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, 2006: Quality-Assurance Data and Comparison to Water-Quality Standards

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

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Cover photograph: John Day Dam on the Columbia River. Water released through the dam's spillways entrains air, increasing the downstream concentration of gasses dissolved in the water. The U.S. Army Corps of Engineers regulates spill to keep dissolved gasses within safe limits for fish passing through its Columbia River dams. (Photograph by Bill Johnson, U.S. Army Corps of Engineers.)

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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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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 concentration and water-temperature data at eight stations on the lower Columbia River in 2006. Significant findings from the data include:

- Variances to the Oregon and Washington water-quality standards for total dissolved gas were exceeded at all of the monitoring stations: Cascade Island (67 days), Camas (60 days), Bonneville forebay (51 days), The Dalles forebay (36 days), John Day tailwater (35 days), John Day navigation lock (20 days), The Dalles tailwater (8 days), and Warrendale (4 days).
- From early July to the end of August 2006, water temperatures were above 20°C (degrees Celsius) at each of the eight lower Columbia River stations. 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. All of the field checks of barometric pressure were within ±1 millimeter of mercury of a secondary standard, and water temperature field checks were all within ±0.2°C.
- For the eight monitoring stations in water year 2006, an average of 99.1% 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 on the basis of calibration data, replicate quality-control measurements in the river, and comparison to ambient river conditions at adjacent stations.

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).

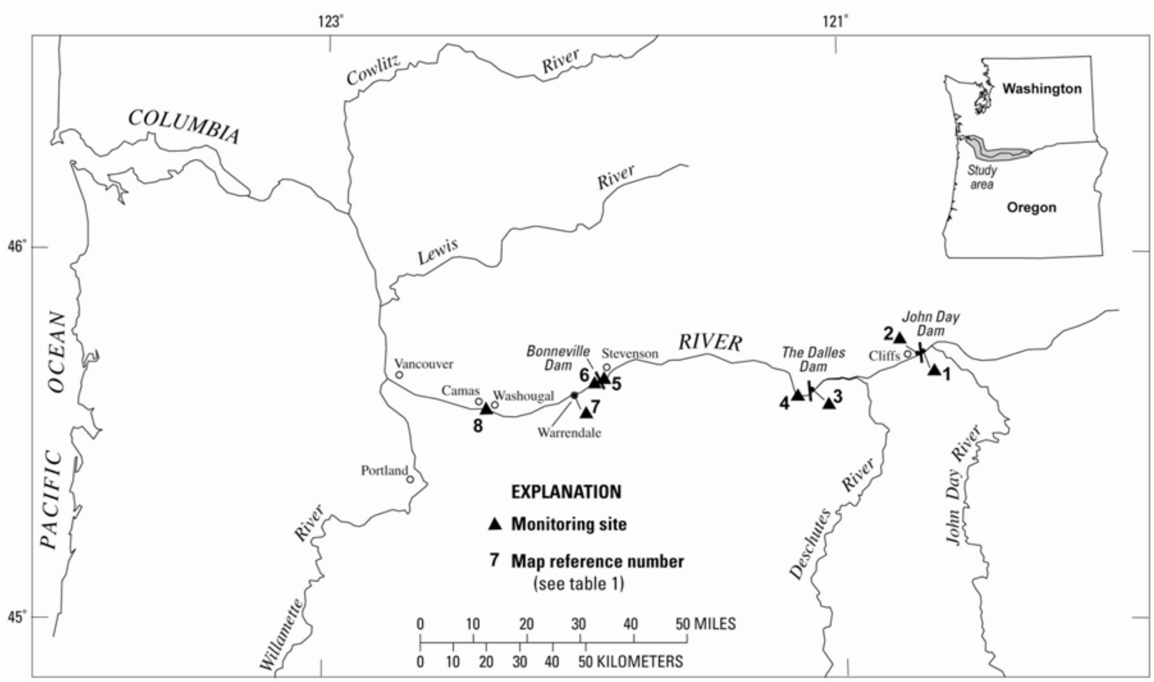

Figure 1. Location of fixed total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2006.

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 real-time TDG and water-temperature data upstream and downstream from Columbia River Basin dams in a network of fixed-station monitors. Data from the lower Columbia River dams are available within about 1 hour of current time.

Background

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/*. Seven reports that were published for water years 1996, 2000, 2001, 2002, 2003, 2004, and 2005 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; and Tanner and others, 2005).

To provide suitable data for managing and modeling TDG in the lower Columbia River, hourly data for 2006 were reviewed relative to laboratory and field measurements made during instrument calibrations and daily intersite comparisons. A small fraction of the TDG data was deleted because they were not of suitable quality. The hourly data were stored in a USGS database and in a USACE database (*http://www.nwd-wc.usace.army.mil/tmt/wcd/tdg/months.html*). The USACE database 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 stations, 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 2006 (October 1, 2005, to September 30, 2006) include hourly measurements of TDG pressure, barometric pressure, water temperature, and probe depth. Six of the stations (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 2006, which is the usual time of spill from the dams. Bonneville forebay was operated year-round and Warrendale was operated year-round except for a period of time in July and August when the station was placed out of service at the request of the USACE.

Table 1. Total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2006

[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 station identifier, °, degree, ’, minute, ”, second]

Map number	USACE station identifier	Columbia River mile	USGS station number	USGS station name (and abbreviated station name)	Latitude and 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”	03/07/06–09/19/06
2	JHAW	214.7	454249120423500	Columbia River, right bank, near Cliffs, Washington (John Day tailwater)	45° 42’ 49” 120° 41’ 37”	03/09/06–09/30/06
3	TDA	192.6	453712121071200	Columbia River at The Dalles Dam forebay, Washington (The Dalles forebay)	45° 37’ 12” 121° 07’ 12”	03/08/06–09/20/06
4	TDDO	188.9	14105700	Columbia River at The Dalles, Oregon (The Dalles tailwater)	45° 36’ 27” 121° 10’ 20”	03/08/06–09/30/06
5	BON	146.1	453845121562000	Columbia River at Bonneville Dam forebay, Washington (Bonneville forebay)	45° 38’ 45” 121° 56’ 20”	Year-round until 09/20/06
6	CCIW	145.9	453845121564001	Columbia River at Cascade Island, Washington (Cascade Island)	45° 38’ 45” 121° 56’ 40”	02/28/06–09/20/06
7	WRNO	140.4	453630122021400	Columbia River, left bank, near Dodson, Oregon (Warrendale)	45° 36’ 30” 122° 02’ 14”	10/01/05–07/13/06 and 08/30/06–09/30/06
8	CWMW	121.7	453439122223900	Columbia River, right bank, at Washougal, Washington (Camas)	45° 34’ 39” 122° 22’ 39”	02/27/06–09/21/06

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 Hach Hydrolab water-quality probe, a Vaisala electronic barometer, a power supply, and a Sutron SatLink2 data-collection platform (DCP). The instruments at each station 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, logged, and transmitted every hour. 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 database and to the USGS database.

The eight fixed-station monitors 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 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 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 (millimeters of mercury) 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 2006 is shown in table 2. (The USACE satellite downlink was a parallel system, so the amount and quality of data received by the USACE were similar). Values in table 2 are 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, divided by the barometric pressure, in mm Hg, multiplied by 100. 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 ±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 stations. At each station, at least 97.0% of the data were received in real time by the USGS downlink and met quality-control checks, with an overall average of 99.1% (table 2).

Table 2. Total-dissolved-gas data completeness and quality, lower Columbia River, Oregon and Washington, water year 2006

[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	4,705	2	100.0
John Day tailwater	4,931	148	97.0
The Dalles forebay	4,702	1	100.0
The Dalles tailwater	4,950	69	98.6
Bonneville forebay	8,509	2	100.0
Cascade Island	4,895	115	97.7
Warrendale	7,610	21	99.7
Camas	4,943	2	100.0
Average	--	--	99.1

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, whereas table 2 included only TDG data. The John Day tailwater station had the most missing or deleted data. Data loss for barometric pressure in April and May at that station was caused by a faulty DCP, which was replaced. There were two occurrences of TDG-membrane failure at John Day tailwater; TDG data lost in those cases cannot be recovered or reconstructed. At The Dalles tailwater during a period in April and May, the power supply was not sufficient to enable transmission of complete data streams, but the data were later recovered onsite from the data logger. At Cascade Island, transmissions ceased for several days due to rainwater damaging the DCP, but again the data were recovered later and restored to the databases.

Table 3. Missing or deleted data from total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2006

[Station abbreviations: JDY, John Day navigation lock; JHAW, John Day tailwater; TDDO, The Dalles tailwater; BON, Bonneville forebay; CCIW, Cascade Island; WRNO, Warrendale; CWMW, Camas. Parameter and unit abbreviations: TDG, total dissolved gas; BP, barometric pressure; WT, water temperature; DCP, data collection platform]

Date & Time	Station	Parameter	Reason / Notes
3/29/06 14:00	JDY	TDG BP WT Depth	Station calibration
4/29/06 09:00 through 5/02/06 13:00 (intermittent)	JHAW	BP	DCP malfunction
6/29/06 17:00 through 6/30/06 12:00	JHAW	TDG	Ruptured membrane
7/30/06 05:00 through 7/31/06 14:00	JHAW	TDG WT Depth	Vandalism
9/18/06 11:00 through 9/19/06 17:00	JHAW	TDG	Ruptured membrane
4/20/06 09:00	TDDO	BP	Station calibration
4/28/06 23:00 through 5/01/06 16:00	TDDO	TDG BP WT depth	Low battery; no transmissions, but data recovered
9/08/06 06:00	TDDO	BP	Erroneous data
12/19/96 16:00	BON	WT	Erroneous data
3/16/06 11:00	BON	TDG	Erroneous data

Table 3. Missing or deleted data from total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2006—continued

[Station abbreviations: JDY, John Day navigation lock; JHAW, John Day tailwater; TDDO, The Dalles tailwater; BON, Bonneville forebay; CCIW, Cascade Island; WRNO, Warrendale; CWMW, Camas. Parameter and unit abbreviations: TDG, total dissolved gas; BP, barometric pressure; WT, water temperature; DCP, data collection platform]

Date & Time	Station	Parameter	Reason / Notes
3/16/06 19:00 through 3/21/06 11:00	CCIW	TDG BP WT depth	DCP got wet - no transmissions, but data recovered
3/30/06 19:00	CCIW	TDG BP WT depth	Station calibration
5/11/06 13:00	CCIW	WT	Station calibration
12/19/05 12:00 through 12/19/05 15:00	WRNO	TDG BP WT depth	No transmission
6/07/06 23:00	WRNO	WT	Erroneous data - faulty sensor
6/08/06 08:00	WRNO	WT	Erroneous data
6/08/06 10:00	WRNO	WT	Erroneous data
6/08/06 15:00	WRNO	WT	Erroneous data
6/08/06 16:00	WRNO	WT	Erroneous data
6/09/06 07:00	WRNO	WT	Erroneous data
6/09/06 11:00	WRNO	WT	Erroneous data
6/09/06 12:00	WRNO	WT	Erroneous data
6/11/06 14:00	WRNO	WT	Erroneous data
6/11/06 15:00	WRNO	WT	Erroneous data
6/14/06 22:00	WRNO	WT	Erroneous data
6/16/06 19:00	WRNO	WT	Erroneous data
6/16/06 20:00	WRNO	WT	Erroneous data
6/17/06 00:00	WRNO	WT	Erroneous data
6/17/06 01:00	WRNO	WT	Erroneous data
6/18/06 19:00	WRNO	WT	Erroneous data
6/18/06 20:00	WRNO	WT	Erroneous data
6/18/06 21:00	WRNO	WT	Erroneous data
6/20/06 13:00	WRNO	WT	Erroneous data

Table 3. Missing or deleted data from total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2006—continued

[Station abbreviations: JDY, John Day navigation lock; JHAW, John Day tailwater; TDDO, The Dalles tailwater; BON, Bonneville forebay; CCIW, Cascade Island; WRNO, Warrendale; CWMW, Camas. Parameter and unit abbreviations: TDG, total dissolved gas; BP, barometric pressure; WT, water temperature; DCP, data collection platform]

Date & Time	Station	Parameter	Reason / Notes
9/13/06 21:00 through 9/14/06 12:00	WRNO	TDG	Ruptured membrane
7/08/06 22:00	CWMW	TDG BP WT depth	Erroneous data
8/04/06 11:00	CWMW	WT	Station calibration

Quality-Assurance Data

Data collection for TDG, barometric pressure and water temperature involves 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 2006 are presented in this section.

After field deployment of the Hydrolabs for 3 weeks, the TDG sensors were calibrated in the laboratory. First, each 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 approximately 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 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 (113%, 126%, and 139% saturation, respectively). The accuracy of the TDG sensors was calculated by computing the difference between the pressure-gage 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, most of the sensor readings were within 1% saturation of the certified pressure gage after 3 weeks of deployment. The TDG sensor from Cascade Island produced the two data points more than +1% saturation off for the 126% and 139% saturation tests. It had been installed from February 28 to March 30, a time period when TDG was less than 120% saturation at the Cascade Island station. The sensor was recalibrated and performed within specifications for the remainder of the field season.

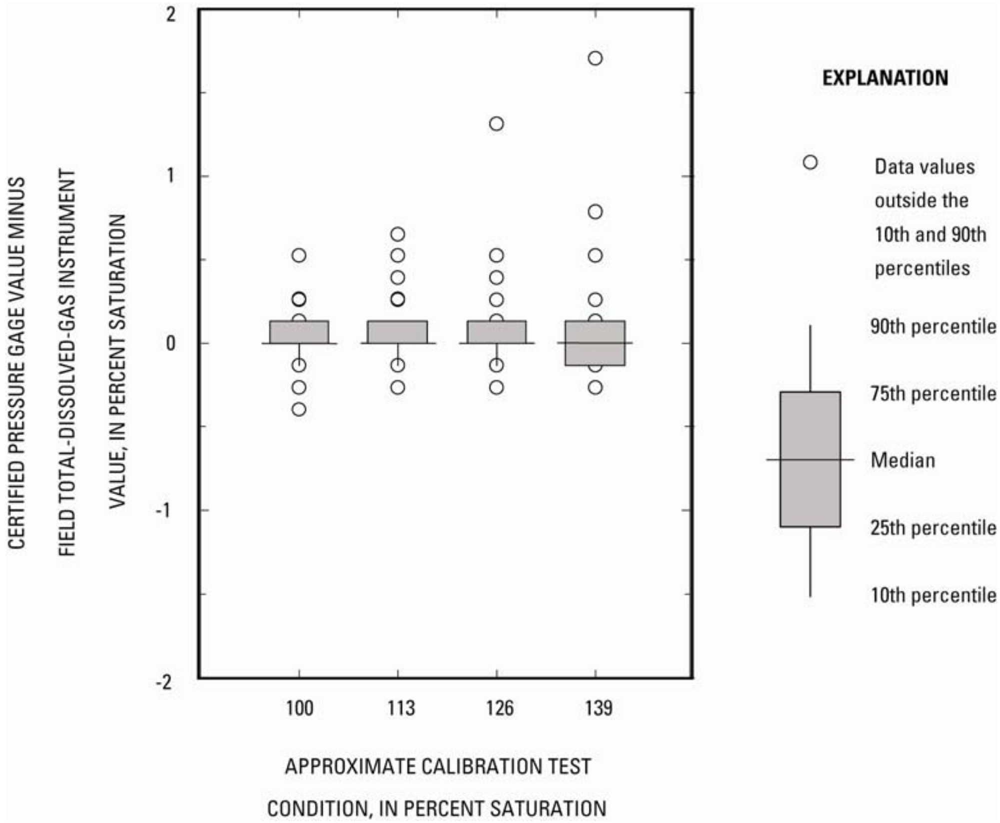

Figure 2. Accuracy of total-dissolved-gas sensors after 3 weeks of field deployment. (Number of comparison values = 99.)

The differences in barometric pressure, water temperature, and TDG between the secondary standard instruments and the fixed-station instruments after 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. A hand-held 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 stations.

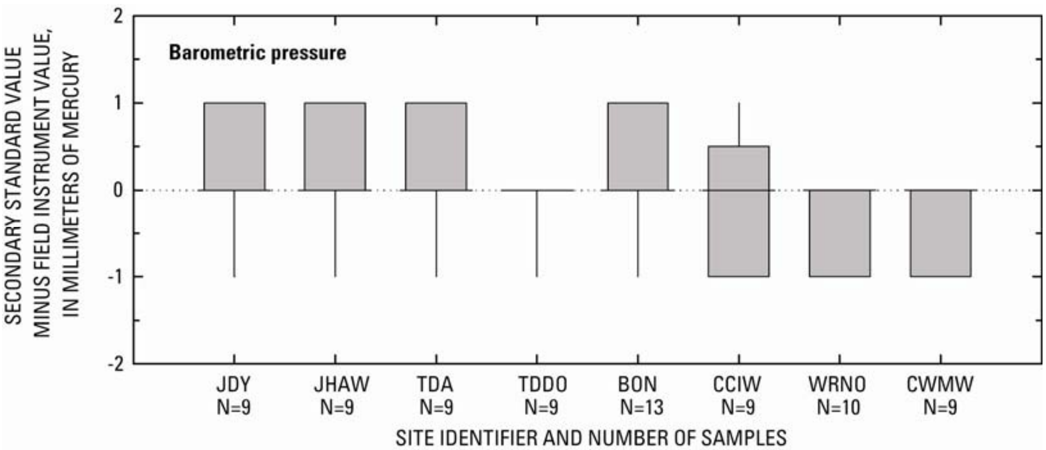

Figure 3. Difference between the secondary standard and the field barometers after 3 weeks of deployment. (See figure 2 for an explanation of the box and whisker diagrams.)

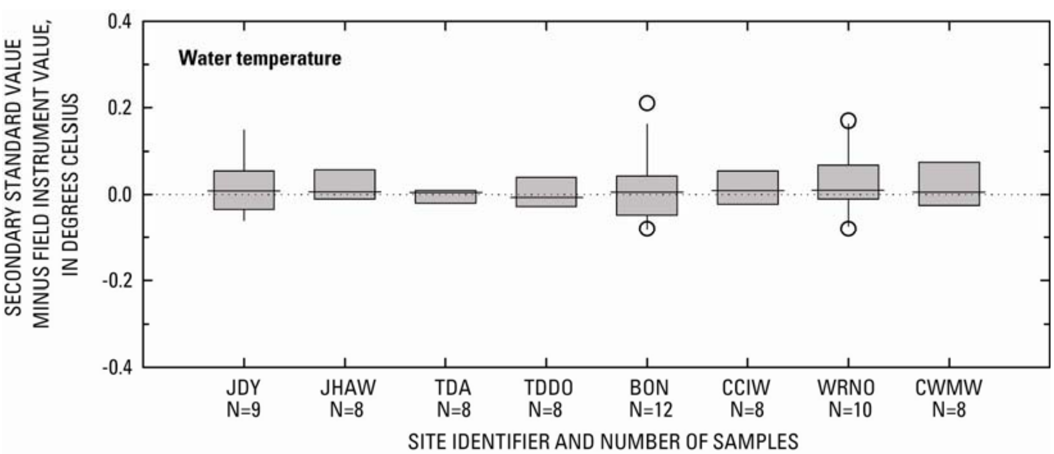

Figure 4. Difference between the secondary standard and the field temperature instruments after 3 weeks of deployment. (See figure 2 for an explanation of the box and whisker diagrams.)

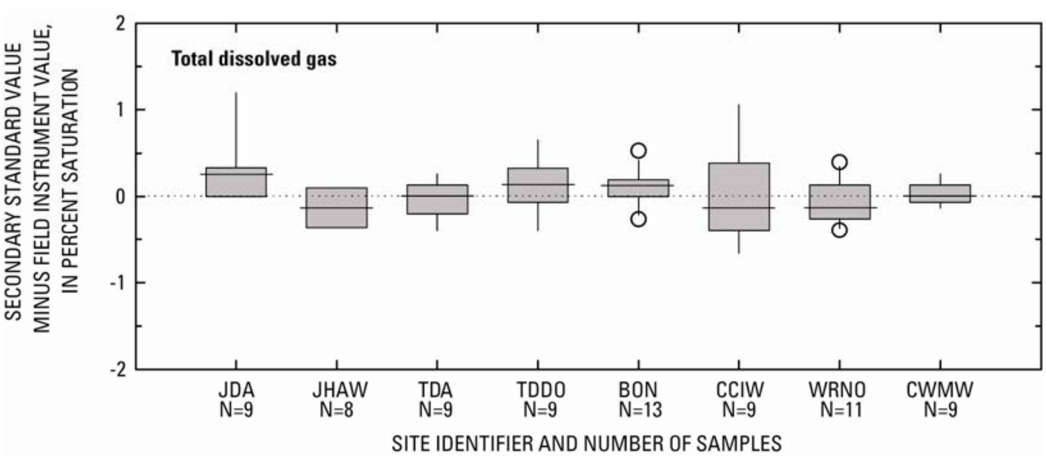

Figure 5. Difference between the secondary standard and the field total-dissolved-gas instruments after 3 weeks of deployment. (See figure 2 for an explanation of the box and whisker diagrams.)

The comparisons of the hand-held barometer and the electronic field barometers are shown in figure 3. All of the field values are within 1 mm Hg of the standard values. 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. Most of the data show less than a 1% saturation difference between the two TDG sensors (fig. 5).

The two greatest differences are +1.2% saturation at John Day navigation lock and +1.0% saturation at Cascade Island. The data point at John Day navigation lock was the final field check of the season (September 19) before the monitoring equipment was removed. The field instrument passed post-deployment calibration tests. It is possible that more equilibration time of the secondary standard instrument would have resulted in a lesser difference between the two instruments. The data point at Cascade Island was the result of the TDG sensor, mentioned above, that was shown to be out of calibration during post-deployment testing. After it was recalibrated, the sensor performed well for the remainder of the season.

Effects of Spill on Total-Dissolved-Gas Concentration

Spill from each dam increased the level of dissolved gases 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 without significant pause from April 5 to August 31 (fig. 6). All occurrences of spill larger than 100,000 ft^3/s and most TDG values larger than 120% saturation were recorded before June 29. At about 70,000 ft^3/s of spill, TDG begins to exceed 120% saturation.

Spill from The Dalles Dam (fig. 7) was almost continuous from April 5 to August 31. Most occurrences of spill larger than 100,000 ft^3/s and all TDG levels larger than 120% saturation were before June 27. At about 90,000 ft^3/s of spill, TDG begins to exceed 120% saturation.

Spill from Bonneville Dam was almost continuous from April 4 to August 31. Most occurrences of spill larger than150,000 ft^3/s were recorded before June 17. Both Cascade Island and Warrendale are downstream of Bonneville Dam (see fig. 1). TDG levels larger than 120% saturation at Warrendale (fig. 8) and Cascade Island (fig. 9) occurred mostly before June 14 and June 25, respectively. The monitoring station at Warrendale had a planned shutdown from July 13 to August 30.

TDG at Cascade Island exceeded 120% saturation sporadically when Bonneville spill was less than 3,000 ft^3/s and greater than 80,000 ft^3/s. At Warrendale, TDG exceeded 120% saturation when Bonneville spill exceeded 120,000 ft^3/s. When TDG exceeded 120% saturation at Cascade Island, TDG only occasionally exceeded 120% saturation at Warrendale.

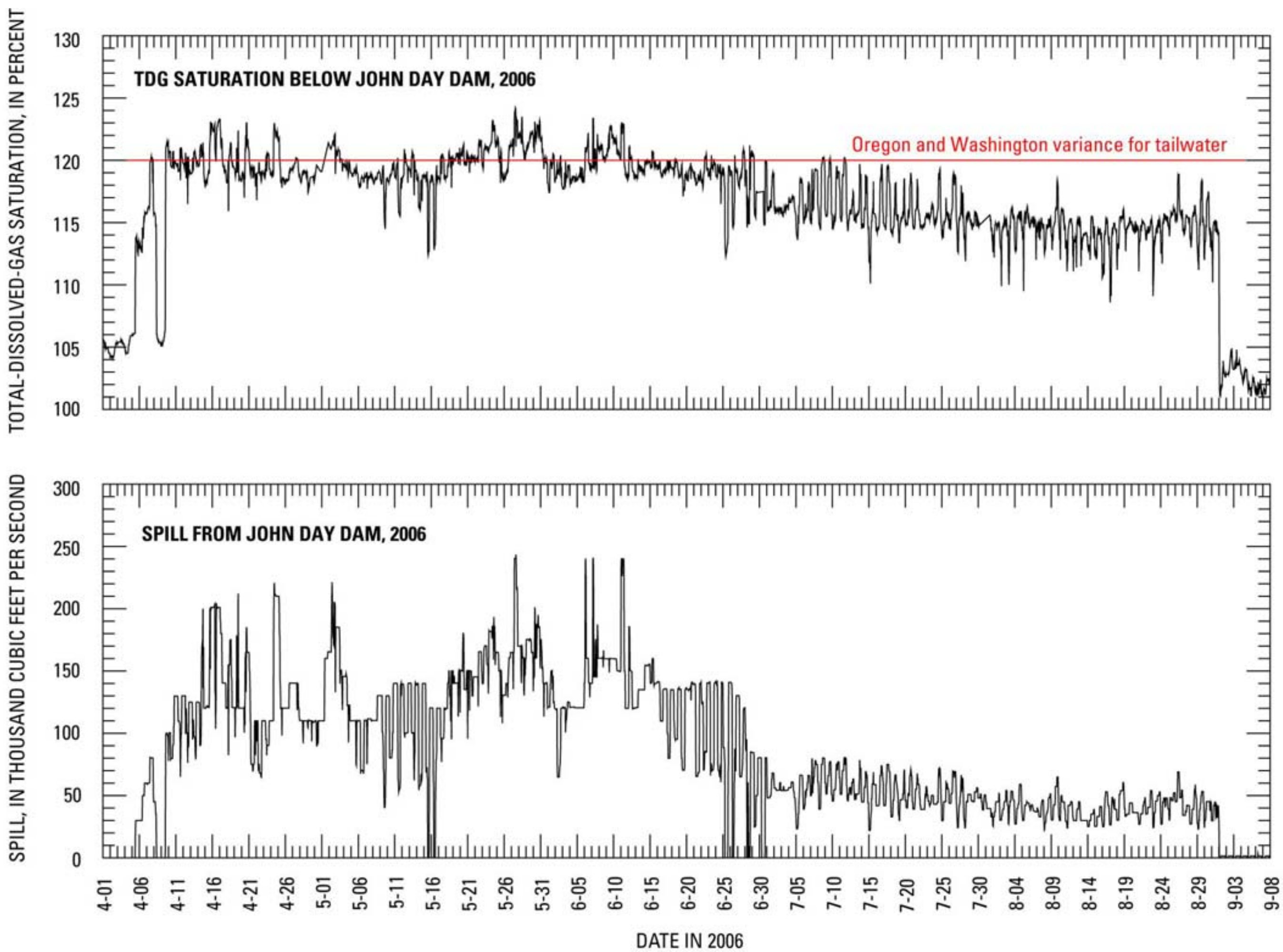

Figure 6. Total dissolved gas saturation downstream from John Day Dam and spill from John Day Dam, April 1 to September 8, 2006. (Date format = M-DD.)

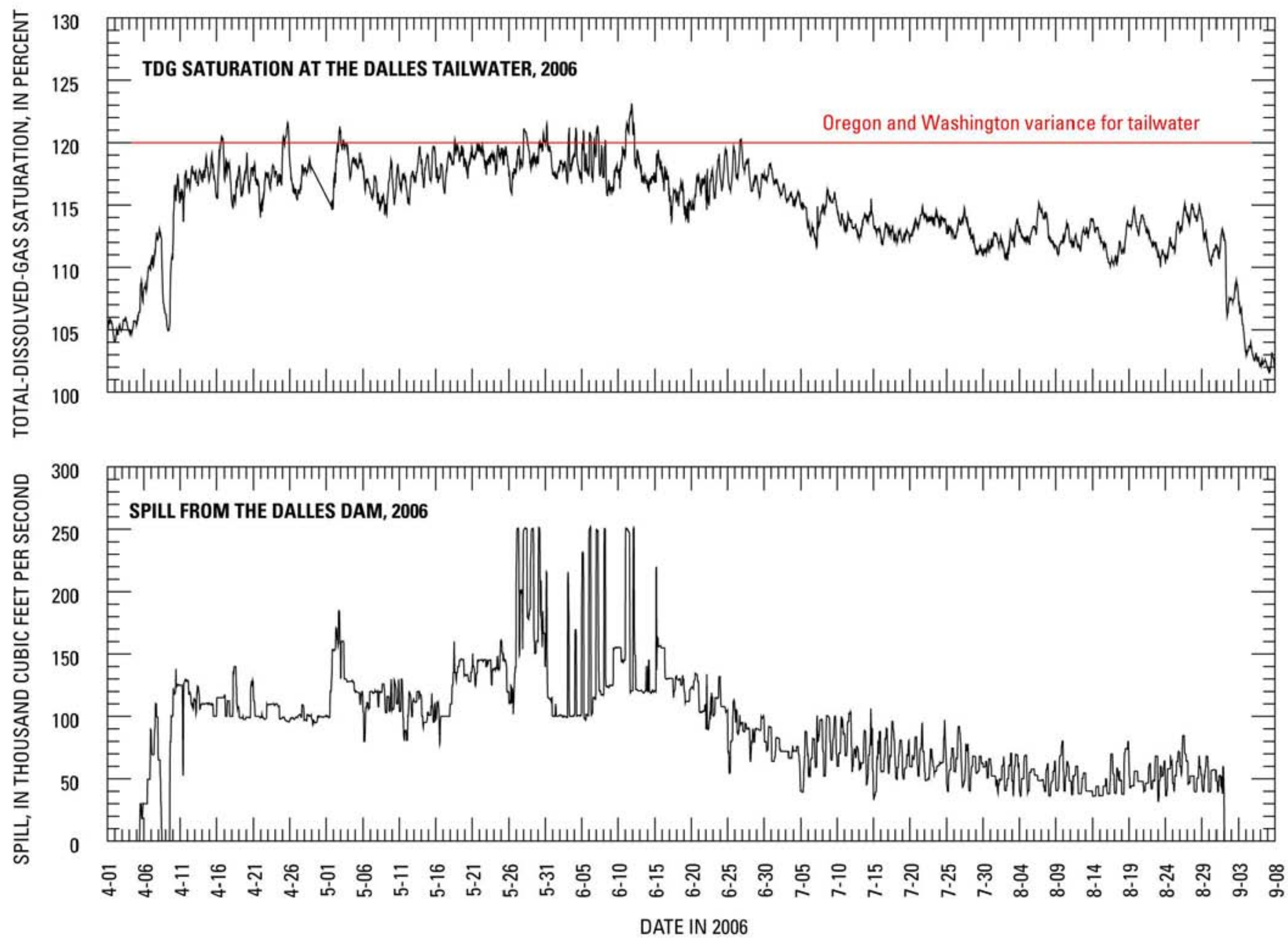

Figure 7. Total dissolved gas saturation downstream from The Dalles Dam and spill from The Dalles Dam, April 1 to September 8, 2006. (Date format = M-DD.)

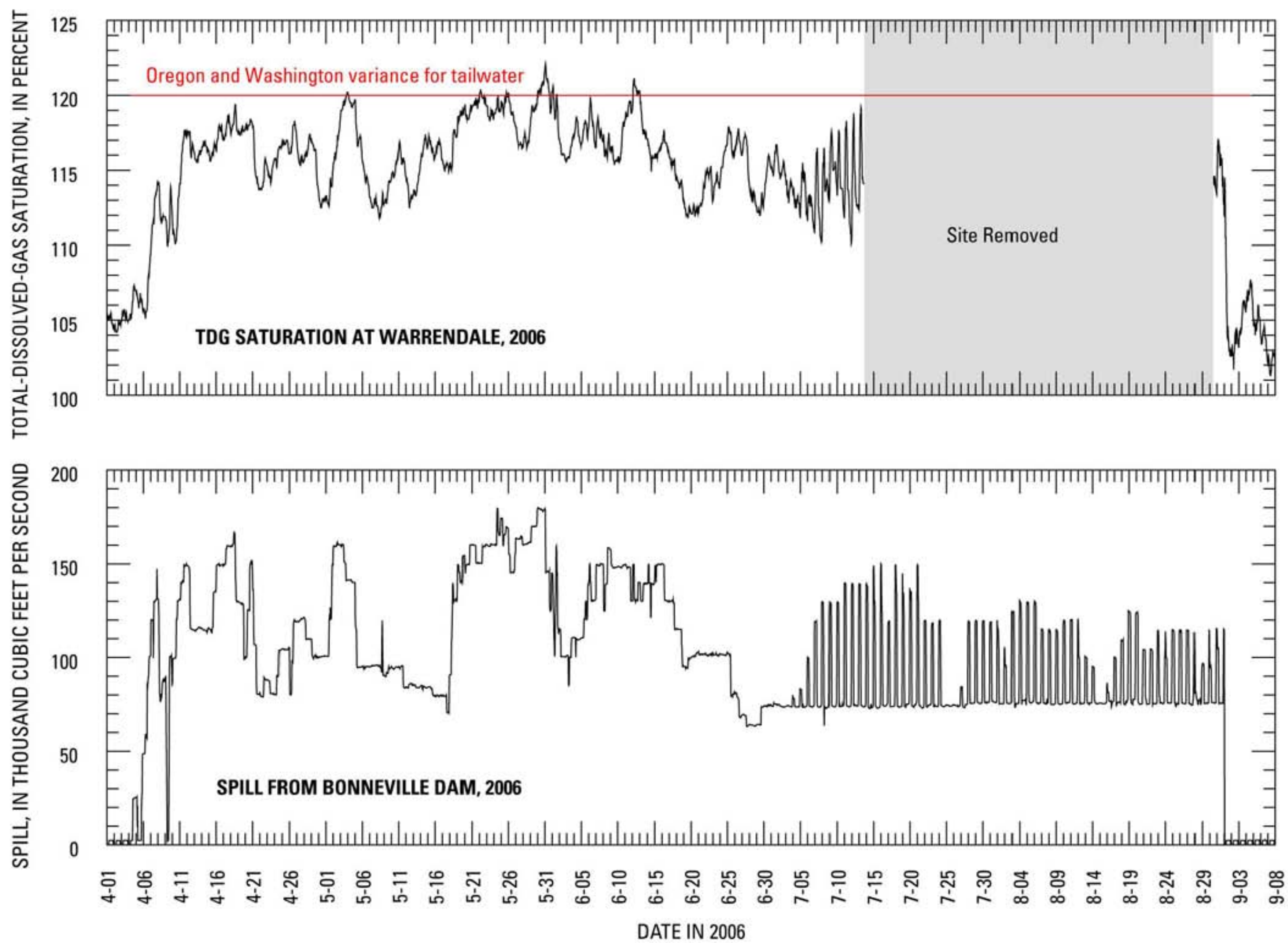

Figure 8. Total dissolved gas saturation downstream from Bonneville Dam at Warrendale and spill from Bonneville Dam, April 1 to September 8, 2006. (Date format = M-DD.)

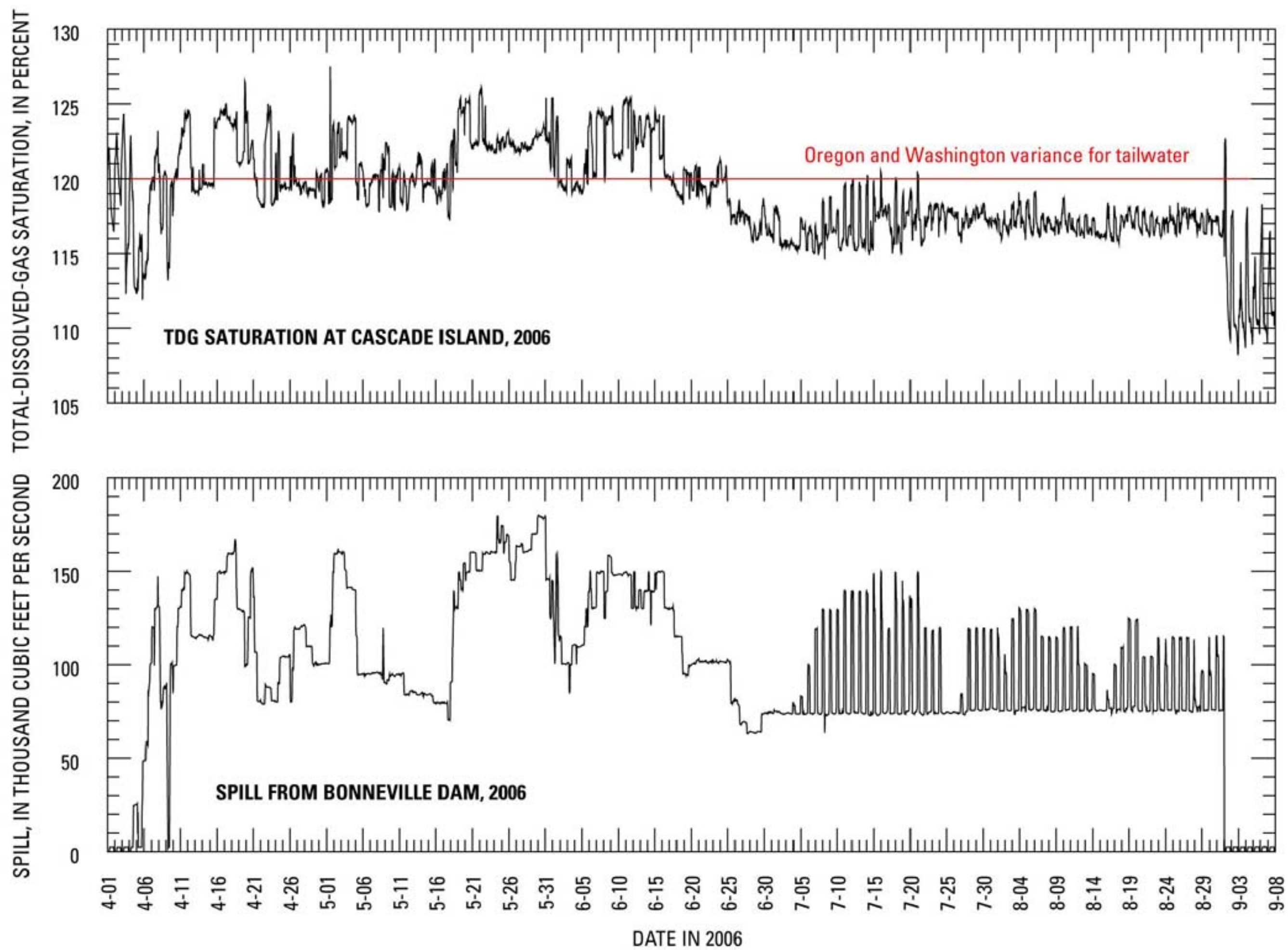

Figure 9. Total dissolved gas saturation downstream from Bonneville Dam at Cascade Island and spill from Bonneville Dam, April 1 to September 8, 2006. (Date format = M-DD.)

The forebay stations, John Day navigation lock, The Dalles forebay, Bonneville forebay, and Camas, are each located immediately upstream of a dam, except for Camas, which is 24.4 miles downstream of Bonneville Dam. As a result, the forebay stations were expected to have lower levels of total dissolved gas than the tailwater stations. Early in the 2006 spill season, TDG levels at John Day navigation lock (fig. 10), The Dalles Dam forebay (fig. 11), and Bonneville Dam forebay (fig. 12) were often above 120% saturation due to spill from upstream dams; but after late June the TDG level was lower. At Camas (fig. 13), however, TDG saturation was higher than 115% on numerous occasions from April to August. As documented previously (Tanner and Bragg, 2001), some of the daily increases in TDG at Camas may have been due to the production of oxygen by aquatic plants and to temperature increases caused by daytime heating.

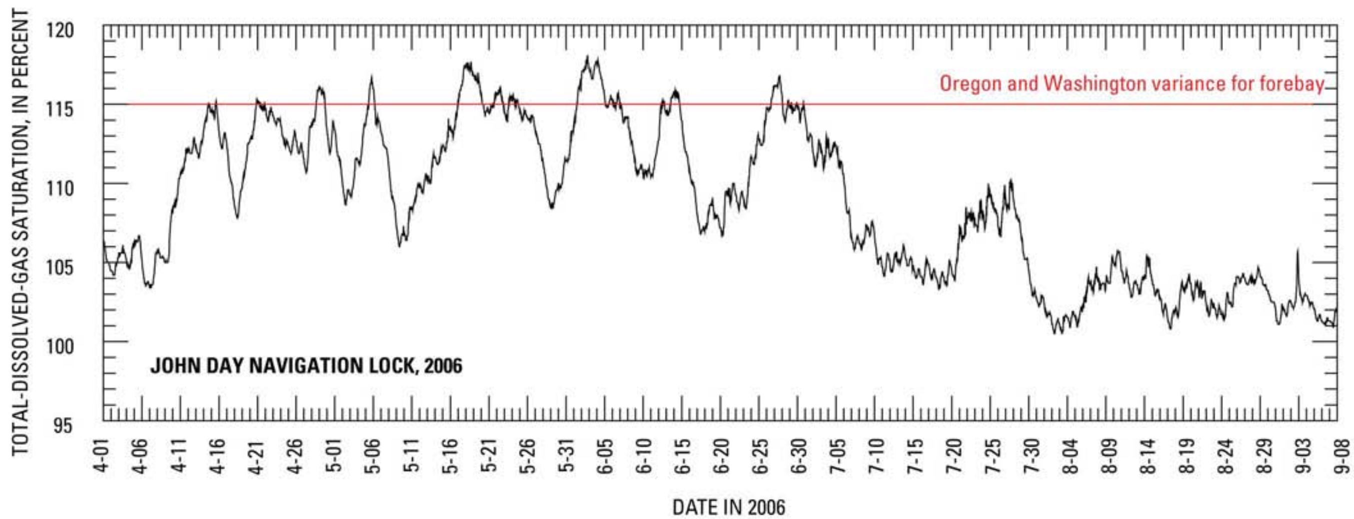

Figure 10. Total-dissolved-gas saturation upstream from John Day Dam, April 1 to September 8, 2006. (Date format = M-DD.)

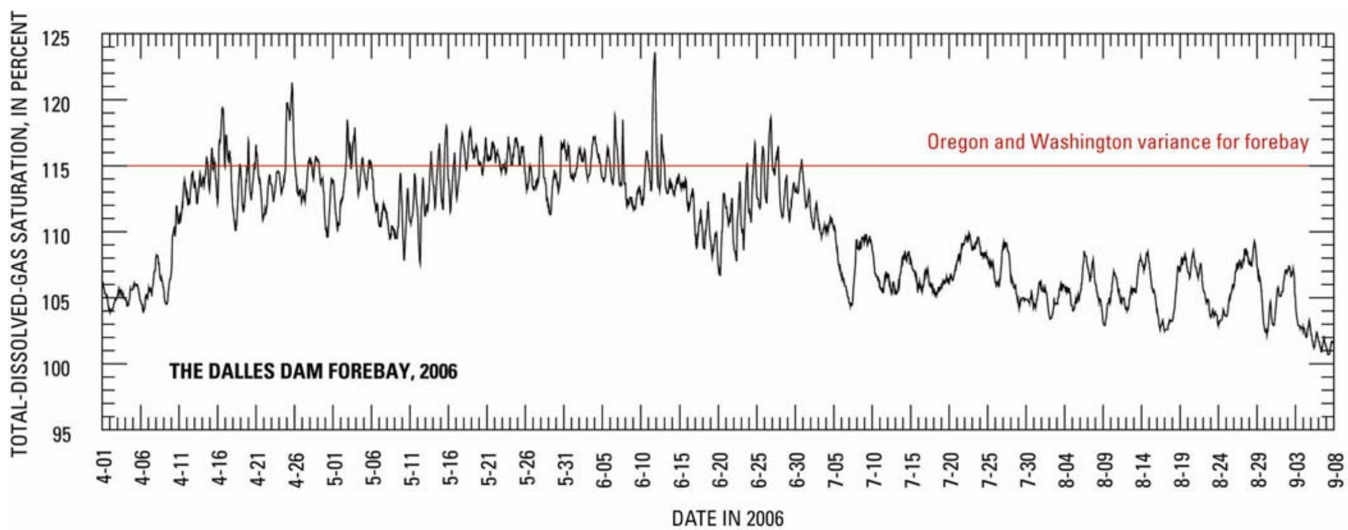

Figure 11. Total-dissolved-gas saturation upstream from The Dalles Dam, April 1 to September 8, 2006. (Date format = M-DD.)

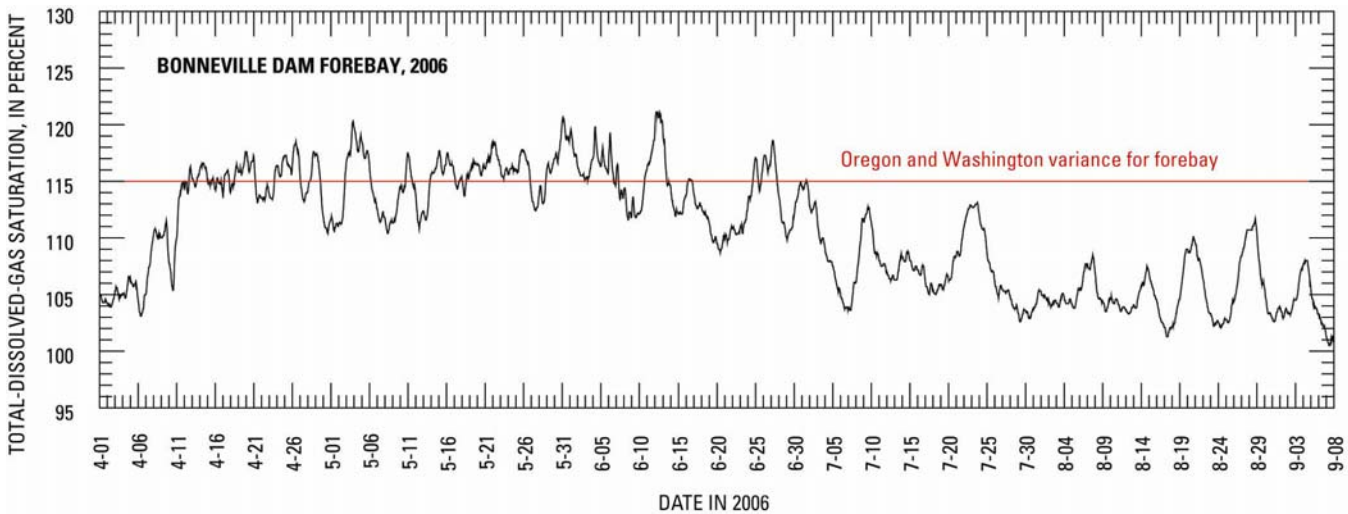

Figure 12. Total-dissolved-gas saturation upstream from Bonneville Dam, April 1 to September 8, 2006. (Date format = M-DD.)

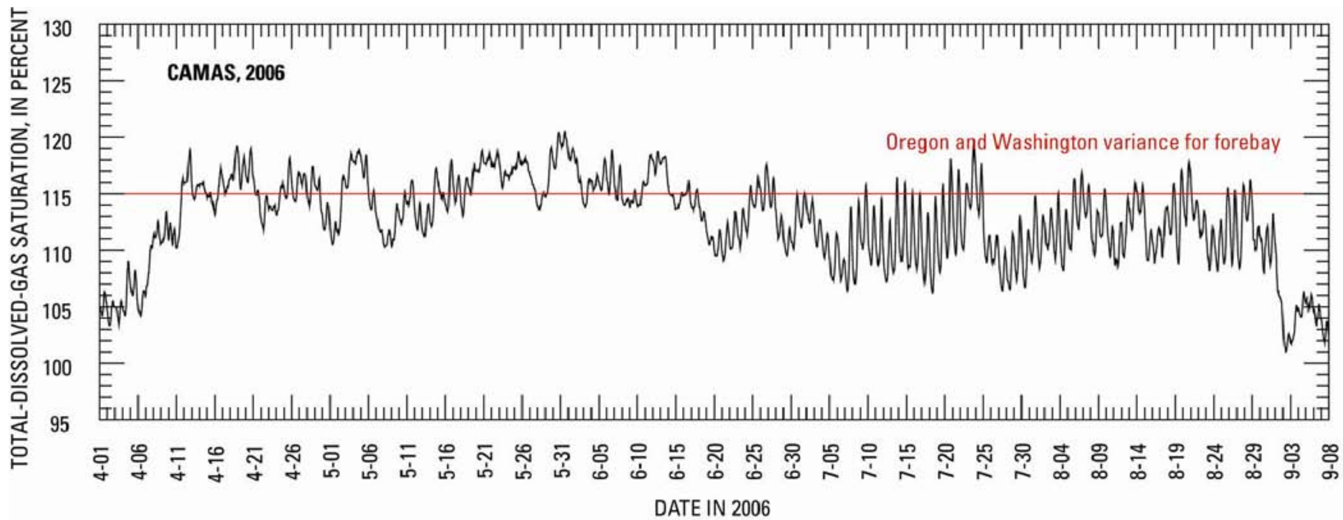

Figure 13. Total-dissolved-gas saturation at Camas, April 1 to September 8, 2006. (Date format = M-DD.)

Comparison of Total Dissolved Gas and Temperature to Standards

In 2006, 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://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-200*, accessed November 15, 2006). From April 1 to August 31, 2006, the USACE was granted variances allowing TDG to reach 115% for forebay stations (John Day navigation lock, The Dalles forebay, Bonneville forebay, and Camas) and 120% for tailwater stations, directly downstream from dams (John Day tailwater, The Dalles tailwater, Cascade Island, 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 stations 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://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-200*, accessed November 15, 2006). Although the Camas station is not located at the forebay of a dam, it is 24.4 miles downstream from Bonneville Dam and is regulated as a forebay station.

The Oregon and Washington variance for TDG was exceeded at some time during water year 2006 at all monitoring stations (table 4). The three stations with the most exceedances were all near Bonneville Dam. Cascade Island, below the dam, had 67 exceedances, followed by Camas, below the dam, (60 exceedances) and Bonneville forebay (51 exceedances).

Table 4. Exceedances of States of Oregon and Washington water-quality variances for total dissolved gas, lower Columbia River, Oregon and Washington, water year 2006

Abbreviated station name	Numerical variance for total dissolved gas, in percent saturation	Number of days in exceedance of variance
John Day navigation lock	115	20
John Day tailwater	120	35
The Dalles forebay	115	36
The Dalles tailwater	120	8
Bonneville forebay	115	51
Cascade Island	120	67
Warrendale	120	4
Camas	115	60

The distribution of TDG values for the spill season (April 1 to August 31, 2006) is shown in figure 14. The applicable variance is shown with the data for each station, along with the number of exceedances of each variance. Data from the forebay stations show an increase in the median TDG (from JDY to TDA to BON to CWMW), which probably reflects the river's inability to de-gas to a "baseline" level downstream of each dam before another dam is encountered to again cause an increase in TDG. The number of days in exceedance at the forebay stations also shows an increase from 20 days at JDY to 36 days at TDA to 51 days at BON to 60 days at CWMW.

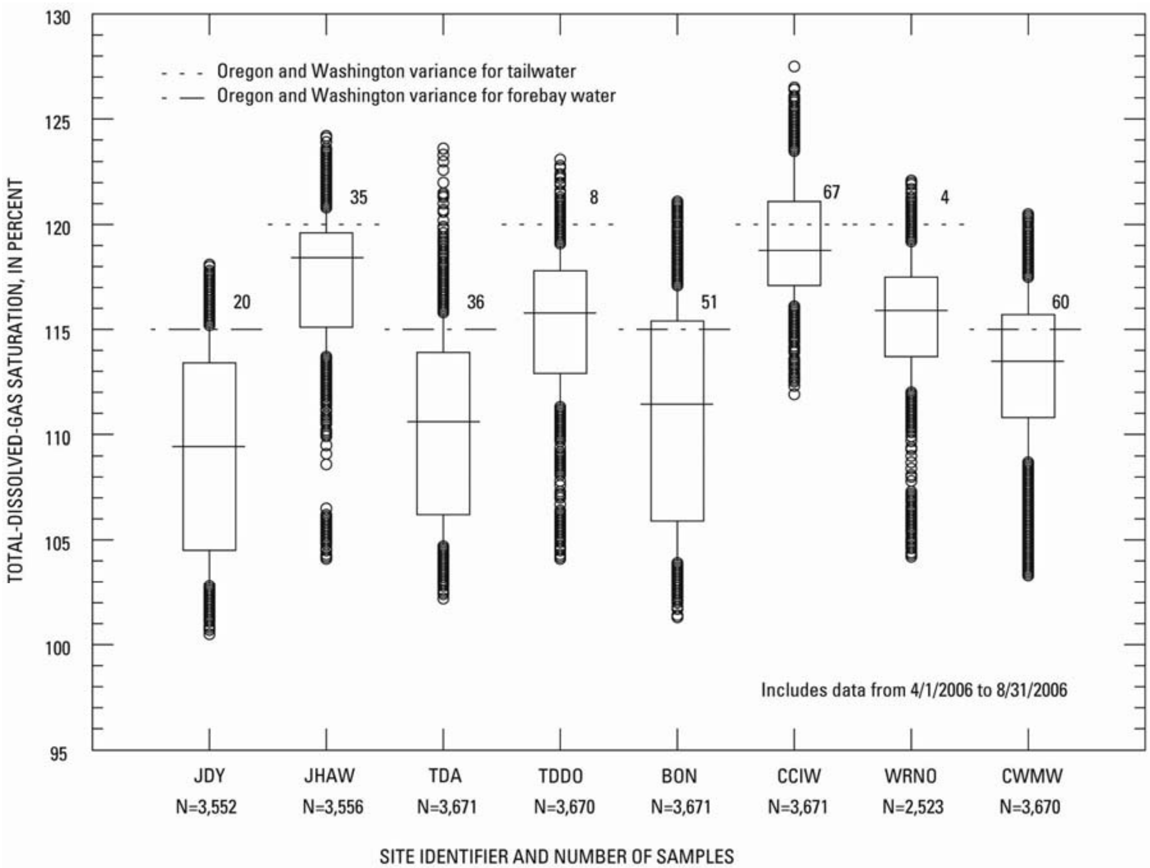

Figure 14. Distributions of hourly total-dissolved-gas data and exceedances of Oregon and Washington water-quality variances, April 1, 2006, to August 31, 2006. (See figure 2 for an explanation of the box and whisker diagrams.)

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://arcweb.sos.state.or.us/rules/OARs_300/OAR_340/340_041.html*, accessed December 30, 2006). 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 15, 2006).

Water temperatures upstream and downstream from John Day Dam (fig. 15), The Dalles Dam (fig. 16), Bonneville Dam (fig. 17), and at Camas (fig. 18) were equal to or larger than 20.0°C continuously from early July until the end of August. Water temperatures at the forebay stations were approximately equal to the temperatures at the tailwater stations, indicating well-mixed conditions in the forebays. At the Camas station, (fig. 18), there was a distinct daily temperature cycle, with an amplitude of about 1°C, the minimum occurring at about 09:00 hours and the maximum at about 19:00 hours.

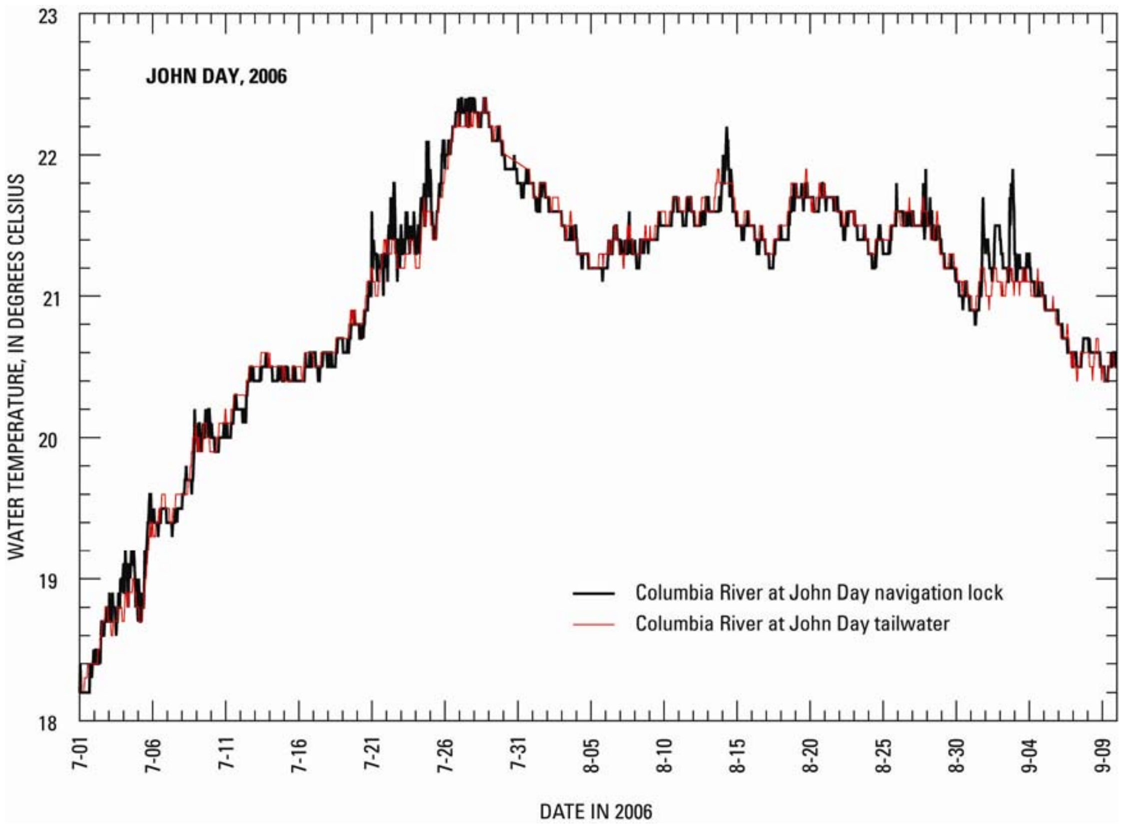

Figure 15. Water temperature upstream and downstream from John Day Dam, summer 2006

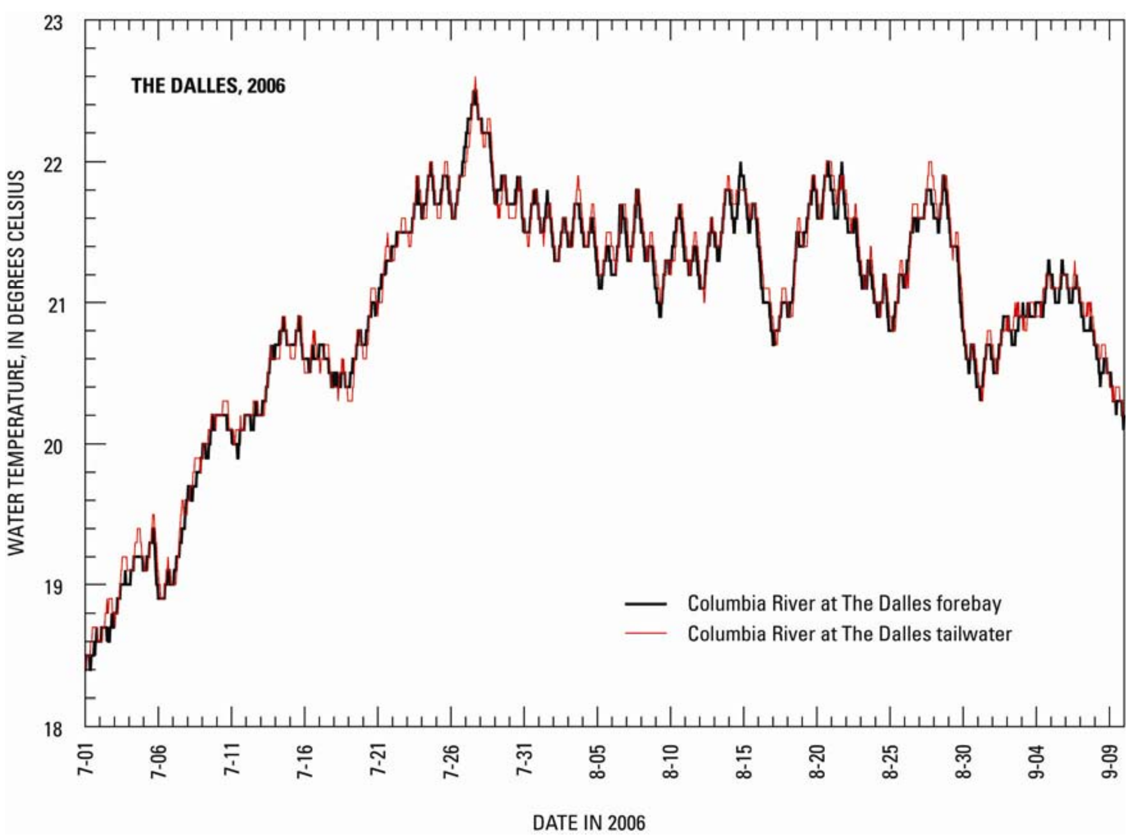

Figure 16. Water temperature upstream and downstream from The Dalles Dam, summer 2006

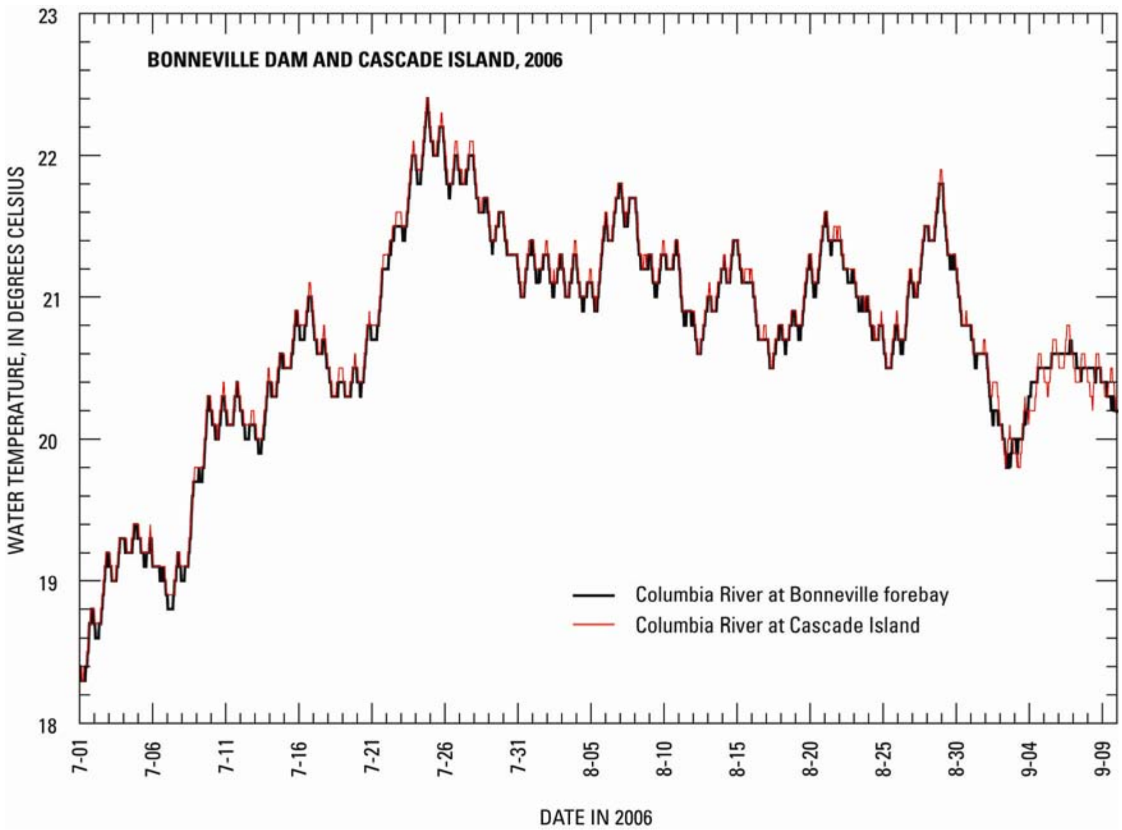

Figure 17. Water temperature upstream and downstream from Bonneville Dam, summer 2006

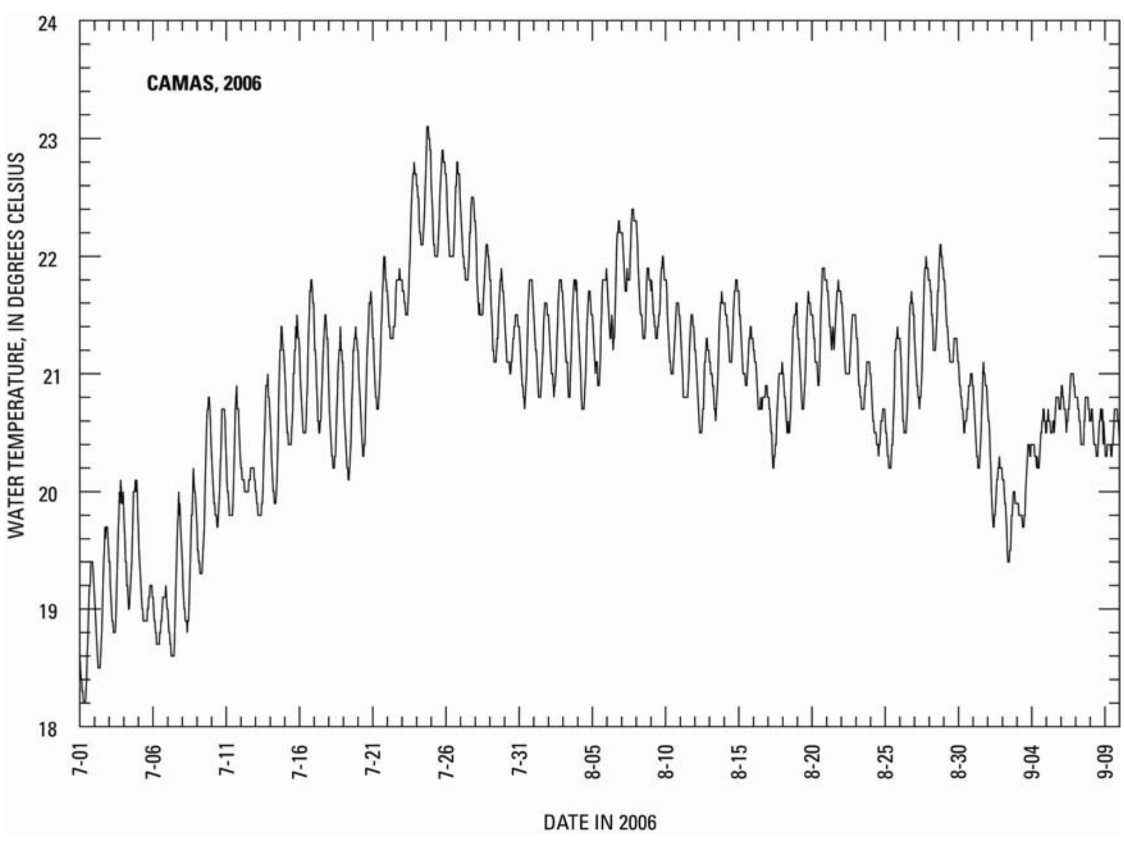

Figure 18. Water temperature at Camas, summer 2006

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