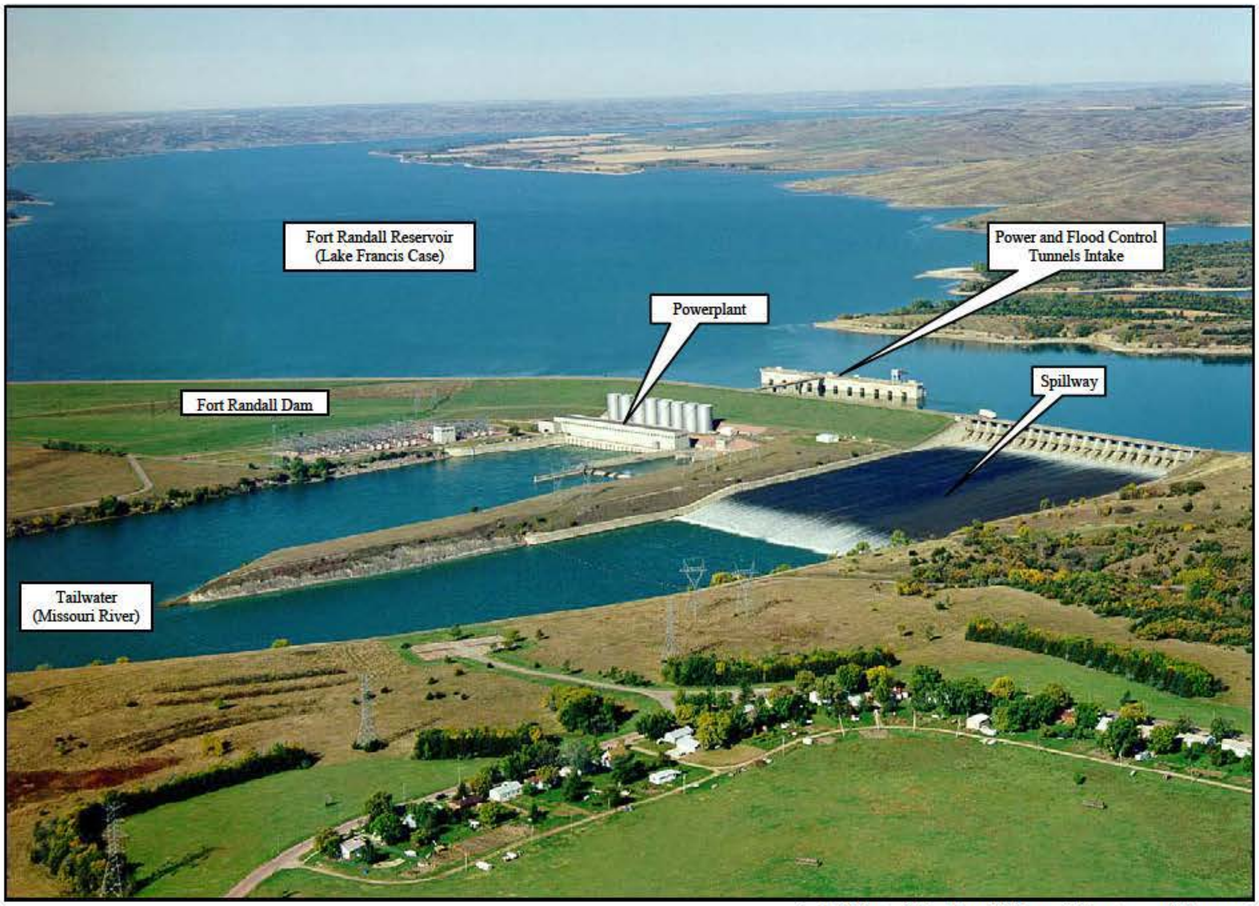
# Water Quality Special Study Report

**U.S. Army Corps of Engineers**
**Omaha District**

## Water Quality Conditions Monitored at the Corps' Fort Randall Project in South Dakota during the 3-Year Period 2006 through 2008




*Aerial Photo of Fort Randall Dam, Tailwaters and Reservoir*

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# Water Quality Special Report

# Water Quality Conditions Monitored at the Corps' Fort Randall Project in South Dakota during the 3-Year Period 2006 through 2008

*(Report Number: CENWO-ED-HA/WQSS/Fort Randall/2009)*

**Prepared by:**

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**February 2009**

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# EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (Corps) Fort Randall Project consists of Fort Randall Dam and Fort Randall Reservoir (i.e., Lake Francis Case). Fort Randall Dam is located on the Missouri River at river mile (RM) 880 in southeastern South Dakota, about 6 miles south of Lake Andes, 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. Habitat for one endangered species, interior least tern (*Sterna antillarum*), and one threatened species, piping plover (*Charadrius melodus*), occurs in the Missouri River downstream of the reservoir. Recreation at Fort Randall Reservoir is of great economic importance to the State of South Dakota, especially with respect to the reservoir's fishery.

Water quality monitoring was conducted at the Fort Randall Project by the Omaha District (District) over the 3-year period of 2006 through 2008. 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 Dam; and 3) intensive water quality surveys in 2006, 2007, and 2008. The results of this monitoring were used to assess the existing water quality conditions of Fort Randall Reservoir.

Overall, the existing water quality conditions monitored in Fort Randall Reservoir were good. Water quality conditions in the reservoir vary along its length, and strong thermal stratification occurs in the deeper area of the reservoir during the summer. Water quality monitoring indicated that the trophic status of the downstream half of the reservoir is mesotrophic; while the upstream half is moderately eutrophic to eutrophic. The phytoplankton community of Fort Randall Reservoir was dominated by diatoms and only minor "blooms" of cyanobacteria were monitored.

Water discharged through Fort Randall Dam exhibited good water quality. The temperature of the discharge water is reflective of the near-bottom elevation of its withdrawal from Fort Randall Reservoir. Monitoring of the Fort Randall Dam discharge indicates that the vertical extent of the withdrawal zone in the reservoir is dependent upon the discharge rate of the dam. This is believed to be a result of the design of the intake structure (i.e., bottom withdrawal) and the presence of the submerged coffer dam and approach channel leading to the intake structure.

Inflow temperatures of the Missouri River to Fort Randall Reservoir are generally warmer than the outflow temperatures of Fort Randall Dam during the period of April through September. Outflow temperatures of the Fort Randall Dam discharge are generally warmer than the inflow temperatures of the Missouri River during the period of September through March. A maximum temperature difference occurs in late-spring and early summer when the Missouri River inflow temperature is about 4°C warmer than the Fort Randall Dam discharge temperature

The Omaha District is planning to pursue the application of the Corps' CE-QUAL-W2 (Version 3.2) hydrodynamic and water quality model to Fort Randall Reservoir. CE-QUAL-W2 is an extremely 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 Fort Randall Project affects the water quality of the reservoir and the Missouri River below Fort Randall Dam. It is almost a certainty that water quality issues at the Fort Randall Project will remain important in the future.

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# 1 INTRODUCTION

## 1.1 RECENT WATER QUALITY MONITORING AT THE CORPS' FORT RANDALL PROJECT

Water quality monitoring conducted by the Omaha District (District) at the Fort Randall 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 Fort Randall Dam; and 3) intensive water quality surveys in 2006, 2007, and 2008. The continuing long-term, fixed-station monitoring consisted of monthly (i.e., May through September) field measurements and sample collection. The monitoring in the Fort Randall powerplant was on water drawn from the penstocks prior to passing through the dam's turbines. The intensive surveys included monitoring at six additional in-reservoir sites and monitoring of the White River inflow to the reservoir. This report presents the findings of the water quality monitoring conducted by the District at the Fort Randall Project during the period 2006 though 2008.

## 1.2 MISSOURI RIVER MAINSTEM SYSTEM

The Missouri River Mainstem System (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). The water in storage at the all Mainstem System reservoirs at the end of 2008 (i.e., December 31, 2008) was 44.193 MAF, which is 60 percent of the total system storage volume and 84 percent of the 1967-2008 average. 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 is still appreciably below the total system storage volume and long-term average.

### 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 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 DESCRIPTION OF THE FORT RANDALL PROJECT

Fort Randall Dam and Reservoir are authorized for the purposes of flood control, recreation, fish and wildlife, hydroelectric power production, water supply, water quality, navigation, and irrigation. Habitat for one endangered species, interior least tern, and one threatened species, piping plover, occurs in the Missouri River downstream of the reservoir.

### 1.3.1 FORT RANDALL DAM AND POWERPLANT

Fort Randall Dam is located on the Missouri River at river mile (RM) 880 in southeastern South Dakota, about 6 miles south of Lake Andes, South Dakota. Construction of the project was initiated in August 1946 and dam closure was made in July 1952. Filling of the reservoir was initiated in January 1953 and reached the minimum operating pool elevation of 1320 ft-msl in November 1953. Fort Randall Dam is a rolled earth fill embankment with a 165-foot maximum height and a 10,700-foot length, including the spillway section. The spillway is a conventional chute-type spillway located near the left abutment (i.e., east end) of the dam. The outlet works are located approximately 800 feet riverward (i.e., westward) of the spillway. Initial power generation began in March 1954, and the project reached an essentially complete status in January 1956, when the eighth and final unit of the 320,000-kilowatt installation came into service. Over the period 1967 through 2008, the eight generating units at Fort Randall Dam have produced an annual average 1.746 million mega-watt hours (MWh) of electricity, which has a current revenue value of approximately $26 million. The ongoing drought in the interior western United States has curtailed releases and power production at the Missouri River mainstem system projects, including Fort Randall. Power production at the Fort Randall Dam generating units averaged an annual 1.024 MWh over the 3-year period 2006 through 2008.

The Fort Randall Dam outlet works consists of an approach channel, intake structure, 12 tunnels, a stilling basin, and a discharge channel. Photos 1.1 through 1.6 show construction of the intake structure and approach channel over the period of 24-March-1951 to 15-September-1952. The approach channel begins approximately 6,000 feet upstream from the intake structure (Photo 1.6). It is excavated to a bottom elevation of 1227 ft-msl which is 2 feet below the intake invert elevation (Photos 1.1, 1.2, and 1.3). The approach channel has a bottom width of 580 feet for the upper 5,000 feet and then gradually increases to the full width of the intake structure (836 feet) at its terminus. A reinforced concrete slab extends 100 feet upstream of the intake to protect the bottom of the approach channel. The reinforced concrete intake structure is located approximately 2,000 feet from the left abutment (i.e. east end of dam) and 450 feet upstream from the centerline of the main embankment at the upstream end of the tunnels. It consists of 12 towers spaced on 70-foot centers and rising about 180 feet above the chalk foundation – tower 1 is the most riverward with tower 12 nearest the left abutment )Photo 1.3). Twelve tunnels, one per tower, extend downstream from the intake structure. The invert elevation of the tunnels is 1229 ft-msl at the intake and 1219 ft-msl at the downstream end. Tunnels one through eight are power tunnels and terminate at the powerplant. Tunnels 9, 11, and 12 are flood control tunnels and discharge directly to the stilling basin. Tunnel 10 is a flood control regulating tunnel and terminates at the regulating gate structure that discharges to the stilling basin. A fine-regulating gate was provided near the lower end of tunnel 10 but failed during an extended period of high releases in 1975 and was not replaced. Trashracks are installed in the water passages in Tunnels 1 through 8 and Tunnel 10. Cooling water for the individual units in the Fort Randall powerplant is drawn from the "raw water" supply line which is supplied from Units 2, 4, 6, and 8 through 14-inch connections to the scroll cases.

**Photo 1.1.** Early construction of the intake structure at Fort Randall Dam showing the left bank of the excavated approach channel (*Photo date: 24-Mar-1951)*.

**Photo 1.2.** Ongoing construction of the intake structure at Fort Randall Dam looking at the right bank of the excavated approach channel *(Photo Date: 31-Aug-1951)*.

**Photo 1.3.** General view of upstream face of intake structure at Fort Randall Dam, after final cleanup of approach area, and before release of water through river plugs in the coffer dam *(Photo Date: 27-May-1952).*

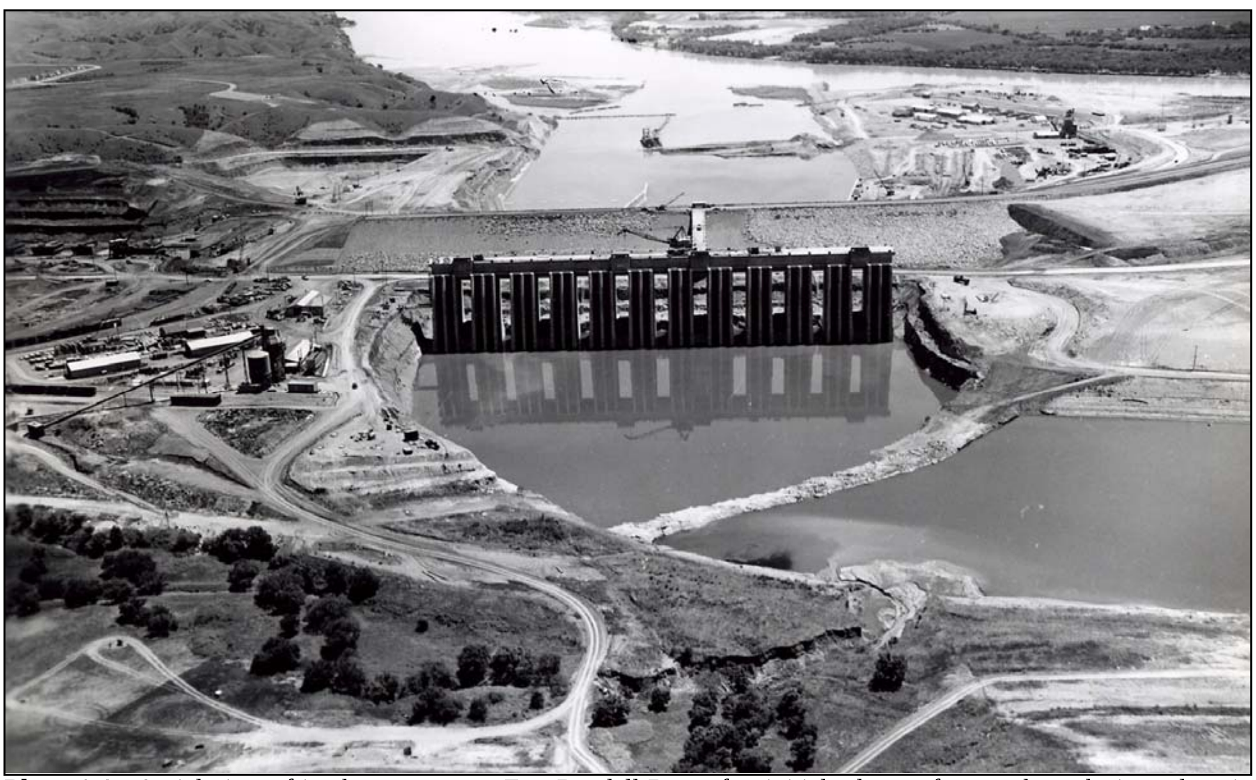

**Photo 1.4.** Aerial view of intake structure at Fort Randall Dam after initial release of water through river plugs in the coffer dam *(Photo Date: 5-Jun-1952)*. It is believed the coffer dam was later removed.

**Photo 1.5.** Aerial view looking southwest along the axis of Fort Randall Dam toward the right bank of the Missouri River *(Photo Date: 10-July-1952).* The coffer dam has seemingly been submerged.

**Photo 1.6.** Near vertical aerial view of Fort Randall Dam showing the approach channel conveying flows through the intake structure after initial blocking of the natural channel of the Missouri River *(Photo Date: 15-September-1952).*

**Fort Randall Reservoir**

The closing of Fort Randall Dam in 1952, and the deliberate accumulation of storage in 1953, resulted in the formation of Fort Randall Reservoir. When full the reservoir, also known as Lake Francis Case, extends to Big Bend Dam. The maximum reservoir level experienced to date was in July 1997, when an elevation of 1372.2 occurred, 2.6 feet below the top of the Exclusive Flood Control Zone. The reservoir, at the end of December 2008, was at pool elevation 1340.9 ft-msl. This is 9.1 feet below the top of the Carryover Multiple Use Zone (1350.0 ft-msl). A “low” pool level is typical for Fort Randall Reservoir at the end of December because this reservoir is drawn down each fall to provide storage space for high winter power releases from Oahe and Big Bend Reservoirs.

When full, Fort Randall Reservoir is 107 miles long, covers 102,000 acres, and has 540 miles of shoreline. Table 1.1 summarizes how the surface area, volume, mean depth, and retention time of Fort Randall Reservoir vary with pool elevations. Major inflows to Fort Randall Reservoir are the Missouri River (RM987) and White River (RM955). The reservoir is used as a water supply by the communities of Chamberlain, Dante, Geddes, Greenwood, Kimball, Lake Andes, Marty, Oacoma, Platte, Pickstown, Pukkwana, Ravinia, Reliance, Wagner, and White Lake South Dakota. Fort Randall Reservoir is an important recreational resource and a major visitor destination in South Dakota.

**Table 1.1.** Surface area, volume, mean depth, and retention time of Fort Randall Reservoir at different pool elevations.

| Elevation (Feet-msl) | Surface Area (Acres) | Volume (Acre-Feet) | Mean Depth (Feet)* | Retention Time (Years)** |
|---|---|---|---|---|
| 1370 | 98,438 | 4,916,698 | 49.9 | 0.277 |
| 1365 | 94,801 | 4,433,011 | 46.7 | 0.250 |
| 1360 | 89,808 | 3,971,266 | 44.2 | 0.224 |
| 1355 | 85,453 | 3,531,526 | 41.3 | 0.199 |
| 1350 | 76,747 | 3,124,368 | 40.7 | 0.176 |
| 1345 | 68,588 | 2,761,139 | 40.3 | 0.156 |
| 1340 | 59,783 | 2,439,591 | 40.8 | 0.138 |
| 1335 | 50,547 | 2,165,606 | 42.8 | 0.122 |
| 1330 | 45,845 | 1,926,136 | 42.0 | 0.109 |
| 1325 | 40,277 | 1,711,773 | 42.5 | 0.096 |
| 1320 | 37,911 | 1,517,486 | 40.0 | 0.086 |
| 1315 | 35,000 | 1,335,568 | 38.2 | 0.075 |
| 1310 | 33,632 | 1,164,645 | 34.6 | 0.066 |
| 1305 | 32,119 | 1,000,024 | 31.1 | 0.056 |
| 1300 | 30,297 | 843,949 | 27.9 | 0.048 |
| 1295 | 28,608 | 696,350 | 24.3 | 0.039 |
| 1290 | 26,042 | 559,475 | 21.5 | 0.032 |

Average Annual Inflow (1967 through 2008) = 18.01 Million Acre-Feet.
Average Annual Outflow: (1967 through 2008) = 17.74 Million Acre-Feet.
* Mean Depth = Volume ÷ Surface Area.
** Retention Time = Volume ÷ Average Annual Outflow.
Note: Exclusive Flood Control Zone (elev. 1375-1365 ft-msl), Annual Flood Control and Multiple Use Zone (elev. 1365-1350 ft-msl), Carryover Multiple Use Zone (1350-1320 ft-msl), and Permanent Pool Zone (elev. 1320-1227 ft-msl). All elevations are in the NGVD 29 datum.

### 1.3.2 MISSOURI RIVER DOWNSTREAM OF FORT RANDALL DAM

The Missouri River downstream from Fort Randall Dam flows in a southeasterly direction for approximately 44 miles in an unchannelized river to Gavins Point Reservoir. The major tributary in this reach is the Niobrara River which enters the Missouri River from Nebraska at RM843.5. In this reach, the Missouri River meanders in a wide channel with flow restricted to generally one main channel. Only a few side channels and backwaters are present, except at the lower end of the reach in the Gavins Point Reservoir delta. The 39-mile reach of the Missouri River from Fort Randall Dam to Running Water, SD has been designated a National Recreational River under the Federal Wild and Scenic Rivers Act (WSRA). The tailwater area of Fort Randall Dam, from RM 880 to 860, has experienced up to 6 feet of riverbed degradation and channel widening during the 1953 to 1997 time period. The rate of erosion has decreased over this period. Streambank erosion since closure of the dam in 1953 has averaged about 35 acres per year. This compares to a pre-dam rate of 135 acres per year. The Missouri River has coarser bed material above RM 870 than below, indicating some armoring of the channel below the dam. Downstream of the tailwater area, less erosion of the bed and streambank occurs. The minimum flow release from Fort Randall Dam recommended to protect fish spawning in the Missouri River is 9,000 cfs from April through June.

The 39-mile "natural-channel" reach of the Missouri River from Fort Randall Dam to the headwaters of Gavins Point Reservoir has been designated as a National Recreational River under the Federal WSRA. The National Park Service (NPS) manages the 39-mile reach pursuant to the WSRA. The justification that supported that this reach of the Missouri River be protected as a recreational river identified its outstanding remarkable recreational, fish and wildlife, aesthetic, historical, and cultural values. Under the WSRA, the U.S. Department of Interior (i.e., NPS) is mandated to administer this reach in a manner that will protect and enhance these values for the benefit and enjoyment of present and future generations.

## 1.4 WATER QUALITY MANAGEMENT CONCERNS AT THE FORT RANDALL PROJECT

### 1.4.1 APPLICABLE WATER QUALITY STANDARDS

#### 1.4.1.1 Fort Randall Reservoir

The State of South Dakota has designated the following water quality-dependent beneficial uses for Fort Randall Reservoir in the State's water quality standards: recreation (i.e., immersion and limited-contact), warmwater permanent fish life propagation, domestic water supply, agricultural water supply (i.e., irrigation and stock watering), commerce and industrial waters, and fish and wildlife propagation.

#### 1.4.1.2 Missouri River Downstream of Fort Randall Dam

South Dakota's water quality standards designate the following beneficial uses for the Missouri River downstream of Fort Randall Dam: recreation (i.e., immersion and limited-contact), warmwater permanent fish life propagation, domestic water supply, agricultural water supply (i.e., irrigation and stock watering), commerce and industrial waters, and fish and wildlife propagation.

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

#### 1.4.2.1 Fort Randall Reservoir

Pursuant to Section 303(d) of the Federal Clean Water Act (CWA), the State of South Dakota has not placed Fort Randall Reservoir on the State's Section 303(d) list of impaired waters. The State has not issued a fish consumption advisory for the reservoir.

#### 1.4.2.2 Missouri River Downstream of Fort Randall Dam

The State of South Dakota has not placed the reach of the Missouri River downstream of Fort Randall Dam on its Section 303(d) list of impaired waters. The State has not issued a fish consumption advisory for this reach of the Missouri River.

# 2 WATER QUALITY MONITORING CONSIDERATIONS

## 2.1 WATER QUALITY MONITORING OBJECTIVES

### 2.1.1 GENERAL MONITORING OBJECTIVES

The Omaha District has identified four purposes and 12 general monitoring objectives for surface water quality monitoring to facilitate implementation of the District's Water Quality Management Program (USACE, 2009). The water quality monitoring conducted at the Fort Randall Project over the 3-year period, 2006 through 2008, was implemented to address 6 of the 12 identified monitoring objectives. The six general water quality monitoring objectives that were addressed are:

- 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 six general water quality monitoring objectives, one specific monitoring objective was identified for the intensive water quality surveys of Fort Randall Reservoir:

1) Collect the information needed to allow application and "full calibration" of the Version 3.2 CE-QUAL-W2 hydrodynamic and water quality model to Fort Randall 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 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, well mixed, and although water current velocities are decreasing, 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, particulate, 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 at dams. In addition, a dam 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).

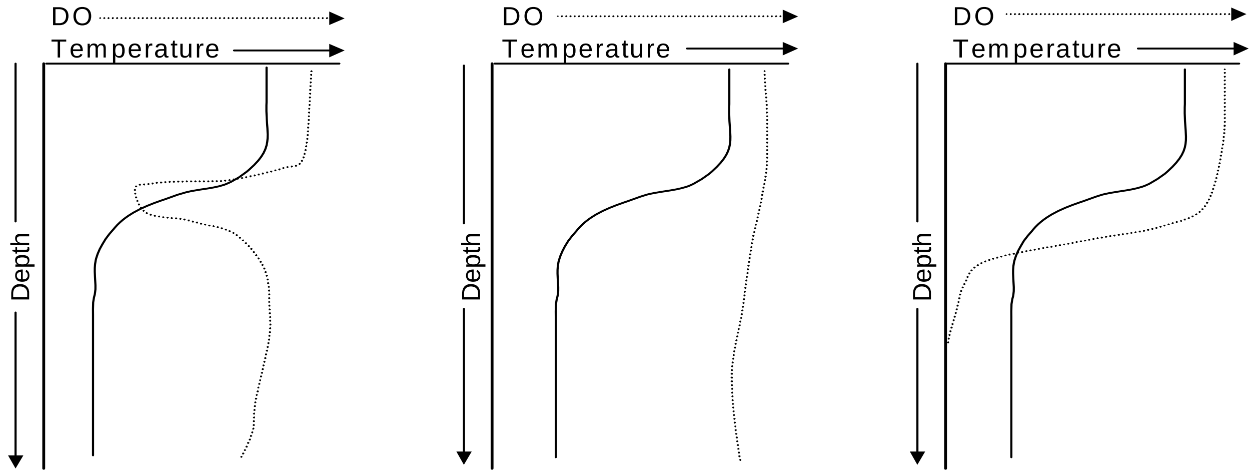


**Figure 2.1.** Vertical dissolved oxygen concentrations possible in thermally stratified reservoirs.

<u>Nitrogen</u>: 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.

<u>Phosphorus</u>: 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.

<u>Silica</u>: 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 in the hypolimnion are reduced to approximately 2 to 3 mg/l, the oxygen regime at the sediment/water interface is generally considered hypoxic, 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 so 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 through 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 (i.e., blue-green algae), 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. Green algae usually succeed the diatoms as silica depletion in the photic zone occurs with increased settling as viscosity decreases because of increased temperatures. 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 <u>Organic Carbon and Detritus</u>

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 affect 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 structures are 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 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.

The intake structure at Fort Randall Dam withdraws water from the bottom of Fort Randall Reservoir. The intake structure consists of 12 individual control towers 180 feet high that have inverts for water intake at elevation 1229 ft-msl. The intake invert elevation of 1229 ft-msl is 2 feet above the bottom of the approach channel to the intake structure. When constructed in the late 1940's, the approach channel was excavated to a bottom elevation of 1227 ft-msl which was the lowest elevation of Fort Randall Reservoir in the area near the dam. Elevation 1229 ft-msl would be at a depth of 121 feet when the reservoir is at the top of the Carryover Multiple Use Zone (i.e., elevation 1350 ft-msl). Water drawn into the power tunnels would typically come from the hypolimnion during summer thermal stratification Fort Randall Reservoir.

## 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 3.2 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 (Version 3.2) 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 Version 3.2 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. 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 FORT RANDALL RESERVOIR

The 3-year intensive water quality survey was conducted at the Fort Randall Project during 2006 through 2008, and the application and calibration of the model to Fort Randall Reservoir is planned for 2010. The Fort Randall Project will be the fourth Mainstem System Project on which the Version 3.2 CE-QUAL-W2 model is applied. Model application will focus on modifying the earlier developed reservoir bathymetry files, refining the calibration of outflow water quality conditions, and activating the model's water quality algorithms. Much more detailed outflow data regarding monitored water quality conditions now exists to refine the calibration of the model. The water quality algorithms that describe the nutrient/algae/dissolved oxygen interactions will be calibrated. The goals are to have the model mechanistically determine reservoir dissolved oxygen levels and to use the model's predictive capabilities to evaluate factors influencing the occurrence of dissolved oxygen in Fort Randall Reservoir. A Water Quality Modeling Report will be prepared at a future date describing the application and calibration of the CE-QUAL-W2 Version 3.2 model to Fort Randall Reservoir.

# 3 DATA COLLECTION METHODS

## 3.1 DATA COLLECTION DESIGN

### 3.1.1 MONITORING LOCATIONS

The Omaha District collected water quality data at 11 locations at the Fort Randall Project during the period 2006 through 2008. Of the 11 locations, 7 were located on Fort Randall Reservoir, 2 were located on the major inflows to the reservoir (i.e., Missouri River and White River), 1 was located at the Fort Randall Dam powerplant, and 1 was located in the Fort Randall Dam tailwaters. 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 stations were meant to represent "deepwater" pelagic conditions and were established at the deepest part of the reservoir in the area being monitored. The seven reservoir monitoring sites (i.e., L1-L7) were approximately equally spaced along the submerged old Missouri River channel from near the dam to near Chamberlain, South Dakota – a total distance of approximately 88 miles (Figure 3.1). The two inflow stations were located on the Missouri River at Big Bend Dam (i.e., NF1) and on the White River just upstream of its confluence with Fort Randall Reservoir (i.e., NF2) (Figure 3.1). Site NF1 was in the Big Bend Dam powerplant and monitored water quality conditions indicative of the Big Bend Dam discharge. The two outflow sites were located in the Fort Randall powerplant (i.e., OF1) and in the tailwaters below Fort Randall Dam (OF2) (Figure 3.1). Site OF1 monitored water quality conditions from the "raw water" supply line in the powerplant and was indicative of the Fort Randall Dam discharge. Site OF2 was located in the Fort Randall tailwaters approximately 1 mile downstream from the dam. Depending on the pool elevation of Fort Randall Reservoir, the monitoring sites are believed to be associated with the following reservoir zones: Lacustrine Zone (L1, L2, L3, OF1), Zone of Transition (L4, L5), and Riverine Zone (L6, L7, NF1).

**Table 3.1.** Location and description of monitoring sites that were sampled by the Omaha District for water quality at the Fort Randall Project during the period 2006 through 2008.

| Station Number | Station Alias | Name | Location | Site Type | Latitude | Longitude |
|---|---|---|---|---|---|---|
| BBDPP1* | NF1 | Big Bend Dam | Big Bend Dam Powerplant | Inflow | ----- | ----- |
| FTRNFWHTR1 | NF2 | White River near Oacoma, SD | At SD Hwy 47 bridge crossing | Inflow | ----- | ----- |
| FTRLK0880A** | L1 | Fort Randall Reservoir – Near Dam | Reservoir (RM880), Deepwater | Lake | 43 03' 28.9" | 98 34' 37.8" |
| FTRLK0892DW | L2 | Fort Randall Reservoir – Pease Creek Area | Reservoir (RM892), Deepwater | Lake | 43 08' 17.5" | 98 45' 41.6" |
| FTRLK0911DW | L3 | Fort Randall Reservoir – Platte Creek Area | Reservoir (RM911), Deepwater | Lake | 43 16' 47.0" | 99 00' 40.6" |
| FTRLK0924DW | L4 | Fort Randall Reservoir – Snake Creek Area | Reservoir (RM924), Deepwater | Lake | 43 25' 47.1" | 99 09' 23.8" |
| FTRLK0940DW | L5 | Fort Randall Reservoir – Elm Creek Area | Reservoir (RM940), Deepwater | Lake | 43 33' 54.8" | 99 19' 37.4" |
| FTRLK0955DW | L6 | Fort Randall Reservoir – White River Area | Reservoir (RM955), Deepwater | Lake | 43 41' 38.8" | 99 26' 03.6" |
| FTRLK0968DW | L7 | Fort Randall Reservoir – Chamberlain Area | Reservoir (RM968), Deepwater | Lake | 43 49' 50.9" | 99 19' 36.6" |
| FTRPP1* | OF1 | Fort Randall Dam | Fort Randall Dam Powerplant | Outflow | ----- | ----- |
| FTRRRTW1*** | OF2 | Fort Randall Dam Tailwaters (Missouri River) | 1 mile downstream of Fort Randall Dam | Outflow | 43 03' 04.2" | 98 32' 22.5" |

* Site was monitored as part of the ambient water quality monitoring of the Missouri River at mainstem powerplants.
** Site was monitored as part of the ambient water quality monitoring of the Missouri River mainstem reservoirs.
*** Site was monitored as part of the ambient water quality monitoring of the lower Missouri River.

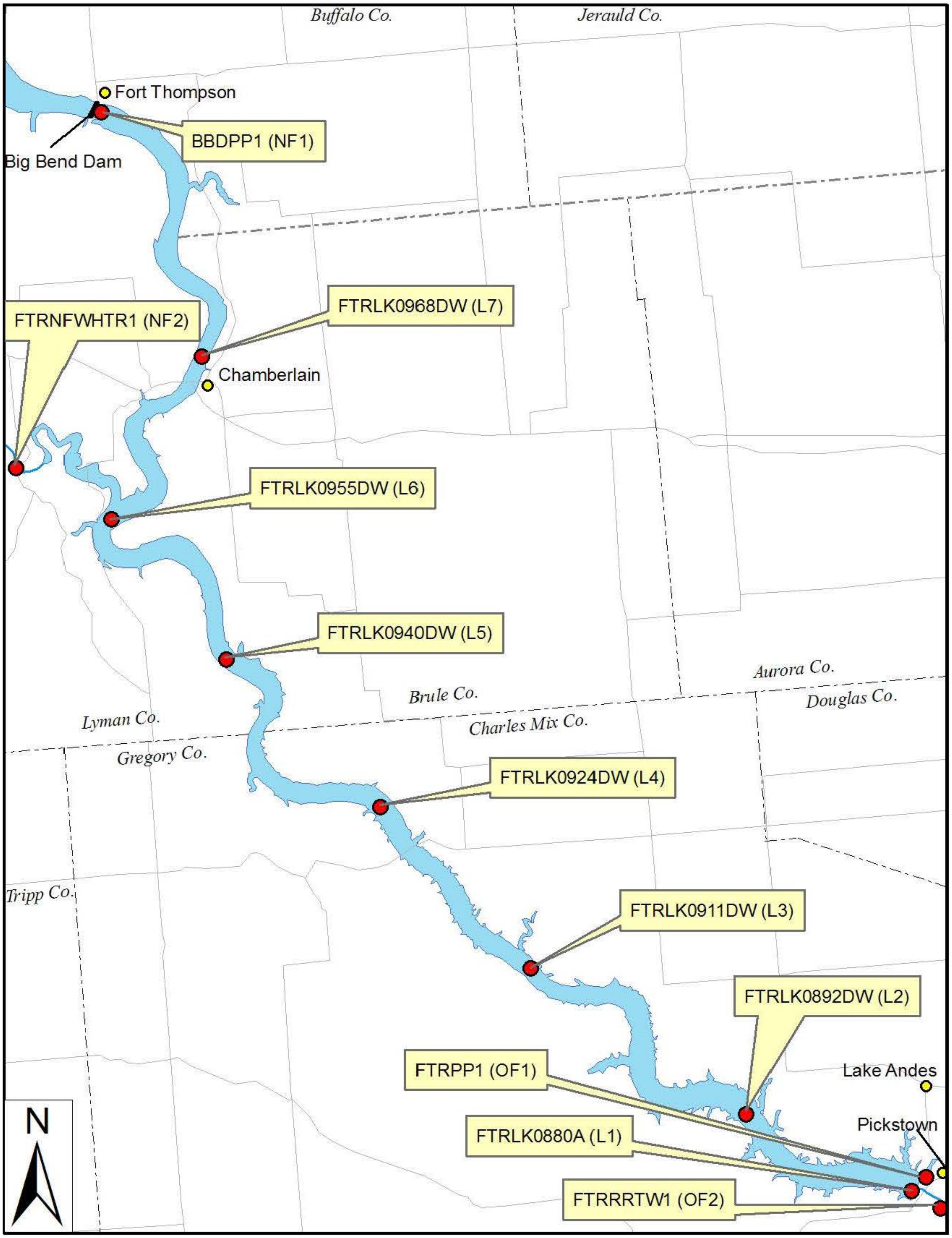


**Figure 3.1.** Location of sites where water quality monitoring was conducted by the Omaha District at the Fort Randall Project during the period 2006 through 2008.

### 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 discrete-depth "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 May through September.

#### 3.1.2.2 Inflow Monitoring Stations

Monitoring at the Big Bend powerplant (i.e., NF1) was collected under a separate project that included sampling at all the Missouri River mainstem powerplants. Monitoring at the Big Bend 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 White River inflow station (i.e., NF2) consisted of field measurements and collection of grab samples. A near-surface grab sample was collected from near the bank in an area of faster current. Monitoring at this site occurred monthly during the period May through September.

#### 3.1.2.3 Outflow Monitoring Station

Monitoring at the Fort Randall powerplant was conducted under the same project which monitored conditions at the Big Bend 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 Fort Randall powerplant the raw water supply is drawn from penstock numbers 2, 4, 6 or 8. From the reservoir raw water passes through the intake structure into the tunnels consisting of a 22-foot diameter concrete tunnel for 107 feet that then transitions into a 22-foot diameter, 692-foot long steel penstock. At this point, the water enters a 14-inch pipe and travels for nine feet to a twin basket strainer and then for an additional 13 feet to the 14-inch raw water supply header. The raw water header runs the length of the powerplant – 560 feet. Raw water is drawn from this header and supplied to the water quality monitoring location (i.e., OF1) through a plastic pipe.

The Fort Randall Dam tailwaters was monitored under a separate project that included sampling of the lower Missouri River from Fort Randall Dam to Rulo, Nebraska. The tailwaters site was located along the left bank (i.e., east bank) of the Missouri River approximately 1 mile downstream from Fort Randall Dam. Monitoring at the tailwaters site included year-round collection of monthly field measurements and samples for laboratory analyses.

### 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.

**Table 3.2.** Parameters measured and analyzed at the various monitoring sites.

| Parameter | L1, L3, L5, L7 | L2, L4, L6 | NF1, OF1 | NF2 | OF2 |
|---|---|---|---|---|---|
| Dissolved Solids, Total | ✓ | | ✓ | ✓ | ✓ |
| Organic Carbon, Total (TOC) | ✓ | | ✓ | ✓ | ✓ |
| Orthophosphorus, Dissolved | ✓ | | ✓ | ✓ | |
| Phosphorus, Total | ✓ | | ✓ | ✓ | ✓ |
| Dissolved Phosphorus, Total | ✓ | | ✓ | ✓ | |
| Nitrate-Nitrite as N, Total | ✓ | | ✓ | ✓ | ✓ |
| Ammonia as N, Total | ✓ | | ✓ | ✓ | ✓ |
| Kjeldahl Nitrogen, Total | ✓ | | ✓ | ✓ | ✓ |
| Suspended Solids, Total | ✓ | | ✓ | ✓ | ✓ |
| Alkalinity | ✓ | | ✓ | ✓ | ✓ |
| Sulfate | ✓ | | ✓ | ✓ | |
| Chloride | | | | | ✓ |
| Chemical Oxygen Demand, Total | | | | | ✓ |
| Chlorophyll a | ✓ | | | | |
| Phytoplankton Biomass and Taxa Identification | ✓ | | | | |
| Iron, Total and Dissolved | ✓ | | ✓ | ✓ | ✓ |
| Manganese, Total and Dissolved | ✓ | | ✓ | ✓ | ✓ |
| Metals and Hardness | | | ✓ | | ✓ |
| Pesticide Scan | | | ✓ | | ✓ |
| Microcystin | ✓ | | | | |
| Secchi Depth/Transparency | ✓ | ✓ | | | |
| Field Measurements (HydroLab)** | Depth Profile | Depth Profile | Grab Sample | Grab Sample | Grab Sample |
| Continuous Monitoring ("HydroLab")*** | | | ✓ | | |

Note: Not all parameters were monitored at all the sites indicated.

** 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.

#### 3.1.3.2 Explanatory Variables

Explanatory variables that were quantified included inflow discharge, outflow discharge, and reservoir pool elevation. Inflow discharge at station NF1 was taken as the recorded discharge at Big Bend Dam. Inflow discharge at station NF2 was determined from the USGS gage (06452000) on the White River near Oacoma, SD. Outflow discharge from Fort Randall Dam and the pool elevation of Fort Randall Reservoir were obtained from Fort Randall Project records.

## 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 4, 4a, and 5 to Directly Measure Water Quality" (USACE, 2008). 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 AND ANALYSIS

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, 2003). 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.

## 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 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 |
| Nitrate/Nitrite, Total as N | EPA - 353.2 | 0.02 mg/l | 0.1 mg/l |
| Ammonia, Total as N | EPA - 350.1 | 0.02 mg/l | 0.1 mg/l |
| Kjeldahl Nitrogen, Total as N | EPA - 351.3 | 0.2 mg/l | 0.5 mg/l |
| Phosphorus, Total as P | SM4500PF | 0.02 mg/l | 0.05 mg/l |
| Phosphorus, Total Dissolved | SM4500PF | 0.02 mg/l | 0.05 mg/l |
| Orthophosphorus | EPA - 365.4 | 0.02 mg/l | 0.05 mg/l |
| Sulfate, Total | EPA - 375.2 | 1 mg/l | 5 mg/l |
| Dissolved Solids, Total | SM2540C | 4 mg/l | 10 mg/l |
| Suspended Solids, Total | SM2540D | 4 mg/l | 10 mg/l |
| Organic Carbon, Total (TOC) | SM5310B | 0.2 mg/l | 1 mg/l |
| Dissolved Metals: | | | |
| Antimony | EPA - 200.8 | 0.5 ug/l | 2 ug/l |
| Arsenic, Silver | EPA - 200.8/200.7 | 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 |
| Total Metals: | | | |
| Iron | EPA - 200.7 | 40 ug/l | 120 ug/l |
| Mercury | EPA - 245.1 | 0.4 ug/l | 1.2 ug/l |
| Selenium | EPA – 200.8 | 1 ug/l | 3 ug/l |
| Chlorophyll *a* | SM - 10200H2 | 1 ug/l | 3 ug/l |
| Pesticide scan*: | EPA - 507 | 0.05 ug/l | 0.1 ug/l |
| Immunoassay – Microcystin | Rapid Assay | 0.2 ug/l | 1 ug/l |

* Pesticide scan included: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chloropyrifos, 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 period 2006 through 2008. 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 Fort Randall Reservoir was evaluated. Longitudinal contour plots were constructed for water temperature, dissolved oxygen, and turbidity to display likely conditions in Fort Randall Reservoir from its upper reaches to Fort Randall 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 Fort Randall Reservoir were evaluated and are displayed using a box plot. The variation of selected parameters with depth was evaluated at site L1 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 ($\alpha = 0.05$).

The phytoplankton community was assessed based on collected grab samples. The collected phytoplankton samples were analyzed by a contract laboratory. Laboratory analyses consisted of identification of phytoplankton taxa to the lowest practical level and quantification of taxa umbers and biovolume. These results were used to determine the relative abundance of phytoplankton taxa at the division level based on the measured biovolumes, and the occurrence of dominant taxa. Dominant taxa were defined as taxa that comprised more than 10 percent of the total biovolume of the collected sample. Collected near-surface reservoir water quality samples were also analyzed for the cyanobacteria toxin microcystin.

## 4.2 TROPHIC STATUS

Reservoirs are commonly classified or grouped by trophic or nutrient status. The natural progression of reservoirs through time is from an oligotrophic (i.e., low nutrient/low productivity) through a mesotrophic (i.e., intermediate nutrient/intermediate productivity) to a eutrophic (i.e., high nutrient/high productivity) condition. The prefixes "ultra" and "hyper" are sometimes added to oligotrophic or eutrophic, respectively, as additional degrees of trophic status. The tendency toward the eutrophic, or nutrient-rich, status is common to all impounded waters. The eutrophication, or enrichment process, can adversely impact water quality conditions in reservoirs (e.g., increased occurrence of algal blooms, noxious odors, and fish kills; reduced water clarity; reduced hypolimnetic dissolved oxygen concentrations; etc.). Eutrophication of reservoirs can be accelerated by nutrient additions through cultural activities (e.g., point-source discharges and nonpoint sources such as runoff from cropland, livestock facilities, urban areas, etc.).

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

TSI(Secchi Depth) = TSI(SD) = 10[6 - (ln SD/ln 2)]
TSI(Chlorophyll *a*) = TSI(Chl) = 10[6 - ((2.04-0.68 ln Chl)/ln 2)]
TSI(Total Phosphorus) = TSI(TP) = 10[6 – (ln (48/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 disk 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 condition 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. Care should be taken if a TSI average score is calculated from the three individual parameter TSI values. If significant differences exist between parameter TSI values, the calculated average value may not be indicative of the trophic condition estimated by the individual parameter values. With this in mind, a TSI average value [TSI(Avg)] calculated as the average of the three individually determined TSI values [i.e., TSI(SD), TSI(Chl), and TSI(TP)] is used by the Omaha District as an overall indicator of a reservoir's trophic state. The Omaha District uses the criteria defined in Table 4.1 for determining reservoir trophic status from TSI values.

**Table 4.1.** Reservoir trophic status based on calculated Trophic State Index (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 Fort Randall Reservoir based on the monitoring conducted during the 3-year period 2006 through 2008. The data evaluated consisted of Secchi depth measurements and total phosphorus and chlorophyll *a* analytical results obtained at the reservoir sites L1, L3, L5, and L7. TSI values were calculated and compared to the above criteria.

## 4.3 IMPAIRMENT OF DESIGNATED WATER QUALITY-DEPENDENT BENEFICIAL USES

Water quality-dependent beneficial uses are designated to waterbodies at the Fort Randall Project by the State of South Dakota in the State's water quality standards, and criteria are defined to protect these uses (see Section 1.4.1.1). Water quality data collected at the Fort Randall Project during the 3-year period 2006 through 2008 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' 2008 Integrated Report for Surface Water Quality Assessment (SDDENR, 2008). A summary of the 2008 beneficial use impairment assessment methods is given in Table 4.2. It is noted that the "official" determination of whether water quality-dependent beneficial uses are impaired, pursuant to the Federal CWA, is by the State of South Dakota pursuant to their Section 305(b) and Section 303(d) assessments compiled in their biennial Integrated Water Quality Report.

**Table 4.2.** Impairment assessment criteria defined by the South Dakota Department of Environment and Natural Resources for preparing the State's 2008 Integrated Report for Surface Water Quality Assessment.

| Parameter | Metric | Waterbody Type | Criteria |
|---|---|---|---|
| Conventional * | Number of observations (samples) required to consider data representative of actual conditions. | Lake | Two separate years of samples for conventional and Trophic State Index (TSI) parameters. Must include at least one Secchi disk and chlorophyll *a* value. Sample dates must be between May 15 and September 15. |
| | | Stream | At least 20 samples for any one parameter are usually required at any site. The sample threshold is reduced 10 samples if greater than 25% of the samples exceed water quality standards since impairment is more likely. In addition, the sample threshold is reduced to 5 samples if 100% of the samples indicate nonsupport for that parameter. |
| | Required percentage of samples exceeding water quality standards in order to consider waterbody impaired. | Lake | Greater than 10% of surface samples (greater than 25% if less than 20 samples available). If one surface exceedence occurs for water temperature, dissolved oxygen, or pH; lake profile data is used to make impairment determinations. Lakes are considered fully supporting the aquatic life beneficial use if profile data indicate a region within the water column where water temperature, pH, and dissolved oxygen meet numeric water quality standards. If a region does not exist the lake is considered impaired. |
| | | Stream | Greater than 10% (greater than 25% if less than 20 samples available). |
| | Data age. | Lake | Data collected from 2000 through 2008. |
| | | Stream | Data must be less than 5 years old. |
| Toxics** | Number of observations (samples) required. | Lake | At least one fish flesh sampling event. |
| | | Stream | At least one water quality sampling event. |
| | Required percentage of samples exceeding water quality standards in order to consider waterbody impaired. | Lake | If fish flesh samples are above the Federal Drug Administration's recommended action levels |
| | | Stream | More than one exceedence of toxic criteria within the past 3 years. |
| | Data age. | Lake | Data collected from 2000 through 2008. |
| | | Streams | Data must be less than 5 years old. |
| Conventional * and Toxics** | Quality Assurance Quality Control | Lakes and Streams | Data meets Quality Assurance and Quality Control requirements similar to those outlined in SDDENR protocols. |

* Conventional parameters are considered to be parameters such as dissolved oxygen, total suspended solids, pH, water temperature, fecal coliform bacteria, etc.

** Toxic parameters are considered to be parameters such as metals, mercury, total ammonia, etc.

## 4.4 TIME-SERIES PLOTS OF FLOW, WATER TEMPERATURE, AND DISSOLVED OXYGEN OF WATER DISCHARGED THROUGH FORT RANDALL DAM

Time series plots were prepared for conditions measured at the Fort Randall Dam powerplant during the 2006 through 2008 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 OF1).

# 5 FORT RANDALL RESERVOIR WATER QUALITY CONDITIONS

## 5.1 EXISTING WATER QUALITY CONDITIONS – 2006 THROUGH 2008

### 5.1.1 STATISTICAL SUMMARY AND WATER QUALITY STANDARDS ATTAINMENT

Tables 5.1 through 5.7 summarize the water quality conditions that were monitored at the seven monitoring sites on Fort Randall Reservoir during the 3-year period of 2006 through 2008. A review of these results did not indicate any significant water quality concerns. A few (< 10%) dissolved oxygen measurements collected along the reservoir were below the water quality standard of 5 mg/l (Tables 5.1 - 5.4 and 5.6). However, these lower dissolved oxygen concentrations were measured near the reservoir bottom and do not indicate impairment to the warmwater fishery use. It is also noted that 10 percent of the samples collected from Fort Randall Reservoir near Elm Creek exceeded the lower suspended solids criterion of 90 mg/l for the protection of the warmwater fishery use (Table 5.5).

### 5.1.2 WATER TEMPERATURE

#### 5.1.2.1 Annual Temperature Regime

The water temperature regime of Fort Randall Reservoir 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 stratification, 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, Fort Randall Reservoir will be inversely stratified from the surface to the bottom as the more dense water (i.e., 4°C) settles to the bottom. When the ice cover melts in the spring, the reservoir will become isothermal at about 4°C, and complete mixing of the reservoir volume will occur as spring turnover takes place. As the reservoir gradually warms in the spring, isothermal conditions (>4°C) will occur as long as sufficient energy (i.e., wind) is present to completely mix the reservoir water column. As the reservoir continues to warm in late spring and early summer, thermal stratification will occur, and a hypolimnion will become established. At some point in mid-summer, the reservoir will reach maximum thermal stratification (i.e., maximum temperature difference between water at the reservoir surface and bottom), and a distinct thermocline will be present. As the reservoir begins to cool in late summer, the epilimnion will expand downward, pushing the thermocline deeper, and the hypolimnetic volume of colder water will decrease. The reservoir will continue to cool until it becomes isothermal and mixing occurs through the entire water column and fall turnover occurs. As the reservoir continues to cool, temperatures will remain relatively isothermal until it cools to 4°C. Ice cover will then be established, and the annual thermal cycle of Fort Randall Reservoir will be completed.

**Table 5.1.** Summary of monthly (May through September) water quality conditions monitored in Fort Randall Reservoir near Fort Randall Dam (site L1) during the 3-year period 2006 through 2008.

| 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 Exceedences | Percent WQS Exceedence |
| Pool Elevation (ft-msl) | 0.1 | 15 | 1354.9 | 1354.9 | 1346.7 | 1361.8 | ----- | ----- | ----- |
| Water Temperature ( C) | 0.1 | 501 | 18.4 | 19.9 | 6.3 | 26.1 | 27[1] | 0 | 0% |
| Dissolved Oxygen (mg/l) | 0.1 | 498 | 8.4 | 8.0 | 2.2 | 11.5 | $\geq 5.0$[1] | 20 | 4% |
| Dissolved Oxygen (% Sat.) | 0.1 | 498 | 91.5 | 94.3 | 26.2 | 107.3 | ---- | ----- | ----- |
| Specific Conductance (umho/cm) | 1 | 501 | 720 | 731 | 622 | 741 | ----- | ----- | ----- |
| pH (S.U.) | 0.1 | 468 | 8.4 | 8.4 | 7.7 | 8.8 | $\geq 6.5$ & $\leq 9.0$[1] | 0 | 0% |
| Turbidity (NTUs) | 1 | 496 | 3 | 2 | n.d. | 32 | ----- | ----- | ----- |
| Oxidation-Reduction Potential (mV) | 1 | 501 | 334 | 328 | 253 | 427 | ----- | ----- | ----- |
| Secchi Depth (in.) | 1 | 15 | 110 | 92 | 56 | 229 | ----- | ----- | ----- |
| Alkalinity, Total (mg/l) | 7 | 28 | 159 | 158 | 140 | 180 | ----- | ----- | ----- |
| Ammonia, Total (mg/l) | 0.02 | 28 | ----- | 0.02 | n.d. | 0.20 | 2.6 [1,2,3], 1.2 [1,2,4] | 0 | 0% |
| Carbon, Total Organic (mg/l) | 0.05 | 26 | 3.0 | 3.1 | 1.7 | 3.6 | ----- | ----- | ----- |
| Chemical Oxygen Demand (mg/l) | 2 | 28 | 10 | 11 | n.d. | 21 | ----- | ----- | ----- |
| Chloride (mg/l) | 1 | 28 | 11 | 11 | 10 | 12 | ----- | ----- | ----- |
| Chlorophyll *a* (ug/l) – Field Probe | 1 | 460 | 2 | 1 | n.d. | 8 | ----- | ----- | ----- |
| Chlorophyll *a* (ug/l) – Lab Determined | 1 | 14 | 3 | 2 | 1 | 9 | ----- | ----- | ----- |
| Dissolved Solids, Total (mg/l) | 4 | 28 | 476 | 473 | 450 | 500 | 1,750[5] | 0 | 0% |
| Iron, Total (ug/l) | 40 | 19 | 85 | 90 | n.d. | 194 | ----- | ----- | ----- |
| Kjeldahl N, Total (mg/l) | 0.1 | 28 | 0.4 | 0.3 | n.d. | 0.8 | ----- | ----- | ----- |
| Manganese, Total (ug/l) | 2 | 19 | 36 | 19 | n.d. | 141 | ----- | ----- | ----- |
| Nitrate-Nitrite N, Total (mg/l) | 0.02 | 28 | ----- | n.d. | n.d. | 0.24 | 10[5] | 0 | 0% |
| Phosphorus, Dissolved (mg/l) | 0.02 | 28 | ----- | n.d. | n.d. | 0.08 | ----- | ----- | ----- |
| Phosphorus, Total (mg/l) | 0.02 | 28 | 0.05 | 0.03 | n.d. | 0 25 | ----- | ----- | ----- |
| Phosphorus-Ortho, Dissolved (mg/l) | 0.02 | 28 | ----- | n.d. | n.d. | 0.06 | ----- | ----- | ----- |
| Sulfate (mg/l) | 1 | 28 | 208 | 206 | 176 | 230 | 875[5] | 0 | 0% |
| Suspended Solids, Total (mg/l) | 4 | 28 | ----- | n.d. | n.d. | 6 | 158[1,3], 90[1,4] | 0 | 0% |
| Microcystin, Total (ug/l) | 0.2 | 14 | ----- | n.d. | n.d. | 1.8 | ----- | ----- | ----- |

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 microcystins 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, Turbidity, Oxidation-Reduction Potential, and Secchi Depth are actually resolution limits for field measured parameters.

(C) Non-detect values set to 0 to calculate mean. The mean is not reported if 20% or more of the observations were non-detect. The mean value reported for pH is an arithmetic mean based on measured values (i.e , log conversion of logarithmic pH values was not done to calculate mean).

(D) (1) Criteria for warmwater permanent fish life propagation waters.
(2) Total ammonia criteria are pH and temperature dependent. Criteria listed are for median pH and temperature values.
(3) Acute criterion for freshwater aquatic life.
(4) Chronic criterion for freshwater aquatic life.
(5) Daily maximum criterion for domestic water supply.

**Table 5.2.** Summary of monthly (June through September) water quality conditions monitored in Fort Randall Reservoir near Pease Creek (site L2) during the 3-year period 2006 through 2008.

| Parameter | Monitoring Results[A] | | | | | | Water Quality Standards Attainment | | |
|---|---|---|---|---|---|---|---|---|---|
| | Resolution Limit[B] | No. of Obs. | Mean[C] | Median | Min. | Max. | State WQS Criteria[D] | No. of WQS Exceedences | Percent WQS Exceedence |
| Pool Elevation (ft-msl) | 0.1 | 12 | 1354.0 | 1354.4 | 1346.7 | 1362.0 | ----- | ----- | ----- |
| Water Temperature ( C) | 0.1 | 346 | 21.2 | 21.4 | 9.7 | 26.2 | 27[1] | 0 | 0% |
| Dissolved Oxygen (mg/l) | 0.1 | 345 | 7.7 | 7.9 | 1.5 | 9.8 | $\geq 5.0$[1] | 19 | 6% |
| Dissolved Oxygen (% Sat.) | 0.1 | 345 | 89.8 | 93.3 | 18.0 | 104.5 | ----- | ----- | ----- |
| Specific Conductance (umho/cm) | 1 | 346 | 728 | 730 | 698 | 740 | ----- | ----- | ----- |
| pH (S.U.) | 0.1 | 317 | 8.4 | 8.4 | 7.7 | 8.8 | $\geq 6.5$ & $\leq 9.0$[1] | 0 | 0% |
| Turbidity (NTUs) | 0.1 | 345 | 3 | 2 | n.d. | 23 | ----- | ----- | ----- |
| Oxidation-Reduction Potential (mV) | 1 | 346 | 329 | 320 | 252 | 427 | ----- | ----- | ----- |
| Chlorophyll *a* (ug/l) – Field Probe | 1 | 341 | 2 | 1 | n.d. | 5 | ----- | ----- | ----- |
| Secchi Depth (in) | 1 | 11 | 107 | 96 | 56 | 194 | ----- | ----- | ----- |

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.

(B) Resolution limits for field measured parameters.

(C) Non-detect values set to 0 to calculate mean. The mean is not reported if 20% or more of the observations were non-detect. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(D) (1) Criteria for warmwater permanent fish life propagation waters.

**Table 5.3.** Summary of monthly (June through September) water quality conditions monitored in Fort Randall Reservoir near Platte Creek (site L3) during the 3-year period 2006 through 2008.

| 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 Exceedences | Percent WQS Exceedence |
| Pool Elevation (ft-msl) | 0.1 | 12 | 1354.0 | 1354.4 | 1346.7 | 1361.9 | ----- | ----- | ----- |
| Water Temperature ( C) | 0.1 | 291 | 21.6 | 22.1 | 10.8 | 26.5 | 27[1] | 0 | 0% |
| Dissolved Oxygen (mg/l) | 0.1 | 291 | 7.7 | 7.9 | 0.9 | 9.7 | ≥ 5.0[1] | 9 | 3% |
| Dissolved Oxygen (% Sat.) | 0.1 | 291 | 90.2 | 92.9 | 10.4 | 106.3 | ---- | ----- | ----- |
| Specific Conductance (umho/cm) | 1 | 291 | 724 | 725 | 703 | 743 | ----- | ----- | ----- |
| pH (S.U.) | 0.1 | 267 | 8.4 | 8.5 | 7.7 | 8.8 | ≥ 6.5 & ≤ 9.0[1] | 0 | 0% |
| Turbidity (NTUs) | 1 | 291 | 5 | 4 | 1 | 26 | ----- | ----- | ----- |
| Oxidation-Reduction Potential (mV) | 1 | 291 | 325 | 309 | 247 | 425 | ----- | ----- | ----- |
| Secchi Depth (in.) | 1 | 12 | 80 | 74 | 48 | 148 | ----- | ----- | ----- |
| Alkalinity, Total (mg/l) | 7 | 23 | 161 | 156 | 110 | 319 | ----- | ----- | ----- |
| Ammonia, Total (mg/l) | 0.02 | 23 | ----- | 0.03 | n.d. | 0.23 | 2.1 [1,2,3], 1.0 [1,2,4] | 0 | 0% |
| Carbon, Total Organic (mg/l) | 0.05 | 21 | 3.0 | 2.9 | 2.2 | 3.7 | ----- | ----- | ----- |
| Chemical Oxygen Demand (mg/l) | 2 | 23 | 11 | 12 | n.d. | 19 | ----- | ----- | ----- |
| Chloride (mg/l) | 1 | 23 | 11 | 11 | 9 | 12 | ----- | ----- | ----- |
| Chlorophyll *a* (ug/l) – Field Probe | 1 | 282 | 3 | 2 | n.d. | 11 | ----- | ----- | ----- |
| Chlorophyll *a* (ug/l) – Lab Determined | 1 | 12 | 5 | 5 | 2 | 10 | ----- | ----- | ----- |
| Dissolved Solids, Total (mg/l) | 4 | 23 | 478 | 480 | 448 | 510 | 1,750[5] | 0 | 0% |
| Iron, Total (ug/l) | 40 | 19 | 113 | 100 | 40 | 240 | ----- | ----- | ----- |
| Kjeldahl N, Total (mg/l) | 0.1 | 23 | 0.4 | 0.3 | n.d. | 0.9 | ----- | ----- | ----- |
| Manganese, Total (ug/l) | 2 | 19 | 45 | 32 | 10 | 160 | ----- | ----- | ----- |
| Nitrate-Nitrite N, Total (mg/l) | 0.02 | 23 | ----- | n.d. | n.d. | 0.19 | 10[5] | 0 | 0% |
| Phosphorus, Dissolved (mg/l) | 0.02 | 23 | ----- | n.d. | n.d. | 0.05 | ----- | ----- | ----- |
| Phosphorus, Total (mg/l) | 0.02 | 23 | ----- | 0.04 | n.d. | 0.11 | ----- | ----- | ----- |
| Phosphorus-Ortho, Dissolved (mg/l) | 0.02 | 23 | ----- | n.d. | n.d. | 0.03 | ----- | ----- | ----- |
| Sulfate (mg/l) | 1 | 23 | 208 | 206 | 180 | 270 | 875[5] | 0 | 0% |
| Suspended Solids, Total (mg/l) | 4 | 23 | ----- | n.d. | n.d. | 15 | 158[1,3], 90[1,4] | 0 | 0% |
| Microcystin, Total (ug/l) | 0.2 | 12 | ----- | n.d. | n.d. | 0.3 | ----- | ----- | ----- |

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 microcystins 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, Turbidity, Oxidation-Reduction Potential, and Secchi Depth are actually resolution limits for field measured parameters.

(C) Non-detect values set to 0 to calculate mean. The mean is not reported if 20% or more of the observations were non-detect. The mean value reported for pH is an arithmetic mean based on measured values (i.e , log conversion of logarithmic pH values was not done to calculate mean).

(D) (1) Criteria for warmwater permanent fish life propagation waters.
(2) Total ammonia criteria are pH and temperature dependent. Criteria listed are for median pH and temperature values.
(3) Acute criterion for freshwater aquatic life.
(4) Chronic criterion for freshwater aquatic life
(5) Daily maximum criterion for domestic water supply.

**Table 5.4.** Summary of monthly (June through September) water quality conditions monitored in Fort Randall Reservoir near Snake Creek (site L4) during the 3-year period 2006 through 2008.

| Parameter | Monitoring Results[A] | | | | | | Water Quality Standards Attainment | | |
|---|---|---|---|---|---|---|---|---|---|
| | Resolution Limit[B] | No. of Obs. | Mean[C] | Median | Min. | Max. | State WQS Criteria[D] | No. of WQS Exceedences | Percent WQS Exceedence |
| Pool Elevation (ft-msl) | 0.1 | 12 | 1354.0 | 1354.4 | 1347.1 | 1362.0 | ----- | ----- | ----- |
| Water Temperature ( C) | 0.1 | 214 | 22.2 | 22.9 | 11.6 | 27.2 | 27[1] | 1 | <1% |
| Dissolved Oxygen (mg/l) | 0.1 | 214 | 7.9 | 7.9 | 3.2 | 9.5 | ≥ 5.0[1] | 1 | <1% |
| Dissolved Oxygen (% Sat.) | 0.1 | 214 | 93.7 | 94.7 | 39.4 | 114.4 | ----- | ----- | ----- |
| Specific Conductance (umho/cm) | 1 | 214 | 721 | 720 | 693 | 738 | ----- | ----- | ----- |
| pH (S.U.) | 0.1 | 196 | 8.4 | 8.5 | 7.8 | 8.6 | ≥ 6.5 & ≤ 9.0[1] | 0 | 0% |
| Turbidity (NTUs) | 0.1 | 213 | 9 | 8 | 2 | 58 | ----- | ----- | ----- |
| Oxidation-Reduction Potential (mV) | 1 | 214 | 330 | 314 | 255 | 498 | ----- | ----- | ----- |
| Chlorophyll *a* (ug/l) – Field Probe | 1 | 211 | 3 | 2 | n.d. | 21 | ----- | ----- | ----- |
| Secchi Depth (in) | 1 | 12 | 47 | 47 | 25 | 84 | ----- | ----- | ----- |

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.

(B) Resolution limits for field measured parameters.

(C) Non-detect values set to 0 to calculate mean. The mean is not reported if 20% or more of the observations were non-detect. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(D) (1) Criteria for warmwater permanent fish life propagation waters.

**Table 5.5.** Summary of monthly (June through September) water quality conditions monitored in Fort Randall Reservoir near Elm Creek (site L5) during the 3-year period 2006 through 2008.

| 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 Exceedences | Percent WQS Exceedence |
| Pool Elevation (ft-msl) | 0.1 | 10 | 1354.8 | 1354.7 | 1347.1 | 1361.9 | ----- | ----- | ----- |
| Water Temperature ( C) | 0.1 | 53 | 22.8 | 24.6 | 13.8 | 26.4 | 27[1] | 0 | 0% |
| Dissolved Oxygen (mg/l) | 0.1 | 53 | 8.3 | 8.1 | 7.6 | 9.2 | ≥ 5.0[1] | 0 | 0% |
| Dissolved Oxygen (% Sat.) | 0.1 | 53 | 100.3 | 99.4 | 82.1 | 115.1 | ---- | ----- | ----- |
| Specific Conductance (umho/cm) | 1 | 53 | 721 | 719 | 701 | 738 | ----- | ----- | ----- |
| pH (S.U.) | 0.1 | 47 | 8.4 | 8.5 | 8.1 | 8.6 | ≥ 6.5 & ≤ 9.0[1] | 0 | 0% |
| Turbidity (NTUs) | 1 | 53 | 28 | 14 | 3 | 284 | ----- | ----- | ----- |
| Oxidation-Reduction Potential (mV) | 1 | 53 | 316 | 312 | 265 | 400 | ----- | ----- | ----- |
| Secchi Depth (in.) | 1 | 9 | 26 | 24 | 7 | 52 | ----- | ----- | ----- |
| Alkalinity, Total (mg/l) | 7 | 20 | 155 | 158 | 131 | 170 | ----- | ----- | ----- |
| Ammonia, Total (mg/l) | 0.02 | 20 | ----- | 0.02 | n.d. | 0.24 | 2.6 [1,2,3], 1.2 [1,2,4] | 0 | 0% |
| Carbon, Total Organic (mg/l) | 0.05 | 18 | 3.1 | 3.2 | 1.7 | 4.0 | ----- | ----- | ----- |
| Chemical Oxygen Demand (mg/l) | 2 | 20 | 14 | 14 | 4 | 30 | ----- | ----- | ----- |
| Chloride (mg/l) | 1 | 20 | 11 | 11 | 9 | 12 | ----- | ----- | ----- |
| Chlorophyll *a* (ug/l) – Field Probe | 1 | 53 | 4 | 4 | n.d. | 11 | ----- | ----- | ----- |
| Chlorophyll *a* (ug/l) – Lab Determined | 1 | 10 | 7 | 8 | n.d. | 10 | ----- | ----- | ----- |
| Dissolved Solids, Total (mg/l) | 4 | 20 | 470 | 467 | 444 | 540 | 1,750[5] | 0 | 0% |
| Iron, Total (ug/l) | 40 | 17 | 851 | 391 | 110 | 4,321 | ----- | ----- | ----- |
| Kjeldahl N, Total (mg/l) | 0.1 | 20 | 0.5 | 0.4 | n.d. | 1.0 | ----- | ----- | ----- |
| Manganese, Total (ug/l) | 2 | 17 | 48 | 30 | 10 | 193 | ----- | ----- | ----- |
| Nitrate-Nitrite N, Total (mg/l) | 0.02 | 20 | ----- | n.d. | n.d. | 0.30 | 10[5] | 0 | 0% |
| Phosphorus, Dissolved (mg/l) | 0.02 | 20 | ----- | n.d. | n.d. | 0.04 | ----- | ----- | ----- |
| Phosphorus, Total (mg/l) | 0.02 | 20 | 0.05 | 0.05 | n.d. | 0 13 | ----- | ----- | ----- |
| Phosphorus-Ortho, Dissolved (mg/l) | 0.02 | 20 | ----- | n.d. | n.d. | 0.03 | ----- | ----- | ----- |
| Sulfate (mg/l) | 1 | 20 | 205 | 204 | 176 | 230 | 875[5] | 0 | 0% |
| Suspended Solids, Total (mg/l) | 4 | 20 | 21 | 7 | n.d. | 140 | 158[1,3], 90[1,4] | 0, 2 | 0%, 10% |
| Microcystin, Total (ug/l) | 0.2 | 10 | ----- | n.d. | n.d. | 0.2 | ----- | ----- | ----- |

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 microcystins 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, Turbidity, Oxidation-Reduction Potential, and Secchi Depth are actually resolution limits for field measured parameters.

(C) Non-detect values set to 0 to calculate mean. The mean is not reported if 20% or more of the observations were non-detect. The mean value reported for pH is an arithmetic mean based on measured values (i.e , log conversion of logarithmic pH values was not done to calculate mean).

(D) (1) Criteria for warmwater permanent fish life propagation waters.

(2) Total ammonia criteria are pH and temperature dependent. Criteria listed are for median pH and temperature values.

(3) Acute criterion for freshwater aquatic life.

(4) Chronic criterion for freshwater aquatic life

(5) Daily maximum criterion for domestic water supply.

**Table 5.6.** Summary of monthly (June through September) water quality conditions monitored in Fort Randall Reservoir near the White River (site L6) during the 3-year period 2006 through 2008.

| Parameter | Monitoring Results[A] | | | | | | Water Quality Standards Attainment | | |
|---|---|---|---|---|---|---|---|---|---|
| | Resolution Limit[B] | No. of Obs. | Mean[C] | Median | Min. | Max. | State WQS Criteria[D] | No. of WQS Exceedences | Percent WQS Exceedence |
| Pool Elevation (ft-msl) | 0.1 | 12 | 1354.0 | 1354.3 | 1347.1 | 1361.6 | ----- | ----- | ----- |
| Water Temperature ( C) | 0.1 | 50 | 22.6 | 24.4 | 14.9 | 26.0 | 27[1] | 0 | 0% |
| Dissolved Oxygen (mg/l) | 0.1 | 49 | 8.1 | 8.1 | 0.1 | 9.5 | ≥ 5.0[1] | 1 | 2% |
| Dissolved Oxygen (% Sat.) | 0.1 | 49 | 96.9 | 100.8 | 1.6 | 104.1 | ----- | ----- | ----- |
| Specific Conductance (umho/cm) | 1 | 50 | 706 | 704 | 559 | 735 | ----- | ----- | ----- |
| pH (S.U.) | 0.1 | 45 | 8.4 | 8.5 | 8.0 | 8.7 | ≥ 6.5 & ≤ 9.0[1] | 0 | 0% |
| Turbidity (NTUs) | 0.1 | 47 | 33 | 20 | 8 | 210 | ----- | ----- | ----- |
| Oxidation-Reduction Potential (mV) | 1 | 50 | 354 | 311 | 250 | 614 | ----- | ----- | ----- |
| Chlorophyll *a* (ug/l) – Field Probe | 1 | 49 | 5 | 4 | n.d. | 12 | ----- | ----- | ----- |
| Secchi Depth (in) | 1 | 11 | 20 | 18 | 11 | 32 | ----- | ----- | ----- |

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.

(B) Resolution limits for field measured parameters.

(C) Non-detect values set to 0 to calculate mean. The mean is not reported if 20% or more of the observations were non-detect. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(D) (1) Criteria for warmwater permanent fish life propagation waters.

**Table 5.7.** Summary of monthly (June through September) water quality conditions monitored in Fort Randall Reservoir near Chamberlain, SD (site L7) during the 3-year period 2006 through 2008.

| 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 Exceedences | Percent WQS Exceedence |
| Pool Elevation (ft-msl) | 0.1 | 12 | 1354.0 | 1354.3 | 1347.1 | 1361.6 | ----- | ----- | ----- |
| Water Temperature ( C) | 0.1 | 75 | 22 1 | 23.6 | 15.6 | 28.3 | 27(1) | 1 | 1% |
| Dissolved Oxygen (mg/l) | 0.1 | 75 | 8.4 | 8.3 | 7.6 | 9.4 | ≥ 5.0(1) | 0 | 0% |
| Dissolved Oxygen (% Sat.) | 0.1 | 75 | 99.7 | 99.6 | 92.4 | 112.1 | ---- | ----- | ----- |
| Specific Conductance (umho/cm) | 1 | 75 | 715 | 720 | 672 | 746 | ----- | ----- | ----- |
| pH (S.U.) | 0.1 | 69 | 8 5 | 8.4 | 8.1 | 8.7 | ≥ 6.5 & ≤ 9.0(1) | 0 | 0% |
| Turbidity (NTUs) | 0.1 | 75 | 17 | 12 | 6 | 40 | ----- | ----- | ----- |
| Oxidation-Reduction Potential (mV) | 1 | 75 | 340 | 308 | 258 | 545 | ----- | ----- | ----- |
| Secchi Depth (in.) | 1 | 11 | 23 | 24 | 14 | 32 | ----- | ----- | ----- |
| Alkalinity, Total (mg/l) | 7 | 24 | 158 | 160 | 140 | 170 | ----- | ----- | ----- |
| Ammonia, Total (mg/l) | 0.02 | 24 | ----- | 0.03 | n.d. | 0.22 | 2.6 (1,2,3), 1.2 (1,2,4) | 0 | 0% |
| Carbon, Total Organic (mg/l) | 0.05 | 22 | 2 9 | 2.9 | 1.5 | 5 3 | ----- | ----- | ----- |
| Chemical Oxygen Demand (mg/l) | 2 | 24 | 11 | 12 | n.d. | 20 | ----- | ----- | ----- |
| Chloride (mg/l) | 1 | 24 | 11 | 11 | 9 | 13 | ----- | ----- | ----- |
| Chlorophyll *a* (ug/l) – Field Probe | 1 | 74 | 4 | 4 | 1 | 12 | ----- | ----- | ----- |
| Chlorophyll *a* (ug/l) – Lab Determined | 1 | 11 | 7 | 6 | 1 | 16 | ----- | ----- | ----- |
| Dissolved Solids, Total (mg/l) | 5 | 24 | 490 | 483 | 450 | 582 | 1,750(5) | 0 | 0% |
| Iron, Total (ug/l) | 40 | 20 | 453 | 448 | 130 | 830 | ----- | ----- | ----- |
| Kjeldahl N, Total (mg/l) | 0.1 | 24 | 0.6 | 0.4 | 0.2 | 2.5 | ----- | ----- | ----- |
| Manganese, Total (ug/l) | 1 | 20 | 61 | 60 | 30 | 110 | ----- | ----- | ----- |
| Nitrate-Nitrite N, Total (mg/l) | 0.02 | 24 | ----- | n.d. | n.d. | 0.11 | 10(5) | 0 | 0% |
| Phosphorus, Dissolved (mg/l) | 0.02 | 24 | ----- | 0.02 | n.d. | 0.08 | ----- | ----- | ----- |
| Phosphorus, Total (mg/l) | 0.02 | 24 | 0.07 | 0.05 | n.d. | 0.31 | ----- | ----- | ----- |
| Phosphorus-Ortho, Dissolved (mg/l) | 0.02 | 24 | ----- | n.d. | n.d. | 0.04 | ----- | ----- | ----- |
| Sulfate (mg/l) | 1 | 24 | 201 | 202 | 173 | 230 | 875(5) | 0 | 0% |
| Suspended Solids, Total (mg/l) | 4 | 24 | 12 | 12 | n.d. | 27 | 158(1,3), 90(1,4) | 0 | 0% |
| Microcystin, Total (ug/l) | 0.2 | 12 | ----- | n.d. | n.d. | 0.3 | ----- | ----- | ----- |

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 microcystins 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, Turbidity, Oxidation-Reduction Potential, and Secchi Depth are actually resolution limits for field measured parameters.

(C) Non-detect values set to 0 to calculate mean. The mean is not reported if 20% or more of the observations were non-detect. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(D) (1) Criteria for warmwater permanent fish life propagation waters.

(2) Total ammonia criteria are pH and temperature dependent. Criteria listed are for median pH and temperature values.

(3) Acute criterion for freshwater aquatic life.

(4) Chronic criterion for freshwater aquatic life

(5) Daily maximum criterion for domestic water supply.

### 5.1.2.2 <u>Spatial Variation</u>

Monthly (i.e., June, July, August, and September) longitudinal temperature contour plots of Fort Randall Reservoir were constructed for the 3-year period 2006 through 2008 (Plates 1 - 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 that temperatures in Fort Randall Reservoir varied longitudinally from the dam to the reservoir's upper reaches and vertically from the reservoir surface to the bottom (Plates 1 - 12). The Big Bend Dam discharge and the White River inflow appear to have an appreciable influence on the water temperatures in the upper reaches of Fort Randall Reservoir (Plates 1 - 12). Near-surface waters in the middle reaches of the reservoir generally had the warmest temperatures during the summer (Plates 2, 3, 6, 7, 10, and 11). Vertical variation in temperature was most prevalent in the deeper area of the reservoir in the vicinity of Fort Randall Dam where a strong thermocline became established from mid-June through early-August (Plates 1, 2, 5, 6, 10, and 11). By late August to early September, the thermocline had dissipated and the reservoir in the vicinity of the dam was fairly well mixed through the water column (Plate 3, 4, 7, 8, and 12). Wind action seemingly allowed for complete mixing of the water column in the shallower upper reaches of Fort Randall Reservoir during the summer (Plates 1 - 12).

#### 5.1.2.3 Summer Thermal Stratification

Fort Randall Reservoir exhibited significant thermal stratification during the summer of all 3 years (Plates 1, 2, 5, 6, 10, and 11). During maximum stratification in mid-summer, the thermocline in Fort Randall Reservoir in 2006, 2007, and 2008 was at a depth of about 22 meters (72 feet). The depth of the thermocline defines the upper limit of the hypolimnion. Where the corresponding elevation of the thermocline intersects the reservoir bottom defines the longitudinal boundary of the hypolimnion in the upper reaches of Fort Randall Reservoir. During 2006 through 2008, the longitudinal boundary of the hypolimnion was around River Mile 920. Taking the slope of the reservoir bottom to be about 1 foot/mile along the old Missouri River channel, every foot of elevation increase in the pool elevation would extend the boundary of the hypolimnion about 1 mile up the reservoir.

### 5.1.3 DISSOLVED OXYGEN

#### 5.1.3.1 Spatial Variation

Monthly (i.e., June, July, August, and September) longitudinal dissolved oxygen contour plots of Fort Randall Reservoir were constructed for the 3-year period 2006 through 2008 (Plates 13 - 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 lower reservoir in July and August (Plates 2, 3, 6, 7, 10, and 11). The area of low dissolved oxygen occurred along the reservoir bottom in the hypolimnion, and generally did not exhibit appreciable longitudinal variability through the hypolimnion. The area of low dissolved oxygen dissipated in August when thermal stratification broke down and reservoir mixing occurred.

### 5.1.4 WATER CLARITY

#### 5.1.4.1 Secchi Transparency

Figure 5.1 displays a box plot of the Secchi depth transparencies measured in Fort Randall Reservoir during the 3-year period 2006 through 2008. The measurements were taken at the seven reservoir monitoring sites located along the submerged old Missouri River channel at River Miles 968, 955, 940, 924, 911, 892, and 880. The monitoring site near RM968 was approximately 21 miles downstream of Big Bend Dam. The inflow of the White River to Fort Randall Reservoir was just upstream of the monitoring site near RM955. Secchi depth transparency generally increased in a downstream direction from the upper reaches of the reservoir to near the dam (Figure 5.1). However, the inflow of the White River did slightly reduced the transparency of the reservoir from levels measured upstream of the inflow. The near-surface transparency of Fort Randall Reservoir measured near the dam was significantly higher than the transparency measured in upstream reaches of the reservoir (Figure 5.1).

#### 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 Fort Randall Reservoir were constructed for the 3-year period 2006 through 2007 (Plates 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 Fort Randall Reservoir vary longitudinally and vertically. The inflow of the White River near RM955 significantly influences the turbidity of Fort Randall Reservoir in the area near the inflow of the River (Plates 25 - 36). Elevated levels of turbidity attributable to the inflow of the White River were regularly seen in Fort Randall Reservoir up to 25 miles downstream from the White River inflow (Plates 25, 28, 30, 31, 32, 33, 34, and 36). Turbidity levels in Fort Randall Reservoir near the dam were typically quite low. Given the low chlorophyll *a* concentrations monitored during the 3-year period, (Tables 5.1 through 5.7), the variable turbidity in the reservoir is believed to be largely due to suspended inorganic material delivered by the White River; especially during runoff events.

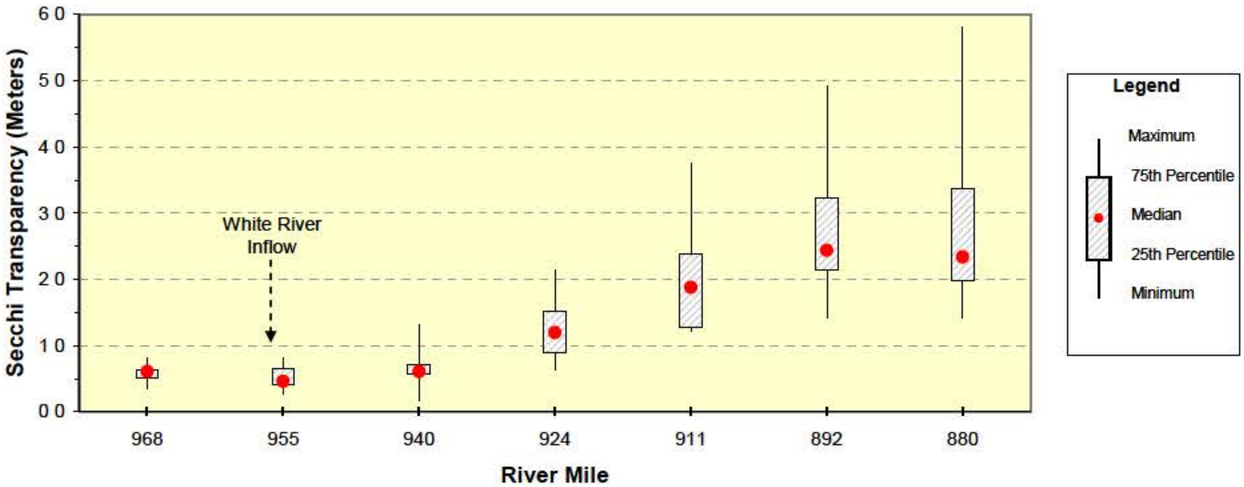


**Figure 5.1.** Box plot of Secchi depth transparencies measured in Fort Randall Reservoir at monitoring sites located along the submerged old Missouri River channel at River Miles 968, 955, 940, 924, 911, 892, and 880 during the 3-year period 2006 through 2008.

### 5.1.5 COMPARISON OF NEAR-SURFACE AND NEAR-BOTTOM WATER QUALITY CONDITIONS

Near-surface and near-bottom water quality conditions were monitored in Fort Randall Reservoir in the near-dam area over the 3-year period 2006 through 2008. Paired near-surface and near-bottom water quality samples collected monthly from May through September at site FTRLK0880A (L1) were compared. Near-surface samples were defined to be samples collected within 2 meters of the reservoir surface, and near-bottom samples were defined as samples collected within 1 meter of the reservoir bottom. During the 3-year period a total of 15 paired samples were collected monthly from May through September. Of the 15 paired samples collected, four had near-bottom samples with less than the 5 mg/l dissolved oxygen criterion for aquatic life protection. None of the near-bottom samples of 15 paired samples were hypoxic (i.e., < 2.5 mg/l dissolved oxygen). Box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature *(15)*, dissolved oxygen *(15)*, oxidation-reduction potential *(15)*, pH *(14)*, total alkalinity *(14)*, total organic carbon *(13)*, total Kjeldahl nitrogen *(14)*, total ammonia *(14)*, and total phosphorus *(14)* (Figure 5.2). *[Note: the number in parentheses is the number of paired samples available for each parameter.]* 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 not found to be significantly different for total alkalinity, total organic carbon, total Kjeldahl nitrogen, total ammonia, or total phosphorus Parameters that were found to be significantly lower in the near-bottom water of Fort Randall Reservoir included: water temperature ($p < 0.001$), dissolved oxygen ($p < 0.01$) and pH ($p < 0.01$). One parameter, oxidation-reduction potential, was found to be significantly higher ($p < 0.001$) in the near-bottom water.

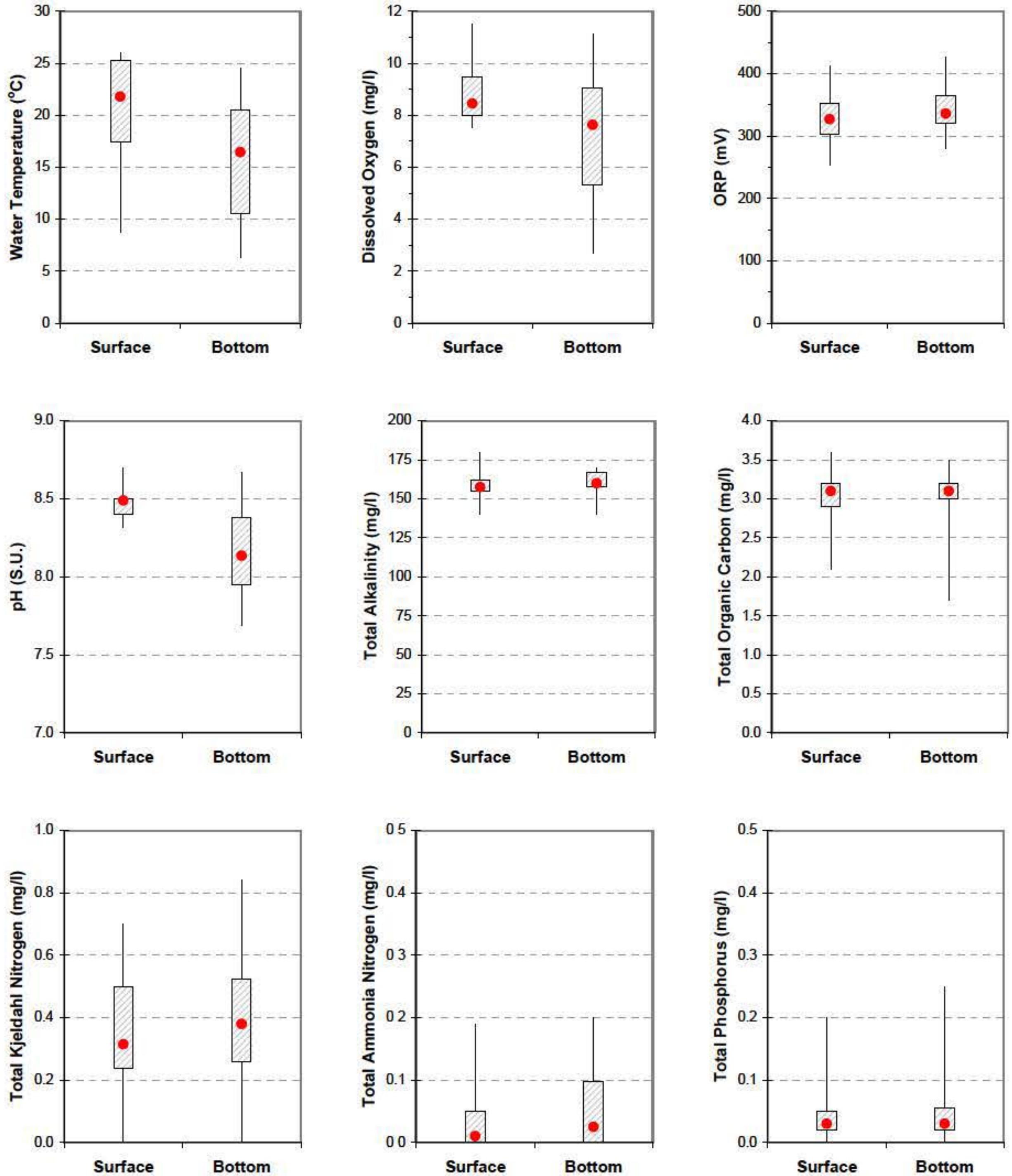


**Figure 5.2.** Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total organic carbon, total Kjeldahl nitrogen, total ammonia nitrogen, and total phosphorus monitored in Fort Randall Reservoir at site L1 monthly, May through September, during the 3-year period 2006 through 2008. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

### 5.1.6 TROPHIC STATUS

Trophic State Index (TSI) values for Fort Randall Reservoir were calculated from the monitoring data collected at sites L1, L3, L5, and L7 during the 3-year period 2006 through 2008 (Table 5.8). The calculated TSI values indicate that region of Fort Randall Reservoir represented by site L1 is in a mesotrophic state, the region represented by site L3 is in a moderately eutrophic state, and the upstream region of the reservoir represented by sites L5 and L7 is in a eutrophic state.

**Table 5.8.** Mean Trophic State Index (TSI) values calculated for Fort Randall Reservoir based on measured Secchi depth, total phosphorus, and chlorophyll *a* values collected at sites L1, L3, L5, and L7 during the 3-year period 2006 through 2008.

| Site | No. of Obs. | Mean – TSI (Secchi Depth) | Mean – TSI (Total Phos.) | Mean – TSI (Chlorophyll) | Mean – TSI (Average) |
|---|---|---|---|---|---|
| L1 | 15 | 46 | 53 | 47 | 49 |
| L3 | 12 | 51 | 51 | 54 | 52 |
| L5 | 10 | 68 | 54 | 57 | 59 |
| L7 | 12 | 68 | 57 | 56 | 60 |

### 5.1.7 PHYTOPLANKTON COMMUNITY

Phytoplankton grab samples collected from Fort Randall Reservoir at sites L1, L3, L5, and L7 during May through September over the 3-year period 2006 through 2008 are summarized in Plates 37 through 40. 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 general prevalence of these taxonomic divisions in the reservoir, based on taxa occurrence, were Bacillariophyta > Chlorophyta > Cyanobacteria > Cryptophyta > Chrysophyta > Pyrrophyta > Euglenophyta. The diatoms were generally the most abundant algae based on percent composition (Plates 37 - 40). The Shannon-Weaver genera diversity indices calculated for the 49 phytoplankton samples collected at the four sites ranged from 0.27 to 2.86 and averaged 1.37 at site L1, 1.53 at site L3, 1.76 at site L5, and 1.53 at site L7. Dominant phytoplankton species (i.e., ≥ 10% of the total sample biovolume) occurring in the 15 samples collected at site L1 included the Bacillariophyta *Fragilaria sp.* (15 occasions), *Aulacoseira sp.* (7 occasions), *Asterionella sp.* (4 occasions), *Tabellaria sp.* (3 occasions), and *Stephanodiscus sp.* (2 occasions); Chlorophyta *Chlamydomonas sp.* (1 occasion), *Pyramichlamys sp.* (1 occasion), and *Staurastrum sp.* (1 occasion); Cryptophyta *Rhodomonas sp.* (4 occasions); and Pyrrophyta *Ceratium sp.* (3 occasions) (Plate 41). The highest value of the cyanobacteria toxin microcystin measured at the four sites L1, L3, L5, and L7 over the 3-year period 2006 through 2008 was 1.8 ug/l at site L1 (Tables 5.1, 5.3, 5.5, and 5.7).

# 6 WATER QUALITY CONDITIONS OF INFLOWS TO FORT RANDALL RESERVOIR

## 6.1 STATISTICAL SUMMARY AND WATER QUALITY STANDARDS ATTAINMENT

Statistical summaries of water quality conditions monitored at the two inflow sites (NF1 and NF2), based on the collected grab samples, are given in Tables 6.1 and 6.2. Table 6.1 summarizes the water quality conditions that were monitored in the Big Bend Dam discharge to the Missouri River just upstream of Fort Randall Reservoir (site NF1) during the 3-year period 2006 through 2008. Table 6.2 and summarizes the water quality conditions that were monitored in the White River about 5 miles upstream of Fort Randall Reservoir (site NF2) during the 3-year period 2006 through 2008. Review of these results indicated no major water quality concerns in the Missouri River inflow (i.e., Big Bend Dam discharge). The White River, overall, has poor water quality. The river exhibited warm water temperatures and high levels of suspended solids, turbidity, total phosphorus, and total metals. The poor water quality in the White River is believed to be a natural condition associated with the geology and soils of the river basin.

## 6.2 CONTINUOUS WATER TEMPERATURE MONITORING OF THE MISSOURI RIVER AT THE BIG BEND DAM DISCHARGE

Figures 6.1 through 6.3, respectively, plot mean daily water temperature and flow for the Big Bend Dam discharge to the Missouri River just upstream of Fort Randall Reservoir for calendar years 2006, 2007, and 2008.

## 6.3 MISSOURI RIVER NUTRIENT FLUX CONDITIONS

Nutrient flux rates for the inflow of the Missouri River to Fort Randall Reservoir were calculated based on the monthly water quality samples collected at the Big Bend powerplant (i.e. site NF1) and the average hourly discharge at Big Bend Dam at the time of sample collection (Table 6.3).

**Table 6.1.** Summary of monthly water quality conditions monitored in the Big Bend Dam discharge to the Missouri River just upstream of Fort Randall Reservoir (site NF1) during the 3-year period 2006 through 2008.

| 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 Exceedences | Percent WQS Exceedence |
| Stream Flow (cfs) | 1 | 31 | 21,871 | 22,944 | 0 | 71,717 | ----- | ----- | ----- |
| Water Temperature ( C) | 0.1 | 31 | 12.5 | 13.3 | 0.5 | 25.4 | 27[1] | 0 | 0% |
| Dissolved Oxygen (mg/l) | 0.1 | 30 | 9.8 | 9.8 | 5.7 | 13 5 | ≥ 5.0[1] | 0 | 0% |
| Dissolved Oxygen (% Sat.) | 0.1 | 30 | 92.6 | 94.4 | 68.7 | 105.5 | ----- | ----- | ----- |
| Specific Conductance (umho/cm) | 1 | 30 | 699 | 702 | 645 | 739 | ----- | ----- | ----- |
| pH (S.U.) | 0.1 | 29 | 8.3 | 8.3 | 7.6 | 8.7 | ≥6.5 & ≤9.0[1] | 0 | 0% |
| Turbidity (NTUs) | 1 | 22 | 10 | 3 | n.d. | 60 | ----- | ----- | ----- |
| Oxidation-Reduction Potential (mV) | 1 | 22 | 344 | 357 | 243 | 385 | ----- | ----- | ----- |
| Alkalinity, Total (mg/l) | 7 | 31 | 167 | 162 | 140 | 195 | ----- | ----- | ----- |
| Ammonia N, Total (mg/l) | 0.02 | 31 | ----- | n.d. | n.d. | 0.05 | 3.15[1,2,3], 1.54[1,2,4] | 0 | 0% |
| Carbon, Total Organic (mg/l) | 0.05 | 30 | 3.2 | 3.1 | 1.5 | 5.6 | ----- | ----- | ----- |
| Chemical Oxygen Demand (mg/l) | 2 | 31 | 10 | 10 | n.d. | 21 | ----- | ----- | ----- |
| Chloride (mg/l) | 1 | 29 | 12 | 11 | 9 | 25 | ----- | ----- | ----- |
| Dissolved Solids, Total (mg/l) | 4 | 31 | 469 | 470 | 380 | 576 | 1,750[5] | 0 | 0% |
| Iron, Dissolved (ug/l) | 40 | 14 | ----- | n.d. | n.d. | n.d. | ----- | ----- | ----- |
| Iron, Total (ug/l) | 40 | 14 | 178 | 121 | n.d. | 553 | ----- | ----- | ----- |
| Kjeldahl N, Total (mg/l) | 0.1 | 31 | 0.6 | 0.5 | n.d. | 1.7 | ----- | ----- | ----- |
| Manganese, Dissolved (ug/l) | 2 | 14 | ----- | n.d. | n.d. | 15 | ----- | ----- | ----- |
| Manganese, Total (ug/l) | 2 | 14 | 51 | 30 | n.d. | 178 | ----- | ----- | ----- |
| Nitrate-Nitrite N, Total (mg/l) | 0.02 | 31 | ----- | n.d. | n.d. | 0.40 | 10[5] | 0 | 0% |
| Phosphorus, Total (mg/l) | 0.02 | 31 | ----- | 0.03 | n.d. | 0.15 | ----- | ----- | ----- |
| Phosphorus-Ortho, Total Dissolved (mg/l) | 0.02 | 31 | ----- | n.d. | n.d. | 0.04 | ----- | ----- | ----- |
| Phosphorus, Dissolved (mg/l) | 0.02 | 29 | ----- | n.d. | n.d. | 0.07 | ----- | ----- | ----- |
| Sulfate (mg/l) | 1 | 31 | 196 | 195 | 172 | 230 | 875[5] | 0 | 0% |
| Suspended Solids, Total (mg/l) | 4 | 31 | ----- | n.d. | n.d. | 57 | 158[1,3], 90[1,4] | 0 | 0% |
| Hardness, Dissolved (mg/l) | 1 | 3 | 201 | 205 | 169 | 228 | ----- | ----- | ----- |
| Aluminum, Dissolved (ug/l) | 25 | 3 | ----- | n.d. | n.d. | n.d. | ----- | ----- | ----- |
| Antimony, Dissolved (ug/l) | 0.5 | 3 | ----- | n.d. | n.d. | 0.6 | 5.6[6] | 0 | 0% |
| Arsenic, Dissolved (ug/l) | 3 | 3 | ----- | n.d. | n.d. | n.d. | 340[3], 150[4], 0.018[6] | 0, 0, b.d. | 0%, 0%, b.d. |
| Beryllium, Dissolved (ug/l) | 2 | 3 | ----- | n.d. | n.d. | n.d. | 4[6] | 0 | 0% |
| Cadmium, Dissolved (ug/l) | 0.5 | 3 | ----- | n.d. | n.d. | n.d. | 10[3], 4.3[4] | 0 | 0% |
| Chromium, Dissolved (ug/l) | 10 | 3 | ----- | n.d. | n.d. | n.d. | 3,246[3], 155[4] | 0 | 0% |
| Copper, Dissolved (ug/l) | 2 | 3 | ----- | n.d. | n.d. | n.d. | 28[3], 17[4], 1,300[6] | 0 | 0% |
| Lead, Dissolved (ug/l) | 2 | 3 | ----- | n.d. | n.d. | n.d. | 204[3], 7.9[4] | 0 | 0% |
| Mercury, Dissolved (ug/l) | 0.02 | 3 | ----- | n.d. | n.d. | n.d. | 1.4[3], 0.05[6] | 0 | 0% |
| Mercury, Total (ug/l) | 0.02 | 3 | ----- | n.d. | n.d. | n.d. | 0.012[4] | b.d. | b.d. |
| Nickel, Dissolved (ug/l) | 10 | 3 | ----- | n.d. | n.d. | n.d. | 861[3], 96[4], 610[6] | 0 | 0% |
| Selenium, Total (ug/l) | 4 | 3 | ----- | n.d. | n.d. | n.d. | 4.6[2], 170[6] | 0 | 0% |
| Silver, Dissolved (ug/l) | 1 | 3 | ----- | n.d. | n.d. | n.d. | 15[3] | 0 | 0% |
| Thallium, Dissolved (ug/l) | 6 | 3 | ----- | n.d. | n.d. | n.d. | 0.24[6] | b.d. | b.d. |
| Zinc, Dissolved (ug/l) | 3 | 2 | 9 | 9 | 7 | 10 | 220[3,4], 7,400[6] | 0 | 0% |
| Pesticide Scan (ug/l)[E] | 0.05 | 3 | ----- | n.d. | n.d. | n.d. | ----- | ----- | ----- |

n.d. = Not detected.

[A] Metals samples were collected on August 23, 2006; August 22, 2007; and August 12, 2008. Pesticide samples were collected on May 16, 2006; May 16, 2007; and May 13, 2008.

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

[C] Non-detect values set to 0 to calculate mean. The mean is not reported if 20% or more of the observations were non-detect. The mean value reported for pH is an arithmetic mean based on measured values (i.e , log conversion of logarithmic pH values was not done to calculate mean).

[D] [1] Criteria for warmwater permanent fish life propagation waters.

[2] Total ammonia criteria are pH and temperature dependent. Criteria listed are for median pH and temperature values.

[3] Acute criterion for freshwater aquatic life.

[4] Chronic criterion for freshwater aquatic life.

[5] Daily maximum criterion for domestic water supply.

[6] Human health value concentration.

Note: South Dakota's water quality standards criteria for the metals cadmium, chromium, copper, lead, nickel, silver, and zinc are dependent upon hardness – criteria listed are based on the median hardness value.

[E] The pesticide scan includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chloropyrifos, cyanazine, cycloate, deethylatrazine, deisprplatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, isopropalin, metolachlor, metribuzin, molinate, oxiadiazon, oxyfluorfen, pebulate, pendimethalin, phorate, profluralin, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

**Table 6.2.** Summary of monthly (May through September) water quality conditions monitored in the White River approximately 5 miles upstream of Fort Randall Reservoir (site NF2) during the 3-year period 2006 through 2008.

| 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 Exceedences | Percent WQS Exceedence |
| Stream Flow (cfs) | 1 | 14 | 617 | 95 | 14 | 4,960 | ----- | ----- | ----- |
| Water Temperature ( C) | 0.1 | 14 | 23.3 | 24.2 | 9.9 | 31.3 | 27[1] | 6 | 43% |
| Dissolved Oxygen (mg/l) | 0.1 | 14 | 8.4 | 8.2 | 7.2 | 10.3 | ≥ 5.0[1] | 0 | 0% |
| Dissolved Oxygen (% Sat.) | 0.1 | 14 | 100.4 | 98.8 | 90.0 | 111.0 | ----- | ----- | ----- |
| Specific Conductance (umho/cm) | 1 | 14 | 548 | 529 | 430 | 840 | ----- | ----- | ----- |
| pH (S.U.) | 0.1 | 13 | 8.6 | 8.6 | 8.1 | 8.9 | ≥6.5 & ≤9.0[1] | 0 | 0% |
| Turbidity (NTUs) | 1 | 14 | 1,316 | 1,035 | 140 | 3,360 | ----- | ----- | ----- |
| Oxidation-Reduction Potential (mV) | 1 | 13 | 355 | 330 | 204 | 422 | ----- | ----- | ----- |
| Alkalinity, Total (mg/l) | 7 | 14 | 239 | 169 | 81 | 760 | ----- | ----- | ----- |
| Ammonia N, Total (mg/l) | 0.02 | 14 | ----- | 0.04 | n.d. | 0.33 | 1.77[1,2,3], 0.82[1,2,4] | 0 | 0% |
| Carbon, Total Organic (mg/l) | 0.05 | 13 | 6.0 | 5.4 | 2.7 | 9.2 | ----- | ----- | ----- |
| Chemical Oxygen Demand (mg/l) | 2 | 14 | 38 | 32 | 3 | 114 | ----- | ----- | ----- |
| Chloride (mg/l) | 1 | 14 | 7 | 7 | 3 | 11 | ----- | ----- | ----- |
| Dissolved Solids, Total (mg/l) | 4 | 14 | 897 | 613 | 352 | 3,300 | 1,750[5] | 1 | 7% |
| Iron, Dissolved (ug/l) | 40 | 12 | ----- | 50 | n.d. | 508 | ----- | ----- | ----- |
| Iron, Total (ug/l) | 40 | 14 | 119,960 | 58,513 | 1,140 | 627,100 | ----- | ----- | ----- |
| Kjeldahl N, Total (mg/l) | 0.1 | 14 | 2.6 | 2.4 | 0.8 | 6.9 | ----- | ----- | ----- |
| Manganese, Dissolved (ug/l) | 2 | 12 | ----- | 11 | n.d. | 40 | ----- | ----- | ----- |
| Manganese, Total (ug/l) | 2 | 14 | 2,123 | 1,051 | 100 | 8,680 | ----- | ----- | ----- |
| Nitrate-Nitrite N, Total (mg/l) | 0.02 | 14 | ----- | 0.05 | n.d. | 2.10 | 10[5] | 0 | 0% |
| Phosphorus, Dissolved (mg/l) | 0.02 | 12 | 0.11 | 0.05 | n.d. | 0.68 | ----- | ----- | ----- |
| Phosphorus, Total (mg/l) | 0.02 | 14 | 3.67 | 1.66 | 0.16 | 17.30 | ----- | ----- | ----- |
| Phosphorus-Ortho, Dissolved (mg/l) | 0.02 | 14 | ----- | 0.02 | n.d. | 0.12 | ----- | ----- | ----- |
| Sulfate (mg/l) | 1 | 14 | 99 | 93 | 40 | 250 | 875[5] | 0 | 0% |
| Suspended Solids, Total (mg/l) | 4 | 14 | 4,095 | 1,465 | 64 | 19,800 | 158[1,3], 90[1,4] | 12, 13 | 86%, 93% |
| Hardness, Dissolved (mg/l) | 1 | 1 | 9 | 9 | 9 | 9 | ----- | ----- | ----- |
| Hardness, Total (mg/l) | 1 | 1 | 2,236 | 2,236 | 2,236 | 2,236 | ----- | ----- | ----- |
| Aluminum, Dissolved (ug/l) | 25 | 1 | 886 | 886 | 886 | 886 | ----- | ----- | ----- |
| Aluminum, Total (ug/l) | 25 | 1 | 1,015,000 | 1,015,000 | 1,015,000 | 1,015,000 | ----- | ----- | ----- |
| Antimony, Dissolved (ug/l) | 0.5 | 1 | ----- | n.d. | n.d. | n.d. | 5.6[3] | 0 | 0% |
| Antimony, Total (ug/l) | 0.5 | 1 | ----- | n.d. | n.d. | n.d. | ----- | ----- | ----- |
| Arsenic, Dissolved (ug/l) | 3 | 1 | 42 | 42 | 42 | 42 | 340[3], 150[4], 0.018[6] | 0, 0, 1 | 0%, 0%, 100% |
| Arsenic, Total (ug/l) | 3 | 1 | 97 | 97 | 97 | 97 | ----- | ----- | ----- |
| Beryllium, Dissolved (ug/l) | 2 | 1 | ----- | n.d. | n.d. | n.d. | 4[6] | 0 | 0% |
| Beryllium, Total (ug/l) | 2 | 1 | 31 | 31 | 31 | 31 | ----- | ----- | ----- |
| Cadmium, Dissolved (ug/l) | 0.5 | 1 | ----- | n.d. | n.d. | n.d. | 150[3], 28[4] | 0 | 0% |
| Cadmium, Total (ug/l) | 0.5 | 1 | 3 | 3 | 3 | 3 | ----- | ----- | ----- |
| Chromium, Dissolved (ug/l) | 10 | 1 | ----- | n.d. | n.d. | n.d. | 22,973[3], 1,098[4] | 0 | 0% |
| Chromium, Total (ug/l) | 10 | 1 | 3,745 | 3,745 | 3,745 | 3,745 | ----- | ----- | ----- |
| Copper, Dissolved (ug/l) | 2 | 1 | 5 | 5 | 5 | 5 | 262[3], 133[4], 1,300[6] | 0 | 0% |
| Copper, Total (ug/l) | 2 | 1 | 417 | 417 | 417 | 417 | ----- | ----- | ----- |
| Lead, Dissolved (ug/l) | 2 | 1 | ----- | n.d. | n.d. | n.d. | 4,264[3], 166[4] | 0 | 0% |
| Lead, Total (ug/l) | 2 | 1 | 2,519 | 2,519 | 2,519 | 2,519 | ----- | ----- | ----- |
| Mercury, Dissolved (ug/l) | 0.02 | 1 | ----- | n.d. | n.d. | n.d. | 1.4[3], 0.05[6] | 0 | 0% |
| Mercury, Total (ug/l) | 0.02 | 1 | 0.29 | 0.29 | 0.29 | 0.29 | 0.012[4] | 1 | 100% |
| Nickel, Dissolved (ug/l) | 10 | 1 | ----- | n.d. | n.d. | n.d. | 6,501[3], 723[4], 610[6] | 0 | 0% |
| Nickel, Total (ug/l) | 10 | 1 | 2,627 | 2,627 | 2,627 | 2,627 | ----- | ----- | ----- |
| Silver, Dissolved (ug/l) | 1 | 1 | ----- | n.d. | n.d. | n.d. | 15[3] | 0 | 0% |
| Silver, Total (ug/l) | 1 | 1 | ----- | n.d. | n.d. | n.d. | ----- | ----- | ----- |
| Zinc, Dissolved (ug/l) | 3 | 1 | 9 | 9 | 9 | 9 | 1,667[3,4], 7,400[6] | 0 | 0% |
| Zinc, Total (ug/l) | 3 | 1 | 1,497 | 1,497 | 1,497 | 1,497 | ----- | ----- | ----- |

n.d. = Not detected.

(A) Metal samples were collected on August 15, 2007.

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

(C) Non-detect values set to 0 to calculate mean. The mean is not reported if 20% or more of the observations were non-detect. The mean value reported for pH is an arithmetic mean based on measured values (i.e , log conversion of logarithmic pH values was not done to calculate mean).

(D) (1) Criteria for warmwater permanent fish life propagation waters.

(2) Total ammonia criteria are pH and temperature dependent. Criteria listed are for median pH and temperature values.

(3) Acute criterion for freshwater aquatic life.

(4) Chronic criterion for freshwater aquatic life.

(5) Daily maximum criterion for domestic water supply.

(6) Human health value concentration.

Note: South Dakota's water quality standards criteria for the metals cadmium, chromium, copper, lead, nickel, silver, and zinc are dependent upon hardness – criteria listed are based on the median hardness value.

**Table 6.3.** Summary of nutrient flux rates (kg/sec) calculated for the Big Bend Dam discharge to the Missouri River just upstream of Fort Randall Reservoir during the 3-year period 2006 through 2008.

| Statistic | 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 | 25 | 26 |
| Mean* | ----- | 0.367 | ----- | ----- | ----- | 2.278 |
| Median | n.d. | 0.323 | n.d. | 0.013 | n.d. | 2.058 |
| Minimum | n.d. | n.d. | n.d. | n.d. | n.d. | 0.316 |
| Maximum | 0.048 | 1.218 | 0.266 | 0.115 | 0.014 | 5.483 |

n.d. = non-detectable.
* Non-detect values set to 0 to calculate mean. If > 20% of observations were non-detects, mean is not reported.
Note: Statistics of Big Bend Dam discharges used for flux calculations were: mean = 25,112 cfs, median = 23,200 cfs, minimum = 3,600 cfs, and maximum = 71,717 cfs.

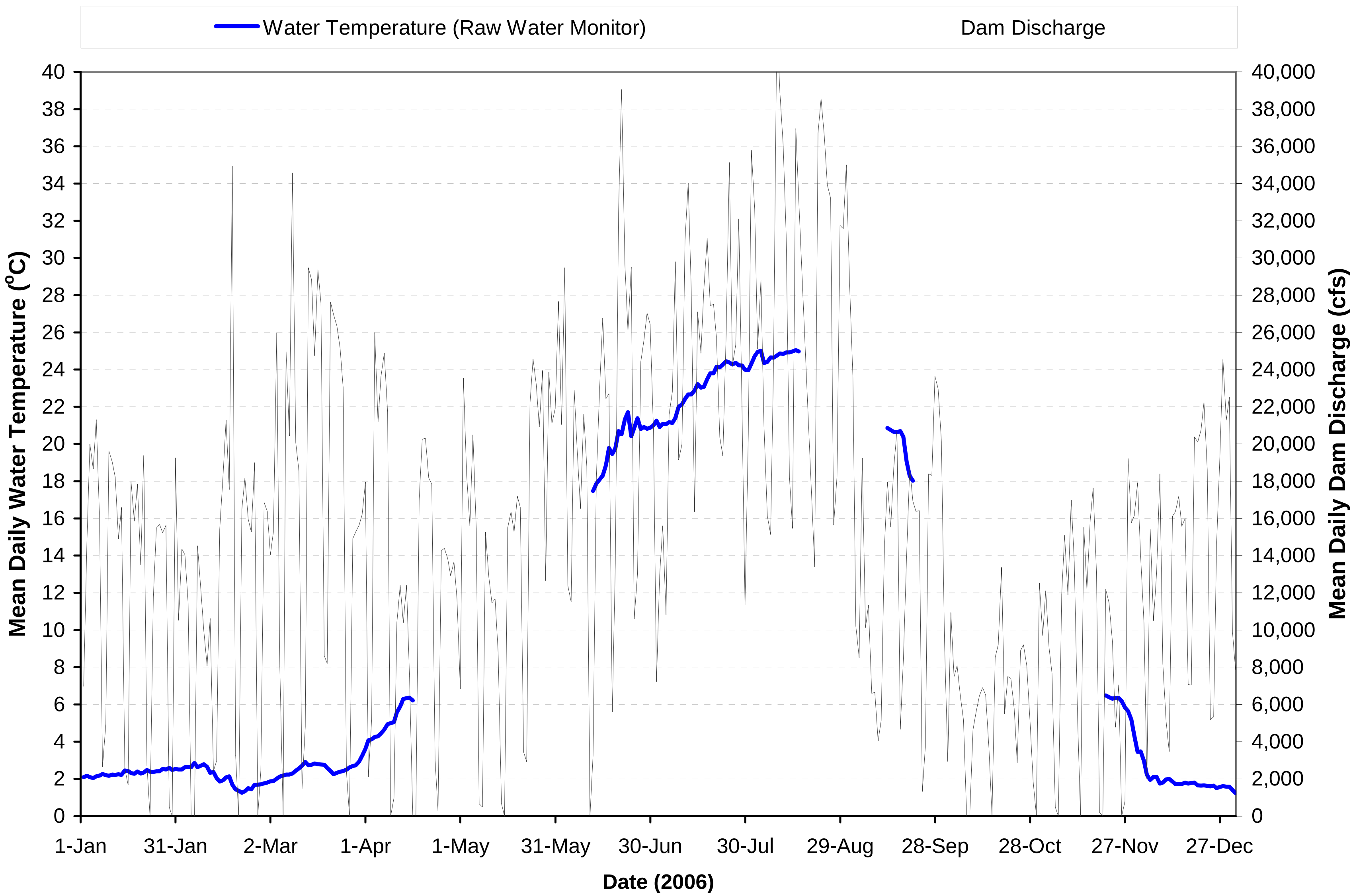


**Figure 6.1.** Mean daily water temperature and discharge of the Big Bend Dam releases to the Missouri River just upstream of Fort Randall Reservoir (inflow site NF1) for 2006. (Gaps in plot indicate periods when monitoring equipment was not operational.)

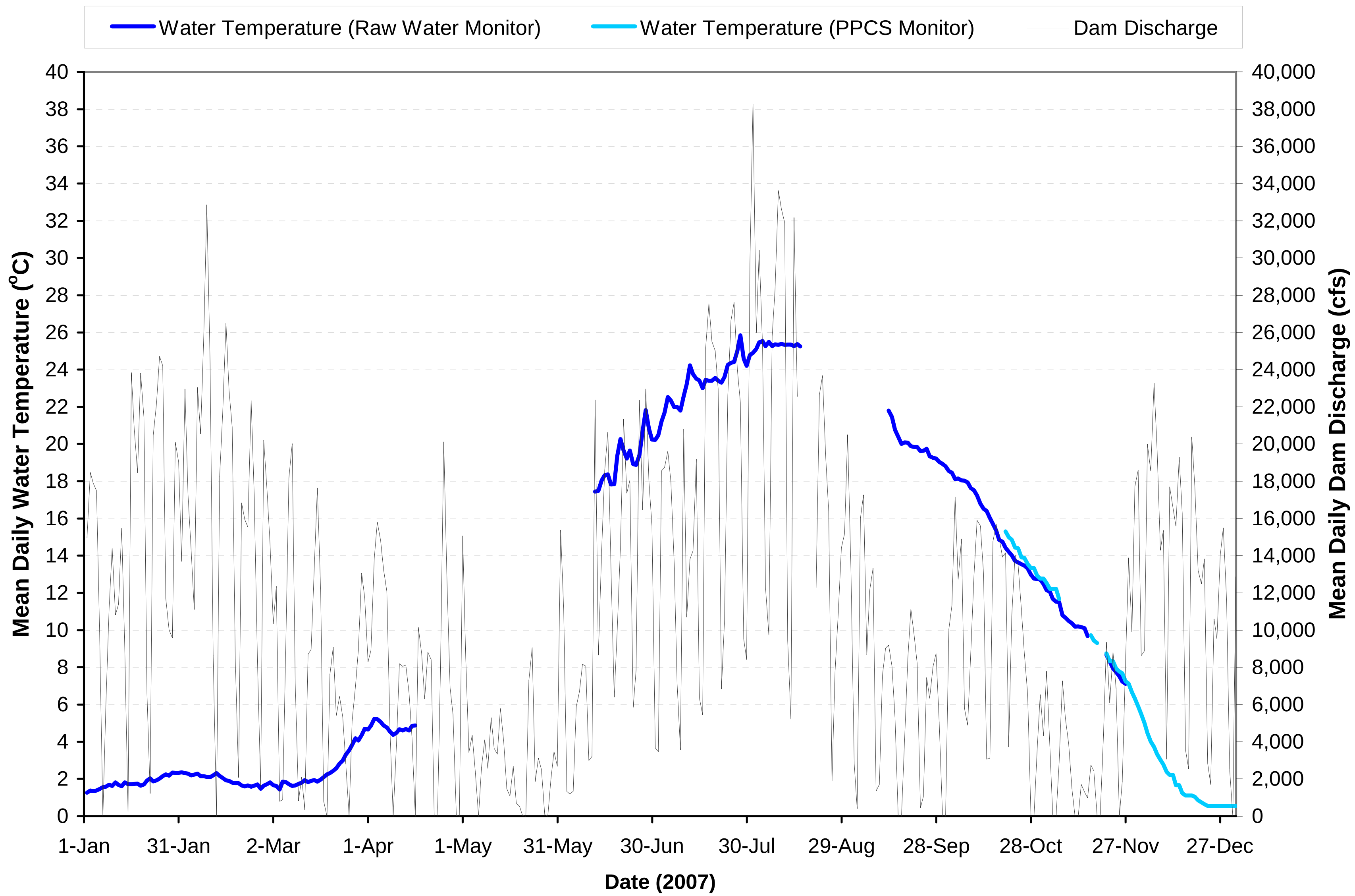


**Figure 6.2.** Mean daily water temperature and discharge of the Big Bend Dam releases to the Missouri River just upstream of Fort Randall Reservoir (inflow site NF1) for 2007. (Gaps in plot indicate periods when monitoring equipment was not operational.)

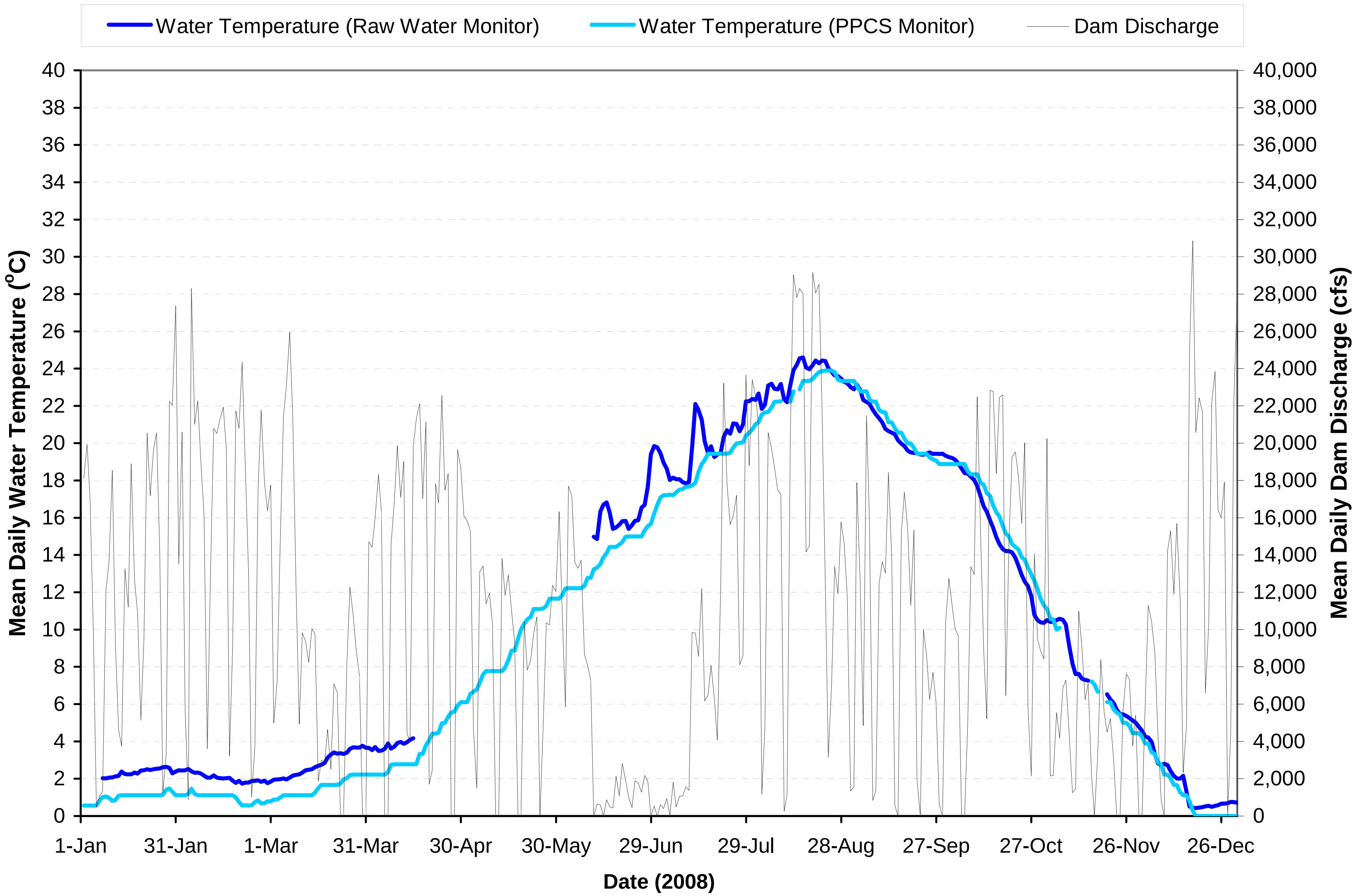


**Figure 6.3.** Mean daily water temperature and discharge of the Big Bend Dam releases to the Missouri River just upstream of Fort Randall Reservoir (inflow site NF1) for 2007. (Gaps in plot indicate periods when monitoring equipment was not operational.)

# 7 WATER QUALITY CONDITIONS OF THE MISSOURI RIVER DOWNSTREAM OF FORT RANDALL DAM

## 7.1 WATER QUALITY CONDITIONS OF WATER DISCHARGED THROUGH FORT RANDALL DAM

### 7.1.1 STATISTICAL SUMMARY AND WATER QUALITY STANDARDS ATTAINMENT

Table 7.1 summarizes the water quality conditions that were monitored monthly on water discharged through the Fort Randall powerplant during the 3-year period 2006 through 2008. These results indicate no major water quality standards concerns.

### 7.1.2 CONTINUOUS MONITORING OF WATER QUALITY CONDITIONS OF WATER DISCHARGED THROUGH THE FORT RANDALL POWERPLANT

Continuous monitoring (i.e., hourly measurements) of water passed through the Fort Randall powerplant and discharged to the Missouri River downstream of the dam was conducted year-round during the 3-year period of 2006 through 2008. Water quality parameters monitored at site FTRPP1 (i.e., OF1) included water temperature, dissolved oxygen, and conductivity. The average hourly discharge of water through the powerplant turbines was compiled from project records.

#### 7.1.2.1 Water Temperature

Plots of the hourly water temperatures and dam discharge for the 3 years 2006, 2007, and 2008 are shown in Plates 42 through 53. During the January through March period, water temperatures remained around 2°C (Plates 42, 46, and 50). From April through June, water temperatures exhibited a steady increase to a maximum of about 18 to 20°C at the end of June (Plates 43, 47, and 51). During the July through September period, water temperatures increased from around 18 to 20°C, at the start of July, to a high of around 25°C in mid- to late-August, and then fell back to around 18 to 20°C by late-September (Plates 44, 48, and 52). From October through December, water temperatures steadily declined from around 18 to 20°C to about 2°C (Plates 45, 49, and 53).

Temperature of water passed through the Fort Randall powerplant is also measured as part of the Power Plant Control System (PPCS). As part of this system the temperature of the water in the raw water supply is monitored. Prior to late 2007 only midnight temperature measurements were retained. In late 2007 the PPCS was modified to allow hourly temperature data to be retained. The PPCS temperature probe and water quality monitoring station (i.e., site OF1) monitor raw water drawn of the same supply header. The PPCS data is plotted with the "raw water" data in Plates 49 through 53.

In late-spring when thermal stratification becomes established in Fort Randall Reservoir, the temperature of the water discharged through the dam becomes highly dependent upon the discharge rate of the dam. Warmer water is discharged during higher flows and colder water during lower discharge rates. This indicates that the vertical extent of the withdrawal zone in the reservoir is dependent upon the discharge rate of the dam. This is believed to be a result of the design of the intake structure (i.e., bottom withdrawal) and the presence of the submerged approach channel (see Photos 1.1 and 1.6). At high dam discharge rates water is likely drawn from an extended vertical zone in Fort Randall Reservoir year-round, but is only evident in the temperatures monitored at the powerhouse during reservoir thermal stratification in the summer. When summer thermal stratification breaks down the high correlation between dam discharge and the temperature of the discharged water no longer occurs. This occurred in late-July in 2006 (Plate 44) and late-August/early-September in 2007 and 2008 (Plates 48 and 52). The bottom location of the dam intake, in combination with the submerged approach channel and high dam discharge rates, may induce Fort Randall Reservoir to mix and experience “fall turnover” at an earlier time than would be expected based on “natural” conditions.

#### 7.1.2.2 Dissolved Oxygen

Plots of the hourly dissolved oxygen (DO) concentrations and average dam discharge for the 3 years 2006, 2007, and 2008 are shown in Plates 54 through 63. No DO measurements were collected from June 7, 2008 through December 31, 2008 due to equipment failure. During the January through March period, monitored DO levels exhibited daily variability, but generally remained at about 12 mg/l (Plates 54, 58, and 62). From April through June, DO levels steadily declined to about 7 to 8 mg/l at the end of June (Plates 55, 59, and 63). During the July through September period, monitored DO levels decreased from 8 mg/l to a low of 2 to 4 mg/l in early August and then rose back to around 8 mg/l by the end of September (Plates 56 and 60). The lower summer DO levels are attributed to ongoing degradation of DO in the hypolimnion of Fort Randall Reservoir. From October through December, DO levels steadily increased from about 8 to 13 mg/l. As with temperature, dam discharge rates had a significant affect on the DO levels monitored during the summers of 2006 and 2007.

Monitored DO levels exhibited extreme daily variability in the summers of both 2006 and 2007 (no DO monitoring data are available for 2008). Daily summer DO levels in 2006 ranged from 4 to 7 mg/l and in 2007 they ranged from 2 to 7 mg/l (Plates 56 and 60). The monitored DO levels were directly related to dam discharge – low DO levels were associated with low dam discharge rates and high DO levels were associated with high discharge rates. During summer thermal stratification, DO levels continually degrade in the hypolimnion; especially near the reservoir bottom. This is believed to be particularly true in the submerged approach channel to the dam intake structure. The invert elevation of the power tunnels is 2 feet above the bottom of the approach channel. As discussed above regarding temperature, the vertical extent of the withdrawal zone in the reservoir is believed dependent upon the discharge rate of the dam. Seemingly low dam discharge rates pull water with low DO along the bottom of the approach channel, and high dam discharge rates pull water with higher DO from higher elevations in the reservoir.

## 7.2 WATER QUALITY CONDITIONS IN THE FORT RANDALL DAM TAILWATERS

Table 7.2 summarizes the water quality conditions that were monitored monthly in the Fort Randall tailwaters (site OF2) during the 3-year period 2006 through 2008. These results indicate no major water quality standards concerns.

## 7.3 COMPARISON OF MONITORED INFLOW AND OUTFLOW TEMPERATURES OF THE MISSOURI RIVER AT FORT RANDALL RESERVOIR

Figures 7.1 through 7.3, respectively, plot the mean daily water temperatures monitored for the Big Bend Dam discharge (site NF1) and the Fort Randall Dam discharge (site OF1) during 2006, 2007, and 2008. Inflow temperatures of the Missouri River to Fort Randall Reservoir are generally warmer than the outflow temperatures of Fort Randall Dam during the period of April through August (Figures 7.1 - 7.3). Outflow temperatures of the Fort Randall Dam discharge are generally warmer than the inflow temperatures of the Missouri River during the period of September through March (Figures 7.1 - 7.3). A maximum temperature difference occurs in late-spring and early summer when the Missouri River inflow temperature is about 4°C warmer than the Fort Randall Dam discharge temperature (Figures 7.1 - 7.3).

**Table 7.1.** Summary of monthly water quality conditions monitored in water discharged through the Fort Randall powerplant (site OF1) during the 3-year period 2006 through 2008.

| 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 Exceedences** | **Percent WQS Exceedence** |
| Dam Discharge (cfs) | 1 | 31 | 18,874 | 17,128 | 0 | 41,200 | ----- | ----- | ----- |
| Water Temperature ( C) | 0.1 | 30 | 12.1 | 10.4 | 0.6 | 25.4 | 27[1] | 0 | 0% |
| Dissolved Oxygen (mg/l) | 0.1 | 30 | 10.0 | 10.5 | 6.6 | 13.4 | ≥ 5.0[1] | 0 | 0% |
| Dissolved Oxygen (% Sat.) | 0.1 | 30 | 93.7 | 96.4 | 73.7 | 103.9 | ----- | ----- | ----- |
| Specific Conductance (umho/cm) | 1 | 30 | 712 | 720 | 580 | 753 | ----- | ----- | ----- |
| pH (S.U.) | 0.1 | 24 | 8.2 | 8.3 | 7.2 | 8.7 | ≥6.5 & ≤9.0[1] | 0 | 0% |
| Turbidity (NTUs) | 1 | 22 | 4 | 3 | n.d. | 17 | ----- | ----- | ----- |
| Oxidation-Reduction Potential (mV) | 1 | 23 | 359 | 358 | 273 | 452 | ----- | ----- | ----- |
| Alkalinity, Total (mg/l) | 7 | 31 | 164 | 163 | 140 | 191 | ----- | ----- | ----- |
| Ammonia N, Total (mg/l) | 0.02 | 31 | ----- | n.d. | n.d. | 0.29 | 3 15[1,2,3], 1.86[1,2,4] | 0 | 0% |
| Carbon, Total Organic (mg/l) | 0.05 | 29 | 3.3 | 3.1 | 2.5 | 5.0 | ----- | ----- | ----- |
| Chemical Oxygen Demand (mg/l) | 2 | 31 | 11 | 11 | n.d. | 22 | ----- | ----- | ----- |
| Chloride (mg/l) | 1 | 29 | 11 | 12 | 9 | 14 | ----- | ----- | ----- |
| Dissolved Solids, Total (mg/l) | 4 | 31 | 473 | 476 | 314 | 568 | 1,750[5] | 0 | 0% |
| Iron, Dissolved (ug/l) | 40 | 14 | ----- | n.d. | n.d. | n.d. | ----- | ----- | ----- |
| Iron, Total (ug/l) | 40 | 14 | 74 | 74 | n.d. | 152 | ----- | ----- | ----- |
| Kjeldahl N, Total (mg/l) | 0.1 | 31 | 0.5 | 0.3 | n.d. | 3.6 | ----- | ----- | ----- |
| Manganese, Dissolved (ug/l) | 2 | 14 | ----- | n.d. | n.d. | 9 | ----- | ----- | ----- |
| Manganese, Total (ug/l) | 2 | 14 | 16 | 19 | n.d. | 30 | ----- | ----- | ----- |
| Nitrate-Nitrite N, Total (mg/l) | 0.02 | 31 | ----- | n.d. | n.d. | 0.10 | 10[5] | 0 | 0% |
| Phosphorus, Total (mg/l) | 0.02 | 31 | ----- | 0.02 | n.d. | 0.25 | ----- | ----- | ----- |
| Sulfate (mg/l) | 1 | 31 | 199 | 199 | 117 | 230 | 875[5] | 0 | 0% |
| Suspended Solids, Total (mg/l) | 4 | 31 | ----- | n.d. | n.d. | 14 | 158[1,3], 90[1,4] | 0 | 0% |
| Hardness, Dissolved (mg/l) | 1 | 3 | 220 | 211 | 211 | 238 | ----- | ----- | ----- |
| Aluminum, Dissolved (ug/l) | 25 | 3 | ----- | n.d. | n.d. | n.d. | ----- | ----- | ----- |
| Antimony, Dissolved (ug/l) | 0.5 | 2 | ----- | n.d. | n.d. | n.d. | 5.6[6] | 0 | 0% |
| Arsenic, Dissolved (ug/l) | 3 | 3 | ----- | n.d. | n.d. | n.d. | 340[3], 150[4], 0.018[6] | 0, 0, b.d. | 0%, 0%, b.d. |
| Beryllium, Dissolved (ug/l) | 2 | 3 | ----- | n.d. | n.d. | n.d. | 4[6] | 0 | 0% |
| Cadmium, Dissolved (ug/l) | 0.5 | 3 | ----- | n.d. | n.d. | n.d. | 10[3], 4.4[4] | 0 | 0% |
| Chromium, Dissolved (ug/l) | 10 | 3 | ----- | n.d. | n.d. | n.d. | 3,323[3], 159[4] | 0 | 0% |
| Copper, Dissolved (ug/l) | 2 | 3 | ----- | n.d. | n.d. | 4 | 28[3], 18[4], 1,300[6] | 0 | 0% |
| Lead, Dissolved (ug/l) | 2 | 3 | ----- | n.d. | n.d. | n.d. | 211[3], 8.2[4] | 0 | 0% |
| Mercury, Dissolved (ug/l) | 0.02 | 3 | ----- | n.d. | n.d. | n.d. | 1.4[3], 0.05[6] | 0 | 0% |
| Mercury, Total (ug/l) | 0.02 | 3 | ----- | n.d. | n.d. | n.d. | 0.012[4] | b.d. | b.d. |
| Nickel, Dissolved (ug/l) | 10 | 3 | ----- | n.d. | n.d. | n.d. | 882[3], 98[4], 610[6] | 0 | 0% |
| Selenium, Total (ug/l) | 4 | 3 | ----- | n.d. | n.d. | n.d. | 4.6[4], 170[6] | 0 | 0% |
| Silver, Dissolved (ug/l) | 1 | 3 | ----- | n.d. | n.d. | n.d. | 15[3] | 0 | 0% |
| Thallium, Dissolved (ug/l) | 6 | 3 | ----- | n.d. | n.d. | n.d. | 0.24[6] | b.d. | b.d. |
| Zinc, Dissolved (ug/l) | 3 | 3 | ----- | n.d. | n.d. | 11 | 226[3,4], 7,400[6] | 0 | 0% |
| Pesticide Scan (ug/l)[D] | 0.05 | 3 | ----- | n.d. | n.d. | n.d. | ----- | ----- | ----- |

n.d. = Not detected.

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

(B) Non-detect values set to 0 to calculate mean. The mean is not reported if 20% or more of the observations were non-detect. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(C) (1) Criteria for warmwater permanent fish life propagation waters.
(2) Total ammonia criteria are pH and temperature dependent. Criteria listed are for median pH and temperature values.
(3) Acute criterion for freshwater aquatic life.
(4) Chronic criterion for freshwater aquatic life.
(5) Daily maximum criterion for domestic water supply.
(6) Human health value concentration.

Note: South Dakota's water quality standards criteria for the metals cadmium, chromium, copper, lead, nickel, silver, and zinc are dependent upon hardness – criteria listed are based on the median hardness value.

(D) The pesticide scan includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chloropyrifos, cyanazine, cycloate, deethylatrazine, deisprplatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, isopropalin, metolachlor, metribuzin, molinate, oxiadiazon, oxyfluorfen, pebulate, pendimethalin, phorate, profluralin, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

**Table 7.2.** Summary of monthly water quality conditions monitored in the Fort Randall Dam tailwaters (site OF2) during the 3-year period 2006 through 2008.

| 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 Exceedences | Percent WQS Exceedence |
| Dam Discharge (cfs) | 1 | 49 | 18,662 | 16,146 | 0 | 42,400 | ----- | ----- | ----- |
| Water Temperature ( C) | 0.1 | 48 | 12.6 | 13.0 | 0.7 | 26.2 | 27(1) | 0 | 0% |
| Dissolved Oxygen (mg/l) | 0.1 | 47 | 10.3 | 10.4 | 6.2 | 16.9 | ≥ 5.0(1) | 0 | 0% |
| Dissolved Oxygen (% Sat.) | 0.1 | 47 | 95.8 | 98.6 | 65.8 | 117.4 | ----- | ----- | ----- |
| Specific Conductance (umho/cm) | 1 | 47 | 713 | 723 | 634 | 803 | ----- | ----- | ----- |
| pH (S.U.) | 0.1 | 46 | 8.2 | 8.3 | 6.8 | 8.6 | ≥6.5 & ≤9.0(1) | 0 | 0% |
| Turbidity (NTUs) | 1 | 47 | 11 | 6 | n.d. | 67 | ----- | ----- | ----- |
| Oxidation-Reduction Potential (mV) | 1 | 15 | 376 | 355 | 305 | 485 | ----- | ----- | ----- |
| Alkalinity, Total (mg/l) | 7 | 50 | 167 | 167 | 130 | 209 | ----- | ----- | ----- |
| Ammonia N, Total (mg/l) | 0.02 | 50 | ----- | 0.02 | n.d. | 0.58 | 3 15(1,2,3), 1.58(1,2,4) | 0 | 0% |
| Carbon, Total Organic (mg/l) | 0.05 | 47 | 3.5 | 3.1 | 1.6 | 16.1 | ----- | ----- | ----- |
| Chemical Oxygen Demand (mg/l) | 2 | 50 | 9 | 10 | n.d. | 53 | ----- | ----- | ----- |
| Chloride (mg/l) | 1 | 50 | 13 | 13 | 8 | 31 | ----- | ----- | ----- |
| Dissolved Solids, Total (mg/l) | 4 | 47 | 496 | 480 | 440 | 840 | 1,750(5) | 0 | 0% |
| Iron, Dissolved (ug/l) | 40 | 6 | ----- | n.d. | n.d. | 152 | ----- | ----- | ----- |
| Iron, Total (ug/l) | 40 | 6 | 116 | 114 | 60 | 201 | ----- | ----- | ----- |
| Kjeldahl N, Total (mg/l) | 0.1 | 50 | 0.7 | 0.5 | n.d. | 3.2 | ----- | ----- | ----- |
| Manganese, Dissolved (ug/l) | 2 | 6 | ----- | n.d. | n.d. | 22 | ----- | ----- | ----- |
| Manganese, Total (ug/l) | 2 | 3 | ---- | 10 | n.d. | 20 | ----- | ----- | ----- |
| Nitrate-Nitrite N, Total (mg/l) | 0.02 | 49 | ----- | n.d. | n.d. | 1.40 | 10(5) | 0 | 0% |
| Phosphorus, Total (mg/l) | 0.02 | 50 | ----- | 0.03 | n.d. | 0.73 | ----- | ----- | ----- |
| Suspended Solids, Total (mg/l) | 4 | 50 | ----- | n.d. | n.d. | 178 | 158(1,3), 90(1,4) | 1, 1 | 2%, 2% |
| Hardness, Dissolved (mg/l) | 1 | 10 | 221 | 220 | 186 | 239 | ----- | ----- | ----- |
| Aluminum, Dissolved (ug/l) | 25 | 6 | ----- | n.d. | n.d. | 50 | ----- | ----- | ----- |
| Antimony, Dissolved (ug/l) | 0.5 | 7 | ----- | n.d. | n.d. | 0.7 | 5.6(6) | 0 | 0% |
| Arsenic, Dissolved (ug/l) | 3 | 12 | ----- | n.d. | n.d. | 3 | 340(3), 150(4), 0.018(3) | 0, 0, b.d. | 0%, 0%, b.d. |
| Beryllium, Dissolved (ug/l) | 2 | 7 | ----- | n.d. | n.d. | n.d. | 4(6) | 0 | 0% |
| Cadmium, Dissolved (ug/l) | 0.5 | 12 | ----- | n.d. | n.d. | n.d. | 11(3), 4.6(4) | 0 | 0% |
| Chromium, Dissolved (ug/l) | 10 | 12 | ----- | n.d. | n.d. | n.d. | 3,439(3), 164(4) | 0 | 0% |
| Copper, Dissolved (ug/l) | 2 | 11 | ----- | n.d. | n.d. | 3 | 29(3), 18(4), 1,300(6) | 0 | 0% |
| Lead, Dissolved (ug/l) | 2 | 12 | ----- | n.d. | n.d. | n.d. | 223(3), 8.7(4) | 0 | 0% |
| Mercury, Dissolved (ug/l) | 0.02 | 12 | ----- | n.d. | n.d. | n.d. | 1.4(3), 0.05(6) | 0 | 0% |
| Mercury, Total (ug/l) | 0.02 | 12 | ----- | n.d. | n.d. | n.d. | 0.012(4) | b.d. | b.d. |
| Nickel, Dissolved (ug/l) | 10 | 12 | ----- | n.d. | n.d. | n.d. | 914(3), 102(4), 610(6) | 0 | 0% |
| Selenium, Total (ug/l) | 4 | 12 | ----- | n.d. | n.d. | 4. | 4.6(4), 170(6) | 0 | 0% |
| Silver, Dissolved (ug/l) | 1 | 11 | ----- | n.d. | n.d. | n.d. | 15(31) | 0 | 0% |
| Thallium, Dissolved (ug/l) | 6 | 7 | ----- | n.d. | n.d. | n.d. | 0.24(6) | b.d. | b.d. |
| Zinc, Dissolved (ug/l) | 3 | 12 | ----- | n.d. | n.d. | 20 | 234(3,4), 7,400(6) | 0 | 0% |
| Acetochlor, Total (ug/l)(D) | 0.05 | 9 | ----- | n.d. | n.d. | n.d. | ----- | ----- | ----- |
| Alachlor, Total (ug/l)(D) | 0.05 | 30 | ----- | n.d. | n.d. | n.d. | ----- | ----- | ----- |
| Atrazine, Total (ug/l)(D) | 0.05 | 39 | ----- | n.d. | n.d. | 0.11 | ----- | ----- | ----- |
| Metolachlor, Total (ug/l)(D) | 0.05 | 39 | ----- | n.d. | n.d. | 0.30 | ----- | ----- | ----- |
| Pesticide Scan (ug/l)(E) | 0.05 | 10 | ----- | n.d. | n.d. | n.d. | ----- | ----- | ----- |

n.d. = Not detected.

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

(B) Non-detect values set to 0 to calculate mean. The mean is not reported if 20% or more of the observations were non-detect. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(C) (1) Criteria for warmwater permanent fish life propagation waters.
(2) Total ammonia criteria are pH and temperature dependent. Criteria listed are for median pH and temperature values.
(3) Acute criterion.
(4) Chronic criterion.
(5) Daily maximum criterion for domestic water supply.
(6) Human health value concentration.

Note: South Dakota's water quality standards criteria for the metals cadmium, chromium, copper, lead, nickel, silver, and zinc are dependent upon hardness – criteria listed are based on the median hardness value.

(D) Immunoassay analysis.

(E) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chloropyrifos, cyanazine, cycloate, deethylatrazine, deisprplatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, isopropalin, metolachlor, metribuzin, molinate, oxiadiazon, oxyfluorfen, pebulate, pendimethalin, phorate, profluralin, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

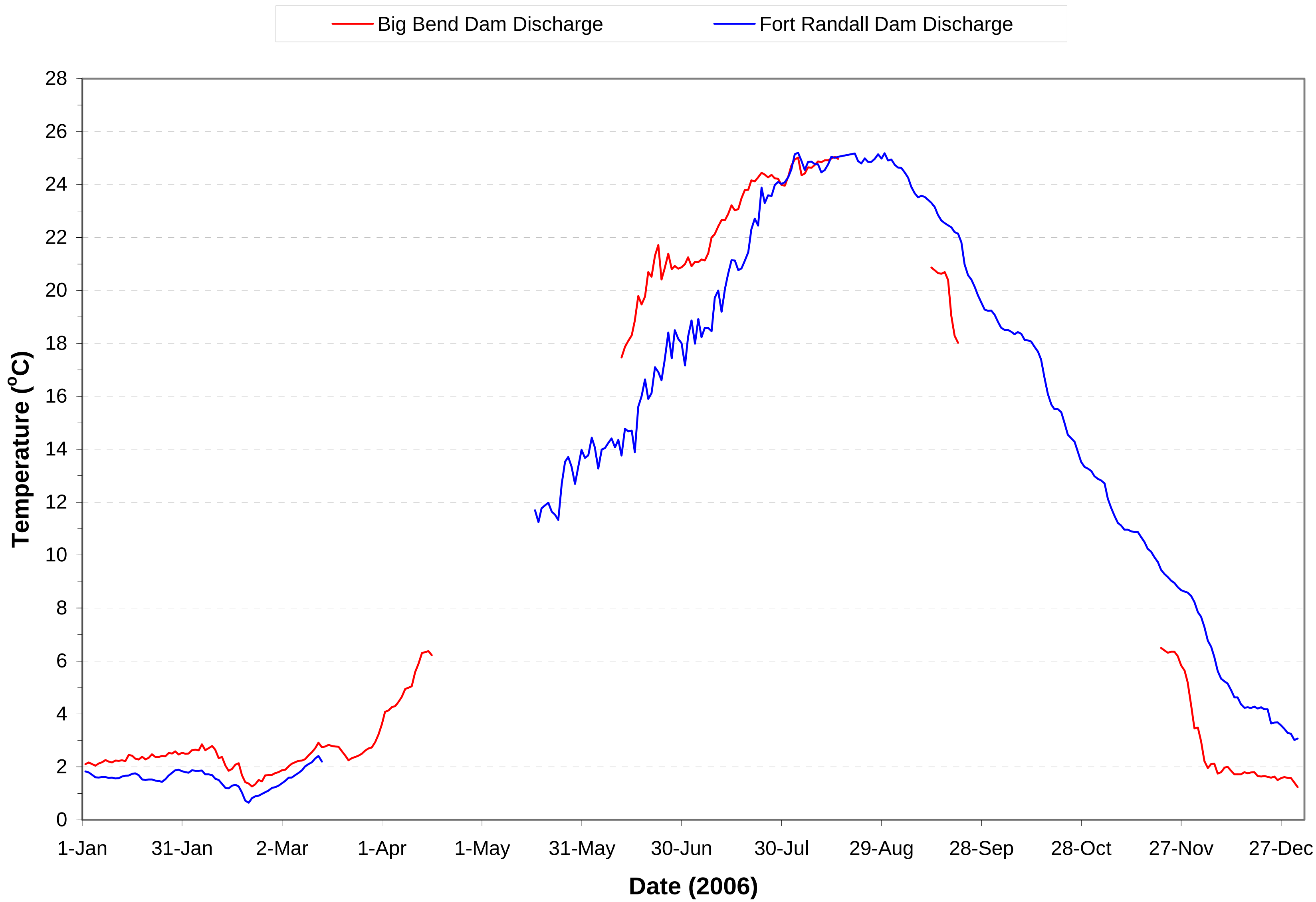


**Figure 7.1.** Mean daily water temperatures of the inflow and outflow to Fort Randall Reservoir for 2006 as monitored at the Big Bend (site NF1) and Fort Randall (site OF1) powerplants. (Note: Gaps in temperature plots are periods when monitoring equipment was not operational.)

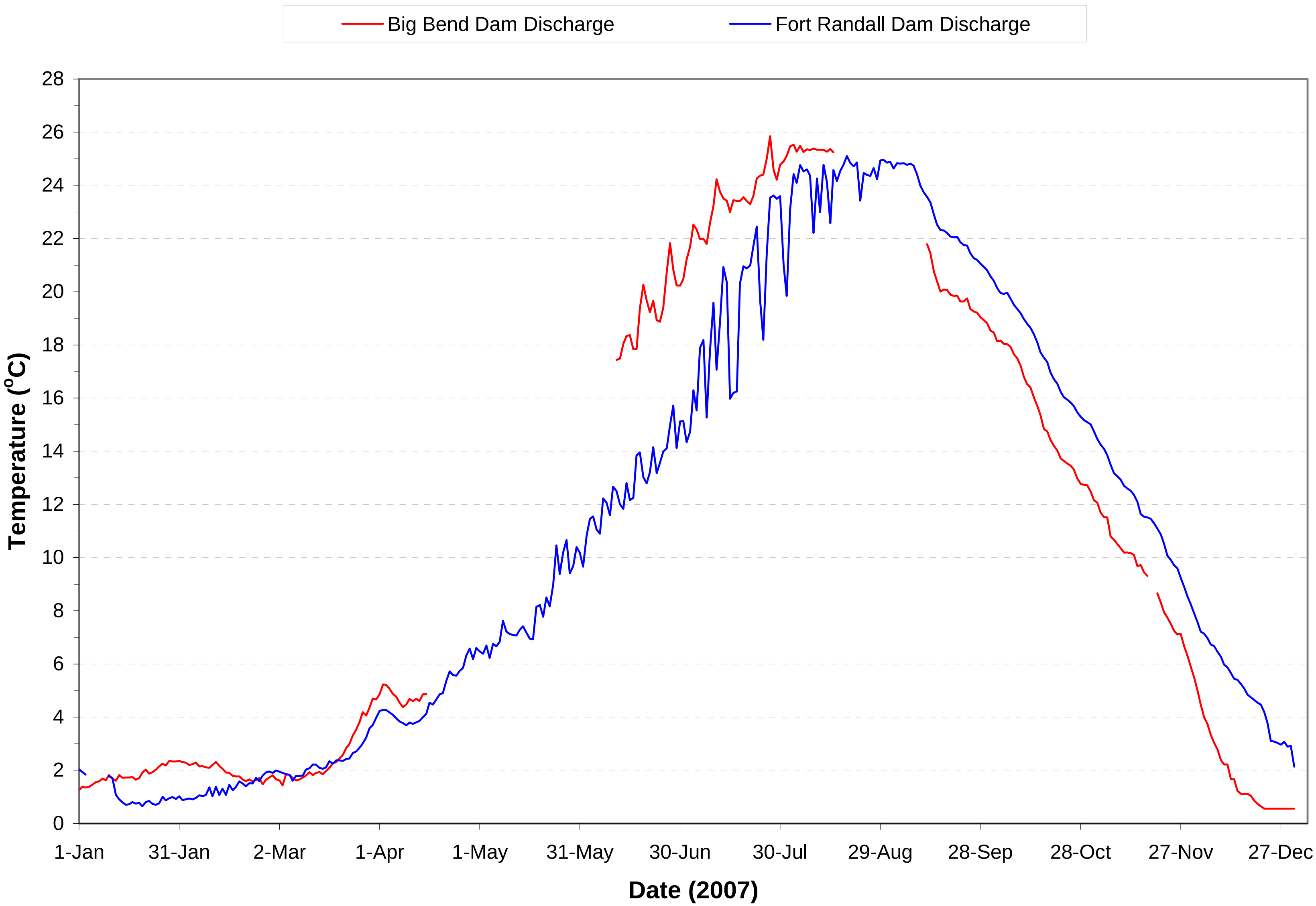


**Figure 7.2.** Mean daily water temperatures of the inflow and outflow to Fort Randall Reservoir for 2007 as monitored at the Big Bend (site NF1) and Fort Randall (site OF1) powerplants. (Note: Gaps in temperature plots are periods when monitoring equipment was not operational.)

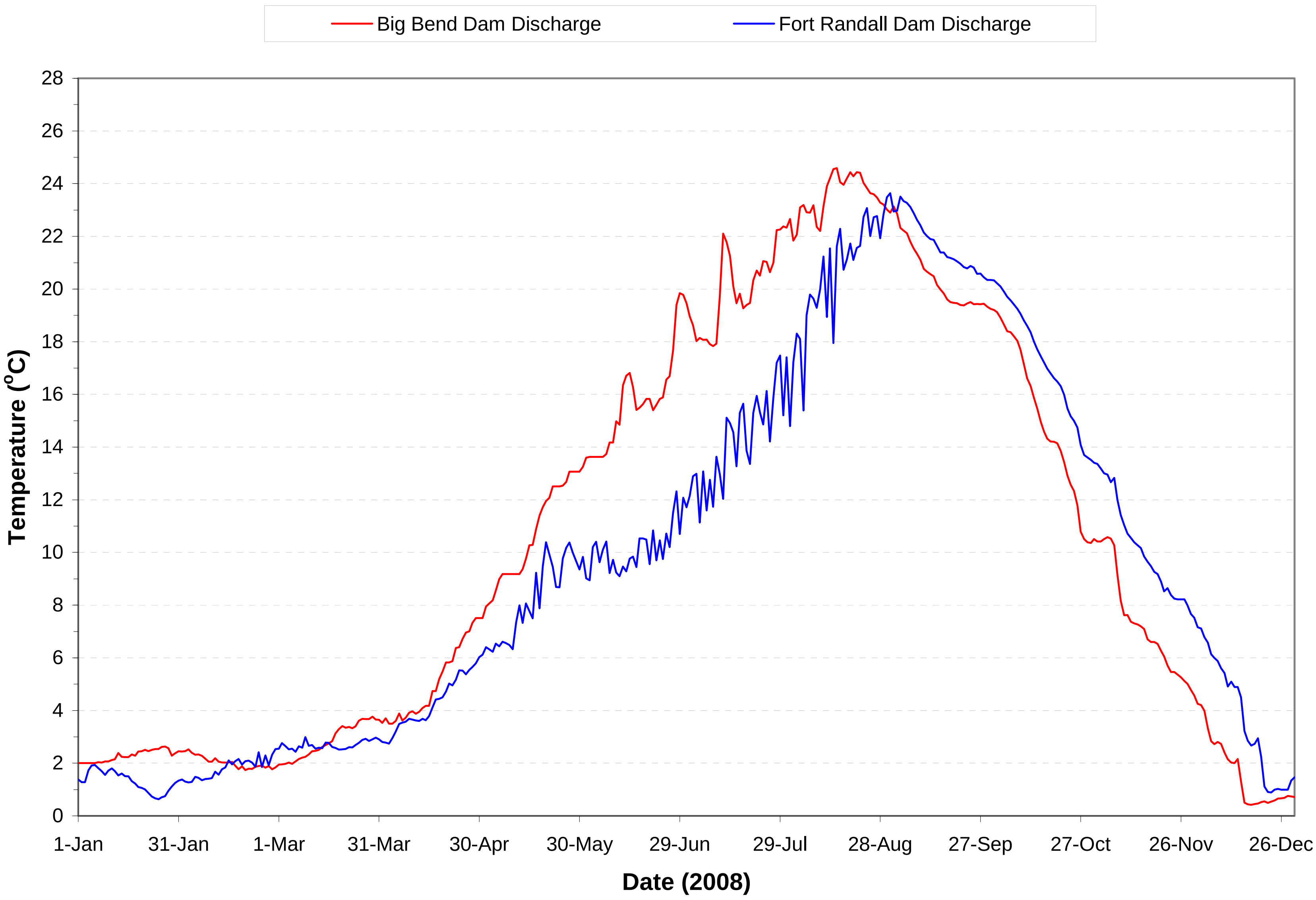


**Figure 7.3.** Mean daily water temperatures of the inflow and outflow to Fort Randall Reservoir for 2008 as monitored at the Big Bend (site NF1) and Fort Randall (site OF1) powerplants.

# 8 CONCLUSIONS AND RECOMMENDATIONS

## 8.1 EXISTING WATER QUALITY CONDITIONS

### 8.1.1 FORT RANDALL RESERVOIR

Water quality monitoring of Fort Randall Reservoir during the 3-year period of 2006 through 2008 indicated good water quality conditions in the reservoir. Water quality conditions in Fort Randall Reservoir vary along its length. Strong thermal stratification occurs in the deeper area of the reservoir nearer Fort Randall Dam during the summer. Water quality monitoring indicated that the trophic status of the downstream half of the reservoir is mesotrophic; while the upstream half is moderately eutrophic to eutrophic. The phytoplankton community of Fort Randall Reservoir was dominated by diatoms and only minor "blooms" of cyanobacteria were monitored.

### 8.1.2 WATER DISCHARGED THROUGH FORT RANDALL DAM

Water discharged through Fort Randall Dam exhibited good water quality during the monitored 3-year period of 2006 through 2008. The temperature of the discharge water is reflective of the near-bottom elevation of its withdrawal from Fort Randall Reservoir. Monitoring of the Fort Randall Dam discharge indicates that the vertical extent of the withdrawal zone in the reservoir is dependent upon the discharge rate of the dam. This is believed to be a result of the design of the intake structure (i.e., bottom withdrawal) and the presence of the submerged approach channel leading to the intake structure.

## 8.2 WATER QUALITY MANAGEMENT

The Omaha District is planning to pursue the application of the Corps' CE-QUAL-W2 (Version 3.2) hydrodynamic and water quality model to Fort Randall Reservoir. CE-QUAL-W2 is an extremely 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 Fort Randall Project affects the water quality in the reservoir and the Missouri River below Fort Randall Dam. It is almost a certainty that water quality issues at the Fort Randall 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 Fort Randall Reservoir at four sites: FTRLK0880A, FTRLK0911DW, FTRLK0940DW, and FTRLK0968DW. Continue year-round monitoring (i.e., monthly water samples and hourly data-logging) of water drawn from the raw-water supply lines at the Big Bend (i.e., Missouri River inflow) and at the Fort Randall (i.e., Missouri River outflow) powerplants.

# 9 REFERENCES


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# 10 PLATES

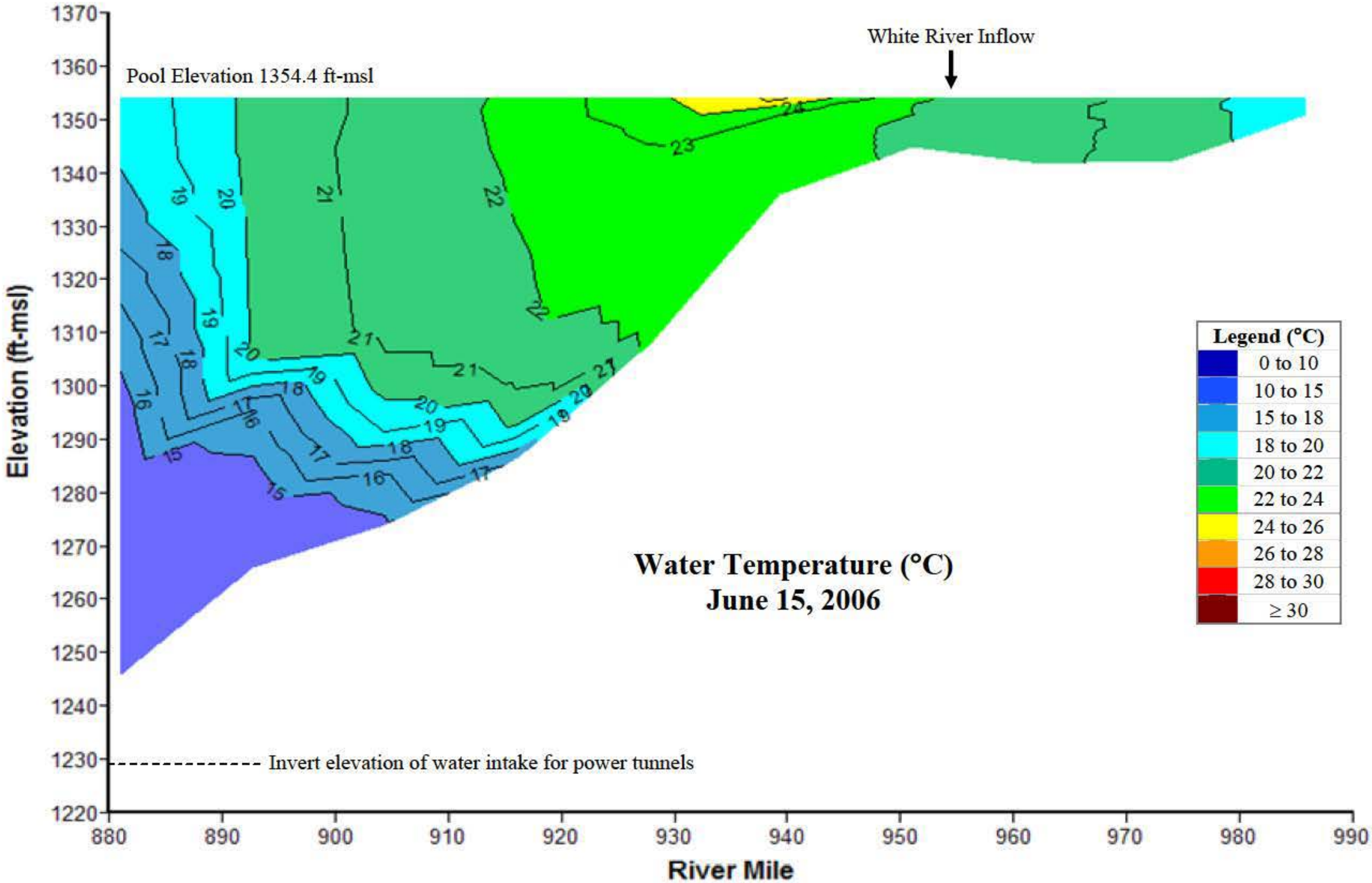


**Plate 1.** Longitudinal water temperature (°C) contour plot of Fort Randall Reservoir based on depth-profile water temperatures measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on June 15, 2006.

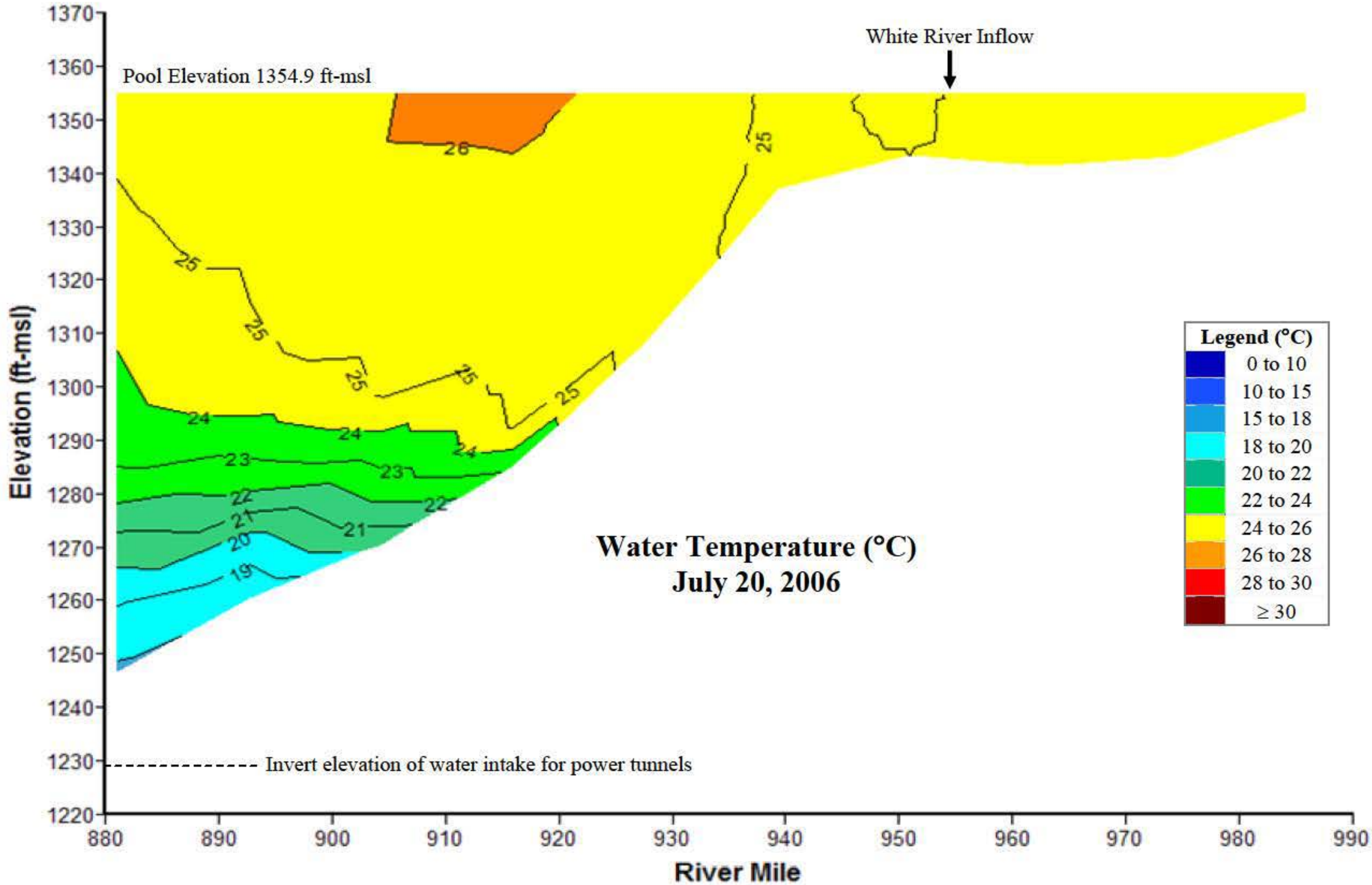


**Plate 2.** Longitudinal water temperature (°C) contour plot of Fort Randall Reservoir based on depth-profile water temperatures measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on July 20, 2006.

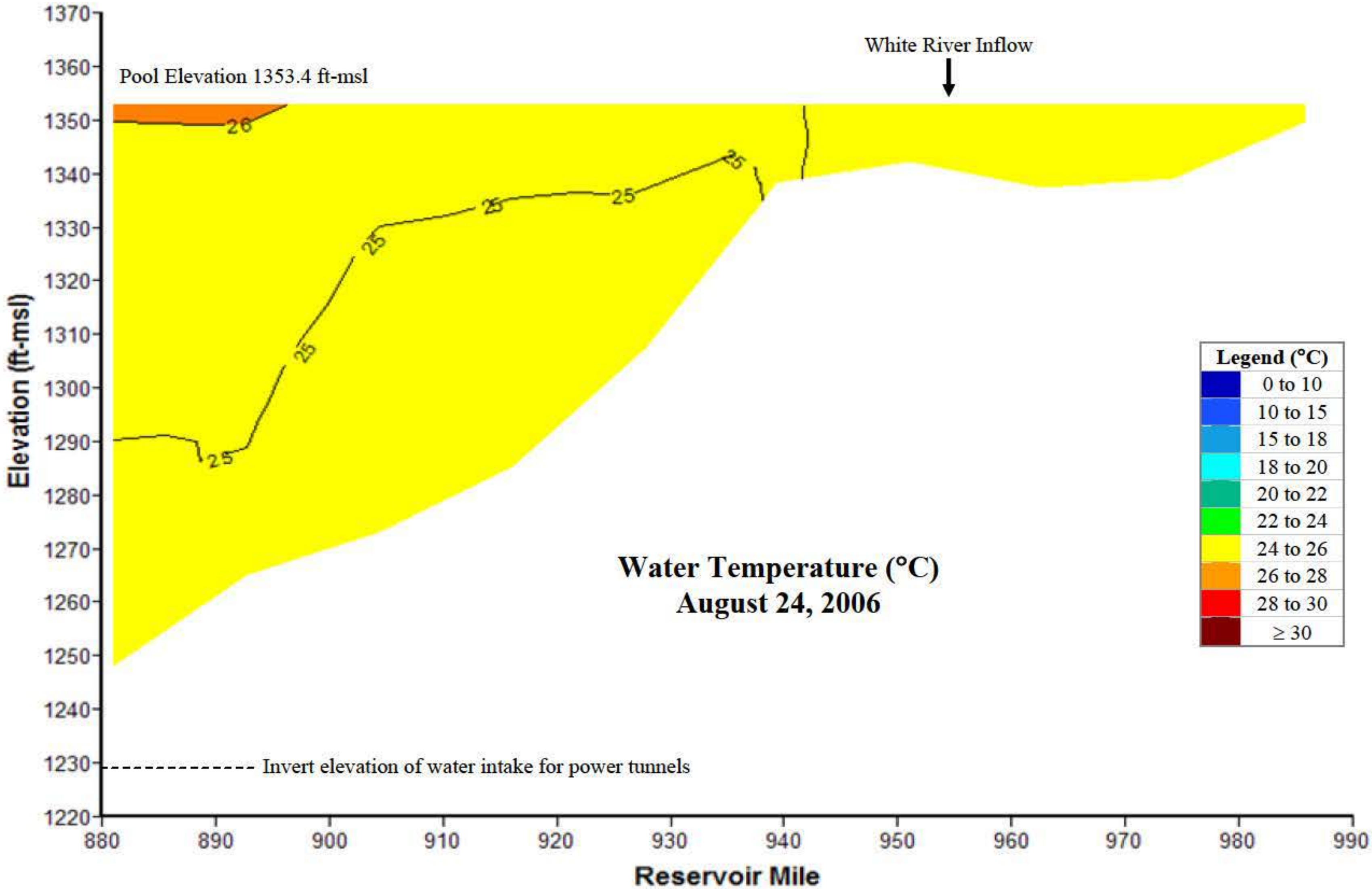


**Plate 3.** Longitudinal water temperature (°C) contour plot of Fort Randall Reservoir based on depth-profile water temperatures measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on August 24, 2006.

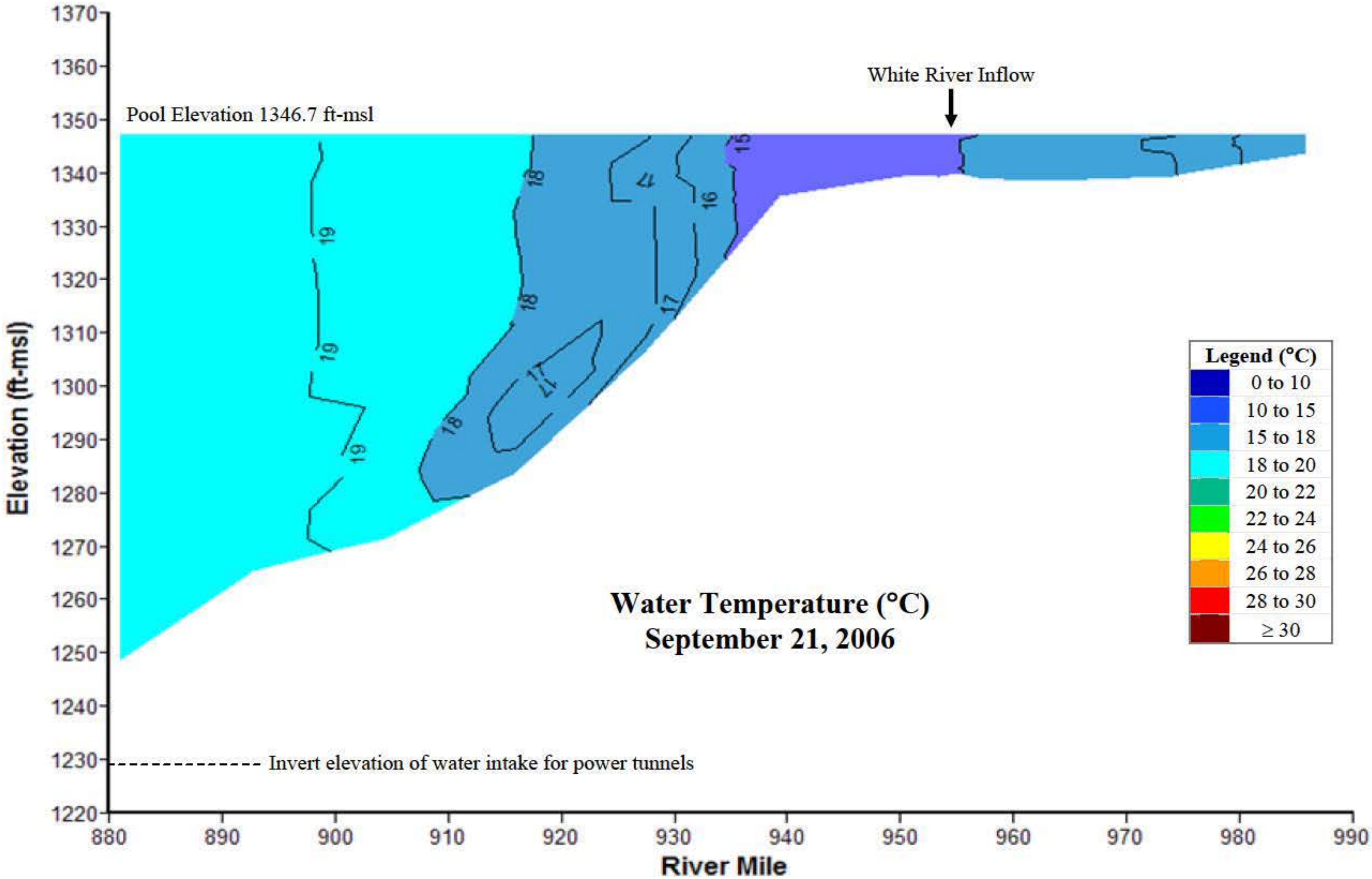


**Plate 4.** Longitudinal water temperature (°C) contour plot of Fort Randall Reservoir based on depth-profile water temperatures measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on September 21, 2006.

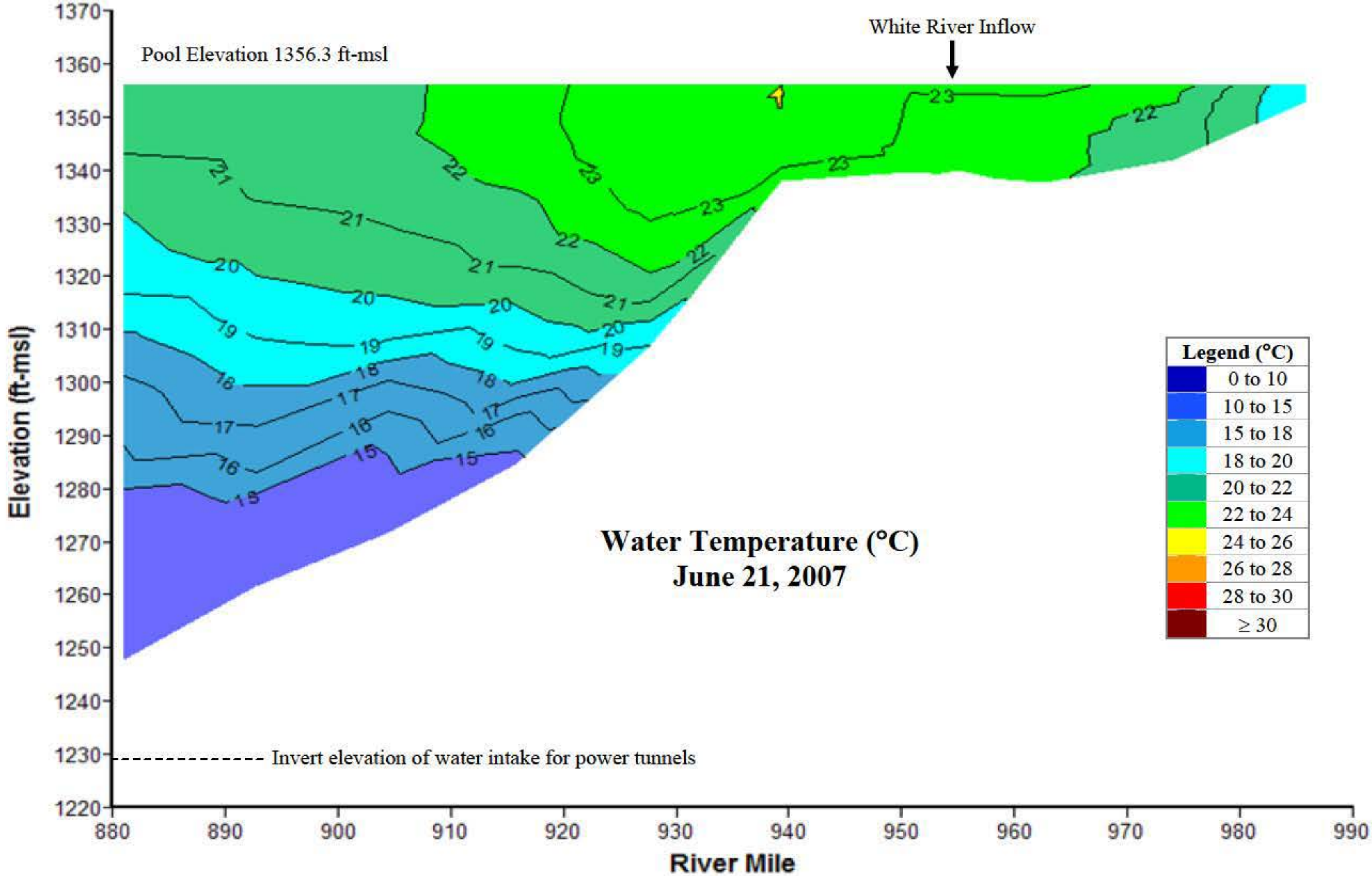


**Plate 5.** Longitudinal water temperature (°C) contour plot of Fort Randall Reservoir based on depth-profile water temperatures measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on June 21, 2007.

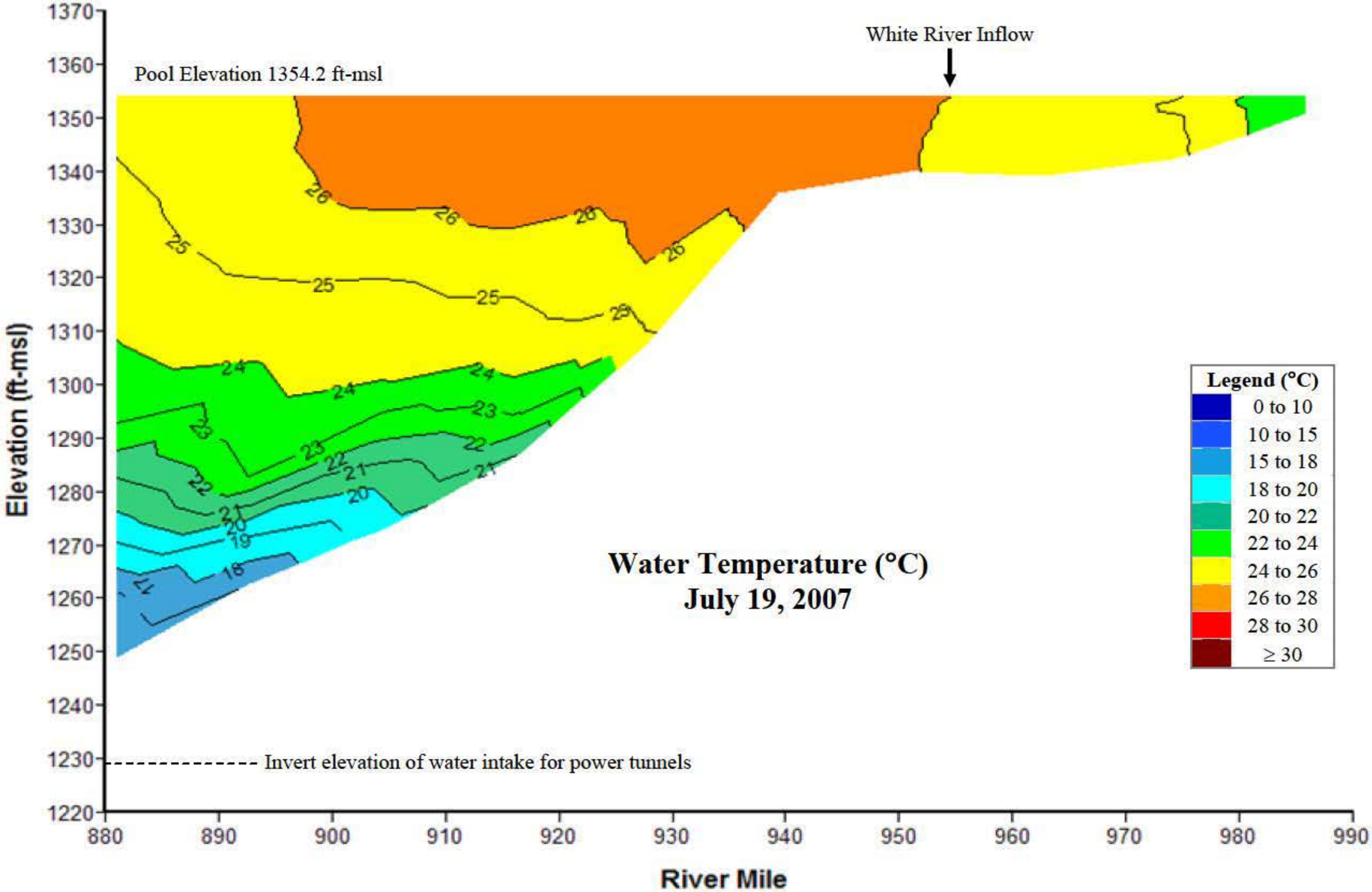


**Plate 6.** Longitudinal water temperature (°C) contour plot of Fort Randall Reservoir based on depth-profile water temperatures measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on July 19, 2007.

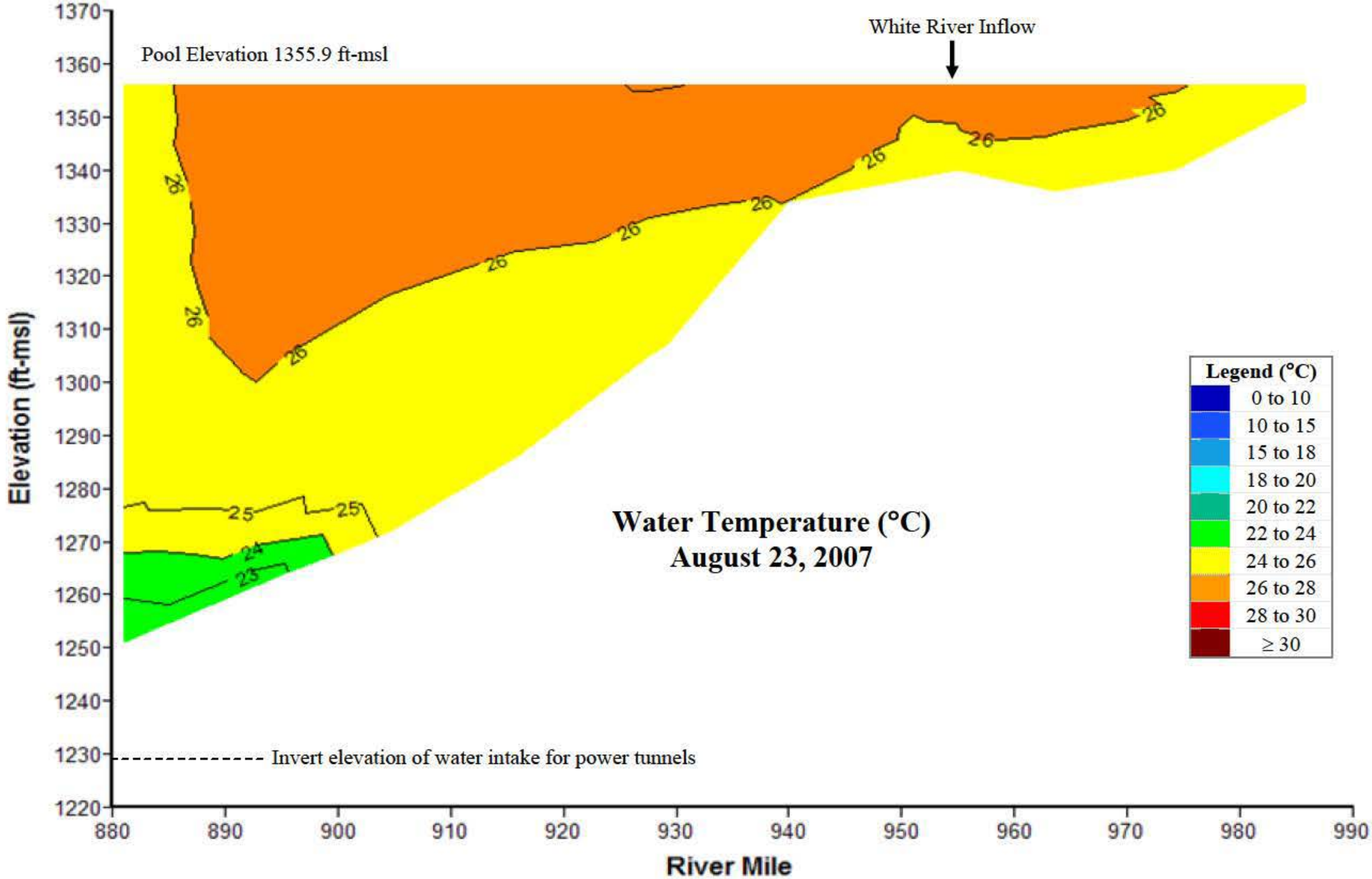


**Plate 7.** Longitudinal water temperature (°C) contour plot of Fort Randall Reservoir based on depth-profile water temperatures measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on August 23, 2007.

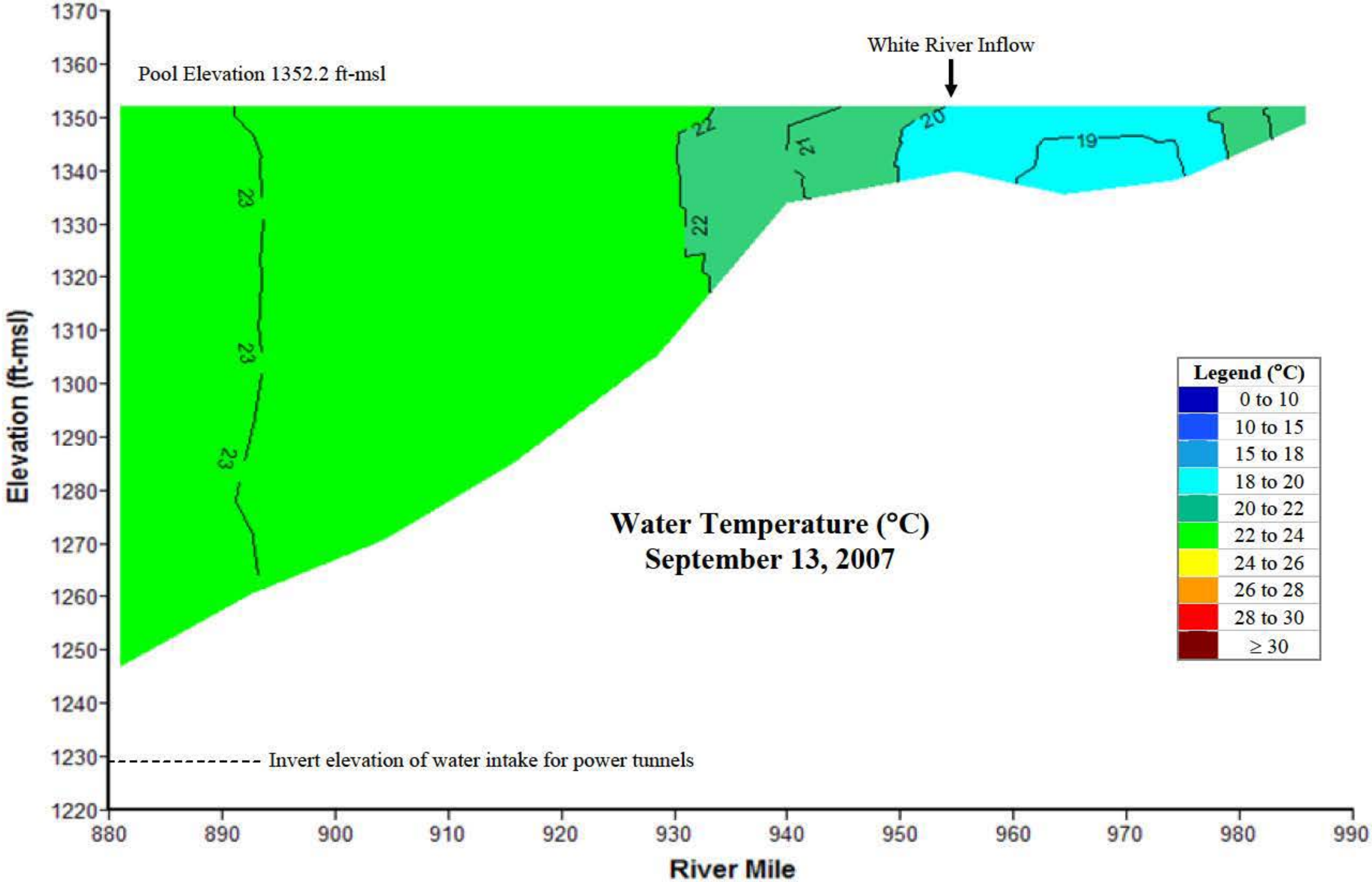


**Plate 8.** Longitudinal water temperature (°C) contour plot of Fort Randall Reservoir based on depth-profile water temperatures measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on September 13, 2007.

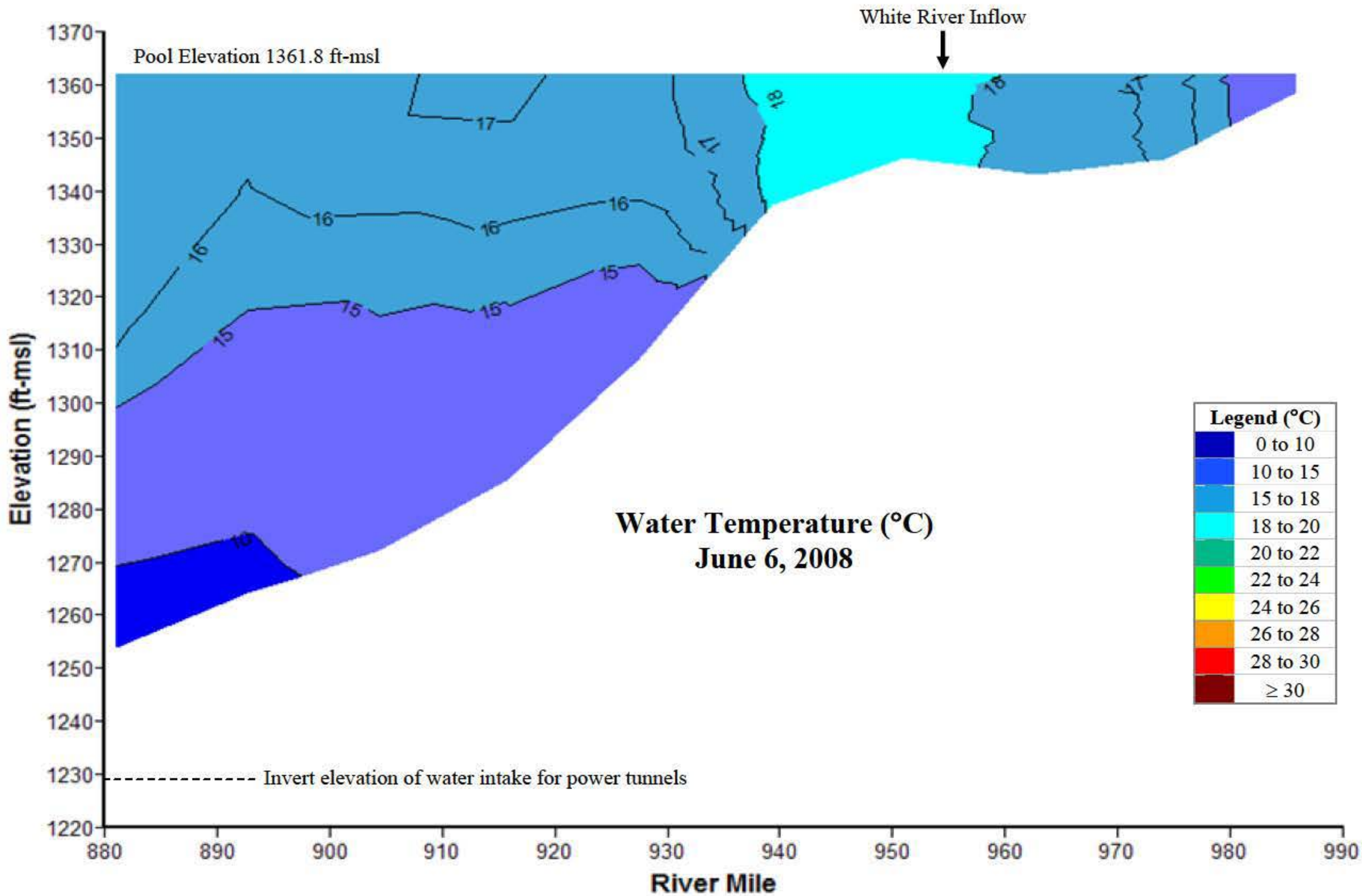


**Plate 9.** Longitudinal water temperature (°C) contour plot of Fort Randall Reservoir based on depth-profile water temperatures measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on June 6, 2008.

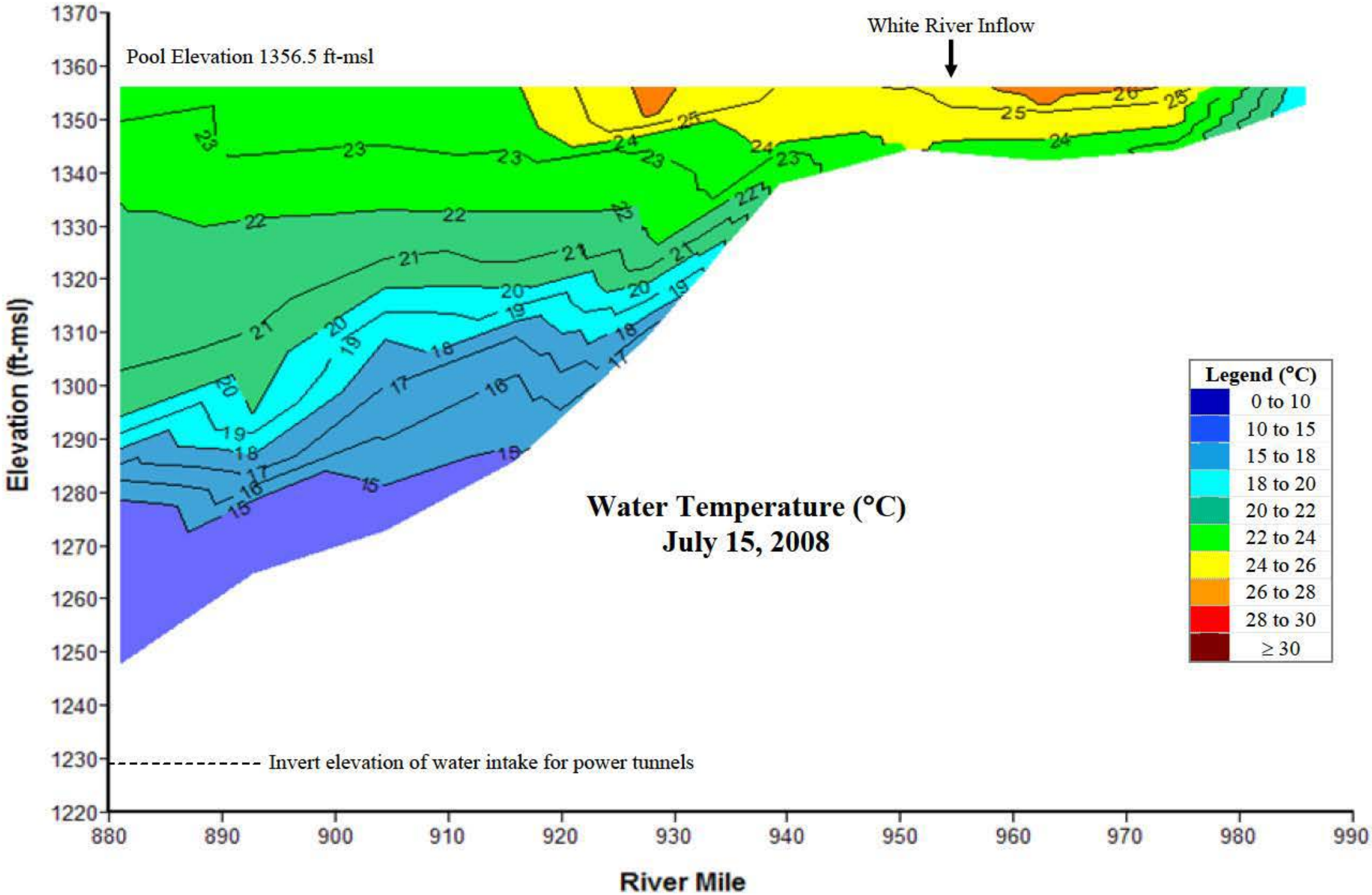


**Plate 10.** Longitudinal water temperature (°C) contour plot of Fort Randall Reservoir based on depth-profile water temperatures measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on July 15, 2008.

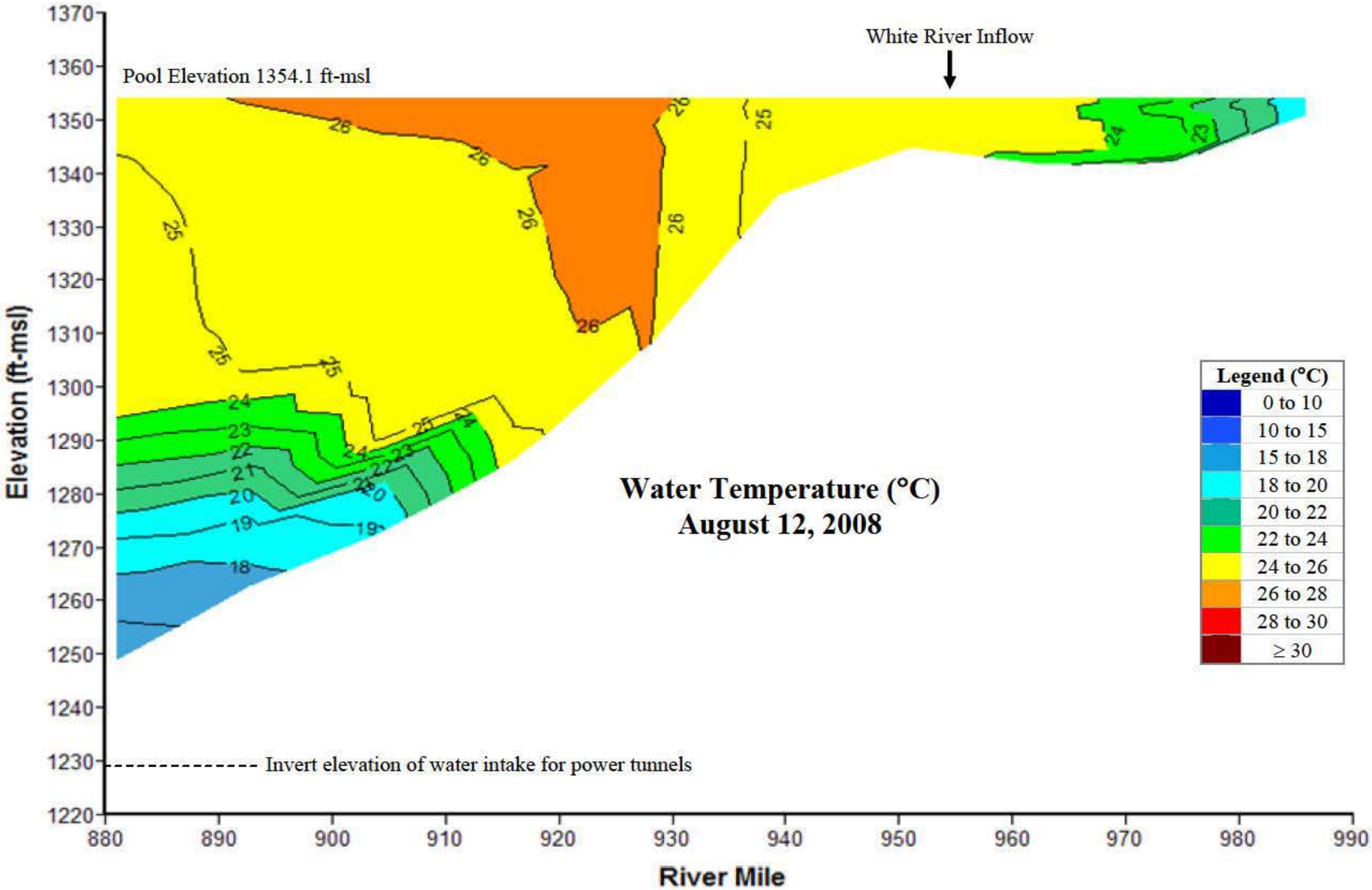


**Plate 11.** Longitudinal water temperature (°C) contour plot of Fort Randall Reservoir based on depth-profile water temperatures measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on August 12, 2008.

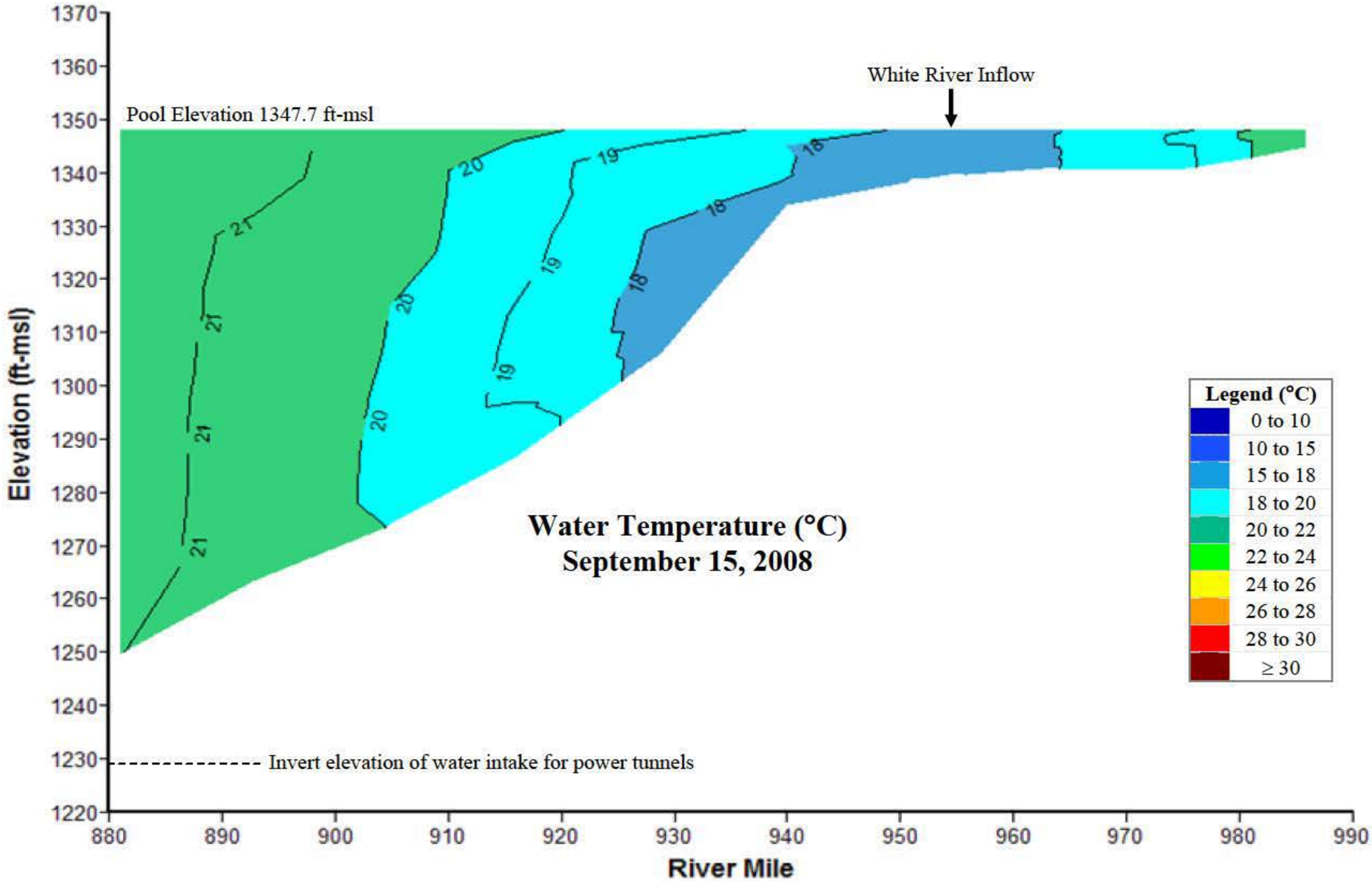


**Plate 12.** Longitudinal water temperature (°C) contour plot of Fort Randall Reservoir based on depth-profile water temperatures measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on September 15, 2008.

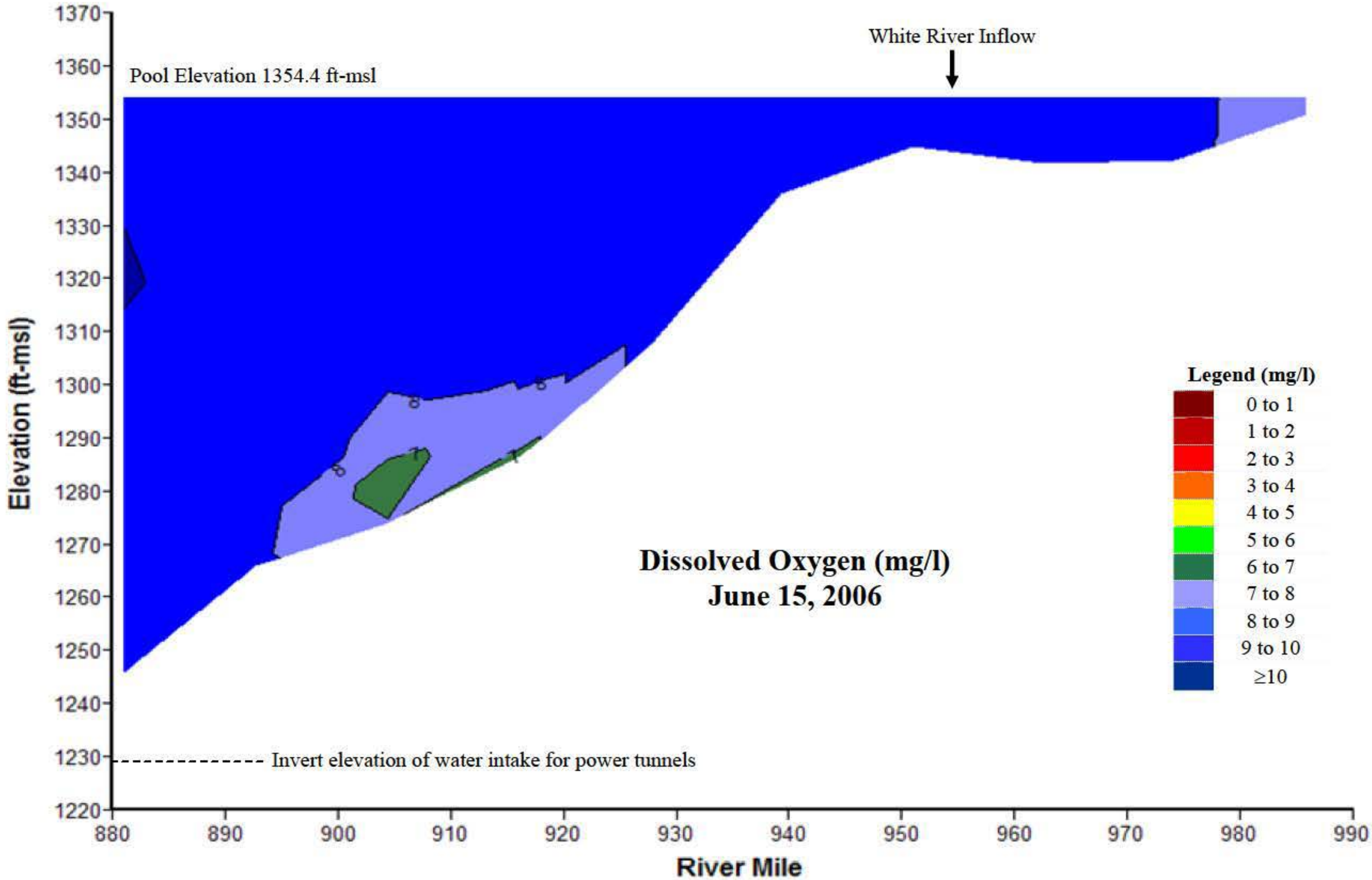


**Plate 13.** Longitudinal dissolved oxygen (mg/l) contour plot of Fort Randall Reservoir based on depth-profile dissolved oxygen concentrations measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on June 15, 2006.

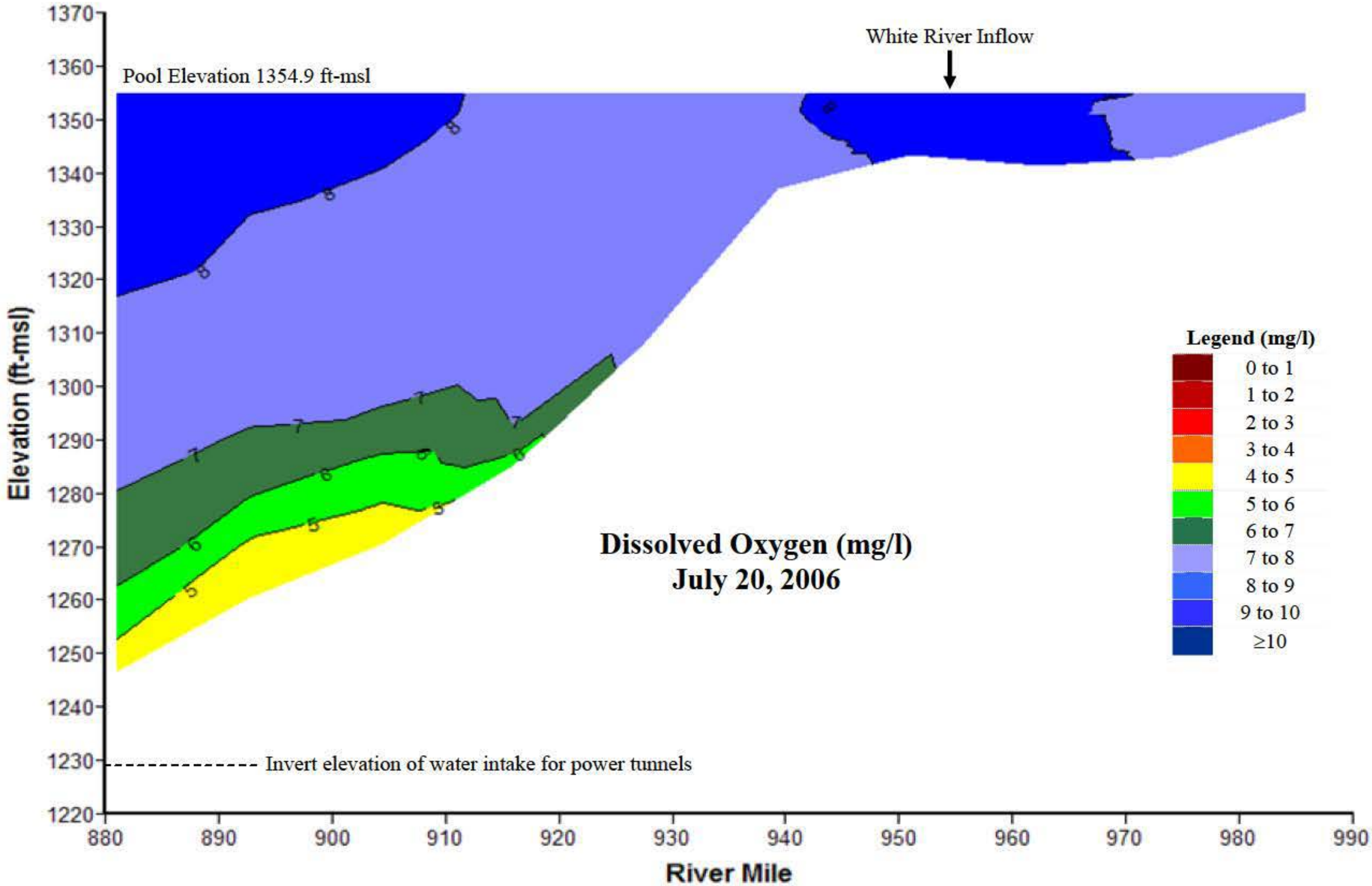


**Plate 14.** Longitudinal dissolved oxygen (mg/l) contour plot of Fort Randall Reservoir based on depth-profile dissolved oxygen concentrations measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on July 20, 2006.

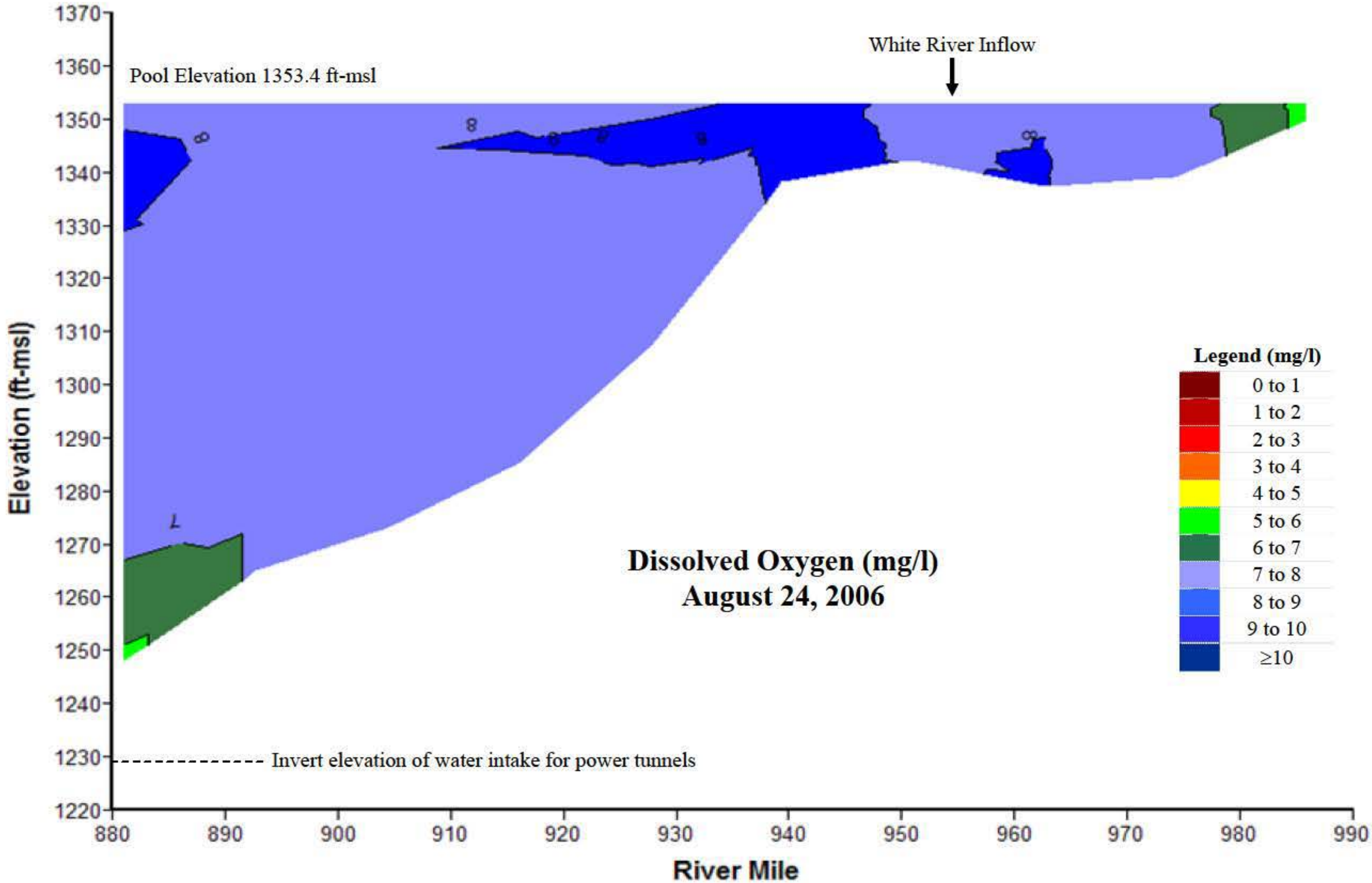


**Plate 15.** Longitudinal dissolved oxygen (mg/l) contour plot of Fort Randall Reservoir based on depth-profile dissolved oxygen concentrations measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on August 24, 2006.

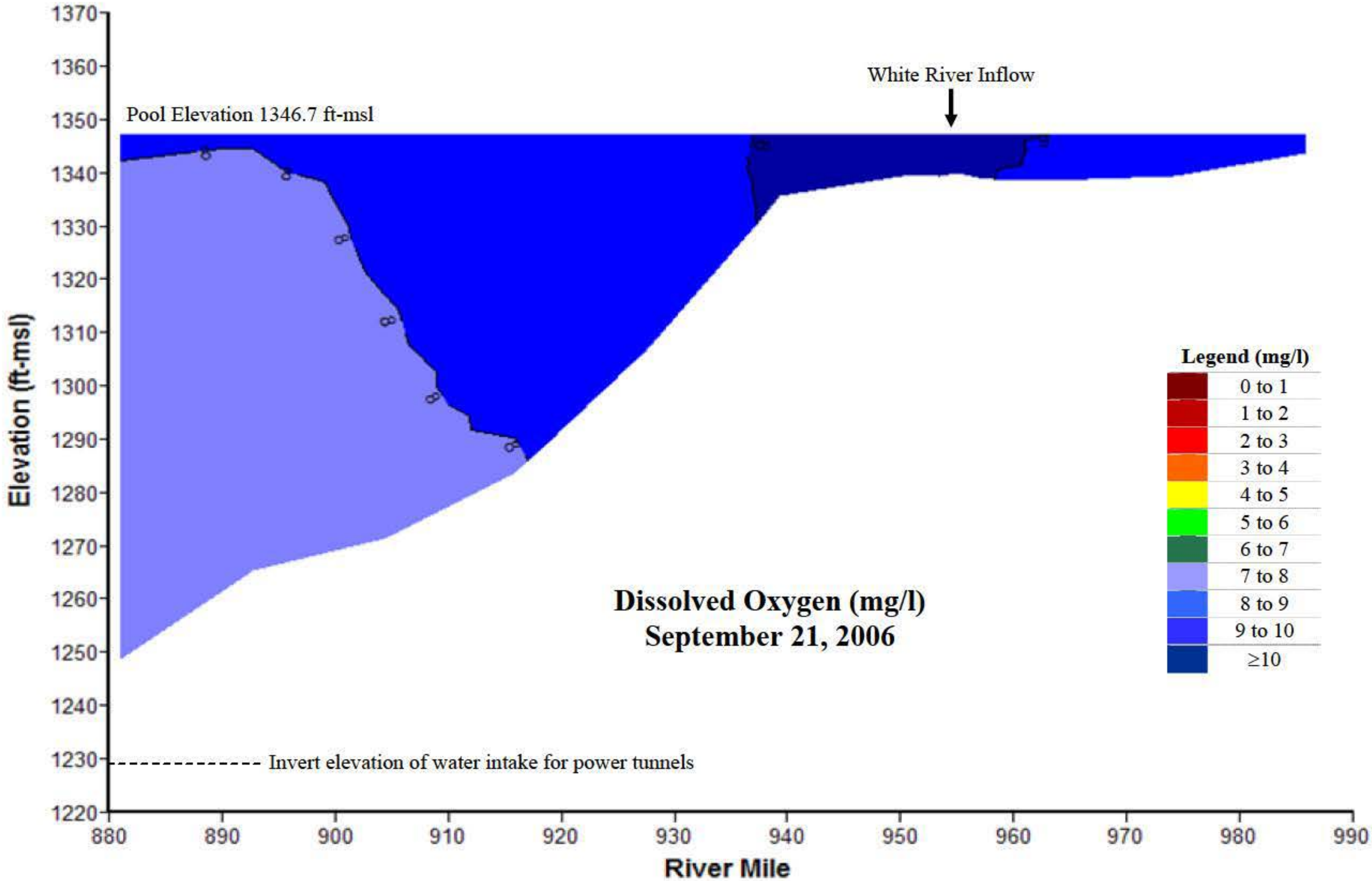


**Plate 16.** Longitudinal dissolved oxygen (mg/l) contour plot of Fort Randall Reservoir based on depth-profile dissolved oxygen concentrations measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on September 21, 2006.

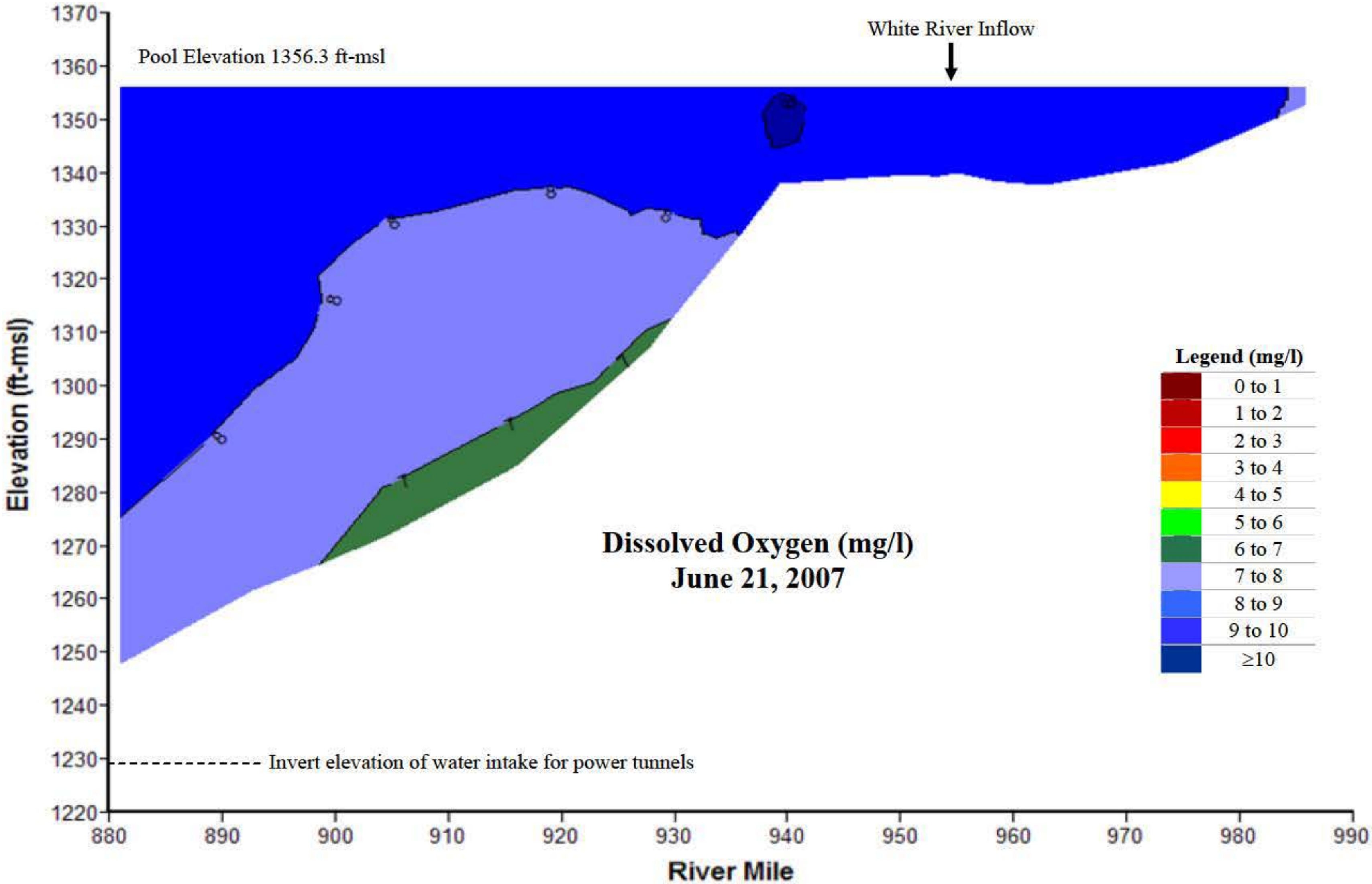


**Plate 17.** Longitudinal dissolved oxygen (mg/l) contour plot of Fort Randall Reservoir based on depth-profile dissolved oxygen concentrations measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on June 21, 2007.

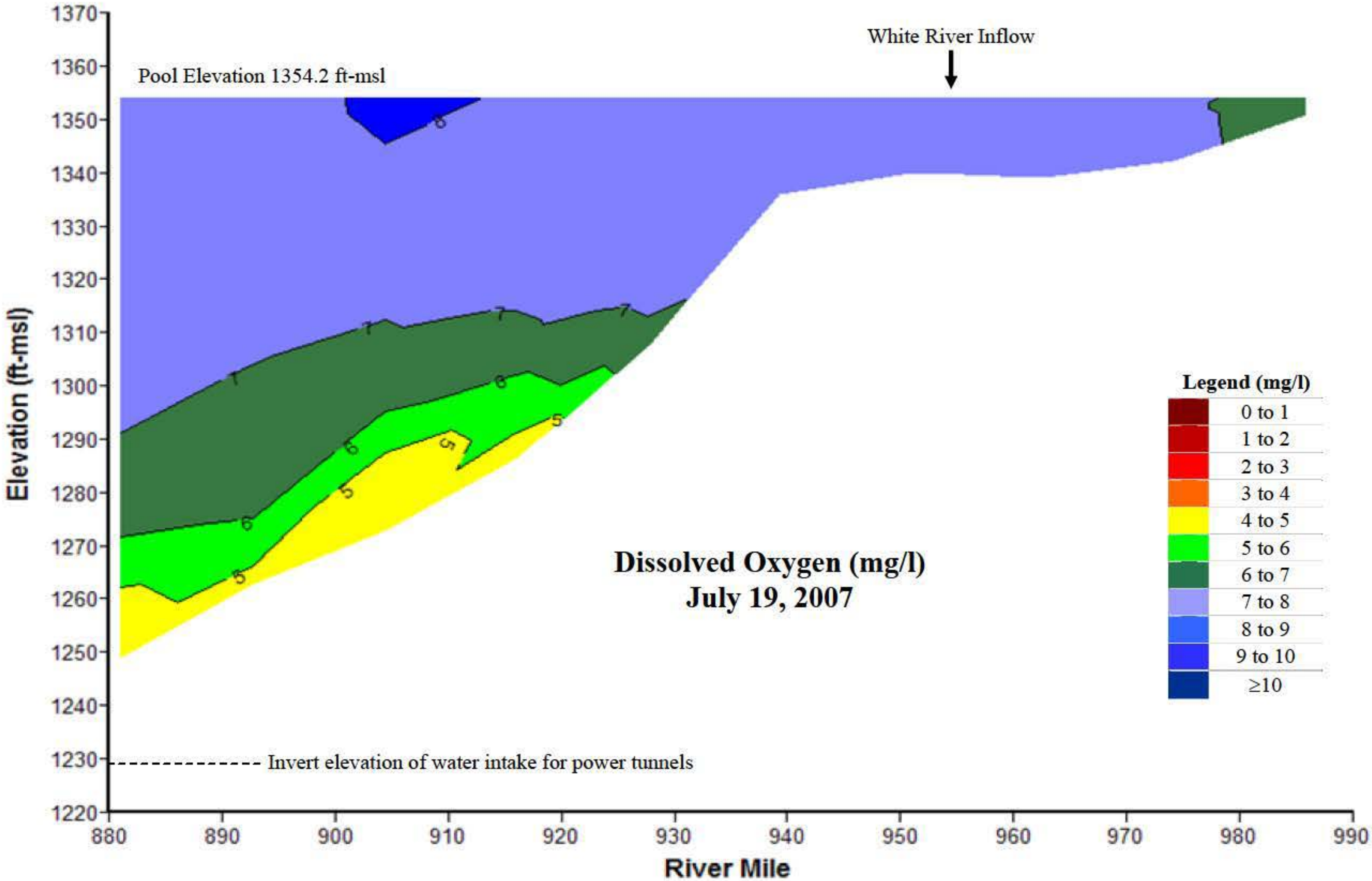


**Plate 18.** Longitudinal dissolved oxygen (mg/l) contour plot of Fort Randall Reservoir based on depth-profile dissolved oxygen concentrations measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on July 19, 2007.

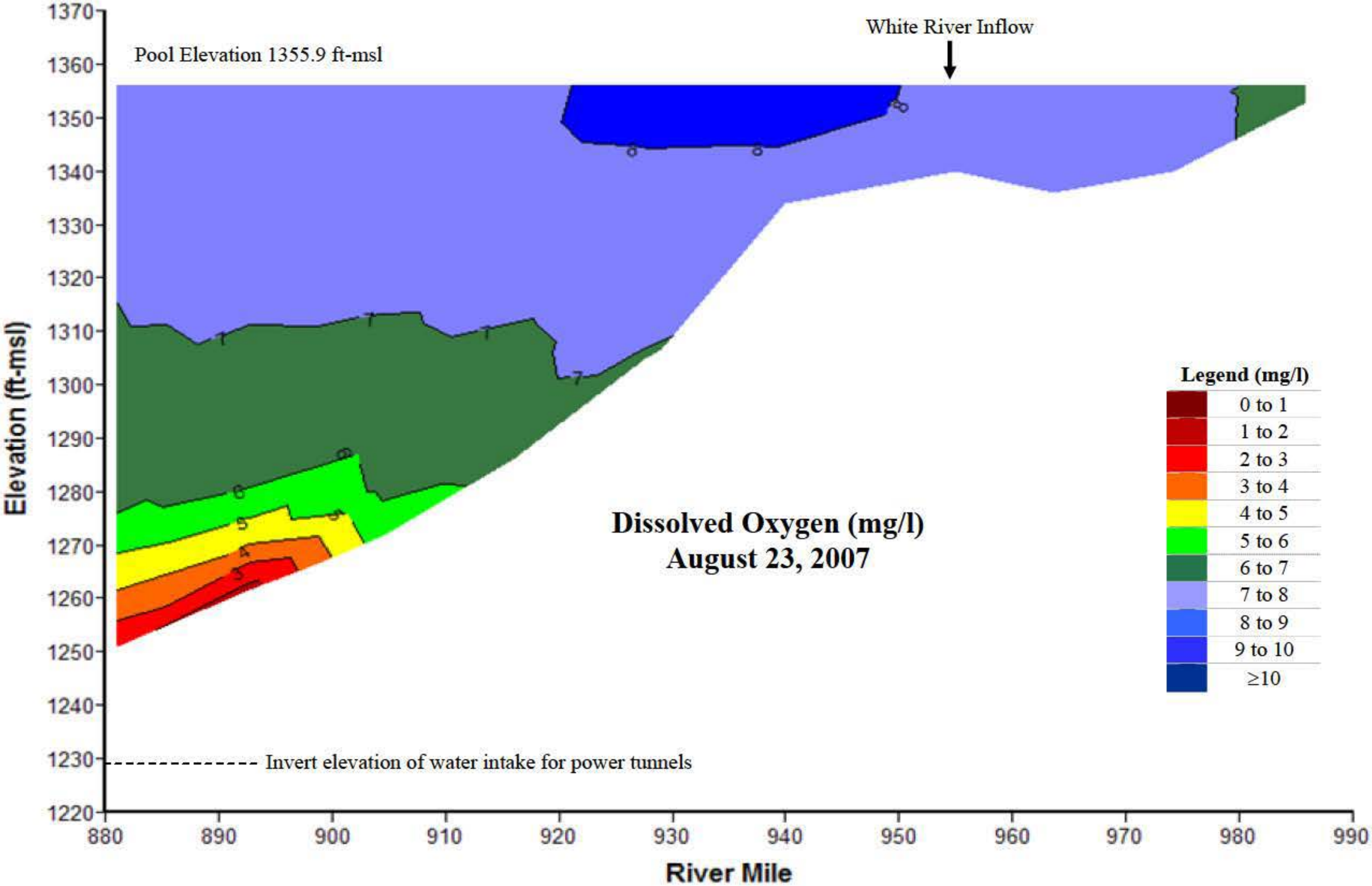


**Plate 19.** Longitudinal dissolved oxygen (mg/l) contour plot of Fort Randall Reservoir based on depth-profile dissolved oxygen concentrations measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on August 23, 2007.

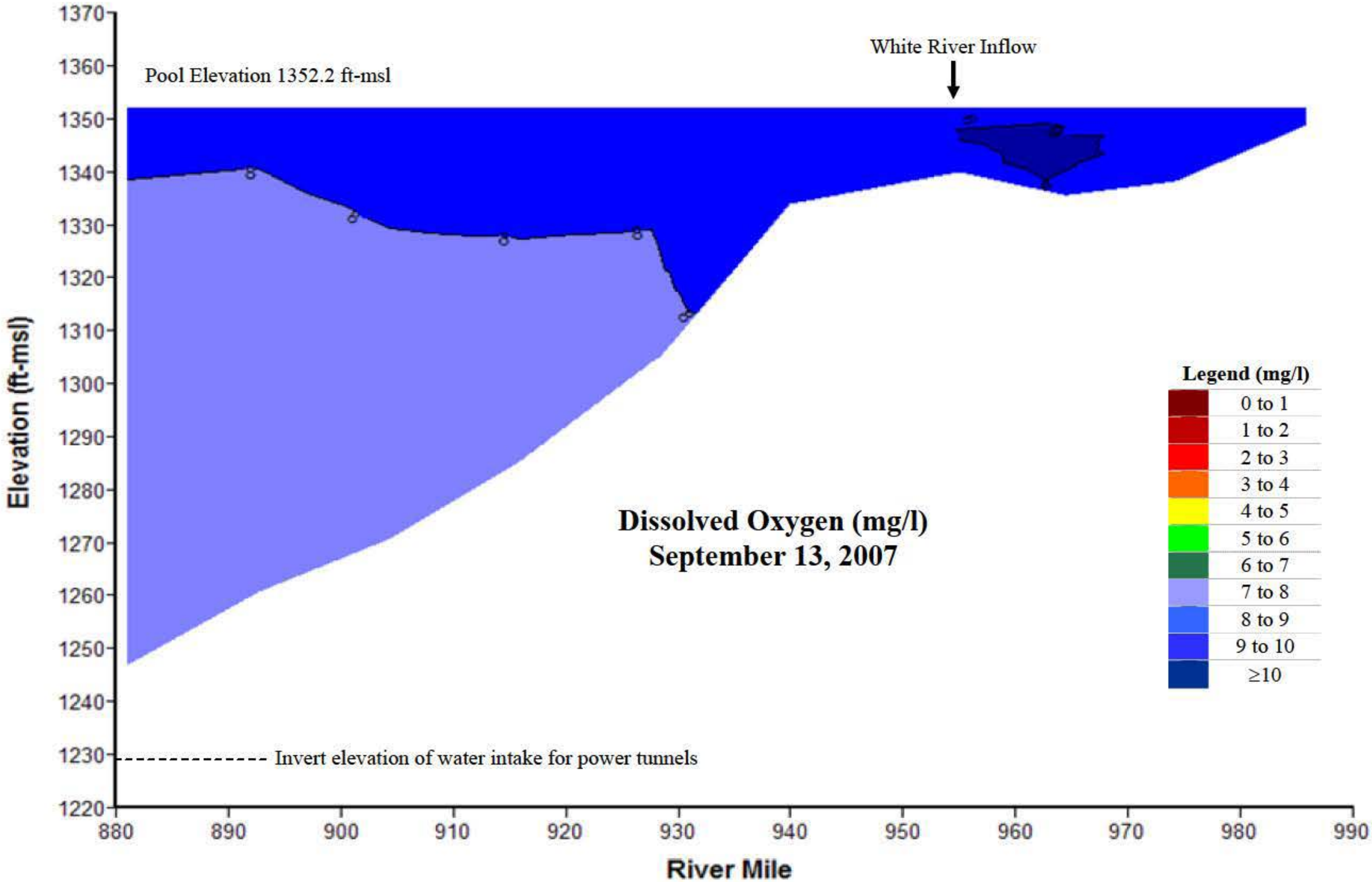


**Plate 20.** Longitudinal dissolved oxygen (mg/l) contour plot of Fort Randall Reservoir based on depth-profile dissolved oxygen concentrations measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on September 13, 2007.

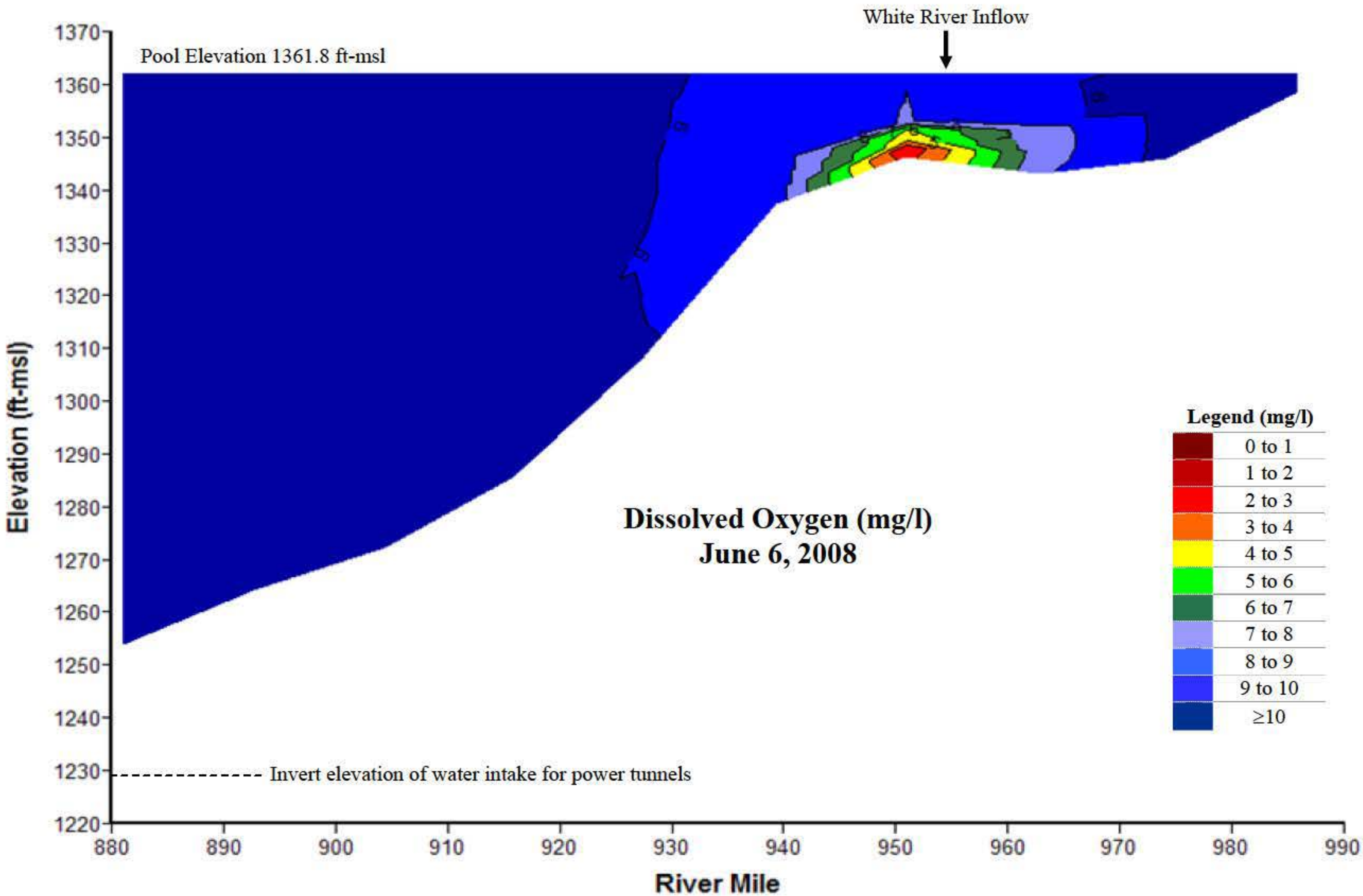


**Plate 21.** Longitudinal dissolved oxygen (mg/l) contour plot of Fort Randall Reservoir based on depth-profile dissolved oxygen concentrations measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on June 6, 2008.

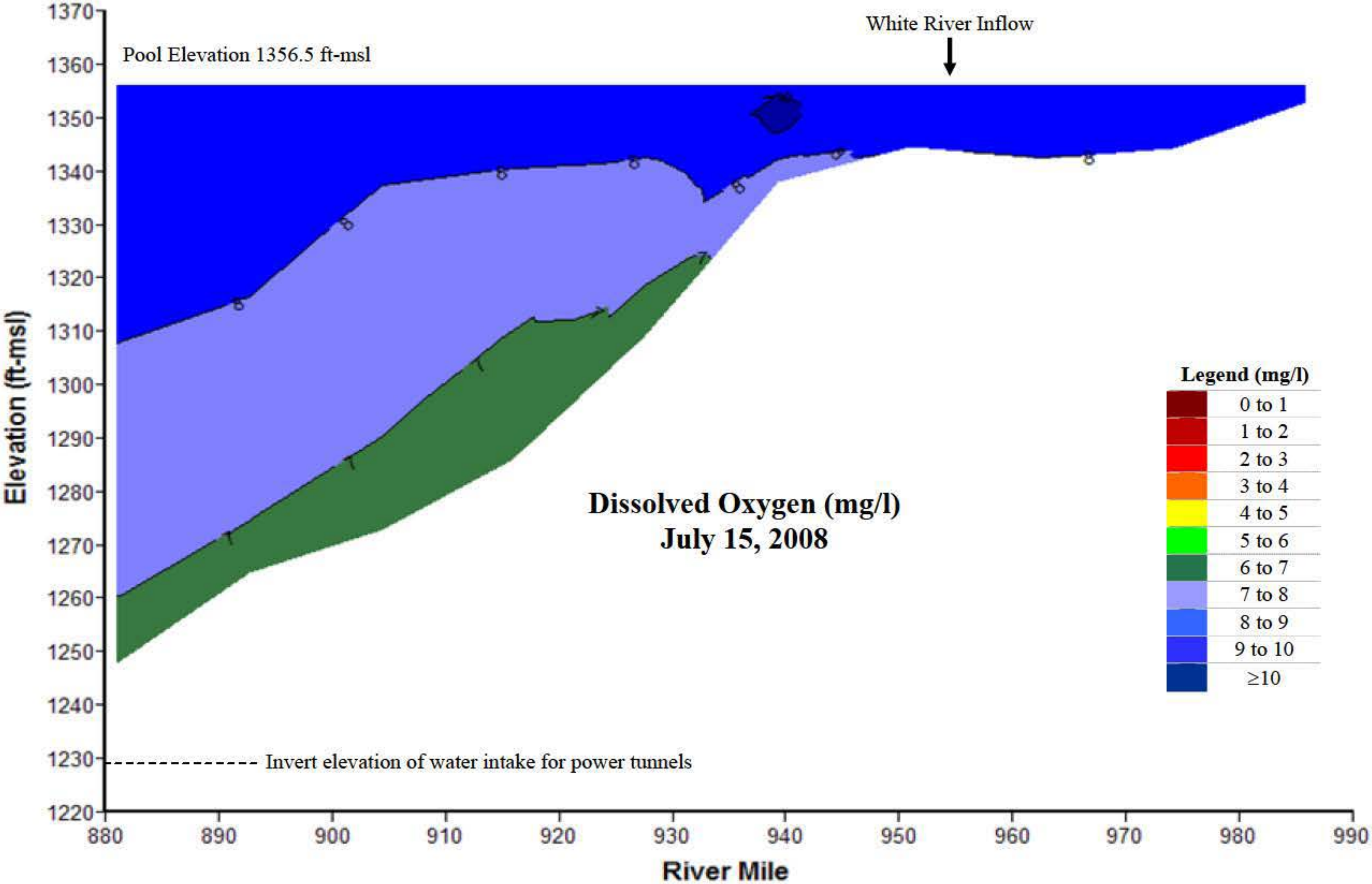


**Plate 22.** Longitudinal dissolved oxygen (mg/l) contour plot of Fort Randall Reservoir based on depth-profile dissolved oxygen concentrations measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on July 15, 2008.

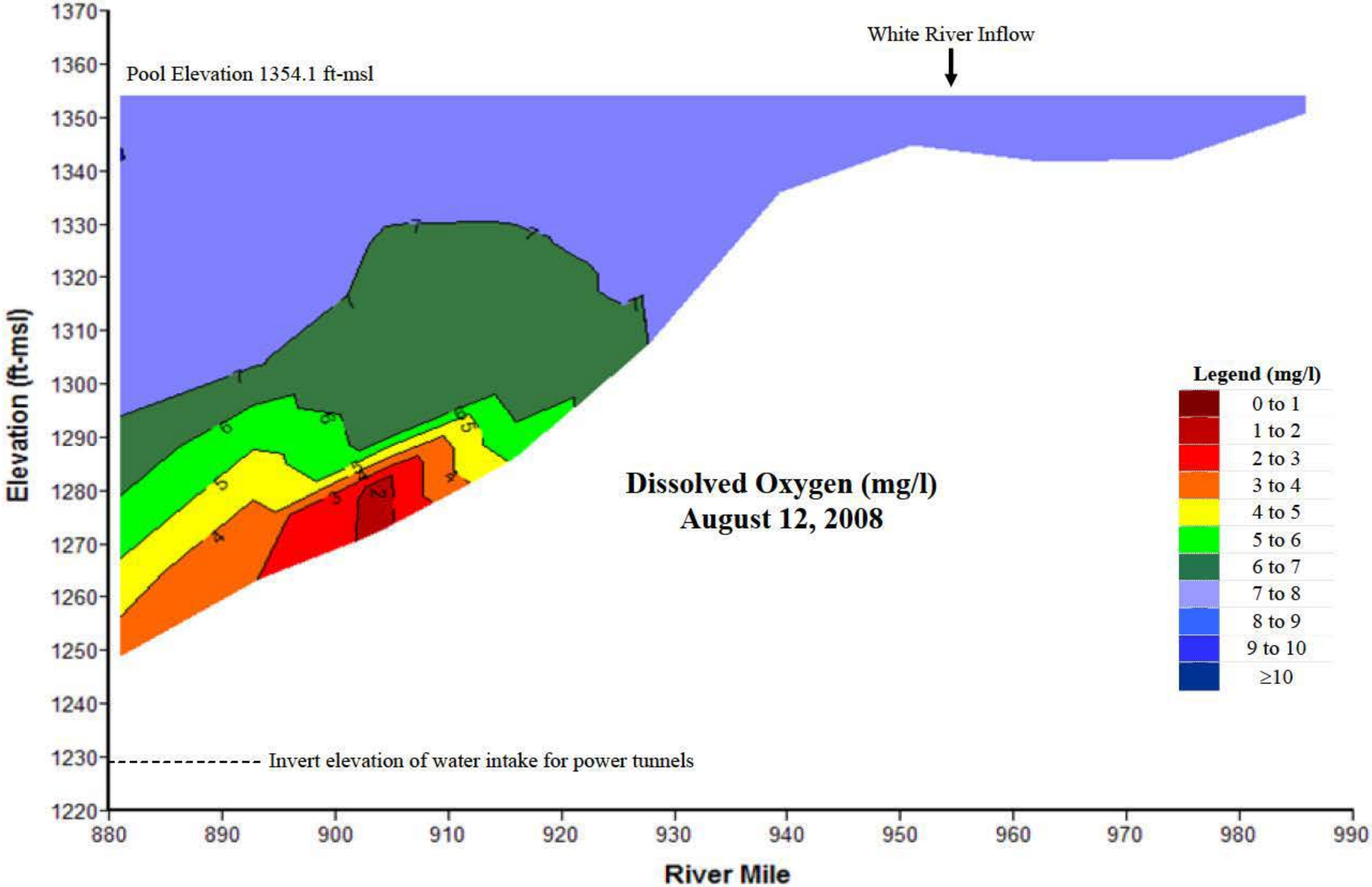


**Plate 23.** Longitudinal dissolved oxygen (mg/l) contour plot of Fort Randall Reservoir based on depth-profile dissolved oxygen concentrations measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on August 12, 2008.

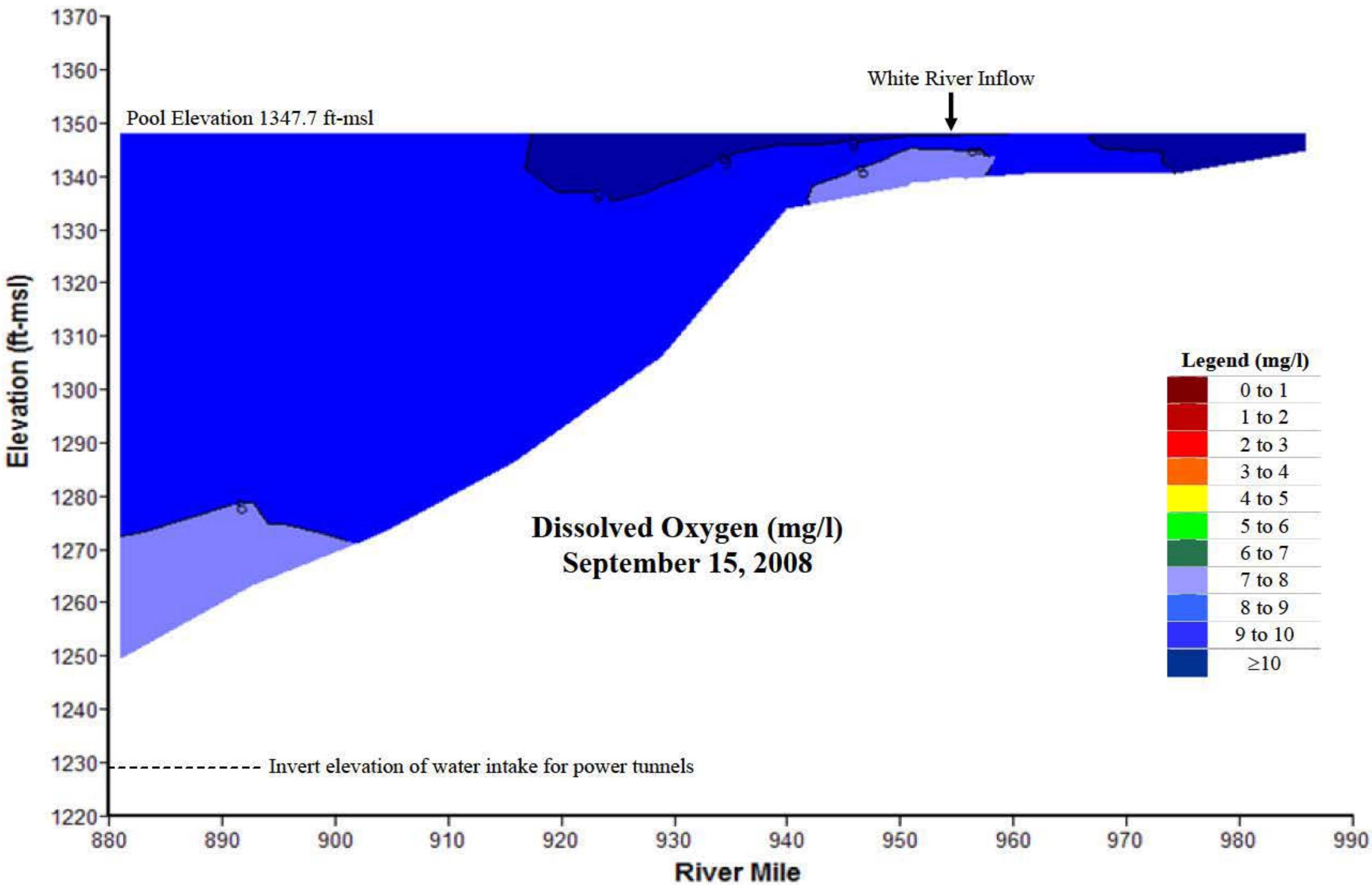


**Plate 24.** Longitudinal dissolved oxygen (mg/l) contour plot of Fort Randall Reservoir based on depth-profile dissolved oxygen concentrations measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on September 15, 2008.

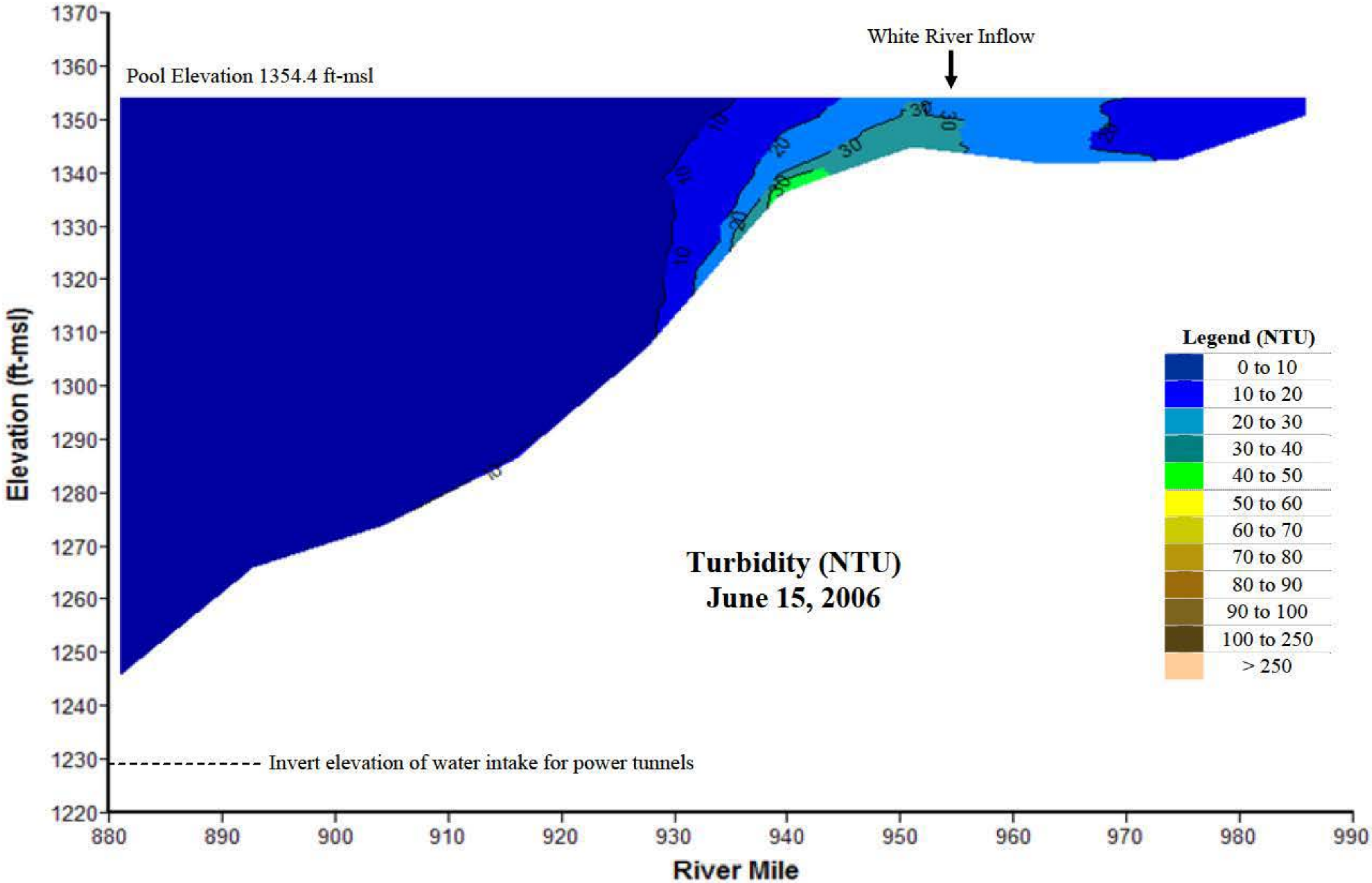


**Plate 25.** Longitudinal turbidity (NTU) contour plot of Fort Randall Reservoir based on depth-profile turbidity levels measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on June 15, 2006.

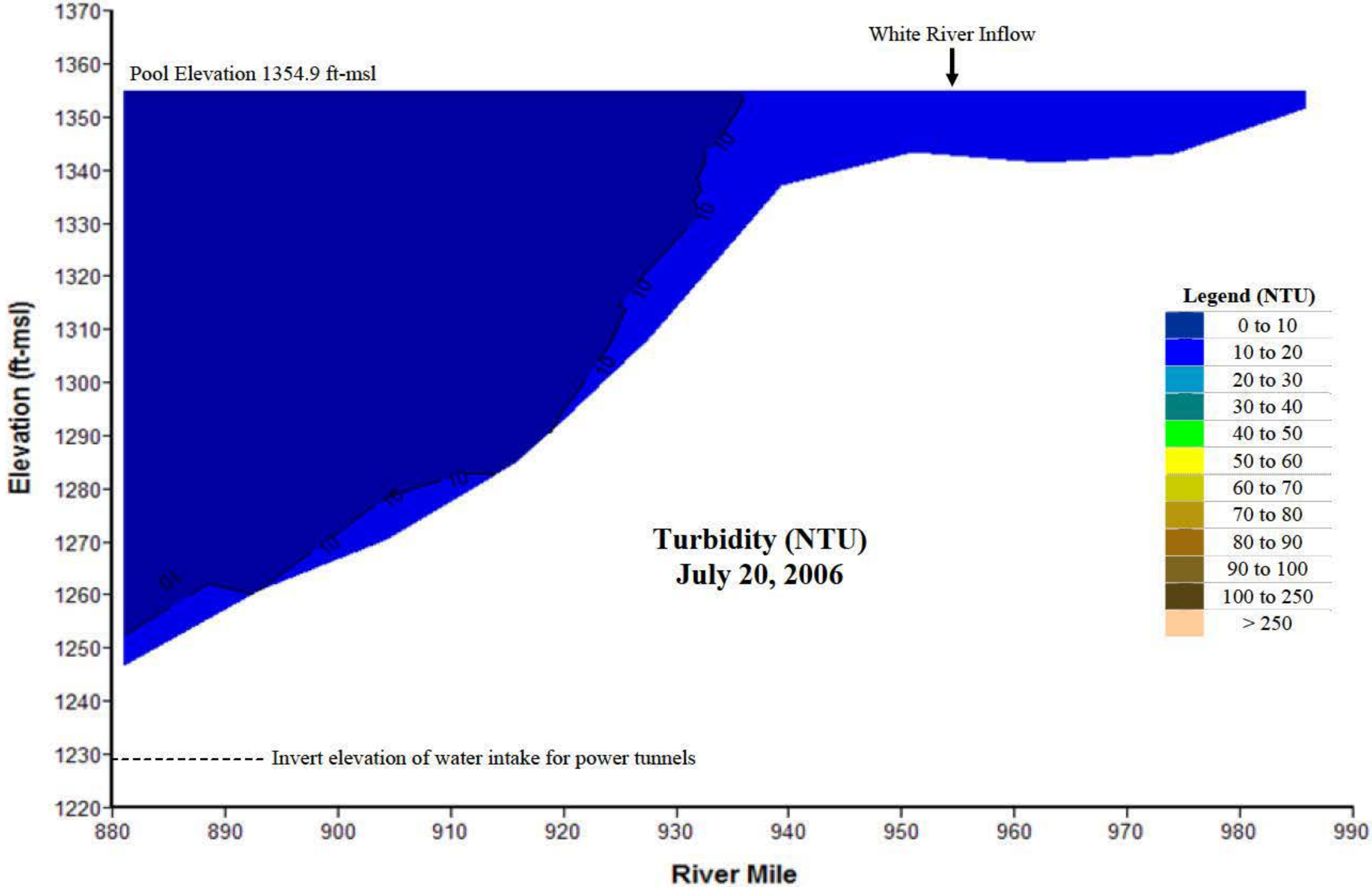


**Plate 26.** Longitudinal turbidity (NTU) contour plot of Fort Randall Reservoir based on depth-profile turbidity levels measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on July 20, 2006.

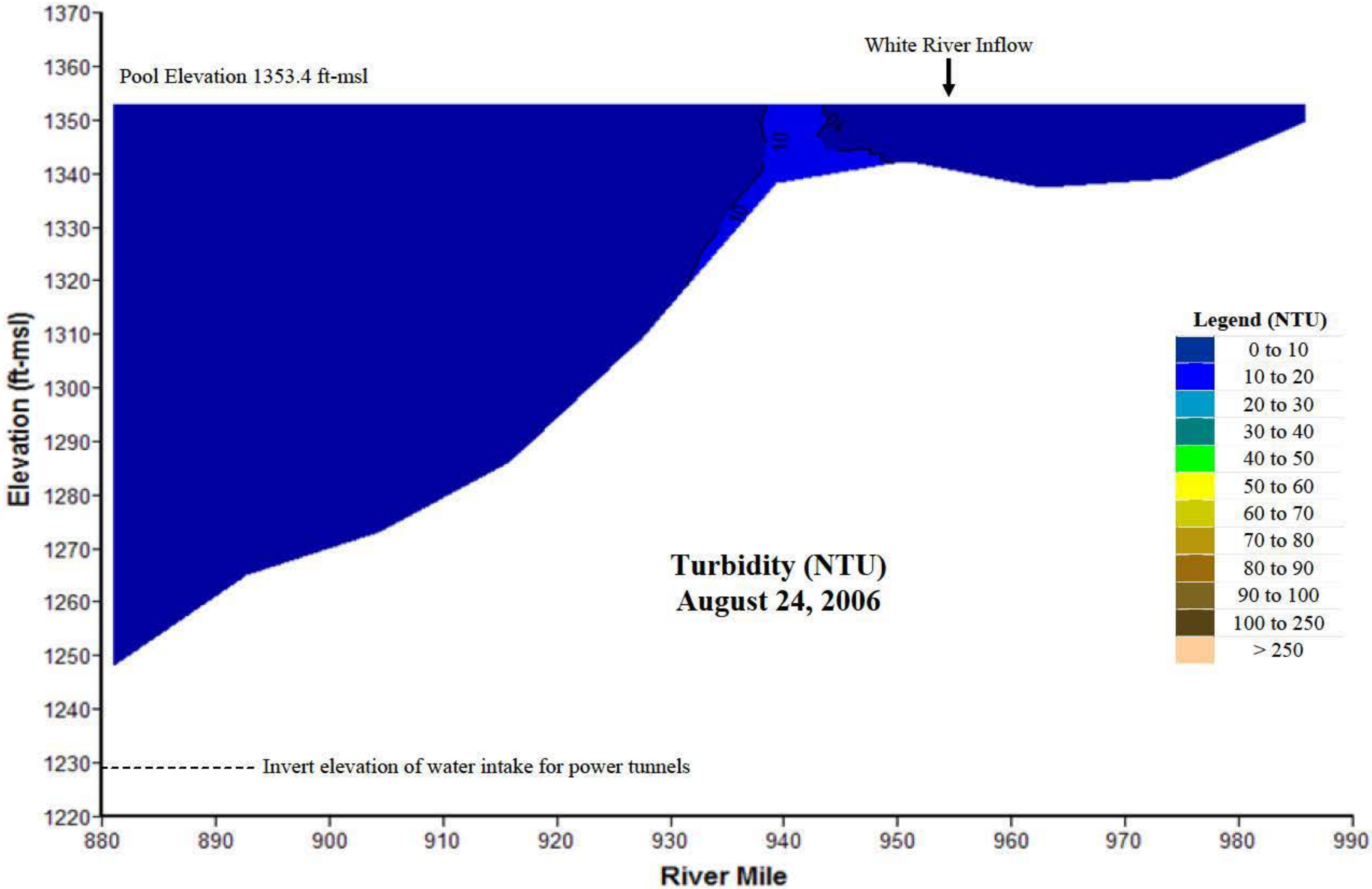


**Plate 27.** Longitudinal turbidity (NTU) contour plot of Fort Randall Reservoir based on depth-profile turbidity levels measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on August 24, 2006.

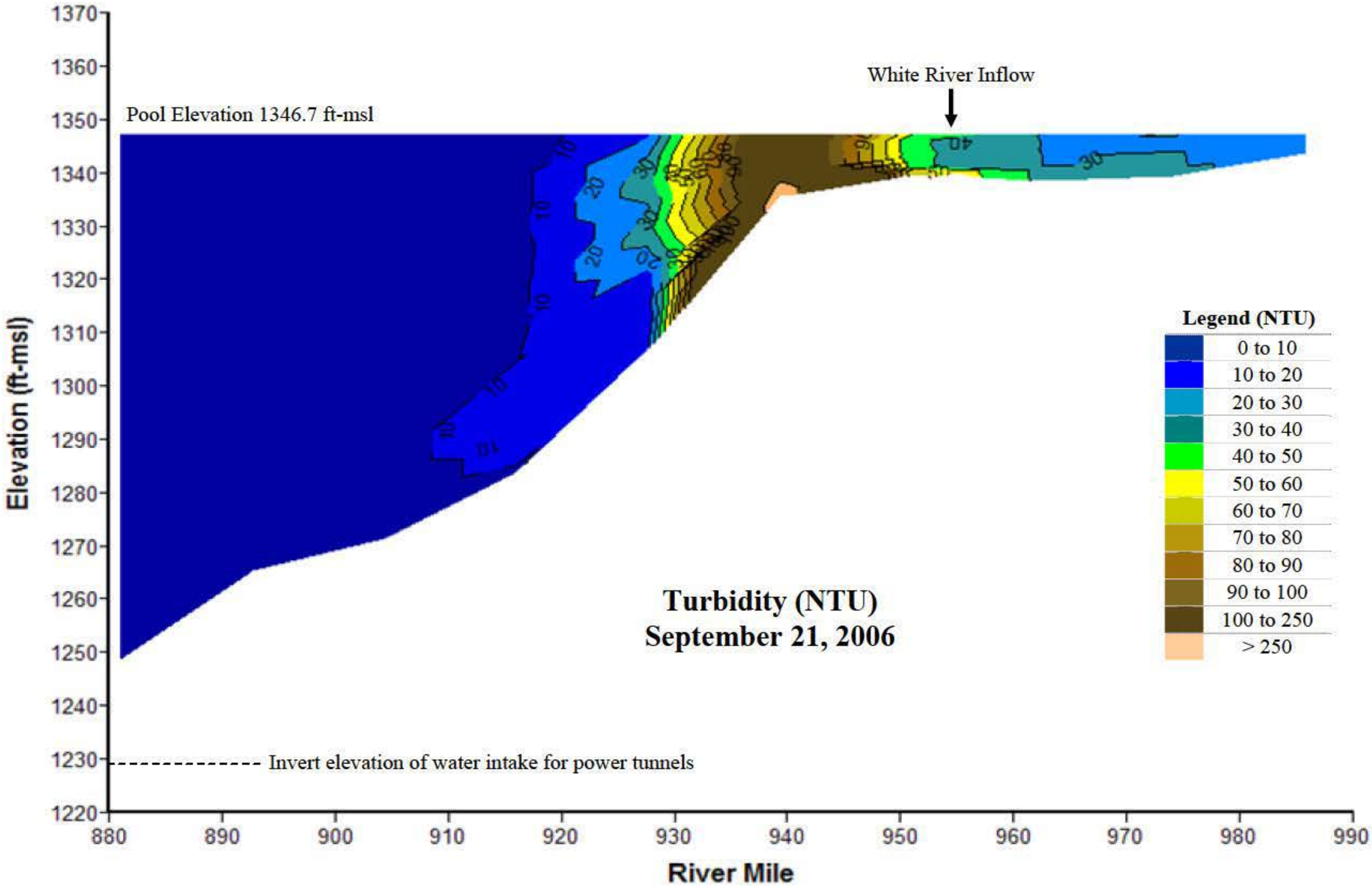


**Plate 28.** Longitudinal turbidity (NTU) contour plot of Fort Randall Reservoir based on depth-profile turbidity levels measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on September 21, 2006.

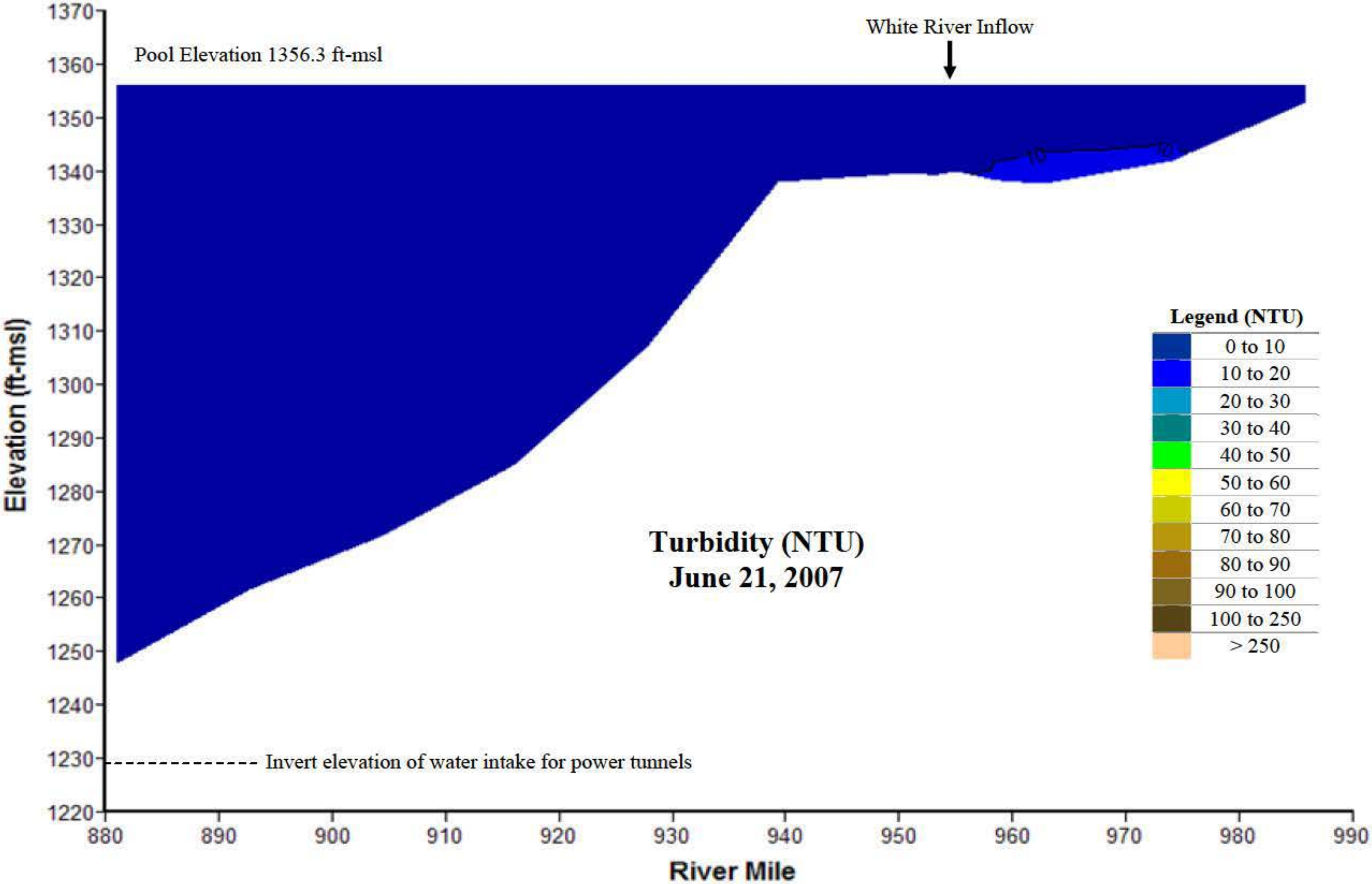


**Plate 29.** Longitudinal turbidity (NTU) contour plot of Fort Randall Reservoir based on depth-profile turbidity levels measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on June 21, 2007.

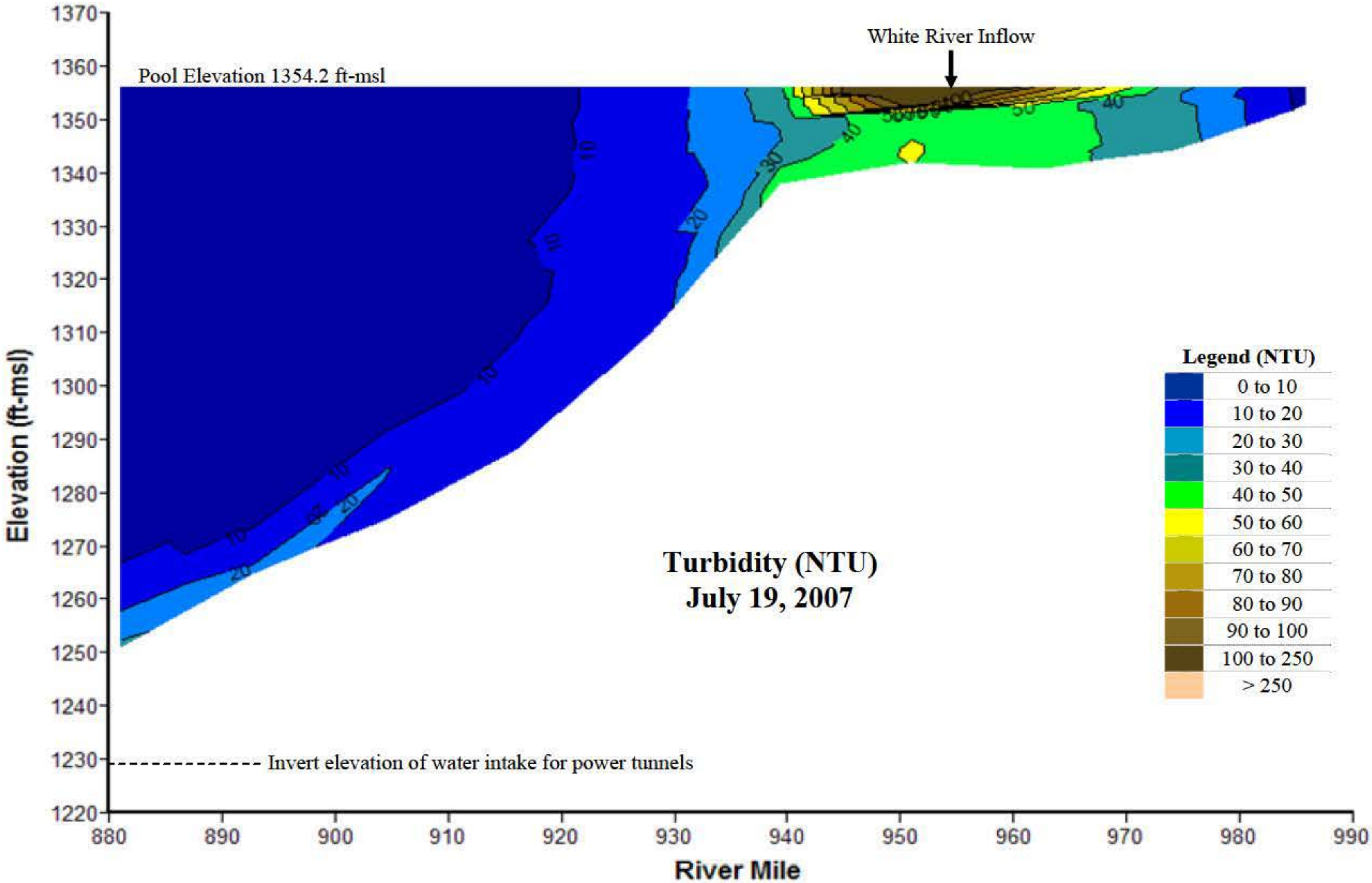


**Plate 30.** Longitudinal turbidity (NTU) contour plot of Fort Randall Reservoir based on depth-profile turbidity levels measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on July 19, 2007.

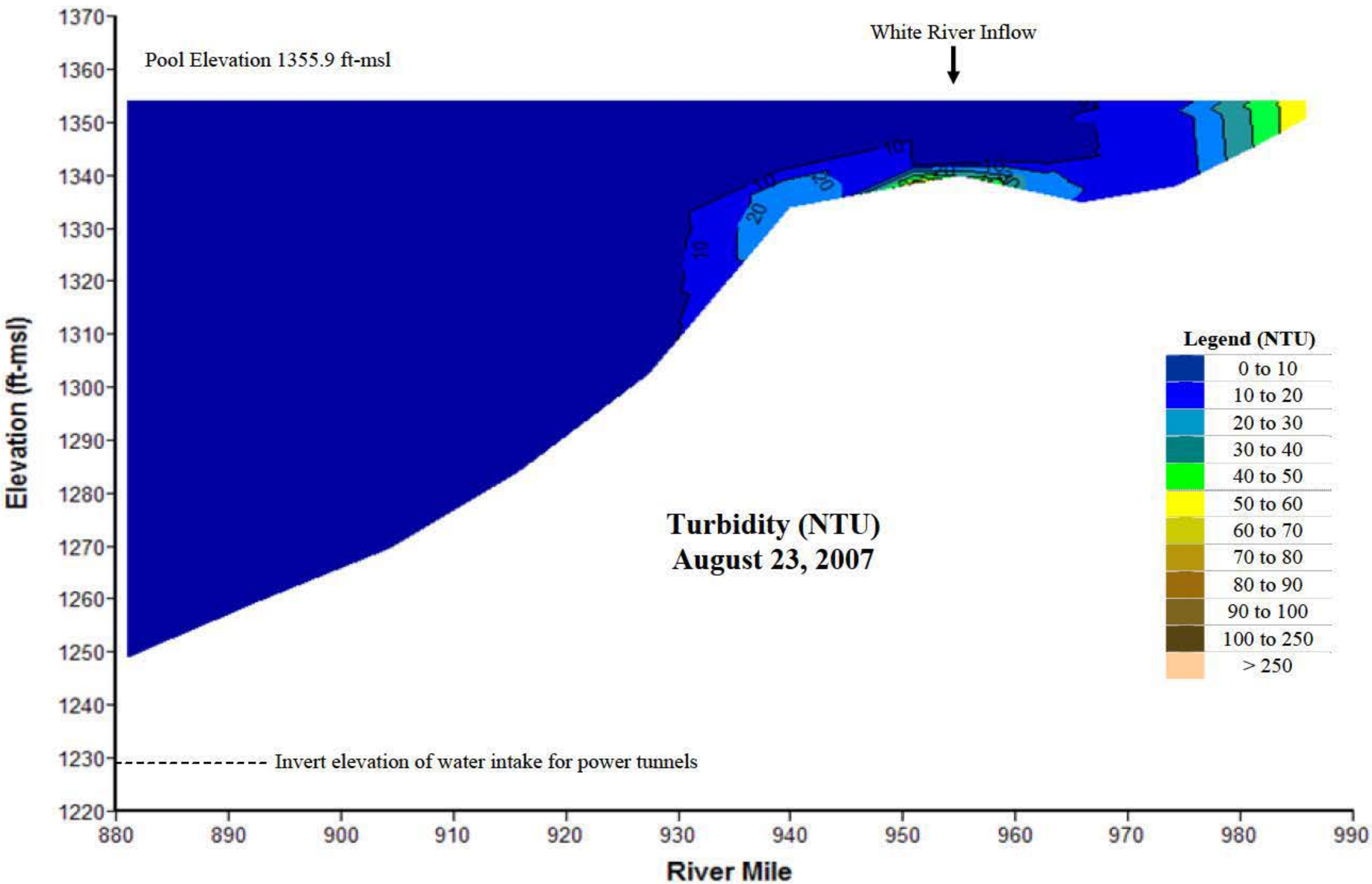


**Plate 31.** Longitudinal turbidity (NTU) contour plot of Fort Randall Reservoir based on depth-profile turbidity levels measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on August 23, 2007.

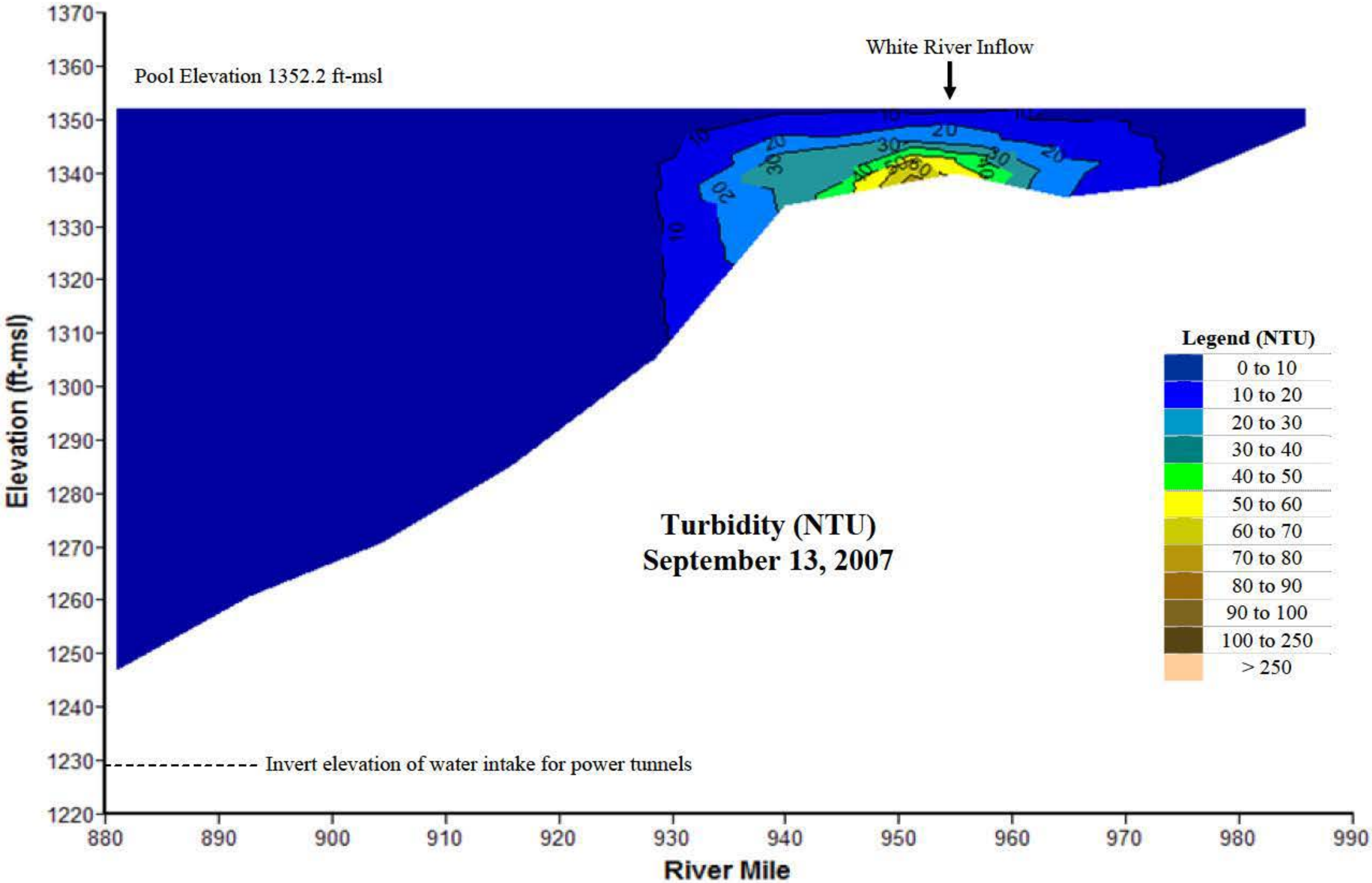


**Plate 32.** Longitudinal turbidity (NTU) contour plot of Fort Randall Reservoir based on depth-profile turbidity levels measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on September 13, 2007.

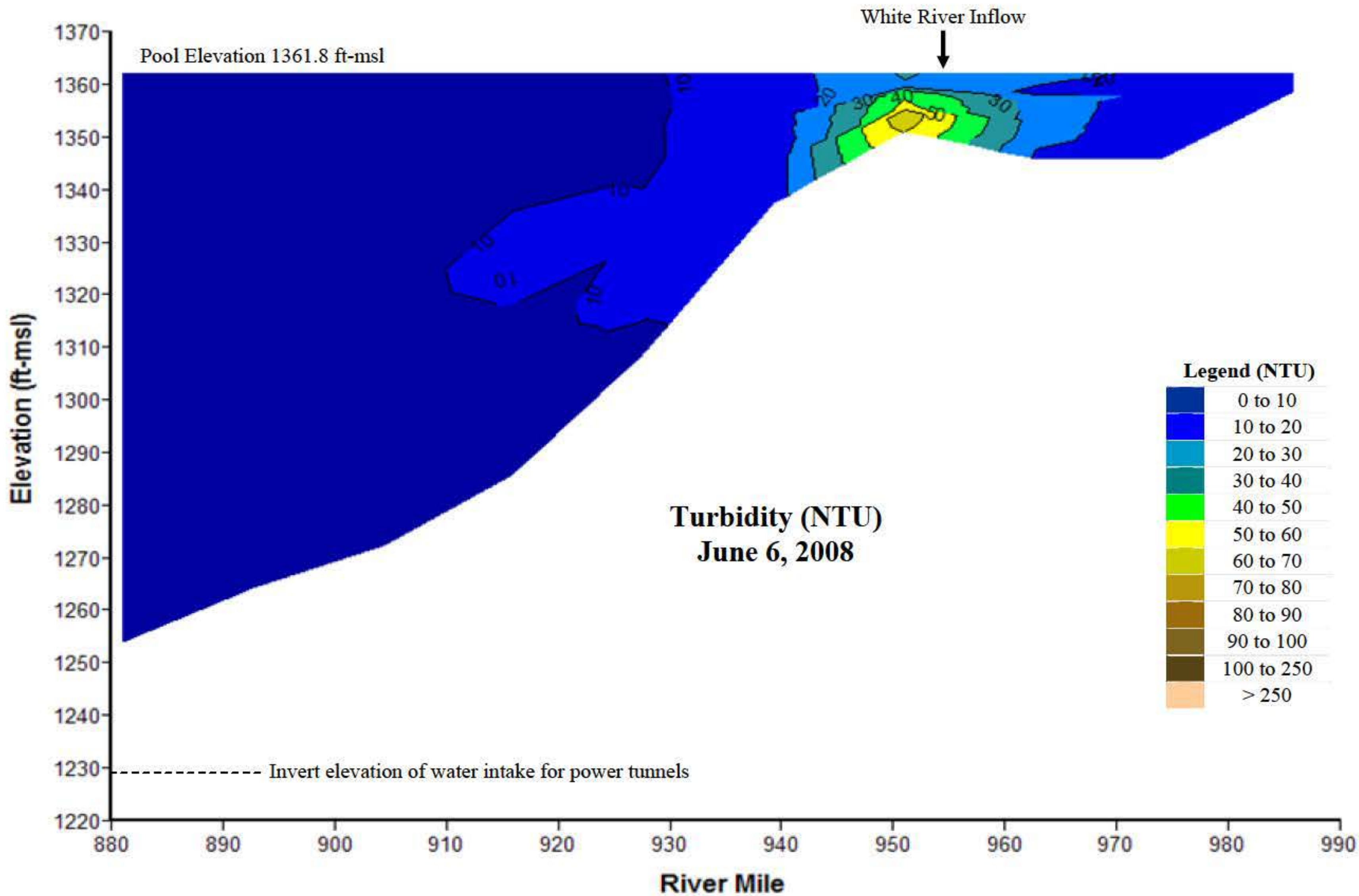


**Plate 33.** Longitudinal turbidity (NTU) contour plot of Fort Randall Reservoir based on depth-profile turbidity levels measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on June 6, 2008.

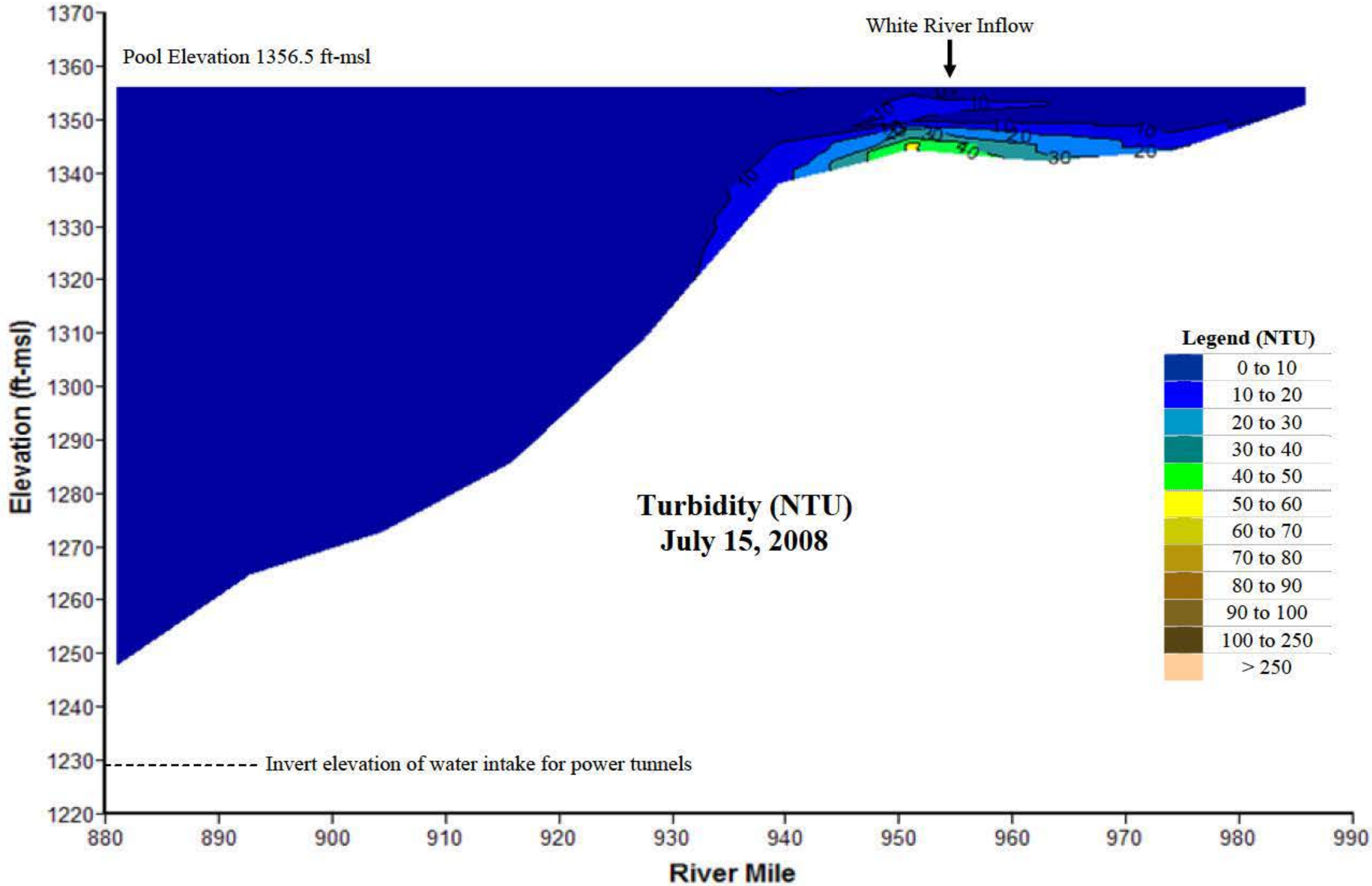


**Plate 34.** Longitudinal turbidity (NTU) contour plot of Fort Randall Reservoir based on depth-profile turbidity levels measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on July 15, 2008.

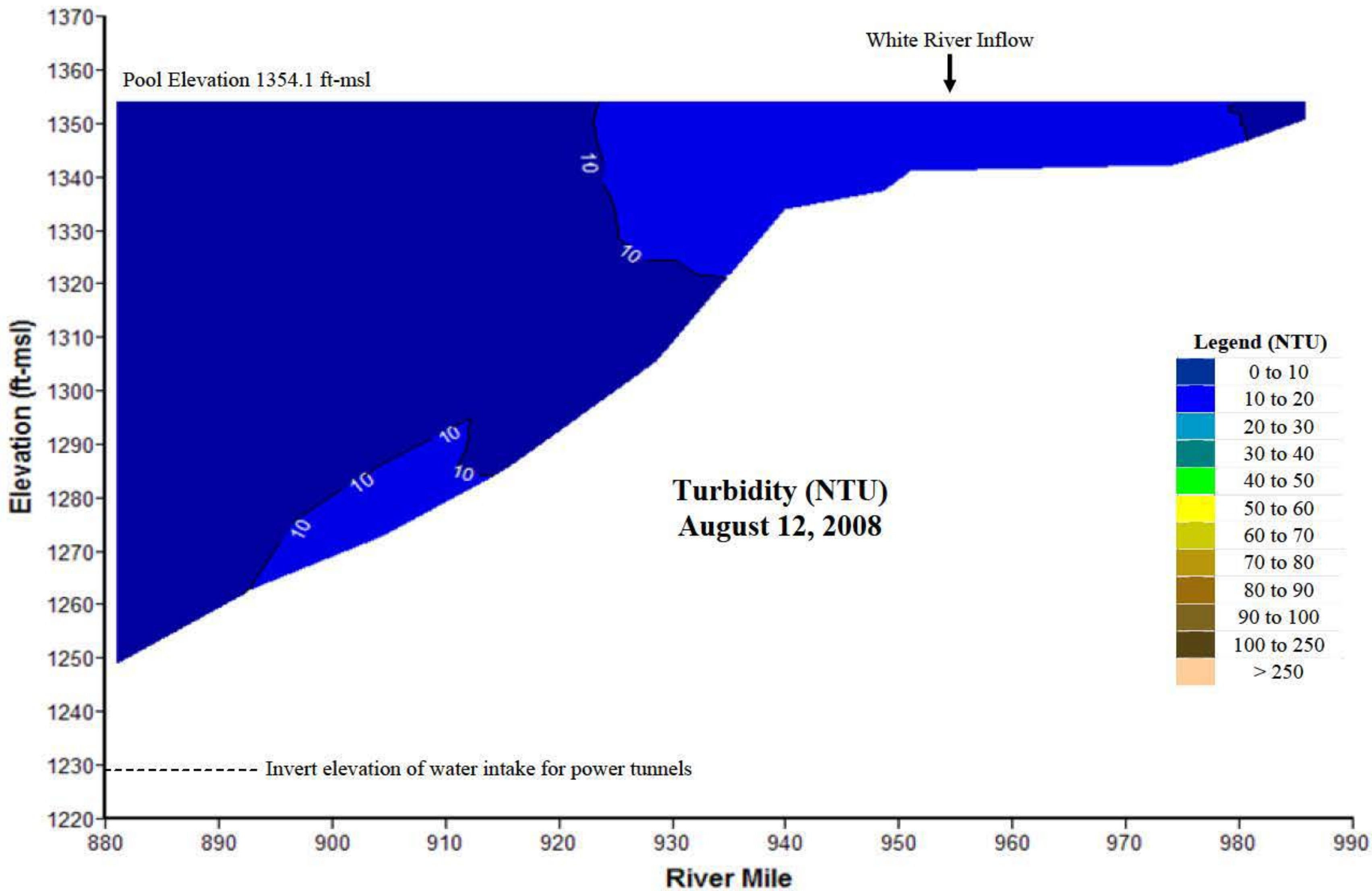


**Plate 35.** Longitudinal turbidity (NTU) contour plot of Fort Randall Reservoir based on depth-profile turbidity levels measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on August 12, 2008.

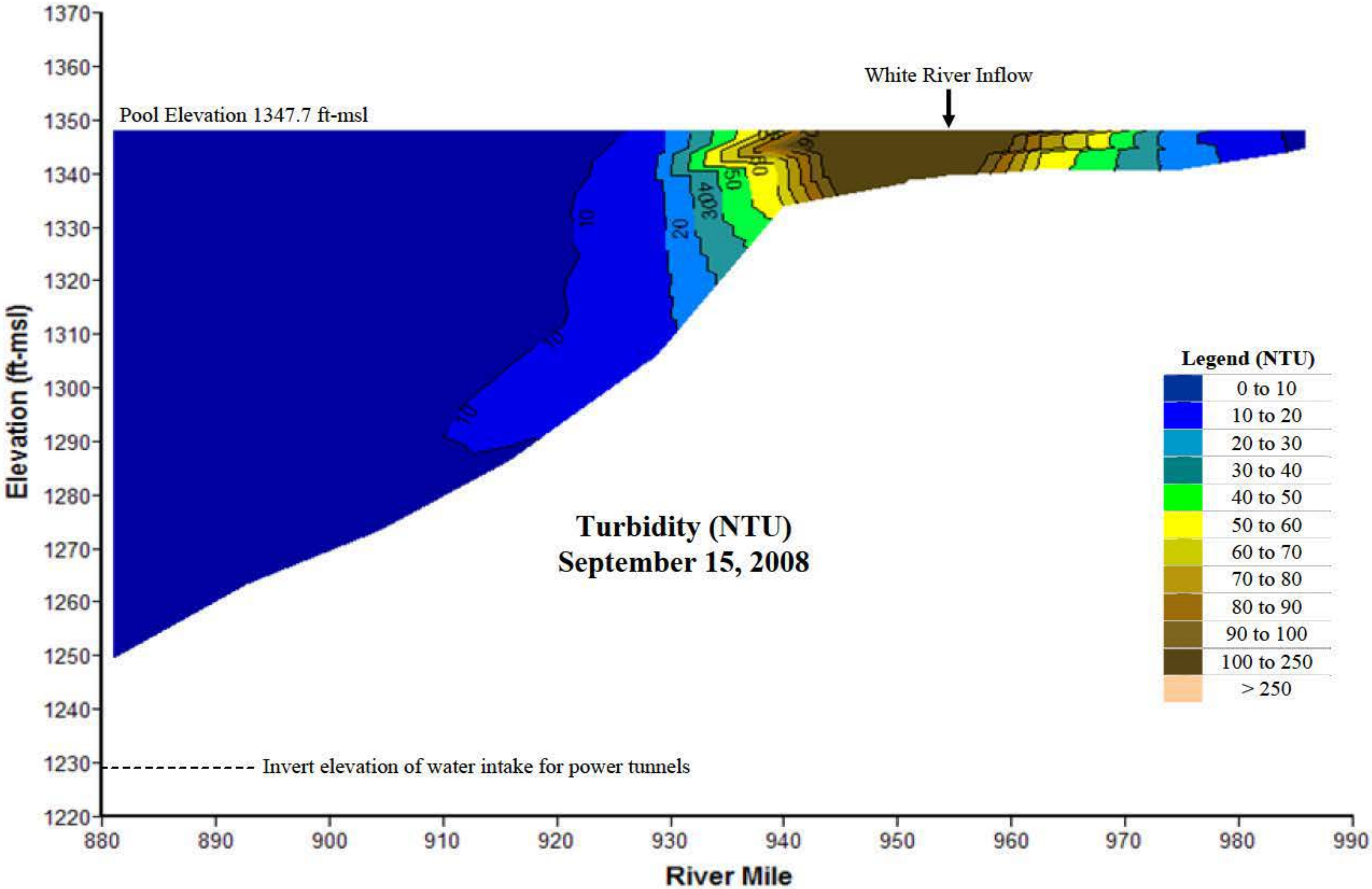


**Plate 36.** Longitudinal turbidity (NTU) contour plot of Fort Randall Reservoir based on depth-profile turbidity levels measured along the submerged old Missouri River channel at River Miles 880, 892, 911, 924, 940, 955, 968, and 987 on September 15, 2008.

**Plate 37.** Total biovolume, number of genera present, and percent composition (based on biovolume) by taxonomic division for phytoplankton grab samples collected in Fort Randall Reservoir at site L1 during the 3-year period 2006 through 2008.

| Date | Total Sample Biovolume ($um^3$) | Bacillariophyta | | Chlorophyta | | Chrysophyta | | Cryptophyta | | Cyanobacteria | | Pyrrophyta | | Euglenophyta | | Shannon-Weaver Genera Diversity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 2006 | 1,511,202,710 | 6 | 1.00 | 2 | <0.01 | 0 | ----- | 1 | <0.01 | 0 | ----- | 0 | ----- | 0 | ----- | 0.73 |
| Jun 2006 | 217,211,152 | 7 | 0.80 | 6 | 0.09 | 1 | 0.09 | 1 | 0.02 | 1 | <0.01 | 0 | ----- | 0 | ----- | 1.44 |
| Jul 2006 | 39,547,409 | 7 | 0.88 | 5 | 0.08 | 0 | ----- | 1 | 0.02 | 3 | 0.02 | 0 | ----- | 1 | <0.01 | 1.44 |
| Aug 2006 | 250,444,849 | 5 | 0.74 | 7 | 0.11 | 2 | 0.09 | 1 | 0.01 | 1 | <0.01 | 1 | 0.03 | 1 | 0.03 | 1.57 |
| Sep 2006 | 391,168,130 | 6 | 0.81 | 11 | 0.11 | 0 | ----- | 1 | 0.02 | 3 | 0.01 | 1 | 0.03 | 1 | 0.01 | 1.88 |
| May 2007 | 1,128,309,549 | 5 | 0.95 | 1 | 0.01 | 1 | <0.01 | 1 | 0.02 | 0 | ----- | 2 | 0.02 | 0 | ----- | 1.1 |
| Jun 2007 | 249,294,812 | 3 | 0 38 | 4 | 0.41 | 1 | <0.01 | 1 | 0.21 | 0 | ----- | 0 | ----- | 0 | ----- | 1.25 |
| Jul 2007 | 101,717,269 | 8 | 0.61 | 8 | 0.15 | 0 | ----- | 1 | 0.10 | 1 | 0.04 | 1 | 0.10 | 0 | ----- | 1.83 |
| Aug 2007 | 312,786,957 | 8 | 0 39 | 8 | 0.03 | 2 | 0.01 | 2 | 0.03 | 3 | <0.01 | 1 | 0.54 | 1 | <0.01 | 1.41 |
| Sep 2007 | 228,330,946 | 7 | 0.70 | 11 | 0.13 | 0 | ----- | 1 | 0.06 | 4 | 0.03 | 1 | 0.04 | 1 | 0.04 | 2.14 |
| May 2008 | 784,108,007 | 10 | 1.00 | 3 | <0.01 | 1 | <0.01 | 1 | <0.01 | 0 | ----- | 0 | ----- | 0 | ----- | 1.14 |
| Jun 2008 | 1,096,885,699 | 6 | 0.97 | 4 | <0.01 | 2 | 0.01 | 1 | 0.02 | 1 | <0.01 | 0 | ----- | 0 | ----- | 1.04 |
| Jul 2008 | 7,177 | 3 | 0.06 | 0 | ----- | 0 | ----- | 1 | 0.94 | 1 | <0.01 | 0 | ----- | 0 | ----- | 0.27 |
| Aug 2008 | 13,678,405 | 2 | 0.02 | 5 | 0.50 | 0 | ----- | 1 | 0.35 | 1 | <0.01 | 1 | 0.13 | 0 | ----- | 1.73 |
| Sep 2008 | 376,464,061 | 6 | 0.80 | 13 | 0.05 | 0 | ----- | 2 | 0.10 | 4 | 0.01 | 1 | 0.01 | 3 | 0.03 | 1.63 |
| **Mean*** | **446,743,809** | **5.93** | **0.67** | **5.87** | **0.12** | **0.67** | **0.03** | **1.13** | **0.13** | **1.53** | **0.01** | **0.60** | **0.11** | **0.53** | **0.02** | **1.37** |

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

**Plate 38.** Total biovolume, number of genera present, and percent composition (based on biovolume) by taxonomic division for phytoplankton grab samples collected in Fort Randall Reservoir at site L3 during the 3-year period 2006 through 2008.

| Date | Total Sample Biovolume ($um^3$) | Bacillariophyta | | Chlorophyta | | Chrysophyta | | Cryptophyta | | Cyanobacteria | | Pyrrophyta | | Euglenophyta | | Shannon-Weaver Genera Diversity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 2006 | 69,931,419 | 5 | 0.44 | 7 | 0.36 | 2 | 0.08 | 1 | 0.04 | 1 | 0.06 | 1 | 0.03 | 0 | ----- | 2.17 |
| Jul 2006 | 98,641,374 | 2 | 0.34 | 5 | 0.13 | 0 | ----- | 1 | 0.11 | 3 | 0.16 | 1 | 0.27 | 0 | ----- | 1.86 |
| Aug 2006 | 133,306,055 | 5 | 0.11 | 12 | 0.44 | 1 | 0.01 | 1 | 0.14 | 4 | 0.14 | 1 | 0.15 | 1 | 0.02 | 2.71 |
| Sep 2006 | 83,623,877 | 10 | 0.32 | 15 | 0.43 | 0 | ----- | 1 | 0.10 | 6 | 0.02 | 1 | 0.12 | 0 | ----- | 2.59 |
| Jun 2007 | 1,697,405,287 | 6 | 0.89 | 8 | 0.06 | 2 | 0.01 | 1 | 0.03 | 0 | ----- | 1 | 0.01 | 0 | ----- | 1.03 |
| Jul 2007 | 529,054,652 | 6 | 0.04 | 7 | 0.02 | 1 | 0.01 | 1 | 0.02 | 3 | 0.88 | 1 | 0.04 | 0 | ---- | 0.73 |
| Aug 2007 | 423,785,980 | 6 | 0 93 | 9 | 0.02 | 3 | <0.01 | 2 | 0.01 | 3 | <0.01 | 1 | 0.05 | 0 | ----- | 1.09 |
| Sep 2007 | 1,013,742,743 | 8 | 0.95 | 12 | 0.02 | 1 | <0.01 | 2 | <0.01 | 5 | 0.01 | 1 | 0.01 | 1 | 0.01 | 1.21 |
| Jun 2008 | 644,247,513 | 8 | 0 95 | 11 | 0.01 | 1 | 0.01 | 1 | 0.02 | 0 | ----- | 0 | ----- | 0 | ----- | 1.07 |
| Jul 2008 | 295,300 | 4 | 0.87 | 6 | 0.02 | 1 | <0.01 | 1 | 0.07 | 2 | <0.01 | 1 | 0.04 | 0 | ----- | 1.07 |
| Aug 2008 | 131,718,414 | 6 | 0.62 | 6 | 0.01 | 0 | ----- | 1 | 0.05 | 3 | 0.32 | 1 | 0.01 | 0 | ----- | 1.41 |
| Sep 2008 | 425,420,567 | 5 | 0.85 | 9 | 0.03 | 1 | <0.01 | 2 | 0.07 | 6 | 0.02 | 2 | 0.02 | 1 | <0.01 | 1.38 |
| **Mean*** | **437,597,765** | **5.92** | **0.61** | **8.92** | **0.13** | **1.08** | **0.01** | **1.25** | **0.06** | **3.00** | **0.16** | **1.00** | **0.07** | **0.25** | **0.01** | **1.53** |

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

**Plate 39.** Total biovolume, number of genera present, and percent composition (based on biovolume) by taxonomic division for phytoplankton grab samples collected in Fort Randall Reservoir at site L5 during the 3-year period 2006 through 2008.

| Date | Total Sample Biovolume ($um^3$) | Bacillariophyta | | Chlorophyta | | Chrysophyta | | Cryptophyta | | Cyanobacteria | | Pyrrophyta | | Euglenophyta | | Shannon-Weaver Genera Diversity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 2006 | 518,893,912 | 11 | 0 92 | 9 | 0.05 | 0 | ----- | 0 | ----- | 1 | 0.03 | 0 | ----- | 0 | ----- | 1.06 |
| Jul 2006 | 119,552,113 | 11 | 0.81 | 8 | 0.07 | 1 | <0.01 | 0 | ----- | 1 | 0.06 | 1 | 0.05 | 1 | 0.01 | 1.77 |
| Aug 2006 | 320,031,467 | 12 | 0.72 | 15 | 0.12 | 1 | 0.01 | 1 | <0.01 | 5 | 0.14 | 1 | 0.01 | 1 | <0.01 | 2.86 |
| Sep 2006 | 365,369,612 | 18 | 0.83 | 10 | 0.11 | 1 | 0.03 | 0 | ----- | 0 | ----- | 1 | 0.04 | 0 | ----- | 2.77 |
| Jun 2007 | 7,768,787,921 | 8 | 0 91 | 10 | 0.03 | 2 | 0.02 | 1 | 0.01 | 5 | 0.03 | 1 | 0.01 | 0 | ----- | 0.80 |
| Jul 2007 | 583,012,381 | 12 | 0.50 | 8 | 0.01 | 0 | ----- | 1 | 0.01 | 3 | 0.47 | 1 | 0.01 | 0 | ----- | 1.69 |
| Aug 2007 | 210,296,968 | 10 | 0.48 | 11 | 0.22 | 1 | <0.01 | 2 | 0.06 | 3 | 0.12 | 2 | 0.11 | 0 | ----- | 2.72 |
| Jun 2008 | 145,687,021 | 10 | 0.84 | 9 | 0.05 | 2 | 0.04 | 1 | 0.06 | 1 | <0.01 | 0 | ----- | 0 | ----- | 1.40 |
| Jul 2008 | 745,624 | 5 | 0.86 | 6 | 0.07 | 1 | <0.01 | 1 | 0.01 | 6 | 0.06 | 2 | <0.01 | 2 | <0.01 | 1.28 |
| Aug 2008 | 217,934,376 | 11 | 0.95 | 4 | <0.01 | 0 | ----- | 1 | <0.01 | 2 | <0.01 | 1 | 0.01 | 3 | 0.01 | 1.27 |
| **Mean*** | **1,025,031,140** | **10.80** | **0.78** | **9.00** | **0.07** | **0.90** | **0.01** | **0.80** | **0.02** | **2.70** | **0.10** | **1.00** | **0.03** | **0.70** | **0.01** | **1.76** |

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

**Plate 40.** Total biovolume, number of genera present, and percent composition (based on biovolume) by taxonomic division for phytoplankton grab samples collected in Fort Randall Reservoir at site L7 during the 3-year period 2006 through 2008.

| Date | Total Sample Biovolume (um$^3$) | Bacillariophyta | | Chlorophyta | | Chrysophyta | | Cryptophyta | | Cyanobacteria | | Pyrrophyta | | Euglenophyta | | Shannon-Weaver Genera Diversity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 2006 | 3,042,159,471 | 9 | 0.94 | 9 | 0.04 | 1 | <0.01 | 1 | <0.01 | 2 | 0.01 | 1 | <0.01 | 0 | ----- | 0.44 |
| Jul 2006 | 235,103,339 | 7 | 0.24 | 6 | 0.72 | 1 | <0.01 | 1 | 0.01 | 1 | 0.03 | 0 | ----- | 1 | <0.01 | 1.37 |
| Aug 2006 | 842,613,801 | 19 | 0 91 | 14 | 0.04 | 2 | <0.01 | 1 | <0.01 | 6 | 0.03 | 1 | 0.01 | 1 | <0.01 | 1.80 |
| Sep 2006 | 270,757,940 | 17 | 0.80 | 11 | 0.14 | 1 | 0.01 | 1 | <0.01 | 1 | <0.01 | 1 | 0.04 | 2 | 0.01 | 2.42 |
| Jun 2007 | 1,073,452,712 | 5 | 0.71 | 11 | 0.14 | 2 | 0.01 | 1 | 0.03 | 1 | <0.01 | 1 | 0.11 | 0 | ----- | 1.49 |
| Jul 2007 | 405,005,185 | 14 | 0.42 | 6 | 0.02 | 1 | <0.01 | 1 | 0.05 | 1 | 0.37 | 1 | 0.12 | 0 | 0.01 | 2.02 |
| Aug 2007 | 162,100,006 | 11 | 0.55 | 6 | 0.03 | 2 | 0.02 | 1 | 0.01 | 3 | <0.01 | 1 | 0.31 | 2 | 0.08 | 2.30 |
| Sep 2007 | 121,850,078 | 8 | 0.73 | 6 | 0.03 | 1 | <0.01 | 1 | 0.05 | 5 | 0.18 | 0 | ----- | 0 | ----- | 2.15 |
| Jun 2008 | 1,161,968,310 | 8 | 0.96 | 9 | 0.01 | 2 | <0.01 | 1 | 0.03 | 1 | <0.01 | 0 | ----- | 0 | ----- | 0.93 |
| Jul 2008 | 238,272 | 4 | 0.86 | 2 | 0.01 | 0 | ----- | 1 | 0.01 | 6 | 0.12 | 0 | ----- | 0 | ----- | 0.63 |
| Aug 2008 | 133,462,205 | 10 | 0.94 | 3 | 0.01 | 0 | ----- | 1 | 0.03 | 3 | <0.01 | 1 | 0.01 | 0 | ----- | 1.30 |
| Sep 2008 | 103,962,738 | 10 | 0.86 | 2 | 0.02 | 1 | <0.01 | 2 | 0.08 | 1 | <0.01 | 0 | ----- | 3 | 0.04 | 1.51 |
| **Mean*** | **629,389,505** | **10.17** | **0.74** | **7.08** | **0.10** | **1.17** | **<0.01** | **1.08** | **0.03** | **2.58** | **0.06** | **0.58** | **0.09** | **0.75** | **0.02** | **1.53** |

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

**Plate 41.** Dominant taxa present in phytoplankton grab samples collected at the near-dam monitoring site (site L1) at Fort Randall Reservoir during the 3-year period 2006 through 2008.

| Date | Division | Dominant Taxa* | Percent of Total Sample Biovolume |
|---|---|---|---|
| May 2006 | Bacillariophyta | *Fragilaria crotonensis* | 0.51 |
| | Bacillariophyta | *Asterionella formossa* | 0.44 |
| June 2006 | Bacillariophyta | *Fragilaria crotonensis* | 0.41 |
| | Bacillariophyta | *Asterionella formossa* | 0.18 |
| | Bacillariophyta | *Fragilaria sp. 2* | 0.16 |
| July 2006 | Bacillariophyta | *Asterionella formossa* | 0.45 |
| | Bacillariophyta | *Fragilaria crotonensis* | 0.35 |
| August 2006 | Bacillariophyta | *Fragilaria crotonensis* | 0.56 |
| | Bacillariophyta | *Aulacoseira granulata* | 0.16 |
| September 2006 | Bacillariophyta | *Aulacoseira granulata* | 0.41 |
| | Bacillariophyta | *Stephanodiscus niagarea* | 0.20 |
| | Bacillariophyta | *Fragilaria crotonensis* | 0.10 |
| May 2007 | Bacillariophyta | *Fragilaria capucina* | 0.36 |
| | Bacillariophyta | *Fragilaria capucina var. gracilis* | 0.32 |
| | Bacillariophyta | *Aulacoseira sp.* | 0.12 |
| | Bacillariophyta | *Tabellaria flocculosa* | 0.10 |
| June 2007 | Chlorophyta | *Pyramichlamys sp.* | 0.39 |
| | Bacillariophyta | *Fragilaria capucina var. gracilis* | 0.26 |
| | Cryptophyta | *Rhodomonas sp.* | 0.21 |
| July 2007 | Bacillariophyta | *Fragilaria capucina* | 0.27 |
| | Bacillariophyta | *Fragilaria capucina var. gracilis* | 0.21 |
| | Pyrrophyta | *Ceratium hirundinella* | 0.10 |
| August 2007 | Pyrrophyta | *Ceratium hirundinella* | 0.54 |
| | Bacillariophyta | *Fragilaria capucina var. gracilis* | 0.25 |
| | Bacillariophyta | *Aulacoseira sp.* | 0.11 |
| September 2007 | Bacillariophyta | *Stephanodiscus niagarae* | 0.27 |
| | Bacillariophyta | *Aulacoseira sp.* | 0.21 |
| May 2008 | Bacillariophyta | *Fragilaria crotonensis* | 0.61 |
| | Bacillariophyta | *Tabellaria flocculosa* | 0.19 |
| | Bacillariophyta | *Aulacoseira granulata* | 0.12 |
| June 2008 | Bacillariophyta | *Fragilaria crotonensis* | 0.58 |
| | Bacillariophyta | *Asterionella formossa* | 0.28 |
| | Bacillariophyta | *Tabellaria flocculosa* | 0.11 |
| July 2008 | Cryptophyta | *Rhodomonas minuta var. nannoplanctica* | 0.60 |
| | Cryptophyta | *Rhodomonas lacustris* | 0.33 |
| August 2008 | Cryptophyta | *Rhodomonas minuta var. nannoplanctica* | 0.32 |
| | Chlorophyta | *Chlamydomonas sp.* | 0.22 |
| | Pyrrophyta | *Ceratium hirundinella* | 0.13 |
| | Chlorophyta | *Staurastrum sp.* | 0.11 |
| September 2008 | Bacillariophyta | *Aulacoseira granulata* | 0.41 |
| | Bacillariophyta | *Fragilaria crotonensis* | 0.35 |

* Dominant taxa are genera or species (depending on identification level) that comprised more than 10% of the total sample biovolume.

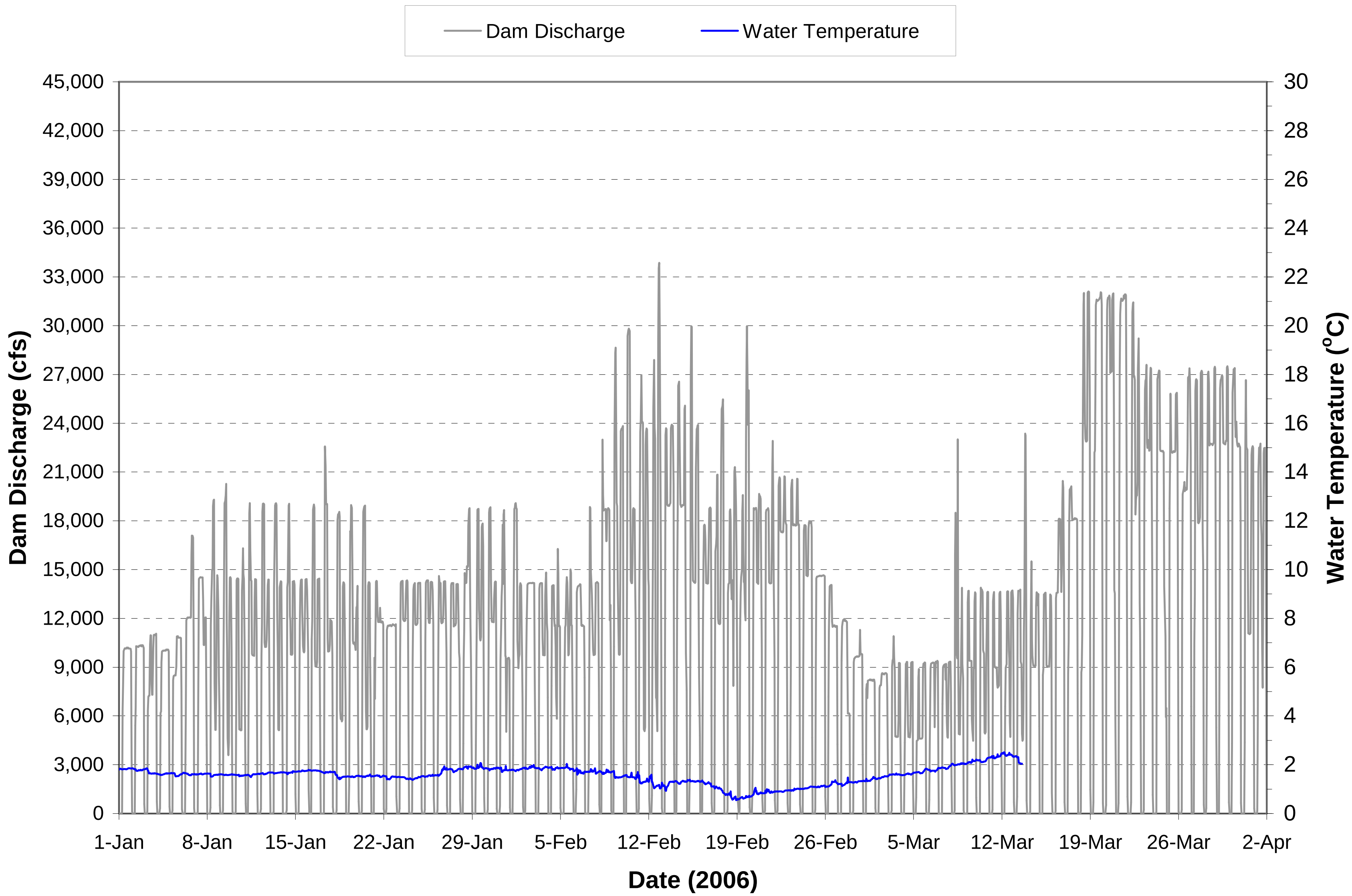


**Plate 42.** Hourly discharge and water temperature monitored at the Fort Randall powerplant during the period January through March 2006**.** (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

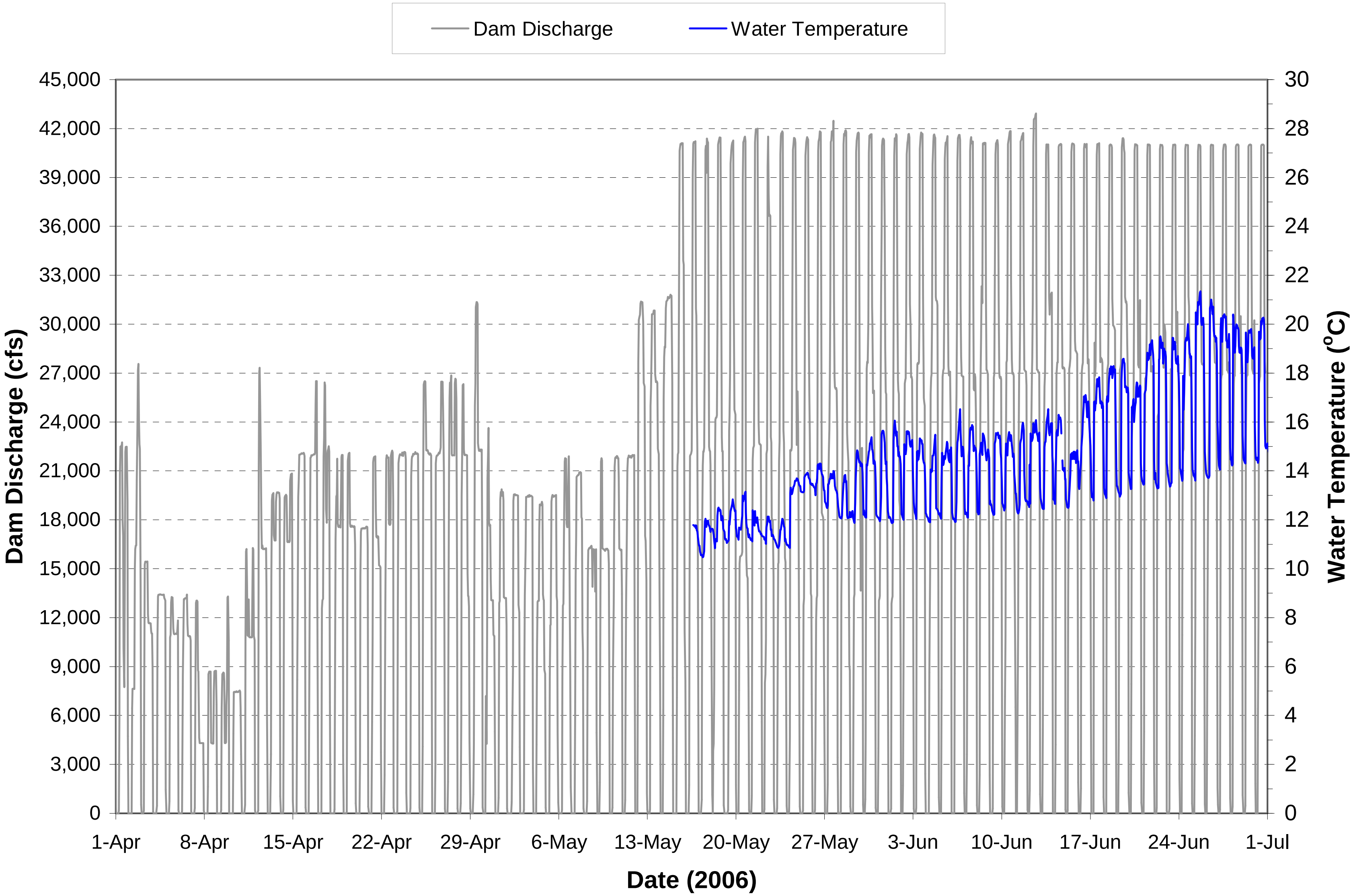


**Plate 43.** Hourly discharge and water temperature monitored at the Fort Randall powerplant during the period April through June 2006. (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

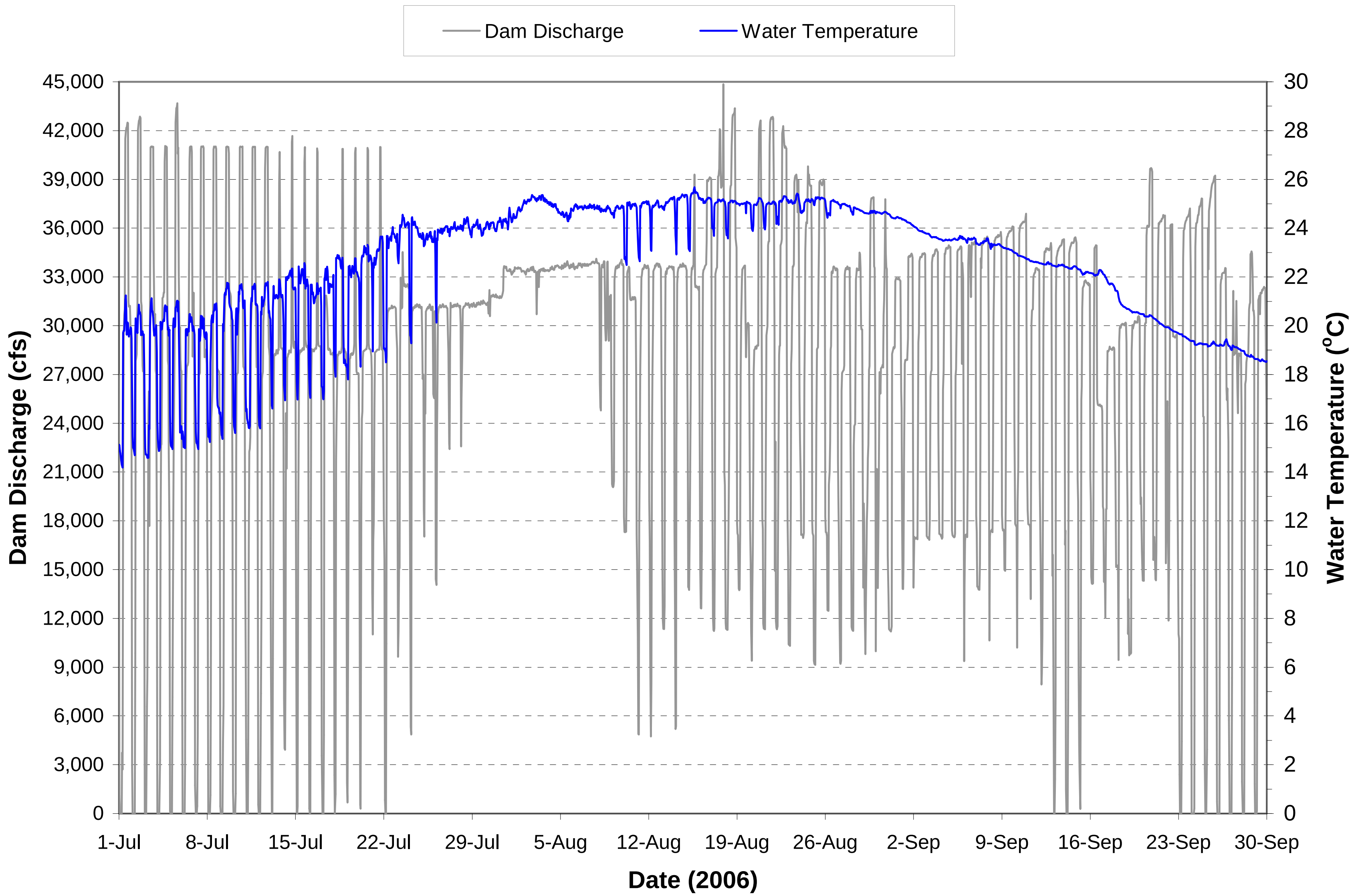


**Plate 44.** Hourly discharge and water temperature monitored at the Fort Randall powerplant during the period July through September 2006.

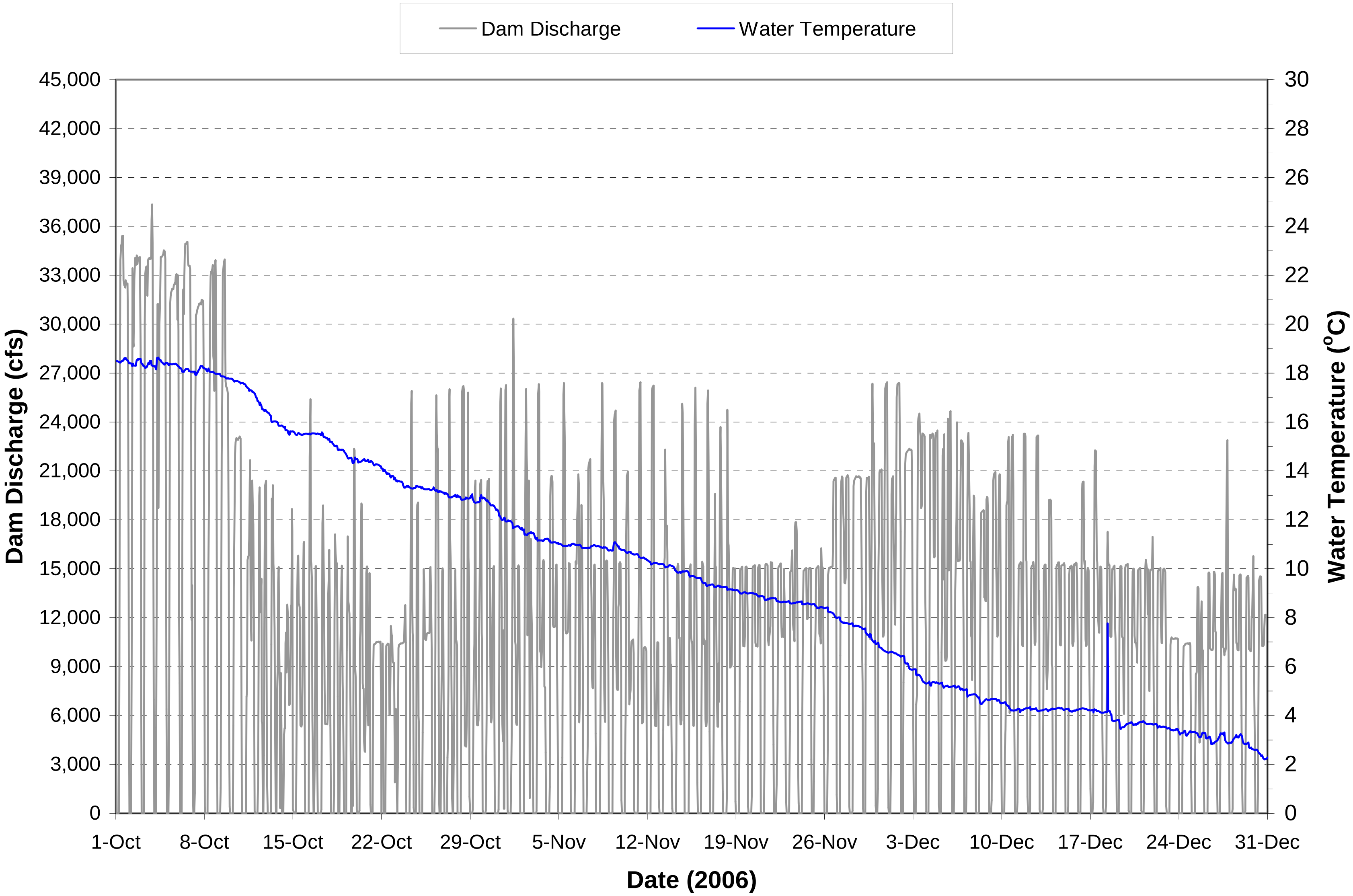


**Plate 45.** Hourly discharge and water temperature monitored at the Fort Randall powerplant during the period October through December 2005.

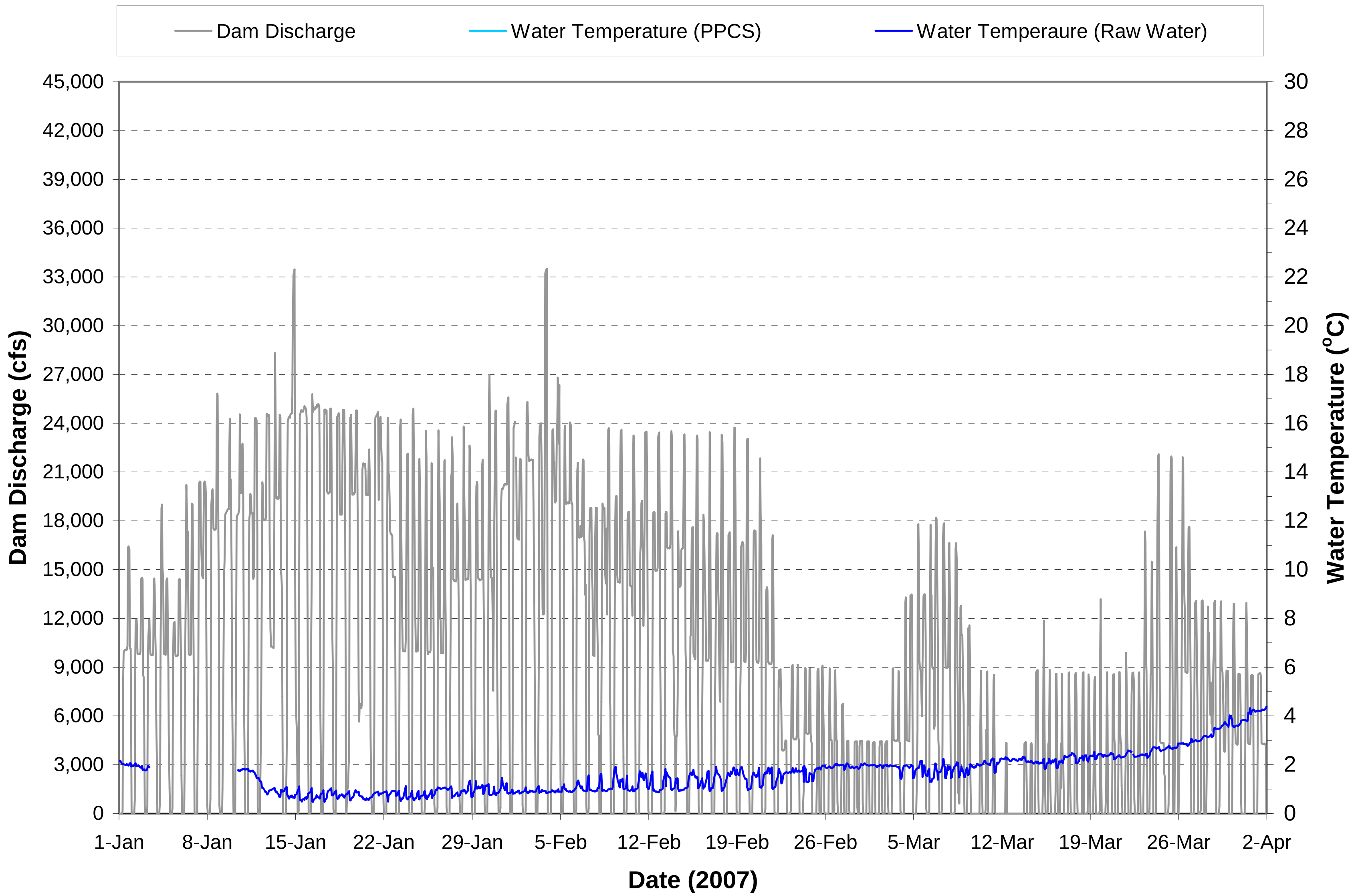


**Plate 46.** Hourly discharge and water temperature monitored at the Fort Randall powerplant during the period January through March 2007. (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

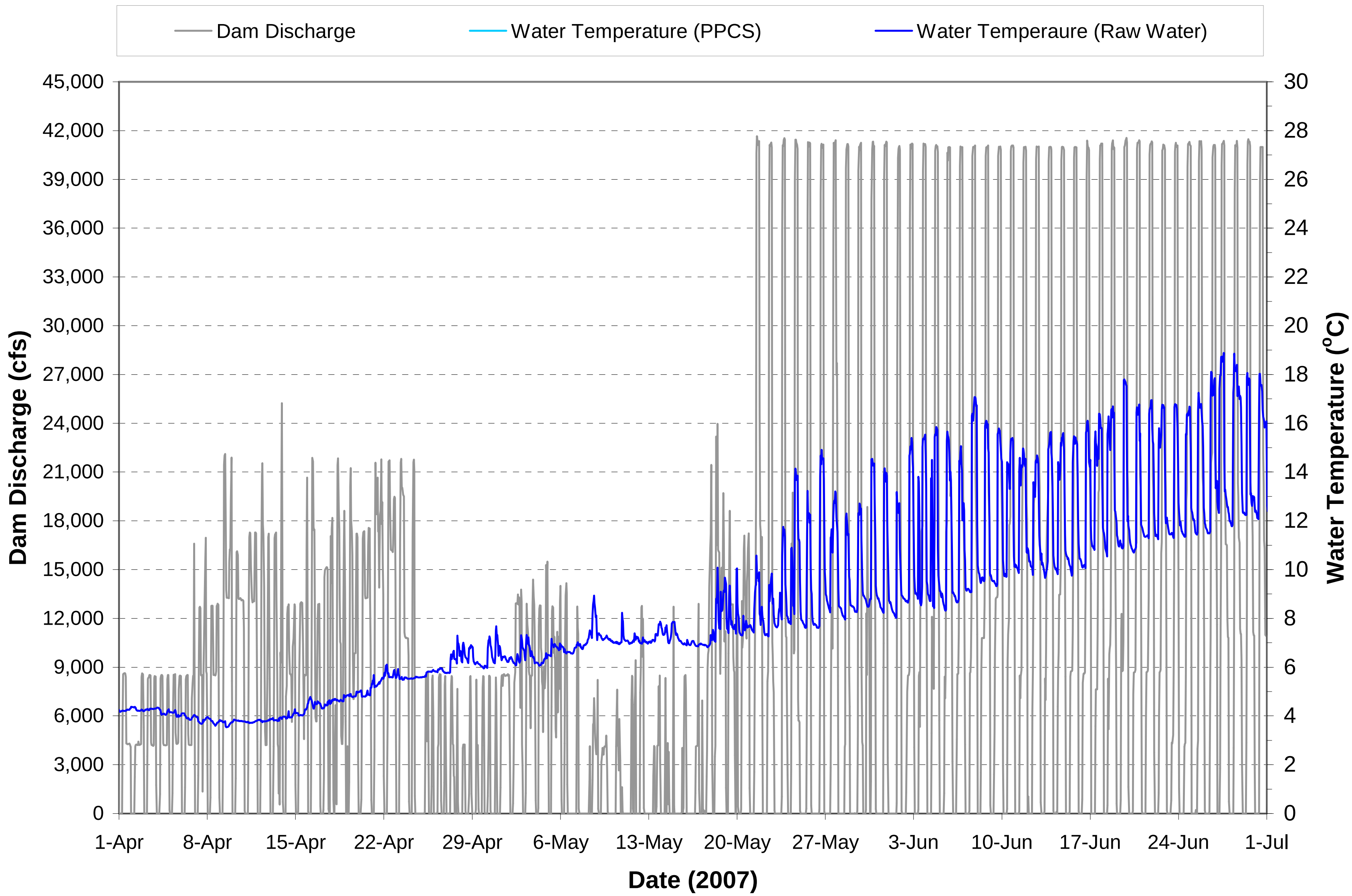


**Plate 47.** Hourly discharge and water temperature monitored at the Fort Randall powerplant during the period April through June 2007. (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

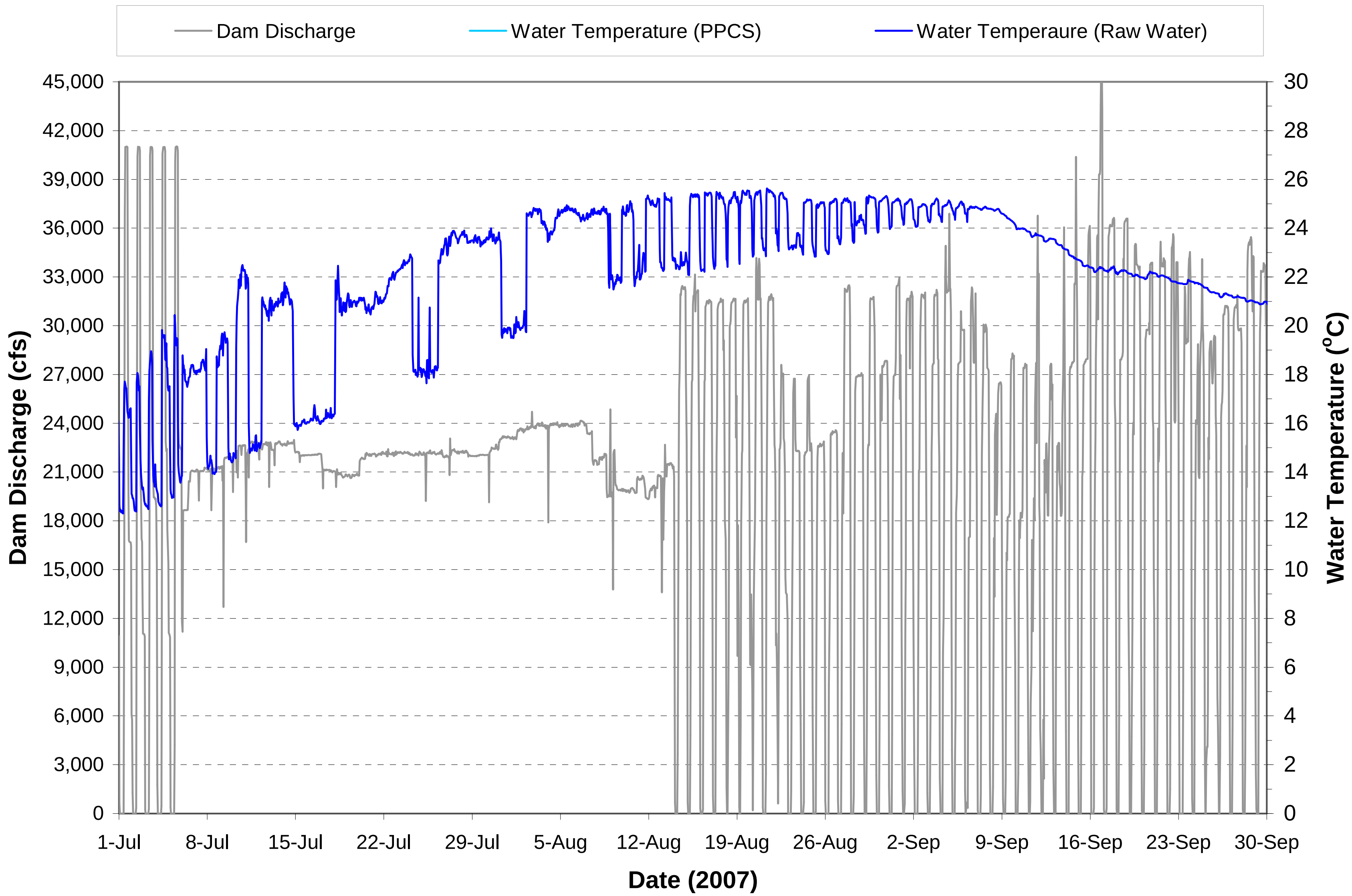


**Plate 48.** Hourly discharge and water temperature monitored at the Fort Randall powerplant during the period July through September 2007. (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

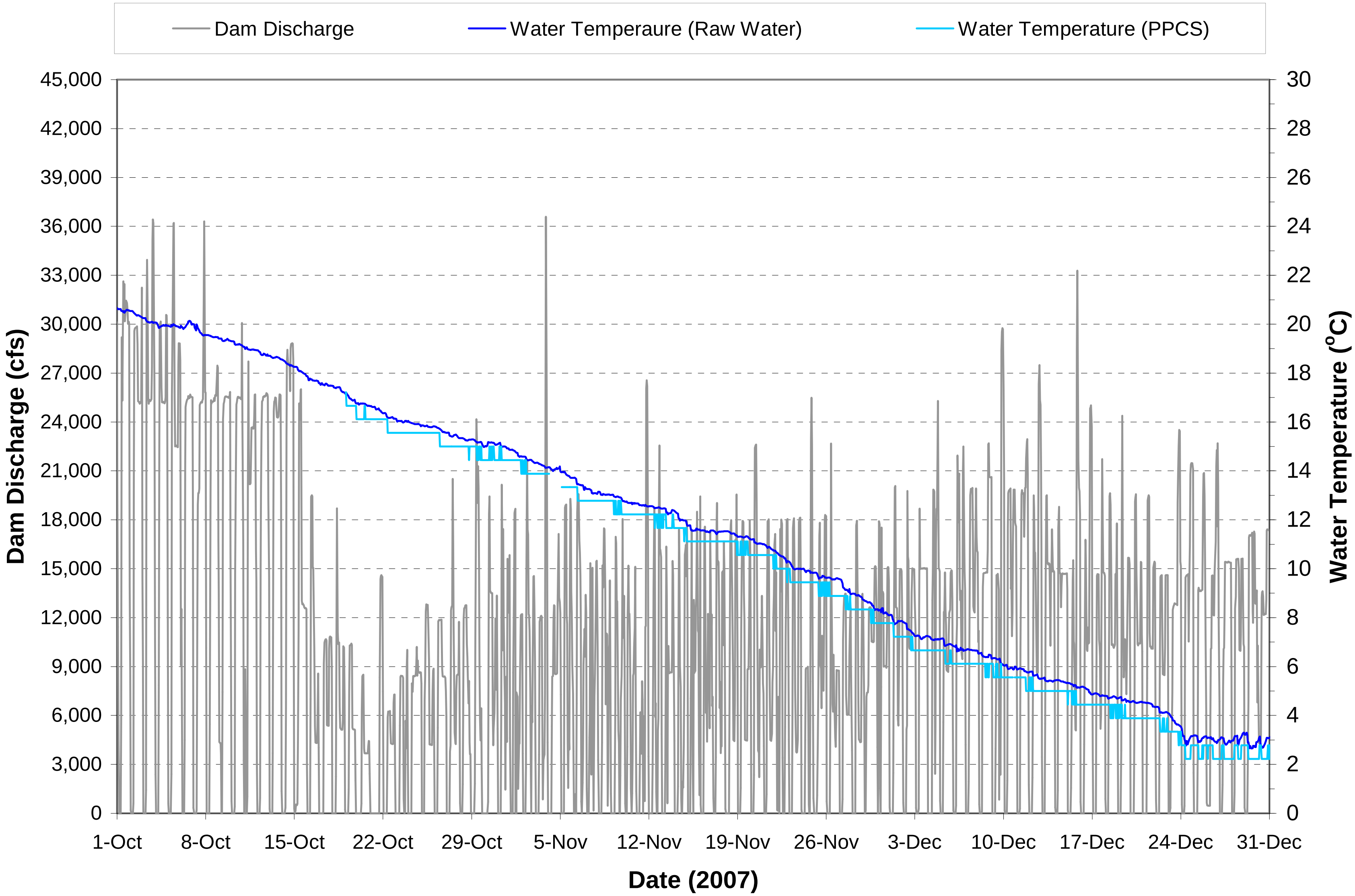


**Plate 49.** Hourly discharge and water temperature monitored at the Fort Randall powerplant during the period October through December 2007. (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

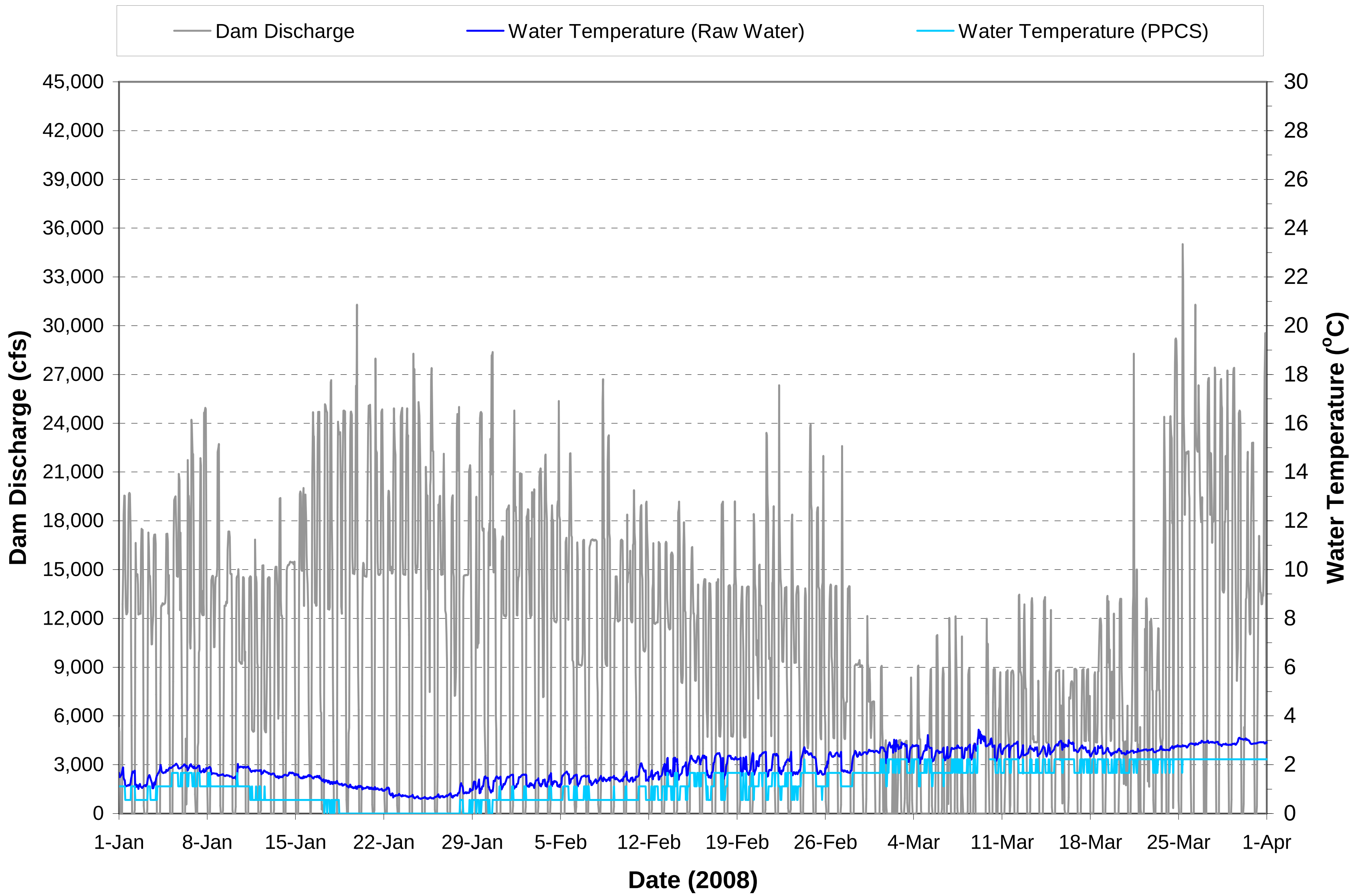


**Plate 50.** Hourly discharge and water temperature monitored at the Fort Randall powerplant during the period January through March 2008.

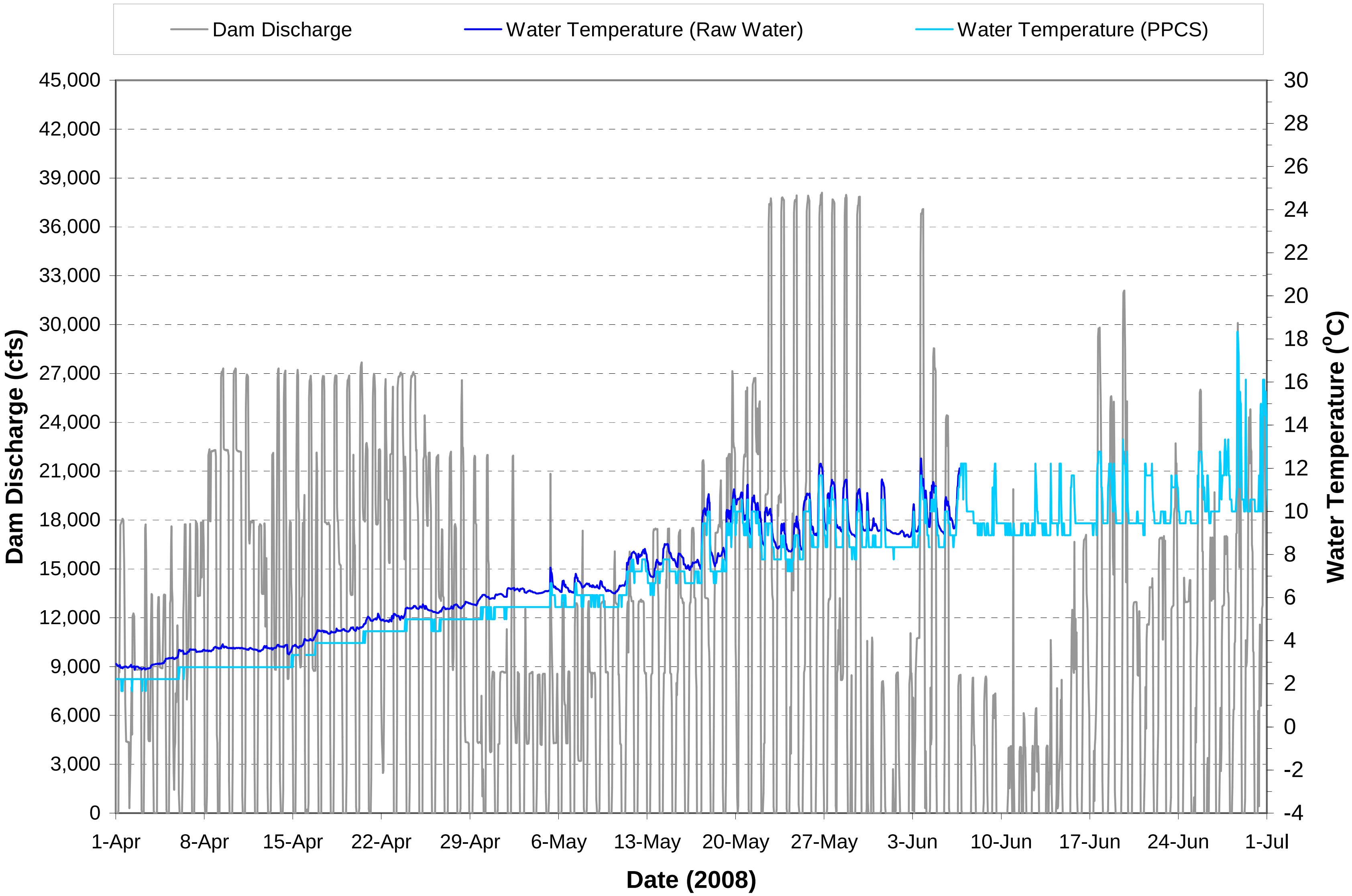


**Plate 51.** Hourly discharge and water temperature monitored at the Fort Randall powerplant during the period April through June 2007. (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

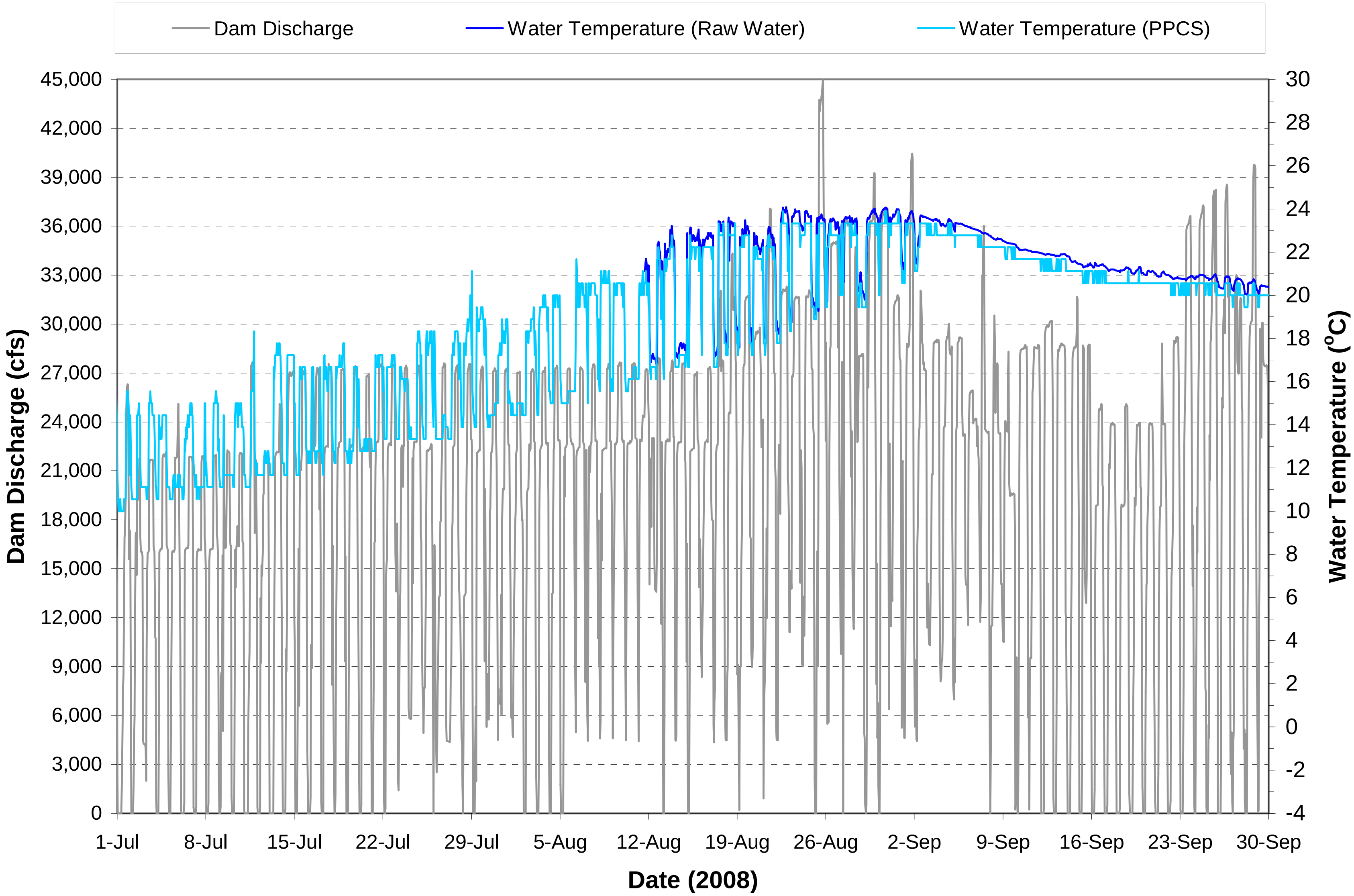


**Plate 52.** Hourly discharge and water temperature monitored at the Fort Randall powerplant during the period July through September 2008. (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

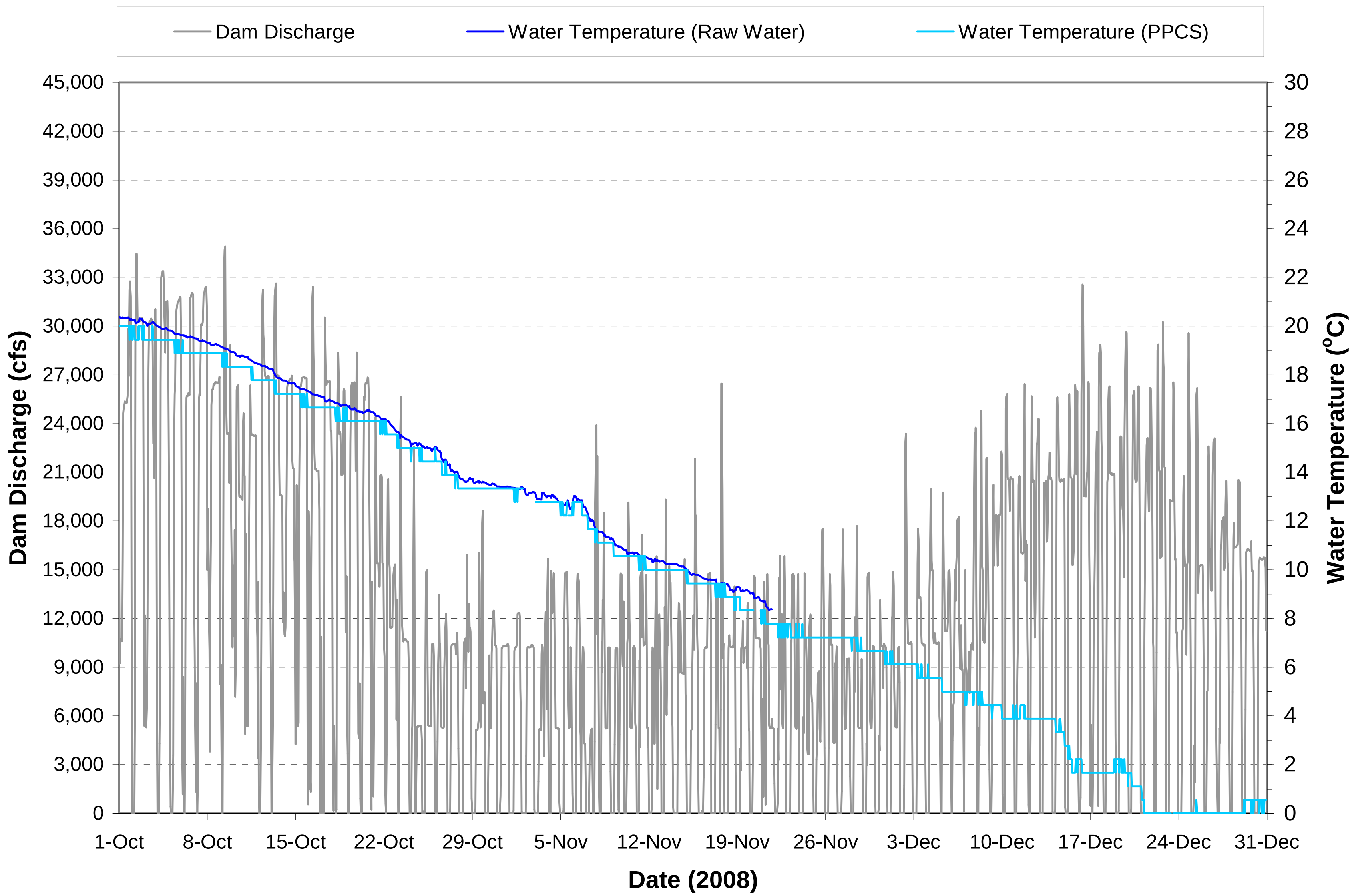


**Plate 53.** Hourly discharge and water temperature monitored at the Fort Randall powerplant during the period October through December 2008. (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

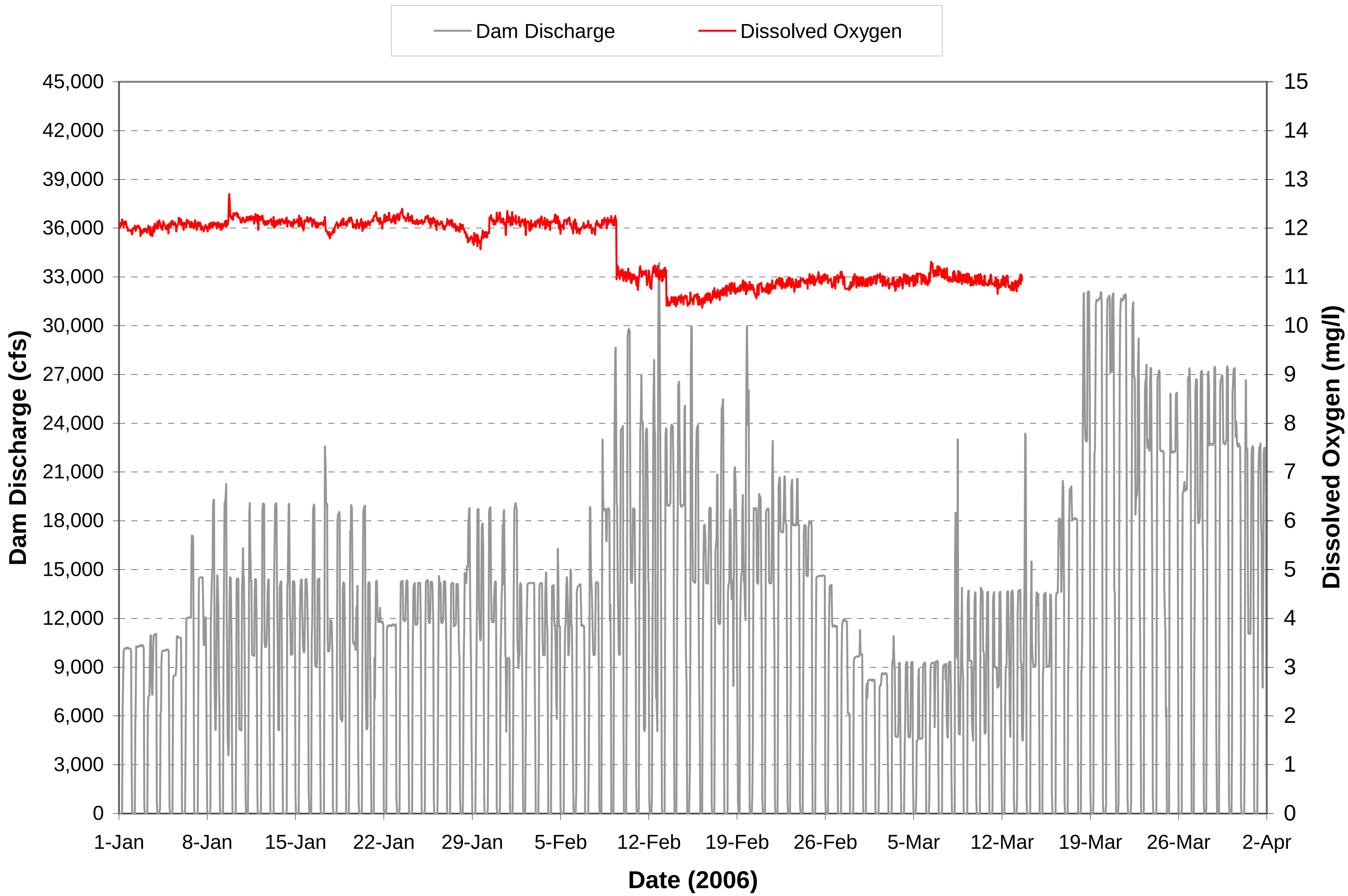


**Plate 54.** Hourly discharge and dissolved oxygen concentrations monitored at the Fort Randall powerplant during the period January through March 2006. (Note: Gaps in dissolved oxygen plot are periods when the monitoring equipment was not operational.)

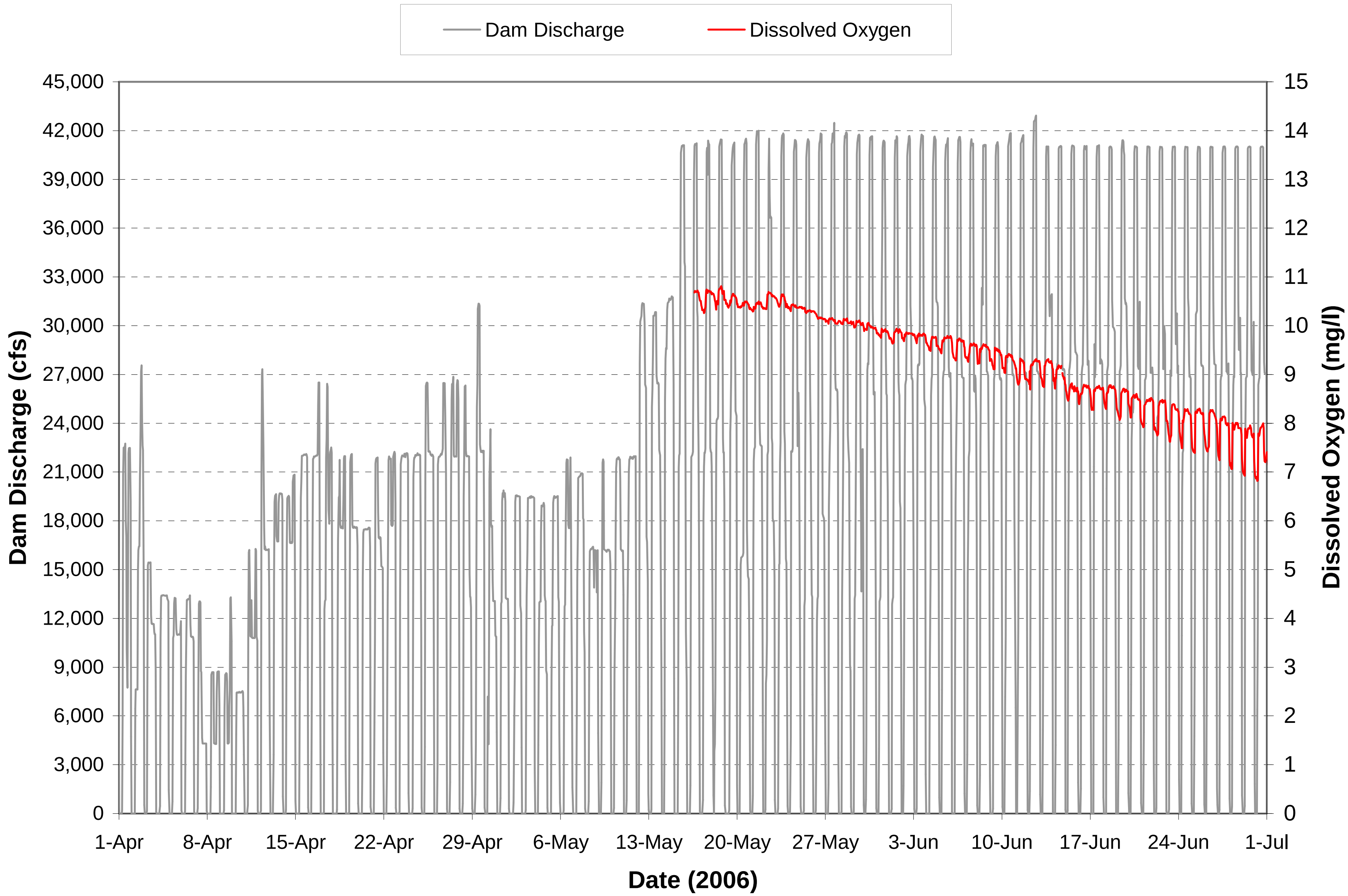


**Plate 55.** Hourly discharge and dissolved oxygen concentrations monitored at the Fort Randall powerplant during the period April through June 2006. (Note: Gaps in dissolved oxygen plot are periods when the monitoring equipment was not operational.)

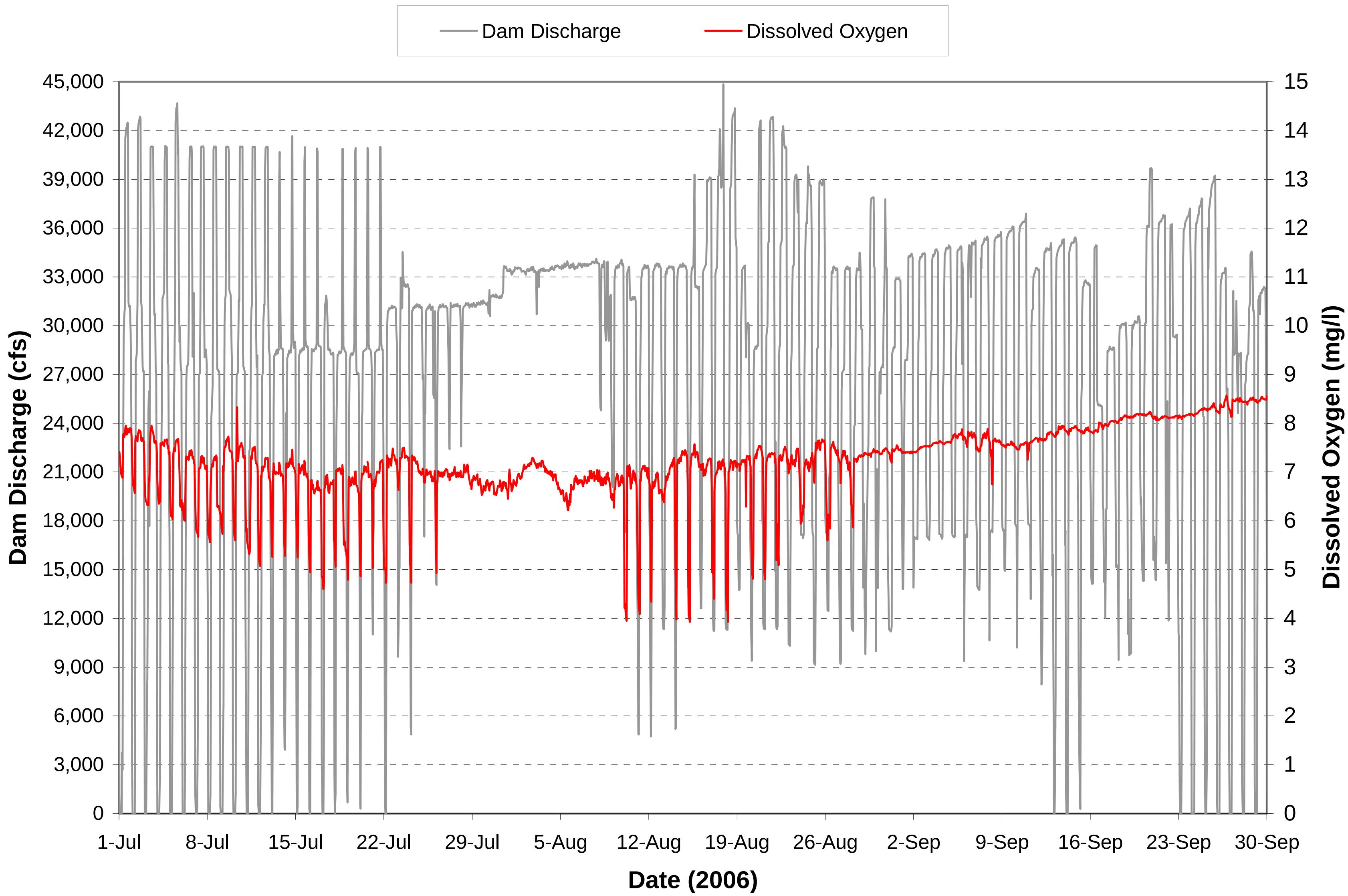


**Plate 56.** Hourly discharge and dissolved oxygen concentrations monitored at the Fort Randall powerplant during the period July through September 2006.

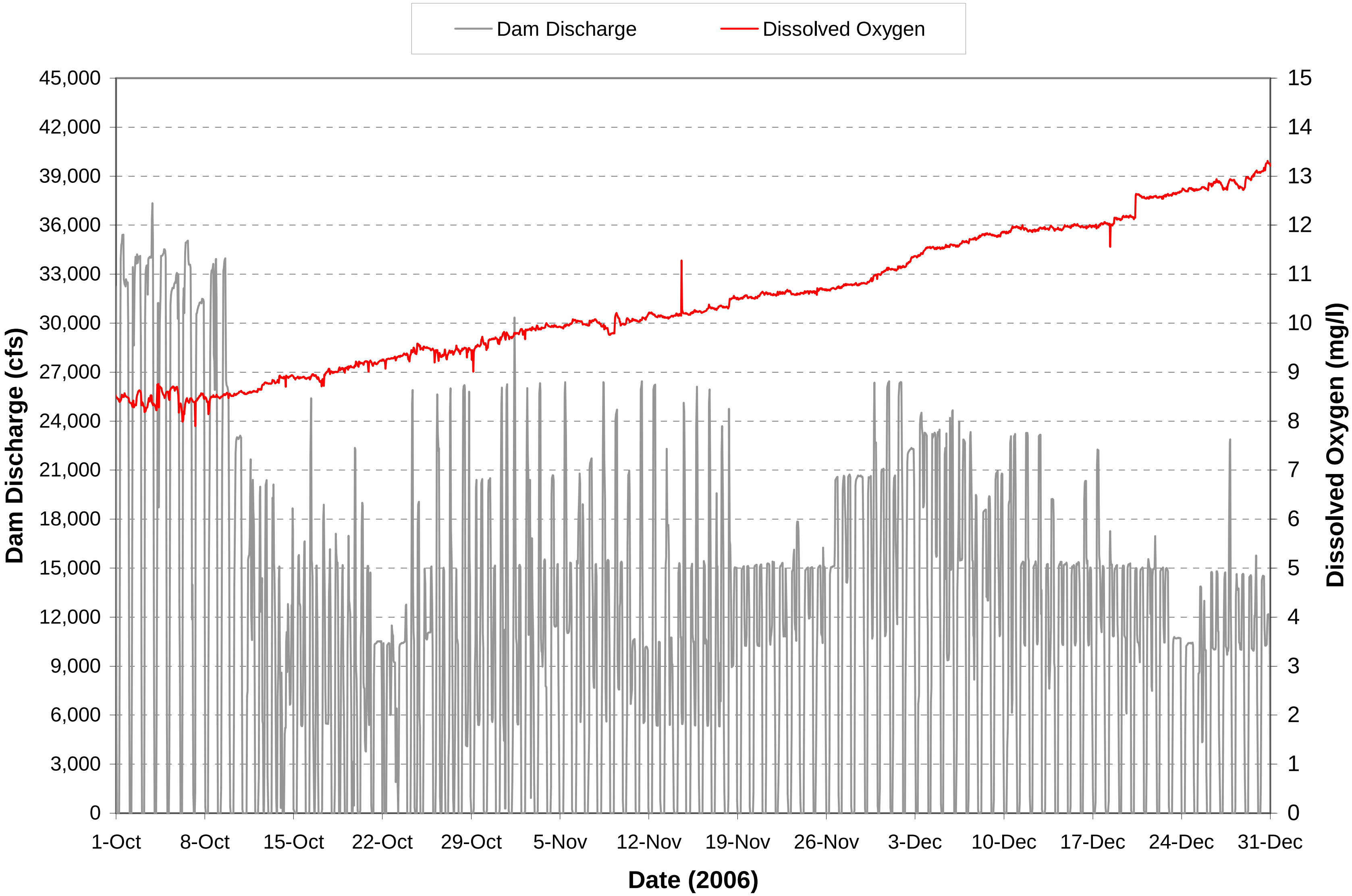


**Plate 57.** Hourly discharge and dissolved oxygen concentrations monitored at the Fort Randall powerplant during the period October through December 2006.

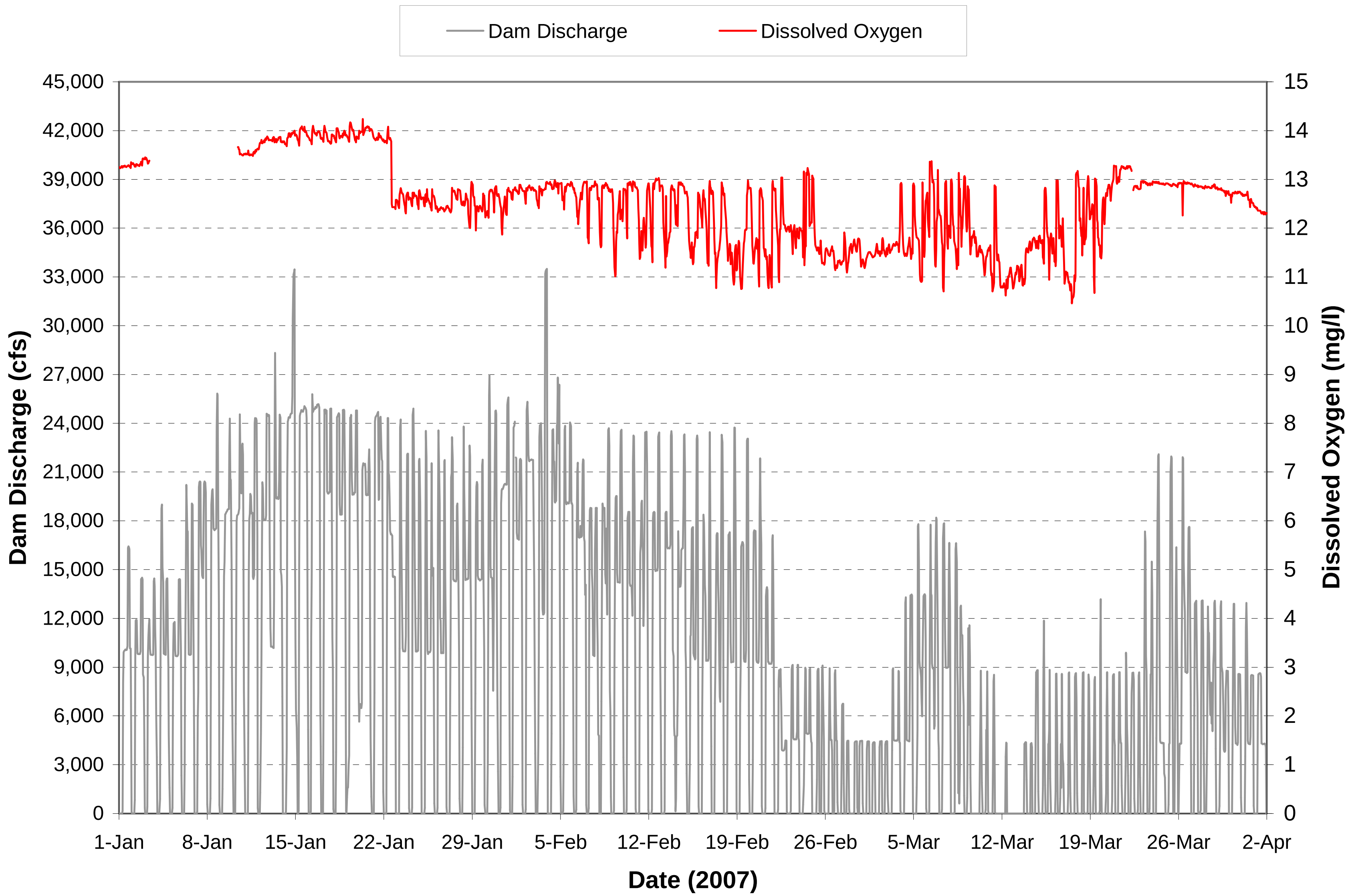


**Plate 58.** Hourly discharge and dissolved oxygen concentrations monitored at the Fort Randall powerplant during the period January through March 2007. (Note: Gaps in dissolved oxygen plot are periods when the monitoring equipment was not operational.)

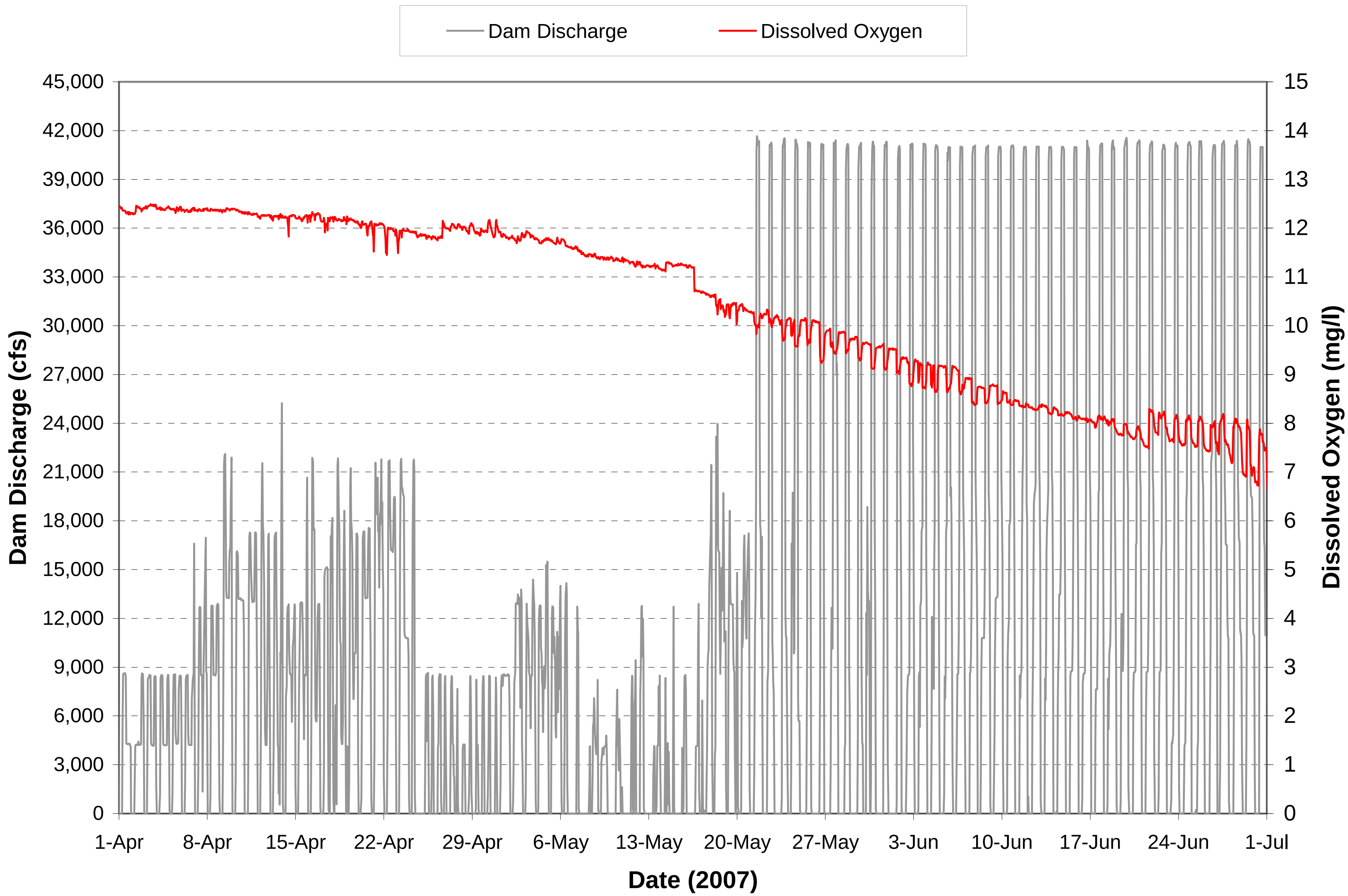


**Plate 59.** Hourly discharge and dissolved oxygen concentrations monitored at the Fort Randall powerplant during the period April through June 2007.

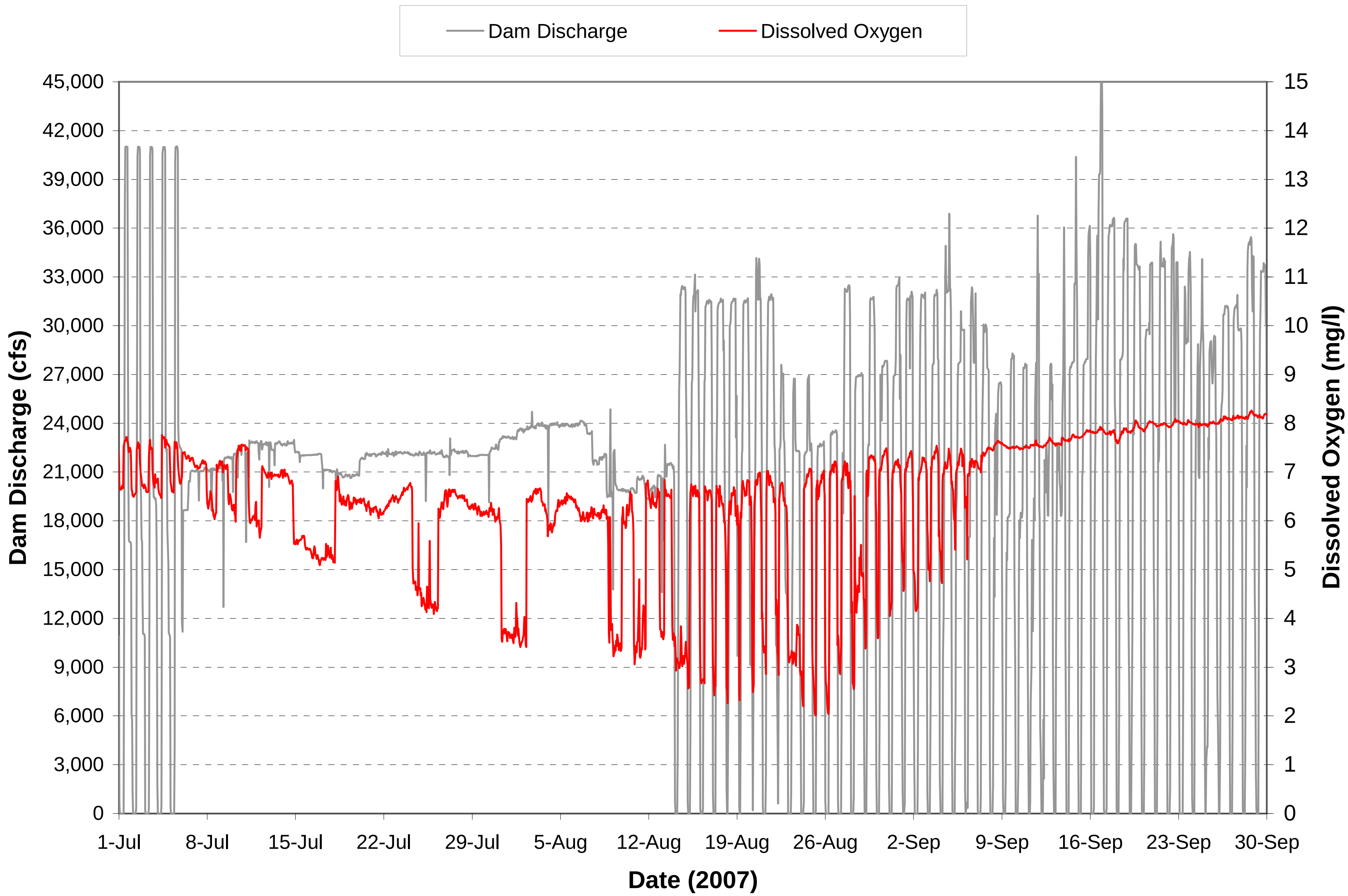


**Plate 60.** Hourly discharge and dissolved oxygen concentrations monitored at the Fort Randall powerplant during the period July through September 2007.

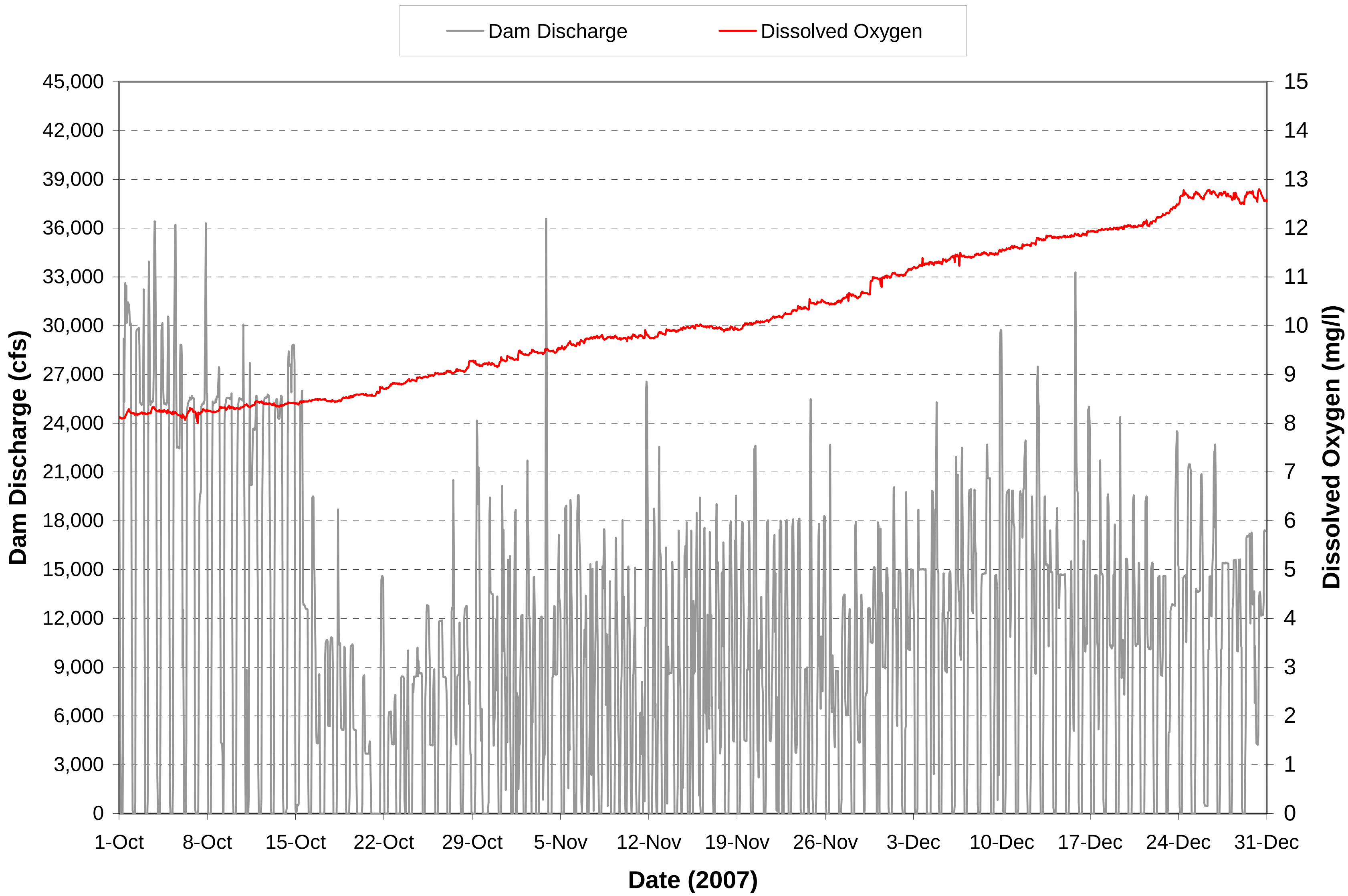


**Plate 61.** Hourly discharge and dissolved oxygen concentrations monitored at the Fort Randall powerplant during the period October through December 2007.

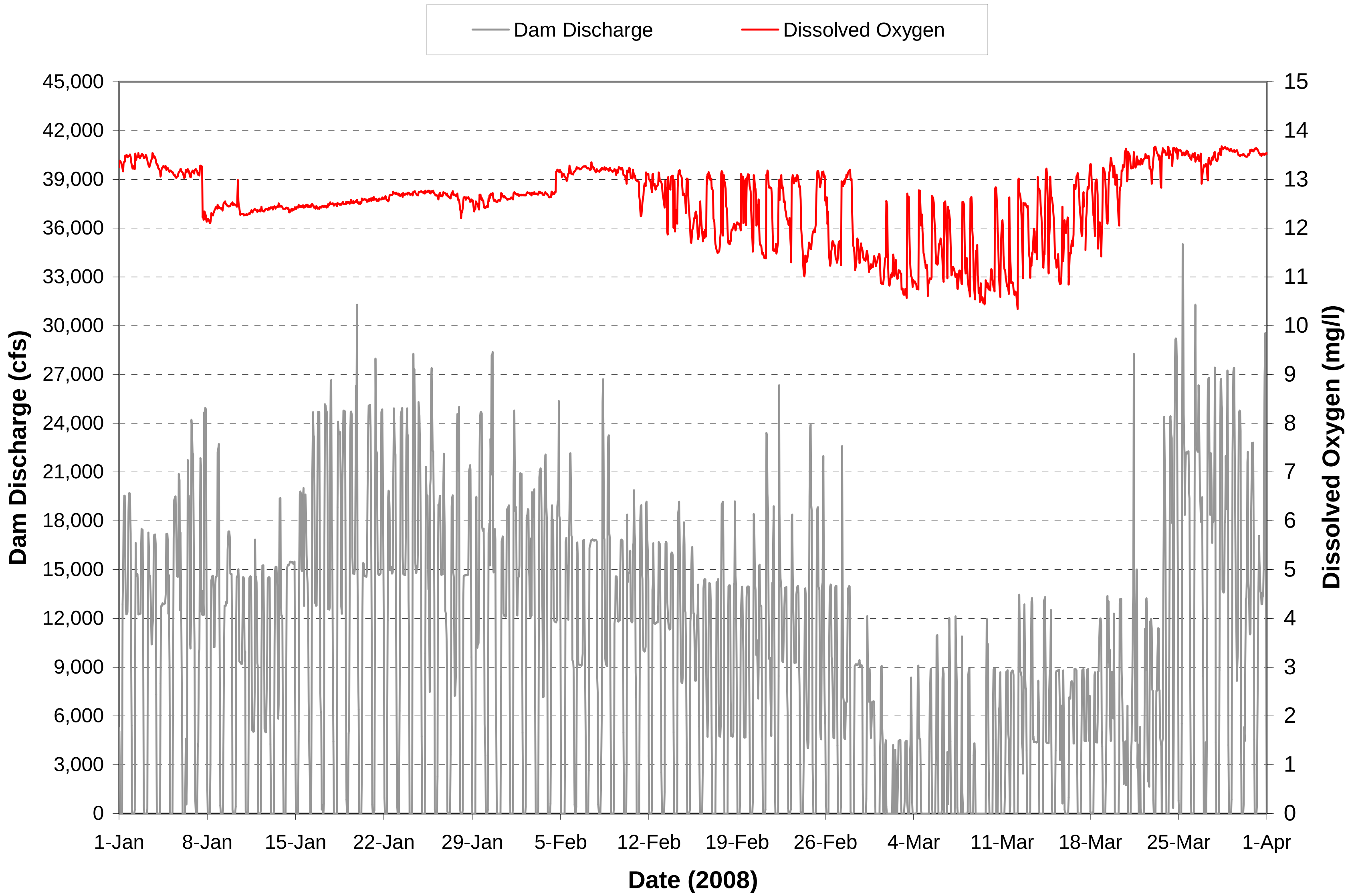


**Plate 62.** Hourly discharge and dissolved oxygen concentrations monitored at the Fort Randall powerplant during the period January through March 2008.

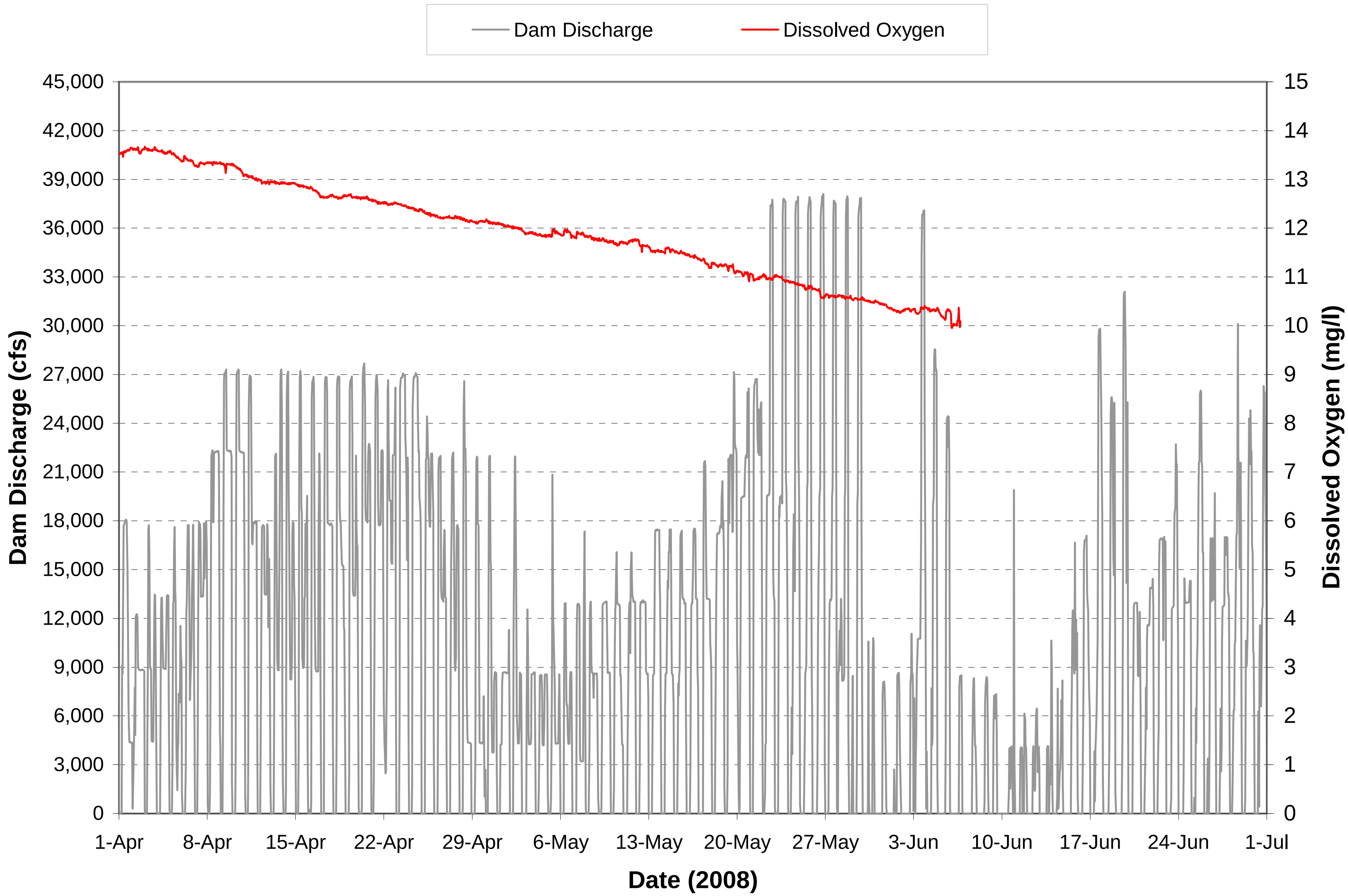


**Plate 63.** Hourly discharge and dissolved oxygen concentrations monitored at the Fort Randall powerplant during the period April through June 2008. (Note: Gaps in dissolved oxygen plot are periods when the monitoring equipment was not operational.)