Total Dissolved Gas and Water Temperature in the Lower Columbia River, Oregon and Washington, Water Year 2011: Quality-Assurance Data and Comparison to Water-Quality Standards

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

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

Open-File Report 2011–1300

U.S. Department of the Interior
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Cover: Total-dissolved-gas monitoring station at Warrendale, lower Columbia River. The dock was tipped by a broken support as the river receded after high summer streamflows. The data-transmitting antenna was not aimed directly overhead at the communication satellite, so real-time data were not available for parts of several days. Data were later recovered from the data logger. (Photograph by Heather Bragg, USGS, September 14, 2011.)

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KEN SALAZAR, Secretary

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Conversion Factors

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
mile (mi)	1.609	kilometer (km)
millimeter (mm)	0.03937	inch (in.)
square mile (mi^2)	2.590	square kilometer (km^2)

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

Datum

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Abbreviations and Acronyms

BON	Bonneville forebay
CCIW	Cascade Island
CWMW	Camas
DCP	Data-collection platform
GOES	Geostationary Operational Environmental Satellite
JDY	John Day navigation lock
JHAW	John Day Dam tailwater
NIST	National Institute of Standards and Technology
RM	River mile
TDA	The Dalles forebay
TDDO	The Dalles tailwater
TDG	Total dissolved gas
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WRNO	Warrendale

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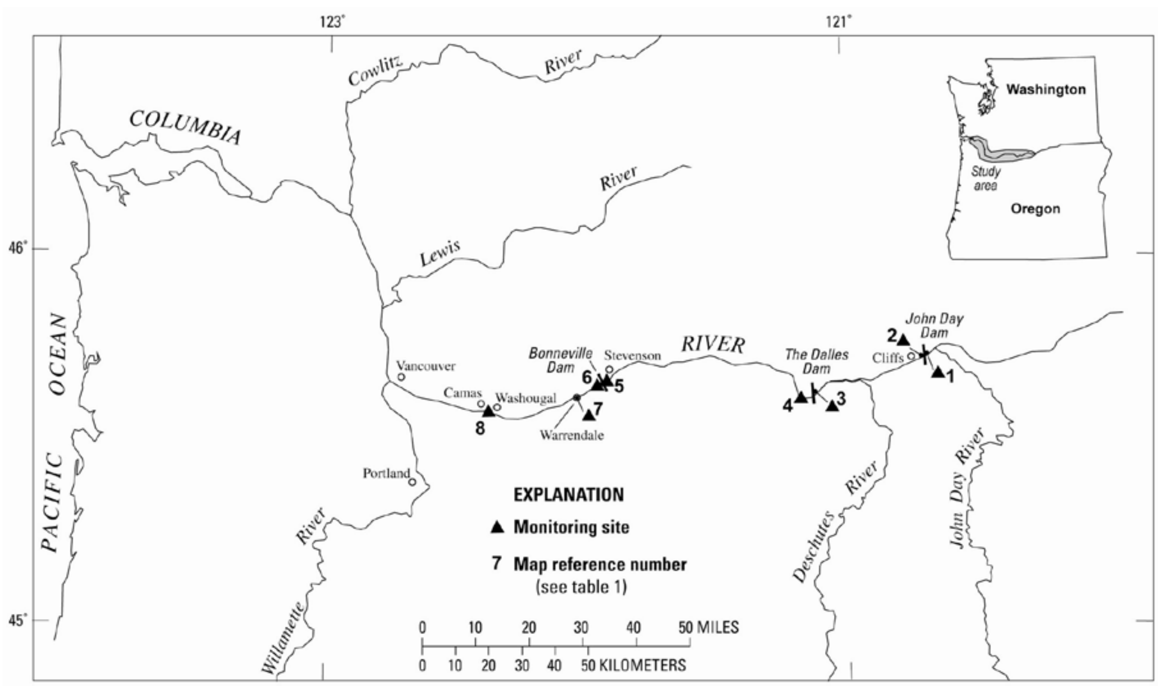
Significant Findings

Air is entrained in water as it is flows through the spillways of dams, which causes an increase in the concentration of total dissolved gas in the water downstream from the dams. The elevated concentrations of total dissolved gas can adversely affect fish and other freshwater aquatic life. An analysis of total-dissolved-gas and water-temperature data collected at eight monitoring stations on the lower Columbia River in Oregon and Washington in 2011 indicated the following:

- During the spill season of April–August 2011, hourly values of total dissolved gas (TDG) were larger than 115-percent saturation for the forebay (John Day navigation lock, The Dalles forebay, and Bonneville forebay) and Camas stations. Hourly values of total dissolved gas were larger than 120-percent saturation for the tailwater stations (John Day Dam tailwater, The Dalles tailwater, Cascade Island, and Warrendale).
- During parts of August and September 2011, hourly water temperatures were greater than 20°C (degrees Celsius) at the eight stations on the lower Columbia River. According to the State of Oregon water-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 as a result of human activities.
- Of the 79 laboratory TDG checks that were performed on instruments after field deployment, all were within ± 0.5-percent saturation and only 2 checks were out of calibration by more than 2 mm of Hg.
- All but 4 of the 66 field checks of TDG sensors with a secondary standard were within ± 1.0-percent saturation after 3–4 weeks of deployment in the river. All 67 of the field checks of barometric pressure were within ±1 millimeter of mercury of a primary standard, and all 66 water-temperature field checks were within ±0.2°C of a secondary standard.
- For the eight monitoring stations in water year 2011, a total of 93.5 percent of the TDG data were received in real time and were within 1-percent 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 sites. Data received from the Cascade Island site were only 34.9% complete because the equipment was destroyed by high water. The other stations ranged from 99.6 to 100 percent complete.

Introduction

The U.S. Army Corps of Engineers (USACE) operates several dams in the lower Columbia River Basin in Oregon and Washington (fig. 1), which encompasses 259,000 mi^2 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, which results in an increase in the concentration of dissolved gases in the water (referred to here as "total dissolved gas," or TDG) downstream of the spillways. Concentrations of TDG greater than 110-percent saturation can cause gas-bubble trauma in fish and adversely affect other aquatic organisms (U.S. Environmental Protection Agency, 1986).



Basemap modified from USGS and other digital data, various scales. Projection unknown.

Figure 1. Location of U.S. Army Corp of Engineers dams and total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2011.

The USACE regulates spills from its dams and streamflow on the lower Columbia River to minimize the production of excess TDG downstream from the dams, with the additional goal of providing for fish passage through the spillways (rather than through the turbines). The States of Oregon and Washington issue variances to the TDG water-quality standards during the spring and summer when the fish are migrating downstream. To monitor compliance with these variances, the USACE oversees the collection of real-time TDG and water-temperature data upstream and downstream of Columbia River Basin dams in a network of monitoring stations.

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 ensure their survival in the lower Columbia River. The U.S. Geological Survey (USGS), in cooperation with the Portland District of the USACE, has collected TDG and related data in the lower Columbia River each year since 1996. Those data are available online within an hour of collection time, and the current and historical TDG and water-temperature data can be accessed at http://oregon.usgs.gov/projs_dir/pn307.tdg/ (accessed November 8, 2011). Twelve reports, published for water years 1996 and 2000–2010, contain TDG data, quality-assurance data, and descriptions of the methods of data collection (Tanner and others, 1996; Tanner and Bragg, 2001; Tanner and Johnston, 2001; and Tanner and others, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2011).

To assure the accuracy and integrity of the data needed for managing and modeling TDG in the lower Columbia River, hourly values for 2011 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 the data did not meet a ± 1-percent criterion during quality control checks. The hourly values were stored in a USGS database and in a USACE database (U.S. Army Corps of Engineers, 2011). The USACE database also includes hourly water temperature, river discharge, and spill data.

Purpose and Scope

This report describes the TDG data and related quality-assurance data from eight monitoring stations on the lower Columbia River, 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 2011 (October 1, 2010–September 30, 2011) include hourly measurements of TDG pressure, barometric pressure, water temperature, and probe depth. Five of the stations (John Day Dam navigation lock, The Dalles Dam forebay, Bonneville Dam forebay, Cascade Island, and Camas) were operated from March through mid-September 2011, the period that includes the usual time of spill from the dams. The stations John Day Dam tailwater, The Dalles Dam tailwater, and Warrendale were operated year-round.

Table 1. Total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2011

[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; latitude and longitude are referenced to the North American Datum of 1927; River mile is distance from the mouth of the Columbia River.]

Map reference number	USACE station identifier	River mile	USGS station number	USGS station name (and abbreviated station name)	Latitude	Longitude	Period of record in water year 2011
1	JDY	215.7	454314120413701	Columbia River at John Day navigation lock, Washington (John Day navigation lock)	45° 43’ 14”	120° 41’ 37”	03/29/11–09/13/11
2	JHAW	214.7	454249120423500	Columbia River, right bank, near Cliffs, Washington (John Day tailwater)	45° 42’ 49”	120° 42’ 35”	Year-round
3	TDA	192.6	453712121071200	Columbia River at The Dalles Dam forebay, Washington (The Dalles forebay)	45° 37’ 12”	121° 07’ 12”	03/29/11–09/14/11
4	TDDO	188.9	14105700	Columbia River at The Dalles, Oregon (The Dalles tailwater)	45° 36’ 27”	121° 10’ 20”	Year-round
5	BON	146.1	453845121562000	Columbia River at Bonneville Dam forebay, Washington (Bonneville forebay)	45° 38’ 45”	121° 56’ 20”	03/28/11–09/14/11
6	CCIW	145.9	453845121564001	Columbia River at Cascade Island, Washington (Cascade Island)	45° 38’ 45”	121° 56’ 40”	03/11/11–09/20/11
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”	03/07/11–09/14/11

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 monitoring 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 or a 120-volt alternating-current line. 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 and USGS databases.

The eight fixed-station monitors were calibrated every 3 weeks, except from October 2010 through March 2011, when they were calibrated at 4-week intervals. At the beginning of the monitoring season in March, a new TDG membrane was installed on each Hydrolab. 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 the field-deployed 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 or 4 weeks). The field Hydrolab was then replaced with another Hydrolab that had been calibrated recently at the laboratory. The secondary standard was used again to check TDG and temperature measured by the newly deployed Hydrolab in the river. The equilibration process for the newly placed Hydrolab usually lasted about 1 hour. The electronic barometer at the fixed station was calibrated using a portable barometer (NovaLynx 230-M202) that had been calibrated to NIST standards.

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

Each Hydrolab that was removed from the field after 3 or 4 weeks of deployment was then calibrated in the laboratory. The integrity of the TDG membrane was checked, and then the membrane was removed and air-dried. The TDG sensor (without the membrane attached) was calibrated at 0, 100, 200, and 300 mm Hg (millimeters of mercury) above atmospheric pressure to span the expected range of TDG in the river (approximately 100-, 113-, 126-, and 139-percent saturation, respectively).

Completeness and Quality of Data for Total Dissolved Gas

A summary of the completeness and quality of the TDG data for water year 2011 is shown in table 2. Data in table 2 were based on the total amount of hourly TDG pressure data that could have been collected during the monitoring season. The fourth column in table 2 shows the percentages of data that were received in real time and passed quality-assurance checks. TDG saturation values were considered to meet quality-assurance standards if they were within ± (plus or minus) 1-percent 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. Sites showing only 1 hour of missing data indicate that data were deleted because the replacement Hydrolab did not equilibrate quickly.

Table 2. Completeness and quality of total-dissolved gas data, lower Columbia River, Oregon and Washington, water year 2011

[TDG, total dissolved gas]

Abbreviated station name	Planned monitoring (hours)	Number of missing or deleted hourly values	Percentage of real-time TDG data passing quality assurance criteria
John Day navigation lock (JDY)	4,029	0	100%
John Day tailwater (JHAW)	8,760	29	99.7%
The Dalles forebay (TDA)	4,051	14	99.7%
The Dalles tailwater (TDDO)	8,760	1	100%
Bonneville forebay (BON)	4,077	0	100%
Cascade Island (CCIW)	4,626	3,013	34.9%
Warrendale (WRNO)	8,760	37	99.6%
Camas (CWMW)	4,586	1	100%
TOTAL	**47,649**	**3,095**	**93.5%**

Periods during which major portions of TDG data are either missing from the database (for example, when data-collection instruments failed) or for which data were later deleted from the database because they did not meet quality-assurance standards, are listed in table 3.

Table 3. Periods of missing real-time Total Dissolved Gas data, lower Columbia River, Oregon and Washington, water year 2011

[USACE station identifier: JHAW, John Day tailwater; TDA, The Dalles forebay; CCIW, Cascade Island; WRNO, Warrendale.]

Date and Time	USACE station identifier	Reason / Notes
9/28–9/29/11	JHAW	The Hydrolab was accidentally disconnected during a site visit; data were not recovered.
6/23/11	TDA	The AC power supply failed, then the battery failed, and real-time transmissions were not made for several hours. Data were later recovered from the onsite data logger.
Beginning 5/18/11	CCIW	The site was destroyed by high water on May 18, 2011. No real-time data were collected after that date; however, a nontransmitting recording monitor was reinstalled for about 34 days in August–September.
11/26/10	WRNO	11 hours of real-time data were lost when an ice storm covered the transmitting antenna. The data were later recovered from the data logger.
9/4–9/5/11	WRNO	17 hours of real-time data were lost because the floating dock tipped so much that the antenna did not point directly at the satellite. The data were later recovered from the data logger.

The Cascade Island station had the most missing or deleted data. Extremely high discharge through the spillway inundated and destroyed the equipment at the site on May 18, 2011. Real-time TDG data were not collected after that date. However, a recording-only Hydrolab was placed in the same area on August 17, and TDG data were collected through September 20, 2011.

Quality-Assurance Data

The collection of accurate data for TDG, barometric pressure, and water temperature involves several quality-assurance procedures, including instrument comparisons in the field, sensor calibrations in the laboratory, daily checks of the data, and data review and archiving. These methods are explained in detail in Tanner and Johnston (2001). The results of the quality-assurance procedures for water year 2011 are presented in this section.

After field deployment for 3 or 4 weeks, the TDG instruments were calibrated in the laboratory. First, the sensor was tested, with the gas-permeable membrane in place, for response to supersaturated conditions. The membrane was then removed from the sensor and allowed to dry in a desiccator for approximately 24 hours. Before replacing the membrane, the TDG sensor was examined independently by comparing the reading of the TDG sensor to barometric pressure (100-percent saturation). Using a certified digital pressure gage (primary standard), comparisons also were made at pressures of 100, 200, and 300 mm Hg above barometric pressure (approximately 113-, 126-, and 139-percent saturation, respectively). The accuracy of the TDG sensors was calculated by computing the difference between the primary standard and the TDG sensor reading (expected minus actual) for each of the four test conditions, dividing that difference by the barometric pressure, and multiplying by 100. Of the 79 laboratory checks that were performed on instruments after field deployment, all were within 0.5-percent saturation and only 2 indicated a difference of more than 2 mm Hg compared to the primary standard and thus required recalibration of the sensor (fig. 2).

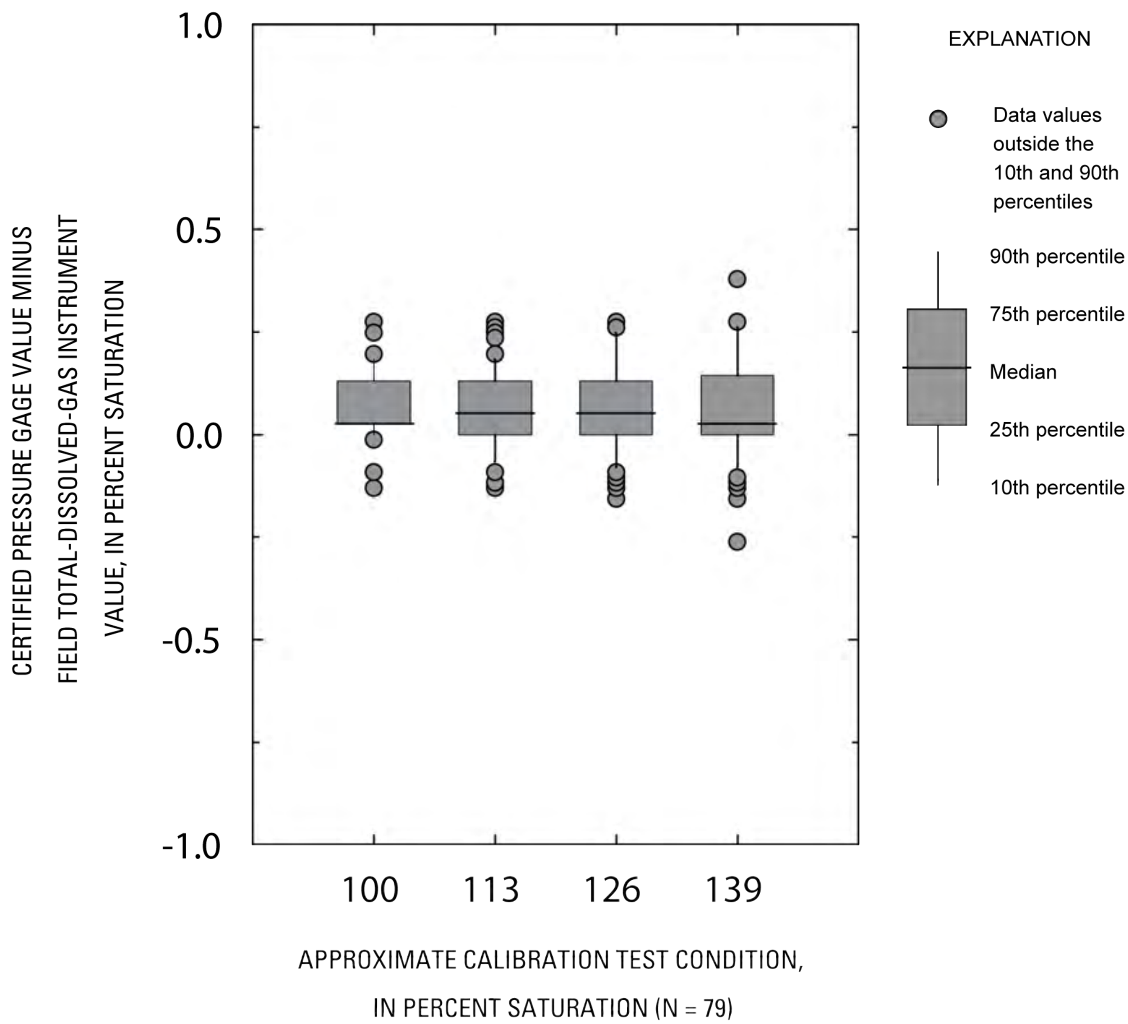


Figure 2. Boxplot showing accuracy of total-dissolved-gas sensors in the laboratory after 3 or 4 weeks of field deployment at eight monitoring stations in the lower Columbia River, Oregon and Washington, water year 2011 (number of comparison values = 79).

The differences in barometric pressure, onsite water temperature, and onsite TDG between the secondary standard instruments and the fixed-station monitors after field deployment were measured and recorded as part of every field inspection and calibration procedure. These differences, calculated as the secondary standard values minus the field instrument values, were used to compare and quantify the accuracy and precision between the two instruments. For water temperature and TDG, the measurements were made onsite with the secondary standard (a recently calibrated Hydrolab) positioned alongside the Hydrolab deployed in the river. A digital barometer, NIST certified through February 2012 served as the primary 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 stations.

Comparisons of the digital barometer and the field barometers are shown in figure 3. All field values were within 1 mm Hg of standard values. Secondary standard temperature sensor and the field temperature sensor results are presented in figure 4. All differences were within 0.2°C.

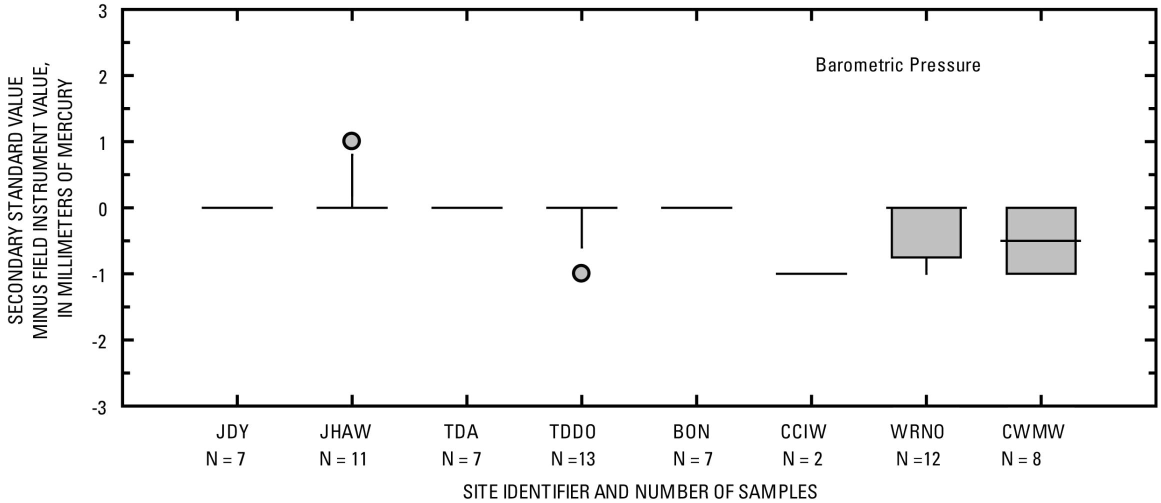


Figure 3. Boxplot showing difference between the secondary standard and the field barometers in the field after 3 or 4 weeks of field deployment at eight stations in the lower Columbia River, Oregon and Washington, water year 2011. See figure 2 for explanation of boxplots.

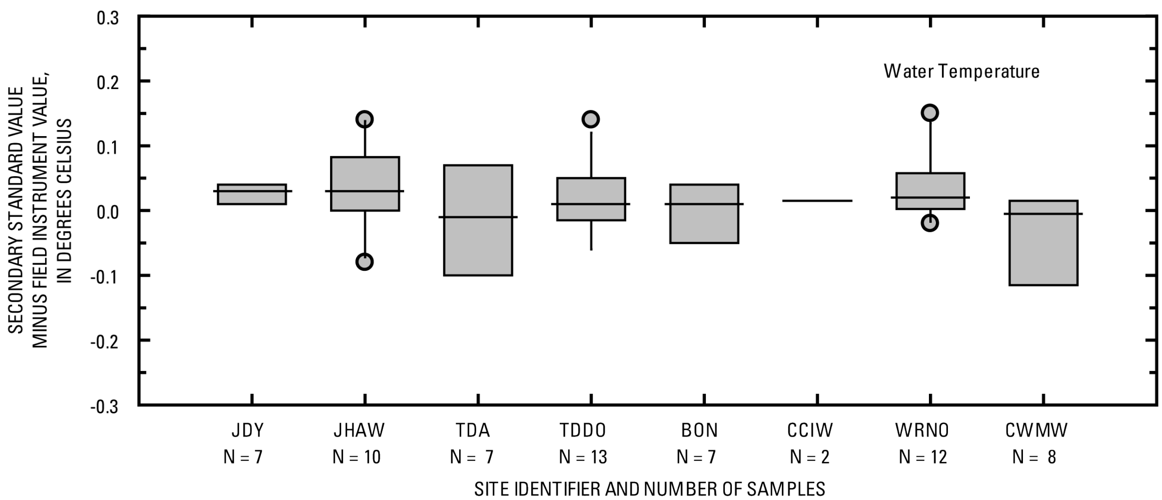


Figure 4. Boxplot showing difference between the secondary standard and the field temperature instruments in the field after 3 or 4 weeks of field deployment at eight stations in the lower Columbia River, Oregon and Washington, water year 2011. See figure 2 for explanation of boxplots.

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 (fig. 5). The side-by-side equilibrium was considered complete after a minimum of 20 minutes when the TDG values for each sensor remained constant for 4–5 minutes.

Four of the 66 field checks indicated saturation differences greater than 1.0 percent. Three of these differences (one at each of the three year-round monitoring stations) occurred in November or December, when lower temperatures and streamflow velocities resulted in slow equilibration of the sensors. The fourth instance occurred at the John Day tailwater station in August. The subsequent laboratory calibration of the field instrument did not indicate a need for recalibration. The saturation difference may have resulted from the difference in the two instruments' response time to changing flow or spill conditions.

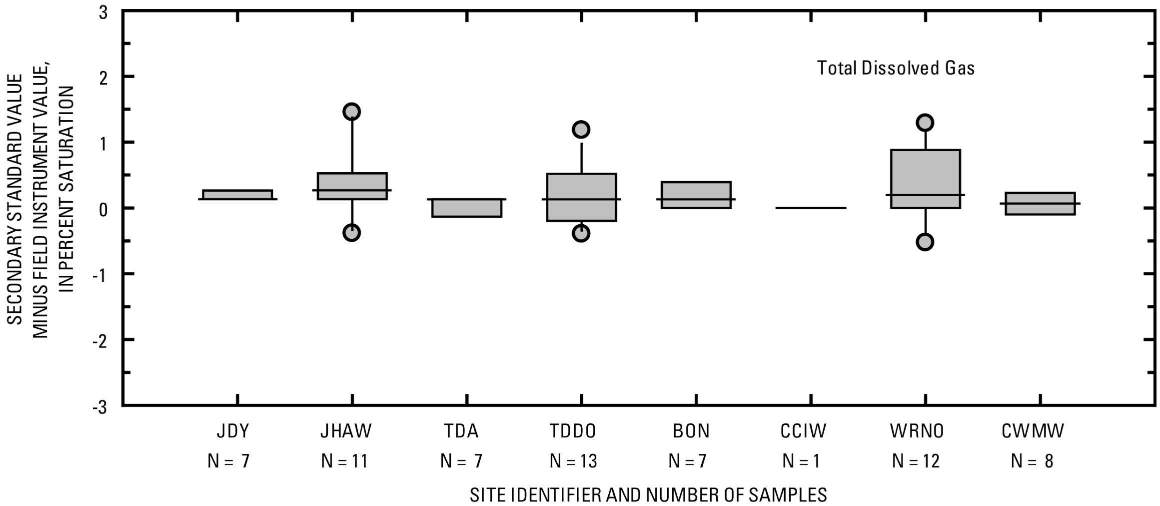


Figure 5. Boxplot showing difference between the secondary standard and the field total-dissolved-gas instruments in the field after 3 or 4 weeks of field deployment at eight stations in the lower Columbia River, Oregon and Washington, water year 2011. See figure 2 for explanation of boxplots.

Effects of Spill on Concentration of Total Dissolved Gas

The relations between spill rates and TDG at the dams and at the corresponding tailwater site or sites were fairly linear for John Day Dam (fig. 6), The Dalles Dam (fig. 7), and Bonneville Dam (figs. 8 and 9).

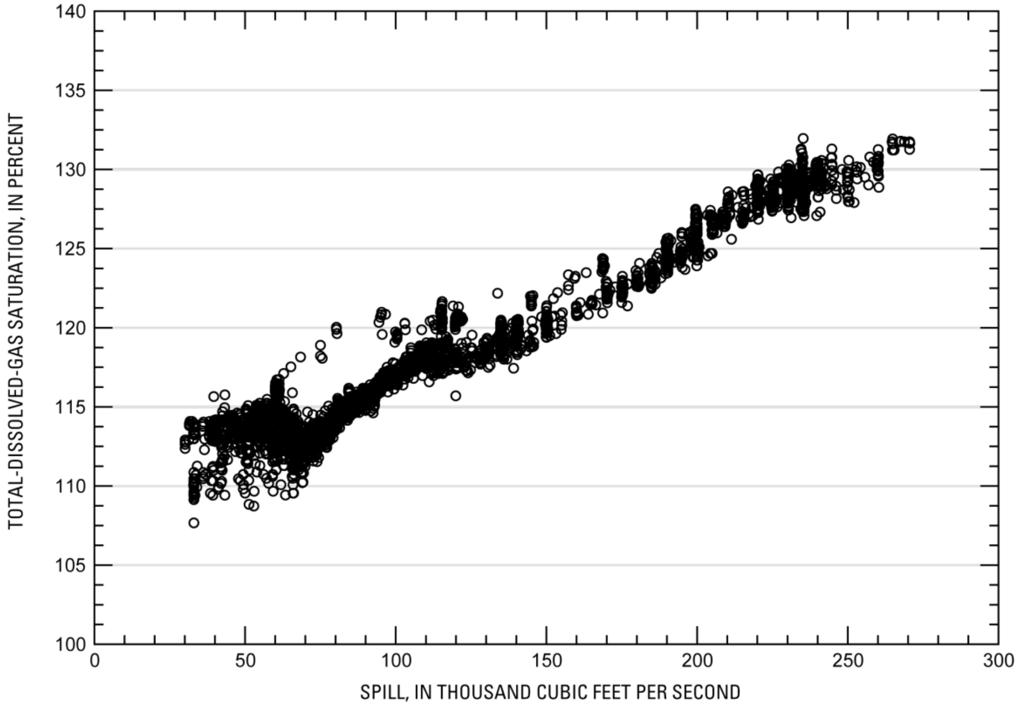


Figure 6. Graph showing relation of total-dissolved-gas saturation downstream of John Day Dam and spill from the John Day dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2011.

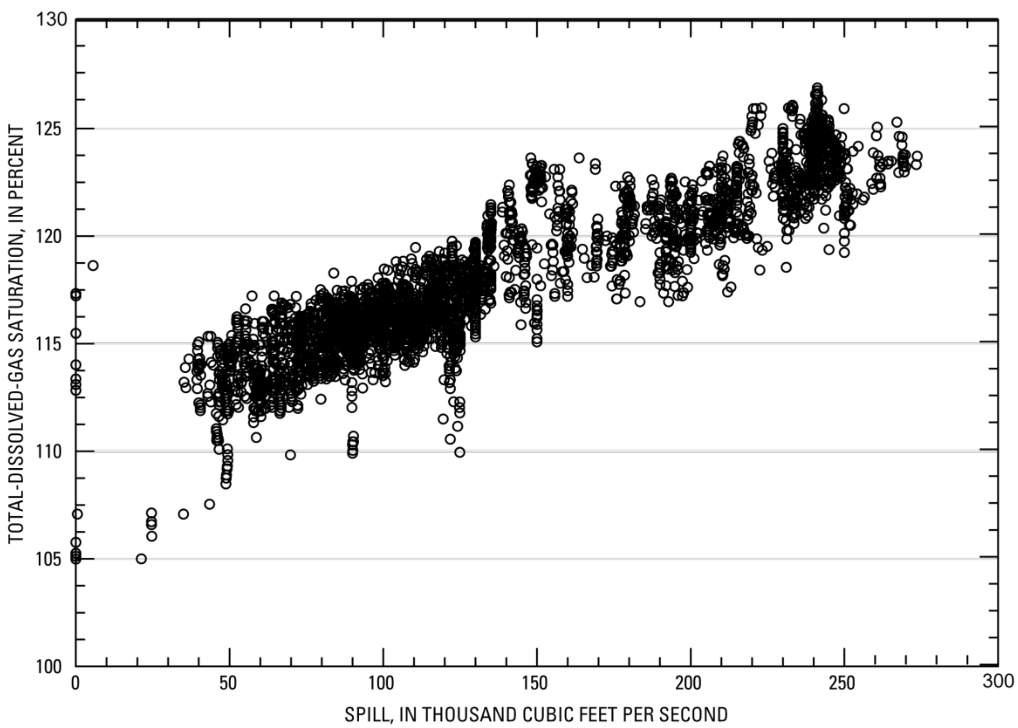


Figure 7. Graph showing relation of total-dissolved-gas saturation downstream of The Dalles Dam and spill from The Dalles Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2011.

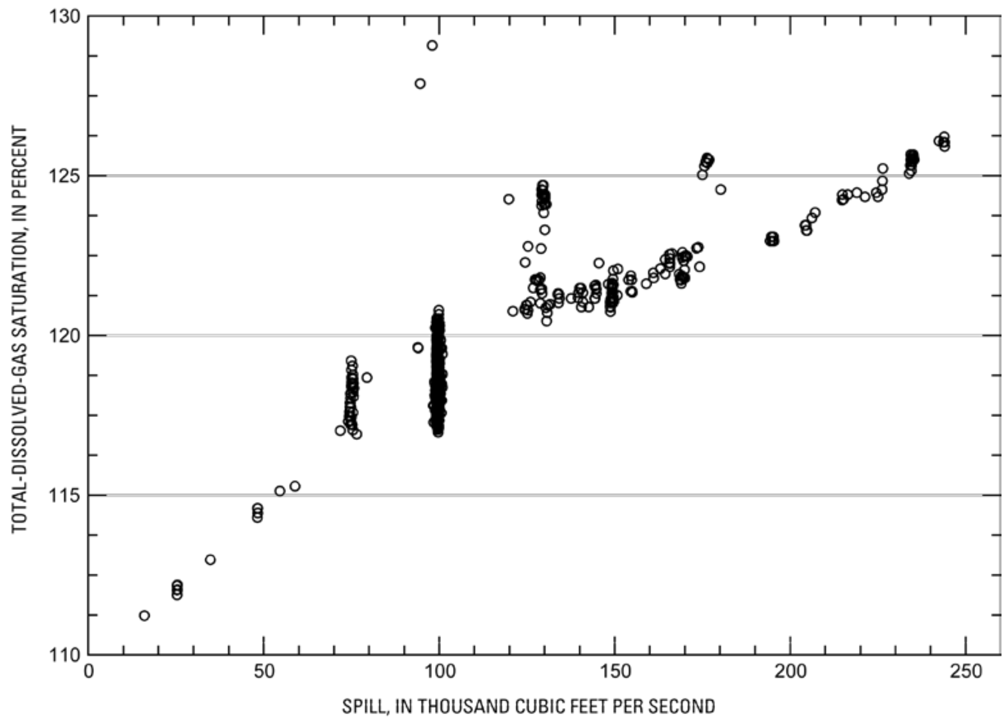


Figure 8. Graph showing relation of total-dissolved-gas saturation downstream of Bonneville Dam at Cascade Island and spill from Bonneville Dam, lower Columbia River, Oregon and Washington, April 1–May 18, 2011.

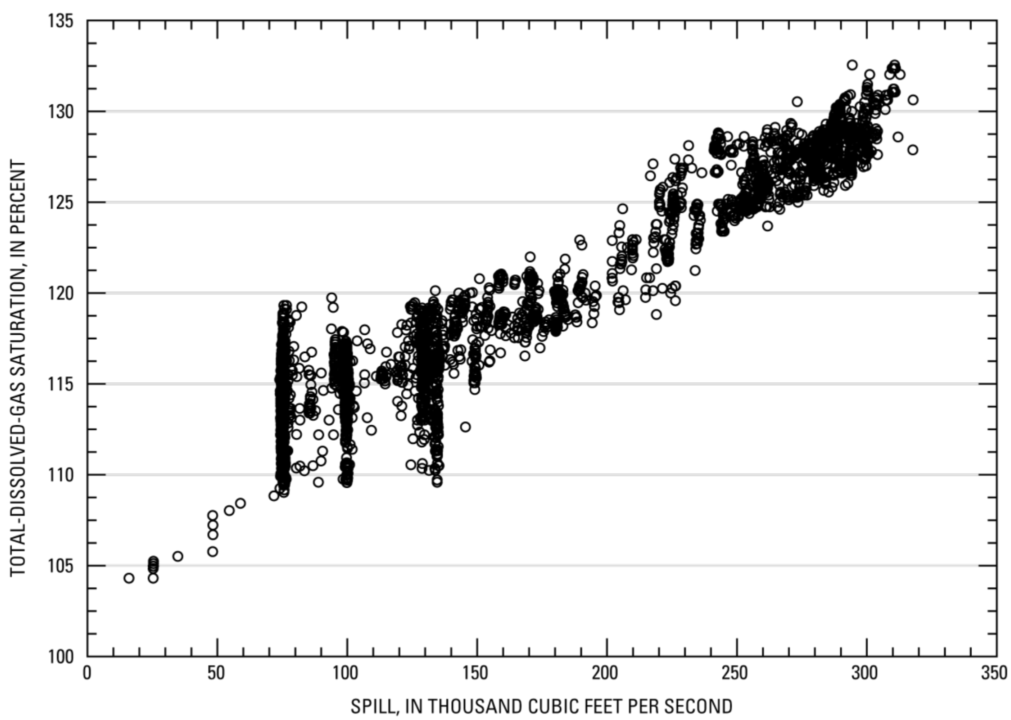


Figure 9. Graph showing relation of total-dissolved-gas saturation downstream of Bonneville Dam at Warrendale and spill from Bonneville Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2011.

Comparison of Total-Dissolved-Gas Concentration and Water Temperature to Water-Quality Standards

In 2011, variances or waivers were granted to the water-quality standard for TDG of 110-percent saturation. These variances were issued to allow spill for fish passage at dams on the Columbia River. The State of Oregon granted a 5-year variance for 2010–2014 (State of Oregon, 2009). The State of Washington provided for fish passage in its water-quality standards consistent with approved gas-abatement plans (State of Washington, 2006a). From April 1 to August 31, 2011, the USACE was granted variances allowing TDG to reach 115-percent saturation at the forebay stations (John Day Dam navigation lock, The Dalles Dam forebay, and Bonneville Dam forebay) and Camas; and 120-percent saturation at tailwater stations, directly downstream of dams (John Day Dam tailwater, The Dalles Dam tailwater, Cascade Island, and Warrendale). The 115- and 120-percent variances were exceeded if the average of the highest 12-hourly values in 1 day (1:00 a.m. to midnight) (Oregon variance), or the average of the12 highest consecutive hourly readings in any 24-hour period (Washington variance) were larger than the numerical variance. A separate variance of 125 percent was established for all stations for either the highest 2-hour average (State of Oregon, 2009), or the highest 1-hour average (State of Washington, 2006a).

The distributions of hourly TDG values for the spill season in 2011 (April 1–August 31, 2011) are shown in figure 10. The applicable variance is shown with the data for each station. The variances apply to an average value, whereas the distribution plots show the hourly values. Consequently, the points larger than the variance lines on the graph do not necessarily represent actual exceedances of the variances. At each site, the 75th percentile of the measurements (represented by the upper "shoulder" of the boxplot) was above or near the TDG variance.

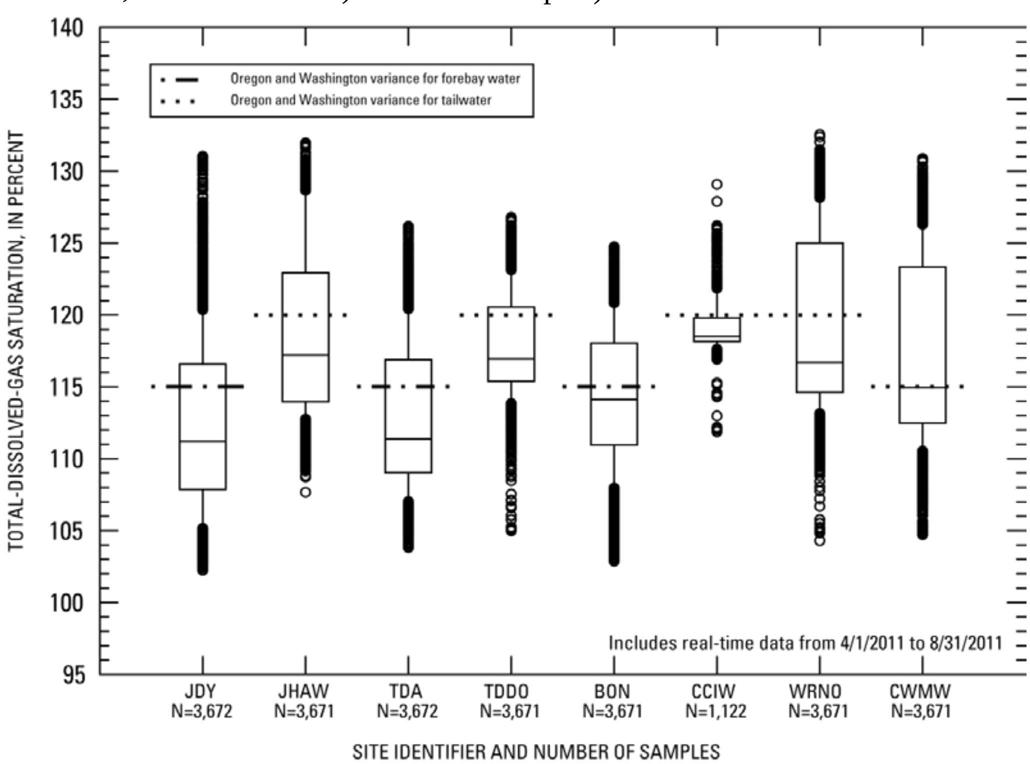


Figure 10. Boxplot showing distributions of hourly total-dissolved-gas data and Oregon and Washington water-quality variances, lower Columbia River, Oregon and Washington, April 1–August 31, 2011. See figure 2 for explanation of boxplots.

The timing of the occurrence of exceedances of TDG variances (high 12-hour daily average for comparison to the Oregon variance) and of spill at the closest upstream dam are shown in figures 11–18. For the calculations of the high 12-hour average, missing TDG data were ignored and the next adjacent data points were used to calculate whether an exceedance had occurred. For each site that has data available for May and June 2011, the TDG variances were exceeded for much of that period. (Data from the Cascade Island site were available only until May 18, 2011).

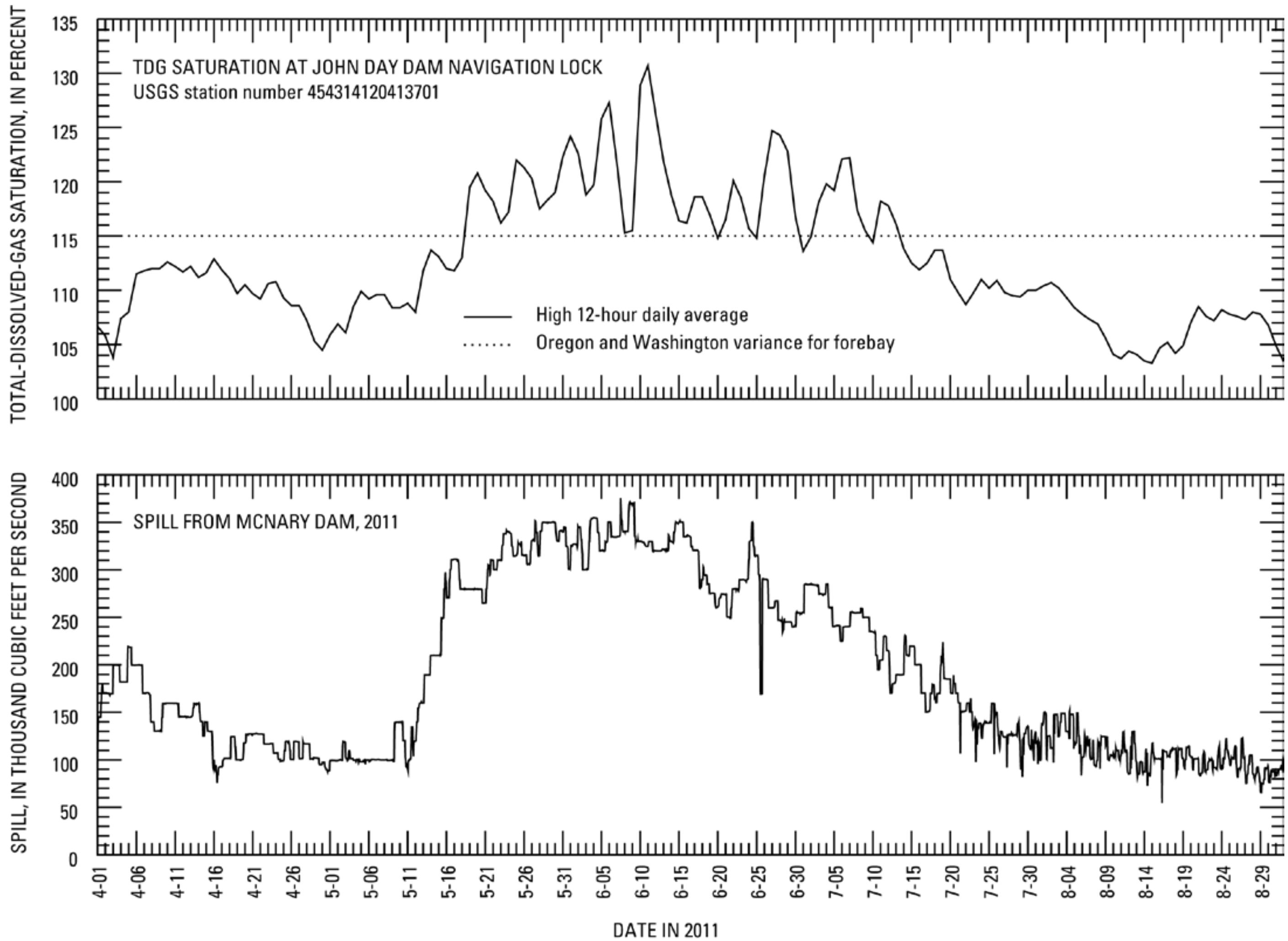


Figure 11. Graphs showing high 12-hour average of total-dissolved-gas saturation at John Day Dam navigation lock and spill from McNary Dam (76 river miles upstream from John Day Dam), lower Columbia River, Oregon and Washington, April 1–August 31, 2011.

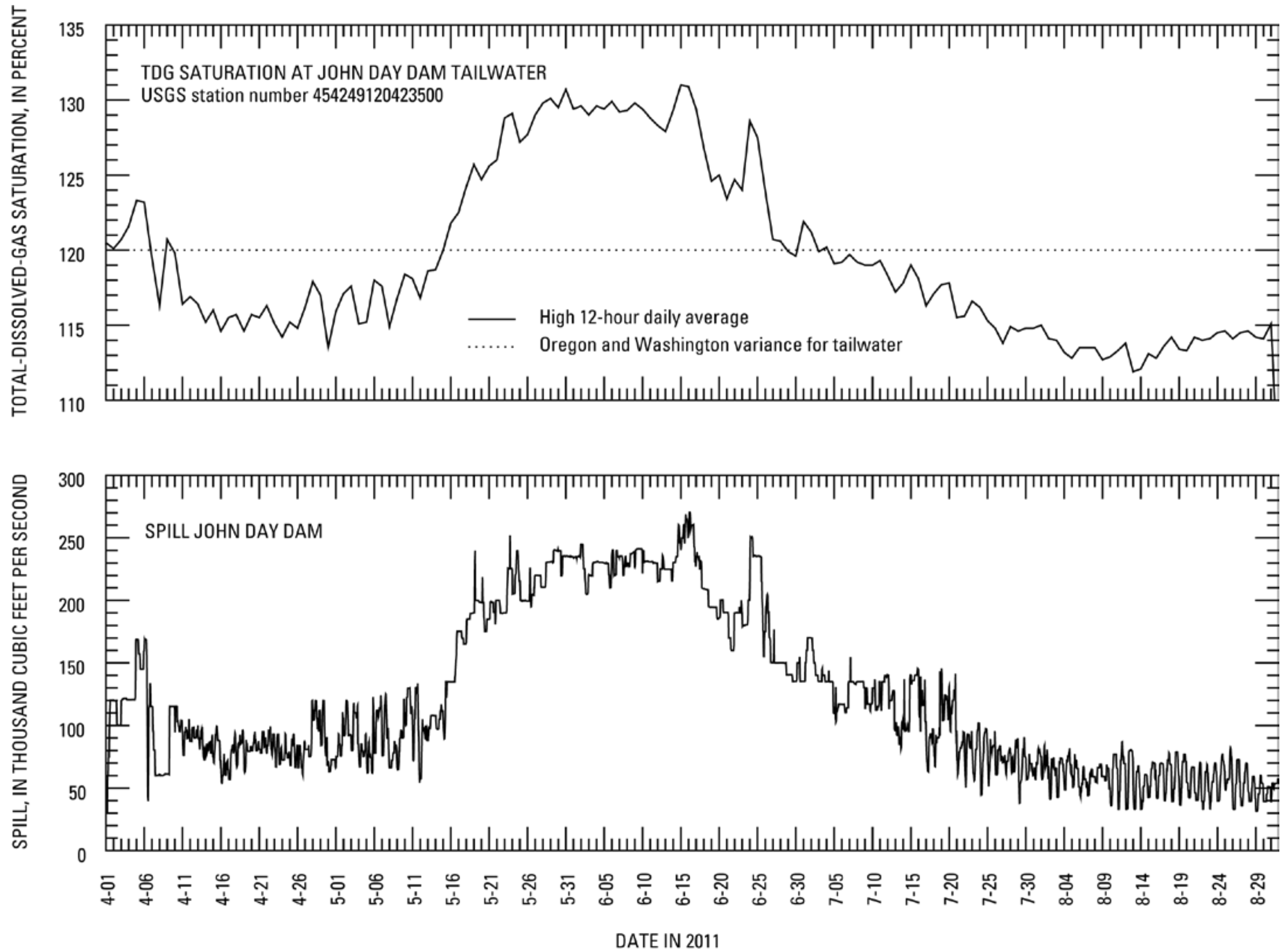


Figure 12. Graphs showing total-dissolved-gas saturation at John Day Dam tailwater and spill from John Day Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2011.

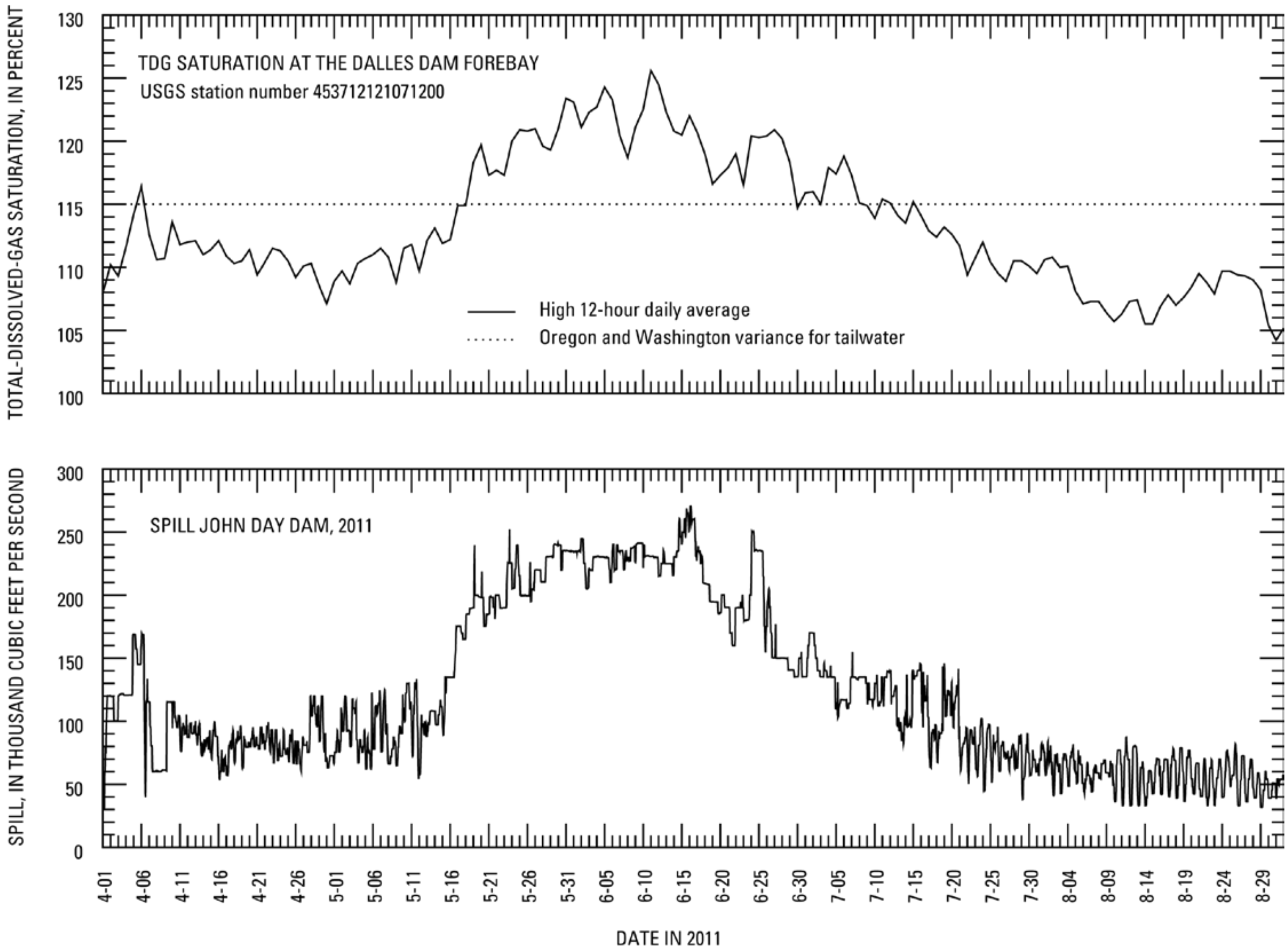


Figure 13. Graphs showing total-dissolved-gas saturation at The Dalles Dam forebay and spill from John Day Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2011.

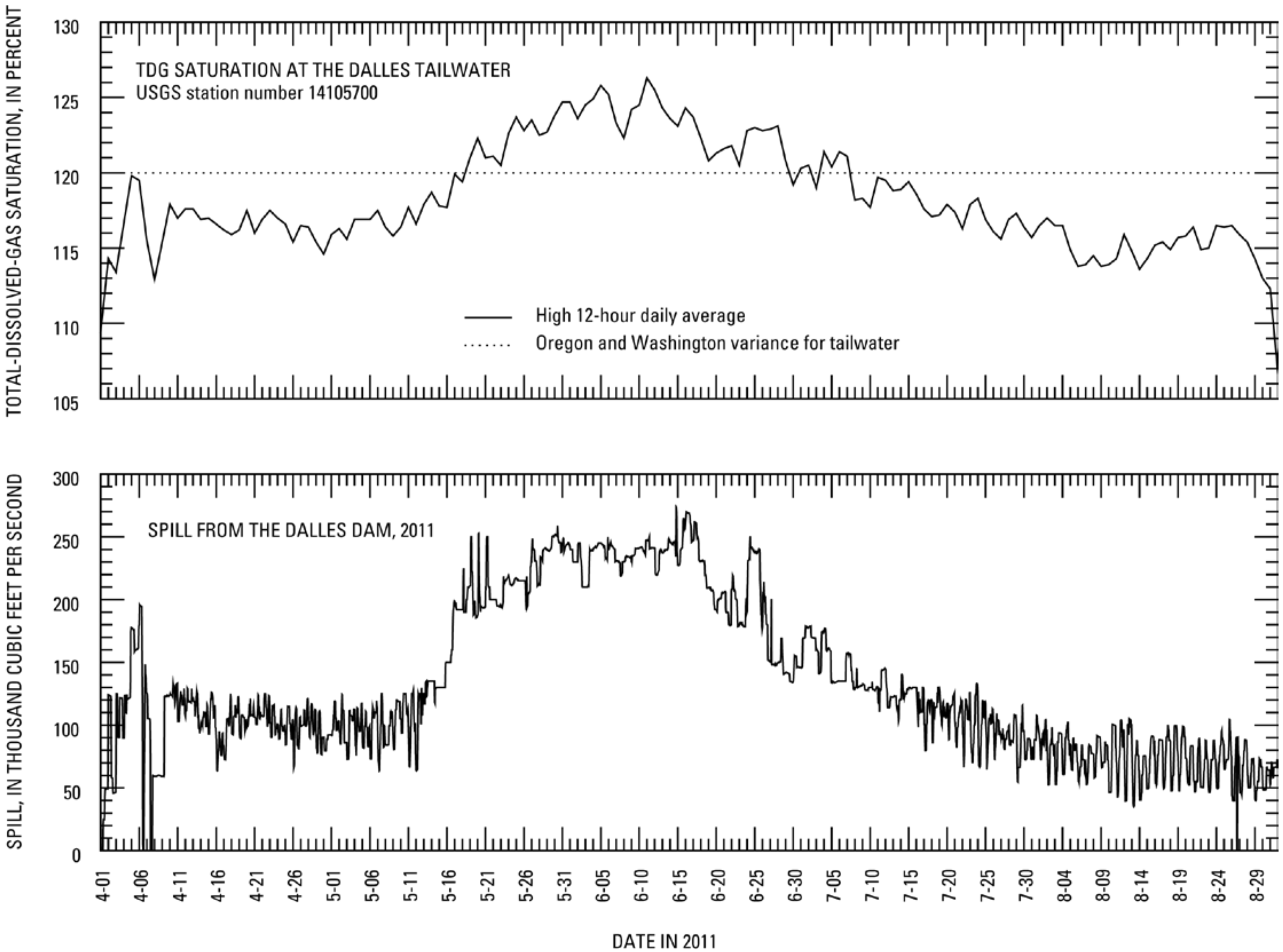


Figure 14. Graphs showing total-dissolved-gas saturation at The Dalles Dam tailwater and spill from The Dalles Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2011.

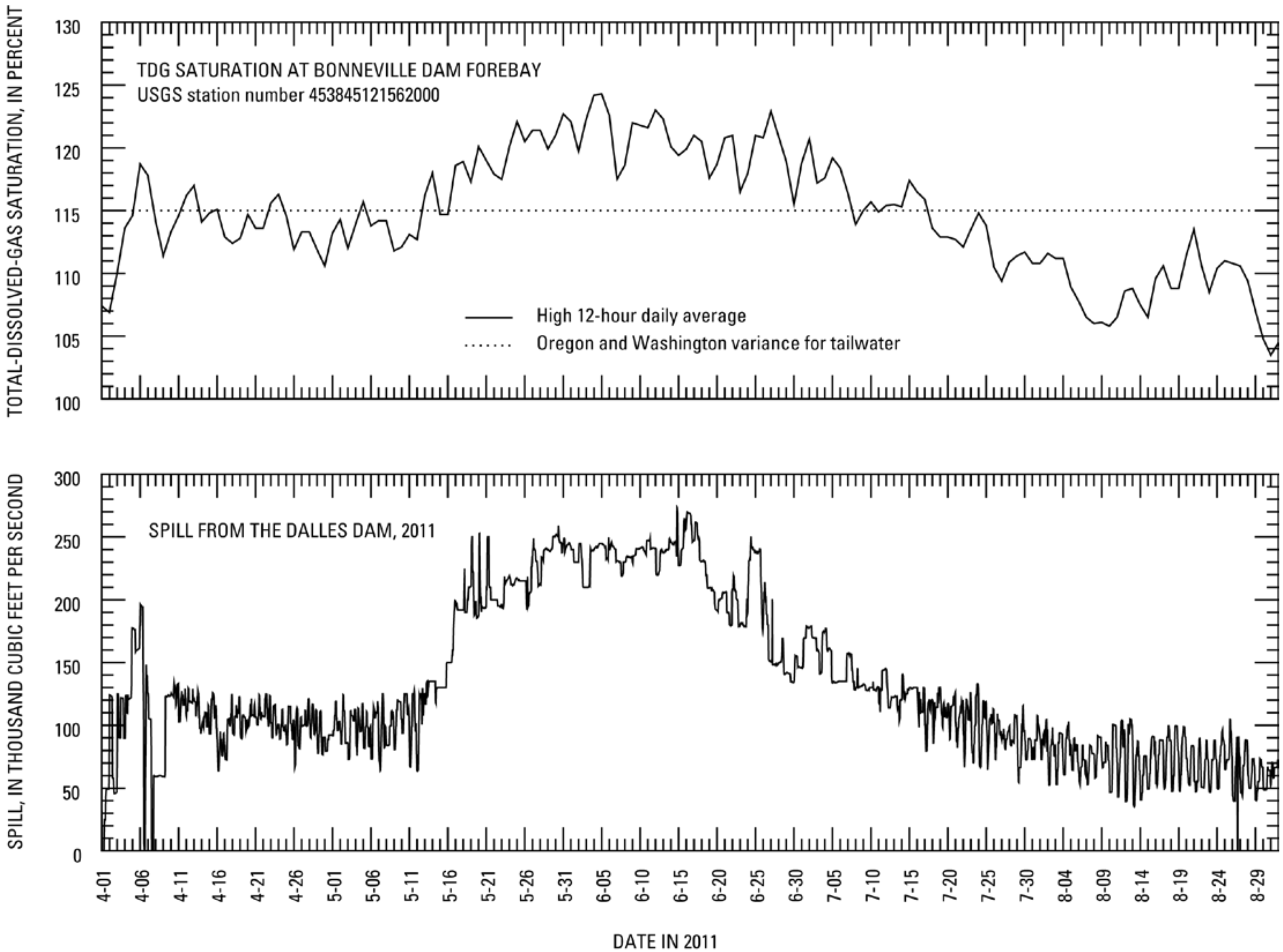


Figure 15. Graphs showing total-dissolved-gas saturation at Bonneville Dam forebay and spill from The Dalles Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2011

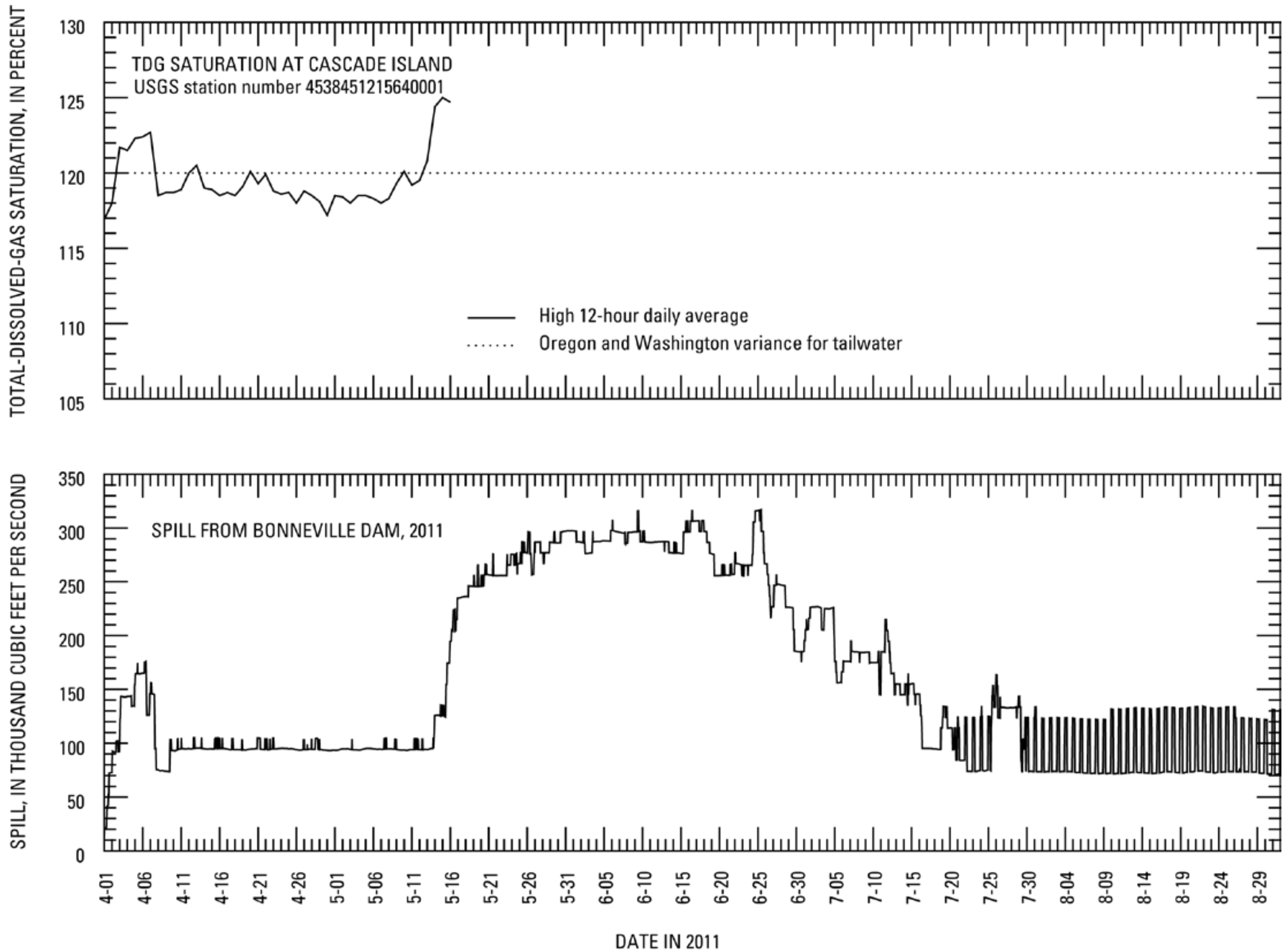


Figure 16. Graphs showing total-dissolved-gas saturation at Cascade Island and spill from Bonneville Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2011

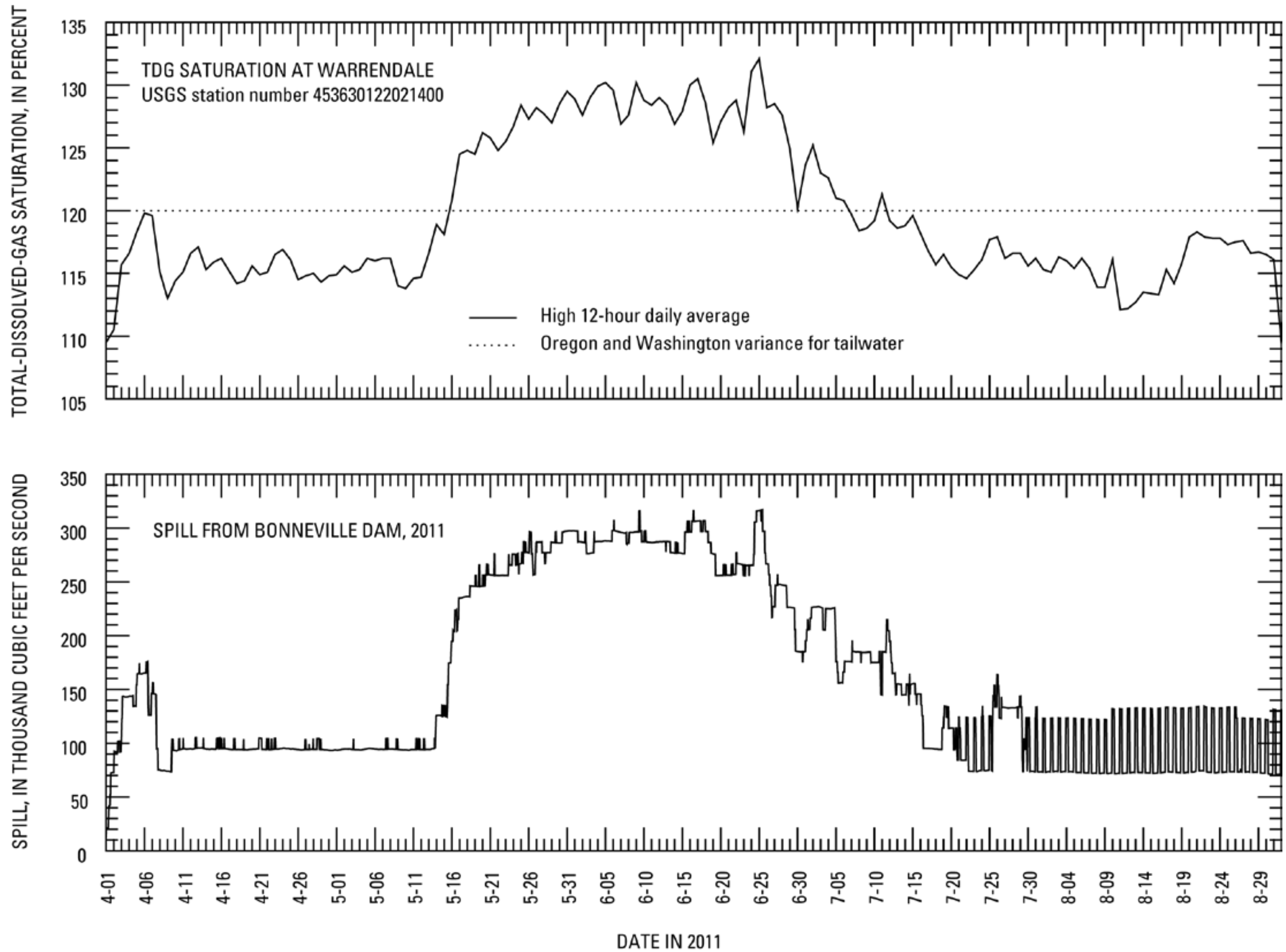


Figure 17. Graphs showing total-dissolved-gas saturation at Warrendale and spill from Bonneville Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2011

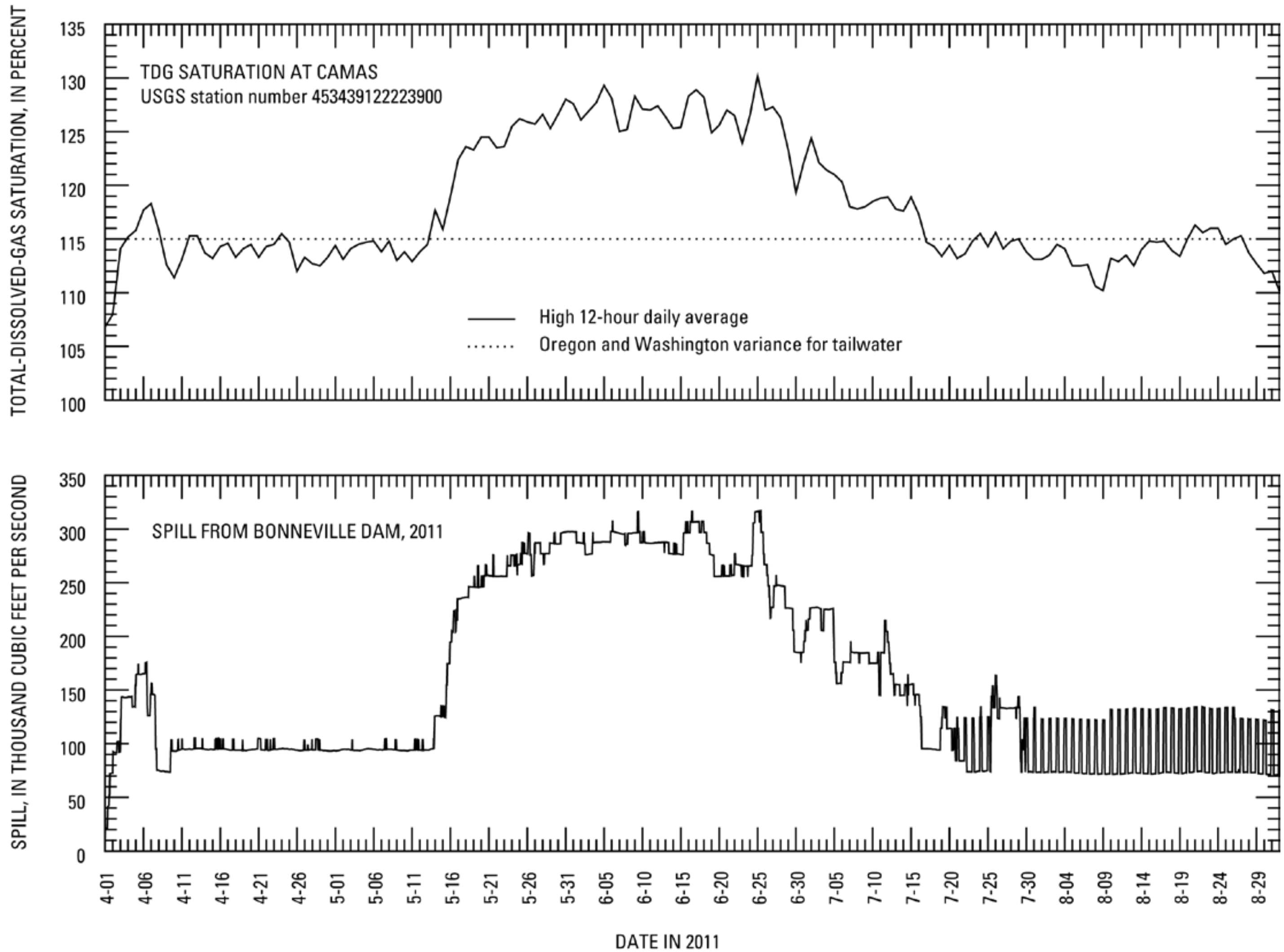


Figure 18. Graphs showing total-dissolved-gas saturation at Camas and spill from Bonneville Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2011

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 Oregon water-temperature standard, the 7-day-average maximum temperature of the lower Columbia River should not exceed 20°C (State of Oregon, 2008). Washington State regulations mandate that the water temperature in the Columbia River shall not exceed a 1-day maximum of 20.0°C due to human activities (State of Washington, 2006b).

This report deals only with the hourly values for water temperature. Water temperatures at all sites were greater than 20°C during parts of August and September. Water temperatures at the forebay stations were approximately equal to the temperatures at the tailwater stations (except during short time periods at the John Day Dam navigation lock), indicating that the sensors were placed in well-mixed waters in the forebays and tailwater sites.

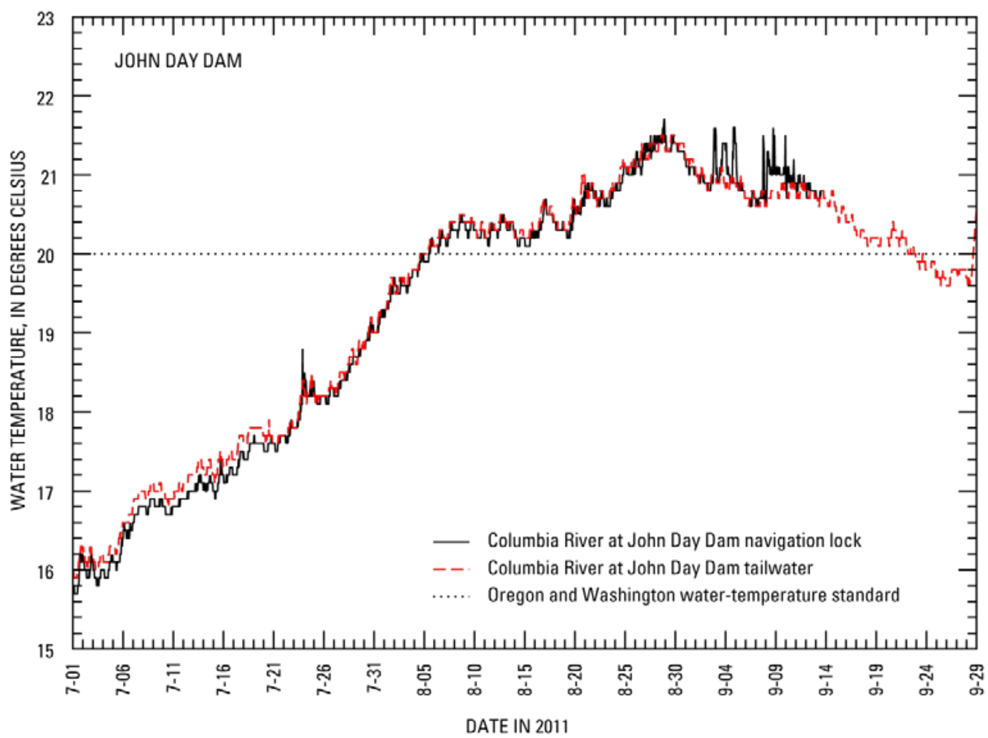


Figure 19. Graph showing water temperature upstream of John Day Dam and downstream of John Day Dam, lower Columbia River, Oregon and Washington, summer 2011.

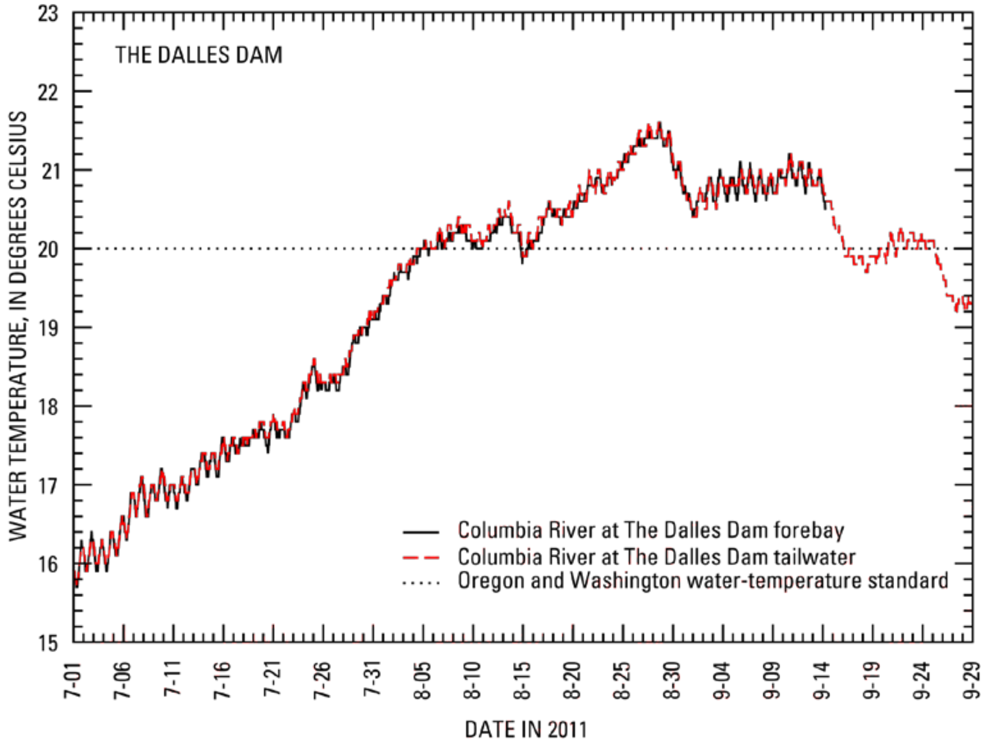


Figure 20. Graph showing water temperature upstream and downstream of The Dalles Dam, lower Columbia River, Oregon and Washington, summer 2011.

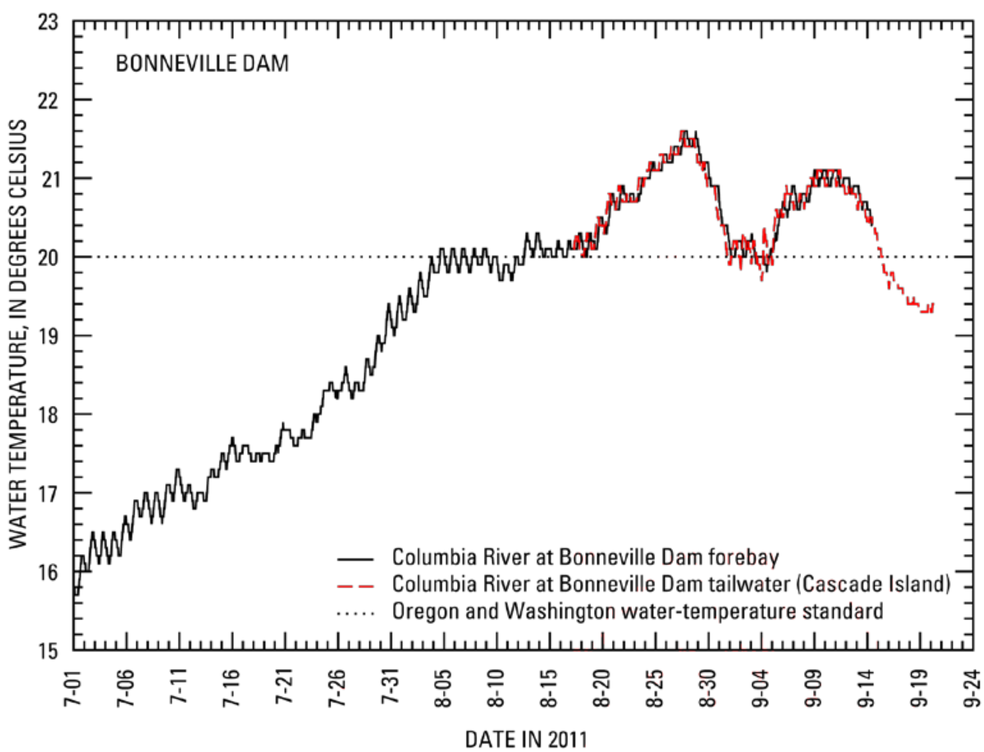


Figure 21. Graph showing water temperature upstream of Bonneville Dam and downstream of Bonneville Dam at Cascade Island, lower Columbia River, Oregon and Washington, summer 2011

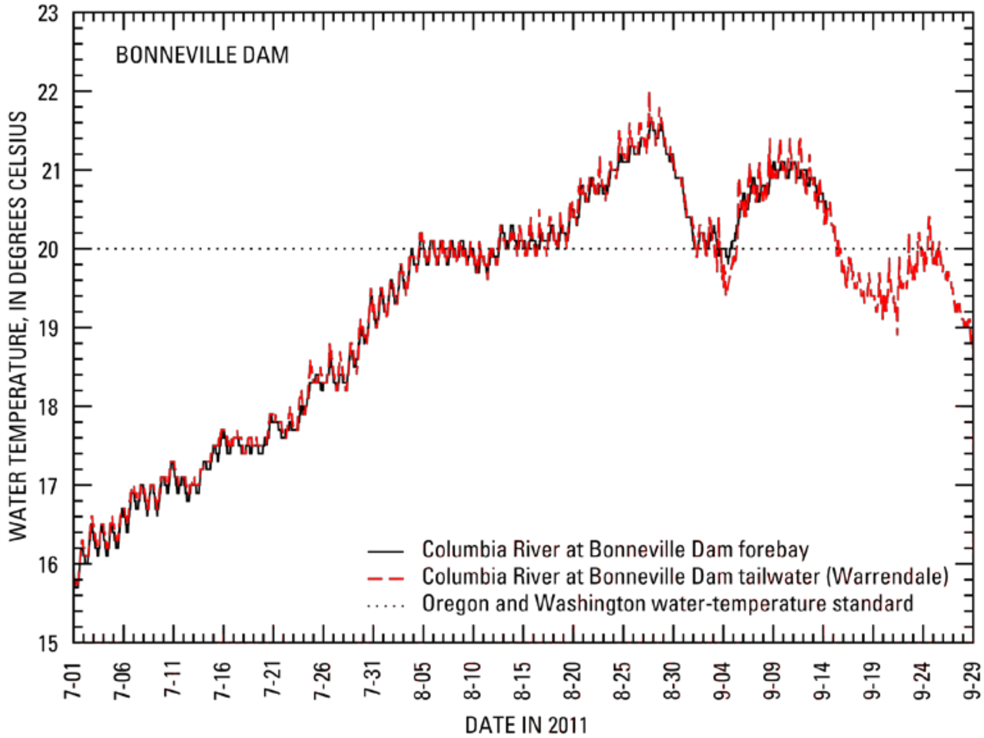


Figure 22. Graph showing water temperature upstream of Bonneville Dam and downstream of Bonneville Dam at Warrendale, lower Columbia River, Oregon and Washington, summer 2011.

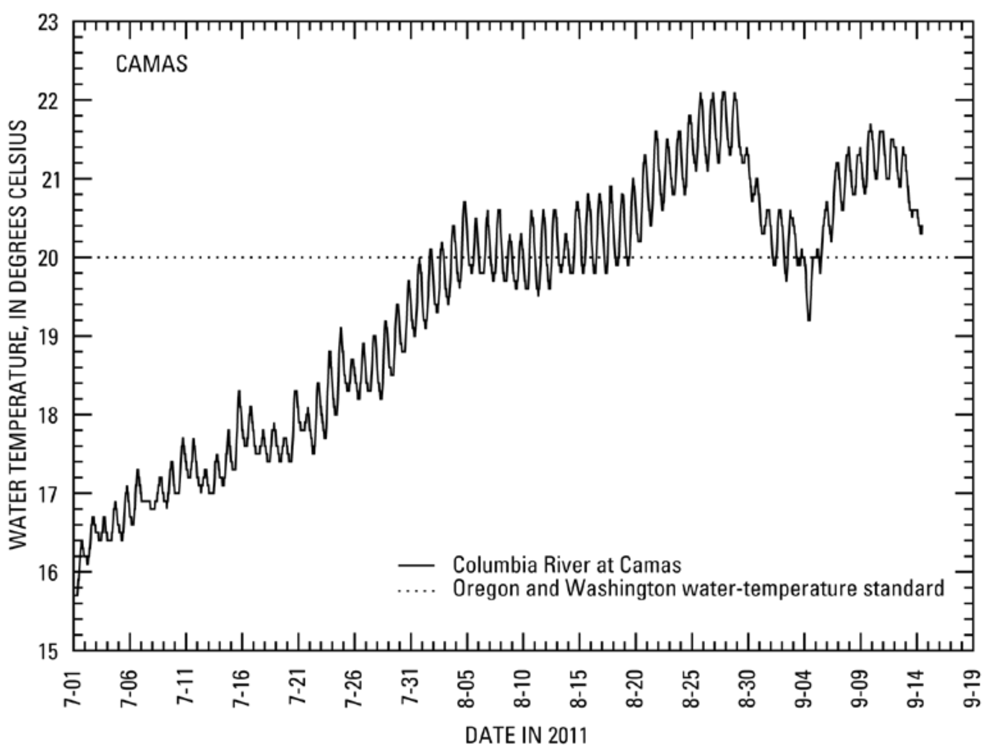


Figure 23. Graph showing water temperature downstream of Bonneville Dam at Camas, lower Columbia River, Oregon and Washington, summer 2011.

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