Water Quality Special Study Report

U.S. Army Corps of Engineers
Omaha District

Water Quality Conditions Monitored at the Corps' Big Bend Project in South Dakota during the 3-Year Period 2008 through 2010

Aerial Photo of Big Bend Dam, Tailwaters and Reservoir

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EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (Corps) Big Bend Project consists of Big Bend Dam and Big Bend Reservoir (i.e., Lake Sharpe). Big Bend Dam is located on the Missouri River at River Mile (RM) 987, near the town of Fort Thompson, South Dakota; about 20 miles upstream (i.e., northwest) from Chamberlain, South Dakota. The reservoir and dam are authorized for the uses of flood control, recreation, fish and wildlife, hydroelectric power production, water supply, water quality, navigation, and irrigation. Lake Sharpe is an important recreational resource.

Water quality monitoring was conducted at the Big Bend Project by the Omaha District (District) over the 3-year period of 2008 through 2010. The water quality monitoring conducted included: 1) continuing long-term, fixed-station monitoring in the reservoir at a near-dam deepwater location; 2) monthly sampling and continuous monitoring (i.e., hourly) of water quality conditions in the powerplant of water discharged through Oahe and Big Bend Dams; and 3) intensive water quality surveys in 2008, 2009, and 2010. The results of this monitoring were used to assess the existing water quality conditions at the Big Bend Project.

Water quality conditions in Lake Sharpe vary longitudinally from the dam to the reservoir's upstream reaches, and vertically from the reservoir surface to the bottom. Water quality monitoring indicated that the reservoir is probably discontinuous polymictic with a hypolimnion only forming on an irregular basis. The trophic status of Lake Sharpe is mesotrophic to moderately eutrophic in the area near the dam, eutrophic in the middle reaches, and eutrophic to borderline hypereutrophic in the upper reaches of the reservoir. The phytoplankton community of Lake Sharpe was dominated by diatoms and no concentrations of the cyanotoxin microcystin above 1 ug/l were measured. The zooplankton community in Lake Sharpe was dominated by Cladocerans and Copepods.

Water quality conditions monitored in Lake Sharpe during the 3-year period 2008 through 2010 indicate that the Coldwater Permanent Fish Life Propagation (CPFLP) use designated to Lake Sharpe is not being attained. The most crucial period for the support of CPFLP habitat (≤ 18.3°C temperature and > 6 mg/l dissolved oxygen) in Lake Sharpe is during mid-summer. Due to its shallowness, a hypolimnion rarely forms in Lake Sharpe and water temperatures throughout the reservoir regularly exceed 18.3°C in the summer. When stratification does persist, dissolved oxygen degradation to levels below 6 mg/l occurs near the reservoir bottom in deeper waters near the dam. The suspended solids criteria for the protection of CPFLP are regularly exceeded in the upper end of Lake Sharpe. This is attributed to finer sediment that has been deposited in Lake Sharpe below the confluence of the Bad River and its continual re-suspension with wave action. Consideration should be given to reclassify Lake Sharpe for a Warmwater Permanent Fish Life Propagation use based on a use attainability assessment of "natural conditions" regarding ambient water temperatures.

Water discharged through Big Bend Dam exhibited good water quality during the monitored 3-year period of 2008 through 2010. There appeared to be significant correlation between discharge rates and water temperature and dissolved oxygen concentrations measured during the summer months. The lower dissolved oxygen concentrations monitored in the summer may be attributed to periodic stratification and the degradation of dissolved oxygen conditions near the bottom of the reservoir. Since the inlet to the powerhouse is located at the reservoir bottom, lower flows through the dam may result in more "laminar" flow that pulls in water with degraded dissolved oxygen conditions along the bottom into the powerplant.

Inflow temperatures of the Missouri River to Lake Sharpe are about 4°C warmer than the outflow temperatures of Big Bend Dam during the fall. Outflow temperatures of the Big Bend Dam discharge are about 5°C warmer than the inflow temperatures of the Missouri River during the spring, summer, and fall.

The Omaha District is planning to pursue the application of the Corps' CE-QUAL-W2 hydrodynamic and water quality model to Lake Sharpe. CE-QUAL-W2 is a powerful tool to aid in addressing reservoir water quality management issues. Application of the CE-QUAL-W2 model will allow the Corps to better understand how the operation of the Big Bend Project affects the water quality in Lake Sharpe and the dam discharges to the Missouri River and Lake Francis Case. It is almost a certainty that water quality issues at the Big Bend Project will remain important in the future.

1 INTRODUCTION

1.1 RECENT WATER QUALITY MONITORING AT THE CORPS' BIG BEND PROJECT

Water quality monitoring conducted by the Omaha District (District) at the Big Bend Project over the past 3 years included 1) continuing long-term, fixed-station monitoring in the reservoir at a near-dam deepwater location; 2) monthly sampling and continuous monitoring (i.e., hourly) of water quality conditions in the powerplant of water discharged through Big Bend Dam; and 3) intensive water quality surveys in 2008, 2009, and 2010. The continuing long-term, fixed-station monitoring consisted of monthly (i.e., May through September) field measurements and sample collection. The monitoring in the Big Bend powerplant was on water drawn from the Unit waterways prior to passing through the dam's turbines. The intensive surveys included monitoring at two to four additional in-reservoir sites and monitoring of the Bad River inflow to the reservoir. This report presents the findings of the water quality monitoring conducted by the District at the Big Bend Project during the period 2008 though 2010.

1.2 MISSOURI RIVER MAINSTEM SYSTEM

The Big Bend Project is part of the Missouri River Mainstem System (Mainstem System). The Mainstem System is comprised of six dams and reservoirs constructed by the U.S. Army Corps of Engineers (Corps) on the Missouri River and the free-flowing Missouri River downstream of the project dams. The six reservoirs impounded by the dams contain about 73.3 million acre-feet (MAF) of storage capacity and, at normal pool, an aggregate water surface area of about 1 million acres. The six dams and reservoirs in an upstream to downstream order are: Fort Peck Dam and Reservoir (Montana), Garrison Dam and Reservoir (North Dakota), Oahe Dam (South Dakota) and Oahe Reservoir (North and South Dakota), Big Bend Dam and Reservoir (South Dakota), Fort Randall Dam and Reservoir (South Dakota), and Gavins Point Dam and Reservoir (South Dakota and Nebraska). Drought conditions in the upper Missouri River Basin prior to 2008 had reduced the water stored in the Mainstem System reservoirs to record low levels. Water storage in the Mainstem System showed some recovery by the end of 2008; however, storage at the end of 2008 was still appreciably below the total system storage volume and long-term average. The water in storage at the all Mainstem System reservoirs at the end of 2010 (i.e., December 31, 2010) was 57.03 MAF, which is about 78 percent of the total system storage volume.

1.2.1 REGULATION OF THE MAINSTEM SYSTEM

The Mainstem System is a hydraulically and electrically integrated system that is regulated to obtain the optimum fulfillment of the multipurpose benefits for which the dams and reservoirs were authorized and constructed. The Congressionally authorized purposes of the Mainstem System, including the Big Bend Project, are flood control, navigation, hydropower, water supply, water quality, irrigation, recreation, and fish and wildlife (including threatened and endangered species). The Mainstem System is operated under the guidelines described in the Missouri River Mainstem System Master Water Control Manual, (Master Manual) (USACE-RCC, 2004). The Master Manual details regulation for all authorized purposes as well as emergency regulation procedures in accordance with the authorized purposes.

Mainstem System regulation is, in many ways, a repetitive annual cycle that begins in late winter with the onset of snowmelt. The annual melting of mountain and plains snowpacks along with spring and summer rainfall produces the annual runoff into the Mainstem System. In a typical year, mountain snowpack, plains snowpack, and rainfall events, respectively, contribute 50, 25, and 25 percent of the annual runoff to the Mainstem System. After reaching a peak, usually during July, the amount of water stored in the Mainstem System declines until late in the winter when the cycle begins anew. A similar pattern may be found in rates of releases from the Mainstem System, with the higher levels of flow from mid-March to late November, followed by low rates of winter discharge from late November until mid-March, after which the cycle repeats.

To maximize the service to all the authorized purposes, given the physical and authorization limitations of the Mainstem System, the total storage available is divided into four regulation zones that are applied to the individual reservoirs. These four regulation zones are: 1) Exclusive Flood Control Zone, 2) Annual Flood Control and Multiple Use Zone, 3) Carryover Multiple Use Zone, and 4) Permanent Pool Zone.

1.2.1.1 Exclusive Flood Control Zone

Flood control is the only authorized purpose that requires empty space in the reservoirs to achieve the objective. A top zone in each Mainstem System reservoir is reserved for use to meet the flood control requirements. This storage space is used only for detention of extreme or unpredictable flood flows and is evacuated as rapidly as downstream conditions permit, while still serving the overall flood control objective of protecting life and property. The Exclusive Flood Control Zone encompasses 4.7 MAF and represents the upper 6 percent of the total Mainstem System storage volume. This zone, from 73.3 MAF down to 68.7 MAF, is normally empty. The four largest reservoirs, Fort Peck, Garrison, Oahe, and Fort Randall, contain 97 percent of the total storage reserved for the Exclusive Flood Control Zone.

1.2.1.2 Annual Flood Control and Multiple Use Zone

An upper "normal operating zone" is reserved annually for the capture and retention of runoff (normal and flood) and for annual multiple-purpose regulation of this impounded water. The Mainstem System storage capacity in this zone is 11.7 MAF and represents 16 percent of the total system storage volume. This storage zone, which extends from 68.7 MAF down to 57.0 MAF, will normally be evacuated to the base of this zone by March 1 to provide adequate storage capacity for capturing runoff during the next flood season. On an annual basis, water will be impounded in this zone, as required to achieve the Mainstem System flood control purpose, and also be stored in the interest of general water conservation to serve all the other authorized purposes. The evacuation of water from the Annual Flood Control and Multiple Use Zone is scheduled to maximize service to the authorized purposes that depend on water from the system. Scheduling releases from this zone is limited by the flood control objective in that the evacuation must be completed by the beginning of the next flood season. This is normally accomplished as long as the evacuation is possible without contributing to serious downstream flooding. Evacuation is, therefore, accomplished mainly during the summer and fall because Missouri River ice formation and the potential for flooding from higher release rates limit release rates during the December through March period.

1.2.1.3 Carryover Multiple Use Zone

The Carryover Multiple Use Zone is the largest storage zone extending from 57.0 MAF down to 18.0 MAF and represents 53 percent of the total system storage volume. Serving the authorized purposes during an extended drought is an important regulation objective of the Mainstem System. The Carryover Multiple Use Zone provides a storage reserve to support authorized purposes during drought conditions.

Providing this storage is the primary reason the upper three reservoirs of the Mainstem System are so large compared to other Federal water resource projects. The Carryover Multiple Use Zone is often referred to as the “bank account” for water in the Mainstem System because of its role in supporting authorized purposes during critical dry periods when the storage in the Annual Flood Control and Multiple Use Zone is exhausted. Only the reservoirs at Fort Peck, Garrison, Oahe, and Fort Randall have this storage as a designated storage zone. The three larger reservoirs (Fort Peck, Garrison, and Oahe) provide water to the Mainstem System during drought periods to provide for authorized purposes. The storage space assigned to this zone in Fort Randall Reservoir serves a different purpose. It is normally evacuated each year during the fall season to provide recapture space for upstream winter power releases. The recapture results in complete refill of Fort Randall Reservoir during the winter months. During drought periods, the three smaller project (Fort Randall, Big Bend, and Gavins Point) reservoir levels are maintained at the same elevation they would be at if runoff conditions were normal.

1.2.1.4 Permanent Pool Zone

The Permanent Pool Zone is the bottom zone that is intended to be permanently filled with water. The zone provides for future sediment storage capacity and maintenance of minimum pool levels for power heads, irrigation diversions, water supply, recreation, water quality, and fish and wildlife. A drawdown into this zone is generally not scheduled except in unusual conditions. The Mainstem System storage capacity in this storage zone is 18.0 MAF and represents 25 percent of the total storage volume. The Permanent Pool Zone extends from 18.0 MAF down to 0 MAF.

1.2.2 WATER CONTROL PLAN FOR THE MAINSTEM SYSTEM

Variations in runoff into the Mainstem System necessitates varied regulation plans to accommodate the multipurpose regulation objectives. The two primary high-risk flood periods are the plains snowmelt and rainfall period extending from late February through April, and the mountain snowmelt and rainfall period extending from May through July. Also, the winter ice-jam flood period extends from mid-December through February. The highest average power generation period extends from mid-April to mid-October, with high peaking loads during the winter heating season (mid-December to mid-February) and the summer air conditioning season (mid-June to mid-August). The power needs during the winter are supplied primarily with Fort Peck and Garrison Dam releases and the peaking capacity of Oahe and Big Bend Dams. During the spring and summer period, releases are normally geared to navigation and flood control requirements, and primary power loads are supplied using the four lower dams. During the fall when power needs diminish, Fort Randall is normally drawn down to permit generation during the winter period when Oahe and Big Bend peaking-power releases refill the reservoir. The normal 8-month navigation season extends from April 1 through November 30, during which time Mainstem System releases are increased to meet downstream target flows in combination with downstream tributary inflows. Winter releases after the close of the navigation season are much lower and vary, depending on the need to conserve or evacuate storage volumes with downstream ice conditions permitting. Releases and pool fluctuations for fish spawning management generally occur from April 1 through June. Two threatened and endangered bird species, piping plover (*Charadrius melodus*) and least tern (*Sterna antillarum*), nest on “sandbar” areas from early May through mid-August. Other factors may vary widely from year to year, such as the amount of water-in-storage and the magnitude and distribution of inflow received during the coming year. All these factors will affect the timing and magnitude of Mainstem System releases. The gain or loss in the water stored at each reservoir must also be considered in scheduling the amount of water transferred between reservoirs to achieve the desired storage levels and to generate power. These items are continually reviewed as they occur and are appraised with respect to the expected range of regulation.

1.3 BIG BEND PROJECT DESCRIPTION

The Big Bend Project is located in central South Dakota. The project is basically a run-of-the-river power development with regulation of flows limited almost entirely to daily and weekly power pondage operations. Big Bend Dam is located on the Missouri River at River Mile (RM) 987, near the town of Fort Thompson, South Dakota; about 20 miles upstream (i.e., northwest) from Chamberlain, South Dakota. The closing of Big Bend Dam in 1963 resulted in the formation of Big Bend Reservoir (a.k.a., Lake Sharpe). Table 1-1 provides a summary of selected engineering data for the Big Bend Project.

1.3.1 BIG BEND DAM AND POWERPLANT

Big Bend Dam is a rolled, earth-filled embankment, with the powerplant at the right abutment (i.e., south end of dam) and the spillway at the left abutment (i.e., north end of dam). The total embankment length, including the spillway, is 10,570 feet, and the height of the dam is 95 feet. Conventional outlet works structures were not provided at Big Bend; releases must be made either through the spillway or powerplant. *(See the front cover of this report for an aerial photo of Big Bend Dam showing the location of the powerplant and spillway.)*

The Big Bend powerplant has eight units (i.e., turbines) available for power production. The powerplant intake structure has separate intakes, divided into three water passages by intermediate piers, for each of the eight units. The flow of water from the reservoir to the powerplant intake structure is guided by a curved approach channel. The approach channel has a bottom elevation of 1345 ft-NGVD29 with 1 on 2½ side slopes to berms on both sides to elevation 1355 ft-NGVD29. The side slopes above the berms are 1 on 3. The width of the channel at elevation 1345 ft-NGVD29 is about 400 feet. At elevation 1355 ft-NGVD29, the channel width converges from a maximum of 800 feet approximately 600 feet upstream from the intake to 675 feet at the intake. About 120 feet upstream of the powerplant intake, the bottom of the approach channel slopes downward on a 1 on 8 slope to elevation 1330 ft-NGVD29 to provide sufficient entrance area at the intake. The approach channel has concrete approach walls at the intake. Water is drawn into the Big Bend powerplant at the reservoir bottom at an invert elevation of 1330 ft-NGVD29; however as noted above, the bottom elevation of the approach channel rises to an elevation of 1345 ft-NGVD29 120 feet upstream of the intake structure. Photo 1-1 provides an upstream view of the Big Bend powerplant intake structure in the final stages of construction prior to inundation.

The Big Bend powerplant is operated to meet peak power demands for electricity. The eight turbines have a generating capacity of 494 MW. At this rating, the powerplant capacity is about 110,000 cfs. There are no minimum flow requirements below Big Bend Dam, and hourly releases can fluctuate from 0 to 110,000 cfs for peaking power generation. The average powerplant release is 25,400 cfs and the powerplant produces 1.1 million MW per year. Generally, weekly flows from Oahe Dam are released at Big Bend Dam, and there is minimal fluctuation in the water level of Lake Sharpe. The Annual Flood Control and Multiple Use Zone in the reservoir does not provide for seasonal regulation of flood inflows like the other major upstream Mainstem System projects, but the zone is used for day-to-day and week-to-week power operations. The Corps normally strives to maintain the pool level in Lake Sharpe between elevation 1419 ft-NGVD29 and 1421.5 ft-NGVD29.

Table 1-1. Summary of selected engineering data for the Big Bend Project.

General		
Lake Name	Lake Sharpe	
River Mile (1960 Mileage)	987.4	
Total and Incremental Drainage Area (square miles)[1]	249,330	5,840
Reservoir Length at Top of Carryover Multiple Use Pool (miles)	80	
Shoreline Length at Top of Carryover Multiple Use Pool (miles)	200	
Top Elevation of Carryover Multiple Use Pool (ft-NGVD29)	1422.0	
Year Storage First Available for Regulation of Flows	1964	
Maximum Depth at Dam at "Normal Pool" (feet)	90	
Original "As-Built" Conditions (Year)	(1963)	
Surface Area of Carryover Multiple Use Pool (acres)	59,150	
Capacity of Carryover Multiple Use Pool (acre-feet)	1,920,000	
Mean Depth at top of Carryover Multiple Use Pool[2] (feet)	32.5	
Most Recent Surveyed Conditions (Year)	(1997)	
Surface Area at top of Carryover Multiple Use Pool (acres)	59,700	
Capacity of Carryover Multiple Use Pool (acre-feet)	1,738,000	
Mean Depth at top of Multiple Use Pool[2] (feet)	29.1	
Sediment Deposition to Top of Carryover Multiple Use Pool		
Surveyed Sediment Deposition[3] (acre-feet)	182,000	
Years of Sediment Deposition[4] (Survey Year - "As-Built Year")	34	
Annual Sedimentation Rate[5] (acre-feet/year)	5,353	
Annual Rate of Volume Loss from "As-Built" Condition	0.28%	
Years from "As-Built" to 2010	47	
Estimated Sediment Deposition (acre-feet) through 2010[6]	251,590	
2010 Estimated Capacity of Carryover Multiple Use Pool[7] (acre-feet)	1,668,410	
Estimated Carryover Multiple Use Pool Capacity Lost through 2010	13.1%	
Operational Details – Historic (1967 through 2010)		
Maximum Recorded Pool Elevation (ft-NGVD29)	1422.1	
Minimum Recorded Pool Elevation (ft-NGVD29)	1414.9	
Average Daily Pool Elevation (ft-NGVD29)	1420.4	
Maximum Recorded Daily Inflow (cfs)	79,000	
Maximum Recorded Daily Outflow (cfs)	74,300	
Average Annual Inflow (ac-ft)	16,981,000	
Average Annual Outflow (ac-ft)	16,806,000	
Operational Details – Current (2010)		
Maximum Recorded Pool Elevation (ft-NGVD29)	1421.4	
Minimum Recorded Pool Elevation (ft-NGVD29)	1419.4	
Maximum Recorded Daily Inflow (cfs)	50,000	
Maximum Recorded Daily Outflow (cfs)	56,700	
Total Inflow (% of Average Annual)	16,750,000	(99%)
Total Outflow (% of Average Annual)	16,564,000	(99%)
Power Tunnel Entrance Invert Elevation	1330 ft-NGVD29 (Bottom)	

Note: All elevations given are in the NGVD 29 datum.

(1) Total drainage area is Missouri River headwaters to Big Bend Dam. Incremental drainage area is from Oahe Dam to Big Bend Dam.

(2) Mean Depth to top of Carryover Multiple Use Pool = Capacity of Carryover Multiple Use Pool (divided by) Surface Area of Carryover Multiple Use Pool.

(3) Surveyed Sediment Deposition is for the capacity (ac-ft) below the top of the Carryover Multipurpose Use Pool = "As-Built" capacity of Carryover Multiple Use Pool (minus) most recent surveyed capacity of Carryover Multiple Use Pool.

(4) Years of Sediment Deposition = year of most recent survey (minus) the "as-built" year.

(5) Annual Sedimentation Rate (ac-ft/yr) = Survey Sediment Deposition / Years of Sediment Deposition.

(6) Estimated Sediment Deposition through 2010 = Annual Sedimentation Rate (times) Years from "As-Built" to 2010.

(7) Current Capacity of Carryover Multiple Use Pool (ac-ft) = "As-Built" Capacity of Carryover Multiple Use Pool (minus) Current Estimated Capacity of Carryover Multiple Use Pool.

Photo 1-1. Upstream view of the Big Bend powerplant intake structure in final stages of construction prior to inundation.

1.3.2 LAKE SHARPE

The closing of Big Bend Dam in 1963 resulted in the formation of Lake Sharpe. When at an operating pool elevation of 1421.5 ft-NGVD29, the reservoir is about 80 miles long, has 200 miles of shoreline, covers about 59,000 acres, and has a storage volume of about 1.7 million acre-ft. Table 1-2 summarizes how the surface area, volume, mean depth, and retention time of Lake Sharpe vary with pool elevations. A maximum pool elevation of 1422.1, 0.1 feet into the Exclusive Flood Control Zone, occurred in June 1991. The major inflows to Lake Sharpe are the Missouri River (releases from Oahe Dam) and the Bad River. Three surface water intakes are located in Lake Sharpe: Mni Wiconi Rural Water System (RM1070 – 12 counties and Lower Brule, Rosebud, and Pine Ridge Indian Reservations); Lower Brule Rural Water System (RM993 – Lower Brule); and Fort Thompson Rural Water Service (RM987 – Fort Thompson). Lake Sharpe is an important recreational resource.

1.3.3 MISSOURI RIVER DOWNSTREAM OF BIG BEND DAM

Fort Randall Dam, the next Missouri River mainstem dam downstream of Big Bend Dam, is located 107 miles downstream of Big Bend Dam. At the top of its Carryover Multiple Use Zone (1350 ft-NGVD29), Fort Randall Reservoir (a.k.a.., Lake Francis Case) extends to Big Bend Dam. Thus, there typically is no “free-flowing” Missouri River immediately downstream of Big Bend Dam.

Table 1-2. Surface area, volume, mean depth, and retention time of Lake Sharpe at different pool elevations based on 1997 survey.

Elevation (ft-NGVD29)	Surface Area (Acres)	Volume (Acre-Feet)	Mean Depth (Feet)*	Retention Time (Years)**
1430	70,615	2,259,568	32.0	0.1344
1425	63,808	1,923,508	30.1	0.1144
1420	57,007	1,621,484	28.4	0.0965
1415	50,224	1,353,339	26.9	0.0805
1410	43,146	1,119,548	25.9	0.0666
1405	35,694	923,872	25.9	0.0550
1400	31,842	756,297	23.8	0.0450
1395	27,402	608,587	22.2	0.0362
1390	24,659	479,172	19.4	0.0285
1385	21,779	362,729	16.7	0.0216
1380	18,307	262,285	14.3	0.0156
1375	14,856	179,548	12.1	0.0107
1370	11,747	113,160	9.6	0.0067
1365	8,590	62,333	7.3	0.0037
1360	5,449	27,069	5.0	0.0016
1355	2,021	9,373	4.6	0.0006
1350	836	2,445	2.9	0.0001

Average Annual Inflow (1967 through 2010) = 16.98 Million Acre-Feet.
Average Annual Outflow: (1967 through 2010) = 16.81 Million Acre-Feet
* Mean Depth = Volume ÷ Surface Area.
** Retention Time = Volume ÷ Average Annual Outflow.
Note: Exclusive Flood Control Zone (elev. 1423-1422 ft-NGVD29), Annual Flood Control and Multiple Use Zone (elev. 1422-1420 ft-NGVD29), Carryover Multiple Use Zone (none), and Permanent Pool Zone (elev. 1420-1345 ft-NGVD29). All elevations are in the NGVD 29 datum.

1.4 WATER QUALITY MANAGEMENT CONCERNS AT THE BIG BEND PROJECT

1.4.1 APPLICABLE WATER QUALITY STANDARDS

1.4.1.1 Lake Sharpe

South Dakota has classified the Missouri River impoundments within the State as flowing streams and not reservoirs (South Dakota Administrative Rules 74:51:01:43). The following water quality-dependent beneficial uses have been designated for Lake Sharpe in South Dakota's water quality standards: domestic water supply waters, coldwater permanent fish life propagation waters, immersion recreation waters, limited-contact recreation waters, commerce and industry waters, agricultural water supply (i.e., irrigation and stock watering), and fish and wildlife propagation.

1.4.1.2 Missouri River Downstream of Big Bend Dam (Lake Francis Case)

The State of South Dakota has designated the following water quality-dependent beneficial uses for the Missouri River downstream of Big Bend Dam: domestic water supply waters, warmwater permanent fish life propagation waters, immersion recreation waters, limited-contact recreation waters, commerce and industry waters, agricultural water supply (i.e., irrigation and stock watering), and fish and wildlife propagation. Big Bend Dam is the demarcation point between coldwater and warmwater use designation on the Missouri River system in South Dakota. Therefore, the designated use of Warmwater Permanent Fish Life Propagation applies to the Big Bend Dam tailwaters instead of the Coldwater Permanent Fish Life Propagation use that applies to Lake Sharpe.

1.4.2 FEDERAL CLEAN WATER ACT SECTION 303(D) IMPAIRED WATERBODY LISTINGS AND FISH CONSUMPTION ADVISORIES

The State of South Dakota added Lake Sharpe to the State's 2010 Section 303(d) list of impaired waters. The reservoir use identified as impaired is coldwater permanent fish life propagation waters and the cause of impairment is identified as warm water temperatures. South Dakota is currently pursuing reclassification of Lake Sharpe from a coldwater fishery to a warmwater fishery based on a use attainability assessment of "natural conditions". Summer water temperatures discharged from Oahe Dam, especially during lower pool levels, don't meet the temperature criteria for a coldwater fishery use. South Dakota had recently delisted Lake Sharpe for Section 303(d) impairment due to sedimentation. The reservoir was previously listed as water quality impaired due to accumulated sediment from the Bad River watershed. A total maximum daily load (TMDL) was developed and is being implemented to address this concern, resulting in the delisting of Lake Sharpe for sedimentation. South Dakota has not issued a fish consumption advisory for the reservoir.

2 WATER QUALITY MONITORING CONSIDERATIONS

2.1 WATER QUALITY MONITORING OBJECTIVES

2.1.1 GENERAL MONITORING OBJECTIVES

The Omaha District has identified purposes and general monitoring objectives for surface water quality monitoring to facilitate implementation of the District's Water Quality Management Program (USACE, 2011). The water quality monitoring conducted at the Big Bend Project over the 3-year period, 2008 through 2010, was implemented to address the following general monitoring objectives:

- Characterize the spatial and temporal distribution of surface water quality conditions at District Projects.
- Identify pollutants and their sources that are affecting surface water quality and the aquatic environment at District Projects.
- Determine if surface water quality conditions at District Projects or attributable to District operations or reservoir regulation (i.e., downstream conditions resulting from reservoir discharges) meet applicable Federal, Tribal, and State water quality standards.
- Determine if surface water quality conditions at District Projects or attributable to District operations or reservoir regulation are improving, degrading, or staying the same over time.
- Apply water quality models to assess surface water quality conditions at District Projects.
- Collect the information needed to design, engineer, and implement measures or modifications at District Projects to enhance surface water quality and the aquatic environment.

2.1.2 SPECIFIC MONITORING OBJECTIVES

In addition to the general water quality monitoring objectives, one specific monitoring objective was identified for the intensive water quality survey of Big Bend Reservoir:

1) Collect the information needed to allow application and "full calibration" of the current version of the CE-QUAL-W2 hydrodynamic and water quality model to Big Bend Reservoir.

2.2 LIMNOLOGICAL CONSIDERATIONS

2.2.1 VERTICAL AND LONGITUDINAL WATER QUALITY GRADIENTS

The annual temperature distribution represents one of the most important limnological processes occurring within a reservoir. Thermal variation in a reservoir results in temperature-induced density stratification, and an understanding of the thermal regime is essential to surface water quality assessment. Deep, temperate-zone lakes typically completely mix from the surface to the bottom twice a year (i.e., dimictic). Temperate-zone dimictic lakes exhibit thermally-induced density stratification in the summer and winter months that is separated by periods of "turnover" in the spring and fall. This stratification typically occurs through the interaction of wind and solar insolation at the lake surface and creates density gradients that can influence lake water quality. During the summer, solar insolation has its highest intensity and the reservoir becomes stratified into three zones: 1) epilimnion, 2) metalimnion, and 3) hypolimnion.

Epilimnion: The epilimnion is the upper zone that consists of the less dense, warmer water in the reservoir. It is fairly turbulent since its thickness is determined by the turbulent kinetic energy inputs (e.g., wind, convection, etc.), and a relatively uniform temperature distribution throughout this zone is maintained.

Metalimnion: The metalimnion is the middle zone that represents the transition from warm surface water to colder bottom water. There is a distinct temperature gradient through the metalimnion. The metalimnion contains the thermocline that is the plane or surface of maximum temperature rate change.

Hypolimnion: The hypolimnion is the bottom zone of more dense, colder water that is relatively quiescent. Bottom withdrawal or fluctuating water levels in reservoirs, however, may significantly increase hypolimnetic mixing.

Long, dendritic reservoirs with tributary inflows located a considerable distance from the outflow and unidirectional flow from headwater to dam develop gradients in space and time (USACE, 1987). Although these gradients are continuous from headwater to dam, three characteristic zones result: a riverine zone, a zone of transition, and a lacustrine zone (USACE, 1987).

Riverine Zone: The riverine zone is relatively narrow and well mixed, and there is a significant decrease in water current velocities. Advective forces are still sufficient to transport significant quantities of suspended particles, such as silts, clays, and organic particulate. Light penetration in this zone is minimal and may be the limiting factor that controls primary productivity in the water column. The decomposition of tributary organic loadings often creates a significant oxygen demand, but an aerobic environment is maintained because the riverine zone is generally shallow and well mixed. Longitudinal dispersion may be an important process in this zone.

Zone of Transition: Significant sedimentation occurs through the transition zone, with a subsequent increase in light penetration. Light penetration may increase gradually or abruptly, depending on the flow regime. At some point within the mixed layer of the zone of transition, a compensation point between the production and decomposition of organic matter should be reached. Beyond this point, production of organic matter within the reservoir mixed layer should begin to dominate.

Lacustrine Zone: The lacustrine zone is characteristic of a lake system. Sedimentation of inorganic particulate is low. Light penetration is sufficient to promote primary production, with nutrient levels the limiting factor and production of organic matter exceeds decomposition within the mixed layer. Entrainment of metalimnetic and hypolimnetic water, particulates, and nutrients may occur through internal waves or wind mixing during the passage of large weather fronts. Hypolimnetic mixing may be more extensive in reservoirs than "natural" lakes because of bottom withdrawal. In addition, an intake structure may simultaneously remove water from the hypolimnion and metalimnion.

When tributary inflow enters a reservoir, it displaces the reservoir water. If there is no density difference between the inflow and reservoir waters, the inflow will mix with the reservoir water as the inflow water moves toward the dam. However, if there are density differences between the inflow and reservoir waters, the inflow moves as a density current in the form of overflows, interflows, or underflows. Internal mixing is the term used to describe mixing within a reservoir from such factors as wind, Langmuir circulation, convection, Kelvin-Helmholtz instabilities, and outflow (USACE, 1987).

2.2.2 CHEMICAL CHARACTERISTICS OF RESERVOIR PROCESSES

2.2.2.1 Constituents

Some of the most important chemical constituents in reservoir waters that affect water quality are needed by aquatic organisms for survival. These include oxygen, carbon, nitrogen, and phosphorus. Other important constituents are silica, manganese, iron, and sulfur.

Dissolved oxygen: Oxygen is a fundamental chemical constituent of waterbodies that is essential to the survival of aquatic organisms and is one of the most important indicators of reservoir water quality conditions. The distribution of dissolved oxygen (DO) in reservoirs is a result of dynamic transfer processes from the atmospheric and photosynthetic sources to consumptive uses by the aquatic biota. The resulting distribution of DO in the reservoir water strongly affects the solubility of many inorganic chemical constituents. Often, water quality control or management approaches are formulated to maintain an aerobic, or oxic (i.e., oxygen-containing), environment. Oxygen is produced by aquatic plants (phytoplankton and macrophytes) and is consumed by aquatic plants, other biological organisms, and chemical oxidations. In reservoirs, the DO demand may be divided into two separate but highly interactive fractions: sediment oxygen demand (SOD) and water column oxygen demand.

Sediment oxygen demand: The SOD is typically highest in the upstream area of the reservoir just below the headwaters. This is an area of transition from riverine to lake characteristics. It is relatively shallow but stratifies. The loading and sedimentation of organic matter is high in this transition area and, during stratification, the hypolimnetic DO to satisfy this demand can be depleted. If anoxic conditions develop, they generally do so in this area of the reservoir and progressively move toward the dam during the stratification period. The SOD is relatively independent of DO when DO concentrations in the water column are greater than 3 to 4 mg/l but becomes limited by the rate of oxygen supply to the sediments.

Water column oxygen demand: A characteristic of many reservoirs is a metalimnetic minimum in DO concentrations, or negative heterograde oxygen curve (Figure 2-1). Density interflows not only transport oxygen-demanding material into the metalimnion but can also entrain reduced chemicals from the upstream anoxic area and create additional oxygen demand. Organic matter and organisms from the mixed layer settle at slower rates in the metalimnion because of increased viscosity due to lower temperatures. Since this labile organic matter remains in the metalimnion for a longer time period, decomposition occurs over a longer time, exerting a higher oxygen demand. Metalimnetic oxygen depletion is an important process in deep reservoirs. A hypolimnetic oxygen demand generally starts at the sediment/water interface unless underflows contribute organic matter that exerts a significant oxygen demand. In addition to metalimnetic DO depletion, hypolimnetic DO depletion also is important in shallow, stratified reservoirs since there is a smaller hypolimnetic volume of oxygen to satisfy oxygen demands than in deeper reservoirs.

Dissolved oxygen distribution: Two basic types of vertical DO distribution may occur in the water column: an orthograde and clinograde DO distribution (Figure 2-1). In the orthograde distribution, DO concentration is a function primarily of temperature since DO consumption is limited. The clinograde DO profile is representative of more productive, nutrient-rich reservoirs where the hypolimnetic DO concentration progressively decreases during stratification and can occur during both summer and winter stratification periods.

Inorganic carbon: Inorganic carbon represents the basic building block for the production of organic matter by plants. Inorganic carbon can also regulate the pH and buffering capacity or alkalinity of aquatic systems. Inorganic carbon exists in a dynamic equilibrium in three major forms: carbon dioxide (CO_2), bicarbonate ions (HCO_3), and carbonate ions (CO_3). Carbon dioxide is readily soluble in water and some CO_2 remains in a gaseous form, but the majority of the CO_2 forms carbonic acid that dissociates rapidly into HCO_3 and CO_3 ions. This dissociation results in a weakly alkaline system (i.e., pH $\approx$ 7.1 or 7.2). There is an inverse relationship between pH and CO_2. The pH increases when aquatic plants (phytoplankton or macrophytes) remove CO_2 from the water to form organic matter through photosynthesis during the day. During the night when aquatic plants respire and release CO_2, the pH decreases. The extent of this pH change provides an indication of the buffering capacity of the system. Weakly buffered systems with low alkalinities (i.e., <500 microequivalents per liter) experience larger shifts in pH than well-buffered systems (i.e., >1,000 microequivalents per liter).

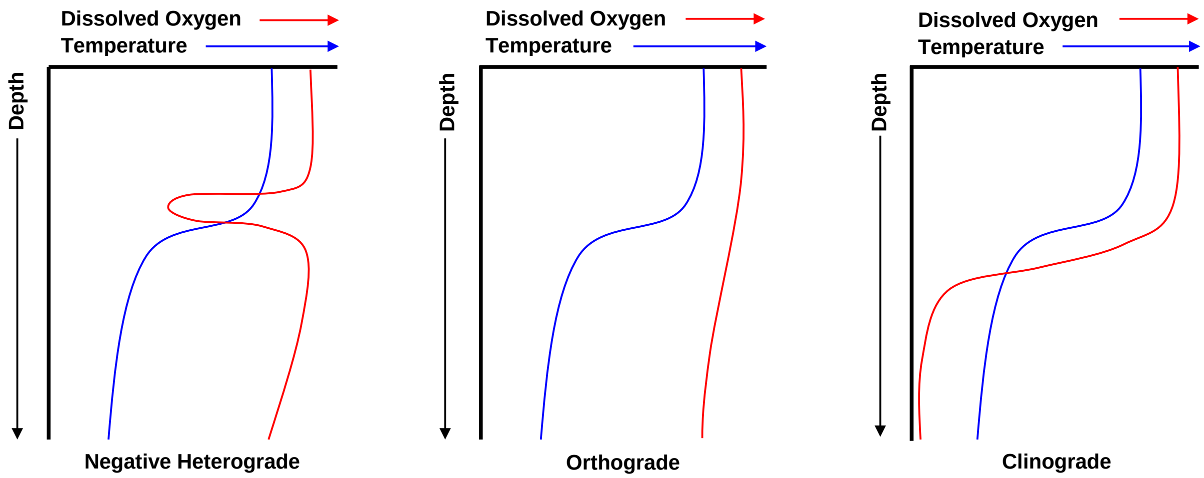

Figure 2-1. Vertical oxygen concentrations possible in thermally stratified lakes.

Nitrogen: Nitrogen is important in the formulation of plant and animal protein. Nitrogen, similar to carbon, also has a gaseous form. Many species of cyanobacteria can use or fix elemental or gaseous N_2 as a nitrogen source. The most common forms of nitrogen in aquatic systems are ammonia (NH_3-N), nitrite (NO_2-N), and nitrate (NO_3-N). All three forms are transported in water in a dissolved phase. Ammonia results primarily from the decomposition of organic matter. Nitrite is primarily an intermediate compound in the oxidation or nitrification of ammonia to nitrate, while nitrate is the stable oxidation state of nitrogen and represents the other primary inorganic nitrogen form, besides NH_3, used by aquatic plants.

Phosphorus: Phosphorus is used by both plants and animals to form enzymes and vitamins and to store energy in organic matter. Phosphorus has received considerable attention as the nutrient controlling algal production and densities and associated water quality problems. The reasons for this emphasis are: phosphorus tends to limit plant growth more than the other major nutrients; phosphorus does not have a gaseous phase and ultimately originates from the weathering of rocks; removal of phosphorus from point sources can reduce the growth of aquatic plants; and the technology for removing phosphorus is more advanced and less expensive than nitrogen removal. Phosphorus is generally expressed in terms of the chemical procedures used for measurement: total phosphorus, particulate phosphorus, dissolved or filterable phosphorus, and soluble reactive phosphorus. Phosphorus is a very reactive element; it reacts with many cations such as iron and calcium and is readily sorbed on particulate matter such as clays, carbonates, and inorganic colloids. Since phosphorus exists in a particulate phase, sedimentation represents a continuous loss from the water column to the sediment. Sediment phosphorus, then, may exhibit longitudinal gradients in reservoirs similar to sediment silt/clay gradients. Phosphorus contributions from sediment under anoxic conditions and macrophyte decomposition are considered internal phosphorus sources or loads, and are in a chemical form readily available for plankton uptake and use. Internal phosphorus loading can represent a major portion of the total phosphorus budget.

Silica: Silica is an essential component of diatom algal frustules or cell walls. Silica uptake by diatoms can markedly reduce silica concentrations in the epilimnion and initiate a seasonal succession of diatom species. When silica concentrations decrease below 0.5 mg/l, diatoms generally are no longer competitive with other phytoplankton species.

Other nutrients: Iron, manganese, and sulfur concentrations generally are adequate to satisfy plant nutrient requirements. Oxidized iron (III) and manganese (IV) are quite insoluble in water and occur in low concentrations under aerobic conditions. Under aerobic conditions, sulfur usually is present as sulfate.

2.2.2.2 Anaerobic (Anoxic) Conditions

When dissolved oxygen concentrations are reduced to approximately 2 to 3 mg/l, the oxygen regime is considered hypoxic. Anoxic conditions occur when there is a complete lack of oxygen. When hypoxic conditions occur in the hypolimnion, the oxygen regime at the sediment/water interface is generally considered anoxic, and anaerobic processes begin to occur in the sediment interstitial water. Nitrate reduction to ammonium and/or N_2O or N_2 (denitrification) is considered to be the first phase of the anaerobic process and places the system in a slightly reduced electrochemical state. Ammonium-nitrogen begins to accumulate in the hypolimnetic water. The presence of nitrate prevents the production of additional reduced forms such as manganese (II), iron (II), or sulfide species. Denitrification probably serves as the main mechanism for removing nitrate from the hypolimnion. Following the reduction or denitrification of nitrate, manganese species are reduced from insoluble forms (i.e., Mn (IV)) to soluble manganous forms (i.e., Mn (II)), which diffuse into the overlying water column. Nitrate reduction is an important step in anaerobic processes since the presence of nitrate in the water column will inhibit manganese reduction. As the electrochemical potential of the system becomes further reduced, iron is reduced from the insoluble ferric (III) form to the soluble ferrous (II) form and begins to diffuse into the overlying water column. Phosphorus, in many instances, is also transported in a complexed form with insoluble ferric (III) species; therefore, the reduction and solubilization of iron also result in the release and solubilization of phosphorus into the water column. The sediments may serve as a major phosphorus source during anoxic periods and a phosphorus sink during aerobic periods. During this period of anaerobiosis, microorganisms also are decomposing organic matter into lower molecular weight acids and alcohols such as acetic, fulvic, humic, and citric acids and methanol. These compounds may also serve as trihalomethane precursors (low-molecular weight organic compounds in water; i.e., methane, formate acetate), which, when subject to chlorination during water treatment, form trihalomethanes, or THMs (carcinogens). As the system becomes further reduced, sulfate is reduced to sulfide, which begins to appear in the water column. Sulfide will readily combine with soluble reduced iron (II), however, to form insoluble ferrous sulfide, which precipitates out of solution. If the sulfate is reduced to sulfide and the electrochemical potential is strongly reducing, methane formation from the reduced organic acids and alcohols may occur. Consequently, water samples from anoxic depths will exhibit these chemical characteristics.

Anaerobic processes are generally initiated in the upstream portion of the hypolimnion where organic loading from the inflow is relatively high and the volume of the hypolimnion is minimal, so oxygen depletion occurs rapidly. Anaerobic conditions are generally initiated at the sediment/water interface and gradually diffuse into the overlying water column and downstream toward the dam. Anoxic conditions may also develop in a deep pocket near the dam due to decomposition of autochthonous organic matter settling to the bottom. This anoxic pocket, in addition to expanding vertically into the water column, may also move upstream and eventually meet the anoxic zone moving downstream.

Anoxic conditions are generally associated with the hypolimnion, but anoxic conditions may occur in the metalimnion. The metalimnion may become anoxic due to microbial respiration and decomposition of plankton settling into the metalimnion, microbial metabolism of organic matter entering as an interflow, or entrainment of anoxic hypolimnetic water from the upper portion of the reservoir.

2.2.3 BIOLOGICAL CHARACTERISTICS AND PROCESSES

2.2.3.1 Microbiological

The microorganisms associated with reservoirs may be categorized as pathogenic or nonpathogenic. Pathogenic microorganisms are of a concern from a human health standpoint and may limit recreational and other uses of reservoirs. Nonpathogenic microorganisms are important in that they often serve as decomposers of organic matter and are a major source of carbon and energy for a reservoir. Microorganisms generally inhabit all zones of the reservoir as well as all layers. Seasonally high concentrations of bacteria will occur during the warmer months, but they can be diluted by high discharges. Anaerobic conditions enhance growth of certain bacteria while aeration facilitates the use of bacterial food sources. Microorganisms, bacteria in particular, are responsible for mobilization of contaminants from sediments.

2.2.3.2 Photosynthesis

Oxygen is a by-product of aquatic plant photosynthesis, which represents a major source of oxygen for reservoirs during the growing season. Oxygen solubility is less during the period of higher water temperatures, and diffusion may also be less if wind speeds are lower during the summer than the spring or fall. Biological activity and oxygen demand typically are high during thermal stratification, so photosynthesis may represent a major source of oxygen during this period. Oxygen supersaturation in the euphotic zone can occur during periods of high photosynthesis.

2.2.3.3 Plankton

Phytoplankton influence dissolved oxygen and suspended solids concentrations, transparency, taste and odor, aesthetics, and other factors that affect reservoir uses and water quality objectives. Phytoplankton are a primary source of organic matter production and form the base of the autochthonous food web in many reservoirs since fluctuating water levels may limit macrophyte and periphyton production. Phytoplankton can be generally grouped as diatoms, green algae, cyanobacteria, or cryptomonad algae. Chlorophyll *a* represents a common variable used to estimate phytoplankton biomass.

Seasonal succession of phytoplankton species is a natural occurrence in reservoirs. The spring assemblage is usually dominated by diatoms and cryptomonads. Silica depletion in the photic zone and increased settling as viscosity decreases because of increased temperatures usually result in green algae succeeding the diatoms. Decreases in nitrogen or a decreased competitive advantage for carbon at higher pH may result in cyanobacteria succeeding the green algae during summer and fall. Diatoms generally return in the fall, but cyanobacteria, greens, or diatoms may cause algae blooms following fall turnover when hypolimnetic nutrients are mixed throughout the water column. The general pattern of seasonal succession of phytoplankton is fairly constant from year to year. However, hydrologic variability, such as increased mixing and delay in the onset of stratification during cool, wet spring periods, can maintain diatoms longer in the spring and shift or modify the successional pattern of algae in reservoirs.

Phytoplankton grazers can reduce the abundance of algae and alter their successional patterns. Some phytoplankton species are consumed and assimilated more readily and are preferentially selected by consumers. Single-celled diatom and green algae species are readily consumed by zooplankton, while filamentous cyanobacteria are avoided by zooplankters. Altering the fish population can result in a change in the zooplankton population that can affect the phytoplankton population.

2.2.3.4 Organic Carbon and Detritus

Total organic carbon (TOC) is composed of dissolved organic carbon (DOC) and particulate organic carbon (POC). Detritus represents that portion of the POC that is nonliving. Nearly all the TOC of natural waters consists of DOC and detritus, or dead POC. The processes of decomposition and consumption of TOC are important in reservoirs and can have a significant effect on water quality.

DOC and POC are decomposed by microbial organisms. This decomposition exerts an oxygen demand that can remove dissolved oxygen from the water column. During stratification, the metalimnion and hypolimnion become relatively isolated from sources of dissolved oxygen, and depletion can occur through organic decomposition. There are two major sources of this organic matter: allochthonous (i.e., produced outside the reservoir and transported in) and autochthonous (i.e., produced within the reservoir). Allochthonous organic carbon in small streams may be relatively refractory since it consists of decaying terrestrial vegetation that has washed or fallen into the stream. Larger rivers, however, may contribute substantial quantities of riverine algae or periphyton that decompose rapidly and can exert a significant oxygen demand. Autochthonous sources include dead plankton settling from the mixed layers and macrophyte fragments and periphyton transported from the littoral zone. These sources are also rapidly decomposed.

POC and DOC absorbed onto sediment particles may serve as a major food source for aquatic organisms. The majority of the phytoplankton production enters the detritus food web with a minority being grazed by primary consumers (USACE, 1987). While autochthonous production is important in reservoirs, typically as much as three times the autochthonous production may be contributed by allochthonous material (USACE, 1987).

2.2.4 BOTTOM WITHDRAWAL RESERVOIRS

Bottom withdrawal reservoirs have outlet structures located near the deepest part of a reservoir. Bottom withdrawal removes hypolimnetic water and nutrients and may promote movement of interflows or underflow into the hypolimnion. They release cold water from the deep portion of the reservoir; however, this water may be hypoxic or anoxic during periods of stratification. Bottom outlets can cause density interflows or underflows (e.g., flow laden with sediment or dissolved solids) through the reservoir and generally provide little or no direct control over release water quality.

As previously discussed, the intake structure at Big Bend Dam withdraws water from the bottom of Lake Sharpe. The powerplant intake structure has separate intakes, divided into three water passages by intermediate piers, for each of the eight units (Photo 1-1). The flow of water from the reservoir to the powerplant intake structure is guided by a curved approach channel. The approach channel has a bottom elevation of 1345 ft-NGVD29. About 120 feet upstream of the powerplant intake, the bottom of the approach channel slopes downward on a 1 on 8 slope to elevation 1330 ft-NGVD29 at the intake. Because of the available fetch and shallower maximum depth (approximately 90 feet) near the dam, Lake Sharpe is seemingly polymixic and a hypolimnion with degraded dissolved oxygen conditions only forms intermittently.

2.3 APPLICATION OF THE CE-QUAL-W2 WATER QUALITY MODEL TO THE MISSOURI RIVER MAINSTEM SYSTEM PROJECTS

Water quality data must be applied to understand and manage water resources effectively. Application of appropriate mathematical models promotes efficient and effective use of data. Models are powerful tools for guiding project operations, refining water quality sampling programs, planning project modifications, evaluating management scenarios, improving project benefits, and illuminating new or understanding complex phenomena. CE-QUAL-W2 is a “state-of-the-art” water quality model that can greatly facilitate addressing reservoir water quality management issues.

CE-QUAL-W2 is a water quality and hydrodynamic model in two dimensions (longitudinal and vertical) for rivers, estuaries, lakes, reservoirs, and river basin systems. CE-QUAL-W2 models basic physical, chemical, and biological processes such as temperature, nutrient, algae, dissolved oxygen, organic matter, and sediment relationships. Version 1.0 of the model was developed by the Corps’ Water

Quality Modeling Group at the Waterways Experiment Station in the late 1980's. The current model release is Version 3.6 and is supported by the Corps' Engineer Research and Development Center (ERDC) and Portland State University.

2.3.1 PAST APPLICATION OF THE CE-QUAL-W2 MODEL

Version 2.0 of the CE-QUAL-W2 model was applied to four of the upper Mainstem System Projects in the early 1990's (i.e., Fort Peck, Garrison, Oahe, and Fort Randall). The application of the model was part of the supporting technical documentation of the Environmental Impact Statement (EIS) that was prepared for the Missouri River Master Water Control Manual Review and Update Study. The results of the model application were included as an Appendix to the Review and Update Study – "Volume 7B: Environmental Studies, Reservoir Fisheries, Appendix C – Coldwater Habitat Model, Temperature and Dissolved Oxygen Simulations for the Upper Missouri River Reservoirs" (Cole et. al., 1994). The report (Cole et. al, 1994) provided results of applying the model to the four reservoirs regarding the effects of operational changes on reservoir coldwater fish habitat. This early application of the model represents the best results that could be obtained based on the model version and water quality data available at that time, and it provided predictive capability for coldwater fish habitat regarding two system operational variables of concern – end-of-month stages and monthly average releases.

Although application of the CE-QUAL-W2 (Version 2.0) model met its intended purpose at the time, a lack of available water data placed limitations on its full utilization. These limitations were discussed in the Master Water Control Review and Update Study report (Cole et. al, 1994). The following excerpts are taken from that report:

> *"Typically, dissolved oxygen (DO) is modeled along with a full suite of water quality variables including algal/nutrient interactions. Lack of available algal/nutrient data necessitated a different approach. DO was assumed to be a function of sediment and water column oxygen demands which were adjusted during calibration to reproduce the average DO depletion during summer stratification. The drawback to this approach is that operational changes which might affect algal/nutrient interactions cannot be predicted. Results from this study show only how physical factors relating to changes in reservoir stage and discharge affect DO."*
>
> *"As a result, model predictions during scenario runs represent only how physical factors affect DO and do not include the effects of reservoir operations on algal/nutrient dynamics and their effects on DO. To include algal/nutrient effects would require at least one year's worth of detailed algal/nutrient data for each reservoir that were not and could not be made available during the time frame of this study."*
>
> *"Steps should be taken to obtain a suitable database that can be used to calibrate the entire suite of water quality algorithms in the model. It is almost a certainty that water quality issues will remain important in the future."*

The current version of the CE-QUAL-W2 model has incorporated numerous enhancements over the Version 2.0 model that was applied to the four Mainstem System Projects in the early 1990's. These enhancements, among other things, include improvements to the numerical solution scheme, water quality algorithms, two-dimensional modeling of the waterbasin, code efficiencies, and user-model interface. Communication with the author of the past application of the Version 2.0 model to the Mainstem System Projects and current model support personnel indicated that the Omaha District should pursue implementing the current version of the model (personal communication, Thomas M. Cole, USACE/ERDC).

2.3.2 FUTURE APPLICATION OF THE CE-QUAL-W2 MODEL

As part of its Water Quality Management Program, the Omaha District initiated the application of the CE-QUAL-W2 (Version 3.2) model to the Mainstem System Projects. The District is approaching the model application as an ongoing, iterative process. Data will be collected, and the model will be run and continuously calibrated as new information is gathered. The goal is to have a fully functioning model in place for all the Mainstem System Projects that meets the uncertainty requirements of decision-makers.

The current plan for applying the model to a single project will encompass a 5-year period. During years 1 through 3 an intensive water quality survey will be conducted to collect the water quality data needed to fully apply the model. The water quality data will be compiled and a Special Water Quality Report assessing the water quality data will be compiled in year 4 (this report). Application and calibration of the model will be initiated in year 5 or a soon as possible. Once the model has been applied and calibrated, a Water Quality Modeling report will be prepared documenting the application of the model to the specific reservoir. The calibrated model will then be used to facilitate the development of a Project-Specific Water Quality Report and water quality management objectives for the specific reservoir. The current plan is to stagger the application of the model by annually beginning the application process at a different Mainstem System project. The current order for applying the model to the Projects is: 1) Garrison Project, 2) Fort Peck Project, 3) Oahe Project, 4) Fort Randall Project, 5) Big Bend Project, and 6) Gavins Point Project. Eventually it is hoped that the CE-QUAL-W2 models developed for each of the Projects can be linked and used to make integrated water quality management decisions throughout the Mainstem System.

2.3.3 CURRENT APPLICATION OF THE CE-QUAL-W2 MODEL TO LAKE SHARPE

The 3-year intensive water quality survey was conducted at the Big Bend Project during 2008 through 2010, and the application and calibration of the model to Lake Sharpe is planned for 2014. The Big Bend Project is targeted to be the fifth Mainstem System Project on which the updated CE-QUAL-W2 model is applied. A Water Quality Modeling Report will be prepared at a future date describing the application and calibration of the CE-QUAL-W2 model to Lake Sharpe.

3 DATA COLLECTION METHODS

3.1 DATA COLLECTION DESIGN

3.1.1 MONITORING LOCATIONS

The Omaha District collected water quality data at 8 locations at the Big Bend Project during the 3-year period 2008 through 2010. Of the 8 locations, 5 were located on Lake Sharpe, 2 were located on the major inflows to the reservoir (i.e., Oahe powerplant and Bad River), and 1 was located at the Big Bend Dam powerplant. Table 3-1 describes the monitoring locations in greater detail, and Figure 3-1 shows their locations.

The monitoring sites were categorized into three types: 1) lake, 2) inflow, and 3) outflow (Table 3-1). All of the reservoir sites were meant to represent "deepwater" pelagic conditions and were established at the deepest part of the reservoir in the area being monitored. The five reservoir monitoring sites (i.e., BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, and BBDLK1055DW) were approximately equally spaced along the submerged old Missouri River channel from near the dam to near Pierre, South Dakota – a total distance of approximately 68 miles. The two inflow stations (i.e., OAHPP1 and BBDNFBADR1) were located on the Missouri River at Oahe Dam and on the Bad River at its confluence with Lake Sharpe. The Missouri River inflow site was in the Oahe Dam powerplant and monitored water quality conditions indicative of the Oahe Dam discharge. The outflow site (i.e., BBDPP1) was located in the Big Bend Dam powerplant, and monitored water quality conditions from the "raw water" supply line in the powerplant that was indicative of the Big Bend Dam discharge. The monitoring sites are believed to be associated with the following reservoir zones: Lacustrine Zone (BBDLK0987, BBDLK1004DW, and BBDPP1), Zone of Transition (BBDLK1020DW and BBDLK1036DW), and Riverine Zone (BBDLK1055DW).

Table 3-1. Location and description of monitoring sites that were sampled by the Omaha District for water quality at the Big Bend Project during the 3-year period 2008 through 2010.

Station Number	Name	Location	Site Type	Latitude	Longitude
OAHPP1	Oahe Dam Powerplant	"Raw Water" Supply Line	Inflow	44° 27' 02.8"	100° 23' 11.4"
BBDNFBADR1	Bad River at Fort Pierre	Bad River Confluence	Inflow	44° 21' 02.1"	100° 22' 20.7"
BBDLK0987A	Big Bend Reservoir – Near Dam	Reservoir (RM0988), Deepwater	Lake	44° 02' 56.8"	99° 28' 03.5"
BBDLK1004DW	Big Bend Reservoir – North Bend Area	Reservoir (RM1004), Deepwater	Lake	44° 12' 42.0"	99° 37' 11.7"
BBDLK1020DW	Big Bend Reservoir – Iron Nation Area	Reservoir (RM1020), Deepwater	Lake	44° 06' 50.7"	99° 41' 54.4"
BBDLK1036DW	Big Bend Reservoir – Cedar Creek Area	Reservoir (RM1036), Deepwater	Lake	44° 12' 38.2"	99° 55' 34.5"
BBDLK1055DW	Big Bend Reservoir – Antelope Creek Area	Reservoir (RM1055), Deepwater	Lake	44° 19' 26.3"	100° 09' 57.2"
BBDPP1	Big Bend Dam Powerplant	"Raw Water" Supply Line	Outflow	44° 02' 18.9"	99° 26' 44.4"

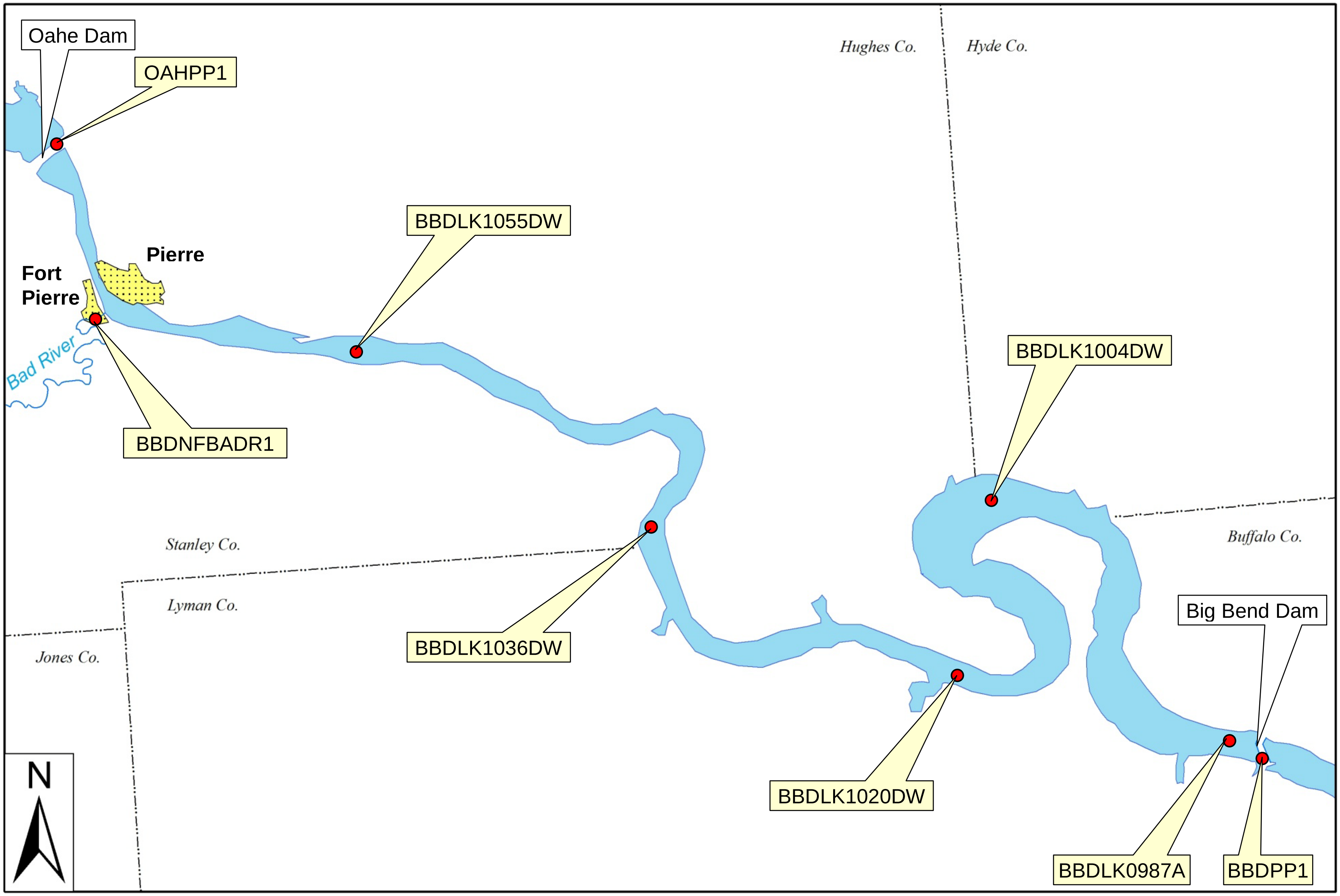

Figure 3-1. Location of sites where water quality monitoring was conducted by the District at the Big Bend Project during the 3-year period 2008 through 2010.

3.1.2 MEASUREMENTS, SAMPLE TYPES, AND COLLECTION FREQUENCY

3.1.2.1 Reservoir Monitoring Stations

Monitoring at the reservoir monitoring sites consisted of field measurements and collection of depth-discrete "grab" samples for laboratory analysis. Field measurements consisted of depth-profiles for selected parameters and a surface Secchi depth measurement. Two depth-discrete grab samples, near-surface (i.e., ½ the measured Secchi depth) and near-bottom (i.e., within 1 meter of the reservoir bottom), were collected. Measurements and samples were collected monthly during the period April/May/June through September.

3.1.2.2 Inflow Monitoring Stations

Monitoring at the Oahe powerplant was collected under a separate project that included sampling at all the Missouri River mainstem powerplants. Monitoring at the powerplant included year-round collection of monthly samples for laboratory analyses and hourly measurements of water temperature, dissolved oxygen (mg/l and % saturation), and conductivity via an installed data-logger.

Monitoring at the Bad River inflow site consisted of field measurements and collection of grab samples. A near-surface grab sample was collected from near the bank. Monitoring at this site occurred monthly during the period April through September.

3.1.2.3 Outflow Monitoring Station

Monitoring at the Big Bend powerplant was conducted under the same project which monitored conditions at the Oahe powerplant. Monitoring consisted of year-round hourly data-logging of water quality measurements and monthly collection of grab samples for laboratory analyses. Measurements and samples were collected from a "flow-chamber" drawing water from the "raw-water" supply line in the powerplant. At the Big Bend Project, the raw water supply elevation is at 1344.2 feet-msl, approximately 14 feet above the reservoir bottom. The raw water is obtained at headwater pressure from each of the 8 unit waterways through 12-inch grated intakes located on the on the downstream side of the spiral cases and also through a 14-inch diameter grated intake from the forebay of units 3 and 7. Each raw water intake has a duplex strainer and is connected to a 14-inch raw water header running 600 feet from bay 2 though 8. The raw water header is reduced to a 4-inch pipe for 100 feet, 2-inch pipe for 80 feet, and finally a 1-inch pipe for the remaining 55 feet to the water quality sampling chamber and monitoring location.

3.1.3 PARAMETERS MEASURED AND ANALYZED

3.1.3.1 Water Quality Parameters

The water quality parameters that were measured and analyzed at the various monitoring stations are given in Table 3-2.

3.1.3.2 Explanatory Variables

Explanatory variables that were quantified included inflow discharge, outflow discharge, and reservoir pool elevation. Inflow discharge at station OAHPP1 was taken as the recorded discharge at Oahe Dam. Inflow discharge at station BBDNFBADR1 was determined from the USGS gage (06441500) on the Bad River near Fort Pierre, South Dakota. Outflow discharge from Big Bend Dam and the pool elevation of Lake Sharpe were obtained from Big Bend Project records.

Table 3-2. Parameters measured and analyzed at the various monitoring sites.

Parameter	Monitoring Site Number			
	BBDLK0987A BBDLK1020DW BBDLK1055DW	**BBDLK1004DW BBDLK1036DW**	**OAHPP1 BBDPP1**	**BBDNFBADR 1**
Alkalinity	✓		✓	✓
Carbon, Total Organic	✓		✓	✓
Chemical Oxygen Demand, Total	✓		✓	✓
Chlorophyll *a*	✓			
Color, True	✓		✓	✓
Dissolved Solids, Total	✓		✓	✓
Microcystins	✓		✓	
Nitrogen, Total Ammonia	✓		✓	✓
Nitrogen, Total Kjeldahl	✓		✓	✓
Nitrogen, Nitrate-Nitrite	✓		✓	✓
Phosphorus, Dissolved	✓		✓	✓
Phosphorus, Orthophosphate	✓		✓	✓
Phosphorus, Total	✓		✓	✓
Plankton – Zooplankton Taxa. Id. and Biovolume	✓			
Plankton – Phytoplankton Taxa. Id. and Biovolume	✓			
Silica, Dissolved and Total	✓			✓
Sulfate, Dissolved	✓		✓	✓
Suspended Solids, Total	✓		✓	✓
Metal Scan, Total and Dissolved			✓	✓
Pesticide Scan, Total			✓	✓
Secchi Depth/Transparency	✓	✓		
Field Measurements (HydroLab)*	Depth Profile	Depth Profile	Grab Sample	Grab Sample
Continuous Monitoring ("HydroLab")**			✓	

* HydroLab field measurements included: water temperature, dissolved oxygen (mg/l and % saturation), pH, conductivity, ORP, turbidity, and chlorophyll *a*. Depth profile measurements taken at 1-meter intervals from the reservoir surface to the bottom.

** Continuous monitored parameters include temperature, dissolved oxygen (mg/l and % saturation), and conductivity.

3.2 WATER QUALITY MEASUREMENT AND SAMPLING METHODS

3.2.1 FIELD MEASUREMENTS

Depth-profile and surface measurements for water temperature, dissolved oxygen (mg/l and % saturation), pH, conductivity, Oxidation-Reduction Potential (ORP), turbidity, and chlorophyll *a* were taken using a "HydroLab". Profile measurements were taken at 1-meter intervals. The HydroLab was operated as specified in the USACE – Water Quality Unit's Standard Operating Procedures (SOPs) Number WQ-21201, "Using a HydroLab DS5 to Directly Measure Water Quality" (USACE, 2010a). Secchi transparency was measured in accordance with the USACE – Water Quality Unit's SOP Number WQ-21202, "Determining Secchi Depth" (USACE, 2004b).

3.2.2 WATER QUALITY SAMPLE COLLECTION

All water quality samples were collected in accordance with the USACE – Water Quality Unit's SOP Number WQ-21101, "Collection of Surface Water Samples" (USACE, 2010b). Surface grab samples were collected by dipping a rinsed plastic churn bucket just below the surface (i.e., approximately 6 inches below the surface). Depth-discrete grab samples were collected with a Kemmerer sampler that was lowered to the desired sampling depth, triggered, and retrieved to the boat. Phytoplankton samples were taken from the near-surface reservoir samples. Zooplankton samples were collected in 2010 by using a "Wisconsin Net and Bucket" to take a vertical tow from near the reservoir bottom to the surface.

3.3 ANALYTICAL METHODS

Laboratory analyses of all collected water quality samples were done by the District's contract laboratory, Midwest Laboratories, Inc. in Omaha, Nebraska. The analytical methods, detection limits, and reporting limits for the analysis of the collected water quality samples are given in Table 3-3. Plankton analyses were done by a laboratory (i.e., BSA Environmental Services, Inc., Beachwood, Ohio) under contract to Midwest Laboratories.

Table 3-3. Methods, detection limits, and reporting limits for laboratory analyses.

Analyte	Method	Detection Limit	Reporting Limit
Alkalinity, Total	SM2320B	4 mg/l	10 mg/l
Carbon, Total Organic(TOC)	SM5310B	0.2 mg/l	1 mg/l
Chlorophyll *a*	SM - 10200H2	1 ug/l	3 ug/l
Color, True	ASTMD1252	2 SU	5 SU
Dissolved Solids, Total	SM2540C	4 mg/l	10 mg/l
Microcystins (Immunoassay)	Rapid Assay	0.2 ug/l	1 ug/l
Nitrogen, Total Ammonia as N	EPA - 350.1	0.02 mg/l	0.1 mg/l
Nitrogen, Total Kjeldahl as N	EPA - 351.3	0.2 mg/l	0.5 mg/l
Nitrogen, Nitrate/Nitrite as N	EPA - 353.2	0.02 mg/l	0.1 mg/l
Phosphorus, Dissolved	SM4500PF	0.02 mg/l	0.05 mg/l
Phosphorus, Total as P	SM4500PF	0.02 mg/l	0.05 mg/l
Phosphorus, Orthophosphate	EPA - 365.4	0.02 mg/l	0.05 mg/l
Silica, Total and Dissolved	EPA - 200.7	0.5 mg/l	1 mg/l
Sulfate, Dissolved	EPA - 300.0	1 mg/l	5 mg/l
Suspended Solids, Total	SM2540D	4 mg/l	10 mg/l
Metals Scan, Dissolved and Total:			
Antimony	EPA - 200.8	0.5 ug/l	2 ug/l
Arsenic, Silver	EPA - 200.7	1 ug/l	3 ug/l
Beryllium	EPA - 200.7	2 ug/l	5 ug/l
Cadmium	EPA - 200.8	0.2 ug/l	1 ug/l
Calcium, Chromium, Magnesium, Nickel, Zinc	EPA - 200.7	10 ug/l	30 ug/l
Copper, Manganese	EPA - 200.7	2 ug/l	10 ug/l
Iron	EPA - 200.7	40 ug/l	120 ug/l
Lead, Thallium	EPA - 200.8	0.5 ug/l	2 ug/l
Mercury	EPA - 7470	0.4 ug/l	1.2 ug/l
Selenium	EPA – 200.8	1 ug/l	3 ug/l
Pesticide scan*:	EPA - 507	0.05 ug/l	0.1 ug/l

* Pesticide scan included: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, cycloate, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, isopropalin, metolachlor, metribuzin, molinate, oxiadiazon, oxyfluorfen, pebulate, pendimethalin, phorate, profluralin, prometon, propachlor, propazine, simazine, terbufos, triallate, trifluralin, and vernolate.

4 DATA ASSESSMENT METHODS

4.1 GENERAL WATER QUALITY CONDITIONS

Statistical analyses were performed on the water quality monitoring data collected at reservoir, inflow, and outflow sites during the 3-year period 2008 through 2010. Descriptive statistics (i.e., mean, median, minimum, maximum) were calculated to describe central tendencies and the range of observations. Where appropriate, monitoring results were compared to defined water quality standards criteria for the State of South Dakota.

Spatial variation of selected water quality parameters in Lake Sharpe was evaluated. Longitudinal contour plots were constructed for water temperature, dissolved oxygen, and turbidity to display likely conditions in Lake Sharpe from its upper reaches to Big Bend Dam. The longitudinal contour plots were constructed using the “Hydrologic Information Plotting Program” included in the “Data Management and Analysis System for Lakes, Estuaries, and Rivers” (DASLER-X) software developed by HydroGeoLogic, Inc. (Hydrogeologic Inc., 2008). Secchi depth measurements collected along Lake Sharpe are displayed using a box plot. The variation of selected parameters with depth was evaluated at site BBDLK0987A by comparing near-surface and near-bottom conditions. Near-surface conditions were represented by samples collected within 2-meters of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. Water quality conditions represented by paired near-surface and near-bottom samples are graphically displayed by box plots. A paired two-tailed t-test was used to determine if the paired near-surface and near-bottom samples were significantly different ($\alpha = 0.05$).

4.2 TROPHIC STATUS

A Trophic State Index (TSI) was calculated, as described by Carlson (1977). TSI values were determined from Secchi depth transparency, total phosphorus, and chlorophyll *a* measurements. Values for these three parameters were converted to an index number ranging from 0 to 100 according to the following equations:

$$\text{TSI(Secchi Depth)} = \text{TSI(SD)} = 10[6 - (\ln \text{SD}/\ln 2)]$$
$$\text{TSI(Chlorophyll } a) = \text{TSI(Chl)} = 10[6 - ((2.04\text{-}0.68 \ln \text{Chl})/\ln 2)]$$
$$\text{TSI(Total Phosphorus)} = \text{TSI(TP)} = 10[6 - (\ln (48/\text{TP})/\ln 2)]$$

Accurate TSI values from total phosphorus depend on the assumptions that phosphorus is the major limiting factor for algal growth and that the concentrations of all forms of phosphorus present are a function of algal biomass. Accurate TSI values from Secchi depth transparency depend on the assumption that water clarity is primarily limited by phytoplankton biomass. Carlson indicates that the chlorophyll TSI value may be a better indicator of a lake’s trophic conditions during mid-summer when algal productivity is at its maximum, while the total phosphorus TSI value may be a better indicator in the spring and fall when algal biomass is below its potential maximum. Calculation of TSI values from data collected from a lake’s epilimnion during summer stratification provide the best agreement between all of the index parameters and facilitate comparisons between lakes. A TSI average value, calculated as the average of the three individually determined TSI values, is used by the District as an overall indicator of a reservoir’s trophic state. The District uses the criteria defined in Table 4-1 for determining lake trophic status from TSI values.

Table 4-1. Lake trophic status based on calculated TSI values.

TSI	Trophic Condition
0-35	Oligotrophic
36-50	Mesotrophic
51-55	Moderately Eutrophic
56-65	Eutrophic
66-100	Hypereutrophic

Existing trophic conditions were assessed for Lake Sharpe based on the monitoring conducted during the 3-year period 2008 through 2010. The data evaluated consisted of Secchi depth measurements and total phosphorus and chlorophyll *a* analytical results obtained at the reservoir sites BBDLK0987A, BBDLK1020DW, and BBDLK1055DW. TSI values were calculated and compared to the above criteria.

4.3 PLANKTON COMMUNITY

4.3.1 PHYTOPLANKTON

Assessment of the phytoplankton community was based on grab samples that were analyzed by a contract laboratory. Laboratory analyses consisted of identification of phytoplankton taxa to the lowest practical level and quantification of taxa biovolume. These results were used to determine the relative abundance of phytoplankton taxa at the division level based on the measured biovolumes.

4.3.2 ZOOPLANKTON

Assessment of the zooplankton community was based on vertical tow samples (i.e., near-bottom to surface) that were collected in May, July, and September of 2010. Zooplankton samples were analyzed by a contract laboratory, and consisted of identification of zooplankton taxa to the lowest practical level and quantification of taxa biomass. These results were used to determine the relative abundance of zooplankton taxa at the division level based on the measured biomass.

4.4 IMPAIRMENT OF DESIGNATED WATER QUALITY-DEPENDENT BENEFICIAL USES

Water quality-dependent beneficial uses are designated to waterbodies at the Big Bend Project by the State of South Dakota in their water quality standards, and criteria are defined to protect these uses (see Section 1.4.1). Water quality data collected at the Big Bend Project during the 3-year period 2008 through 2010 were assessed to determine if monitored water quality conditions indicate impairment of the designated beneficial uses. Impairment of beneficial uses was assessed using the methodologies defined by the South Dakota Department of Environment and Natural Resources to prepare the States' 2010 Integrated Report for Surface Water Quality Assessment (SDDENR, 2010). SDDENR methodologies require that beneficial use support determinations be based on sufficient and credible data. Data must meet QA/QC requirements that assure data are representative. The decision criteria regarding data age, sample size, and exceedances that the State of South Dakota uses to determine beneficial use support are given in Table 4-2, Table 4-3, and Table 4-4.

4.5 TIME-SERIES PLOTS OF FLOW, WATER TEMPERATURE, AND DISSOLVED OXYGEN OF WATER DISCHARGED THROUGH BIG BEND DAM

Time series plots were prepared for conditions measured at the Big Bend Dam powerplant during the 2008 through 2010 period. Discharge was plotted with hourly temperature and dissolved oxygen measurements. Plots were for measurements taken on water drawn from the "raw water" supply line within the powerplant (site BBDPP1).

Table 4-2. Data age requirements specified by South Dakota to consider data representative of actual conditions.

Description	Criteria Used
CONVENTIONAL PARAMETRS (e.g., dissolved oxygen, total suspended solids, pH, temperature, fecal coliform bacteria, etc.) TOXIC PARAMETERS (e.g., metals, ammonia, etc.)	• STREAMS: Data must be less than 5 years old. • LAKES: Data must be less than 10 years old. Unless there is justification that data is (or is not) representative of current conditions.

Table 4-3. Sample size requirements specified by South Dakota to consider data representative of actual conditions.

Description	Criteria Used
CONVENTIONAL PARAMETERS (e.g., DO, TSS, pH, temperature, fecal coliform bacteria, etc.)	• STREAMS: At least 20 samples for any one parameter are usually required at any site. The sample threshold is reduced to 10 samples if 3 or more samples exceed daily maximum water quality standards. • LAKES: At least two independent years of sample data and at least two sampling events per year.
TOXIC PARAMETERS (e.g., metals, ammonia, etc.)	• STREAMS: At least one water quality sampling event. • LAKES: At least one fish flesh sampling event. More than one exceedance of toxic criteria within the past 3 years.

Table 4-4. Decision criteria for beneficial use support determination identified by South Dakota.

Description	Criteria
CONVENTIONAL PARAMETERS (e.g., DO, TSS, pH, temperature, fecal coliform bacteria, etc.) Required percentage of samples exceeding water quality standards to consider segment water quality-limited.	STREAMS: >10% (or 3 or more exceedances between 10 and 19 samples) for daily maximum criteria. >10% (2 or more exceedances between 2 and 19 samples) for 30-day average criteria. LAKES: >10% exceedances when 20 or more samples are available. If <20 samples available, 3 exceedances are considered impaired. If one surface exceedance was observed for water temperature, DO, or pH; lake profile data is used to make use support determination. Lakes are considered fully supporting the aquatic life beneficial use if profile data indicate a region within the water column where temperature, pH, and dissolved oxygen meet numeric water quality standards criteria. If a region does not exist, the lake is listed for the parameter in exceedance.
TOXIC PARAMETERS (e.g., metals, ammonia, etc.) Required percentage of samples exceeding water quality standards to consider segment water quality-limited.	STREAMS: More than one exceedance of toxic criteria within the past 3 years for both the acute and chronic standard. LAKES: If flesh samples are above the Federal Drug Administration's recommended action levels (such as 1 part per million for mercury).

5 LAKE SHARPE WATER QUALITY CONDITIONS

5.1 EXISTING WATER QUALITY CONDITIONS – 2008 THROUGH 2010

5.1.1 STATISTICAL SUMMARY AND WATER QUALITY STANDARDS ATTAINMENT

Table 5-1, Table 5-2, Table 5-3, Table 5-4, and Table 5-5 summarize the water quality conditions that were monitored at the five monitoring sites on Lake Sharpe during the 3-year period of 2008 through 2010. A review of these results indicated water quality concerns regarding water temperature and dissolved oxygen for the support of Coldwater Permanent Fish Life Propagation (CPFLP). Due to its shallowness, a hypolimnion rarely forms in Lake Sharpe and water temperatures throughout the reservoir regularly exceed 18.3°C in the summer. Dissolved oxygen levels near the bottom of the reservoir occasionally fall below the 6.0 mg/l CPFLP criterion during the summer. The lowest dissolved oxygen concentration measured during the 3-year period at the five sites was 3.2 mg/l, and occurred near the dam at site BBDLK0987A in August 2008. The suspended solids criteria for the protection of CPFLP are regularly exceeded in the upper end of Lake Sharpe (Table 5-5). This is attributed to finer sediment that has been deposited in Lake Sharpe below the confluence of the Bad River and its continual re-suspension with wave action.

5.1.2 WATER TEMPERATURE

5.1.2.1 <u>Annual Temperature Regime</u>

The water temperature regime of Lake Sharpe can be described by an annual cycle consisting of eight thermal periods: 1) winter ice cover, 2) spring turnover, 3) spring isothermal conditions, 4) late-spring/early-summer warming, 5) mid-summer maximum thermal warming, 6) late-summer/early-fall cooling, 7) fall turnover, and 8) fall isothermal conditions leading to winter ice cover. During the winter ice-cover period, Lake Sharpe can exhibit an inverse thermal gradient as warmer, more dense water (i.e., 4°C) settles to the bottom. Thermal stratification of Lake Sharpe is influenced by the reservoir's depth and the management of its inflows and outflows for hydropower production. Compared to the four larger Missouri River mainstem reservoirs, Lake Sharpe is relatively shallow with a maximum depth of 90 feet near the dam. The shallower depth, given the available fetch, allows Lake Sharpe to periodically mix to the bottom during the summer thermal stratification period. Lake Sharpe also experiences extremely variable and high inflows and outflows under the management of the Big Bend Project as a run-of-the-river power development. The high inflows and outflows induce Lake Sharpe to mix throughout the water column and inhibit thermal stratification. The periodic mixing of Lake Sharpe results in the reservoir being polymixic with irregular periods of the thermal stratification.

Table 5-1. Summary of monthly (May through September) water quality conditions monitored in Lake Sharpe near Big Bend Dam (Site BBDLK0987A) during the 3-year period 2008 through 2010.

Parameter	Monitoring Results(A)						Water Quality Standards Attainment		
	Detection Limit(B)	No. of Obs.	Mean(C)	Median	Min.	Max.	State WQS Criteria(D)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	15	1420.3	1420.2	1419.9	1420.8	-----	-----	-----
Water Temperature (°C)	0.1	332	18.8	19.5	9.7	27.6	18.3(1,5)	215	65%
Hypolimnion Water Temperature (°C)(E)	0.1	22	21.8	22.7	18.5	24.3	18.3(1,5)	22	100%
Dissolved Oxygen (mg/l)	0.1	332	8.4	8.4	3.2	10.8	6(1,6,8), 7(1,6,8)	24, 36	7%, 11%
Dissolved Oxygen (% Sat.)	0.1	332	92.8	95.2	37.2	126.5	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/l)(E)	0.1	309	8.6	8.5	5.5	10.8	5(3,6)	0	0%
Hypolimnion Dissolved Oxygen (mg/l)(E)	0.1	22	4.9	5.1	3.2	6.4	6(1,6,8)	20	91%
Specific Conductance (umhos/cm)	1	332	723	724	660	783	-----	-----	-----
pH (S.U.)	0.1	332	8.4	8.4	7.5	8.9	6.5(1,2,6), 9.0(1,2,5), 9.5(4,5)	0	0%
Turbidity (NTUs)	1	330	3	2	n.d.	23	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	310	327	320	198	426	-----	-----	-----
Secchi Depth (in.)	1	14	94	75	30	228	-----	-----	-----
Alkalinity, Total (mg/l)	7	30	150	155	114	162	-----	-----	-----
Carbon, Total Organic (mg/l)	0.05	30	3.4	3.2	2.1	5.2	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	30	11	11	n.d.	19	-----	-----	-----
Chloride (mg/l)	1	20	12	12	11	14	175(1,5), 100(1,7), 438(2,5), 250(2,7)	0	0%
Chlorophyll *a* (ug/l) – Field Probe	1	302	13	7	1	73	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab Determined	1	15	8	6	1	26	-----	-----	-----
Color, True (APHA)	1	21	7	6	4	19	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	30	495	507	370	624	1,750(2,5), 1,000(2,7), 3,500(4,5), 2,000(4,7)	0	0%
Nitrogen, Ammonia Total (mg/l)	0.02	30	-----	n.d.	n.d.	0.19	2.6 (1,5,9), 0.88 (1,7,9)	0	0%
Nitrogen, Kjeldahl Total (mg/l)	0.1	30	-----	0.4	n.d.	1.0	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/l)	0.02	30	-----	n.d.	n.d.	1.00	10(2,5)	0	0%
Nitrogen, Total (mg/l)	0.1	30	-----	0.6	n.d.	1.6	-----	-----	-----
Phosphorus, Dissolved (mg/l)	0.02	30	-----	0.02	n.d.	0.06	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	30	0.03	0.03	n.d.	0.07	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	30	-----	n.d.	n.d.	0.06	-----	-----	-----
Sulfate (mg/l)	1	30	207	209	171	238	875(2,5), 500(2,7)	0	0%
Suspended Solids, Total (mg/l)	4	30	-----	n.d.	n.d.	11	53(1,5), 30(1,7)	0	0%
Microcystin, Total (ug/l)	0.2	14	-----	n.d.	n.d.	0.3	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat(F)	-----	15	-----	-----	-----	-----	D.O ≥ 6 mg/l W. Temp. ≤ 18.3°C	9	60%

n.d. = Not detected.

(A) Results for water temperature, dissolved oxygen, specific conductance, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll *a* (lab determined) and microcystin are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.

(B) Detection limits given for the parameters Pool Elevation, Water Temperature, Dissolved Oxygen (mg/l and % Sat.), Specific Conductance, pH, Oxidation-Reduction Potential, and Secchi Depth are resolution limits for field measured parameters.

(C) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(D) Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.

- (1) Criteria for the protection of coldwater permanent fish life propagation waters.
- (2) Criteria for the protection of domestic water supply waters.
- (3) Criteria for the protection of immersion and limited contact recreation waters (applies only to epilimnion and metalimnion if water body stratified).
- (4) Criteria for the protection of commerce and industry waters.
- (5) Daily maximum criterion (monitoring results directly comparable to criterion).
- (6) Daily minimum criterion (monitoring results directly comparable to criterion).
- (7) 30-day average criterion (monitoring results not directly comparable to criterion).
- (8) The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.
- (9) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates at least a 5°C difference between surface and bottom temperature, or at some point in the measured profile there is at least at 1°C drop in temperature over a 1-meter increment. The top of the hypolimnion is delineated as the lowest depth where a temperature drop of 1.0°C or at least 0.5°C occurs over a 1-meter depth increment. A defined hypolimnion was monitored on 4 of the 25 occasions (i.e., 16%) that monthly depth profiles were measured from May through September. Measured water depths in this area of Lake Sharpe were < 23 meters.

(F) Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e., at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/l). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile. During the 5-year period 2006 through 2010, water temperatures greater than 18.3°C throughout the water column precluded the occurrence of Coldwater Permanent Fish Life Propagation habitat from late-June through early-September.

Table 5-2. Summary of monthly (June through September) water quality conditions monitored at Lake Sharpe in the North Bend area (site BBDLK1004DW) during the 2-year period 2008 through 2009.

Parameter	Monitoring Results(A)						Water Quality Standards Attainment		
	Detection Limit(B)	No. of Obs.	Mean(C)	Median	Min.	Max.	State WQS Criteria(D)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	7	1420.3	1420.4	1419.7	1420.8	-----	-----	-----
Water Temperature (°C)	0.1	126	21.0	21.1	14.5	26.8	18.3(1,5)	108	86%
Hypolimnion Water Temperature (°C)(E)	0.1	14	21.1	21.3	19.0	22.8	18.3(1,5)	14	100%
Dissolved Oxygen (mg/l)	0.1	126	8.2	8.4	5.2	9.7	6(1,6,8), 7(1,6,8)	2, 22	2%, 17%
Dissolved Oxygen (% Sat.)	0.1	126	94.9	97.7	65.3	113.5	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/l)(E)	0.1	112	8.2	8.4	5.2	9.7	5(3,6)	0	0%
Hypolimnion Dissolved Oxygen (mg/l)(E)	0.1	14	7.8	7.8	6.1	9.7	6(1,6,8)	0	0%
Specific Conductance (umhos/cm)	1	126	728	727	704	756	-----	-----	-----
pH (S.U.)	0.1	126	8.4	8.3	7.8	8.9	6.5(1,2,6), 9.0(1,2,5), 9.5(4,5)	0	0%
Turbidity (NTUs)	1	126	4	4	n.d.	16	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	108	333	319	254	462	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	123	10	7	2	27	-----	-----	-----
Secchi Depth (in)	1	7	74	67	48	146	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat(f)	-----	7	-----	-----	-----	-----	D.O ≥ 6 mg/l W. Temp. ≤ 18.3°C	6	86%

n.d. = Not detected.

(A) Results for water temperature, dissolved oxygen, specific conductance, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll *a* (lab determined) and microcystin are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.

(B) Detection limits given for the parameters Pool Elevation, Water Temperature, Dissolved Oxygen (mg/l and % Sat.), Specific Conductance, pH, Oxidation-Reduction Potential, and Secchi Depth are resolution limits for field measured parameters.

(C) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(D) Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.
- (1) Criteria for the protection of coldwater permanent fish life propagation waters.
- (2) Criteria for the protection of domestic water supply waters.
- (3) Criteria for the protection of immersion and limited contact recreation waters (applies only to epilimnion and metalimnion if water body stratified).
- (4) Criteria for the protection of commerce and industry waters.
- (5) Daily maximum criterion (monitoring results directly comparable to criterion).
- (6) Daily minimum criterion (monitoring results directly comparable to criterion).
- (7) 30-day average criterion (monitoring results not directly comparable to criterion).
- (8) The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.
- (9) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates at least a 5°C difference between surface and bottom temperature, or at some point in the measured profile there is at least at 1°C drop in temperature over a 1-meter increment. The top of the hypolimnion is delineated as the lowest depth where a temperature drop of at least 0.5°C occurs over a 1-meter depth increment. A defined hypolimnion was monitored on 1 of the 7 occasions (i.e., 14%) that monthly depth profiles were measured from June through September. Measured water depths in this area of Lake Sharpe were < 18 meters.

(F) Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e., at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/l). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile. During the 2-year period 2008 through 2009, water temperatures greater than 18.3°C throughout the water column precluded the occurrence of Coldwater Permanent Fish Life Propagation habitat from late-June through mid-September.

Table 5-3. Summary of monthly (May through September) water quality conditions monitored in Lake Sharpe in the Iron Nation area (Site BBDLK1020DW) during the 3-year period 2008 through 2010.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	12	1420.3	1420.3	1419.8	1420.9	-----	-----	-----
Water Temperature (°C)	0.1	148	20.3	20.0	15.1	27.3	18.3(1,5)	112	76%
Hypolimnion Water Temperature (°C)[E]	0.1	0	-----	-----	-----	-----	18.3(1,5)	-----	-----
Dissolved Oxygen (mg/l)	0.1	148	8.8	8.9	6.4	10.5	6(1,6,8), 7(1,6,8)	0, 6	0%, 4%
Dissolved Oxygen (% Sat.)	0.1	148	101.0	98.9	75.9	133.9	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/l)[E]	0.1	148	8.8	8.9	6.4	10.5	5(3,6)	0	0%
Hypolimnion Dissolved Oxygen (mg/l)[E]	0.1	0	-----	-----	-----	-----	6(1,6,8)	0	0%
Specific Conductance (umhos/cm)	1	148	722	723	683	770	-----	-----	-----
pH (S.U.)	0.1	148	8.4	8.4	7.8	9.0	6.5(1,2,6), 9.0(1,2,5), 9.5(4,5)	0	0%
Turbidity (NTUs)	1	147	8	8	2	22	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	136	323	338	205	408	-----	-----	-----
Secchi Depth (in.)	1	12	42	36	24	96	-----	-----	-----
Alkalinity, Total (mg/l)	7	24	152	153	133	165	-----	-----	-----
Carbon, Total Organic (mg/l)	0.05	24	3.6	3.6	2.4	5.0	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	24	12	12	7	18	-----	-----	-----
Chloride (mg/l)	1	16	12	12	11	13	175(1,5), 100(1,7), 438(2,5), 250(2,7)	0	0%
Chlorophyll *a* (ug/l) – Field Probe	1	146	9	8	3	30	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab Determined	1	12	8	9	4	13	-----	-----	-----
Color, True (APHA)	1	8	7	6	4	13	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	24	507	487	386	726	1,750(2,5), 1,000(2,7), 3,500(4,5), 2,000(4,7)	0	0%
Nitrogen, Ammonia Total (mg/l)	0.02	24	-----	n.d.	n.d.	0.20	2.6 (1,5,9), 0.86 (1,7,9)	0	0%
Nitrogen, Kjeldahl Total (mg/l)	0.1	24	0.7	0.5	0.2	2.6	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/l)	0.02	24	-----	n.d.	n.d.	0.23	10(2,5)	0	0%
Nitrogen, Total (mg/l)	0.1	24	0.8	0.6	0.2	2.6	-----	-----	-----
Phosphorus, Dissolved (mg/l)	0.02	24	-----	0.02	n.d.	0.04	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	24	0.04	0.04	n.d.	0.21	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	24	-----	n.d.	n.d.	0.04	-----	-----	-----
Sulfate (mg/l)	1	24	206	208	182	222	875(2,5), 500(2,7)	0	0%
Suspended Solids, Total (mg/l)	4	24	-----	6	n.d.	32	53(1,5), 30(1,7)	0	0%
Microcystin, Total (ug/l)	0.2	12	-----	n.d.	n.d.	0.4	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat[F]	-----	12	-----	-----	-----	-----	D.O ≥ 6 mg/l W. Temp. ≤ 18.3°C	8	67%

n.d. = Not detected.

(A) Results for water temperature, dissolved oxygen, specific conductance, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll *a* (lab determined) and microcystin are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.

(B) Detection limits given for the parameters Pool Elevation, Water Temperature, Dissolved Oxygen (mg/l and % Sat.), Specific Conductance, pH, Oxidation-Reduction Potential, and Secchi Depth are resolution limits for field measured parameters.

(C) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(D) Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.

- (1) Criteria for the protection of coldwater permanent fish life propagation waters.
- (2) Criteria for the protection of domestic water supply waters.
- (3) Criteria for the protection of immersion and limited contact recreation waters (applies only to epilimnion and metalimnion if water body stratified).
- (4) Criteria for the protection of commerce and industry waters.
- (5) Daily maximum criterion (monitoring results directly comparable to criterion).
- (6) Daily minimum criterion (monitoring results directly comparable to criterion).
- (7) 30-day average criterion (monitoring results not directly comparable to criterion).
- (8) The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.
- (9) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates at least a 5°C difference between surface and bottom temperature, or at some point in the measured profile there is at least at 1°C drop in temperature over a 1-meter increment. The top of the hypolimnion is delineated as the lowest depth where a temperature drop of 1.0°C or at least 0.5°C occurs over a 1-meter depth increment. A defined hypolimnion was monitored on 1 of the 8 occasions (i.e., 13%) that monthly depth profiles were measured from June through September. Measured water depths in this area of Lake Sharpe were < 12.5 meters.

(F) Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e., at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/l). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile. During the 3-year period 2008 through 2010, water temperatures greater than 18.3°C throughout the water column precluded the occurrence of Coldwater Permanent Fish Life Propagation habitat from late-June through early-September.

Table 5-4. Summary of monthly (June through September) water quality conditions monitored at Lake Sharpe in the Cedar Creek area (site BBDLK1036DW) during the 2-year period 2008 through 2009.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	7	1420.4	1420.4	1420.0	1420.9	-----	-----	-----
Water Temperature (°C)	0.1	43	19.6	18.1	16.7	24.3	18.3[1,5]	12	50%
Hypolimnion Water Temperature (°C)[E]	0.1	0	-----	-----	-----	-----	18.3[1,5]	-----	-----
Dissolved Oxygen (mg/l)	0.1	43	8.6	8.7	7.6	9.2	6[1,6,8], 7[1,6,8]	0	0%
Dissolved Oxygen (% Sat.)	0.1	43	96.8	96.0	91.6	104.9	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/l)[E]	0.1	43	8.6	8.7	7.6	9.2	5[3,6]	0	0%
Hypolimnion Dissolved Oxygen (mg/l)[E]	0.1	0	-----	-----	-----	-----	6[1,6,8]	-----	-----
Specific Conductance (umhos/cm)	1	43	760	723	712	908	-----	-----	-----
pH (S.U.)	0.1	43	8.4	8.3	8.0	9.0	6.5[1,2,6], 9.0[1,2,5], 9.5[4,5]	0	0%
Turbidity (NTUs)	1	43	30	27	12	65	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	43	351	319	268	469	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	43	10	10	4	16	-----	-----	-----
Secchi Depth (in)	1	7	13	13	8	20	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat[F]	-----	7	-----	-----	-----	-----	D.O ≥ 6 mg/l W. Temp. ≤ 18.3°C	3	43%

n.d. = Not detected.

(A) Results for water temperature, dissolved oxygen, specific conductance, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll *a* (lab determined) and microcystin are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.

(B) Detection limits given for the parameters Pool Elevation, Water Temperature, Dissolved Oxygen (mg/l and % Sat.), Specific Conductance, pH, Oxidation-Reduction Potential, and Secchi Depth are resolution limits for field measured parameters.

(C) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(D) Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.

- (1) Criteria for the protection of coldwater permanent fish life propagation waters.
- (2) Criteria for the protection of domestic water supply waters.
- (3) Criteria for the protection of immersion and limited contact recreation waters (applies only to epilimnion and metalimnion if water body stratified).
- (4) Criteria for the protection of commerce and industry waters.
- (5) Daily maximum criterion (monitoring results directly comparable to criterion).
- (6) Daily minimum criterion (monitoring results directly comparable to criterion).
- (7) 30-day average criterion (monitoring results not directly comparable to criterion).
- (8) The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.
- (9) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates at least a 5°C difference between surface and bottom temperature, or at some point in the measured profile there is at least at 1°C drop in temperature over a 1-meter increment. The top of the hypolimnion is delineated as the lowest depth where a temperature drop of 1.0°C or at least 0.5°C occurs over a 1-meter depth increment. A defined hypolimnion was not monitored on any of the 7 occasions that monthly depth profiles were measured from June through September. This is attributed to the shallower water depths (<6.5 meters) in this area of Lake Sharpe.

(F) Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e., at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/l). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile. During the 2-year period 2008 through 2009, water temperatures greater than 18.3°C throughout the water column precluded the occurrence of Coldwater Permanent Fish Life Propagation habitat in July and August 2008, and August 2009.

Table 5-5. Summary of monthly (May through September) water quality conditions monitored in Lake Sharpe in the Antelope Creek area (Site BBDLK1055DW) during the 3-year period 2008 through 2010.

	Monitoring Results[A]						Water Quality Standards Attainment		
Parameter	**Detection Limit[B]**	**No. of Obs.**	**Mean[C]**	**Median**	**Min.**	**Max.**	**State WQS Criteria[D]**	**No. of WQS Exceedances**	**Percent WQS Exceedance**
Pool Elevation (ft-NGVD29)	0.1	13	1420.3	1420.4	1419.9	1420.8	-----	-----	-----
Water Temperature (°C)	0.1	46	18.4	18.6	12.9	22.8	18.3[1,5]	25	54%
Hypolimnion Water Temperature (°C)[E]	0.1	0	-----	-----	-----	-----	18.3[1,5]	-----	-----
Dissolved Oxygen (mg/l)	0.1	46	8.7	8.5	7.6	10.2	6[1,6,8], 7[1,6,8]	0	0%
Dissolved Oxygen (% Sat.)	0.1	46	95.6	93.6	79.7	109.7	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/l)[E]	0.1	46	8.7	8.5	7.6	10.2	5[3,6]	0	0%
Hypolimnion Dissolved Oxygen (mg/l)[E]	0.1	0	-----	-----	-----	-----	6[1,6,8]	-----	-----
Specific Conductance (umhos/cm)	1	46	745	715	689	1,454	-----	-----	-----
pH (S.U.)	0.1	46	8.3	8.3	7.9	8.9	6.5[1,2,6], 9.0[1,2,5], 9.5[4,5]	0	0%
Turbidity (NTUs)	1	46	56	45	7	188	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	46	343	319	210	474	-----	-----	-----
Secchi Depth (in.)	1	12	12	8	6	26	-----	-----	-----
Alkalinity, Total (mg/l)	7	13	152	151	122	179	-----	-----	-----
Carbon, Total Organic (mg/l)	0.05	13	4.2	4.0	2.6	9.1	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	13	12	11	4	28	-----	-----	-----
Chloride (mg/l)	1	8	12	12	10	16	175[1,5], 100[1,7], 438[2,5], 250[2,7]	0	0%
Chlorophyll *a* (ug/l) – Field Probe	1	44	6	6	2	12	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab Determined	1	13	6	6	2	11	-----	-----	-----
Color, True (APHA)	1	5	9	6	5	20			
Dissolved Solids, Total (mg/l)	5	13	580	554	382	1,042	1,750[2,5], 1,000[2,7], 3,500[4,5], 2,000[4,7]	0, 1, 0, 0	0%, 8%, 0%, 0%
Nitrogen, Ammonia Total (mg/l)	0.02	13	-----	0.03	n.d.	0.27	3.1 [1,5,9], 1.1 [1,7,9]	0	0%
Nitrogen, Kjeldahl Total (mg/l)	0.1	13	1.2	0.5	n.d.	9.1	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/l)	0.02	13	-----	0.05	n.d.	1.2	10[2,5]	0	0%
Nitrogen, Total (mg/l)	0.1	13	1.4	0.5	0.1	10.3	-----	-----	-----
Phosphorus, Dissolved (mg/l)	0.02	13	-----	0.02	n.d.	0.05	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	13	0.08	0.07	0.02	0.26	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	13	-----	0.02	n.d.	0.05	-----	-----	-----
Sulfate (mg/l)	1	13	233	207	190	509	875[2,5], 500[2,7]	0, 1	0%, 8%
Suspended Solids, Total (mg/l)	4	13	69	67	7	285	53[1,5], 30[1,7]	7, 9	54%, 69%
Microcystin, Total (ug/l)	0.2	12	-----	n.d.	n.d.	0.3	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat[F]	-----	13	-----	-----	-----	-----	D.O ≥ 6 mg/l W. Temp. ≤ 18.3°C	5	38%

n.d. = Not detected.

[A] Results for water temperature, dissolved oxygen, specific conductance, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll *a* (lab determined) and microcystin are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.

[B] Detection limits given for the parameters Pool Elevation, Water Temperature, Dissolved Oxygen (mg/l and % Sat.), Specific Conductance, pH, Oxidation-Reduction Potential, and Secchi Depth are resolution limits for field measured parameters.

[C] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

[D] Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.
- [1] Criteria for the protection of coldwater permanent fish life propagation waters.
- [2] Criteria for the protection of domestic water supply waters.
- [3] Criteria for the protection of immersion and limited contact recreation waters (applies only to epilimnion and metalimnion if water body stratified).
- [4] Criteria for the protection of commerce and industry waters.
- [5] Daily maximum criterion (monitoring results directly comparable to criterion).
- [6] Daily minimum criterion (monitoring results directly comparable to criterion).
- [7] 30-day average criterion (monitoring results not directly comparable to criterion).
- [8] The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.
- [9] Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

[E] A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates at least a 5°C difference between surface and bottom temperature, or at some point in the measured profile there is at least at 1°C drop in temperature over a 1-meter increment. The top of the hypolimnion is delineated as the lowest depth where a temperature drop of 1.0°C or at least 0.5°C occurs over a 1-meter depth increment. A defined hypolimnion was not monitored on any of the 8 occasions that monthly depth profiles were measured from June through September. This is attributed to the shallower water depths (<5 meters) in this area of Lake Sharpe.

[F] Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e., at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/l). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile. During the 5-year period 2006 through 2010, water temperatures greater than 18.3°C throughout the water column precluded the occurrence of Coldwater Permanent Fish Life Propagation habitat from late-June through early-September.

5.1.2.2 Spatial Variation

Monthly (i.e., June, July, August, and September) longitudinal temperature contour plots of Lake Sharpe were constructed for the 3-year period 2008 through 2010 (Plate 1 - Plate 12). The longitudinal temperature contour plots were developed from the temperature depth-profiles measured at the reservoir monitoring sites along the submerged old Missouri River channel. The contour plots show appreciable longitudinal variation in Lake Sharpe water temperatures from the dam to the reservoir's upper reaches during the June through September period. Cooler water is typically discharged from Oahe Dam from late-spring through mid-summer which quickly warms in Lake Sharpe. Due to the polymixic nature of the reservoir, appreciable vertical variation in Lake Sharpe water temperatures was observed on only three occasions – July 2008 (Plate 2), August 2008 (Plate 3), and August 2010 (Plate 11).

5.1.2.3 Summer Thermal Stratification

Although some summer thermal stratification of Lake Sharpe can occur, the relative shallowness, short retention time, and bottom withdrawal of the reservoir seemingly inhibit the formation of a strong thermocline and long-lasting stratification during the summer.

5.1.3 DISSOLVED OXYGEN

Monthly (i.e., June, July, August, and September) longitudinal dissolved oxygen contour plots of Lake Sharpe were constructed for the 3-year period 2008 through 2010 (Plate 13- Plate 24). The longitudinal dissolved oxygen contour plots were developed from dissolved oxygen depth-profiles measured at the reservoir monitoring sites along the submerged old Missouri River channel. The contour plots show that the dissolved oxygen levels varied longitudinally from the dam to reservoir's upper reaches and vertically from the reservoir surface to the bottom. Monitoring during the 3-year period indicated that an area of low dissolved oxygen (<5 mg/l) developed in the area near the dam in August of 2008 (Plate 15) and July and August of 2010 (Plate 22 and Plate 23). The area of low dissolved oxygen occurred along the reservoir bottom when thermal stratification lasted long enough for a hypolimnion to become established. The area of low dissolved oxygen is seemingly periodic, and dissipates when conditions allow for complete mixing of the water column.

5.1.4 WATER CLARITY

5.1.4.1 Secchi Transparency

Figure 5-1 displays a box plot of the Secchi depth transparencies measured along Lake Sharpe during the 3-year period 2008 through 2010. The measurements were taken at the five reservoir monitoring sites (i.e., BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, and BBDLK1055DW) and in Lake Oahe near Oahe Dam. The Secchi depth measurements in Lake Oahe are believed to represent the transparency of the water in the Oahe Dam tailwaters above the confluence of the Bad River. The Oahe Dam tailwaters are approximately 7 miles upstream of the Bad River confluence, and monitoring site BBDLK1055DW is approximately 10 miles downstream of the Bad River confluence. Secchi depth transparency decreased significantly in the upstream reaches of Lake Sharpe. This pronounced decrease in transparency is attributed to turbid runoff from the Bad River and sedimentation in the upstream reaches of the reservoir attributed to the Bad River. The "light" nature of these sediments and the shallowness of Lake Sharpe in its upstream reaches allows for wind action to continually re-suspend deposited sediment in this area of the reservoir.

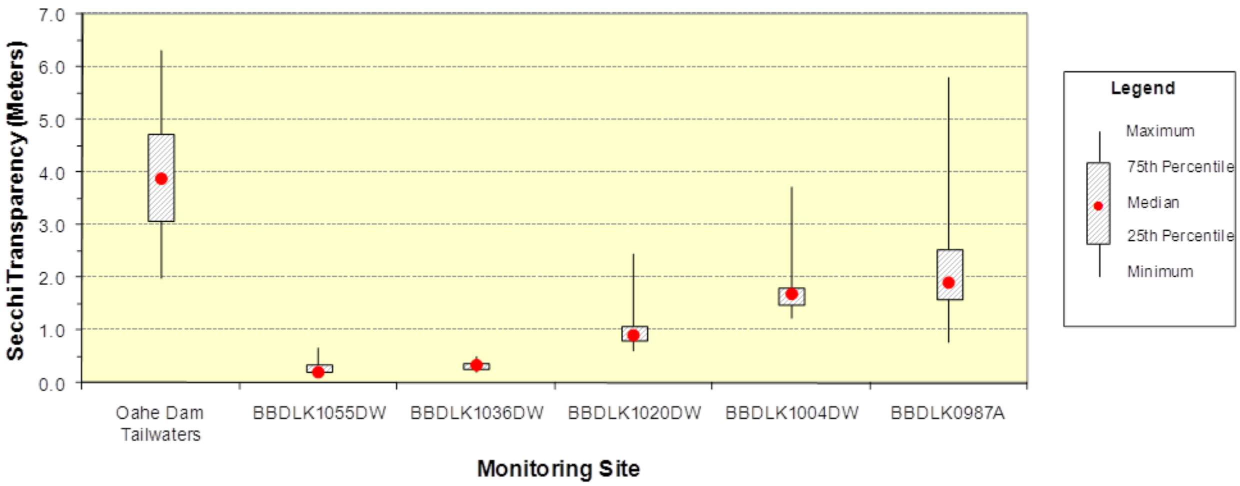

Figure 5-1. Box plot of Secchi depth transparencies measured in Lake Sharpe during the 3-year period 2008 through 2010.

5.1.4.2 Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level. Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. Monthly (i.e., June, July, August, and September) longitudinal turbidity contour plots of Lake Sharpe were constructed for the 3-year period 2008 through 2010 (Plate 25 - 36). The turbidity contour plots were developed from the turbidity depth-profiles measured at the reservoir monitoring sites along the submerged old Missouri River channel. The contour plots show that turbidity levels in Lake Sharpe vary longitudinally and vertically. Given the lower chlorophyll *a* concentrations monitored during the 3-year period, the variable turbidity in the reservoir is believed to be largely due to suspended inorganic material delivered by the Bad River. The Bad River inflow and sedimentation delta seemingly have a pronounced impact on turbidity in the upstream reaches of Lake Sharpe.

5.1.5 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

Paired near-surface and near-bottom water quality samples collected from Lake Sharpe during the summer were compared. Near-surface conditions were represented by samples collected within 2-meters of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site BBDLK0987A during the 3-year period 2008 through 2010. During the period a total of 12 paired samples were collected monthly from June through September. Box plots were constructed to display the distribution of the paired near-surface and near-bottom measurements for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, alkalinity, total organic carbon (TOC), total Kjeldahl nitrogen (TKN), total ammonia, and total phosphorus (Figure 5-2). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for water temperature, dissolved oxygen, ORP, pH, and total phosphorus. Parameters that were significantly lower in the near-bottom water of Lake Sharpe included: water temperature ($p < 0.001$), dissolved oxygen ($p < 0.001$), and pH ($p < 0.001$). Parameters that were significantly higher in the near-bottom water included: ORP ($p < 0.01$) and total phosphorus ($p < 0.01$). Total Kjeldahl nitrogen ($p = 0.07$) and total ammonia ($p = 0.11$) were nearly significantly different.

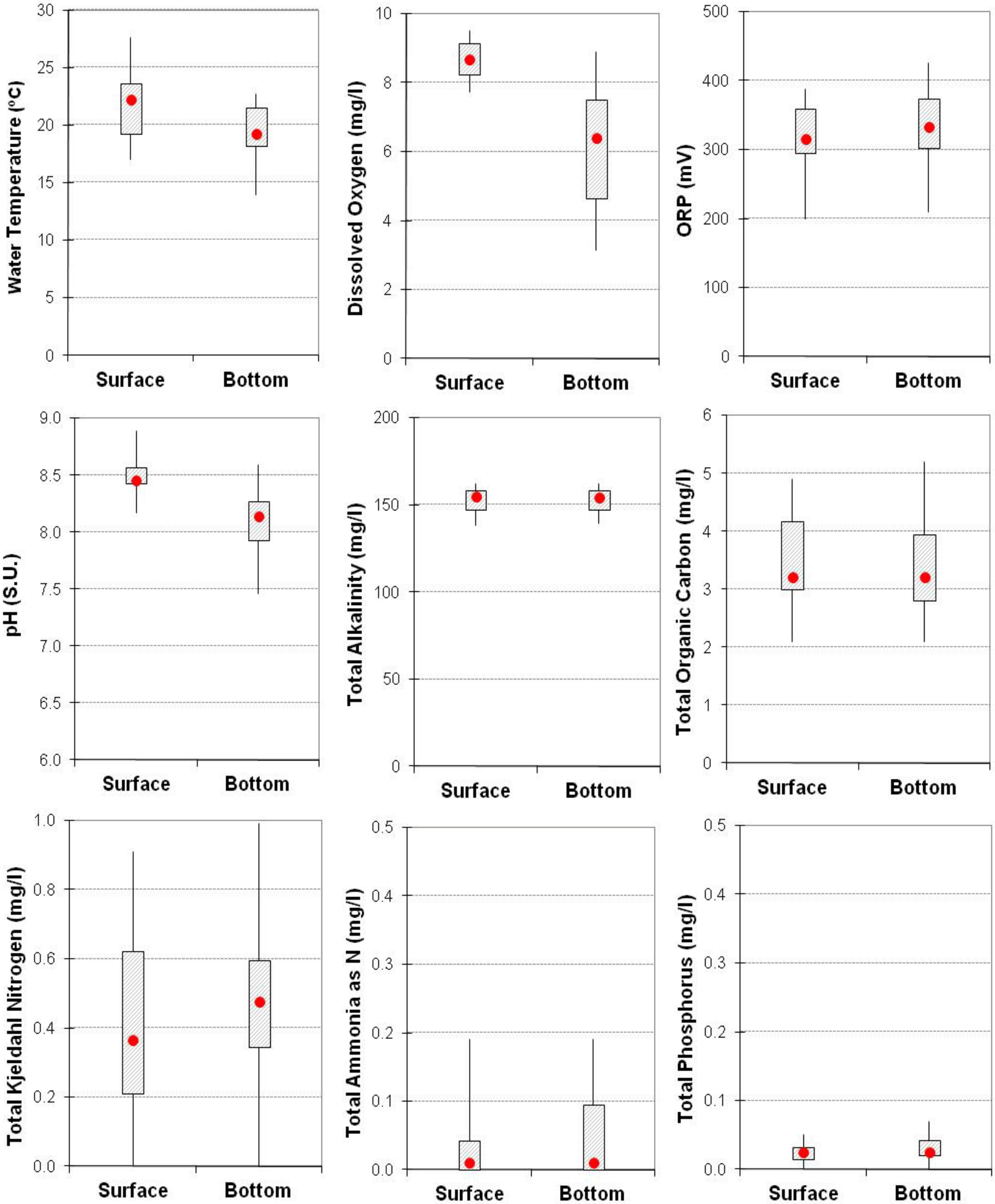

Figure 5-2. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total organic carbon, total Kjeldahl nitrogen, total ammonia nitrogen, and total phosphorus monitored in Lake Sharpe at site BBDLK0987A monthly, May through September, during the 3-year period 2008 through 2010.
(Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

5.1.6 RESERVOIR TROPHIC STATUS

Trophic State Index (TSI) values for Lake Sharpe were calculated from monitoring data collected during the 3-year period 2008 through 2010 (Table 5-6). The calculated TSI values indicate that the area near the dam (i.e., site BBDLK0987A) is mesotrophic to moderately eutrophic, the middle reaches of the reservoir (i.e., site BBDLK1020DW) is eutrophic, and the upstream reaches of the reservoir (i.e., site BBDLK1055DW) is eutrophic to borderline hypereutrophic. However, it is noted that the calculated average TSI value for the upstream reaches is greatly influenced by the low water clarity in this part of the reservoir. This lack of water clarity is largely attributed to suspended inorganic material delivered to the reservoir by the Bad River. Thus, the higher TSI values in the upstream reaches may not be indicative of increased algal growth associated with nutrient enrichment.

Table 5-6. Mean Trophic State Index (TSI) values calculated for Lake Sharpe. TSI values are based on monitoring at the identified three sites during the 3-year period 2008 through 2010.

Monitoring Site	Mean – TSI (Secchi Depth)	Mean – TSI (Total Phos.)	Mean – TSI (Chlorophyll)	Mean – TSI (Average)
BBDLK0987A	47	49	54	50
BBDLK1020DW	60	53	60	58
BBDLK1055DW	79	60	56	65

Note: See Section 4.2 for discussion of TSI calculation.

5.1.7 PLANKTON COMMUNITY

5.1.7.1 Phytoplankton

Phytoplankton grab samples collected from Lake Sharpe at sites BBDLK0987A, BBDLK1020DW, and BBDLK1055DW during the spring and summer over the 3-year period 2008 through 2010 are summarized in Table 5-7, Table 5-8, and Table 5-9. The following seven taxonomic divisions were represented by taxa collected in the phytoplankton samples: Bacillariophyta (Diatoms), Chlorophyta (Green Algae), Chrysophyta (Golden Algae), Cryptophyta (Cryptomonad Algae), Cyanobacteria (Blue-Green Algae), Pyrrophyta (Dinoflagellate Algae), and Euglenophyta (Euglenoid Algae). The relative abundance of phytoplankton in samples collected from Lake Sharpe in May, July, and September 2010, based on biovolume, is shown in Figure 5-3. Diatoms (Bacillariophyta) are by far the most dominant phytoplankton group present in Lake Sharpe. Major phytoplankton genera sampled in Lake Sharpe during 2010 (i.e., genera comprising more than 10% of the total biovolume of at least one sample) included the Bacillariophyta *Asterionella*, *Aulacoseria, Fragilaria, Navicula, Surirella, Synedra*, and *Tabellaria*. No concentrations of the cyanobacteria toxin microcystin above 1 ug/l were monitored in the lake during the 3-year period 2008 through 2010 (Table 5-1, Table 5-3, and Table 5-5).

Table 5-7. Total biovolume, number of genera present and percent composition (based on biovolume) by taxonomic division for phytoplankton grab samples collected at the near-dam, deepwater ambient monitoring site (i.e., site BBDLK0987A) at Lake Sharpe during the 3-year period 2008 through 2010.

Date	Total Sample Biovolume (mm^3/L)	Bacillariophyta		Chlorophyta		Chrysophyta		Cryptophyta		Cyanobacteria		Pyrrophyta		Euglenophyta	
		No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.
May 2008	0.2285	12	0.97	6	0.01	0	-----	1	0.02	0	-----	1	<0.01	0	-----
Jun 2008	0.2918	6	0.87	5	0.01	1	0.09	1	0.02	1	<0.01	1	0.01	0	-----
Jul 2008	0.0002	3	0.83	2	<0.01	1	0.03	1	0.12	2	0.01	0	-----	1	0.01
Aug 2008	0.0551	3	0.59	4	0.02	2	0.06	1	0.08	4	0.11	2	0.14	0	-----
Sep 2008	0.0107	2	0.08	16	0.55	1	<0.01	2	<0.01	4	<0.01	3	<0.01	0	-----
May 2009	2.2921	7	0.97	3	<0.01	0	-----	1	0.02	0	-----	0	-----	1	<0.01
Jun 2009	0.6403	9	0.36	3	0.20	2	0.04	2	0.40	1	0.01	0	-----	0	-----
Jul 2009	0.1125	12	0.39	7	0.10	1	0.02	1	0.41	2	0.01	1	0.08	0	-----
Aug 2009	0.1002	10	0.23	9	0.19	1	0.12	1	0.25	5	0.12	2	0.10	0	-----
Sep 2009	0.7875	7	0.33	12	0.07	2	<0.01	2	0.41	5	0.02	1	0.16	2	<0.01
May 2010	0.7544	15	1.00	6	<0.01	0	-----	0	-----	0	-----	0	-----	0	-----
Jul 2010	0.3707	6	0.88	8	0.03	0	-----	2	0.04	2	0.03	2	0.02	1	0.01
Sep 2010	0.3919	10	0.84	10	0.05	0	-----	2	0.10	2	<0.01	1	<0.01	0	-----
Mean	**0.4643**	**7.9**	**0.64**	**7.0**	**0.09**	**0.9**	**0.05**	**1.3**	**0.16**	**2.2**	**0.03**	**1.1**	**0.06**	**0.4**	**0.01**

* Mean percent composition represents the mean when taxa of that division are present.

Table 5-8. Total biovolume, number of genera present and percent composition (based on biovolume) by taxonomic division for phytoplankton grab samples collected at the mid-lake site (i.e., site BBDLK1020DW) at Lake Sharpe during the 3-year period 2008 through 2010.

Date	Total Sample Biovolume (mm^3/L)	Bacillariophyta		Chlorophyta		Chrysophyta		Cryptophyta		Cyanobacteria		Pyrrophyta		Euglenophyta	
		No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.
Jun 2008	0.1121	10	0.88	6	0.01	1	0.01	1	0.10	1	<0.01	0	-----	0	-----
Jul 2008	0.0001	3	0.46	6	0.05	1	0.08	1	0.30	3	0.02	2	0.06	2	0.02
Aug 2008	0.1207	7	0.41	13	0.14	0	-----	1	0.25	7	0.02	2	0.08	2	0.10
Sep 2008	0.0550	7	0.41	6	0.21	0	-----	2	0.37	1	<0.01	1	<0.01	0	-----
Jun 2009	2.4765	6	0.98	2	<0.01	1	<0.01	1	0.02	0	-----	1	<0.01	0	-----
Jul 2009	2.0086	13	0.94	8	0.01	1	<0.01	2	0.05	1	<0.01	1	<0.01	3	<0.01
Aug 2009	1.7067	11	0.83	15	0.08	1	<0.01	1	0.05	4	<0.01	2	0.03	3	<0.01
Sep 2009	1.4041	11	0.67	10	0.05	2	0.05	2	0.20	3	0.01	1	0.02	0	-----
Jul 2010	1.3819	6	0.95	14	0.04	3	<0.01	2	0.01	2	<0.01	1	<0.01	0	-----
Sep 2010	0.4405	6	0.92	9	0.04	1	<0.01	2	0.02	3	0.01	1	0.01	0	-----
Mean	**0.9706**	**8.0**	**0.75**	**8.9**	**0.06**	**1.1**	**0.02**	**1.5**	**0.14**	**2.5**	**0.01**	**1.3**	**0.02**	**1.0**	**0.03**

* Mean percent composition represents the mean when taxa of that division are present.

Table 5-9. Total biovolume, number of genera present and percent composition (based on biovolume) by taxonomic division for phytoplankton grab samples collected in the upstream reaches of Lake Sharpe (i.e., site BBDLK1055DW) during the 3-year period 2008 through 2010.

Date	Total Sample Biovolume (mm^3/L)	Bacillariophyta		Chlorophyta		Chrysophyta		Cryptophyta		Cyanobacteria		Pyrrophyta		Euglenophyta	
		No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.
Jun 2008	0.1113	13	0.96	0	-----	0	-----	1	0.04	0	-----	0	-----	0	-----
Jul 2008	0.0001	7	0.27	4	0.04	1	0.05	1	0.45	0	-----	2	0.18	0	-----
Aug 2008	0.0433	9	0.82	1	0.01	1	0.06	1	0.05	2	<0.01	1	0.06	0	-----
Sep 2008	0.2041	13	0.86	3	0.02	0	-----	2	0.02	2	0.01	1	0.09	0	-----
Jun 2009	0.1767	17	0.95	0	-----	0	-----	1	0.05	1	<0.01	0	-----	0	-----
Jul 2009	0.3163	16	0.95	5	0.04	0	-----	1	0.01	0	-----	0	-----	0	-----
Aug 2009	0.0394	13	0.90	3	0.04	0	-----	1	0.05	1	0.01	0	-----	0	-----
Sep 2009	0.8525	15	0.79	5	0.03	1	<0.01	2	0.18	1	<0.01	0	-----	0	-----
May 2010	0.2792	13	0.95	1	0.05	0	-----	0	-----	0	-----	0	-----	0	-----
Jul 2010	0.6252	12	0.96	2	0.1	0	-----	0	-----	1	<0.01	1	0.01	2	0.02
Sep 2010	0.4151	15	0.99	7	0.01	0	-----	2	<0.01	0	-----	0	-----	1	<0.01
Mean	**0.2785**	**13.0**	**0.85**	**2.8**	**0.04**	**0.3**	**0.04**	**1.1**	**0.09**	**0.7**	**<0.01**	**0.05**	**0.09**	**0.3**	**0.01**

* Mean percent composition represents the mean when taxa of that division are present.

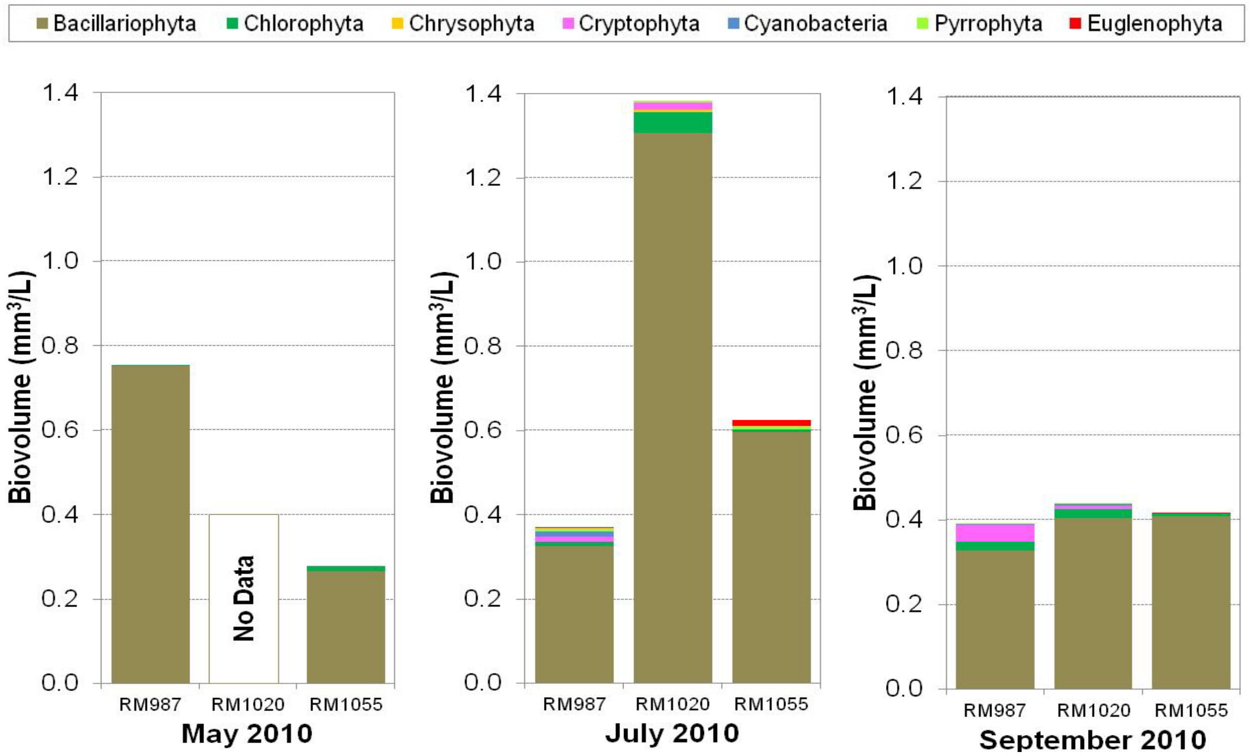

Figure 5-3. Relative abundance of phytoplankton in samples collected from Lake Sharpe during 2010.

5.1.7.2 Zooplankton

Zooplankton vertical-tow samples were collected from Lake Sharpe at sites BBDLK0987A, BBDLK1020DW, and BBDLK1055DW in May, July, and September of 2010 (Table 5-10). The sampled zooplankton included three taxonomic groupings: Cladocerans, Copepods, and Rotifers. The relative abundance of these three taxonomic grouping in the zooplankton samples collected in 2010 is shown in Figure 5-4. Cladocerans and copepods dominated the zooplankton community in Lake Sharpe. Major zooplankton species sampled in Lake Sharpe during 2010 (i.e., species comprising more than 10% of the total biomass of at least one sample) included Cladocerans *Bosmina longirostris*, *Daphnia retrocurva*, and *Eubosmina coregoni*; Copepods *Calanoid copepodid*, *Cyclopoid copepodid*, *Diacyclops*, *thomasi*, and *Mesocyclops edax*; and Rotifers *Polyarthra major*, and *Synchaeta pectinata.* Dominant species (i.e., species comprising more than 25% of the total biomass of at least one sample) included Cladocerans *Daphnia retrocurva*; Copepods *Calanoid copepodid*, *Cyclopoid copepodid*, *Diacyclops thomasi*, and *Mesocyclops edax*, and Rotifers *Polyarthra major.*

Table 5-10. Estimated biomass, number of species, and percent composition (based on biomass) by taxonomic grouping for zooplankton tow samples collected in Lake Sharpe at Sites BBDLK0987A, BBDLK1020DW, and BBDLK1055DW during 2010.

Date	Estimated Biomass (µg/L dry wt.)	Cladocerans		Copepods		Rotifers	
		No. of Species	Percent Comp.	No. of Species	Percent Comp.	No. of Species	Percent Comp.
Site BBDLK0987A – Near Dam							
May 2010	14.925	0	-----	2	0.79	8	0.21
July 2010	79.281	3	0.86	4	0.12	6	0.02
Sept 2010	11.532	2	0.13	4	0.67	8	0.27
Mean	**35.246**	**1.7**	**0.50**	**3.3**	**0.53**	**7.3**	**0.17**
Site BBDLK1020DW – Iron Nation							
May 2010	No Data						
July 2010	27.954	3	0.26	3	0.50	6	0.24
Sept 2010	6.588	0	-----	4	0.59	5	0.41
Mean	**17.271**	**1.5**	**0.26**	**3.5**	**0.55**	**5.5**	**0.33**
Site BBDLK1055DW – Antelope Creek							
May 2010	No Data						
July 2010	16.107	2	0.13	4	0.85	5	0.02
Sept 2010	15.510	2	0.11	5	0.71	6	0.18
Mean	**15.809**	**2.0**	**0.12**	**4.5**	**0.78**	**5.5**	**0.10**

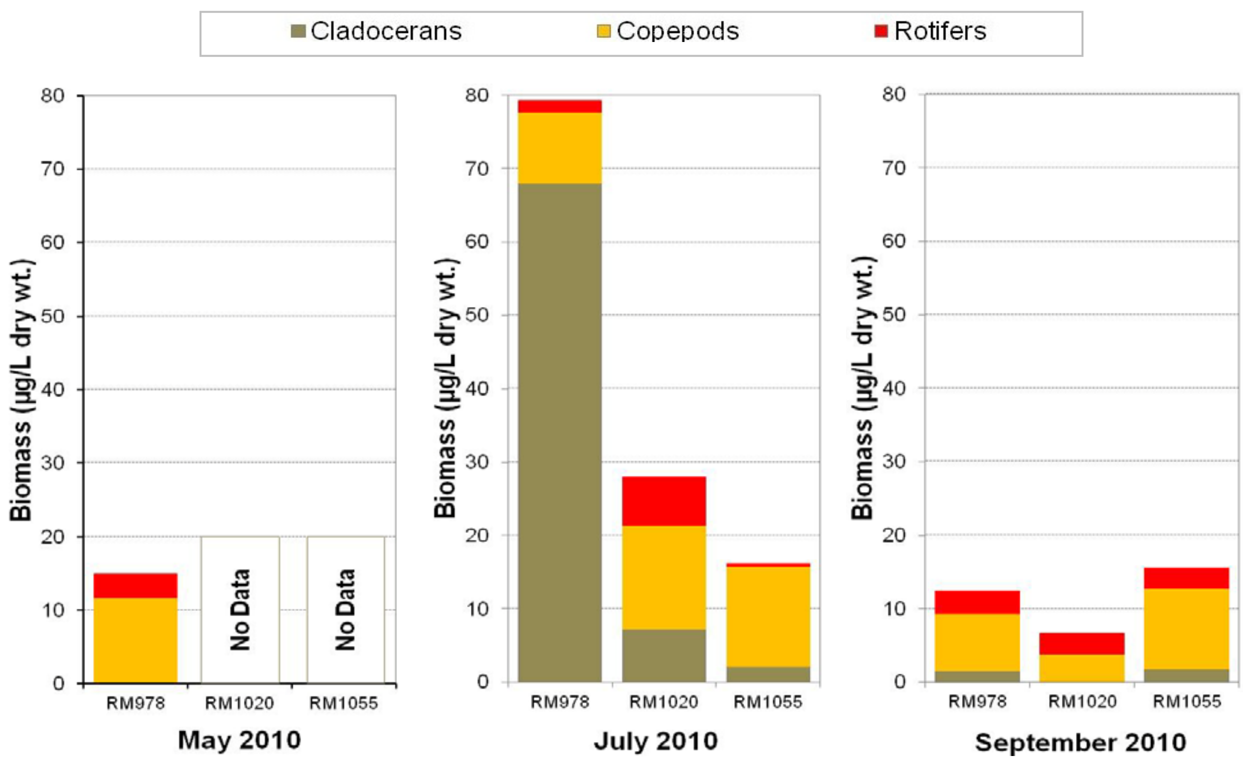

Figure 5-4. Relative abundance of zooplankton in samples collected from Lake Sharpe during 2010**.**

6 WATER QUALITY CONDITIONS OF INFLOWS TO LAKE SHARPE

6.1 STATISTICAL SUMMARY AND WATER QUALITY STANDARDS ATTAINMENT

Statistical summaries of water quality conditions monitored at the two inflow sites (OAHPP1 and BBDNFBADR1) over the 3-year period 2008 through 2010 were prepared. Table 6-1and Table 6-2 summarize the water quality conditions that were monitored in the Oahe Dam discharge to the Missouri River just upstream of Lake Sharpe (site OAHPP1). Table 6-3 summarizes the water quality conditions that were monitored in the Bad River at its confluence with Lake Sharpe (site BBDNFBADR1).

Based on the State of South Dakota's impairment assessment methodology (Section 4.4), the water quality conditions monitored at the Oahe powerplant during the 3-year period 2008 through 2010 indicate impairment of the designated Coldwater Permanent Fish Life Propagation water quality beneficial use. Eighteen percent of the "grab sample" water temperature measurements taken on the water passed through Oahe Dam exceeded the Coldwater Permanent Fish Life Propagation temperature criterion of 18.3°C. The exceedances of the temperature criterion occurred during the summer. In the summer when Lake Oahe is thermally stratified, water temperatures in the epilimnion of the reservoir regularly exceed 18.3°C, while temperatures in the hypolimnion are less than 18.3°C. Water discharged through Oahe Dam for power production is withdrawn from Lake Oahe at elevation 1524 ft-NGVD29, approximately 114 feet above the reservoir bottom. Thus, water withdrawn from the reservoir in the summer, especially when pool elevations are lower due to drought conditions, can pull water down from the epilimnion. When water passed through Oahe Dam during the summer is withdrawn from the epilimnion of the reservoir, the temperature criterion of 18.3°C for the Missouri River and Lake Sharpe just downstream of the dam are likely to be exceeded when Lake Oahe is thermally stratified. During 2010, pool elevations were near to above normal and two samples (August and September) collected at the Oahe powerplant exceeded the 18.3°C temperature criterion. Continuous water temperatures monitored at the Oahe powerplant during the past 3 years are shown in the time-series plots discussed in the following section of this report.

All of the three total arsenic samples collected over the past 3 years exceeded the 0.018 ug/l criterion identified for the protection of human health. This criterion is concerned with bioaccumulation in the food chain and possible human health concerns regarding fish consumption.

6.2 MISSOURI RIVER NUTRIENT FLUX CONDITIONS

Nutrient flux rates for the inflows of the Missouri and Bad Rivers to Lake Sharpe were calculated based on the collected water quality samples and the estimated instantaneous flow rates. Table 6-4 and Table 6-5, respectively, summarize the nutrient flux rates calculated for the Missouri River (i.e., site OAHPP1) and Bad River (i.e., site BBDNFBADR1) over the 3-year period 2008 through 2010.

Table 6-1. Summary of monthly water quality conditions monitored on water discharged through Oahe Dam (i.e., site OAHPP1) during the 3-year period of 2008 through 2010.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[A]	No. of Obs.	Mean[B]	Median	Min.	Max.	State WQS Criteria[C]	No. of WQS Exceedances	Percent WQS Exceedance
Dam Discharge (cfs)	1	28	26,196	23,925	0	56,047	-----	-----	-----
Water Temperature (°C)	0.1	28	10.8	12.1	0.8	21.9	18.3[1,5]	5	18%
Dissolved Oxygen (mg/l)	0.1	28	10.4	10.1	7.1	15.0	5[3,6], 6[1,6,8], 7[1,6,8]	0	0%
Dissolved Oxygen (% Sat.)	0.1	28	95.5	96.5	72.3	112.1	-----	-----	-----
pH (S.U.)	0.1	26	8.2	8.2	7.3	8.8	6.5[1,2,6], 9.0[1,2,5], 9.5[4,5]	0	0%
Specific Conductance (umhos/cm)	1	28	712	712	622	816	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	28	366	362	210	666	-----	-----	-----
Turbidity (NTU)	1	28	5	2	n.d	50	-----	-----	-----
Alkalinity, Total (mg/l)	7	28	154	157	140	167	-----	-----	-----
Carbon, Total Organic (mg/l)	0.05	28	3.5	3.4	1.6	5.9	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	28	8	8	n.d.	16	-----	-----	-----
Chloride, Dissolved (mg/l)	1	20	12	11	6	22	175[1,5], 438[2,5] 100[1,7], 250[2,7]	0	0%
Dissolved Solids, Total (mg/l)	5	28	487	469	360	850	1,750[2,5], 3,500[4,5] 1,000[2,7], 2,000[4,7]	-----	-----
Nitrogen, Ammonia Total (mg/l)	0.02	28	-----	n.d.	n.d.	0.31	3.8 [1,5,9], 1.7 [1,7,9]	0	0%
Nitrogen, Kjeldahl Total (mg/l)	0.1	28	-----	0.3	n.d.	0.8	-----	-----	-----
Nitrogen, Nitrate-Nitrite (mg/l)	0.02	28	-----	0.02	n.d.	0.20	10[2,5]	0	0%
Nitrogen, Total (mg/l)	0.1	28	0.4	0.4	n.d.	0.8	-----	-----	-----
Phosphorus, Dissolved (mg/l)	0.02	28	-----	0.02	n.d.	0.06	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	28	-----	0.02	n.d.	0.11	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	28	-----	n.d.	n.d.	0.04	-----	-----	-----
Sulfate (mg/l)	1	28	198	201	167	222	875[2,5], 500[2,7]	0	0%
Suspended Solids, Total (mg/l)	4	28	-----	n.d.	n.d.	73	53[1,5], 30[1,7]	1, 1	4%, 4%

n.d. = Not detected, b.d. = Criterion below detection limit.

(A) Detection limits given for the parameters Streamflow, Water Temperature, Dissolved Oxygen (mg/l and % Sat.), pH, Specific Conductance, and Oxidation-Reduction Potential are resolution limits for field measured parameters.

(B) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(C) Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.

- (1) Criteria for the protection of coldwater permanent fish life propagation waters.
- (2) Criteria for the protection of domestic water supply waters.
- (3) Criteria for the protection of immersion and limited contact recreation waters (applies only to epilimnion and metalimnion if water body stratified).
- (4) Criteria for the protection of commerce and industry waters.
- (5) Daily maximum criterion (monitoring results directly comparable to criterion).
- (6) Daily minimum criterion (monitoring results directly comparable to criterion).
- (7) 30-day average criterion (monitoring results not directly comparable to criterion).
- (8) The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.
- (9) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

Table 6-2. Summary of annual metals and pesticide levels monitored on water discharged through Oahe Dam (i.e., site OAHPP1) during the 3-year period of 2008 through 2010.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/l)	25	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Aluminum, Total (ug/l)	25	3	-----	80	n.d.	110	-----	-----	-----
Antimony, Dissolved (ug/l)	0.5	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Antimony, Total (ug/l)	0.5	3	-----	n.d.	n.d.	n.d.	5.6[3]	0	0%
Arsenic, Dissolved (ug/l)	1	3	1	1	1	2	340[1], 150[2]	0	0%
Arsenic, Total (ug/l)	1	3	1	1	1	2	0.018[3]	3	100%
Barium, Dissolved (ug/l)	5	3	40	41	36	42	-----	-----	-----
Barium, Total (ug/l)	5	3	45	45	39	50	-----	-----	-----
Beryllium, Dissolved (ug/l)	2	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Beryllium, Total (ug/l)	2	3	-----	n.d.	n.d.	n.d.	4[3]	0	0%
Cadmium, Dissolved (ug/l)	0.2	3	-----	n.d.	n.d.	n.d.	4.1[1], 0.41[2]	0	0%
Cadmium, Total (ug/l)	0.2	3	-----	n.d.	n.d.	n.d.	5[3]	0	0%
Chromium, Dissolved (ug/l)	10	3	-----	n.d.	n.d.	n.d.	1,042[1], 136[2]	0	0%
Chromium, Total (ug/l)	10	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Copper, Dissolved (ug/l)	2	3	-----	n.d.	n.d.	n.d.	27[1], 17[2],	0	0%
Copper, Total (ug/l)	2	3	-----	n.d.	n.d.	n.d.	1,300[3]	0	0%
Hardness, Total (mg/l)	0.4	3	219	209	209	240	-----	-----	-----
Iron, Dissolved (ug/l)	40	3	-----	103	n.d.	21	-----	-----	-----
Iron, Total (ug/l)	40	3	90	60	59	150	-----	-----	-----
Lead, Dissolved (ug/l)	0.5	3	-----	n.d.	n.d.	n.d.	143[1], 5.6[2]	0	0%
Lead, Total (ug/l)	0.5	3	1.3	1.0	0.9	2.1	-----	-----	-----
Manganese, Dissolved (ug/l)	2	3	-----	n.d.	n.d.	16	-----	-----	-----
Manganese, Total (ug/l)	2	3	17	20	11	20	-----	-----	-----
Mercury, Dissolved (ug/l)	0.05	3	-----	n.d.	n.d.	n.d.	1.4[1]	0	0%
Mercury, Total (ug/l)	0.05	3	-----	n.d.	n.d.	n.d.	0.77[2], 0.05[3]	0	0%
Nickel, Dissolved (ug/l)	10	3	-----	n.d.	n.d.	n.d.	874[1], 97[2]	0	0%
Nickel, Total (ug/l)	10	3	-----	n.d.	n.d.	n.d.	610[3]	0	0%
Selenium, Total (ug/l)	1	3	-----	2	1	2	4.6[2], 170[3]	0	0%
Silver, Dissolved (ug/l)	1	3	-----	n.d.	n.d.	n.d.	11[1]	0	0%
Silver, Total (ug/l)	1	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Dissolved (ug/l)	0.5	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Total (ug/l)	0.5	3	-----	n.d.	n.d.	n.d.	0.24[3]	b.d.	b.d.
Zinc, Dissolved (ug/l)	10	3	-----	n.d.	n.d.	11	219[1,2]	0	0%
Zinc, Total (ug/l)	10	3	-----	n.d.	n.d.	n.d.	7,400[3]	0	0%
Pesticide Scan (ug/l)[C]	0.05[D]	3	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected, b.d. = Criterion below detection limit.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.

(1) Acute (CMC) criterion for the protection of freshwater aquatic life.

(2) Chronic (CCC) criterion for the protection of freshwater aquatic life.

(3) Criterion for the protection of human health.

Note: Some of South Dakota's criteria for metals (i.e., cadmium, chromium, copper, lead, nickel, silver, and zinc) are based on hardness. Criteria shown for those metals were calculated using the median hardness value.

(C) The pesticide scan includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, de-ethylatrazine, de-isopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

(D) Detection limits vary by pesticide – 0.05 ug/l is a median detection limit for the pesticides in the pesticide scan.

Table 6-3. Summary of water quality conditions monitored in the Bad River at site BBDNFBADR1 during the 3-year period 2008 through 2010.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit(A)	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Flow (cfs)	1	13	404	30	0.2	3,760	-----	-----	-----
Water Temperature (°C)	0.1	13	19.0	19.2	8.3	24.9	27(1,4)	0	0%
Dissolved Oxygen (mg/l)	0.1	13	9.5	8.9	6.8	17.0	5(1,5)	1	2%
Dissolved Oxygen (% Sat.)	0.1	13	103.0	99.5	78.2	145.2	-----	-----	-----
pH (S.U.)	0.1	12	8.2	8.1	7.7	8.8	6.5(1,2,5), 9.0(1,2,4), 9.5(3,4)	0	0%
Specific Conductance (umhos/cm)	1	13	945	755	378	1,745	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	13	350	334	211	552	-----	-----	-----
Turbidity (NTU)	1	13	250	10	2	1,359	-----	-----	-----
Alkalinity, Total (mg/l)	7	15	147	148	116	165	-----	-----	-----
Carbon, Total Organic (mg/l)	0.05	15	5.5	5.1	2.5	10.8	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	15	20	11	3	82	-----	-----	-----
Chloride, Dissolved (mg/l)	1	9	22	13	9	74	175(1,4), 100(1,6), 438(2,4), 250(2,6)	0	0%
Dissolved Solids, Total (mg/l)	5	15	685	616	360	1,226	1,750(2,4), 1,000(2,7), 3,500(3,4), 2,000(3,6)	0, 3, 0, 0	0%, 20%, 0%, 0%
Iron, Total (ug/l)	40	8	12,038	320	210	93,000	-----	-----	-----
Manganese, Total (ug/l)	2	8	670	20	20	5,060	-----	-----	-----
Nitrogen, Ammonia Total (mg/l)	0.02	15	-----	0.03	n.d.	0.34	7.0 (1,4,7), 1.5(1,6,7)	0	0%
Nitrogen, Kjeldahl Total (mg/l)	0.1	15	1.0	0.9	0.3	3.3	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/l)	0.02	15	-----	0.12	n.d.	2.30	10(2,4)	0	0%
Nitrogen, Total (mg/l)	0.1	15	1.3	0.9	0.3	3.7	-----	-----	-----
Phosphorus, Dissolved (mg/l)	0.02	15	-----	0.03	n.d.	0.09	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	15	0.26	0.05	n.d.	2.90	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	15	-----	0.02	n.d.	0.06	-----	-----	-----
Sulfate (mg/l)	1	15	315	225	135	630	875(2,4), 500(2,6)	0, 3	0%, 20%
Suspended Solids, Total (mg/l)	4	15	275	26	n.d.	3,478	158(1,4), 90(1,6)	3, 3	20%, 20%
Pesticide Scan (ug/l)(D)	0.05(E)						-----	-----	-----

n.d. = Not detected, b.d. = Criterion below detection limit.

(A) Detection limits given for the parameters Streamflow, Water Temperature, Dissolved Oxygen (mg/l and % Sat.), pH, Specific Conductance, and Oxidation-Reduction Potential are resolution limits for field measured parameters.

(B) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(C) Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.

(1) Criteria for the protection of warmwater permanent fish life propagation waters.
(2) Criteria for the protection of domestic water supply waters.
(3) Criteria for the protection of commerce and industry waters.
(4) Daily maximum criterion (monitoring results directly comparable to criterion).
(5) Daily minimum criterion (monitoring results directly comparable to criterion).
(6) 30-day average criterion (monitoring results not directly comparable to criterion).
(7) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

(D) The pesticide scan includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, de-ethylatrazine, de-isopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

(E) Detection limits vary by pesticide – 0.05 ug/l is a median detection limit for the pesticides in the pesticide scan.

Table 6-4. Summary of nutrient flux rates (kg/sec) calculated for the Oahe Dam discharge to the Missouri River (i.e., site OAHPP1) just upstream from Lake Sharpe over the 3-year period 2008 through 2010.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	27	27	27	27	27	27	27
Mean	27,540	0.0171	0.2477	0.0598	0.0204	0.0122	2.7331
Median	28,445	n.d.	0.1456	0.0241	0.0172	0.0095	2.7385
Minimum	1,427	n.d.	n.d.	n.d.	n.d.	n.d.	0.1010
Maximum	56,047	0.0818	1.0239	0.1902	0.0759	0.0448	7.4590

Note: Nondetectable values set to 0 for flux calculations.

Table 6-5. Summary of nutrient flux rates (kg/sec) calculated for the Bad River inflow to Lake Sharpe (i.e., site BBDNFBADR1) over the 3-year period 2008 through 2010.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	15	15	15	15	15	15	15
Mean	351	0.0026	0.0263	0.0065	0.0210	0.0005	0.0963
Median	21	n.d.	0.0003	0.0001	n.d.	n.d.	0.0022
Minimum	0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Maximum	3,760	0.0362	0.3556	0.0426	0.3088	0.0053	1.1499

Note: Nondetectable values set to 0 for flux calculations.

6.3 OAHE DAM TEMPERATURE, DISSOLVED OXYGEN, AND DISCHARGE TIME-SERIES PLOTS

Semiannual time-series plots for temperature, dissolved oxygen, and dam discharge monitored at the Oahe powerplant during the 3-year period 2008 through 2010 were constructed. Water temperatures showed seasonal warming and cooling through each calendar year (Plate 37 - Plate 42). Dissolved oxygen levels remained relatively high and stable during the winter, steadily declined through the spring and summer, and steadily increased during the fall (Plate 43 - Plate 48). The lowest dissolved oxygen levels occurred during the late-summer period. The higher winter, declining spring, and increasing fall dissolved oxygen concentrations are attributed to decreasing dissolved oxygen solubility with warmer water temperatures. The decreasing dissolved oxygen in the July to September period may also be attributed somewhat to the influence of ongoing degradation of dissolved oxygen in the hypolimnion as the summer progressed. Overall, there appeared to be minor correlation between discharge rates and measured water temperature and dissolved oxygen concentrations. However, there appeared to be more correlation between discharge and water temperature in the summers of 2009 and 2010. In 2009 and 2010 pool levels returned to normal after several years of prolonged drought. This resulted in the summer thermocline in Lake Oahe setting up at a higher elevation; above the intake elevation of the power tunnels. This seemingly resulted in colder water being drawn from the hypolimnion under lower discharges, and warmer water being drawn down from the epilimnion under higher discharges. In the drought years of 2005 through 2007 and the drought recovery year of 2008, discharge water temperatures in the summer regularly exceeded the coldwater permanent fish life protection criterion of 18.3°C. With the higher pool elevations in 2009 and 2010, the overall water temperature of the Oahe Dam discharge was cooler during the summer and the 18.3°C criterion was exceeded less frequently.

7 WATER QUALITY CONDITIONS OF THE MISSOURI RIVER DOWNSTREAM OF BIG BEND DAM

7.1 WATER QUALITY CONDITIONS OF WATER DISCHARGED THROUGH BIG BEND DAM

7.1.1 STATISTICAL SUMMARY AND WATER QUALITY STANDARDS ATTAINMENT

Table 7-1 and Table 7-2 summarize the water quality conditions that were monitored monthly on water discharged through the Big Bend powerplant during the 3-year period 2008 through 2010. These results indicate no major water quality standards concerns.

7.1.2 NUTRIENT FLUX CONDITIONS OF THE BIG BEND DAM DISCHARGE TO THE MISSOURI RIVER

Nutrient flux rates for the Big Bend Dam discharge to the Missouri River over the 3-year period 2008 through 2010 were calculated based on samples taken from the Big Bend powerplant (i.e. site BBDPP1) and the dam discharge at the time of sample collection (Table 7-3). The samples collected in the powerplant are taken from the raw water supply line and are believed to be unbiased regarding particulate-associated constituents. Therefore, the flux rates calculated for the Big Bend Dam discharge give an unbiased estimate of the flux rates for all the constituents, including total phosphorus and total organic carbon. The maximum flux rates for all the constituents are believed to be attributed to higher dam discharges.

7.1.3 BIG BEND DAM TEMPERATURE, DISSOLVED OXYGEN, AND DISCHARGE TIME-SERIES PLOTS

Semiannual time-series for temperature, dissolved oxygen, and dam discharge monitored at the Big Bend powerplant during the 3-year period 2008 through 2010 were plotted. Water temperatures showed seasonal warming and cooling through each calendar year (Plate 49 - Plate 54). Dissolved oxygen levels remained relatively high and fairly stable during the winter, steadily declined through the spring and summer, and steadily increased during the fall (Plate 55 - Plate 60). The lowest dissolved oxygen levels occurred during the July to August period. The higher winter, declining spring, and increasing fall dissolved oxygen concentrations are attributed to decreasing dissolved oxygen solubility with warmer water temperatures. There appeared to be significant correlation between discharge rates and water temperature and dissolved oxygen concentrations measured during the summer months. The lower dissolved oxygen concentrations monitored in the summer may be attributed to periodic stratification and the degradation of dissolved oxygen conditions near the bottom of the reservoir. Since the inlet to the powerhouse is located at the reservoir bottom, lower flows through the dam may result in more “laminar” flow that pulls in water with degraded dissolved oxygen conditions along the bottom into the powerplant.

7.2 COMPARISON OF MONITORED INFLOW AND OUTFLOW TEMPERATURES OF THE MISSOURI RIVER AT LAKE SHARPE

Figure 7-1, Figure 7-2, and Figure 7-3, respectively, plot the mean daily water temperatures monitored for the Missouri River at Oahe Dam (site OAHPP1) and the Big Bend Dam powerplant (site BBDPP1) for 2008, 2009, and 2010. Inflow temperatures of the Missouri River to Lake Sharpe are about 4°C warmer than the outflow temperatures of Big Bend Dam during the fall. Outflow temperatures of the Big Bend Dam discharge are about 5°C warmer than the inflow temperatures of the Missouri River during the spring, summer, and fall.

Table 7-1. Summary of water quality conditions monitored on water discharged through Big Bend Dam powerplant (i.e., site BBDPP1) during the 3-year period of 2008 through 2010.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[A]	No. of Obs.	Mean[B]	Median	Min.	Max.	State WQS Criteria[C]	No. of WQS Exceedances	Percent WQS Exceedance
Dam Discharge (cfs)	1	28	30,524	24,213	0	71,717	-----	-----	-----
Water Temperature (°C)	0.1	28	12.2	10.7	1.0	25.0	27[1,2]	0	0%
Dissolved Oxygen (mg/l)	0.1	28	10.1	9.6	5.5	15.0	5[1,3]	0	0%
Dissolved Oxygen (% Sat.)	0.1	28	94.1	94.9	68.3	113.9	-----	-----	-----
pH (S.U.)	0.1	27	8.2	8.3	7.2	8.8	6.5[1,3], 9.0[1,2]	0	0%
Specific Conductance (umhos/cm)	1	28	715	719	642	864	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	27	365	354	177	714	-----	-----	-----
Turbidity (NTU)	1	28	8	3	n.d.	82	-----	-----	-----
Alkalinity, Total (mg/l)	7	28	155	158	116	167	-----	-----	-----
Carbon, Total Organic (mg/l)	0.05	28	3.6	3.6	1.4	5.7	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	28	11	11	n.d.	33	-----	-----	-----
Chloride, Dissolved (mg/l)	1	20	13	12	10	25	438[2,4], 250[2,6]	0	0%
Color, True (APHA)	1	8	10	6	5	23	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	28	477	480	378	592	1,750[2,4], 1,000[2,7], 3,500[3,4], 2,000[3,6]	0	0%
Nitrogen, Ammonia Total (mg/l)	0.02	28	-----	0.02	n.d.	0.26	4.7 [1,4,7], 1.4 [1,6,7]	0	0%
Nitrogen, Kjeldahl Total (mg/l)	0.1	27	0.5	0.5	n.d.	1.0	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/l)	0.02	28	-----	n.d.	n.d.	1.00	10[2,4]	0	0%
Nitrogen, Total (mg/l)	0.1	27	0.6	0.6	n.d.	1.7	-----	-----	-----
Phosphorus, Dissolved (mg/l)	0.02	28	-----	0.02	n.d.	0.06	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	27	0.04	0.03	n.d.	0.15	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	28	-----	n.d.	n.d.	0.06	-----	-----	-----
Sulfate (mg/l)	1	28	203	206	172	237	875[2,4], 500[2,6]	0	0%
Suspended Solids, Total (mg/l)	4	27	11	4	n.d.	67	158[1,4], 90[1,6]	0	0%

n.d. = Not detected, b.d. = Criterion below detection limit.

(A) Detection limits given for the parameters Streamflow, Water Temperature, Dissolved Oxygen (mg/l and % Sat.), pH, Specific Conductance, and Oxidation-Reduction Potential are resolution limits for field measured parameters.

(B) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(C) Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.

(1) Criteria for the protection of warmwater permanent fish life propagation waters.
(2) Criteria for the protection of domestic water supply waters.
(3) Criteria for the protection of commerce and industry waters.
(4) Daily maximum criterion (monitoring results directly comparable to criterion).
(5) Daily minimum criterion (monitoring results directly comparable to criterion).
(6) 30-day average criterion (monitoring results not directly comparable to criterion).
(7) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

Table 7-2. Summary of annual metals and pesticide levels monitored on water discharged through Big Bend Dam (i.e., site BBDPP1) during the 3-year period of 2008 through 2010.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[B]	Median	Min.	Max.	State WQS Criteria[C]	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/l)	25	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Aluminum, Total (ug/l)	25	3	378	200	190	745	-----	-----	-----
Antimony, Dissolved (ug/l)	0.5	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Antimony, Total (ug/l)	0.5	3	-----	n.d.	n.d.	n.d.	5.6[3]	0	0%
Arsenic, Dissolved (ug/l)	1	3	1	1	1	2	340[1], 150[2]	0, 0	0%, 0%
Arsenic, Total (ug/l)	1	3	2	2	2	2	0.018[3]	3	100%
Barium, Dissolved (ug/l)	5	3	41	41	37	46	-----	-----	-----
Barium, Total (ug/l)	5	3	47	50	40	51	-----	-----	-----
Beryllium, Dissolved (ug/l)	2	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Beryllium, Total (ug/l)	2	3	-----	n.d.	n.d.	n.d.	4[3]	0	0%
Cadmium, Dissolved (ug/l)	0.2	3	-----	n.d.	n.d.	n.d.	4.3[1], 0.42[2]	0	0%
Cadmium, Total (ug/l)	0.2	3	-----	n.d.	n.d.	n.d.	5[3]	0	0%
Chromium, Dissolved (ug/l)	10	3	-----	n.d.	n.d.	n.d.	1,075[1], 140[2]	0	0%
Chromium, Total (ug/l)	10	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Copper, Dissolved (ug/l)	2	3	-----	n.d.	n.d.	n.d.	28[1], 17[2],	0	0%
Copper, Total (ug/l)	2	3	-----	n.d.	n.d.	n.d.	1,300[3]	0	0%
Hardness, Total (mg/l)	0.4	3	218	210	205	238	-----	-----	-----
Iron, Dissolved (ug/l)	7	3	-----	n.d.	n.d.	10	-----	-----	-----
Iron, Total (ug/l)	7	3	284	160	150	543	-----	-----	-----
Lead, Dissolved (ug/l)	0.5	3	-----	n.d.	n.d.	n.d.	148[1], 5.8[2]	0	0%
Lead, Total (ug/l)	0.5	3	-----	n.d.	n.d.	6	-----	-----	-----
Manganese, Dissolved (ug/l)	2	3	-----	n.d.	n.d.	2	-----	-----	-----
Manganese, Total (ug/l)	2	3	135	50	40	315	-----	-----	-----
Mercury, Dissolved (ug/l)	0.05	3	-----	n.d.	n.d.	n.d.	1.4[1]	0	0%
Mercury, Total (ug/l)	0.05	3	-----	n.d.	n.d.	n.d.	0.77[2], 0.05[3]	0	0%
Nickel, Dissolved (ug/l)	10	3	-----	n.d.	n.d.	n.d.	902[1], 100[2]	0	0%
Nickel, Total (ug/l)	10	3	-----	n.d.	n.d.	n.d.	610[3]	0	0%
Selenium, Total (ug/l)	1	3	2	2	2	2	4.6[2], 170[3]	0	0%
Silver, Dissolved (ug/l)	1	3	-----	n.d.	n.d.	n.d.	12[1]	0	0%
Silver, Total (ug/l)	1	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Dissolved (ug/l)	0.5	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Total (ug/l)	0.5	3	-----	n.d.	n.d.	n.d.	0.24[3]	b.d.	b.d.
Zinc, Dissolved (ug/l)	10	3	-----	n.d.	n.d.	10	226[1,2]	0	0%
Zinc, Total (ug/l)	10	3	-----	25	n.d.	50	7,400[3]	0	0%
Pesticide Scan (ug/l)[D]	0.05[E]	3	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected, b.d. = Criterion below detection limit.

[A] Results for iron (dissolved and total) and manganese (dissolved and total) include some monthly samples.

[B] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

[C] Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.

[1] Acute (CMC) criterion for the protection of freshwater aquatic life.

[2] Chronic (CCC) criterion for the protection of freshwater aquatic life.

[3] Criterion for the protection of human health.

Note: Some of South Dakota's criteria for metals (i.e., cadmium, chromium, copper, lead, nickel, silver, and zinc) are based on hardness. Criteria shown for those metals were calculated using the median hardness value.

[D] The pesticide scan includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, de-ethylatrazine, de-isopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

[E] Detection limits vary by pesticide – 0.05 ug/l is a median detection limit for the pesticides in the pesticide scan.

Table 7-3. Summary of nutrient flux rates (kg/sec) calculated for the Big Bend Dam discharge to the Missouri River (i.e., site BBDPP1) during the 3-year period 2008 through 2010.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	28	28	28	28	28	28	28
Mean	30,524	0.0260	0.4673	0.1019	0.0579	0.0165	3.1336
Median	24,213	n.d.	0.3261	n.d.	0.0206	0.0107	2.7133
Minimum	0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Maximum	71,717	0.1422	1.3553	1.7608	0.5848	0.1056	8.9799

Note: Nondetectable values set to 0 for flux calculations.

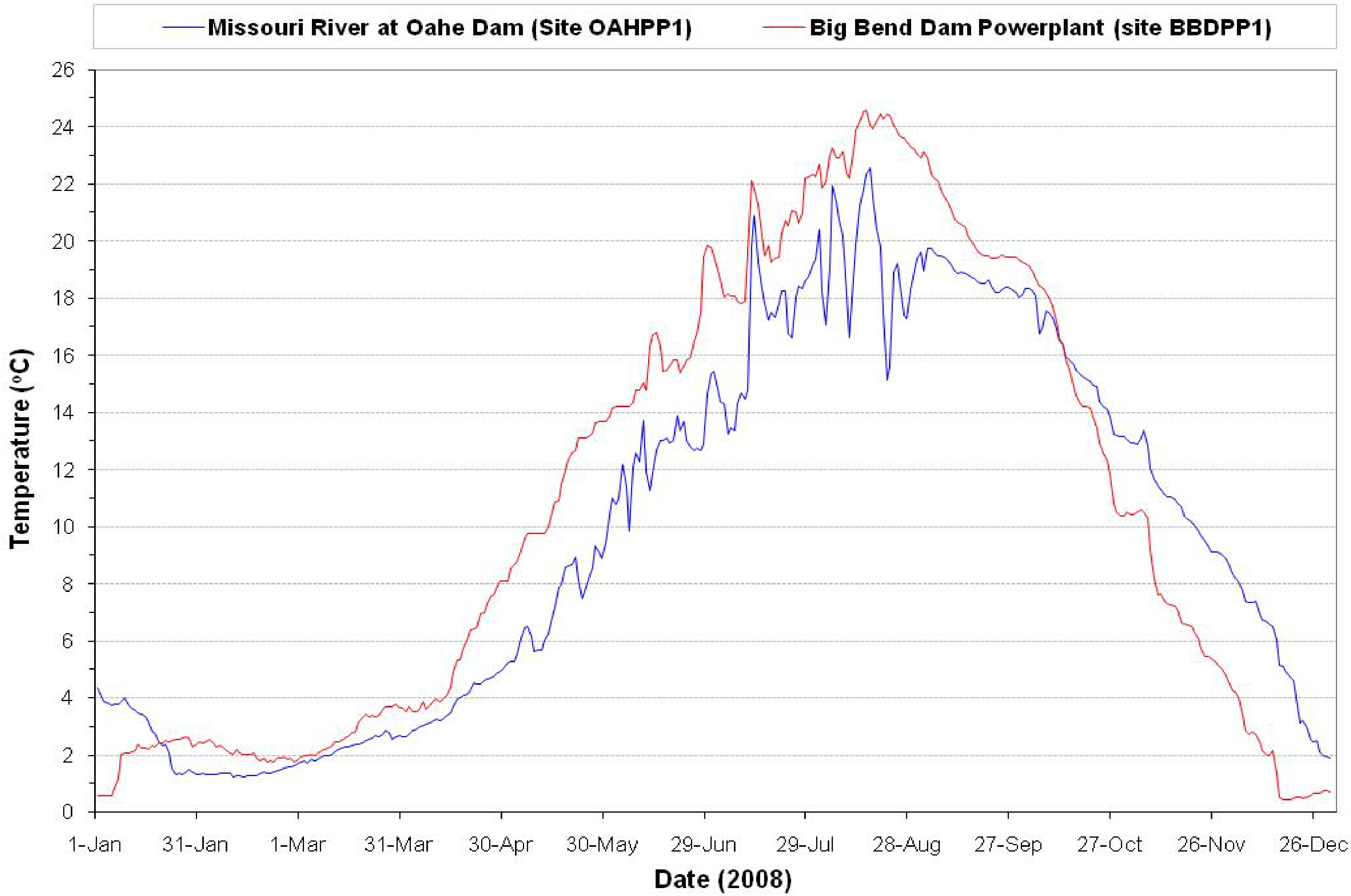

Figure 7-1. Mean daily water temperatures monitored at the Big Bend Powerplant (i.e., site BBDPP1) and the Missouri River at Oahe Dam (i.e., site OAHPP1) during 2008.

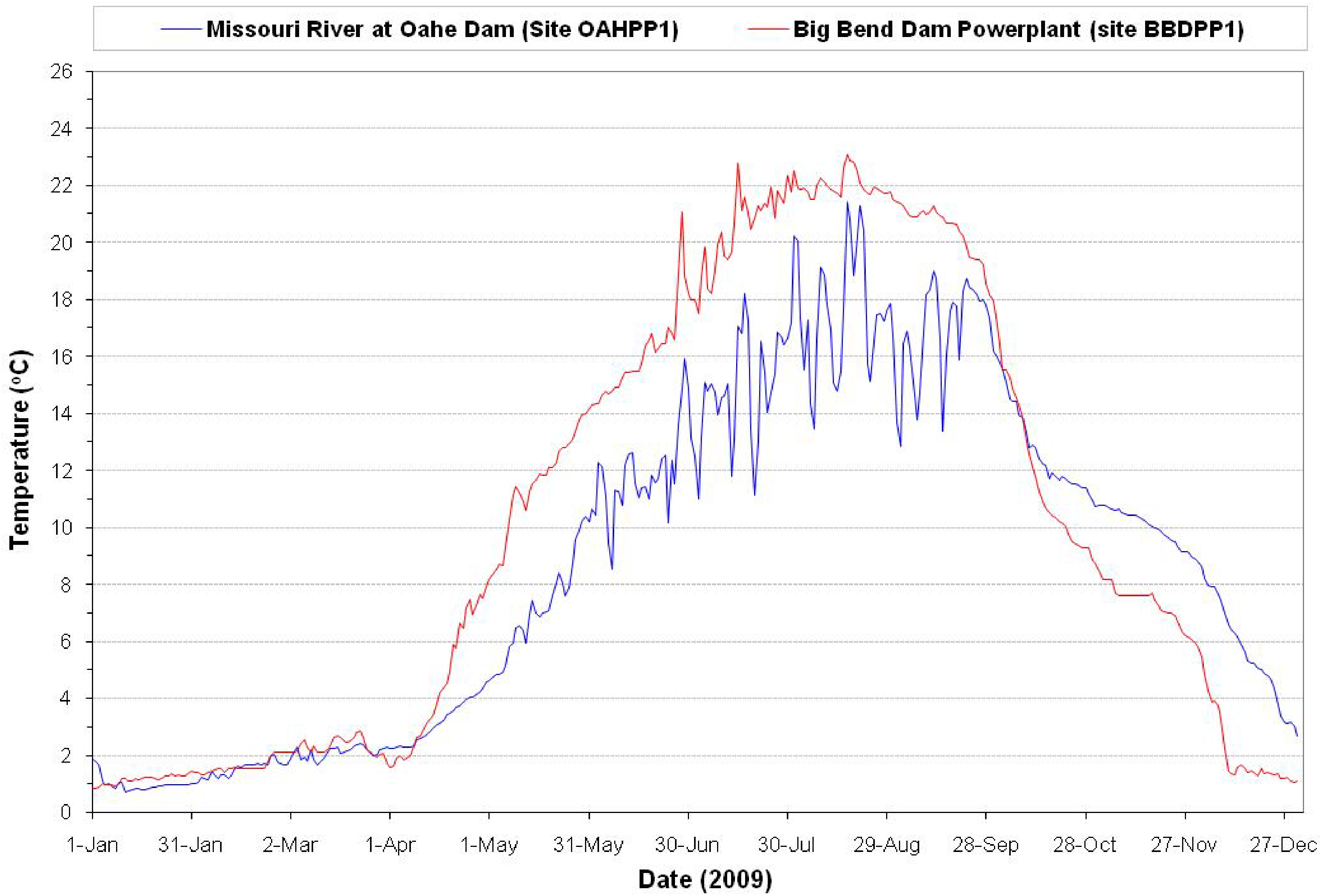

Figure 7-2. Mean daily water temperatures monitored at the Big Bend Powerplant (i.e., site BBDPP1) and the Missouri River at Oahe Dam (i.e., site OAHPP1) during 2009.

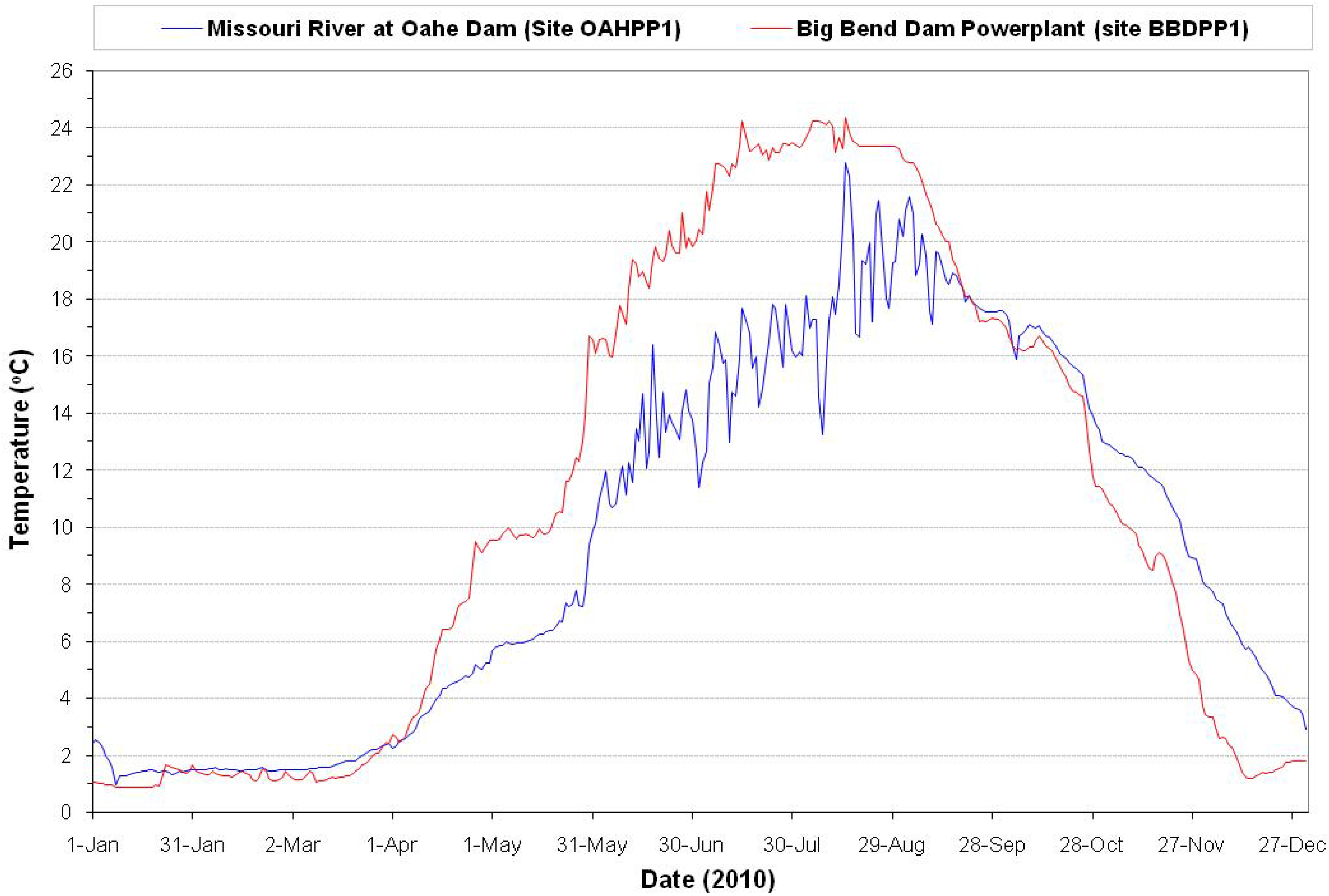

Figure 7-3. Mean daily water temperatures monitored at the Big Bend Powerplant (i.e., site BBDPP1) and the Missouri River at Oahe Dam (i.e., site OAHPP1) during 2010.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 EXISTING WATER QUALITY CONDITIONS

8.1.1 LAKE SHARPE

Water quality conditions in Lake Sharpe vary longitudinally from the dam to the reservoir's upstream reaches, and vertically from the reservoir surface to the bottom. Water quality monitoring indicated that the reservoir is probably discontinuous polymictic with a hypolimnion only forming on an irregular basis. The trophic status of Lake Sharpe is mesotrophic to moderately eutrophic in the area near the dam, eutrophic in the middle reaches, and eutrophic to borderline hypereutrophic in the upper reaches of the reservoir. The phytoplankton community of Lake Sharpe was dominated by diatoms and no concentrations of the cyanotoxin microcystin above 1 ug/l were measured. The zooplankton community in Lake Sharpe was dominated by Cladocerans and Copepods.

Water quality conditions monitored in Lake Sharpe during the 3-year period 2008 through 2010 indicate that the Coldwater Permanent Fish Life Propagation (CPFLP) use designated to Lake Sharpe is not being attained. The most crucial period for the support of CPFLP habitat (≤ 18°C temperature and > 6 mg/l dissolved oxygen) in Lake Sharpe is during mid-summer. Due to its shallowness, a hypolimnion rarely forms in Lake Sharpe and water temperatures throughout the reservoir regularly exceed 18.3°C in the summer. When stratification does persist, dissolved oxygen degradation to levels below 6 mg/l occurs near the reservoir bottom in deeper waters near the dam. The suspended solids criteria for the protection of CPFLP are regularly exceeded in the upper end of Lake Sharpe. This is attributed to finer sediment that has been deposited in Lake Sharpe below the confluence of the Bad River and its continual re-suspension with wave action. Consideration should be given to reclassify Lake Sharpe for a Warmwater Permanent Fish Life Propagation use based on a use attainability assessment of "natural conditions" regarding ambient water temperatures.

8.1.2 WATER DISCHARGED THROUGH BIG BEND DAM

Water discharged through Big Bend Dam exhibited good water quality during the monitored 3-year period of 2008 through 2010. There appeared to be significant correlation between discharge rates and water temperature and dissolved oxygen concentrations measured during the summer months. The lower dissolved oxygen concentrations monitored in the summer may be attributed to periodic stratification and the degradation of dissolved oxygen conditions near the bottom of the reservoir. Since the inlet to the powerhouse is located at the reservoir bottom, lower flows through the dam may result in more "laminar" flow that pulls in water with degraded dissolved oxygen conditions along the bottom into the powerplant.

Inflow temperatures of the Missouri River to Lake Sharpe are about 4°C warmer than the outflow temperatures of Big Bend Dam during the fall. Outflow temperatures of the Big Bend Dam discharge are about 5°C warmer than the inflow temperatures of the Missouri River during the spring, summer, and fall.

8.2 **WATER QUALITY MANAGEMENT**

The Omaha District is planning to pursue the application of the Corps' CE-QUAL-W2 hydrodynamic and water quality model to Lake Sharpe. CE-QUAL-W2 is a powerful tool to aid in addressing reservoir water quality management issues. Application of the CE-QUAL-W2 model will allow the Corps to better understand how the operation of the Big Bend Project affects the water quality in Lake Sharpe and the dam discharges to the Missouri River and Lake Francis Case. It is almost a certainty that water quality issues at the Big Bend Project will remain important in the future.

8.3 **WATER QUALITY MONITORING RECOMMENDATIONS**

Continue monthly (i.e., May, June, July, August, and September) monitoring of ambient water quality conditions in Lake Sharper at three sites: BBDLK0987A, BBDLK1020DW, and BBDLK1055DW. Continue year-round monitoring (i.e., monthly water samples and hourly data-logging) of water drawn from the raw-water supply lines at the Oahe (i.e., Missouri River inflow) and at the Big Bend (i.e., Missouri River outflow) powerplants.

9 REFERENCES

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_______. **2011.** Program Management Plan for Implementing the Omaha District's Water Quality Management Program. Water Quality Unit, Water Control and Water Quality Section, Hydrologic Engineering Branch, Engineering Division, Omaha District, U.S. Army Corps of Engineers, Omaha, Nebraska.

10 PLATES

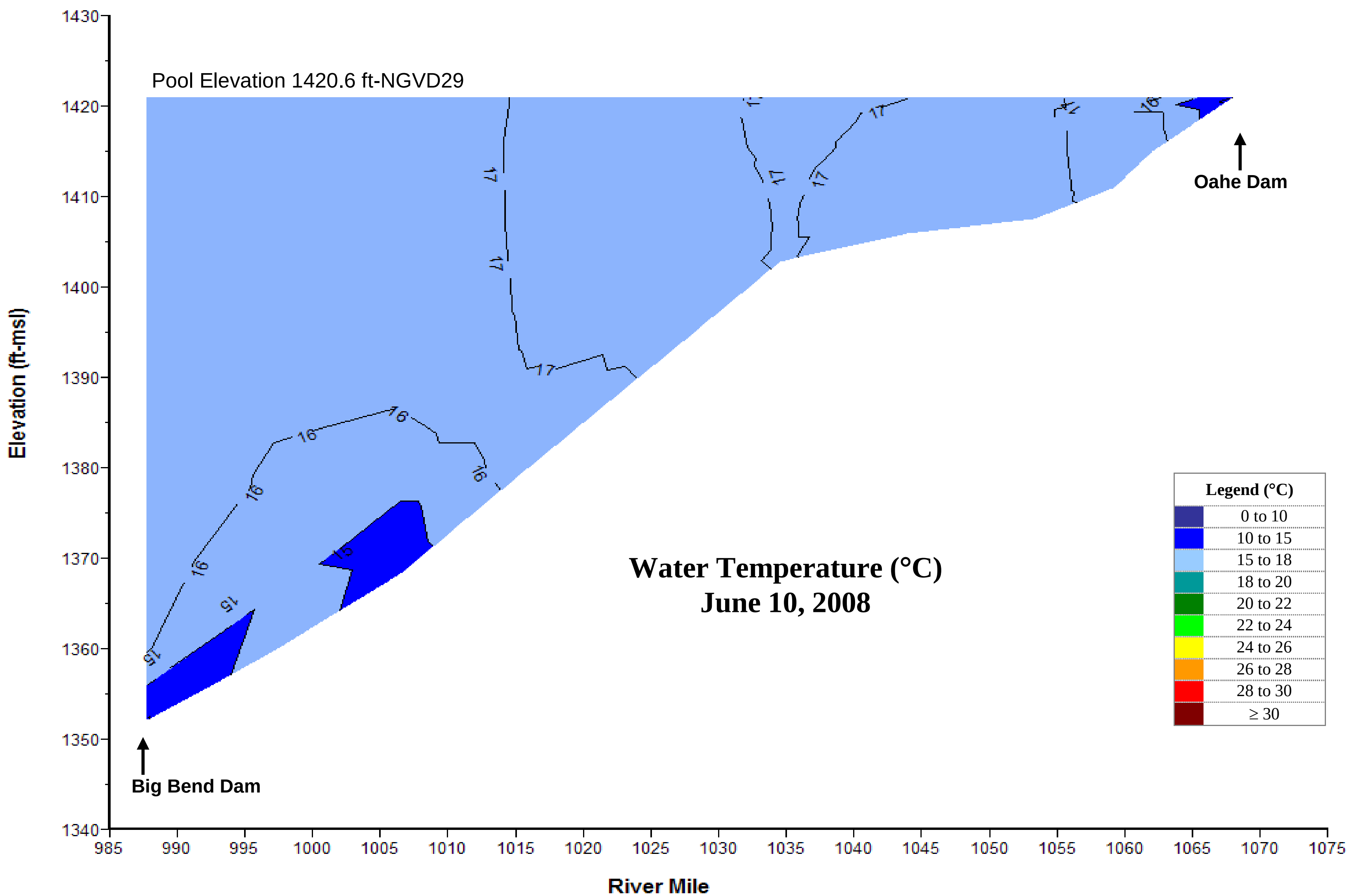

Plate 1. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on June 10, 2008.

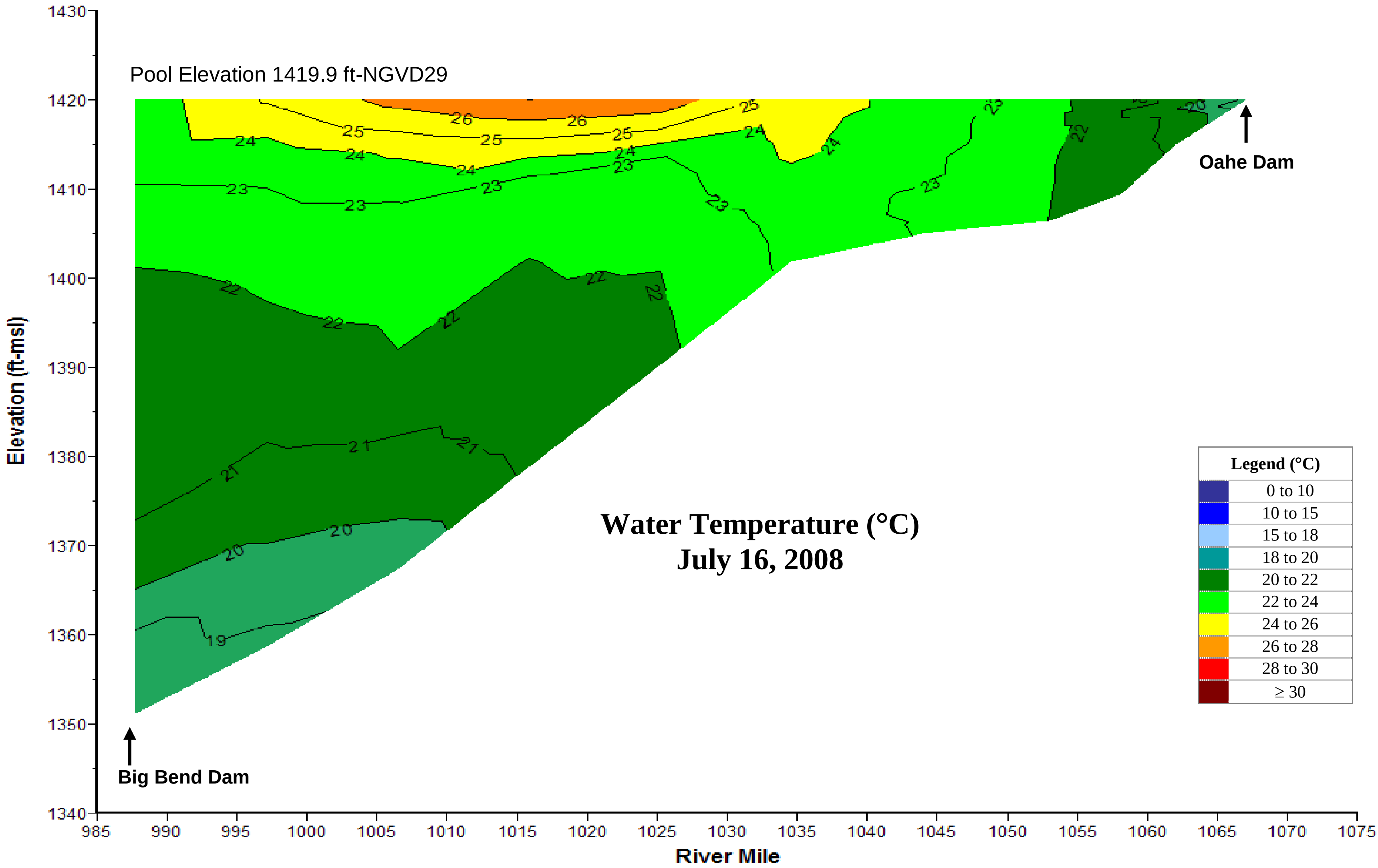

Plate 2. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on July 16, 2008.

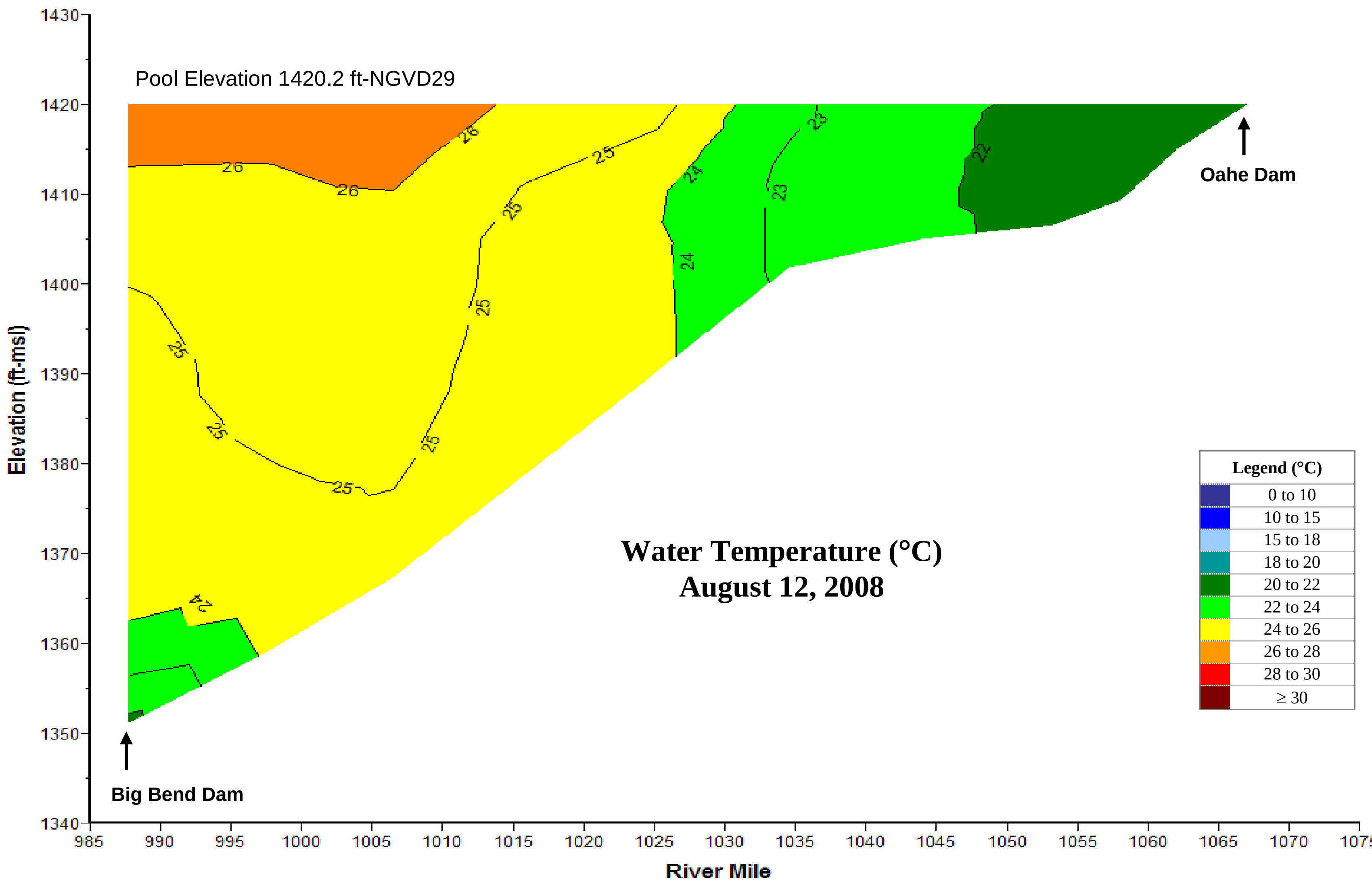

Plate 3. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on August 12, 2008.

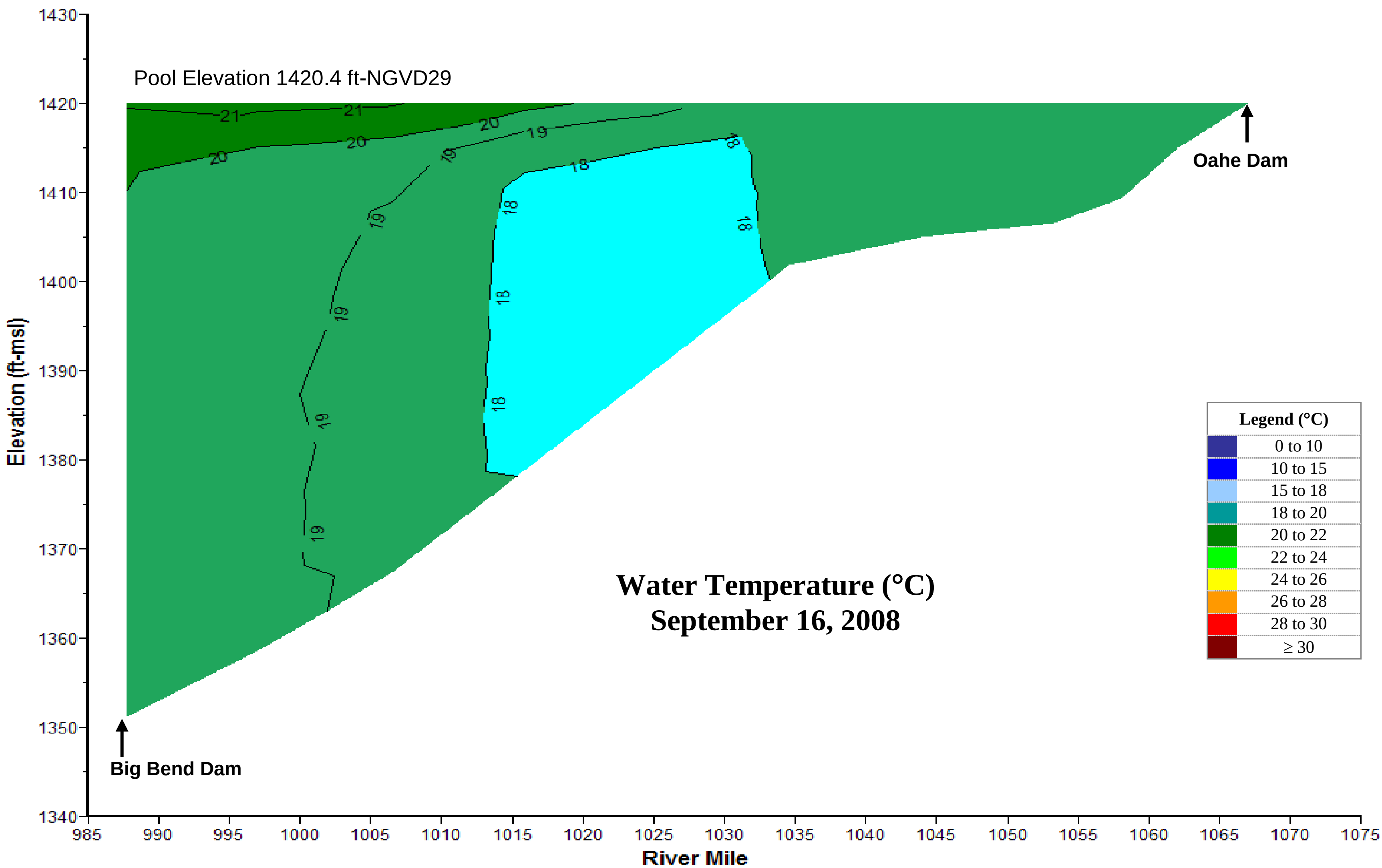

Plate 4. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on September 16, 2008.

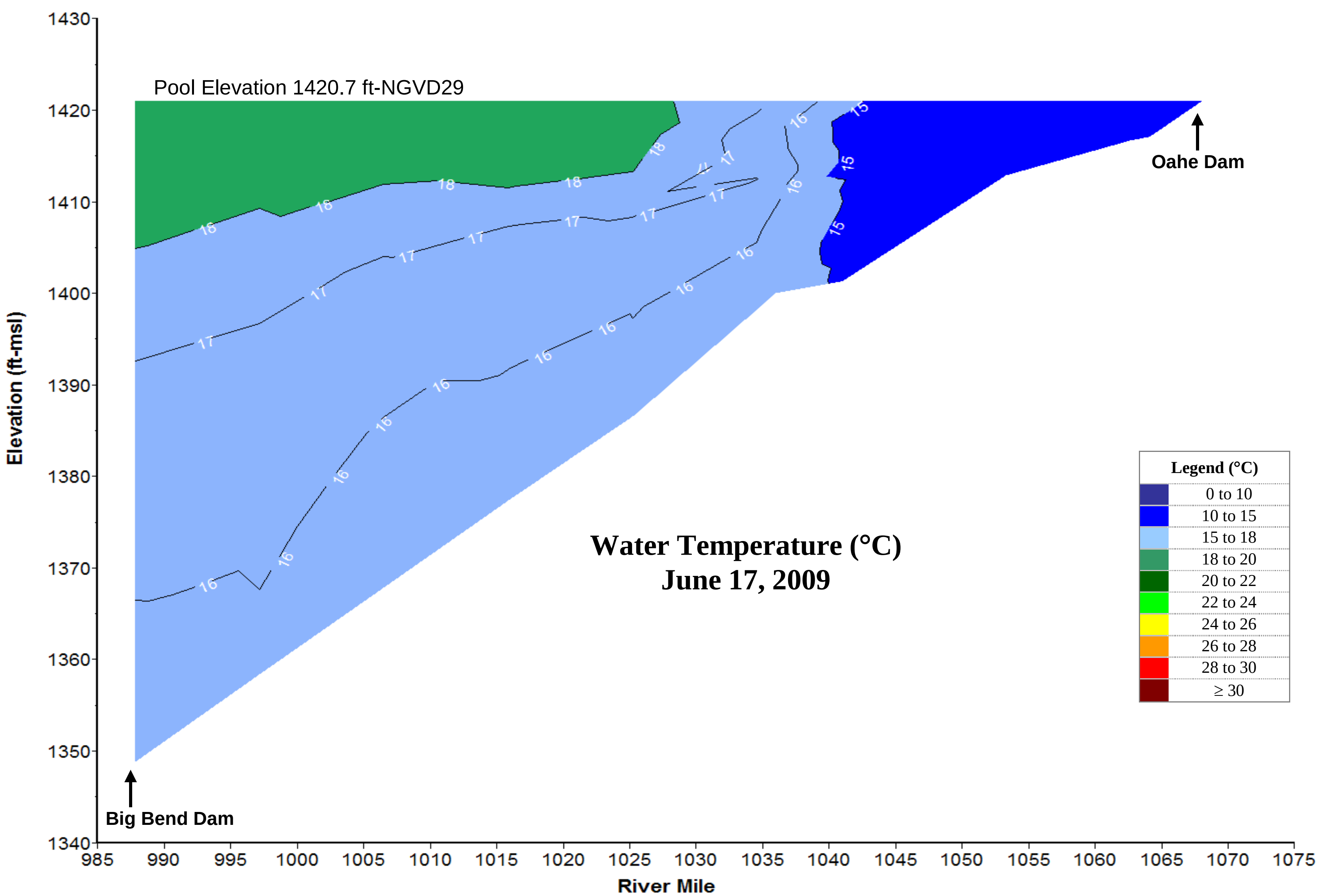

Plate 5. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on June 17, 2009.

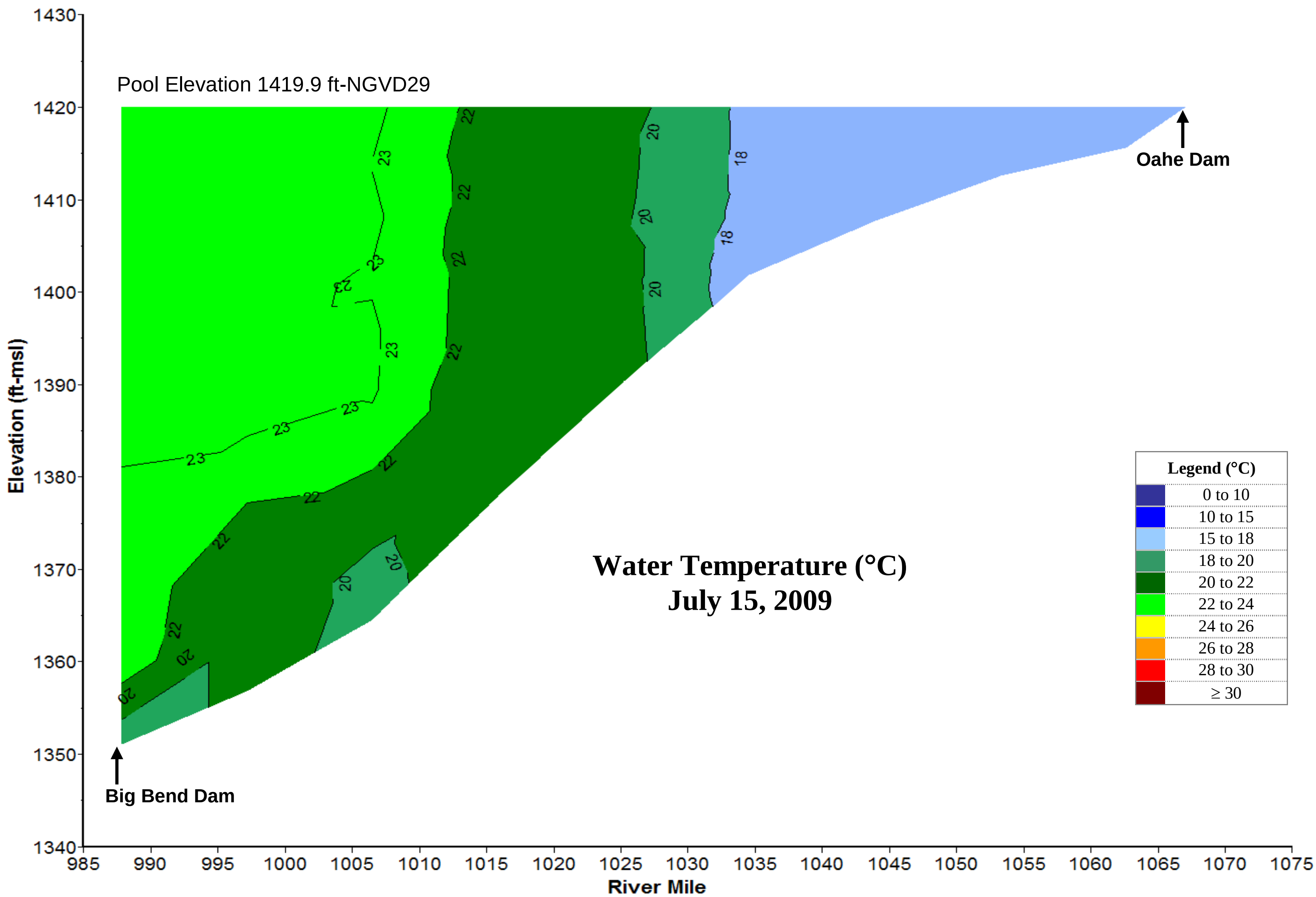

Plate 6. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on July 15, 2009.

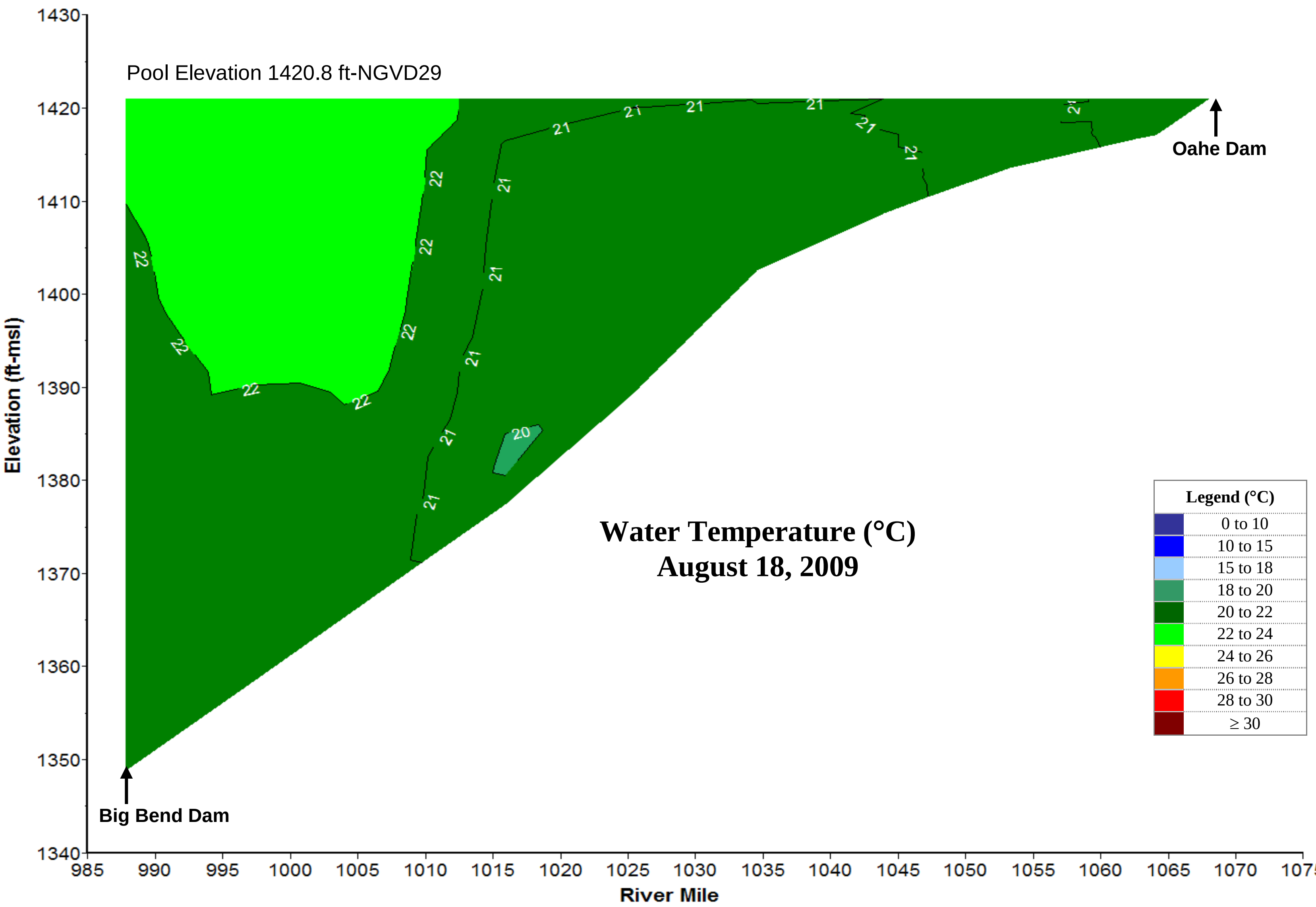

Plate 7. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on August 18, 2009.

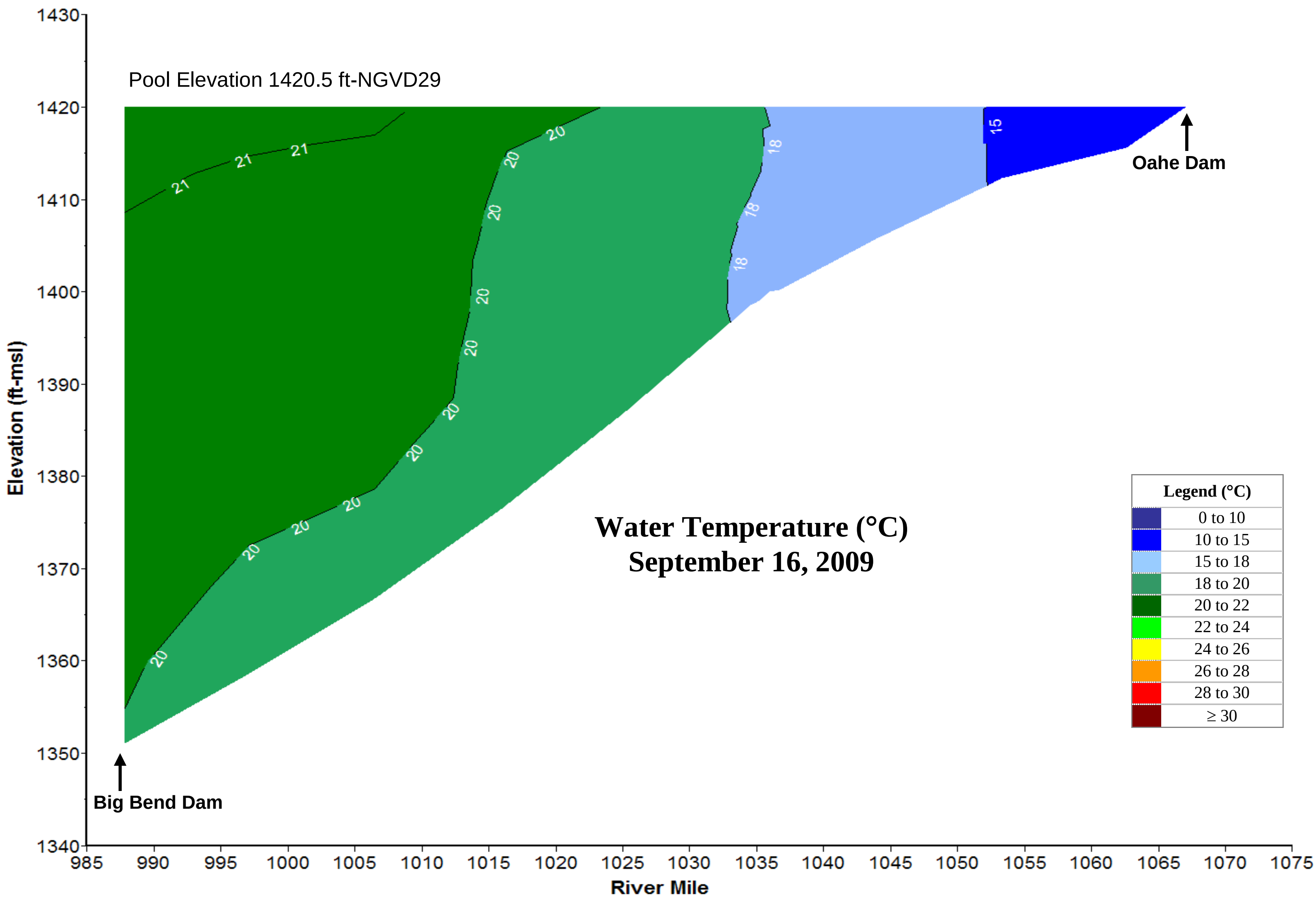

Plate 8. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on September 16, 2009.

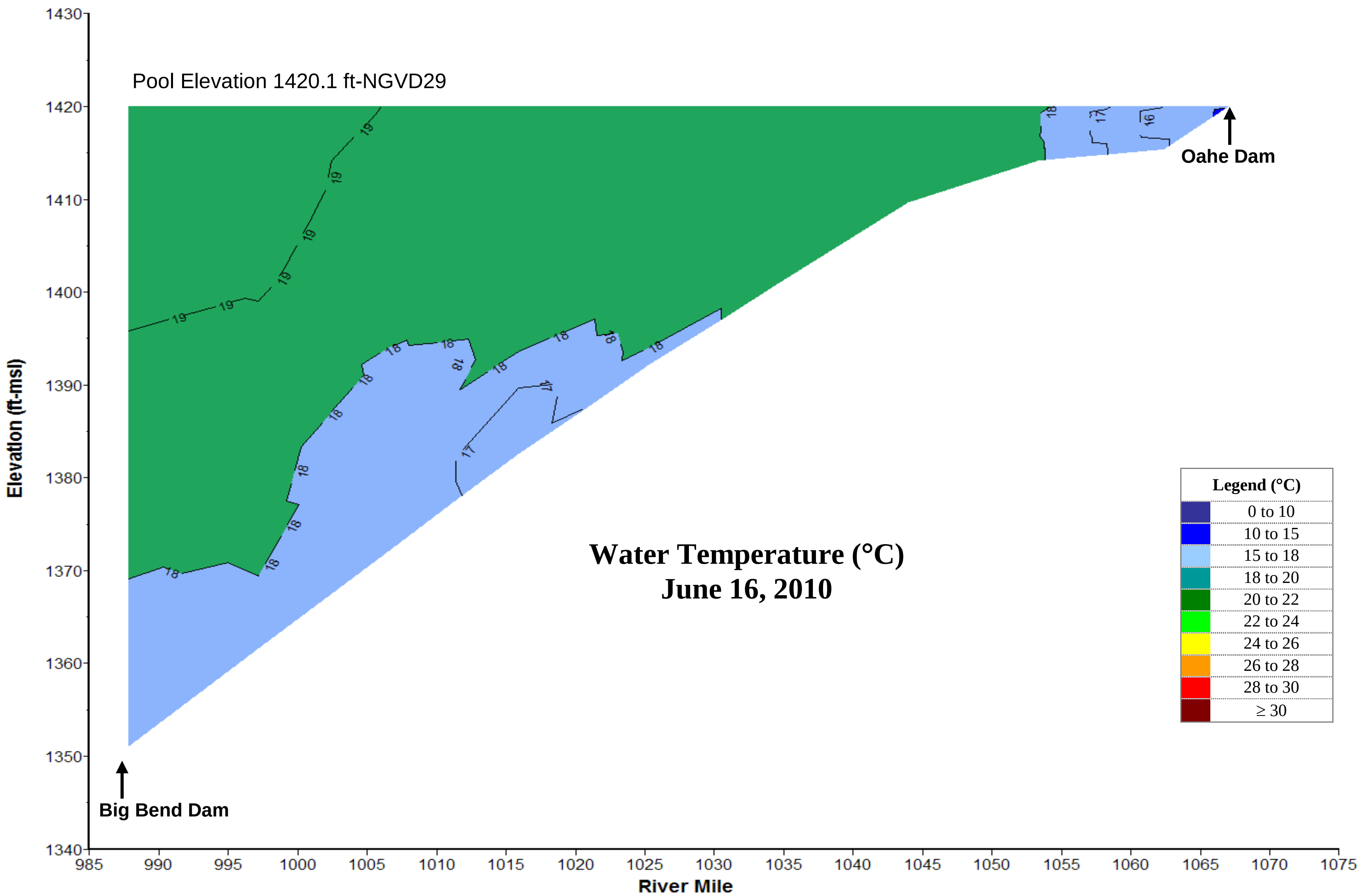

Plate 9. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW, and OAHPP1 on June 16, 2010.

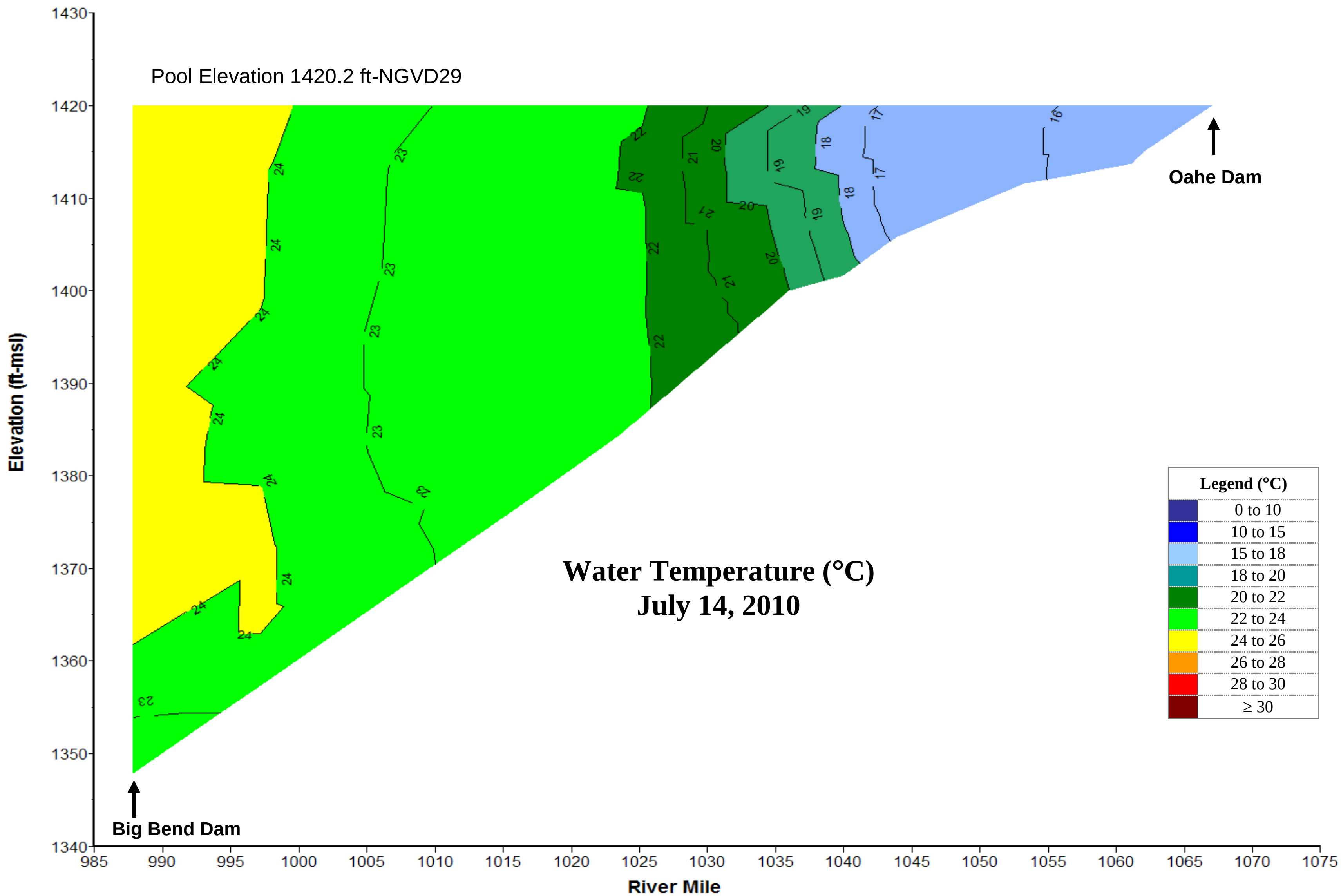

Plate 10. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW, and OAHPP1 on July 14, 2010.

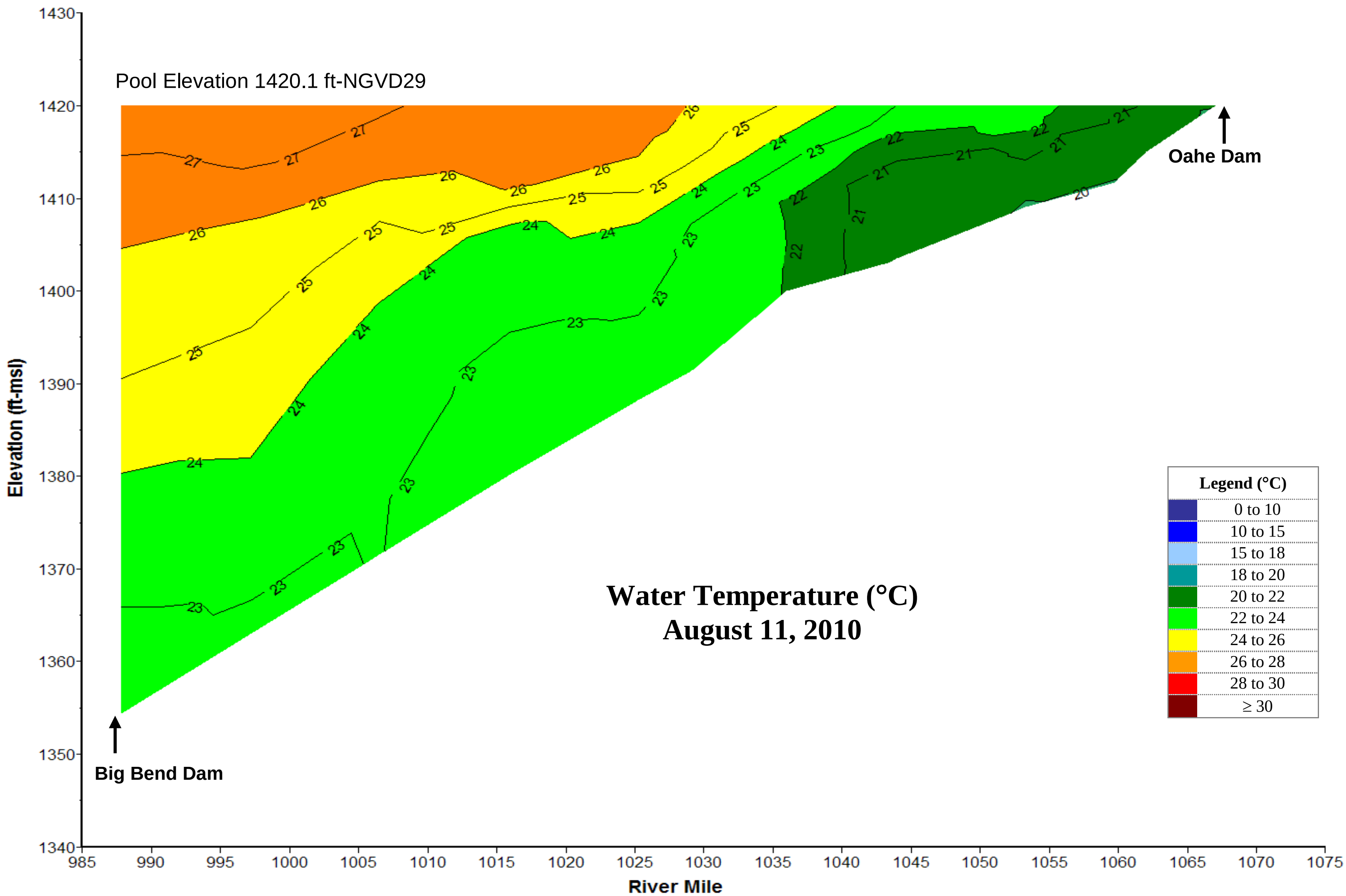

Plate 11. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW, and OAHPP1 on August 11, 2010.

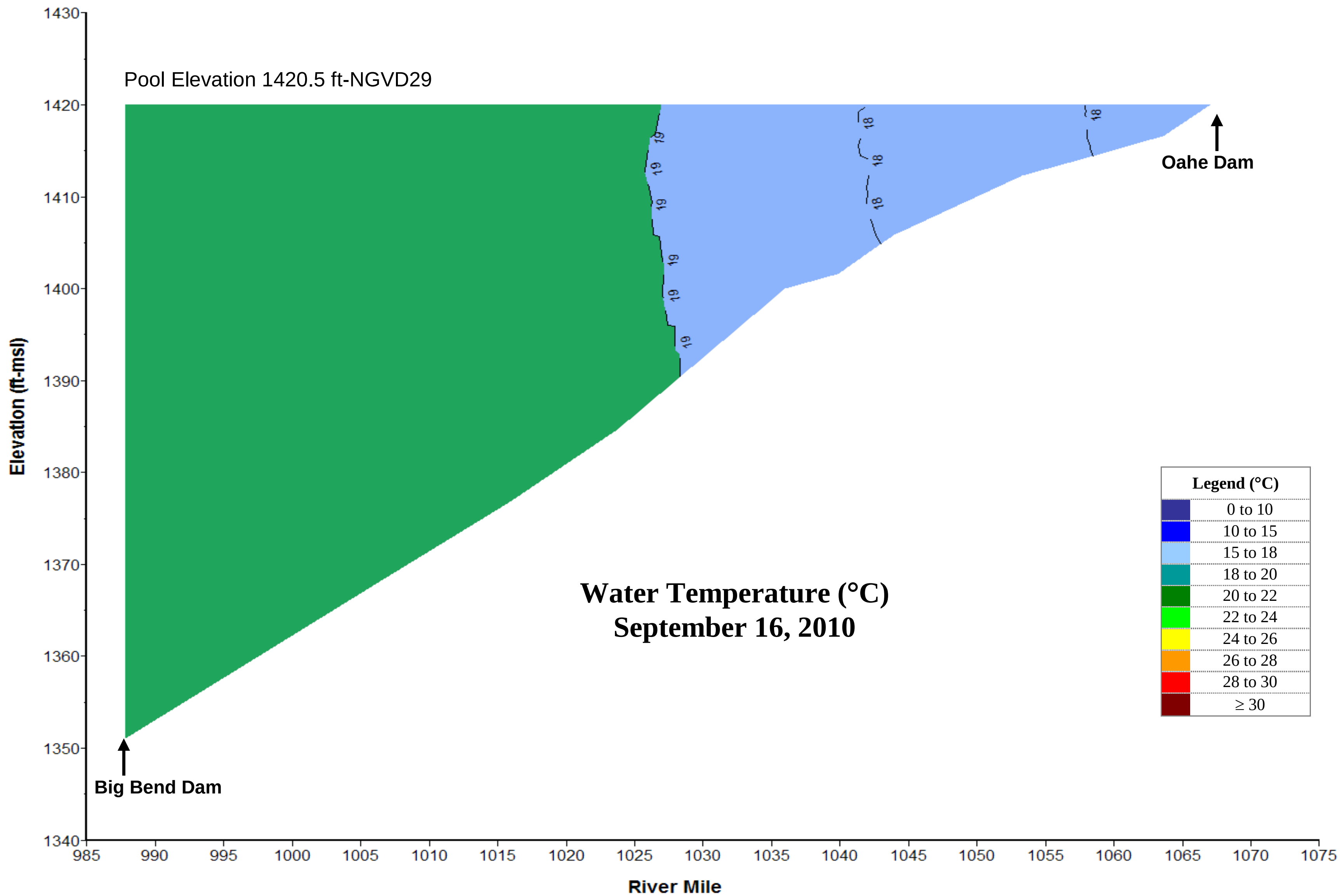

Plate 12. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW, and OAHPP1 on September 16, 2010.

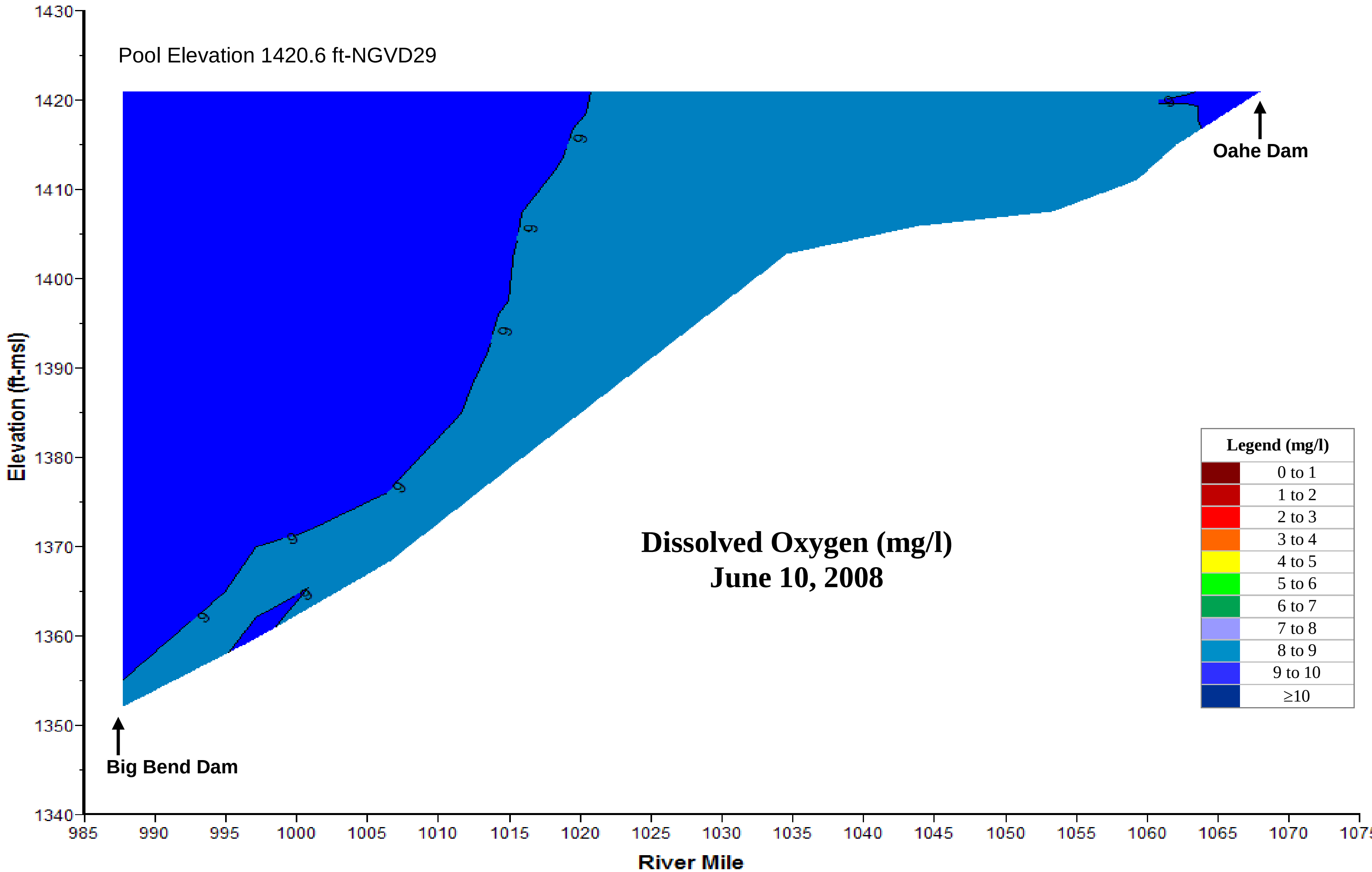

Plate 13. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on June 10, 2008.

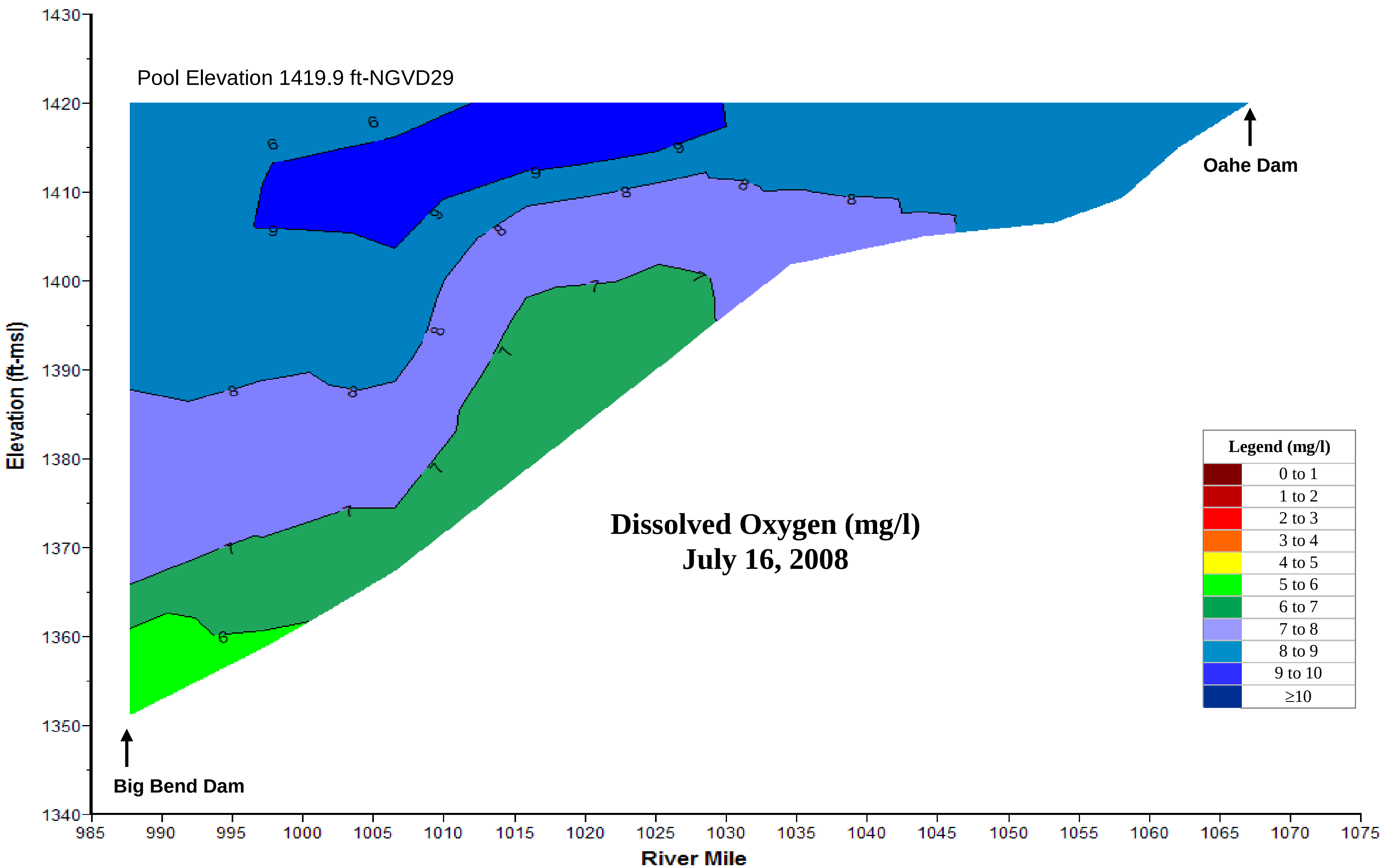

Plate 14. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on July 16, 2008.

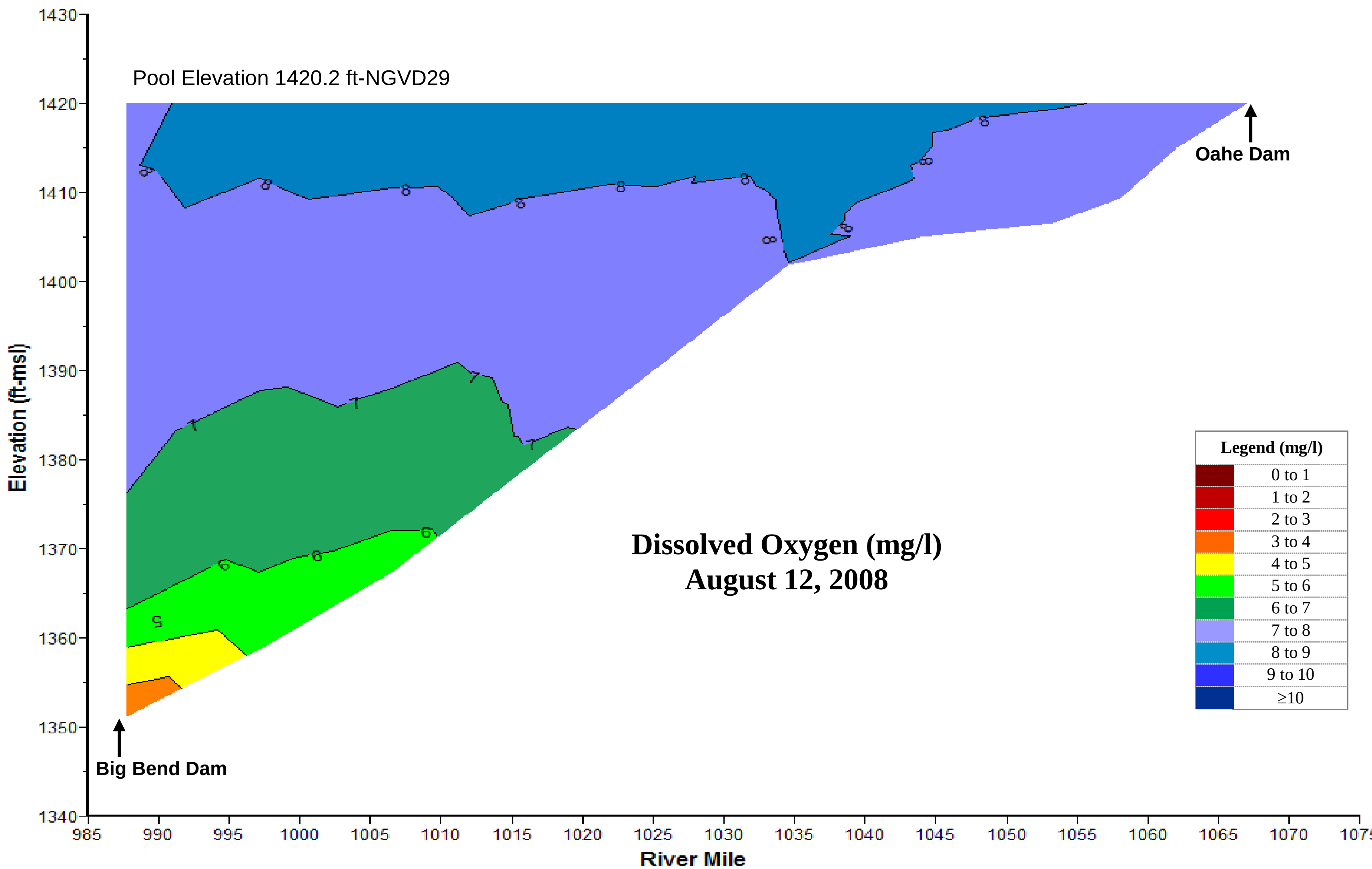

Plate 15. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on August 12, 2008.

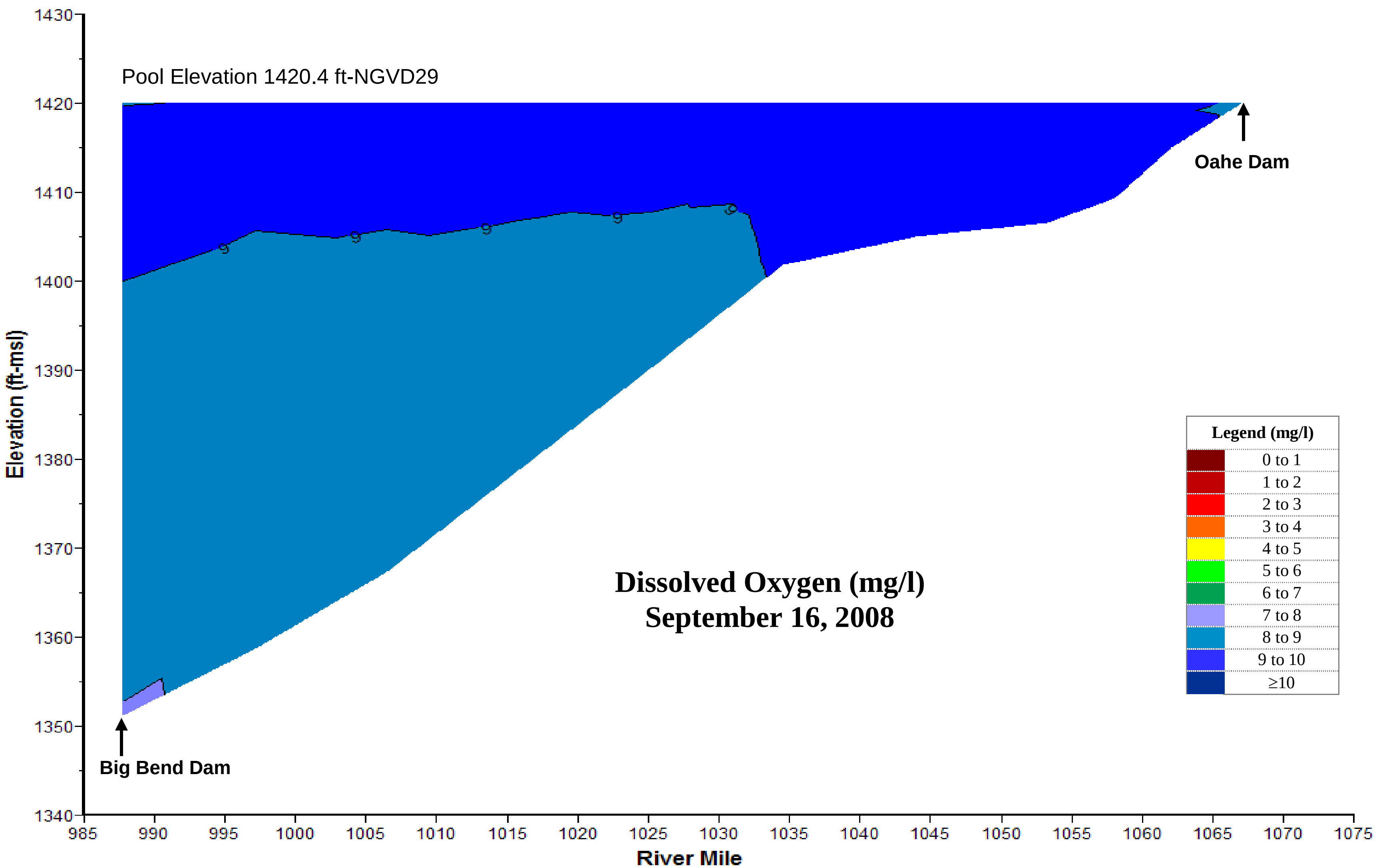

Plate 16. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1on September 16, 2008.

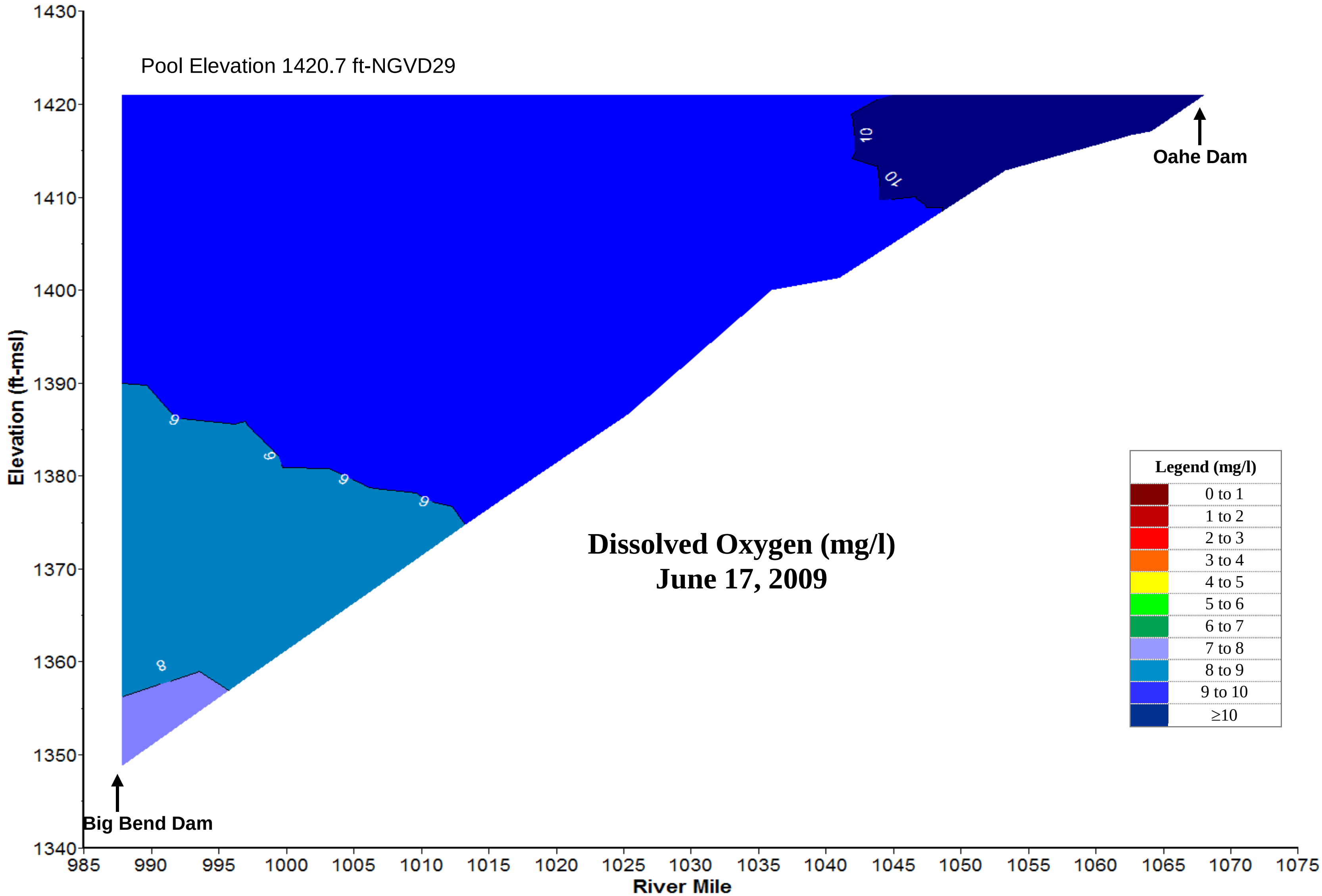

Plate 17. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1on June 17, 2009.

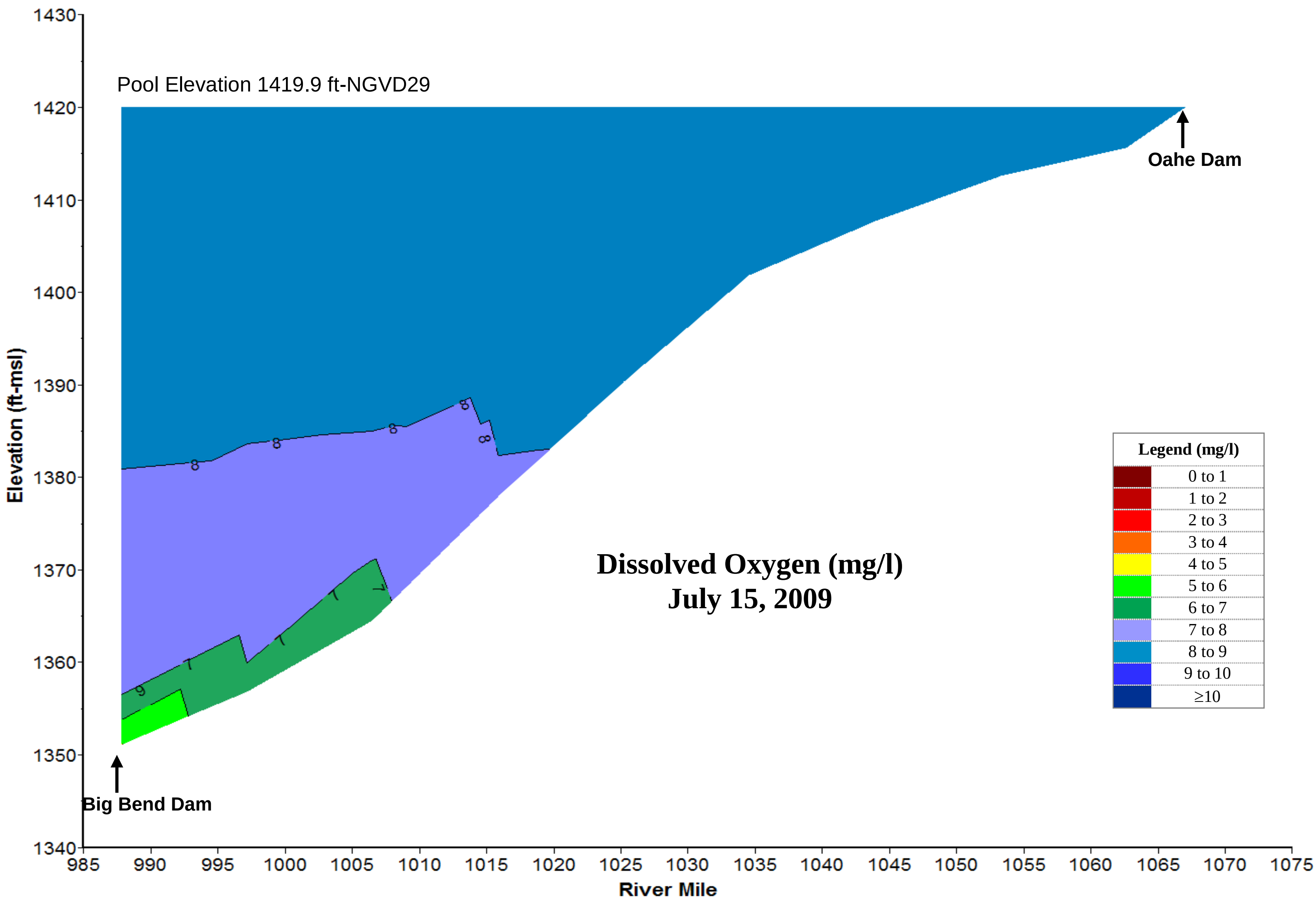

Plate 18. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on July 15, 2009.

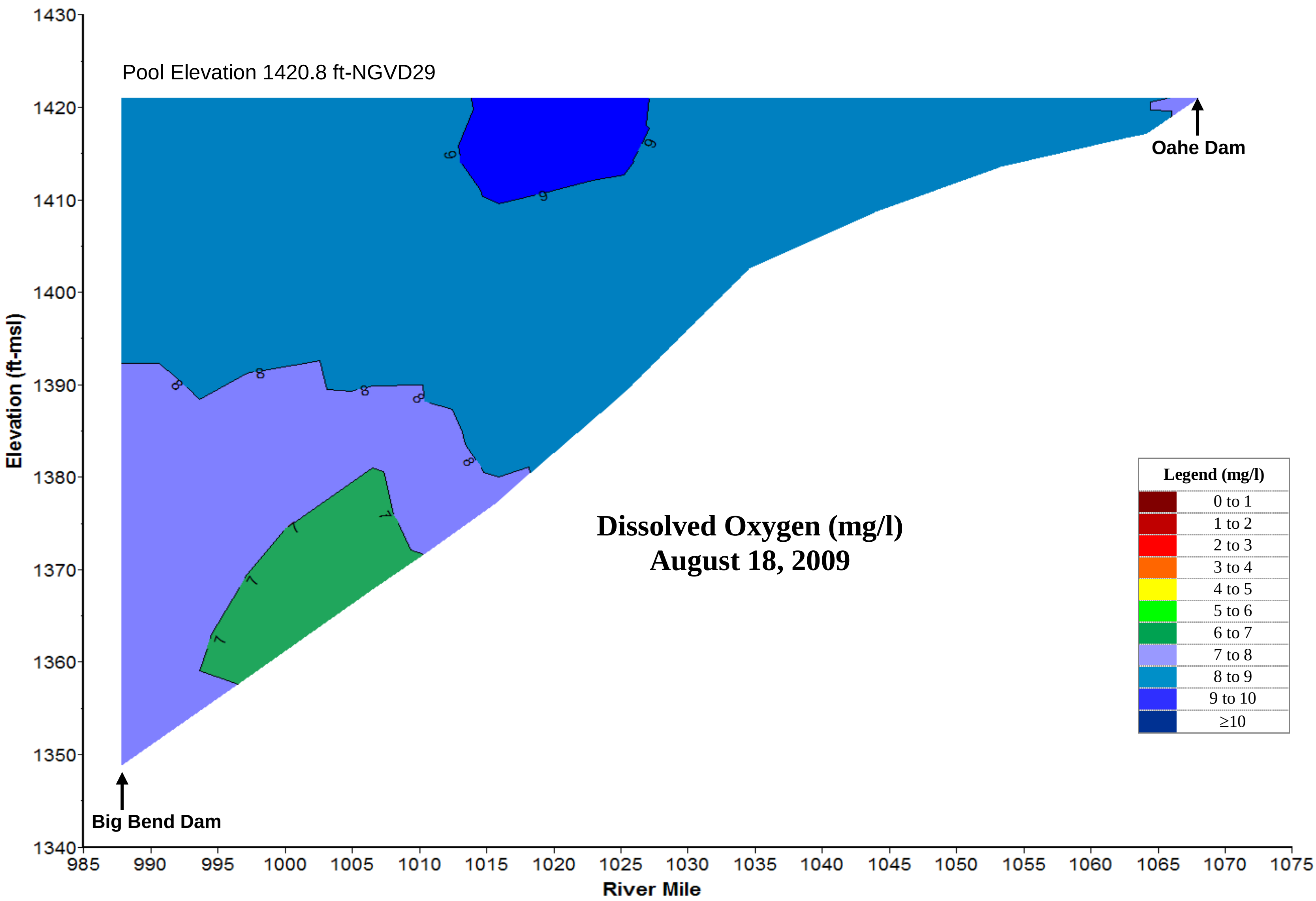

Plate 19. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on August 18, 2009.

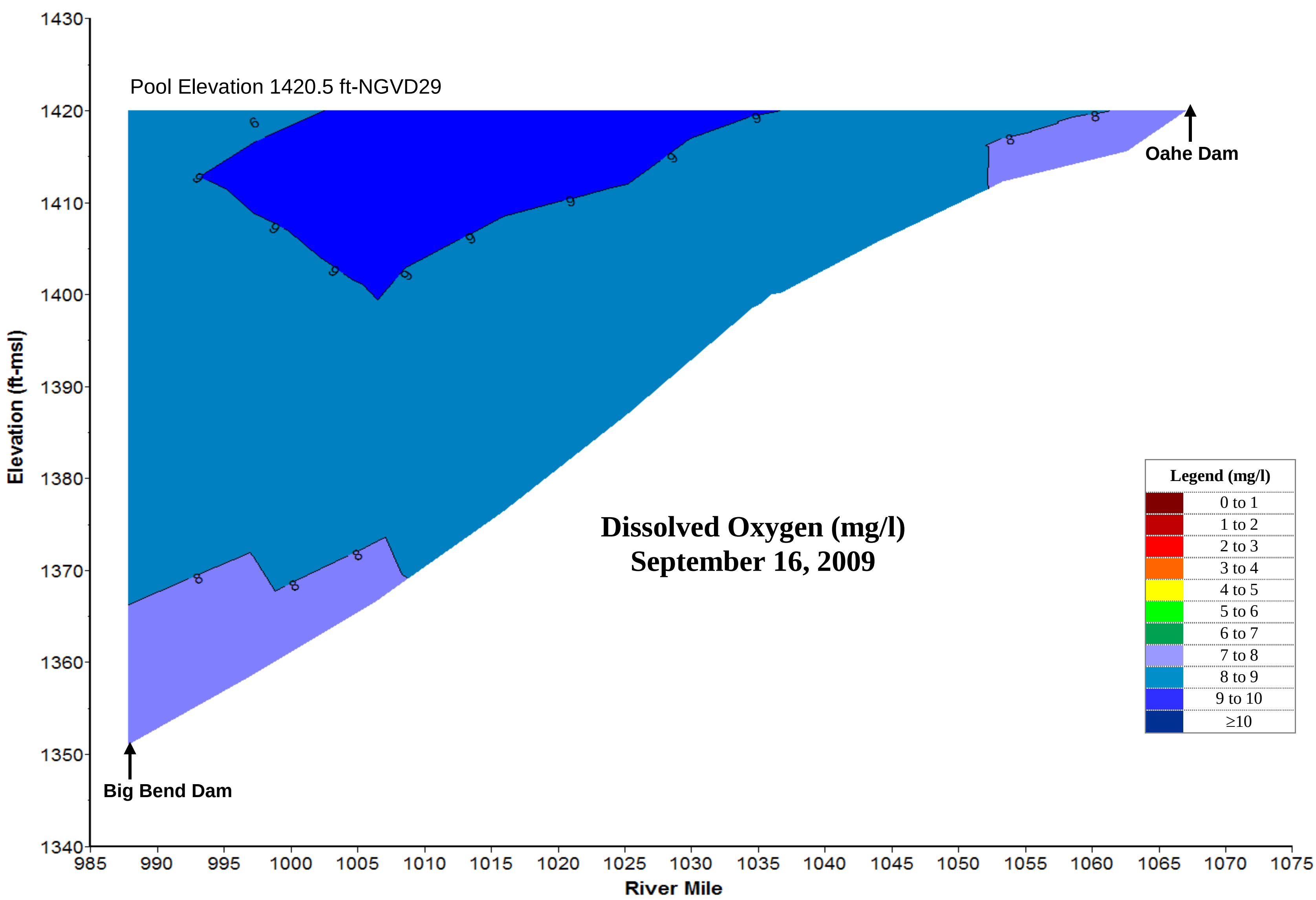

Plate 20. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on September 16, 2009.

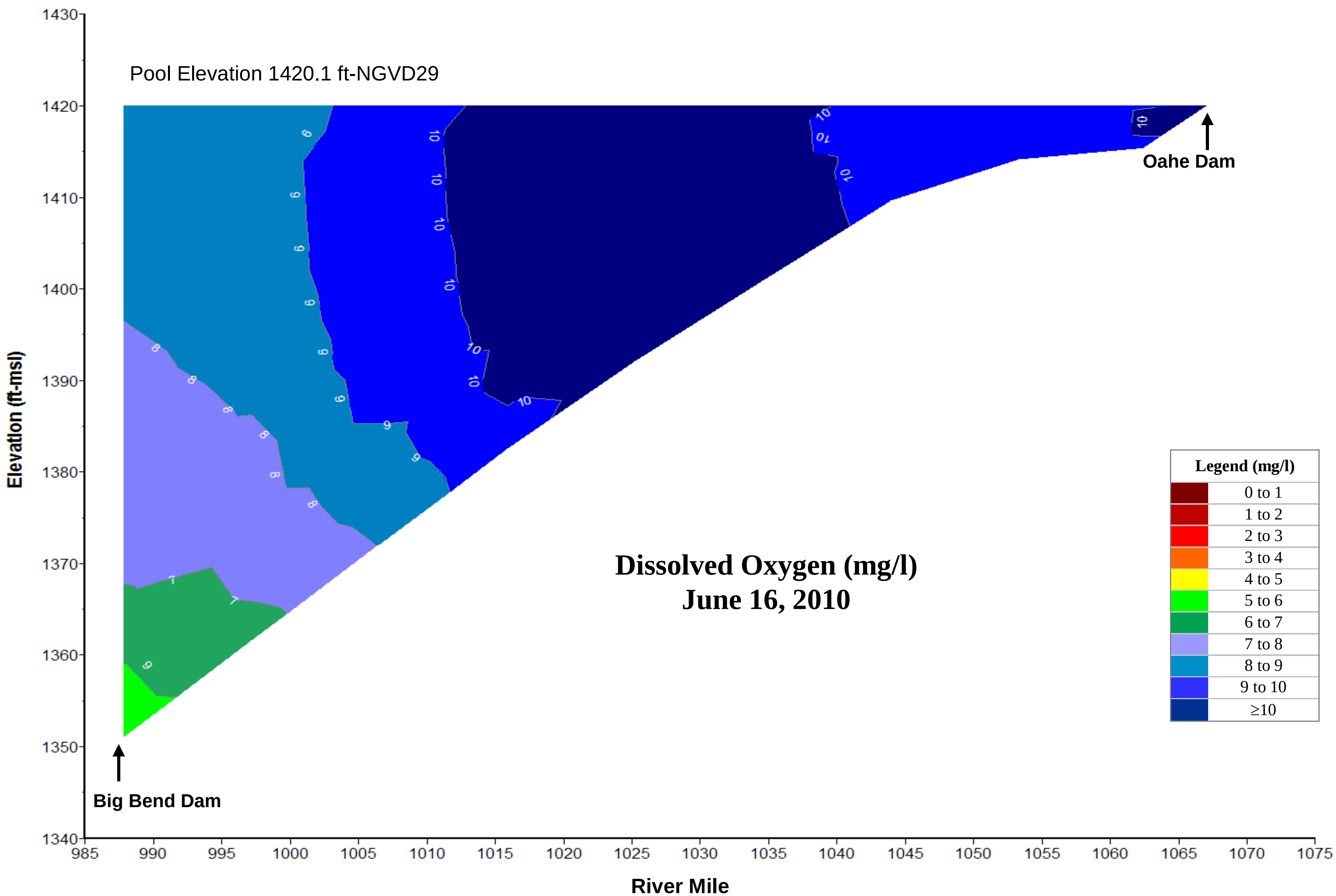

Plate 21. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW, and OAHPP1 on June 16, 2010.

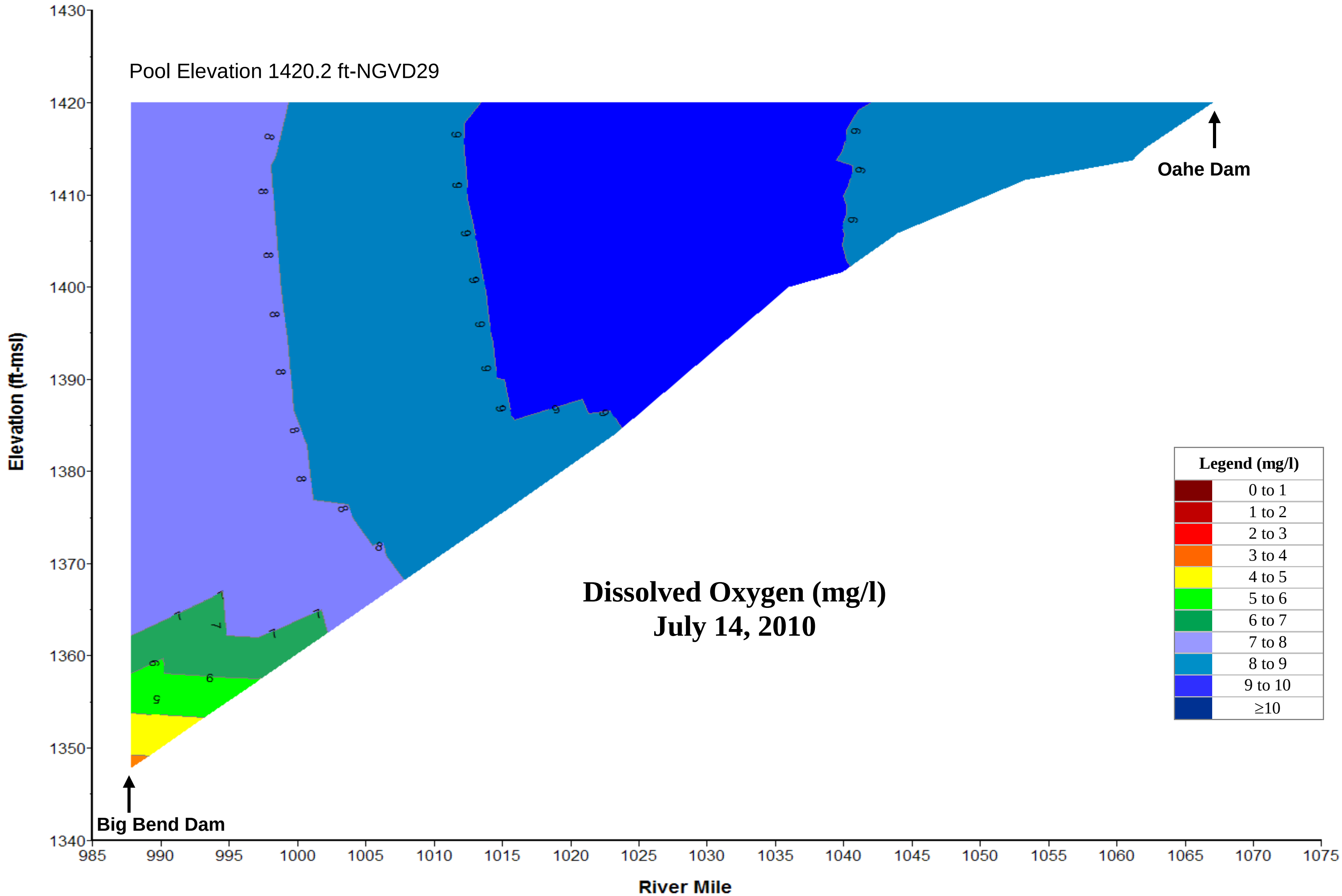

Plate 22. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW, and OAHPP1 on July 14, 2010.

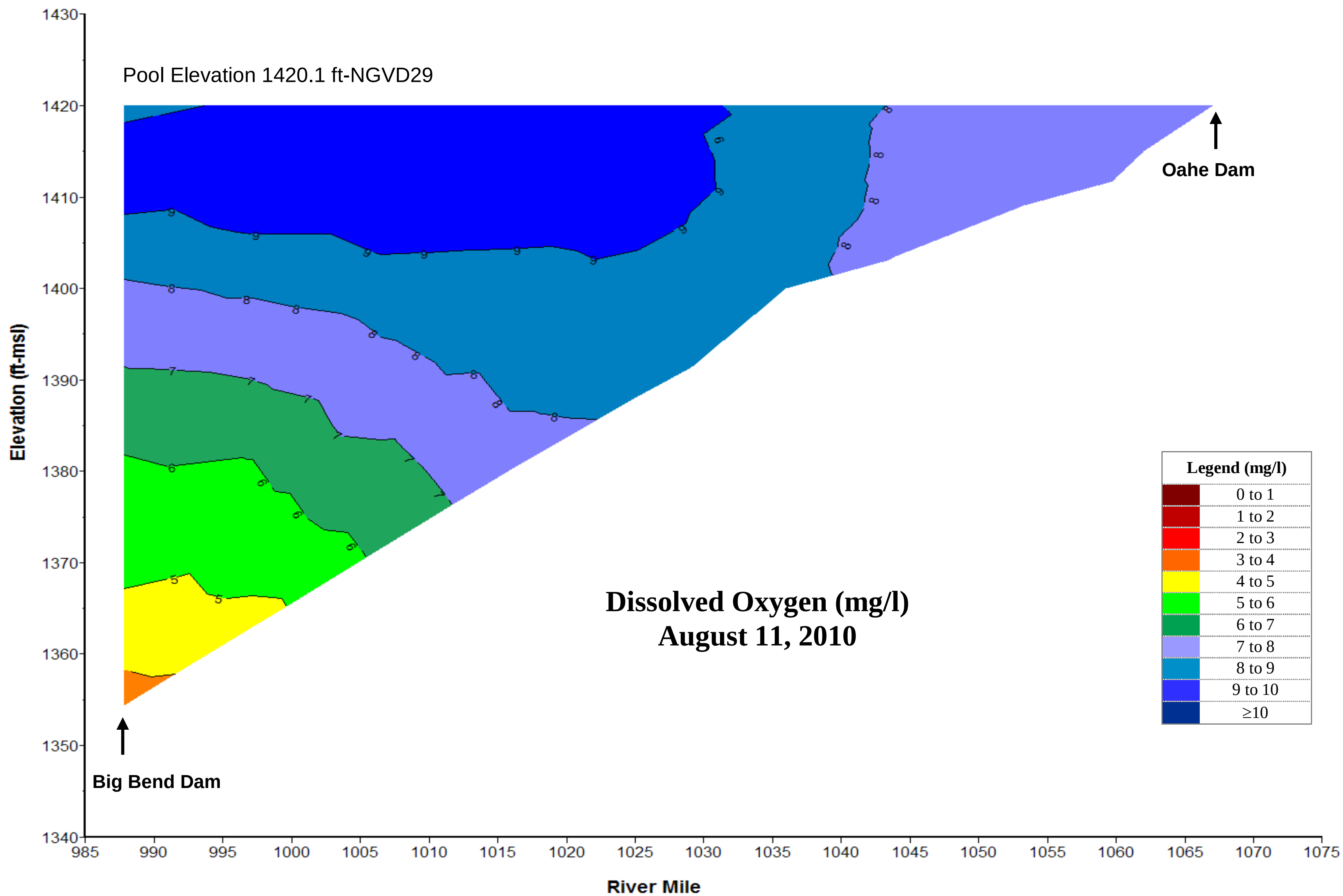

Plate 23. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW, and OAHPP1 on August 11, 2010.

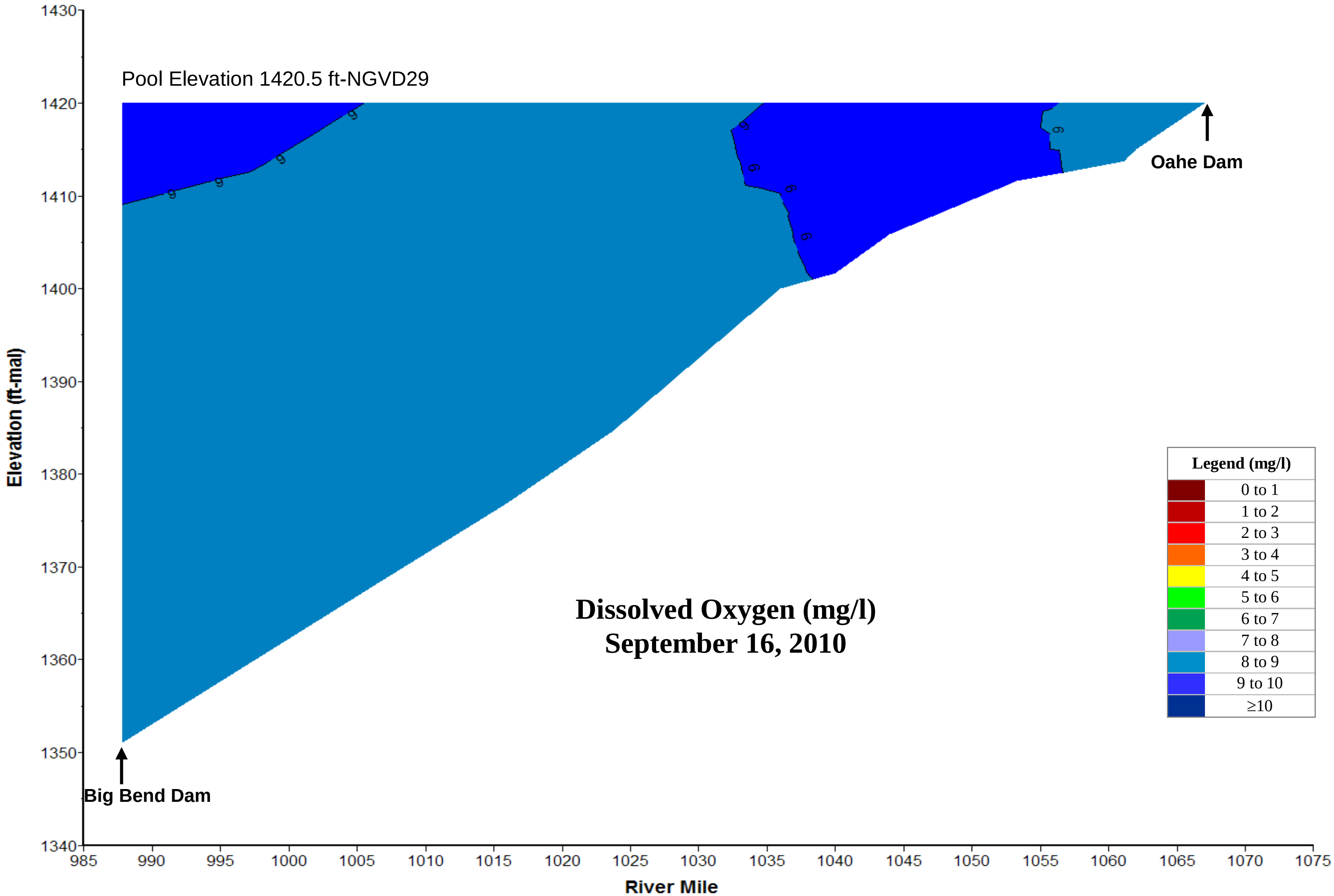

Plate 24. Longitudinal dissolved oxygen (mg/l) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW, and OAHPP1 on September 16, 2010.

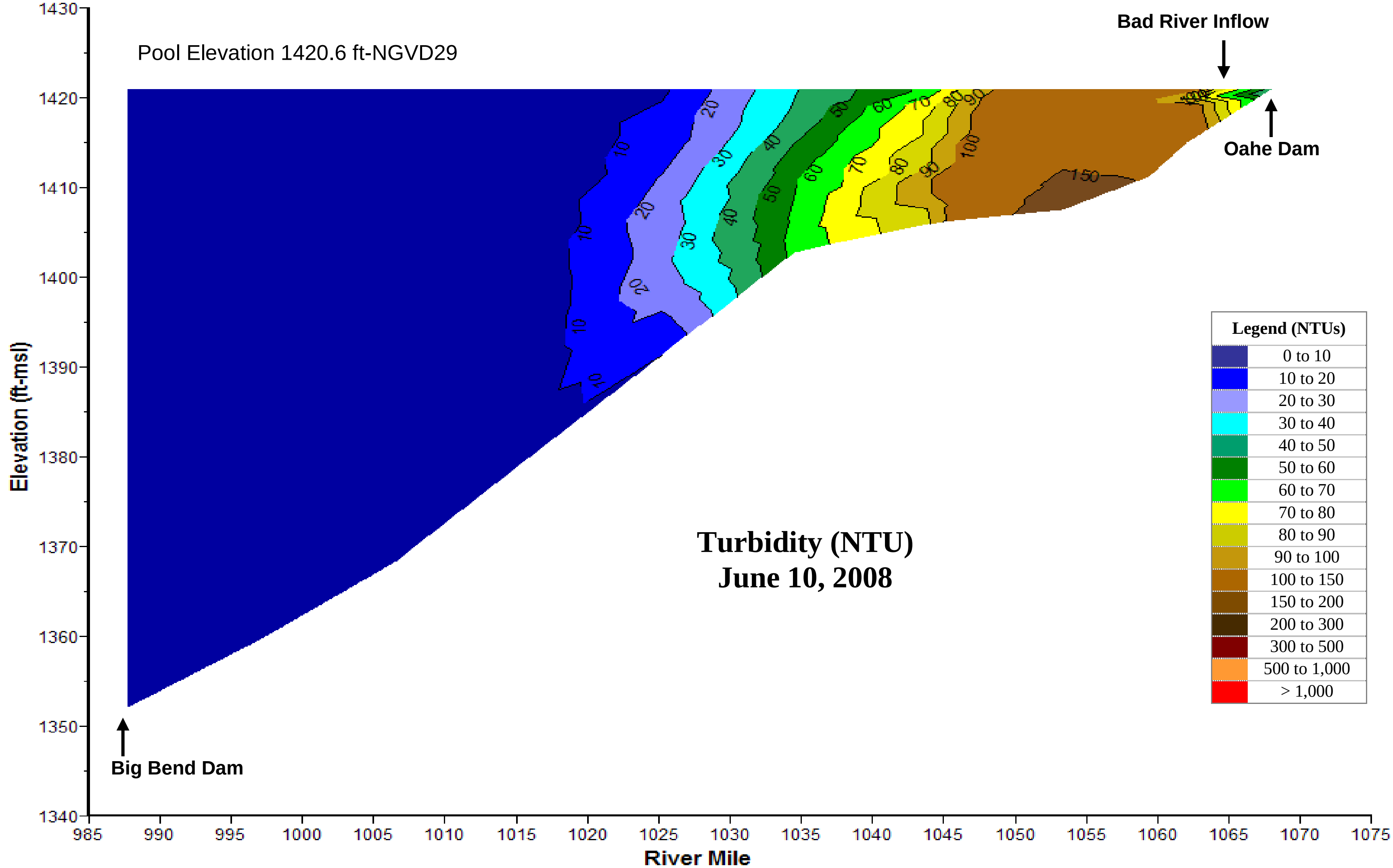

Plate 25. Longitudinal turbidity (NTU) contour plot of Lake Sharpe based on depth-profile turbidity levels measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on June 10, 2008.

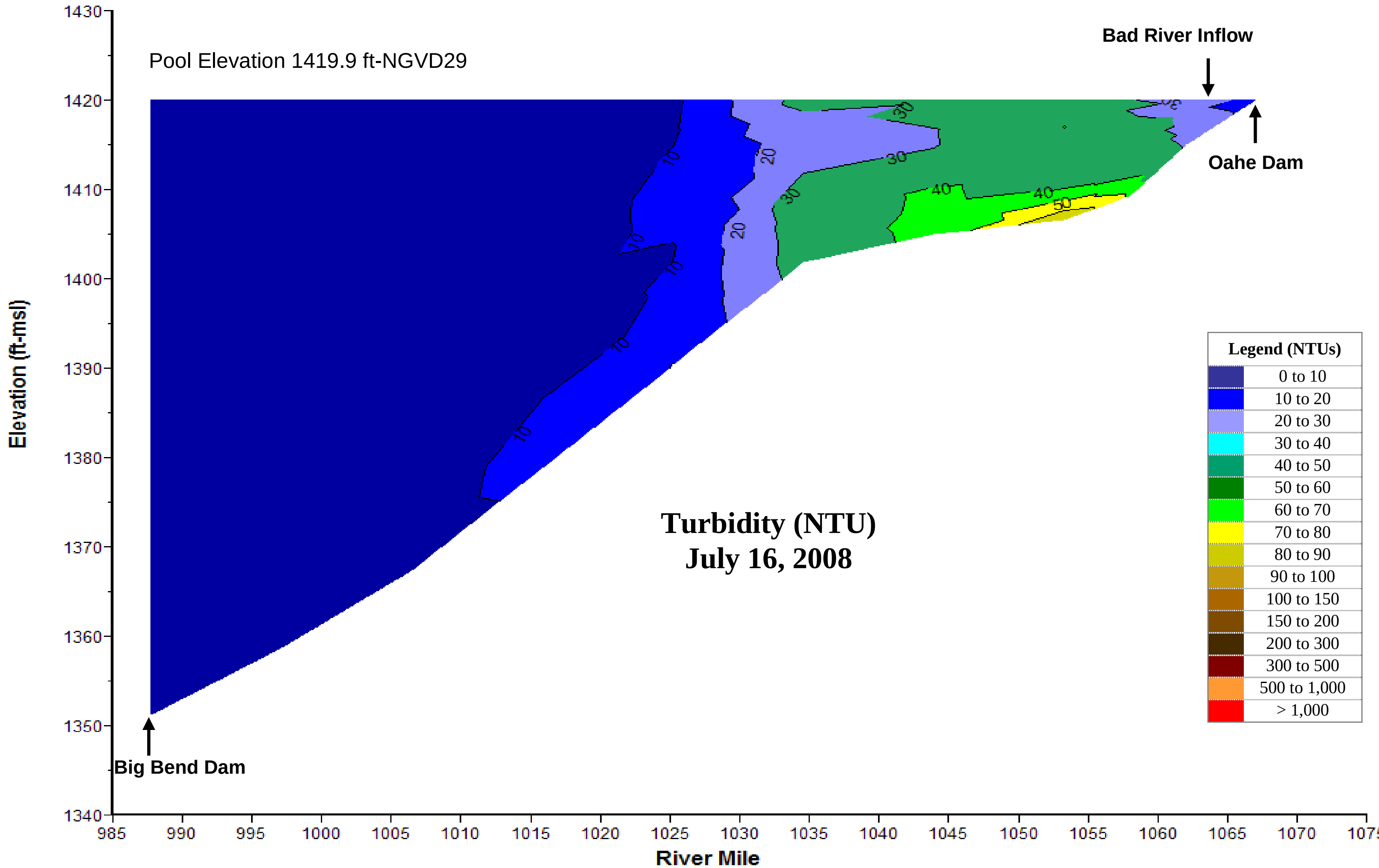

Plate 26. Longitudinal turbidity (NTU) contour plot of Lake Sharpe based on depth-profile turbidity levels measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on July 16, 2008.

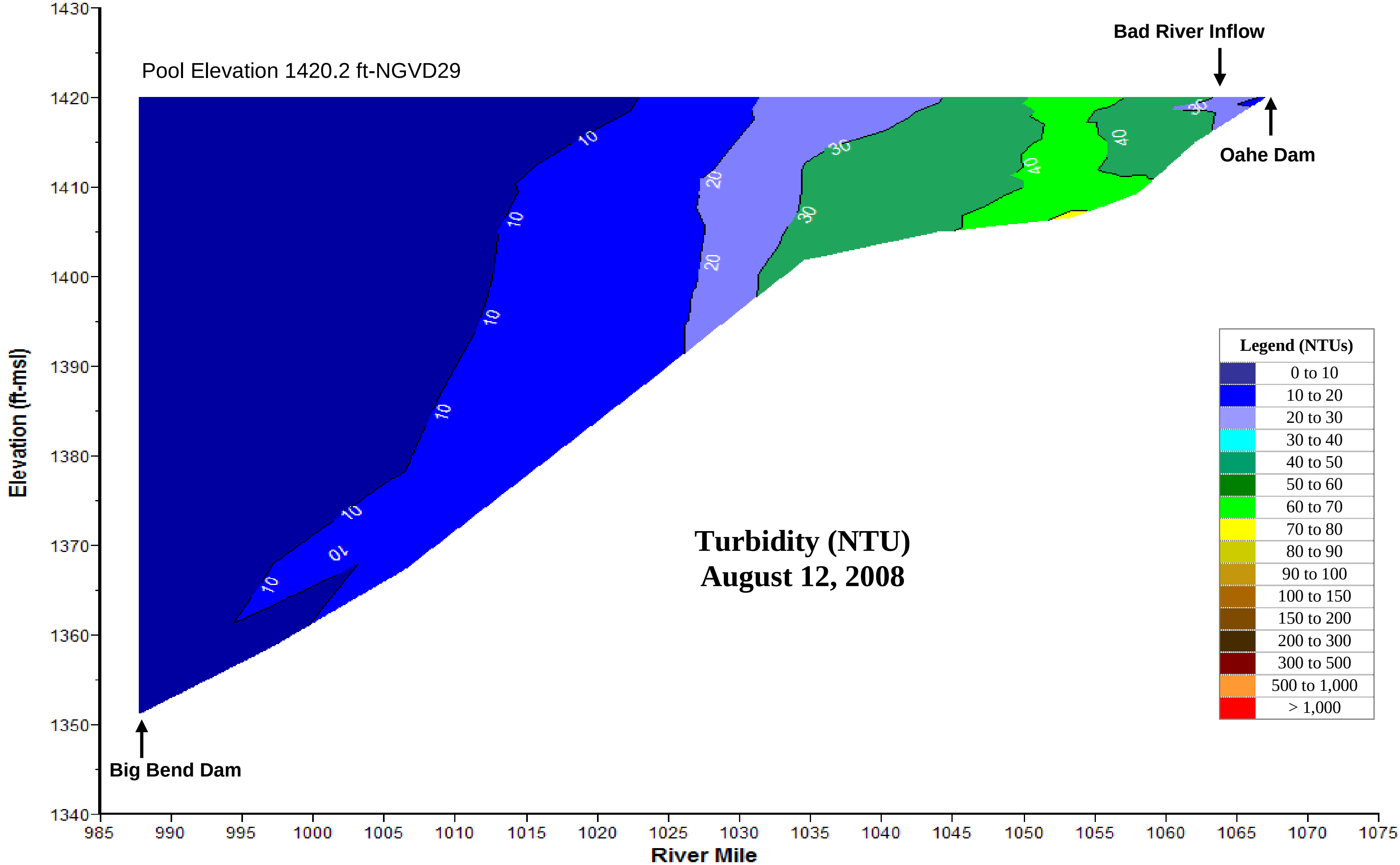

Plate 27. Longitudinal turbidity (NTU) contour plot of Lake Sharpe based on depth-profile turbidity levels measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on August 12, 2008.

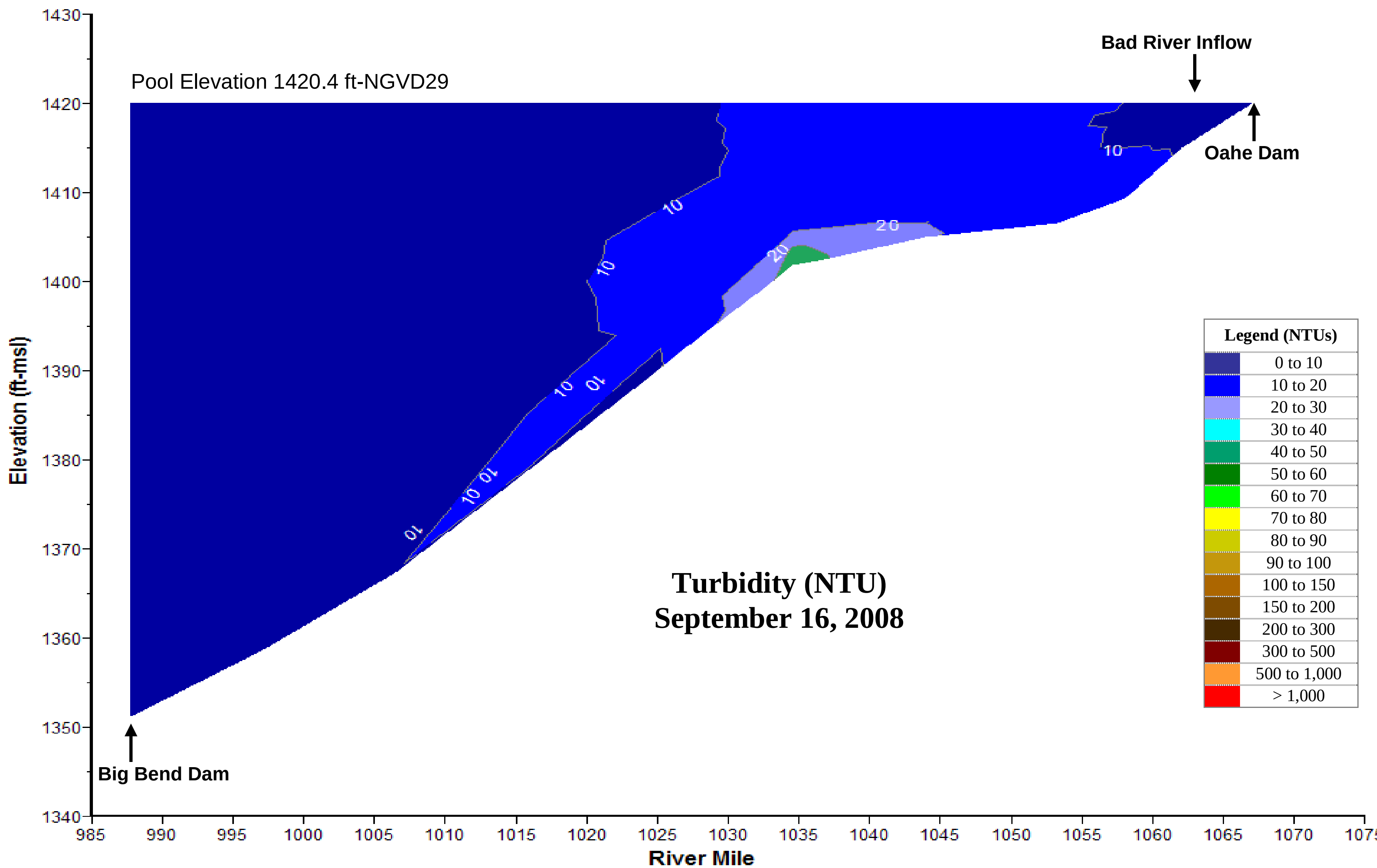

Plate 28. Longitudinal turbidity (NTU) contour plot of Lake Sharpe based on depth-profile turbidity levels measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on September 16, 2008.

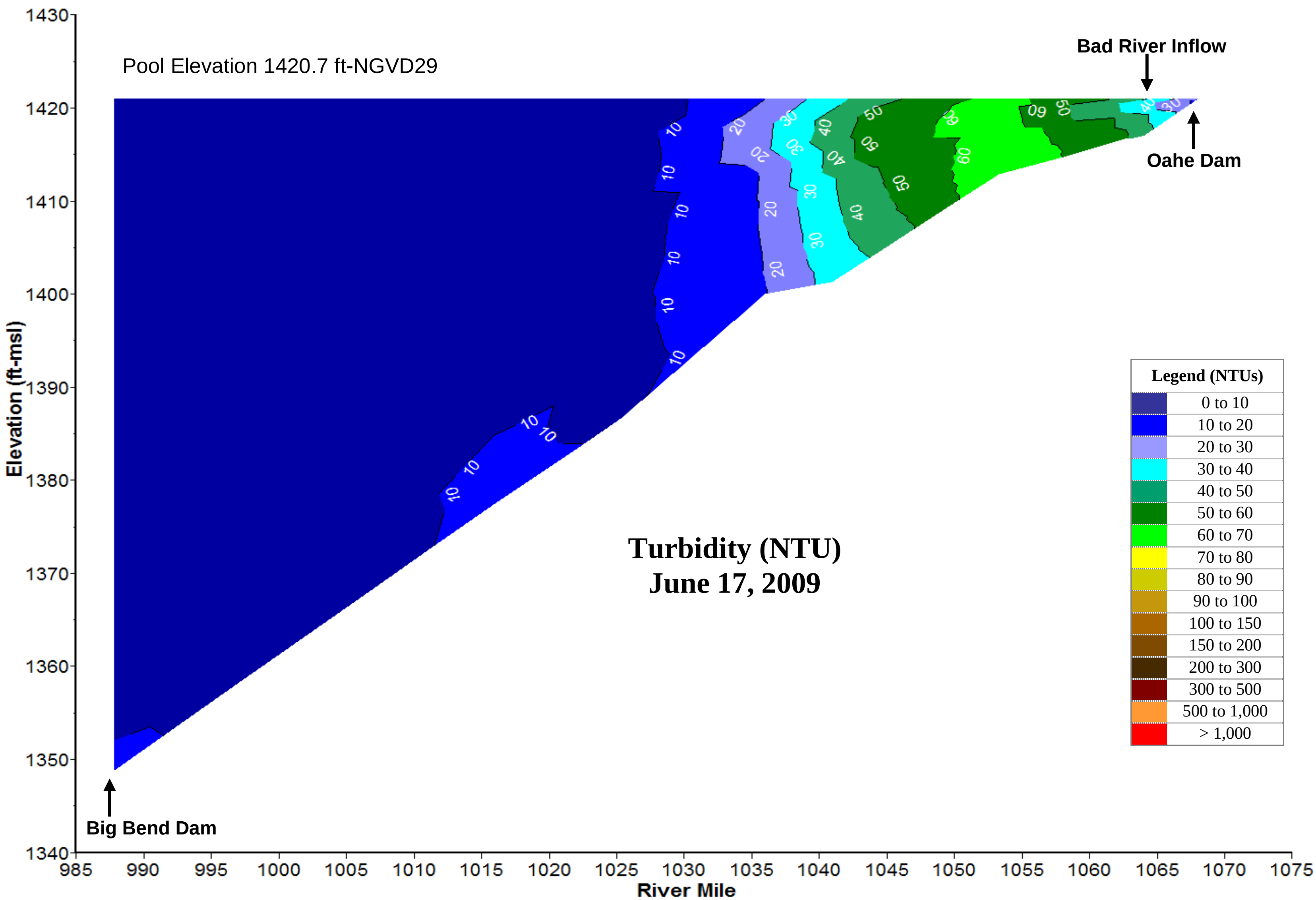

Plate 29. Longitudinal turbidity (NTU) contour plot of Lake Sharpe based on depth-profile turbidity levels measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on June 17, 2009.

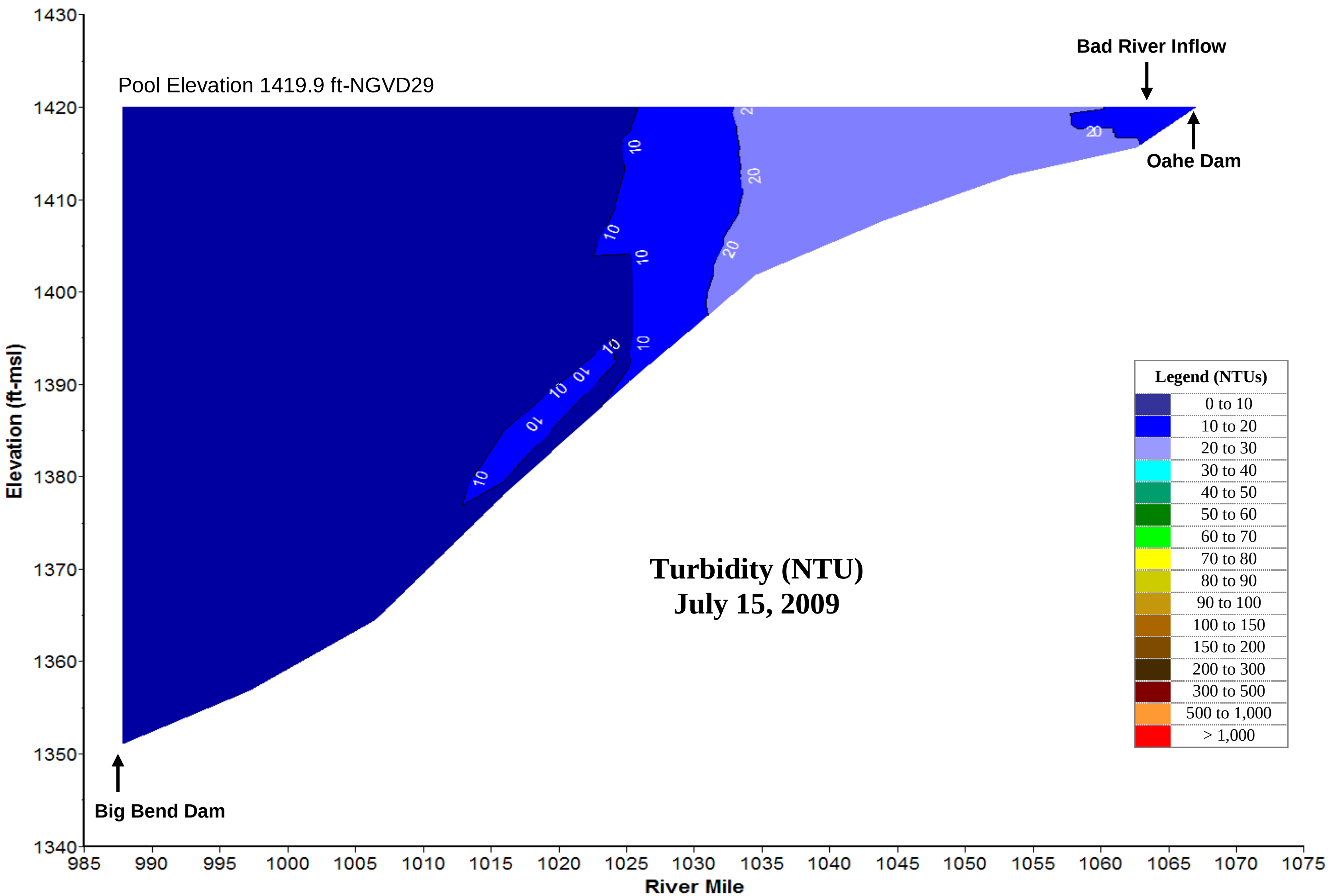

Plate 30. Longitudinal turbidity (NTU) contour plot of Lake Sharpe based on depth-profile turbidity levels measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on July 15, 2009.

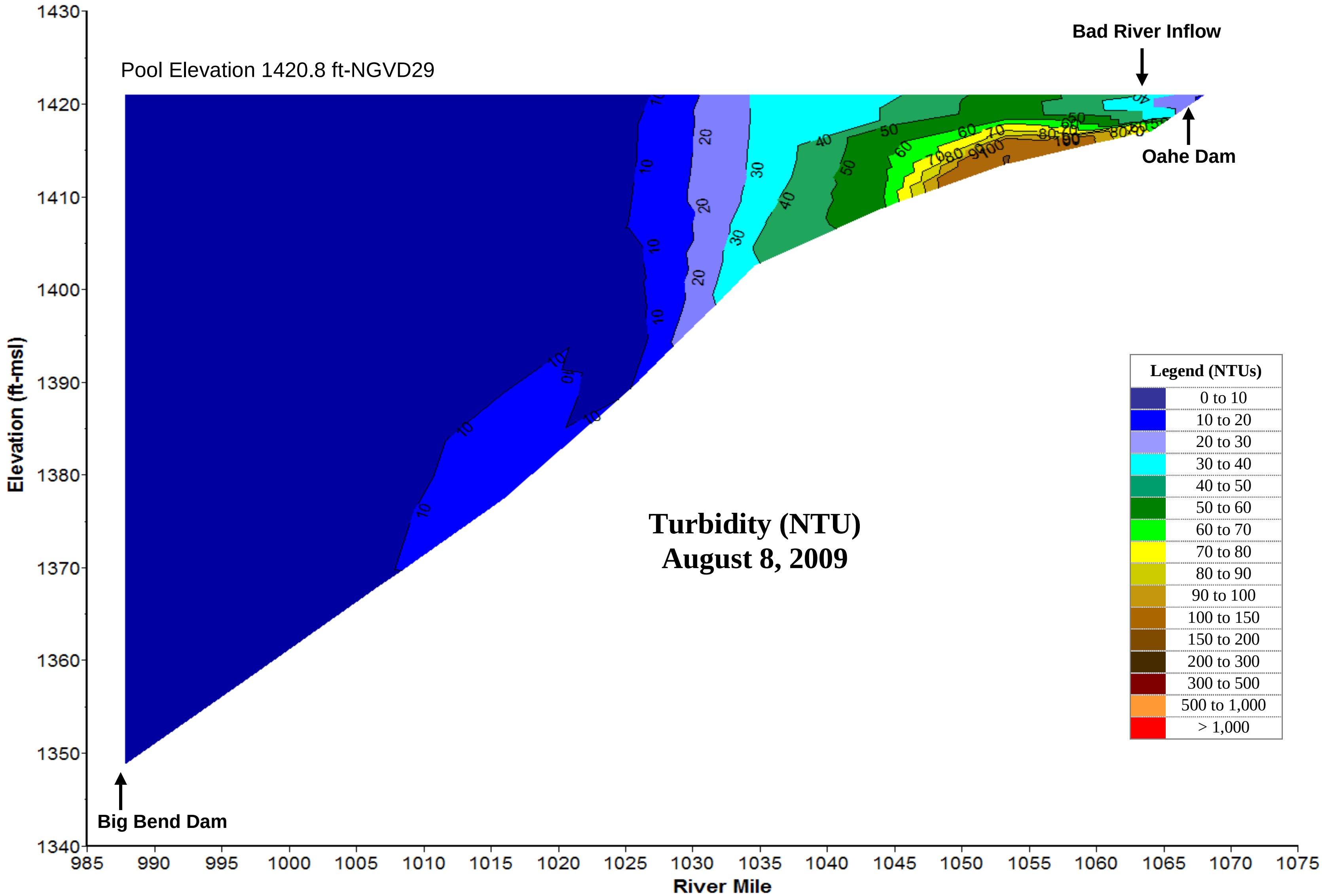

Plate 31. Longitudinal turbidity (NTU) contour plot of Lake Sharpe based on depth-profile turbidity levels measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on August 8, 2009.

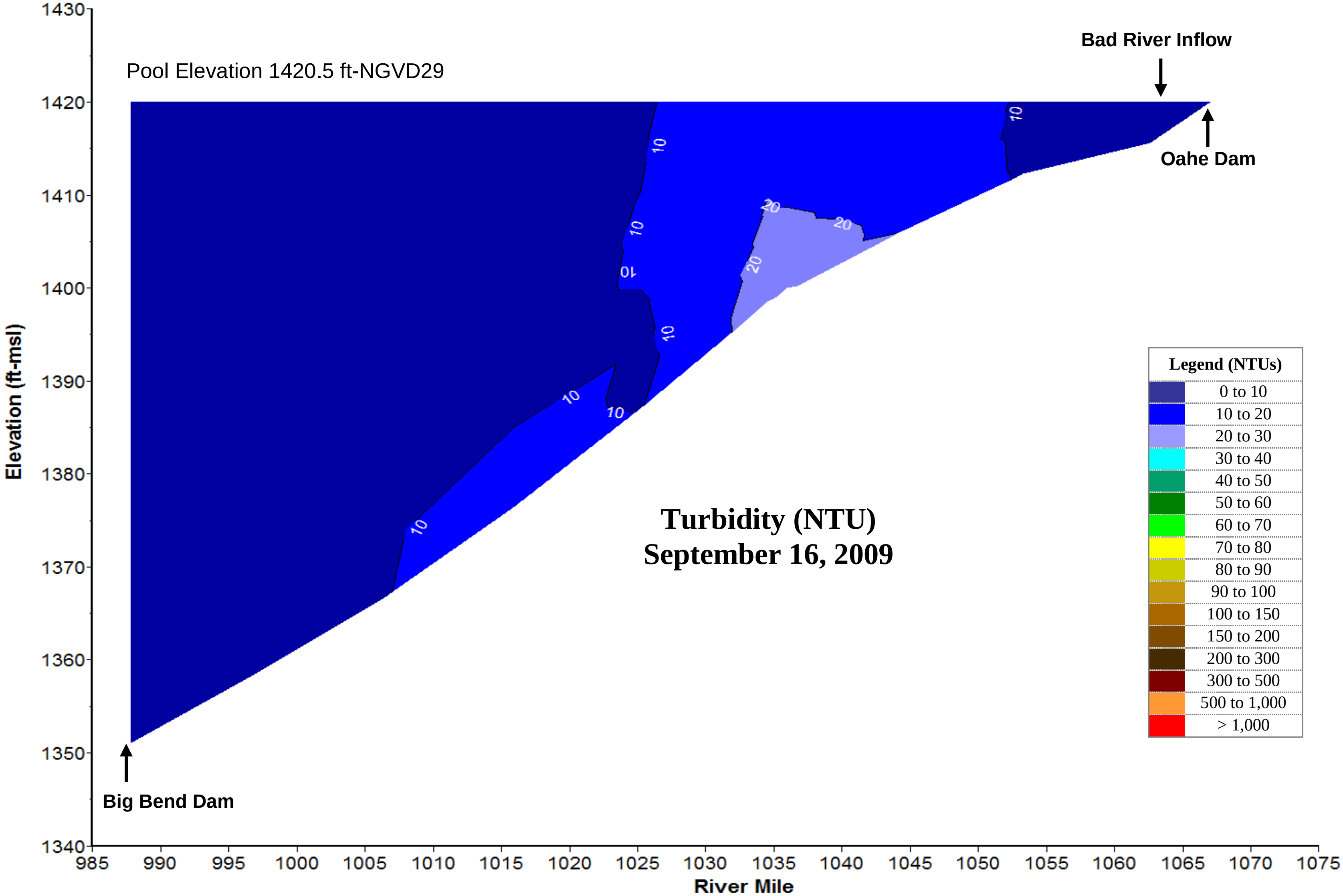

Plate 32. Longitudinal turbidity (NTU) contour plot of Lake Sharpe based on depth-profile turbidity levels measured at sites BBDLK0987A, BBDLK1004DW, BBDLK1020DW, BBDLK1036DW, BBDLK1055DW, and OAHPP1 on September 16, 2009.

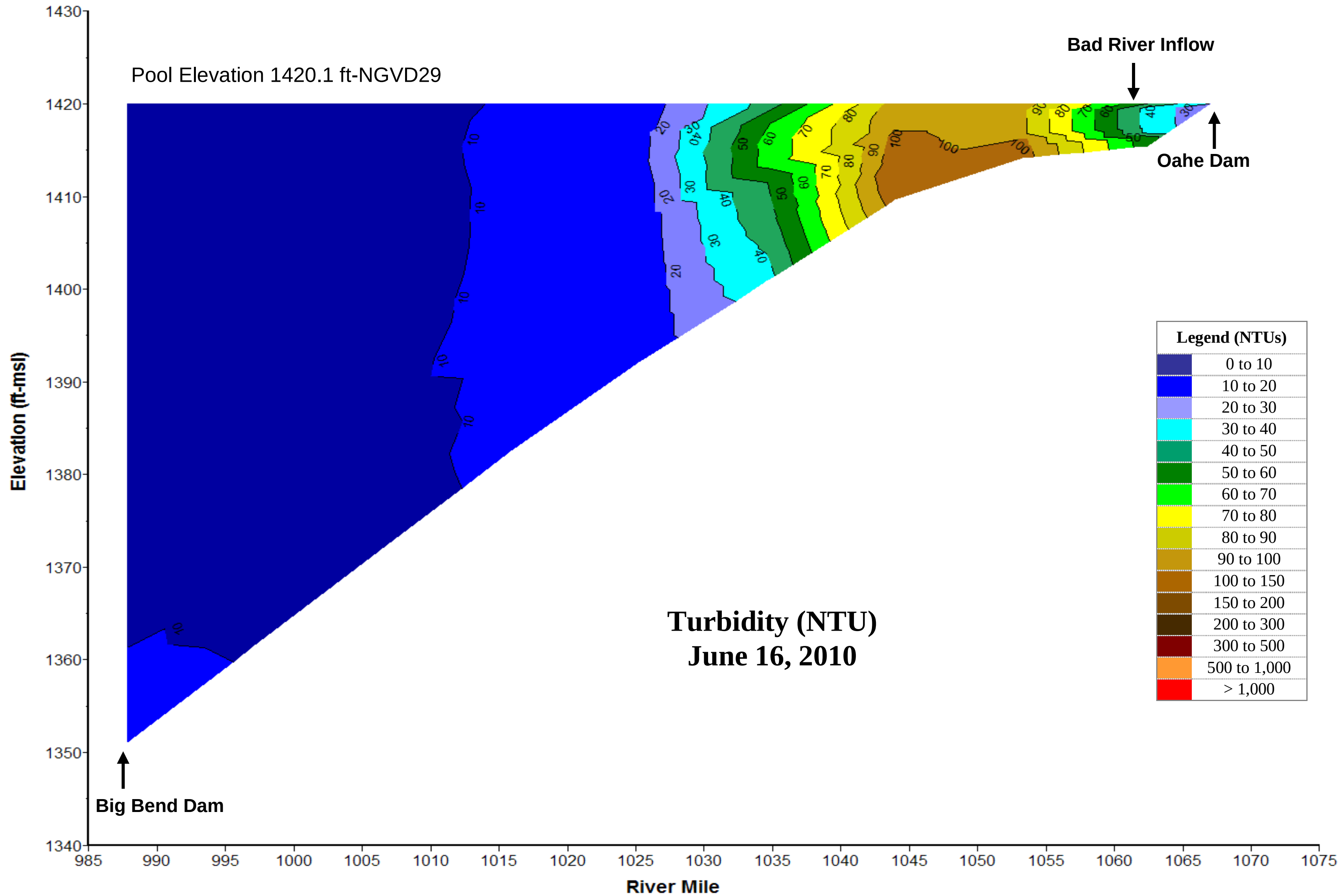

Plate 33. Longitudinal turbidity (NTU) contour plot of Lake Sharpe based on depth-profile turbidity levels measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW, and OAHPP1 on June 16, 2010.

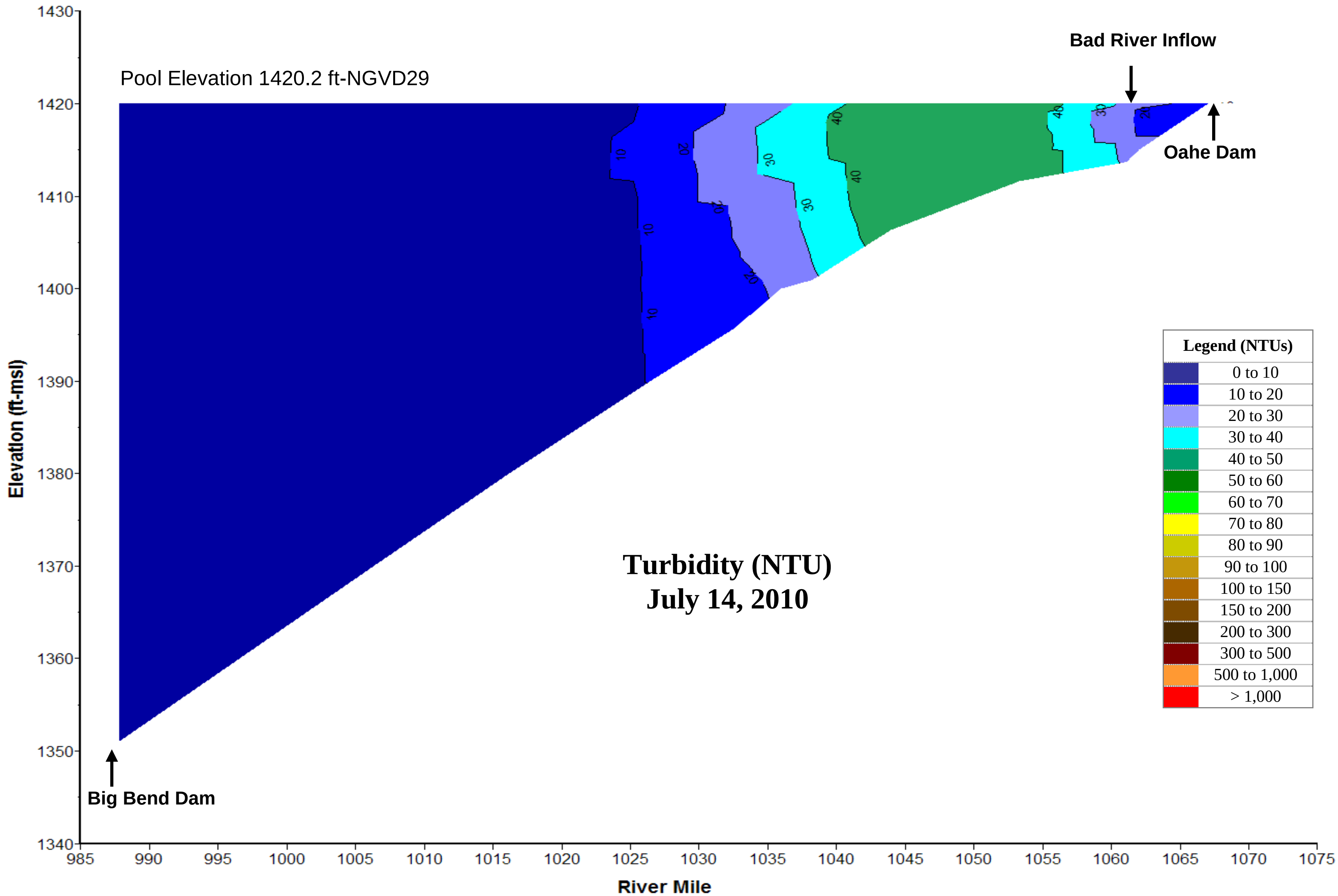

Plate 34. Longitudinal turbidity (NTU) contour plot of Lake Sharpe based on depth-profile turbidity levels measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW, and OAHPP1 on July 14, 2010.

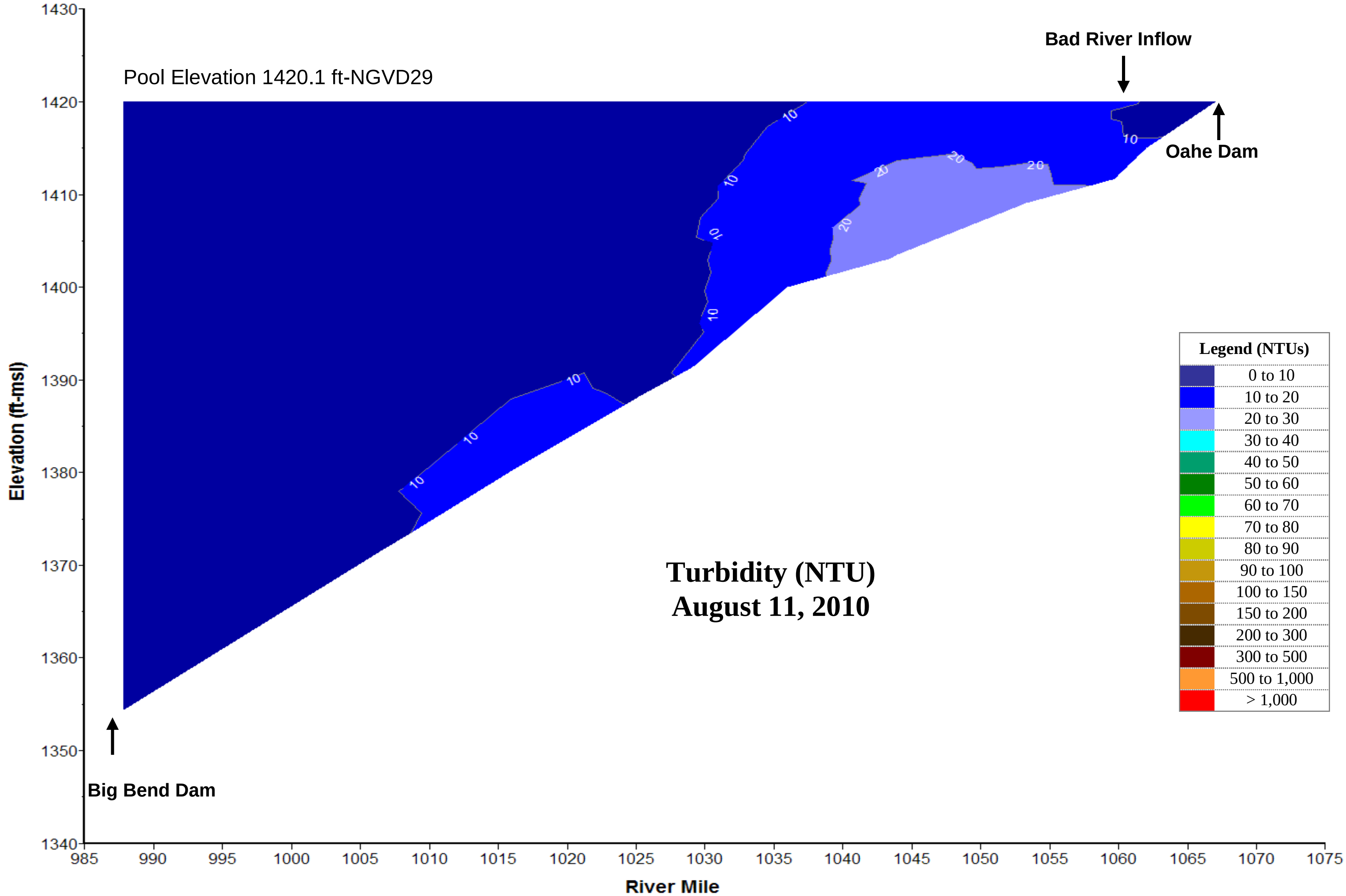

Plate 35. Longitudinal turbidity (NTU) contour plot of Lake Sharpe based on depth-profile turbidity levels measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW, and OAHPP1 on August 11, 2010.

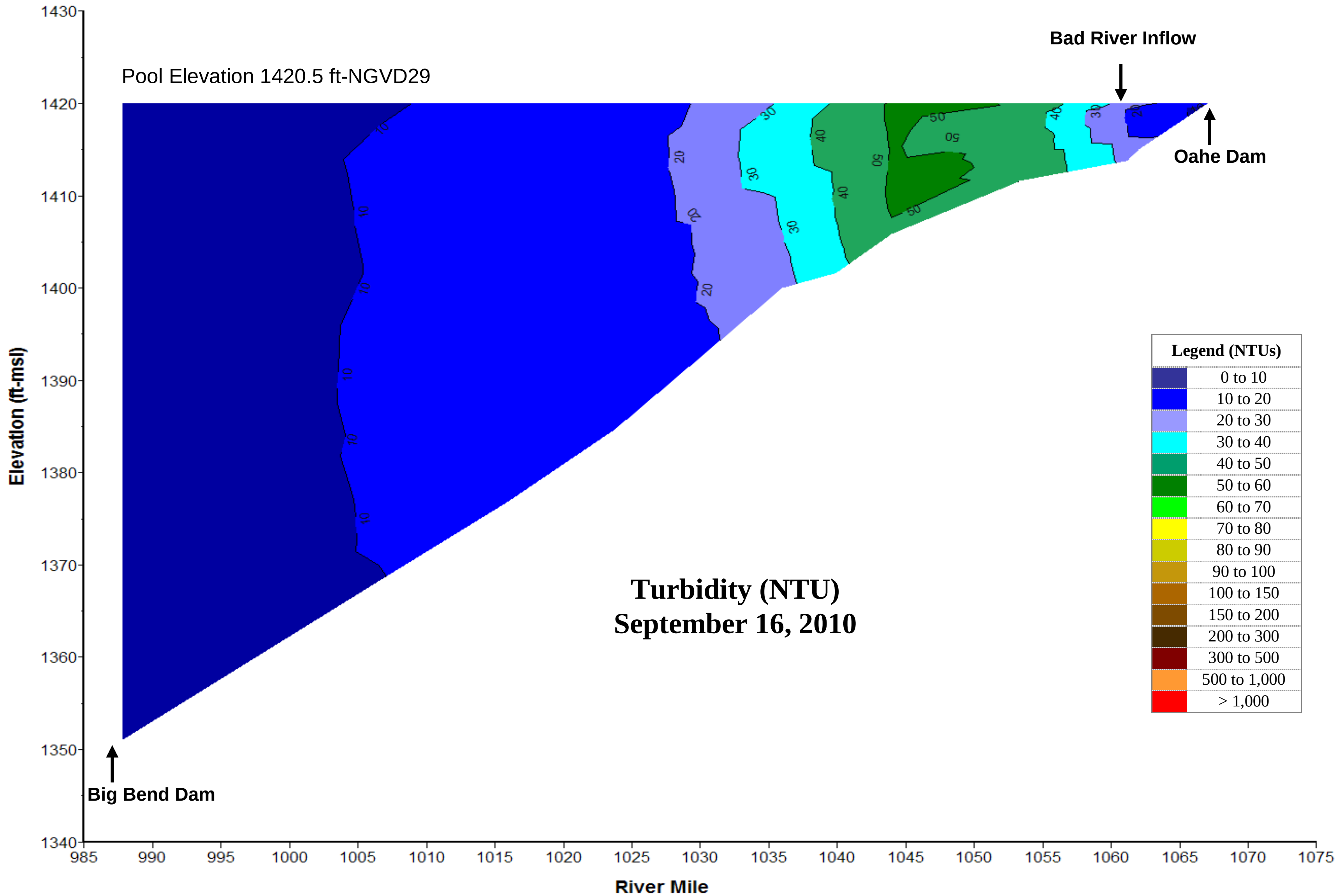

Plate 36. Longitudinal turbidity (NTU) contour plot of Lake Sharpe based on depth-profile turbidity levels measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW, and OAHPP1 on September 16, 2010.

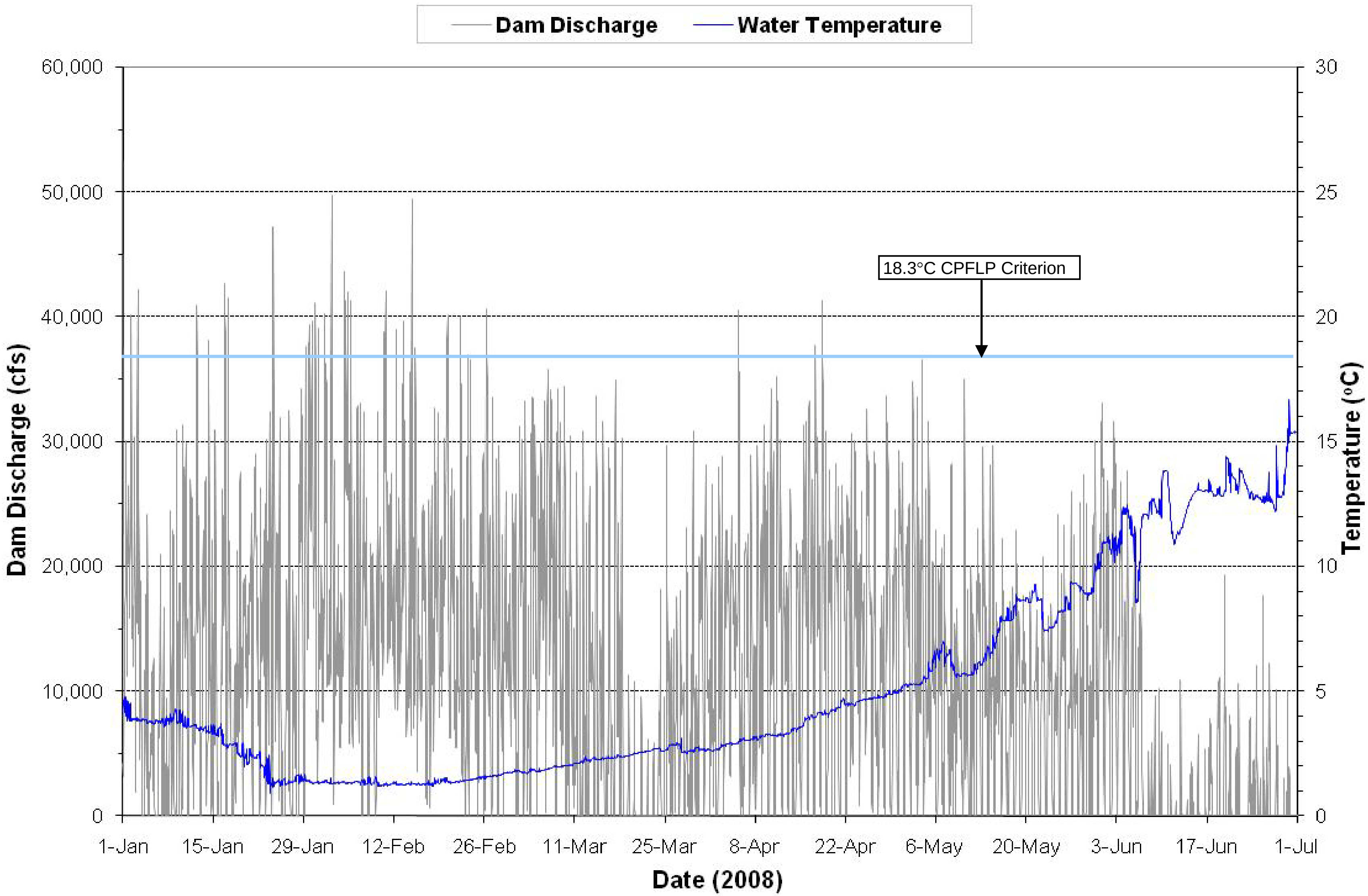

Plate 37. Hourly discharge and water temperature monitored at the Oahe powerplant on water discharged through the dam during the period January through June 2008.

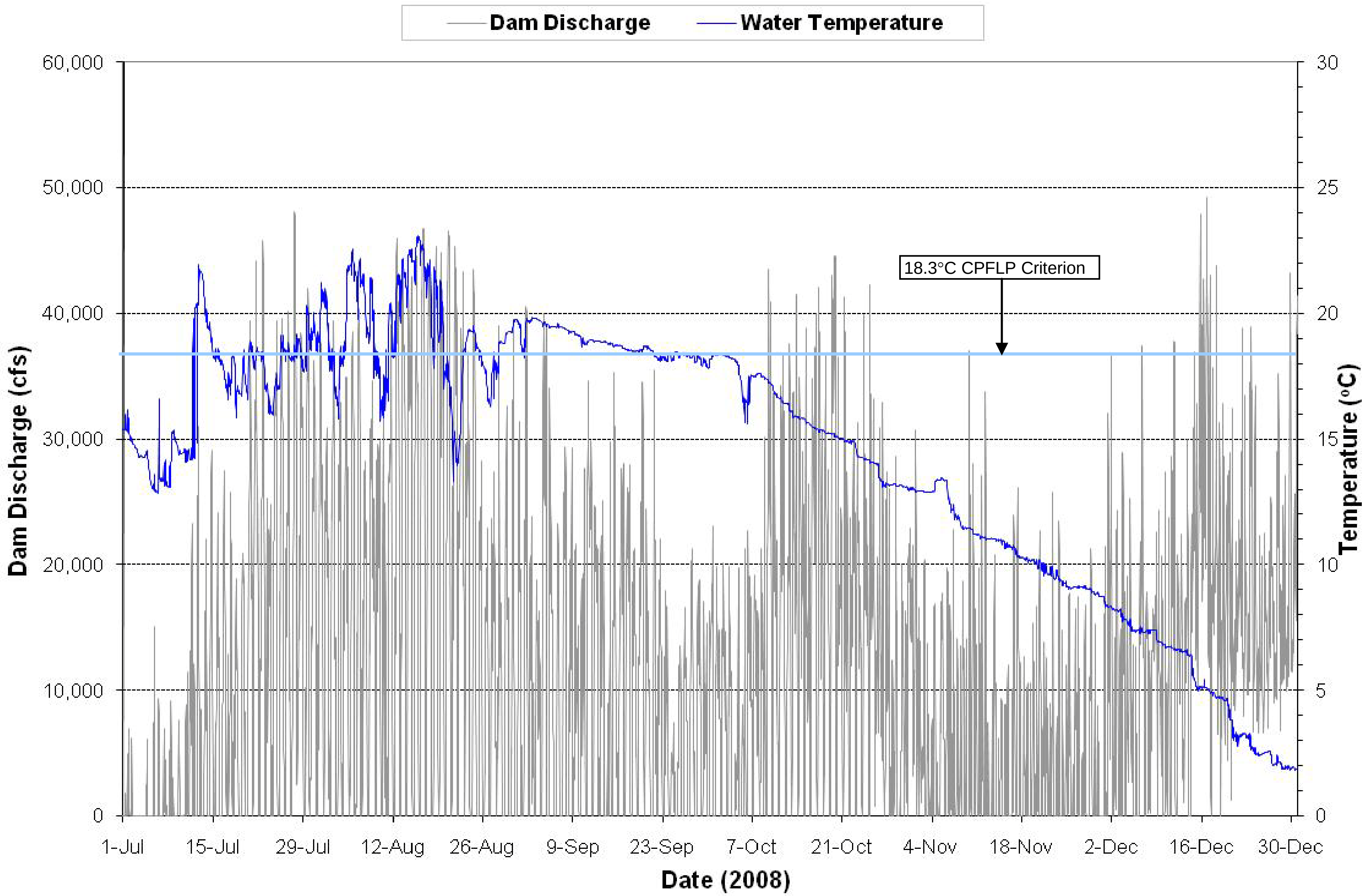

Plate 38. Hourly discharge and water temperature monitored at the Oahe powerplant on water discharged through the dam during the period July through December 2008.

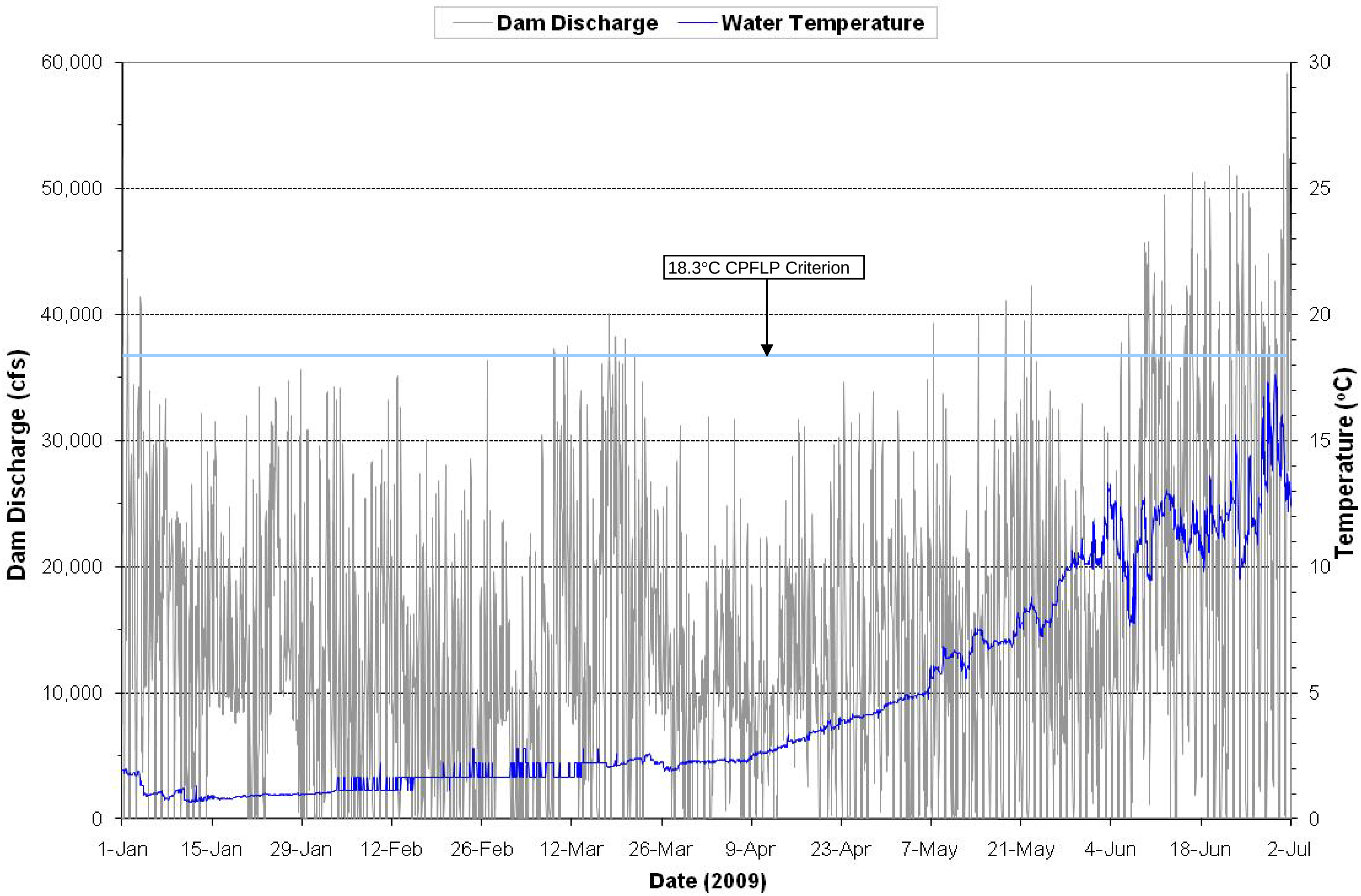

Plate 39. Hourly discharge and water temperature monitored at the Oahe powerplant on water discharged through the dam during the period January through June 2009.

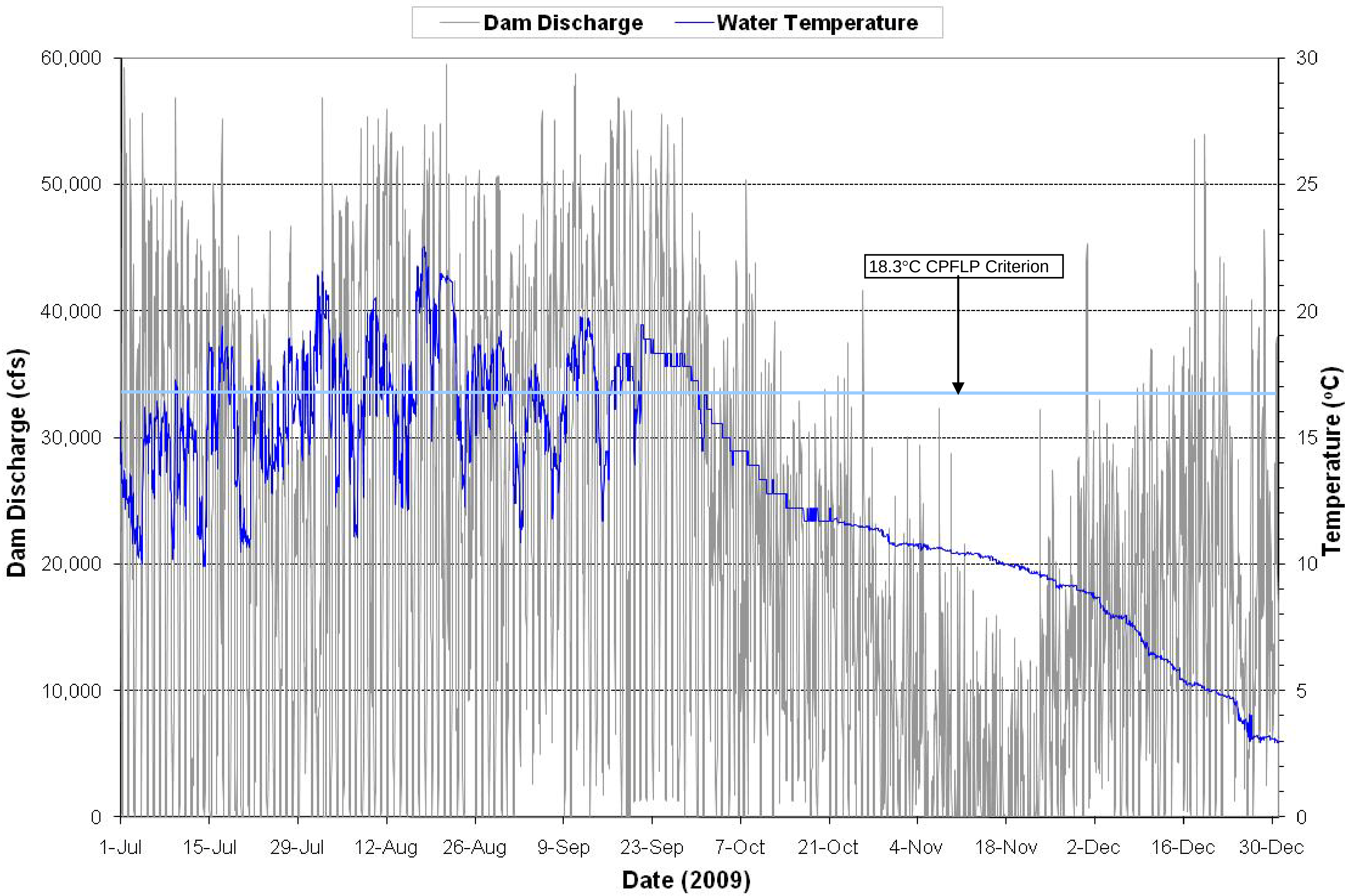

Plate 40. Hourly discharge and water temperature monitored at the Oahe powerplant on water discharged through the dam during the period July through December 2009.

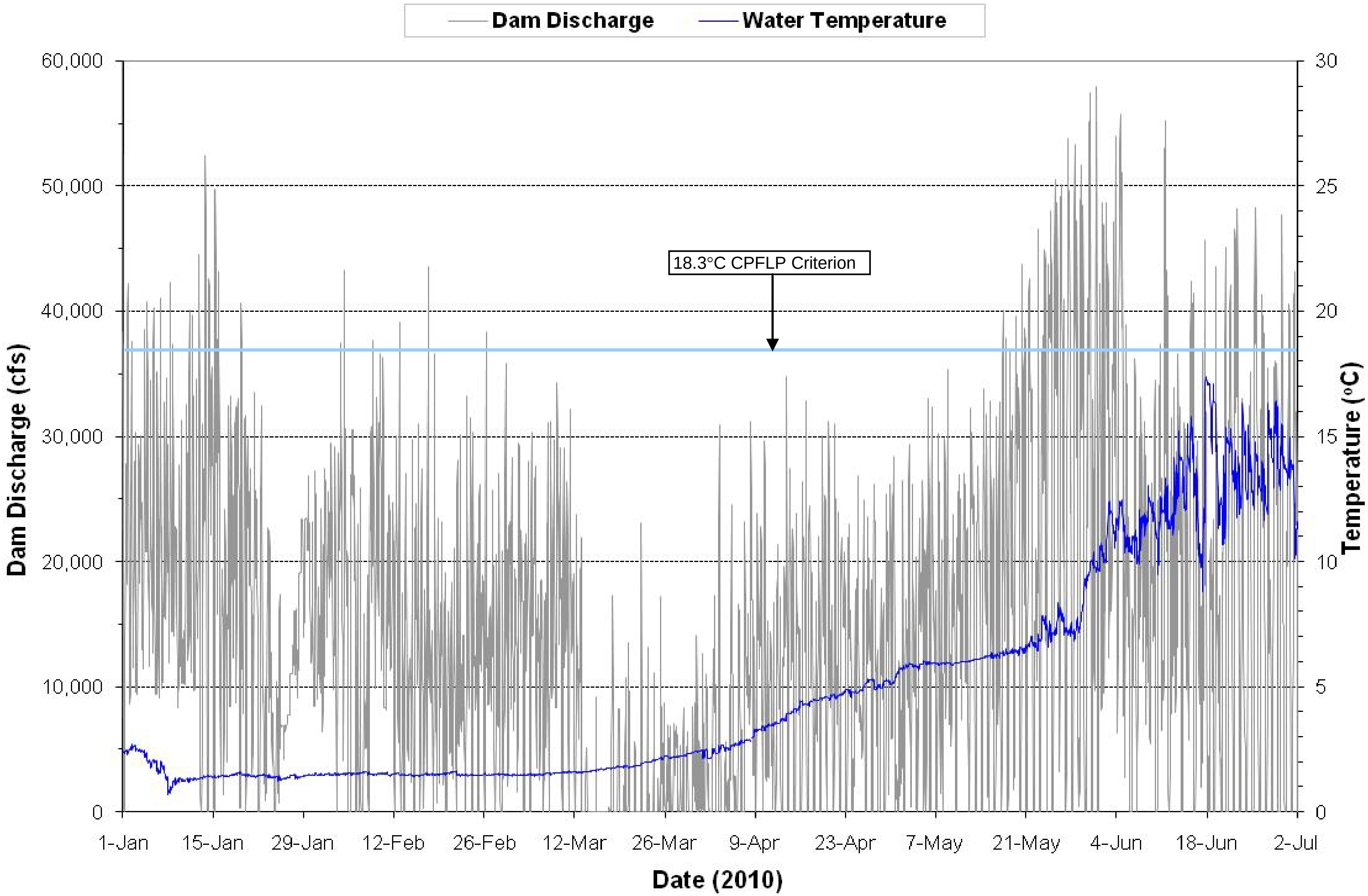

Plate 41. Hourly discharge and water temperature monitored at the Oahe powerplant on water discharged through the dam during the period January through June 2010.

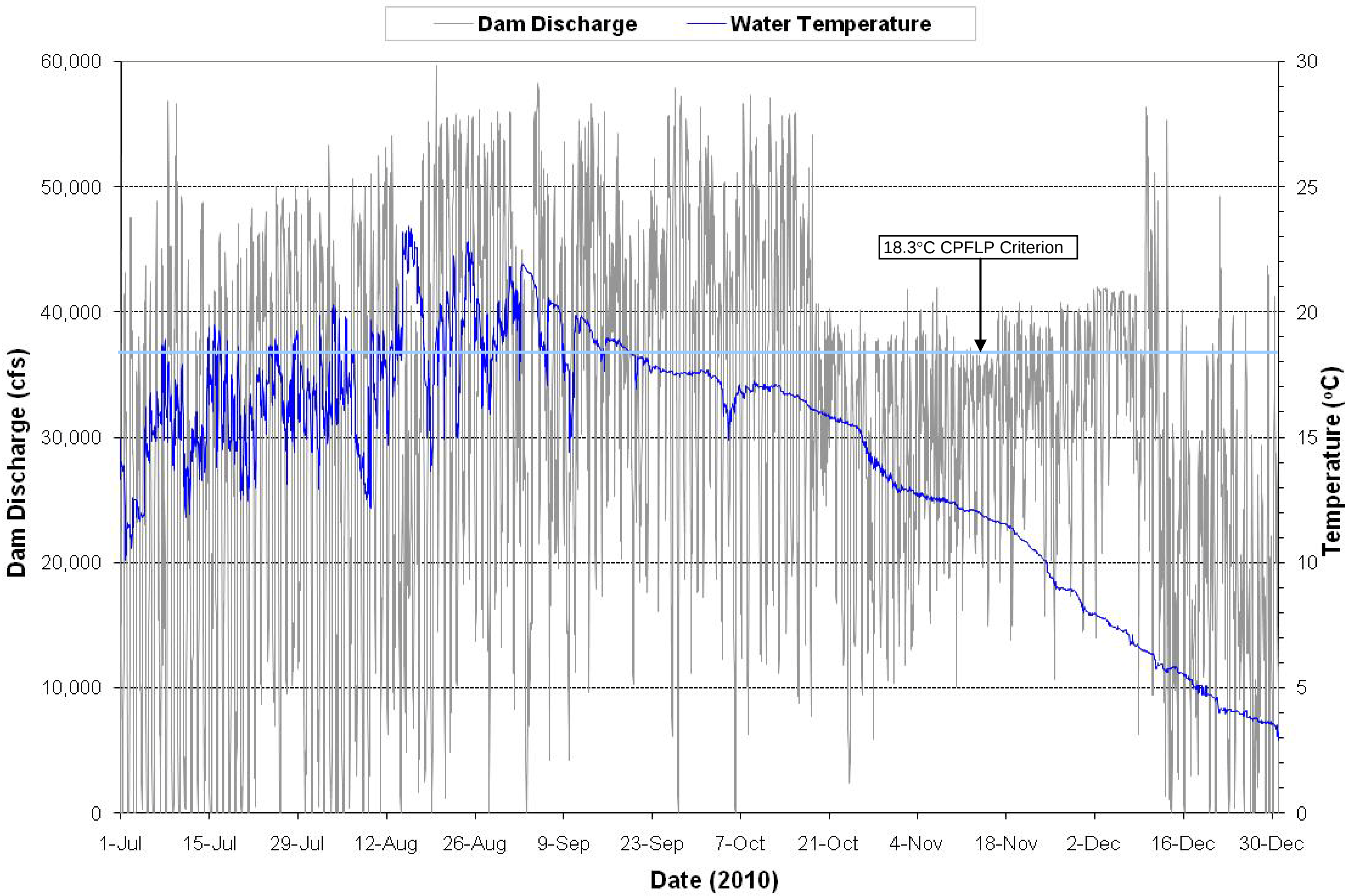

Plate 42. Hourly discharge and water temperature monitored at the Oahe powerplant on water discharged through the dam during the period July through December 2010.

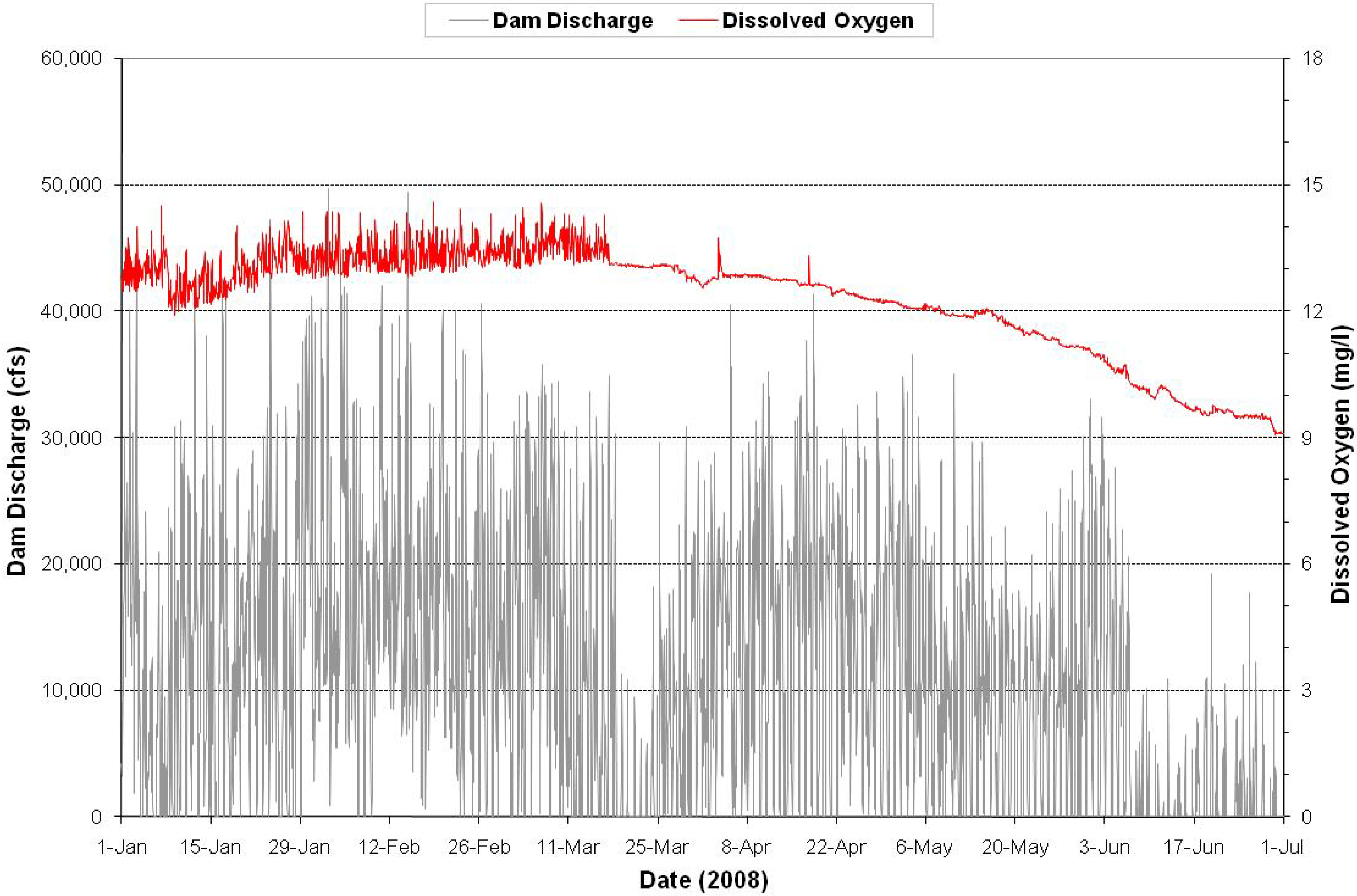

Plate 43. Hourly discharge and dissolved oxygen monitored at the Oahe powerplant on water discharged through the dam during the period January through June 2008.

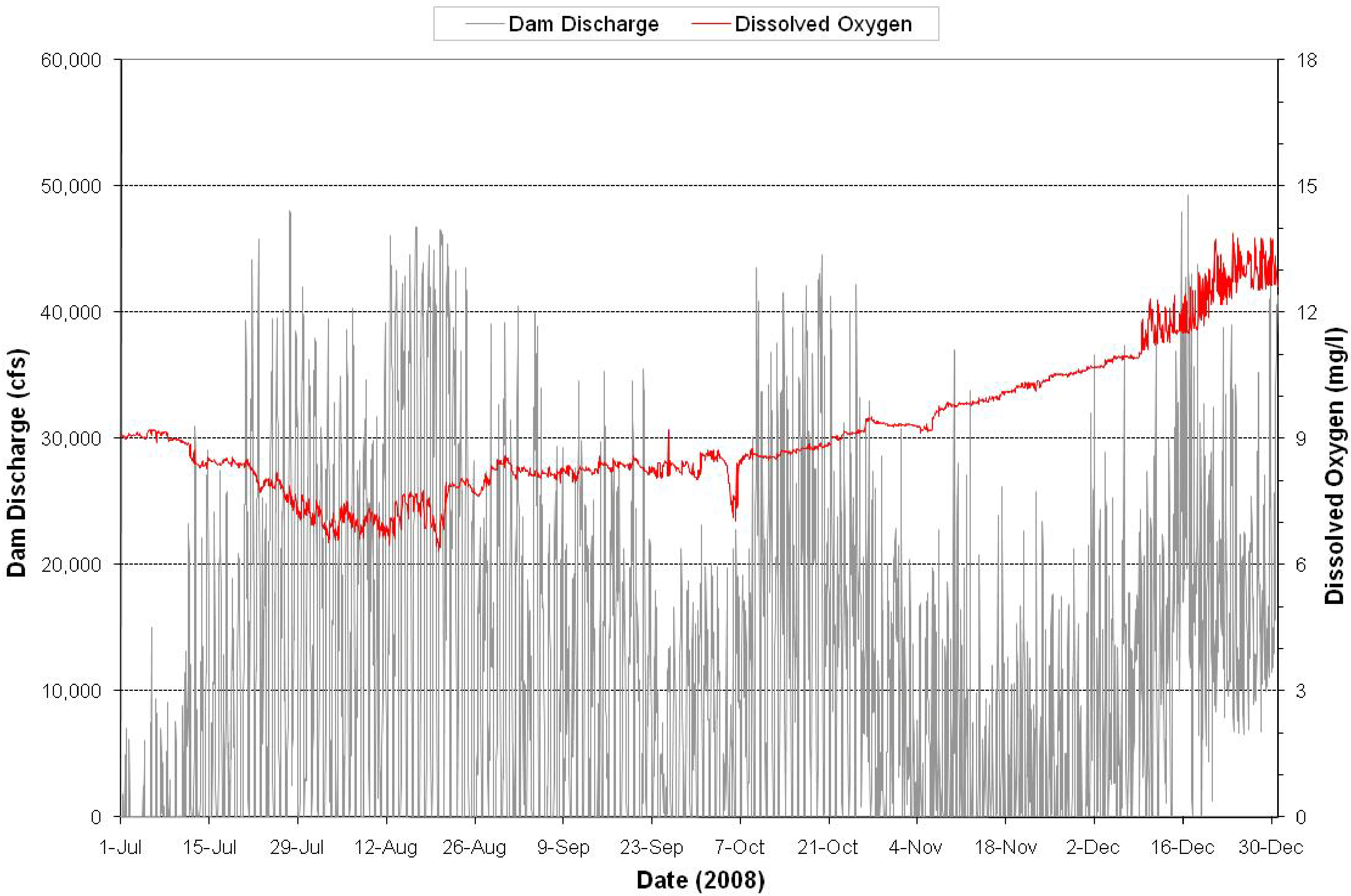

Plate 44. Hourly discharge and dissolved oxygen monitored at the Oahe Powerplant on water discharged through the dam during the period July through December 2008.

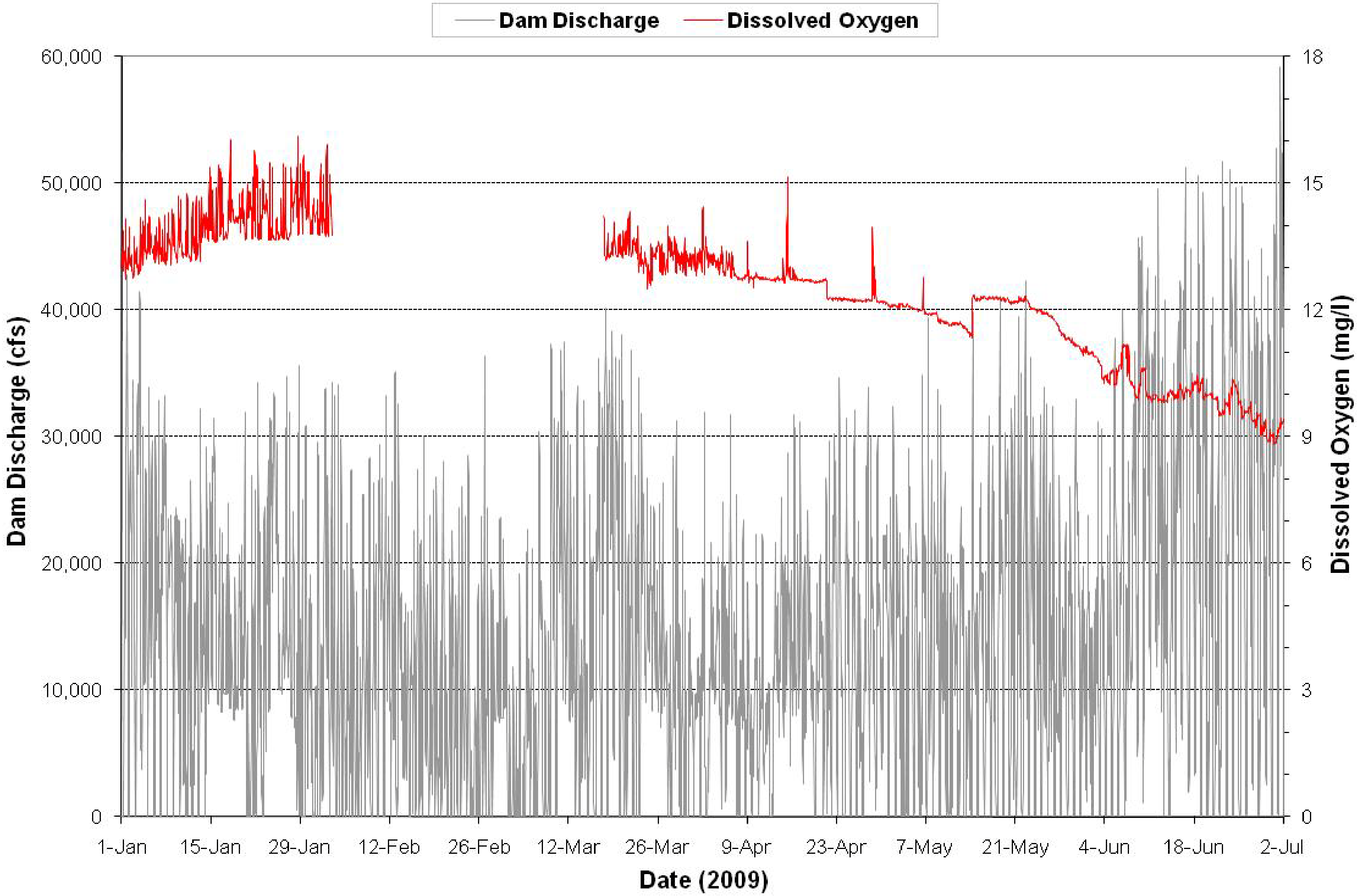

Plate 45. Hourly discharge and dissolved oxygen monitored at the Oahe Powerplant on water discharged through the dam during the period January through June 2009.

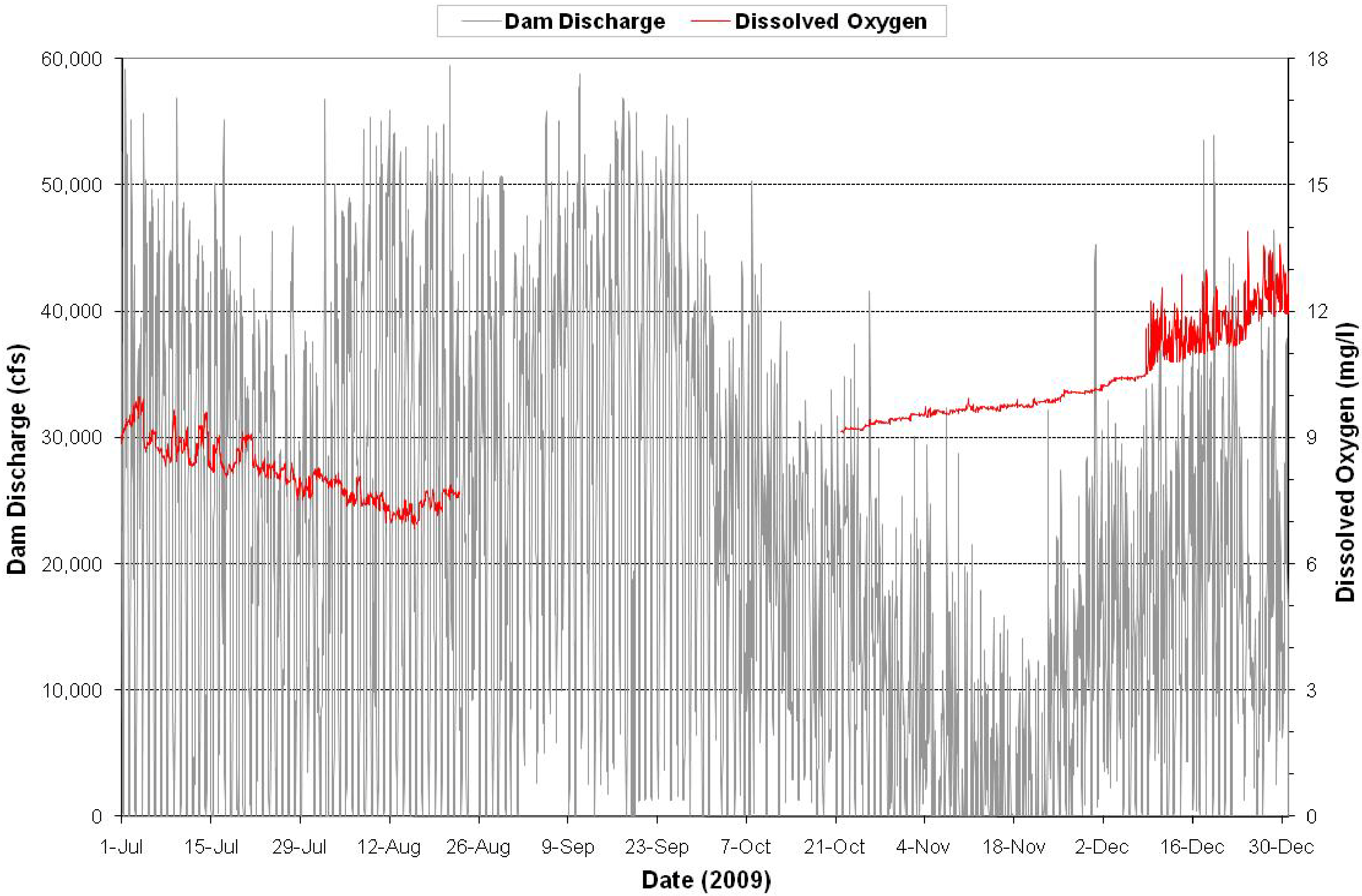

Plate 46. Hourly discharge and dissolved oxygen monitored at the Oahe Powerplant on water discharged through the dam during the period July through December 2009.

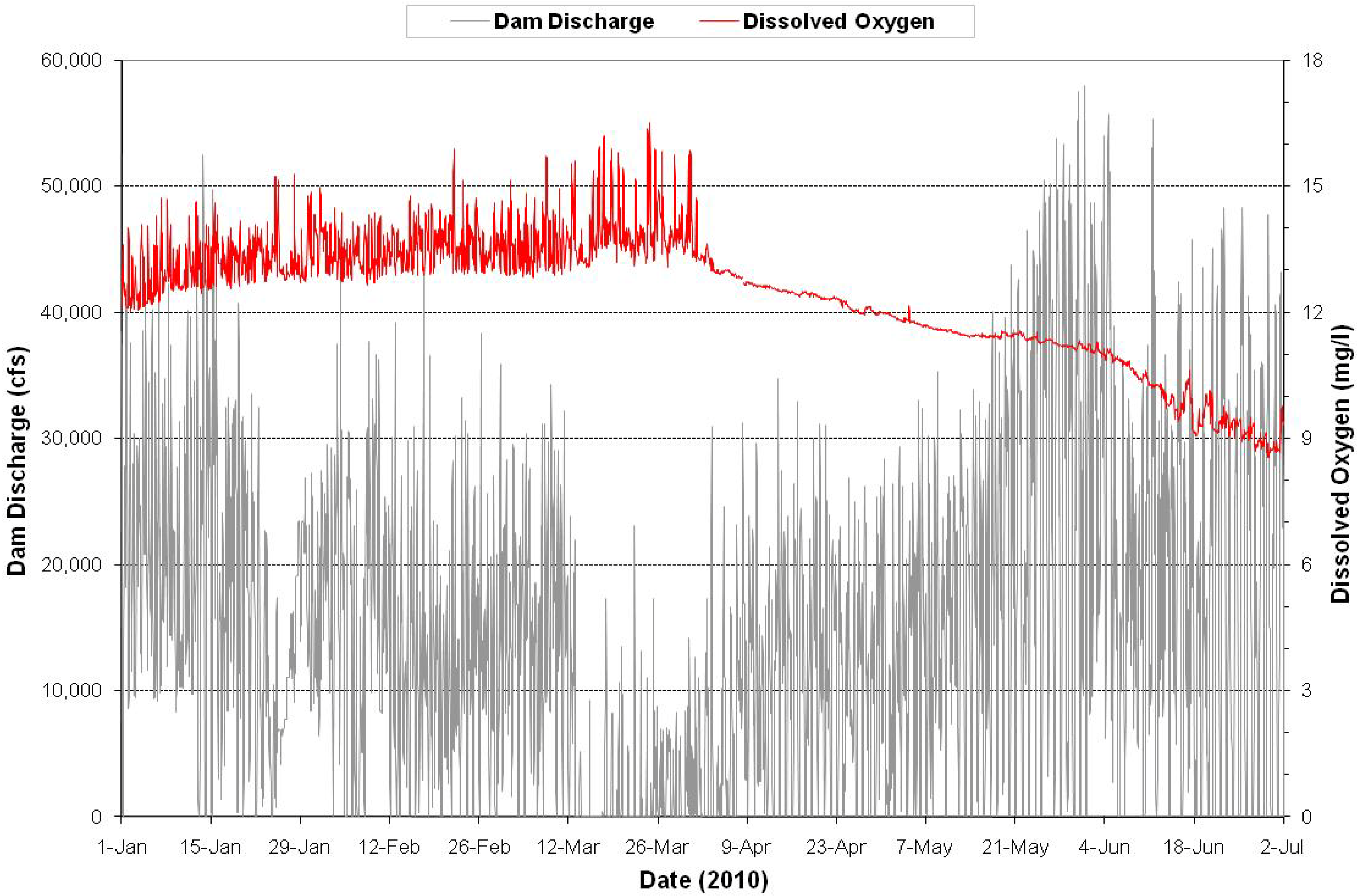

Plate 47. Hourly discharge and dissolved oxygen monitored at the Oahe Powerplant on water discharged through the dam during the period January through June 2010.

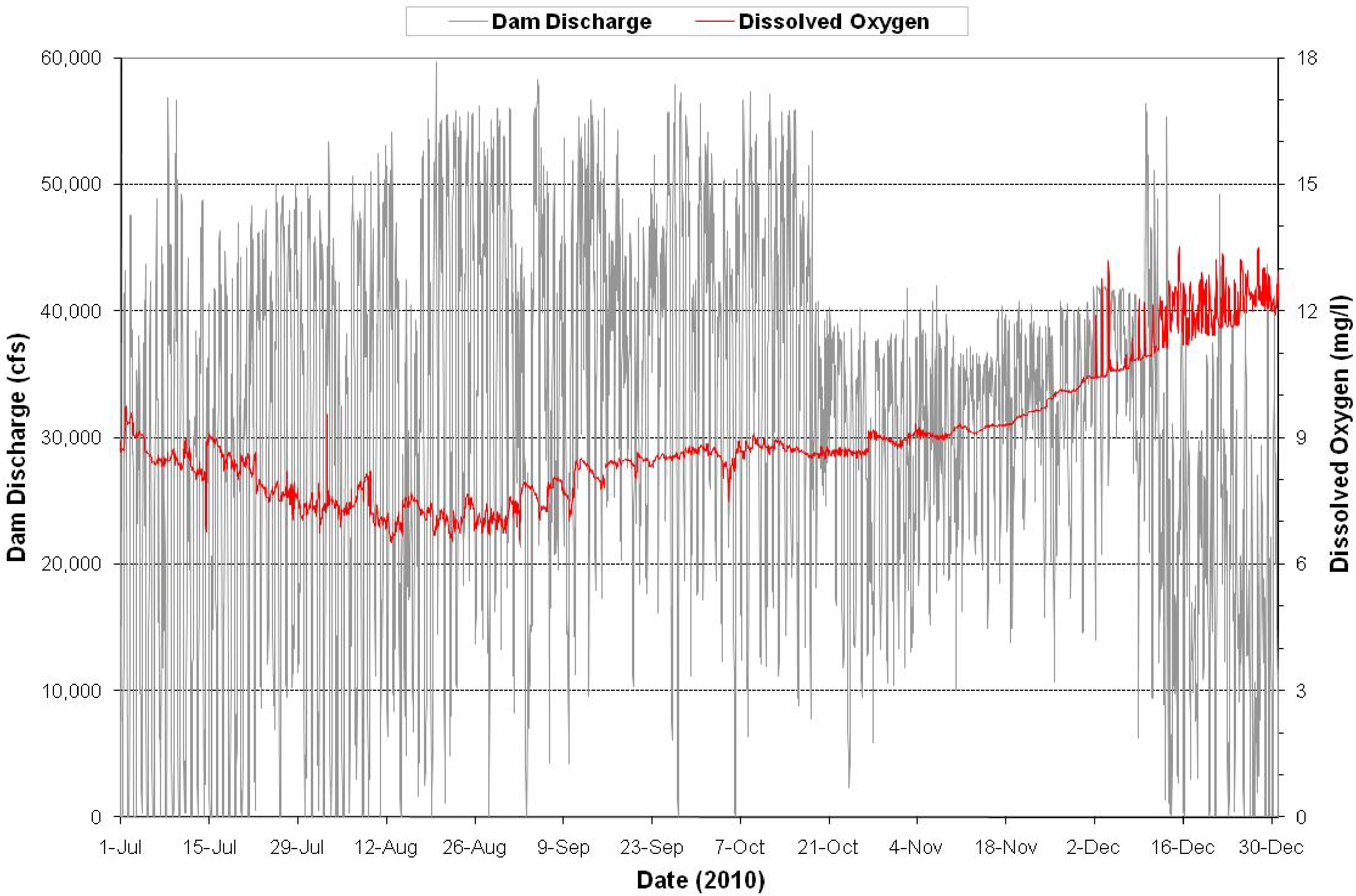

Plate 48. Hourly discharge and dissolved oxygen monitored at the Oahe Powerplant on water discharged through the dam during the period July through December 2010.

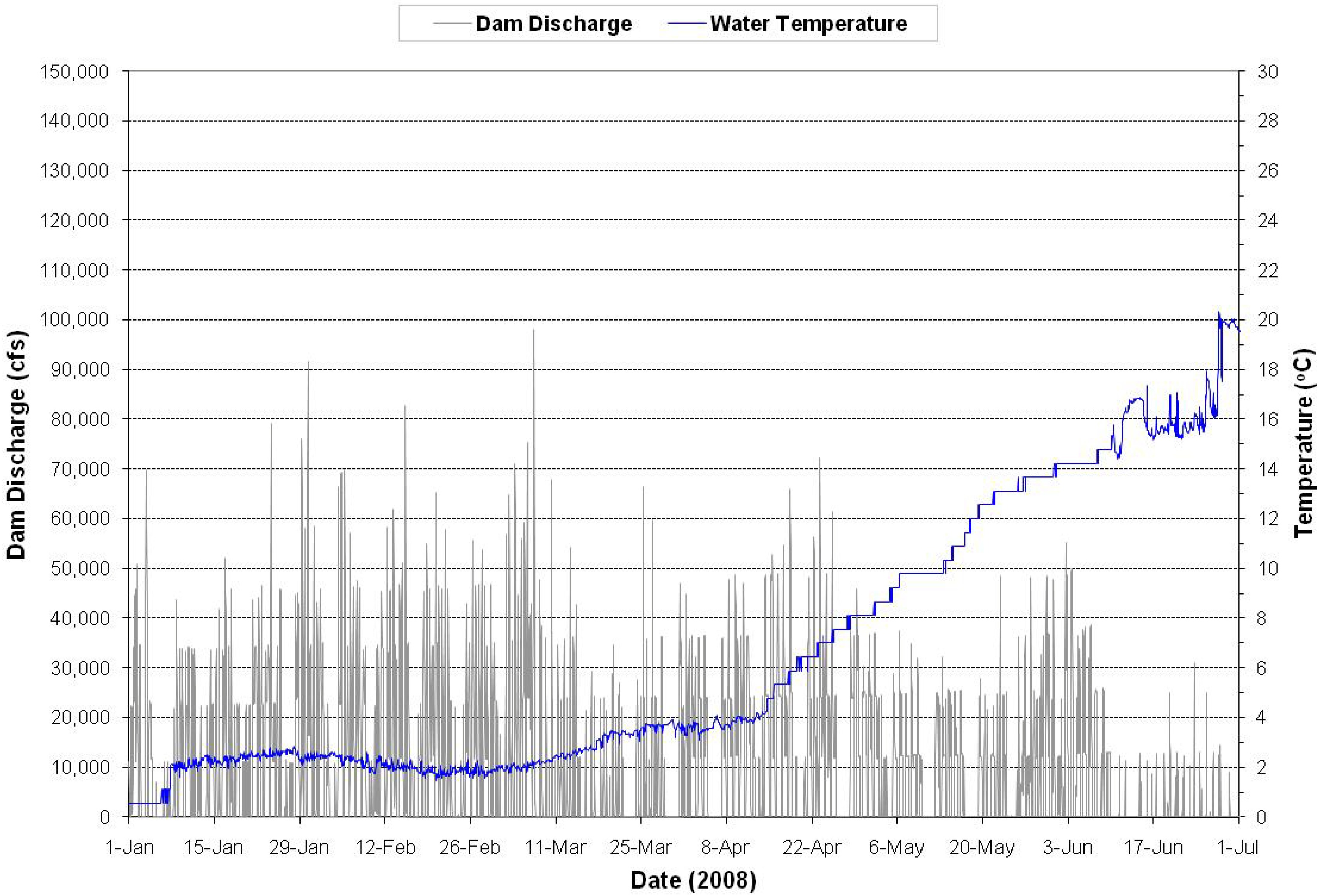

Plate 49. Hourly discharge and water temperature monitored at the Big Bend powerplant on water discharged through the dam during the period January through June 2008.

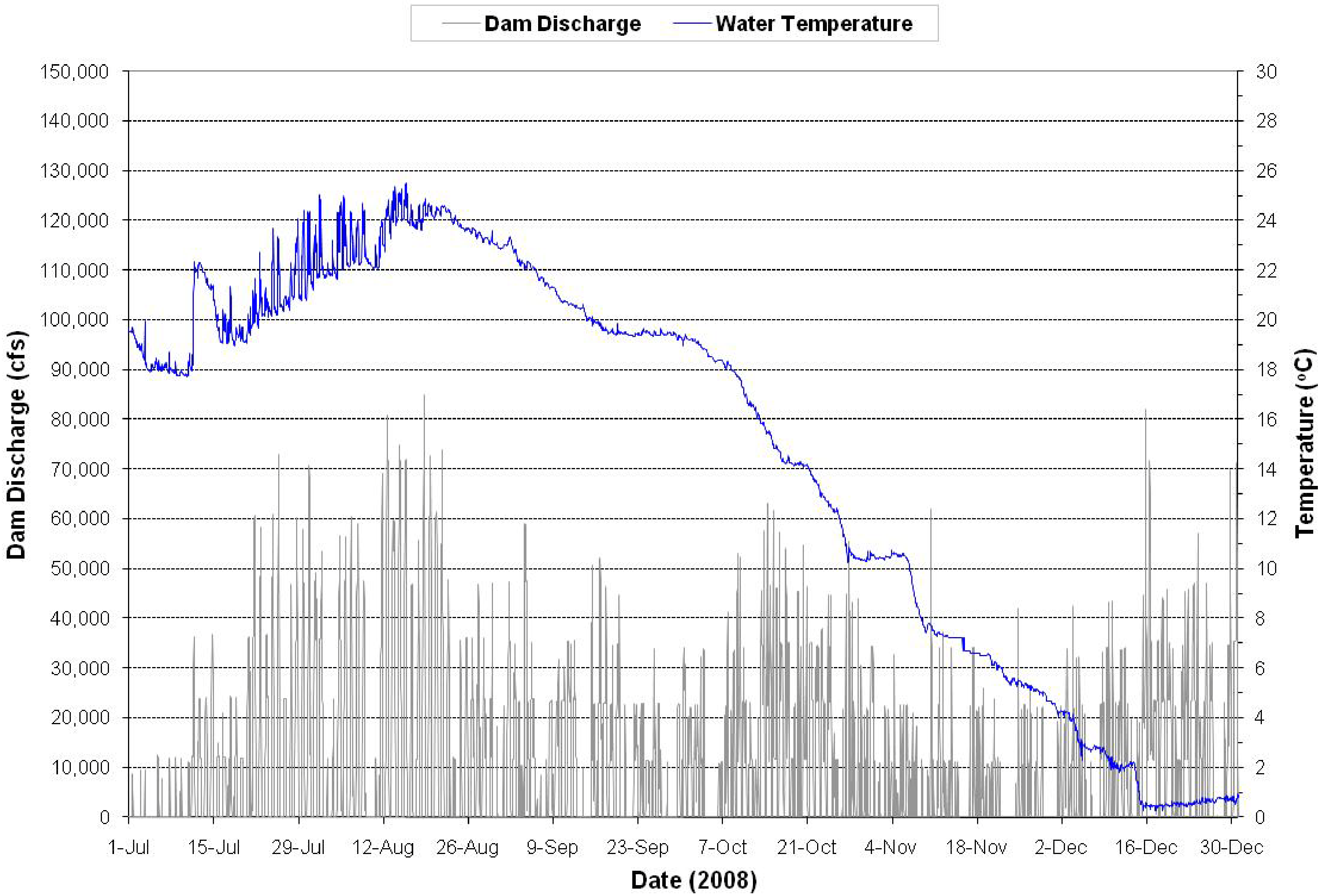

Plate 50. Hourly discharge and water temperature monitored at the Big Bend powerplant on water discharged through the dam during the period July through December 2008.

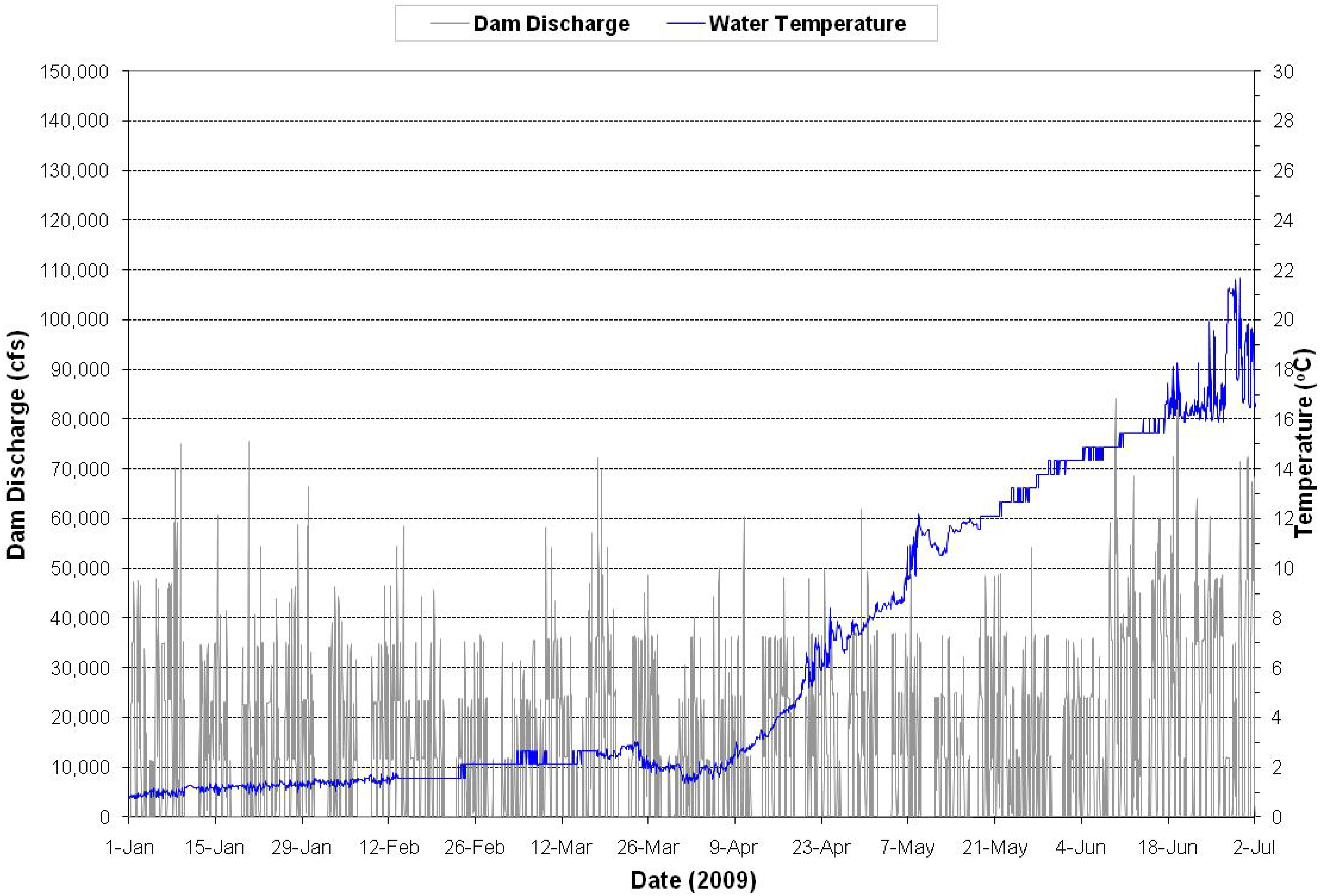

Plate 51. Hourly discharge and water temperature monitored at the Big Bend powerplant on water discharged through the dam during the period January through June 2009.

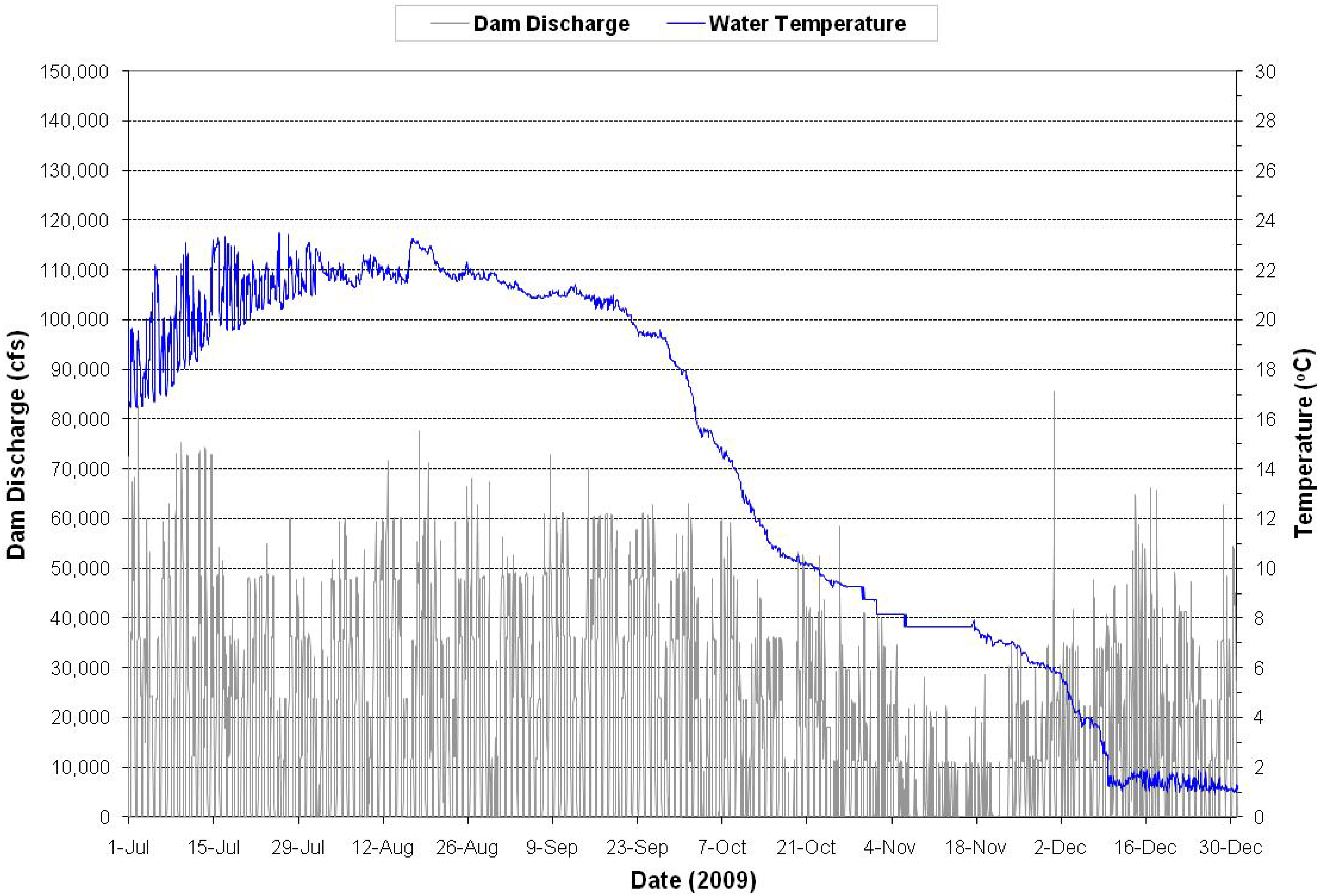

Plate 52. Hourly discharge and water temperature monitored at the Big Bend powerplant on water discharged through the dam during the period July through December 2009.

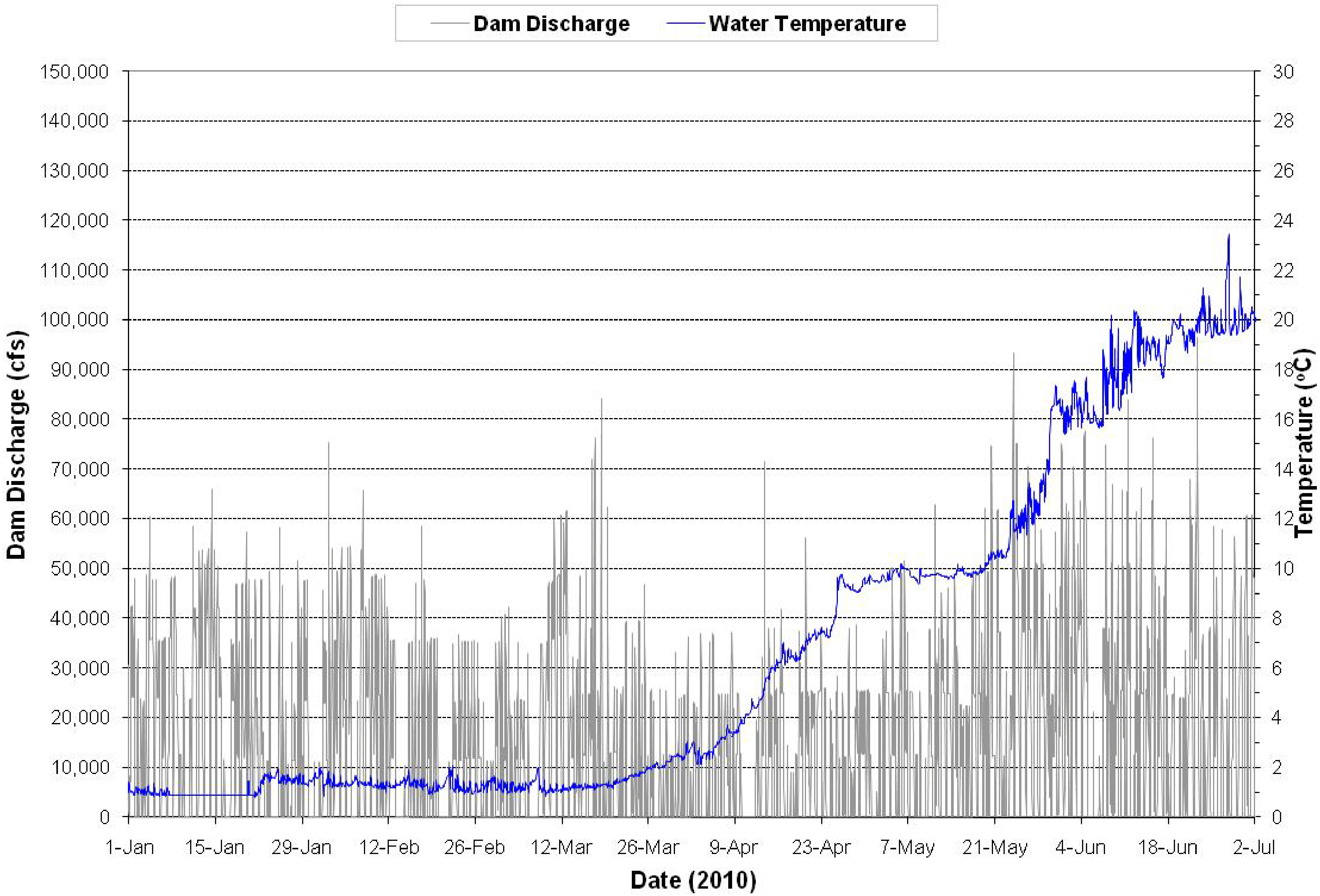

Plate 53. Hourly discharge and water temperature monitored at the Big Bend powerplant on water discharged through the dam during the period January through June 2010.

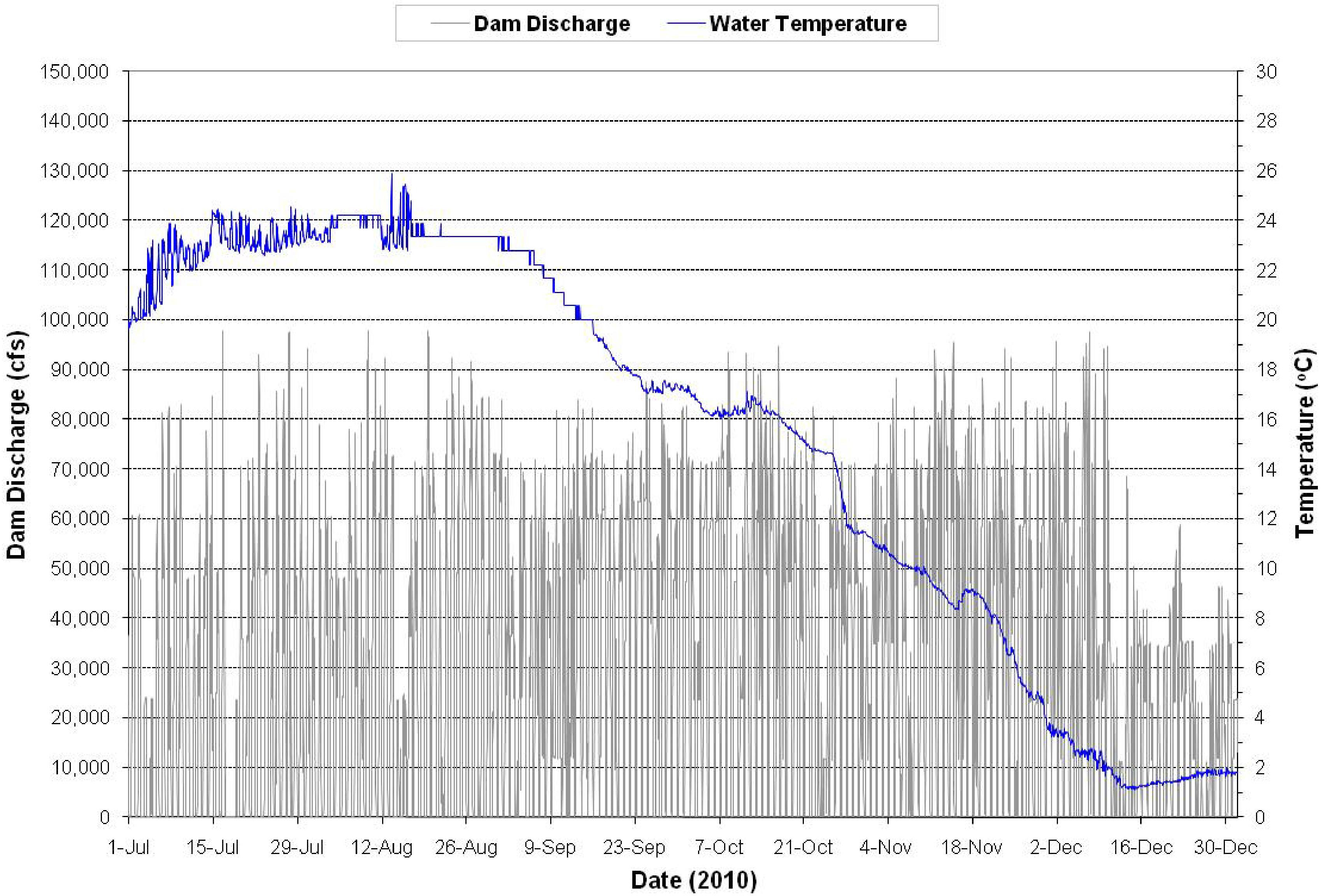

Plate 54. Hourly discharge and water temperature monitored at the Big Bend powerplant on water discharged through the dam during the period July through December 2010.

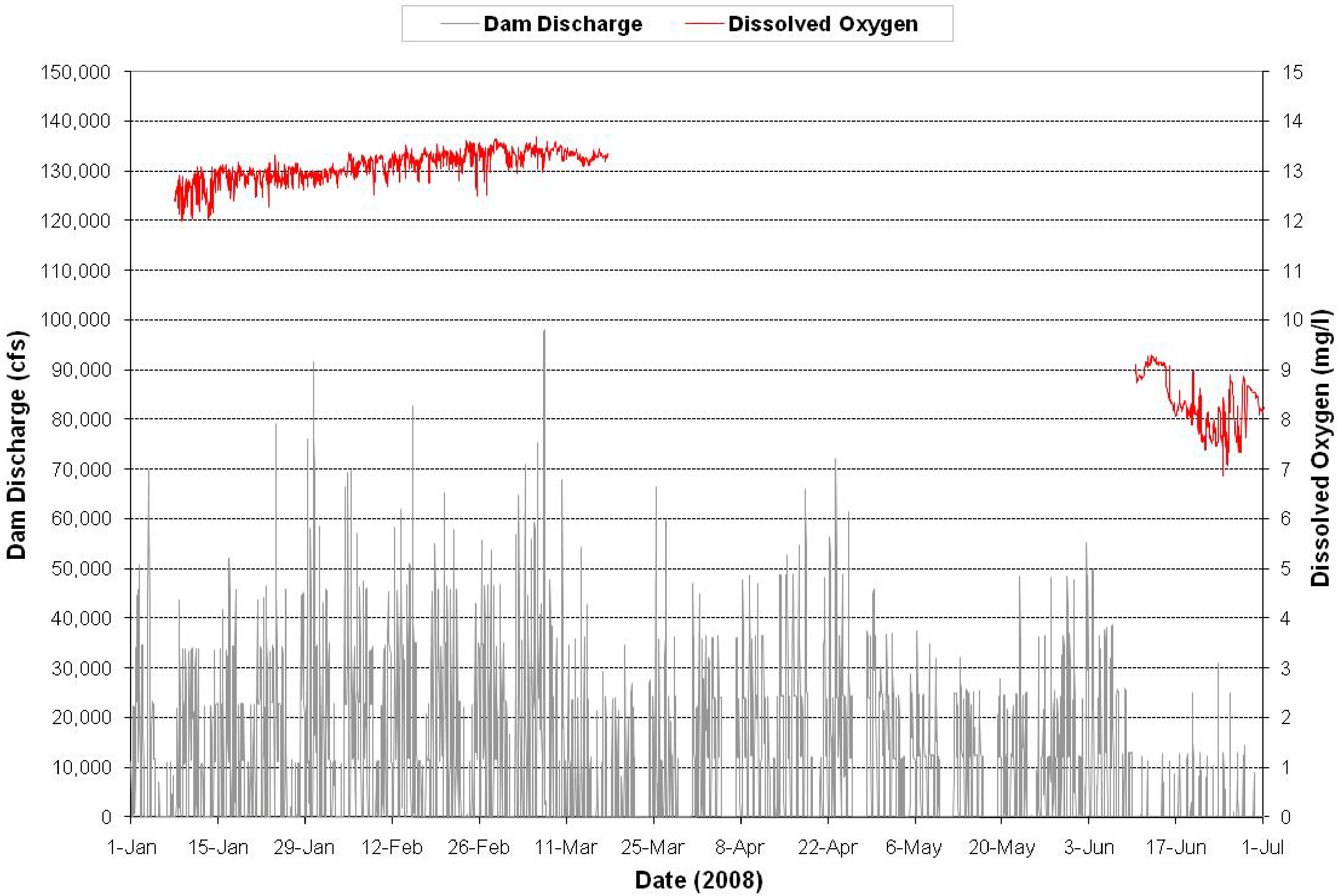

Plate 55. Hourly discharge and dissolved oxygen concentrations monitored at the Big Bend powerplant on water discharged through the dam during the period January through July 2008.
(Note: Gaps in dissolved oxygen plot represents periods when monitoring equipment was not operational.

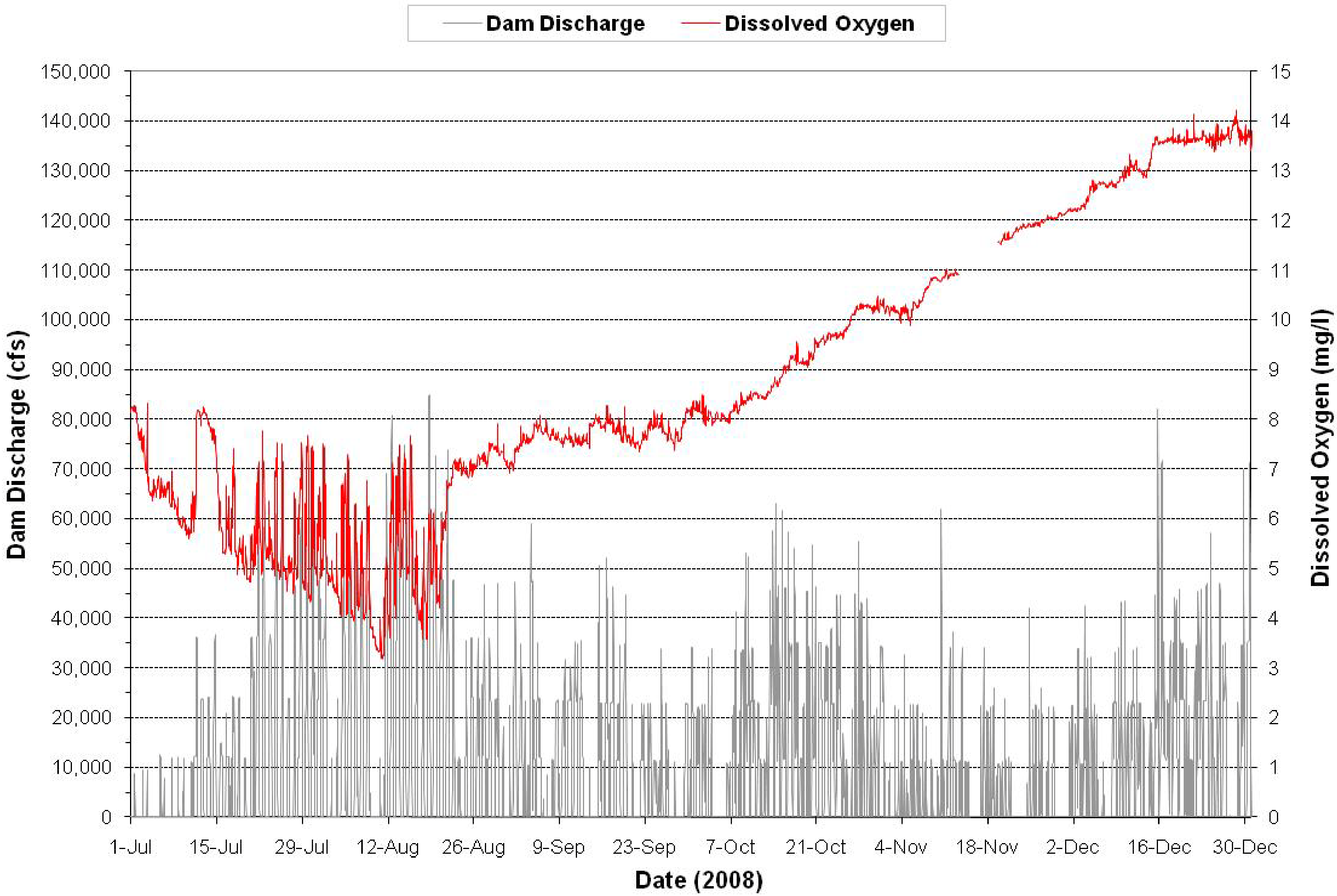

Plate 56. Hourly discharge and dissolved oxygen concentrations monitored at the Big Bend powerplant on water discharged through the dam during the period July through December 2008.
(Note: Gaps in dissolved oxygen plot represents periods when monitoring equipment was not operational.

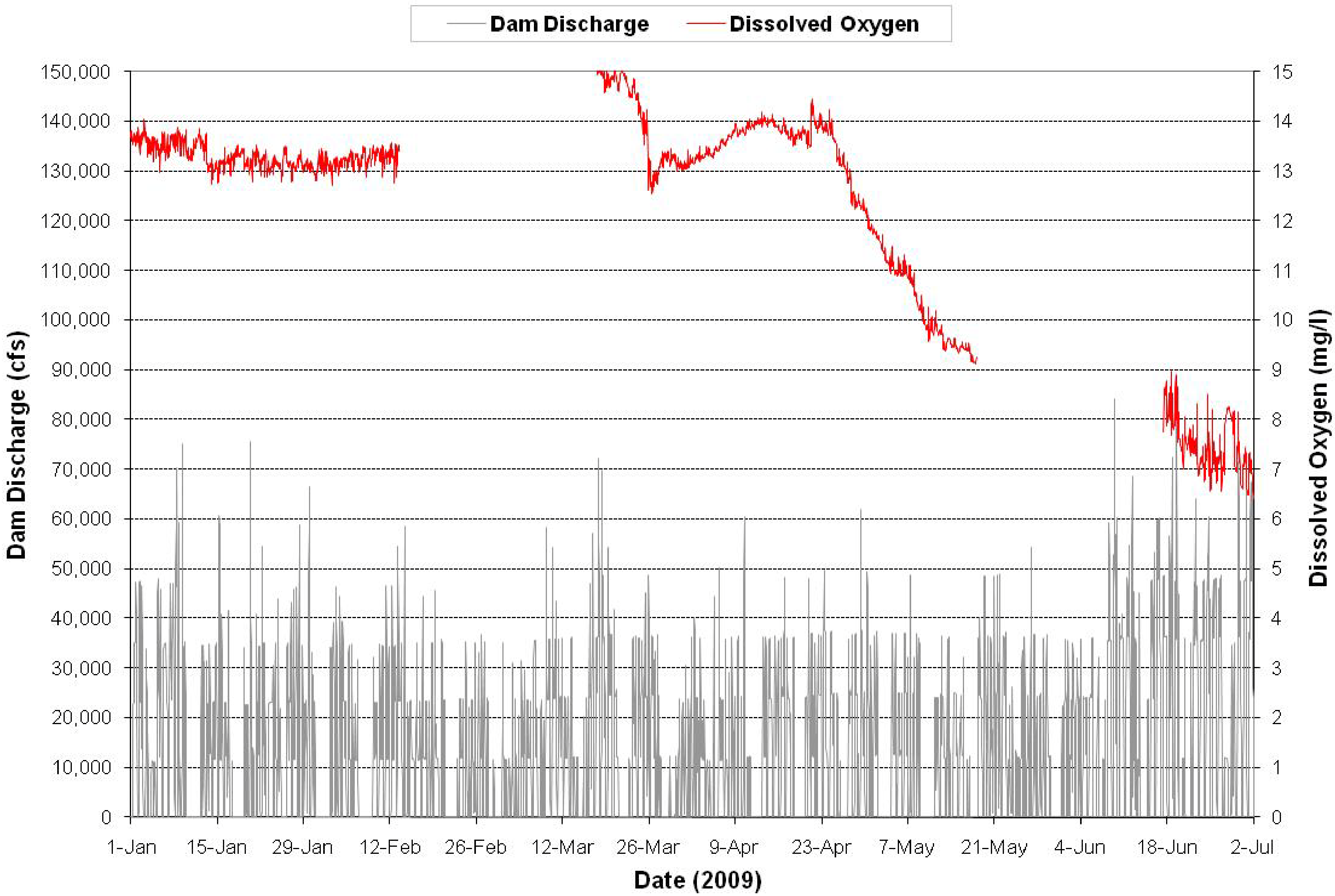

Plate 57. Hourly discharge and dissolved oxygen concentrations monitored at the Big Bend powerplant on water discharged through the dam during the period January through July 2009.
(Note: Gaps in dissolved oxygen plot represents periods when monitoring equipment was not operational.

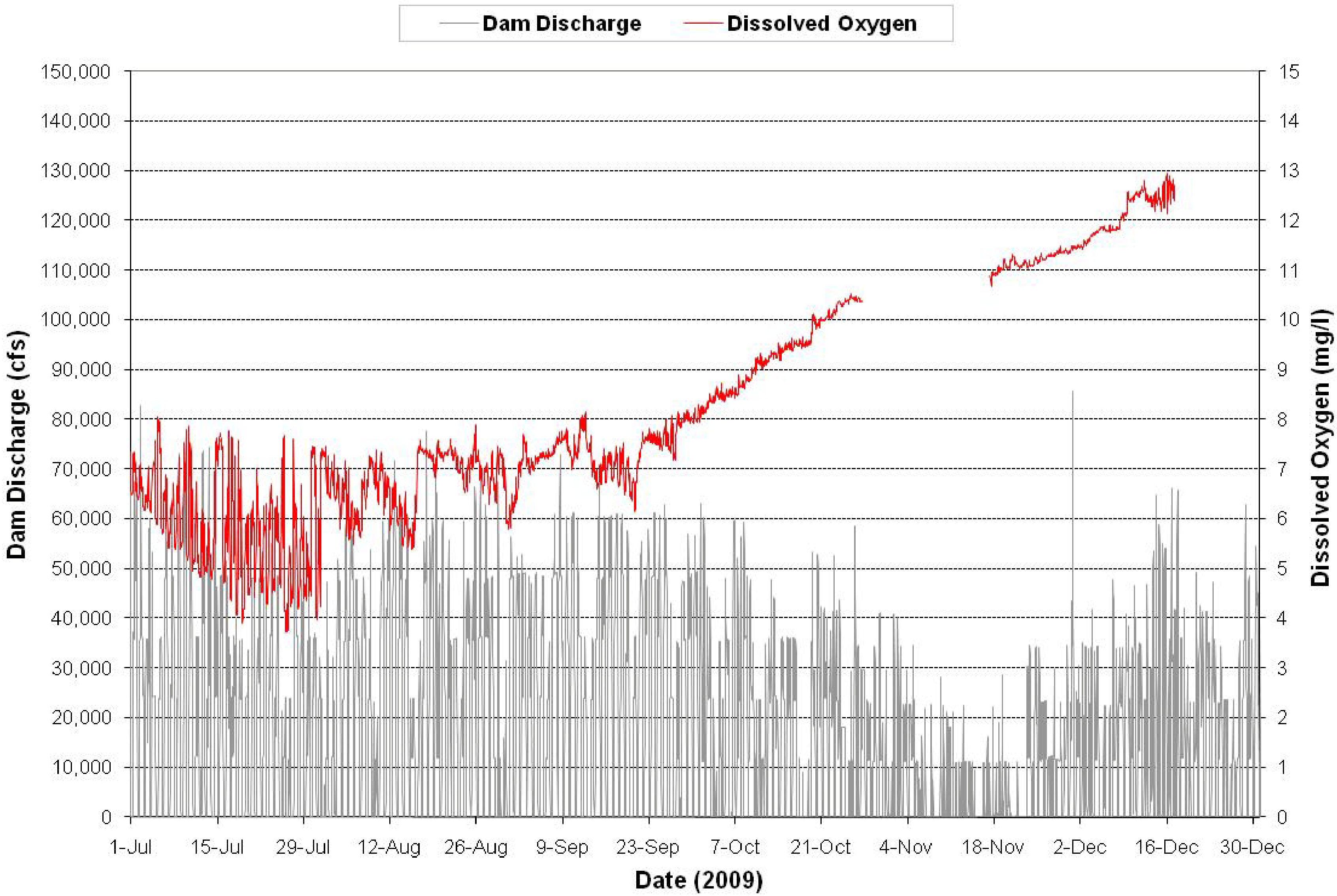

Plate 58. Hourly discharge and dissolved oxygen concentrations monitored at the Big Bend powerplant on water discharged through the dam during the period July through December 2009.
(Note: Gaps in dissolved oxygen plot represents periods when monitoring equipment was not operational.

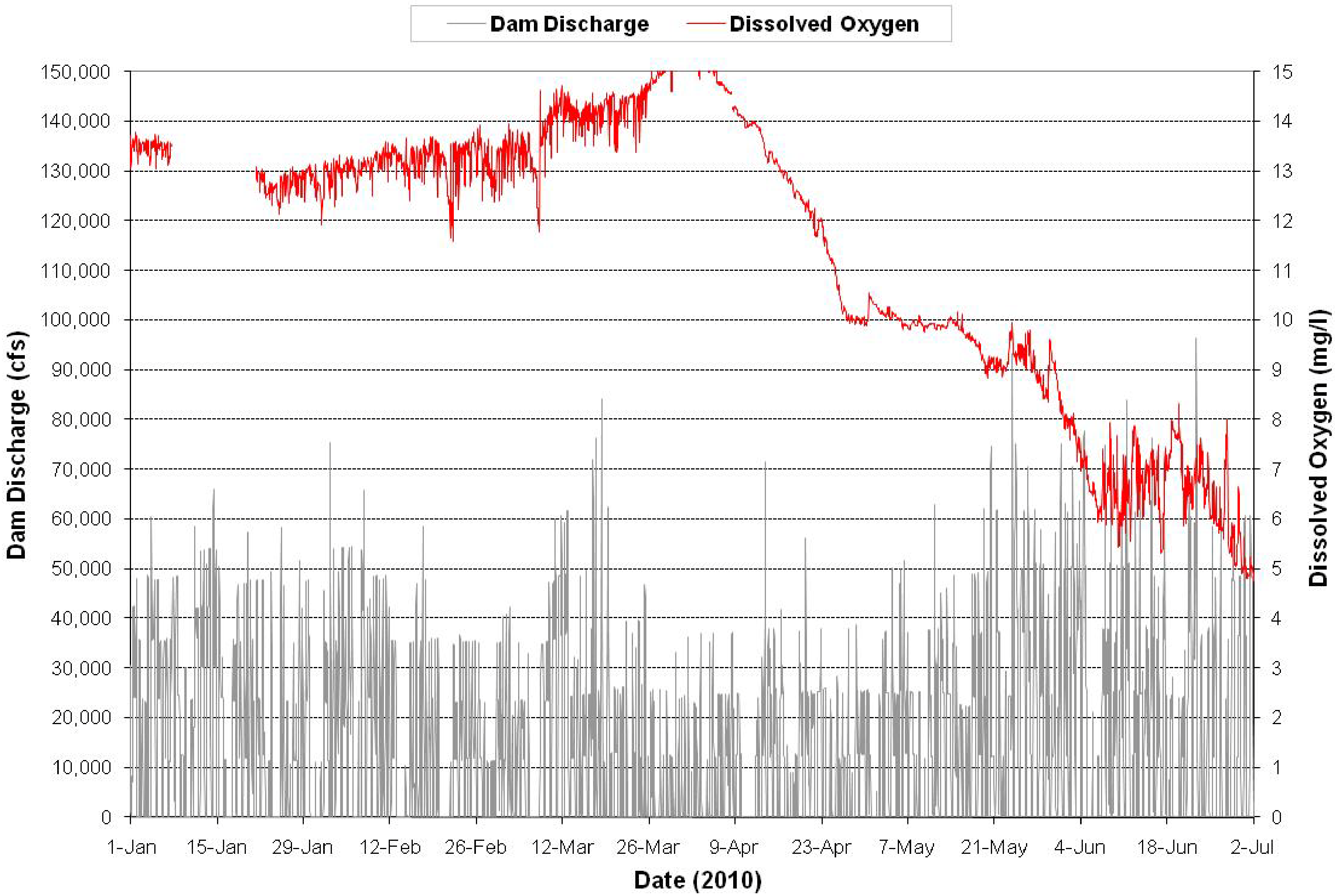

Plate 59. Hourly discharge and dissolved oxygen concentrations monitored at the Big Bend powerplant on water discharged through the dam during the period January through July 2010.
(Note: Gaps in dissolved oxygen plot represents periods when monitoring equipment was not operational.

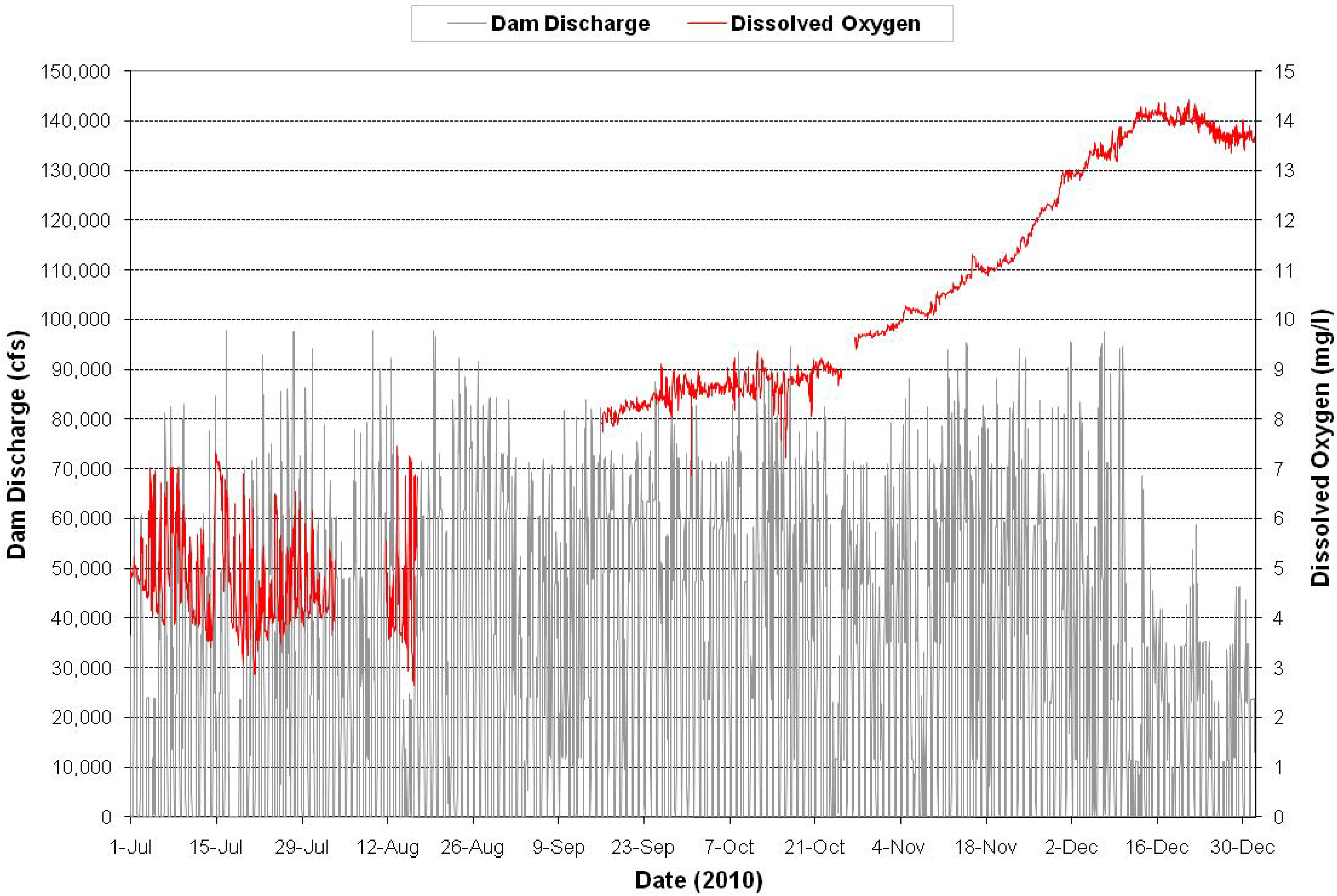

Plate 60. Hourly discharge and dissolved oxygen concentrations monitored at the Big Bend powerplant on water discharged through the dam during the period July through December 2010.
(Note: Gaps in dissolved oxygen plot represents periods when monitoring equipment was not operational.