



Water Quality Monitoring for Devils Tower National Monument *2016 Data Report*

Natural Resource Data Series NPS/DETO/NRDS—2020/1256



ON THE COVER

Photograph of Belle Fourche River at Devils Tower National Monument, WY, 2013
Photograph courtesy of NPS

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2016 Data Report

Natural Resource Data Series NPS/DETO/NRDS—2020/1256

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of those protocols

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Abstract

The Northern Great Plains Inventory and Monitoring Network (NGPN) began monitoring water quality in the Belle Fourche River at Devils Tower National Monument (DETO) in 2013, with the assistance of the U.S. Geological Survey (USGS). This report summarizes the second sampling season in 2016 for streamflow, water temperature, dissolved oxygen, specific conductance, and pH. The sampling was conducted during the ice-free season from March 9, 2016 to November 1, 2016.

2016 was a dry year and stage height on the Belle Fourche River peaked at 2.9 feet in early August, 5 ft lower than the highest recorded in 2013. There was considerable seasonal variation in all water quality measures. A summary of our results can be found in Descriptive Statistics Summary tables for the ice-free season (Table 3 in Results section) and for each month (Table 4 in Results section). Notably, dissolved oxygen concentrations dropped below 5 mg/ L, a Wyoming state water quality standard, 21 times during mid-June 2016.

NGPN's collaboration with USGS supported real-time and archived access to this data through the USGS National Water Information System Website, where it remains available to the public.

Introduction

Devils Tower National Monument (DETO) was established in 1906 as the first National Monument in the United States, with a mission to preserve the Tower and the surrounding 1347 acres (545 ha) of ponderosa pine forests, mixed-grass prairies, and riparian corridor along the Belle Fourche River. Although there are several springs in the Monument, the Belle Fourche River is the major hydrologic feature of the park (NPS 1997). The Belle Fourche River is about 290 miles (470 km) long from the headwaters in northeastern Wyoming to its confluence with the Cheyenne River near Rapid City, South Dakota (Figure 1). Northeastern Wyoming is a dry region; on average receiving 17 inches of precipitation annually, with two-thirds occurring as rain in the spring and summer.

Approximately 2 miles (3.6 km) of the Belle Fourche River run through DETO as the river flows northeast toward South Dakota. In this area, river flow tends to peak between March and June, while annual low flows occur in November and December. River flow seasonality has been limited since 1952 by the construction of the Keyhole Reservoir and dam upstream of DETO. This reduced floods that cottonwood seedlings relied on for germination and establishment (Martin 1995). The river has become deeply incised, creating areas along the river where the water table is now 1.7-2.2 m deep and typical riparian vegetation, such as willows, are largely absent, having been replaced by grassland (Anderson 2013).

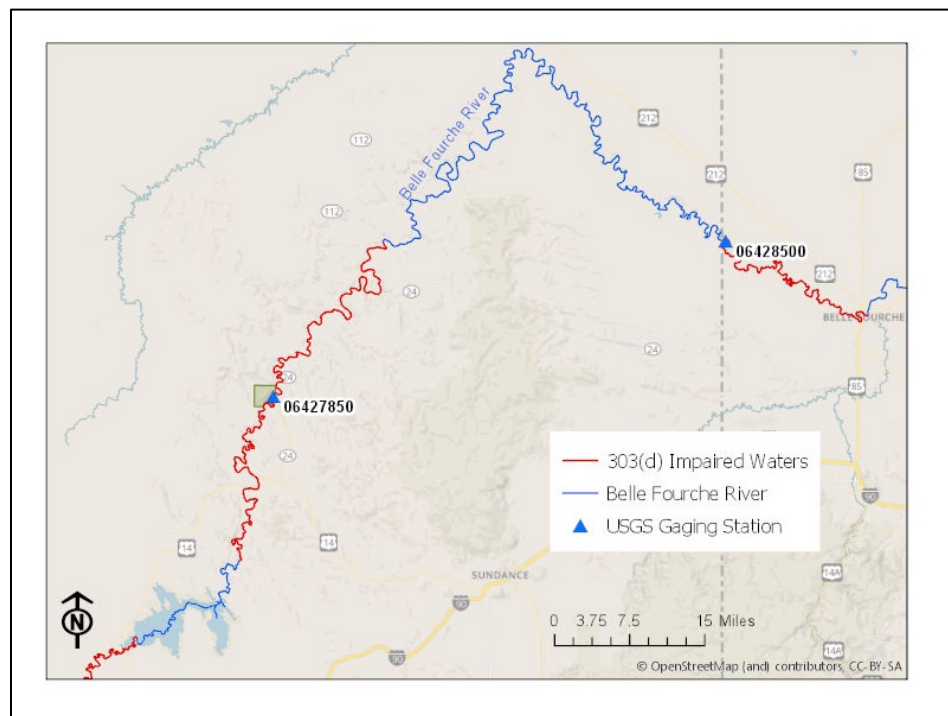


Figure 1. Map of the Devils Tower National Monument and the Belle Fourche River in Wyoming. The stretch of the river running through the monument, highlighted in red is listed as impaired under 303(d) criteria for fecal coliform bacteria.

Primary land uses in the region and river basin include livestock grazing, hay production, mineral extraction, and oil and gas production (WYDEQ 2018b). The Belle Fourche River is designated as a Class 2AB warm water fishery, defined as a water known to support game fish populations or spawning and nursery areas at least seasonally and where a game fishery and drinking water use is attainable (WYDEQ 2018b). Several stretches of the river are listed as impaired waterways under section 303(d) of the Clean Water Act, including the 20-mile stretch running through DETO. This section is 303(d) listed for fecal coliform bacteria (WYDEQ 2018b). Water quality monitoring at DETO in the 1970s found fecal coliform bacteria levels above state thresholds on several occasions in 1974 and 1975 (NPS 1997). Failing septic systems and livestock are likely contributing to the high bacteria loads (Tetra Tech Inc 2013). Crook County Natural Resource District developed a watershed plan to address these impairments, and has been conducting monitoring, and implementing septic, range, and water improvement projects (WYDEQ 2018b). For more details and current impairment information visit the Wyoming Department of Environmental Quality website.

The Northern Great Plains Inventory & Monitoring Network (NGPN) began monitoring water quality at DETO in 2013 to better understand current conditions and changes over time in the Belle Fourche River (Ashton et al. 2020). The monitoring is conducted at the gaging station at Devils Tower National Monument, WY (Monitoring Location 06427850; Figure 2) in collaboration with the United States Geological Survey (USGS). The objective is to determine the status and long-term trends of core water quality parameters during the ice-free season. NGPN repeats water quality monitoring at DETO every three years, (Wilson et al. 2014), conducting in-depth analysis of status and trends after 3 to 5 cycles of sampling. This report summarizes data from the second season of water quality sampling in 2016.

NGPN's core water quality parameters include streamflow, dissolved oxygen (DO), pH, specific conductivity, and water temperature (Table 1). These parameters were measured every 15 minutes throughout the ice-free season (typically March to November), and results were made available in real-time on the USGS National Water Information System Website.



Figure 2. Map of Devils Tower National Monument and water quality monitoring location (blue triangle) and nearby weather stations (red flags). Climate data in this report is taken from the DEVILS TWR 2 weather station.

Table 1. Water quality parameters measured as part of the Northern Great Plains Inventory & Monitoring Water Quality Program and associated state standards (WYDEQ 2018a). These standards are not enforceable in periods of low flow, as defined by the minimum seven consecutive day flow which has the probability of occurring once in ten years (WYDEQ 2018a).

Water Quality Parameter	Description	WY state standards applicable to warm water fisheries designations
Water temperature (°C)	Water temperature is affected by solar radiation, air temperature, rainfall, flow dynamics, stream shading, in-stream bed material and reflectance and land use/cover in the watershed.	Pollution attributable to the activities of man shall not change ambient water temperatures to levels which result in harmful acute or chronic effects to aquatic life, or which would not fully support existing and designated uses. When ambient temperatures are above 15.6°C, pollution attributable to the activities of man shall not result in an increase of more than 2.2°C The maximum allowable stream temperature will be the maximum natural daily stream temperature plus the allowable change, provided that this temperature is not lethal to existing fish life and under no circumstance shall pollution attributable to the activities of man result in a temperature that exceeds 30°C
Dissolved Oxygen (mg/L)	Dissolved oxygen level is a measure of the amount of oxygen in the water column and an important indicator of a water body's ability to support aquatic life.	Minimum criteria include • 30-day mean of 5.5 mg/L • 7-day mean of 6.0 mg/L • 7-day mean minimum of 4.0 mg/L • 1-day minimum of 5.0 mg/L
Specific Conductance (µS/cm)	Specific conductivity is a measure of the water's ability to conduct electricity. Specific conductivity is typically proportional to the dissolved major ions in the water such as calcium, magnesium, sodium, and sulfate.	No criteria
pH	The pH of the stream is a measure of the hydrogen ion concentration in the water. Different organisms flourish within different ranges of pH.	Pollution attributable to the activities of man shall not be present in amounts which will cause the pH to be less than 6.5 or greater than 9.0 standard units. Pollution attributable to the activities of man shall not change the pH to levels which result in harmful acute or chronic effects to aquatic life, directly or in conjunction with other chemical constituents, or which would not fully support existing and designated uses.

Methods

The NGPN Water Quality Monitoring Protocol (Wilson et al. 2014) sets out the methods used for sampling water quality and streamflow. The general approach is briefly described below. For more detail, please see Wilson et al. 2014 (available at <https://www.nps.gov/im/ngpn/water-quality.htm>).

Data Collection

Water quality data are collected at a real-time USGS stream gage (ID number 06427850) inside the park, at 3840 ft. elevation. Water quality and stage height are measured every 15 minutes throughout the ice-free season. Monitoring at DETO began in 2013 and was repeated in 2016, 2019, and every three years thereafter. Program funding currently limits monitoring to a cycle of one year of monitoring, followed by two years without.

In 2016, NGPN partnered with the USGS Wyoming-Montana Water Science Center to have USGS staff collect water quality and streamflow data at DETO. The USGS deployed a continuous, multi-parameter sonde at the gage on March 8, 2016 (Figure 3) and visited the gaging station every 3–4 weeks for equipment maintenance (Table 2). This instrument recorded dissolved oxygen, pH, specific conductivity, and water temperature every 15 minutes, while the gage simultaneously measured stream stage (or gage height).



Figure 3. A researcher deploys a sonde device to measure water quality on the Belle Fourche River at Devils Tower, WY (right panel). The United States Geological Survey Belle Fourche River gaging station (06427850) is set up for real-time data transmission via satellite. Photographs courtesy of NPS.

Satellite telemetry transmitted the water data to the Water Science Center in near real-time (<https://waterdata.usgs.gov/monitoring-location/06427850/>). The USGS staff reviewed the real-time data daily to verify the accurate transfer of provisional field data and to identify sensor malfunctions

or erroneous data. Access to the real-time data allowed them to recognize problems recording equipment malfunction, sedimentation, electrical disruption, debris, or vandalism. If disruptions occurred, the USGS staff scheduled additional site visits to minimize the loss of data.

During each site visit, USGS staff conducted a site inspection and a side-by-side comparison with the in-the-water sonde and an independent field sonde. They serviced and calibrated the sensors as needed (Table 2). Calibration included pre- and post-calibration checks to quantify fouling errors and equipment drift – data critical to correction and grading of the final data. On November 1, 2016, the USGS removed the multi-parameter sonde from the Belle Fourche River.

Quality assurance and quality control was conducted by USGS staff following established USGS guidelines (Wagner et al. 2006). NGPN received the final corrected (approved) data in February of 2017 from the USGS, and used AQUARIUS Workstation by Aquatic Informatics (<http://aquaticinformatics.com/>) and R (R Core Team 2019) to store and analyze water data. Water year reports are provided by USGS and the text can be found in Appendix A. Figures were generated in R and daily mean values were calculated from 15-minute interval data. In the case where there were missing data due to instrument error, means were generated by excluding the missing values and the maximum and minimum were left blank. Means were not calculated for days where all time steps were missing (i.e. the instrument didn't collect any data that day). Discharge data were not available for this site (only stage height), so a nearby stream gauge on the Belle Fourche River at the Wyoming and South Dakota border was used as a proxy (USGS ID number 06428500).

Climate data were downloaded from the Devils Tower 2 (482466) National Weather Service Cooperator Observer Program station. The data were accessed and graphed using the web-based tool [Climate Analyzer](#).

Table 2. Field journal for 2016 Water Quality Sampling at Devils Tower National Monument.

Date	Notes
March 8, 2016	Instrument installed between 12:30 pm and 2 pm.
March 16, 2016	–
March 22, 2016	–
March 24, 2016	–
April 12, 2016	–
May 3, 2016	–
May 24, 2016	Minor algae
June 15, 2016	Lots of algae all through channel, moderate debris.
July 6, 2016	–
July 28, 2016	Moderate to heavy floating moss
August 5, 2016	Cleaned algae off pipe
August 24, 2016	–
October 3, 2016	Algae affecting
November 1, 2016	Moderate algae. Instrument removed ~ 11 am.

Results

The water quality monitoring season (ice-free) on the Belle Fourche River at DETO lasted from March 8, 2016 to November 1, 2016. The discharge of the Belle Fourche River peaked in late April but was generally low during the monitoring period (Figure 4). The maximum recorded gage height was on August 3, 2016 at 2.9 ft and the minimum recorded gage height was recorded in September at 1.09 ft (Appendix A). Compared to the sampling year in 2013 where the peak stage height was over 7 feet and discharge peaked at close to 2500 cubic ft per second, 2016 had much lower flow (Ashton et al. 2020). 2016 was drier than average when compared to 1981-2010 (~85% of average) and average minimum and maximum temperatures were warmer (Figure 5). During 2016 water year, it rained and snowed 15.17 inches with total monthly precipitation peaking in September (Figure 5).

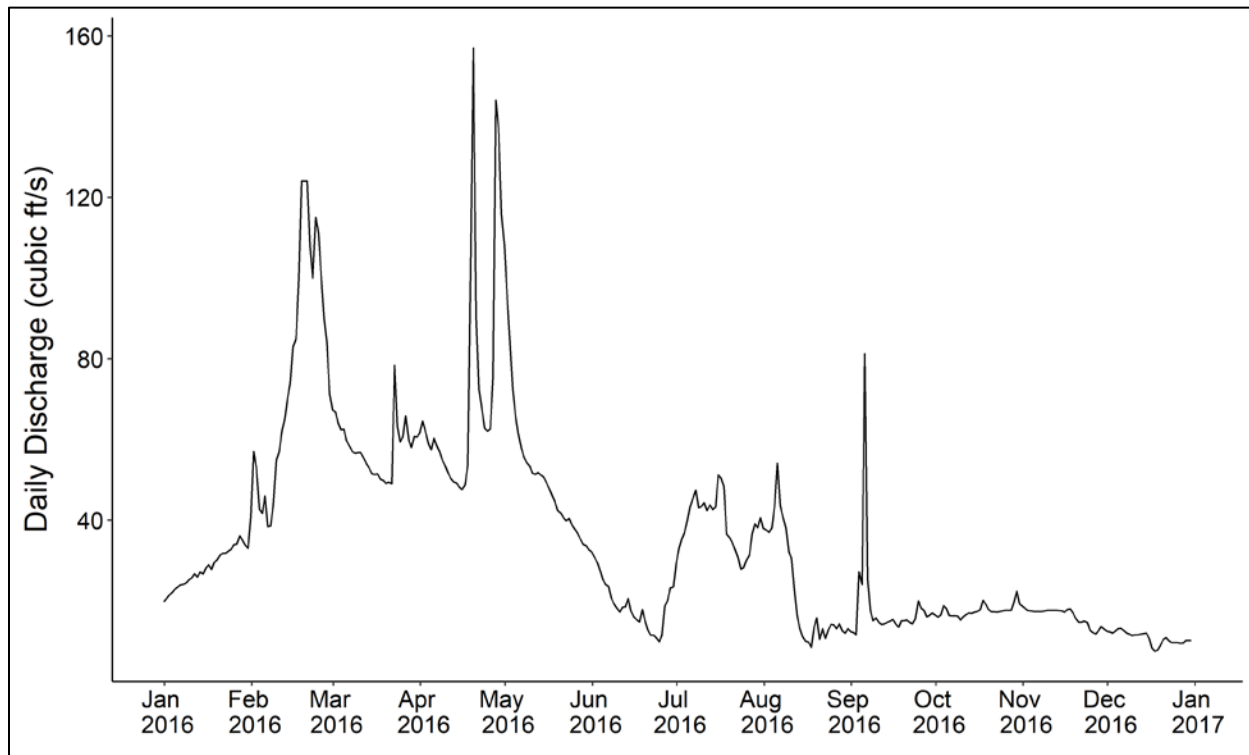


Figure 4. Daily mean discharge (black line) in 2016 on the Belle Fourche River at the Wyoming – South Dakota border, USGS Gaging Station 06428500.

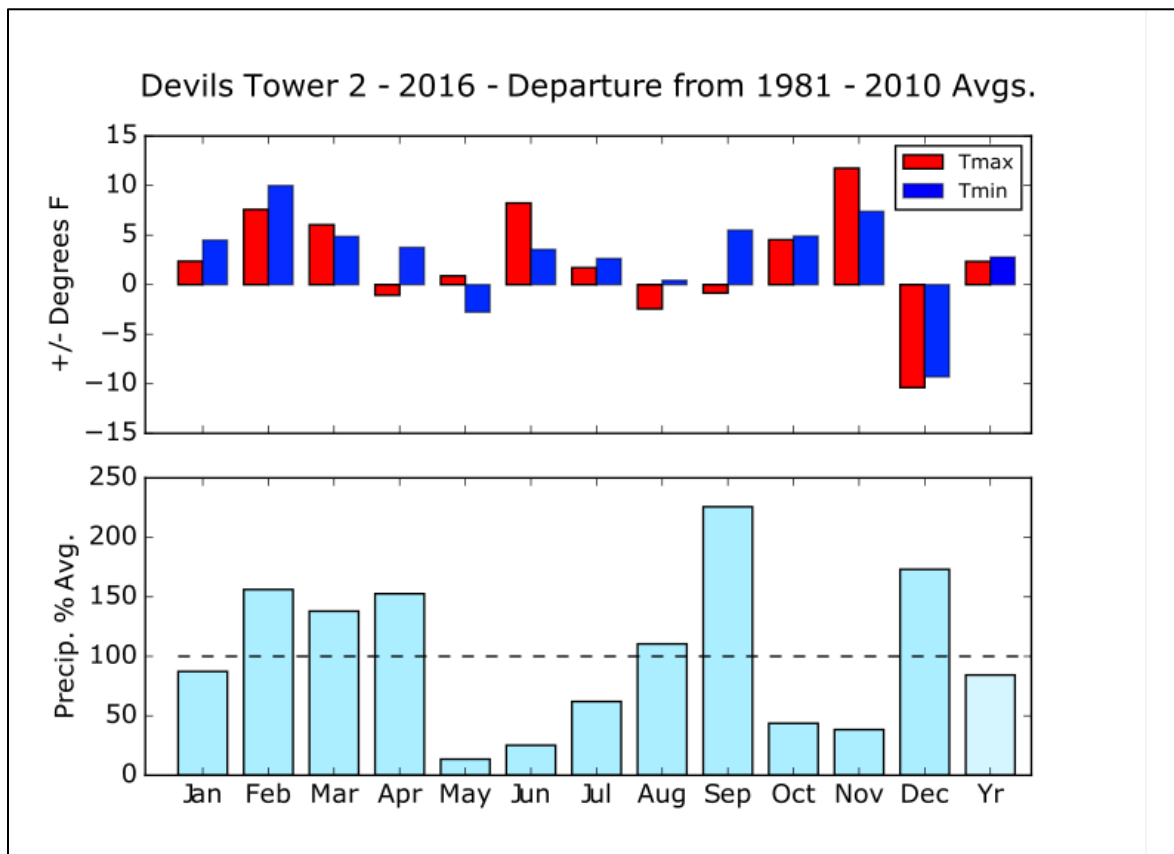
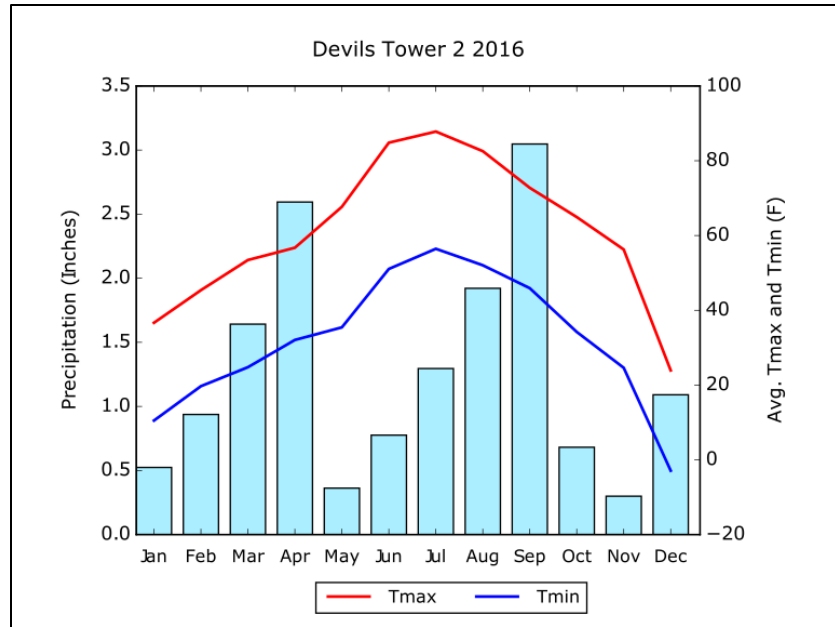


Figure 5. Total monthly precipitation (light blue) and average monthly minimum (blue) and maximum (red) temperature for 2016 in Devils Tower National Monument (top panel). Monthly departures from 1981-2010 average temperature and precipitation for 2016 in Devils Tower National Monument (bottom panel). Climate data are from Devils Tower 2 Station (482466). The data were accessed and graphed using the web-based tool [Climate Analyzer](#).

During the ice-free season at DETO, we collected over 22,000 water quality measurements in the Belle Fourche River (Table 3). We found mean water temperature of 16°C, dissolved oxygen concentrations of 9 mg/L, specific conductance of 1860, and pH of 8 (Table 3). There was, however, variation across months in all parameters (Table 4). Mean water temperature in March was 6°C and increased to a mean of close to 23°C in July before declining back to 10°C in October (Table 4, Figure 6). Maximum water temperature never exceeded the Wyoming water quality standard of 30°C (Table 1), but we did record temperatures as high as 29.6°C in June (Table 4).

Table 3. Summary of descriptive statistics for water temperature, dissolved oxygen, specific conductance, and pH measured for the ice-free sampling period on the Belle Fourche River at Devils Tower National Monument from March 9, 2016 through October 31, 2016. Percent exceedance is the proportion of samples that exceed the respective state regulatory threshold described in Table 1 (water temperature max. limit is 30.0°C; dissolved oxygen $\geq$ 5.0 mg/L and pH range is <6.5 or >9.0).

Descriptive Statistic	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Specific Conductance (µS/cm)	pH
Mean	16.35	9.43	1859.98	8.26
Standard Deviation	6.48	1.99	104.31	0.18
Median	17.1	9.6	1850	8.2
Minimum	0.4	4.9	1550	7.7
Maximum	29.6	15.1	2190	8.7
Number of Points	22440	22342	19533	22336
Number of Points below or above standard	0 (above)	21 (below)	NA	0 (above) 0 (below)
% Exceedance	0%	0.09%	NA	0%

Table 4. Monthly summary of descriptive statistics and percent exceedances for core water quality parameters for the ice-free sampling period at Devils Tower National Monument on the Belle Fourche River from March 9, 2016 through October 31, 2016. Percent exceedance is the proportion of samples that exceed the respective state regulatory threshold described in Table 1 (water temperature max. limit is 30.0°C; dissolved oxygen $\geq$ 5.0 mg/L and pH range is <6.5 or >9.0).

Dates	Descriptive Statistic	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Specific Conductivity (μ S/cm)	pH
March 9-31, 2016	Number of measurements	1909	2193	2090	2193
	Mean	6.39	11.1	1756.77	8.22
	Standard Deviation	2.61	0.91	44.61	0.05
	Median	6.5	11.1	1770	8.2
	Minimum	0.4	9.1	1650	8.1
	Maximum	12.9	13.2	1840	8.3
	% Exceedance	0	0	-	0
April, 2016	Number of measurements	2880	2880	2366	2879
	Mean	10.47	9.98	1804.98	8.2
	Standard Deviation	3.56	1.18	62.16	0.07
	Median	10.2	10.1	1810	8.2
	Minimum	3.2	7.1	1650	8
	Maximum	20.2	12.5	1920	8.4
	% Exceedance	0	0	-	0
May, 2016	Number of measurements	2972	2972	2755	2971
	Mean	16.1	9.08	1814.3	8.25
	Standard Deviation	3.65	1.34	74.86	0.12
	Median	16.3	9.2	1830	8.3
	Minimum	7	6.3	1550	7.9
	Maximum	23.6	11.6	1930	8.5
	% Exceedance	0	0	-	0
June, 2016	Number of measurements	2879	2879	2824	2878
	Mean	22.68	8.14	1988.47	8.23
	Standard Deviation	3.14	1.82	79.41	0.25
	Median	22.6	8	1990	8.3
	Minimum	11.1	4.9	1820	7.7
	Maximum	29.6	11.9	2190	8.6
	% Exceedance	0	0.73 %	-	0

Table 4 (continued). Monthly summary of descriptive statistics and percent exceedances for core water quality parameters for the ice-free sampling period at Devils Tower National Monument on the Belle Fourche River from March 9, 2016 through October 31, 2016. Percent exceedance is the proportion of samples that exceed the respective state regulatory threshold described in Table 1 (water temperature max. limit is 30.0°C; dissolved oxygen $\geq$ 5.0 mg/L and pH range is <6.5 or >9.0).

Dates	Descriptive Statistic	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Specific Conductivity (μ S/cm)	pH
July, 2016	Number of measurements	2973	2974	2770	2971
	Mean	23.14	7.78	1787.94	8.26
	Standard Deviation	1.92	1.33	57.48	0.17
	Median	23	7.5	1760	8.3
	Minimum	18.2	5.6	1710	7.9
	Maximum	28.2	10.7	1910	8.6
	% Exceedance	0	0	-	0
August, 2016	Number of measurements	2973	2590	2569	2590
	Mean	21.5	8.67	1894.8	8.31
	Standard Deviation	2.82	2.26	51.4	0.22
	Median	21.8	8.2	1880	8.3
	Minimum	13.6	5.4	1800	7.8
	Maximum	27.2	13.1	2030	8.7
	% Exceedance	0	0	-	0
September, 2016	Number of measurements	2880	2880	2267	2880
	Mean	16.69	10.53	1946.44	8.28
	Standard Deviation	3.25	2.3	103.24	0.25
	Median	16.5	10.3	2000	8.2
	Minimum	10	5.7	1750	7.8
	Maximum	25.6	14.9	2070	8.7
	% Exceedance	0	0	-	0
October, 2016	Number of measurements	2974	2974	1892	2974
	Mean	10.33	10.51	1872.07	8.32
	Standard Deviation	3.24	1.37	70.47	0.16
	Median	9.9	10.3	1870	8.3
	Minimum	4.1	7	1640	8
	Maximum	22	15.1	1990	8.7
	% Exceedance	0	0	-	0

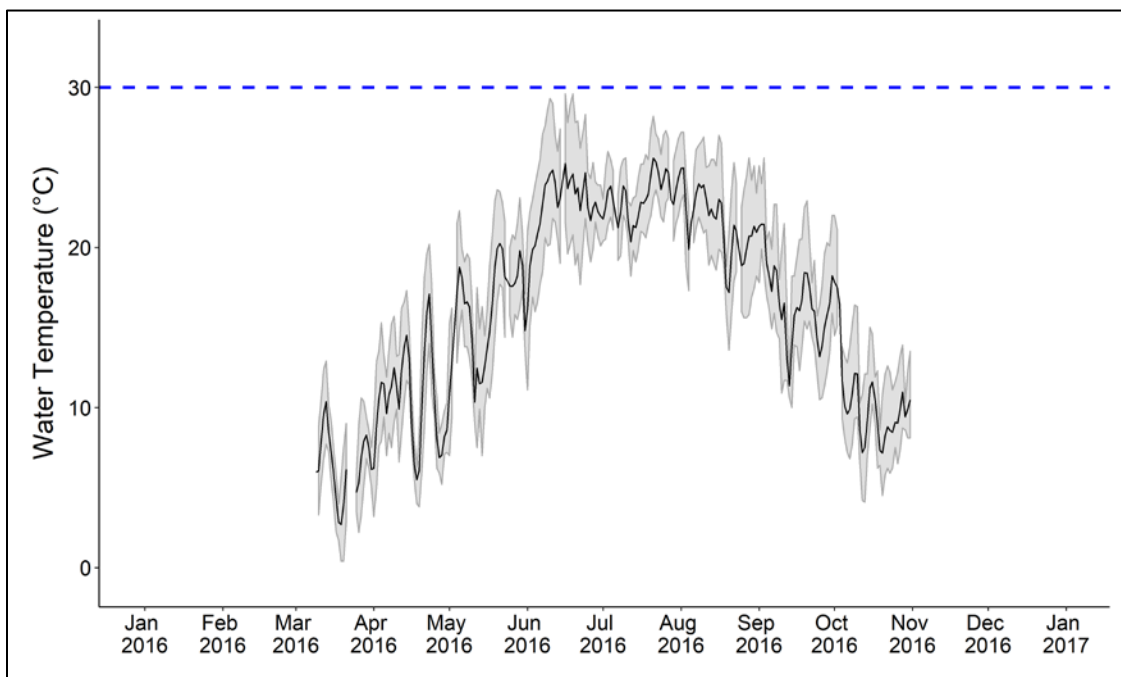


Figure 6. Daily mean water temperature (black line) collected on the Belle Fourche River at Devils Tower National Monument in 2016. The sonde was in the water from March 9, 2016 through October 31, 2016. The gray ribbon shows the daily maximum and minimum water temperature for the same period. The dashed blue line indicates one of the Wyoming state water quality standards (see Table 1 for more details). The periods where the instrument did not collect data are indicated by gaps in the record.

Dissolved oxygen also displayed seasonal variation (Table 3, Figure 7). The highest mean dissolved oxygen concentrations were in the spring and fall, averaging greater than 10 mg/ L in March, September, and October. Dissolved oxygen was the only water quality parameter that was below one of the Wyoming state water quality criteria (Table 1). Dissolved oxygen concentrations measured below 5 mg/ L in the Belle Fourche River 21 times during mid-June (Table 3, Figure 7).

Specific conductance of the Belle Fourche River was highly variable throughout the year (Table 3, Figure 8), but showed a less predictable seasonal pattern than temperature or dissolved oxygen concentrations. The pH of the Belle Fourche River ranged between 7.8 and 8.7 (Figure 9) and was never outside the range of the Wyoming state standards of 6.5 -9.

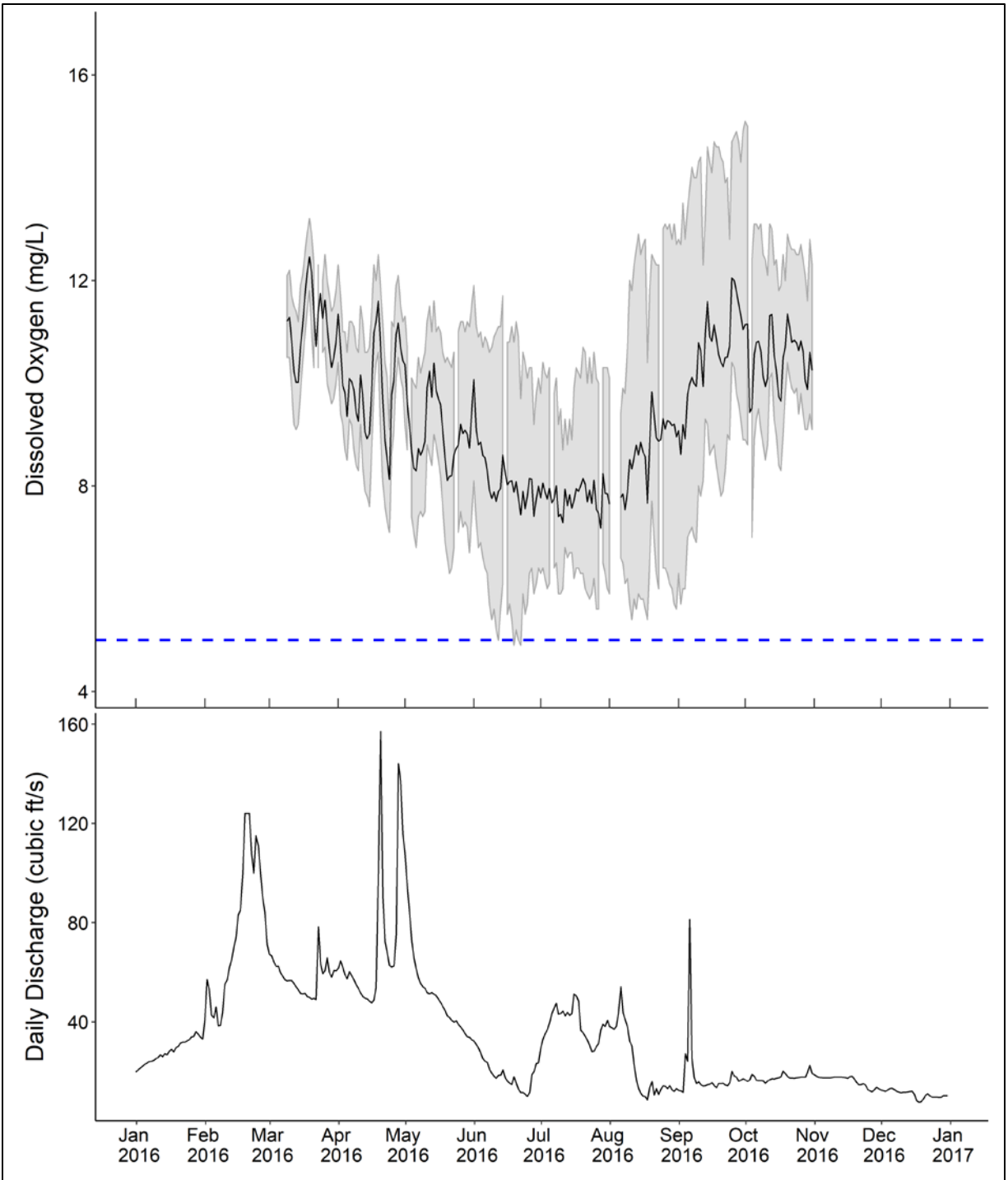


Figure 7. Daily mean dissolved oxygen concentrations (top) of the Belle Fourche River at Devils Tower National Monument in 2016 and daily discharge (bottom) of the Belle Fourche River at the Wyoming and South Dakota border. The gray ribbon shows the daily maximum and minimum dissolved oxygen for the same period. The dashed blue line indicates one of the Wyoming state water quality standards (see Table 1 for more details). The periods where the instrument did not collect data are indicated by gaps in the record.

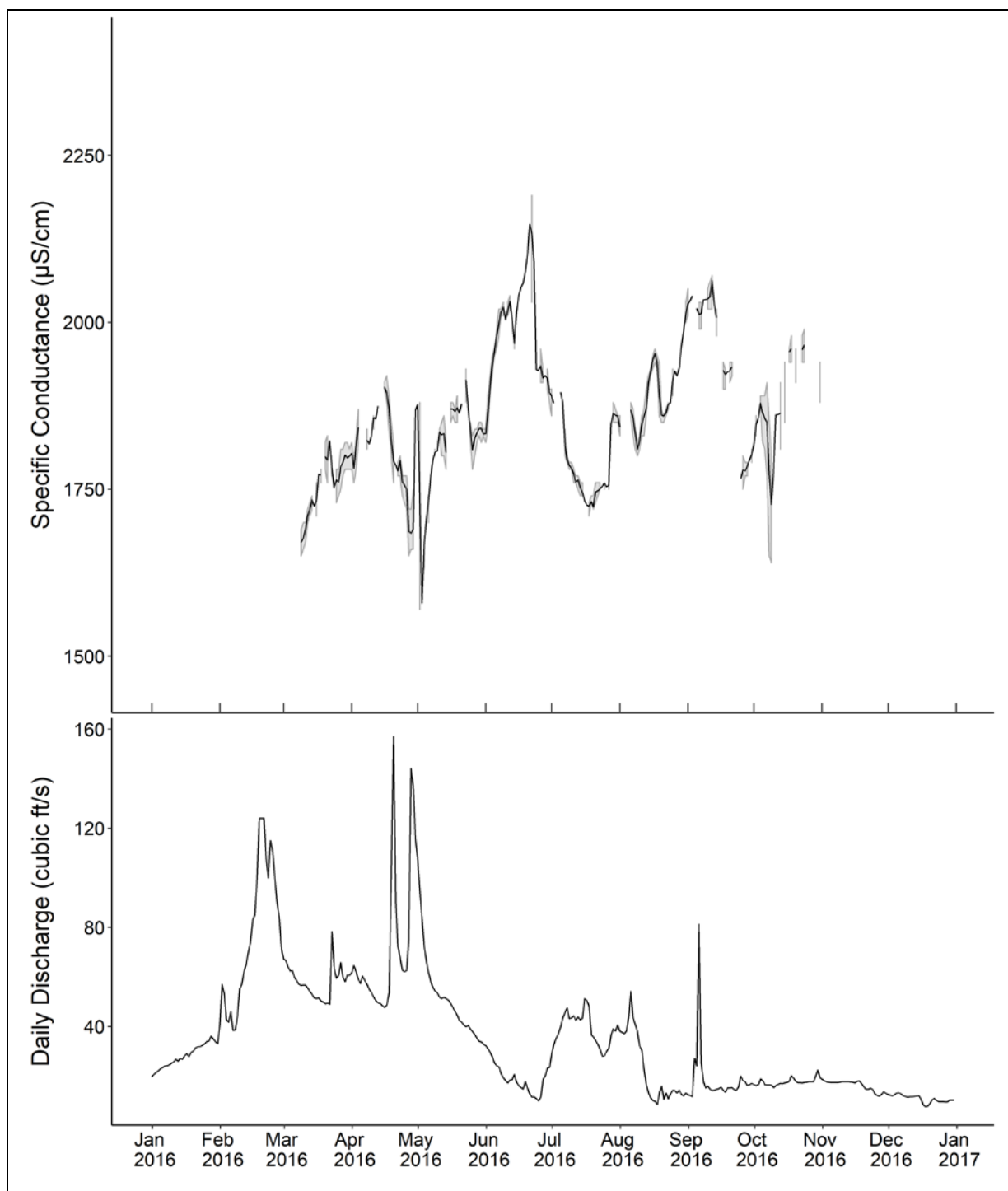


Figure 8. Daily mean specific conductance (top) of the Belle Fourche River at Devils Tower National Monument in 2016 and daily discharge (bottom) of the Belle Fourche River at the Wyoming and South Dakota border. The gray ribbon shows the daily maximum and minimum specific conductivity for the same period. The periods where the instrument did not collect data are indicated by gaps in the record.

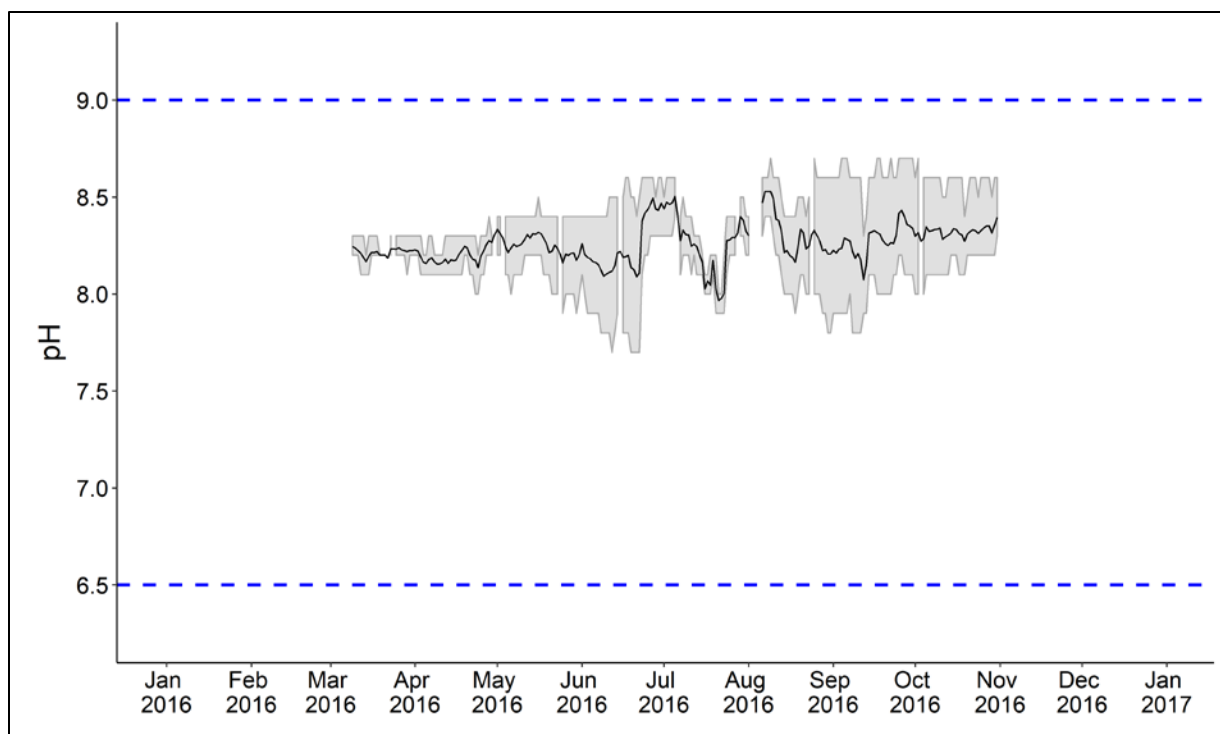


Figure 9. Daily mean pH (black line) of the Belle Fourche River at Devils Tower National Monument in 2016. Measurements were taken from March 9, 2016 through October 31, 2016. The gray ribbon shows the daily maximum and minimum pH for the same period. The dashed blue lines indicate the Wyoming state water quality standards (see Table 1 for more details). The periods where the instrument did not collect data are indicated by gaps in the record.

Further Analysis

This Data Report is intended to provide a basic review of data collected during the 2016 water quality monitoring season at Devils Tower National Monument. All data included in this report is available upon request from the [Northern Great Plains Inventory and Monitoring Network](#), as well as in the archives found on the [USGS National Water Information System for site 06427850](#)

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Appendix A. USGS Water Data Quality Report for Belle Fourche River, 2016

06427850 Belle Fourche River at Devils Tower, WY

LOCATION – Lat 44°35'22"long 104°42'12" referenced to North American Datum of 1927, Crook County, WY, Hydrologic Unit 10120201,

Surface-Water Records

PERIOD OF RECORD – March 2013 to November 2013, March to November 2016.

GAGE – Water-stage recorder. Elevation of gage is 3,840 ft above sea level, from topographic map. U.S. Geological survey data collection platform with satellite telemetry at station.

REMARKS – Records excellent.

EXTREMES FOR PERIOD OF RECORD – Maximum recorded gage height, 7.13 ft, June 2, 2013; minimum recorded gage height, 1.07 ft, October 3, 2013.

Water-Quality Records

PERIOD OF RECORD – water years 1968-1992.

PERIOD OF DAILY RECORD – March to November 2013, March to November 2016.

INSTRUMENTATION – Water quality monitors for specific conductance, pH, water temperature and dissolved oxygen.

REMARKS –

SPECIFIC CONDUCTANCE

03-08-2016 to 11-01-2016: records are excellent except records from May 16-24, June 24 to July 6, Aug. 12-24, and Oct. 22 to Nov. 1 are good.

pH

03-08-2016 to 11-01-2016: records are excellent except records from Aug. 18-24 are good.

WATER TEMPERATURE

03-08-2016 to 11-01-2016: records are excellent. Water-temperature records represent water temperature at sensor within 0.2°C.

DISSOLVED OXYGEN

03-08-2016 to 11-01-2016: records are excellent except records from June 29, July 3-5, and Aug. 28-30, which are good; records from Aug. 31 to Sept. 7 and Sept. 10, 13, are fair; and records from Sept. 8, 9, 11, 12, and Sept. 14 to Oct. 3 are poor.

Maximum and minimum recorded values in the extremes paragraphs may have occurred during days of partial record and may not appear in the daily values tables.

EXTREMES FOR PERIOD OF DAILY RECORD – SPECIFIC CONDUCTANCE: Maximum recorded, 2,190 uS/cm, June 22, 2016; minimum recorded, 452 uS/cm, October 10, 2013. pH: Maximum recorded 8.7 units, many days 2016; minimum recorded 7.6 units, August 12 and September 6-8, 2013. WATER TEMPERATURE: Maximum recorded, 29.6°C, July 11, 2013, June 16, 19, 2016; minimum recorded -0.1°C, March 23-26, April 9, 10, and November 18, 2013. DISSOLVED OXYGEN: Maximum recorded, 13.8 mg/L, October 5, 2013; minimum recorded, 4.4 mg/L, August 13, 2013.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
U.S. Department of the Interior



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