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, Water Year 2009: Quality-Assurance Data and Comparison to Water-Quality Standards

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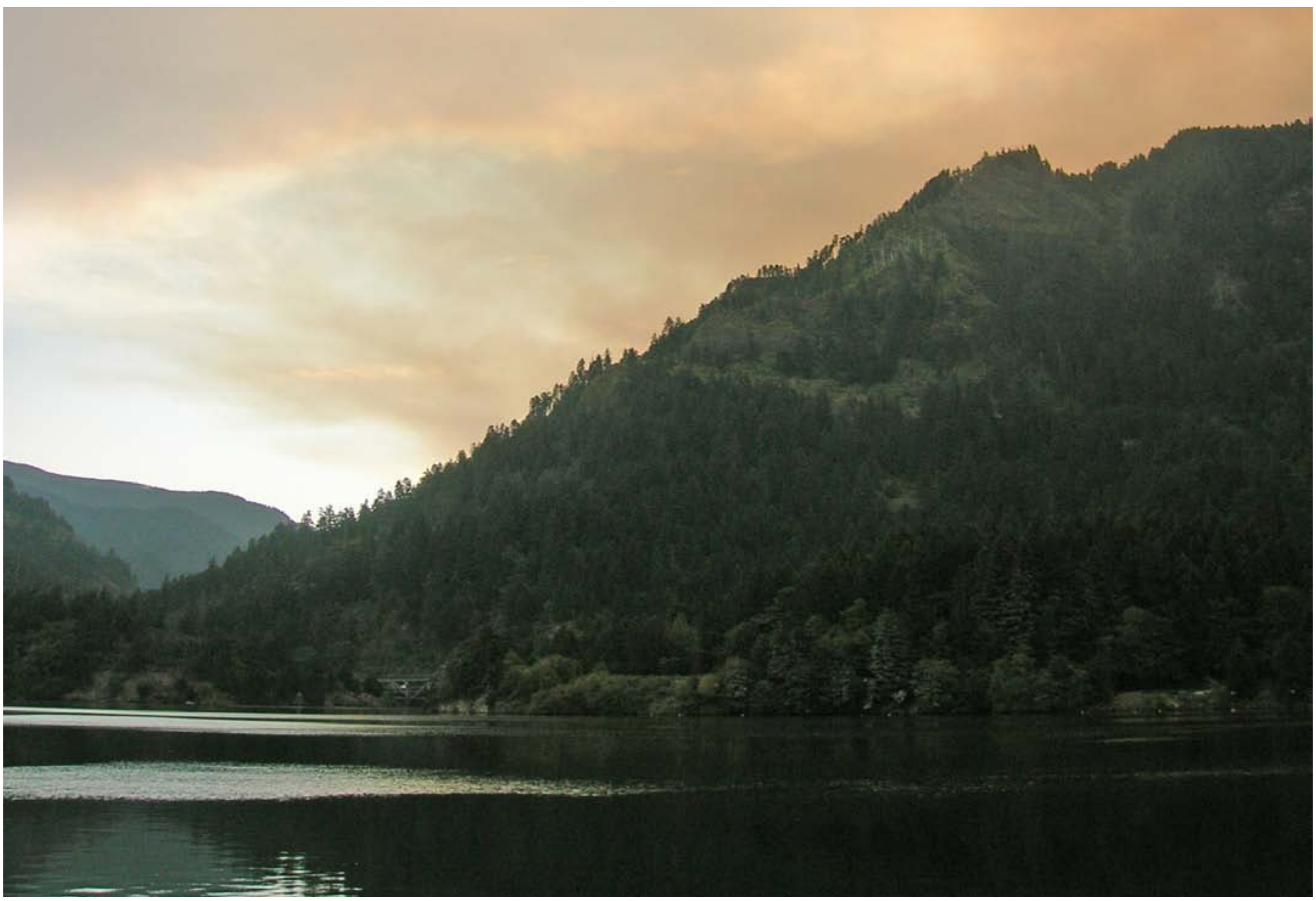

Open-File Report 2009–1288

U.S. Department of the Interior
U.S. Geological Survey

Cover photo: Bonneville Dam forebay on the Columbia River. Smoke is from a forest fire. (Photograph by Heather Bragg, U.S. Geological Survey, September 17, 2008.)

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KEN SALAZAR, Secretary

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Contents

Figures

Tables

Conversion Factors, Datum, Abbreviations, and Acronyms

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
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
WT	Water temperature

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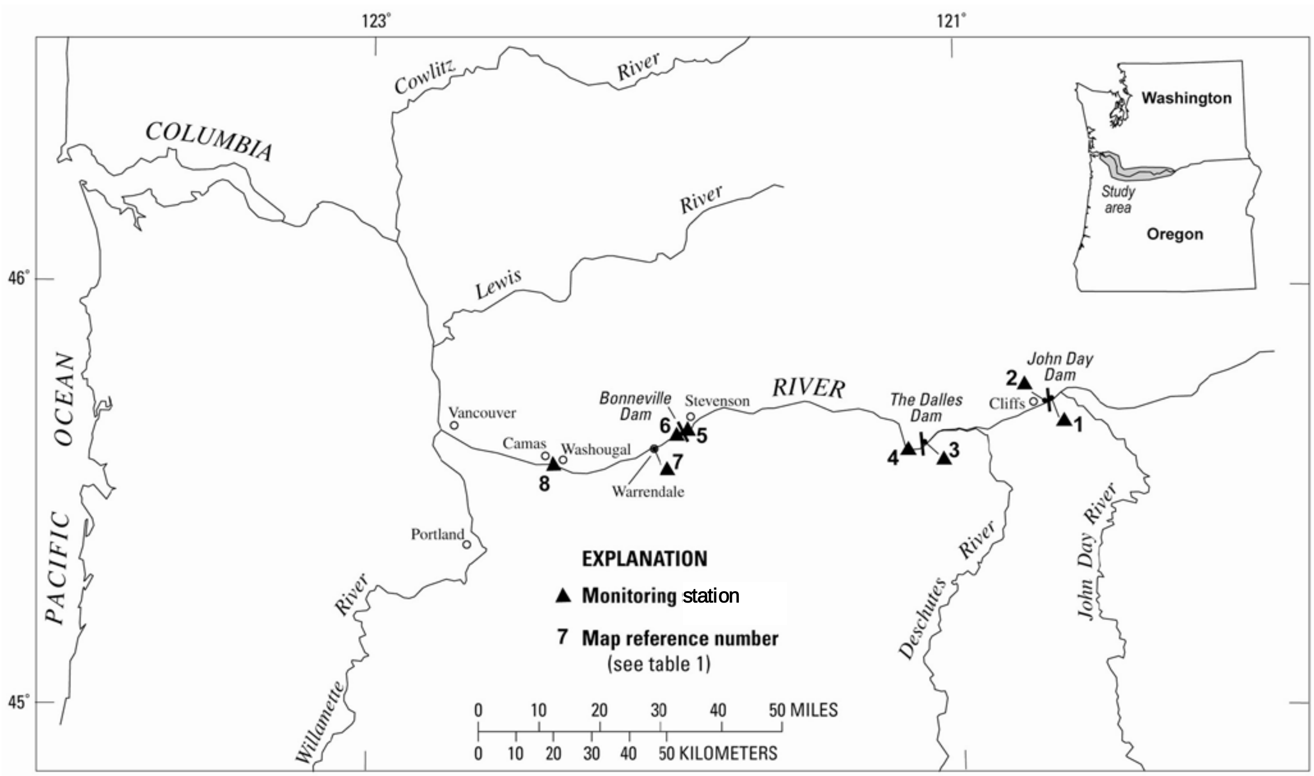
Significant Findings

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 monitoring stations on the lower Columbia River in Oregon and Washington in 2009. Significant findings from the data include:

- During the spill season of April through August 2009, hourly values of total dissolved gas (TDG) were occasionally larger than 115-percent saturation for the forebay stations (John Day navigation lock, The Dalles forebay, Bonneville forebay, and Camas). Hourly values of total dissolved gas were occasionally larger than 120-percent saturation for two tailwater stations (John Day Dam tailwater and Cascade Island).
- From mid- to late July to mid-September 2009, water temperatures were greater than 20°C (degrees Celsius) at seven stations on the lower Columbia River. According to the State of 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 as a result of human activities.
- All 96 laboratory checks of the TDG sensors with a certified pressure gage were within 0.4percent saturation after 3 to 4 weeks of deployment in the river.
- All but 2 of the 73 in situ field checks of TDG sensors with a secondary standard were within ± (plus or minus) 1.0-percent saturation after 3–4 weeks of deployment in the river. All 74 of the field checks of barometric pressure were within ±2.0 millimeters of mercury of a secondary standard, and all 65 water-temperature field checks were within ±0.2°C.
- For the eight monitoring stations in water year 2009, a total of 99.2 percent of the TDG data were received in real time by the USGS satellite downlink 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 individual stations ranged from 97.0 to 100.0 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, increasing the concentration of dissolved gases (known as the "total dissolved gas" concentration [TDG]) downstream of the spillways. TDG conditions 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, variable scales. Projection unknown.

Figure 1. Location of total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2009.

The USACE regulates spill and streamflow to minimize the production of excess TDG downstream from its dams, but also with the 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. 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. Data from the lower Columbia River monitoring stations 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 each year since 1996. Current and historical TDG and water-temperature data can be accessed at http://oregon.usgs.gov/projs_dir/pn307.tdg/ (accessed October 13, 2009). Ten reports, published for water years 1996 and 2000–2008, 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, Tanner and others, 2002, 2003, 2004, 2005, 2006, 2007, 2008).

To assure data quality for managing and modeling TDG in the lower Columbia River, hourly data for 2009 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 data were stored in a USGS database and in a USACE database (*http://www.nwd-wc.usace.army.mil/tmt/wcd/tdg/months.html, accessed October 13, 2009*). The USACE database also includes hourly water temperature, discharge, and spill data.

Purpose and Scope

TDG monitoring in the lower Columbia River provides 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 concentrations.

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 2009 (October 1, 2008, to September 30, 2009) 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 to September 2009, the period that includes the usual time of spill from the dams. John Day Dam tailwater and The Dalles Dam tailwater were operated year-round and Warrendale was operated year-round except for mid-April to mid-September, when station operation was stopped at the request of the USACE.

Table 1. Total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2009

[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 NAD27.]

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 2009
1	JDY	215.7	454314120413701	Columbia River at John Day navigation lock, Washington (John Day navigation lock)	45° 43’ 14”	120° 41’ 37”	03/18/09–09/15/09
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”	03/18/09–09/17/09
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”	03/19/09–09/16/09
6	CCIW	145.9	453845121564001	Columbia River at Cascade Island, Washington (Cascade Island)	45° 38’ 45”	121° 56’ 40”	10/01/08–10/21/08 and 03/19/09–09/30/09
7	WRNO	140.4	453630122021400	Columbia River, left bank, near Dodson, Oregon (Warrendale)	45° 36’ 30”	122° 02’ 14”	10/01/08–04/16/09 and 09/16/09–09/30/09
8	CWMW	121.7	453439122223900	Columbia River, right bank, at Washougal, Washington (Camas)	45° 34’ 39”	122° 22’ 39”	03/24/09–09/30/09

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 and (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 database and to the USGS database.

The eight fixed-station monitors were calibrated every 3 weeks, except from October 2008 through March 2009, 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 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 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 (Suunto©, Escape 203) that recently had been calibrated at the National Weather Service facility in northeast Portland.

For part of the season at the Cascade Island site, it was not possible to get the secondary-standard (Hydrolab) near the field Hydrolab, due to blocked access to a probe pipe. A dual-sensor Hydrolab was installed at that site to provide the field quality-assurance check.

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, p. 104), is the depth above which degassing will occur due to decreased hydrostatic pressure. To measure TDG accurately, the Hydrolabs were positioned at a depth below the calculated minimum compensation depth whenever possible.

The 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 cover the expected range of TDG in the river (approximately 100-, 113-, 126-, and 139-percent saturation, respectively).

Summary of Total-Dissolved-Gas Data Completeness and Quality

A summary of USGS TDG data completeness and quality for water year 2009 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 almost identical). 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 divided by the barometric pressure (both in mm Hg) multiplied by 100. The fourth column in table 2 shows the percentages of data that were 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-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. At each station, at least 97.0 percent of the data were received in real time by the USGS downlink and met quality-control checks, with an overall completeness of 99.2 percent (table 2).

Table 2. Total-dissolved-gas data completeness and quality, lower Columbia River, Oregon and Washington, water year 2009

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

Abbreviated station name	Planned monitoring	Number of missing or deleted	Percentage of real-time TDG data passing quality
John Day navigation lock (JDY)	4,346	4	99.9
John Day tailwater (JHAW)	8,760	265	97.0
The Dalles forebay (TDA)	4,387	0	100.0
The Dalles tailwater (TDDO)	8,760	0	100.0
Bonneville forebay (BON)	4,345	83	98.1
Cascade Island (CCIW)	5,172	1	100.0
Warrendale (WRNO)	5,091	21	99.6
Camas (CWMW)	4,561	1	100.0
TOTAL	45,422	375	99.2

Table 3 is a list of the major portions of data that were either missing from the database (for example, when data collection failed) or data that were later deleted from the database because they did not meet quality-assurance standards. Table 3 includes TDG and temperature data, whereas table 2 includes only TDG data. A common cause for loss of data is the failure or tearing of the plastic tubing material that comprises the TDG membrane. This failure is easy to diagnose because the TDG pressure rises immediately to a high value, which results from water suddenly entering the membrane and exerting hydrostatic pressure (instead of the pressure of dissolved gases).

Table 3. Major portions of missing or deleted data, lower Columbia River, Oregon and Washington, water year 2009

[USACE station identifier: JHAW, John Day tailwater; BON, Bonneville forebay. Parameter abbreviations: TDG, total dissolved gas; WT, water temperature]

Date and Time	USACE station identifier	Parameter	Reason / Notes
8/03/09 01:00 through 8/03/09 15:00	JHAW	TDG	Torn membrane; data not recovered
9/08/09 17:00 through 9/15/09 13:00	JHAW	TDG	Slow leak in membrane; data not recovered
9/18/09 07:00 through 9/21/09 15:00	JHAW	TDG	Slow leak in membrane; data not recovered
3/30/09 16:00 through 3/31/09 17:00	BON	TDG	Torn membrane; data not recovered
7/01/09 10:00 through 7/02/09 12:00	BON	TDG, WT	Hydrolab malfunction; data not recovered
8/04/09 05:00 through 8/05/09 10:00	BON	TDG	Torn membrane; data not recovered

The John Day Dam tailwater station had the most missing or deleted data. TDG data were lost at that station for several hours on August 3 and could not be recovered because of a torn membrane. Leaky membranes seemed to be the cause of missing data at John Day Dam tailwater from September 8 to 21. During those periods, the TDG values increased slowly and steadily for no apparent reason. Small invertebrates (amphipods) were found on the membrane and were thought to have caused the damage that might have resulted in a slow leak. These data were deleted and could not be recovered or corrected. Torn membranes occurred twice at the Bonneville Dam forebay station, where the probe can be damaged by debris that gathers just upstream of the spillgate.

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 2009 are presented in this section.

After field deployment for 3 or 4 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 supersaturation 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 (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 by the barometric pressure, and multiplying by 100. All sensor readings were within 0.5-percent saturation (fig. 2). Of the 96 laboratory checks that were performed, only 2 indicated that a sensor needed recalibrating because the difference between the expected reading and the sensor reading exceeded 2 mm Hg. The largest difference between expected versus actual TDG pressure was 3 mm Hg.

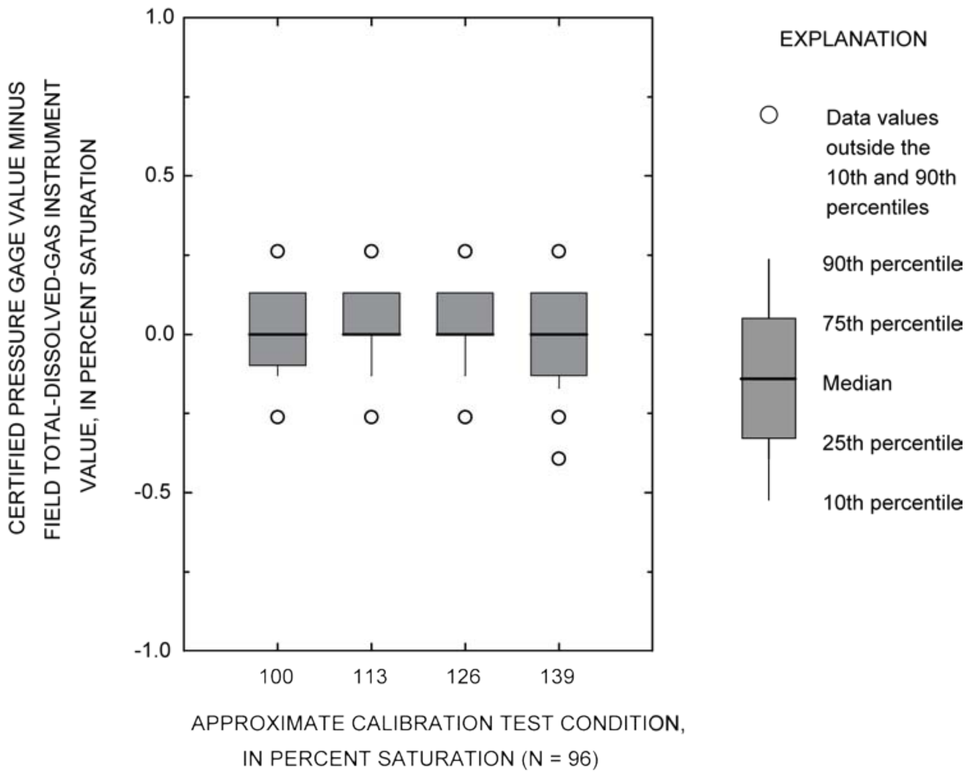


Figure 2. Accuracy of total-dissolved-gas sensors after 3 or 4 weeks of field deployment at eight monitoring stations in the lower Columbia River, Oregon and Washington, water year 2009 (number of comparison values = 96).

The differences in barometric pressure, in situ water temperature, and in situ TDG between the secondary standard instruments and the fixed-station monitors after field deployment were measured and recorded as part of the 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 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 digital 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 stations.

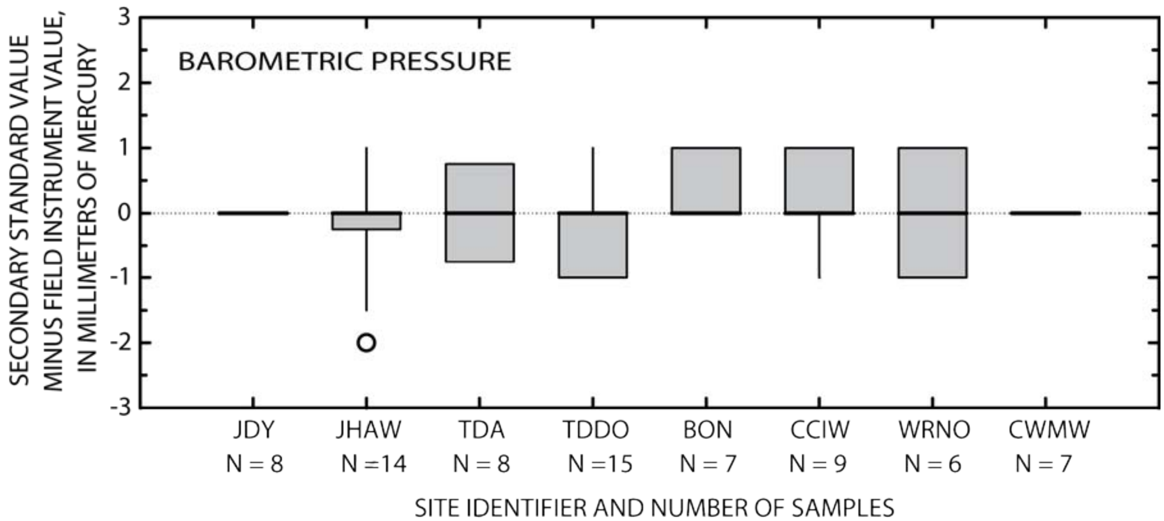


Figure 3. Difference between the secondary standard and the field barometers after 3 or 4 weeks of field deployment at eight stations in the lower Columbia River, Oregon and Washington, water year 2009. See figure 2 for explanation of boxplot.

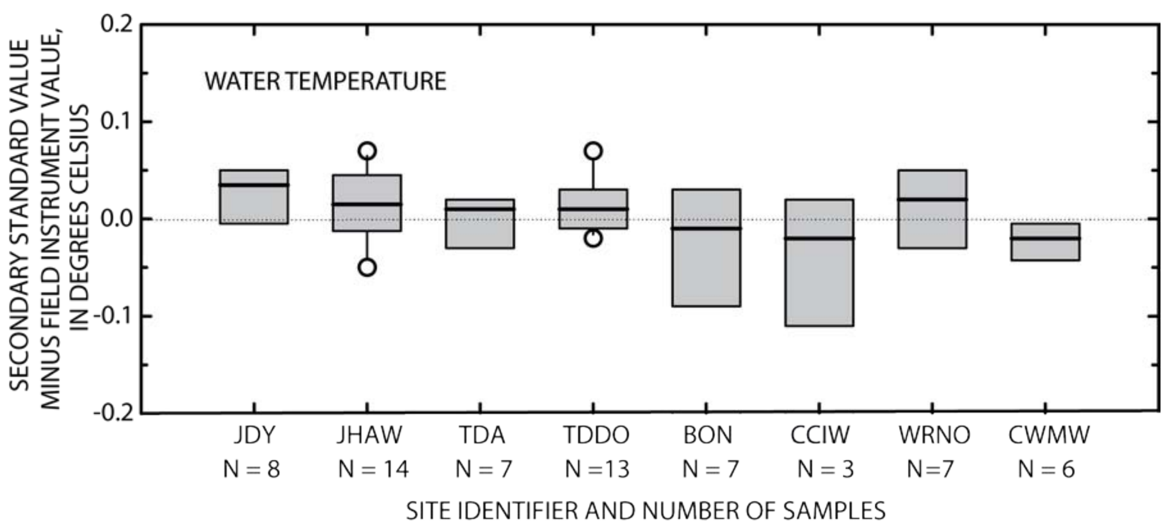


Figure 4. Difference between the secondary standard and the field temperature instruments after 3 or 4 weeks of field deployment at eight stations in the lower Columbia River, Oregon and Washington, water year 2009. See figure 2 for explanation of boxplot.

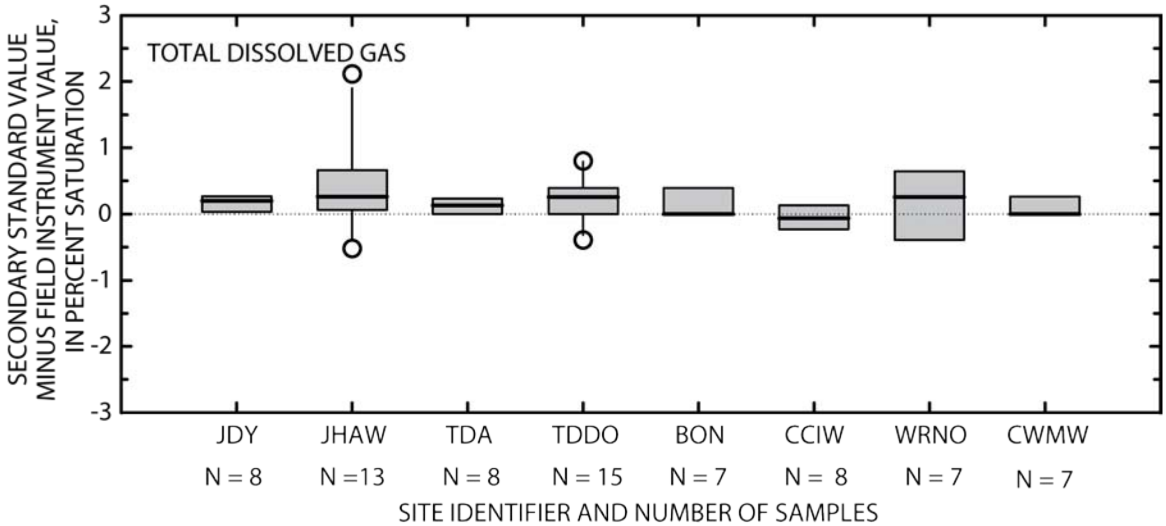


Figure 5. Difference between the secondary standard and the field total-dissolved-gas instruments after 3 or 4 weeks of field deployment at eight stations in the lower Columbia River, Oregon and Washington, water year 2009. See figure 2 for explanation of boxplot.

The comparisons of the digital barometer and the field barometers are shown in figure 3. All field values were within 2 mm Hg of standard values. The secondary standard temperature sensor and the field temperature sensor results are presented in figure 4. All differences were within 0.2°C, with all but one falling within 0.1°C.

Because of the blocked pipe access at the Cascade Island station, side-by-side temperature checks were not performed during the site visits from June to September. Instead, the temperature of the newly deployed Hydrolab was calibrated to the temperature of the recently removed Hydrolab immediately prior to its removal. The differences between the two sondes were less than 0.2°C for all comparisons. The data for these checks were not included in the analysis shown in figure 4 because the method was not consistent with the earlier data.

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.

All but two of the field checks show less than 1.0-percent saturation difference between the two TDG sensors (fig. 5). The two greatest differences were +1.6-percent saturation (July 8, 2009) and +2.1-percent saturation (August 26, 2009) at the John Day Dam tailwater station. Both differences occurred following an increase in spill at the dam while checking field performance of the same instrument. The combination of a slowly equilibrating sensor and the changing spill conditions may have resulted in an exaggerated difference between the secondary standard and the deployed instrument. Although the TDG sensor on the instrument passed post-deployment calibration tests, it was not used for the rest of the field season because of its slow response in the field. The sonde that was removed from service was in use at the John Day Dam tailwater station during March 18–April 15, 2009; May 6–27, 2009; June 17–July 8, 2009, and July 29–August 26, 2009.

Effects of Spill on Total–Dissolved-Gas Concentration

The graph of spill from John Day Dam and the TDG at the John Day Dam tailwater station shows two linear relations, with the data after June 4 showing higher TDG for a given spill (fig. 6). On June 4, 2009, the spill pattern at John Day Dam was modified. The relation between spill from the other two dams and TDG at the corresponding tailwater site were fairly linear for The Dalles Dam (fig. 7) and Bonneville Dam (fig. 8). There was some variability in the magnitude of TDG that is associated with each spill level.

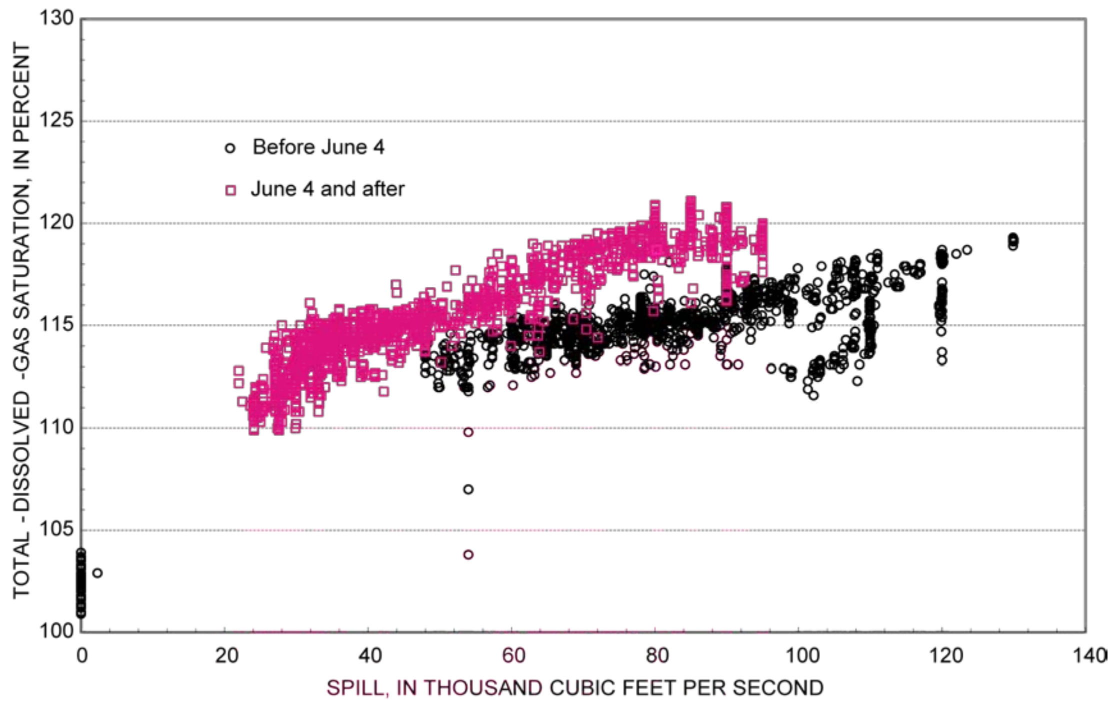


Figure 6. Relation of total-dissolved-gas saturation downstream of John Day Dam and spill from John Day Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2009.

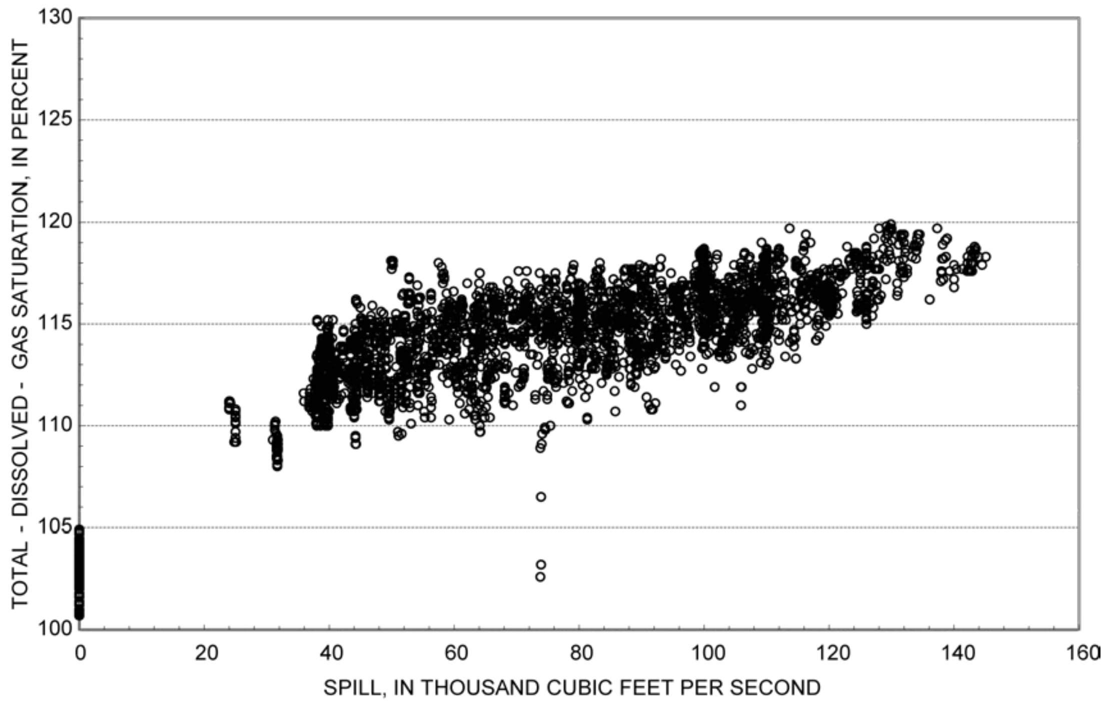


Figure 7. Relation of total-dissolved-gas saturation downstream of The Dalles Dam and spill from The Dalles Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2009.

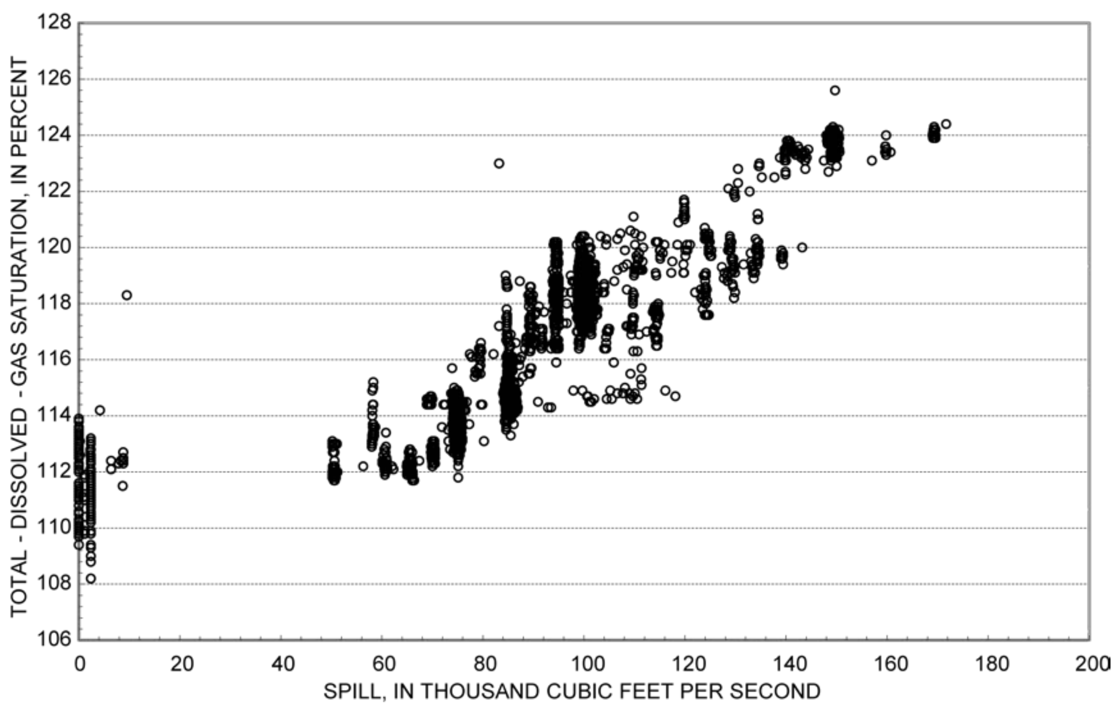


Figure 8. Relation of total-dissolved-gas saturation downstream of Bonneville Dam at Cascade Island and spill from Bonneville Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2009.

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

In 2009, variances or waivers were granted to the water-quality standard for TDG of 110-percent saturation. These variances were established to allow spill for fish passage at dams on the Columbia River. The State of Oregon granted a 2-year variance for 2008 and 2009 (State of Oregon, 2007). The State of Washington provided for fish passage in its water-quality standards consistent with approved gas-abatement plans through February 2010 (State of Washington, 2006a). From April 1 to August 31, 2009, the USACE was granted variances allowing TDG to reach 115-percent saturation for forebay stations (John Day Dam navigation lock, The Dalles Dam forebay, Bonneville Dam forebay, and Camas) and 120-percent saturation for 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 12 highest consecutive hourly readings in any 24-hour period (Washington variance) was larger than the numerical standard. A separate variance of 125 percent was in place for all stations for the highest 2-hour average (Oregon Environmental Quality Commission, written commun., 2007), or the highest 1-hour average (State of Washington, 2006a). Although the Camas station is not located at the forebay of a dam, it is 24.4 mi downstream of Bonneville Dam and is regulated as a forebay station.

The distribution of hourly TDG values for the spill season (April 1 through August 31, 2009) is shown in figure 9. 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 outside of the variances on the graph do not necessarily represent actual exceedances of the variances.

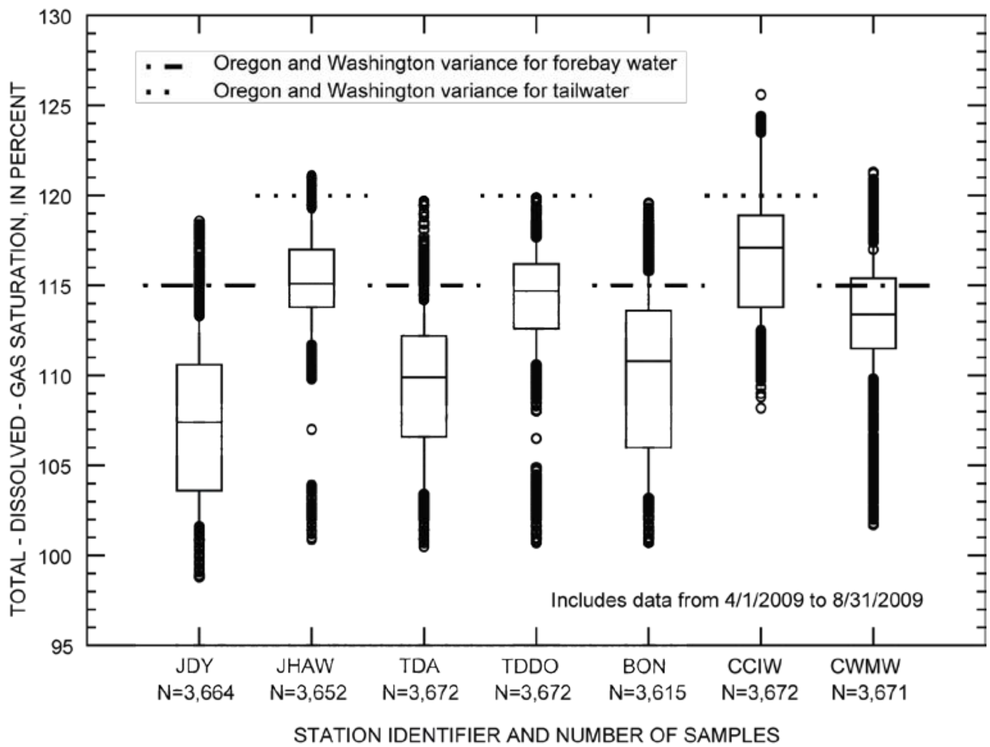


Figure 9. Distributions of hourly total-dissolved-gas data and Oregon and Washington water-quality variances, lower Columbia River, Oregon and Washington, April 1–August 31, 2009. See table 1 for explanation of station identifiers. See figure 2 for explanation of boxplot.

Data from the forebay stations in figure 9 show an increase in the median TDG (from John Day Dam to The Dalles Dam to Bonneville Dam to Camas), which probably reflects the river's inability to de-gas downstream of each dam before another dam is encountered to again cause an increase in TDG.

Figures 10–16 show the timing of the occurrence of exceedances (high 12–hour average), along with the spill at the closest upstream dam. 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. The figures are in order from upstream to downstream, and in the cases of the forebay stations, the spill data provided are from a dam several miles upstream. Overall, many of the exceedances happened in late May through early June, when the spill levels were the highest for the season.

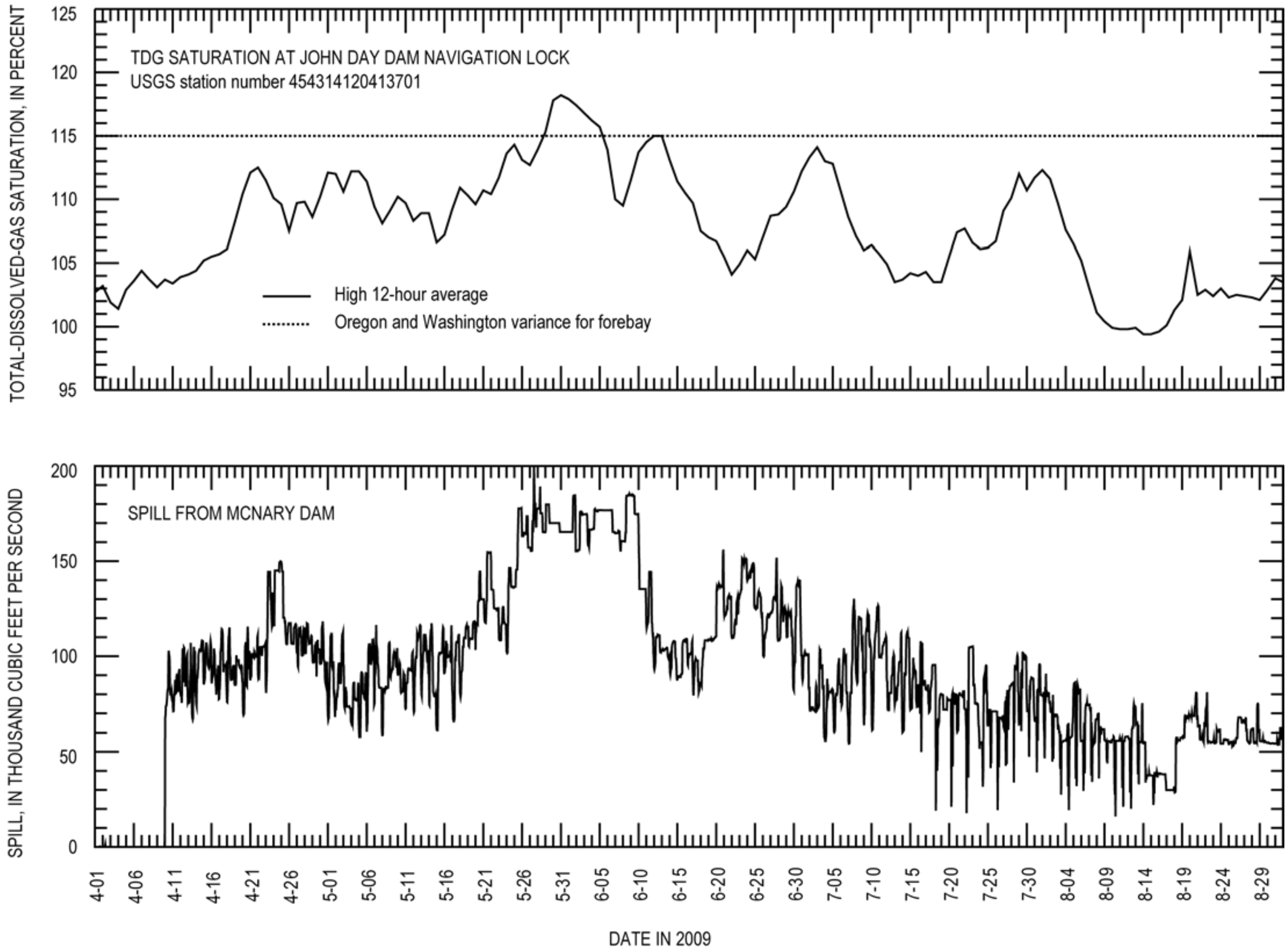


Figure 10. Exceedances of variances for total-dissolved-gas saturation at John Day Dam navigation lock and spill from McNary Dam (76 river miles upstream from John Day Dam), lower Columbia River, Oregon and Washington, April 1–August 31, 2009. Date format is month and day (M-DD).

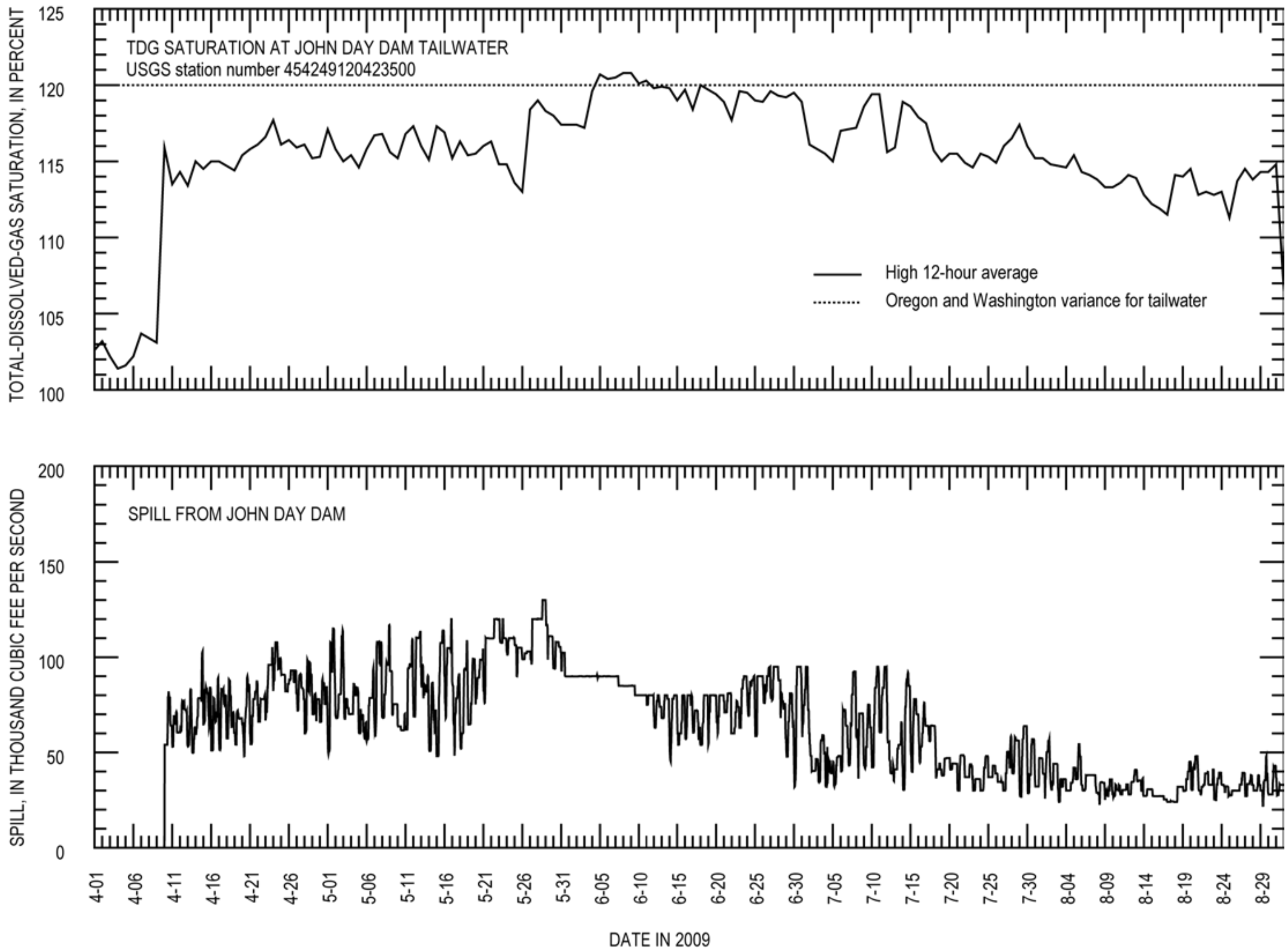


Figure 11. Exceedances of variances for total-dissolved-gas saturation at John Day Dam tailwater and spill from John Day Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2009. Date format is month and day (M-DD).

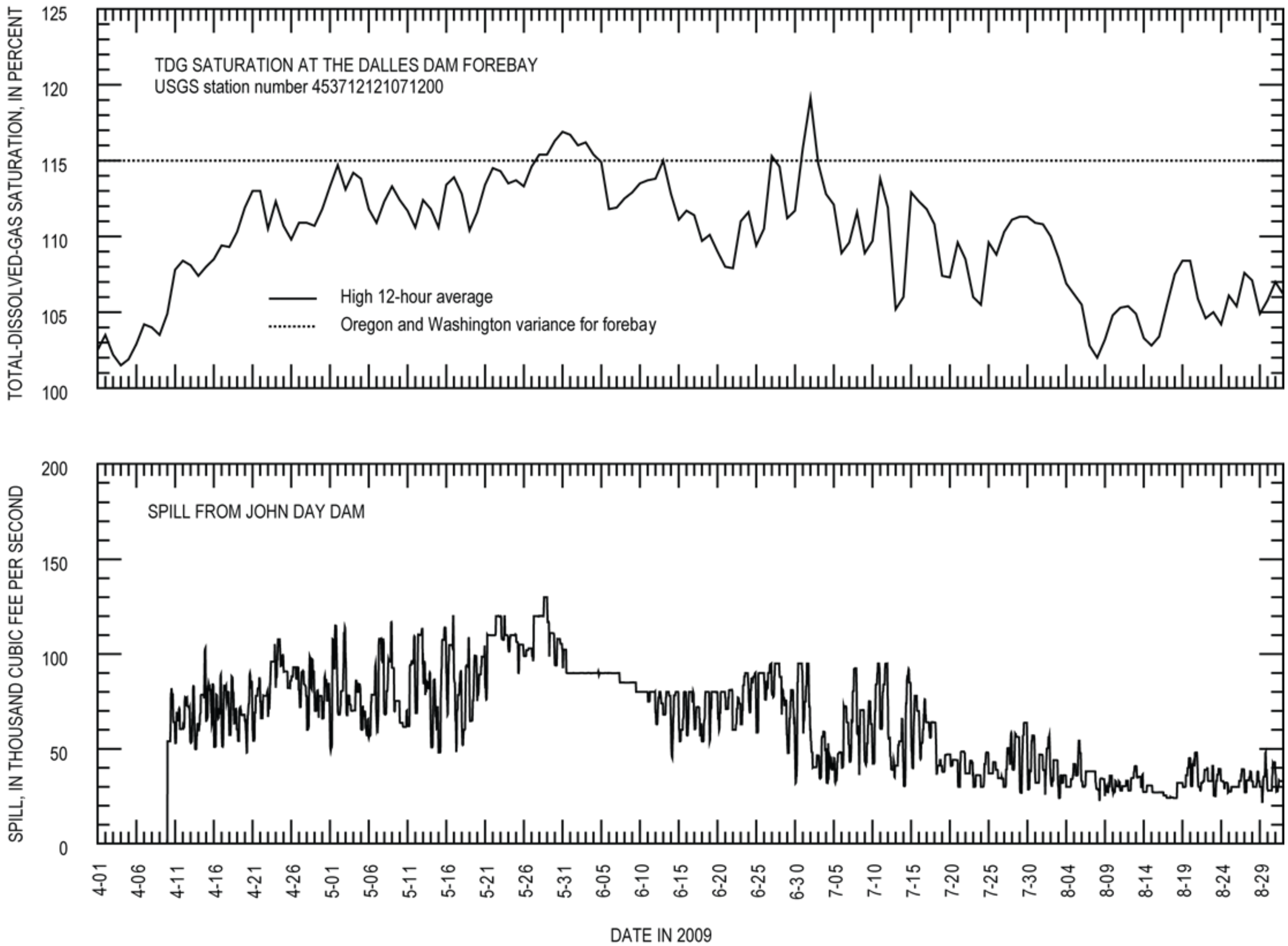


Figure 12. Exceedances of variances for total-dissolved-gas saturation at The Dalles Dam forebay and spill from John Day Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2009. Date format is month and day (M-DD).

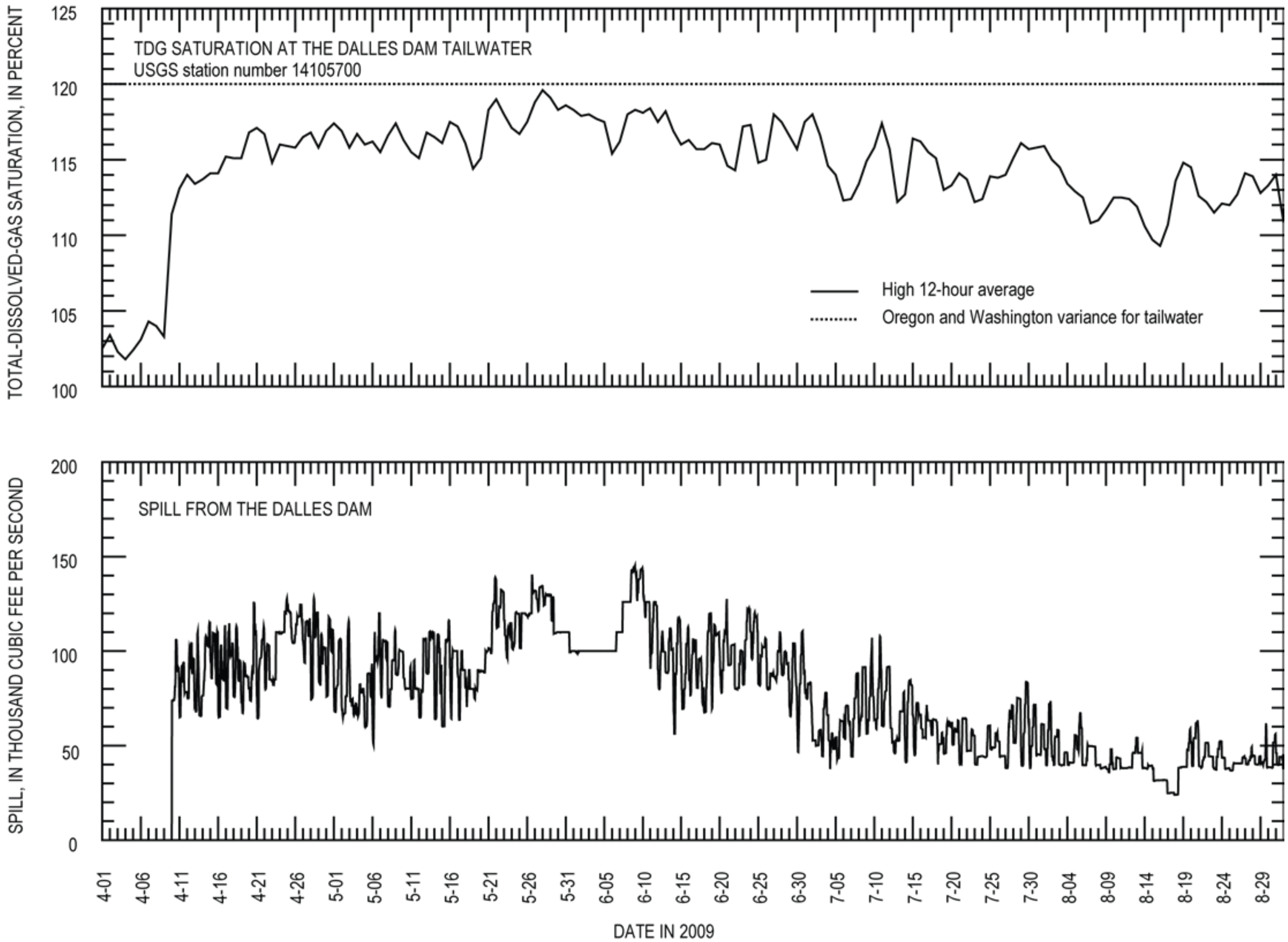


Figure 13. Exceedances of variances for total-dissolved-gas saturation at The Dalles Dam tailwater and spill from The Dalles Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2009. Date format is month and day (M-DD).

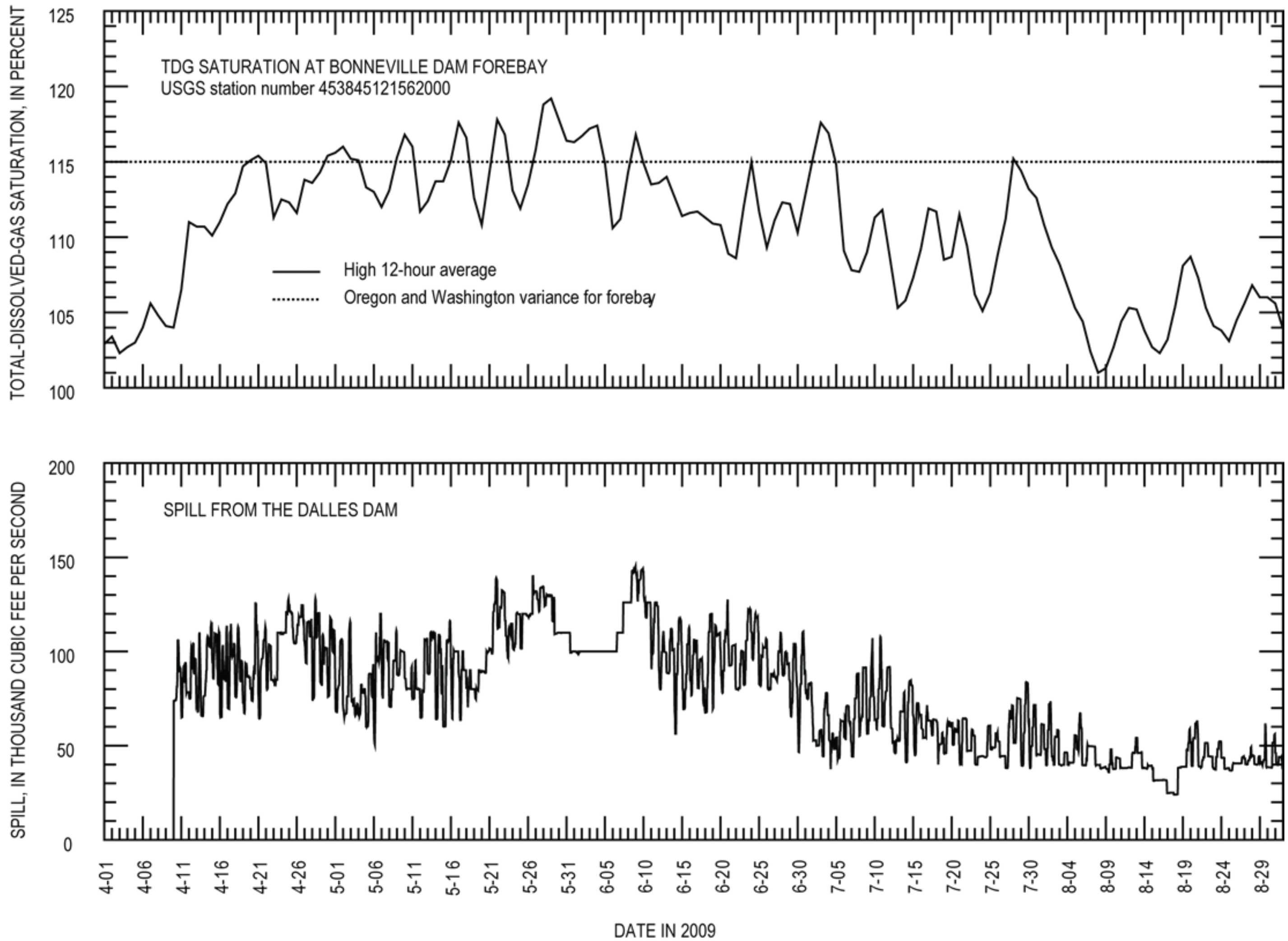


Figure 14. Exceedances of variances for total-dissolved-gas saturation at Bonneville Dam forebay and spill from The Dalles Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2009. Date format is month and day (M-DD).

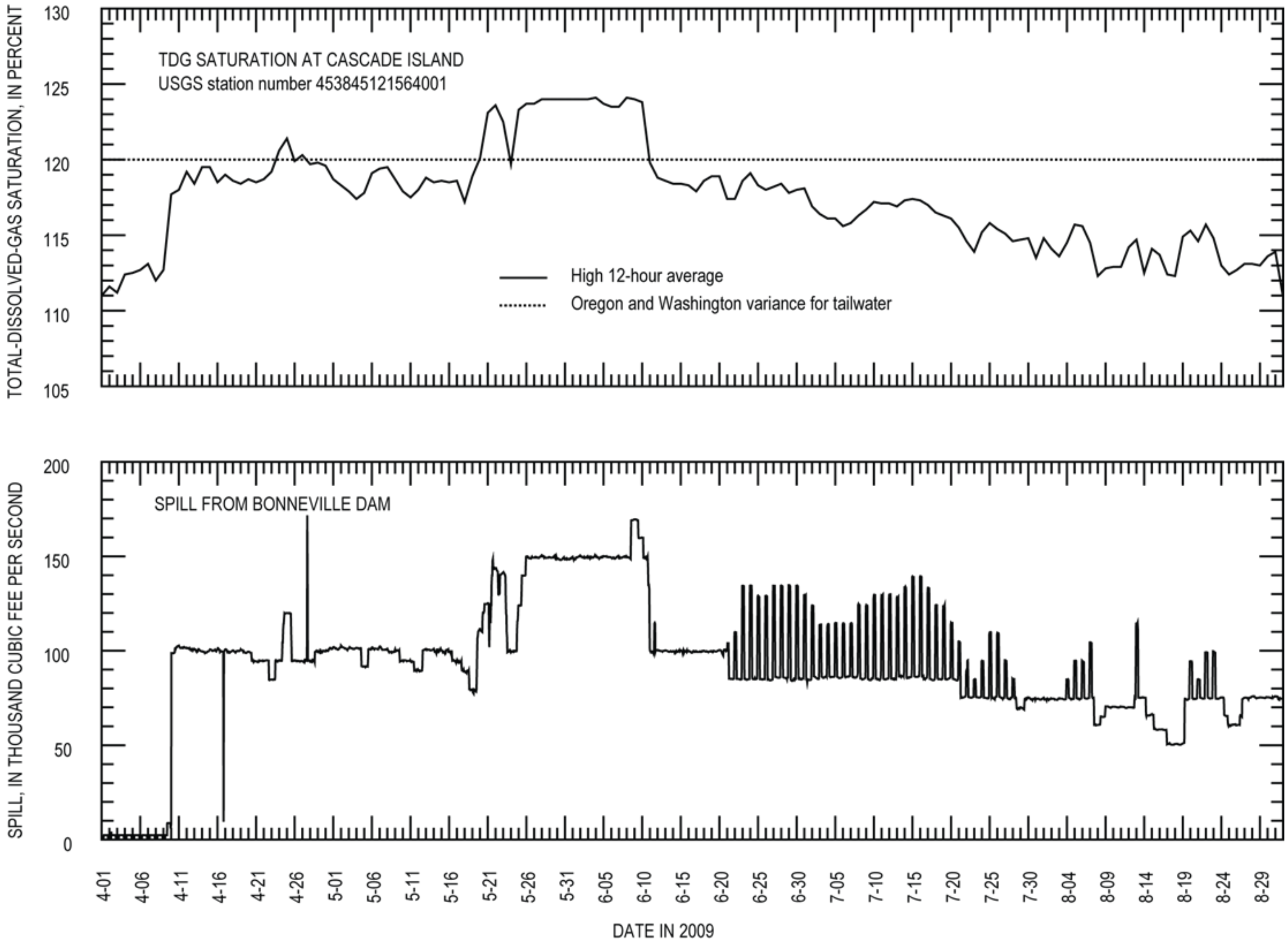


Figure 15. Exceedances of variances for total-dissolved-gas saturation at Cascade Island and spill from Bonneville Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2009. Date format is month and day (M-DD).

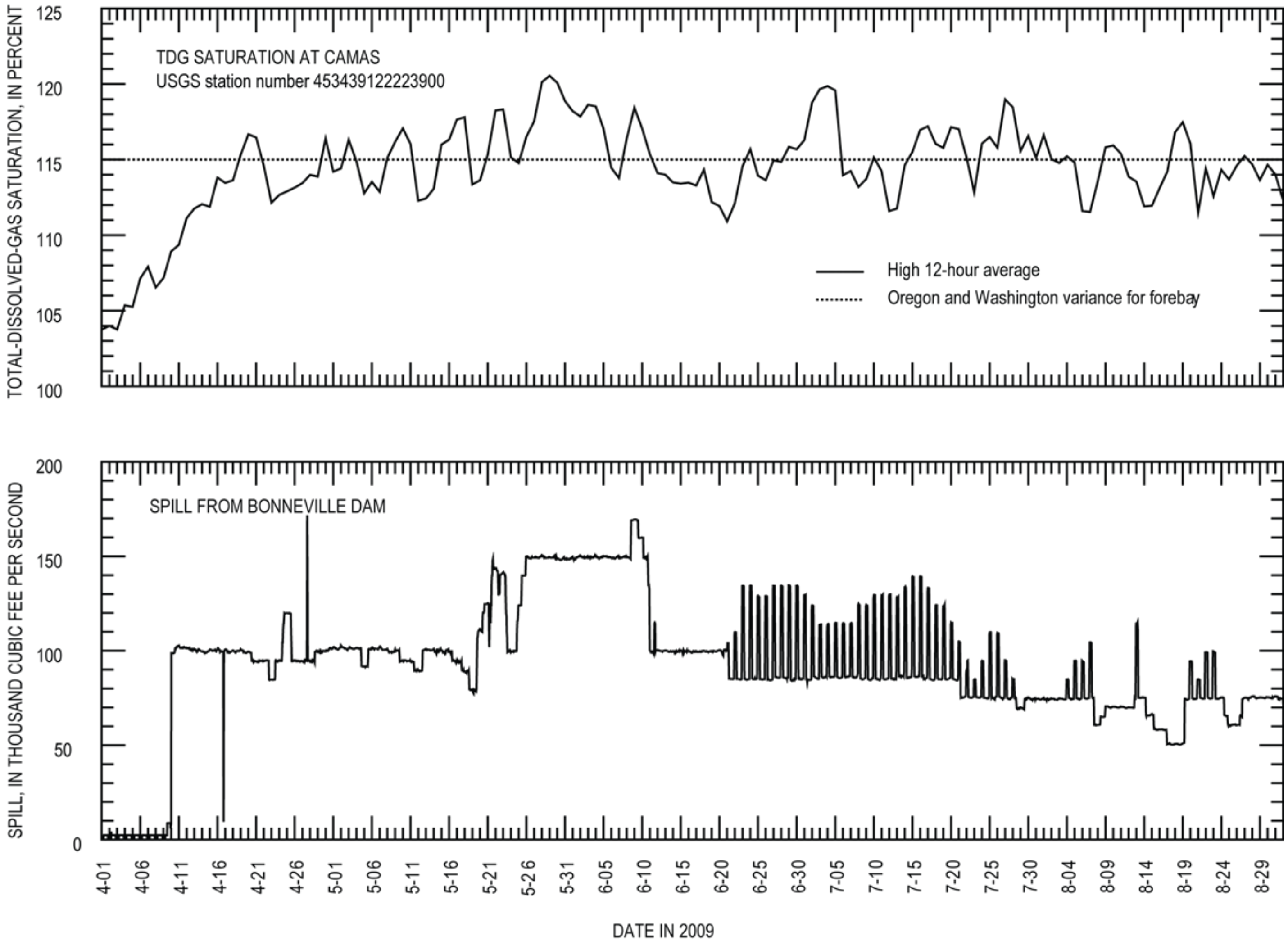


Figure 16. Exceedances of variances for total-dissolved-gas saturation at Camas and spill from Bonneville Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2009. Date format is month and day (M-DD).

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-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 upstream and downstream of John Day Dam (fig. 17), The Dalles Dam (fig. 18), and Bonneville Dam (fig. 19), and at Camas (fig. 20) were greater than 20.0°C from late July through early September. Water temperatures at the forebay stations were approximately equal to the temperatures at the tailwater stations (except during a short period at the John Day Dam navigation lock), indicating that the sensors were placed in well-mixed conditions in the forebays.

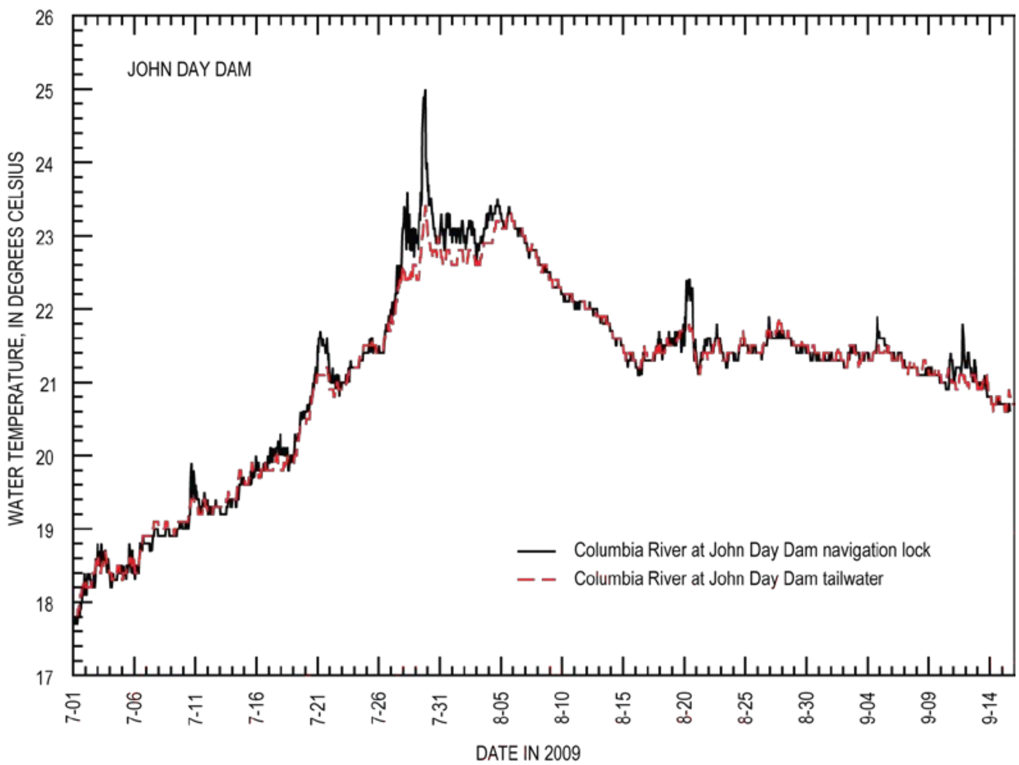


Figure 17. Water temperature upstream and downstream of John Day Dam, lower Columbia River, Oregon and Washington, summer 2009. Date format is month and day (M-DD).

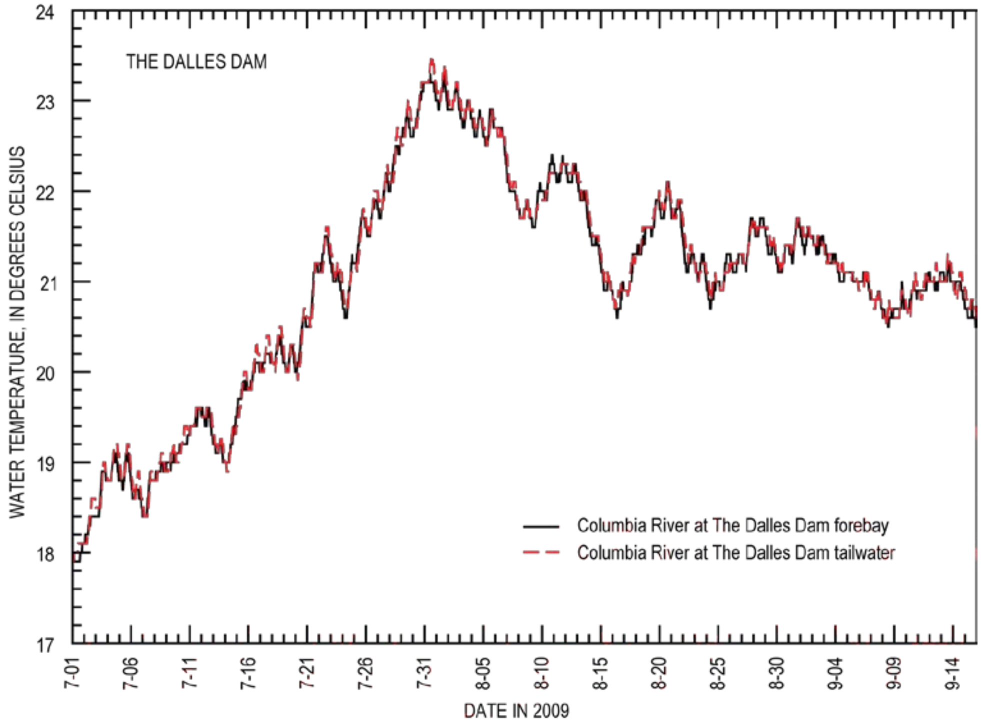


Figure 18. Water temperature upstream and downstream of The Dalles Dam, lower Columbia River, Oregon and Washington, summer 2009. Date format is month and day (M-DD).

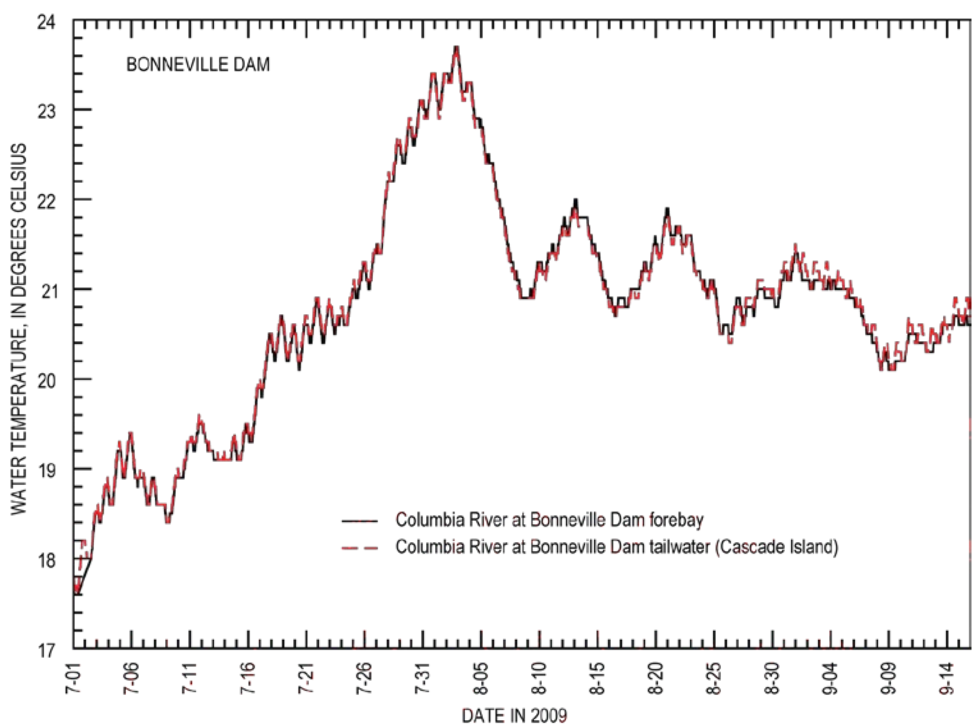


Figure 19. Water temperature upstream and downstream of Bonneville Dam, lower Columbia River, Oregon and Washington, summer 2009. Date format is month and day (M-DD).

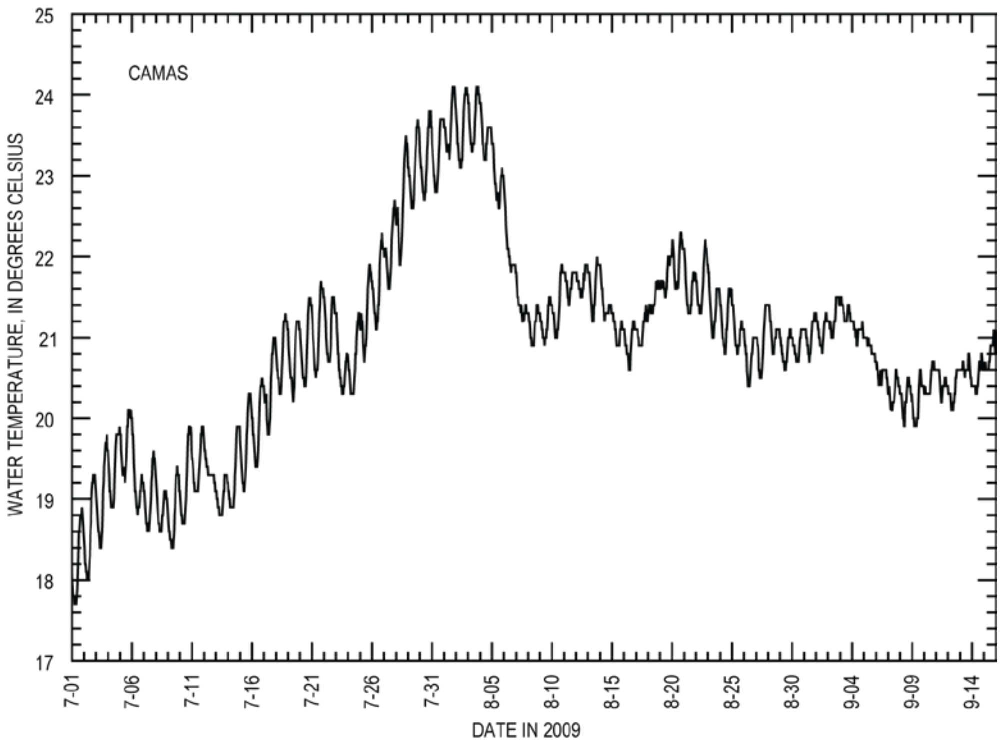


Figure 20. Water temperature at Camas, lower Columbia River, Oregon and Washington, summer 2009. Date format is month and day (M-DD).

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