuous spill from John Day Dam varied from about 20,000 ft^3/s to about 80,000 ft^3/s, and the TDG at the John Day tailwater site was always less than 120% saturation.

Spill from The Dalles Dam (fig. 7) was almost continuous at levels generally between 40,000 and 80,000 ft^3/s from April 11 to August 31. TDG levels at The Dalles tailwater site generally were less than 120% saturation during the period of spill.

Spill from Bonneville Dam was continuous from April 15 to August 31. After May 11, the spill generally was 75,000 ft^3/s during the daylight hours and between about 100,000 and 150,000 ft^3/s at night. During that time, the TDG exceeded 120% saturation several times at Warrendale (fig. 8) and at Cascade Island (fig. 9).

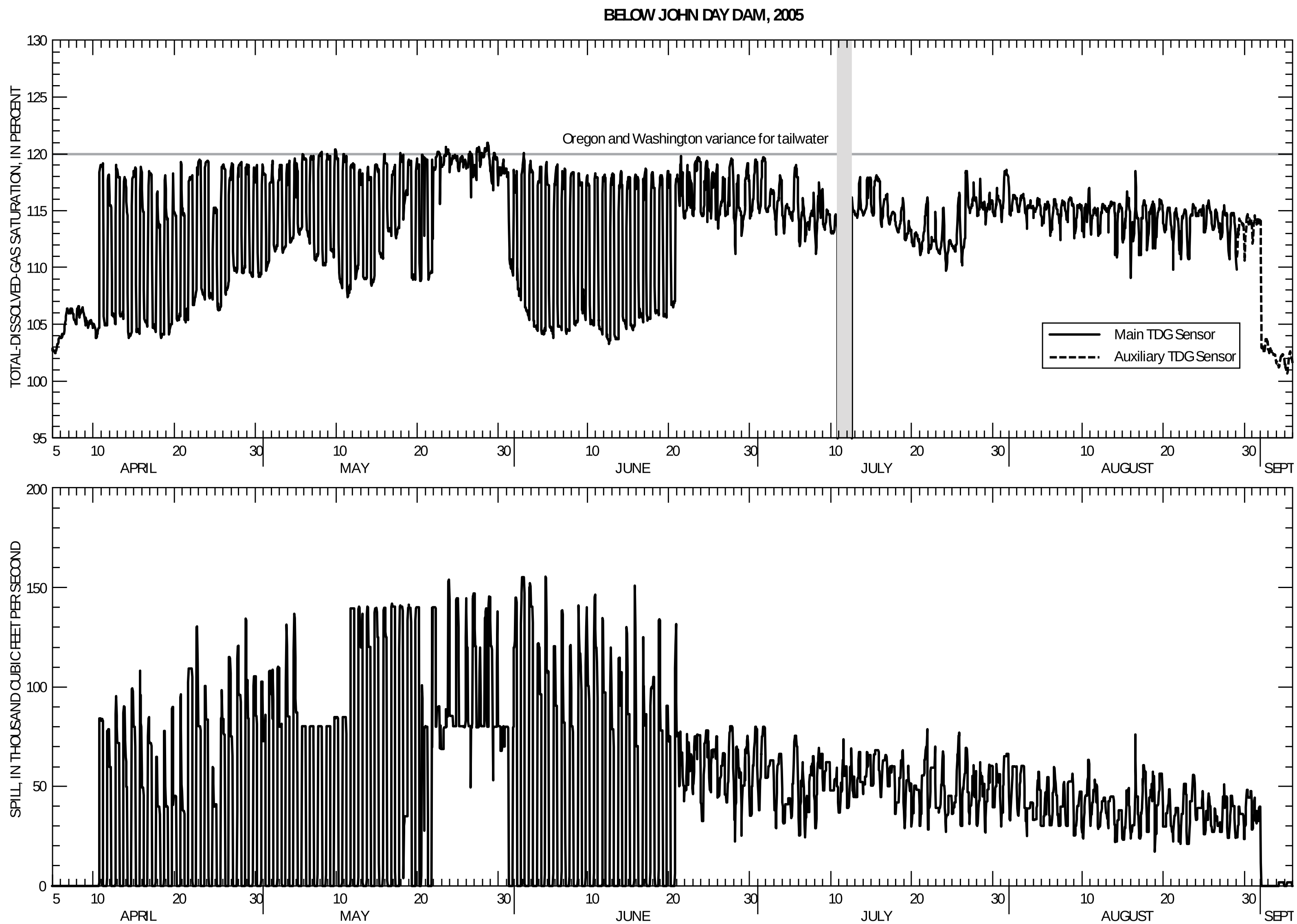

Figure 6. Total dissolved gas saturation downstream from John Day Dam and spill from John Day Dam, April 5 to September 5, 2005

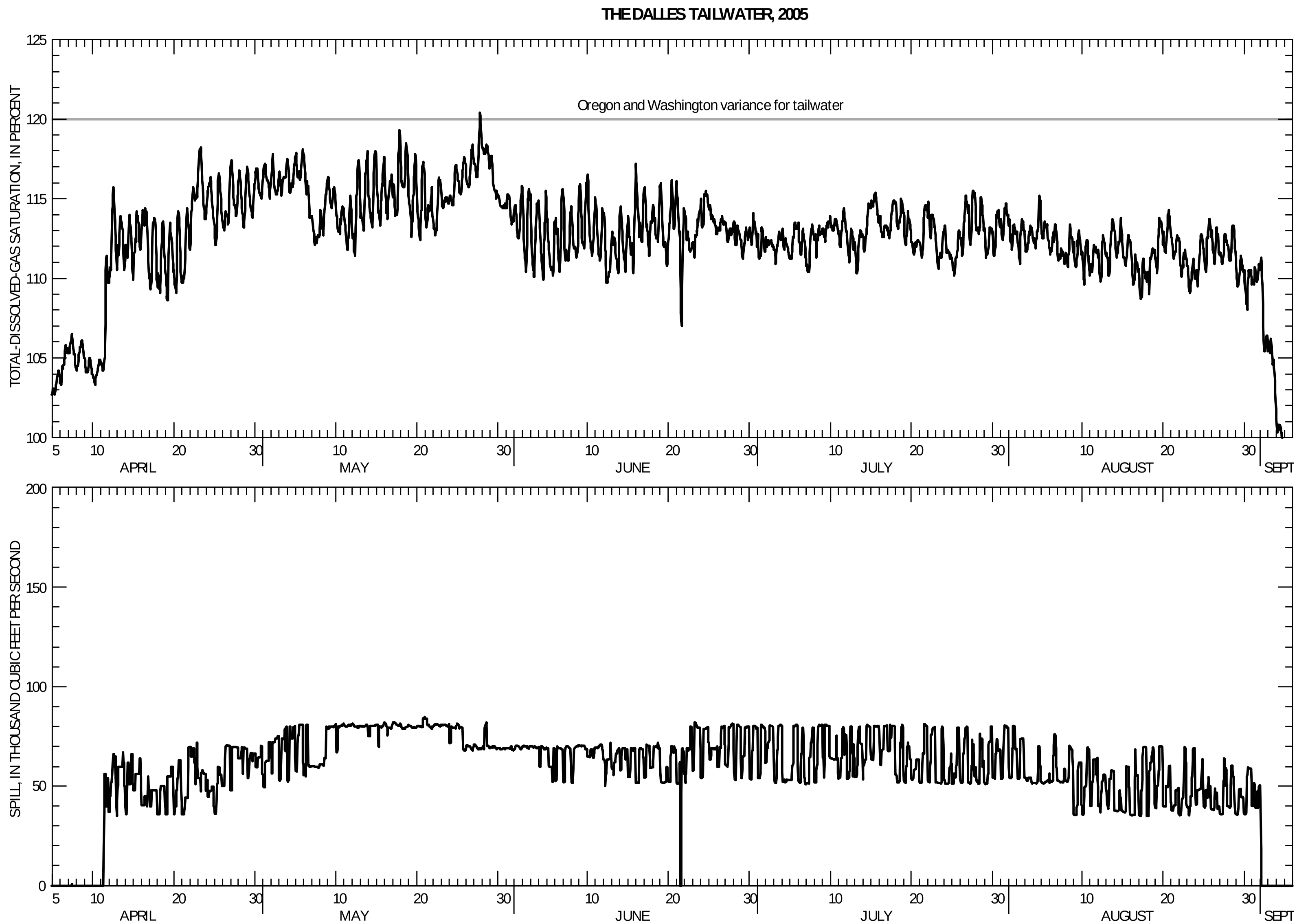

Figure 7. Total dissolved gas saturation downstream from The Dalles Dam and spill from The Dalles Dam, April 5 to September 5, 2005

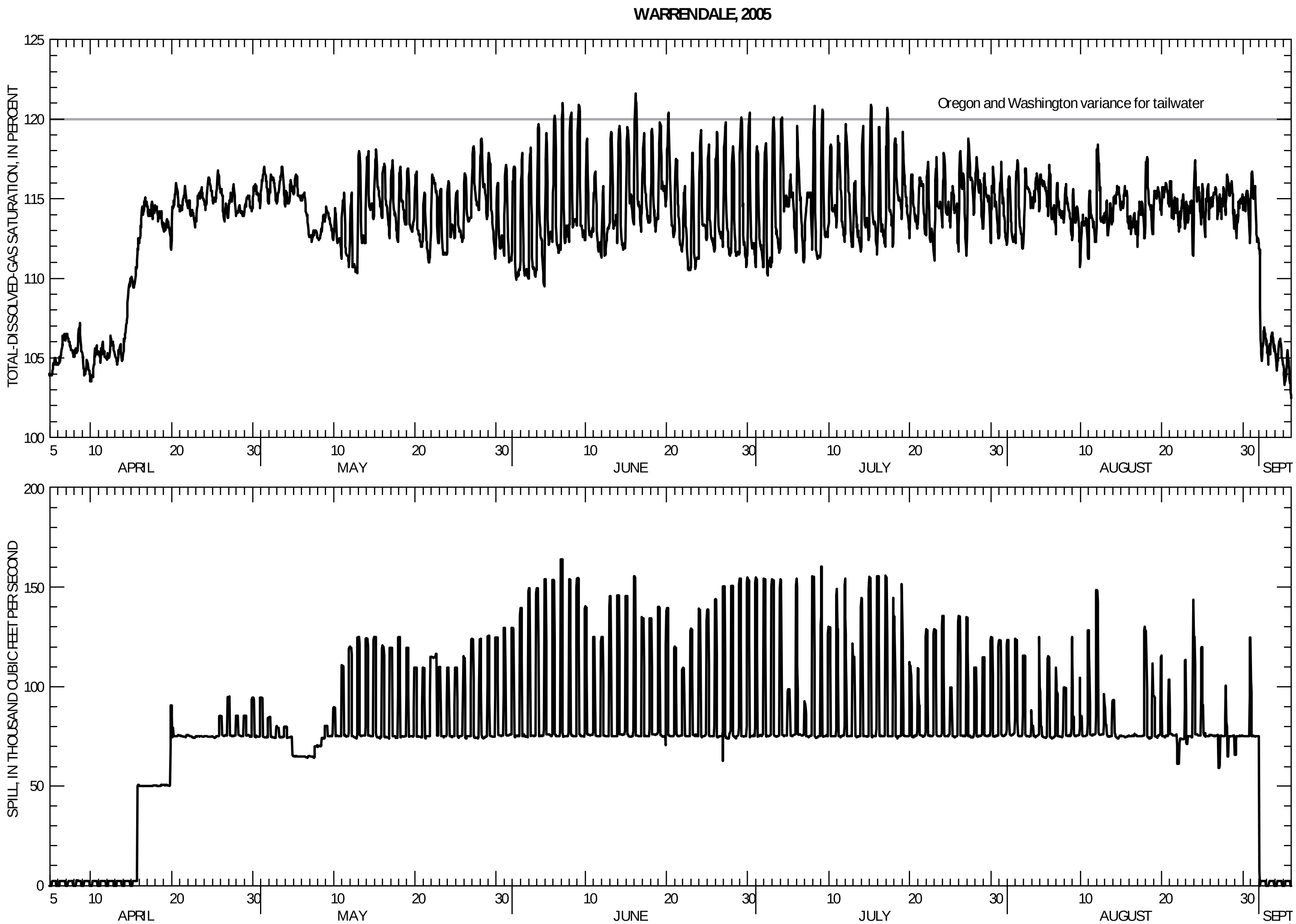

Figure 8. Total dissolved gas saturation downstream from Bonneville Dam at Warrendale and spill from Bonneville Dam, April 5 to September 5, 2005

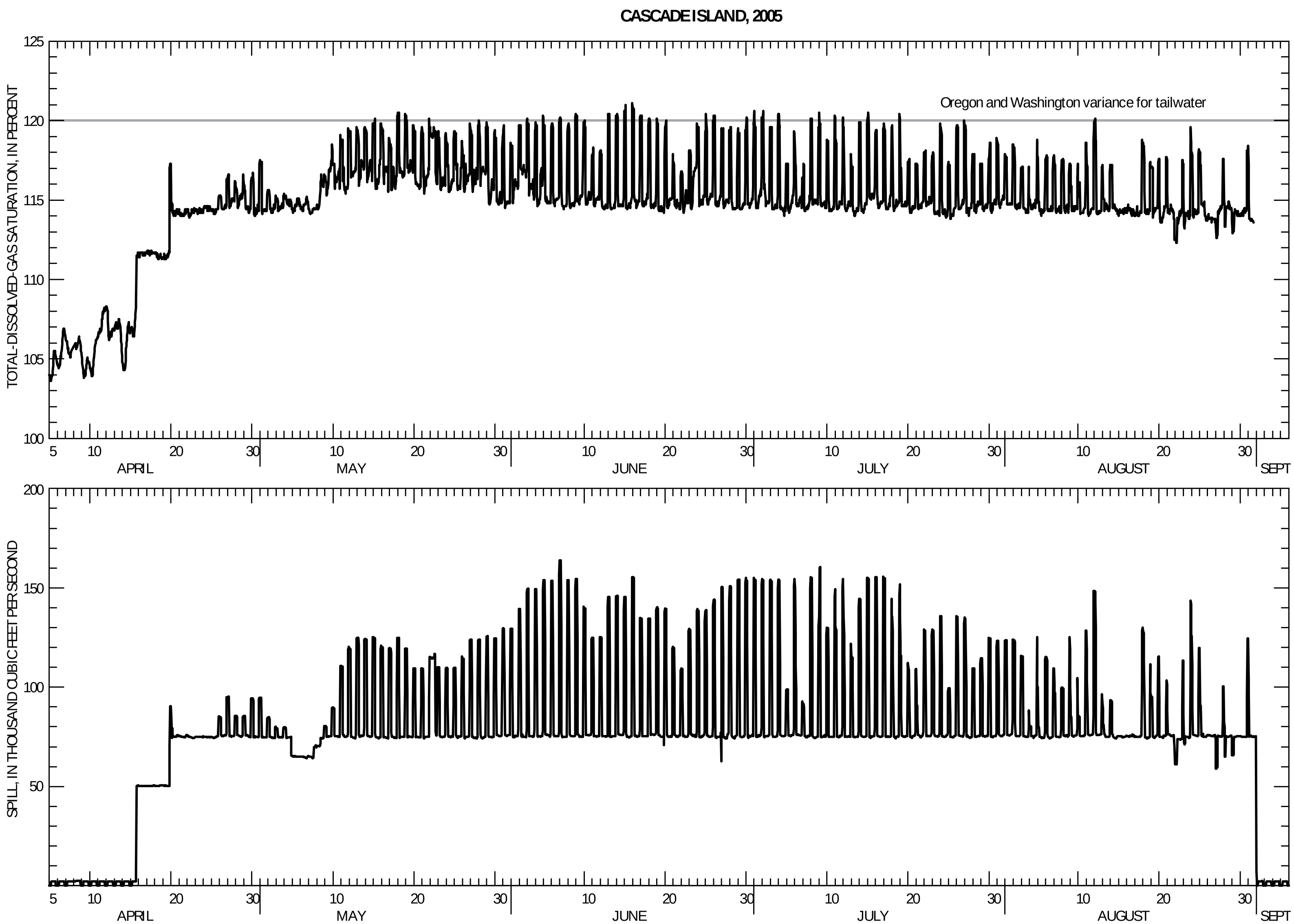

Figure 9. Total dissolved gas saturation downstream from Bonneville Dam at Cascade Island and spill from Bonneville Dam, April 5 to September 5, 2005

The forebay sites, John Day navigation lock, The Dalles forebay, Bonneville forebay, and Camas, were located immediately upstream of a dam, except for Camas, which is located 24.4 miles downstream of Bonneville Dam. As a result, the forebay sites were expected to have lower levels of total dissolved gas. At John Day navigation lock (fig. 10), TDG saturation was less than 115% saturation with the exception of 2 days, May 27 and May 28. At The Dalles forebay (fig. 11), TDG saturation was periodically above 115% saturation for short periods in April and May. At Bonneville forebay (fig. 12), TDG saturation was more than 115% a few times in May. Finally, at Camas (fig 13), TDG saturation was higher than 115% on several occasions from April to August. As documented previously (Tanner and Bragg, 2001), some of the daily increases in TDG at Camas may be due to the production of oxygen by aquatic plants and to temperature variations.

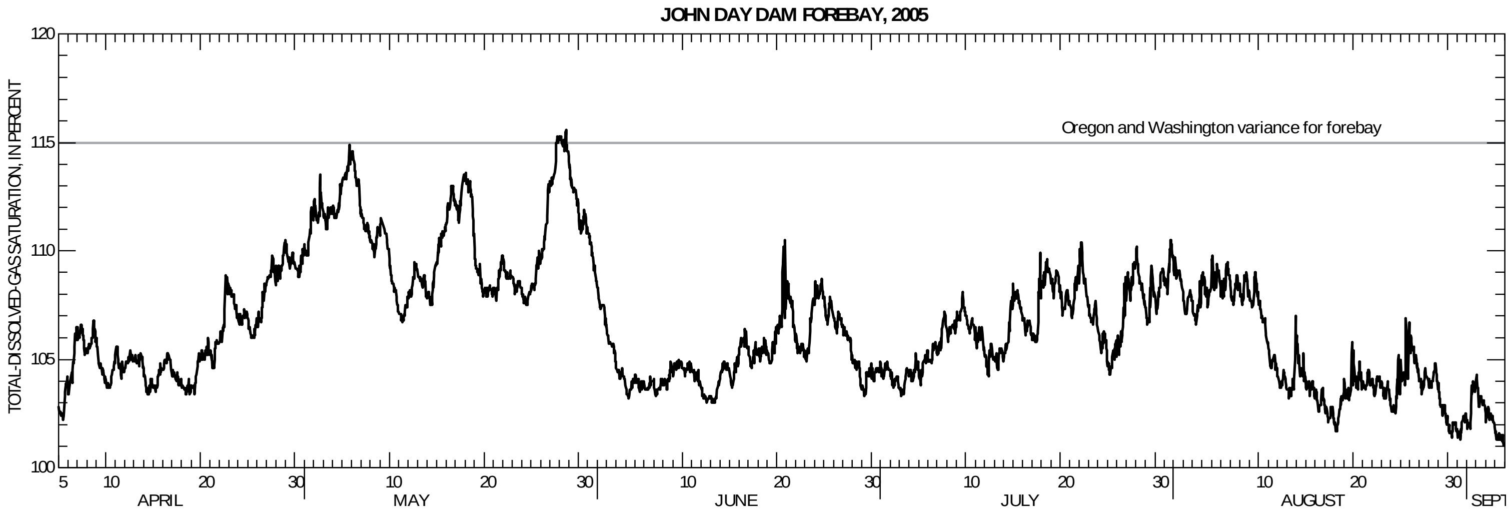

Figure 10. Total dissolved gas saturation upstream from John Day Dam, April 5 to September 5, 2005

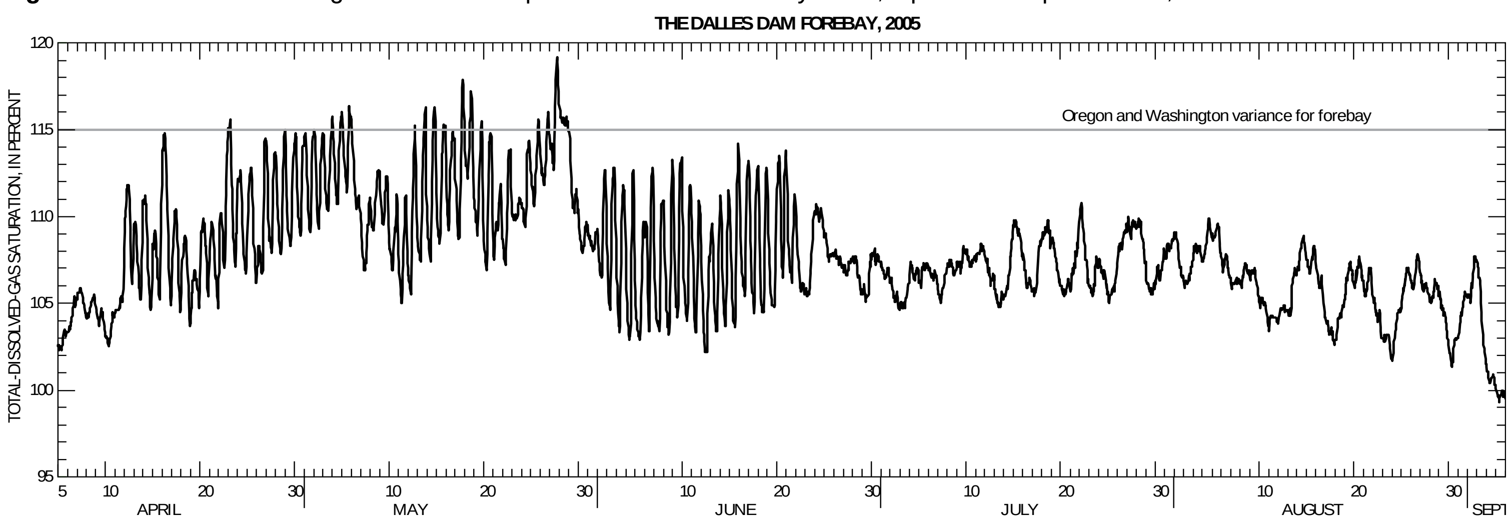

Figure 11. Total dissolved gas saturation upstream from The Dalles Dam, April 5 to September 5, 2005

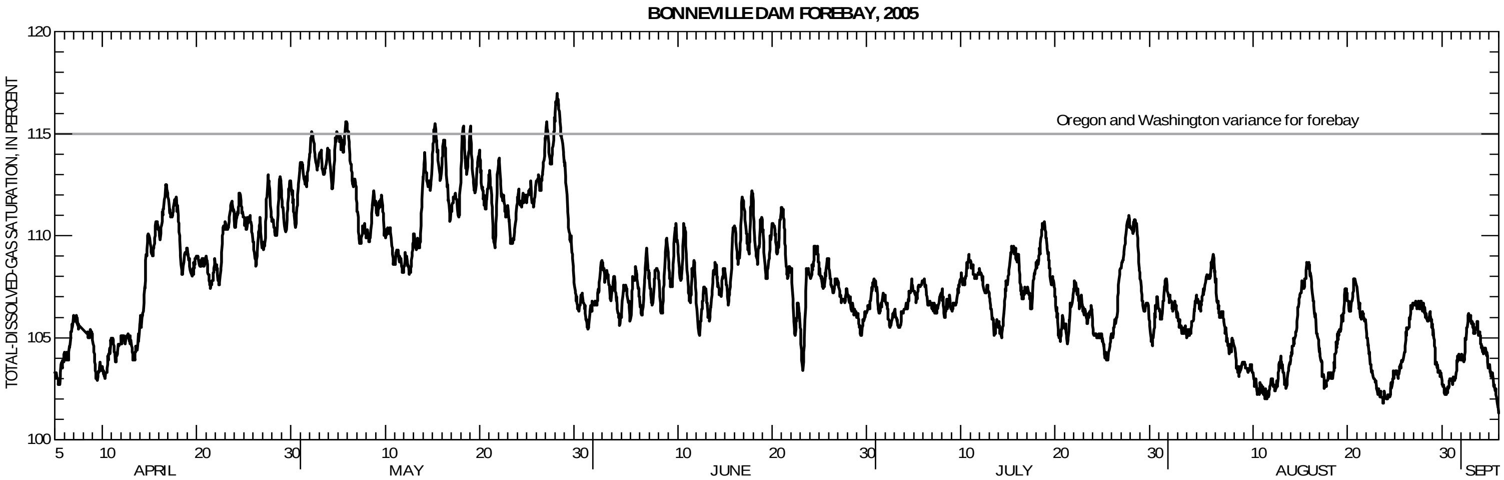

Figure 12. Total dissolved gas saturation upstream from Bonneville Dam, April 5 to September 5, 2005

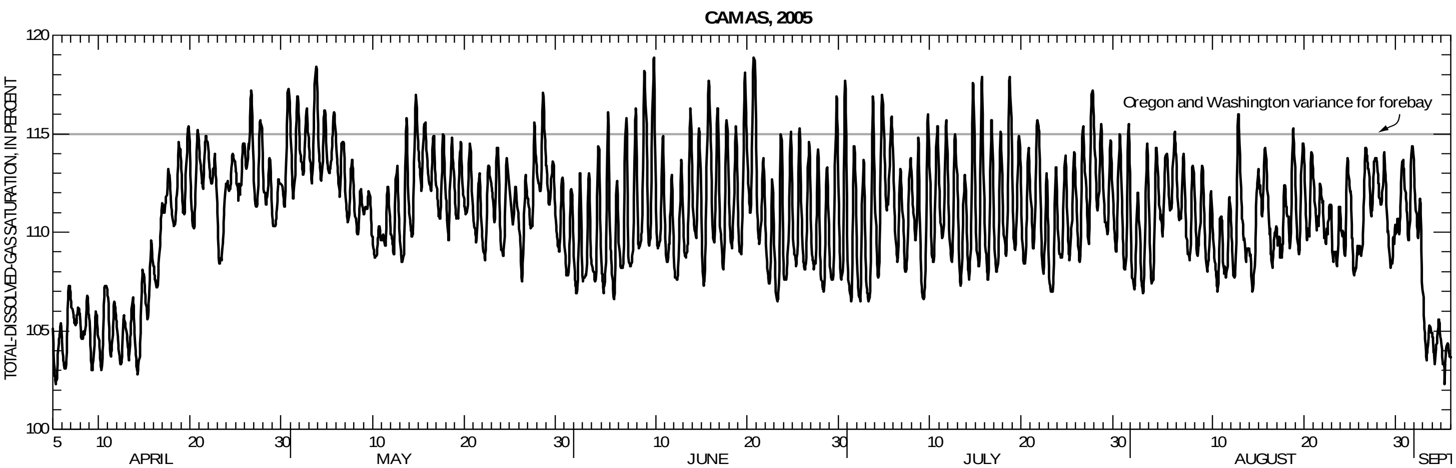

Figure 13. Total dissolved gas saturation at Camas, April 5 to September 5, 2005

Comparison of Total Dissolved Gas and Temperature to Standards

In 2005, there were variances or exceptions to the water-quality standard for TDG of 110% saturation. These variances were established to allow spill for fish passage at dams on the Columbia River. The State of Oregon granted a multiyear variance, covering 2003 to 2007 (Stephanie Hallock, Oregon Environmental Quality Commission, written commun., 2003). The State of Washington provided for fish passage in its water quality standards consistent with approved gas abatement plans (Washington Administrative Code 173-201A-200(1)(f), *http://www.leg.wa.gov/WAC/index.cfm?section=173-201A-200&fuseaction=section*, accessed November 10, 2005). From April 1 to August 31, 2005, the USACE was granted variances of 115% for forebay sites (John Day navigation lock, The Dalles forebay, Bonneville forebay, and Camas) and 120% for tailwater sites, directly downstream from dams (John Day tailwater, The Dalles tailwater, and Warrendale). The 115% and 120% variances were exceeded if the average of the highest 12 hourly values in 1 day (1:00 a.m. to midnight) was larger than the numerical standard. A separate variance of 125% was in place for all sites for the highest 2-hour average (Oregon Environmental Quality Commission, written commun., 2003), or the highest 1-hour average (Washington Administrative Code 173-201A-200(1)(f), *http://www.leg.wa.gov/WAC/index.cfm?section=173-201A-200&fuseaction=section*, accessed November 10, 2005). Although the Camas site is not located at the forebay of a dam, it is 24.4 miles downstream from Bonneville Dam and is regulated as a forebay site.

There was no water-quality variance in place for the site at Cascade Island. This site was established in 2004 for the purpose of collecting data directly in the spillway of Bonneville Dam. The USACE did not use TDG data from the Cascade Island site to regulate spill or flow on the Columbia River.

At five of the eight monitoring stations, the Oregon and Washington variance for TDG was exceeded at some time during water year 2005 (table 4). Table 4 includes data from Cascade Island; even though there was no variance for that site, it was grouped in the category tailwater sites with a variance of 120% saturation. The site with the most exceedances was Camas, which exceeded the 115% variance 11 times. There were no exceedances at the following tailwater sites: The Dalles tailwater, Cascade Island, and Warrendale.

Table 4. Exceedances of States of Oregon and Washington water-quality variances for total dissolved gas, lower Columbia River, Oregon and Washington, water year 2005

Abbreviated station name	Numerical variance for total dissolved gas, in percent saturation	Number of days in exceedance of variance
John Day navigation lock	115	1
John Day tailwater	120	3
The Dalles forebay	115	3
The Dalles tailwater	120	0
Bonneville forebay	115	3
Cascade Island	120	0
Warrendale	120	0
Camas	115	11

The distribution of TDG values for the spill season (April 10 to August 31, 2005) is shown in figure 14. The applicable variance is shown with the data for each site, along with the number of exceedances of each variance. At several sites (for instance, Warrendale), there were several hourly TDG values larger than the variance, but the number of exceedances was still zero because the highest 12-hour average was below the numerical limit. Data from the forebay sites show an increase in the median TDG (from JDY to TDA to BON to CWMW), which probably reflects the river's inability to degas to a "baseline" level downstream of each dam before another dam is encountered to again cause an increase in TDG.

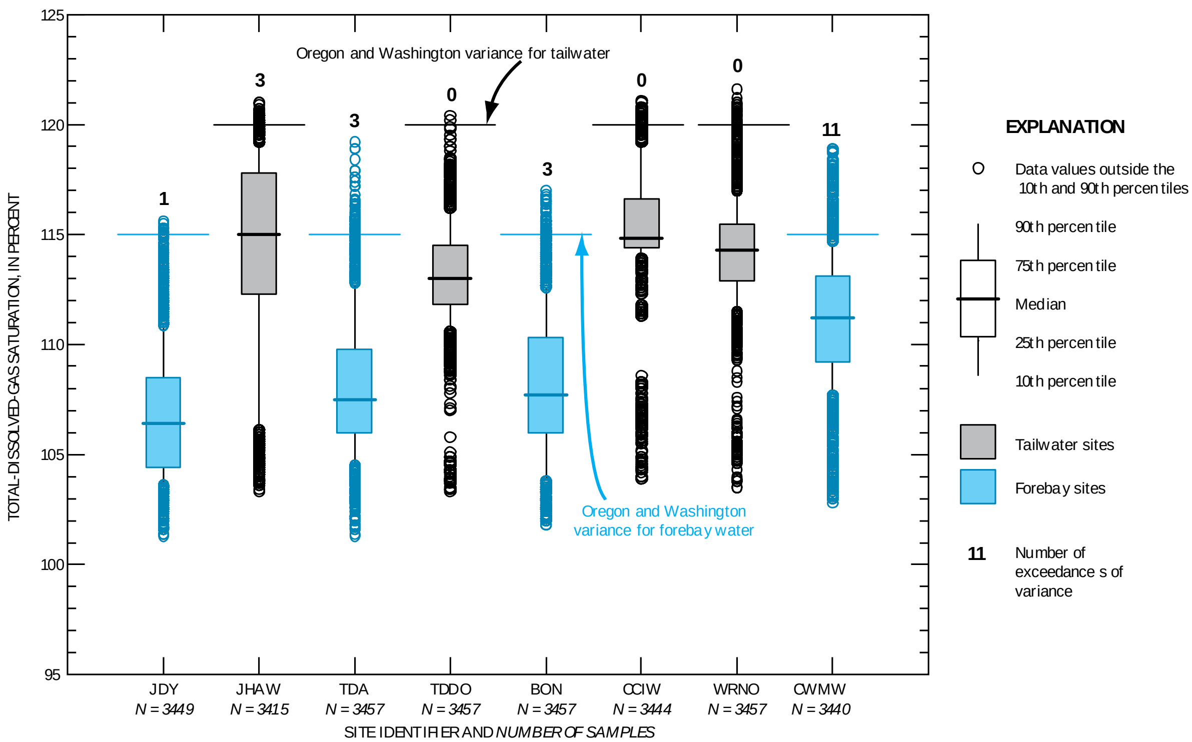

Figure 14. Distributions of hourly total-dissolved-gas data and exceedances of Oregon and Washington water-quality variances, April 10, 2005, to August 31, 2005

Water temperature standards that apply to the lower Columbia River are complex and depend on the effects of human activities and the locations of salmonid rearing, spawning, and egg incubation areas. According to the State of Oregon water-quality standard, the 7-day-average maximum temperature of the lower Columbia River should not exceed 20 °C (Oregon Department of Environmental Quality, Temperature Criteria Rules OAR 340-041-0028, modified 05/20/2004, at *http://www.deq.state.or.us/wq/wqrules/Div41/OAR340Div41.pdf*, accessed November 10, 2005). Washington State regulations state that the water temperature in the Columbia River shall not exceed a 1-day maximum of 20.0 °C due to human activities (Water Quality Standards for Surface Waters of the State of Washington, Chapter 173-201A WAC, amended July 1, 2003, *http://www.ecy.wa.gov/pubs/wac173201a.pdf*, accessed November 10, 2005).

Water temperatures upstream and downstream from John Day Dam (fig. 15), The Dalles Dam (fig. 16), Bonneville Dam (fig. 17); and at Cascade Island (fig. 18) were equal to or larger than 20.0 °C continuously from mid-July until the end of monitoring in early September. Water temperatures at the forebay sites were approximately equal to the temperatures at the tailwater sites, indicating well-mixed conditions in the forebays.

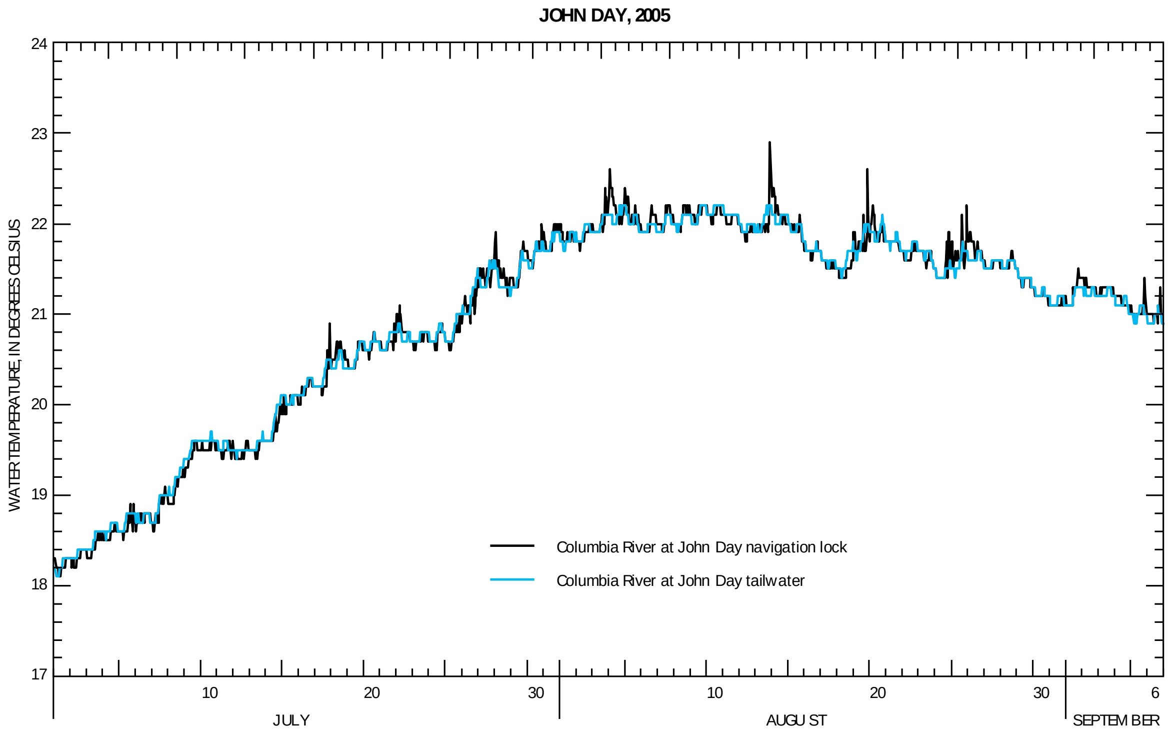

Figure 15. Water temperature upstream and downstream from John Day Dam, summer 2005

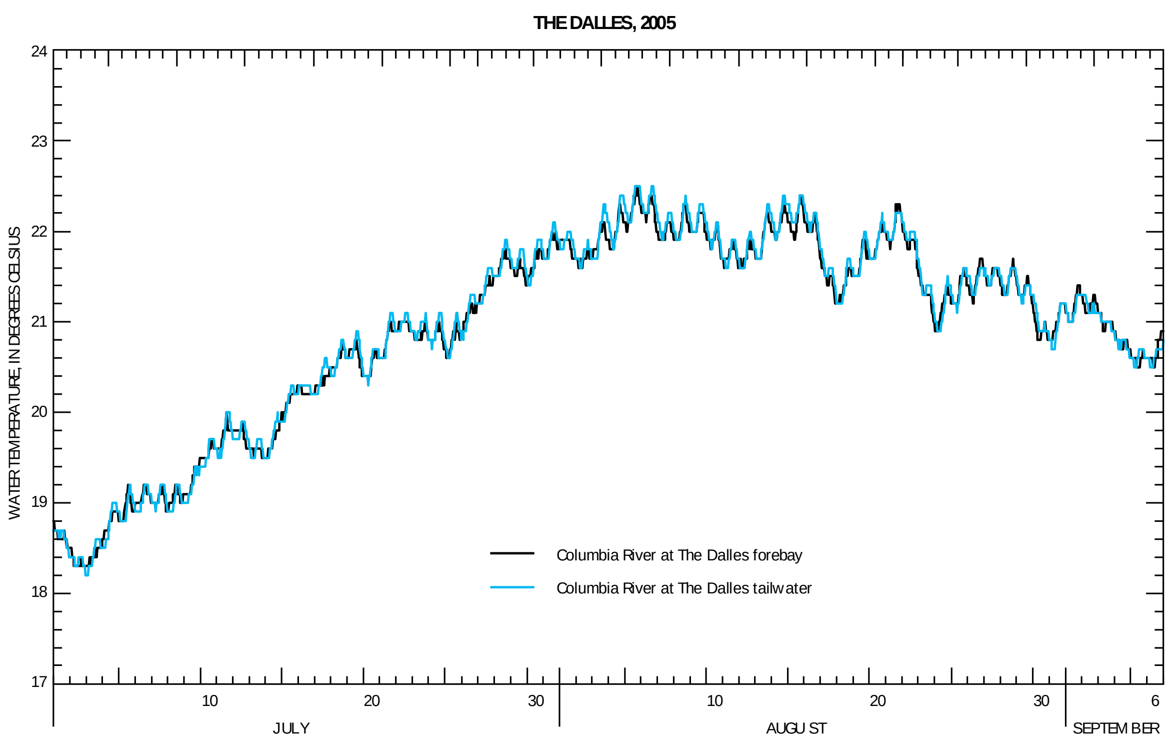

Figure 16. Water temperature upstream and downstream from The Dalles Dam, summer 2005

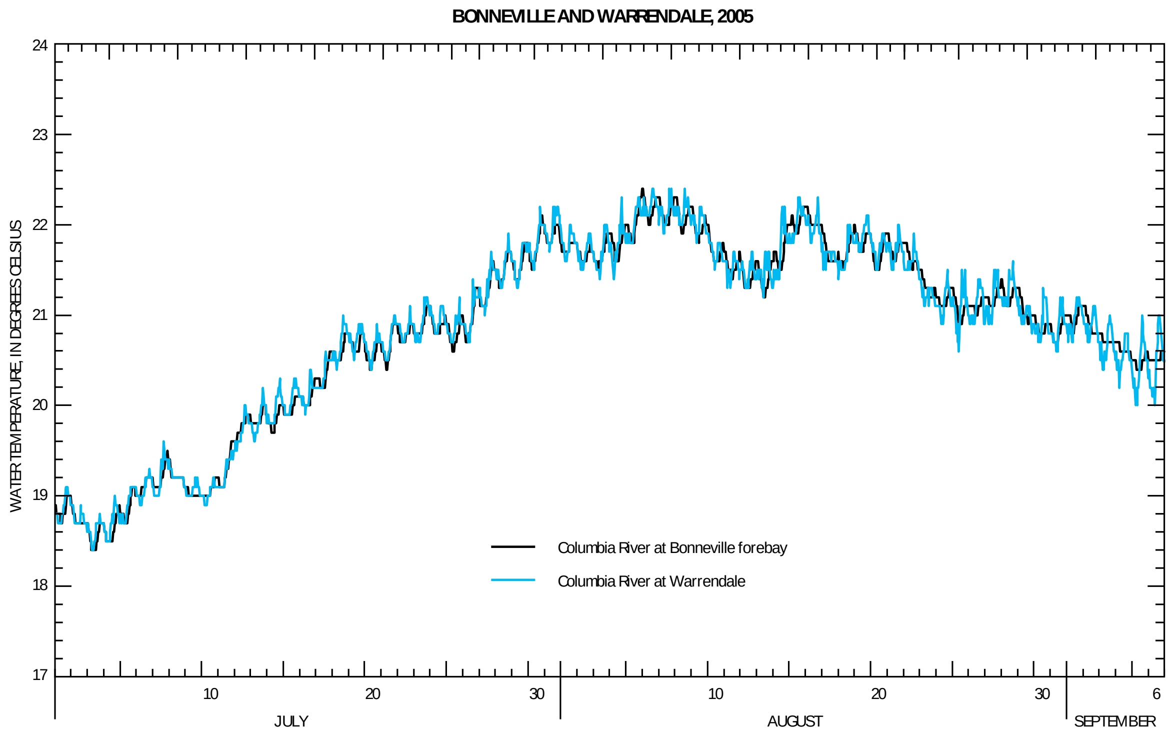

Figure 17. Water temperature upstream and downstream from Bonneville Dam, summer 2005

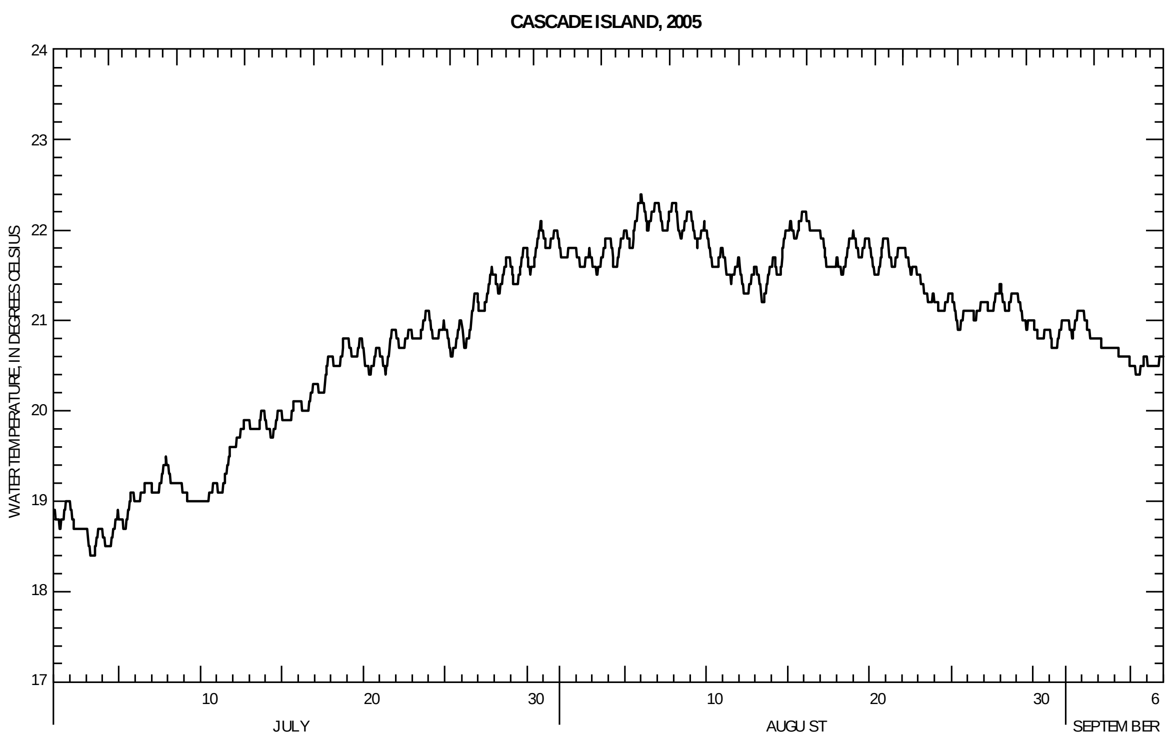

Figure 18. Water temperature at Cascade Island, summer 2005

Water temperature differences between the sites at John Day navigation lock (river mile 215.7) and Warrendale (river mile 140.4) in late summer were unusual (fig. 19). In July and early August, temperatures at the two sites were nearly the same, whereas later in the summer, the water temperature at Warrendale was about 1 °C less than at the John Day site, upstream. Summer air temperatures commonly have larger maxima east of the Cascade Mountains compared with those on the west side, which probably explains the difference in water temperatures.

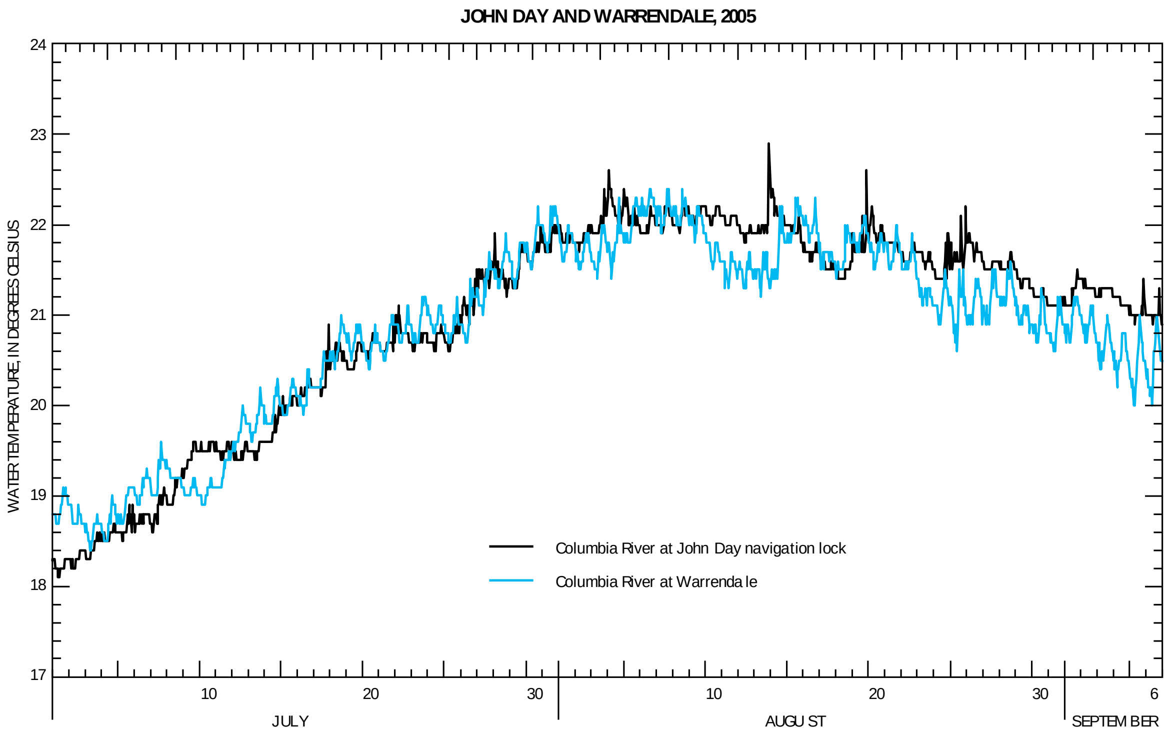

Figure 19. Water temperature at John Day navigation lock and Warrendale, summer 2005

At the Camas site, the water temperature also was 20 °C or higher from mid-July until the end of monitoring in early September (fig. 20). As in the past, there was a distinct daily cycle to temperature, with an amplitude of about 1 °C, a minimum occurring at about 0900 hours and a maximum at about 1900 hours.

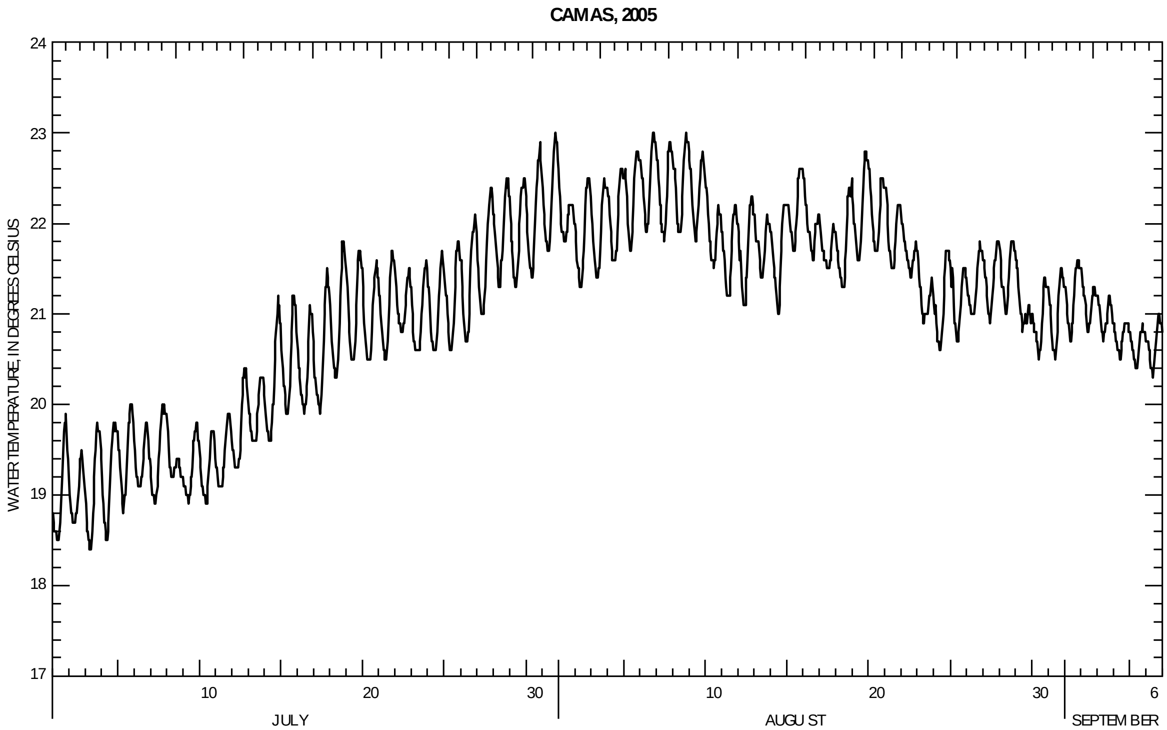

Figure 20. Water temperature at Camas, summer 2005

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