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 2015

Open-File Report 2015–1212

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

Cover: Bonneville Dam on the Columbia River, looking east The U.S. Geological Survey measures dissolved gas levels in the river to help the U.S. Army Corps of Engineers regulate spill from its dams on the lower Columbia River to minimize the production of excess dissolved gas downstream of the dams. Dissolved gas concentration greater than 110 percent saturation is harmful to fish migrating downstream through the spillways on their way to the ocean. (Photograph courtesy of the U.S. Army Corps of Engineers.)

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

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Conversion Factors

Inch/Pound to International System of Units

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)
square mile (mi^2)	2.590	square kilometer (km^2)

International System of Units to Inch/Pound

Multiply	By	To obtain
millimeter (mm)	0.03937	inch (in.)

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

BON	Bonneville forebay
CCIW	Cascade Island
CWMW	Camas
DCP	Data-collection platform
JDY	John Day navigation lock
JHAW	John Day 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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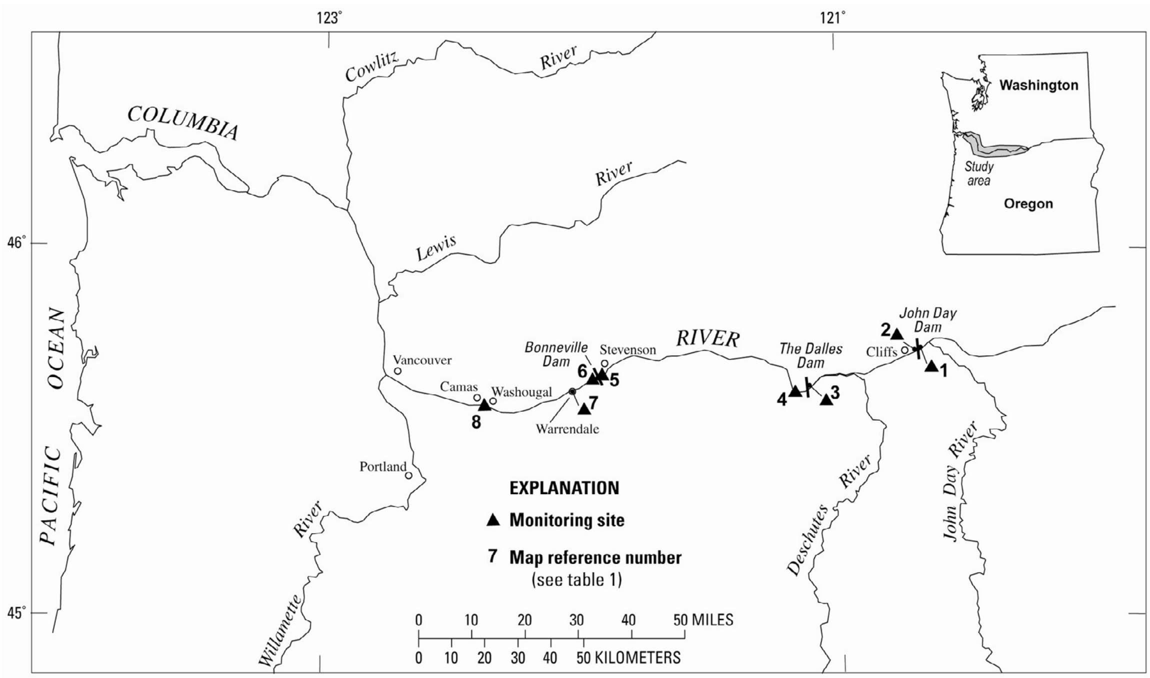
Significant Findings

An analysis of total-dissolved-gas (TDG) and water-temperature data collected at eight fixed monitoring stations on the lower Columbia River in Oregon and Washington in water year 2015 indicated the following:

- All but 1 of the 85 TDG sensor laboratory checks that were performed after field deployment were within ±0.5-percent saturation of a primary standard.
- After 3–4 weeks of deployment in the river, 79 of 89 TDG sensor field checks were within ±1.0-percent saturation of a secondary standard. Nine of the field checks greater than ±1.0-percent saturation occurred at the John Day Dam tailwater station and resulted in periods of deleted TDG data at the station.
- All 90 barometric pressure field checks were within ±1 millimeter of mercury of a primary standard, and all 90 water-temperature field checks were within ±0.2 degrees Celsius of a secondary standard.
- TDG data were considered complete if received in real time and within 1-percent saturation of the expected value on the basis of calibration data, replicate quality-control measurements, and comparison to river conditions at adjacent stations. For the eight monitoring stations, data completeness ranged from 71.9 to 99.8 percent.
- All quality-assurance values exceed the criteria established by the U.S. Army Corps of Engineers TDG monitoring plan. Criteria for data completeness (95-percent) were met at seven of the eight monitoring stations. Deleted data at the John Day tailwater station resulted in data completeness below criteria.

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 fulfill 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, resulting in an increase in the concentration of dissolved gases (referred to here as "total dissolved gas," or "TDG") in the water downstream of the spillways. Concentrations of TDG greater than 110percent saturation can cause gas-bubble trauma in fish and adversely affect other aquatic organisms (U.S. Environmental Protection Agency, 1986). The USACE regulates streamflow and spill from its dams on the lower Columbia River to minimize the production of excess TDG downstream of the dams, with an additional goal of providing fish passage through the spillways (rather than through the turbines).



Base map modified from USGS and other digital data, variable scales. Projection unknown.

Figure 1. Map showing location of U.S. Army Corp of Engineers dams and total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2015.

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. The hourly values were stored in the USGS NWIS database (U.S. Geological Survey, 2016) and in a USACE database (U.S. Army Corps of Engineers, 2015). Those data are available online within approximately 1 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 October 22, 2015). The USACE database also includes hourly river discharge and spill data.

Sixteen previous reports, published for water years 1996 and 2000–2014, describe the TDG data, quality-assurance data, and 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, 2009, 2011, 2012, 2013; and Bragg and Johnston, 2014, 2015).

This report presents the TDG data and related quality-assurance data that demonstrate the USACE Portland District compliance with the TDG4 monitoring plan (U.S. Army Corps of Engineers, 2008). To assure the accuracy and integrity of the data needed for managing and modeling TDG in the lower Columbia River, hourly values were reviewed relative to concurrent field measurements, laboratory sensor calibrations, and intersite comparisons. All deleted or missing data are explained in detail.

Data Collection

Eight monitoring stations were operated 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 2015 (October 1, 2014–September 30, 2015) include hourly measurements of TDG pressure, barometric pressure, water temperature, and sensor depth. Five of the stations (John Day navigation lock, The Dalles forebay, Bonneville forebay, Cascade Island, and Camas) were operated from March to September 2015, encompassing the usual period for dam spill operations. The stations John Day tailwater, The Dalles tailwater, and Warrendale were operated year-round. Warrendale and Camas remain part of the monitoring program although TDG data from the stations are no longer part of the USACE spill management program.

Table 1. Total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2015.

[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 2015
1	JDY	215.7	454314120413701	Columbia River at John Day Dam navigation lock, Washington (John Day navigation lock)	45° 43’ 14”	120° 41’ 37”	03/17/15–09/14/15
2	JHAW	214.7	454249120423500	Columbia River, right bank, near Cliffs, Washington (John Day tailwater)	45° 42’ 49”	120° 42’ 35”	10/01/14–09/30/15
3	TDA	192.6	453712121071200	Columbia River at The Dalles Dam forebay, Washington (The Dalles forebay)	45° 37’ 12”	121° 07’ 12”	03/18/15–09/15/15
4	TDDO	188.9	14105700	Columbia River at The Dalles, Oregon (The Dalles tailwater)	45° 36’ 27”	121° 10’ 20”	10/01/14–09/30/15
5	BON	146.1	453845121562000	Columbia River at Bonneville Dam forebay, Washington (Bonneville forebay)	45° 38’ 45”	121° 56’ 20”	03/18/15–09/16/15
6	CCIW	145.9	453845121564001	Columbia River at Cascade Island, Washington (Cascade Island)	45° 38’ 45”	121° 56’ 40”	03/18/15–09/16/15
7	WRNO	140.4	453630122021400	Columbia River, left bank, near Dodson, Oregon (Warrendale)	45° 36’ 30”	122° 02’ 14”	10/01/14–09/30/15
8	CWMW	121.7	453439122223900	Columbia River, right bank, at Washougal, Washington (Camas)	45° 34’ 39”	122° 22’ 39”	03/12/15–09/17/15

Instrumentation at each monitoring station consists of a Hach® Hydrolab water-quality instrument, a Vaisala electronic barometer, a Sutron SatLink2 data-collection platform (DCP), and a power supply. 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 are collected, logged, and transmitted every hour. The DCP transmits the 4 most recent hours of logged data to the Geostationary Operational Environmental Satellite system (Jones and others, 1991). The data are automatically decoded and transferred to the USACE and USGS databases.

Station visits were completed every 4 weeks at the three year-round stations during September 2014 through March 2015, and every 3 weeks during March 2015–September 2015 at all eight stations. The field calibration procedure was as follows: A reference Hydrolab (which was calibrated before the field trip for use as a secondary standard) was deployed alongside the field-deployed instrument to obtain comparison measurements of TDG and water temperature. The field instrument (which had been deployed for 3 or 4 weeks) was then removed and replaced with another Hydrolab that had been recently calibrated in the laboratory. The newly deployed instrument was allowed to equilibrate and the secondary standard was again used to compare TDG and temperature values. The electronic barometer at the monitoring station was calibrated using a portable barometer (NovaLynx 230-M202) that is calibrated annually to National Institute of Standards and Technology (NIST) standards.

During each field visit, 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 because of decreased hydrostatic pressure. To measure TDG accurately, the instruments were positioned, whenever possible, at a depth below the calculated minimum compensation depth.

The Hydrolab that was removed from the field after 3 or 4 weeks of deployment was later calibrated in the laboratory. The integrity of the TDG membrane was tested, and the membrane was removed and air-dried. The TDG sensor (without the membrane attached) was calibrated at a range of pressures spanning the expected range of TDG in the river. The membrane was then installed on the TDG sensor and retested.

Data Completeness

To ensure the accuracy and integrity of the TDG data in the lower Columbia River, hourly values were reviewed relative to concurrent field measurements, laboratory instrument calibrations, and daily intersite comparisons. A summary of the completeness of the TDG percent saturation data is shown in table 2. Data were based on the total number of hourly TDG and barometric pressure data values that could have been collected during the monitoring season. No barometric pressure data were missing when TDG data were available during water year 2015, so data completeness relies on TDG data only. TDG saturation values were considered to meet quality-assurance standards if they were within ±1-percent saturation of the expected value.

Table 2. Completeness and quality of total-dissolved gas data, lower Columbia River, Oregon and Washington, water year 2015.

[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)	4,342	8	99.8
John Day tailwater (JHAW)	8,760	2,459	71.9
The Dalles forebay (TDA)	4,344	12	99.7
The Dalles tailwater (TDDO)	8,760	12	99.9
Bonneville forebay (BON)	4,368	7	99.8
Cascade Island (CCIW)	4,535	11	99.8
Warrendale (WRNO)	8,760	172	98.0
Camas (CWMW)	4,535	33	99.3

Periods for which substantial amounts of TDG data were either missing from the database or were later deleted from the database because they did not meet quality-assurance standards, are listed in table 3. Failed Geostationary Operational Environmental Satellite (GOES) transmissions and interrupted communications between the DCPs and Hydrolabs were the most common causes of missing data.

Most deleted data were from the John Day tailwater station. Erroneously low TDG values, determined by comparisons with the reference instrument in an adjacent pipe, have occasionally been a problem during the last several years. As part of the investigation of the low TDG values, an auxiliary TDG sensor was deployed in the reference (secondary) pipe at the site from August 19, 2015, to September 14, 2015,. Comparison of the TDG values between the instruments in the two pipes during this period indicated that decreased TDG values did not occur within the secondary pipe. The deleted data from August 19, 2015, to September 14, 2015, were therefore replaced with auxiliary data (514 hourly values), improving the data completeness at the site to 77.8 percent for the water year.

Table 3. Periods of missing or deleted real-time total-dissolved-gas (TDG) data, lower Columbia River, Oregon and Washington, water year 2015.

[USACE (U.S. Army Corps of Engineers); Station identifier: JHAW, John Day tailwater; WRNO, Warrendale; CWMW, Camas; GOES, Geostationary Operational Environmental Satellite]

Date	USACE station identifier	Reason / Note
10/06/14 to 10/15/14 04/27/15 to 04/30/15 05/07/15 to 05/13/15 05/15/15 to 05/19/15 06/13/15 to 06/29/15 07/09/15 to 07/21/15 07/29/15 to 08/10/15 08/15/15 to 08/19/15 08/21/15 to 09/14/15 09/16/15 to 09/30/15	JHAW	Erroneously low TDG values due to conditions within the deployment pipe. Data deleted.
11/02/14 to 11/04/14 11/06/14 to 11/14/14 04/09/15 to 04/10/15	WRNO	Failed communication between the datalogger and the water-quality instrument. Data missing.
09/06/15 to 09/08/15 09/21/15 to 09/23/15	WRNO	Erroneously low TDG values due to instrument resting on riverbed. Data deleted.
08/12/15 to 08/13/15	CWMW	Erroneous values due to ruptured membrane on TDG sensor. Data deleted.
07/29/15 to 07/30/15	All sites	Failed transmissions due to regional GOES outage. Data recovered.

Quality-Assurance Data

The collection of accurate data for TDG, barometric pressure, and water temperature involves several quality-assurance procedures, including side-by-side instrument comparisons in the field, sensor calibrations in the laboratory, daily checks of the data, and data review and archiving. The results of the quality-assurance procedures for water year 2015 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 for at least 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 were also made at pressures of 100, 200, and 300 mm Hg (mercury) greater than barometric pressure (approximately 113-, 126-, and 139-percent saturation, respectively). The accuracy of the TDG sensors was calculated as the difference between the primary standard and the TDG sensor reading (expected minus actual) for each of the four test conditions divided by the barometric pressure and multiplied by 100 to obtain a percentage difference. Of the 85 laboratory checks that were performed on instruments after field deployment, all but 1 were within ±0.5-percent saturation for all 4 test conditions (fig. 2).

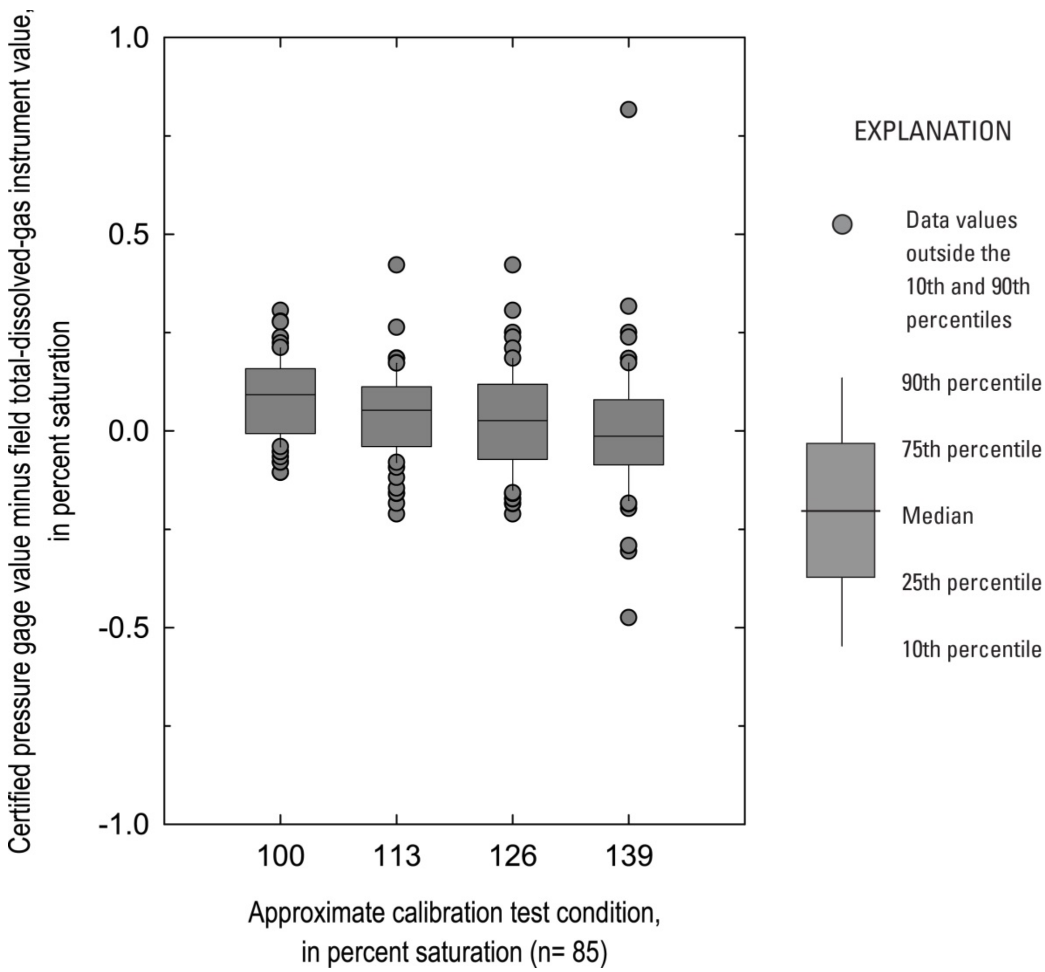


Figure 2. Boxplot showing accuracy of total-dissolved-gas sensors in the laboratory after 3 or 4 weeks of field deployment at eight monitoring stations in the lower Columbia River, Oregon and Washington, water year 2015 (number of comparison values =85).

The differences in barometric pressure, water temperature, and TDG between the secondary standard instruments and the station monitors at the end of their field deployment were measured and recorded as part of every field inspection. These differences, calculated as the 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 with the secondary standard (a recently calibrated Hydrolab) positioned alongside the monitor deployed in the river. A digital barometer (NIST certified through March 2016) served as the primary standard for barometric pressure. The distribution of quality-assurance data for each of the three parameters from the eight stations is shown in figures 3, 4, and 5.

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. The secondary standard temperature sensor and the field temperature sensor results are presented in figure 4. All differences were within 0.2°C.

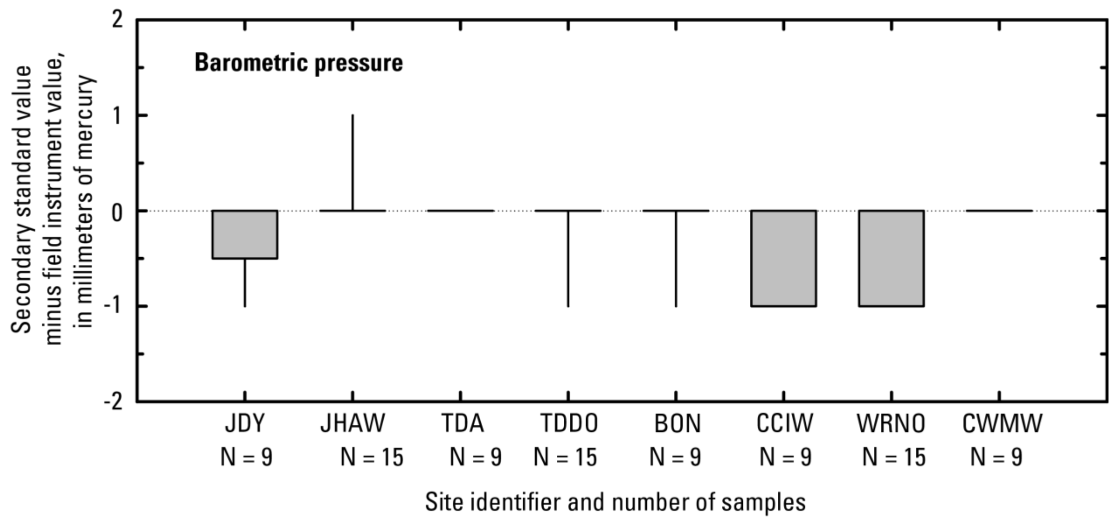


Figure 3. Boxplot showing difference between the secondary standard and the field barometers in the field after 3 or 4 weeks of deployment at eight stations in the lower Columbia River, Oregon and Washington, water year 2015. See figure 2 for explanation of boxplots.

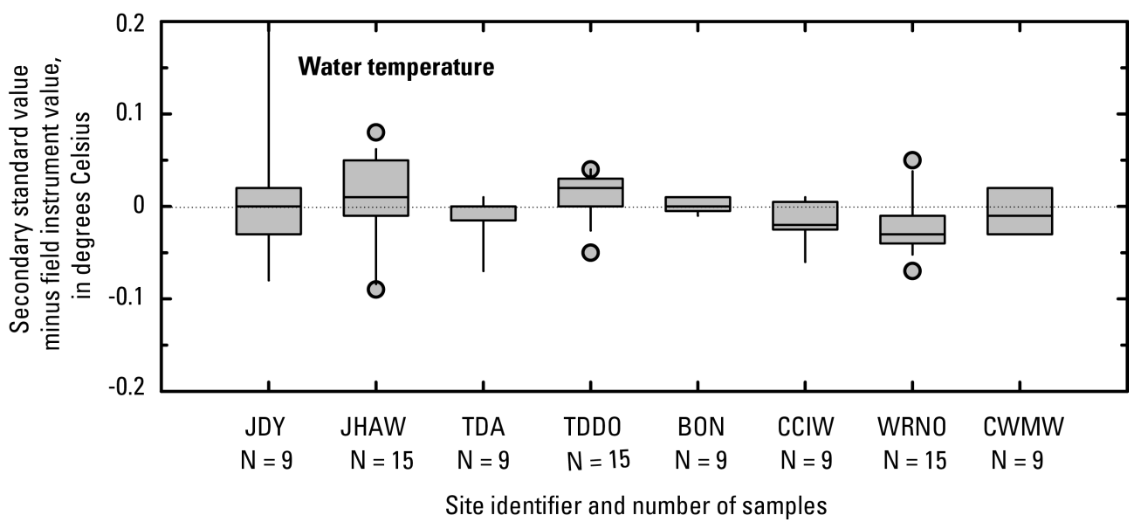


Figure 4. Boxplot showing difference between the secondary standard and the field temperature instruments in the field after 3 or 4 weeks of deployment at eight stations in the lower Columbia River, Oregon and Washington, water year 2015. See figure 2 for explanation of boxplots.

Differences between the secondary standard TDG sensor and the field TDG sensors were calculated following equilibration of the secondary standard instrument to the site conditions before removing the field instrument. The side-by-side equilibrium was considered complete after a minimum of 20 minutes when the TDG values for each sensor remained constant for 3–5 minutes. Excluding the John Day tailwater station, only 1 of the 73 TDG field checks indicated a saturation difference greater than ±1.0 percent (fig. 5). That difference (+1.7 percent) was recorded at The Dalles tailwater station and appeared to be the result of an incomplete equilibration of the reference sensor and no data were deleted.

Of the 16 field checks at the John Day tailwater station, 5 were +2–5 percent and 4 were +5–10 percent. All of the checks with greater than +2 percent difference resulted in periods of deleted data (see table 3). During a station visit on August 19, 2015, the difference between the equilibrated reference sensor (after 40 minutes) and the field sensor was 71 mm Hg (9.4 percent TDG saturation). Rather than removing the field instrument, it was raised and lowered within the deployment pipe for several minutes to increase the water exchange between the pipe and the river. After allowing the field TDG sensor to fully equilibrate again (45 minutes), the two instruments were within 2 mm Hg, indicating that a lack of flow through the primary deployment pipe was causing the low TDG values. Stagnant conditions within the pipe might have been supporting biological processes that depleted dissolved oxygen and lowered TDG values. Hourly data from the auxiliary TDG sensor deployed in the reference (secondary) pipe at the site from August 19, 2015, to September 14, 2015, indicated that TDG values were not decreased in the secondary pipe. Therefore, on October 1, 2015, the secondary reference pipe was designated as the primary deployment pipe and the field instrument was moved into it for data collection.

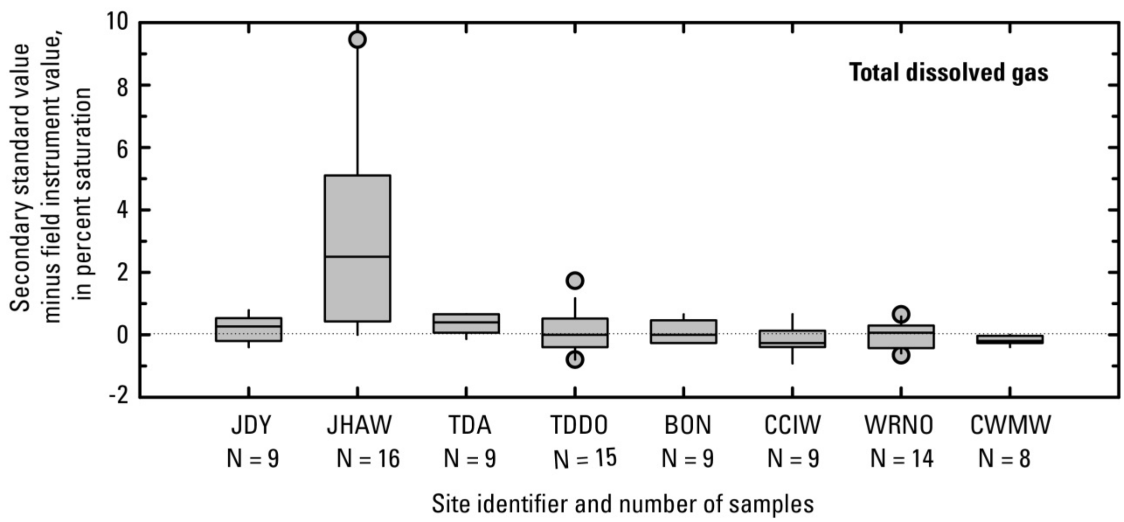


Figure 5. Boxplot showing difference between the secondary standard and the field total-dissolved-gas instruments in the field after 3 or 4 weeks of deployment at eight stations in the lower Columbia River, Oregon and Washington, water year 2015. See figure 2 for explanation of boxplots.

Effects of Spill on Total-Dissolved-Gas Saturation

The relation between spill discharge at the dams and TDG at the corresponding tailwater station or stations are shown for John Day Dam (fig. 6), The Dalles Dam (fig. 7), and Bonneville Dam (fig. 8). For spill between approximately 30,000 and 70,000 ft^3/s, the TDG saturation downstream of John Day Dam generally remained between 110 percent and 116 percent. For spill greater than 70,000 ft^3/s, the TDG saturation increased steadily with greater spill. At the stations downstream of The Dalles Dam and Bonneville Dam, the TDG saturation values generally increased with greater spill over the entire range of values.

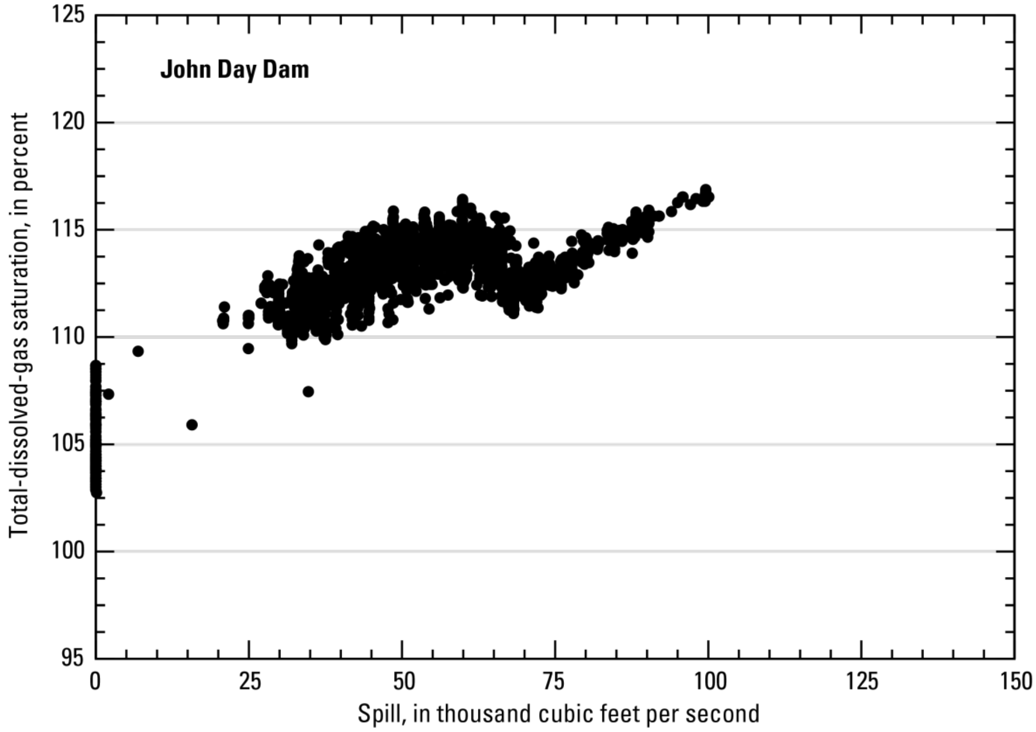


Figure 6. Graph showing relation of total-dissolved-gas saturation downstream of John Day Dam and spill from John Day Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2015.

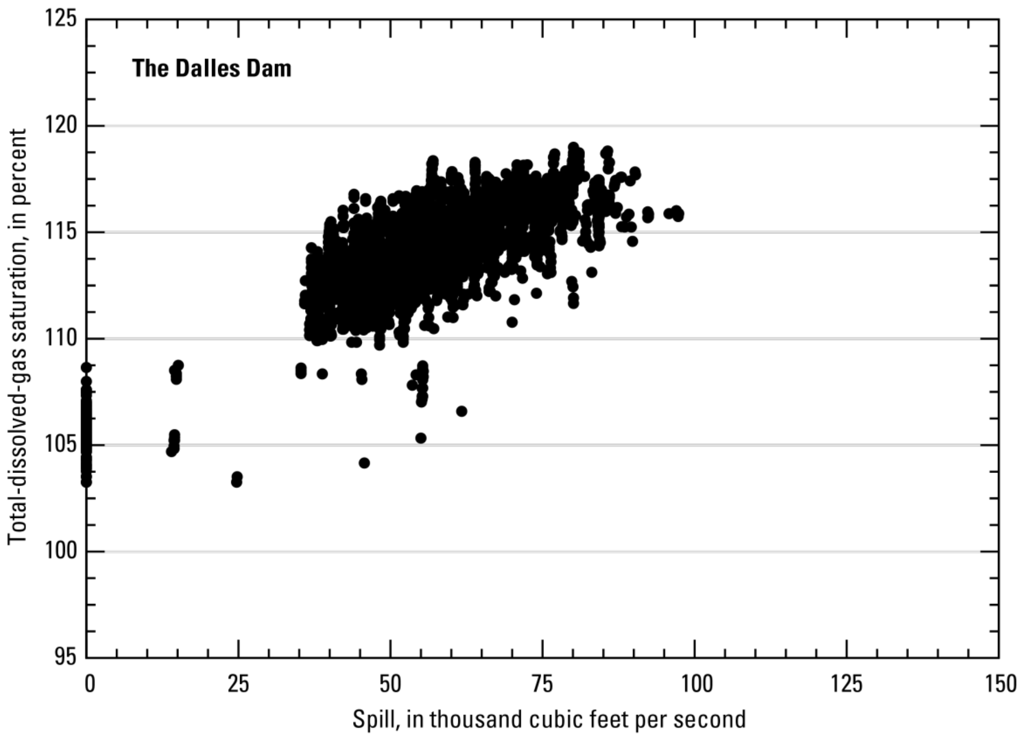


Figure 7. Graph showing relation of total-dissolved-gas saturation downstream of The Dalles Dam and spill from The Dalles Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2015.

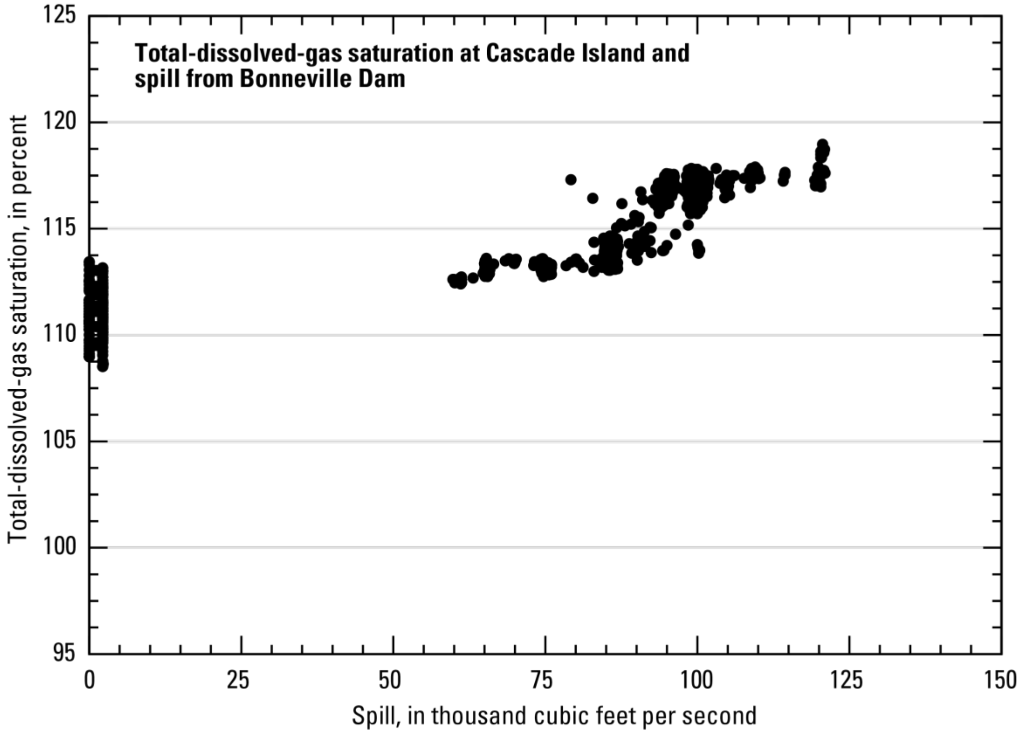


Figure 8. Graph showing relation of total-dissolved-gas saturation downstream of Bonneville Dam at Cascade Island and spill from Bonneville Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2015

Total-Dissolved-Gas and Water-Temperature Data

The distribution of hourly TDG values for the 2015 spill season (April 1–August 31, 2015) is shown in figure 9. Time-series plots of the hourly TDG percent saturation and the spill at the closest upstream dam are shown in figures 10–17.

The hourly values for water temperature are shown in figures 18–22. Water temperatures at the forebay stations were approximately equal to the temperatures at the tailwater stations, except during short periods at the John Day Dam stations and at the Bonneville forebay and Warrendale stations.

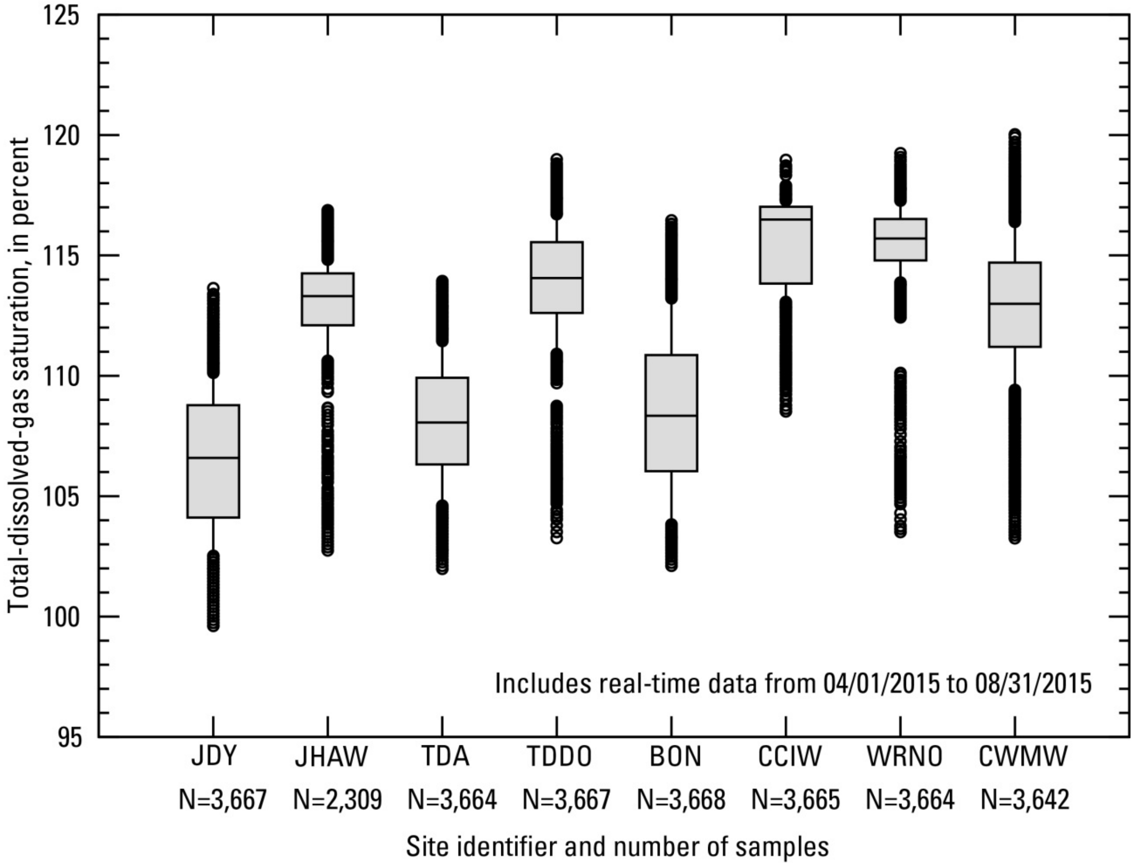


Figure 9. Boxplot showing distributions of hourly total-dissolved-gas data, lower Columbia River, Oregon and Washington, April 1–August 31, 2015. See figure 2 for explanation of boxplots.

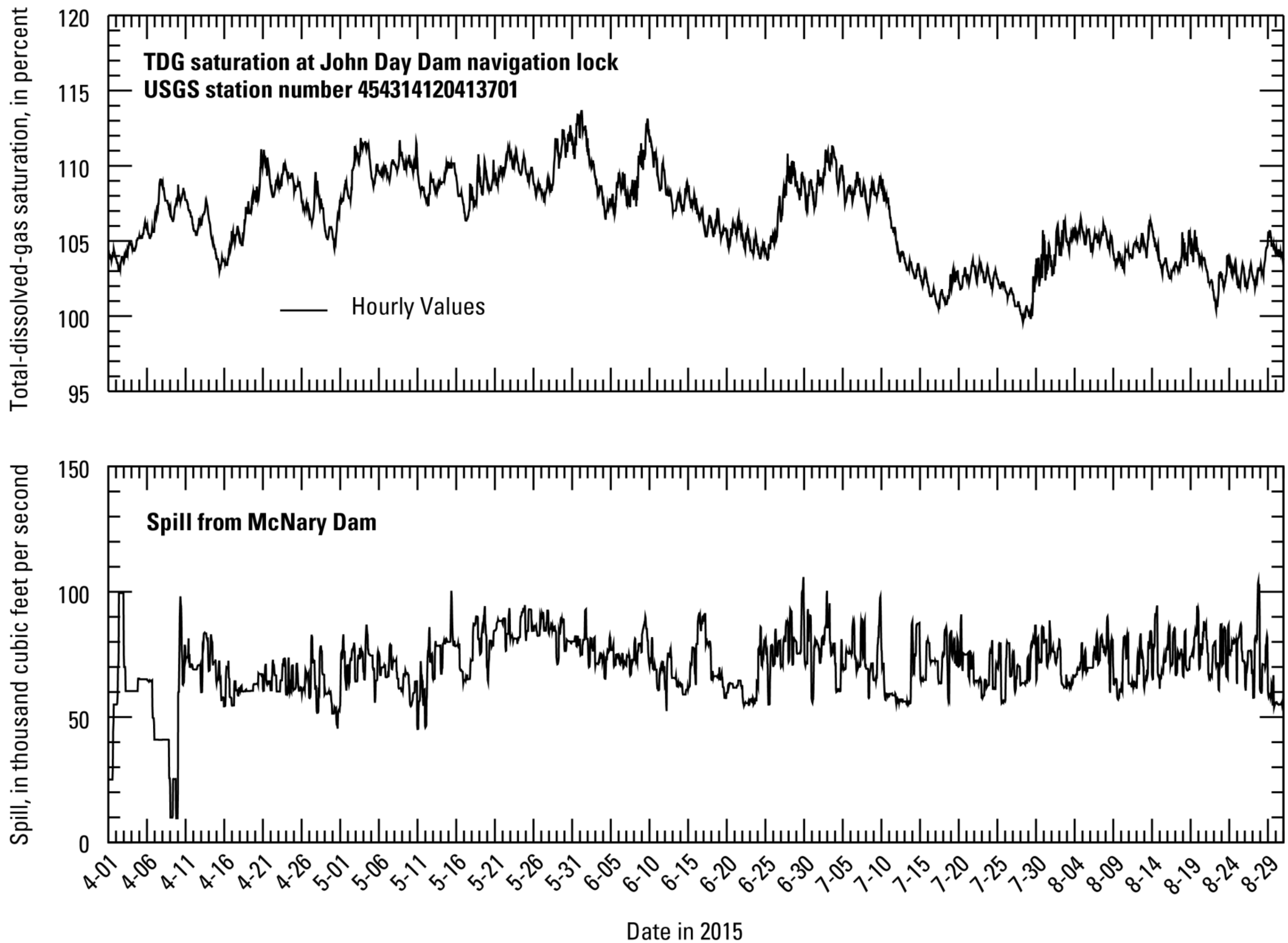


Figure 10. Graphs showing total-dissolved-gas (TDG) saturation at John Day navigation lock and spill from McNary Dam (76 river miles upstream of John Day Dam), lower Columbia River, Oregon and Washington, April 1–August 31, 2015.

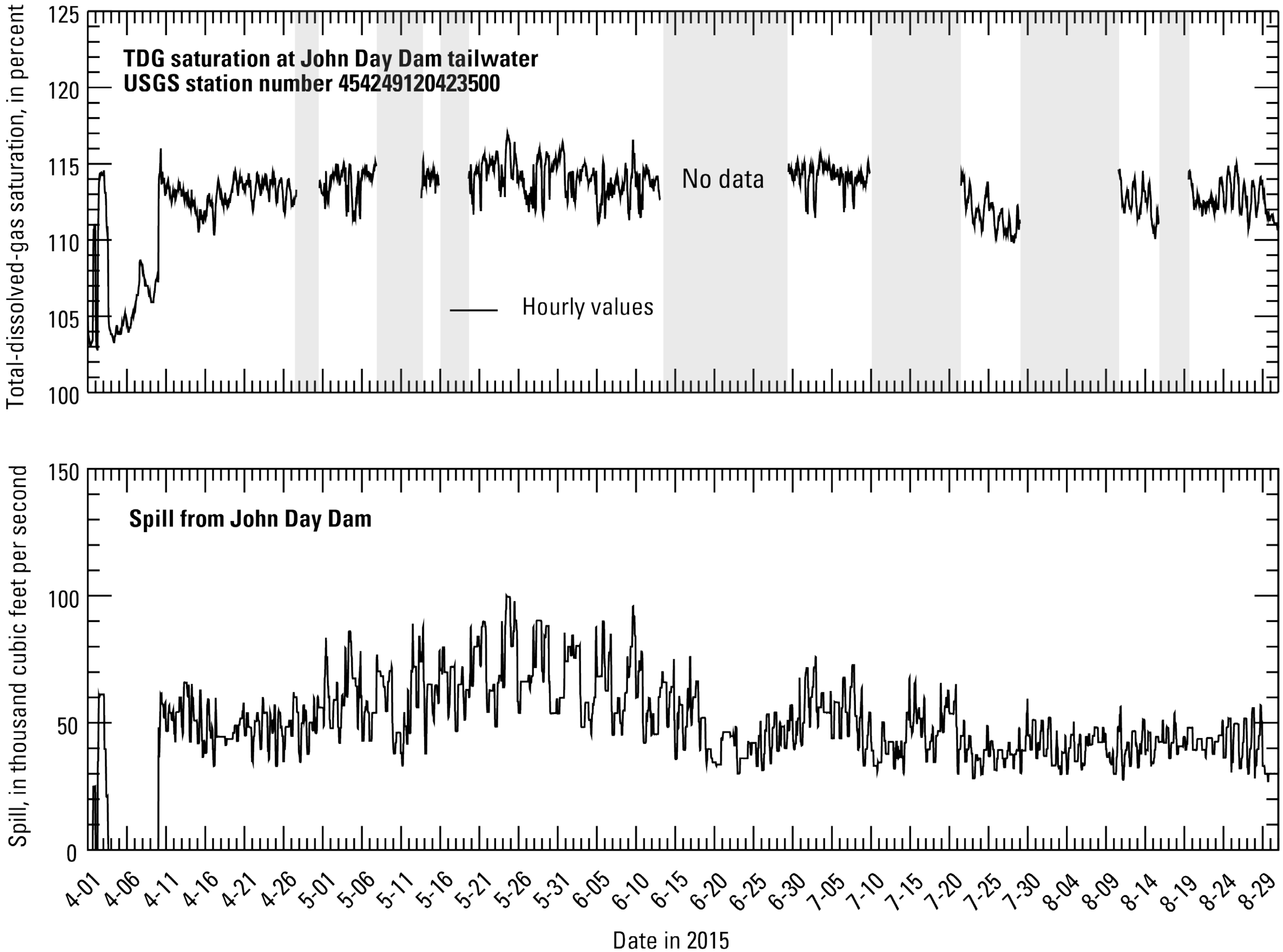


Figure 11. Graphs showing total-dissolved-gas (TDG) saturation at John Day tailwater and spill from John Day Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2015.

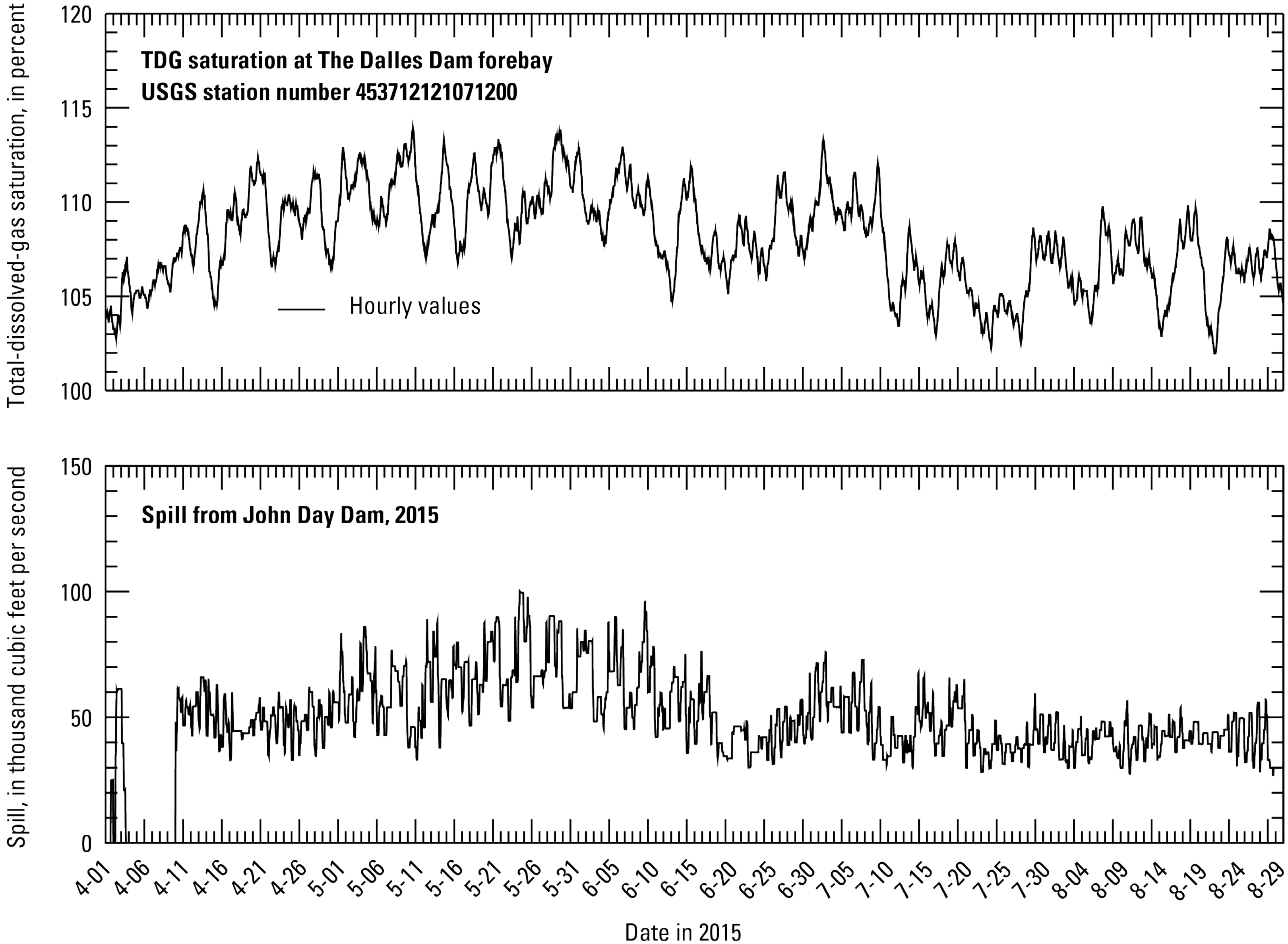


Figure 12. Graphs showing total-dissolved-gas (TDG) saturation at The Dalles forebay and spill from John Day Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2015.

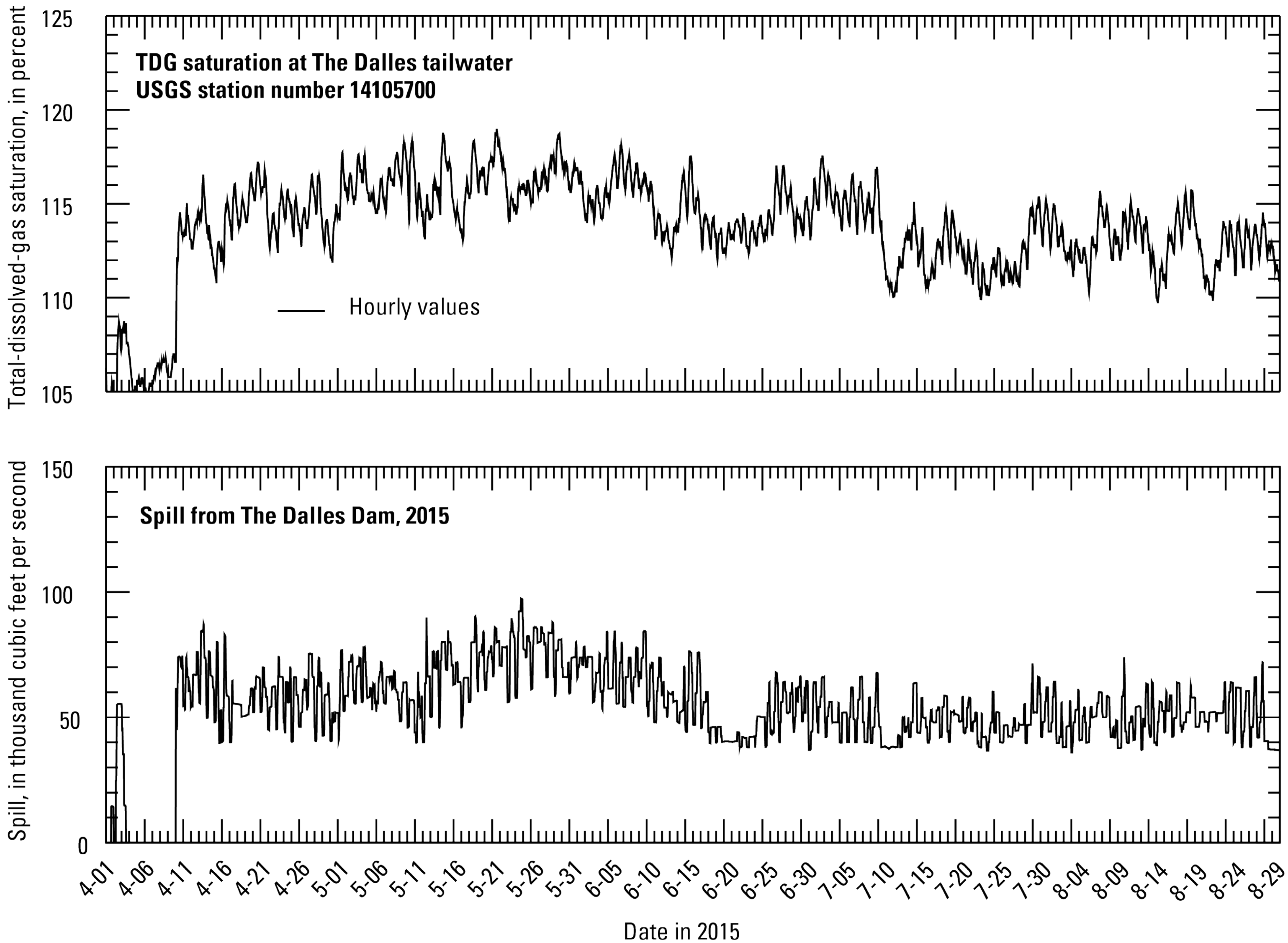


Figure 13. Graphs showing total-dissolved-gas (TDG) saturation at The Dalles tailwater and spill from The Dalles Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2015.

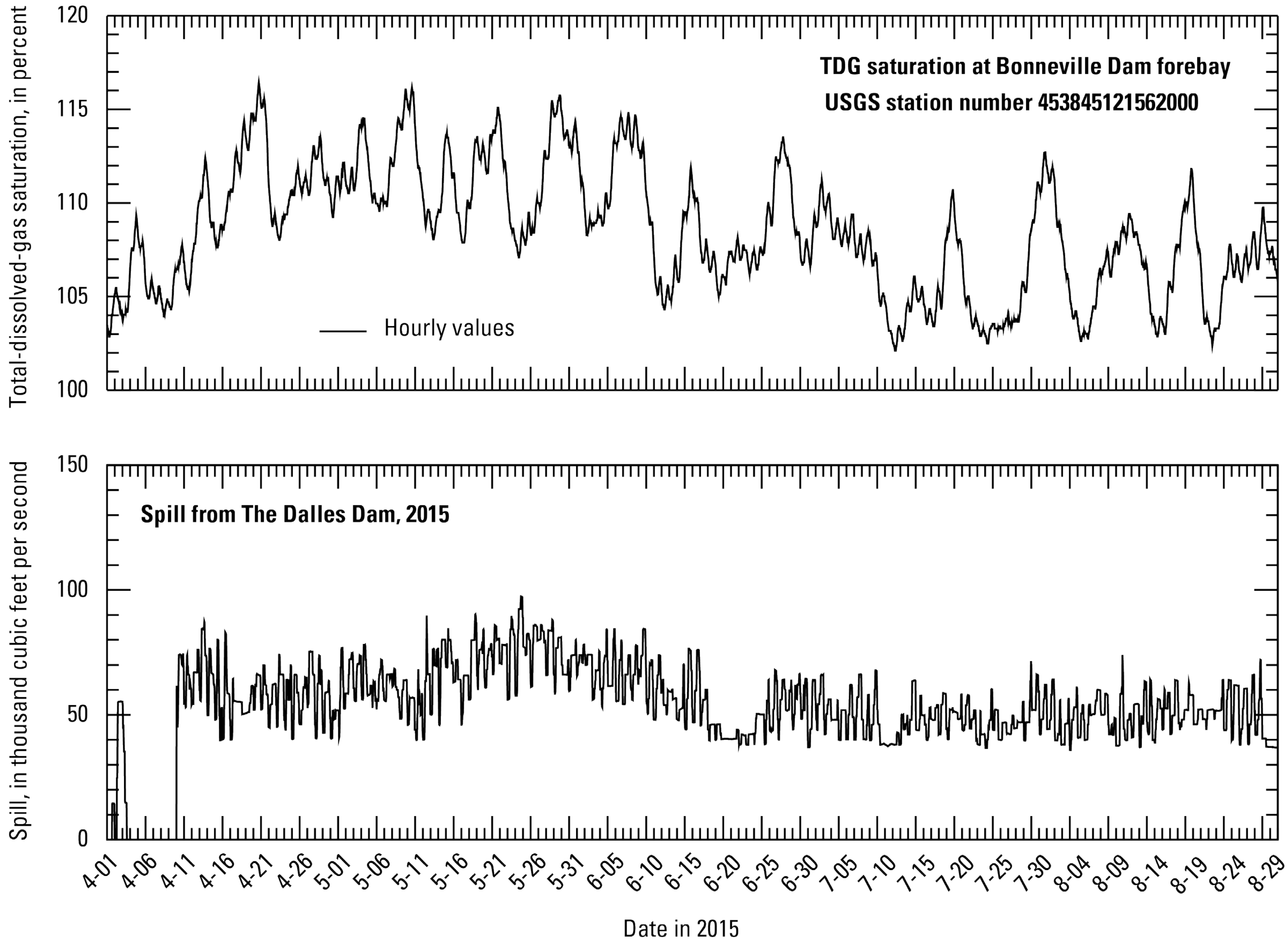


Figure 14. Graphs showing total-dissolved-gas (TDG) saturation at Bonneville forebay and spill from The Dalles Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2015.

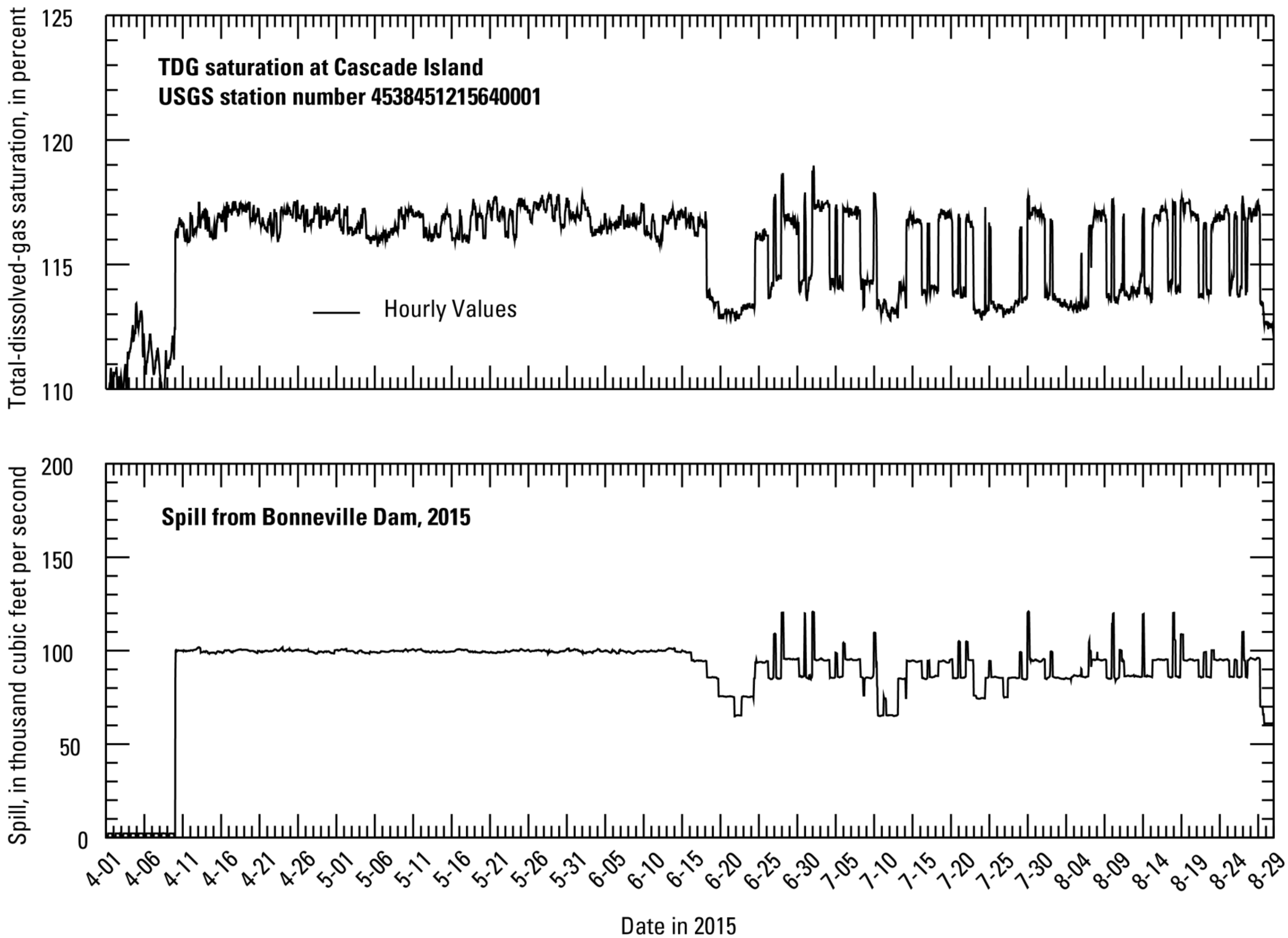


Figure 15. Graphs showing total-dissolved-gas (TDG) saturation at Cascade Island and spill from Bonneville Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2015.

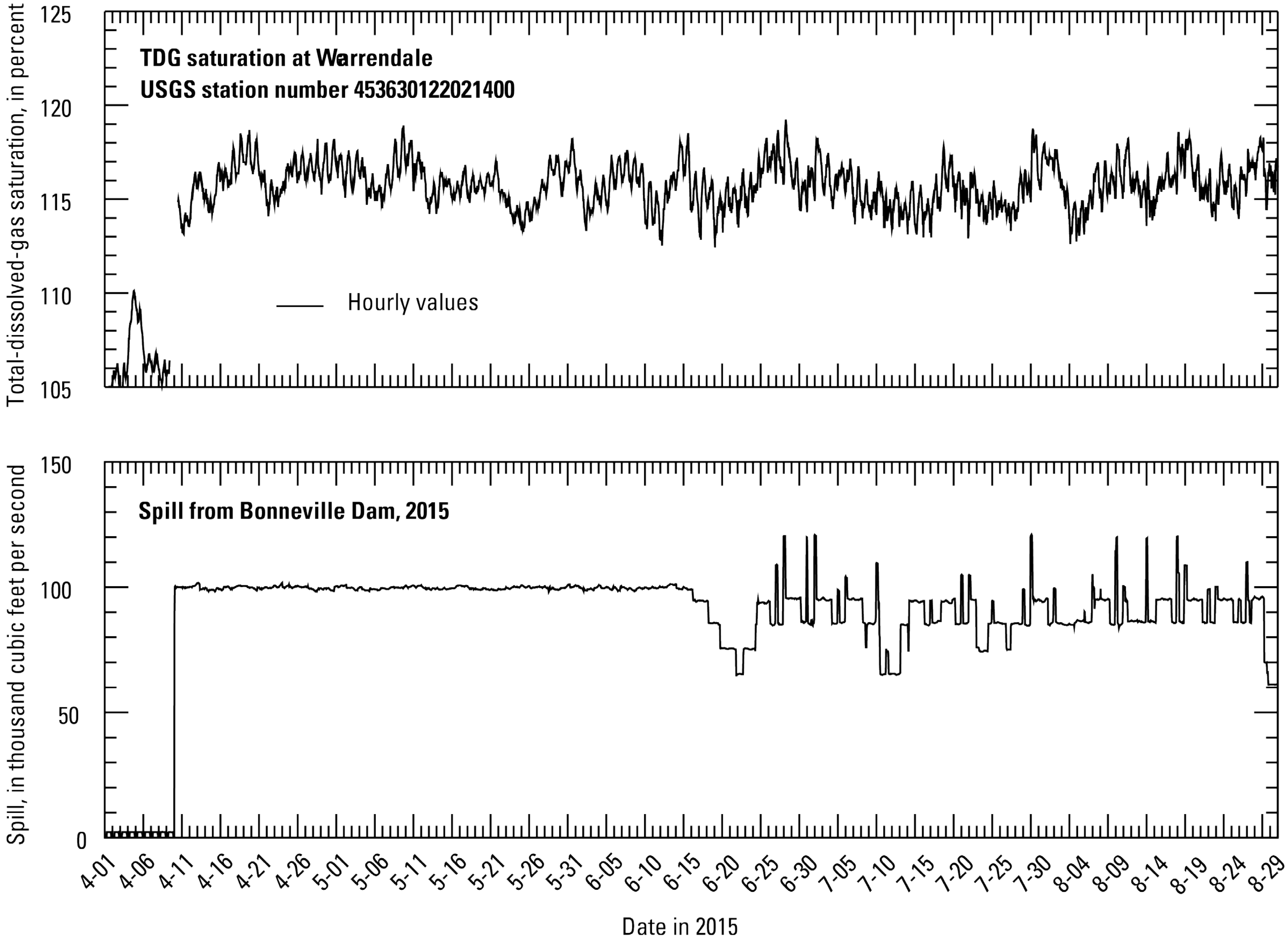


Figure 16. Graphs showing total-dissolved-gas (TDG) saturation at Warrendale and spill from Bonneville Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2015.

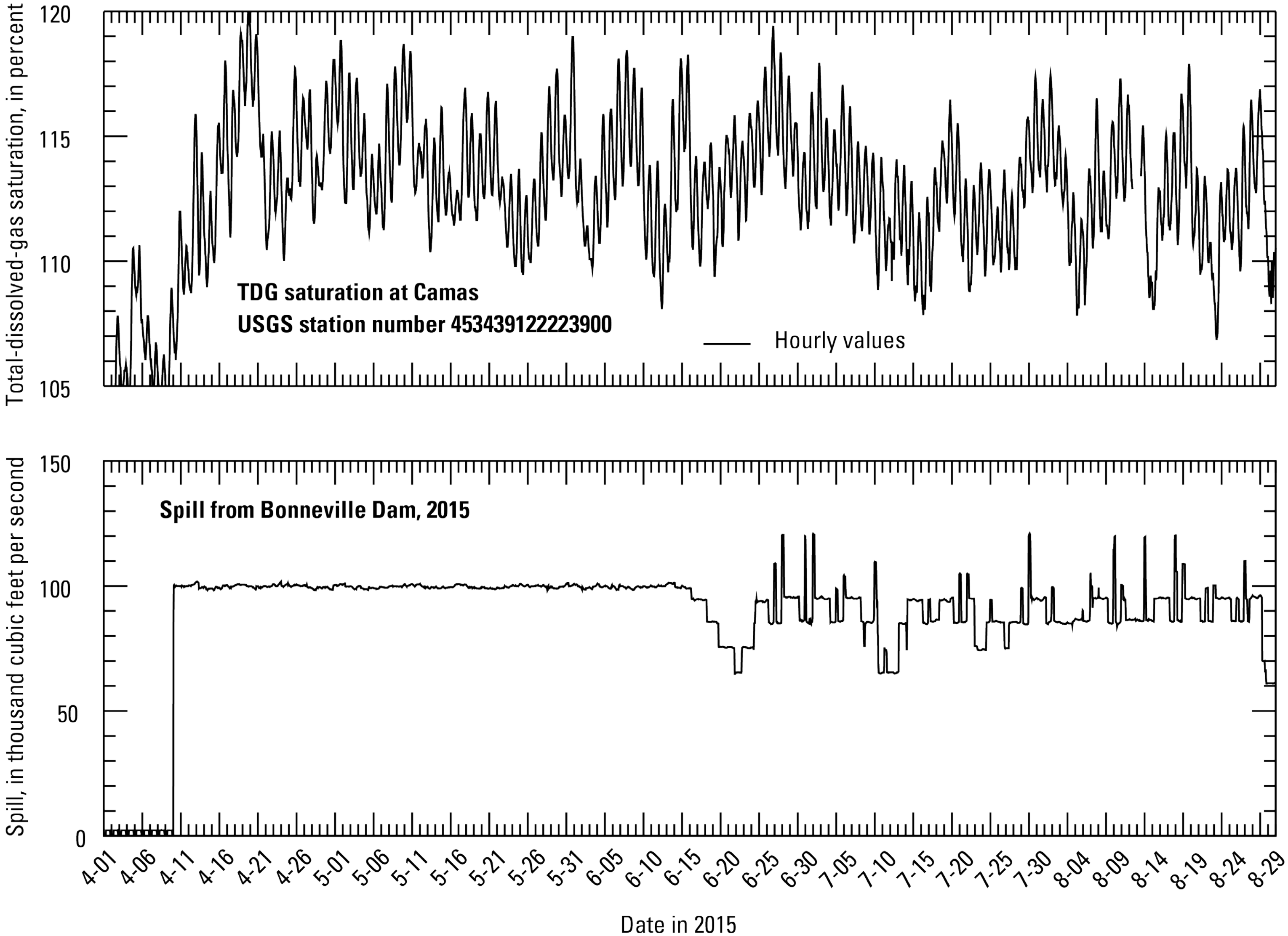


Figure 17. Graphs showing total-dissolved-gas (TDG) saturation at Camas and spill from Bonneville Dam, lower Columbia River, Oregon and Washington, April 1–August 31, 2015.

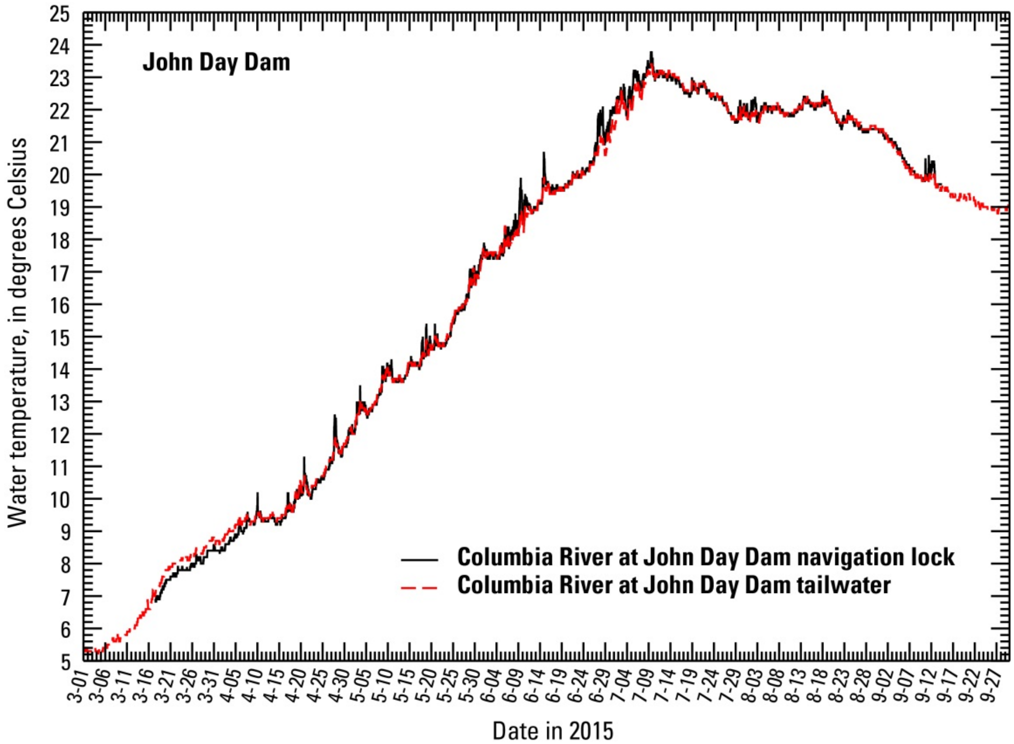


Figure 18. Graph showing water temperature upstream of John Day Dam and downstream of John Day Dam, lower Columbia River, Oregon and Washington, March–September 2015.

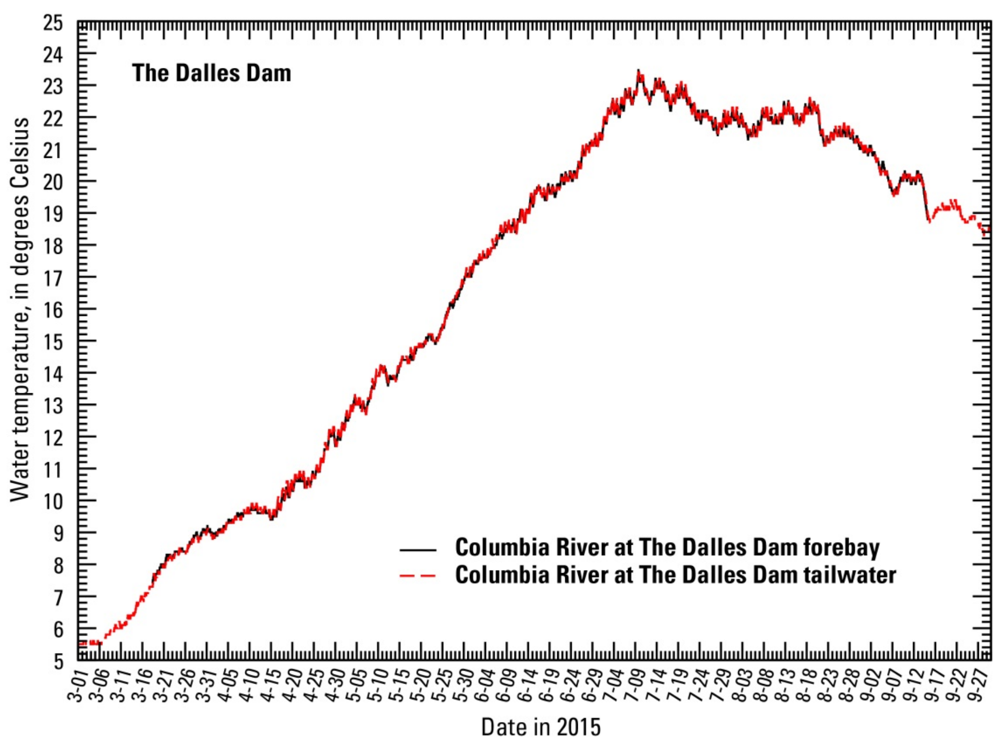


Figure 19. Graph showing water temperature upstream and downstream of The Dalles Dam, lower Columbia River, Oregon and Washington, March–September 2015.

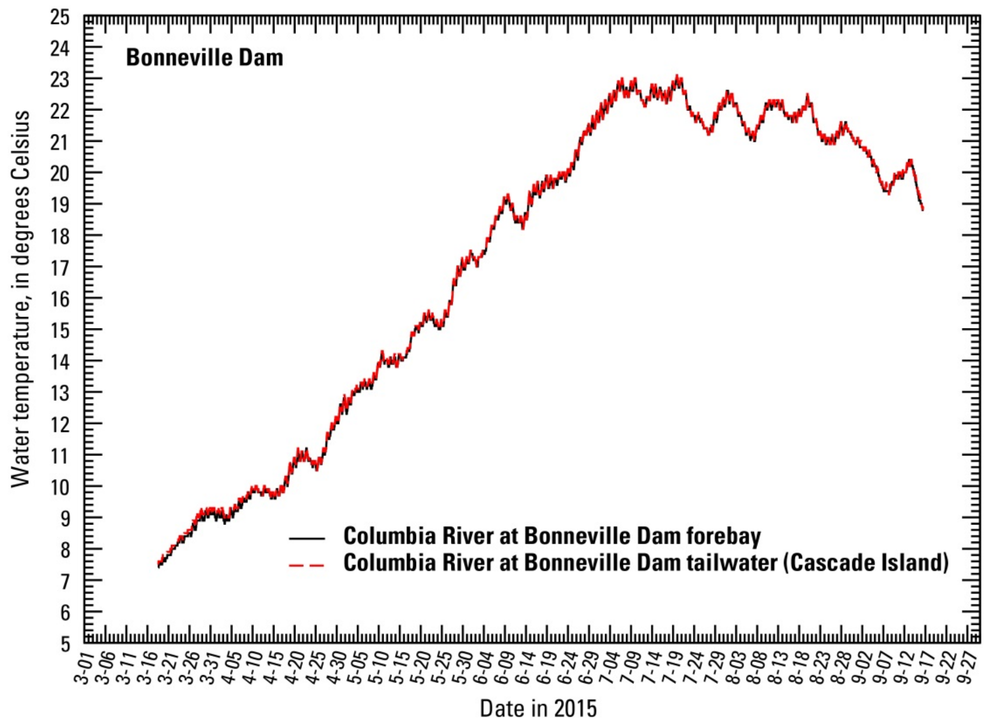


Figure 20. Graph showing water temperature upstream of Bonneville Dam and downstream of Bonneville Dam at Cascade Island, lower Columbia River, Oregon and Washington, March–September 2015.

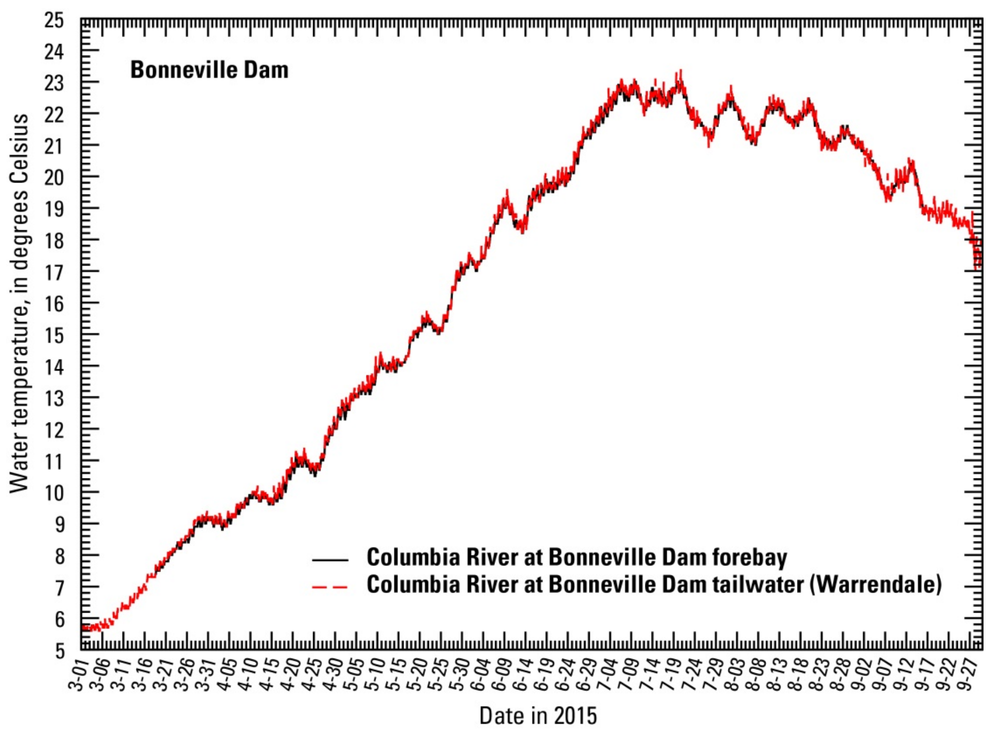


Figure 21. Graph showing water temperature upstream of Bonneville Dam and downstream of Bonneville Dam at Warrendale, lower Columbia River, Oregon and Washington, March–September 2015.

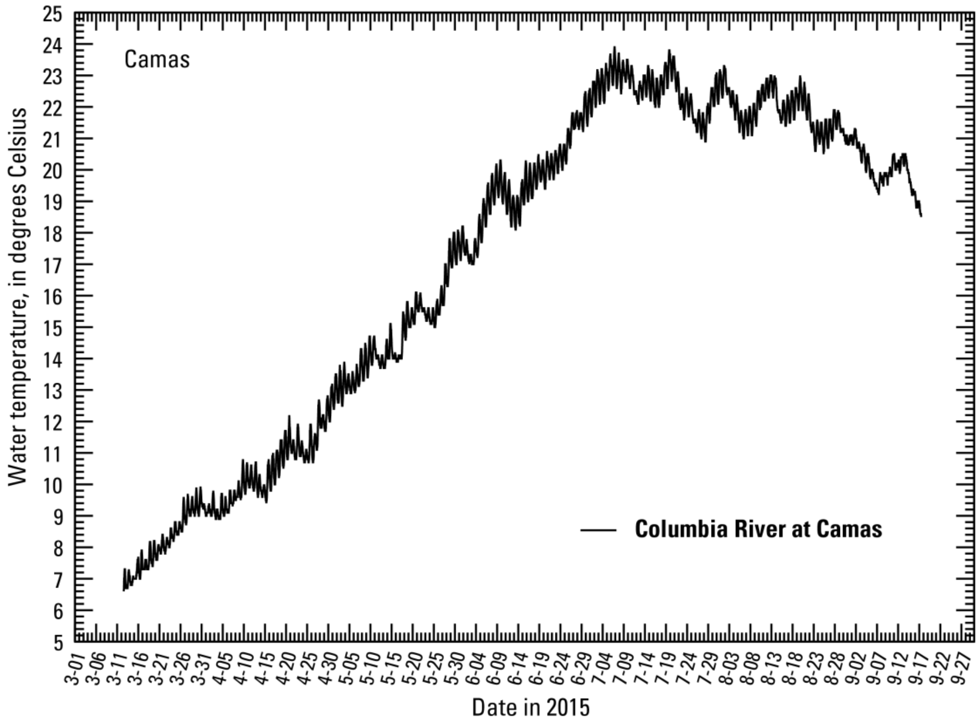


Figure 22. Graph showing water temperature downstream of Bonneville Dam at Camas, lower Columbia River, Oregon and Washington, March–September 2015.

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