U.S. Army Corps of Engineers
Omaha District

2015 Report

Water Quality Conditions in the Missouri River Mainstem System

February 2017

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U.S. Army Corps of Engineers

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1 INTRODUCTION

1.1 OMAHA DISTRICT WATER QUALITY MANAGEMENT PROGRAM

The Omaha District (District) of the U.S. Army Corps of Engineers (Corps) is implementing a Water Quality Management Program (WQMP) as part of the operation and maintenance (O&M) activities associated with managing the Corps' civil works projects in the District. The WQMP addresses surface water quality management issues and adheres to the guidance and requirements specified in the Corps' Engineering Regulation – ER 1110-2-8154, "Water Quality and Environmental Management for Corps Civil Works Projects" (USACE, 1995). To guide implementation of the WQMP, the District maintains a Program Management Plan (PgMP) that is annually reviewed. The current PgMP identifies the following four goals for the District's WQMP (USACE, 2016):

1) Ensure that surface water quality, as affected by District projects and their regulation, is suitable for Project purposes, existing water uses, public health and safety, and is in compliance with applicable Federal, Tribal, and State water quality standards.
2) Establish and maintain a surface water quality monitoring and data evaluation program that facilitates the achievement of surface water quality management objectives, allows for the characterization of surface water quality conditions, and defines the influence of District Projects on surface water quality.
3) Establish and maintain strong working partnerships and collaboration with appropriate entities within and outside the Corps regarding surface water quality management at District Projects.
4) Document the water quality management activities of the District's Water Quality Management Program and surface water quality conditions at District Projects to record trends, identify problems and accomplishments, and provide guidance to program and Project managers.

The annual reporting of water quality conditions is done to document and assess water quality conditions occurring at Corps civil works projects in the District. This report describes existing and historic water quality conditions and identifies any evident surface water quality management issues. The reporting of water quality conditions is done to facilitate water quality management decisions regarding the operation and regulation of Corps projects.

1.2 CORPS MISSOURI RIVER MAINSTEM SYSTEM PROJECTS WITHIN THE OMAHA DISTRICT

The location of the Corps' Missouri River Mainstem System (Mainstem System) civil works project areas within the District and background information on the projects are provided in Figure 1-1 and Table 1-1. These are the Mainstem System civil works projects under the purview of the District's WQMP.

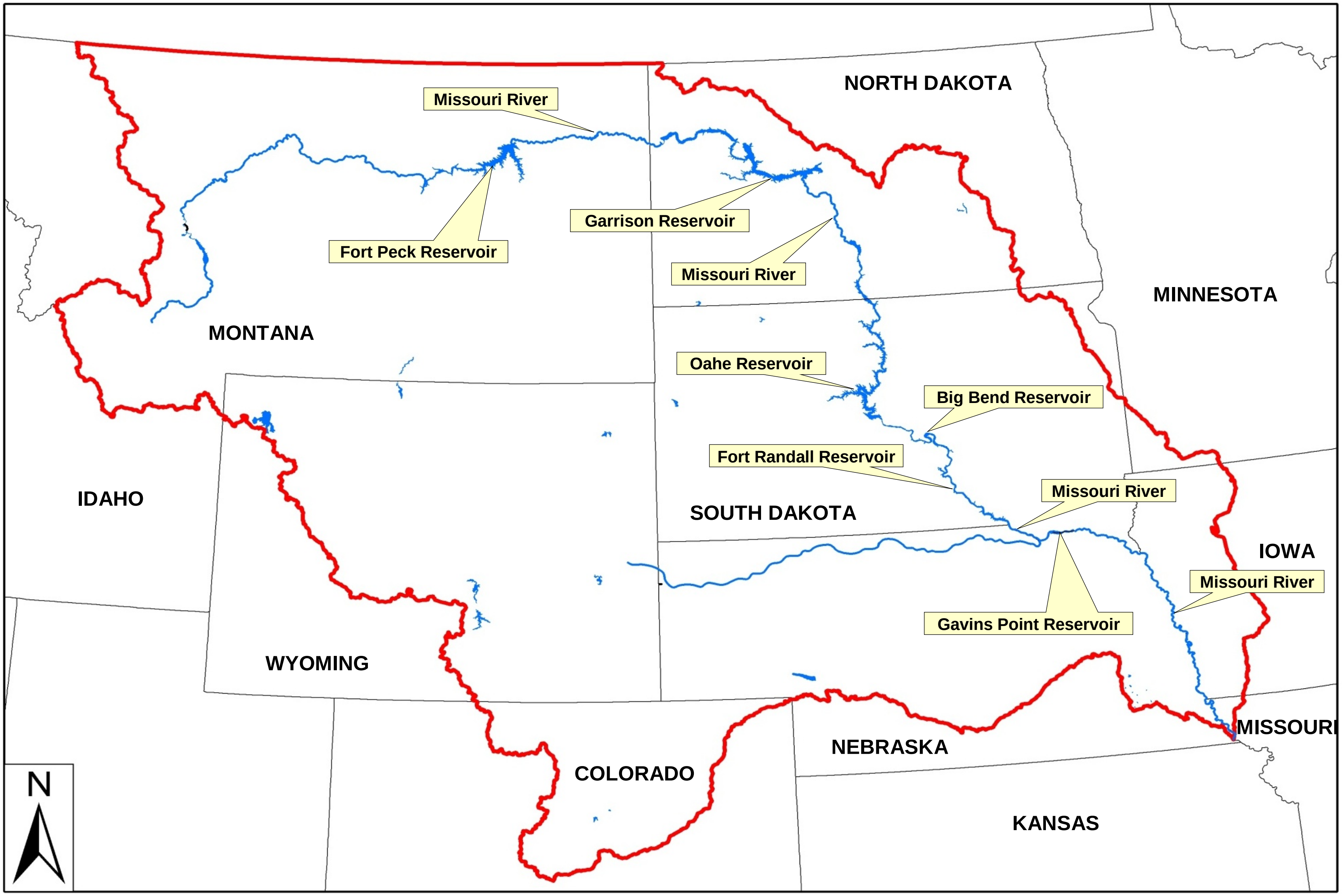


Figure 1-1. Missouri River Mainstem System civil works projects in the Omaha District. (Refer to Table 1-1 for project information.)

Table 1-1. Background information for the Corps' Missouri River Mainstem System project areas located in the Omaha District**.**

Project Area	Location	Dam Closure	Lake Size or River Length[(1)]	Authorized Proposes[(2)]	Water Quality Designated Beneficial Uses[(3)]
MAINSTEM RESERVOIRS					
Fort Peck (Fort Peck Lake)	Fort Peck, MT	1937	246,000 A (mp)	FC, Rec, FW, HP, WS, WQ, Nav, Irrig[(4)]	Rec, FW, WAL, DWS, IWS, AWS
Garrison (Lake Sakakawea)	Garrison, ND	1953	380,000 A (mp)	FC, Rec, FW, HP, WS, WQ, Nav, Irrig[(5)]	Rec, FW, CAL, DWS, IWS, AWS
Oahe (Lake Oahe)	Pierre, SD	1958	374,000 A (mp)	FC, Rec, FW, HP, WS, WQ, Nav, Irrig[(4)]	Rec, FW, CAL, DWS, IWS, AWS
Big Bend (Lake Sharpe)	Chamberlain, SD	1963	61,000 A (mp)	FC, Rec, FW, HP, WS, WQ, Nav, Irrig[(4)]	Rec, FW, CAL, DWS, IWS, AWS
Fort Randall (Lake Francis Case)	Pickstown, SD	1952	102,000 A (mp)	FC, Rec, FW, HP, WS, WQ, Nav, Irrig[(4)]	Rec, FW, WAL, DWS, IWS, AWS
Gavins Point (Lewis and Clark Lake)	Yankton, SD	1955	31,000 A (mp)	FC, Rec, FW, HP, WS, WQ, Nav, Irrig[(4)]	Rec, FW, WAL, DWS, IWS, AWS, Aes
MISSOURI RIVER					
Fort Peck Reach	Fort Peck Dam to Lake Sakakawea	-----	204 M	-----	Rec, FW, CAL, WAL, DWS, IWS, AWS
Garrison Reach	Garrison Dam to Lake Oahe	-----	87 M	-----	Rec, FW, WAL, DWS, IWS, AWS
Oahe Reach	Oahe Dam to Lake Sharpe	-----	5 M	-----	Rec, FW, CAL, DWS, IWS, AWS
Fort Randall Reach	Fort Randall Dam to Lewis and Clark Lake	-----	39 M	National Recreational River[(6)]	Rec, FW, WAL, DWS, IWS, AWS, Aes, OSRW
Gavins Point Reach	Gavins Point Dam to Ponca, NE	-----	59 M	National Recreational River[(6)]	Rec, FW, WAL, DWS, IWS, AWS, Aes, OSRW
Kensler's Bend Reach	Ponca, NE to Sioux City, IA	-----	17 M	-----	Rec, FW, WAL, DWS, IWS, AWS, Aes, OSRW
Lower Missouri River Reach	Sioux City, IA to Rulo, NE	-----	237 M	BS, Nav	Rec, FW, WAL, DWS, IWS, AWS, Aes

(1) A = acres, M = miles, mp = top of multipurpose pool, cp = top of conservation pool.

(2) Purposes authorized under Federal laws for the operation of the Corps projects.
FC = Flood Control, Rec = Recreation, FW = Fish & Wildlife, HP = Hydroelectric Power, WS = Water Supply, WQ = Water Quality, Nav = Navigation, Irrig = Irrigation, BS = Bank Stabilization.

(3) Water quality dependent beneficial uses designated to the waterbody in State water quality standards pursuant to the Federal Clean Water Act.
Rec = Recreation, FW = Fish and Wildlife, WAL, Warmwater Aquatic Life, CAL = Coldwater Aquatic Life, DWS = Domestic Water Supply, IWS = Industrial Water Supply, AWS = Agricultural Water Supply, Aes = Aesthetics, OSRW = Outstanding State Resource Water (NE).

(4) Section 8 (PL 78-534) Federal irrigation has not been developed at this project; however, water is being withdrawn for private irrigation use.

(5) There is a Section 8 Federal irrigation project authorized at this project, but it is not yet operational; however, water is being withdrawn for private irrigation use.

(6) Designated a Recreational River under the Federal Wild and Scenic Rivers Act.

2 MAINSTEM SYSTEM WATER QUALITY MONITORING

2.1 MAINSTEM SYSTEM RESERVOIRS

2.1.1 LONG-TERM, FIXED-STATION AMBIENT MONITORING

The District conducts long-term, fixed-station ambient water quality monitoring at the six Mainstem System reservoirs. Recent ambient water quality monitoring has included monthly (May through September) monitoring at deepwater sites along the length of the reservoirs, and monthly (April through October) monitoring of the Missouri River inflow. Water quality monitoring included field measurements and collection of surface water samples for laboratory analysis. Field measurements included water transparency (i.e. Secchi depth), temperature, dissolved oxygen, pH, specific conductance, oxidation-reduction potential (ORP), turbidity, and chlorophyll-*a* at 1-meter increments from the reservoir surface to the bottom. Near-surface and near-bottom grab samples were collected and delivered to the laboratory where they were analyzed for various physicochemical and biological constituents. Plankton samples were also collected.

2.1.2 BACTERIA MONITORING AT SWIMMING BEACHES

The District has cooperated with the Nebraska Department of Environmental Quality (NDEQ) to monitor bacteria levels present at swimming beaches at the Gavins Point project since 2002. Five swimming beaches on Lewis and Clark Lake and one on Lake Yankton were monitored. Weekly grab samples were collected from May through September and analyzed for fecal coliform and *E. coli* bacteria and the cyanobacteria toxin microcystin. The bacteria monitoring was conducted to meet a 6-hour holding time for analysis of collected samples.

2.2 MAINSTEM SYSTEM POWERPLANTS

As part of the operation of the Mainstem System powerplants, water is drawn from the intake structure of each dam and piped through the powerplant in a “raw water” supply line that is tapped for various uses. The “raw water” supply line is an open-ended, flow-through system. A monitoring station, that measures water quality conditions of water drawn from near the start of the “raw water” supply line, has been irregularly maintained at each of the powerplants in the past. Since 2004 water quality monitoring has consisted of year-round, hourly measurements of temperature, dissolved oxygen, and specific conductance through the use of a data-logger. Monthly grab samples (year-round) have also been collected and analyzed for various physicochemical constituents. The water quality conditions measured in the “raw water” supply lines of the Mainstem System powerplants are believed to represent the water quality conditions present in the reservoirs near the dam intakes and in the tailwaters (i.e. Missouri River) immediately downstream of the dam.

2.3 MISSOURI RIVER FROM FORT RANDALL DAM TO RULO, NE

Since 2003, the District has cooperated with the State of Nebraska (NDEQ) to monitor ambient water quality conditions along the Missouri River from Fort Randall Dam, SD to Rulo, NE. Fixed-station monitoring has occurred at the following nine sites: Fort Randall Dam tailwaters, SD; near Verdel, NE; Gavins Point Dam tailwaters, NE; near Maskell, NE; near Ponca, NE; at Decatur, NE; at Omaha, NE; at Nebraska City, NE; and at Rulo, NE. Water quality monitoring consisted of collecting monthly near-surface grab samples year-round. Depth-discrete grab samples were collected monthly, March through October, at most locations downstream of Gavins Point Dam. The collected grab samples were analyzed for various physicochemical and biological constituents, and various field measurements were also taken.

3 WATER QUALITY ASSESSMENT METHODS

3.1 EXISTING WATER QUALITY

For the purposes of this report, existing water quality is defined as the water quality conditions that occurred during the past 5-year period 2011 through 2015.

3.1.1 STATISTICAL SUMMARY AND COMPARISON TO APPLICABLE WATER QUALITY STANDARDS CRITERIA

Statistical analyses were performed on surface water quality monitoring data collected at the Mainstem System reservoirs (including inflow and outflow sites), powerplants, and the Missouri River. Descriptive statistics were calculated to describe central tendencies and the range of observations in water quality conditions. Monitoring results were compared to applicable water quality standards criteria established by the appropriate States pursuant to the Federal Clean Water Act. Tables were constructed that list the parameters measured; number of observations; and the mean, median, minimum, and maximum of the data collected over the 5-year period 2011 through 2015. The constructed tables also list the water quality standards criteria applicable to the individual parameters and the frequency that these criteria were not met.

3.1.2 SPATIAL AND TEMPORAL VARIATION IN WATER QUALITY CONDITIONS MONITORED AT THE MAINSTEM RESERVOIRS, MISSOURI RIVER, AND MAINSTEM POWERPLANTS

3.1.2.1 Mainstem Reservoirs

3.1.2.1.1 Temperature and Dissolved Oxygen Depth-Profile Plots

Depth-profile plots were constructed to display depth-discrete temperature and dissolved oxygen conditions measured at the Mainstem System reservoirs during 2015. Depth-profiles measured in 1-meter increments from the reservoir's water surface to the bottom were plotted monthly from May through September.

3.1.2.1.2 Longitudinal Contour Plots

Longitudinal contour plots for temperature and dissolved oxygen were constructed from depth-profile measurements collected along the length of the six Mainstem System reservoirs during 2015. 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-Pro, Version 6.2) software developed by HydroGeoLogic Inc. (HydroGeoLogic Inc., 2012).

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

The variation of selected parameters with depth was evaluated by comparing paired near-surface and near-bottom samples collected at the near-dam monitoring location over the past 5 years. The parameters compared included water temperature, dissolved oxygen, pH, alkalinity, total ammonia, and total phosphorus. Box plots were constructed to display the distribution of the paired near-surface and near-bottom measurements, and 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 ($\alpha = 0.05$).

3.1.2.2 <u>Missouri River</u>

3.1.2.2.1 Missouri River Nutrient Levels from Landusky, MT to Rulo, NE

Nutrient levels (i.e. total nitrogen, nitrate-nitrite nitrogen, and total phosphorus) sampled along the Missouri River from near Landusky, MT (RM1921) to Rulo, NE (RM498) were plotted. Boxplots were used to display nutrient concentrations sampled over the 5-year period 2011 through 2015. Flux rates were calculated and mean flows were used to estimate nutrient loadings along the Missouri River during the same 5-year period.

3.1.2.2.2 Lower Missouri River Longitudinal Box Plots

Longitudinal box plots were constructed for the lower Missouri River from Gavins Point Dam to Rulo, NE. The box plots were constructed from the water quality monitoring conducted in cooperation with the NDEQ during the period 2011 through 2015. The box plots are oriented to display the measured change in selected water quality parameters along the Missouri River downstream of Gavins Point Dam.

3.1.2.2.3 Variation of Water Quality with Depth in the Lower Missouri River

It is recognized that the concentrations of particulate-associated constituents (e.g. total suspended solids, total suspended sediment, total phosphorus, etc.) can vary from the river surface to its bottom because of the sinking of particulate matter and its transport nearer the river bottom. Thus, sampling of water quality conditions near the surface of a river could under estimate the “true” water-column composite concentration for these constituents. However, the sinking effect, especially for “lighter” material, can be reduced by resuspension if current velocity and turbulence are significant. Depth-profile measurements and depth-discrete samples were collected on the lower Missouri River to assess depth variation.

3.1.2.2.3.1 Depth-Profile Plots

Measured water temperature, dissolved oxygen, pH, conductivity, and turbidity depth profiles were plotted for the lower Missouri River at monitoring sites where depth-profile measurements were collected in 2015. The plotted depth profiles were measured in the deepest area of the river thalweg based on electronic sounding equipment.

3.1.2.2.3.2 Comparison of Near-Surface, Mid-Depth, and Near-Bottom Water Quality Conditions

The variation of potential particulate-associated constituents (i.e. total suspended solids, total suspended sediment, total phosphorus, total organic carbon, and total Kjeldahl nitrogen) with depth was evaluated by comparing paired near-surface, mid-depth, and near-bottom collected samples collected over the past 5 years. The paired samples compared were collected in the deepest area of the river thalweg based on electronic sounding equipment. Box plots were constructed to display the distribution of the paired near-surface, mid-depth, and near-bottom measurements, and 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 ($\alpha = 0.05$).

3.1.2.3 <u>Mainstem Powerplants</u>

Time series plots were prepared for water quality conditions monitored at the Missouri River Mainstem System powerplants during the 2015. Annual plots of hourly measured water temperature, dissolved oxygen, and dam discharge were constructed. Water temperature and dissolved oxygen plots represent monitoring of water drawn from the “raw water” supply line in each powerplant.

3.1.3 RESERVOIR TROPHIC STATUS

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

$$\text{TSI(Secchi Depth)} = \text{TSI(SD)} = 10(6 - (\ln SD/\ln 2))$$

$$\text{TSI(Chlorophyll } a) = \text{TSI(Chl)} = 10(6 - ((2.04\text{-}0.68 \ln Chl)/\ln 2))$$

$$\text{TSI(Total Phosphorus)} = \text{TSI(TP)} = 10(6 – (\ln (48/TP)/\ln 2))$$

A TSI average value, calculated as the average of the three individually determined TSI values, is used by the District as an overall indicator of a reservoir’s trophic state. The District uses the criteria defined in Table 3-1 for determining lake trophic status from TSI values.

Table 3-1. Lake trophic status based on calculated TSI values.

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

3.1.4 RESERVOIR PLANKTON COMMUNITY

3.1.4.1 <u>Phytoplankton</u>

Assessment of the phytoplankton community in the Mainstem System reservoirs was based on grab samples collected in 2015. Grab samples were collected at a near-surface depth of one-half the measured Secchi depth. Laboratory analyses consisted of identification of phytoplankton taxa to the lowest practical level and quantification of taxa biovolume. These results were used to plot the relative abundance of phytoplankton taxa based on the measured biovolumes. Phytoplankton were categorized into the following seven groups for plotting purposes: Bacillariophyta (diatoms), Chlorophyta (green algae), Chrysophyta (yellow-green algae), Cryptophyta (cryptomonads), Cyanobacteria (blue-green algae), Euglenophyta (euglenids), and Pyrrophyta (dinoflagellates).

3.1.4.2 <u>Zooplankton</u>

Assessment of the zooplankton community was based on vertical-tow samples collected in 2015 from near the reservoir bottom or 25-meter depth (whichever was less) to the surface. Laboratory analyses consisted of identification of zooplankton taxa to the lowest practical level and quantification of taxa biomass. These results were used to plot the relative abundance of zooplankton taxa based on the measured biomasses. Zooplankton were categorized into the following four groups for plotting purposes: Cladocerans, Copepods, Rotifers, and Ostracods.

3.2 WATER QUALITY TRENDS

Surface water quality trends were assessed for water clarity (i.e. Secchi depth), total phosphorus, chlorophyll *a*, and calculated average TSI from monitoring results obtained at long-term, fixed-station ambient monitoring sites. Scatter plots were prepared by plotting the four parameters over the time period 1980 through 2015. A linear regression trend line was also plotted. Analysis of variance (ANOVA) was used to determine an R^2 value and to test for the significance ($\alpha = 0.05$) of a linear trend over time.

4 MAINSTEM SYSTEM RESERVOIRS -- OVERVIEW

The Mainstem System is comprised of six dams and reservoirs constructed by the Corps on the Missouri River and, where present, the free-flowing Missouri River downstream of the dams. The six dams and reservoirs in an upstream to downstream order are: Fort Peck Dam and Fort Peck Lake (MT), Garrison Dam and Lake Sakakawea (ND), Oahe Dam (SD) and Lake Oahe (ND and SD), Big Bend Dam and Lake Sharpe (SD), Fort Randall Dam and Lake Francis Case (SD), and Gavins Point Dam and Lewis and Clark Lake (NE and SD) (Figure 1-1). 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. Drought conditions in the upper Missouri River Basin in the early to mid-2000's reduced the water stored in the upper three Mainstem System reservoirs to record low levels. In 2011 unprecedented runoff resulted in historic discharges from the Mainstem System. The water in storage at the all Mainstem System reservoirs at the end of 2015 (i.e. December 31, 2015) was 56.927 MAF, which is about 78 percent of the total normal pool Mainstem System storage volume. Table 4-1 gives selected engineering data for each of the six reservoirs

4.1 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, 2006). 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 snow packs along with spring and summer rainfall produces the annual runoff into the Mainstem System. In a typical year, mountain snow pack, plains snow pack, 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 of the authorized purposes, given the physical and authorization limitations of the Mainstem System, the total storage available in the Mainstem System 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.

Table 4-1. Summary of selected engineering data for the Missouri River Mainstem System.

	Fort Peck	Garrison	Oahe	Big Bend	Fort Randall	Gavins Point
General						
Lake Name	Fort Peck Lake	Lake Sakakawea	Lake Oahe	Lake Sharpe	Lake Francis Case	Lewis and Clark Lake
River Mile (1960 Mileage)	1771.5	1389.9	1072.3	987.4	880.0	811.1
Total and Incremental Drainage Area (square miles)	57,500	181,400 123,900	243,490 62,900	249,330 5,840	263,480 145,150	279,480 16,000
Reservoir Length at Top of Carryover Multiple Use Pool (miles)	134	178	231	80	107	25
Shoreline Length at Top of Carryover Multiple Use Pool (miles)	1,520	1,340	2,250	200	540	90
Top Elevation of Carryover Multiple Use Pool (ft-NGVD29)	2234.0	1837.5	1607.5	1422.0	1350.0	1208.0
Year Storage First Available for Regulation of Flows	1940	1955	1962	1964	1953	1955
Original "As-Built" Conditions (Year)	(1937)	(1953)	(1958)	(1963)	(1953)	(1955)
Surface Area of Carryover Multiple Use Pool (acres)	214,718	322,030	311,478	59,150	82,000	31,100
Capacity of Carryover Multiple Use Pool (acre-feet)	15,869,000	18,917,000	19,490,000	1,920,000	3,911,000	510,000
Mean Depth at top of Carryover Multiple Use Pool(1) (feet)	73.9	58.7	62.6	32.5	47.7	16.4
Most Recent Surveyed Conditions (Year)	(2007)	(2010-2012)	(2007-2012)	(1997)	(2011)	(2011)
Surface Area at top of Carryover Multiple Use Pool (acres)	210,700	307,775	312,100	59,700	76,206	25,081
Capacity of Carryover Multiple Use Pool (acre-feet)	14,788,000	17,744,640	18,667,635	1,738,000	3,000,732	374,434
Mean Depth at top of Multiple Use Pool(1) (feet)	70.2	57.7	59.8	29.1	39.4	14.9
Sediment Deposition to Top of Carryover Multiple Use Pool						
Surveyed Sediment Deposition(2) (acre-feet)	1,081,000	1,172,360	822,365	182,000	910,268	135,566
Years of Sediment Deposition(3) (Survey Year - "As-Built Year")	70	58	52	34	58	56
Annual Sedimentation Rate(4) (acre-feet/year)	15,443	20,213	15,815	5,353	15,694	2,421
Annual Rate of Volume Loss from "As-Built" Condition	0.10%	0.11%	0.08%	0.28%	0.40%	0.48%
Years from "As-Built" to 2015	78	62	57	52	62	60
Estimated Sediment Deposition (acre-feet) through 2015(5)	1,204,554	1,253,206	901,455	278,356	973,028	145,260
2015 Estimated Capacity of Carryover Multiple Use Pool(6) (acre-feet)	14,664,446	17,663,794	18,588,545	1,641,644	2,937,972	364,740
Estimated Carryover Multiple Use Pool Capacity Lost through 2015	7.6%	6.6%	4.6%	14.5%	24.9%	28.5%
Operational Details – Historic (1967 through 2015)						
Maximum Recorded Pool Elevation (ft-NGVD29)	2252.3	1854.8	1619.7	1422.1	1374.0	1209.7
Minimum Recorded Pool Elevation (ft-NGVD29)	2196.2	1805.8	1570.2	1414.9	1317.9	1199.8
Average Daily Pool Elevation (ft-NGVD29)	2229.7	1835.1	1601.9	1420.4	1351.1	1206.8
Maximum Recorded Daily Inflow (cfs)	160,000	190,000	210,000	195,000	218,000	168,000
Maximum Recorded Daily Outflow (cfs)	65,900	150,600	160,300	166,300	160,000	160,700
Average Annual Inflow (ac-ft)	7,238,000	16,608,000	18,441,000	17,365,000	18,449,000	20,150,000
Average Annual Outflow (ac-ft)	6,645,000	15,672,000	17,523,000	17,190,000	18,189,000	20,053,000
Operational Details – Current (2015)						
Maximum Recorded Pool Elevation (ft-NGVD29)	2237.2	1845.2	1613.5	1421.4	1360.7	1208.4
Minimum Recorded Pool Elevation (ft-NGVD29)	2233.3	1838.2	1606.8	1419.8	1338.5	1205.8
Maximum Recorded Daily Inflow (cfs)	29,000	78,000	105,000	35,000	46,000	33,000
Maximum Recorded Daily Outflow (cfs)	9,400	23,500	33,400	38,500	29,500	29,500
Total Inflow (% of Average Annual)	5,687,000 ac-ft (79%)	14,418,000 ac-ft (87%)	16,711,000 ac-ft (91%)	14,291,000 ac-ft (82%)	16,298,000 ac-ft (88%)	17,606,000 ac-ft (87%)
Total Outflow (% of Average Annual)	4,848,000 ac-ft (73%)	13,579,000 ac-ft (87%)	15,169,000 ac-ft (87%)	14,115,000 ac-ft (82%)	16,100,000 ac-ft (89%)	17,465,000 ac-ft (87%)
Power Tunnel Entrance Invert Elevation	2095 ft-NGVD29 (65 feet above bottom)	1672 ft-NGVD29 (2 feet above bottom)	1525 ft-NGVD29 (110 feet above bottom)	1330 ft-NGVD29 (Bottom)	1229 ft-NGVD29 (2 feet above bottom)	1139.5 ft-NGVD29 (Bottom)

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

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

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

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

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

(5) Estimated Sediment Deposition through 2013 = Annual Sedimentation Rate (times) Years from "As-Built" to 2013.

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

4.1.1 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 72.4 MAF down to 67.7 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.

4.1.2 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 11.6 MAF and represents 16 percent of the total Mainstem System storage. This storage zone, which extends from 67.7 MAF down to 56.1 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 Mainstem 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.

4.1.3 CARRYOVER MULTIPLE USE ZONE

The Carryover Multiple Use Zone is the largest storage zone extending from 56.1 MAF down to 17.6 MAF, and represents 53 percent of the total Mainstem 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. During drought periods, the three smaller projects (i.e. Fort Randall, Big Bend, and Gavins Point) reservoir levels are maintained at the same elevation they would be at if runoff conditions were normal.

4.1.4 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 17.6 MAF and represents 25 percent of the total storage volume. The Permanent Pool Zone extends from 17.6 MAF down to 0 MAF.

4.2 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 seasons are the plains snowmelt and rainfall season 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, which extends from mid-December through February, can be a high-risk flood period. The highest average power generation period extends from mid-April to mid-October, while high peaking loads occur 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, 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.

4.3 OCCURRENCE OF “TWO-STORY” FISHERIES

Fort Peck, Garrison, and Oahe Reservoirs maintain “two-story” fisheries that are comprised of warmwater and coldwater species. The ability of the reservoirs to maintain “two-story” fisheries is due to their thermal stratification in the summer that allows coldwater fishery habitat to be maintained in the hypolimnion. Warmwater fish species present in the reservoirs that are recreationally important include walleye (*Sander vitreus*), sauger (*Sander canadensis*), northern pike (*Esox lucius*), smallmouth bass (*Micropterus dolomieu*), catfish (*Ictalurus spp.*), and yellow perch (*Perca flavescens*). Coldwater fish species of recreational importance are the Chinook salmon (*Oncorhynchus tshawytscha*) and lake trout (*Salvelinus namaycush*). Chinook salmon are maintained in all three reservoirs through regular stocking, and a naturally-reproducing lake trout fishery is present in Fort Peck Reservoir. Other coldwater species present are rainbow smelt (*Osmerus mordax*) and lake cisco/lake herring (*Coregonus artedi*). Both these species are important forage fish that are utilized extensively by all recreational fish species in the respective reservoirs. Maintaining healthy populations of these coldwater forage fish is important to maintaining the recreational fisheries in the three reservoirs.

The occurrence of coldwater fishery habitat in Fort Peck, Garrison, and Oahe Reservoirs is directly dependent on each reservoir’s annual thermal regime. Early in the winter ice-cover period, the entire reservoir volume will be supportive of coldwater fishery habitat. As the winter ice-cover period continues, lower dissolved oxygen concentrations will occur near the bottom as organic matter decomposes and reservoir mixing is prevented by ice cover. As dissolved oxygen concentrations in the near-bottom water fall below 5 mg/L, coldwater fishery habitat will not be supported. During the spring isothermal period (spring turnover), water temperatures and dissolved oxygen levels in the entire reservoir volume will be supportive of coldwater fishery habitat. During the early-summer warming period, the epilimnion will become non-supportive of coldwater fishery habitat. During mid-summer when the reservoirs are experiencing maximum thermal stratification, water temperatures will only be supportive of coldwater fishery habitat in the hypolimnion. Theoretically, coldwater fishery habitat should remain stable during this period unless degradation of dissolved oxygen concentrations near the reservoir bottom becomes non-supportive of coldwater fishery habitat. The most crucial period for the support of coldwater fishery habitat in the three reservoirs is when they begin to cool in late summer. Coldwater fishery habitat is reduced as convective cooling and wind-induced mixing of the epilimnion forces the thermocline deeper. As the thermocline moves deeper, the volume of the colder hypolimnion will continue to decrease while the expanding epilimnion may not yet be cold enough to be supportive of coldwater fishery habitat. At the same time, dissolved oxygen levels in the hypolimnion are approaching their maximum degradation and dissolved oxygen concentrations below 5 mg/L are moving upward from the reservoir bottom; pinching off coldwater fishery habitat from below. This situation will continue to worsen until the epilimnion cools enough to be supportive of coldwater fishery habitat. When fall turnover occurs, dissolved oxygen concentrations at all depths will be near saturation and supportive of coldwater fishery habitat. However, depending on the conditions of the reservoir, the isothermal temperature at the beginning of fall turnover may not be supportive of coldwater fishery habitat. This situation will continue to occur until the isothermal temperature cools to a suitable temperature, at which time the entire reservoir volume will be supportive of coldwater fishery habitat.

5 FORT PECK PROJECT

(Note: Referenced Plates are located at the end of the chapter in which they are referenced.)

5.1 BACKGROUND INFORMATION

5.1.1 PROJECT OVERVIEW

Fort Peck Dam is located on the Missouri River at river mile (RM) 1771.5 in northeastern Montana, 17 miles southeast of Glasgow, MT. The closing of Fort Peck Dam in 1937 resulted in the formation of Fort Peck Reservoir (Fort Peck Lake). When full, the reservoir is 134 miles long, covers 246,000 acres, and has 1,520 miles of shoreline. Table 5-1 summarizes how the surface area, volume, mean depth, and retention time of Fort Peck Lake vary with pool elevations. The major inflow to Fort Peck Lake is the Missouri River with minor inflows coming from the Musselshell River and Big Dry Creek. Water discharged through Fort Peck Dam for power production is withdrawn from Fort Peck Lake at elevation 2095 ft-NGVD29 – approximately 65 feet above the reservoir bottom. Figure 5-1 provides a schematic drawing of the outlet works at Fort Peck Dam.

Table 5-1. Surface area, volume, mean depth, and retention time of Fort Peck Lake at different pool elevations based on 2007 bathymetric survey.

Pool Elevation (Feet-NGVD29)	Surface Area (Acres)	Volume (Acre-Feet)	Mean Depth (Feet)*	Retention Time (Years)**
2250	245,405	18,462,840	75.2	2.78
2245	237,605	17,253,500	72.6	2.60
2240	225,065	16,094,980	71.5	2.42
2235	213,025	15,000,180	70.4	2.26
2230	201,130	13,964,500	69.4	2.10
2225	188,765	12,991,390	68.8	1.96
2220	180,590	12,069,610	66.8	1.82
2215	171,930	11,188,080	65.1	1.68
2210	163,400	10,349,820	63.3	1.56
2205	154,773	9,554,578	61.7	1.44
2200	146,595	8,801,156	60.0	1.32
2195	138,081	8,090,417	58.6	1.22
2190	132,175	7,415,889	56.1	1.12
2185	126,146	6,769,319	53.7	1.02
2180	118,608	6,156,918	51.9	0.92
2175	111,285	5,582,093	50.2	0.84
2170	103,394	5,045,002	48.8	0.76
2165	95,316	4,549,151	47.7	0.68
2160	89,461	4,087,903	45.7	0.62

Average Annual Inflow (1967 through 2015) = 7.238 Million Acre-Feet
Average Annual Outflow: (1967 through 2015) = 6.645 Million Acre-Feet
* Mean Depth = Volume ÷ Surface Area.
** Retention Time = Volume ÷ Average Annual Outflow.
Note: Exclusive Flood Control Zone (elev. 2250-2246 ft-NGVD29), Annual Flood Control and Multiple Use Zone (elev. 2246-2234 ft-NGVD29), Carryover Multiple Use Zone (elev. 2234-2160 ft-NGVD29), and Permanent Pool Zone (elev. 2160-2030 ft-NGVD29). All elevations are in the NGVD 29 datum.

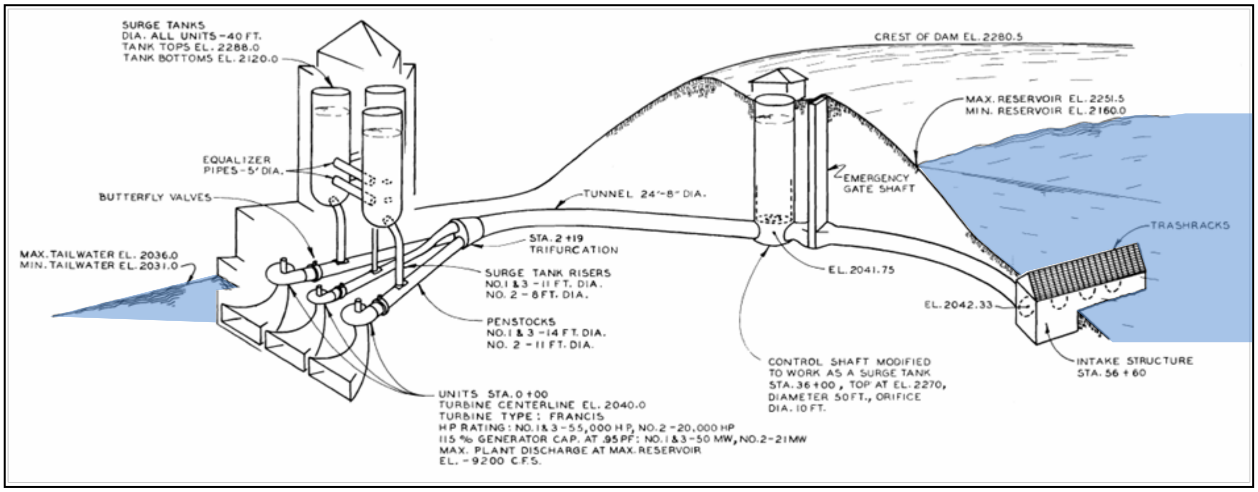


Figure 5-1. **S**chematic drawing of the outlet works at Fort Peck Dam.

The Fort Peck Project was 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, pallid sturgeon (*Scaphirhynchus albus*), occurs within the project area. The reservoir is used as a water supply by the town of Fort Peck, MT (RM1772 – penstock) and by individual cabins in the area. Fort Peck Lake is an important recreational resource and a major visitor destination in Montana.

Drought conditions in the western United States during the first decade of the 21th century lead to an appreciable drawdown of Fort Peck Lake. A historic low pool elevation of 2196.2 ft-NGVD29 was recorded in March 2007. Drought conditions broke at the end of the decade with the occurrence of above normal precipitation, and Fort Peck Lake recovered to normal pool elevations in 2010. Excessive runoff in 2011 raised the pool elevation of Fort Peck Lake into the Exclusive Flood Control Zone from May to October, with a period-of-record maximum pool elevation of 2252.3 ft-NGVD29 occurring in June. The recorded pool elevation at Fort Peck Lake at the end of December 2015 was 2234.3 ft-NGVD29; 0.3 feet above the Carryover Multiple Use Zone upper elevation of 2234 ft-NGVD29. Figure 5-2 plots the midnight pool elevation of Fort Peck Lake and the mean daily discharge of Fort Peck Dam over the 5-year period 2011 through 2015. The extreme discharges in 2011 reflect additional releases made through the spillway to manage the historic inflows during 2011.

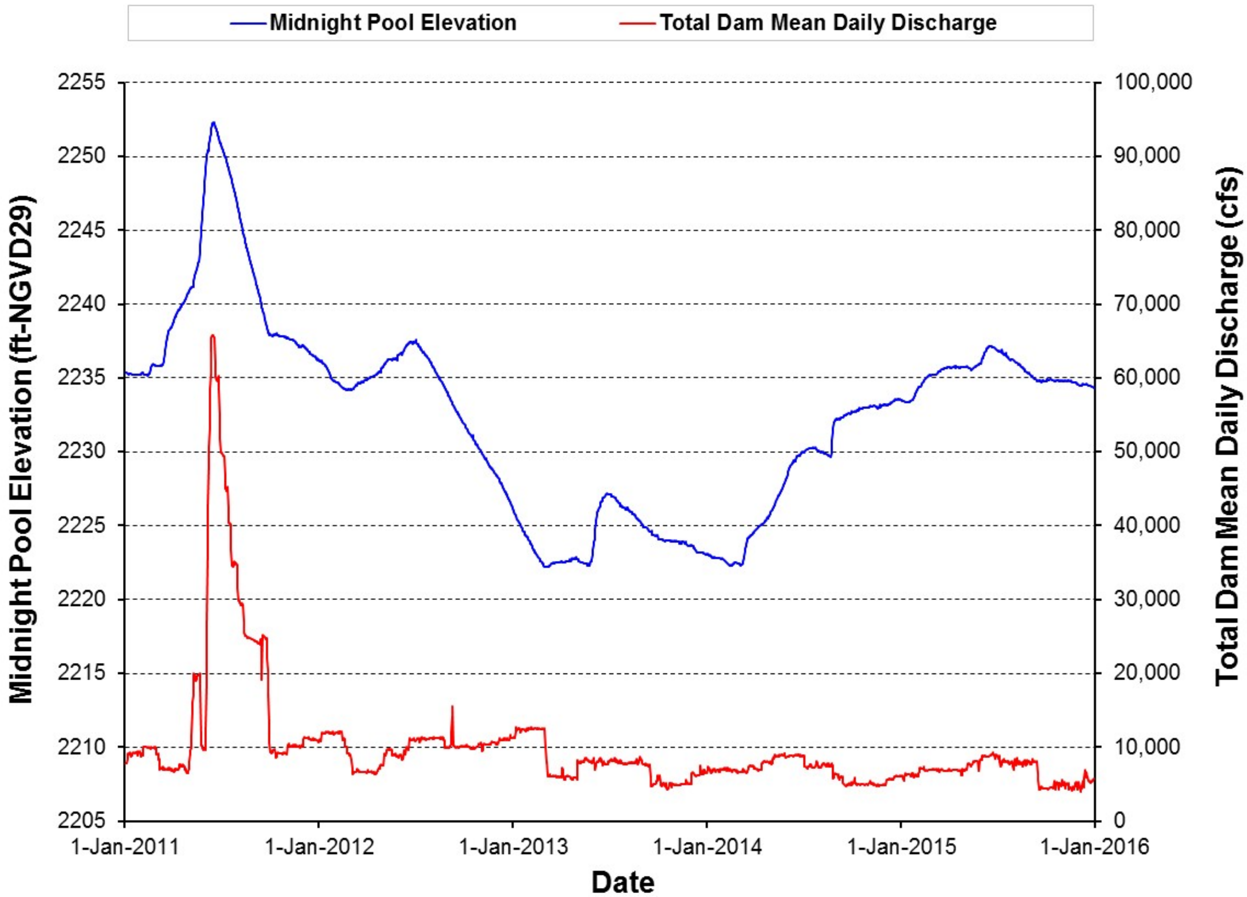


Figure 5-2. Fort Peck Lake midnight pool elevation and the total mean daily discharge of Fort Peck Dam over the 5-year period 2011 through 2015.

5.1.2 WATER QUALITY STANDARDS CLASSIFICATIONS AND SECTION 303(D) LISTINGS

5.1.2.1 <u>Fort Peck Lake</u>

The State of Montana has assigned Fort Peck Lake a B-3 classification in the State's water quality standards. As such, the reservoir is to be maintained suitable for drinking, culinary, and food processing purposes, after conventional treatment; bathing, swimming, and recreation; growth and propagation of non-salmonid fishes and associated aquatic life, waterfowl, and furbearers; and agricultural and industrial water supply. Fort Peck Lake is not assigned a coldwater fishery use by the State in their water quality standards; however, the reservoir supports a stocked salmon fishery and a naturally reproducing lake trout and lake cisco fishery – all are considered coldwater species. Since a coldwater fishery is currently supported in Fort Peck Lake it is seemingly an existing use and must be protected pursuant to the Federal Clean Water Act (CWA) and antidegradation policy provisions (40 CFR 131.3). Pursuant to Section 303(d) of the Federal CWA, Montana has placed Fort Peck Lake on the State's 2014 list of impaired waters citing impairment to the uses of aquatic life and drinking water. The impairment of the uses is attributed to the pollutants of lead and mercury. The identified sources of these pollutants are atmospheric deposition, historic bottom deposits (not sediment), and impacts from abandoned mine lands (inactive). The State of Montana has also issued a fish consumption advisory for Fort Peck Lake due to mercury concerns.

5.1.2.2 Missouri River Downstream of Fort Peck Dam

The Missouri River downstream of Fort Peck Dam has been designated a B-2 classification from the dam to the confluence of the Milk River, and a B-3 classification from the Milk River confluence to the Montana/North Dakota state line (Montana water quality standards). Both B-2 and B-3 waters are to be maintained suitable for drinking, culinary, and food processing purposes, after conventional treatment; bathing, swimming, and recreation; waterfowl and furbearers; and agricultural and industrial water supply. In addition, B-2 waters are to maintain growth and marginal propagation of salmonid fishes and associated aquatic life, and B-3 waters are to maintain growth and propagation of non-salmonid fishes and associated aquatic life. The river is used as a water supply by several towns along the reach. Pursuant to Section 303(d) of the Federal Clean Water Act, Montana has placed the Missouri River downstream of Fort Peck Dam on the State's 2014 list of impaired waters citing impairment to aquatic lie. The coldwater aquatic life use from Fort Pect Dam to the Milk River is believed impaired due to alterations in stream-side or littoral vegetative cover, flow regime alterations, and water temperature. The source of the impairments is identified as impacts from hydrostructure flow regulation/modification. The warmwater aquatic life use from the Milk River to the Popular River is believed impaired due to alterations in stream-side or littoral vegetative cover, flow regime alterations, and water temperature. The sources of the impairments are identified as impacts from hydrostructure flow regulation/modification and loss of riparian habitat. The warmwater aquatic life use from the Popular River to the North Dakota border is believed impaired due to flow regime alterations and water temperature. The sources of the impairments are identified as dam or impoundment and impacts from hydrostructure flow regulation/modification. No fish consumption advisory has been issued for the Missouri River downstream of Fort Peck Dam by the State of Montana.

The Assiniboine and Sioux Tribes of the Fort Peck Indian Reservation have developed water quality standards, approved by the U.S. Environmental Protection Agency, that are applicable to their tribal lands. This includes an area on the north side of the Missouri River downstream of Fort Peck Dam from the Milk River to Big Muddy Creek. The tribal water quality standards applicable to this reach of the Missouri River are comparable to the State of Montana's water quality standards.

5.1.3 WATER QUALITY FOR THE ENHANCEMENT OF PALLID STURGEON POPULATIONS IN THE MISSOURI RIVER DOWNSTREAM OF FORT PECK DAM

One of the few remaining populations of pallid sturgeon occurs in the Missouri River between Fort Peck Dam and the headwaters of Lake Sakakawea. Individuals in this population also inhabit the lower Yellowstone River. As such, this reach of the Missouri River has been identified as a priority recovery area for the pallid sturgeon (USFWS, 1993). It is believed that the building and operation of Fort Peck Dam and Reservoir have adversely impacted the pallid sturgeon population in this reach of the Missouri River by regulating flows, lowering water temperatures, reducing sediment and nutrient transport, and decreasing turbidity (USFWS, 2003).

Historically, the lower Missouri River in Montana was a turbid, warmwater environment with seasonally fluctuating flows. The sediment and turbidity of the water through these cycles contributed significantly to the evolution of the pallid sturgeon. The fish adapted to highly turbid and low visibility environments by physiologically evolving to enhance their ability to capture prey and avoid capture as juveniles and larvae in this low visibility environment. It is also believed that the pallid sturgeon adapted by developing spawning cues based on historical conditions in the river. The fish requires a spawning cue of suitable magnitude, duration, and timing to complete this life cycle element. It is believed that increasing flow and water temperature in the late spring is a primary factor for pallid sturgeon to initiate spawning.

Water temperature is believed to be a controlling factor on the pallid sturgeon in this reach of the Missouri River in regards to spawning cues and larval survival during the summer. Because the Fort Peck powerplant has a deepwater withdrawal from Fort Peck Lake, water temperature in the Missouri River downstream of the dam are appreciably colder than "pre-dam" conditions. A water temperature of around 18°C (64.4°F) is believed necessary to initiate a spawning response in pallid sturgeon. Colder water temperatures can affect larval pallid sturgeon survival and development, and likely adversely affects the production and availability of suitable forage (i.e. plankton and other invertebrate species) for the juvenile pallid sturgeon throughout the summer. With this in mind, a late-spring/early-summer water temperature of 18°C in the Missouri River at Frazer Rapids (approximately 25 miles downstream of Fort Peck Dam) has been identified as critical for pallid sturgeon spawning and recruitment in this reach of the river.

Fort Peck Dam and Reservoir is trapping sediment that historically moved down the Missouri River. It is also believed that the current colder water temperatures in the river downstream of the dam are likely suppressing production of plankton and other invertebrate organisms that contribute to turbidity of the water. The resulting clearer water is believed to adversely affect young pallid sturgeon by making them more vulnerable to sight-feeding predators and increasing competition for food by sight-adapted predators. In addition, adult fish may be adversely affected by the increased ability of prey to avoid capture in clearer water.

5.1.4 AMBIENT WATER QUALITY MONITORING

The District has monitored water quality conditions at the Fort Peck Project since the late 1970's. Water quality monitoring locations have included sites on Fort Peck Lake and on the inflow to and outflow from the reservoir. Figure 5-3 shows the location of sites at the Fort Peck Project that were regularly monitored by the District for water quality during the 5-year period 2011 through 2015. The near-dam location (i.e. site FTPLK1772A) has been continuously monitored since 1980.

5.2 WATER QUALITY IN FORT PECK LAKE

5.2.1 EXISTING WATER QUALITY CONDITIONS

5.2.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Water quality conditions that were monitored in Fort Peck Lake at sites FTPLK1772A, FTPLK1805DW, and FTPLKBDCA02 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 5-1, Plate 5-2, and Plate 5-3. A review of these results found no significant water quality concerns. On a few occasions measured dissolved oxygen concentrations were below the water quality standards criterion of 5 mg/L for the protection of Class B-3 warmwater aquatic life. The measured low dissolved oxygen concentrations occurred in the hypolimnion near the reservoir bottom during the latter part of the summer thermal stratification period. The lowest dissolved oxygen concentration measured was 0.6 mg/L and occurred at site FTPLK1805DW on 29-August-2012.

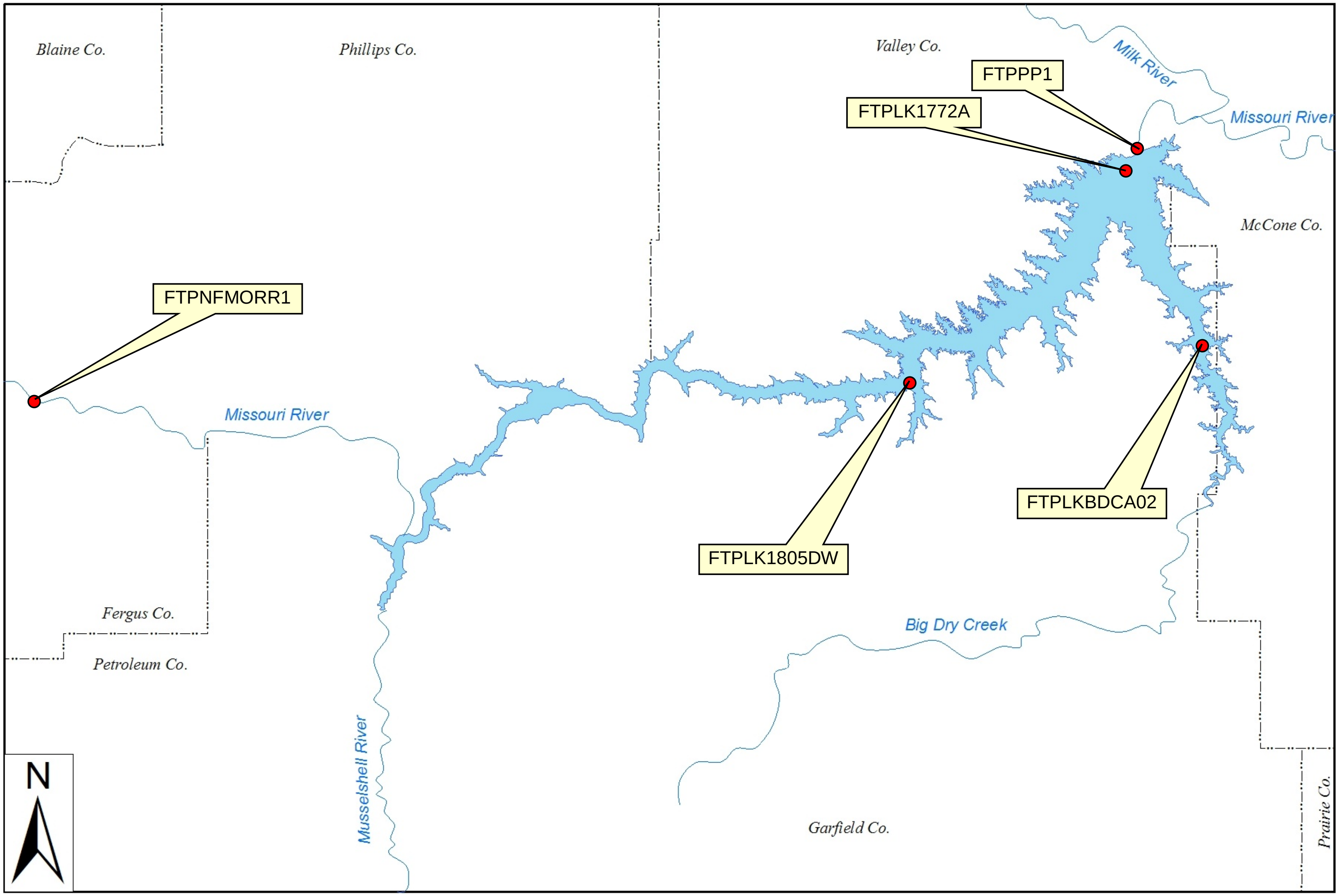


Figure 5-3. Location of sites where water quality monitoring was regularly conducted by the District at the Fort Peck Project during the 5-year period 2011 through 2015.

5.2.1.2 Summer Thermal Stratification and Dissolved Oxygen Conditions during 2015

5.2.1.2.1 Depth-Profile Plots

Depth-profile plots of temperature and dissolved oxygen measurements taken at sites FTPLK1772A, FTPLK1805DW, and FTPLKBDCA02 during 2015 are shown in Plate 5-4.

5.2.1.2.2 Longitudinal Contour Temperature Plots

Summer thermal stratification of Fort Peck Lake during 2015 is described by longitudinal temperature contour plots based on depth-profile temperature measurements taken during May, June, August, and September (Plate 5-5, Plate 5-6, Plate 5-7, and Plate 5-8). The contour plots were constructed along the Missouri River mainstem arm. As seen in the contour plots, temperatures in Fort Peck Lake vary longitudinally from the dam to the Missouri River inflow and vertically from the reservoir surface to the bottom. The near-surface water in the upstream reach of the reservoir warms up sooner in the spring than the near-surface water near the dam. By mid-summer a strong thermocline becomes established in the downstream reach of the reservoir, and the near-surface waters of the entire reservoir above the thermocline are a fairly uniform temperature. As the near-surface waters of the reservoir cool in the late summer, the thermocline moves deeper, and the wind-mixed upper waters are fairly uniform in temperature. The vertical variation in temperature is most prevalent in the deeper area of the reservoir towards the dam, where a strong thermocline becomes established during the summer. The shallower upper reaches of Fort Peck Lake do not exhibit much vertical variation of temperature during mid- to late summer, as wind action allows for complete mixing of the water column.

5.2.1.2.3 Longitudinal Contour Dissolved Oxygen Plots

Summer dissolved oxygen conditions in Fort Peck Lake during 2015 are described by the monthly longitudinal dissolved oxygen contour plots based on depth-profile temperature measurements taken in May, June, August, and September (Plate 5-9, Plate 5-10, Plate 5-11, and Plate 5-12). The contour plots were constructed along the Missouri River mainstem arm. As shown in the contour plots, dissolved oxygen conditions in Fort Peck Lake vary longitudinally from the dam to the reservoir's upstream reaches and vertically from the reservoir surface to the bottom. The occurrence of lower dissolved oxygen concentrations in the near-bottom water of the middle reaches of Fort Peck Lake is attributed to the increased organic loading in the transition zone of the reservoir and the lesser hypolimnetic volume available for assimilation of the oxygen demand. As this material decomposes, a "pool" of water with lower dissolved oxygen levels accumulates near the bottom in this area of the reservoir. Decomposition of autochthonous organic matter also occurs in the lacustrine zone and results in dissolved oxygen degradation as the summer progresses, although at a slower rate than what occurs in the transition zone. The recovery of near-bottom dissolved oxygen concentrations to saturation levels takes longer in the lacustrine zone nearer the dam because of the time needed for thermal stratification to breakdown and mixing within the water column to occur in the deeper water.

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

Paired near-surface and near-bottom water quality samples collected from Fort Peck Lake during the summer thermal stratification period were compared. Near-surface conditions were represented by samples collected within 2-meters of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site FTPLK1772A during the 5-year period 2011 through 2015. During the period a total of 19 paired samples were collected monthly from June through October. Box plots were constructed to display the distribution of the paired near-surface and near-bottom measurements for the following parameters: water temperature, dissolved oxygen, pH, alkalinity, total ammonia, and total phosphorus (Plate 5-13). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for water temperature, dissolved oxygen, pH, total ammonia, and total phosphorus. Parameters that were significantly lower in the near-bottom water of Fort Peck Lake included: water temperature ($p < 0.001$), dissolved oxygen ($p < 0.001$), and pH ($p < 0.001$). Parameters that were significantly higher in the near-bottom water included: total ammonia ($p < 0.05$) and total phosphorus ($p < 0.05$).

5.2.1.4 Reservoir Trophic Status

Trophic State Index (TSI) values for Fort Peck Lake were calculated from monitoring data collected during the 5-year period 2011 through 2015 (Table 5-2). The calculated TSI values indicate that the regions of the reservoir represented by the monitored sites are in a mesotrophic state.

Table 5-2. Mean Trophic State Index (TSI) values calculated for three sites on Fort Peck Lake based on monitoring conducted during the 5-year period 2011 through 2015.

Monitoring Site	Mean – TSI (Secchi Depth)	Mean – TSI (Total Phosphorus)	Mean – TSI (Chlorophyll)	Mean – TSI (Average)
FTPLK1772A	43	39	48	43
FTPLK1805DW	47	42	54	48
FTPLKBDCA02	43	39	48	43

Note: See Section 3.1.3 for discussion of TSI calculation.

5.2.1.5 Plankton Community

5.2.1.5.1 Phytoplankton

The relative abundance of phytoplankton, based on biovolume, in samples collected from Fort Peck Lake in early-June, late-July, and late-September 2015 is shown in Figure 5-4. Diatoms (Bacillariophyta), yellow-green algae (Chrysophyta), and cyptomonads (Chyptophyta) were the dominant phytoplankton group present in Fort Peck Lake during 2015. Cyanobacteria genera sampled during 2015 included: *Anabaena*, *Aphanizomenon, Chrococcus, Oscillatoria*, *Planktolyngbya, and Raphidiopsis.* No concentrations of the cyanobacteria toxin microcystin above 1 ug/L were monitored in Fort Peck Lake during the 5-year period 2011 through 2015 (Plate 1, Plate 2, and Plate 3).

5.2.1.5.2 Zooplankton

The zooplankton sampled in Fort Peck Lake during 2015 included three taxonomic groupings: Cladocerans, Copepods, and Rotifers. The relative abundance of these three taxonomic groupings in the zooplankton samples collected in 2015 is shown in Figure 5-5. Cladocerans and copepods dominated the zooplankton community in Fort Peck Lake in 2015.

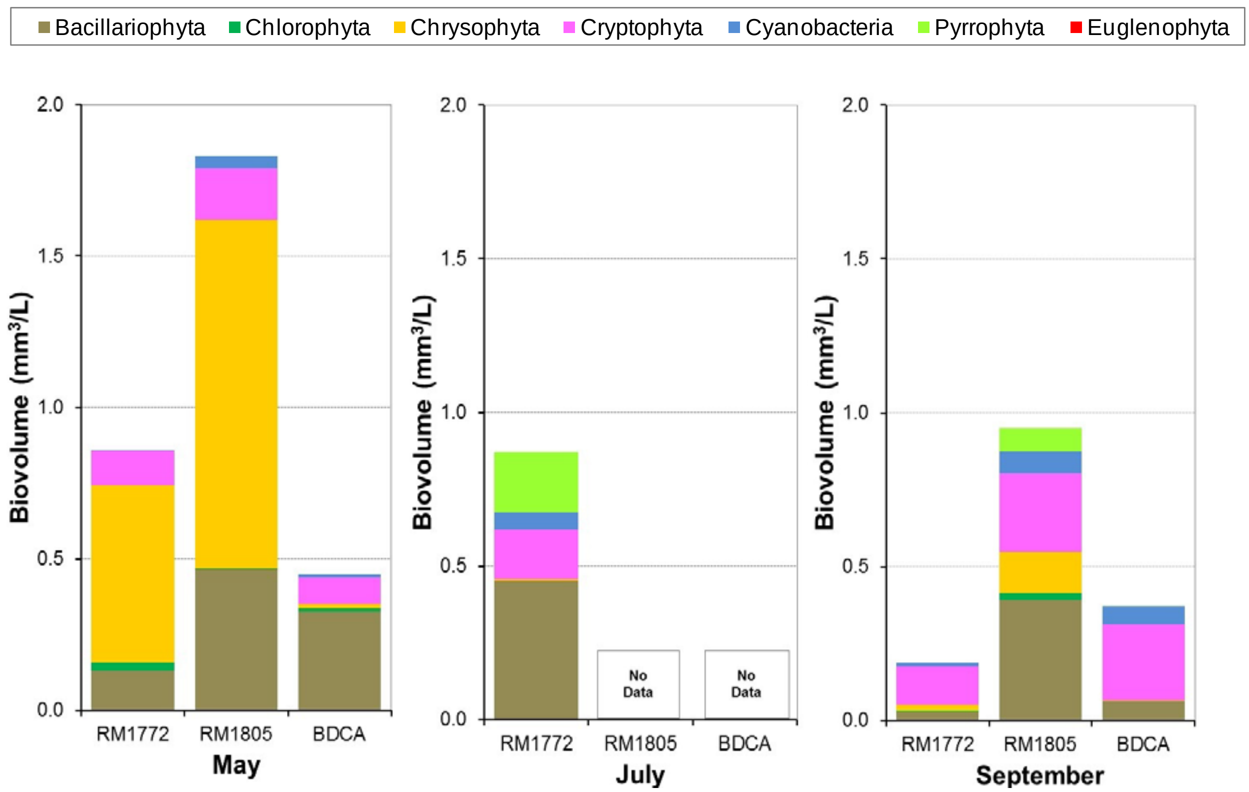


Figure 5-4. Relative abundance of phytoplankton in samples collected from Fort Peck Lake during 2015.

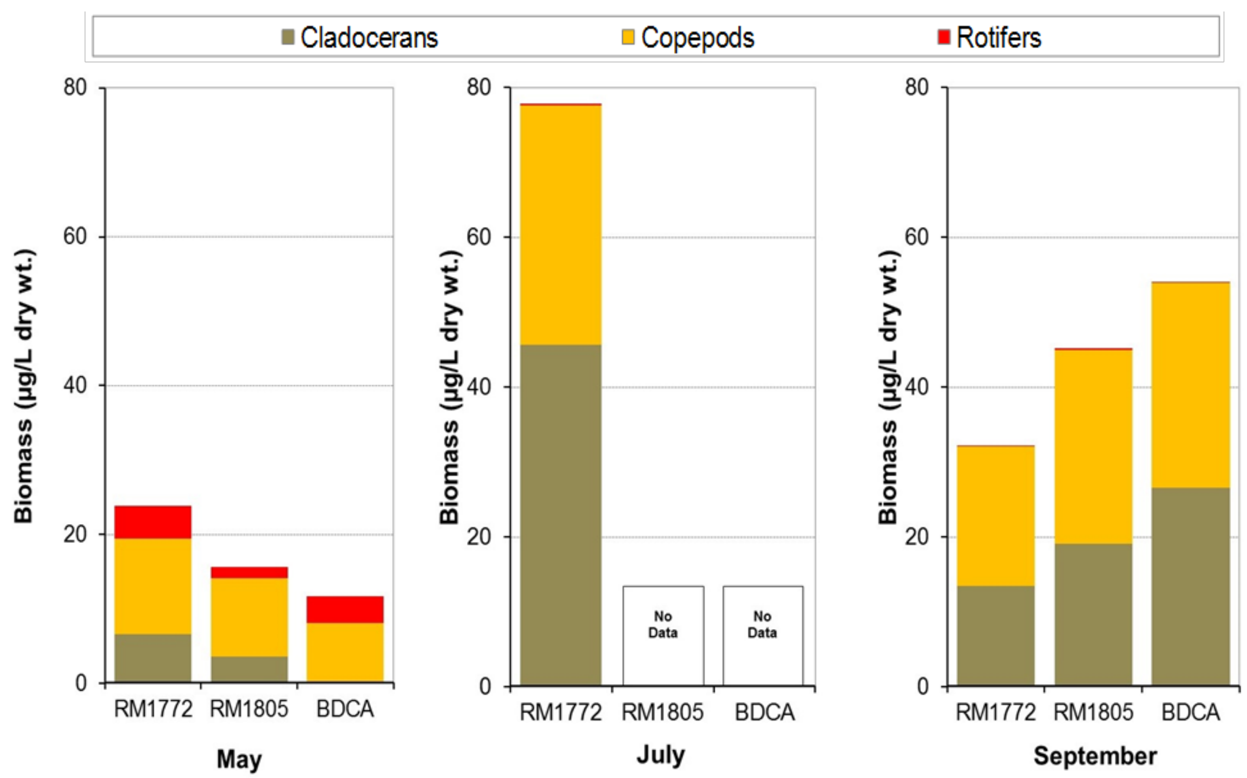


Figure 5-5. Relative abundance of zooplankton in samples collected from Fort Peck Lake during 2015.

5.2.2 WATER QUALITY TRENDS (1980 THROUGH 2015)

Water quality trends over the 36-year period of 1980 to 2015 were determined for Fort Peck Lake for Secchi depth, total phosphorus, chlorophyll a, and TSI (i.e. trophic status). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through September at the near-dam, ambient monitoring site (i.e. site FTPLK1772A). Plate 5-14 displays a scatter-plot of the collected data for the four parameters, a linear regression trend line, and the significance of the trend line (i.e. $\alpha = 0.05$). For the assessment period, Fort Peck Lake exhibited significant trends for Secchi depth (decreasing), chlorophyll *a* (increasing), and TSI (increasing). No significant trend was detected for total phosphorus. Over the 36-year period, the reservoir has generally remained in a mesotrophic state.

5.3 EXISTING WATER QUALITY CONDITIONS OF THE MISSOURI RIVER INFLOW TO FORT PECK LAKE

5.3.1 STATISTICAL SUMMARY AND COMPARISON TO APPLICABLE WATER QUALITY STANDARDS CRITERIA

The water quality conditions that were monitored in the Missouri River near Landusky, MT (i.e. site FTPNFMORR1) April through October during the 5-year period 2011 through 2015 are summarized in Plate 5-15 and Plate 5-16. A review of these results indicated no major water quality concerns. It is noted that the human health standard for arsenic was exceeded in four of the five samples collected. The human health standard for arsenic is derived from the maximum contaminant level from Montana's drinking water regulations and uses a bioconcentration factor of 44. Very high levels of total aluminum, iron and manganese were monitored. Although total aluminum levels were high, only 1 of 5 dissolved samples exceeded Montana's water quality standards for dissolved aluminum. Three of the five total iron samples exceeded the chronic criterion for aquatic life protection. Four of the total iron and one of the total manganese samples exceeded the secondary maximum contaminant level for aesthetics. The high levels of aluminum, iron, and manganese are believed to be a natural condition associated with the geology and soils of the region.

5.3.2 MISSOURI RIVER INFLOW NUTRIENT FLUX CONDITIONS

Nutrient flux rates for the Missouri River inflow to Fort Peck Lake over the 5-year period 2011 through 2015 were calculated based on near-surface water quality samples collected near Landusky, MT (i.e. site FTPNFMORR1) and the instantaneous flow conditions at the time of sample collection (Table 5-3). It must be recognized that the concentrations of particulate-associated constituents can vary from the river surface to its bottom because of the sinking of particulate matter and its potential transport nearer the river bottom. Since the instantaneous concentration of particulate-associated constituents (i.e. total phosphorus and total organic carbon) are likely higher nearer the river bottom, near-surface grab samples likely under estimate the "true" water-column composite concentration for these constituents. Thus, the flux rate given for total phosphorus in Table 5-3 should be considered a minimum estimate with the actual flux rate likely being higher. The maximum flux rates for all the constituents are believed to be attributed to higher nonpoint-source loadings during runoff conditions.

Table 5-3. Summary of nutrient flux rates (kg/sec) calculated for the Missouri River near Landusky, MT (i.e. site FTPNFMORR1) during April through September over the 5-year period 2011 through 2015.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	28	28	28	28	28	28	28
Mean	10,596	0.0076	0.2127	0.0497	0.0750	0.0066	0.9262
Median	8,195	n.d.	0.1339	0.0060	0.0238	0.0026	0.6504
Minimum	5,010	n.d.	0.0181	n.d.	n.d.	n.d.	0.2277
Maximum	34,899	0.0417	1.0093	0.3953	0.5881	0.0395	3.7552

Note: Nondetectable values set to 0 for flux calculations.

5.3.3 CONTINUOUS WATER TEMPERATURE MONITORING OF THE MISSOURI RIVER AT USGS GAGE SITE 06115200 NEAR LANDUSKY, MONTANA

Through an agreement with the U.S. Geological Survey (USGS), a water temperature probe was added to the USGS's gage (06115200) on the Missouri River near Landusky, Montana (i.e. site FTPNFMORR1) in October 2004. Plate 5-17 shows plots of mean daily water temperature and streamflow for 2015.

5.4 WATER QUALITY AT THE FORT PECK POWERPLANT

5.4.1 STATISTICAL SUMMARY AND COMPARISON TO APPLICABLE WATER QUALITY STANDARDS CRITERIA

Plate 5-18 and Plate 5-19 summarize the water quality conditions that were monitored from water discharged through Fort Peck Dam during the 5-year period of 2011 through 2015. A review of these results indicated only one possible water quality concern regarding dissolved oxygen. The 1-day dissolved oxygen minimum criterion of 8.0 mg/L for the protection of coldwater B-2 early life stages was not met for 29 percent of the dissolved oxygen measurements. The 8.0 mg/L criterion is a water column concentration recommended to achieve an in-gravel dissolved oxygen concentrations of 5.0 mg/L. For species that have early life stages exposed directly to the water column, the criterion is 5.0 mg/L. The B-2 classification of the Missouri River downstream of Fort Peck Dam only extends to the confluence of the Milk River, a distance of approximately 10 miles. Given the coldwater species and recruitment present, the 5.0 mg/L water column dissolved criterion may be appropriate for this reach. The dissolved oxygen measurements below 8.0 mg/L tended to occur in later summer when the effects on early life stages are likely to be reduced. On one occasion (25-Sep-2012), the dissolved oxygen concentration measured in the Fort Peck powerplant was below 5 mg/L. In response, additional water quality monitoring was done in the Fort Peck Dam tailwaters to assess dissolved oxygen conditions in the Missouri River immediately downstream of Fort Peck Dam (see Section 5.5.2 for a summary of the monitoring results).

5.4.2 TEMPERATURE, DISSOLVED OXYGEN, AND DAM DISCHARGE TIME-SERIES PLOTS

Hourly temperature, dissolved oxygen, and dam discharge recorded at the Fort Peck powerplant during 2015 were used to construct time-series plots (Plate 5-20 and Plate 5-21). Water temperatures showed seasonal warming and cooling through each calendar year. Dissolved oxygen levels remained relatively high and stable during the winter, steadily declined through the spring and summer, and steadily increased during the fall. The lowest dissolved oxygen levels occurred during the late summer/early fall period. The higher winter, declining spring/summer, and increasing fall dissolved oxygen concentrations are attributed to decreasing dissolved oxygen solubility with warmer water temperatures. The decreasing dissolved oxygen in the July to September period is attributed to ongoing degradation of dissolved oxygen in the hypolimnion of Fort Peck Lake as the summer progressed. Water is withdrawn from the reservoir into the dam's power tunnels from below the thermocline at an elevation 65 feet above the reservoir bottom. There appeared to be little correlation between discharge rates and measured water temperature and dissolved oxygen concentrations.

5.4.3 NUTRIENT FLUX CONDITIONS OF THE FORT PECK POWERPLANT DISCHARGE TO THE MISSOURI RIVER

Nutrient flux rates for the Fort Peck powerplant discharge to the Missouri River over the 5-year period 2011 through 2015 were calculated based on samples taken from the Fort Peck powerplant (i.e. site FTPPP1) and the powerplant discharge at the time of sample collection (Table 5-4). During 2011 significant water was discharged via the spillway for flood management; thus, the nutrient flux rates calculated for 2011 are not indicative of the total nutrient flux from Fort Peck Dam discharges as the spillway flows are not considered. Only minor spillway releases from Fort Peck Dam occurred in 2012 and none occurred in 2013, 2014, 2015. The water quality samples collected in the powerplant are taken from the raw water supply line and are believed to be unbiased regarding particulate-associated constituents. Therefore, the flux rates calculated for the Fort Peck powerplant discharge give an unbiased estimate of the flux rates for all the constituents, including total phosphorus. The maximum flux rates for all the constituents are believed to be attributed to higher powerplant discharges.

Table 5-4. Summary of nutrient flux rates (kg/sec) calculated for the Fort Peck powerplant discharge to the Missouri River (i.e. site FTPPP1) during January through December over the 5-year period 2011 through 2015.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	39	39	39	39	39	39	39
Mean	8,350	0.0030	0.0698	0.0105	0.0032	0.0022	0.8082
Median	7,914	n.d.	0.0679	0.0040	0.0022	n.d.	0.7511
Minimum	4,247	n.d.	n.d.	n.d.	n.d.	n.d.	0.2994
Maximum	13,491	0.0259	0.1521	0.0539	0.0274	0.0274	1.9427

Note: Nondetectable values set to 0 for flux calculations.

5.5 WATER QUALITY IN THE MISSOURI RIVER DOWNSTREAM FROM FORT PECK DAM

5.5.1 EXISTING WATER QUALITY CONDITIONS

Daily water temperatures have been monitored in the Missouri River downstream of Fort Peck Dam over the past several years as part of a multi-agency effort to study the pallid sturgeon population in the Missouri and Yellowstone Rivers. Three sites on the Missouri River that have been monitored by the USGS under this effort are the Fort Peck Dam tailwaters (RM1765), Nickels Ferry (RM1760), and Frazer Rapids (RM1748).

The water temperatures monitored at the Fort Peck Dam powerplant during 2015 were plotted with the Missouri River water temperatures monitored by the USGS. Plate 5-22 plots mean daily water temperatures monitored at the sites and the mean daily discharge of Fort Peck Dam from April through October during 2015.

During 2015, water temperatures monitored at the Fort Peck Dam powerplant from June through August were generally 1°C to 2°C cooler than the water temperatures monitored in the Missouri River at the Fort Peck Dam tailwaters site, and 3°C to 5°C cooler than the water temperatures monitored in the Missouri River at Nickels and Frazer Rapids. Around 1-October, water temperatures monitored at the Fort Peck Dam powerplant exhibited warming. This is attributed to the cooling and downward expansion of the epilimnion in Fort Peck Lake as “fall turnover” of the reservoir approached, and resulted in warmer epilimnetic warmer being captured in the reservoir and discharged through the Fort Peck powerplant. After about 1-October, water temperatures monitored at the Fort Peck powerplant were generally warmer than those monitored in the Missouri River downstream of Fort Peck Dam. This is attributed to the slower heat loss from Fort Peck Lake than the Missouri River in early fall. Warmer water drawn from Fort Peck Lake is discharged through the Fort Peck powerplant that cools as it flows down the Missouri River. It is during this time period that the relationship of warmer water temperatures occurring in the Missouri River at Frazer Rapids and cooler water temperatures occurring at the Fort Peck Dam powerplant reverses.

5.5.2 DISSOLVED OXYGEN CONDITIONS MONITORED IN THE FORT PECK DAM TAILWATERS OF THE MISSOURI RIVER IN 2012

An assessment of low dissolved oxygen conditions that were monitored in the tailwaters of Fort Peck Dam during late-September 2012 is available in the Final Situation Report, “Low Dissolved Oxygen Levels in Discharges from Fort Peck Dam” (USACE, 2012).

Plate 5-1. Summary of monthly (May through September) water quality conditions monitored in Fort Peck Lake near Fort Peck Dam (Site FTPLK1772A) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	25	2234.5	2234.8	2222.4	2251.8	-----	-----	-----
Water Temperature (°C)	0.1	1,494	11.6	10.8	4.0	25.7	26.7[1,2]	0	0%
Dissolved Oxygen (mg/L)	0.1	1,494	8.8	8.7	1.6	12.7	5.0[1,3]	70	5%
Dissolved Oxygen (% Sat.)	0.1	1,494	82.9	88.7	15.2	122.9	-----	-----	-----
Specific Conductance (uS/cm)	1	1,494	720	726	553	815	-----	-----	-----
pH (S.U.)	0.1	1,494	8.1	8.1	7.3	8.6	6.5[1,3], 9.0[1,2]	0	0%
Turbidity (NTUs)	1	1,491	-----	n.d.	n.d.	31	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	1,494	345	357	156	539	-----	-----	-----
Secchi Depth (M)	0.02	22	3.50	3.35	2.03	5.49	-----	-----	-----
Alkalinity, Total (mg/L)	7	47	155	156	146	160	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	47	3.4	3.2	1.7	13.1	-----	-----	-----
Chloride (mg/L)	1	28	9	9	8	10	-----	-----	-----
Chlorophyll *a* (ug/L) – Field Measured	1	24	4	2	n.d.	27	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	24	-----	3	n.d.	9	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	47	16	16	n.d.	27	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	47	526	530	326	732	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	47	-----	n.d.	n.d.	0.07	4.6 [1,2,4], 2.0[1,4,5]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	47	0.3	0.3	n.d.	2.0	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	47	-----	n.d.	n.d.	0.17	-----	-----	-----
Nitrogen, Total (mg/L)	0.1	47	0.3	0.3	0.1	2.0	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	47	-----	n.d.	n.d.	0.04	-----	-----	-----
Phosphorus, Orthophosphate (mg/L)	0.02	47	-----	n.d.	n.d.	0.04	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	47	-----	n.d.	n.d.	0.09	-----	-----	-----
Sulfate (mg/L)	1	47	213	213	131	262	-----	-----	-----
Suspended Solids, Total (mg/L)	4	47	-----	n.d.	n.d.	70	-----	-----	-----
Microcystin, Extracellular (ug/L)	0.1	24	-----	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 microcystin are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.

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

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

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

(1) Criteria for B-3 classified waters.
(2) Daily maximum criterion (monitoring results directly comparable to criterion).
(3) Daily minimum criterion (monitoring results directly comparable to criterion).
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
(5) 30-day average criterion (monitoring results not directly comparable to criterion).

Plate 5-2. Summary of monthly (May through September) water quality conditions monitored in Fort Peck Lake near Hell Creek Bay (site FTPLK1805DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	22	2233.7	2234.4	2222.4	2251.8	-----	-----	-----
Water Temperature (°C)	0.1	717	14.2	14.1	4.9	25.1	26.7[1,2]	0	0%
Dissolved Oxygen (mg/L)	0.1	717	8.4	8.7	0.6	13.4	5.0[1,3]	58	8%
Dissolved Oxygen (% Sat.)	0.1	717	84.4	90.2	5.9	152.6	-----	-----	-----
Specific Conductance (uS/cm)	1	717	729	718	577	1149	-----	-----	-----
pH (S.U.)	0.1	717	8.1	8.2	6.7	8.8	6.5[1,3], 9.0[1,2]	0	0%
Turbidity (NTUs)	1	716	-----	1	n.d.	67	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	717	329	337	116	484	-----	-----	-----
Secchi Depth (M)	0.02	22	2.55	2.51	1.27	4.57	-----	-----	-----
Alkalinity, Total (mg/L)	7	44	152	152	134	160	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	44	3.2	3.1	1.8	5.6	-----	-----	-----
Chloride (mg/L)	1	26	9	9	8	11	-----	-----	-----
Chlorophyll *a* (ug/L) – Field Measured	1	716	9	4	n.d.	103	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	22	8	5	1	45	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	44	22	19	12	57	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	44	549	529	372	800	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	44	-----	n.d.	n.d.	0.11	5.7 [1,2,4], 1.7[1,4,5]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	44	0.3	0.3	n.d.	0.7	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	44	-----	0.06	n.d.	0.30	-----	-----	-----
Nitrogen, Total (mg/L)	0.1	44	0.4	0.4	n.d.	0.9	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	44	-----	n.d.	n.d.	0.03	-----	-----	-----
Phosphorus, Orthophosphate (mg/L)	0.02	44	-----	n.d.	n.d.	0.02			
Phosphorus, Total (mg/L)	0.02	44	-----	0.02	n.d.	0.08	-----	-----	-----
Sulfate (mg/L)	1	44	218	212	143	438	-----	-----	-----
Suspended Solids, Total (mg/L)	4	44	-----	n.d.	n.d.	46	-----	-----	-----
Microcystin (ug/L)	0.1	22	-----	n.d.	n.d.	0.1	-----	-----	-----

n.d. = Not detected.

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

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

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

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

- (1) Criteria for B-3 classified waters.
- (2) Daily maximum criterion (monitoring results directly comparable to criterion).
- (3) Daily minimum criterion (monitoring results directly comparable to criterion).
- (4) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (5) 30-day average criterion (monitoring results not directly comparable to criterion).

Plate 5-3. Summary of monthly (May through September) water quality conditions monitored in Fort Peck Lake near Rock Creek Bay (site FTPLKBDCA02) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	21	2233.7	2234.1	2222.4	2251.8	-----	-----	-----
Water Temperature (°C)	0.1	526	14.9	15.8	5.8	23.6	26.7[1,2]	0	0%
Dissolved Oxygen (mg/L)	0.1	526	9.0	8.9	3.4	11.8	5.0[1,3]	9	2%
Dissolved Oxygen (% Sat.)	0.1	526	92.1	94.8	33.5	111.5	-----	-----	-----
Specific Conductance (uS/cm)	1	526	721	736	544	794	-----	-----	-----
pH (S.U.)	0.1	526	8.3	8.3	7.5	9.0	6.5[1,3], 9.0[1,2]	0	0%
Turbidity (NTUs)	1	523	-----	n.d.	n.d.	49	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	526	327	340	113	494	-----	-----	-----
Secchi Depth (M)	0.02	21	3.24	3.35	1.78	4.42	-----	-----	-----
Alkalinity, Total (mg/L)	7	42	156	157	147	164	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	42	3.2	3.2	1.7	4.3	-----	-----	-----
Chloride (mg/L)	1	24	9	9	8	10	-----	-----	-----
Chlorophyll *a* (ug/L) – Field Measured	1	524	4	3	n.d.	17	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	21	3	3	n.d.	6	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	42	16	16	n.d.	25	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	52	540	526	338	746	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	42	-----	n.d.	n.d.	0.08	4.7 [1,2,4], 1.3[1,4,5]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	42	0.3	0.3	n.d.	0.7	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	42	-----	n.d.	n.d.	0.10	-----	-----	-----
Nitrogen, Total (mg/L)	0.1	42	0.3	0.3	n.d.	0.7	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	42	-----	n.d.	n.d.	0.02	-----	-----	-----
Phosphorus, Orthophosphate	0.02	42	-----	n.d.	n.d.	0.02	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	42	-----	n.d.	n.d.	0.33	-----	-----	-----
Sulfate (mg/L)	1	42	215	218	126	249	-----	-----	-----
Suspended Solids, Total (mg/L)	4	42	-----	n.d.	n.d.	20	-----	-----	-----
Microcystin (ug/L)	0.1	21	-----	n.d.	n.d.	0.1	-----	-----	-----

n.d. = Not detected.

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

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

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

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

- (1) Criteria for B-3 classified waters.
- (2) Daily maximum criterion (monitoring results directly comparable to criterion).
- (3) Daily minimum criterion (monitoring results directly comparable to criterion).
- (4) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (5) 30-day average criterion (monitoring results not directly comparable to criterion).

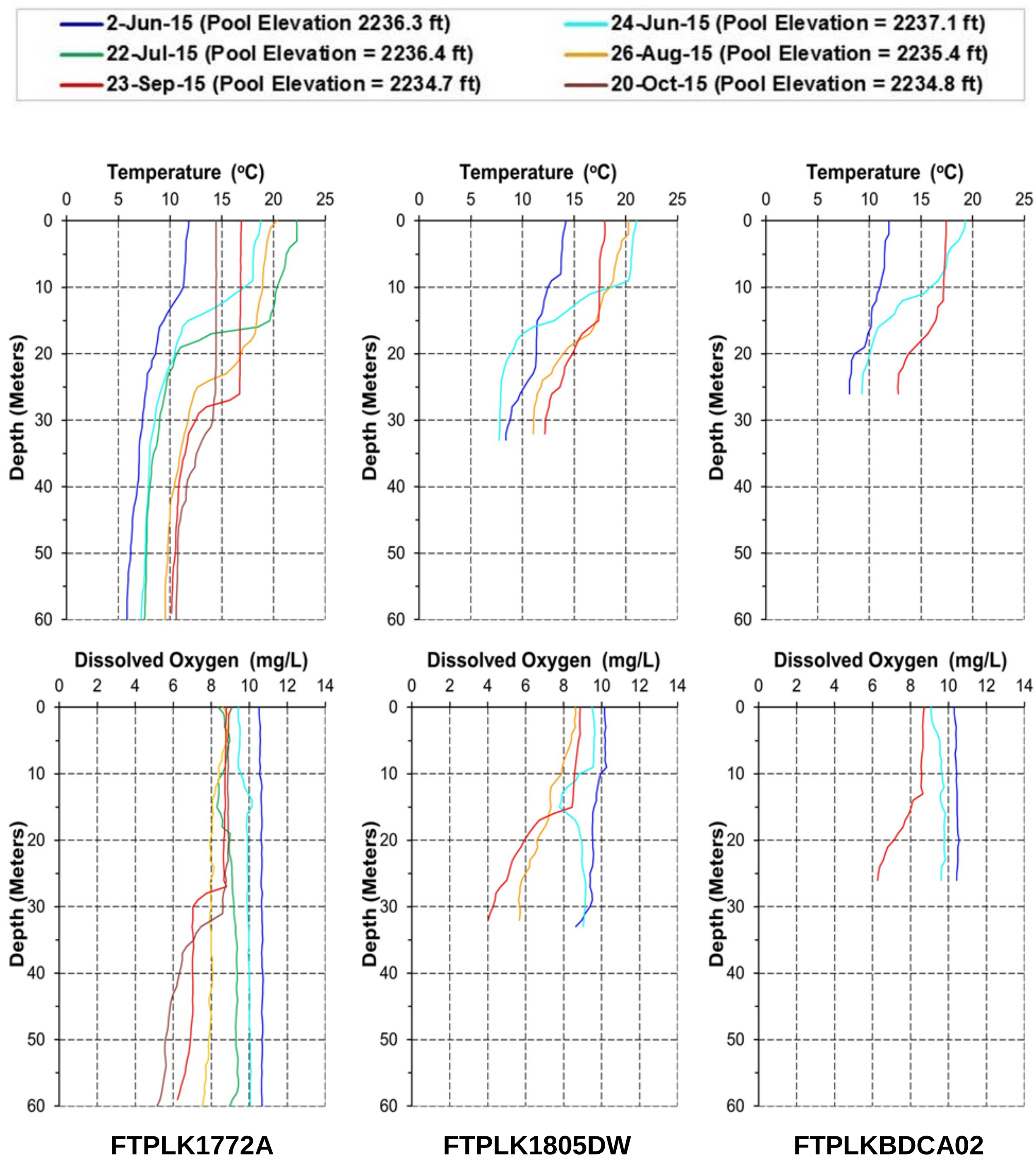


Plate 5-4. Depth-profile plots of temperature and dissolved oxygen conditions of Fort Peck Lake measured at sites FTPLK1772A, FTPLK1805DW, and FTPLKBDCA02 during 2015**.**

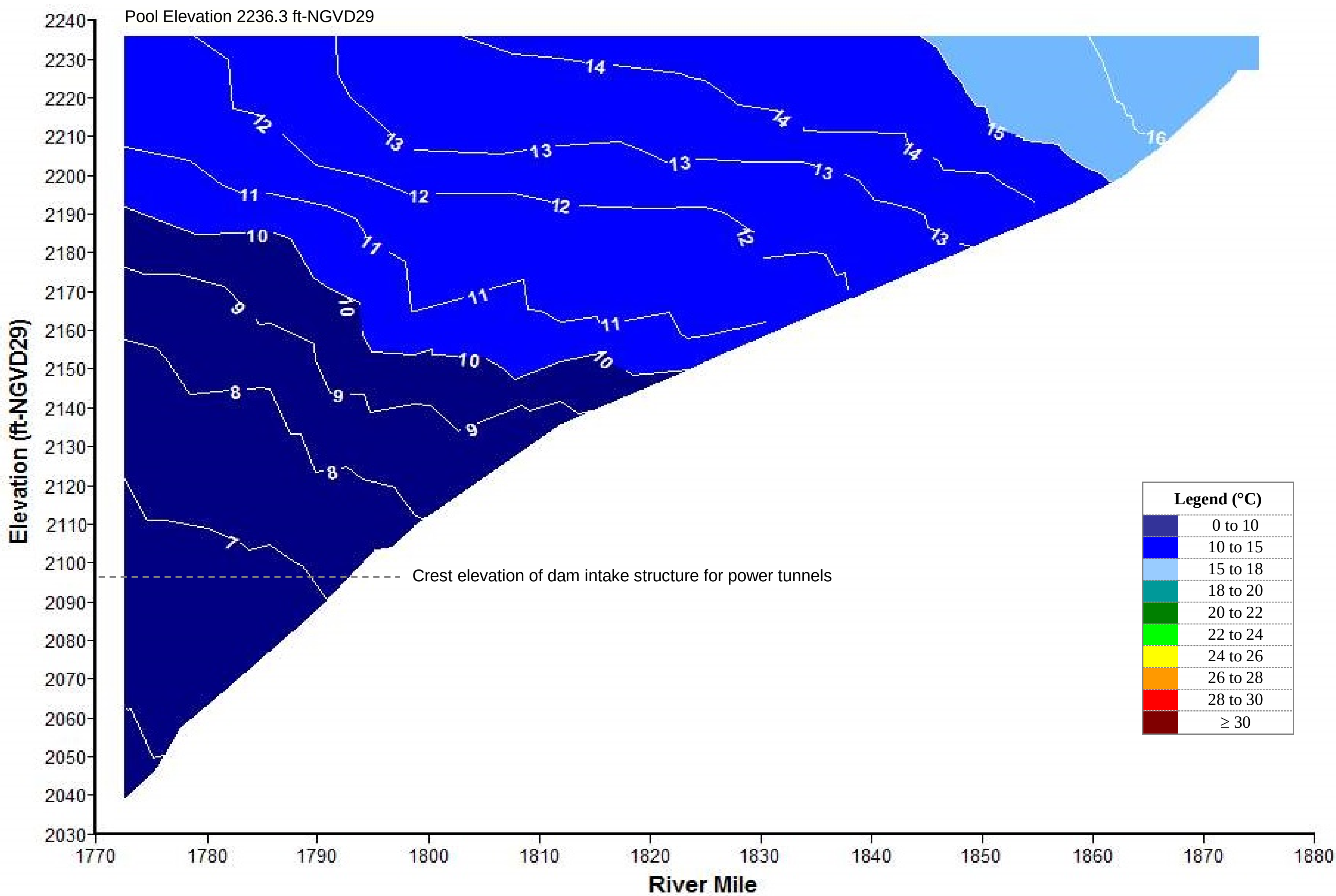


Plate 5-5. Longitudinal water temperature (°C) contour plot of Fort Peck Lake (Missouri River Arm) based on depth-profile water temperatures measured at sites FTPLK1772A, FTPLK1805DW, and FTPNFMORR1 on 2-Jun-2015.

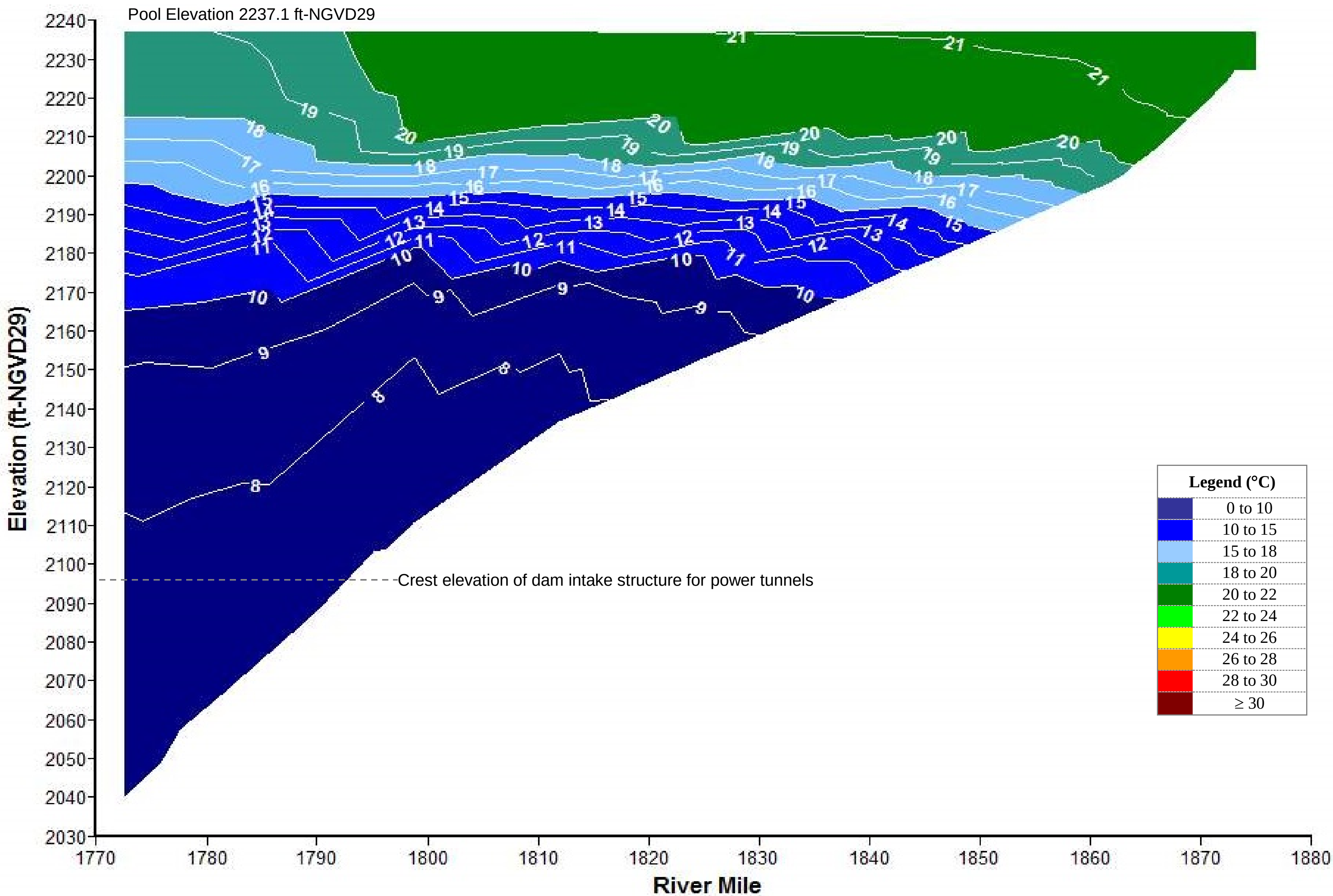


Plate 5-6. Longitudinal water temperature (°C) contour plot of Fort Peck Lake based on depth-profile water temperatures measured at sites FTPLK1772A, FTPLK1805DW, and FTPNFMORR1 on 24-Jun-2015.

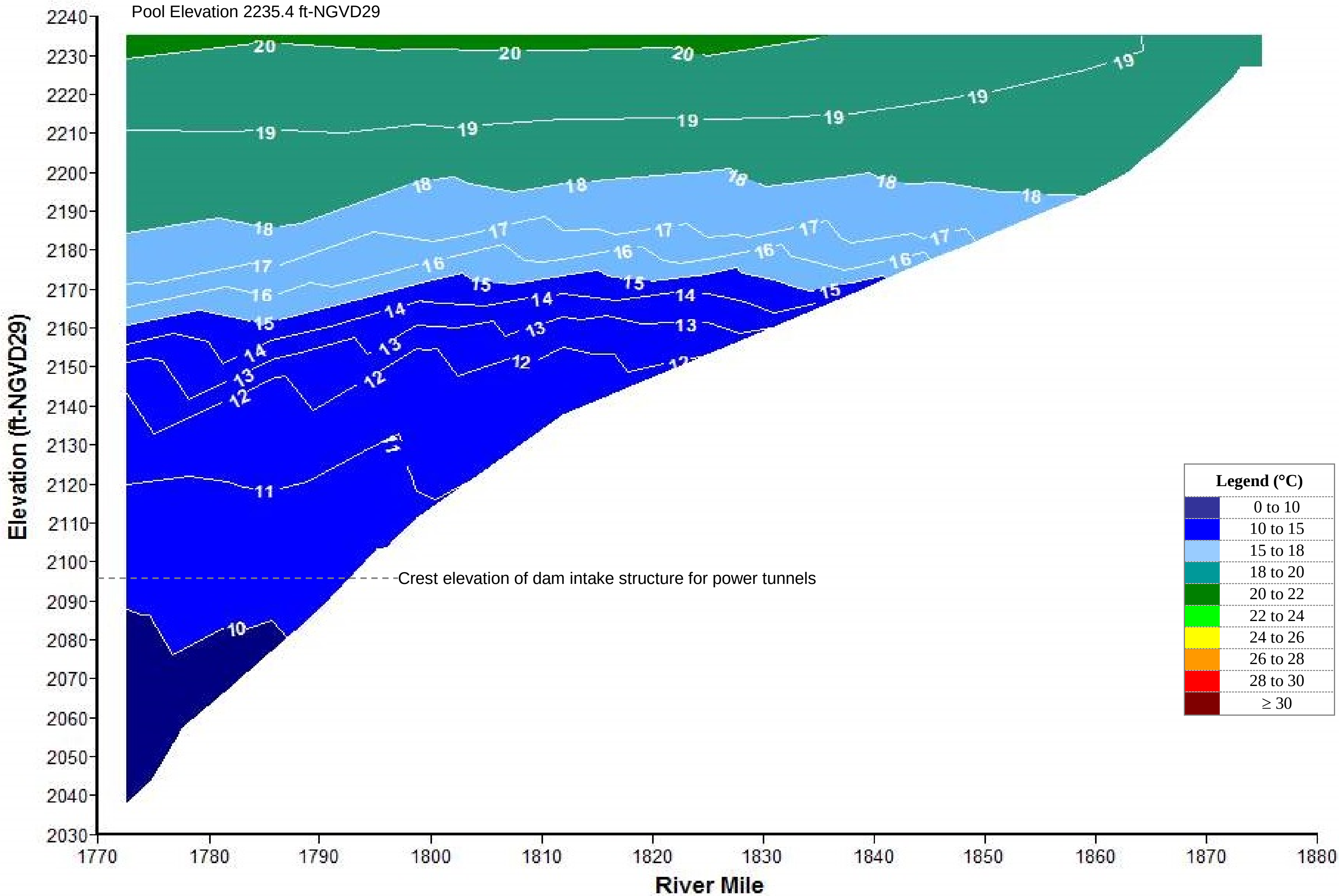


Plate 5-7. Longitudinal water temperature (°C) contour plot of Fort Peck Lake based on depth-profile water temperatures measured at sites FTPLK1772A, FTPLK1805DW, and FTPNFMORR1 on 26-Aug-2015.

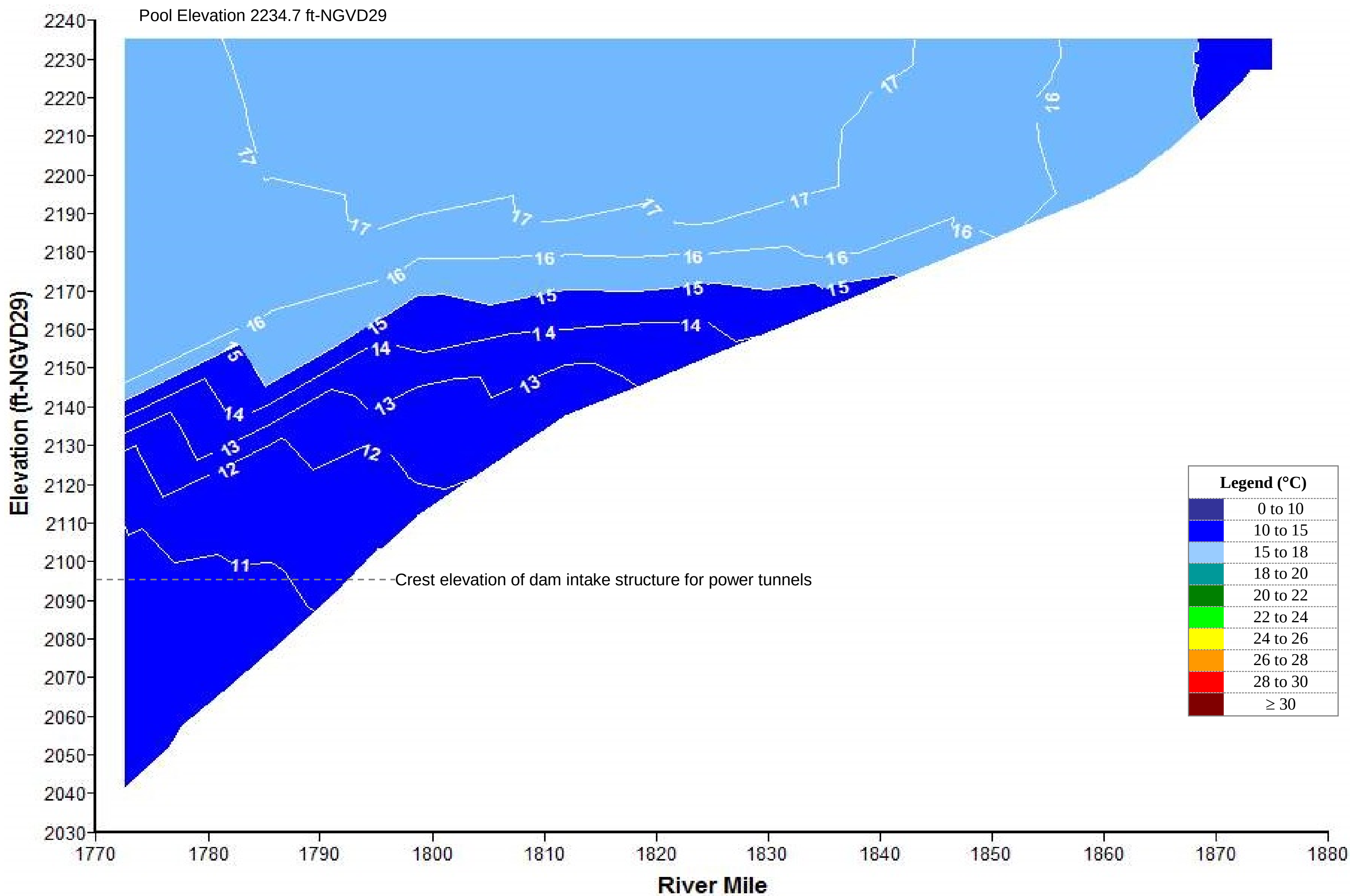


Plate 5-8. Longitudinal water temperature (°C) contour plot of Fort Peck Lake based on depth-profile water temperatures measured at sites FTPLK1772A, FTPLK1805DW, and FTPNFMORR1 on 23-Aug-2015.

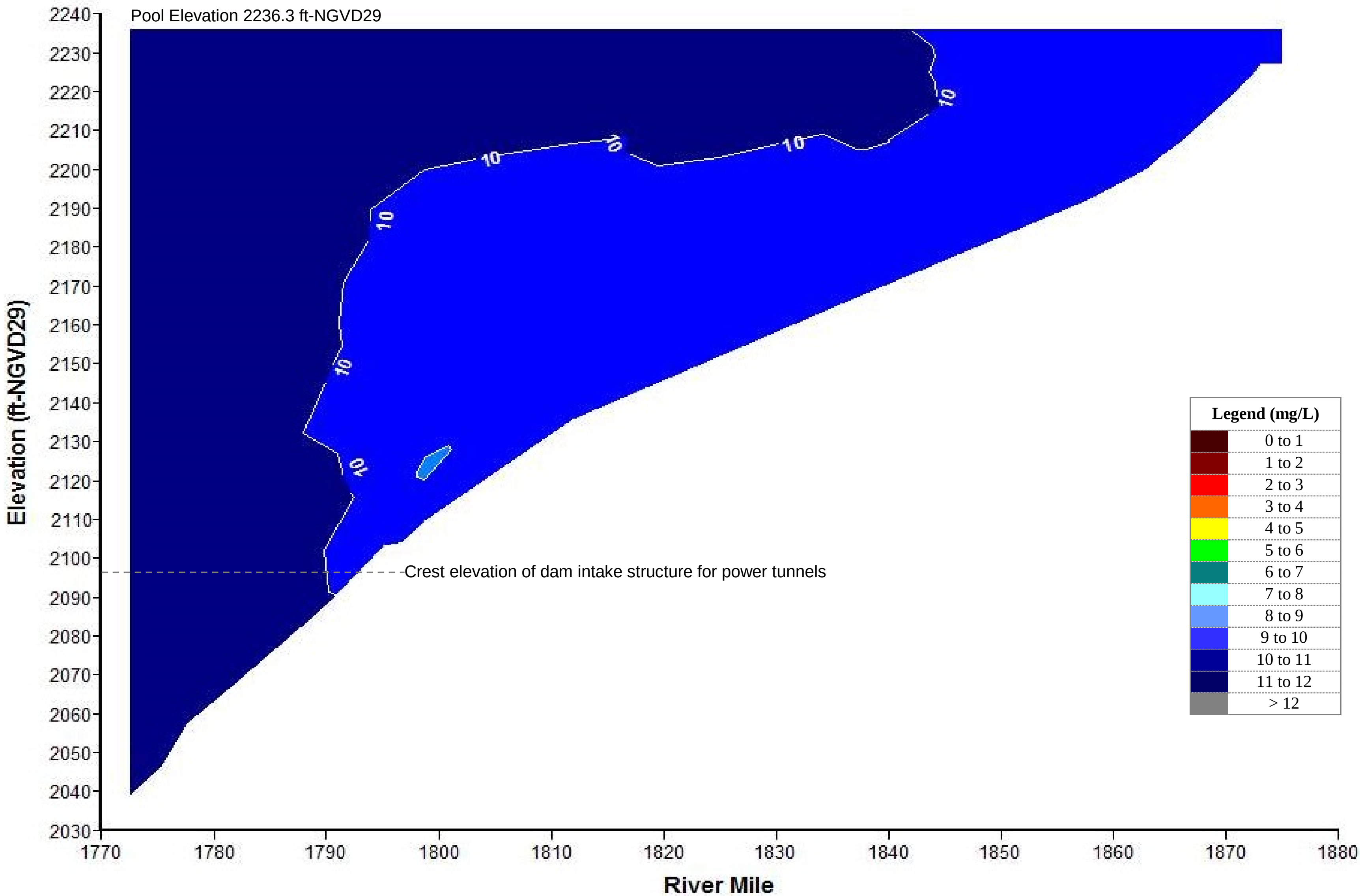


Plate 5-9. Longitudinal dissolved oxygen (mg/L) contour plot of Fort Peck Lake based on depth-profile dissolved oxygen concentrations monitored at sites FTPLK1772A, FTPLK1805DW, and FTPNFMORR1 on 2-Jun-2015.

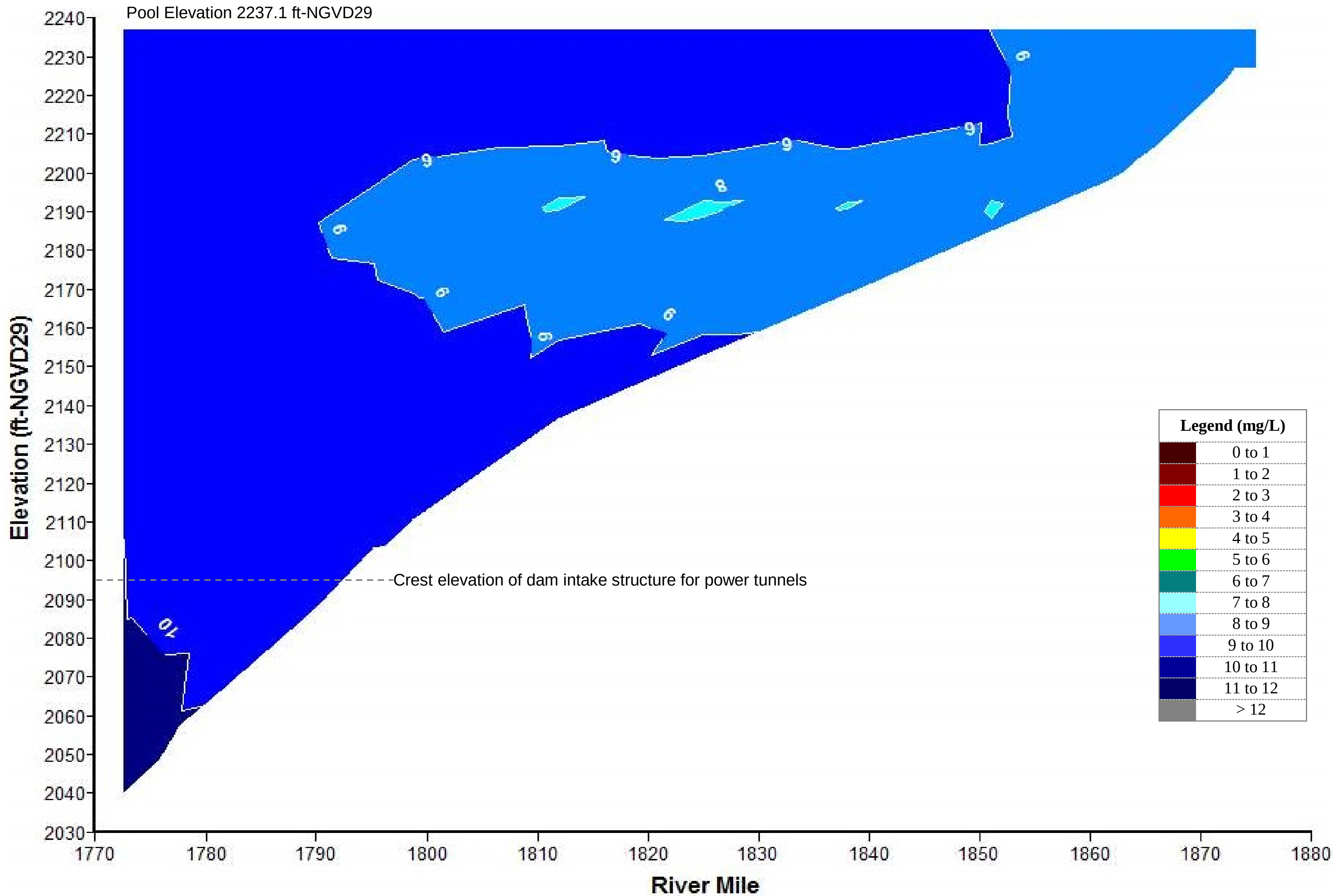


Plate 5-10. Longitudinal dissolved oxygen (mg/L) contour plot of Fort Peck Lake based on depth-profile dissolved oxygen concentrations monitored at sites FTPLK1772A, FTPLK1805DW, and FTPNFMORR1 on 24-Jun-2015.

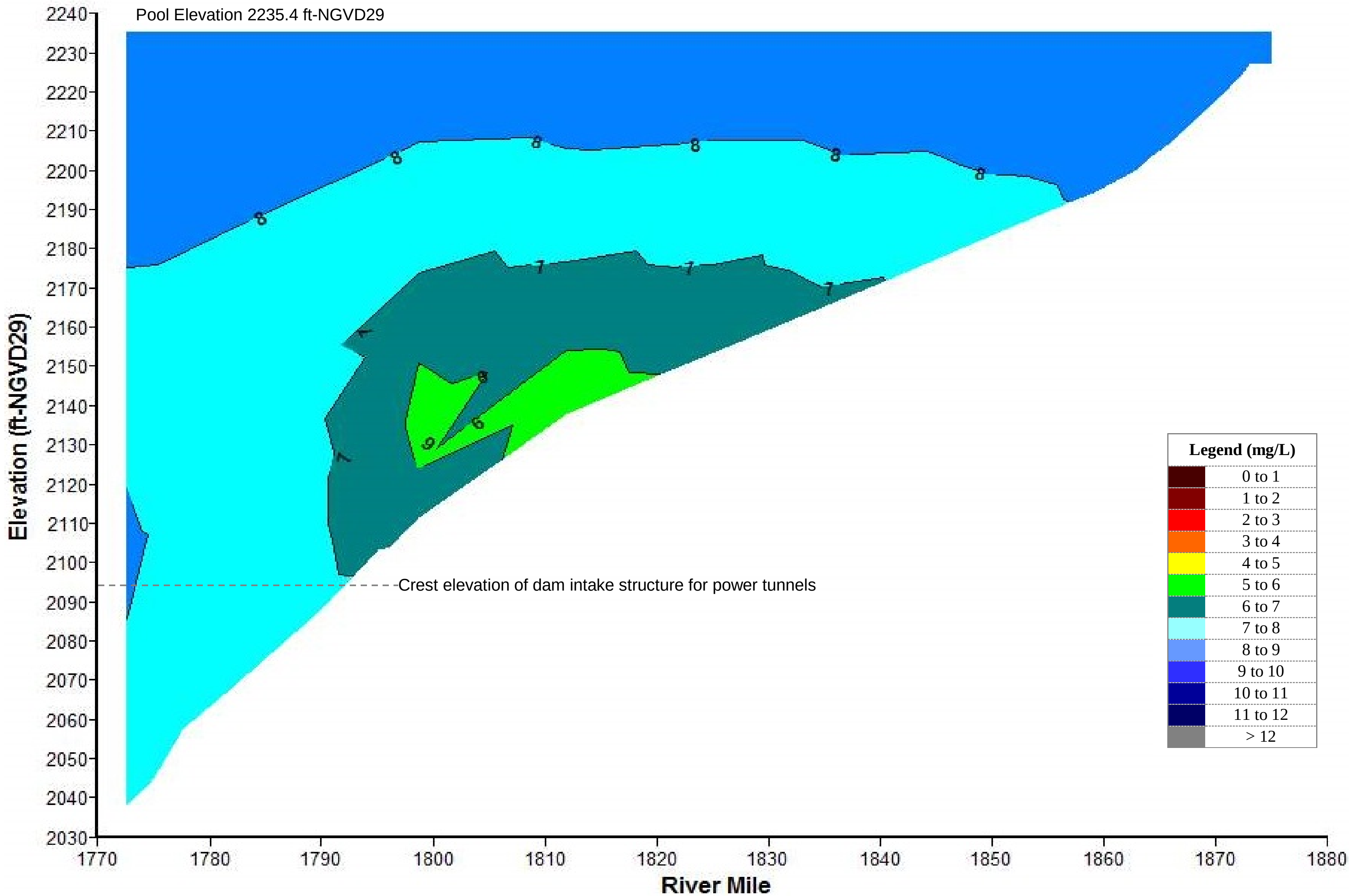


Plate 5-11. Longitudinal dissolved oxygen (mg/L) contour plot of Fort Peck Lake based on depth-profile dissolved oxygen concentrations monitored at sites FTPLK1772A, FTPLK1805DW, and FTPNFMORR1 on 26-Aug-2015.

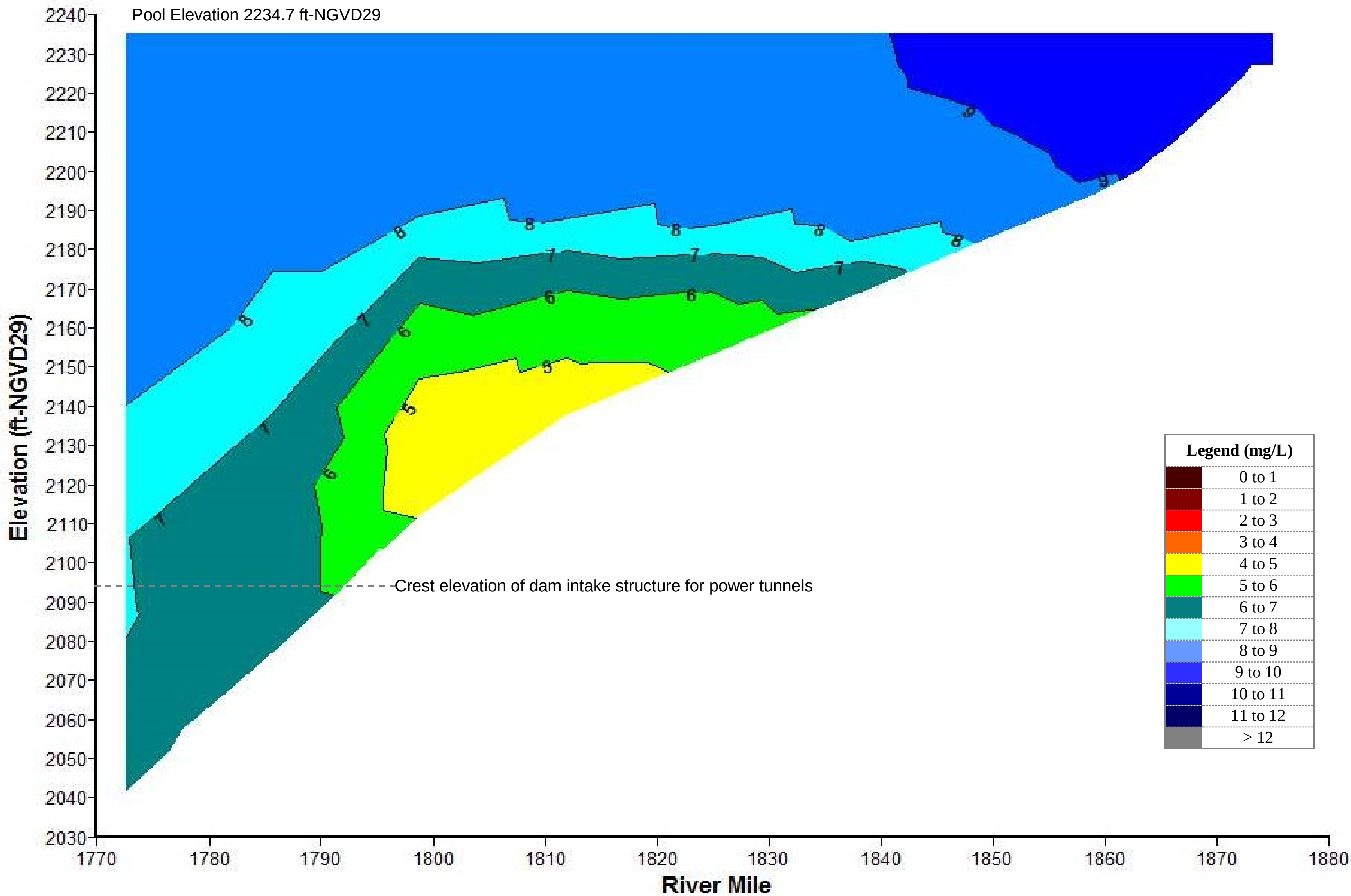


Plate 5-12. Longitudinal dissolved oxygen (mg/L) contour plot of Fort Peck Lake based on depth-profile dissolved oxygen concentrations monitored at sites FTPLK1772A, FTPLK1805DW, and FTPNFMORR1 on 23-Sep-2015.

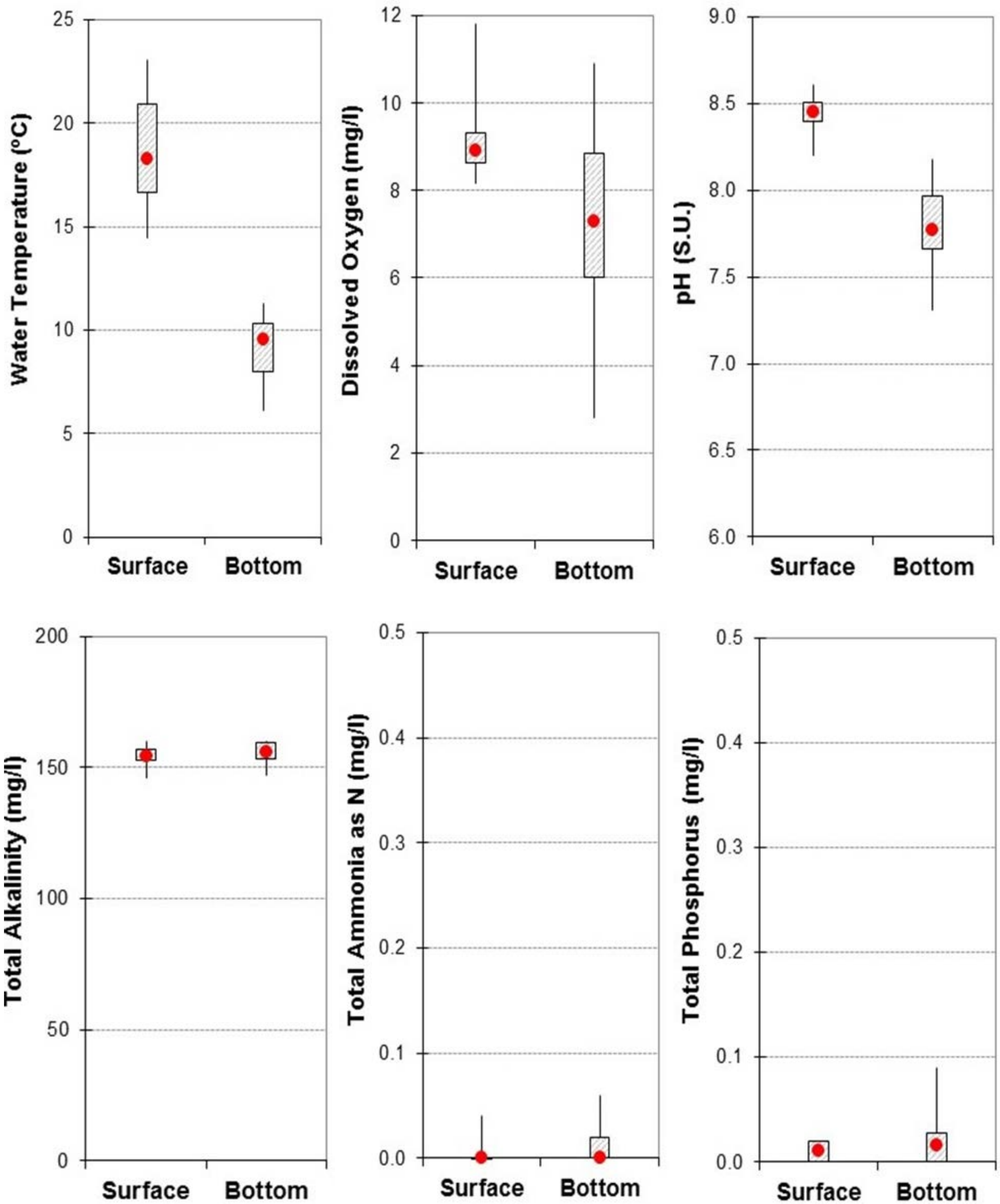


Plate 5-13. Box plots comparing paired surface and bottom water temperature, dissolved oxygen, pH, alkalinity, total ammonia nitrogen, and total phosphorus measurements taken in Fort Peck Lake at site FTPLK1772A during the summer thermal stratification period of 2011 through 2015.
(Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

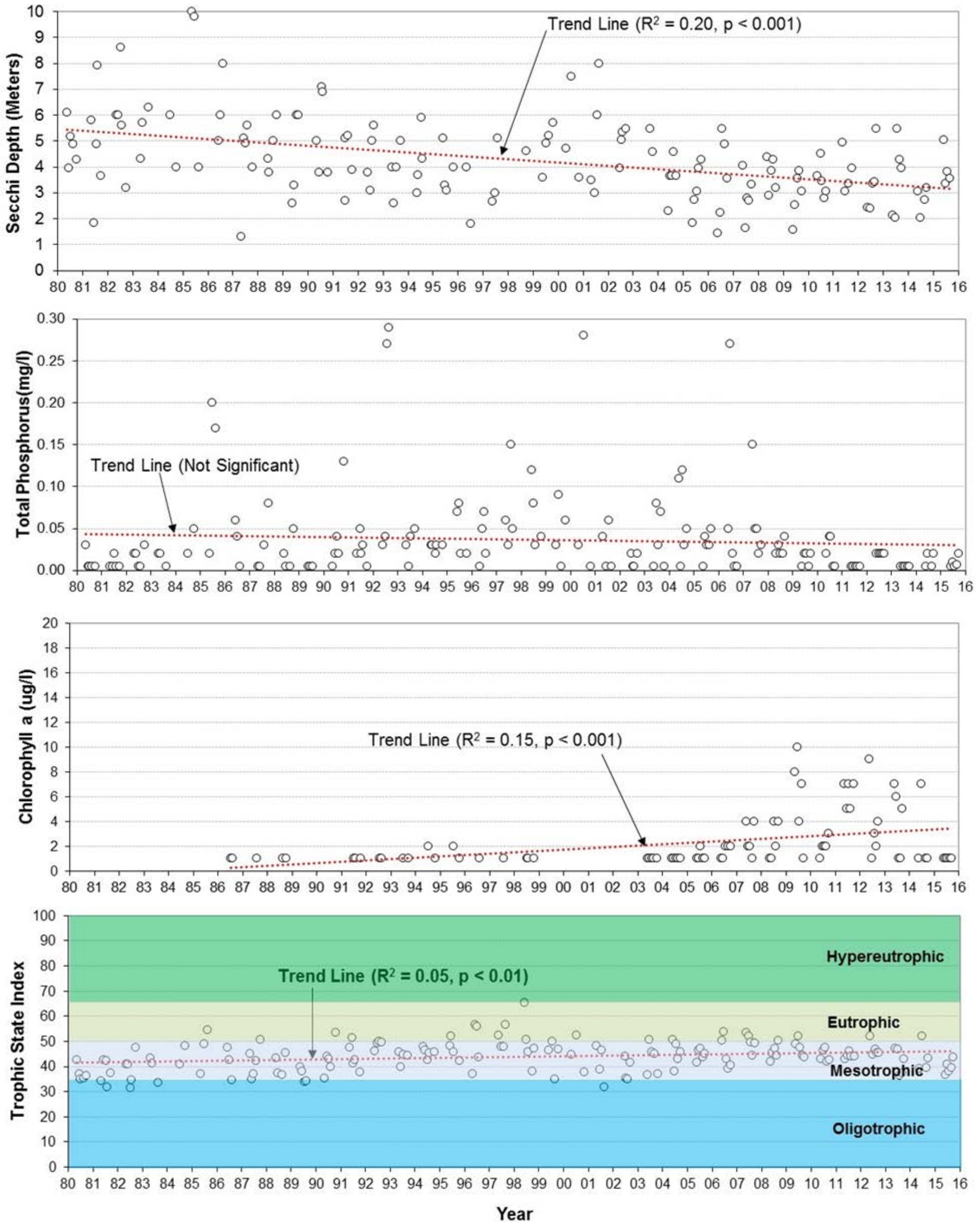


Plate 5-14. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Fort Peck Lake at site FTPLK1772A over the 36-year period of 1980 through 2015.

Plate 5-15. Summary of monthly (April through September) near-surface water quality conditions monitored in the Missouri River near Landusky, Montana at monitoring site FTPNFMORR1 during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[(A)]	No. of Obs.	Mean[(B)]	Median	Min.	Max.	State WQS Criteria[(C)]	No. of WQS Exceedances	Percent WQS Exceedance
Streamflow (cfs)	1	28	10,596	8,195	5,010	34,899	-----	-----	-----
Water Temperature (°C)	0.1	26	16.7	17.5	3.0	26.7	26.7[(1,2)]	0	0%
Dissolved Oxygen (mg/L)	0.1	26	8.3	9.0	7.6	12.4	5.0[(1,3)]	0	0%
Dissolved Oxygen (% Sat.)	0.1	26	97.6	96.9	90.4	105.4	-----	-----	-----
pH (S.U.)	0.1	26	8.4	8.4	7.7	8.9	6.5[(1,3)], 9.0[(1,2)]	0	0%
Specific Conductance (uS/cm)	1	26	550	498	419	920	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	26	345	336	140	502	-----	-----	-----
Turbidity (NTU)	1	26	129	58	2	1,040	-----	-----	-----
Alkalinity, Total (mg/L)	7	28	149	147	138	178	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	28	3.0	2.8	0.6	6.4	-----	-----	-----
Chloride, Dissolved (mg/L)	1	17	9	8	6	12	-----	-----	-----
Chlorophyll a (ug/L)	1	26	15	10	1	54	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	28	25	20	12	78	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	27	406	334	278	1,220	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	28	----	n.d.	n.d.	0.11	3.9 [(1,2,4)], 1.0[(1,4,5)]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	28	0.6	0.5	0.1	2.7	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	28	-----	0.03	n.d.	0.50	-----	-----	-----
Nitrogen, Total (mg/L)	0.1	28	0.7	0.6	0.2	3.1	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.01	28	-----	0.01	n.d.	0.10	-----	-----	-----
Phosphorus, Total (mg/L)	0.01	28	0.18	0.09	n.d.	1.55	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.01	28	-----	n.d.	n.d.	0.05	-----	-----	-----
Sulfate (mg/L)	1	28	124	102	65	316	-----	-----	-----
Suspended Solids, Total (mg/L)	4	28	239	107	10	2,810	-----	-----	-----
Suspended Sediment, Total (mg/L)	4	25	253	105	12	2,640	-----	-----	-----

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

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

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

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

(1) Criteria for B-3 classified waters.

(2) Daily maximum criterion (monitoring results directly comparable to criterion).

(3) Daily minimum criterion (monitoring results directly comparable to criterion).

(4) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

(5) 30-day average criterion (monitoring results not directly comparable to criterion).

Plate 5-16. Summary of annual metal and pesticide levels monitored in the Missouri River near Landusky, Montana at monitoring site FTPNFMORR1 during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[(A)]	Median	Min.	Max.	State WQS Criteria[(B)]	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/L)	40	5	-----	n.d.	n.d.	2,210	750[(1)], 87[(2)]	1, 1	20%, 20%
Aluminum, Total (ug/L)	40	5	14,045	1,340	330	66,330	-----	-----	-----
Antimony, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	0.6	-----	-----	-----
Antimony, Total (ug/L)	0.5	5	-----	0.5	n.d.	0.6	5.6[(1)]	0	0%
Arsenic, Dissolved (ug/L)	1	5	9	11	3	13	-----	-----	-----
Arsenic, Total (ug/L)	1	5	15	12	10	28	340[(1)], 150[(2)], 10[(3)]	0, 0, 4	0%, 0%, 80%
Barium, Dissolved (ug/L)	5	5	53	52	48	56	-----	-----	-----
Barium, Total (ug/L)	5	5	171	70	54	589	2,000[(3)]	0	0%
Beryllium, Dissolved (ug/L)	2	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Beryllium, Total (ug/L)	2	5	-----	n.d.	n.d.	3	4[(3)]	0	0%
Cadmium, Dissolved (ug/L)	0.2	4	-----	n.d.	n.d.	n.d.	-----	-----	-----
Cadmium, Total (ug/L)	0.2	4	-----	n.d.	n.d.	n.d.	4.1[(1)], 0.44[(2)], 5[(3)]	0	0%
Calcium, Dissolved (mg/L)	0.01	5	50.8	46.2	45.2	68.3	-----	-----	-----
Chromium, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Chromium, Total (ug/L)	10	5	-----	n.d.	n.d.	70	3,050[(1)], 146[(2)], 100[(3)]	0	0%
Copper, Dissolved (ug/L)	6	5	-----	n.d.	n.d.	9	-----	-----	-----
Copper, Total (ug/L)	6	5	-----	n.d.	n.d.	70	26[(1)], 16[(2)], 1,300[(3)]	1, 1, 0	20%, 20%, 0%
Hardness, Dissolved (mg/L)	0.4	5	211	190	187	289	-----	-----	-----
Iron, Dissolved (ug/L)	7	5	325	20	10	1,560	-----	-----	-----
Iron, Total (ug/L)	7	5	13,158	1,060	240	62,340	1,000[(2)], 300[(4)]	3, 4	60%, 80%
Lead, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	1.0	-----	-----	-----
Lead, Total (ug/L)	0.5	5	8.2	0.7	n.d.	39.1	185[(1)], 7.2[(2)], 15[(3)]	0, 1, 1	0%, 20%, 20%
Magnesium, Dissolved (mg/L)	0.01	5	26.5	19.9	17.6	55.9	-----	-----	-----
Manganese, Dissolved (ug/L)	2	5	7	3	3	20	-----	-----	-----
Manganese, Total (ug/L)	2	5	180	30	10	790	50[(4)]	1	20%
Mercury, Dissolved (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Mercury, Total (ug/L)	0.05	5	-----	n.d.	n.d.	0.10	1.7[(1)], 0.91[(2)], 0.05[(3)]	0, 0, 1	0%, 0%, 20%
Nickel, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Nickel, Total (ug/L)	10	5	-----	n.d.	n.d.	70	808[(1)], 90[(2)], 100[(3)]	0	0%
Selenium, Total (ug/L)	1	5	-----	2	n.d.	4	20[(1)], 5[(2)], 50[(3)]	0	0%
Silver, Dissolved (ug/L)	1	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Silver, Total (ug/L)	1	5	-----	n.d.	n.d.	n.d.	12[(1)], 100[(3)]	0	0%
Sodium, Dissolved (mg/L)	0.01	5	37.0	26.6	22.1	82.2	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Total (ug/L)	0.5	5	-----	n.d.	n.d.	0.9	0.24[(3)]	b.d.	b.d.
Zinc, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Zinc, Total (ug/L)	10	5	-----	10	n.d.	240	206[(6,7)], 2,000[(3)]	1, 0	20%, 0%
Pesticide Scan (ug/L)[(C)]	0.05[(D)]	5	-----	n.d.	n.d.	n.d.	-----	-----	-----

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

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

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

(1) Acute criterion for aquatic life.

(2) Chronic criterion for aquatic life.

(3) Human health criterion for surface waters.

(4) Secondary Maximum Contaminant Level based on aesthetic properties.

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

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

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

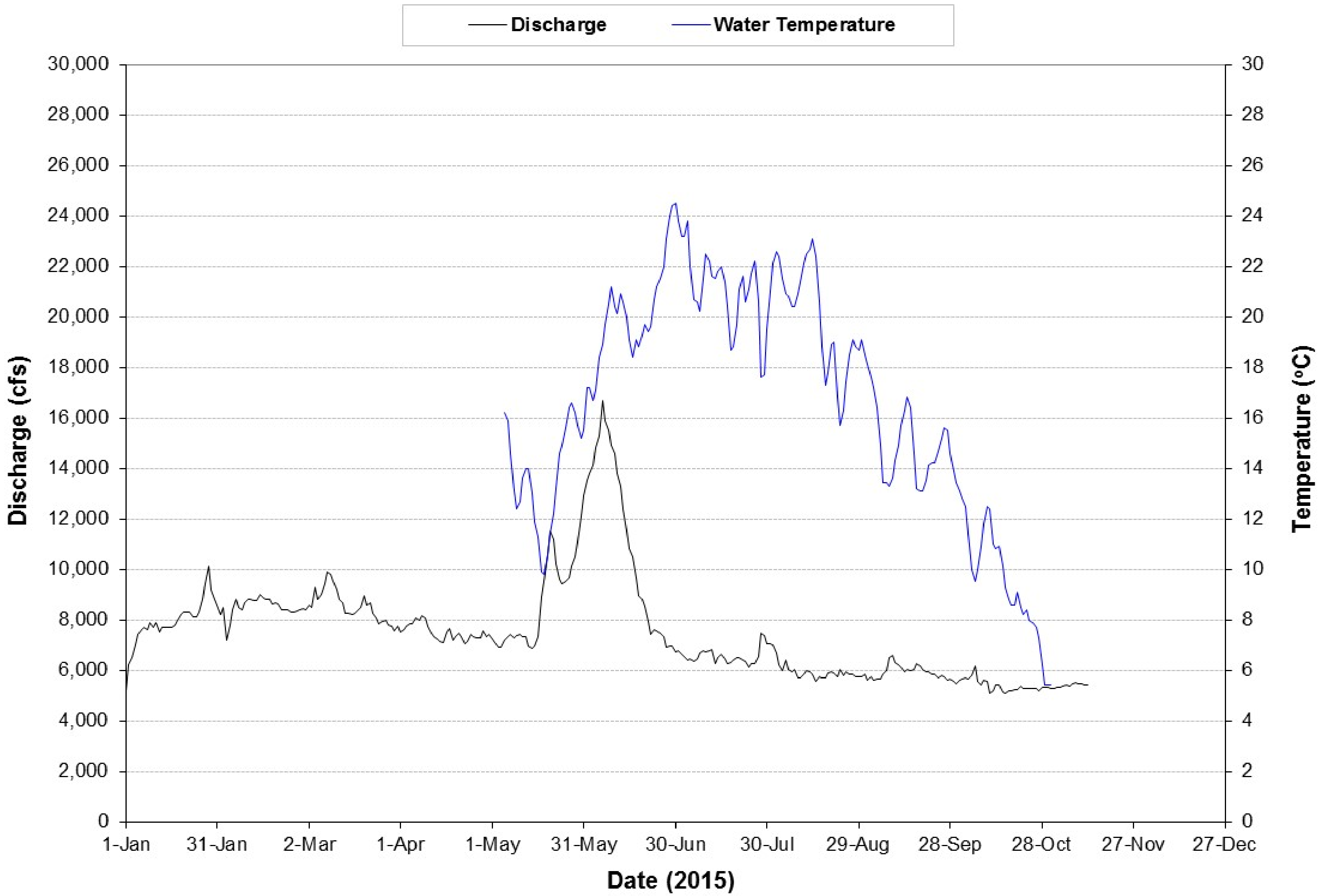


Plate 5-17. Mean daily discharge and water temperature of the Missouri River near Landusky, Montana (i.e. site FTPNFMORR1) for 2015. Means based on measurements recorded at USGS gaging station 06115200.

Plate 5-18. Summary of monthly water quality conditions monitored from water discharged through Fort Peck Dam (i.e. site FTPPP1) during the 5-year period of January 2011 through December 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[(A)]	No. of Obs.	Mean[(B)]	Median	Min.	Max.	State WQS Criteria[(C)]	No. of WQS Exceedances	Percent WQS Exceedance
Dam Discharge, Powerplant (cfs)	1	40	8,443	7,969	4,247	13,491	-----	-----	-----
Dam Discharge, Spillway (cfs)[(D)]	1	40	2,925	0	0	46,618	-----	-----	-----
Water Temperature (°C)	0.1	41	9.1	9.2	1.8	15.8	19.4[(1,4)]	0	0%
Dissolved Oxygen (mg/L)	0.1	41	9.5	9.2	4.1	12.9	8.0[(1,2,4)], 5.0[(1,3,4)]	12, 1	29%, 1%
Dissolved Oxygen (% Sat.)	0.1	41	83.9	88.0	39.6	107.0	-----	-----	-----
pH (S.U.)	0.1	40	8.1	8.1	7.6	8.6	6.5[(1,5)], 9.0[(1,4)]	0	0%
Specific Conductance (uS/cm)	1	41	714	734	544	786	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	40	359	360	167	568	-----	-----	-----
Turbidity (NTU)	0.1	40	2	1	n.d.	30	-----	-----	-----
Alkalinity, Total (mg/L)	7	40	156	157	147	164	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	40	3.4	3.3	1.6	7.2	-----	-----	-----
Chloride, Dissolved (mg/L)	1	23	9	9	8	11	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	39	17	15	10	26	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	40	519	520	282	690	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	40	-----	n.d.	n.d.	0.07	6.9[(1,4,6)], 2.0[(1,4,7)]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	39	0.3	0.3	0.1	0.6	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	40	-----	0.02	n.d.	0.25	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.01	40	-----	n.d.	n.d.	0.17	-----	-----	-----
Phosphorus, Total (mg/L)	0.01	40	-----	0.01	n.d.	0.17	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.01	40	-----	n.d.	n.d.	0.06	-----	-----	-----
Sulfate (mg/L)	1	40	211	216	126	250	-----	-----	-----
Suspended Solids, Total (mg/L)	4	40	-----	n.d.	n.d.	59	-----	-----	-----

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

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

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

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

(1) Criteria for B-3 classified waters.
(2) Early life stages.
(3) Non-early life stages.
(4) Daily maximum criterion (monitoring results directly comparable to criterion).
(5) Daily minimum criterion (monitoring results directly comparable to criterion).
(6) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
(7) 30-day average criterion (monitoring results not directly comparable to criterion).

(D) May through September 2011.

Plate 5-19. Summary of annual metals and pesticide levels monitored from water discharged through Fort Peck Dam (i.e. site FTPPP1) during the 5-year period of January 2011 through December 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/L)	40	5	-----	n.d.	n.d.	50	750(1), 87(2)	0	0%
Aluminum, Total (ug/L)	40	5	68	60	n.d.	180	-----	-----	-----
Antimony, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	0.8	-----	-----	-----
Antimony, Total (ug/L)	0.5	5	0.6	0.5	0.5	0.7	5.6(1)	0	0%
Arsenic, Dissolved (ug/L)	1	5	5	5	4	5	-----	-----	-----
Arsenic, Total (ug/L)	1	5	5	5	4	6	340(1), 150(2), 10(3)	0	0%
Barium, Dissolved (ug/L)	5	5	39	40	35	42	-----	-----	-----
Barium, Total (ug/L)	5	5	39	41	35	41	2,000(3)	0	0%
Beryllium, Dissolved (ug/L)	2	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Beryllium, Total (ug/L)	2	5	-----	n.d.	n.d.	n.d.	4(3)	0	0%
Cadmium, Dissolved (ug/L)	0.2	5	-----	n.d.	n.d.	1.2	-----	-----	-----
Cadmium, Total (ug/L)	0.2	5	-----	n.d.	n.d.	2.0	5.5(1), 0.54(2), 5(3)	0, 1, 0	0%, 20%, 0%
Calcium, Dissolved (mg/L)	0.01	5	56.8	58.8	50.0	60.8	-----	-----	-----
Chromium, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Chromium, Total (ug/L)	10	5	-----	n.d.	n.d.	n.d.	3,856(1), 184(2), 100(3)	0	0%
Copper, Dissolved (ug/L)	6	5	-----	n.d.	n.d.	10	-----	-----	-----
Copper, Total (ug/L)	6	5	6	7	n.d.	10	34(1), 21(2), 1,300(3)	0	0%
Hardness, Total (mg/L)	0.4	5	243	253	209	264	-----	-----	-----
Iron, Dissolved (ug/L)	7	5	14	10	n.d.	30	-----	-----	-----
Iron, Total (ug/L)	7	5	71	50	30	180	1,000(2), 300(4)	0	0%
Lead, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Lead, Total (ug/L)	0.5	5	-----	n.d.	n.d.	0.9	266(1), 10(2), 15(3)	0	0%
Magnesium, Dissolved (mg/L)	0.01	5	24.4	24.7	20.4	27.5	-----	-----	-----
Manganese, Dissolved (ug/L)	2	5	-----	n.d.	n.d.	6	-----	-----	-----
Manganese, Total (ug/L)	2	5	14	10	7	30	50(4)	0	0%
Mercury, Dissolved (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Mercury, Total (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	1.7(1), 0.91(2), 0.05(3)	0	0%
Nickel, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Nickel, Total (ug/L)	10	5	-----	n.d.	n.d.	n.d.	1,029(1), 114(2), 100(3)	0	0%
Selenium, Total (ug/L)	1	5	2	1	n.d.	7	20(1), 5(2), 50(3)	0, 1, 0	0%, 20%, 0%
Silver, Dissolved (ug/L)	1	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Silver, Total (ug/L)	1	5	-----	n.d.	n.d.	n.d.	20(1), 100(3)	0	0%
Sodium, Dissolved (mg/L)	0.01	4	60.1	62.6	48.3	71.6	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Total (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	0.24(3)	b.d.	b.d.
Zinc, Dissolved (ug/L)	10	5	10	10	n.d.	20	-----	-----	-----
Zinc, Total (ug/L)	10	5	14	11	10	20	263(6,7), 2,000(3)	0	0%
Pesticide Scan (ug/L)(C)	0.05(D)	5	-----	n.d.	n.d.	n.d.	-----	-----	-----

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

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

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

(1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(3) Human health criterion for surface waters.
(4) Secondary Maximum Contaminant Level based on aesthetic properties.

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

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

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

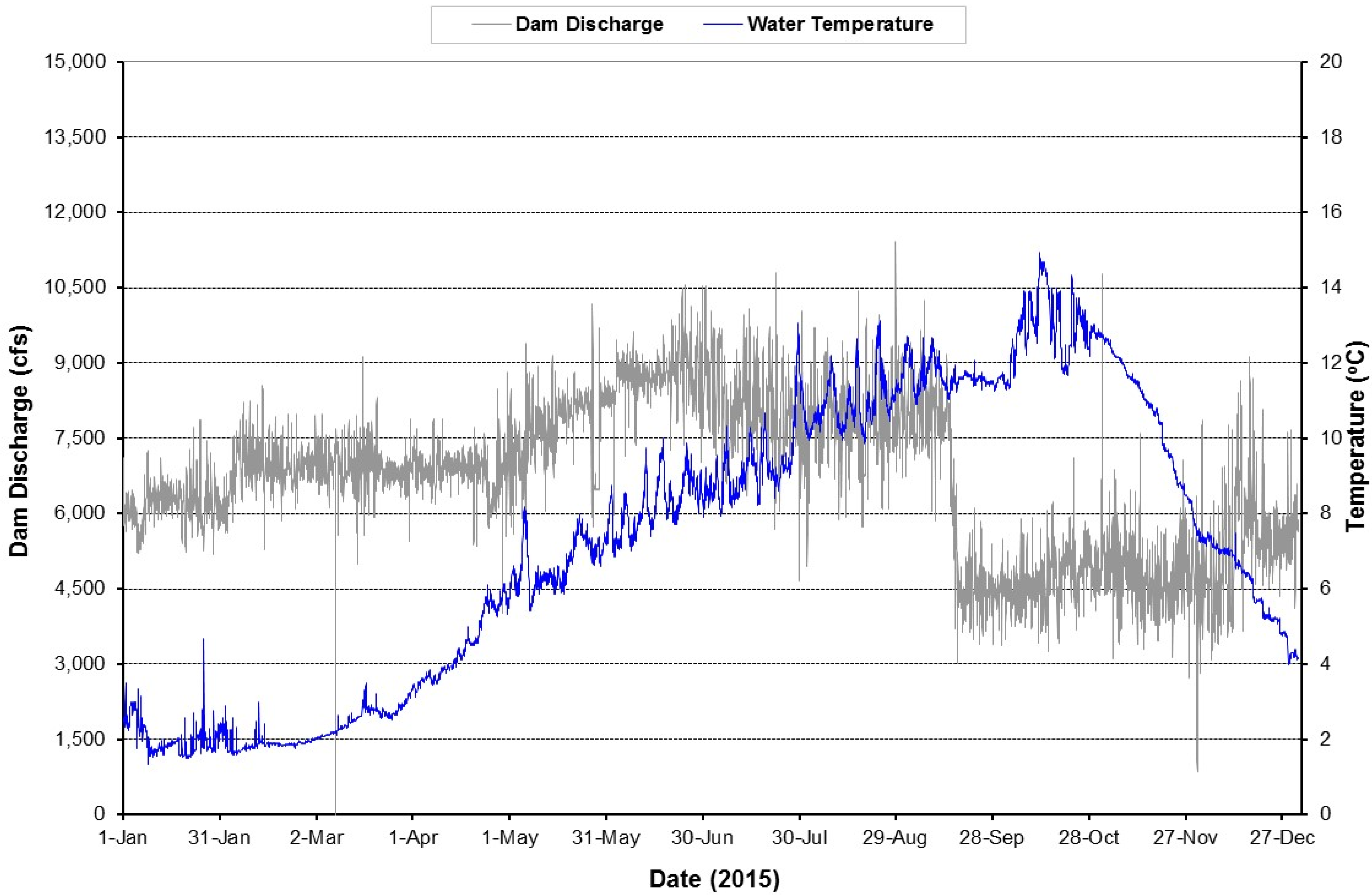


Plate 5-20. Hourly discharge and water temperature monitored at the Fort Peck powerplant on water discharged through the dam during 2015.

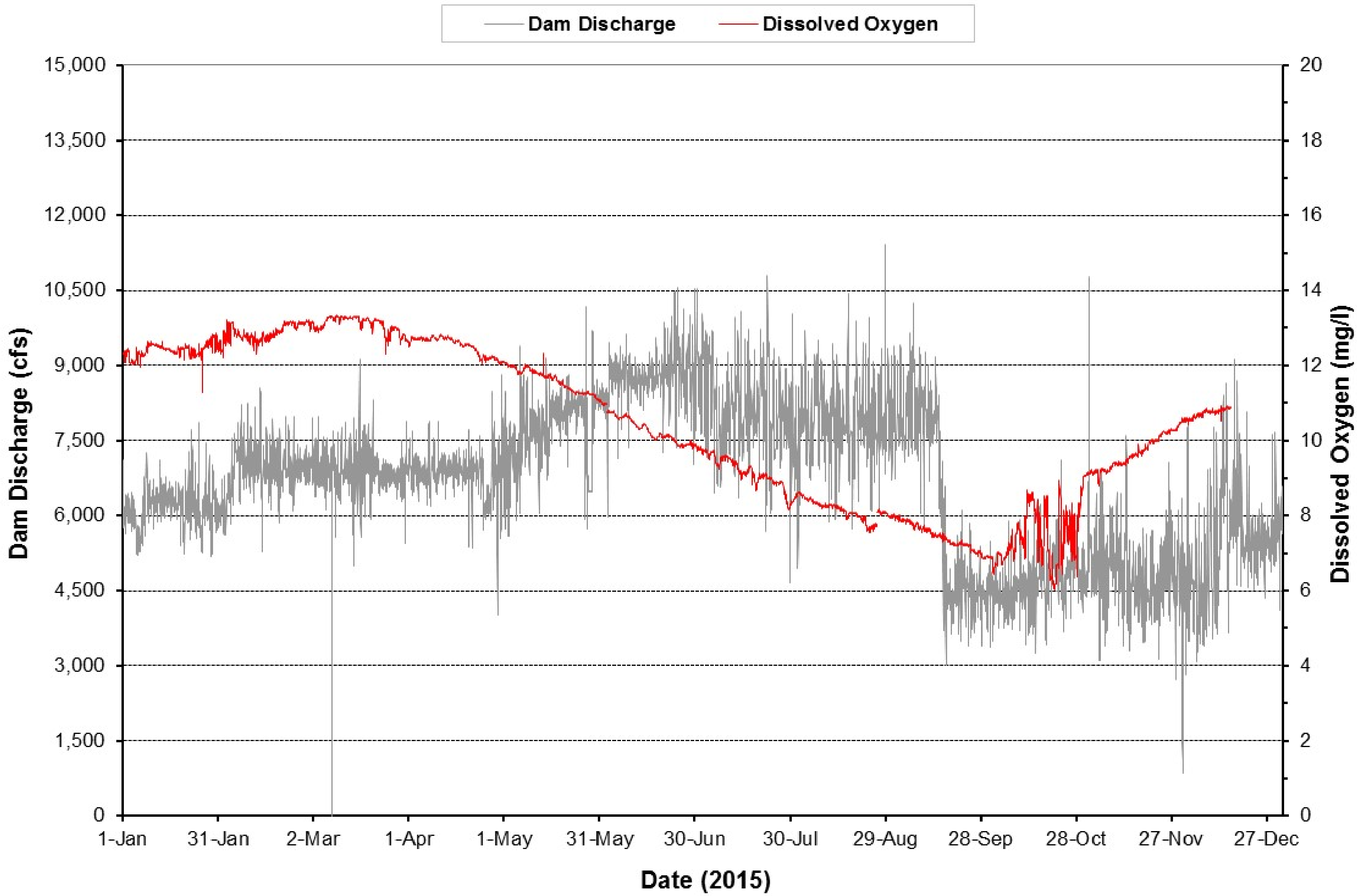


Plate 5-21. Hourly discharge and dissolved oxygen monitored at the Fort Peck powerplant on water discharged through the dam during 2015.

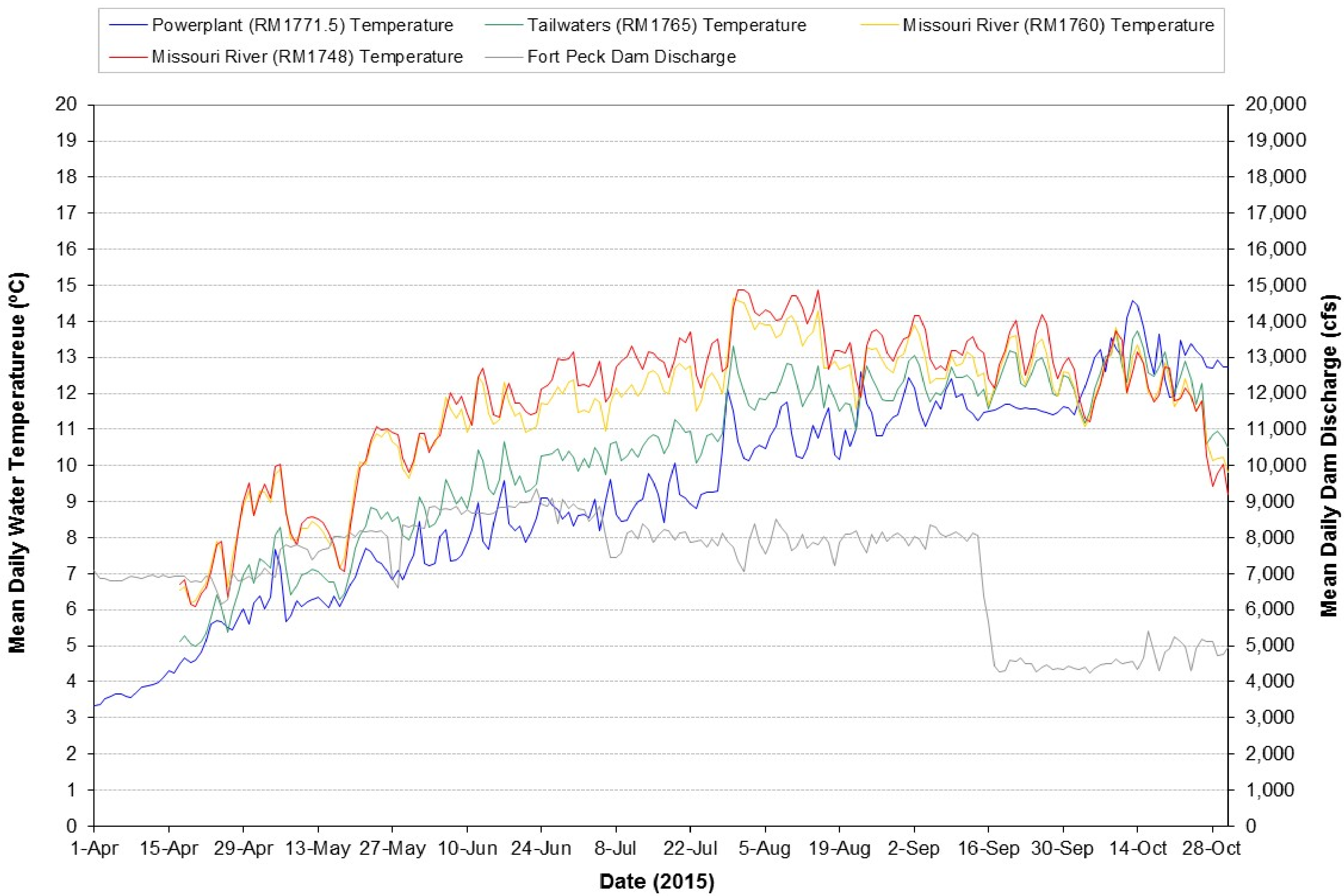


Plate 5-22. Mean daily water temperature monitored at the Fort Peck powerplant and along the Missouri River downstream of Fort Peck Dam at the Fort Peck Dam tailwaters, Nickels Ferry, and Frazer Rapids and the mean daily discharge of Fort Peck Dam from April through October during 2015.

6 GARRISON PROJECT

6.1 BACKGROUND INFORMATION

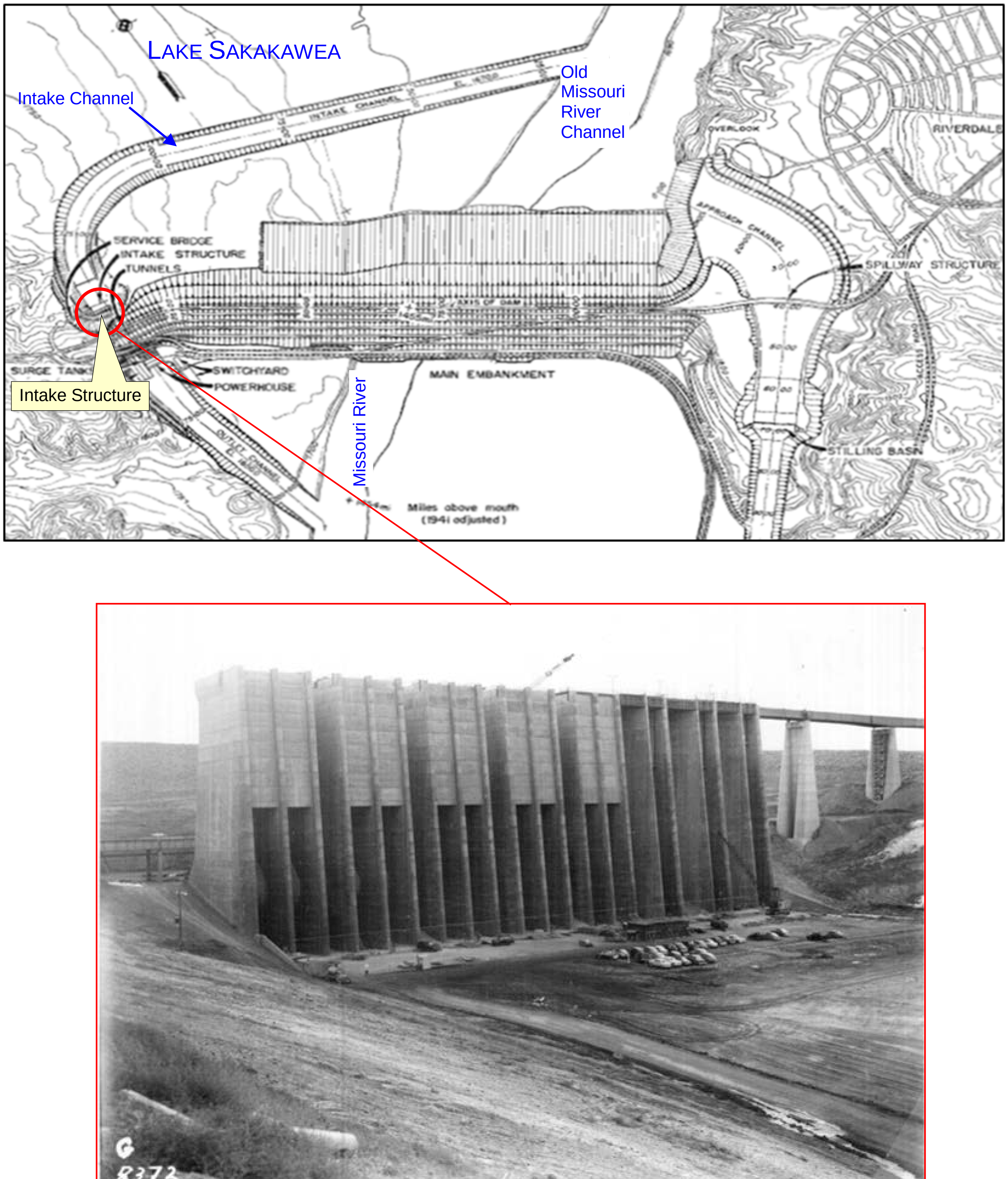
6.1.1 PROJECT OVERVIEW

Garrison Dam is located in central North Dakota on the Missouri River at RM 1389.9, about 75 miles northwest of Bismarck, ND and 11 miles south of the town of Garrison, ND. Construction of the project began in 1946, and closure of Garrison Dam in 1953 resulted in the formation of Garrison Reservoir (Lake Sakakawea), which is the largest Corps reservoir in the United States. When full, the reservoir is 178 miles long, up to 6 miles wide, and has 1,884 miles of shoreline. The reservoir contains almost a third of the total storage capacity of the Mainstem System, nearly 24 million acre-ft. Table 6-1 summarizes how the surface area, volume, mean depth, and retention time of Lake Sakakawea vary with pool elevations. Major inflows to the reservoir are the Missouri and Yellowstone Rivers, and a minor inflows are the Little Missouri and Little Muddy Rivers. Water discharged through Garrison Dam for power production is withdrawn from Lake Sakakawea at elevation 1672.0 ft-NGVD29, approximately 2 feet above the reservoir bottom. Figure 6-1 shows a schematic drawing and photo of the outlet works at Garrison Dam.

Table 6-1. Surface area, volume, mean depth, and retention time of Lake Sakakawea at different pool elevations based on 2010-2012 bathymetric survey.

Elevation (Feet-NGVD29)	Surface Area (Acres)	Volume (Acre-Feet)	Mean Depth (Feet)*	Retention Time (Years)**
1855	387,135	23,836,210	61.6	1.52
1850	364,935	21,956,050	60.2	1.40
1845	342,750	20,186,770	58.9	1.29
1840	320,190	18,528,780	57.9	1.18
1835	296,890	16,988,790	57.2	1.08
1830	280,485	15,547,850	55.4	0.99
1825	263,065	14,189,340	53.9	0.91
1820	247,910	12,913,020	52.1	0.82
1815	232,725	11,710,380	50.3	0.75
1810	215,125	10,589,550	49.2	0.68
1805	197,322	9,560,189	48.4	0.61
1800	183,545	8,609,286	46.9	0.55
1795	168,911	7,729,308	45.8	0.49
1790	157,953	6,913,512	43.8	0.44
1785	146,409	6,152,905	42.0	0.39
1780	136,204	5,446,709	40.0	0.35
1775	125,469	4,793,691	38.2	0.31
1770	118,070	4,186,230	35.5	0.27

Average Annual Inflow (1967 through 2015) = 16.608 Million Acre-Feet
Average Annual Outflow: (1967 through 2015) = 15.672 Million Acre-Feet
* Mean Depth = Volume ÷ Surface Area.
** Retention Time = Volume ÷ Average Annual Outflow.
Note: Exclusive Flood Control Zone (elev. 1854-1850 ft-NGVD29), Annual Flood Control and Multiple Use Zone (elev. 1850-1837.5 ft-NGVD29), Carryover Multiple Use Zone (elev. 1837.5-1775 ft-NGVD29), and Permanent Pool Zone (elev. 1775-1670 ft-NGVD29). All elevations are in the NGVD 29 datum.



Garrison Dam Intake Structure during Construction (10-Dec-1952)

Figure 6-1. Schematic drawing of Garrison Dam and channel to intake structure and photo of intake structure during construction.

The Garrison Project was authorized for the purposes of flood control, recreation, fish and wildlife, hydroelectric power production, water supply, water quality, navigation, and irrigation. Habitat for two endangered species, pallid sturgeon and interior least tern, and one threatened species, piping plover, occurs within the project area. The reservoir is used as a water supply by some individual cabins and by the towns of Williston (RM1553), Four Bears (RM1481), Mandaree (RM1467), Twin Buttes (RM1432), White Shield (RM1415), Parshall (RM1451), Garrison (RM1395), Riverdale (RM1390 – Garrison Dam), and Pick City (RM1390 – Garrison Dam), ND. The Shared Southwest Pipeline Project intake is at RM1414 (Dickinson, ND). Lake Sakakawea is an important recreational resource and a major visitor destination in North Dakota.

Drought conditions in the western United States during the first decade of the 21th century lead to an appreciable drawdown of Lake Sakakawea. An historic low pool elevation of 1805.8 ft-NGVD29 was recorded in May 2005. Drought conditions dissipated at the end of the decade with the occurrence of above normal precipitation, and Lake Sakakawea recovered to normal pool elevations in 2009. Historic runoff in 2011 raised the pool elevation of Lake Sakakawea into the Exclusive Flood Control Zone from May to August, with a maximum pool elevation of 1854.6 ft-NGVD29 occurring in July. The recorded pool elevation at Lake Sakakawea at the end of December 2015 was 1840.0 ft-NGVD29; 2.5 feet above the Carryover Multiple Use Zone upper elevation of 1837.5. Figure 6-2 plots the midnight pool elevation of Lake Sakakawea and the mean daily total discharge of Garrison Dam over the 5-year period 2011 through 2015. The extreme discharges in 2011 reflect additional releases made through the flood tunnels and spillway to manage the flood conditions during 2011.

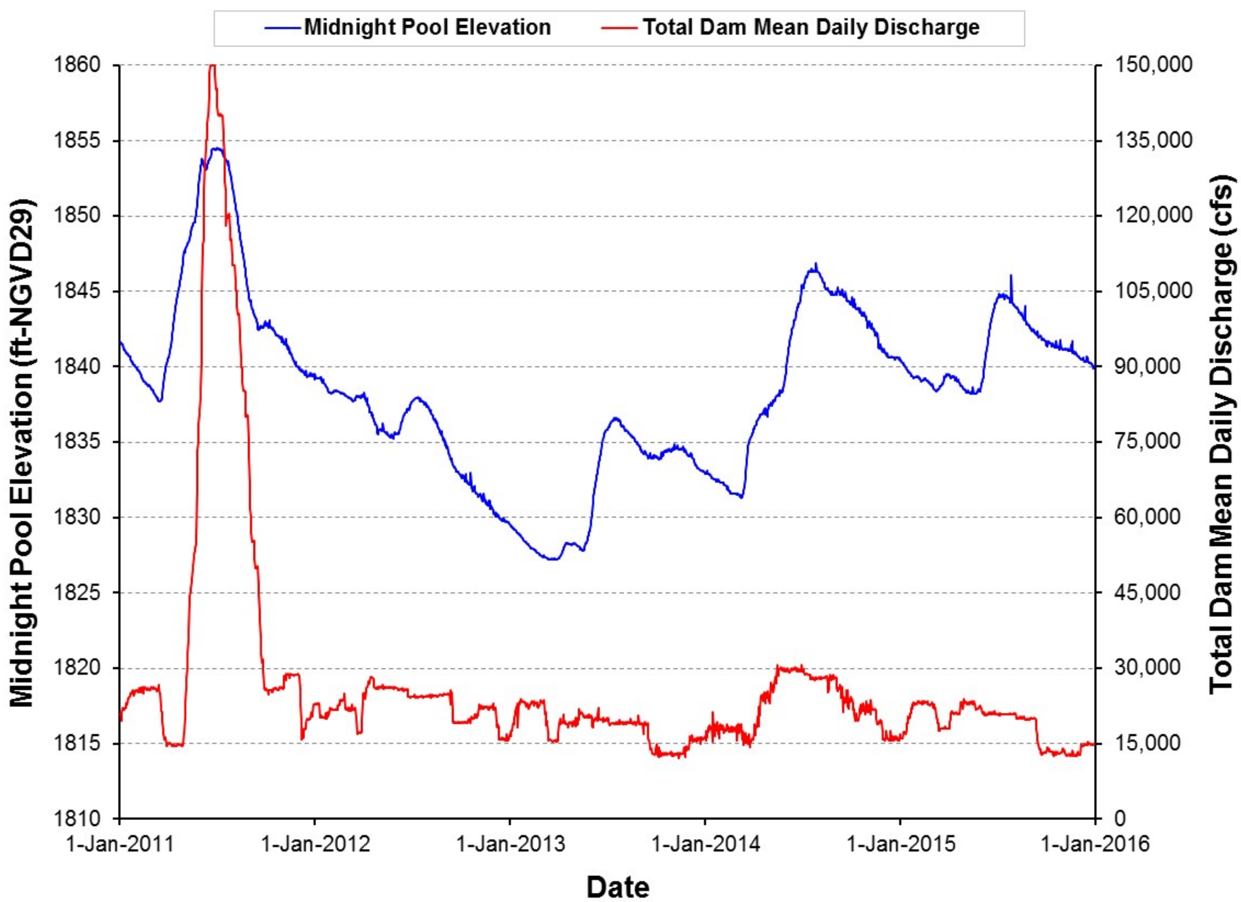


Figure 6-2. Lake Sakakawea midnight pool elevation and the mean daily discharge of Garrison Dam over the 5-year period 2011 through 2015.

6.1.2 WATER QUALITY STANDARDS CLASSIFICATIONS AND SECTION 303(D) LISTINGS

6.1.2.1 Lake Sakakawea

The State of North Dakota has classified Lake Sakakawea as a Class 1 lake. As such, the reservoir is to be protected for a coldwater fishery; swimming, boating, and other water recreation; irrigation; stock watering; wildlife; and municipal or domestic use after appropriate treatment. Pursuant to Section 303(d) of the Federal Clean Water Act, North Dakota has placed the Lake Sakakawea on the State's list of impaired waters citing impairment to the use of fish consumption. The impairment to fish consumption is attributed to methyl-mercury contamination of fish tissue. The State of North Dakota has issued a fish consumption advisory for Lake Sakakawea due to mercury concerns.

6.1.2.2 Missouri River Downstream of Garrison Dam

The State of North Dakota has classified the entire Missouri River as a Class 1 stream. As such, the river is to be suitable for the propagation and/or protection of resident fish species and other aquatic biota; swimming, boating, and other water recreation; irrigation; stock watering; wildlife; and municipal or domestic use after appropriate treatment. The river has not been placed on the State's Section 303(d) list of impaired waters. The State of North Dakota has issued a fish consumption advisory for the Missouri River due to mercury concerns.

6.1.3 MANAGEMENT OF COLDWATER FISHERY HABITAT IN LAKE SAKAKAWEA

North Dakota defines Class 1 lakes, including Lake Sakakawea, as waters capable of supporting growth of coldwater fish species (e.g. salmonids) and associated biota. Water temperature and dissolved oxygen levels are primary water quality factors that determine the suitability of water for coldwater aquatic life. The State of North Dakota has promulgated a hypolimnetic maximum temperature criterion of 15°C for Class 1 lakes and reservoirs that are thermally stratified. The State also adopted a water quality standard that states that Lake Sakakawea must maintain a minimum volume of water of 500,000 acre-feet that has a temperature of 15°C or less and a dissolved oxygen concentration of not less than 5 mg/L.

6.1.4 AMBIENT WATER QUALITY MONITORING

The District has monitored water quality conditions at the Garrison Project since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow to and outflow from the reservoir. Figure 6-3 shows the location of sites at the Garrison Project that were monitored by the District for water quality during the 5-year period 2011 through 2015. The near-dam location (i.e. site GARLK1390A) has been continuously monitored since 1980.

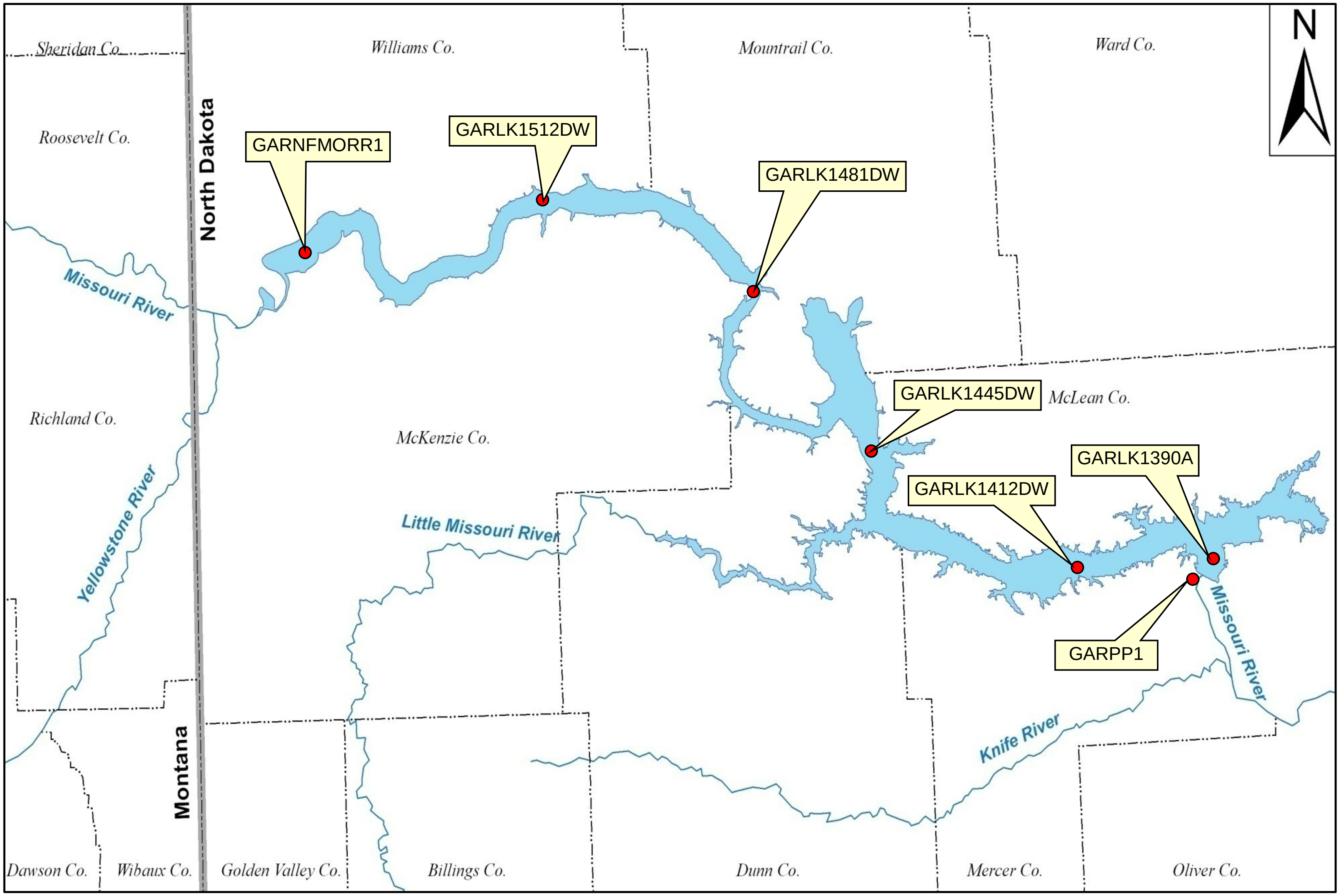


Figure 6-3. Location of sites where water quality monitoring was conducted by the District at the Garrison Project during the 5-year period 2011 through 2015.

6.2 WATER QUALITY IN LAKE SAKAKAWEA

6.2.1 EXISTING WATER QUALITY CONDITIONS

6.2.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Water quality conditions that were monitored in Lake Sakakawea at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, and GARLK1512DW from May through September during the 5-year period 2011 through 2015 are summarized in Plate 6-1, Plate 6-2, Plate 6-3, Plate 6-4, and Plate 6-5. A review of these results indicated possible water quality concerns regarding water temperature and dissolved oxygen for the support of coldwater fishery habitat in the hypolimnion of Lake Sakakawea. For assessment purposes, the bottom of the metalimnion and top of the hypolimnion is generally defined as the depth where a temperature drop of 1.0°C last occurs over a 1-meter depth increment. Monitored water quality conditions in the hypolimnion of Lake Sakakawea regularly exceeded the 15°C and 5 mg/L coldwater fishery habitat criteria for temperature and dissolved oxygen. Dissolved oxygen levels in the hypolimnion continually degrade along the reservoir bottom as summer progresses. Dissolved oxygen levels fall below 5 mg/L in the upstream reaches of the hypolimnion first and progress towards the dam. Also, as the summer progresses, low dissolved oxygen conditions move up from the reservoir bottom into the mid and upper elevations of the hypolimnion. This pinching off of coldwater habitat threatens the support of the coldwater fishery in the reservoir, especially under low pool levels during drought conditions. The assessment of coldwater fishery habitat in Lake Sakakawea is further discussed in Section 6.2.1.6. The lowest dissolved oxygen concentration measured in Lake Sakakawea over the 5-year period was 0.4 mg/L and occurred at the reservoir bottom at site GARLK1481DW in August 2012.

6.2.1.2 Summer Thermal Stratification and Dissolved Oxygen Conditions during 2015

6.2.1.2.1 Depth-Profile Plots

Depth-profile plots of temperature measurements taken at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, and GARLK1512DW during 2015 are shown in Plate 6-6. Depth-profile plots of dissolved oxygen measurements taken at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, and GARLK1512DW during 2015 are shown in Plate 6-7.

6.2.1.2.2 Longitudinal Contour Temperature Plots

Late-spring and summer thermal stratification of Lake Sakakawea during 2015 is described by longitudinal temperature contour plots along the length of the reservoir (Plate 6-8, Plate 6-9, Plate 6-10, Plate 6-11, and Plate 6-12). The contour plots are based on depth-profile temperature measurements taken monthly from May through September along the submerged Missouri River channel. As seen in the contour plots, water temperature in Lake Sakakawea varies longitudinally from the dam to the reservoir's upstream reaches and vertically from the reservoir surface to the bottom. The near-surface water in the upstream reaches of the reservoir warms up sooner in the spring than the near-surface water near the dam. By mid-summer a strong thermocline becomes established in the downstream reaches of the reservoir, and the near-surface waters of the entire reservoir above the thermocline are a fairly uniform temperature. As the near-surface waters of the reservoir cool in the late summer, the thermocline is pushed deeper and the wind-mixed upper waters are isothermal. The vertical variation in temperature is most prevalent in the deeper area of the reservoir towards the dam where a strong thermocline becomes established during the summer. The shallower upstream reaches of Lake Sakakawea do not exhibit much vertical variation of temperature during mid to late summer as wind action allows for the water column to completely mix.

6.2.1.2.3 Longitudinal Contour Dissolved Oxygen Plots

Dissolved oxygen contour plots were constructed along the length of Lake Sakakawea based on depth-profile measurements taken in May, June, July, August, and September of 2015 (Plate 6-13, Plate 6-14, Plate 6-15, Plate 6-16, and Plate 6-17). Dissolved oxygen conditions in Lake Sakakawea varied longitudinally from the dam to the reservoir's upstream reaches and vertically from the reservoir surface to the bottom. Dissolved oxygen levels below 5 mg/L first appeared near the reservoir bottom in the middle reaches of the reservoir in August. In September, dissolved oxygen concentrations were degraded (i.e. < 5 mg/L) along the bottom in the middle-lower reaches of the reservoir. The earlier occurrence of low dissolved oxygen concentrations in the near-bottom water of the middle reaches of Lake Sakakawea is attributed to the increased organic loading in the transition zone of the reservoir and the lesser hypolimnetic volume available for assimilation of the oxygen demand. As this material decomposes, a "pool" of water with low dissolved oxygen levels accumulates near the bottom in this area of the reservoir. Decomposition of autochthonous organic matter also occurs in the lacustrine zone and results in dissolved oxygen degradation as the summer progresses, although at a slower rate than what occurs in the transition zone. The recovery of near-bottom dissolved oxygen concentrations to saturation levels takes longer in the deeper areas of Lake Sakakawea because of the longer time needed for thermal stratification to breakdown and mixing within the water column to occur. The near-bottom outlet at the dam likely results in an interflow along the reservoir bottom that promotes the movement of oxygen-demanding material and low dissolved oxygen water from the middle reaches of the reservoir to the dam.

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

Paired near-surface and near-bottom water quality samples collected from Lake Sakakawea during the summer were compared. Near-surface conditions were represented by samples collected within 2-meters of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site GARLK1390A during the 5-year period 2011 through 2015. During the period a total of 20 paired samples were collected monthly from June through September. Box plots were constructed to display the distribution of the paired near-surface and near-bottom measurements for the following parameters: water temperature, dissolved oxygen, pH, alkalinity, total ammonia, and total phosphorus (Plate 6-18). 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-bottom conditions for water temperature ($p<0.001$), dissolved oxygen ($p<0.01$), and pH ($p<0.001$) were significantly lower than the sampled near-surface conditions. The sampled near-bottom conditions for alkalinity ($p<0.05$) and total phosphorus ($p<0.05$) were significantly higher than the sampled near-surface consitions.

6.2.1.4 Reservoir Trophic Status

Trophic State Index (TSI) values for Lake Sakakawea were calculated from monitoring data collected during the 5-year period 2011 through 2015 (Table 6-2). The calculated TSI values indicate that the lacustrine zone of the reservoir (i.e. sites GARLK1390A and GARLK1412DW) is mesotrophic, the transition zone (i.e. site GARLK1445DW) is mesotrophic, and the riverine zone (i.e. site GARLK1481DW and GARLK1512DW) is eutrophic.

Table 6-2. Mean Trophic State Index (TSI) values calculated for Lake Sakakawea. TSI values are based on monitoring at the identified five sites during the 5-year period 2011 through 2015.

Monitoring Site	Mean – TSI (Secchi Depth)	Mean – TSI (Total Phosphorus)	Mean – TSI (Chlorophyll)	Mean – TSI (Average)
GARLK1390A	47	38	50	45
GARLK1412DW	45	41	51	46
GARLK1445DW	49	40	54	48
GARLK1481DW	59	47	56	54
GARLK1512DW	71	51	59	61

Note: See Section 3.1.3 for discussion of TSI calculation.

6.2.1.5 Plankton Community

6.2.1.5.1 Phytoplankton

The relative abundance of phytoplankton, based on biovolume, in samples collected from Lake Sakakawea in May, July, and September 2015 is shown in Figure 6-4. Diatoms (Bacillariophyta), crytomonads (Cryptophyta), and golden-brown algae (Chrysophyta) are the most dominant phytoplankton groups present in Lake Sakakawea. Cyanobacteria genera sampled during 2015 included: *Anabaena, Aphanizomenon, Aphanocapsa, Chroococcus, Microcystis, Plantolyngbya, Raphidiopsis, Snowella,* and *Woronichinia.* No concentrations of the cyanobacteria toxin microcystin above 1 ug/L were monitored in Lake Sakakawea during the 5-year period 2011 through 2015 (Plate 6-1, Plate 6-2, Plate 6-3, Plate 6-4, and Plate 6-5).

6.2.1.5.2 Zooplankton

The zooplankton sampled in Lake Sakakawea during 2015 included three taxonomic groupings: Cladocerans, Copepods, and Rotifers. The relative abundance of these three taxonomic grouping in the zooplankton samples collected in 2015 is shown in Figure 6-5. Cladocerans and copepods dominated the zooplankton community in Lake Sakakawea.

6.2.1.6 Occurrence of Coldwater Fishery Habitat in Lake Sakakawea

The occurrence of coldwater fishery habitat (i.e. water temperature ≤ 15°C and dissolved oxygen ≥ 5 mg/L) in Lake Sakakawea was estimated from collected water temperature and dissolved oxygen depth-profile measurements and defined reservoir elevation and volume relationships. Plate 6-19 displays a plot of pool elevations and the coldwater fishery habitat estimated to have been present in Lake Sakakawea during the summers of the 5-year period 2011 through 2015. As previously mentioned, the State of North Dakota has promulgated a water quality standard that states that Lake Sakakawea must maintain a minimum volume of water of 500,000 acre-feet that has a temperature of 15°C or less and a dissolved oxygen concentration of not less than 5 mg/L. As seen in Plate 6-19, the 500,000 ac-ft coldwater fishery habitat criterion was not seemingly met in 2011 and 2012, but was seeminglymet in 2015.

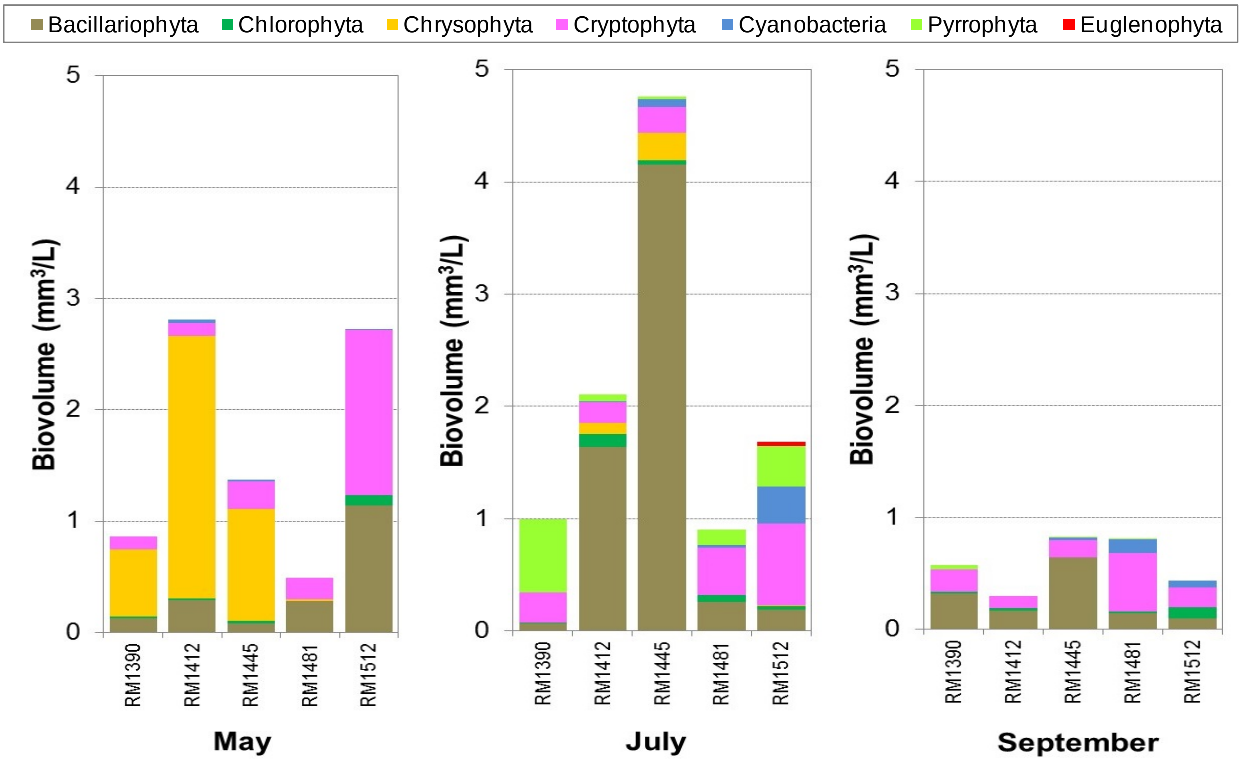


Figure 6-4. Relative abundance of phytoplankton in samples collected from Lake Sakakawea during 2015.

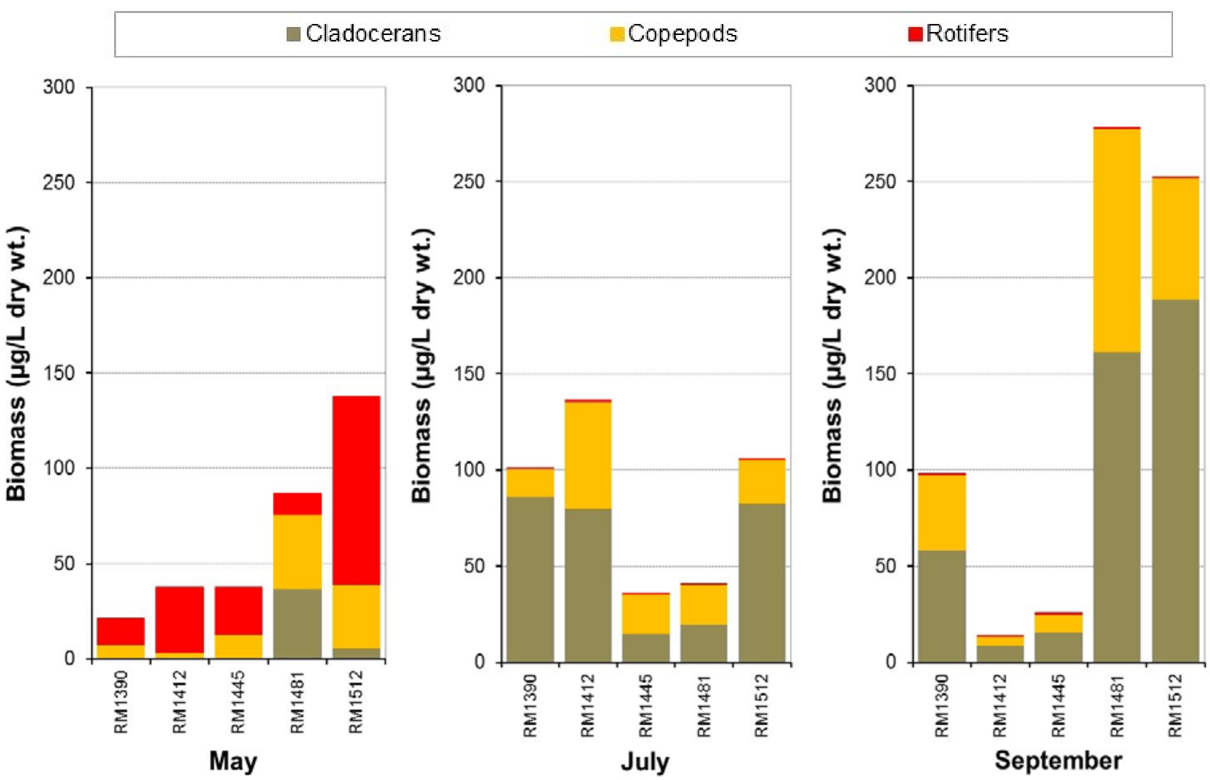


Figure 6-5. Relative abundance of zooplankton in samples collected from Lake Sakakawea during 2015**.**

The occurrence of coldwater habitat in Lake Sakakawea is believed to be highly dependent on pool elevation. Since coldwater habitat only occurs in the hypolimnion of the reservoir during the summer, the size of the hypolimnion will directly determine the amount of coldwater habitat potentially available. The upper extent of the hypolimnion is delineated by the thermocline (i.e. plane of rapid temperature decline) which separates the colder hypolimnion from the warmer, less dense water of the epilimnion. Depending on meterologic factors, the thermocline in an individual reservoir will generally be established at a similar depth from year to year. Therefore, a greater hypolimnetic volume will tend to occur under higher pool elevations and a lesser hypolimnetic volume will tend to occur under lower pool elevations. The pool elevation in late-spring and early-summer, when the thermocline first becomes established, is especially important as later changes in pool elevations are mitigated somewhat by the stratification already established. A larger hypolimnetic volume also has a greater assimilative capacity for oxygen demanding materials which can degrade dissolved oxygen levels in the hypolimnion below the coldwater fishery habitat standard of 5 mg/L.

6.2.2 WATER QUALITY TRENDS (1980 THROUGH 2015)

Water quality trends over the 36-year period of 1980 through 2015 were determined for Lake Sakakawea for Secchi depth, total phosphorus, chlorophyll *a*, and TSI (i.e. trophic status). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam, ambient monitoring site (i.e. site GARLK1390A). Plate 6-20 displays a scatter-plot of the collected data for the four parameters, a linear regression trend line, and the significance of the trend line (i.e. $\alpha = 0.05$). For the assessment period, Lake Sakakawea exhibited no significant trend for for any of the four parametrers. Over the 36-year period, the reservoir has generally remained in a mesotrophic state.

6.3 EXISTING WATER QUALITY CONDITIONS OF INFLOWS TO LAKE SAKAKAWEA

6.3.1 MISSOURI RIVER

6.3.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

The water quality conditions that were monitored in the Missouri River near Williston, ND (i.e. site GARNFMORR1) monthly from May through October during the 5-year period 2011 through 2015 are summarized in Plate 6-21 and Plate 6-22. A review of these results indicated no major water quality concerns. It is noted that monitored levels of total aluminum greatly exceeded the acute total aluminum criterion for aquatic life protection; however, the monitored levels of dissolved aluminum were below the criterion except for one observation. It is not believed the monitored aluminum levels are indicative of a water quality problem. It is also noted that very high levels of total iron and total manganese were monitored. The high levels of total aluminum, iron, and manganese are believed to be a natural condition associated with the geology and soils of the region. All of the maximum levels for the analyzed total metals were measured in single sample collected on 27-August-2014 when streamflow in the Missouri River was 31,300 cfs and total suspended solids was measured at 3,550 mg/L.

6.3.1.2 Missouri River Inflow Nutrient Flux Conditions

Nutrient flux rates for the Missouri River inflow to Lake Sakakawea over the 5-year period 2011 through 2015 were calculated based on near-surface water quality samples collected near Williston, ND (i.e. site GARNFMORR1) and the instantaneous flow conditions at the time of sample collection (Table 6-3). It must be recognized that the concentrations of particulate-associated constituents can vary significantly from the river surface to its bottom because of the sinking of particulate matter and its potential transport nearer the river bottom. Since the instantaneous concentration of particulate-associated constituents (i.e. total phosphorus) are likely higher nearer the river bottom, near-surface grab samples likely under estimate the "true" water-column composite concentration for these constituents. Thus, the flux rate given for total phosphorus in Table 6-3 should be considered a minimum estimate with the actual flux rate likely being higher. The maximum flux rates for all the constituents are believed to be attributed to higher nonpoint-source loadings during runoff conditions.

Table 6-3. Summary of nutrient flux rates (kg/sec) calculated for the Missouri River near Williston, ND (i.e. site GARNFMORR1) during April through October over the 5-year period 2011 through 2015.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	33	33	33	33	33	33	33
Mean	30,145	0.0356	0.5898	0.1001	0.3007	0.1151	4.3138
Median	18,949	0.0097	0.4019	0.0295	0.0758	0.0054	2.5712
Minimum	7,580	n.d.	0.0253	n.d.	0.0023	n.d.	0.4431
Maximum	169,696	0.1993	2.2512	0.5766	3.6519	2.9792	22.1035

Note: Nondetect values set to 0 for flux calculations.

6.3.1.3 <u>Continuous Water Temperature Monitoring of the Missouri River at USGS Gage Site 06330000 near Williston, North Dakota</u>

Through an agreement with the USGS, a water temperature monitoring probe was added to the USGS's gage (06330000) on the Missouri River near Williston, ND (i.e. site GARNFMORR1). Beginning in 2005, water temperature measurements were recorded at the site. Plate 6-23 plots mean daily water temperature and flow determined for 2015.

6.3.2 LITTLE MISSOURI RIVER

6.3.2.1 <u>Statistical Summary and Comparison to Applicable Water Quality Standards Criteria</u>

The water quality conditions that were monitored in the Little Missouri River near Mandaree, ND (i.e. site GARNFLMOR1) monthly from May through October during 2015 are summarized in Plate 6-24 and Plate 6-25. A review of these results indicated high total metals concentrations. The high levels of of total metals are believed to be a natural condition associated with the geology and soils of the region

6.3.2.2 <u>Little Missouri River Inflow Nutrient Flux Conditions</u>

Nutrient flux rates for the Little Missouri River inflow to Lake Sakakawea during 2015 were calculated based on near-surface water quality samples collected near Mandaree, ND (i.e. site GARNFLMOR1) and the instantaneous flow conditions at the time of sample collection (Table 6-4). It must be recognized that the concentrations of particulate-associated constituents can vary significantly from the river surface to its bottom because of the sinking of particulate matter and its potential transport nearer the river bottom. Since the instantaneous concentration of particulate-associated constituents (i.e. total phosphorus) are likely higher nearer the river bottom, near-surface grab samples likely under estimate the "true" water-column composite concentration for these constituents. Thus, the flux rate given for total phosphorus in Table 6-4 should be considered a minimum estimate with the actual flux rate likely being higher. The maximum flux rates for all the constituents are believed to be attributed to higher nonpoint-source loadings during runoff conditions.

Table 6-4. Summary of nutrient flux rates (kg/sec) calculated for the Little Missouri River near Mandaree, ND (i.e. site GARNFLMOR1) during April through October of 2015.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	7	7	7	7	7	7	7
Mean	178	0.0002	0.0175	0.0022	0.0103	0.0007	0.0871
Median	68	0.0001	0.0031	0.0003	0.0006	n.d.	0.0189
Minimum	3	n.d.	0.0002	n.d.	n.d.	n.d.	0.0008
Maximum	748	0.0006	0.0902	0.0129	0.0566	0.0044	0.3147

Note: Nondetect values set to 0 for flux calculations.

6.4 WATER QUALITY AT THE GARRISON POWERPLANT

6.4.1 STATISTICAL SUMMARY AND COMPARISON TO APPLICABLE WATER QUALITY STANDARDS CRITERIA

Plate 6-26 and Plate 6-27 summarize the water quality conditions that were monitored from water discharged through Garrison Dam during the 5-year period 2011 through 2015. The monitored water quality conditions do not indicate any significant water quality concerns. All dissolved oxygen concentrations measured during the 2011 through 2015 period were above 5 mg/L. The maximum water temperature measured during the 5-year period was 16.5°C. The monitored water temperatures are believed supportive of the cool-water fishery that exists in the Garrison Dam tailwaters.

6.4.2 TEMPERATURE, DISSOLVED OXYGEN, AND DAM DISCHARGE TIME-SERIES PLOTS

Hourly temperature and dam discharge recorded at the Garrison powerplant during 2015 were used to construct an annual time-series plot (Plate 6-28). Monitored water temperatures showed seasonal cooling and warming through the year. Daily water temperatures remained fairly stable during the winter, early spring, and late fall and exhibited considerable variability during the late spring, summer, and early fall. When thermal stratification becomes established in Lake Sakakawea during the late spring, the temperature of the water discharged through the dam becomes highly dependent upon the discharge rate of the dam. 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 intake channel leading to the intake structure (Figure 6-1). Water is likely drawn from an extended vertical zone in Lake Sakakawea year-round, but is only evident in the temperatures monitored at the powerplant during thermal stratification of the reservoir in the summer.

Hourly dissolved oxygen and dam discharge recorded at the Garrison powerplant during 2015 were used to construct an annual time-series plot (Plate 6-29). Dissolved oxygen levels remained relatively high and stable during the winter, steadily declined through the spring and summer, and steadily increased during the fall. The lowest dissolved oxygen levels occurred during the late summer/early fall period. The higher winter, declining spring, and increasing fall dissolved oxygen concentrations are attributed to decreasing dissolved oxygen solubility with warmer water temperatures. The decreasing dissolved oxygen in the July to September period is attributed to ongoing degradation of dissolved oxygen in the lower hypolimnion in Lake Sakakawea as the summer progressed. Water is withdrawn from Lake Sakakawea into the dam's power tunnels approximately 2 feet above the reservoir bottom.

6.4.3 NUTRIENT FLUX CONDITIONS OF THE GARRISON DAM DISCHARGE TO THE MISSOURI RIVER

Nutrient flux rates for the Garrison Dam discharge to the Missouri River over the 5-year period 2011 through 2015 were calculated based on samples taken from the Garrison powerplant (i.e. site GARPP1) and the dam discharge at the time of sample collection (Table 6-5). During this 5-year period, all water discharged at Garrison Dam was through the powerplant except during 2011. During 2011 dam discharges occurred via the powerplant, flood tunnels, and spillway. The flood tunnels are located alongside the powerplant tunnels and draw water from the bottom of Lake Sakakawea. Water quality samples collected from the powerplant flow are believed to have been representative of water quality conditions in the flood tunnel flow. The powerplant flow water quality samples were used to calculate flux rates for the combined powerplant and flood tunnel discharge. The spillway discharge is remote from the powerplant and flood tunnel discharge and flux rates for the spillway flow were not calculated. The samples collected in the powerplant are taken from the raw water supply line and are believed to be unbiased regarding particulate-associated constituents. Therefore, the flux rates calculated for the Garrison Dam discharge give an unbiased estimate of the flux rates for all the constituents, including total phosphorus. The maximum flux rates for all the constituents are believed to be attributed to higher dam discharges.

Table 6-5. Summary of nutrient flux rates (kg/sec) calculated for the Garrison Dam discharge to the Missouri River (i.e. site GARPP1) during January through December over the 5-year period 2011 through 2015.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	40	40	40	40	40	40	40
Mean	30,284	0.0134	0.3456	0.0686	0.0065	0.0019	2.7395
Median	24,921	n.d.	0.1745	0.0346	0.0022	n.d.	2.1910
Minimum	8,434	n.d.	n.d.	n.d.	n.d.	n.d.	0.8610
Maximum	104,561	0.1132	1.7049	0.4361	0.0369	0.0175	9.7705

Note: Nondetectable values set to 0 for flux calculations.

6.5 WATER QUALITY IN THE MISSOURI RIVER DOWNSTREAM OF GARRISON DAM

Through an agreement with the USGS, a water temperature monitoring probe was added to the USGS's gage on the Missouri River at Bismarck, ND in 2005. USGS gage number 06342500 at Bismarck, ND is located at RM1314.7 and is approximately 75 miles downstream of Garrison Dam. Plate 6-30 plots the mean daily flows and water temperatures monitored at the Garrison powerplant and USGS gage at Bismarck, ND in 2015. Annually, the mean daily water temperature of the Missouri River at Bismarck is warmer than the Garrison Dam discharge from April through September and generally cooler from October through March.

Plate 6-1. Summary of monthly (May through September) water quality conditions monitored in Lake Sakakawea near Garrison Dam (Site GARLK1390A) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	26	1840.9	1841.6	1828.3	1854.2	-----	-----	-----
Water Temperature (°C)	0.1	1,280	12.6	12.1	3.3	24.8	29.4[1,3]	0	0%
Hypolimnion Water Temperature (°C)[E]	0.1	368	10.4	10.5	5.9	16.9	15.0[2,3]	17	5%
Dissolved Oxygen (mg/L)	0.1	1,280	9.2	8.9	3.9	12.6	5[1,4]	31	2%
Dissolved Oxygen (% Sat.)	0.1	1,280	88.3	92.3	36.8	119.1	-----	-----	-----
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	365	7.8	7.5	3.9	11.3	5[1,4]	30	8%
Specific Conductance (uS/cm)	1	1,280	721	739	599	783	-----	-----	-----
pH (S.U.)	0.1	1,280	8.1	8.1	7.3	8.7	7.0[1,4], 9.0[1,3]	0	0%
Turbidity (NTUs)	1	1,279	-----	1	n.d.	329	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	1,280	357	363	181	470	-----	-----	-----
Secchi Depth (M)	0.02	25	2.64	2.35	1.07	5.79	-----	-----	-----
Alkalinity, Total (mg/L)	7	50	159	159	144	170	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	50	3.7	3.6	2.0	5.9	-----	-----	-----
Chloride (mg/L)	1	30	10	10	8	11	100[1,3]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	1,225	4	3	n.d.	20	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	25	4	3	n.d.	14	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	50	26	24	18	48	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	50	521	510	394	708	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	50	-----	n.d.	n.d.	0.08	4.6[1,3,5], 2.0[1,5,6]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	50	0.3	0.3	n.d.	0.6	-----	-----	-----
Nitrogen, Nitrate-Nitrite N, Total (mg/L)	0.02	50	-----	0.07	n.d.	0.40	1.0[1,3], 0.25[7]	0, 1	0%, 2%
Nitrogen, Total (mg/L)	0.1	50	0.3	0.3	n.d.	0.8	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	50	-----	n.d.	n.d.	0.02	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	50	-----	n.d.	n.d.	0.08	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	50	-----	n.d.	n.d.	0.02	0.02[7]	4	8%
Sulfate (mg/L)	1	50	207	215	152	230	250[1,3]	0	0%
Suspended Solids, Total (mg/L)	4	50	-----	n.d.	n.d.	106	-----	-----	-----
Microcystin, Extracellular (ug/L)	0.1	25	-----	n.d.	n.d.	0.1	-----	-----	-----
Hexane Extractable Material (mg/L)	1.4	18	-----	n.d.	n.d.	1.7	-----	-----	-----
Diesel Range Organics (mg/L)	0.05	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Total Purgeable Hydrocarbon - (ug/L)	3	5	-----	n.d.	n.d.	5	-----	-----	-----
Benzene, Total (ug/L)	0.5	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Eythylbenzene, Total (ug/L)	0.5	4	----	n.d.	n.d.	n.d.	-----	-----	-----
Hexane, Total (ug/L)	0.7	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Naphthalene, Total (ug/L)	0.6	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Toluene, Total (ug/L)	0.5	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Xylenes, Total (ug/L)	1	5	----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

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

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

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

(D) Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.
- (1) Criteria for Class 1 lakes.
- (2) Applies to hypolimnion of Class 1 lakes during periods of thermal stratification.
- (3) Daily maximum criterion (monitoring results directly comparable to criterion).
- (4) Daily minimum criterion (monitoring results directly comparable to criterion).
- (5) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (6) 30-day average criterion (monitoring results not directly comparable to criterion).
- (7) Nutrient guideline for lake or reservoir improvement or management.

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

Plate 6-2. Summary of monthly (May through September) water quality conditions monitored in Lake Sakakawea near Beulah Bay (Site GARLK1412DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	25	1840.9	1841.9	1828.3	1854.2	-----	-----	-----
Water Temperature (°C)	0.1	1,075	13.1	13.1	3.7	25.3	29.4[1,3]	0	0%
Hypolimnion Water Temperature (°C)[E]	0.1	311	10.9	11.0	6.7	16.9	15.0[2,3]	16	5%
Dissolved Oxygen (mg/L)	0.1	1,078	9.1	8.7	2.9	13.0	5[1,4]	19	2%
Dissolved Oxygen (% Sat.)	0.1	1,078	88.8	92.9	27.8	119.9	-----	-----	-----
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	311	7.6	7.3	2.9	10.9	5[1,4]	27	9%
Specific Conductance (uS/cm)	1	1,078	721	738	601	790	-----	-----	-----
pH (S.U.)	0.1	1,078	8.0	8.1	7.1	8.6	7.0[1,4], 9.0[1,4]	0	0%
Turbidity (NTUs)	1	1,075	-----	1	n.d.	38	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	1,078	357	368	154	450	-----	-----	-----
Secchi Depth (M)	0.02	24	3.09	3.05	1.37	7.62	-----	-----	-----
Alkalinity, Total (mg/L)	7	50	158	160	139	168	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	50	3.7	3.7	2.2	5.0	-----	-----	-----
Chloride (mg/L)	1	30	10	10	9	13	100[1,3]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	1,078	-----	3	n.d.	30	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	25	-----	4	n.d.	20	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	50	27	25	18	50	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	50	520	511	390	700	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	50	-----	n.d.	n.d.	0.06	4.6[1,3,5], 2.0[1,5,6]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	50	0.5	0.3	n.d.	2.0	-----	-----	-----
Nitrogen, Nitrate-Nitrite N, Total (mg/L)	0.02	50	-----	0.07	n.d.	0.40	1.0[1,3], 0.25[7]	0, 2	0%, 4%
Nitrogen, Total (mg/L)	0.1	50	0.6	0.4	0.1	2.1	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	50	-----	n.d.	n.d.	0.03	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	50	-----	n.d.	n.d.	0.04	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	50	-----	n.d.	n.d.	0.02	0.02[7]	3	6%
Sulfate (mg/L)	1	50	208	216	149	233	250[1,3]	0	0%
Suspended Solids, Total (mg/L)	4	50	-----	n.d.	n.d.	29	-----	-----	-----
Microcystin, Extracellular (ug/L)	0.1	25	-----	n.d.	n.d.	0.3	-----	-----	-----
Hexane Extractable Material (mg/L)	1.4	18	-----	n.d.	n.d.	2.0	-----	-----	-----
Diesel Range Organics (mg/L)	0.05	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Total Purgeable Hydrocarbon - (ug/L)	3	5	-----	n.d.	n.d.	4	-----	-----	-----
Benzene, Total (ug/L)	0.5	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Eythylbenzene, Total (ug/L)	0.5	4	----	n.d.	n.d.	n.d.	-----	-----	-----
Hexane, Total (ug/L)	0.7	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Naphthalene, Total (ug/L)	0.6	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Toluene, Total (ug/L)	0.5	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Xylenes, Total (ug/L)	1	5	----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

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

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

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

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

- (1) Criteria for Class 1 lakes.
- (2) Applies to hypolimnion of Class 1 lakes during periods of thermal stratification.
- (3) Daily maximum criterion (monitoring results directly comparable to criterion).
- (4) Daily minimum criterion (monitoring results directly comparable to criterion).
- (5) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (6) 30-day average criterion (monitoring results not directly comparable to criterion).
- (7) Nutrient guideline for lake or reservoir improvement or management.

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

Plate 6-3. Summary of monthly (May through September) water quality conditions monitored in Lake Sakakawea near Deepwater Bay (Site GARLK1445DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	24	1840.6	1840.2	1828.3	1854.3	-----	-----	-----
Water Temperature (°C)	0.1	820	14.3	15.0	4.8	23.8	29.4[1,3]	0	0%
Hypolimnion Water Temperature (°C)[E]	0.1	287	11.4	11.2	7.5	18.7	15.0[2,3]	20	7%
Dissolved Oxygen (mg/L)	0.1	820	8.3	8.3	2.2	13.5	5[1,4]	82	10%
Dissolved Oxygen (% Sat.)	0.1	820	83.1	90.4	22.6	134.2	-----	-----	-----
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	284	6.8	7.3	2.2	10.1	5[1,4]	80	28%
Specific Conductance (uS/cm)	1	820	707	705	570	807	-----	-----	-----
pH (S.U.)	0.1	820	8.1	8.1	7.2	8.6	7.0[1,4], 9.0[1,4]	0	0%
Turbidity (NTUs)	1	817	2	1	n.d.	96	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	820	359	358	169	479	-----	-----	-----
Secchi Depth (M)	0.02	24	2.27	2.22	1.17	3.66	-----	-----	-----
Alkalinity, Total (mg/L)	7	48	153	153	127	170	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	48	3.8	3.7	2.2	7.6	-----	-----	-----
Chloride (mg/L)	1	30	10	10	8	12	100[1,3]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	814	5	4	n.d.	23	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	24	6	5	n.d.	22	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	48	28	27	17	66	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	48	512	493	366	716	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	48	-----	0.02	n.d.	0.10	4.6[1,3,5], 2.0[1,5,6]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	48	0.4	0.4	n.d.	0.7	-----	-----	-----
Nitrogen, Nitrate-Nitrite N, Total (mg/L)	0.02	48	-----	0.07	n.d.	0.30	1.0[1,3], 0.25[7]	0, 2	0%, 4%
Nitrogen, Total (mg/L)	0.1	48	0.5	0.5	n.d.	1.0	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	48	-----	n.d.	n.d.	0.04	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	48	-----	0.02	n.d.	0.06	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	48	-----	n.d.	n.d.	0.03	0.02[7]	1	2%
Sulfate (mg/L)	1	48	202	200	151	245	250[1,3]	0	0%
Suspended Solids, Total (mg/L)	4	48	-----	4	n.d.	25	-----	-----	-----
Microcystin, Extracellular (ug/L)	0.1	24	-----	n.d.	n.d.	0.1	-----	-----	-----
Hexane Extractable Material (mg/L)	1.4	18	-----	n.d.	n.d.	2.8	-----	-----	-----
Diesel Range Organics (mg/L)	0.05	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Total Purgeable Hydrocarbon - (ug/L)	3	5	-----	n.d.	n.d.	4	-----	-----	-----
Benzene, Total (ug/L)	0.5	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Eythylbenzene, Total (ug/L)	0.5	4	----	n.d.	n.d.	n.d.	-----	-----	-----
Hexane, Total (ug/L)	0.7	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Naphthalene, Total (ug/L)	0.6	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Toluene, Total (ug/L)	0.5	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Xylenes, Total (ug/L)	1	5	----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

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

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

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

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

- (1) Criteria for Class 1 lakes.
- (2) Applies to hypolimnion of Class 1 lakes during periods of thermal stratification.
- (3) Daily maximum criterion (monitoring results directly comparable to criterion).
- (4) Daily minimum criterion (monitoring results directly comparable to criterion).
- (5) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (6) 30-day average criterion (monitoring results not directly comparable to criterion).
- (7) Nutrient guideline for lake or reservoir improvement or management.

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

Plate 6-4. Summary of monthly (May through September) water quality conditions monitored in Lake Sakakawea near New Town (Site GARLK1481DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	25	1841.0	1842.0	1828.3	1854.3	-----	-----	-----
Water Temperature (°C)	0.1	585	16.2	16.8	6.7	24.3	29.4[1,3]	0	0%
Hypolimnion Water Temperature (°C)[E]	0.1	121	13.5	13.5	9.0	20.8	15.0[2,3]	42	35%
Dissolved Oxygen (mg/L)	0.1	585	7.9	8.2	0.4	11.6	5[1,4]	63	11%
Dissolved Oxygen (% Sat.)	0.1	585	83.0	90.2	4.4	123.8	-----	-----	-----
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	121	5.3	4.8	0.4	10.8	5[1,4]	63	52%
Specific Conductance (uS/cm)	1	585	665	686	473	842	-----	-----	-----
pH (S.U.)	0.1	585	8.1	8.1	7.3	8.6	7.0[1,4], 9.0[1,4]	0	0%
Turbidity (NTUs)	1	585	10	7	n.d.	52	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	585	344	347	170	494	-----	-----	-----
Secchi Depth (M)	0.02	24	1.13	1.07	0.46	2.74	-----	-----	-----
Alkalinity, Total (mg/L)	7	50	147	149	113	176	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	50	3.7	3.5	2.6	7.2	-----	-----	-----
Chloride (mg/L)	1	30	10	10	6	13	100[1,3]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	581	7	6	n.d.	25	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	25	7	6	n.d.	18	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	50	31	29	16	58	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	50	509	508	316	736	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	50	-----	0.02	n.d.	0.16	4.6[1,3,5], 1.7[1,5,6]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	50	0.4	0.4	n.d.	1.0	-----	-----	-----
Nitrogen, Nitrate-Nitrite N, Total (mg/L)	0.02	50	-----	0.06	n.d.	0.31	1.0[1,3], 0.25[7]	0, 4	0%, 8%
Nitrogen, Total (mg/L)	0.1	50	0.5	0.5	0.1	1.3	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	50	-----	n.d.	n.d.	0.03	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	50	0.03	0.03	n.d.	0.06	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	50	-----	n.d.	n.d.	0.02	0.02[7]	0	0%
Sulfate (mg/L)	1	50	189	191	118	251	250[1,3]	1	2%
Suspended Solids, Total (mg/L)	4	50	9	8	n.d.	27	-----	-----	-----
Microcystin, Extracellular (ug/L)	0.1	25	-----	n.d.	n.d.	0.1	-----	-----	-----
Hexane Extractable Material (mg/L)	1.4	18	-----	n.d.	n.d.	2.2	-----	-----	-----
Diesel Range Organics (mg/L)	0.05	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Total Purgeable Hydrocarbon - (ug/L)	3	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Benzene, Total (ug/L)	0.5	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Eythylbenzene, Total (ug/L)	0.5	4	----	n.d.	n.d.	n.d.	-----	-----	-----
Hexane, Total (ug/L)	0.7	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Naphthalene, Total (ug/L)	0.6	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Toluene, Total (ug/L)	0.5	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Xylenes, Total (ug/L)	1	5	----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

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

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

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

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

- (1) Criteria for Class 1 lakes.
- (2) Applies to hypolimnion of Class 1 lakes during periods of thermal stratification.
- (3) Daily maximum criterion (monitoring results directly comparable to criterion).
- (4) Daily minimum criterion (monitoring results directly comparable to criterion).
- (5) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (6) 30-day average criterion (monitoring results not directly comparable to criterion).
- (7) Nutrient guideline for lake or reservoir improvement or management.

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

Plate 6-5. Summary of monthly (May through September) water quality conditions monitored in Lake Sakakawea near White Tail Bay (Site GARLK1512DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	23	1841.3	1842.0	1839.9	1854.3	-----	-----	-----
Water Temperature (°C)	0.1	204	18.9	19.5	11.1	25.1	29.4[1,3]	0	0%
Hypolimnion Water Temperature (°C)[E]	0.1	11	22.8	23.5	19.7	23.6	15.0[2,3]	11	100%
Dissolved Oxygen (mg/L)	0.1	204	8.5	8.4	1.3	10.7	5[1,4]	2	1%
Dissolved Oxygen (% Sat.)	0.1	204	94.3	94.5	15.2	113.4	-----	-----	-----
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	11	6.2	7.2	1.3	7.5	5[1,4]	2	18%
Specific Conductance (uS/cm)	1	204	660	646	405	835	-----	-----	-----
pH (S.U.)	0.1	204	8.2	8.36	7.4	8.6	7.0[1,4], 9.0[1,4]	0	0%
Turbidity (NTUs)	1	202	53	20	1	3000	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	204	330	344	168	438	-----	-----	-----
Secchi Depth (M)	0.02	23	0.51	0.46	0.20	1.22	-----	-----	-----
Alkalinity, Total (mg/L)	7	23	146	146	101	182	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	23	3.5	3.3	2.5	4.7	-----	-----	-----
Chlorophyll *a* (ug/L) – Field Probe	1	204	10	8	1	41	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	23	9	8	3	32	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	23	32	26	20	95	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	23	490	488	220	706	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	23	-----	n.d.	n.d.	0.09	3.1[1,3,5], 1.1[1,5,6]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	23	0.4	0.4	n.d.	0.9	-----	-----	-----
Nitrogen, Nitrate-Nitrite N, Total (mg/L)	0.02	23	-----	n.d.	n.d.	0.50	1.0[1,3], 0.25[7]	0, 1	0%, 4%
Nitrogen, Total (mg/L)	0.1	23	0.4	0.4	n.d.	0.9	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	23	-----	n.d.	n.d.	0.06	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	23	0.04	0.04	n.d.	0.07	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	23	-----	n.d.	n.d.	0.02	0.02[7]	0	0%
Sulfate (mg/L)	1	23	184	177	94	240	250[1,3]	0	0%
Suspended Solids, Total (mg/L)	4	23	15	15	4	34	-----	-----	-----
Microcystin, Extracellular (ug/L)	0.1	23	-----	n.d.	n.d.	0.1	-----	-----	-----
Hexane Extractable Material (mg/L)	1.2	16	-----	n.d.	n.d.	1.6	-----	-----	-----
Diesel Range Organics (mg/L)	0.05	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Total Purgeable Hydrocarbon - (ug/L)	3	5	-----	n.d.	n.d.	4	-----	-----	-----
Benzene, Total (ug/L)	0.5	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Eythylbenzene, Total (ug/L)	0.5	4	----	n.d.	n.d.	n.d.	-----	-----	-----
Hexane, Total (ug/L)	0.7	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Naphthalene, Total (ug/L)	0.6	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Toluene, Total (ug/L)	0.5	5	----	n.d.	n.d.	n.d.	-----	-----	-----
Xylenes, Total (ug/L)	1	5	----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

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

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

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

(D) Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.
- (1) Criteria for Class 1 lakes.
- (2) Applies to hypolimnion of Class 1 lakes during periods of thermal stratification.
- (3) Daily maximum criterion (monitoring results directly comparable to criterion).
- (4) Daily minimum criterion (monitoring results directly comparable to criterion).
- (5) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (6) 30-day average criterion (monitoring results not directly comparable to criterion).
- (7) Nutrient guideline for lake or reservoir improvement or management.

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

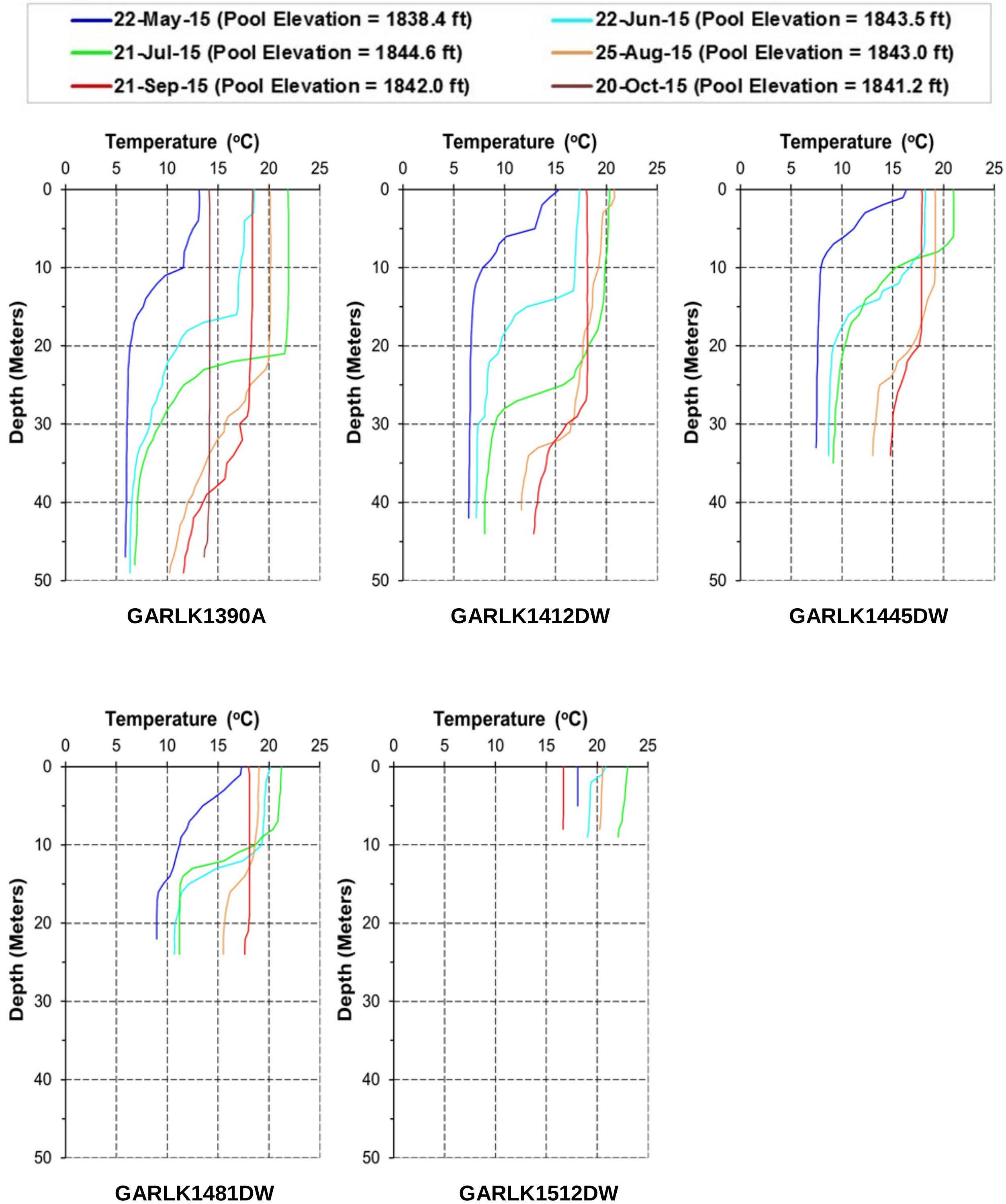


Plate 6-6. Depth-profile plots of temperature conditions of Lake Sakakawea measured at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, and GARLK1512DW during 2015.

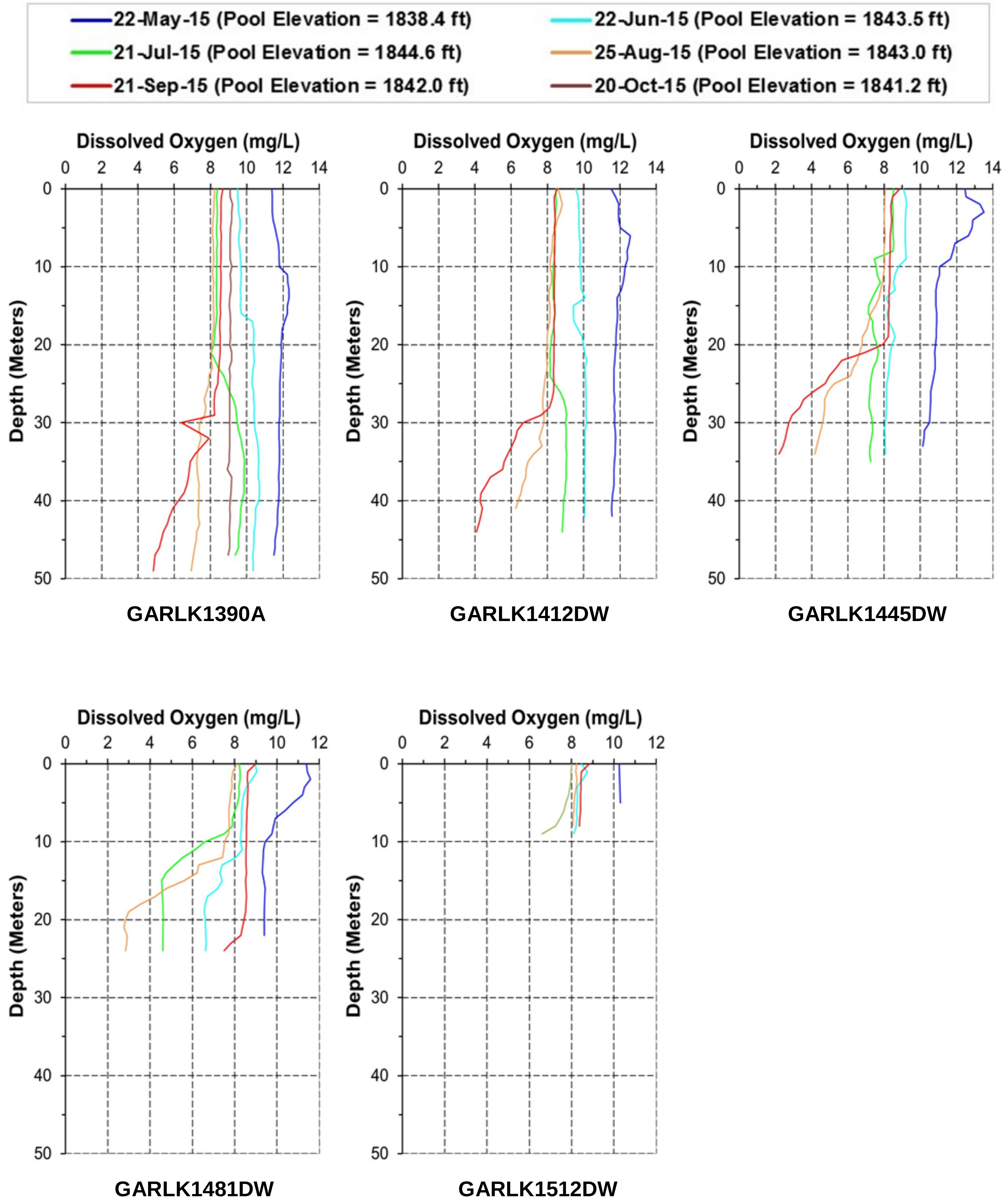


Plate 6-7. Depth-profile plots of dissolved oxygen conditions of Lake Sakakawea measured at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, and GARLK1512DW during 2015**.**

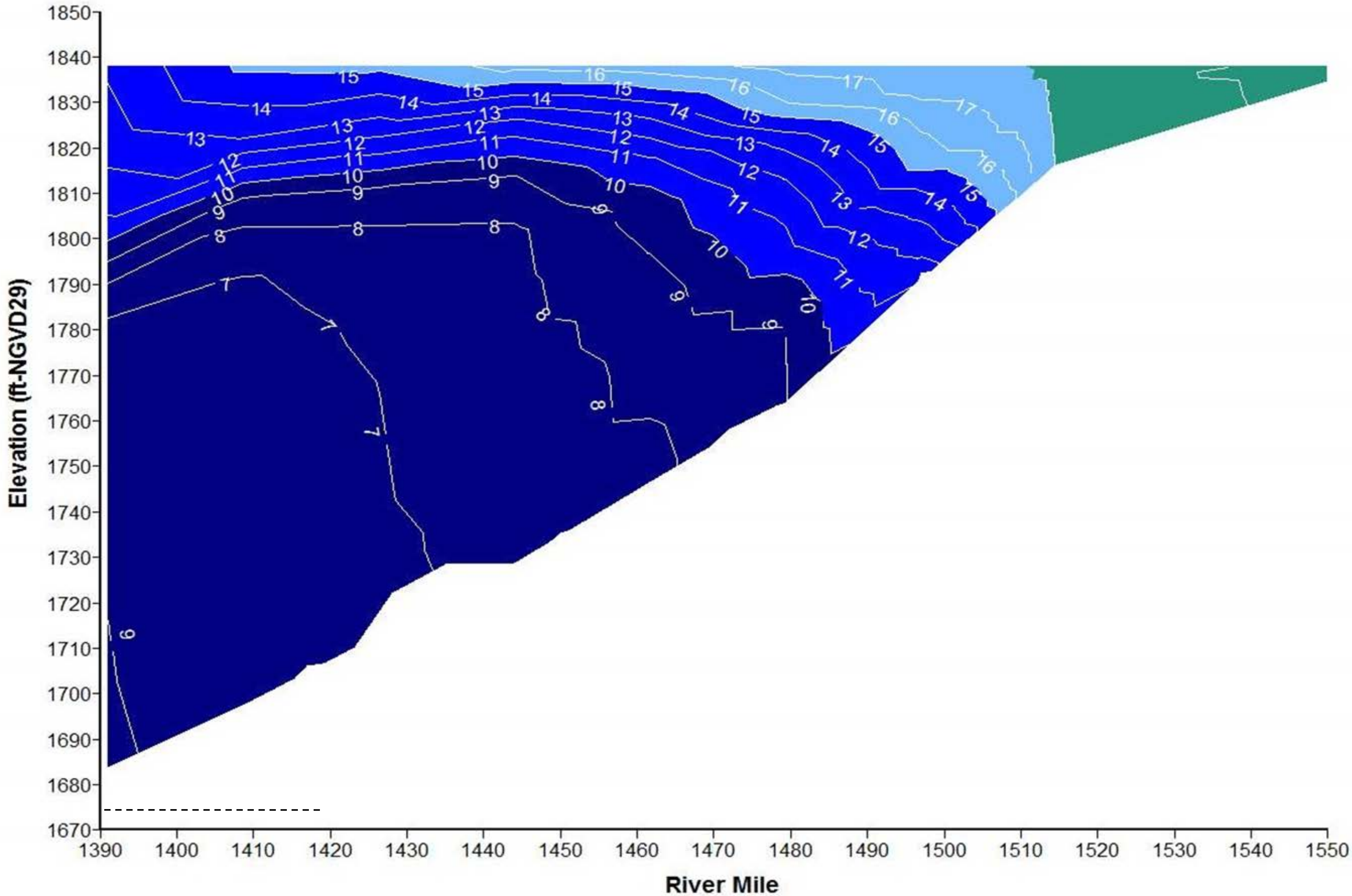


Plate 6-8. Longitudinal water temperature (°C) contour plot of Lake Sakakawea based on depth-profile water temperatures measured at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, and GARNFMORRR1 on May 27, 2015.

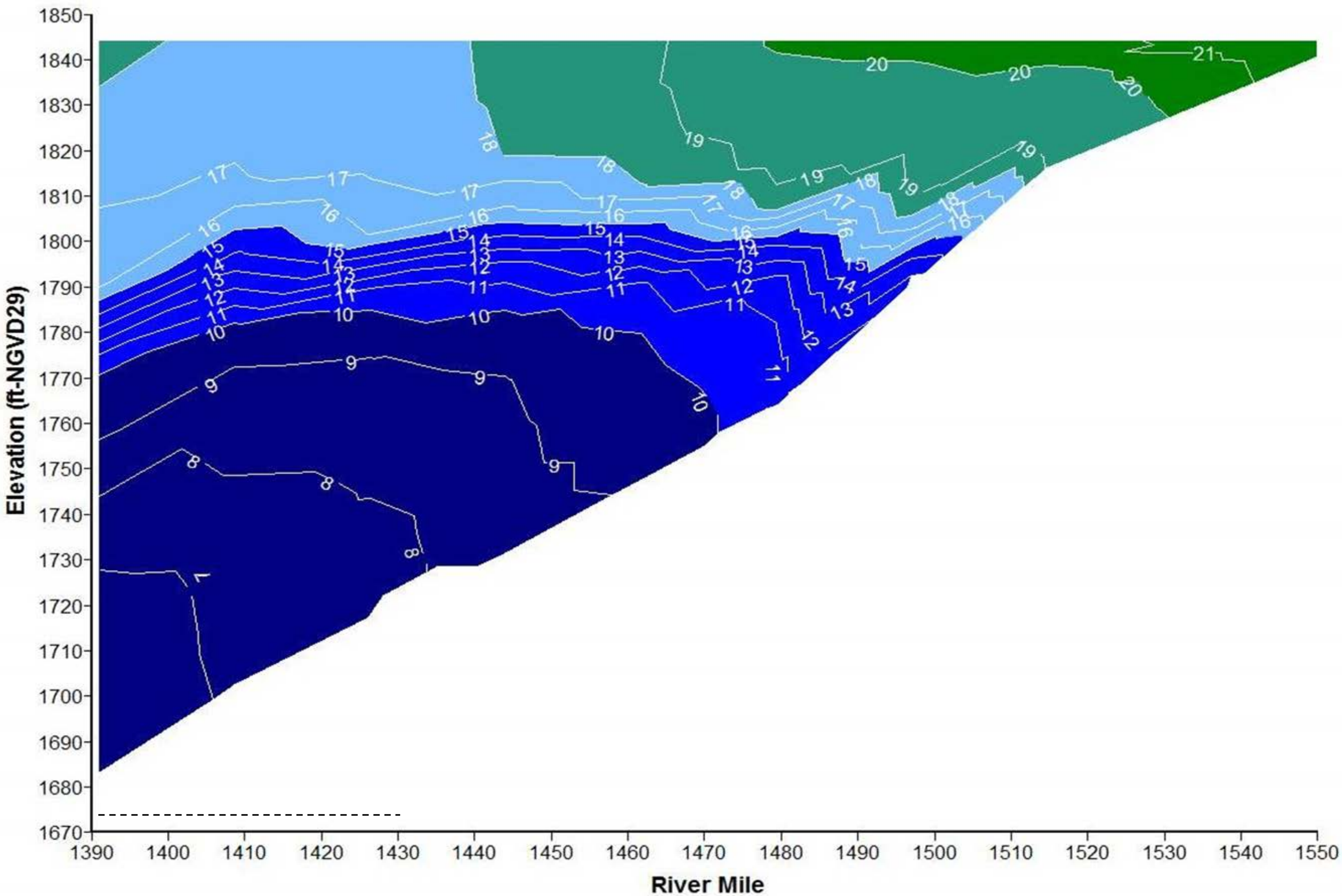


Plate 6-9. Longitudinal water temperature (°C) contour plot of Lake Sakakawea based on depth-profile water temperatures measured at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, GARLK1512DW, and GARNFMORRR1 on June 22, 2015.

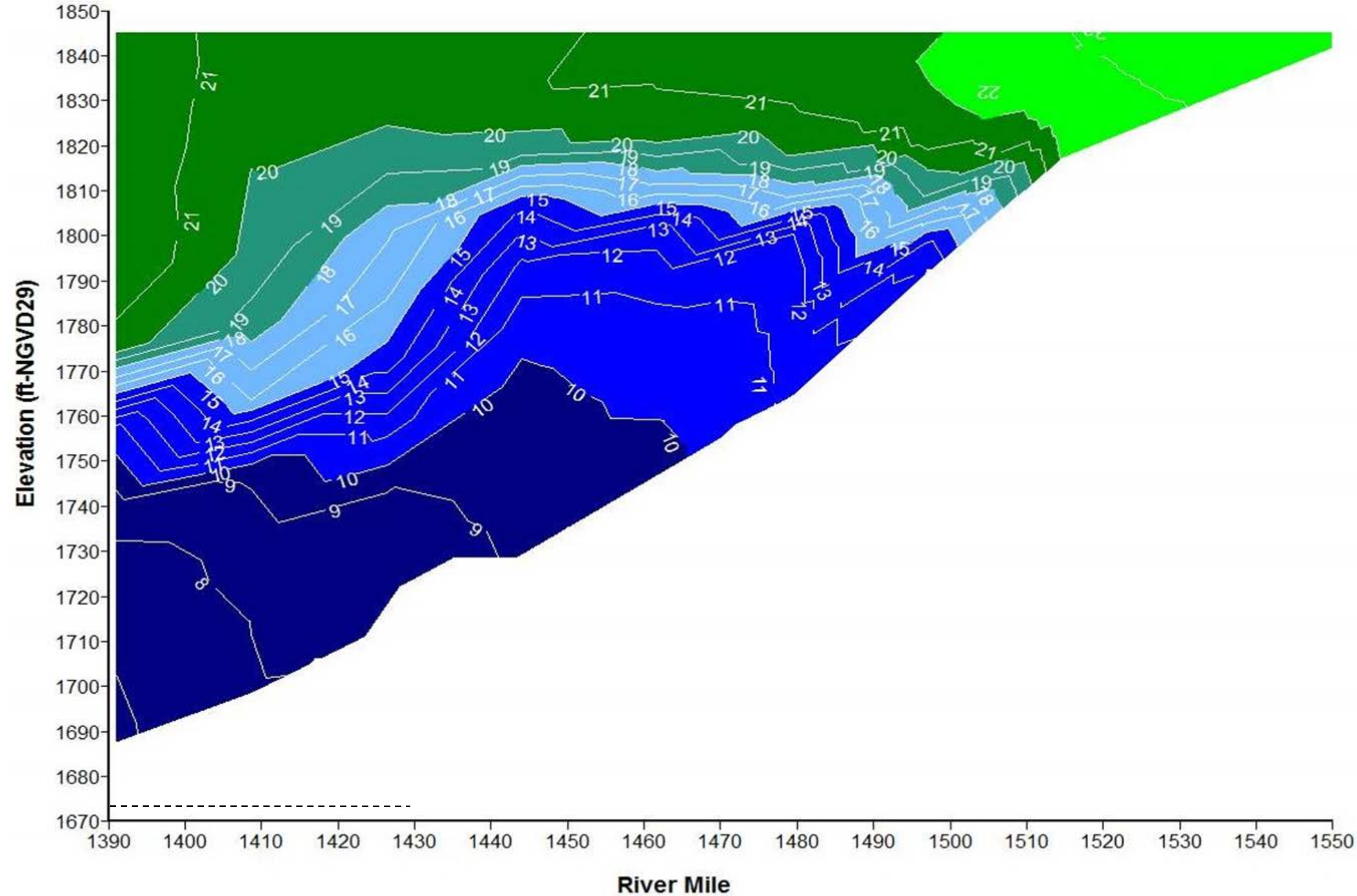


Plate 6-10. Longitudinal water temperature (°C) contour plot of Lake Sakakawea based on depth-profile water temperatures measured at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, GARLK1512DW, and GARNFMORRR1 on July 21, 2015.

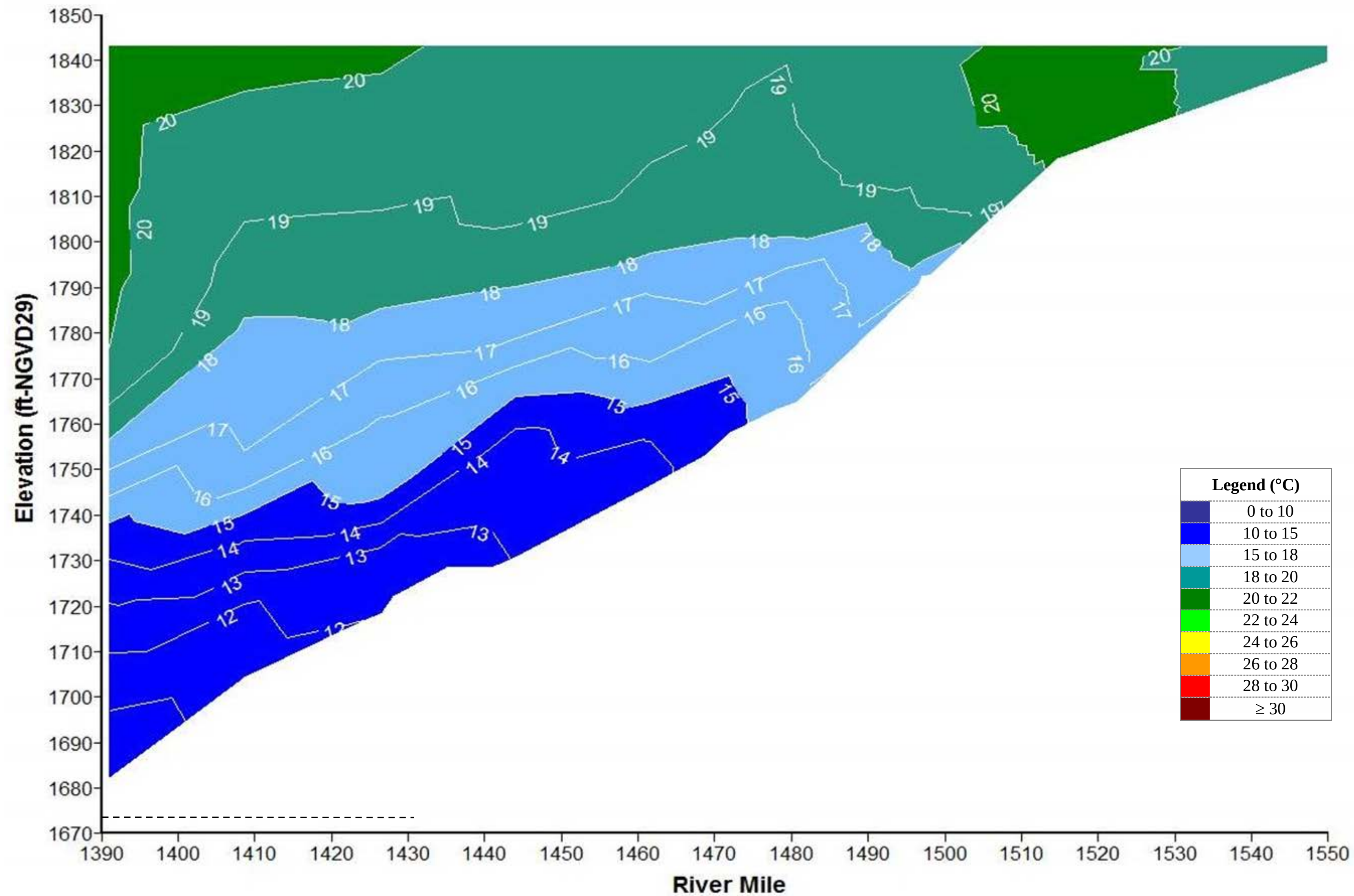


Plate 6-11. Longitudinal water temperature (°C) contour plot of Lake Sakakawea based on depth-profile water temperatures measured at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, GARLK1512DW, and GARNFMORRR1 on August 25, 2015.

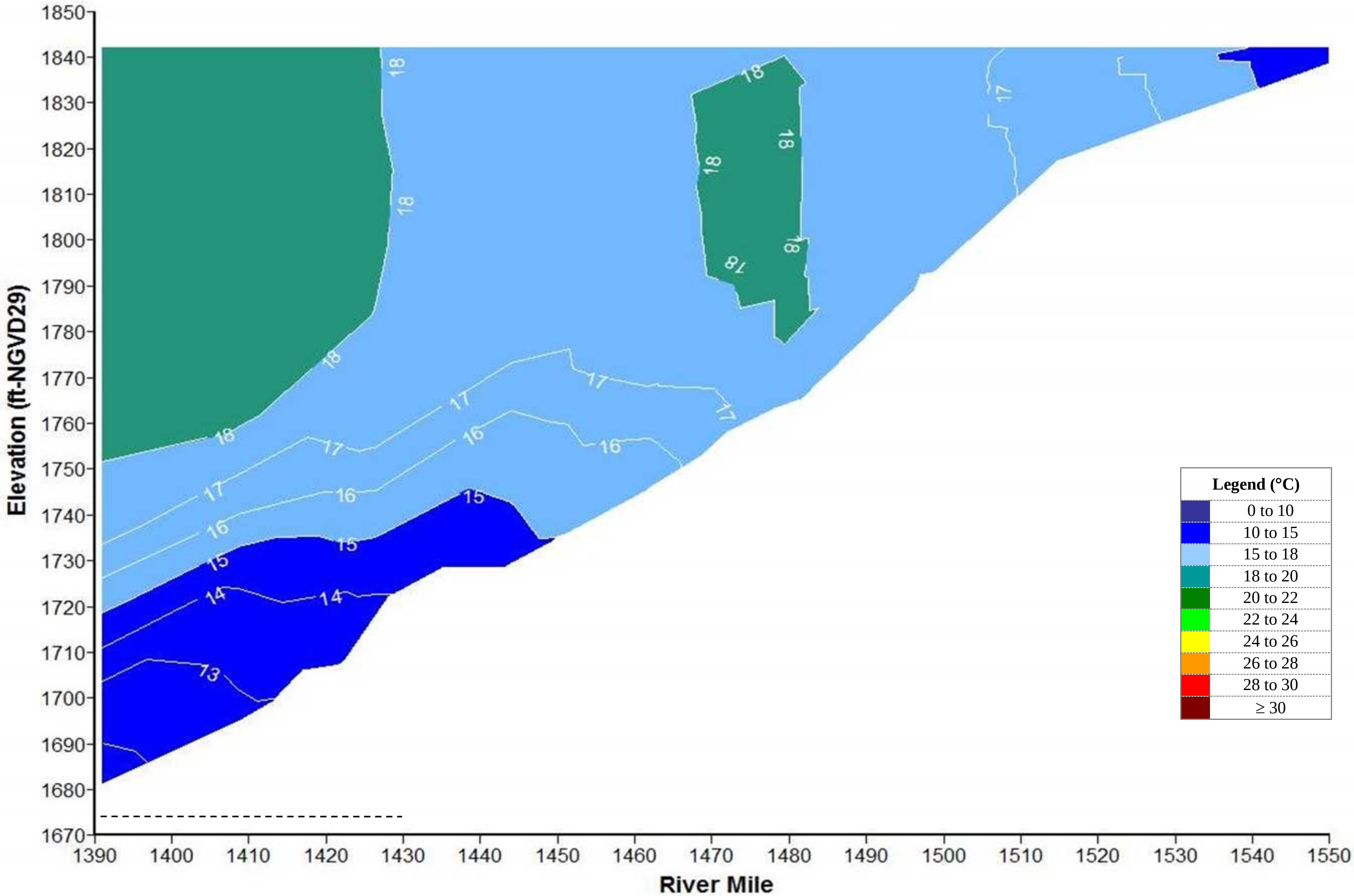


Plate 6-12. Longitudinal water temperature (°C) contour plot of Lake Sakakawea based on depth-profile water temperatures measured at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, GARLK1512DW, and GARNFMORRR1 on September 21, 2015.

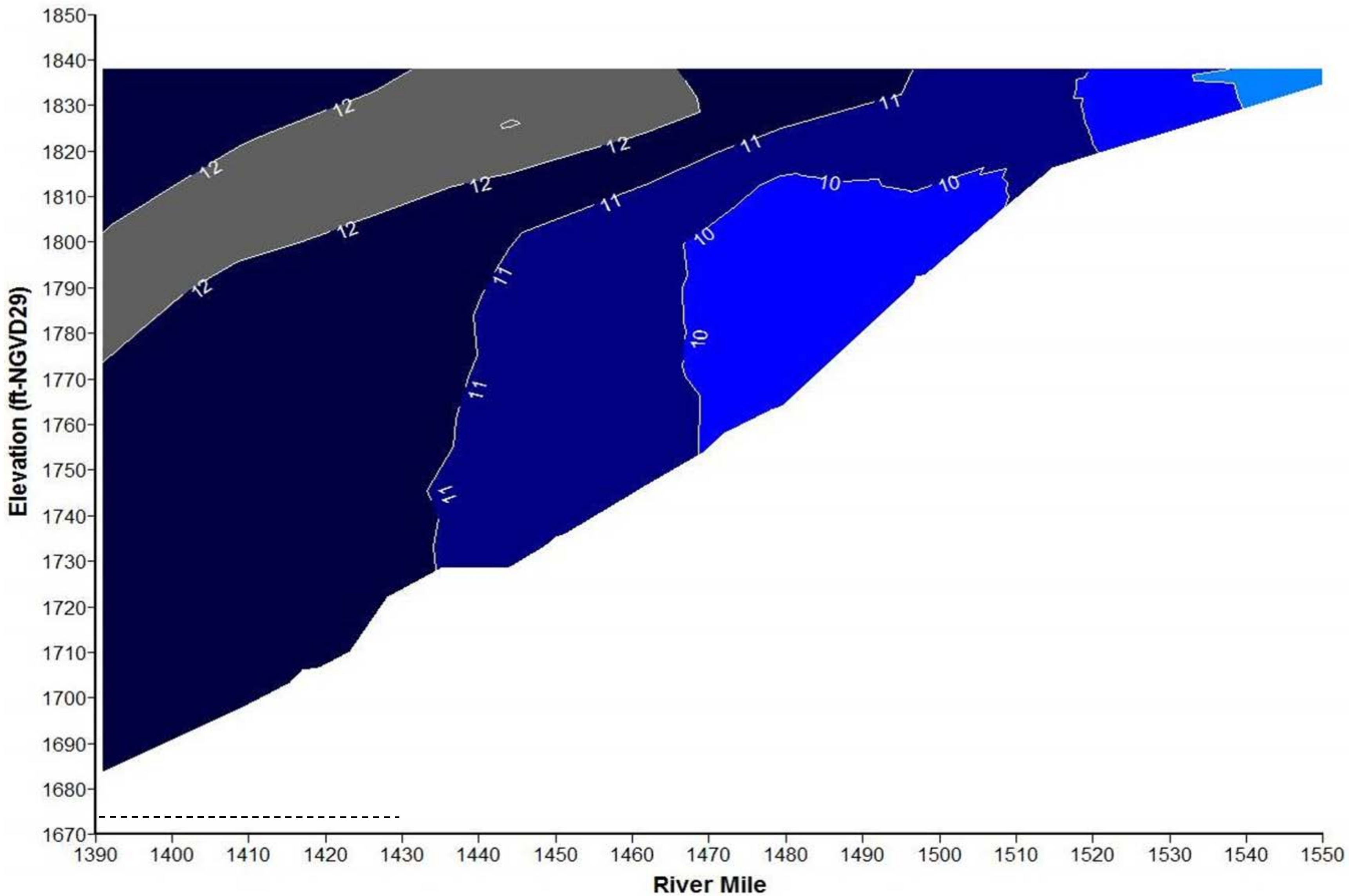


Plate 6-13. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, GARLK1512DW, and GARNFMORRR1 on May 27, 2015.

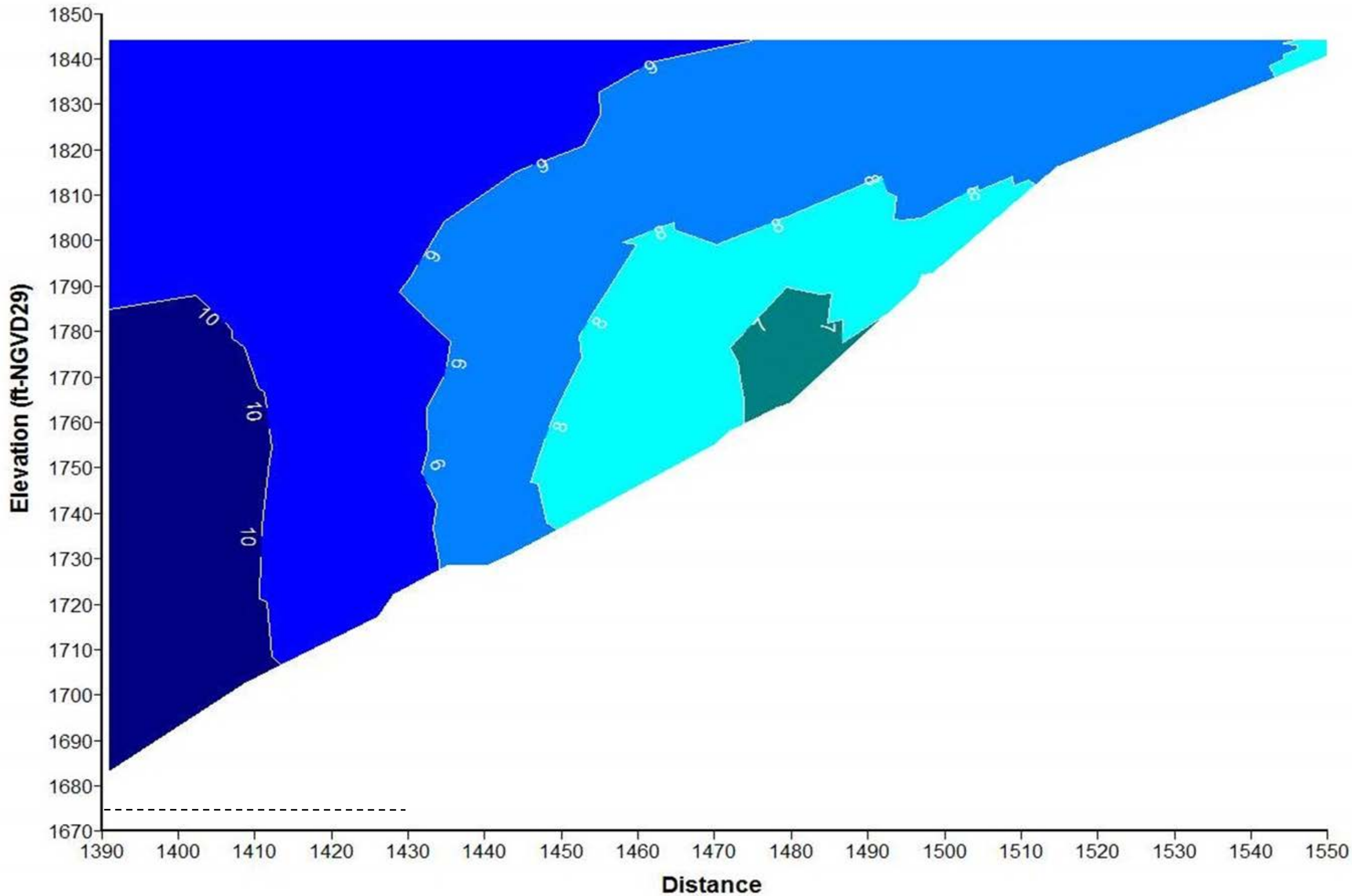


Plate 6-14. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations s measured at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, GARLK1512DW, and GARNFMORRR1 on June 22, 2015.

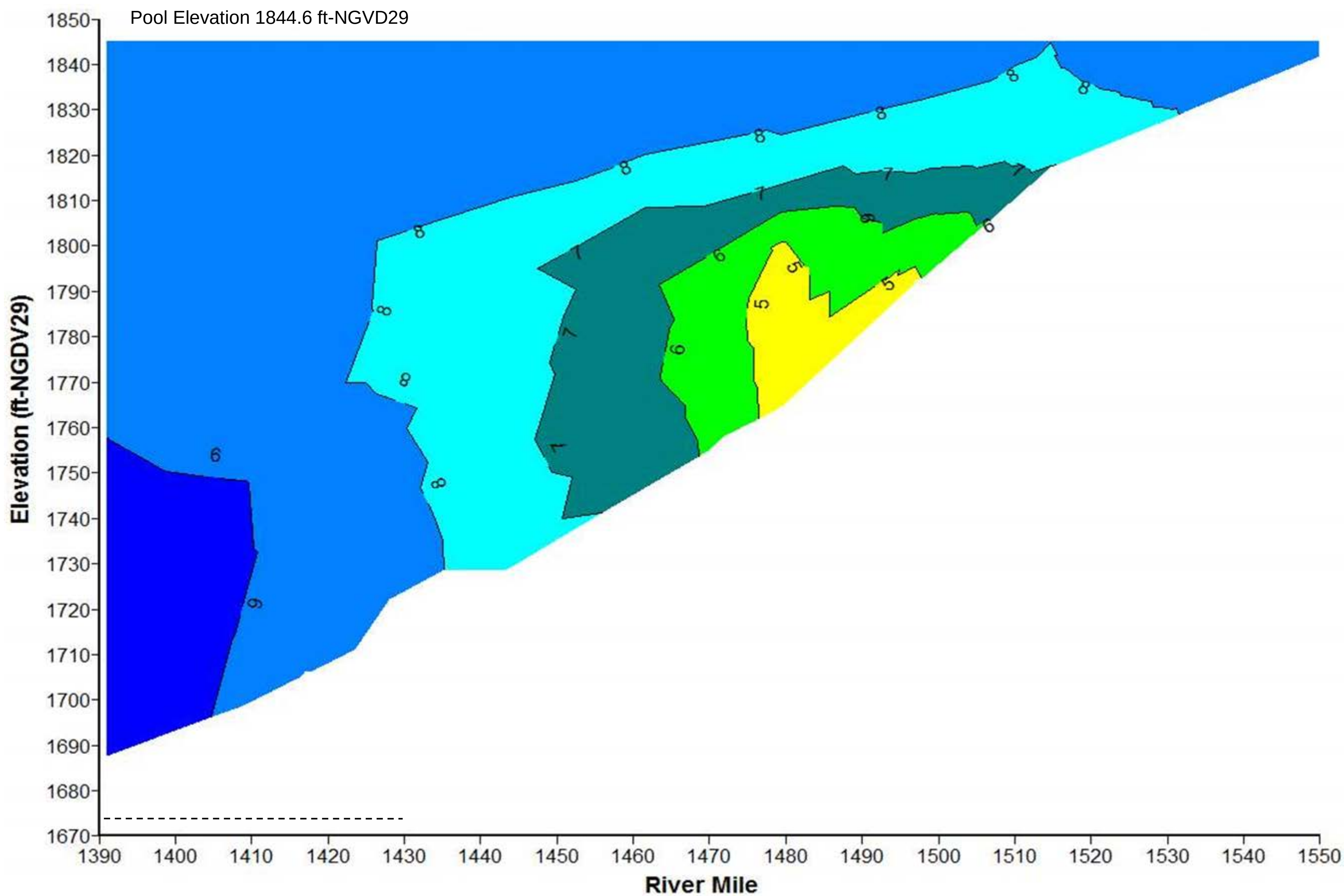


Plate 6-15. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, GARLK1512DW, and GARNFMORRR1 on July 21, 2015.

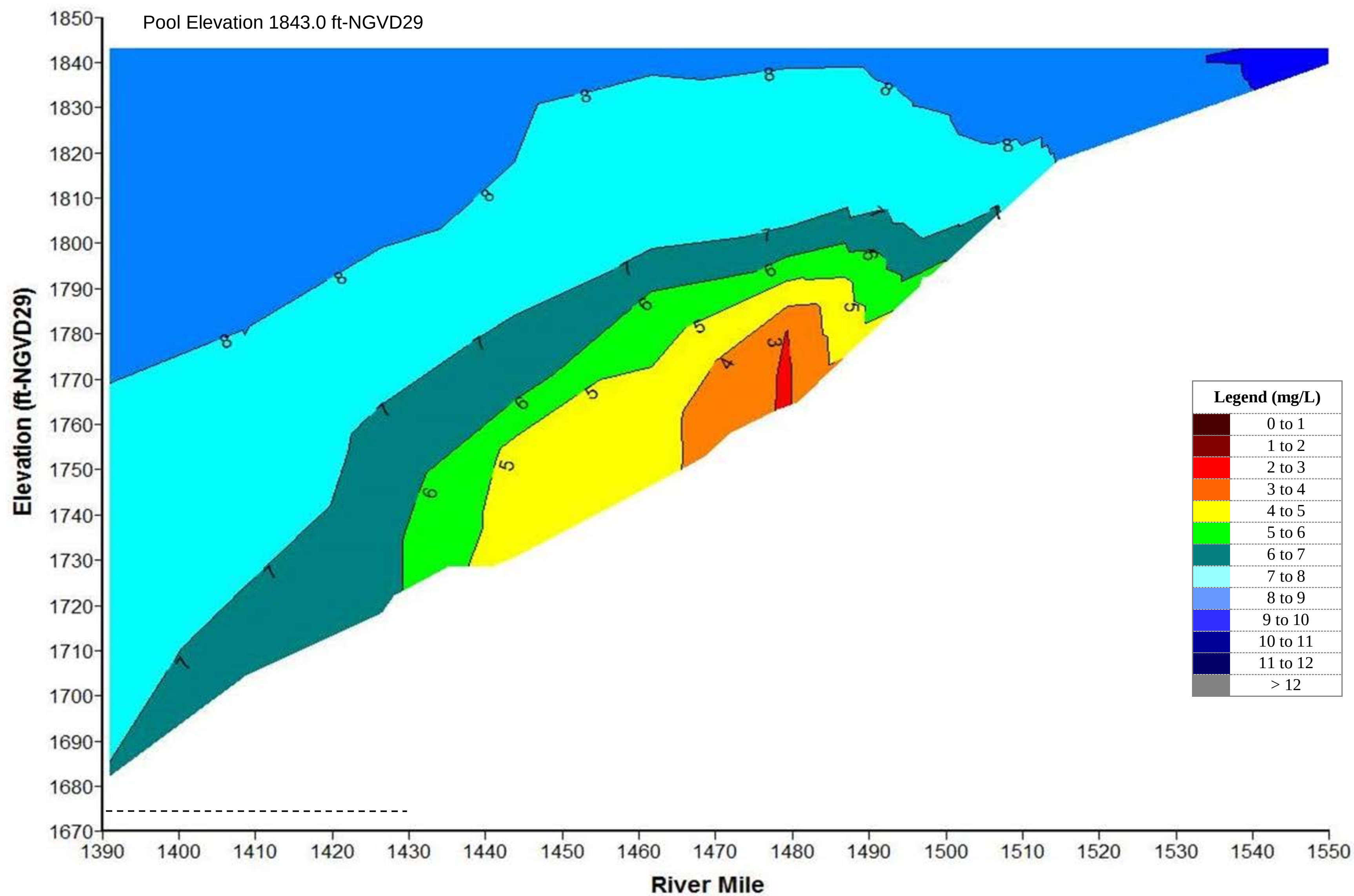


Plate 6-16. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, GARLK1512DW, and GARNFMORRR1 on August 28, 2015.

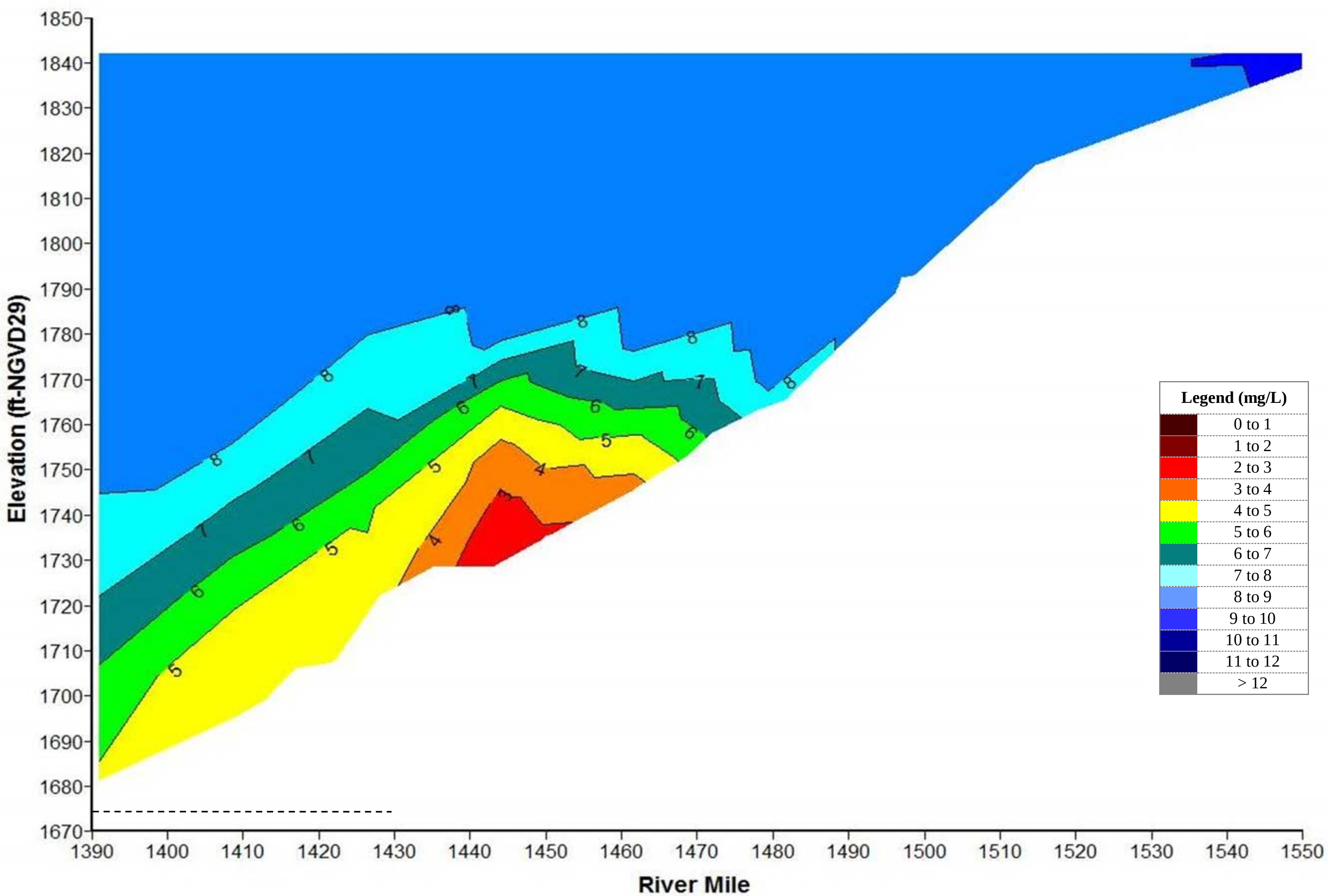


Plate 6-17. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Sakakawea based on depth-profile dissolved oxygen concentrations measured at sites GARLK1390A, GARLK1412DW, GARLK1445DW, GARLK1481DW, GARLK1512DW, and GARNFMORRR1 on September 21, 2015.

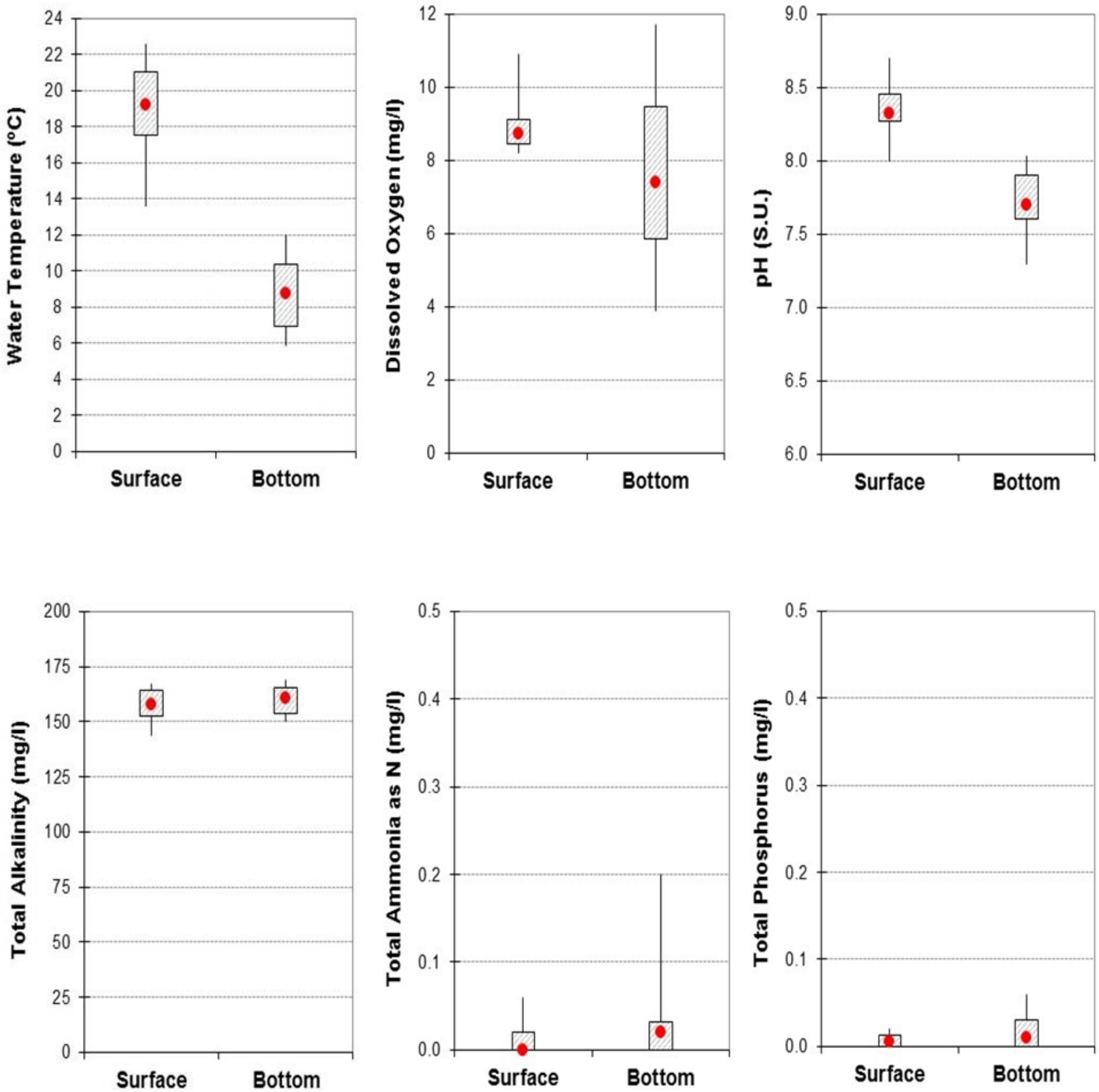


Plate 6-18. Box plots comparing paired surface and bottom water temperature, dissolved oxygen, pH, alkalinity, total ammonia nitrogen, and total phosphorus measurements taken in Lake Sakakawea at site GARLK1390A during the summer months of the 5-year period 2011 through 2015. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

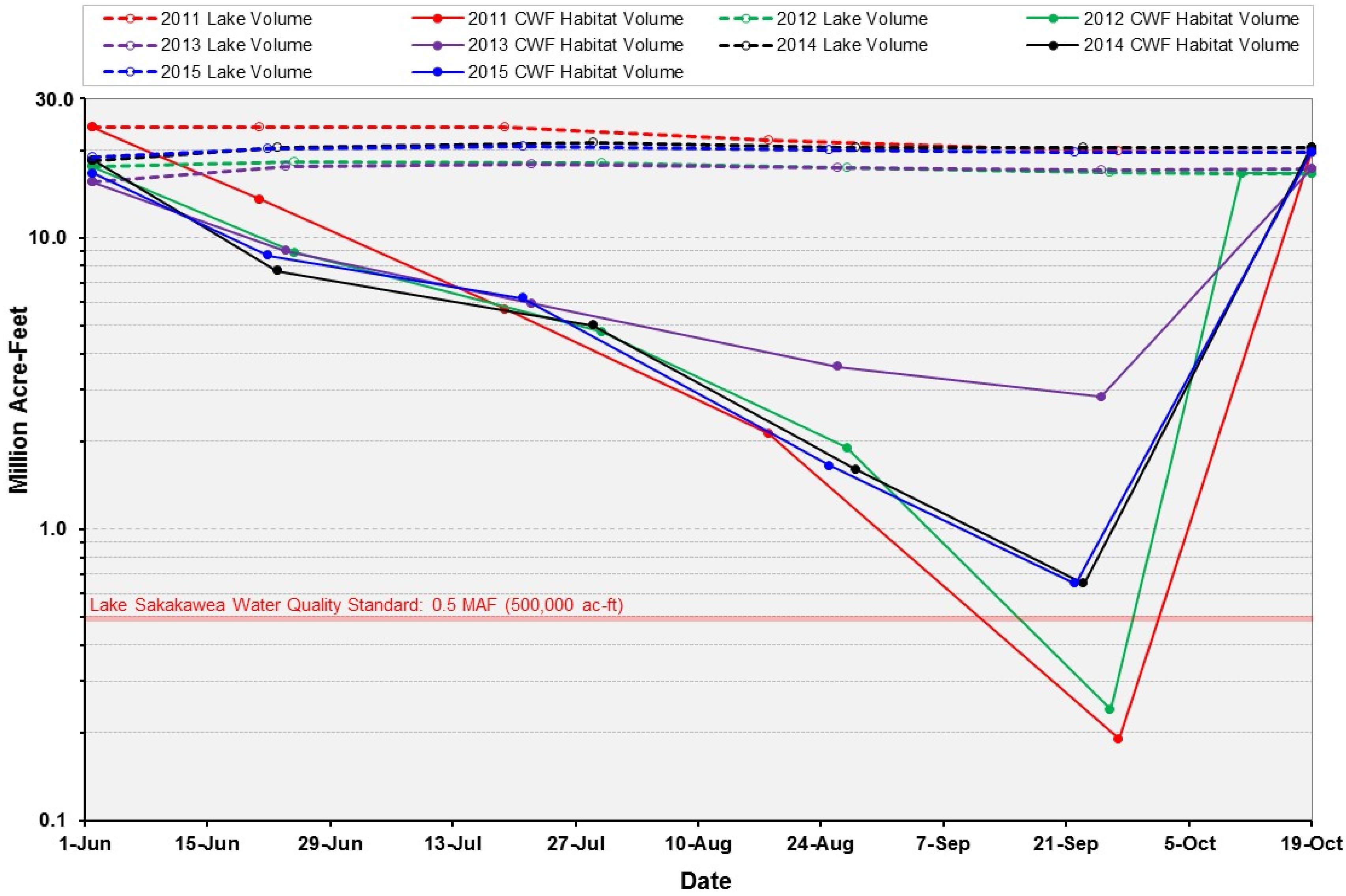


Plate 6-19. Estimated summer volume of coldwater fishery habitat in Lake Sakakawea during the 5-year period 2011 through 2015.

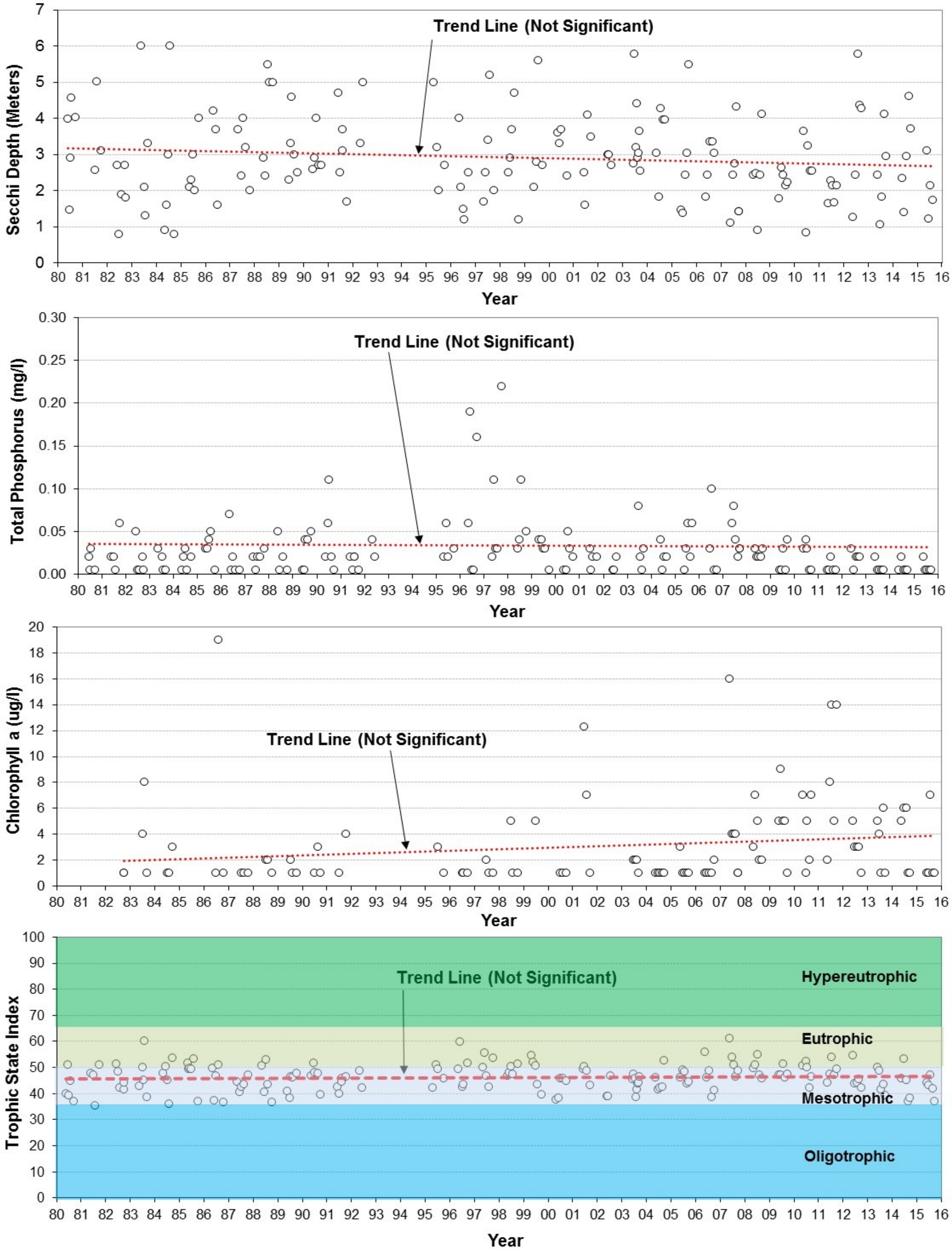


Plate 6-20. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Lake Sakakawea at the near-dam, ambient site (i.e. site GARLK1390A) over the 35-year period of 1980 through 2015.

Plate 6-21. Summary of monthly (April through September) near-surface water quality conditions monitored in the Missouri River near Williston, North Dakota at monitoring site GARNFMORR1 during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[(A)]	No. of Obs.	Mean[(B)]	Median	Min.	Max.	State WQS Criteria[(C)]	No. of WQS Exceedances	Percent WQS Exceedance
Streamflow (cfs)	1	33	30,145	18,949	7,580	169,696	-----	-----	-----
Water Temperature (°C)	0.1	33	16.7	18.6	4.8	24.4	29.4[(1,2)]	0	0%
Dissolved Oxygen (mg/L)	0.1	33	9.1	9.2	7.58	11.6	5[(1,3)]	0	0%
Dissolved Oxygen (% Sat.)	0.1	33	96.6	95.6	87.4	109.9	-----	-----	-----
pH (S.U.)	0.1	33	8.2	8.3	7.4	8.7	7.0[(1,3)], 9.0[(1,2)]	0	0%
Specific Conductance (uS/cm)	1	33	685	715	472	921	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	33	339	332	167	459	-----	-----	-----
Turbidity (NTU)	1	33	218	90	3	1,447	-----	-----	-----
Alkalinity, Total (mg/L)	7	33	152	158	112	187	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	33	5.0	3.6	0.5	20.4	-----	-----	-----
Chloride, Dissolved (mg/L)	1	20	10	11	6	15	100[(1,2)]	0	0%
Chlorophyll *a* (ug/L)	5	26	16	14	n.d.	49	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	33	32	27	18	81	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	32	541	504	310	858	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	33	-----	0.02	n.d.	0.12	4.7 [(1,2,4)], 1.1 [(1,4,5)]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	33	0.7	0.6	0.3	2.2	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	33	-----	0.05	n.d.	0.39	1.0[(1,2)]	0	0%
Nitrogen, Total (mg/L)	0.1	33	0.8	0.6	0.3	2.5	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	33	-----	n.d.	n.d.	0.62	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	33	0.24	0.12	n.d.	1.39	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	33	-----	n.d.	n.d.	0.52	-----	-----	-----
Sulfate (mg/L)	1	33	193	198	123	289	250[(1,2)]	3	9%
Suspended Solids, Total (mg/L)	4	32	364	134	40	3,550	-----	-----	-----
Suspended Sediment, Total (mg/L)	4	32	324	144	28	3,350	-----	-----	-----
Hexane Extractable Material (mg/L)	1.2	21	-----	n.d.	n.d.	5.2	-----	-----	-----
Diesel Range Organics (mg/L)	0.05	7	-----	n.d.	n.d.	n.d.	-----	-----	-----
Total Purgeable Hydrocarbon - (ug/L)	3	7	-----	n.d.	n.d.	5.0	-----	-----	-----
Benzene, Total (ug/L)	0.5	7	-----	n.d.	n.d.	n.d.	-----	-----	-----
Eythylbenzene, Total (ug/L)	0.5	6	-----	n.d.	n.d.	n.d.	-----	-----	-----
Hexane, Total (ug/L)	0.7	7	-----	n.d.	n.d.	n.d.	-----	-----	-----
Naphthalene, Total (ug/L)	0.6	7	-----	n.d.	n.d.	n.d.	-----	-----	-----
Toluene, Total (ug/L)	0.5	7	-----	n.d.	n.d.	n.d.	-----	-----	-----
Xylenes, Total (ug/L)	1	7	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

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

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

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

(1) Criteria for Class 1 streams.

(2) Daily maximum criterion (monitoring results directly comparable to criterion).

(3) Daily minimum criterion (monitoring results directly comparable to criterion).

(4) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

(5) 30-day average criterion (monitoring results not directly comparable to criterion).

Plate 6-22. Summary of annual near-surface metals and pesticide levels monitored in the Missouri River near Williston, North Dakota at monitoring site GARNFMORR1 during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/L)	40	5	-----	n.d.	n.d.	2,170	-----	-----	-----
Aluminum, Total (ug/L)	40	5	23,867	2,810	1,710	109,000	750(6)	5	100%
Antimony, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Antimony, Total (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	5.6(8)	0	0%
Arsenic, Dissolved (ug/L)	1	5	3	3	2	3	-----	-----	-----
Arsenic, Total (ug/L)	1	5	9	5	3	28	340(1), 150(2), 10(3)	0, 0, 1	0%, 0%, 20%
Barium, Dissolved (ug/L)	5	5	53	48	45	73	-----	-----	-----
Barium, Total (ug/L)	5	5	210	82	62	742	1,000(8)	0	0%
Beryllium, Dissolved (ug/L)	2	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Beryllium, Total (ug/L)	2	5	-----	n.d.	n.d.	4.	4(8)	0	0%
Cadmium, Dissolved (ug/L)	0.2	5	-----	n.d.	n.d.	0.2	-----	-----	-----
Cadmium, Total (ug/L)	0.2	5	-----	n.d.	n.d.	1.3	4.7(6), 0.48(7), 5(8)	0, 1, 0	0%, 20%, 0%
Calcium, Dissolved (mg/L)	0.01	5	52.1	54.3	37.9	60.9	-----	-----	-----
Chromium, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Chromium, Total (ug/L)	10	5	-----	n.d.	n.d.	150	3,413(6), 163(7), 100(8)	0, 0, 1	0%, 0%, 20%
Copper, Dissolved (ug/L)	6	5	-----	n.d.	n.d.	10	-----	-----	-----
Copper, Total (ug/L)	6	5	-----	7	n.d.	120	29(6), 18(7), 1,000(8)	1, 1, 0	20%, 20%, 0%
Hardness, Total (mg/L)	0.4	5	275	261	216	392	-----	-----	-----
Iron, Dissolved (ug/L)	7	5	385	13	n.d.	1,760	-----	-----	-----
Iron, Total (ug/L)	7	5	20,517	2,440	1,690	93,150	-----	-----	-----
Lead, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	1.1	-----	-----	-----
Lead, Total (ug/L)	0.5	5	14.4	1.6	0.9	66.6	220(6), 8.6(7), 15(8)	0, 1, 1	0%, 20%, 20%
Magnesium, Dissolved (mg/L)	0.01	5	29.7	26.9	21.7	49.2	-----	-----	-----
Manganese, Dissolved (ug/L)	2	5	12	3	n.d.	50	-----	-----	-----
Manganese, Total (ug/L)	2	5	270	70	40	1,110	-----	-----	-----
Mercury, Dissolved (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Mercury, Total (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	1.7(6), 0.012(7), 0.05(8)	0, b.d., 0	0%, b.d., 0%
Nickel, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Nickel, Total (ug/L)	10	5	-----	n.d.	n.d.	120	907(6), 101(7), 100(8)	0, 1, 1	0%, 20%, 20%
Selenium, Total (ug/L)	1	5	-----	1	n.d.	3	20(6), 5(7), 50(8)	0	0%
Silver, Dissolved (ug/L)	1	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Silver, Total (ug/L)	1	5	-----	n.d.	n.d.	n.d.	14(6)	0	0%
Sodium, Dissolved (mg/L)	0.01	5	70.7	73.7	57.6	82.3	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Total (ug/L)	0.5	5	-----	n.d.	n.d.	1.1	0.24(7)	b.d.	b.d.
Zinc, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	10	-----	-----	-----
Zinc, Total (ug/L)	10	5	76	10	10	330	232(6,7), 7,400(8)	1, 0	20%, 0%
Pesticide Scan (ug/L)(D)	0.05(E)	5	-----	n.d.	n.d.	n.d.	-----	-----	-----

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

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

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

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

- (1) Criteria for Class 1 streams.
- (2) Daily maximum criterion (monitoring results directly comparable to criterion).
- (3) Daily minimum criterion (monitoring results directly comparable to criterion).
- (4) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (5) 30-day average criterion (monitoring results not directly comparable to criterion).
- (6) Acute criterion for aquatic life.
- (7) Chronic criterion for aquatic life.
- (8) Human health criterion for surface waters.

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

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

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

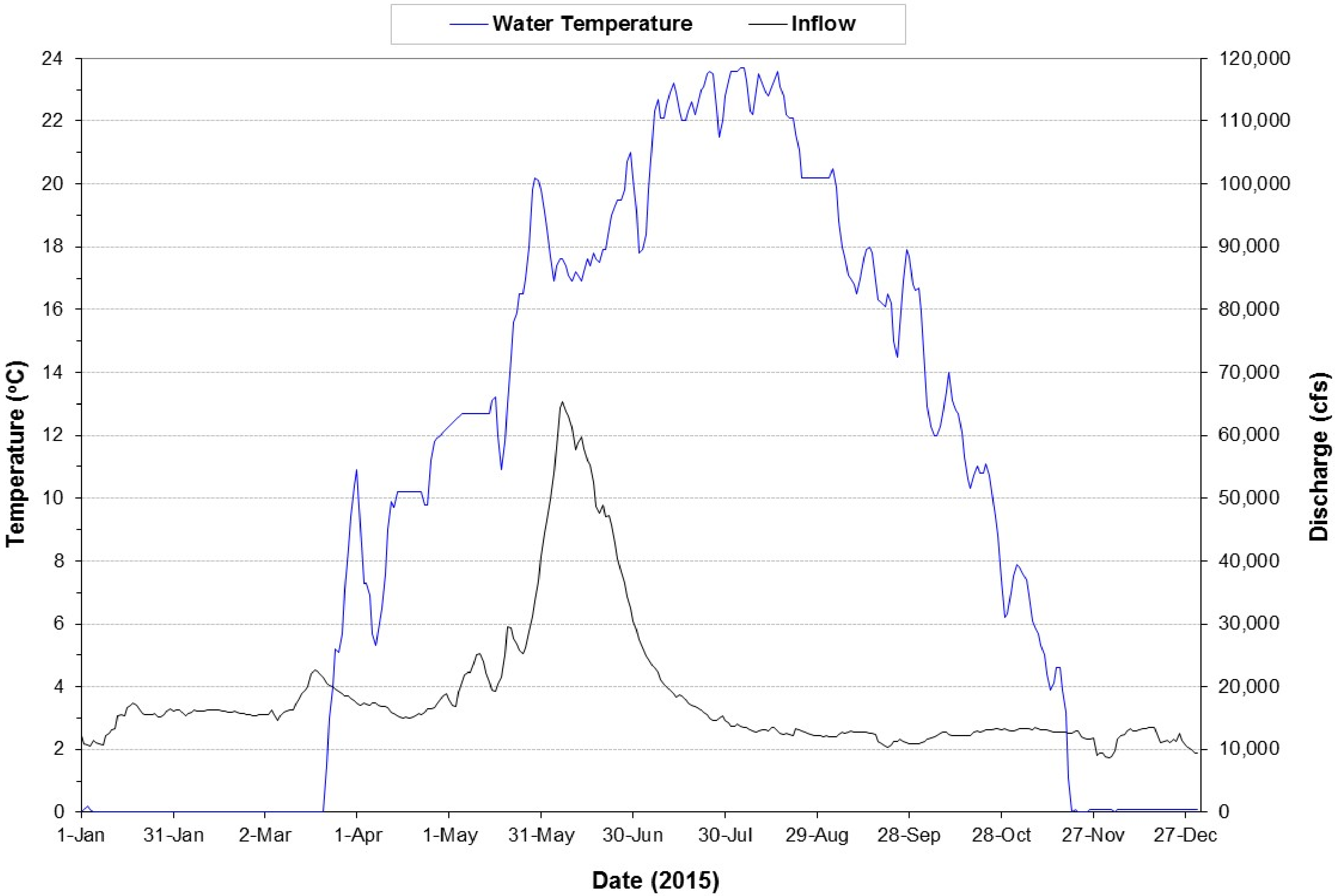


Plate 6-23. Mean daily water temperature and discharge of the Missouri River near Williston, North Dakota (i.e. site GARNFMORRR1) for 2015. Mean temperatures based on hourly measurements recorded on the Missouri River near Williston, North Dakota (USGS gaging station 06330000). Mean daily discharge estimated by adding mean daily discharge recorded for the Missouri River near Culbertson, Montana (USGS gaging station 06185500) and the mean daily discharge recorded for the Yellowstone River near Sidney, Montana (USGS gaging station 06329500). *Note: Missing 2015 temperature data between 28-May and 1-Sep estimated from 2014 temperature data.*

Plate 6-24. Summary of monthly (April through September) near-surface water quality conditions monitored in the Little Missouri River near Mandaree, North Dakota at monitoring site GARNFLMOR1 during 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit(A)	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Streamflow (cfs)	1	7	178	68	3	748	-----	-----	-----
Water Temperature (°C)	0.1	7	18.5	19.6	11.9	25.1	29.4(1,2)	0	0%
Dissolved Oxygen (mg/L)	0.1	7	8.6	7.9	7.5	10.3	5(1,3)	0	0%
Dissolved Oxygen (% Sat.)	0.1	7	95.1	93.8	86.3	109.6	-----	-----	-----
pH (S.U.)	0.1	7	8.4	8.5	8.3	8.7	7.0(1,3), 9.0(1,2)	0	0%
Specific Conductance (uS/cm)	1	7	2,311	2,316	1,871	2,861	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	7	378	356	295	462	-----	-----	-----
Turbidity (NTU)	1	7	1,560	1,758	114	3,000	-----	-----	-----
Alkalinity, Total (mg/L)	7	7	372	417	248	448	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	7	16.6	9.8	8.4	57.0	-----	-----	-----
Chloride, Dissolved (mg/L)	1	7	15	15	11	21	100(1,2)	0	0%
Colorized Dissolved Organic Matter (ug/L)	4	7	164	157	131	205	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	7	1,819	1,790	1,220	2,430	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	7	-----	0.03	n.d.	0.08	3.2 (1,2,4), 0.73 (1,4,5)	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	7	2.9	2.0	0.7	7.9	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	7	-----	0.23	n.d.	0.61	1.0(1,2)	0	0%
Nitrogen, Total (mg/L)	0.1	7	3.1	2.2	0.7	8.4	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	7	-----	n.d.	n.d.	2.26	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	7	1.19	0.80	0.13	2.67	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	7	-----	n.d.	n.d.	0.04	-----	-----	-----
Sulfate (mg/L)	1	7	885	824	654	1,170	250(1,2)	7	100%
Suspended Solids, Total (mg/L)	4	7	3,282	1,420	138	12,000	-----	-----	-----
Suspended Sediment, Total (mg/L)	4	7	3,980	1,350	175	11,800	-----	-----	-----
Diesel Range Organics (mg/L)	0.05	7	-----	0.06	n.d.	0.10	-----	-----	-----
Total Purgeable Hydrocarbon - (ug/L)	3	6	-----	n.d.	n.d.	n.d.	-----	-----	-----
Benzene, Total (ug/L)	0.5	6	-----	n.d.	n.d.	n.d.	-----	-----	-----
Eythylbenzene, Total (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Hexane, Total (ug/L)	0.7	6	-----	n.d.	n.d.	n.d.	-----	-----	-----
Naphthalene, Total (ug/L)	0.6	6	-----	n.d.	n.d.	n.d.	-----	-----	-----
Toluene, Total (ug/L)	0.5	6	-----	n.d.	n.d.	n.d.	-----	-----	-----
Xylenes, Total (ug/L)	1	6	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

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

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

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

(1) Criteria for Class 1 streams.

(2) Daily maximum criterion (monitoring results directly comparable to criterion).

(3) Daily minimum criterion (monitoring results directly comparable to criterion).

(4) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

(5) 30-day average criterion (monitoring results not directly comparable to criterion).

Plate 6-25. Summary of annual metal levels monitored in the Little Missouri River near Mandaree, North Dakota at monitoring site GARNFLMOR1 during 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/L)	40	1	130,700	130,700	130,700	130,700	-----	-----	-----
Aluminum, Total (ug/L)	40	1	317,800	317,800	317,800	317,800	750(6)	1	100%
Antimony, Dissolved (ug/L)	0.5	1	-----	n.d.	n.d.	n.d.	-----	-----	-----
Antimony, Total (ug/L)	0.5	1	-----	n.d.	n.d.	n.d.	5.6(8)	0	0%
Arsenic, Dissolved (ug/L)	1	1	39	39	39	39	-----	-----	-----
Arsenic, Total (ug/L)	1	1	94	94	94	94	340(1), 150(2), 10(3)	0, 0, 1	0%, 0%, 100%
Barium, Dissolved (ug/L)	5	1	654	654	654	654	-----	-----	-----
Barium, Total (ug/L)	5	1	1,620	1,620	1,620	1,620	1,000(8)	1	100%
Beryllium, Dissolved (ug/L)	2	1	6	6	6	6	-----	-----	-----
Beryllium, Total (ug/L)	2	1	17	17	17	17	4(8)	1	100%
Cadmium, Dissolved (ug/L)	0.2	1	2.0	2.0	2.0	2.0	-----	-----	-----
Cadmium, Total (ug/L)	0.2	1	5.1	5.1	5.1	5.1	23(6), 1.5(7), 5(8)	0, 1, 1	0%, 100%, 100%
Calcium, Dissolved (mg/L)	0.01	1	95.7	95.7	95.7	95.7	-----	-----	-----
Calcium, Total (mg/L)	0.01	1	191.1	191.1	191.1	191.1	-----	-----	-----
Chromium, Dissolved (ug/L)	10	1	170	170	170	170	-----	-----	-----
Chromium, Total (ug/L)	10	1	440	440	440	440	12,320(6), 588(7), 100(8)	0, 0, 1	0%, 0%, 100%
Copper, Dissolved (ug/L)	6	1	170	170	170	170	-----	-----	-----
Copper, Total (ug/L)	6	1	480	480	480	480	127(6), 69(7), 1,000(8)	1, 1, 0	100%, 100%, 0%
Hardness, Dissolved (mg/L)	0.4	1	514	514	514	514	-----	-----	-----
Hardness, Total (mg/L)	0.4	1	1,043	1,043	1,043	1,043	-----	-----	-----
Iron, Dissolved (ug/L)	7	1	135,000	135,000	135,000	135,000	-----	-----	-----
Iron, Total (ug/L)	7	1	367,700	367,000	367,000	367,000	-----	-----	-----
Lead, Dissolved (ug/L)	0.5	1	74.5	74.5	74.5	74.5	-----	-----	-----
Lead, Total (ug/L)	0.5	1	168.7	168.7	168.7	168.7	1,615(6), 63(7), 15(8)	0, 1, 1	0%, 100%, 100%
Magnesium, Dissolved (mg/L)	0.01	1	66.7	66.7	66.7	66.7	-----	-----	-----
Magnesium, Total (mg/L)	0.01	1	137.3	137.3	137.3	137.3	-----	-----	-----
Manganese, Dissolved (ug/L)	2	1	1,750	1,750	1,750	1,750	-----	-----	-----
Manganese, Total (ug/L)	2	1	4,870	4,870	4,870	4,870	-----	-----	-----
Mercury, Dissolved (ug/L)	0.05	1	0.40	0.40	0.40	0.40	-----	-----	-----
Mercury, Total (ug/L)	0.05	1	1.00	1.00	1.00	1.00	1.7(6), 0.012(7), 0.05(8)	0, 1, 1	0%, 100%, 100%
Nickel, Dissolved (ug/L)	10	1	170	170	170	170	-----	-----	-----
Nickel, Total (ug/L)	10	1	460	460	460	460	3,410(6), 379(7), 100(8)	0, 1, 1	0%, 100%, 100%
Selenium, Dissolved (ug/L)	1	1	10	10	10	10	-----	-----	-----
Selenium, Total (ug/L)	1	1	13	13	13	13	20(6), 5(7), 50(8)	0, 1, 0	0%, 100%, 0%
Silver, Dissolved (ug/L)	1	1	-----	n.d.	n.d.	n.d.	-----	-----	-----
Silver, Total (ug/L)	1	1	1.4	1.4	1.4	1.4	14(6)	0	0%
Sodium, Dissolved (mg/L)	0.01	1	321.9	321.9	321.9	321.9	-----	-----	-----
Sodium, Total (mg/L)	0.01	1	328.7	328.7	328.7	328.7	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	1	1.1	1.1	1.1	1.1	-----	-----	-----
Thallium, Total (ug/L)	0.5	1	2.3	2.3	2.3	2.3	0.24(7)	1	100%
Zinc, Dissolved (ug/L)	10	1	460	460	460	460	-----	-----	-----
Zinc, Total (ug/L)	10	1	1,280	1,280	1,280	1,280	874(6,7), 7,400(8)	1, 0	100%, 0%

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

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

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

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

(1) Criteria for Class 1 streams.
(2) Daily maximum criterion (monitoring results directly comparable to criterion).
(3) Daily minimum criterion (monitoring results directly comparable to criterion).
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
(5) 30-day average criterion (monitoring results not directly comparable to criterion).
(6) Acute criterion for aquatic life.
(7) Chronic criterion for aquatic life.
(8) Human health criterion for surface waters.

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

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

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

Plate 6-26. Summary of monthly water quality conditions monitored from water discharged through Garrison Dam (i.e. GARPP1) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[(A)]	No. of Obs.	Mean[(B)]	Median	Min.	Max.	State WQS Criteria[(C)]	No. of WQS Exceedances	Percent WQS Exceedance
Dam Discharge, Powerplant (cfs)	1	40	21,084	20,153	8,434	33,059	-----	-----	-----
Dam Discharge, Flood Tunnels (cfs)[(D)]	1	5	38,924	34,177	6,564	73,185	-----	-----	-----
Dam Discharge, Spillway (cfs)[(D)]	1	5	24,416	0	0	61,346	-----	-----	-----
Water Temperature (°C)	0.1	40	9.4	9.9	0.9	16.5	29.4[(1,2)]	0	0%
Dissolved Oxygen (mg/L)	0.1	40	11.8	9.7	6.0	89.8	5[(1,3)]	0	0%
Dissolved Oxygen (% Sat.)	0.1	40	86.1	93.0	12.2	112.0	-----	-----	-----
pH (S.U.)	0.1	40	7.9	8.0	7.3	8.8	7.0[(1,3)], 9.0[(1,2)]	0	0%
Specific Conductance (uS/cm)	1	40	717	742	595	794	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	40	360	362	160	556	-----	-----	-----
Turbidity (NTU)	1	40	5	3	n.d.	45	-----	-----	-----
Alkalinity, Total (mg/L)	7	40	158	160	144	168	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	40	3.8	3.7	2.7	5.7	-----	-----	-----
Chloride, Dissolved (mg/L)	1	23	10	10	9	11	100[(1,2)]	0	0%
Colorized Dissolved Organic Matter (ug/L)	4	39	26	25	19	42	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	40	509	489	330	694	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	40	-----	n.d.	n.d.	0.08	8.4 [(1,2,4)], 2.4 [(1,4,5)]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	39	0.3	0.3	n.d.	1.2	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	40	0.08	0.08	n.d.	0.20	1.0[(1,2)]	0	0%
Nitrogen, Total (mg/L)	0.1	39	0.4	0.4	n.d.	1.3	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	40	-----	n.d.	n.d.	0.02	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	40	-----	n.d.	n.d.	0.06	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	40	-----	n.d.	n.d.	0.02	-----	-----	-----
Sulfate (mg/L)	1	40	206	215	151	234	250[(1,2)]	0	0%
Suspended Solids, Total (mg/L)	4	40	-----	n.d.	n.d.	74	-----	-----	-----

n.d. = Not detected.

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

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

(C) Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.
- (1) Criteria for Class 1 streams.
- (2) Daily maximum criterion (monitoring results directly comparable to criterion).
- (3) Daily minimum criterion (monitoring results directly comparable to criterion).
- (4) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (5) 30-day average criterion (monitoring results not directly comparable to criterion).

(D) May through September 2011.

Plate 6-27. Summary of monthly water quality conditions monitored from water discharged through Garrison Dam (i.e. GARPP1) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[B]	Median	Min.	Max.	State WQS Criteria[C]	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/L)	40	5	-----	30	n.d.	120	-----	-----	-----
Aluminum, Total (ug/L)	40	5	108	110	50	170	750[6]	0	0%
Antimony, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	0.5	-----	-----	-----
Antimony, Total (ug/L)	0.5	5	-----	0.5	n.d.	1.2	5.6[8]	0	0%
Arsenic, Dissolved (ug/L)	1	5	2	2	2	3	-----	-----	-----
Arsenic, Total (ug/L)	1	5	2	2	2	3	340[1], 150[2], 10[3]	0	0%
Barium, Dissolved (ug/L)	5	5	51	50	47	56	-----	-----	-----
Barium, Total (ug/L)	5	5	51	51	46	56	1,000[8]	0	0%
Beryllium, Dissolved (ug/L)	2	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Beryllium, Total (ug/L)	2	5	-----	n.d.	n.d.	n.d.	4[8]	0	0%
Cadmium, Dissolved (ug/L)	0.2	5	-----	n.d.	n.d.	0.3	-----	-----	-----
Cadmium, Total (ug/L)	0.2	4	-----	n.d.	n.d.	0.4	5.1[6], 0.51[7], 5[8]	0	0%
Calcium, Dissolved (mg/L)	0.4	5	52.4	53.3	46.0	56.9	-----	-----	-----
Chromium, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Chromium, Total (ug/L)	10	5	-----	n.d.	n.d.	n.d.	3,643[6], 174[7], 100[8]	0	0%
Copper, Dissolved (ug/L)	6	5	-----	n.d.	n.d.	7.	-----	-----	-----
Copper, Total (ug/L)	6	5	-----	n.d.	n.d.	10	31[6], 19[7], 1,000[8]	0, 1, 0	0%, 20%, 0%
Hardness, Total (mg/L)	0.4	5	224.9	236.3	197.0	241.4	-----	-----	-----
Iron, Dissolved (ug/L)	7	5	42	10	n.d.	110	-----	-----	-----
Iron, Total (ug/L)	7	5	108	100	90	140	-----	-----	-----
Lead, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Lead, Total (ug/L)	0.5	5	-----	n.d.	n.d.	5.0	244[6], 9.5[7], 15[8]	0	0%
Magnesium, Dissolved (mg/L)	0.4	5	22.8	24.0	19.4	24.9	-----	-----	-----
Manganese, Dissolved (ug/L)	2	5	-----	5	n.d.	10	-----	-----	-----
Manganese, Total (ug/L)	2	5	8	8	6	10	-----	-----	-----
Mercury, Dissolved (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Mercury, Total (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	1.7[6], 0.012[7], 0.05[8]	0, b.d., 0	0%
Nickel, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Nickel, Total (ug/L)	10	5	-----	n.d.	n.d.	n.d.	970[6], 108[7], 100[8]	0	0%
Selenium, Total (ug/L)	1	5	3	1	1	8	20[6], 5[7], 50[8]	0	0%
Silver, Dissolved (ug/L)	1	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Silver, Total (ug/L)	1	5	-----	n.d.	n.d.	n.d.	14[6]	0	0%
Sodium, Dissolved (mg/L)	0.4	5	71.1	73.8	65.1	76.5	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Total (ug/L)	0.5	4	-----	n.d.	n.d.	n.d.	0.24[7]	b.d.	b.d.
Zinc, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	10	-----	-----	-----
Zinc, Total (ug/L)	10	5	-----	n.d.	n.d.	20	248[6,7], 7,400[8]	0	0%
Pesticide Scan (ug/L)[D]	0.05[E]	5	-----	n.d.	n.d.	n.d.	-----	-----	-----

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

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

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

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

- (1) Criteria for Class 1 streams.
- (2) Daily maximum criterion (monitoring results directly comparable to criterion).
- (3) Daily minimum criterion (monitoring results directly comparable to criterion).
- (4) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (5) 30-day average criterion (monitoring results not directly comparable to criterion).
- (6) Acute criterion for aquatic life.
- (7) Chronic criterion for aquatic life.
- (8) Human health criterion for surface waters.

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

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

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

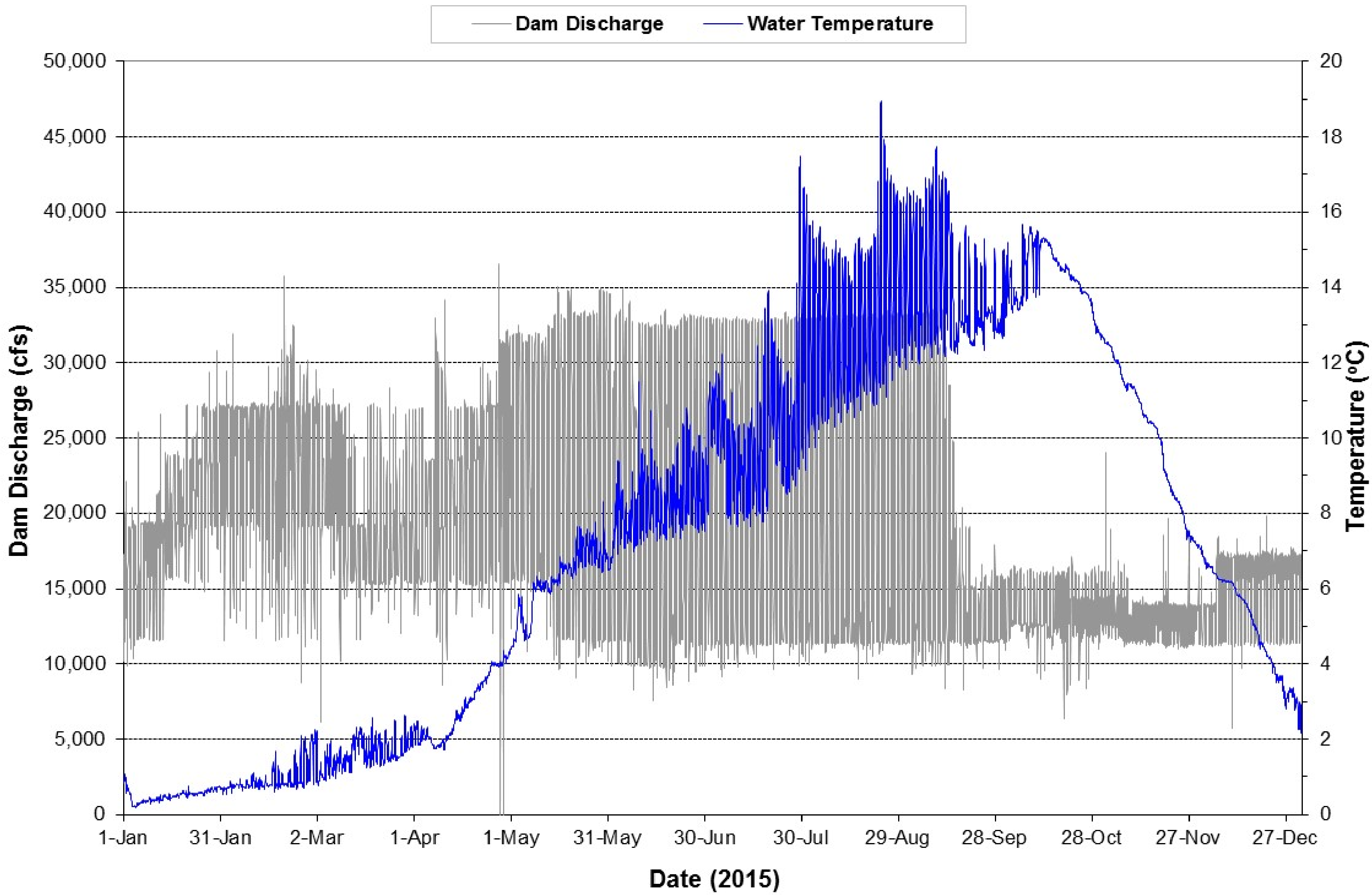


Plate 6-28. Hourly discharge and water temperature monitored at the Garrison powerplant on water discharged through the dam during 2015.

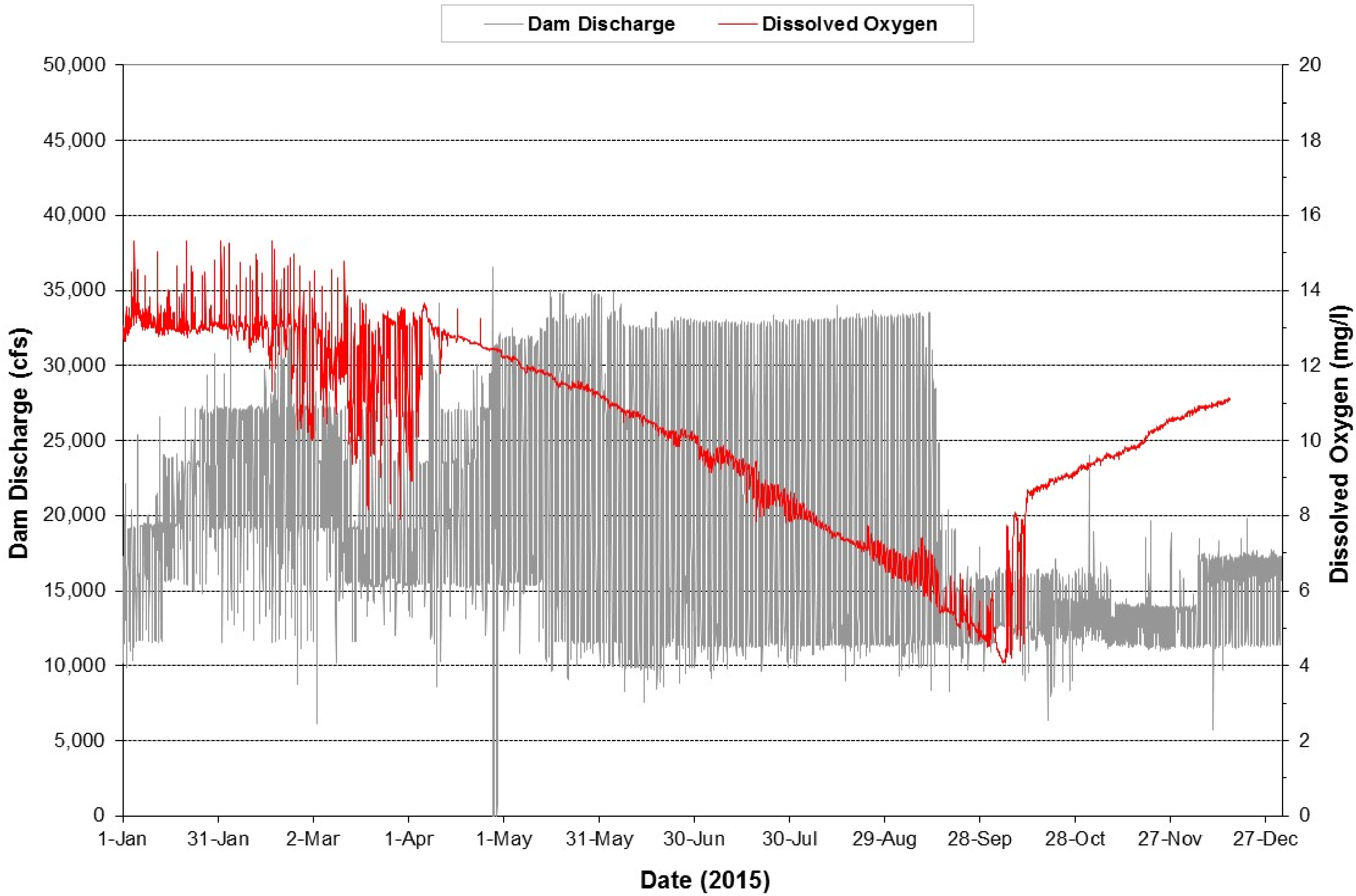


Plate 6-29. Hourly discharge and dissolved oxygen monitored at the Garrison powerplant on water discharged through the dam during 2015.

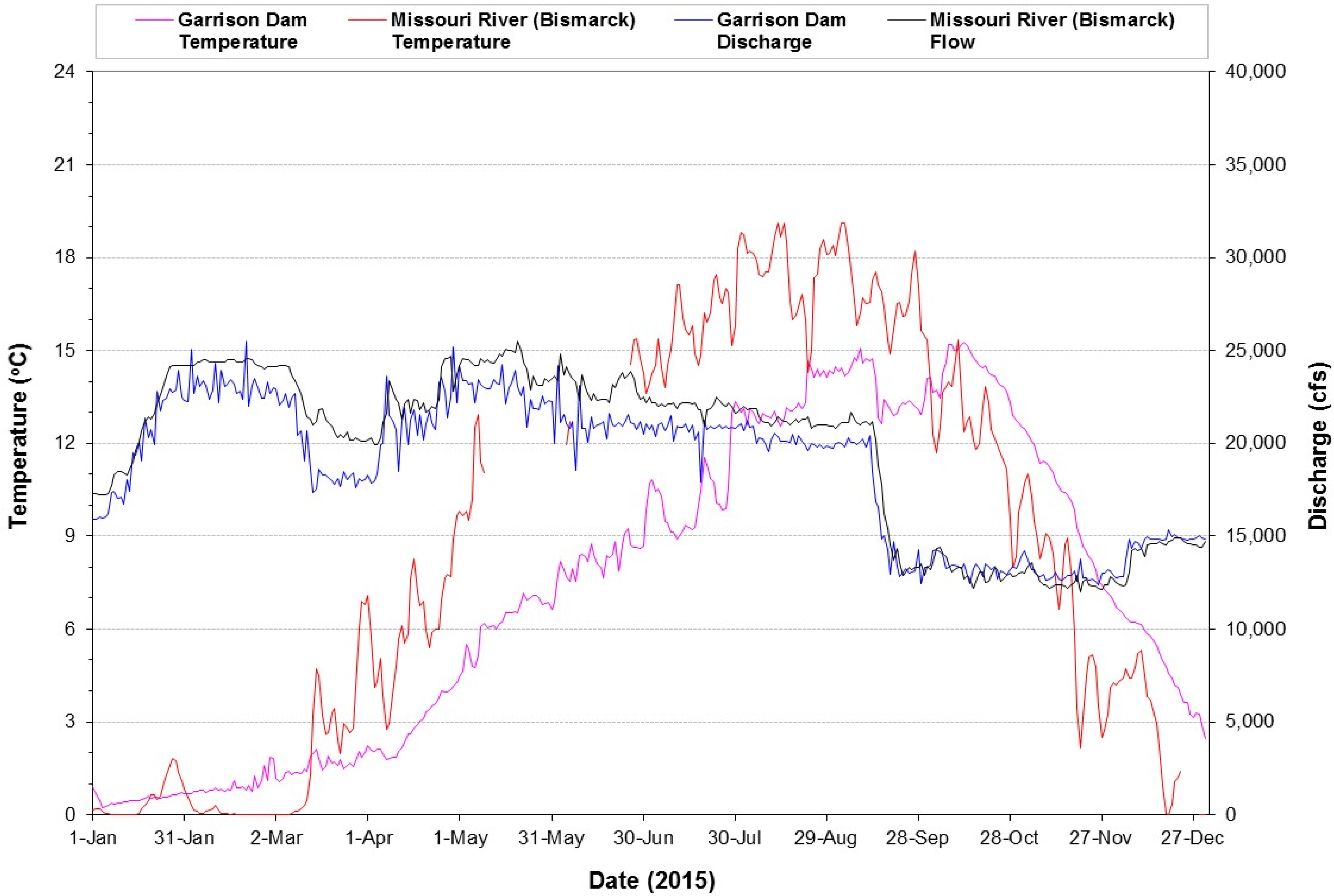


Plate 6-30. Mean daily water temperatures and discharge for the Garrison Dam discharge and the Missouri River at Bismarck for 2015.

7 OAHE PROJECT

7.1 BACKGROUND INFORMATION

7.1.1 PROJECT OVERVIEW

Oahe Dam is located on the Missouri River at RM 1072.3 in central South Dakota, 6 miles northwest of Pierre, SD. The closing of Oahe Dam in 1958 resulted in the formation of Oahe Reservoir (Lake Oahe). When full, the reservoir is 231 miles long, covers 374,000 acres, and has 2,250 miles of shoreline. Table 7-1 summarizes how the surface area, volume, mean depth, and retention time of Lake Oahe vary with pool elevations. Major inflows to the reservoir are the Missouri and Cheyenne Rivers. Water discharged through Oahe Dam for power production is withdrawn from Lake Oahe at elevation 1524 ft-NGVD29, approximately 114 feet above the reservoir bottom. The powerplant intake is on the opposite side of the dam from the outlet works for the flood tunnels. Water discharged from Oahe Dam through the six flood tunnels is withdrawn from near the bottom of Lake Oahe at elevations 1425 to 1455 ft-NGVD29. Figure 7-1 shows a schematic drawing and photo of Oahe Dam and the power intake structure.

Table 7-1. Surface area, volume, mean depth, and retention time of Lake Oahe at different pool elevations based on 2010 bathymetric survey.

Elevation (Feet-NGVD29)	Surface Area (Acres)	Volume (Acre-Feet)	Mean Depth (Feet)*	Retention Time (Years)**
1620	385,585	22,982,900	59.6	1.31
1615	352,515	21,161,350	60.0	1.20
1610	325,930	19,463,330	59.7	1.11
1605	298,850	17,904,680	59.9	1.02
1600	279,520	16,461,230	58.9	0.94
1595	258,595	15,117,980	58.5	0.86
1590	244,405	13,863,320	56.7	0.79
1585	229,685	12,676,740	55.2	0.72
1580	212,675	11,569,960	54.4	0.66
1575	195,760	10,549,470	53.9	0.60
1570	179,831	9,610,441	53.4	0.55
1565	163,143	8,755,206	53.7	0.50
1560	152,181	7,968,796	52.4	0.45
1555	140,063	7,239,563	51.7	0.41
1550	132,594	6,559,882	49.5	0.37
1545	124,749	4,762,793	47.4	0.34
1540	115,352	5,314,664	46.1	0.30

Average Annual Inflow (1967 through 2015) = 18.441 Million Acre-Feet.
Average Annual Outflow: (1967 through 2015) = 17.523 Million Acre-Feet.
* Mean Depth = Volume ÷ Surface Area.
** Retention Time = Volume ÷ Average Annual Outflow.
Note: Exclusive Flood Control Zone (elev. 1620-1617 ft-NGVD29), Annual Flood Control and Multiple Use Zone (elev. 1617-1607.5 ft-NGVD29), Carryover Multiple Use Zone (elev. 1607.5-1540 ft-NGVD29), and Permanent Pool Zone (elev. 1540-1415 ft-NGVD29). All elevations are in the NGVD 29 datum.

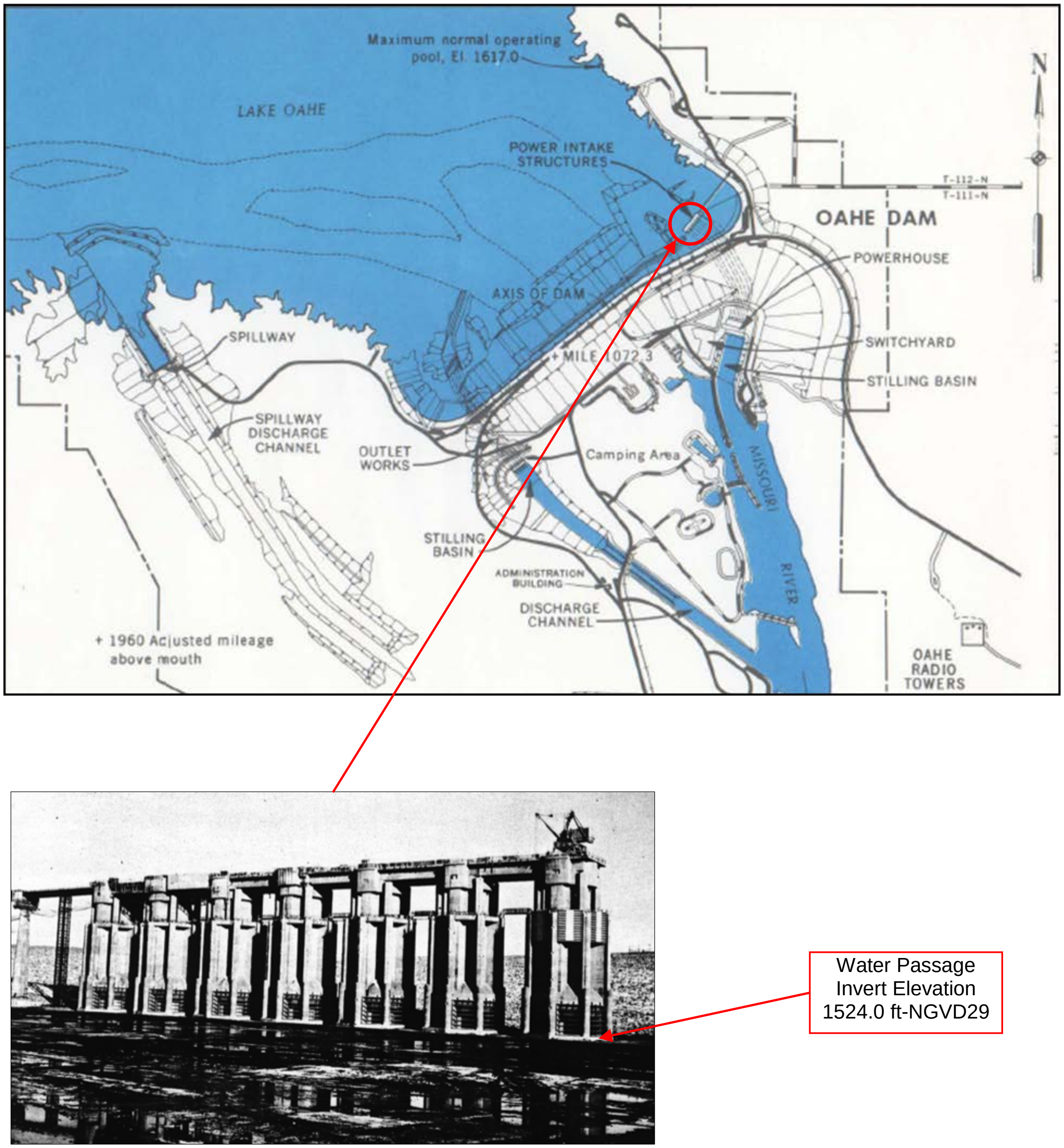


Figure 7-1. Location and photo of the power intake structure at Lake Oahe.

Lake Oahe and Oahe Dam 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 within the project area. Lake Oahe is used as a water supply by the towns of Fort Yates, ND (RM1244); Wakpala, SD (RM1198); Mobridge, SD (RM1193), and Huron, SD (RM1074), SD. The intake for the WEB Water System is at RM 1184 (serves 45 towns and over 7,000 rural households), and the intake for the Cheyenne River Tribe Mni Water Company is at RM 1110 (Eagle Butte, LaPlante, Swiftbird, Whitehorse, Promise, Dupree, Iron Lightning, Thunder Butte, Faith, Howes, Isabel, Takina, Cherry Creek, Bridger, Lantry, Ridgeview, Red Elm, Red Scaffold, Blackfoot, and Parade, SD). Lake Oahe is an important recreational resource and a major visitor destination in South Dakota.

Drought conditions in the western United States during the first decade of the 21th century lead to an appreciable drawdown of Lake Oahe. An historic low pool elevation of 1570.2 ft-NGVD29 was recorded in August 2006. Drought conditions dissipated at the end of the decade with the occurrence of above normal precipitation, and Lake Oahe recovered to normal pool elevations in 2009. Historic runoff in 2011 raised the pool elevation of Lake Oahe into the Exclusive Flood Control Zone from May to August, with a maximum pool elevation of 1619.7 ft-NGVD29 occurring in June. The recorded pool elevation at Lake Oahe at the end of December 2015 was 1609.2.4 ft-NGVD29; 1.7 feet above the top of the Carryover Multiple Use Zone (1607.5 ft-NGVD29). Figure 7-2 plots the midnight pool elevation of Lake Oahe and the mean daily discharge of Oahe Dam over the 5-year period 2011 through 2015. The extreme discharges in 2011 reflect additional releases made through the flood tunnels to manage the high inflows during 2011.

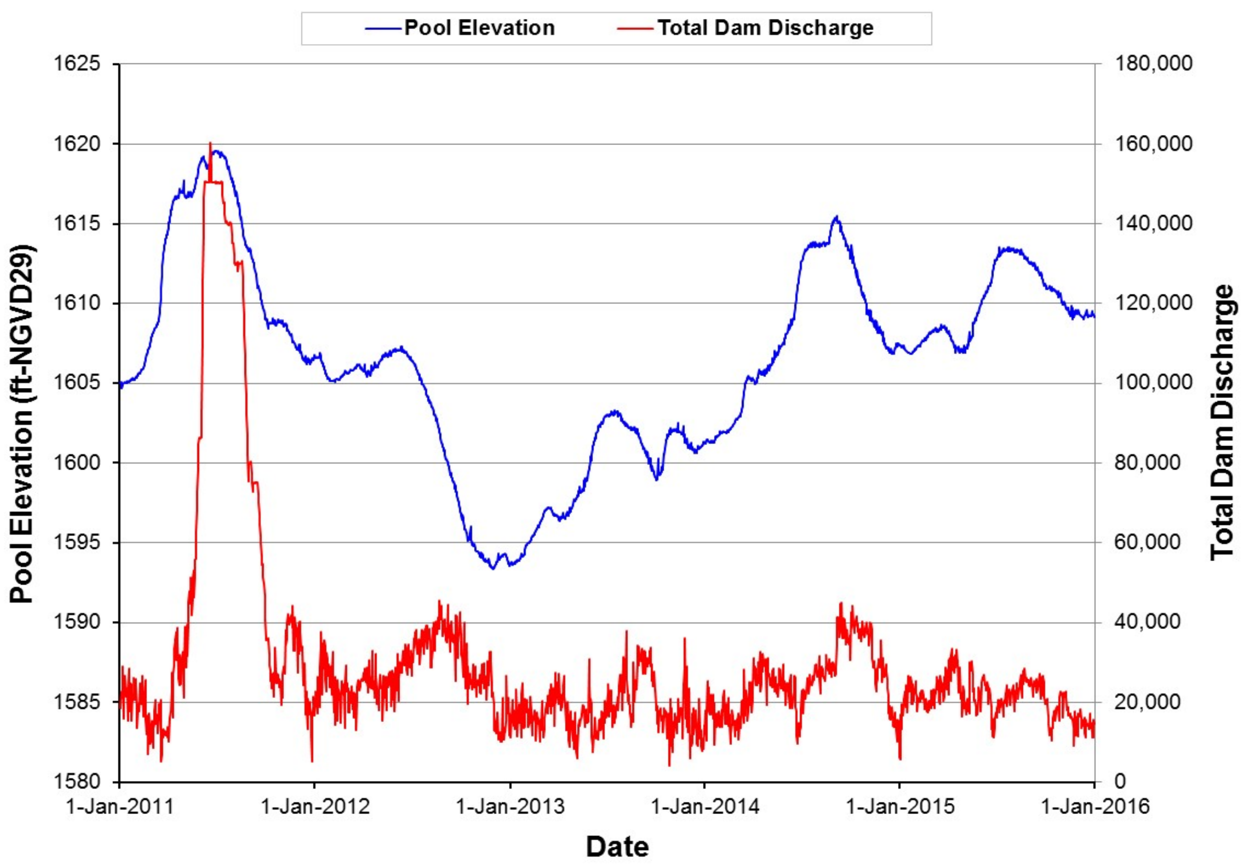


Figure 7-2. Lake Oahe midnight pool elevation and the mean daily discharge of Oahe Dam over the 5-year period 2011 through 2015.

7.1.2 WATER QUALITY STANDARDS CLASSIFICATIONS AND SECTION 303(D) LISTINGS

7.1.2.1 Lake Oahe

Under normal pool levels, Lake Oahe runs along the Missouri River from approximately RM1072 to RM1290, and crosses the North Dakota/South Dakota border which is at RM1232. Therefore under normal pools about 25 and 75 percent of the length of the reservoir is respectively in North Dakota and South Dakota. Water quality standards from each State respectively apply to the portion of the reservoir in each state.

The State of North Dakota has classified Lake Oahe as a Class 1 lake. As such, the reservoir is to be protected for a coldwater fishery; swimming, boating, and other water recreation; irrigation; stock watering; wildlife; and municipal or domestic use after appropriate treatment. Pursuant to Section 303(d) of the Federal CWA, North Dakota has not placed the Lake Oahe on the State's list of impaired waters. The State of North Dakota has issued a fish consumption advisory for Lake Oahe due to mercury concerns.

South Dakota has classified the Missouri River impoundments within the State as flowing streams and not reservoirs (South Dakota Administrative Rules 74:51:01:43). The following water quality-dependent beneficial uses have been designated for Lake Oahe in South Dakota's water quality standards: domestic water supply waters, coldwater permanent fish life propagation waters, immersion recreation waters, limited-contact recreation waters, commerce and industry waters, agricultural water supply (i.e. irrigation and stock watering), and fish and wildlife propagation. The State of South Dakota has not placed the reservoir on the State's Section 303(d) list of impaired waters and has not issued a fish consumption advisory for the reservoir. However, the Cheyenne River Sioux Tribe has issued a fish consumption advisory for Lake Oahe and the Cheyenne and Moreau Rivers. Tribal lands of the Cheyenne River Sioux are located along the west side of Lake Oahe between the Moreau and Cheyenne Rivers.

7.1.2.2 Missouri River Downstream of Oahe Dam

The following beneficial uses have been designated by South Dakota in their water quality standards for the Missouri River from Oahe Dam to Lake Sharpe: recreation (i.e. immersion and limited-contact), coldwater 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. The State of South Dakota has not placed the river on its Section 303(d) list of impaired waters and has not issued a fish consumption advisory for the river.

7.1.3 AMBIENT WATER QUALITY MONITORING

The District has monitored water quality conditions at the Oahe Project since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow to and outflow from the reservoir. Figure 7-3 shows the location of sites at the Oahe Project that have been monitored by the District for water quality during the past 5 years (i.e. 2011 through 2015). The near-dam location (i.e. site OAHLK1073A) has been continuously monitored since 1980.

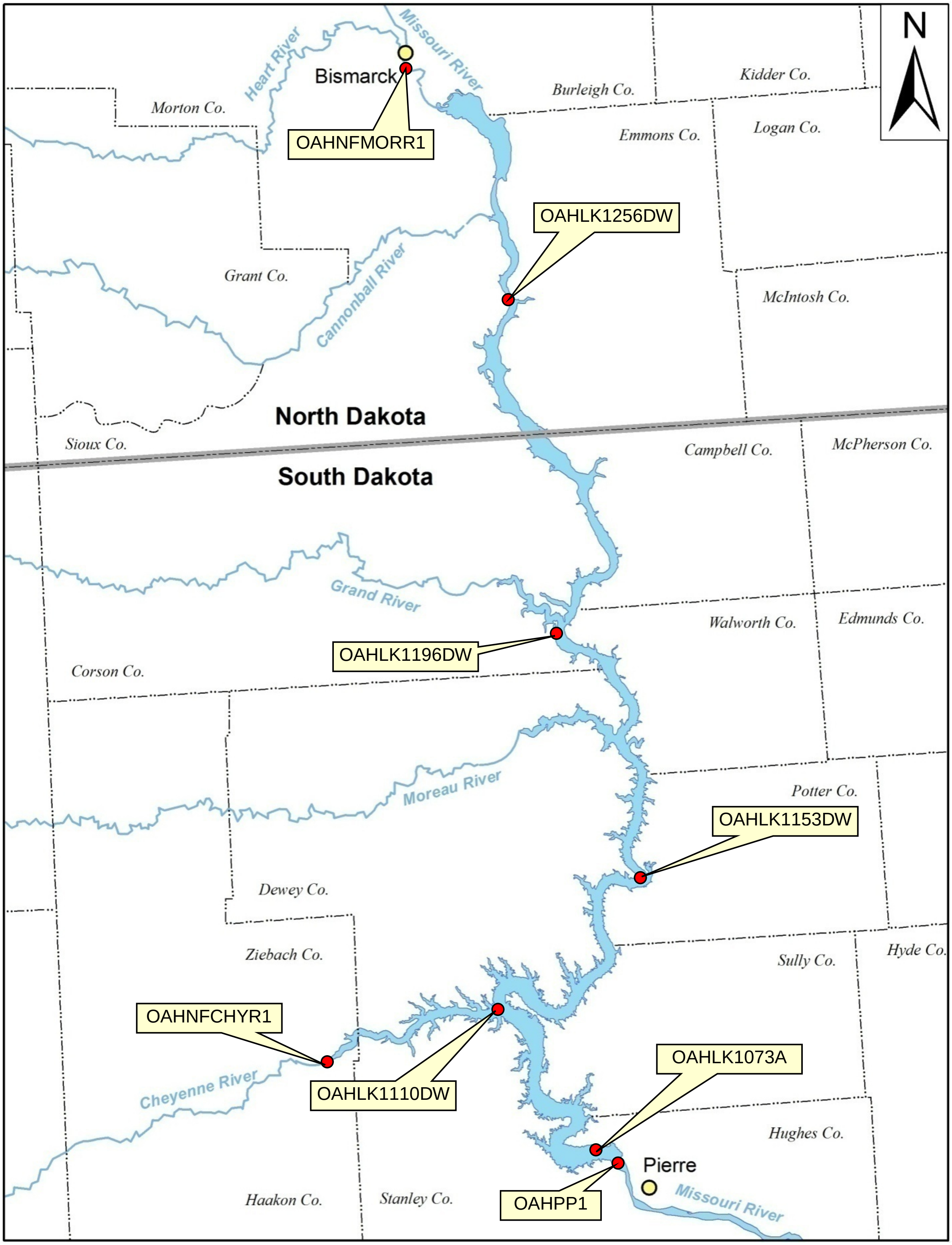


Figure 7-3. Location of sites where water quality monitoring was conducted by the District at the Oahe Project during the 5-year period 2011 through 2015.

7.2 WATER QUALITY IN LAKE OAHE

7.2.1 EXISTING WATER QUALITY CONDITIONS

7.2.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Water quality conditions that were monitored in Lake Oahe at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, and OAHLK1256DW from May through September during the 5-year period 2011 through 2015 are summarized in Plate 7-1, Plate 7-2, Plate 7-3, Plate 7-4, and Plate 7-5. A review of these results indicate possible water quality concerns regarding water temperature and dissolved oxygen for the support of Coldwater Permanent Fish Life Propagation. Water temperatures in the epilimnion of the reservoir regularly exceed 18.3°C in the summer, while temperatures in the hypolimnion are less than 18.3°C. Dissolved oxygen levels in the hypolimnion continually degrade along the reservoir bottom as summer progresses and fall below 7.0 mg/L in late summer (i.e. occurred in non-spawning area outside the spawning season for coldwater species). During the 4 years 2012 through 2015, dissolved oxygen levels generally remained above 6.0 mg/L in the hypolimnion in the area of the reservoir near Oahe Dam (sites OAHLK1073A and OAHLK1110DW). However, during 2011 dissolved oxygen levels fell below 5 mg/L at both these sites during late summer. Dissolved oxygen concentrations regularly fell below 6 mg/L in the middle and upstream reaches of the hypolimnion at sites OAHLK1153DW and OAHLK1196DW (Plate 7-3 and Plate 7-4). The lowest dissolved oxygen concentration measured during the 5-year period at the five sites was 0.6 mg/L, and occurred at site OAHLK1110DW in September 2011. Due to shallower water depth a hypolimnion and low dissolved oxygen levels did not form in the upstream reaches of Lake Oahe at site OAHLK1256DW (Plate 7-5). Conditions supportive of Coldwater Permanent Fish Life Propagation (i.e. water temperature ≤18.3°C and dissolved oxygen ≥ 6 mg/L) were present in 96, 87, 80, 50, and 39 percent of the depth-profile measurements respectively taken at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, and OAHLK1256DW. Depth profiles measured on 13-Sep-2011 indicated that the Coldwater Permanent Fish Life Propagation use was not supported at any of the five monitored sites. The impact to coldwater fishery habitat in 2011 is attributed to the high releases made through the near-bottom flood tunnels to release water for flood management. The high releases made through the bottom-release flood tunnels seemingly pulled water with low dissolved oxygen along the reservoir bottom from the upstream reaches of the hypolimnion. The low dissolved oxygen levels at the bottom of the reservoir pinched off coldwater fishery habitat from below in the hypolimnion near the dam.

7.2.1.2 Summer Thermal Stratification and Dissolved Oxygen Conditions during 2015

7.2.1.2.1 Depth-Profile Plots

Depth-profile plots of temperature measurements taken at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, and OAHLK1256DW during 2015 are shown in Plate 7-6. Depth-profile plots of dissolved oxygen measurements taken at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, and OAHLK1256DW during 2015 are shown in Plate 7-7.

7.2.1.2.2 Longitudinal Temperature Contour Plots

Summer thermal stratification of Lake Oahe during 2015 is described by the monthly longitudinal temperature contour plots based on depth-profile temperature measurements taken in May, June, July, August, and September (Plate 7-8, Plate 7-9, Plate 7-10, Plate 7-11, and Plate 7-12). The contour plots were constructed along the length of the reservoir. As seen in the contour plots, water temperature in Lake Oahe varies longitudinally from the dam to the reservoir's upper reaches and vertically from the reservoir surface to the bottom. The near-surface water in the upper reaches of the reservoir warms up sooner in the spring than the near-surface water near the dam. By mid-summer a strong thermocline becomes established in the lower reaches of the reservoir, and the near-surface waters of the entire reservoir above the thermocline are a fairly uniform temperature. As the near-surface waters of the reservoir cool in the late summer, the thermocline is pushed deeper and these wind-mixed upper waters are fairly uniform in temperature. The vertical variation in temperature is most prevalent in the deeper area of the reservoir towards the dam where a strong thermocline becomes established during the summer. The shallower upper reaches of Lake Oahe do not exhibit much vertical variation of temperature during mid to late summer as wind action allows for complete mixing of the water column.

7.2.1.2.3 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen longitudinal contour plots were constructed along the length of Lake Oahe based on depth-profile measurements taken in May, June, July, August, and September of 2013 (Plate 7-13, Plate 7-14, Plate 7-15, Plate 7-16, and Plate 7-17). During the summer, dissolved oxygen conditions in Lake Oahe varied longitudinally from the dam to the reservoir's upper reaches and vertically from the reservoir surface to the bottom. Dissolved oxygen levels below 6 mg/L first appeared near the reservoir bottom in the middle reaches of the reservoir in July. As the summer progressed, dissolved oxygen concentrations below 6 mg/L expanded along the bottom in the middle reaches of the reservoir. The occurrence of low dissolved oxygen concentrations in the near-bottom water of the middle reaches of Lake Oahe is attributed to the increased allochthonous organic loading in the transition zone of the reservoir and the lesser hypolimnetic volume available for assimilation of the oxygen demand. As this material decomposes, a "pool" of water with low dissolved oxygen levels accumulates near the bottom in this area of the reservoir. Decomposition of autochthonous organic matter also occurs in the lacustrine zone and results in dissolved oxygen degradation as the summer progresses, although at a slower rate than what occurs in the transition zone. The recovery of near-bottom dissolved oxygen concentrations to saturation levels takes longer in the deeper water nearer the dam because of the time needed for thermal stratification to breakdown and mixing within the water column to occur in the deeper water.

7.2.1.3 <u>Comparison of Near-Surface and Near-Bottom Water Quality Conditions</u>

Paired near-surface and near-bottom water quality samples collected from Lake Oahe during the summer were compared. Near-surface conditions were represented by samples collected within 2-meters of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meters of the reservoir bottom. The compared samples were collected at the near-dam site OAHLK1073A during the 5-year period 2011 through 2015. During the period a total of 20 paired samples were collected monthly from June through September. Box plots were constructed to display the distribution of the paired near-surface and near-bottom measurements for the following parameters: water temperature, dissolved oxygen, pH, alkalinity, total ammonia, and total phosphorus (Plate 7-18). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for water temperature, pH, alkalinity, and total phosphorus. Parameters that were significantly lower in the near-bottom water of Lake Oahe included: water temperature ($p < 0.001$) and pH ($p < 0.001$). Parameters that were significantly higher in the near-bottom water included: alkalinity ($p < 0.05$), and total phosphorus ($p < 0.001$).

7.2.1.4 <u>Reservoir Trophic Status</u>

Trophic State Index (TSI) values for Lake Oahe were calculated from monitoring data collected during the 5-year period 2011 through 2015 (Table 7-2). The calculated TSI values indicate that the lacustrine zone of the reservoir (i.e. sites OAHLK1073A and OAHLK1110DW) is mesotrophic, the transition zone (i.e. site OAHLK1153DW) is mesotrophic, and the riverine zone (i.e. sites OAHLK11961DW and OAHLK1256DW) is moderately eutrophic to eutrophic.

Table 7-2. Mean Trophic State Index (TSI) values calculated for Lake Oahe. TSI values are based on monitoring conducted at the identified five sites during 5-year period 2011 through 2015.

Monitoring Site	Mean – TSI (Secchi Depth)	Mean – TSI (Total Phosphorus)	Mean – TSI (Chlorophyll)	Mean – TSI (Average)
OAHLK1073A	41	40	50	44
OAHLK1110DW	45	42	51	46
OAHLK1153DW	44	43	52	46
OAHLK1196DW	51	45	52	49
OAHLK1256DW	67	53	61	60

Note: See Section 4.1.4 for discussion of TSI calculation.

7.2.1.5 <u>Plankton Community</u>

7.2.1.5.1 Phytoplankton

Phytoplankton grab samples were collected from Lake Oahe at five sites (i.e. OAHLK10730A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, and OAHLK1256DW) during the spring and summer of 2015. Taxa identified in the collected phytoplankton samples were from seven taxonomic divisions: Bacillariophyta (Diatoms), Chlorophyta (Green Algae), Chrysophyta (Golden Algae), Cryptophyta (Cryptomonad Algae), Cyanobacteria (Blue-Green Algae), Pyrrophyta (Dinoflagellate Algae), and Euglenophyta (Euglenoid Algae). The relative abundance of phytoplankton, based on biovolume, in samples collected from Lake Oahe in May, July, and September 2015 is shown in Figure 7-4. Diatoms and Cryptomonads were the dominant phytoplankton groups present in Lake Oahe in 2015. No concentrations of the cyanobacteria toxin microcystin above 1 ug/L were monitored in the lake during the 5-year period 2011 through 2015 (Plate 7-1, Plate 7-2, Plate 7-3, Plate 7-4, and Plate 7-5).

7.2.1.5.2 Zooplankton

Zooplankton vertical-tow samples were collected from Lake Oahe at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, and OAHLK1256DW in May, July, and September of 2015. The sampled zooplankton included three taxonomic groupings: Cladocerans, Copepods, and Rotifers. The relative abundance of these three taxonomic grouping in the zooplankton samples collected in 2015 is shown in Figure 7-5. Cladocerans and copepods dominated the zooplankton community in Lake Oahe.

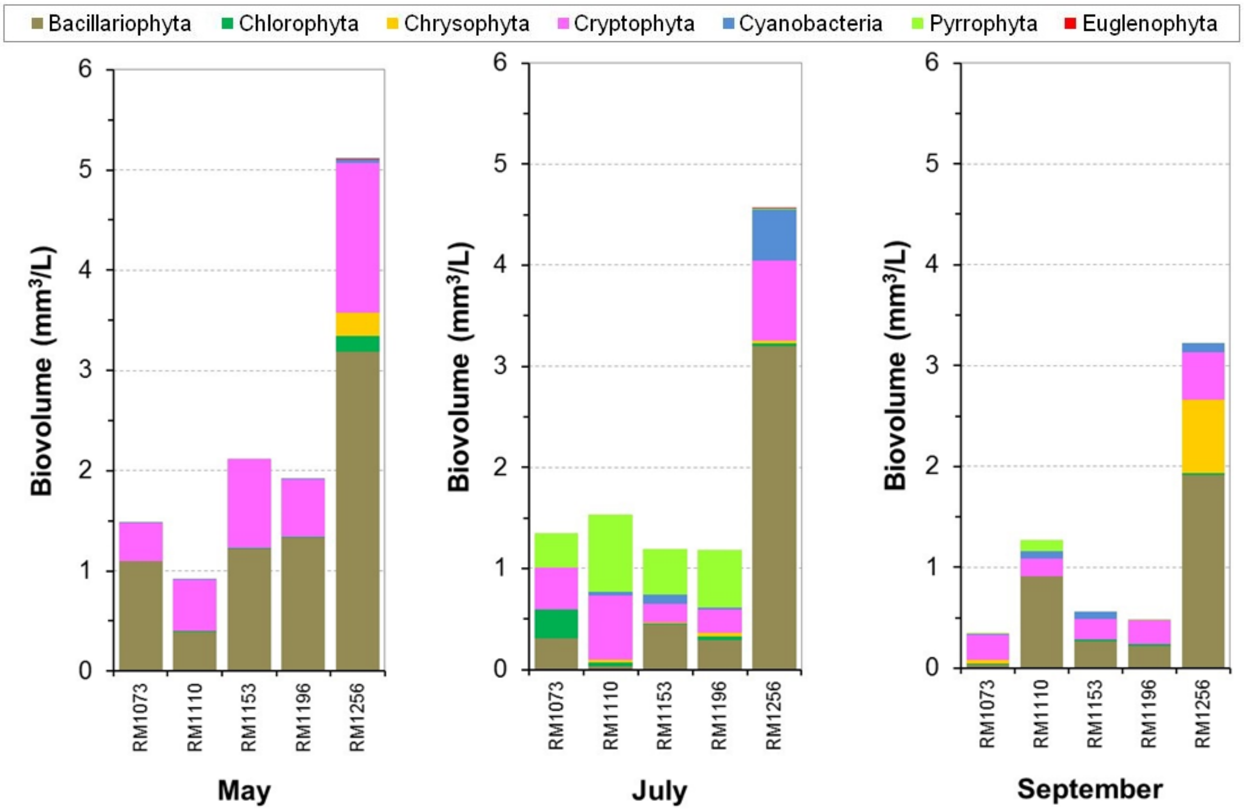


Figure 7-4. Relative abundance of phytoplankton in samples collected from Lake Oahe during 2015

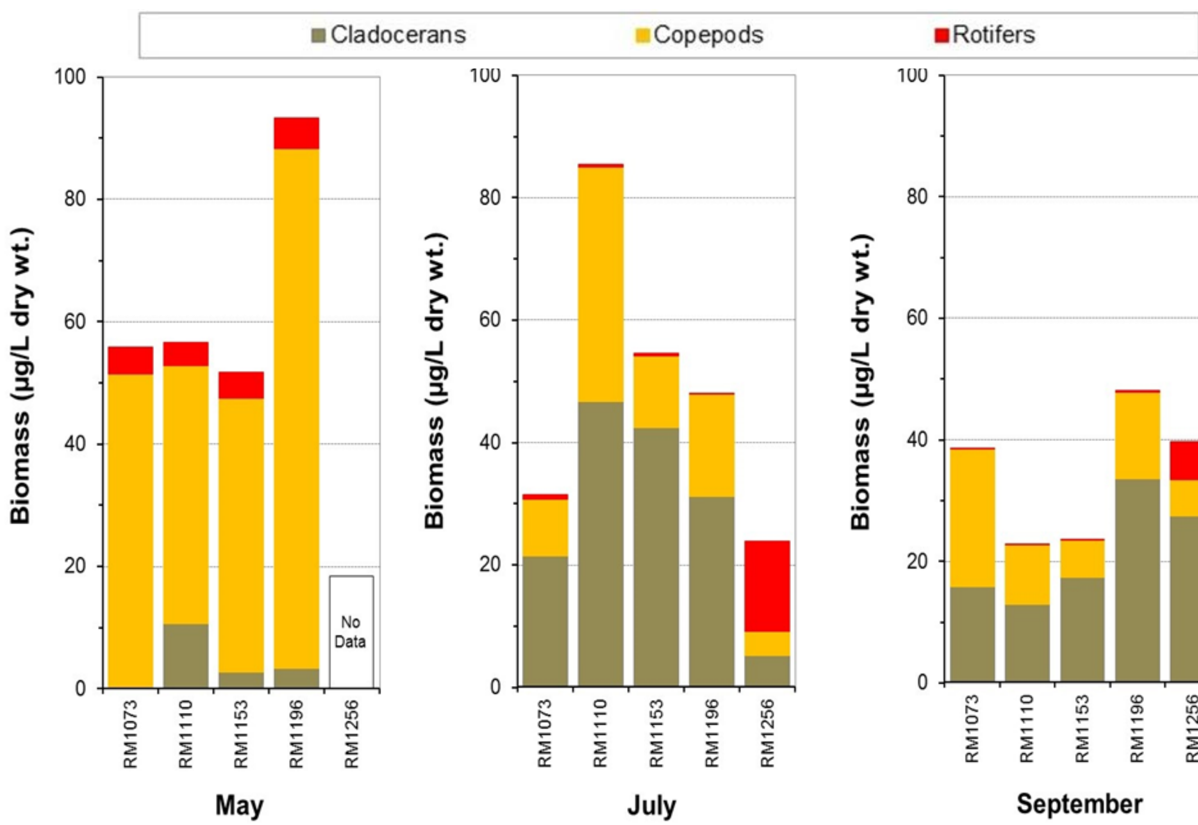


Figure 7-5. Relative abundance of zooplankton in samples collected from Lake Oahe during 2015**.**

7.2.1.6 Occurrence of Coldwater Permanent Fish Life Propagation Habitat in Lake Oahe

The most crucial period for the support of Coldwater Permanent Fish Life Propagation (CPFLP) habitat in Lake Oahe is when the reservoir begins to cool in late summer. As the thermocline moves deeper, the volume of the coldwater hypolimnion continues to decrease while the expanding epilimnion may not have cooled enough to be supportive of CPFLP habitat. At the same time, hypolimnetic dissolved oxygen concentrations are approaching their maximum degradation and low dissolved oxygen levels are moving upward from the reservoir bottom and "pinching off" coldwater habitat from below. This situation continues to worsen until the epilimnion cools enough to be supportive of CPFLP habitat and the reservoir eventually experiences fall turnover. The volume of the hypolimnion (i.e. CPFLP habitat) occurring in Lake Oahe during the summer decreases with lower pool levels.

The occurrence of CPFLP habitat (i.e. water temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/L) in Lake Oahe was estimated from collected water temperature and dissolved oxygen depth-profile measurements and defined reservoir elevation and volume relationships. Plate 7-19 displays a plot of pool elevations and the CPFLP habitat estimated to have been present in Lake Oahe during the summers of the 5-year period 2011 through 2015.

The occurrence of coldwater habitat in Lake Oahe is highly dependent on pool elevation. Since coldwater habitat only occurs in the hypolimnion of the reservoir during the summer, the size of the hypolimnion will determine the amount of coldwater habitat potentially available. The upper extent of the hypolimnion is delineated by the thermocline which separates the colder hypolimnion from the warmer, less dense water of the epilimnion. Depending on climatic factors, the thermocline in an individual reservoir will generally be established at a similar depth from year to year. Therefore, a greater hypolimnetic volume will tend to occur under higher pool elevations and a lesser hypolimnetic volume will tend to occur under lower pool elevations. The pool elevation in late-spring and early summer when the thermocline first becomes established is especially important as later changes in pool elevations are mitigated somewhat by the stratification already established. A larger hypolimnetic volume also has a greater assimilative capacity for oxygen demanding materials which can degrade dissolved oxygen levels in the hypolimnion below the CPFLP habitat standard of 6 mg/L.

7.2.2 WATER QUALITY TRENDS (1980 THROUGH 2015)

Water quality trends over the 36-year period of 1980 through 2015 were determined for Lake Oahe for Secchi depth, total phosphorus, chlorophyll *a*, and TSI (i.e. trophic status). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through September at the near-dam, ambient monitoring site (i.e. site OAHLK1073A). Plate 7-20 displays a scatter-plot of the collected data for the four parameters, a linear regression trend line, and the significance of the trend line (i.e. $\alpha = 0.05$). For the assessment period, no significant trends were detected for Secchi depth, total phosphorus, or chlorophyll *a*. However, an increasing trend was detected for TSI ($p < 0.01$). Over the 36-year period, the reservoir has generally remained in a mesotrophic state.

7.3 EXISTING WATER QUALITY CONDITIONS OF TRIBUTARY INFLOW TO LAKE OAHE

7.3.1 MISSOURI RIVER

The water quality conditions that were monitored in the Missouri River at Bismarck, ND (i.e. site OAFNFMORR1) during the 5-year period 2011 through 2015 are summarized in Plate 7-21 and Plate 7-22. A review of these results indicated no major water quality concerns.

Nutrient flux rates for the Missouri River inflow to Lake Oahe over the 5-year period 2011 through 2015 were calculated based on near-surface water quality samples collected near Bismarck, ND (i.e. site OAHNFMORR1) and the instantaneous flow conditions at the time of sample collection (Table 7-3). It must be recognized that the concentrations of particulate-associated constituents can vary significantly from the river surface to its bottom because of the sinking of particulate matter and its transport nearer the river bottom (see previous discussion). Since the instantaneous concentration of particulate-associated constituents (i.e. total phosphorus) are likely higher nearer the river bottom, near-surface grab samples likely under estimate the "true" water-column composite concentration for these constituents. Thus, the flux rates given for total phosphorus Table 7-3 should be considered minimum estimates with the actual flux rate being somewhat higher. The maximum flux rates for all the constituents are believed to be attributed to higher nonpoint-source loadings during runoff conditions.

Table 7-3. Summary of nutrient flux rates (kg/sec) calculated for the Missouri River at Bismarck, ND during April through September over the 5-year period 2011 through 2015.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	32	32	32	32	32	32	32
Mean	34,550	0.0433	0.4335	0.1005	0.1412	0.1102	4.2746
Median	24,400	n.d.	0.2326	0.0420	0.0189	n.d.	2.9039
Minimum	13,500	n.d.	n.d.	n.d.	n.d.	n.d.	1.4908
Maximum	142,997	0.7645	2.3700	0.5833	3.2492	3.2492	19.0308

n.d. = Nondetectable.
Note: Nondetect values set to 0 for flux calculations.

Through an agreement with the USGS, a water temperature monitoring probe was added to the USGS's gage (06342500) on the Missouri River near Bismarck, ND (i.e. site OAHNFMORR1). See Section 6.5 for a discussion of 2015 monitoring results.

7.3.2 CHEYENNE RIVER

The water quality conditions that were monitored in the Cheyenne River at the SD Highway 63 crossing near Cherry Creek, SD (site OAHNFCHYR1) during 2014 and 2015 are summarized in Plate 7-23 and Plate 7-24. A review of these results indicated water quality conditions indicated that the acute and chronic total suspended solids criteria for the protection of Warmwater Permanent Fish Life Propagation and the sulfate Domestic Water Supply 30-day average criteria were regularly exceeded.

7.4 WATER QUALITY AT THE OAHE POWERPLANT

7.4.1 STATISTICAL SUMMARY AND COMPARISON TO APPLICABLE WATER QUALITY STANDARDS CRITERIA

Plate 7-25 and Plate 7-26 summarize the water quality conditions that were measured in samples collected from water discharged through Oahe Dam during 5-year period 2011 through 2015. A review of these results indicated possible water quality concerns regarding temperature for the support of Coldwater Permanent Fish Life Propagation in the Oahe Dam tailwaters and arsenic for the protection of human health.

7.4.2 TEMPERATURE, DISSOLVED OXYGEN, AND DAM DISCHARGE TIME-SERIES PLOTS

Hourly temperature, dissolved oxygen, and dam discharge recorded at the Oahe powerplant during 2015 were used to construct time-series plots (Plate 7-27 and Plate 7-28). Water temperatures showed seasonal warming and cooling through the calendar year. Dissolved oxygen levels remained relatively high and stable during the winter, steadily declined through the spring and summer, and steadily increased during the fall. The lowest dissolved oxygen levels occurred during the late-summer period. The higher winter, declining spring, and increasing fall dissolved oxygen concentrations are attributed to decreasing dissolved oxygen solubility with warmer water temperatures. The decreasing dissolved oxygen in the July to September period may also be attributed somewhat to the influence of ongoing degradation of dissolved oxygen in the hypolimnion as the summer progressed. Overall, there appeared to be minor correlation between discharge rates and measured water temperature and dissolved oxygen concentrations. Discharge water temperatures in the summer regularly exceeded the coldwater permanent fish life protection criterion of 18.3°C designated to the Missouri River downstream of Oahe Dam.

7.4.3 NUTRIENT FLUX CONDITIONS OF THE OAHE DAM DISCHARGE TO THE MISSOURI RIVER

Nutrient flux rates for the Oahe Dam discharge to the Missouri River over the 5-year period 2011 through 2015 were calculated based on samples taken from the Oahe powerplant (i.e. site OAHPP1) and the dam discharge at the time of sample collection (Table 7-4). The samples collected in the powerplant are taken from the raw water supply line and are believed to be unbiased regarding particulate-associated constituents. Therefore, the flux rates calculated for the Oahe Dam discharge give an unbiased estimate of the flux rates for all the constituents, including total phosphorus and total organic carbon. The maximum flux rates for all the constituents are believed to be attributed to higher dam discharges.

Table 7-4. Summary of nutrient flux rates (kg/sec) calculated for the Oahe Dam discharge to the Missouri River (i.e. site OAHPP1) during January through December over the 5-year period 2011 through 2015.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	40	40	40	40	40	40	40
Mean	29,132	0.0211	0.3895	0.0735	0.0192	0.0044	4.5568
Median	29,009	n.d.	0.2603	0.0340	0.0077	n.d.	3.2824
Minimum	5,300	n.d.	n.d.	n.d.	n.d.	n.d.	0.5553
Maximum	57,233	0.1700	1.7206	0.3699	0.1229	0.0277	15.9769

Note: Nondetectable values set to 0 for flux calculations.

Plate 7-1. Summary of monthly (May through September) water quality conditions monitored in Lake Oahe near Oahe Dam (Site OAHLK1073A) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	26	1609.1	1610.0	1598.4	1619.2	-----	-----	-----
Water Temperature (°C)	0.1	1,362	12.8	10.6	4.8	25.4	18.3[1,6]	310	23%
Hypolimnion Water Temperature (°C)[E]	0.1	637	10.4	9.8	6.2	19.8	18.3[1,6]	5	1%
Dissolved Oxygen (mg/L)	0.1	1,362	9.4	9.4	4.2	12.5	6[1,7,9], 7[1,7,9]	20, 107	2%, 8%
Dissolved Oxygen (% Sat.)	0.1	1,362	91.3	94.8	41.3	126.8	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[E]	0.1	719	9.8	9.6	5.2	12.5	5[3,7]	0	0%
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	641	9.1	9.4	4.2	11.7	6[1,7,9]	19	3%
Specific Conductance (uS/cm)	1	1,362	825	814	672	951	-----	-----	-----
pH (S.U.)	0.1	1,309	8.1	8.2	6.6	8.8	6.5[1,2,7], 9.0[1,2,6], 9.5[4,6]	0, 9, 0	0%
Turbidity (NTUs)	1	1,361	-----	n.d.	n.d.	87	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	1,305	352	370	126	477	-----	-----	-----
Secchi Depth (M)	1	26	3.91	3.75	0.99	7.01	-----	-----	-----
Alkalinity, Total (mg/L)	7	50	168	171	151	178	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	50	4.2	4.0	2.7	10.6	-----	-----	-----
Chloride (mg/L)	1	30	12	12	11	14	175[1,6], 100[1,8], 438[2,6], 250[2,8]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	936	4	3	n.d.	81	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	25	3	3	n.d.	10	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	50	24	24	13	34	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	49	606	612	444	820	1,750[2,6], 1,000[2,8], 3,500[4,6], 2,000[4,8]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	50	-----	n.d.	n.d.	0.07	3.8 [1,6,10], 1.7 [1,8,10]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	50	0.4	0.3	n.d.	3.7	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	50	-----	0.05	n.d.	0.30	88[5,6], 50[5,8], 10[2,6]	0	0%
Nitrogen, Total (mg/L)	0.1	50	0.5	0.4	n.d.	3.7	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	50	-----	n.d.	n.d.	0.04	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	50	-----	0.02	n.d.	0.05	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	50	-----	n.d.	n.d.	0.03	-----	-----	-----
Sulfate (mg/L)	1	50	252	246	185	313	875[2,6], 500[2,8]	0	0%
Suspended Solids, Total (mg/L)	4	50	-----	n.d.	n.d.	34	53[1,6], 30[1,8]	0	0%
Microcystin, Extracellular (ug/L)	0.1	25	-----	n.d.	n.d.	0.1	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat[F]	-----	26	-----	-----	-----	-----	D.O ≥ 6 mg/L W. Temp. ≤ 18.3°C	1	4%

n.d. = Not detected.

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

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

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

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

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

(F) Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e. at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/L). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile.

Plate 7-2. Summary of monthly (May through September) water quality conditions monitored in Lake Oahe near the confluence of the Cheyenne River (Site OAHLK1110DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[(A)]						Water Quality Standards Attainment		
	Detection Limit[(B)]	No. of Obs.	Mean[(C)]	Median	Min.	Max.	State WQS Criteria[(D)]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	25	1609.0	1609.3	1598.4	1619.2	-----	-----	-----
Water Temperature (°C)	0.1	974	14.4	13.1	4.9	25.6	18.3[(1,6)]	275	28%
Hypolimnion Water Temperature (°C)[(E)]	0.1	317	12.2	11.7	7.2	19.9	18.3[(1,6)]	8	3%
Dissolved Oxygen (mg/L)	0.1	974	9.0	8.6	0.6	12.4	6[(1,7,9)], 7[(1,7,9)]	66, 132	7%, 14%
Dissolved Oxygen (% Sat.)	0.1	974	89.6	94.2	6.3	121.0	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[(E)]	0.1	659	9.5	9.3	5.0	12.4	5[(3,7)]	0	0%
Hypolimnion Dissolved Oxygen (mg/L)[(E)]	0.1	315	7.7	8.0	0.6	10.8	6[(1,7,9)]	59	19%
Specific Conductance (uS/cm)	1	974	821	815	621	1,007	-----	-----	-----
pH (S.U.)	0.1	974	8.1	8.2	7.1	8.7	6.5[(1,2,7)], 9.0[(1,2,6)], 9.5[(4,6)]	0	0%
Turbidity (NTUs)	1	971	-----	n.d.	n.d.	81	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	930	360	365	236	495	-----	-----	-----
Secchi Depth (M)	0.02	23	3.23	3.40	0.36	5.79	-----	-----	-----
Alkalinity, Total (mg/L)	7	49	167	167	142	178	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	49	4.2	4.2	2.4	6.2	-----	-----	-----
Chloride (mg/L)	1	29	12	12	10	16	175[(1,6)], 100[(1,8)], 438[(2,6)], 250[(2,8)]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	887	4	3	n.d.	29	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	25	4	4	n.d.	11	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	49	26	26	14	40	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	48	614	627	392	824	1,750[(2,6)], 1,000[(2,8)], 3,500[(4,6)], 2,000[(4,8)]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	49	-----	n.d.	n.d.	0.14	3.8 [(1,6,10)], 1.7 [(1,8,10)]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	49	0.4	0.3	n.d.	2.0	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	49	-----	0.05	n.d.	0.30	88[(5,6)], 50[(5,8)], 10[(2,6)]	0	0%
Nitrogen, Total (mg/L)	0.1	49	0.4	0.4	n.d.	2.0	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	49	-----	n.d.	n.d.	0.04	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	49	0.02	0.02	n.d.	0.08	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	49	-----	n.d.	n.d.	0.04	-----	-----	-----
Sulfate (mg/L)	1	49	251	247	168	337	875[(2,6)], 500[(2,8)]	0	0%
Suspended Solids, Total (mg/L)	4	49	-----	n.d.	n.d.	105	53[(1,6)], 30[(1,8)]	0	0%
Microcystin, Extracellular (ug/L)	0.1	25	-----	n.d.	n.d.	0.1	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat[(F)]	-----	24	-----	-----	-----	-----	D.O ≥ 6 mg/L W. Temp. ≤ 18.3°C	3	13%

n.d. = Not detected.

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

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

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

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

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

(F) Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e. at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/L). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile.

Plate 7-3. Summary of monthly (June through September) water quality conditions monitored in Lake Oahe near Whitlocks Bay (Site OAHLK1153DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	25	1609.1	1609.0	1598.5	1619.3	-----	-----	-----
Water Temperature (°C)	0.1	835	15.6	15.1	6.4	24.2	18.3[1,6]	308	37%
Hypolimnion Water Temperature (°C)[E]	0.1	231	13.2	13.3	8.5	19.9	18.3[1,6]	3	1%
Dissolved Oxygen (mg/L)	0.1	835	8.3	8.3	2.4	13.5	6[1,7,9], 7[1,7,9]	121, 169	14%, 20%
Dissolved Oxygen (% Sat.)	0.1	835	85.5	91.4	25.2	137.0	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[E]	0.1	602	9.0	8.7	5.0	13.5	5[3,7]	0	0%
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	231	6.5	6.5	2.4	10.1	6[1,7,9]	106	46%
Specific Conductance (uS/cm)	1	835	783	793	620	884	-----	-----	-----
pH (S.U.)	0.1	835	8.2	8.2	7.3	8.6	6.5[1,2,7], 9.0[1,2,6], 9.5[4,6]	0	0%
Turbidity (NTUs)	1	834	-----	1	n.d.	15	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	798	355	358	257	457	-----	-----	-----
Secchi Depth (M)	1	23	3.15	3.12	1.70	4.65	-----	-----	-----
Alkalinity, Total (mg/L)	7	49	164	166	145	179	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	49	4.2	4.1	2.5	5.4	-----	-----	-----
Chloride (mg/L)	1	30	10	10	9	12	175[1,6], 100[1,8], 438[2,6], 250[2,8]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	764	5	3	n.d.	46	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	24	4	4	n.d.	11	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	49	29	29	18	45	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	48	583	579	386	804	1,750[2,6], 1,000[2,8], 3,500[4,6], 2,000[4,8]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	49	-----	n.d.	n.d.	0.08	3.8 [1,6,10], 1.7 [1,8,10]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	49	0.3	0.3	n.d.	0.8	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	49	-----	0.07	n.d.	0.30	88[5,6], 50[5,8], 10[2,6]	0	0%
Nitrogen, Total (mg/L)	0.1	49	0.4	0.4	n.d.	0.8	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	47	-----	n.d.	n.d.	0.06	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	48	0.02	0.02	n.d.	0.07	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	47	-----	n.d.	n.d.	0.05	-----	-----	-----
Sulfate (mg/L)	1	49	233	236	163	273	875[2,6], 500[2,8]	0	0%
Suspended Solids, Total (mg/L)	4	49	-----	4	n.d.	20	53[1,6], 30[1,8]	0	0%
Microcystin, Extracellular (ug/L)	0.1	25	-----	n.d.	n.d.	0.1	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat[F]	-----	25	-----	-----	-----	-----	D.O ≥ 6 mg/L W. Temp. ≤ 18.3°C	5	20%

n.d. = Not detected.

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

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

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

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

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

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

(F) Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e. at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/L). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile.

Plate 7-4. Summary of monthly (June through September) water quality conditions monitored in Lake Oahe near Mobridge, South Dakota (Site OAHLK1196DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	27	1609.2	1610.7	1598.4	1619.3	-----	-----	-----
Water Temperature (°C)	0.1	560	18.0	18.8	7.2	25.0	18.3[1,6]	316	56%
Hypolimnion Water Temperature (°C)[E]	0.1	44	16.6	16.4	12.6	21.7	18.3[1,6]	12	27%
Dissolved Oxygen (mg/L)	0.1	560	8.2	8.3	0.9	11.5	6[1,7,9], 7[1,7,9]	39, 64	7%, 11%
Dissolved Oxygen (% Sat.)	0.1	560	89.4	93.0	9.6	110.8	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[E]	0.1	514	8.5	8.4	3.7	11.5	5[3,7]	4	1%
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	45	5.0	4.8	0.9	8.1	6[1,7,9]	31	69%
Specific Conductance (uS/cm)	1	560	795	804	597	923	-----	-----	-----
pH (S.U.)	0.1	560	8.3	8.36	7.4	8.6	6.5[1,2,7], 9.0[1,2,6], 9.5[4,6]	0	0%
Turbidity (NTUs)	1	558	6	4	n.d.	315	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	535	357	361	257	482	-----	-----	-----
Secchi Depth (M)	0.02	25	2.16	1.63	0.76	5.97	-----	-----	-----
Alkalinity, Total (mg/L)	7	50	166	168	130	184	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	50	4.5	4.5	2.9	6.5	-----	-----	-----
Chloride (mg/L)	1	30	10	10	9	11	175[1,6], 100[1,8], 438[2,6], 250[2,8]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	494	6	3	n.d.	106	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	25	5	3	0	19	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	50	32	31	21	70	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	49	587	592	372	798	1,750[2,6], 1,000[2,8], 3,500[4,6], 2,000[4,8]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	50	-----	0.02	n.d.	0.10	3.1 [1,6,10], 1.1 [1,8,10]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	50	0.4	0.4	0.1	1.9	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	50	-----	0.04	n.d.	0.40	88[5,6], 50[5,8], 10[2,6]	0	0%
Nitrogen, Total (mg/L)	0.1	50	0.5	0.4	0.1	1.9	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	50	-----	n.d.	n.d.	0.08	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	50	0.02	0.02	n.d.	0.08	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	50	-----	n.d.	n.d.	0.03	-----	-----	-----
Sulfate (mg/L)	1	50	236	239	162	289	875[2,6], 500[2,8]	0	0%
Suspended Solids, Total (mg/L)	4	50	-----	5	n.d.	25	53[1,6], 30[1,8]	0	0%
Microcystin, Extracellular (ug/L)	0.1	25	-----	n.d.	n.d.	0.2	-----	-----	-----
Glyphosate, Total (ug/L)	0.500	17	-----	n.d.	n.d.	3.31	-----	-----	-----
AMPA, Total (ug/L)	0.500	17	-----	n.d.	n.d.	n.d.	-----	-----	-----
Imazapyr, Total (ug/L)	0.500	17	-----	n.d.	n.d.	0.68	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat[F]	-----	26	-----	-----	-----	-----	D.O ≥ 6 mg/L W. Temp. ≤ 18.3°C	13	50%

n.d. = Not detected.

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

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

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

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

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

(F) Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e. at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/L). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile. (Note: 2009 was the only year where Lake Oahe thermally stratified to the degree that a "true" hypolimnion formed during the summer.)

Plate 7-5. Summary of monthly (June through September) water quality conditions monitored in Lake Oahe near Beaver Creek (Site OAHLK1256DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	25	1610.0	1610.9	1600.0	1619.3	-----	-----	-----
Water Temperature (°C)	0.1	151	16.7	17.6	8.3	30.0	18.3[1,5]	71	47%
Hypolimnion Water Temperature (°C)[E]	0.1	0	-----	-----	-----	-----	18.3[1,5]	-----	-----
Dissolved Oxygen (mg/L)	0.1	151	9.7	9.6	7.4	12.0	6[1,6,8], 7[1,6,8]	0	0%
Dissolved Oxygen (% Sat.)	0.1	151	103.3	102.5	77.8	146.1	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[E]	0.1	151	9.8	9.6	7.4	12.0	5[3,6]	0	0%
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	0	-----	-----	-----	-----	6[1,6,8]	-----	-----
Specific Conductance (uS/cm)	1	151	749	745	620	992	-----	-----	-----
pH (S.U.)	0.1	151	8.2	8.3	7.4	8.6	6.5[1,2,6], 9.0[1,2,5], 9.5[4,5]	0	0%
Turbidity (NTUs)	1	151	20	12	1	76	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	136	354	361	226	464	-----	-----	-----
Secchi Depth (M)	0.02	17	0.69	0.66	0.23	1.30	-----	-----	-----
Alkalinity, Total (mg/L)	7	23	173	167	150	242	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	23	4.6	4.3	2.4	9.8	-----	-----	-----
Chloride (mg/L)	1	14	11	11	9	12	175[1,5], 100[1,7], 438[2,5], 250[2,7]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	127	10	9	n.d.	103	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	23	12	10	n.d.	33	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	23	35	31	24	58	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	23	588	556	400	866	1,750[2,5], 1,000[2,7], 3,500[4,5], 2,000[4,7]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	23	-----	n.d.	n.d.	1.70	3.1 [1,5,9], 1.2 [1,7,9]	0, 1	0%, 4%
Nitrogen, Kjeldahl Total (mg/L)	0.1	23	0.6	0.6	0.1	2.7	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	23	-----	n.d.	n.d.	0.18	10[2,5]	0	0%
Nitrogen, Total (mg/L)	0.1	23	0.7	0.6	0.1	2.8	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	23	-----	n.d.	n.d.	0.05	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	23	0.05	0.04	n.d.	0.26	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	23	-----	n.d.	n.d.	0.03	-----	-----	-----
Sulfate (mg/L)	1	23	228	235	156	304	875[2,5], 500[2,7]	0	0%
Suspended Solids, Total (mg/L)	4	23	28	14	4	224	53[1,5], 30[1,7]	3, 3	13%, 13%
Microcystin, Extracellular (ug/L)	0.1	23	-----	n.d.	n.d.	0.1	-----	-----	-----
Glyphosate, Total (ug/L)	0.500	16	-----	n.d.	n.d.	1.07	-----	-----	-----
AMPA, Total (ug/L)	0.500	16	-----	n.d.	n.d.	n.d.	-----	-----	-----
Imazapyr, Total (ug/L)	0.500	16	-----	n.d.	n.d.	2.83	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat[F]	-----	23	-----	-----	-----	-----	D.O ≥ 6 mg/L W. Temp. ≤ 18.3°C	14	61%

n.d. = Not detected.

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

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

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

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

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

[E] A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

[F] Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e. at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/L). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile.

[G] Depth-profiles did not indicate the presence of a hypolimnion during monitored period. It is assumed that the water column experienced complete mixing due to shallower water depths during the monitored period.

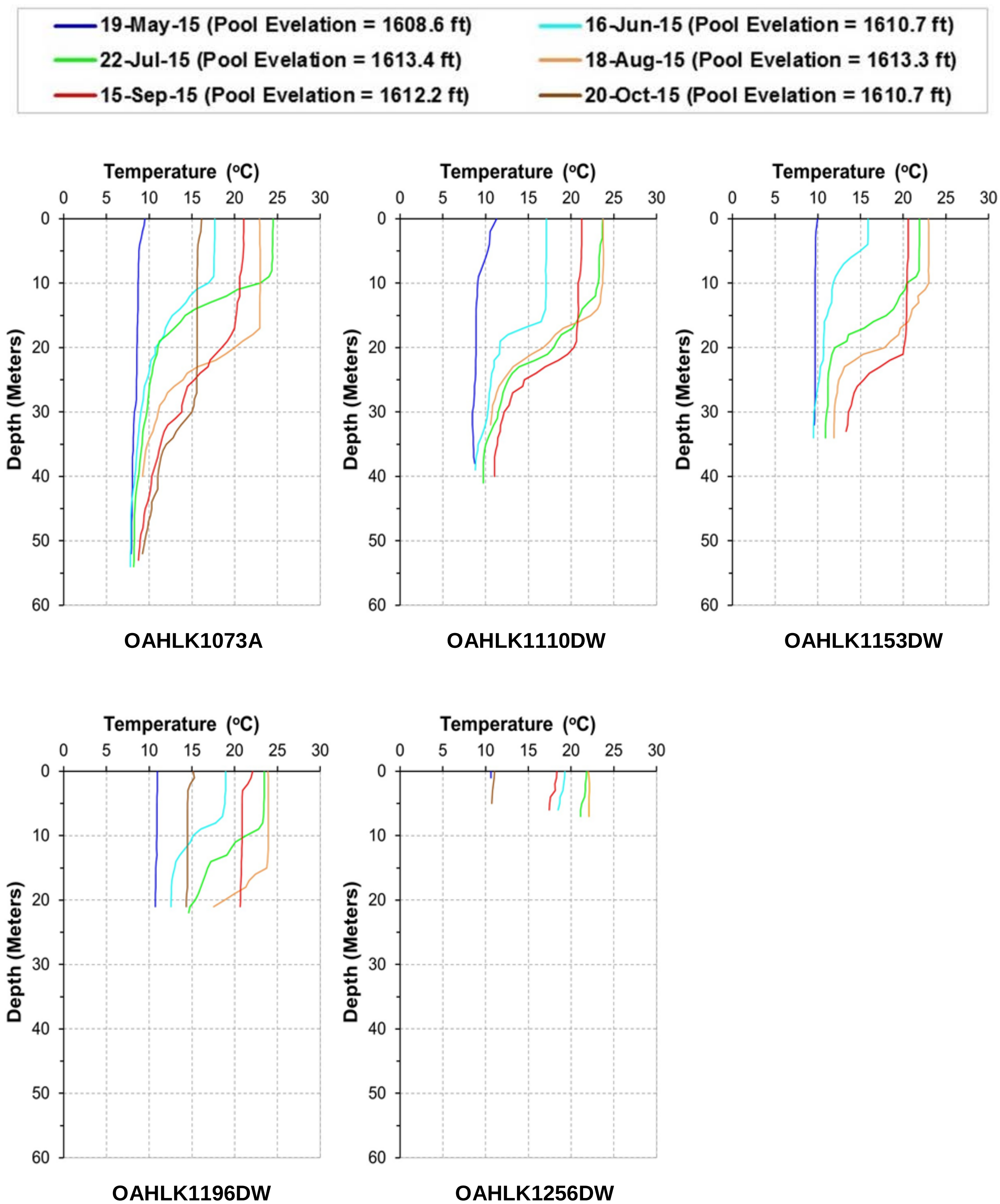


Plate 7-6. Depth-profile plots of temperature conditions of Lake Oahe measured at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, and OAHLK1256DW during 2015**.**

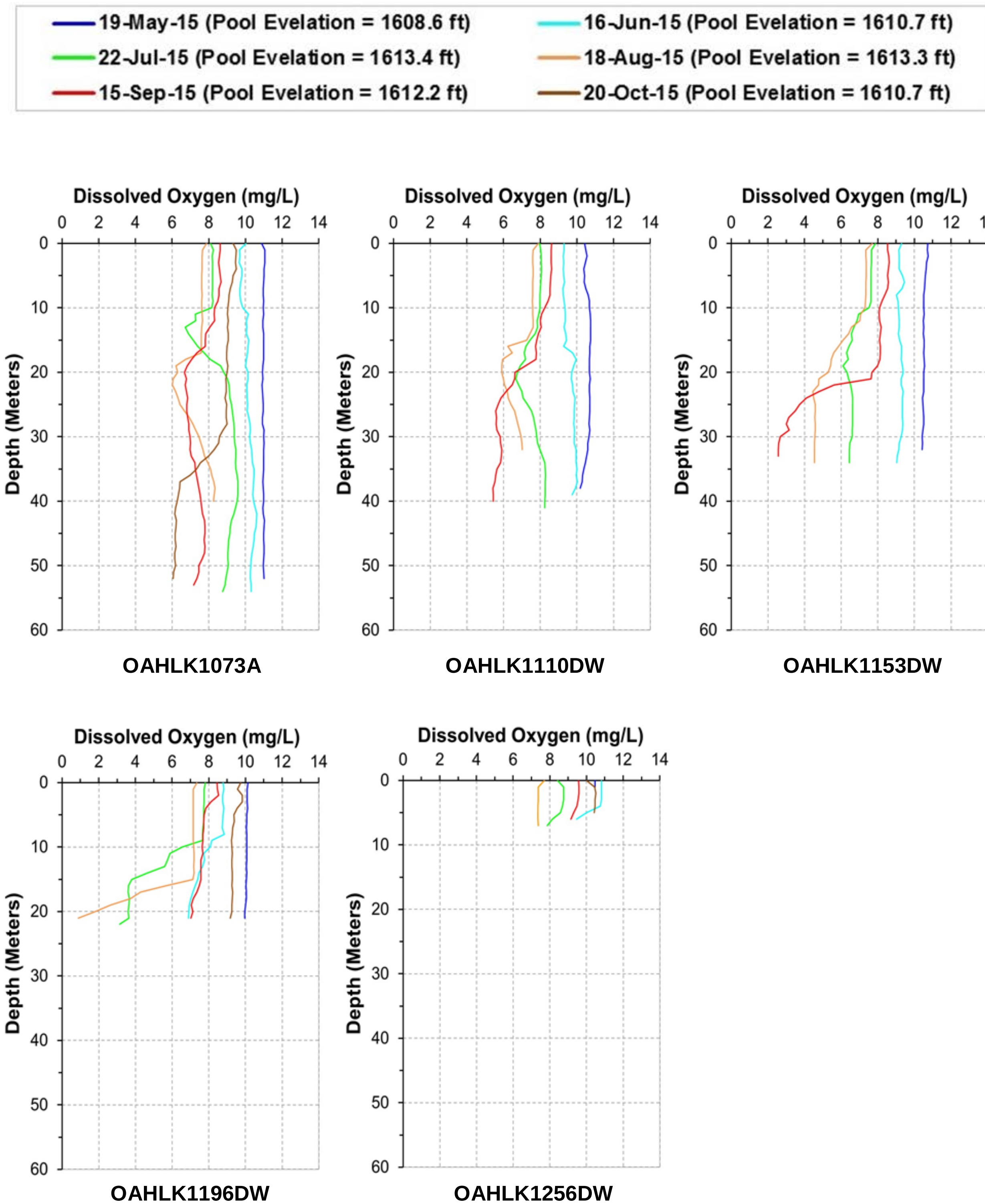


Plate 7-7. Depth-profile plots of dissolved oxygen conditions of Lake Oahe measured at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, and OAHLK1256DW during 2015**.**

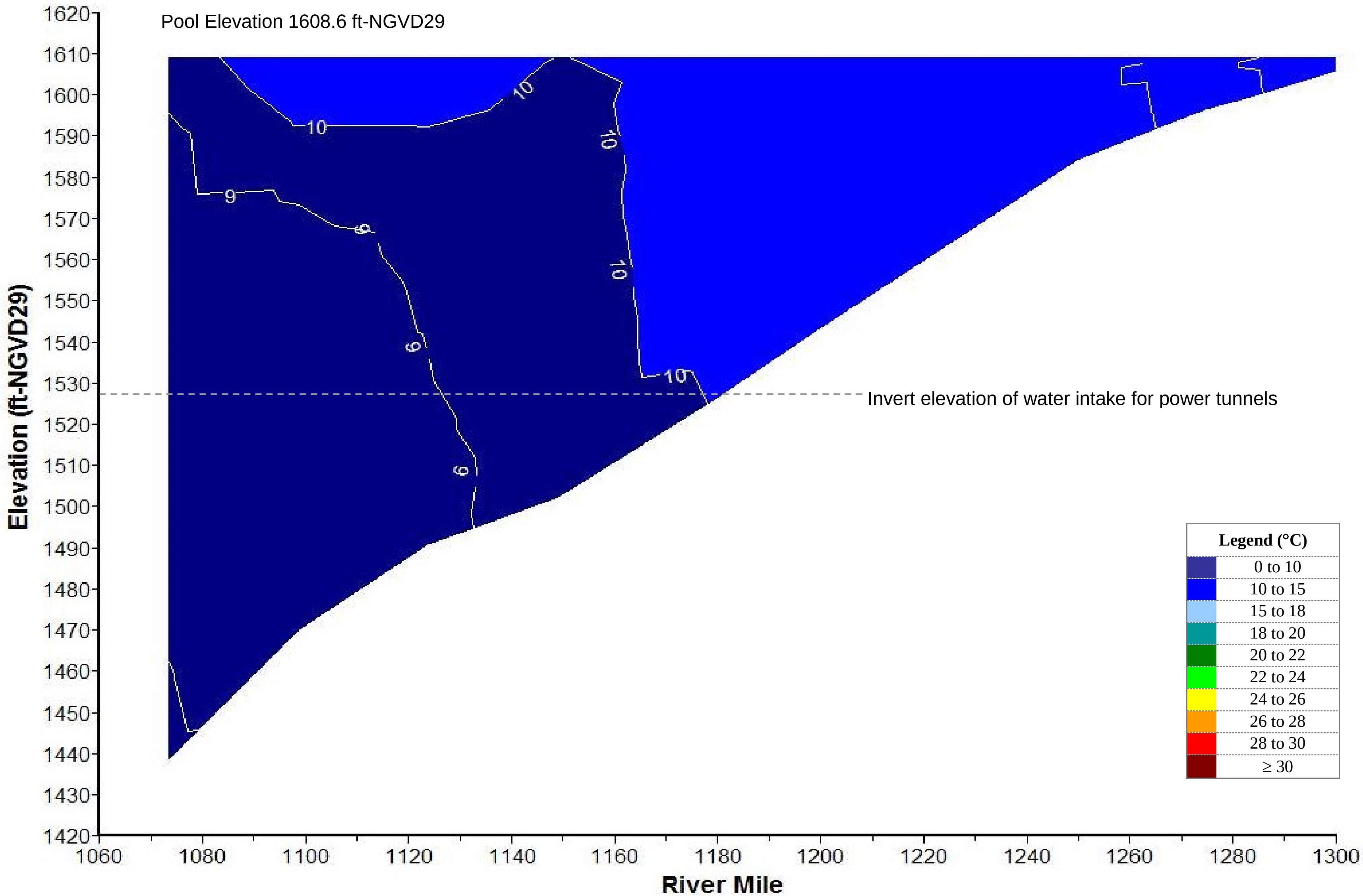


Plate 7-8. Longitudinal water temperature (°C) contour plot of Lake Oahe based on depth-profile water temperatures measured at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, OAHLK1256DW, and OAHNFMORR1 on May 19, 2015.

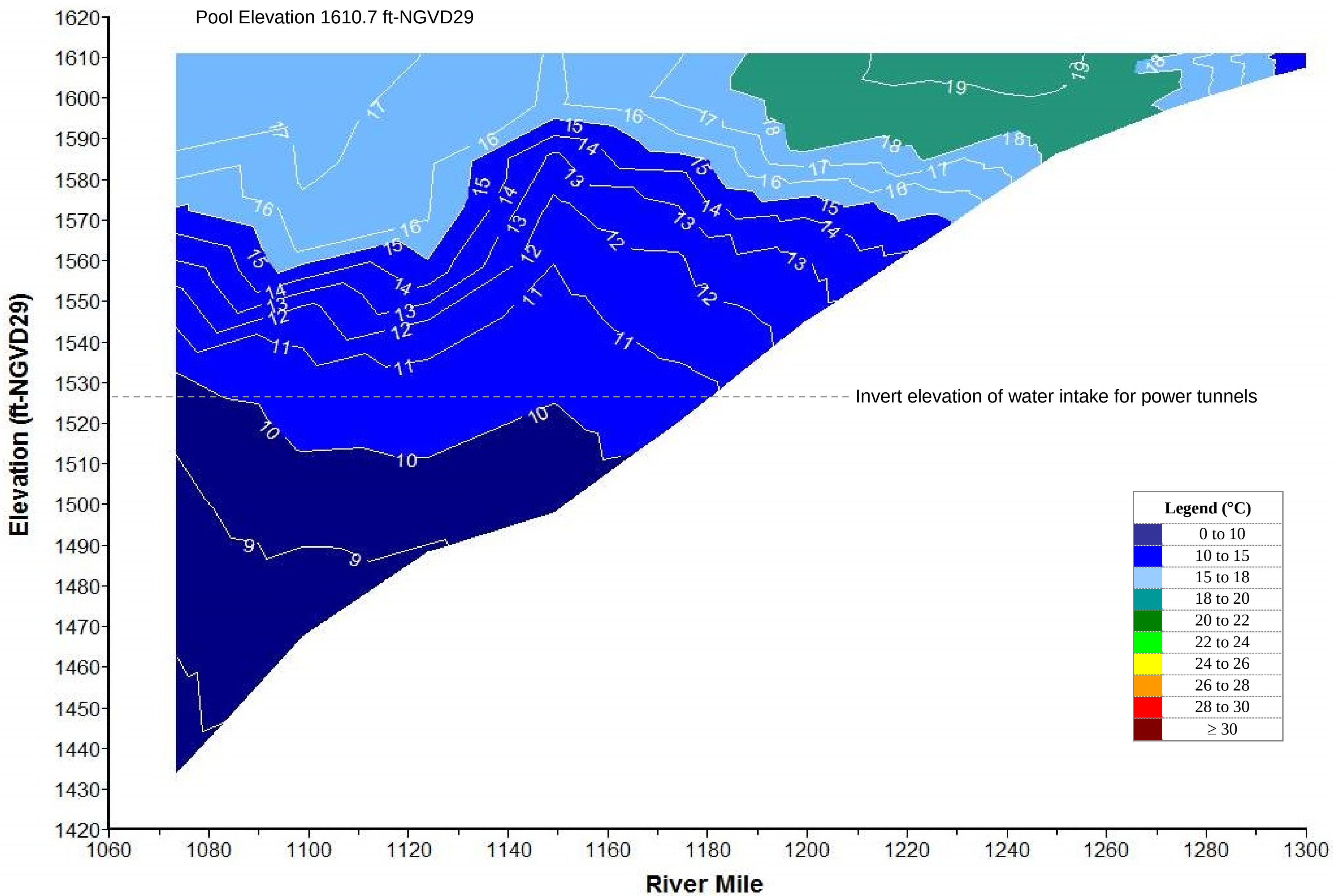


Plate 7-9. Longitudinal water temperature (°C) contour plot of Lake Oahe based on depth-profile water temperatures measured at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, OAHLK1256DW, and OAHNFMORR1 on June 16, 2015.

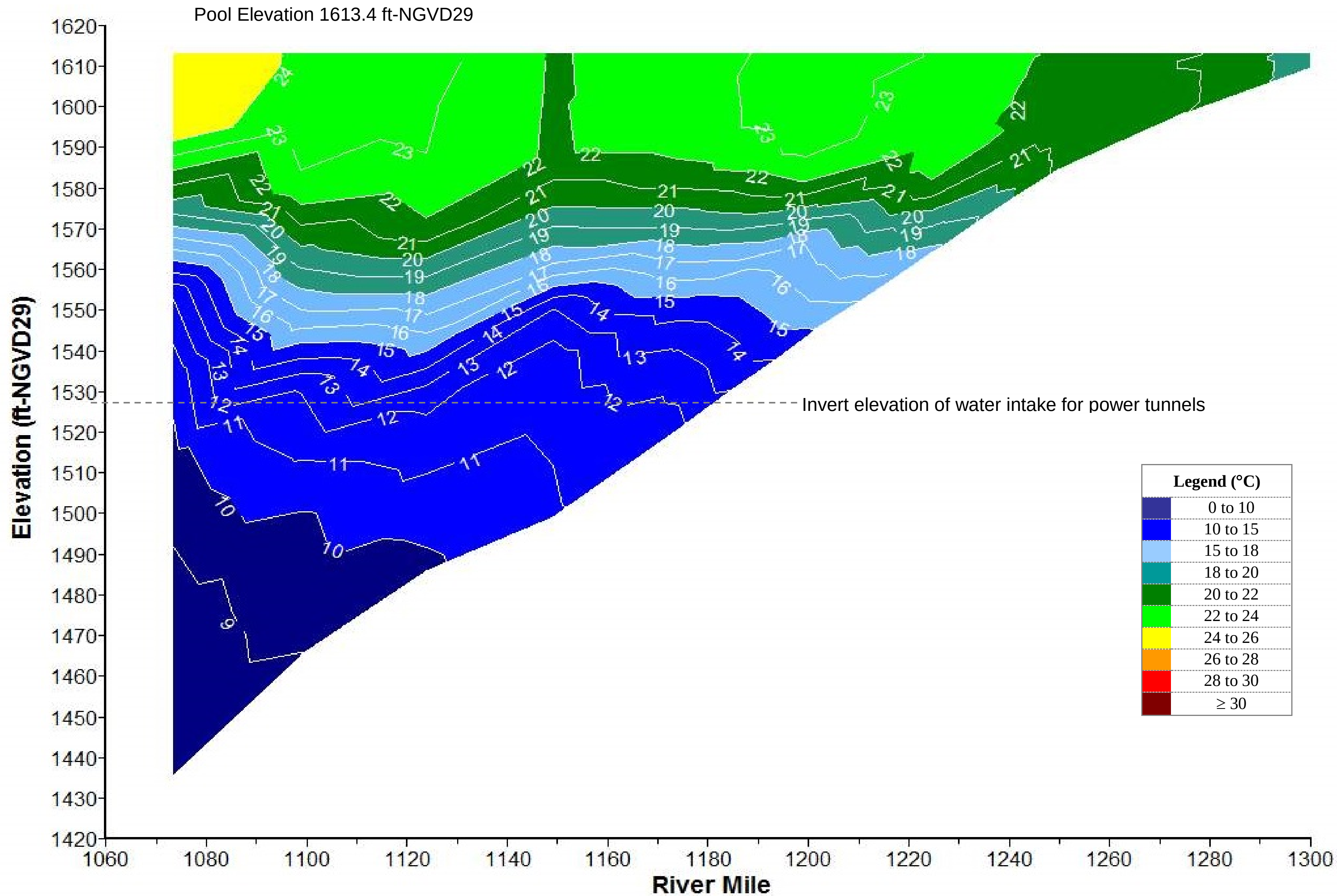


Plate 7-10. Longitudinal water temperature (°C) contour plot of Lake Oahe based on depth-profile water temperatures measured at sites OAHLK1073A, OAHLK1090DW, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, OAHLK1256DW, and OAHNFMORR1 on July 22, 2015.

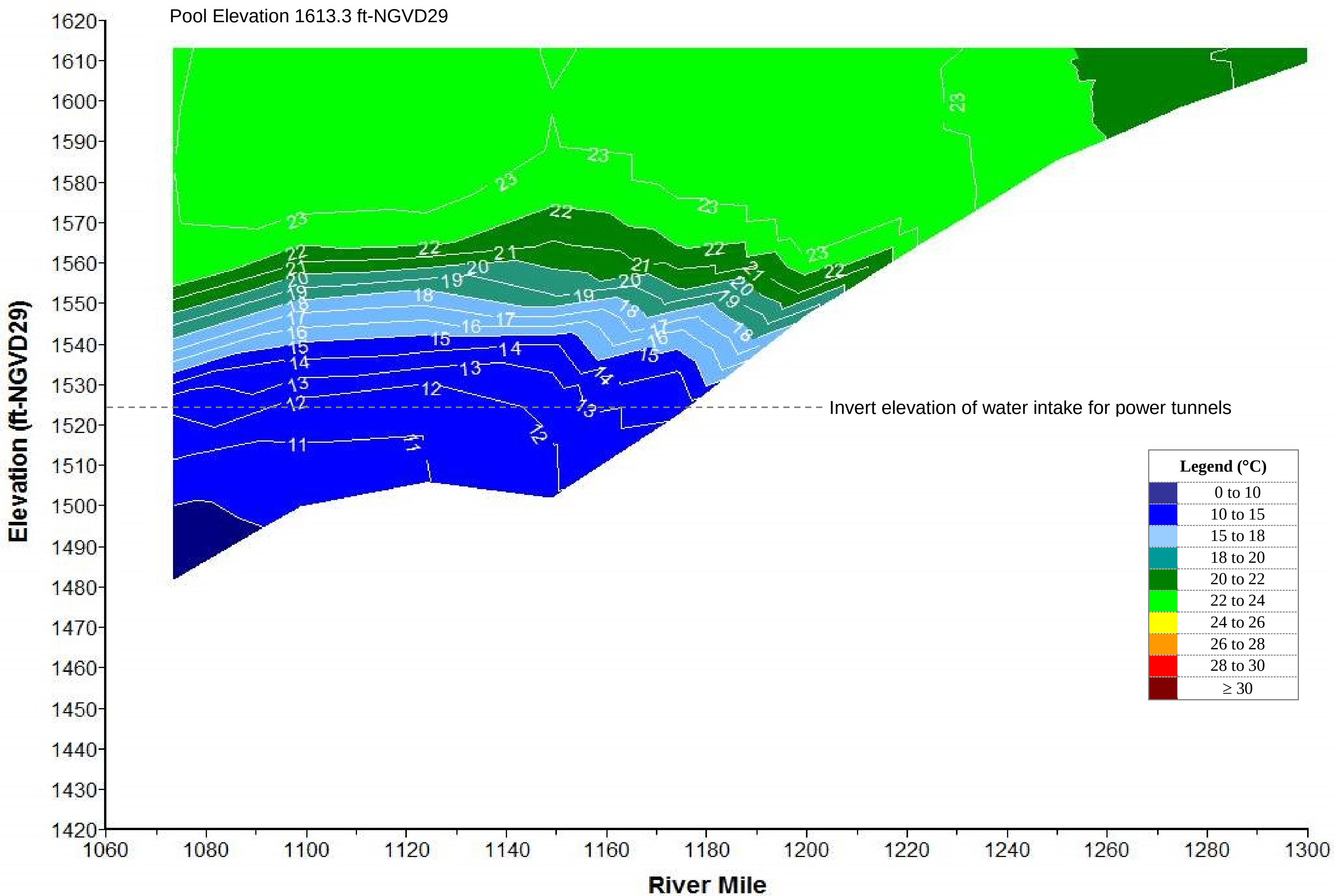


Plate 7-11. Longitudinal water temperature (°C) contour plot of Lake Oahe based on depth-profile water temperatures measured at sites OAHLK1073A, OAHLK1090DW, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, OAHLK1256DW, and OAHNFMORR1 on August 18, 2015.

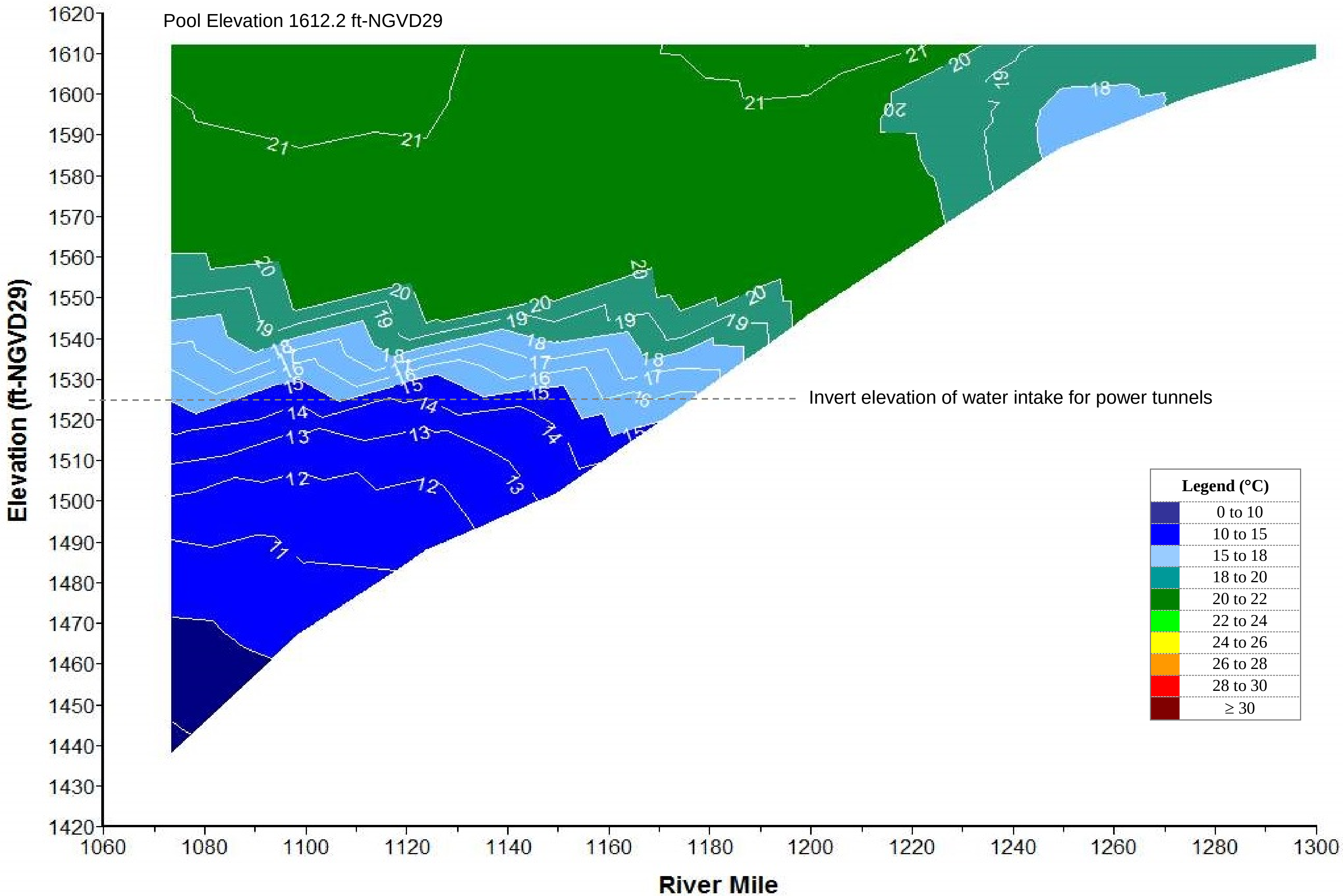


Plate 7-12. Longitudinal water temperature (°C) contour plot of Lake Oahe based on depth-profile water temperatures measured at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, OAHLK1256DW, and OAHNFMORR1 on September 15, 2015.

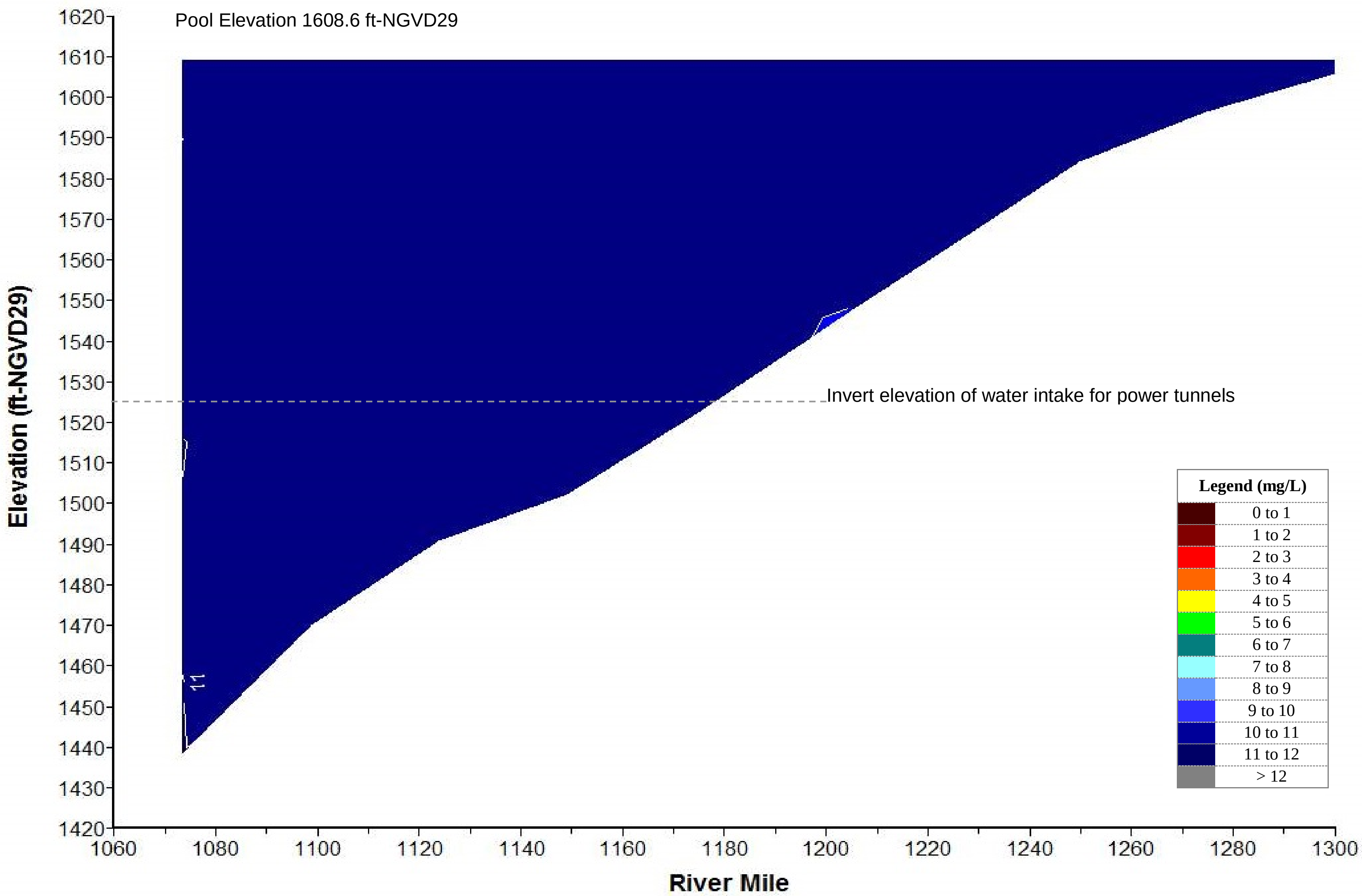


Plate 7-13. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Oahe based on depth-profile dissolved oxygen concentrations measured at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, OAHLK1256DW, and OAHNFMORR1 on May 19, 2015.

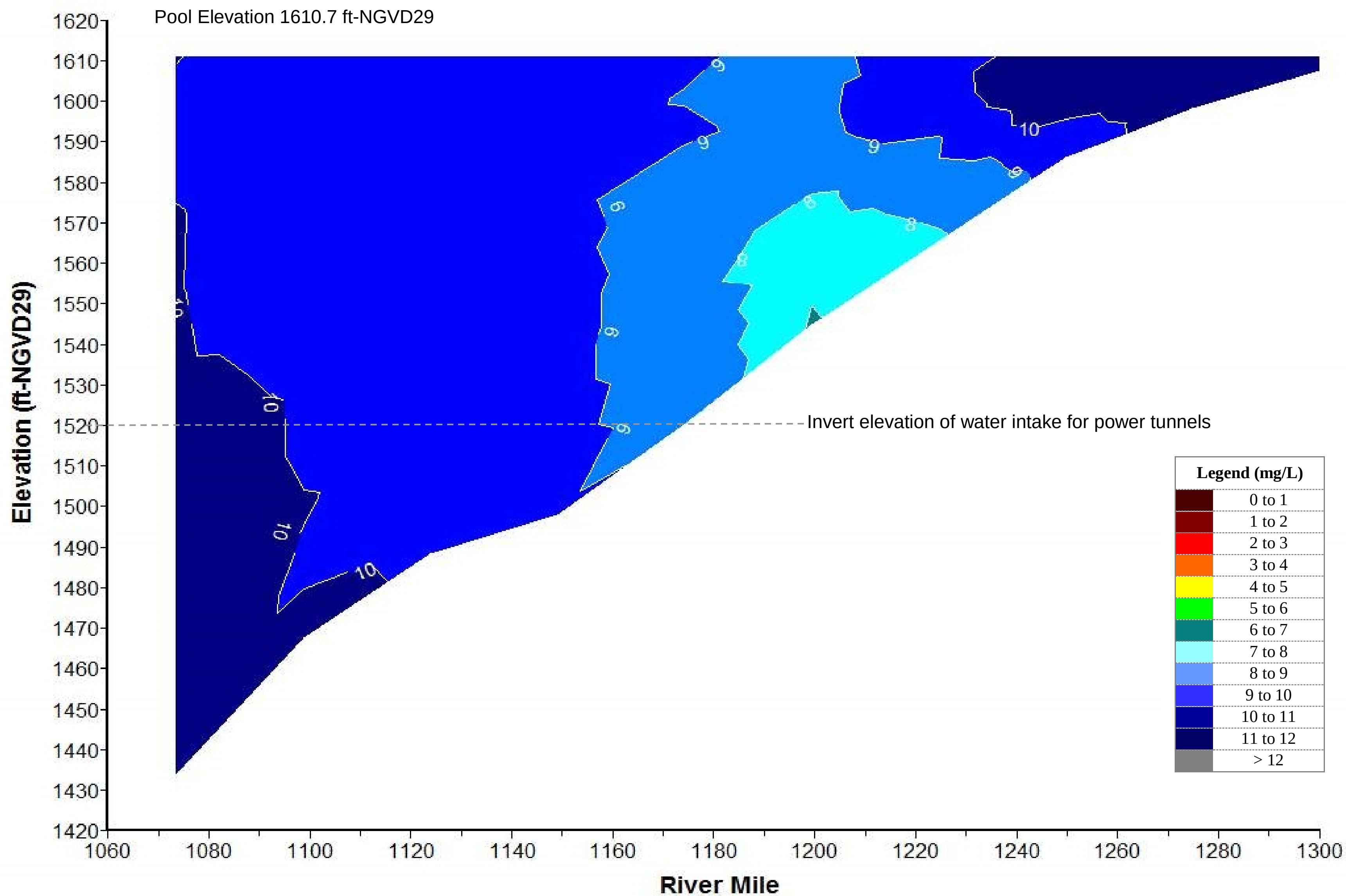


Plate 7-14. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Oahe based on depth-profile dissolved oxygen concentrations measured at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, OAHLK1256DW, and OAHNFMORR1 on June 16, 2015.

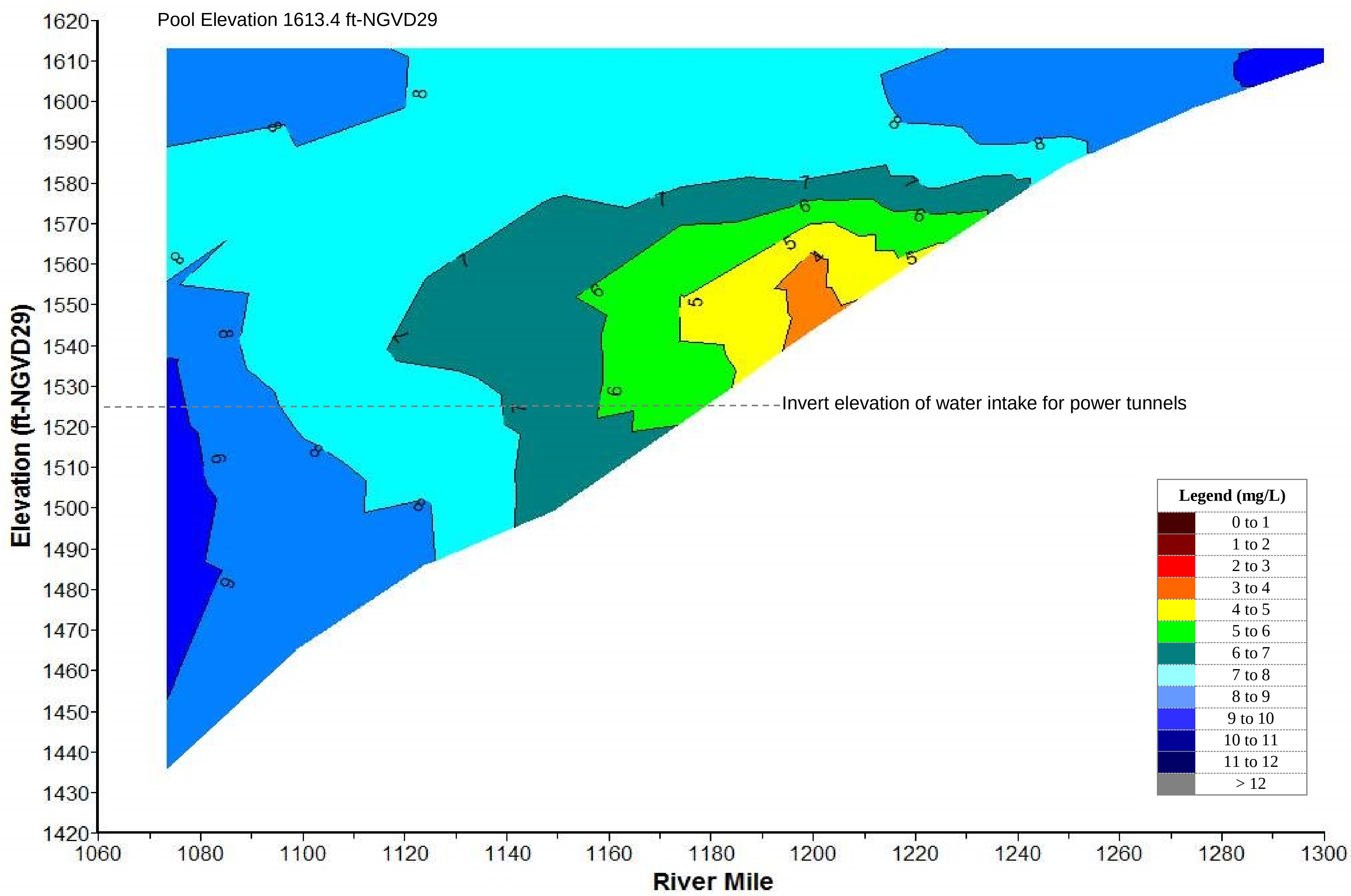


Plate 7-15. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Oahe based on depth-profile dissolved oxygen concentrations measured at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, OAHLK1256DW, and OAHNFMORR1 on July 22, 2015.

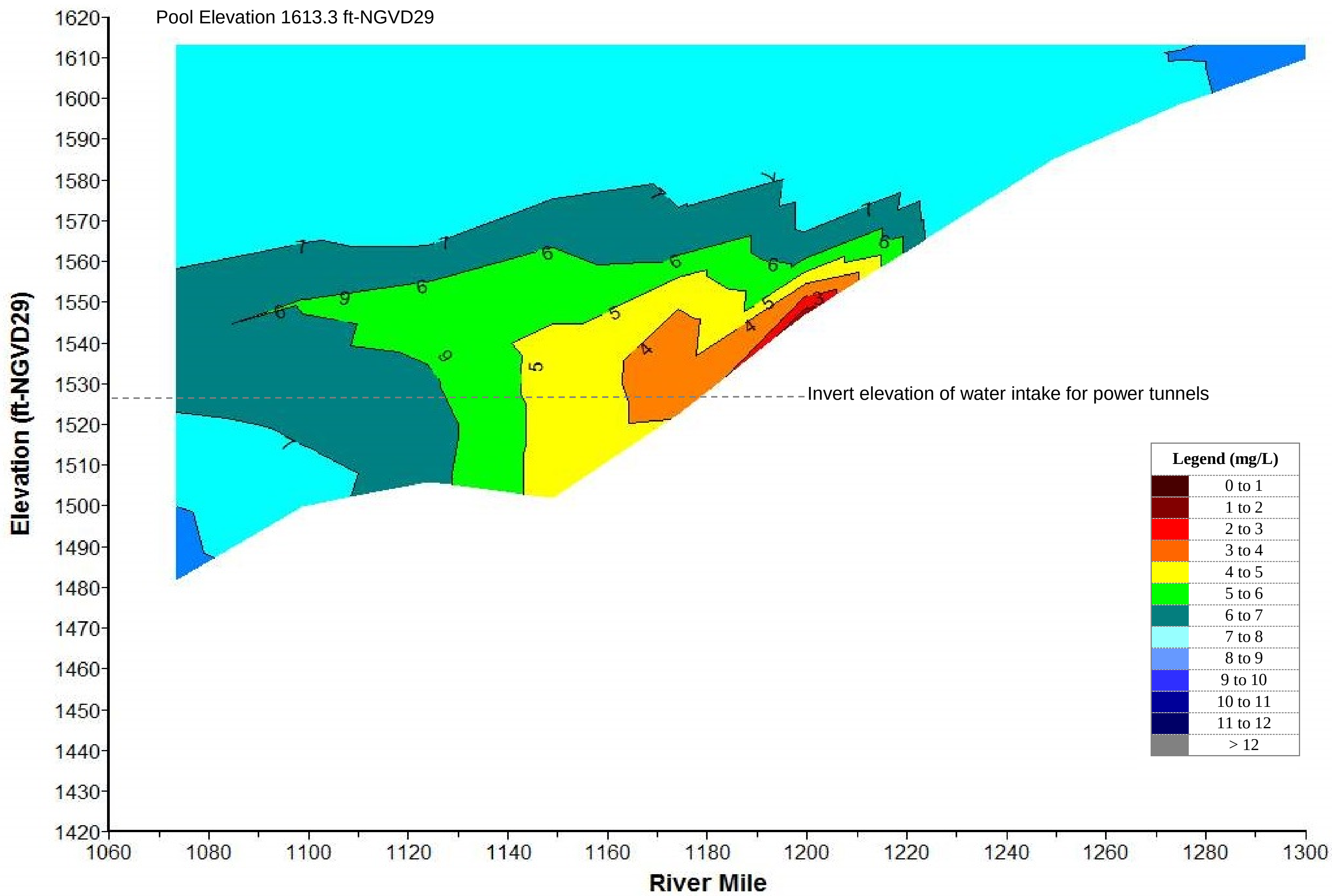


Plate 7-16. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Oahe based on depth-profile dissolved oxygen concentrations measured at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, OAHLK1256DW, and OAHNFMORR1 on August 18, 2015.

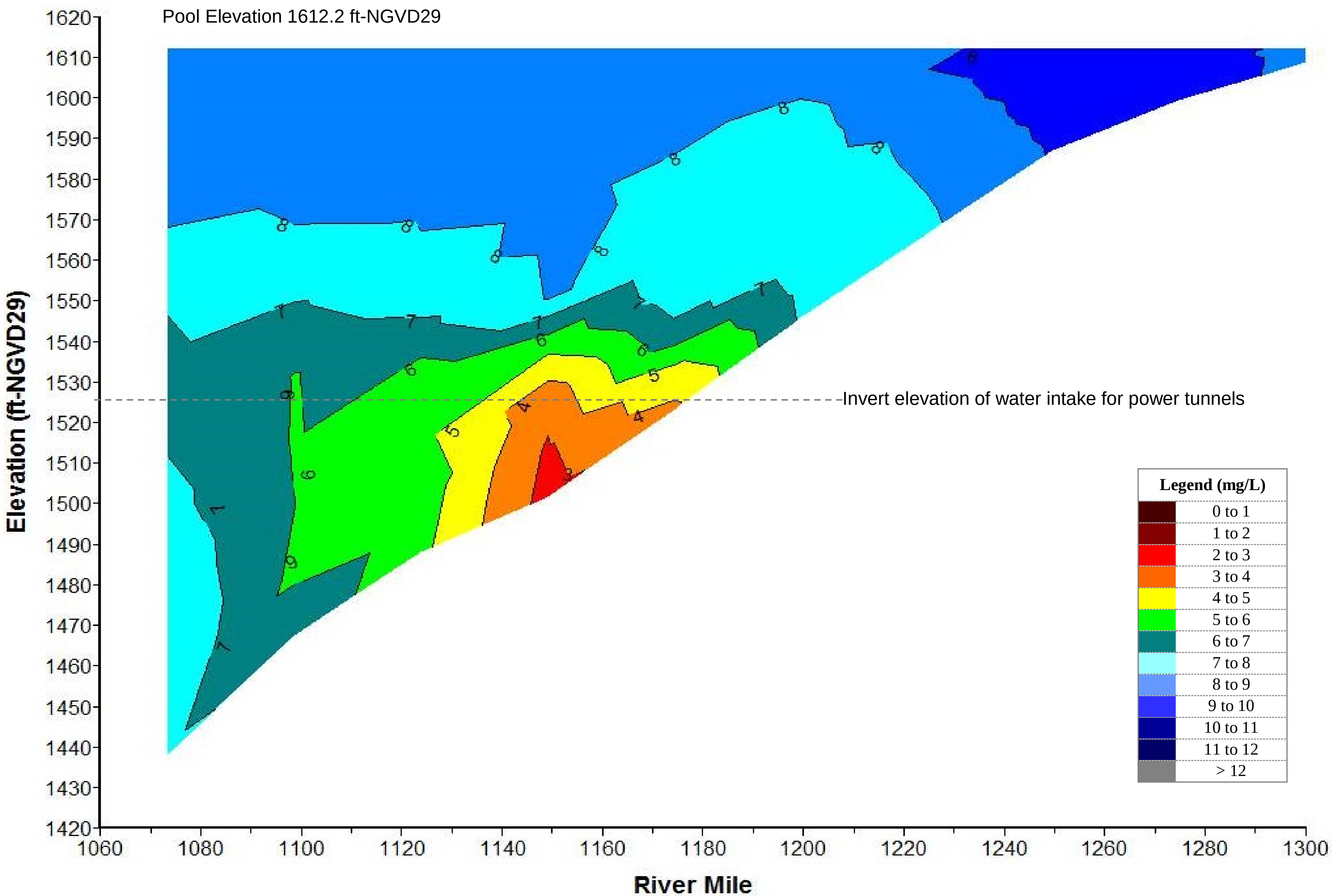


Plate 7-17. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Oahe based on depth-profile dissolved oxygen concentrations measured at sites OAHLK1073A, OAHLK1110DW, OAHLK1153DW, OAHLK1196DW, OAHLK1256DW, and OAHNFMORR1 on September 15, 2015.

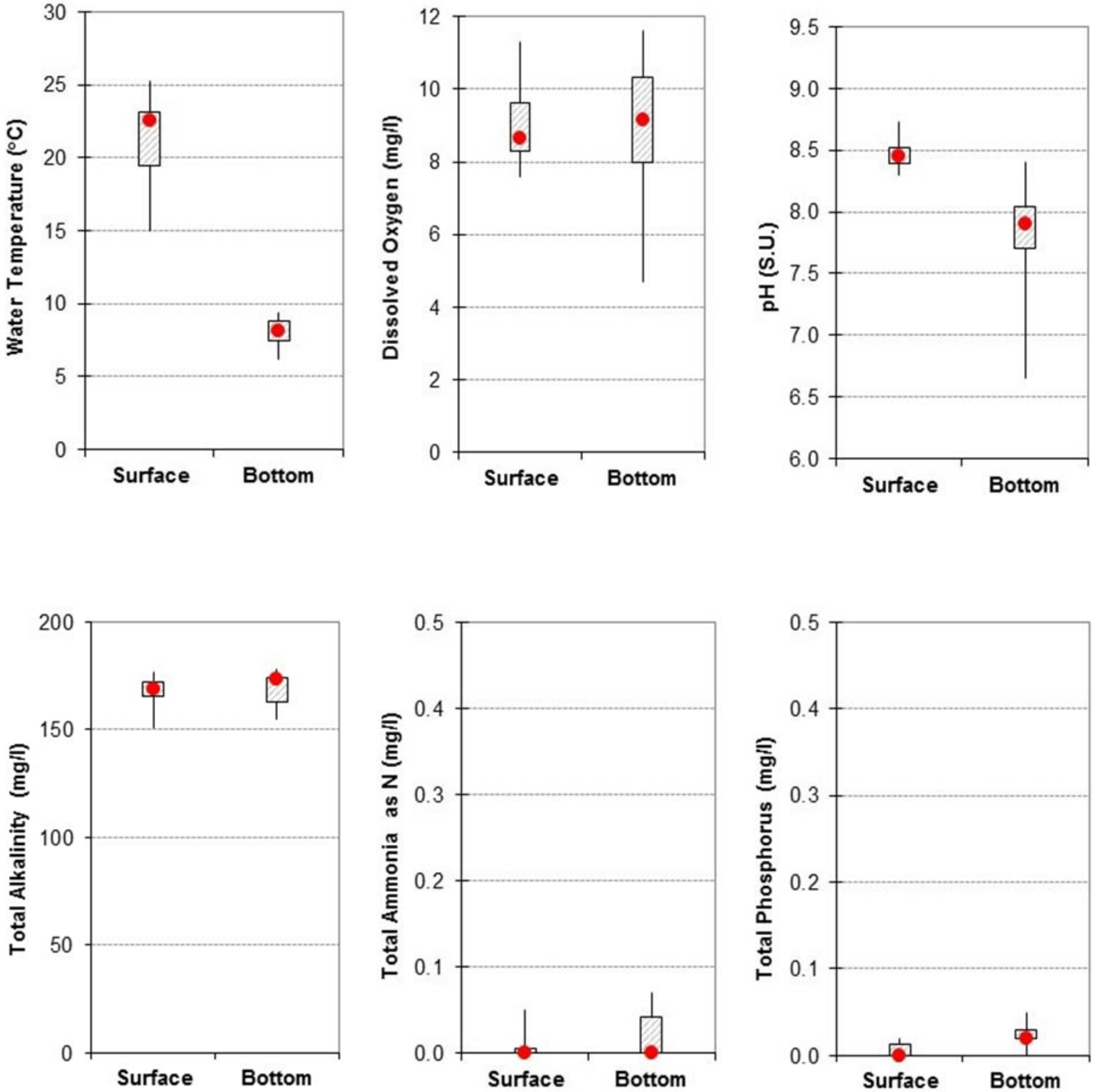


Plate 7-18. Box plots comparing paired surface and bottom water temperature, dissolved oxygen, pH, alkalinity, total ammonia nitrogen, and total phosphorus measurements taken in Lake Oahe at site OAHLK1073A during the summer months of the 5-year period 2011 through 2015.
(Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

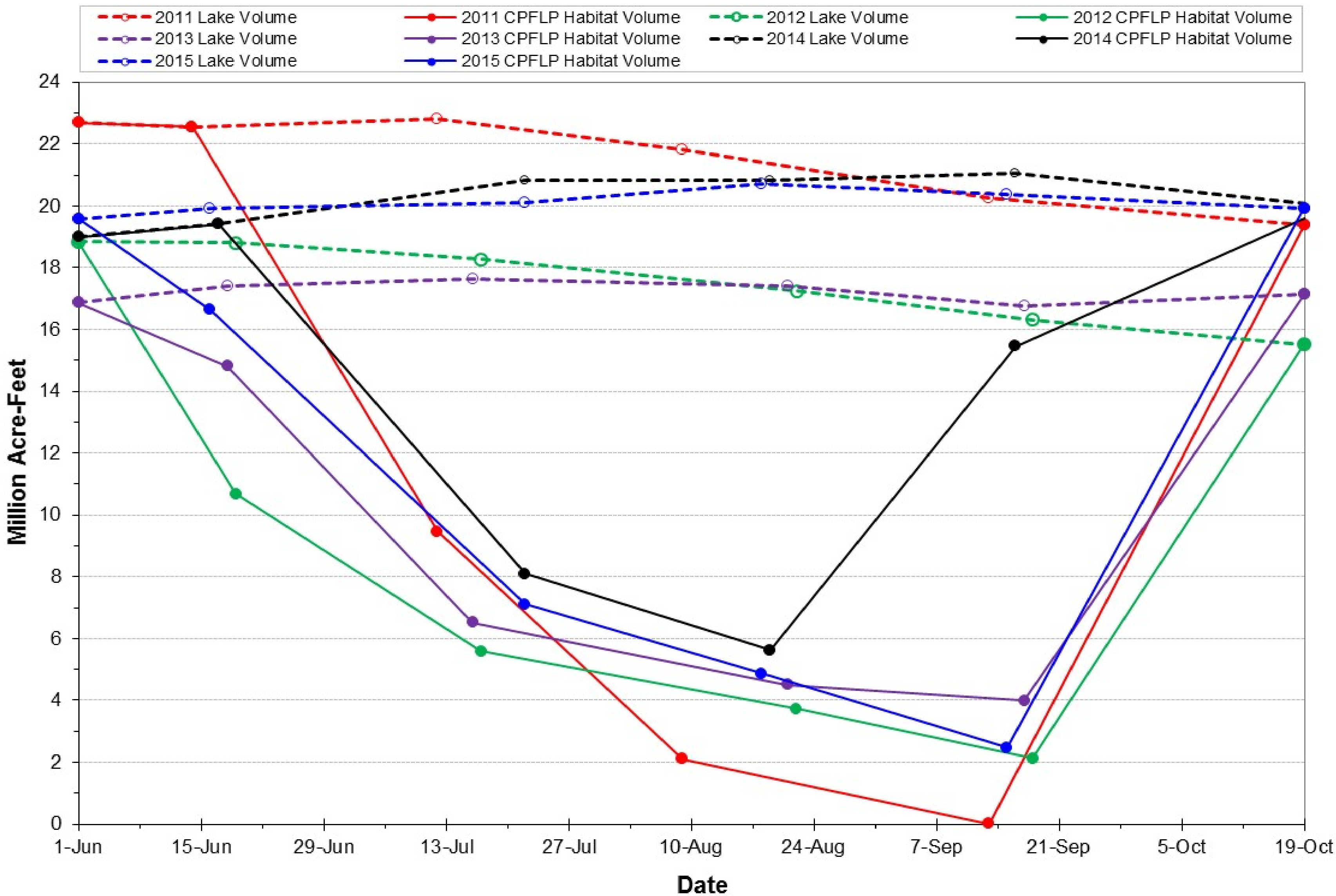


Plate 7-19. Estimated volume of Coldwater Permanent Fish Life Propagation habitat (i.e. ≤ 18.3° C and ≥ 6 mg/L dissolved oxygen) in Lake Oahe during the summers of the 5-year period 2011 through 2015.

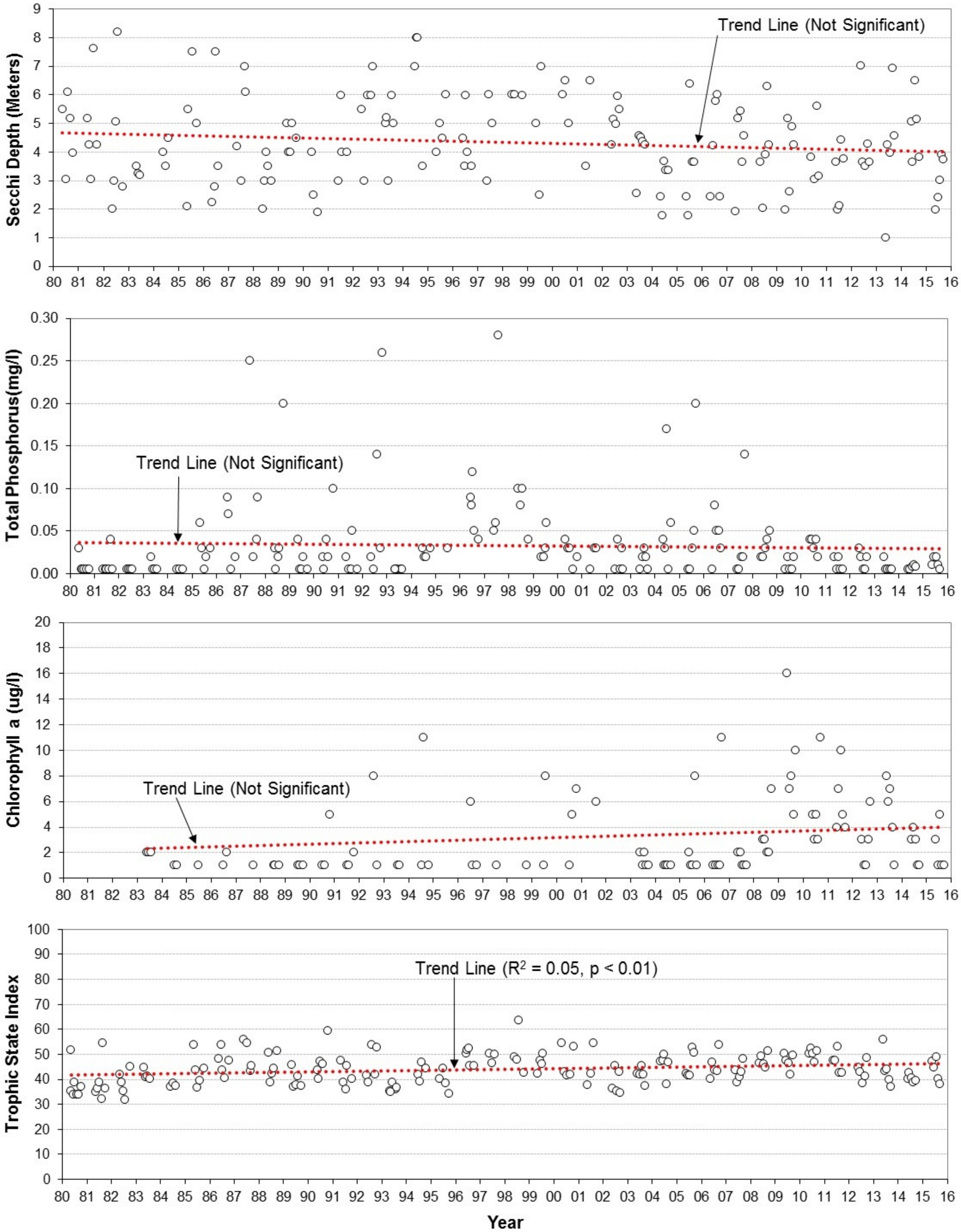


Plate 7-20. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Lake Oahe at the near-dam, ambient site (i.e. site OAHLK1073A) over the 36-year period of 1980 through 2015.

Plate 7-21. Summary of monthly (April through September) near-surface water quality conditions monitored in the Missouri River at Bismarck, North Dakota at monitoring site OAHNFMORR1 during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[(A)]	No. of Obs.	Mean[(B)]	Median	Min.	Max.	State WQS Criteria[(C)]	No. of WQS Exceedances	Percent WQS Exceedance
Streamflow (cfs)	1	33	33,939	24,400	13,500	142,997	-----	-----	-----
Water Temperature (°C)	0.1	33	13.9	14.7	4.0	19.8	29.4[(1,2)]	0	0%
Dissolved Oxygen (mg/L)	0.1	33	10.3	9.8	8.4	12.9	5[(1,3)]	0	0%
Dissolved Oxygen (% Sat.)	0.1	33	101.3	101.2	92.2	115.1	-----	-----	-----
pH (S.U.)	0.1	33	8.1	8.2	7.2	8.4	7.0[(1,3)], 9.0[(1,2)]	0	0%
Specific Conductance (uS/cm)	1	33	754	764	575	877	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	32	362	351	266	548	-----	-----	-----
Turbidity (NTU)	1	33	14	5	n.d.	141	-----	-----	-----
Alkalinity, Total (mg/L)	7	33	163	164	134	187	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	33	4.2	4.0	2.7	8.1	-----	-----	-----
Chloride, Dissolved (mg/L)	1	20	10	11	9	12	100[(1,2)]	0	0%
Chlorophyll *a* (ug/L)	1	26	7	6	n.d.	30	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	33	30	26	20	58			
Dissolved Solids, Total (mg/L)	5	32	550	524	420	802	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	33	-----	n.d.	n.d.	0.20	5.7 [(1,2,4)], 1.7 [(1,4,5)]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	33	0.4	0.3	n.d.	1.0	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	32	0.08	0.06	n.d.	0.40	1.0[(1,2)]	0	0%
Nitrogen, Total (mg/L)	0.1	32	0.5	0.4	n.d.	1.4	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	33	-----	n.d.	n.d.	0.85	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	33	0.06	0.03	n.d.	0.85	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	33	-----	n.d.	n.d.	0.72	-----	-----	-----
Sulfate (mg/L)	1	33	218	220	155	274	250[(1,2)]	1	3%
Suspended Sediment, Total (mg/L)	4	31	34	17	7	242	-----	-----	-----
Suspended Solids, Total (mg/L)	4	33	29	18	4	210	-----	-----	-----
Glyphosate, Total (ug/L)	0.500	17	-----	n.d.	n.d.	30.00	-----	-----	-----
AMPA, Total (ug/L)	0.500	17	-----	n.d.	n.d.	1.52	-----	-----	-----
Imazapyr, Total (ug/L)	0.500	17	-----	n.d.	n.d.	0.58	-----	-----	-----

n.d. = Not detected.

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

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

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

(1) Criteria for Class 1 streams.

(2) Daily maximum criterion (monitoring results directly comparable to criterion).

(3) Daily minimum criterion (monitoring results directly comparable to criterion).

(4) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

(5) 30-day average criterion (monitoring results not directly comparable to criterion).

Plate 7-22. Summary of annual metals and pesticide levels monitored in the Missouri River at Bismarck, North Dakota at monitoring site OAHNFMORR1 during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[B]	Median	Min.	Max.	State WQS Criteria[C]	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/L)	40	5	-----	n.d.	n.d.	1,080	-----	-----	-----
Aluminum, Total (ug/L)	40	5	576	300	210	1,260	750[6]	2	40%
Antimony, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Antimony, Total (ug/L)	0.5	5	-----	n.d.	n.d.	0.5	5.6[8]	0	0%
Arsenic, Dissolved (ug/L)	1	5	2	2	1	2	-----	-----	-----
Arsenic, Total (ug/L)	1	5	2	2	2	2	340[1], 150[2], 10[3]	0	0%
Barium, Dissolved (ug/L)	5	5	57	58	48	70	-----	-----	-----
Barium, Total (ug/L)	5	5	62	62	51	75	1,000[8]	0	0%
Beryllium, Dissolved (ug/L)	2	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Beryllium, Total (ug/L)	2	5	-----	n.d.	n.d.	n.d.	4[8]	0	0%
Cadmium, Dissolved (ug/L)	0.2	5	-----	n.d.	n.d.	0.2	-----	-----	-----
Cadmium, Total (ug/L)	0.2	5	-----	n.d.	n.d.	0.2	5.0[6], 0.50[7], 5[8]	0	0%
Calcium, Dissolved (mg/L)	0.4	5	53	55	47	57	-----	-----	-----
Chromium, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Chromium, Total (ug/L)	10	5	-----	n.d.	n.d.	n.d.	3,553[6], 170[7], 100[8]	0	0%
Copper, Dissolved (ug/L)	6	5	-----	n.d.	n.d.	8	-----	-----	-----
Copper, Total (ug/L)	6	5	-----	n.d.	n.d.	9	31[6], 19[7], 1,000[8]	0	0%
Hardness, Total (mg/L)	0.4	5	229	239	196	248	-----	-----	-----
Iron, Dissolved (ug/L)	7	5	241	10	n.d.	1,180	-----	-----	-----
Iron, Total (ug/L)	7	5	630	310	260	1,430	-----	-----	-----
Lead, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	0.7	-----	-----	-----
Lead, Total (ug/L)	0.5	5	0.9	n.d.	n.d.	2.6	234[6], 9.1[7], 15[8]	0	0%
Magnesium, Dissolved (mg/L)	0.4	5	24	24	20	28	-----	-----	-----
Manganese, Dissolved (ug/L)	2	5	15	5	n.d.	40	-----	-----	-----
Manganese, Total (ug/L)	2	5	26	20	10	50	-----	-----	-----
Mercury, Dissolved (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Mercury, Total (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	1.7[6], 0.012[7], 0.05[8]	0, b.d., 0	0%
Nickel, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Nickel, Total (ug/L)	10	5	-----	n.d.	n.d.	n.d.	945[6], 105[7], 100[8]	0	0%
Selenium, Dissolved (ug/L)	1	5	-----	n.d.	n.d.	n.d.			
Selenium, Total (ug/L)	1	5	-----	1	n.d.	2	20[6], 5[7], 50[8]	0	0%
Silver, Dissolved (ug/L)	1	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Silver, Total (ug/L)	1	5	-----	n.d.	n.d.	n.d.	14[6]	0	0%
Sodium, Dissolved (mg/L)	0.4	5	74	76	65	83	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Total (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	0.24[7]	b.d.	b.d.
Zinc, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Zinc, Total (ug/L)	10	5	-----	n.d.	n.d.	10	242[6,7], 7,400[8]	0	0%
Pesticide Scan (ug/L)[D]	0.05[E]	5	-----	n.d.	n.d.	n.d.	-----	-----	-----

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

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

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

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

- [1] Criteria for Class 1 streams.
- [2] Daily maximum criterion (monitoring results directly comparable to criterion).
- [3] Daily minimum criterion (monitoring results directly comparable to criterion).
- [4] Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- [5] 30-day average criterion (monitoring results not directly comparable to criterion).
- [6] Acute criterion for aquatic life.
- [7] Chronic criterion for aquatic life.
- [8] Human health criterion for surface waters.

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

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

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

Plate 7-23. Summary of monthly (May through September) near-surface water quality conditions monitored in the Cheyenne River at SD Highway 63 crossing near Cherry Creek, at monitoring site OAHNFCHYR1 during 2014 and 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit(A)	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Streamflow (cfs)	1	12	2,458	1,043	372	8,940	-----	-----	-----
Water Temperature (°C)	0.1	12	19.7	20.1	11.5	26.5	27(1,2)	0	0%
Dissolved Oxygen (mg/L)	0.1	12	8.7	8.3	7.9	10.0	5(1,3)	0	0%
Dissolved Oxygen (% Sat.)	0.1	12	98.5	96.5	90.9	107.1	-----	-----	-----
pH (S.U.)	0.1	12	8.1	8.2	7.9	8.3	6.5(1,3), 9.0(1,2)	0	0%
Specific Conductance (uS/cm)	1	12	1,604	1,591	1,189	1,922	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	12	386	396	283	443	-----	-----	-----
Turbidity (NTU)	1	12	748	197	6	3,000	-----	-----	-----
Alkalinity, Total (mg/L)	7	12	186	166	124	426	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	12	12.4	5.9	3.8	74.5	-----	-----	-----
Chloride, Dissolved (mg/L)	1	12	42	41	17	70	438(2,4), 250(2,6)	0	0%
Colorized Dissolved Organic Matter (ug/L)	4	12	37	29	12	76	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	12	1,163	1,250	164	1,490	1,750(2,4), 1,000(2,6), 3,500(3,4), 2,000(3,6)	0, 9, 0, 0	0%, 75% 0%, 0%
Nitrogen, Ammonia Total (mg/L)	0.02	12	-----	n.d.	n.d.	0.96	5.7 (1,4,7), 1.2 (1,6,7)	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	12	1.8	0.8	0.5	6.2	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	12	-----	0.21	n.d.	0.81	10(2,4)	0	0%
Nitrogen, Total (mg/L)	0.1	12	2.1	1.0	0.5	6.9	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.008	12	-----	n.d.	n.d.	0.72	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	12	1.24	0.33	n.d.	6.52	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.005	12	-----	0.01	n.d.	0.03	-----	-----	-----
Sulfate (mg/L)	1	12	682	676	481	816	875(2,4), 500(2,6)	0, 10	0%, 83%
Suspended Sediment (mg/L)	4	12	1,657	411	12	8,980	-----	-----	-----
Suspended Solids, Total (mg/L)	4	12	1,868	349	11	13,000	158(1,4), 90(1,6)	9, 9	75%, 75%

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

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

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

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

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

Plate 7-24. Summary of annual metals and pesticide levels monitored in the Cheyenne River at SD Highway 63 crossing near Cherry Creek, at monitoring site OAHNFCHYR1 during 2014 and 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[B]	Median	Min.	Max.	State WQS Criteria[C]	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/L)	40	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Aluminum, Total (ug/L)	40	2	7,840	7,840	7,090	8,590	-----	-----	-----
Antimony, Dissolved (ug/L)	0.03	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Antimony, Total (ug/L)	0.03	2	-----	0.1	n.d.	0.2	5.6[3]	0	0%
Arsenic, Dissolved (ug/L)	0.008	2	3.0	3.0	3.0	3.0	340[1], 150[2]	0	0%
Arsenic, Total (ug/L)	0.008	2	8.5	8.5	8.0	9.0	0.018[3]	1	100%
Barium, Dissolved (ug/L)	1	2	63	63	44	81	-----	-----	-----
Barium, Total (ug/L)	1	2	143	143	107	179	-----	-----	-----
Beryllium, Dissolved (ug/L)	1	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Beryllium, Total (ug/L)	1	2	-----	n.d.	n.d.	n.d.	4[3]	0	0%
Cadmium, Dissolved (ug/L)	0.2	2	-----	n.d.	n.d.	n.d.	13[1], 1.0[2]	0	0%
Cadmium, Total (ug/L)	0.2	2	-----	n.d.	n.d.	0.3	5[3]	0	0%
Calcium, Dissolved (mg/L)	0.05	2	141	141	127	154	-----	-----	-----
Chromium, Dissolved (ug/L)	4	2	-----	n.d.	n.d.	n.d.	7,864[1], 376[2]	0	0%
Chromium, Total (ug/L)	4	2	5	5	4	5	-----	-----	-----
Copper, Dissolved (ug/L)	6	2	-----	n.d.	n.d.	n.d.	76[1], 43[2],	0	0%
Copper, Total (ug/L)	6	2	9	9	7	10	1,300[3]	0	0%
Hardness, Dissolved (mg/L)	0.4	2	604	604	545	663	-----	-----	-----
Iron, Dissolved (ug/L)	10	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Iron, Total (ug/L)	10	2	5,850	5,850	5,530	6,170	-----	-----	-----
Lead, Dissolved (ug/L)	0.008	2	-----	n.d.	n.d.	n.d.	806[1], 31[2]	0	0%
Lead, Total (ug/L)	0.008	2	4.1	4.1	3.9	4.2	-----	-----	-----
Magnesium, Dissolved (mg/L)	0.05	2	64	64	55	72	-----	-----	-----
Manganese, Dissolved (ug/L)	3	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Manganese, Total (ug/L)	3	2	185	185	160	210	-----	-----	-----
Mercury, Dissolved (ug/L)	0.004	2	0.015	0.015	0.010	0.020	1.4[1]	0	0%
Mercury, Total (ug/L)	0.004	2	0.022	0.022	0.004	0.040	0.77[2], 0.05[3]	0	0%
Nickel, Dissolved (ug/L)	8	2	-----	n.d.	n.d.	n.d.	2,148[1], 239[2]	0	0%
Nickel, Total (ug/L)	8	2	-----	n.d.	n.d.	n.d.	610[3]	0	0%
Selenium, Dissolved (ug/L)	0.06	2	2.5	2.5	2.0	3.0	-----	-----	-----
Selenium, Total (ug/L)	0.06	2	2.5	2.5	2.0	3.0	4.6[2], 170[3]	0	0%
Silver, Dissolved (ug/L)	0.005	2	-----	n.d.	n.d.	n.d.	14[1]	0	0%
Silver, Total (ug/L)	0.005	2	-----	1.00	n.d.	2.00	-----	-----	-----
Sodium, Dissolved (mg/L)	0.01	2	141	141	132	150	-----	-----	-----
Thallium, Dissolved (ug/L)	0.003	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Total (ug/L)	0.003	2	0.10	0.10	0.09	0.10	0.24[3]	0	0%
Zinc, Dissolved (ug/L)	6	2	6	6	6	6	550[1,2]	0	0%
Zinc, Total (ug/L)	6	2	30	30	30	30	50	0	0%
Pesticide Scan (ug/L)[D]	0.05[E]	2	-----	n.d.	n.d.	n.d.	-----	-----	-----

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

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

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

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

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

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

(3) Criterion for the protection of human health.

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

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

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

Plate 7-25. Summary of monthly water quality conditions monitored on water discharged through Oahe Dam (i.e. site OAHPP1) during the 5-year period of 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[(A)]	No. of Obs.	Mean[(B)]	Median	Min.	Max.	State WQS Criteria[(C)]	No. of WQS Exceedances	Percent WQS Exceedance
Powerplant Discharge (cfs)	1	40	29,147	29,009	5,300	57,233	-----	-----	-----
Water Temperature (°C)	0.1	40	13.0	13.6	0.9	24.0	18.3[(1,5)]	10	25%
Dissolved Oxygen (mg/L)	0.1	40	10.1	9.9	7.0	14.3	5[(3,6)], 6[(1,6,8)], 7[(1,6,8)]	0	0%
Dissolved Oxygen (% Sat.)	0.1	40	97.4	97.2	81.6	114.5	-----	-----	-----
pH (S.U.)	0.1	39	8.2	8.2	7.3	8.9	6.5[(1,2,6)], 9.0[(1,2,5)], 9.5[(4,5)]	0	0%
Specific Conductance (uS/cm)	1	39	827	814	686	1,011	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	39	367	370	232	691	-----	-----	-----
Turbidity (NTU)	1	39	-----	1	n.d.	63	-----	-----	-----
Alkalinity, Total (mg/L)	7	40	167	168	150	178	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	40	4.5	4.2	2.3	14.0	-----	-----	-----
Chloride, Dissolved (mg/L)	1	23	12	12	11	14	175[(1,5)], 438[(2,5)] 100[(1,7)], 250[(2,7)]	0	0%
Colorized Dissolved Organic Matter (ug/L)	4	39	25	24	17	34	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	40	602	598	406	890	1,750[(2,5)], 3,500[(4,5)] 1,000[(2,7)], 2,000[(4,7)]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	40	-----	n.d.	n.d.	0.07	3.8 [(1,5,9)], 1.7 [(1,7,9)]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	40	0.4	0.3	n.d.	1.3	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	40	-----	0.04	n.d.	0.20	10[(2,5)]	0	0%
Nitrogen, Total (mg/L)	0.1	40	0.4	0.4	n.d.	1.3	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	40	-----	n.d.	n.d.	0.03	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	40	-----	n.d.	n.d.	0.10	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	40	-----	n.d.	n.d.	0.03	-----	-----	-----
Sulfate (mg/L)	1	40	252	246	194	306	875[(2,5)], 500[(2,7)]	0	0%
Suspended Solids, Total (mg/L)	4	5	-----	n.d.	n.d.	n.d.	53[(1,5)], 30[(1,7)]	3, 4	8%, 10%

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

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

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

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

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

Plate 7-26. Summary of annual metals and pesticide levels monitored on water discharged through Oahe Dam (i.e. site OAHPP1) during the 5-year period of 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/L)	40	4	-----	n.d.	n.d.	n.d.	-----	-----	-----
Aluminum, Total (ug/L)	40	4	121	107	50	220	-----	-----	-----
Antimony, Dissolved (ug/L)	0.5	4	-----	n.d.	n.d.	n.d.	-----	-----	-----
Antimony, Total (ug/L)	0.5	4	-----	n.d.	n.d.	n.d.	5.6(3)	0	0%
Arsenic, Dissolved (ug/L)	1	4	-----	2	n.d.	2	340(1), 150(2)	0, 0	0%
Arsenic, Total (ug/L)	1	4	-----	2	n.d.	2	0.018(3)	(b.d.)	(b.d.)
Barium, Dissolved (ug/L)	5	4	43	43	41	46	-----	-----	-----
Barium, Total (ug/L)	5	4	46	45	43	52	-----	-----	-----
Beryllium, Dissolved (ug/L)	2	4	-----	n.d.	n.d.	n.d.	-----	-----	-----
Beryllium, Total (ug/L)	2	4	-----	n.d.	n.d.	n.d.	4(3)	0	0%
Cadmium, Dissolved (ug/L)	0.2	4	-----	n.d.	n.d.	n.d.	4.9(1), 0.46(2)	0	0%
Cadmium, Total (ug/L)	0.2	4	-----	n.d.	n.d.	0.2	5(3)	0	0%
Calcium, Dissolved (mg/L)	0.4	4	57	57	49	65	-----	-----	-----
Chromium, Dissolved (ug/L)	10	4	-----	n.d.	n.d.	n.d.	1,206(1), 157(2)	0	0%
Chromium, Total (ug/L)	10	4	-----	n.d.	n.d.	n.d.	-----	-----	-----
Copper, Dissolved (ug/L)	6	4	-----	n.d.	n.d.	6	32(1), 20(2),	0	0%
Copper, Total (ug/L)	6	4	-----	n.d.	n.d.	8	1,300(3)	0	0%
Hardness, Total (mg/L)	0.4	4	243	250	197	276	-----	-----	-----
Iron, Dissolved (ug/L)	10	4	-----	n.d.	n.d.	20	-----	-----	-----
Iron, Total (ug/L)	10	4	93	90	40	150	-----	-----	-----
Lead, Dissolved (ug/L)	0.5	4	-----	n.d.	n.d.	n.d.	172(1), 6.7(2)	0	0%
Lead, Total (ug/L)	0.5	4	-----	1.2	n.d.	3.0	-----	-----	-----
Magnesium, Dissolved (mg/L)	0.4	4	25	26	18	29	-----	-----	-----
Manganese, Dissolved (ug/L)	2	4	-----	n.d.	n.d.	10	-----	-----	-----
Manganese, Total (ug/L)	2	4	-----	20	n.d.	60	-----	-----	-----
Mercury, Dissolved (ug/L)	0.05	4	-----	n.d.	n.d.	n.d.	1.4(1)	0	0%
Mercury, Total (ug/L)	0.05	4	-----	n.d.	n.d.	n.d.	0.77(2), 0.05(3)	0	0%
Nickel, Dissolved (ug/L)	10	4	-----	n.d.	n.d.	n.d.	1,016(1), 113(2)	0	0%
Nickel, Total (ug/L)	10	4	-----	n.d.	n.d.	n.d.	610(3)	0	0%
Selenium, Dissolved (ug/L)	1	4	-----	n.d.	n.d.	3	-----	-----	-----
Selenium, Total (ug/L)	1	4	-----	1	n.d.	3	4.6(2), 170(3)	0	0%
Silver, Dissolved (ug/L)	1	4	-----	n.d.	n.d.	n.d.	16(1)	0	0%
Silver, Total (ug/L)	1	4	-----	n.d.	n.d.	n.d.	-----	-----	-----
Sodium, Dissolved (mg/L)	0.4	4	84	87	63	98	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	4	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Total (ug/L)	0.5	4	-----	n.d.	n.d.	n.d.	0.24(3)	b.d.	b.d.
Zinc, Dissolved (ug/L)	10	4	-----	n.d.	n.d.	10	255 (1,2)	0	0%
Zinc, Total (ug/L)	10	4	-----	n.d.	n.d.	20	7,400(3)	0	0%
Pesticide Scan (ug/L)(D)	0.05(E)	4	-----	n.d.	n.d.	n.d.	-----	-----	-----

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

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

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

(C) Criteria given for reference – actual criteria should be verified in appropriate State water quality standards.
- (1) Acute (CMC) criterion for the protection of freshwater aquatic life.
- (2) Chronic (CCC) criterion for the protection of freshwater aquatic life.
- (3) Criterion for the protection of human health.

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

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

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

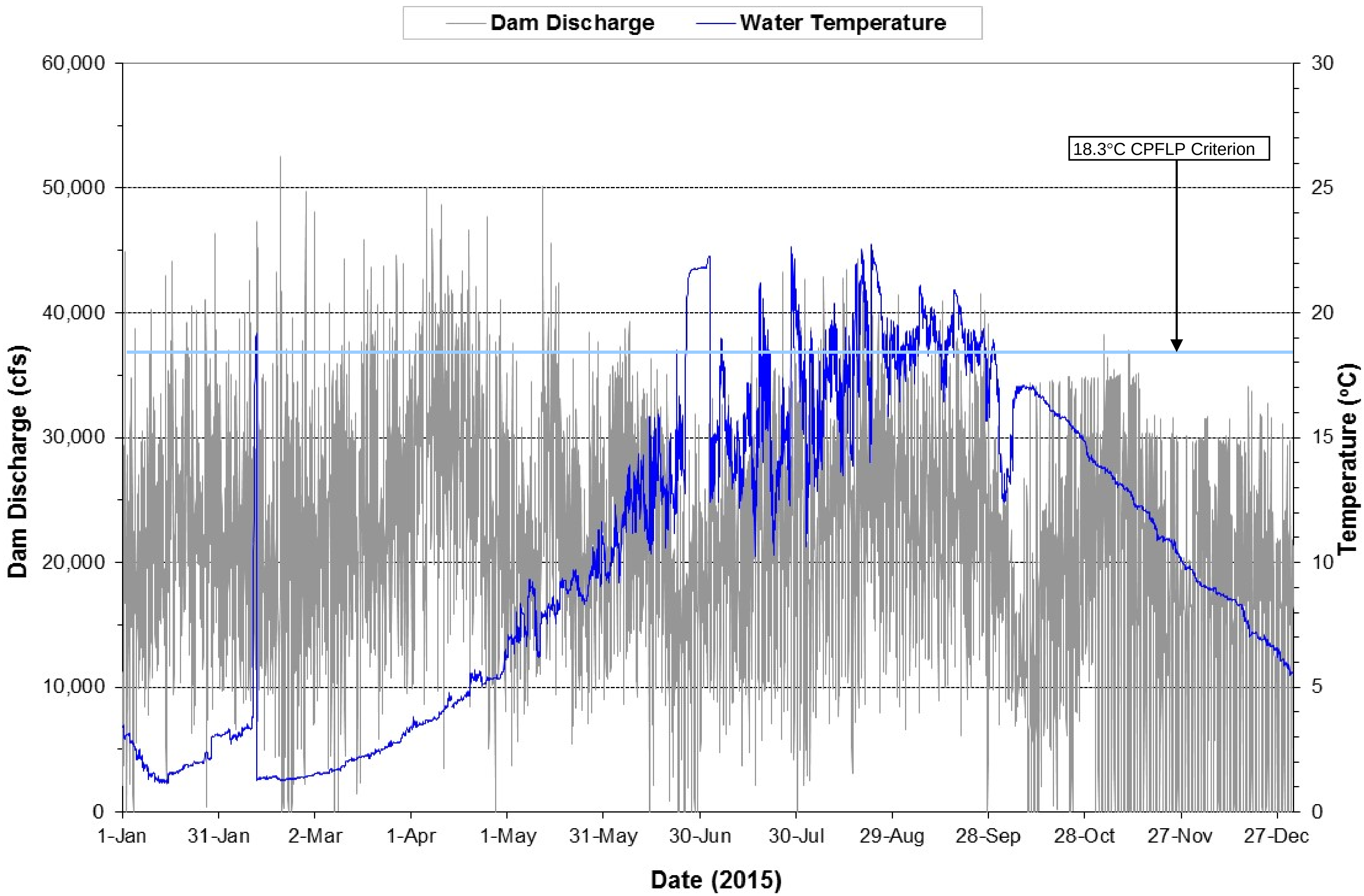


Plate 7-27. Hourly discharge and water temperature monitored at the Oahe powerplant on water discharged through the dam during 2015.

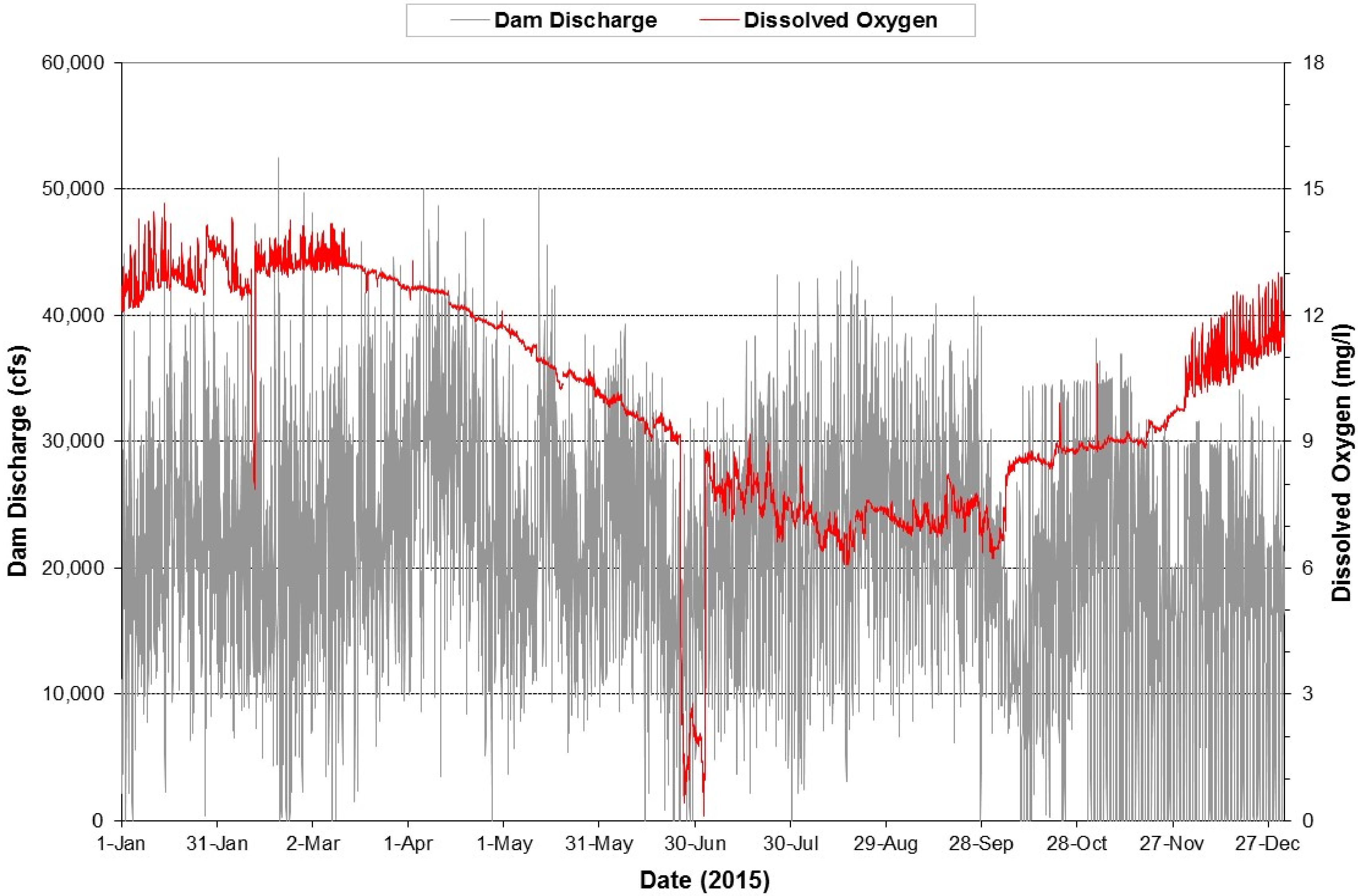


Plate 7-28. Hourly discharge and dissolved oxygen monitored at the Oahe Powerplant on water discharged through the dam during 2015.

8 BIG BEND PROJECT

8.1 BACKGROUND INFORMATION

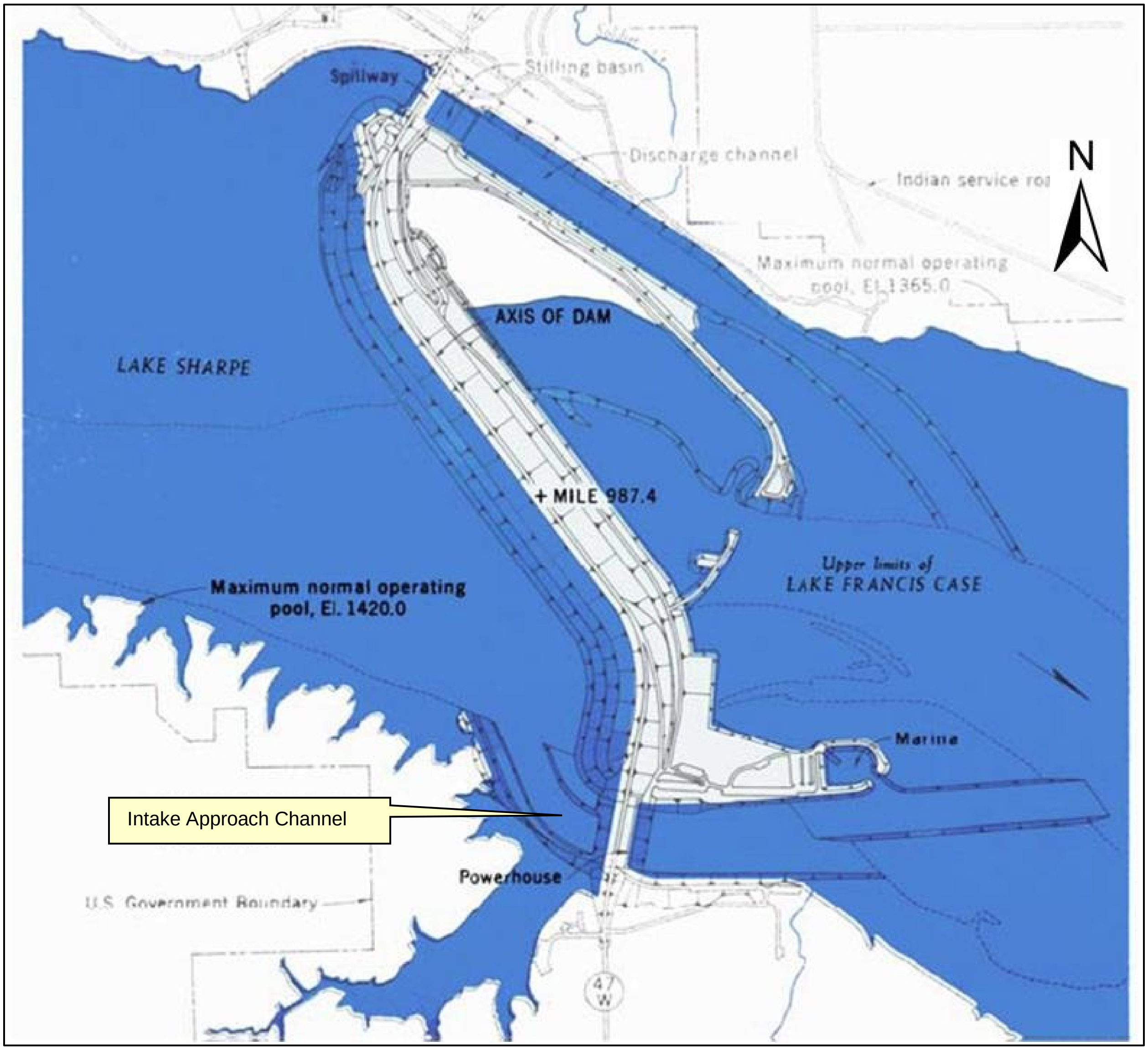
8.1.1 PROJECT OVERVIEW

Big Bend Dam is located in central South Dakota on the Missouri River at RM 987.4, 21 miles northwest of Chamberlain, SD. The closing of Big Bend Dam in 1963 resulted in the formation of Big Bend Reservoir (Lake Sharpe). The reservoir, when full, is 80 miles long, covers 61,000 acres, and has 200 miles of shoreline. Table 8-1 summarizes how the surface area, volume, mean depth, and retention time of Lake Sharpe vary with pool elevations. The major inflows to Lake Sharpe are the Missouri River and Bad River. Figure 8-1 shows a diagrammatic view of the Big Bend Dam area and a photo of the Big Bend Dam powerplant intake structure during construction prior to inundation. The reservoir and dam 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 within the project area. Three surface water intakes are located in Lake Sharpe: Mni Wiconi Rural Water System (RM1070 – 12 counties and Lower Brule, Rosebud, and Pine Ridge Indian Reservations); Lower Brule Rural Water System (RM993 – Lower Brule); and Fort Thompson Rural Water Service (RM987 – Fort Thompson). The reservoir is an important recreational resource.

Table 8-1. Surface area, volume, mean depth, and retention time of Lake Sharpe at different pool elevations based on 2013 bathymetric survey.

Elevation (Feet-NGVD29)	Surface Area (Acres)	Volume (Acre-Feet)	Mean Depth (Feet)*	Retention Time (Years)**
1430	71,120	2,275,184	32.0	0.1324
1425	64,371	1,936,456	30.1	0.1127
1420	57,646	1,631,474	28.3	0.0949
1415	51,003	1,359,562	26.7	0.0791
1410	43,478	1,122,745	25.8	0.0653
1405	35,602	926,657	26.0	0.0539
1400	31,962	759,803	23.8	0.0442
1395	27,124	613,245	22.6	0.0357
1390	24,532	484,949	19.8	0.0282
1385	21,765	368,859	16.9	0.0215
1380	18,464	268,103	14.5	0.0156
1375	15,295	183,998	12.0	0.0107
1370	12,035	115,925	9.6	0.0067
1365	8,857	63,690	7.2	0.0037
1360	5,597	27,341	4.9	0.0016
1355	2,049	9,253	4.5	0.0005
1350	816	2,256	2.8	0.0001

Average Annual Inflow (1967 through 2015) = 17.365 Million Acre-Feet.
Average Annual Outflow: (1967 through 2015) = 17.190 Million Acre-Feet.
* Mean Depth = Volume ÷ Surface Area.
** Retention Time = Volume ÷ Average Annual Outflow.
Note: Exclusive Flood Control Zone (elev. 1423-1422 ft-NGVD29), Annual Flood Control and Multiple Use Zone (elev. 1422-1420 ft-NGVD29), Carryover Multiple Use Zone (none), and Permanent Pool Zone (elev. 1420-1345 ft-NGVD29). All elevations are in the NGVD 29 datum.



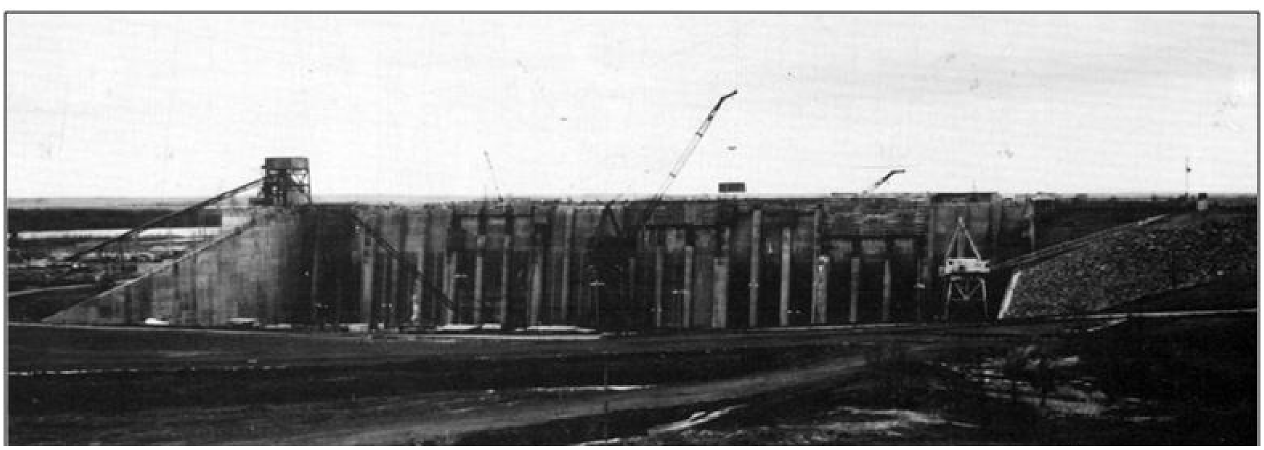


Figure 8-1. Diagrammatic view of Big Bend Dam area and photo of the Big Bend powerplant intake structure in final stages of construction prior to inundation.

The Big Bend powerplant is operated to meet peak power demands for electricity. Generally, weekly flows from Oahe Dam are released at Big Bend Dam, and there is minimal fluctuation in the water level of Lake Sharpe. The Annual Flood Control and Multiple Use Zone in the reservoir does not provide for seasonal regulation of flood inflows like the other major upstream Mainstem System Projects, but the zone is used for day-to-day and week-to-week power operations. The Corps normally strives to maintain the pool level in the reservoir between elevation 1419 and 1421.5 ft-NGVD29. There are no minimum flow requirements below Big Bend Dam, and hourly releases can fluctuate from 0 to 110,000 cfs for peaking power generation. Water discharged through Big Bend Dam for power production is withdrawn from the bottom of Lake Sharpe at an invert elevation of 1330.0 ft-NGVD29. Figure 8-2 plots the midnight pool elevation of Lake Sharpe and the mean daily discharge of Big Bend Dam over the 5-year period 2011 through 2015. The extreme discharges in 2011 reflect additional releases made through the spillway to manage the high inflows during 2011.

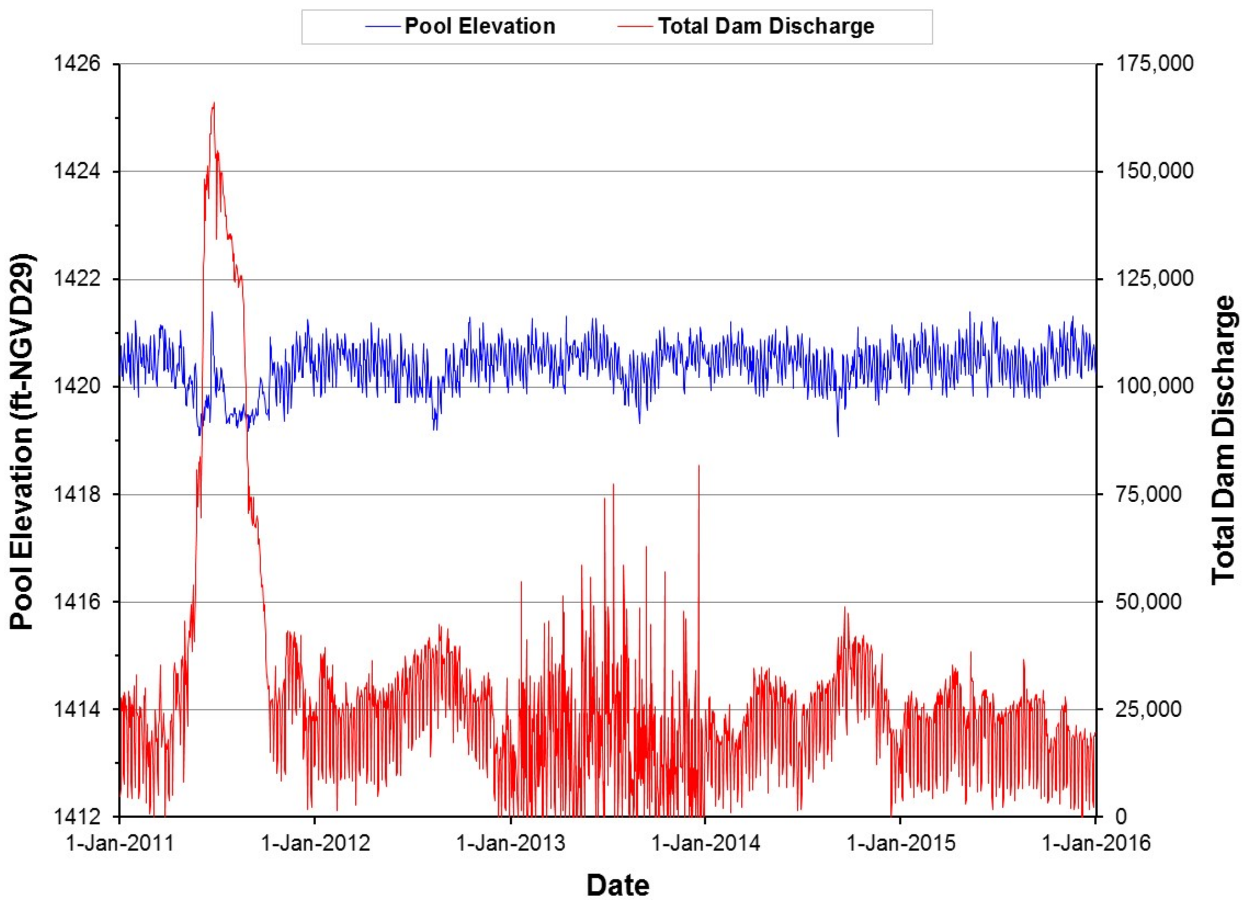


Figure 8-2. Lake Sharpe midnight pool elevation and the mean daily discharge of Big Bend Dam over the 5-year period 2011 through 2015.

8.1.2 WATER QUALITY STANDARDS CLASSIFICATION AND SECTION 303(D) LISTINGS

8.1.2.1 Lake Sharpe

South Dakota has classified the Missouri River impoundments within the State as flowing streams and not reservoirs (South Dakota Administrative Rules 74:51:01:43). The following water quality-dependent beneficial uses have been designated for Lake Sharpe in South Dakota's water quality standards: domestic water supply waters, coldwater permanent fish life propagation waters, immersion recreation waters, limited-contact recreation waters, commerce and industry waters, agricultural water supply (i.e. irrigation and stock watering), and fish and wildlife propagation. The State of South Dakota lists Lake Sharpe on the State's 2016 Section 303(d) list of impaired waters and targets the reservoir for development of a TMDL in 2029 (SDDENR, 2016). The reservoir use identified as impaired is coldwater permanent fish life propagation waters and the cause of impairment is identified as warm water temperatures and low dissolved oxygen concentrations. Consideration should be given to reclassification of Lake Sharpe from a coldwater fishery to a warmwater fishery based on a use attainability assessment of "natural conditions". Lake Sharpe does not regularly form a coldwater hypolimnion, and summer water temperatures discharged from Oahe Dam, especially during lower pool levels, don't meet the temperature criteria for a coldwater fishery use. South Dakota had recently delisted Lake Sharpe for Section 303(d) impairment due to sedimentation. The reservoir was previously listed as water-quality impaired due to accumulated sediment from the Bad River watershed. A total maximum daily load (TMDL) was developed in 2001 and is being implemented to address this concern, resulting in the delisting of Lake Sharpe for sedimentation. South Dakota has not issued a fish consumption advisory for the reservoir.

8.1.2.2 Missouri River Downstream of Big Bend Dam

The State of South Dakota has designated the following water quality-dependent beneficial uses for the Missouri River downstream of Big Bend Dam: domestic water supply waters, warmwater permanent fish life propagation waters, immersion recreation waters, limited-contact recreation waters, commerce and industry waters, agricultural water supply (i.e. irrigation and stock watering), and fish and wildlife propagation. Big Bend Dam is the current demarcation point between coldwater and warmwater use designation on the Missouri River system in South Dakota. Therefore, the designated use of Warmwater Permanent Fish Life Propagation applies to the Big Bend Dam tailwaters rather than the Coldwater Permanent Fish Life Propagation use that applies to Lake Sharpe. South Dakota has not issued a fish consumption advisory for the Missouri River downstream of Big Bend Dam.

8.1.3 AMBIENT WATER QUALITY MONITORING

The District has monitored water quality conditions at the Big Bend Project since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow to and outflow from the reservoir. The water quality conditions of the Oahe Dam discharge are taken to represent the inflow water quality conditions of the Missouri River to Lake Sharpe. Figure 8-3 shows the location of sites at the Big Bend Project that were monitored for water quality during the 5-year period 2011 through 2015. The near-dam location (i.e. site BBDLK0987A) has been continuously monitored since 1980.

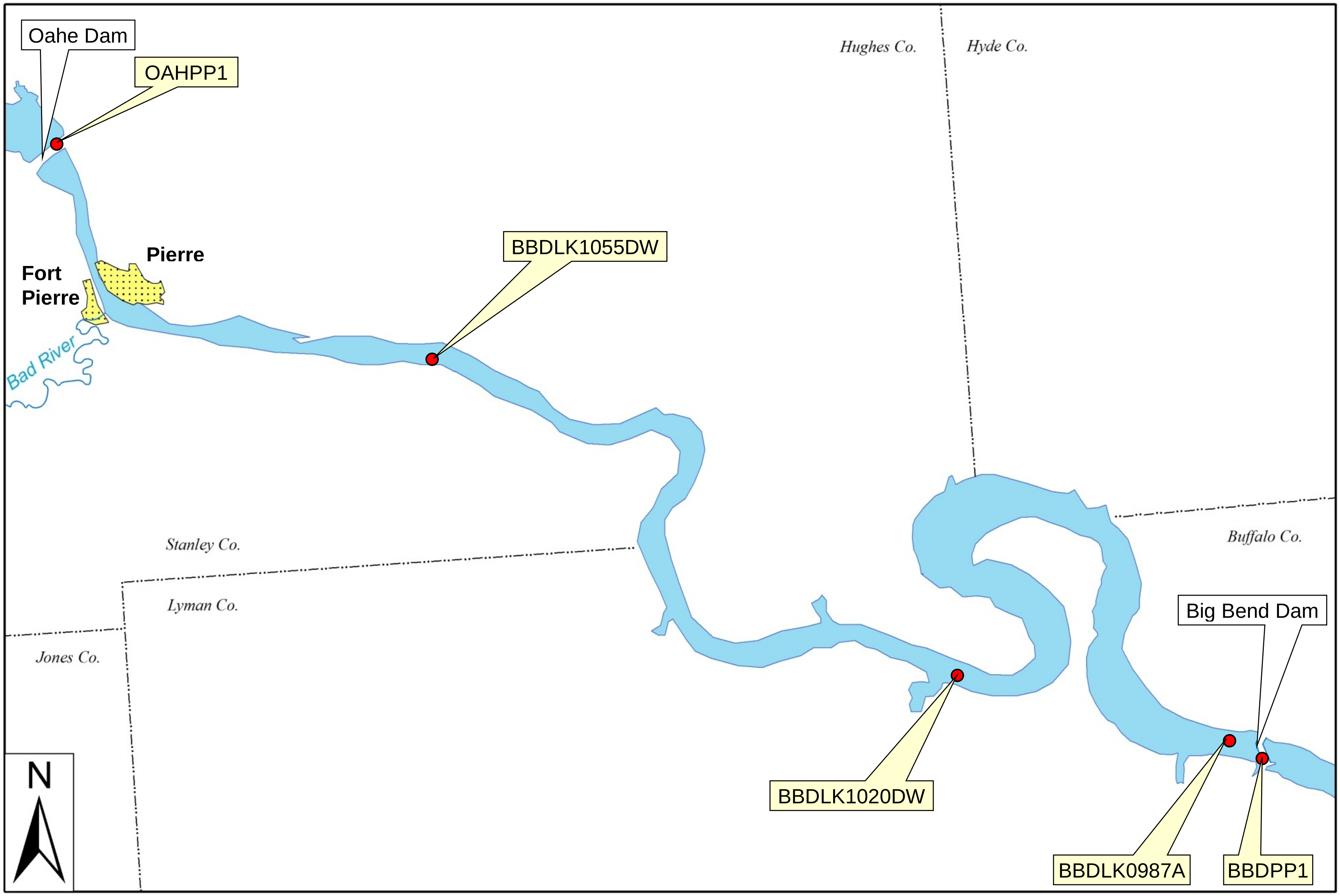


Figure 8-3. Location of sites where long-term, ambient water quality monitoring was conducted by the District at the Big Bend Project during the 5-year period 2011 through 2015.

8.2 WATER QUALITY IN LAKE SHARPE

8.2.1 EXISTING WATER QUALITY CONDITIONS

8.2.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Water quality conditions that were monitored in Lake Sharpe at sites BBDLK0987A, BBDLK1020DW, and BBDLK1055DW from May through September during the 5-year period 2011 through 2015 are summarized in Plate 8-1, Plate 8-2, and Plate 8-3. A review of these results indicated water quality concerns regarding water temperature and dissolved oxygen for the support of Coldwater Permanent Fish Life Propagation (CPFLP). The CPFLP use was not met on 58%, 63%, and 63% of the occasions water quality conditions were monitored monthly during the May through September period, respectively, at sites BBDLK0987A, BBDLK1020DW, and BBDLK1055DW. Due to its shallowness and high flows released from Oahe Dam, a hypolimnion rarely forms in Lake Sharpe and water temperatures throughout the reservoir regularly exceed 18.3°C in the summer. Dissolved oxygen levels near the bottom of the reservoir occasionally fall below the 6.0 mg/L CPFLP criterion during the summer. The lowest dissolved oxygen concentration measured during the 5-year period at the three sites was 3.5 mg/L, and occurred near the dam at site BBDLK0987A in July 2015. The suspended solids criteria for the protection of CPFLP are regularly exceeded in the upper end of Lake Sharpe (Plate 8-3). This is attributed to finer sediment that has been deposited in Lake Sharpe below the confluence of the Bad River and its continual resuspension with wave action.

8.2.1.2 Summer Thermal Stratification and Dissolved Oxygen Conditions during 2015

8.2.1.2.1 Depth-Profile Plots

Depth-profile plots of temperature and dissolved oxygen measurements taken at sites BBDLK0987A, BBDLK1020DW, and BBDLK1055DW during 2015 are shown in Plate 8-4.

8.2.1.2.2 Longitudinal Temperature Contour Plots

Summer thermal stratification of Lake Sharpe during 2015 is described by the monthly longitudinal temperature contour plots based on depth-profile temperature measurements taken in May, June, July, August, and September (Plate 8-5, Plate 8-6, Plate 8-7, Plate 8-8, and Plate 8-9). The contour plots were constructed along the length of the reservoir. As seen in the contour plots, water temperature in Lake Sharpe varies longitudinally from the dam to the reservoir's upstream reaches and vertically from the reservoir surface to the bottom. Cooler water is typically discharged from Oahe Dam from late-spring through mid-summer which quickly warms in Lake Sharpe. Although some summer thermal stratification of Lake Sharpe can occur, the relative shallowness, short retention time, and bottom withdrawal of the reservoir seemingly inhibit the formation of a strong thermocline and long-lasting thermal stratification during the summer.

8.2.1.2.3 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen longitudinal contour plots were constructed along the length of Lake Sharpe based on depth-profile measurements taken in May, June, July, August, and September of 2015 (Plate 8-10, Plate 8-11, Plate 8-12, Plate 8-13, and Plate 8-14). During the summer of 2015, dissolved oxygen conditions in Lake Sharpe varied longitudinally from the dam to the reservoir's upstream reaches and vertically from the reservoir surface to the bottom. The lowest dissolved oxygen concentration monitored in Lake Sharpe during 2015 was 3.5 mg/L in July (Plate 8-12).

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

Paired near-surface and near-bottom water quality samples collected from Lake Sharpe during the summer were compared. Near-surface conditions were represented by samples collected within 2-meters of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site BBDLK0987A during the 5-year period 2011 through 2015. During the period a total of 19 paired samples were collected monthly from June through September. Box plots were constructed to display the distribution of the paired near-surface and near-bottom measurements for the following parameters: water temperature, dissolved oxygen, pH, alkalinity, total ammonia, and total phosphorus (Plate 8-15). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for water temperature ($p < 0.001$), dissolved oxygen ($p < 0.001$), and pH ($p < 0.001$). All three parameters that were significantly lower in the near-bottom water of Lake Sharpe.

8.2.1.4 Reservoir Trophic Status

Trophic State Index (TSI) values for Lake Sharpe were calculated from monitoring data collected during the 5-year period 2011 through 2015 (Table 8-2). The calculated TSI values indicate that the area near the dam (i.e. site BBDLK0987A) is mesotrophic, the middle reach of the reservoir (i.e. site BBDLK1020DW) is moderately eutrophic, and the upstream reach of the reservoir (i.e. site BBDLK1055DW) is eutrophic.

Table 8-2. Mean Trophic State Index (TSI) values calculated for Lake Sharpe. TSI values are based on monitoring at the identified three sites during the 5-year period 2011 through 2015.

Monitoring Site	Mean – TSI (Secchi Depth)	Mean – TSI (Total Phosphorus)	Mean – TSI (Chlorophyll)	Mean – TSI (Average)
BBDLK0987A	52	42	54	49
BBDLK1020DW	62	45	55	54
BBDLK1055DW	81	59	57	61

Note: See Section 4.1.4 for discussion of TSI calculation.

8.2.1.5 Plankton Community

8.2.1.5.1 Phytoplankton

Phytoplankton grab samples were collected from Lake Sharpe at sites BBDLK0987A, BBDLK1020DW, and BBDLK1055DW during 2015. The following six taxonomic divisions were represented by taxa collected in the phytoplankton samples: Bacillariophyta (Diatoms), Chlorophyta (Green Algae), Chrysophyta (Golden Algae), Cryptophyta (Cryptomonad Algae), Cyanobacteria (Blue-Green Algae), Pyrrophyta (Dinoflagellate Algae), and Euglenophyta ((Euglenoid Algae). The relative abundance of phytoplankton in samples collected from Lake Sharpe in May, July, and September 2015, based on biovolume, is shown in Figure 8-4. Diatoms and cryptomonad algae were the most dominant phytoplankton groups sampled in Lake Sharpe during 2015. No concentrations of the cyanobacteria toxin microcystin above 1 ug/L were monitored in the lake during the 5-year period 2011 through 2015 (Plate 8-1, Plate 8-2, and Plate 8-3).

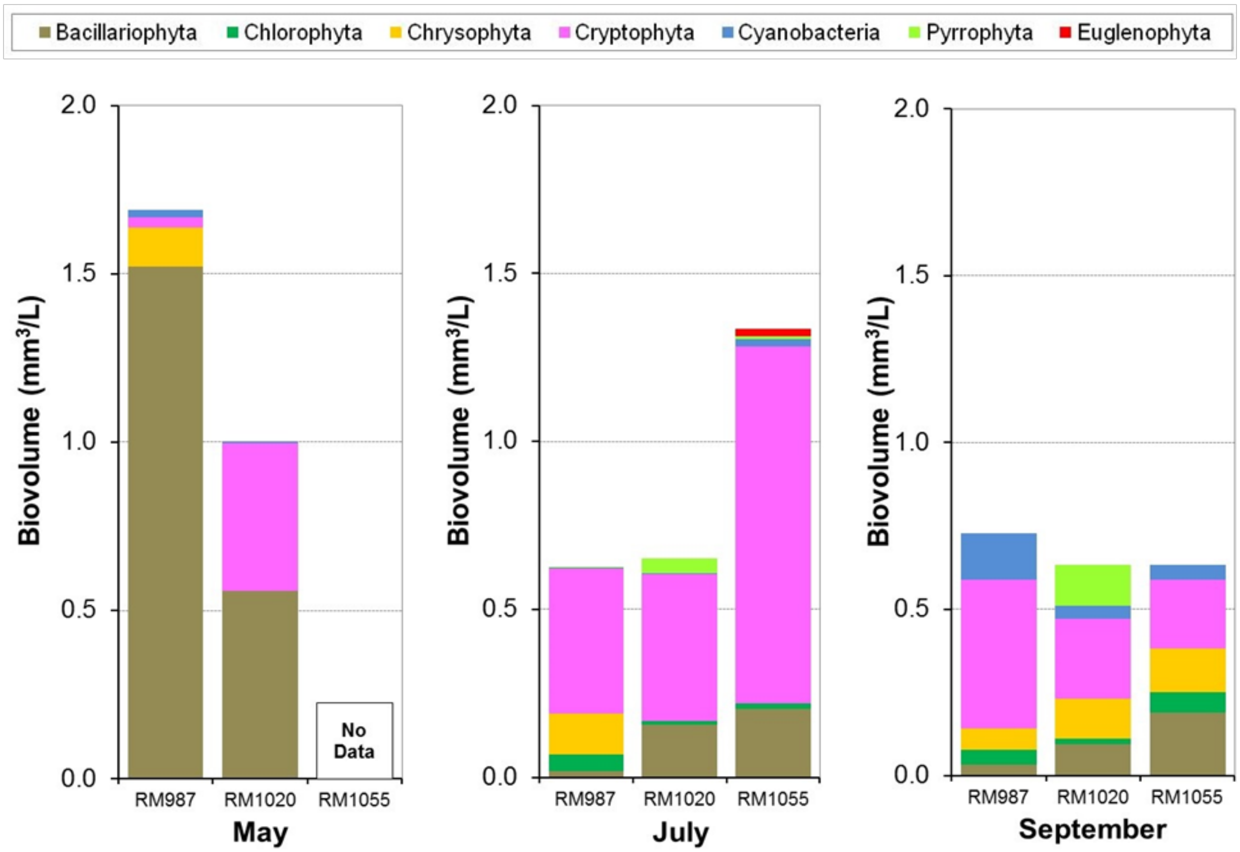


Figure 8-4. Relative abundance of phytoplankton in samples collected from Lake Sharpe during 2015.

8.2.1.5.2 Zooplankton

Zooplankton vertical-tow samples were collected from Lake Sharpe at sites BBDLK0987A and BBDLK1020DW in May, July, and September of 2015. The sampled zooplankton included three taxonomic groupings: Cladocerans, Copepods, and Rotifers. The relative abundance of these four taxonomic grouping in the zooplankton samples collected in 2015 is shown in Figure 8-5. Copepods dominated the zooplankton community in Lake Sharpe.

8.2.1.6 <u>Occurrence of Coldwater Permanent Fish Life Propagation Habitat in Lake Sharpe</u>

The most crucial period for the support of Coldwater Permanent Fish Life Propagation (CPFLP) habitat in Lake Sharpe is during mid-summer. Monitoring indicates that the reservoir is probably discontinuous polymictic with a hypolimnion only forming on an irregular basis. This results in complete mixing and warming of the water column above 18.3°C during the summer. When stratification does persist, dissolved oxygen degradation to levels below 6 mg/L occurs near the reservoir bottom in deeper waters near the dam.

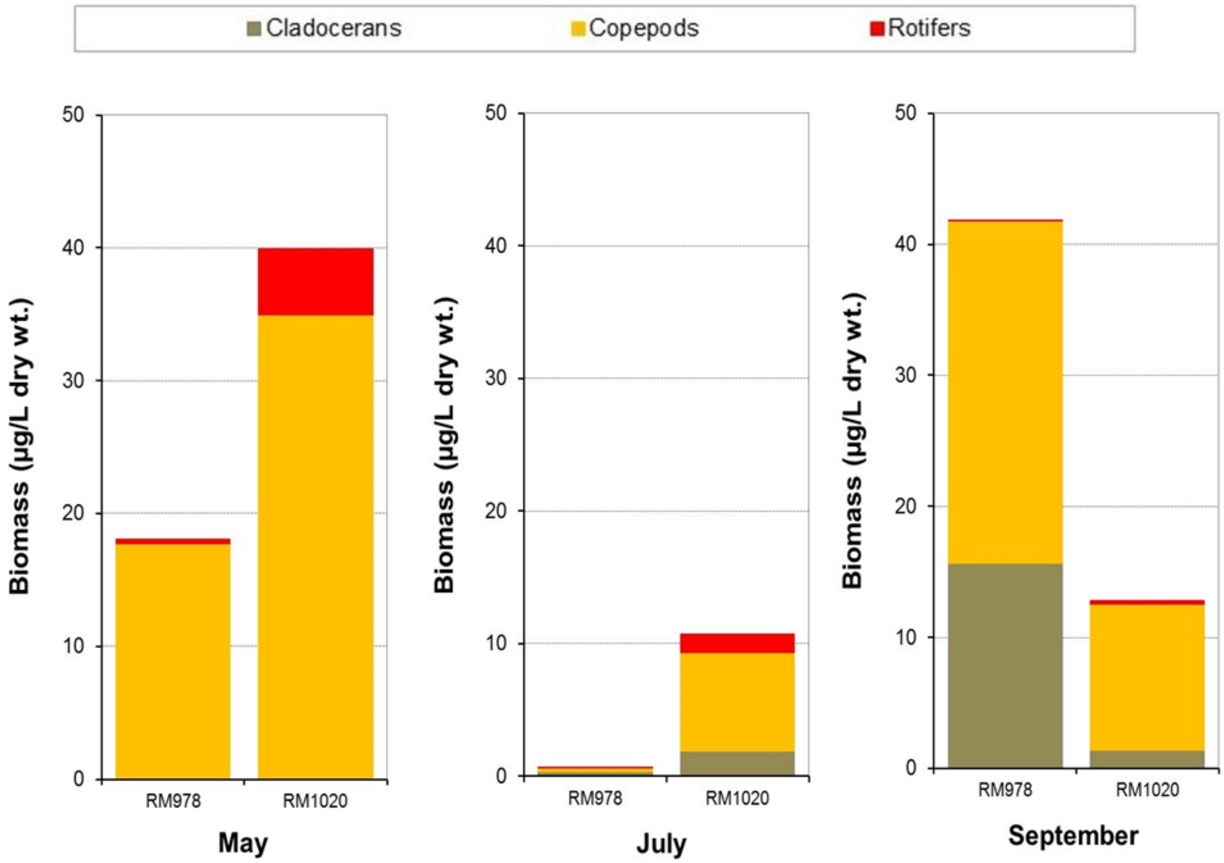


Figure 8-5. Relative abundance of zooplankton in samples collected from Lake Sharpe during 2015**.**

The occurrence of CPFLP habitat (i.e. water temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/L) in Lake Sharpe was estimated from collected water temperature and dissolved oxygen depth-profile measurements. Conditions supportive of CPFLP were present in 42, 38, and 38 percent of the depth-profile measurements respectively taken at sites BBDLK0987A, BBDLK1020DW, and BBDLK1055DW during the 5-year period 2011 through 2015 (Plate 8-1, Plate 8-2, and Plate 8-3). Conditions supportive of CPFLP are rarely present anywhere in the reservoir during the months of July and August. Ambient water temperatures in Lake Sharpe do not appear to be cold enough to support CPFLP, as defined by State water quality criteria, during mid-summer. Consideration should be given to reclassify the reservoir for a Warmwater Permanent Fish Life Propagation use based on a use attainability assessment of "natural conditions" regarding ambient water temperatures.

8.2.2 WATER QUALITY TRENDS (1980 THROUGH 2015)

Water quality trends over the 36-year period of 1980 through 2015 were determined for Lake Sharpe for Secchi depth, total phosphorus, chlorophyll *a*, and TSI (i.e. trophic status). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam, ambient monitoring site (i.e. site BBDLK0987A). Plate 8-16 displays a scatter-plot of the collected data for the four parameters, a linear regression trend line, and the significance of the trend line (i.e. $\alpha = 0.05$). For the assessment period, Lake Sharpe exhibited significant trends for Secchi depth (decreasing, $p < 0.001$) and TSI (increasing, $p < 0.05$). No significant trend was detected for total phosphorus and chlorophyll *a*. Over the 36-year period, the reservoir has generally remained mesotrophic to moderately eutrophic.

8.3 EXISTING WATER QUALITY CONDITIONS OF THE MISSOURI RIVER INFLOW TO LAKE SHARPE

The water quality conditions of the Missouri River inflow to Lake Sharpe is taken to be the monitored water quality conditions of the outflow from Oahe Dam (see Section 7.4).

8.4 WATER QUALITY AT THE BIG BEND DAM POWERPLANT

8.4.1 STATISTICAL SUMMARY AND COMPARISON TO APPLICABLE WATER QUALITY STANDARDS CRITERIA

Plate 8-17 and Plate 8-18 summarize the water quality conditions that were monitored on water discharged through Big Bend Dam during the 5-year period 2011 through 2015. A review of these results indicated no significant water quality concerns. However, the 0.18 ug/L human health criterion for total arsenic was exceeded on all four occasions. The highest total arsenic concentration measured was 2 ug/L.

8.4.2 TEMPERATURE, DISSOLVED OXYGEN, AND DAM DISCHARGE TIME-SERIES PLOTS

Hourly temperature, dissolved oxygen, and dam discharge recorded at the Big Bend powerplant during 2015 were used to a construct time-series plot (Plate 8-19 and Plate 8-20). Water temperatures showed seasonal warming and cooling through each calendar year. Dissolved oxygen levels remained relatively high and fairly stable during the winter, steadily declined through the spring and summer, and steadily increased during the fall. The lowest dissolved oxygen levels occurred during the July to August period. The higher winter, declining spring, and increasing fall dissolved oxygen concentrations are attributed to decreasing dissolved oxygen solubility with warmer water temperatures. There appeared to be significant correlation between discharge rates and water temperature and dissolved oxygen concentrations measured during the summer months. The lower dissolved oxygen concentrations monitored in the summer may be attributed to periodic stratification and the degradation of dissolved oxygen conditions near the bottom of the reservoir. Since the inlet to the powerhouse is located at the reservoir bottom, lower flows through the dam may result in more “laminar” flow that pulls in water with degraded dissolved oxygen conditions along the bottom into the powerplant

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

Nutrient flux rates for the Big Bend Dam discharge to the Missouri River over the 5-year period 2011 through 2015 were calculated based on samples taken from the Big Bend powerplant (i.e. site BBDPP1) and the mean daily dam discharge for the day of sample collection (Table 8-3). During this 5-year period, all water discharged at Big Bend Dam was through the powerplant except during 2011. During June through August of 2011, significant discharge occurred via the spillway. During this period, water quality conditions monitored in the powerplant discharge were taken to represent the water quality of the total discharge to calculate nutrient flux. The samples collected in the powerplant are taken from the raw water supply line and are believed to be unbiased regarding particulate-associated constituents. Therefore, the flux rates calculated for the Big Bend Dam discharge give an unbiased estimate of the flux rates for all the constituents, including total phosphorus and total organic carbon. The maximum flux rates for all the constituents are believed to be attributed to higher dam discharges.

Table 8-3. Summary of nutrient flux rates (kg/sec) calculated for the Big Bend Dam discharge to the Missouri River (i.e. site BBDPP1) during January through December over the 5-year period 2011 through 2015.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	40	40	40	40	40	40	40
Mean	36,637	0.0244	0.5725	0.0921	0.0743	0.0054	4.4680
Median	28,372	n.d.	0.3309	0.0447	0.0180	n.d.	3.5397
Minimum	2,600	n.d.	n.d.	n.d.	n.d.	n.d.	0.2871
Maximum	145,900	0.1653	3.6369	0.6080	1.9045	0.0816	15.5053

Note: Nondetectable values set to 0 for flux calculations.

Plate 8-1. Summary of monthly (May through September) water quality conditions monitored in Lake Sharpe near Big Bend Dam (Site BBDLK0987A) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results(A)						Water Quality Standards Attainment		
	Detection Limit(B)	No. of Obs.	Mean(C)	Median	Min.	Max.	State WQS Criteria(D)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	24	1420.3	1420.5	1419.3	1420.8	-----	-----	-----
Water Temperature (°C)	0.1	522	19.1	20.8	10.3	26.8	18.3(1,5)	330	63%
Hypolimnion Water Temperature (°C)(E)	0.1	27	20.8	21.9	15.7	22.5	18.3(1,5)	22	81%
Dissolved Oxygen (mg/L)	0.1	522	8.4	8.4	3.5	11.5	6(1,6,8), 7(1,6,8)	35, 57	7%, 11%
Dissolved Oxygen (% Sat.)	0.1	522	93.6	96.4	41.1	133.3	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)(E)	0.1	494	8.6	8.4	4.7	11.5	5(3,6)	1	<1%
Hypolimnion Dissolved Oxygen (mg/L)(E)	0.1	27	5.0	4.4	3.5	8.3	6(1,6,8)	22	81%
Specific Conductance (uS/cm)	1	522	847	839	686	957	-----	-----	-----
pH (S.U.)	0.1	522	8.3	8.4	7.7	8.8	6.5(1,2,6), 9.0(1,2,5), 9.5(4,5)	0	0%
Turbidity (NTUs)	1	522	9	3	n.d.	8.8	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	501	339	340	182	482	-----	-----	-----
Secchi Depth (M)	0.02	23	1.86	1.63	0.56	4.06	-----	-----	-----
Alkalinity, Total (mg/L)	7	49	166	169	148	177	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	49	4.0	4.0	2.4	5.4	-----	-----	-----
Chloride (mg/L)	1	29	12	12	9	14	175(1,5), 100(1,7), 438(2,5), 250(2,7)	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	478	5	4	n.d.	18	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	25	6	5	n.d.	14	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	49	24	24	16	34	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	48	605	611	436	842	1,750(2,5), 1,000(2,7), 3,500(4,5), 2,000(4,7)	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	49	-----	n.d.	n.d.	0.25	2.6 (1,5,9), 0.82 (1,7,9)	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.08	48	0.3	0.3	n.d.	0.6	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	49	-----	0.05	n.d.	0.21	10(2,5)	0	0%
Nitrogen, Total (mg/L)	0.08	48	0.4	0.4	n.d.	0.7	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	49	-----	n.d.	n.d.	0.02	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	49	-----	0.02	n.d.	0.04	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	49	-----	n.d.	n.d.	0.02	-----	-----	-----
Sulfate (mg/L)	1	49	259	252	191	310	875(2,5), 500(2,7)	0	0%
Suspended Solids, Total (mg/L)	4	49	-----	5	n.d.	15	53(1,5), 30(1,7)	0	0%
Microcystin, Extracellular (ug/L)	0.1	24	-----	n.d.	n.d.	0.1	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat(F)	-----	24	-----	-----	-----	-----	D.O ≥ 6 mg/L W. Temp. ≤ 18.3°C	14	58%

n.d. = Not detected.

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

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

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

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

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur. A defined hypolimnion was monitored on 4 of the 25 occasions (i.e. 16%) that monthly depth profiles were measured from May through September. Measured water depths in this area of Lake Sharpe were < 23 meters.

(F) Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e. at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/L). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile.

Plate 8-2. Summary of monthly (May through September) water quality conditions monitored in Lake Sharpe in the Iron Nation area (Site BBDLK1020DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	24	1420.3	1420.4	1419.3	1420.7	-----	-----	-----
Water Temperature (°C)	0.1	292	18.6	20.0	8.2	28.0	18.3[1,5]	182	62%
Hypolimnion Water Temperature (°C)[E]	0.1	0	-----	-----	-----	-----	18.3[1,5]	-----	-----
Dissolved Oxygen (mg/L)	0.1	292	9.2	8.9	7.1	12.4	6[1,6,8], 7[1,6,8]	0	0%
Dissolved Oxygen (% Sat.)	0.1	292	101.6	100.4	82.5	116.4	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[E]	0.1	292	9.2	8.9	7.1	12.4	5[3,6]	0	0%
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	0	-----	-----	-----	-----	6[1,6,8]	-----	-----
Specific Conductance (uS/cm)	1	292	839	839	427	957	-----	-----	-----
pH (S.U.)	0.1	292	8.4	8.4	7.8	8.8	6.5[1,2,6], 9.0[1,2,5], 9.5[4,5]	0	0%
Turbidity (NTUs)	1	291	12	8	n.d.	82	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	280	342	336	161	476	-----	-----	-----
Secchi Depth (M.)	1	24	1.02	0.86	0.23	3.35	-----	-----	-----
Alkalinity, Total (mg/L)	7	48	167	169	150	177	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	48	4.1	4.1	2.3	5.8	-----	-----	-----
Chloride (mg/L)	1	28	13	13	11	14	175[1,5], 100[1,7], 438[2,5], 250[2,7]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	269	7	6	n.d.	41	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	24	6	5	n.d.	11	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	48	25	25	14	34	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	47	612	618	440	832	1,750[2,5], 1,000[2,7], 3,500[4,5], 2,000[4,7]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	48	-----	n.d.	n.d.	0.14	2.6 [1,5,9], 0.86 [1,7,9]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.08	45	0.3	0.03	0.1	0.7	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	48	-----	n.d.	n.d.	0.32	10[2,5]	0	0%
Nitrogen, Total (mg/L)	0.08	45	0.4	0.3	0.1	0.8	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	48	-----	n.d.	n.d.	0.02	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	48	-----	0.02	n.d.	0.09	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	48	-----	n.d.	n.d.	0.02	-----	-----	-----
Sulfate (mg/L)	1	48	256	251	190	313	875[2,5], 500[2,7]	0	0%
Suspended Solids, Total (mg/L)	4	48	14	8	n.d.	90	53[1,5], 30[1,7]	3, 5	6%, 10%
Microcystin, Extracellular (ug/L)	0.1	24	-----	n.d.	n.d.	0.1	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat[F]	-----	24	-----	-----	-----	-----	D.O ≥ 6 mg/L W. Temp. ≤ 18.3°C	15	63%

n.d. = Not detected.

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

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

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

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

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

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur. A defined hypolimnion was monitored on 1 of the 8 occasions (i.e. 13%) that monthly depth profiles were measured from June through September. Measured water depths in this area of Lake Sharpe were < 12.5 meters.

(F) Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e. at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/L). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile.

Plate 8-3. Summary of monthly (May through September) water quality conditions monitored in Lake Sharpe in the Antelope Creek area (Site BBDLK1055DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	25	1420.4	1420.5	1419.3	1421.3	-----	-----	-----
Water Temperature (°C)	0.1	28	18.4	19.5	7.1	28.0	18.3[1,5]	15	54%
Hypolimnion Water Temperature (°C)[E]	0.1	0	-----	-----	-----	-----	18.3[1,5]	0	0%
Dissolved Oxygen (mg/L)	0.1	28	9.6	9.2	7.2	13.4	6[1,6,8], 7[1,6,8]	0	0%
Dissolved Oxygen (% Sat.)	0.1	28	105.2	107.2	73.0	132.6	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[E]	0.1	28	9.6	9.2	7.2	13.4	5[3,6]	0	0%
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	0	-----	-----	-----	-----	6[1,6,8]	0	0%
Specific Conductance (uS/cm)	1	28	1,061	851	427	2,462	-----	-----	-----
pH (S.U.)	0.1	28	8.3	8.4	7.8	8.8	6.5[1,2,6], 9.0[1,2,5], 9.5[4,5]	0	0%
Turbidity (NTUs)	1	28	59	39	n.d.	230	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	27	336	332	183	466	-----	-----	-----
Secchi Depth (M)	0.02	11	0.30	0.25	0.05	0.76	-----	-----	-----
Alkalinity, Total (mg/L)	7	25	166	167	126	188	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	25	4.9	4.1	2.8	12.8	-----	-----	-----
Chloride (mg/L)	1	15	38	18	12	118	175[1,5], 100[1,7], 438[2,5], 250[2,7]	0, 1 0, 0	0%, 7%, 0%, 0%
Chlorophyll *a* (ug/L) – Field Probe	1	23	8	6	n.d.	32	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	23	8	6	n.d.	32	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	25	37	27	15	142			
Dissolved Solids, Total (mg/L)	5	25	851	724	462	1,910	1,750[2,5], 1,000[2,7], 3,500[4,5], 2,000[4,7]	2, 7, 0, 0	8%, 28%, 0%, 0%
Nitrogen, Ammonia Total (mg/L)	0.02	25	-----	n.d.	n.d.	0.20	2.6 [1,5,9], 0.88 [1,7,9]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	25	0.66	0.4	0.2	1.5	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	25	-----	n.d.	n.d.	1.28	10[2,5]	0	0%
Nitrogen, Total (mg/L)	0.1	25	0.7	0.5	0.2	2.6	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	25	-----	n.d.	n.d.	0.11	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	25	0.08	0.06	n.d.	0.24	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	25	-----	n.d.	n.d.	0.08	-----	-----	-----
Sulfate (mg/L)	1	25	376	292	204	1,050	875[2,5], 500[2,7]	1, 5	4%, 20%
Suspended Solids, Total (mg/L)	4	25	78	52	14	255	53[1,5], 30[1,7]	12, 21	48%, 84%
Microcystin, Extracellular (ug/L)	0.1	25	-----	n.d.	n.d.	0.1	-----	-----	-----
Coldwater Permanent Fish Life Propagation Habitat[F]	-----	24	-----	-----	-----	-----	D.O ≥ 6 mg/L W. Temp. ≤ 18.3°C	15	63%

n.d. = Not detected.

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

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

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

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

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur. A defined hypolimnion was not monitored on any of the 8 occasions that monthly depth profiles were measured from June through September. This is attributed to the shallower water depths (<5 meters) in this area of Lake Sharpe.

(F) Evaluates the occurrence of Coldwater Permanent Fish Life Propagation habitat (i.e. at least a 1-meter layer of water with a temperature ≤ 18.3°C and dissolved oxygen ≥ 6 mg/L). The "No. of Obs." is the number of monthly water column depth-profiles measured. The "No. of WQS Exceedances" is the number of occurrences where no Coldwater Permanent Fish Life Propagation habitat was present anywhere within the measured water column depth-profile.

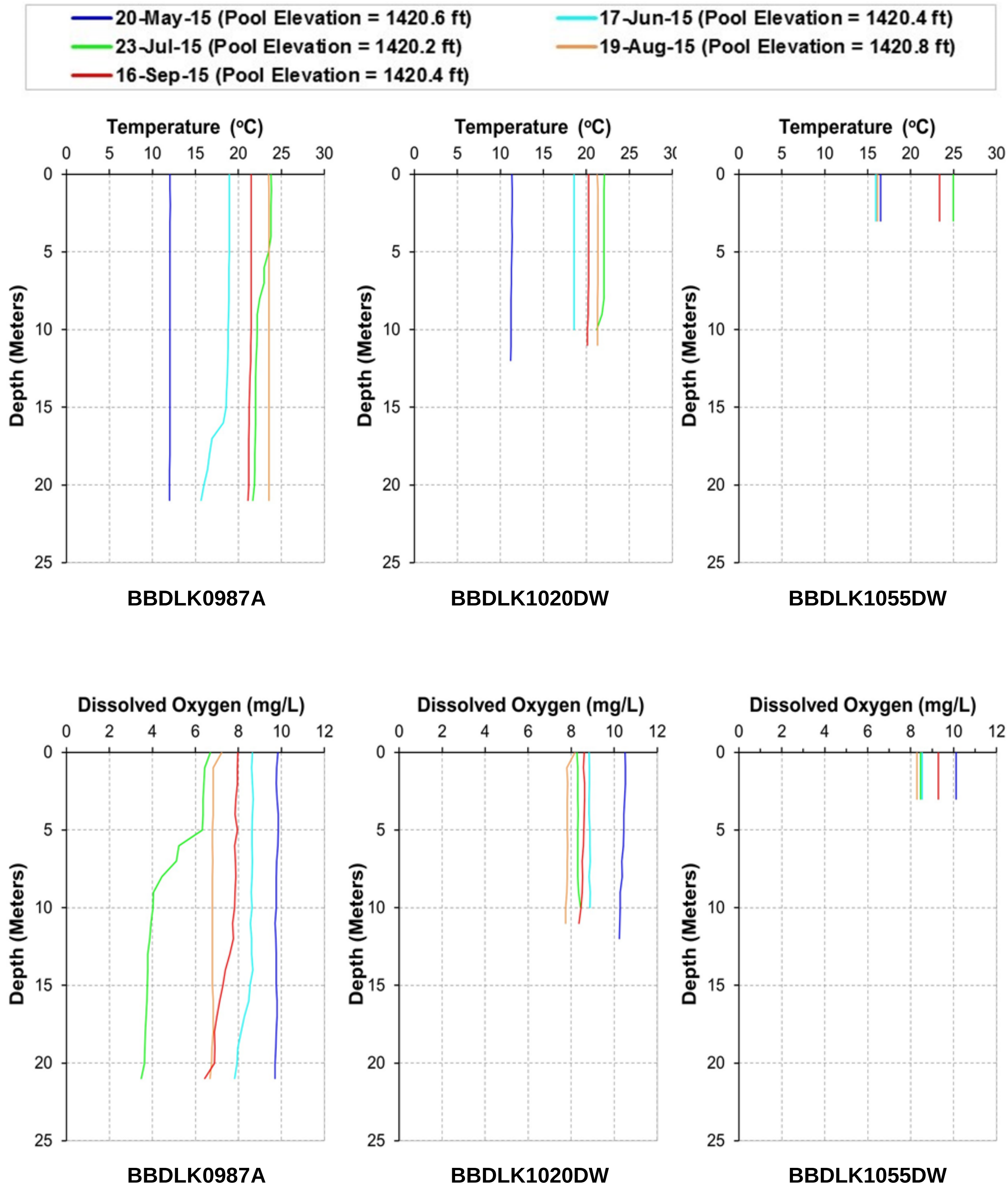


Plate 8-4. Depth-profile plots of temperature and dissolved oxygen conditions of Lake Sharpe measured at sites BBDLK0987A, BBDLK1020DW, and BBDLK1055DW during 2015**.**

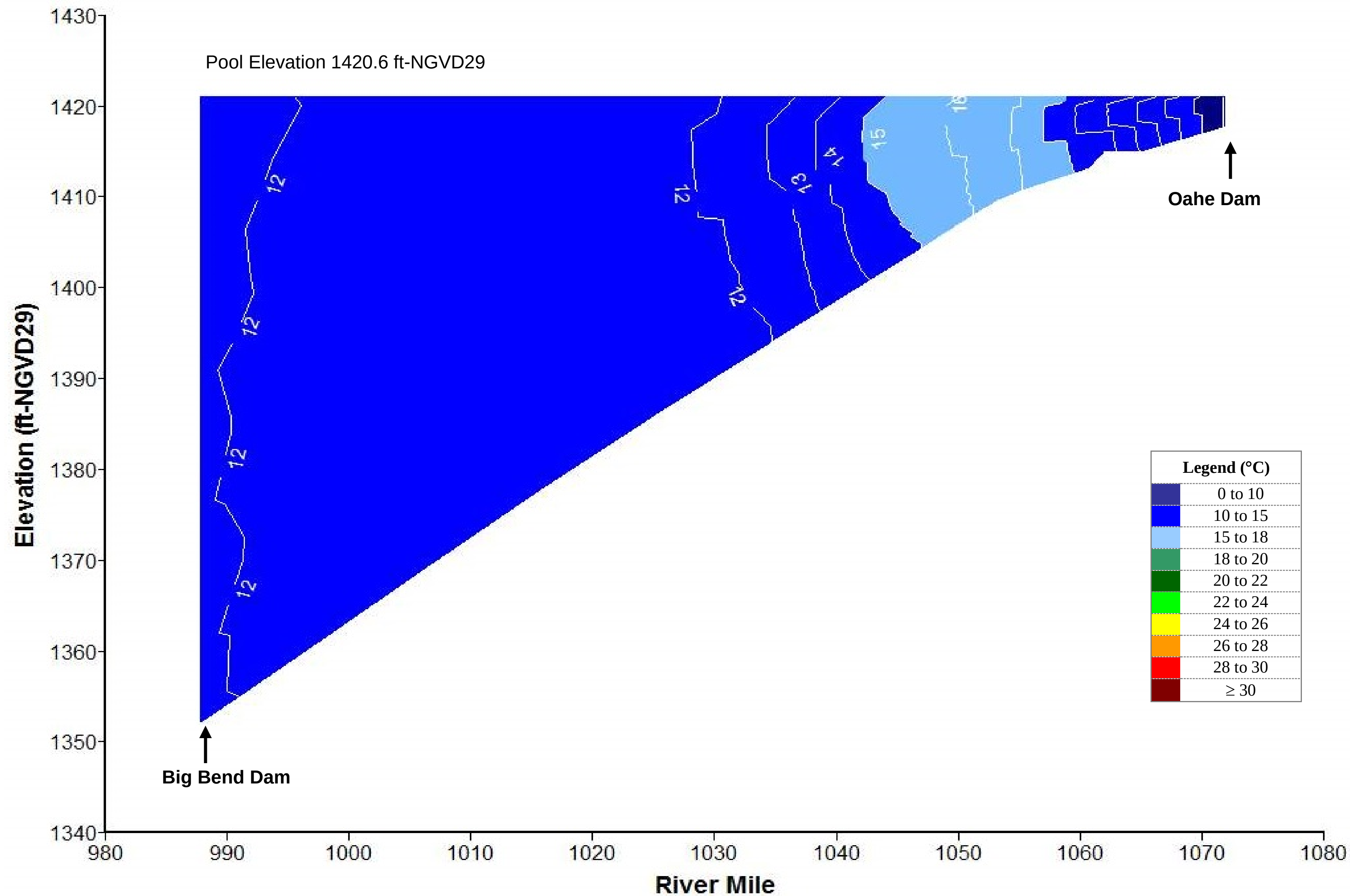


Plate 8-5. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW and OAHPP1 on May 20, 2015.

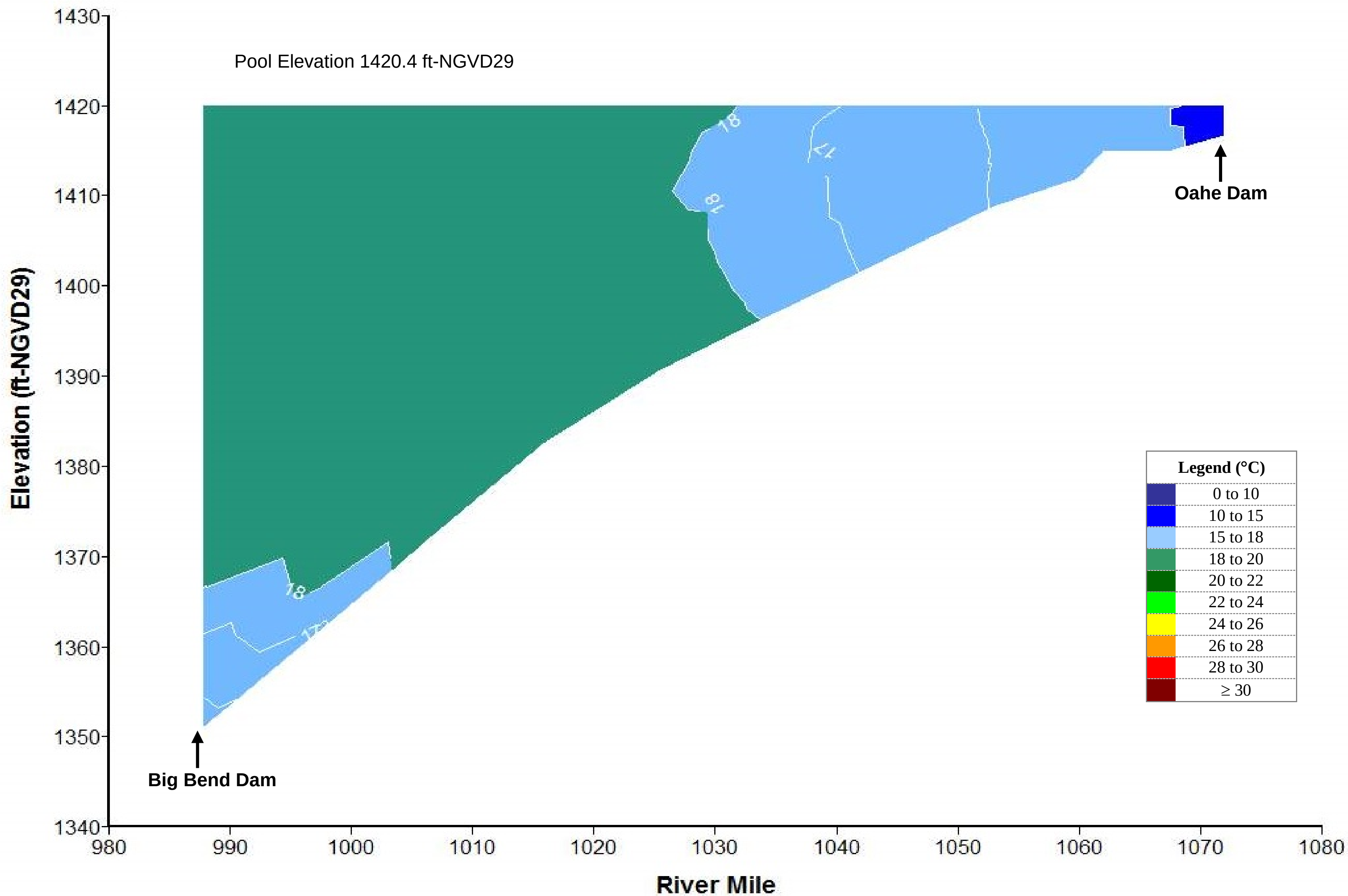


Plate 8-6. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW and OAHPP1 on June 17, 2015.

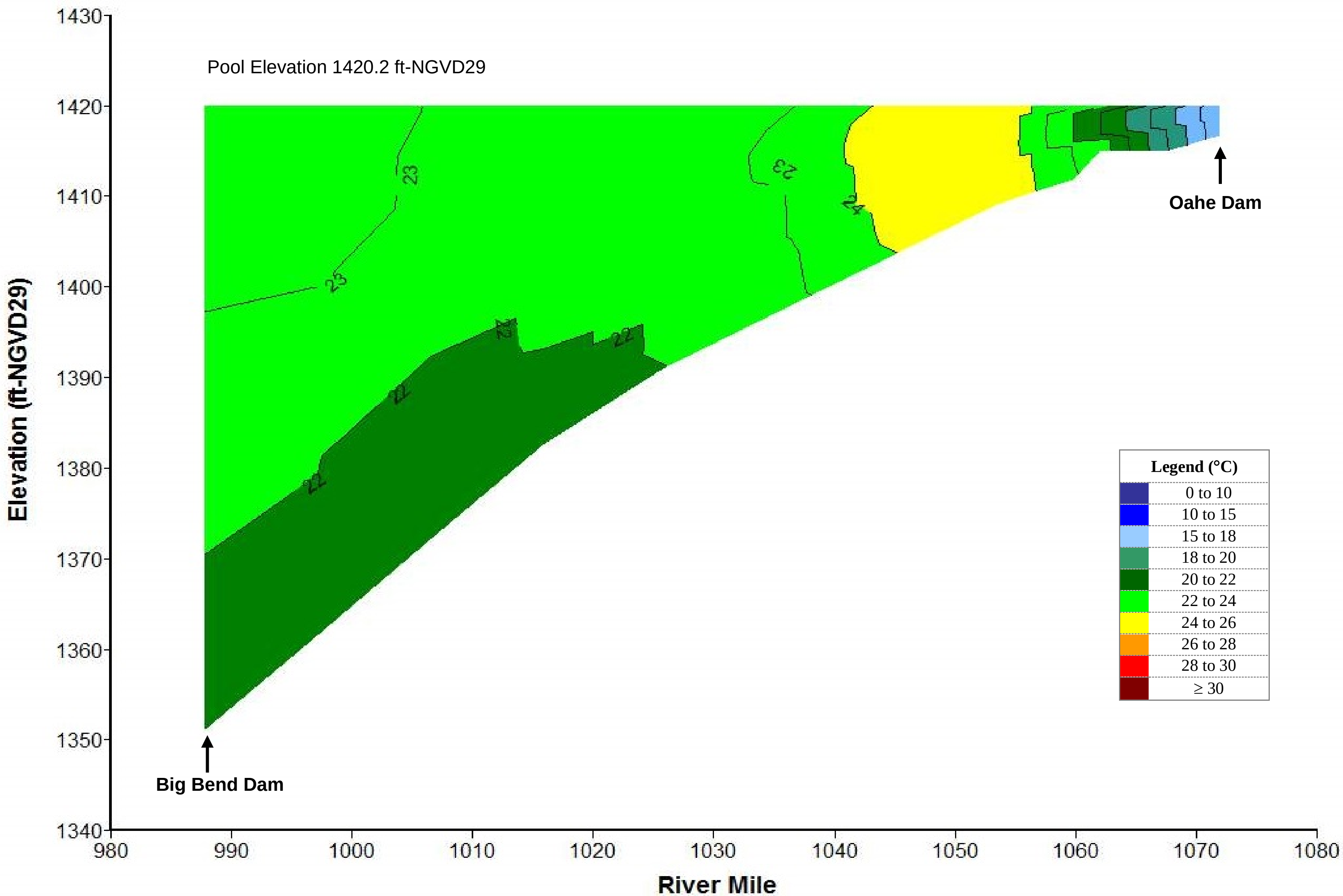


Plate 8-7. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW and OAHPP1 on July 23, 2015.

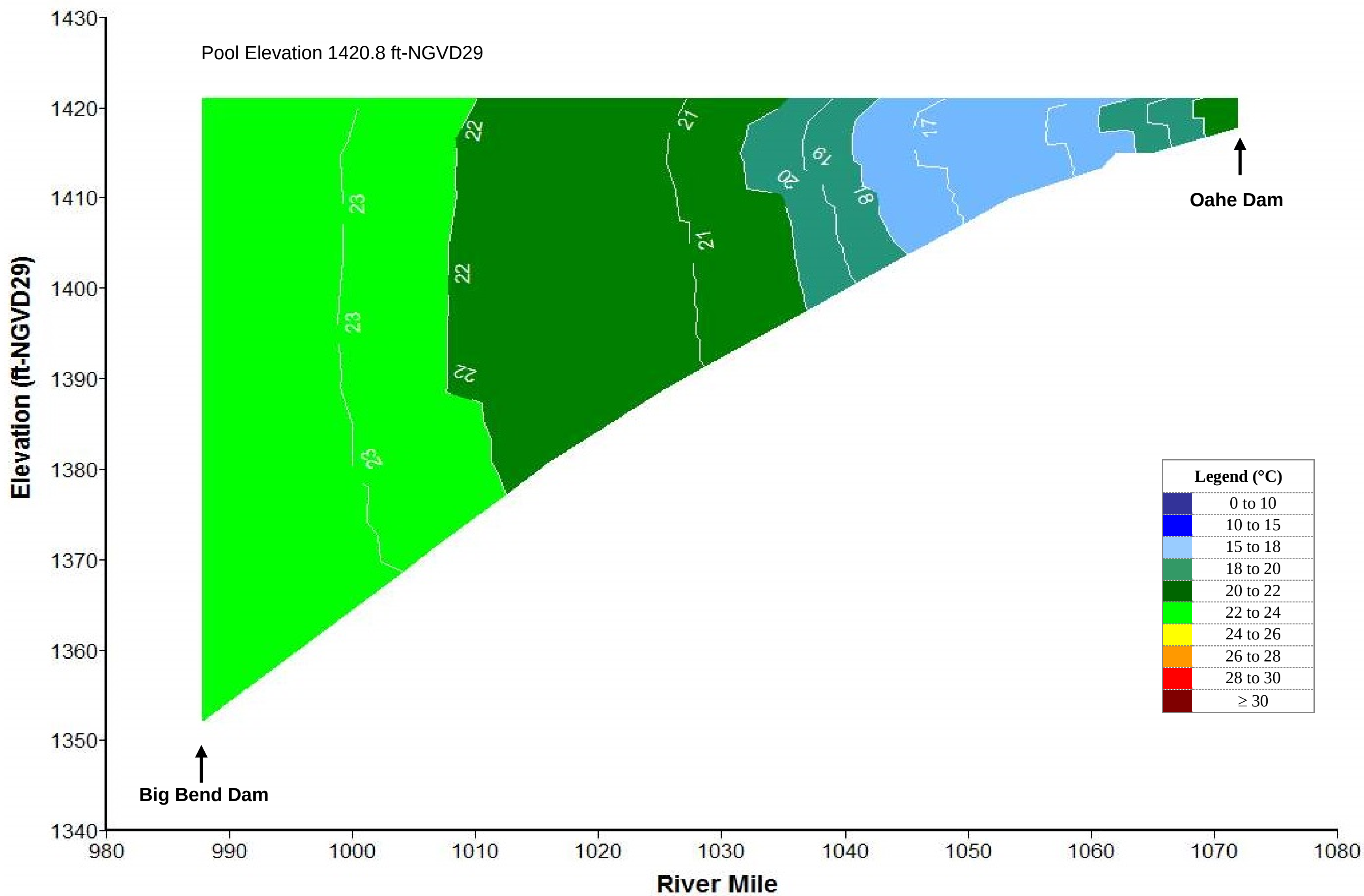


Plate 8-8. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW and OAHPP1 on August 19, 2015**.**

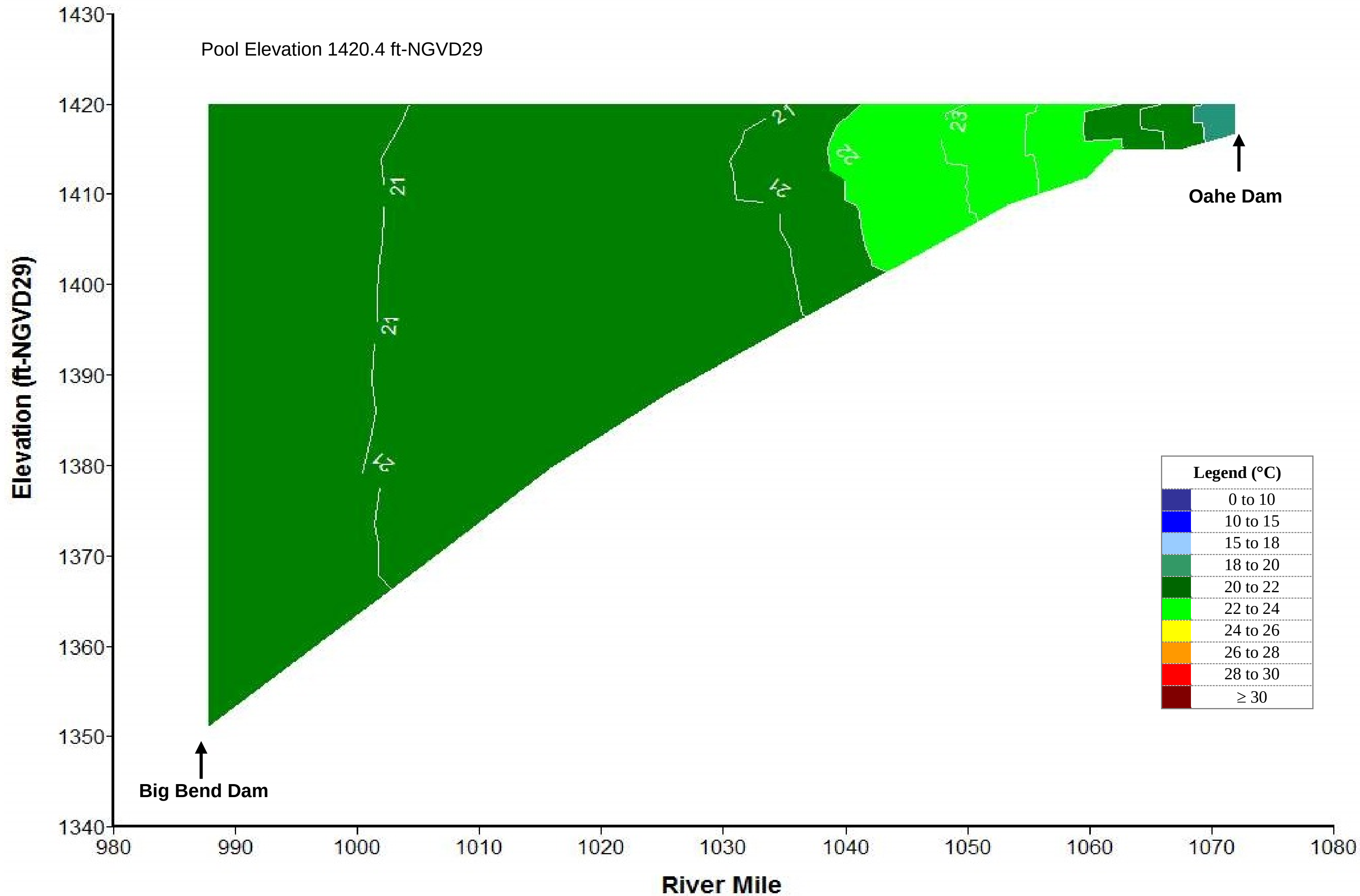


Plate 8-9. Longitudinal water temperature (°C) contour plot of Lake Sharpe based on depth-profile water temperatures measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW and OAHPP1 on September 16, 2015.

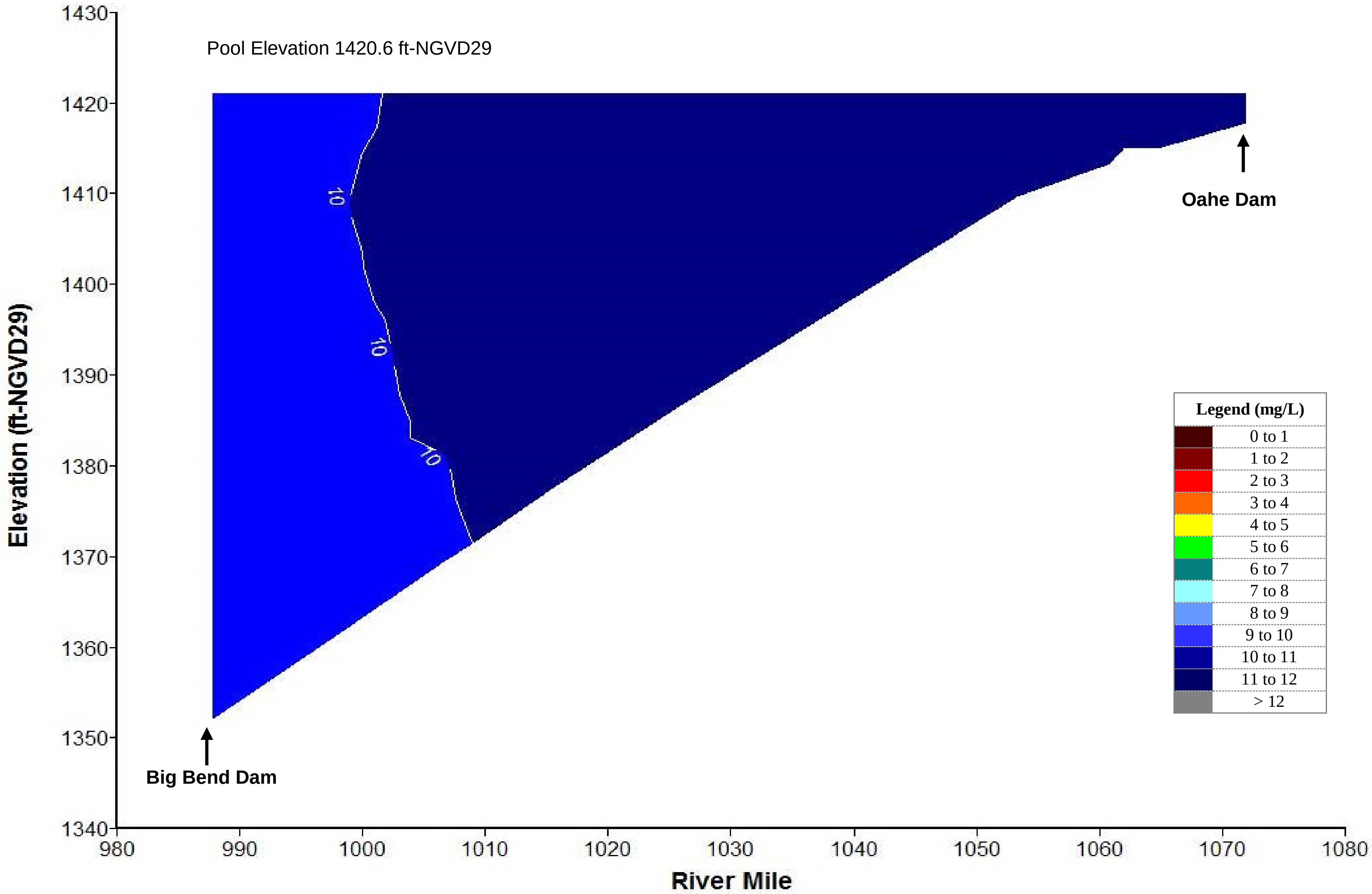


Plate 8-10. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW and OAHPP1 on May 20, 2015.

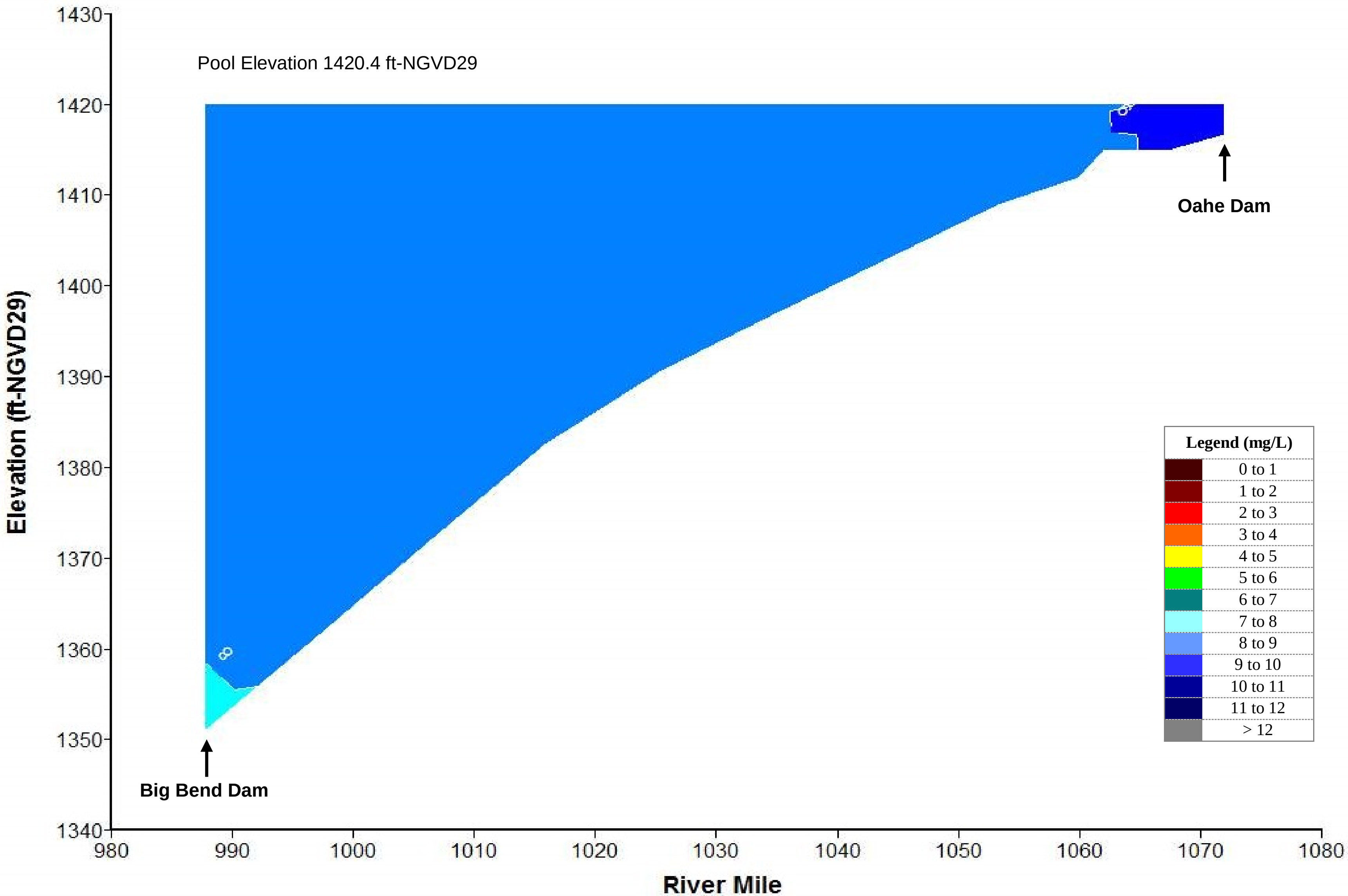


Plate 8-11. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW and OAHPP1 on June 17, 2015.

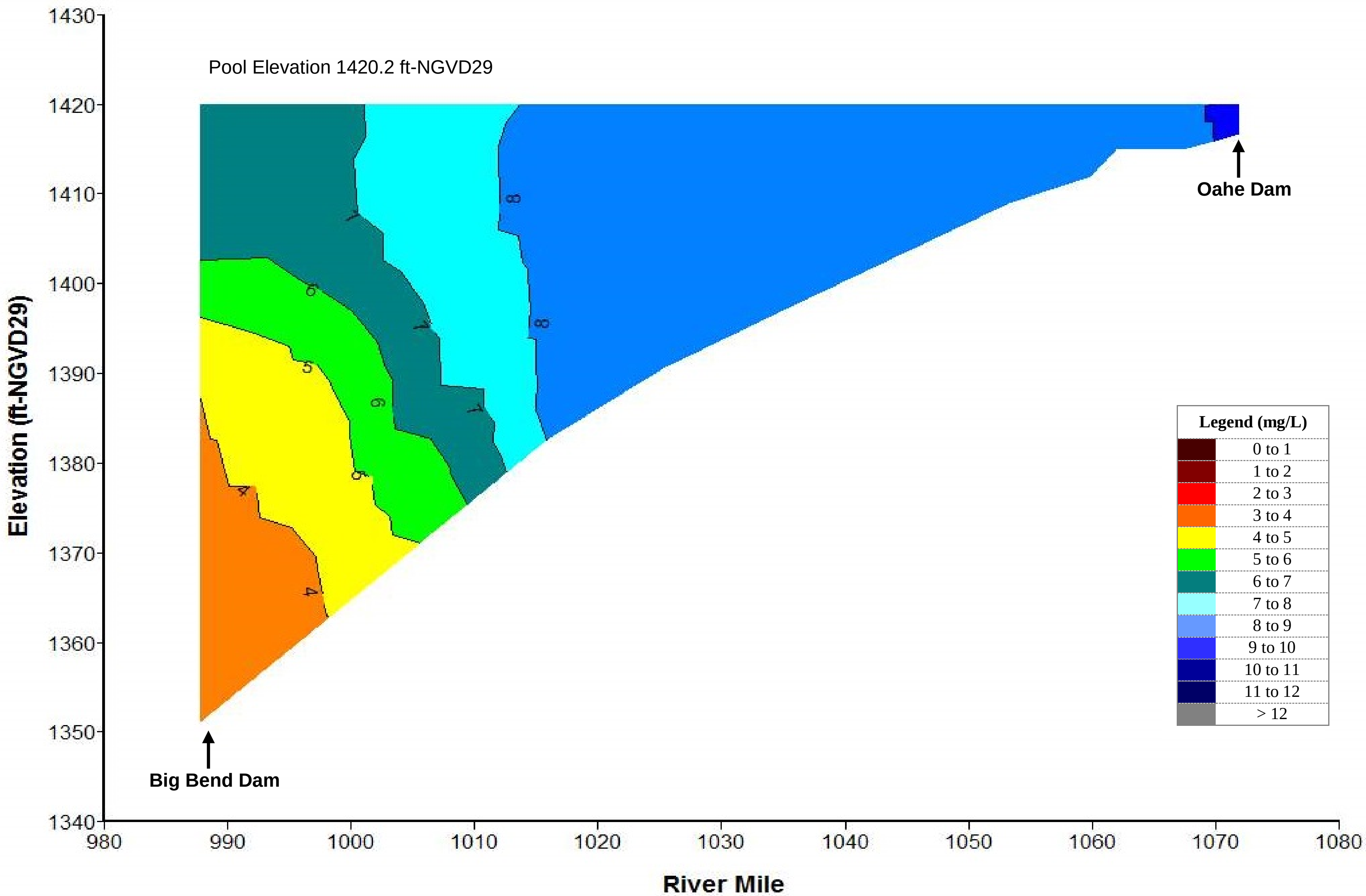


Plate 8-12. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW and OAHPP1 on July 23, 2015.

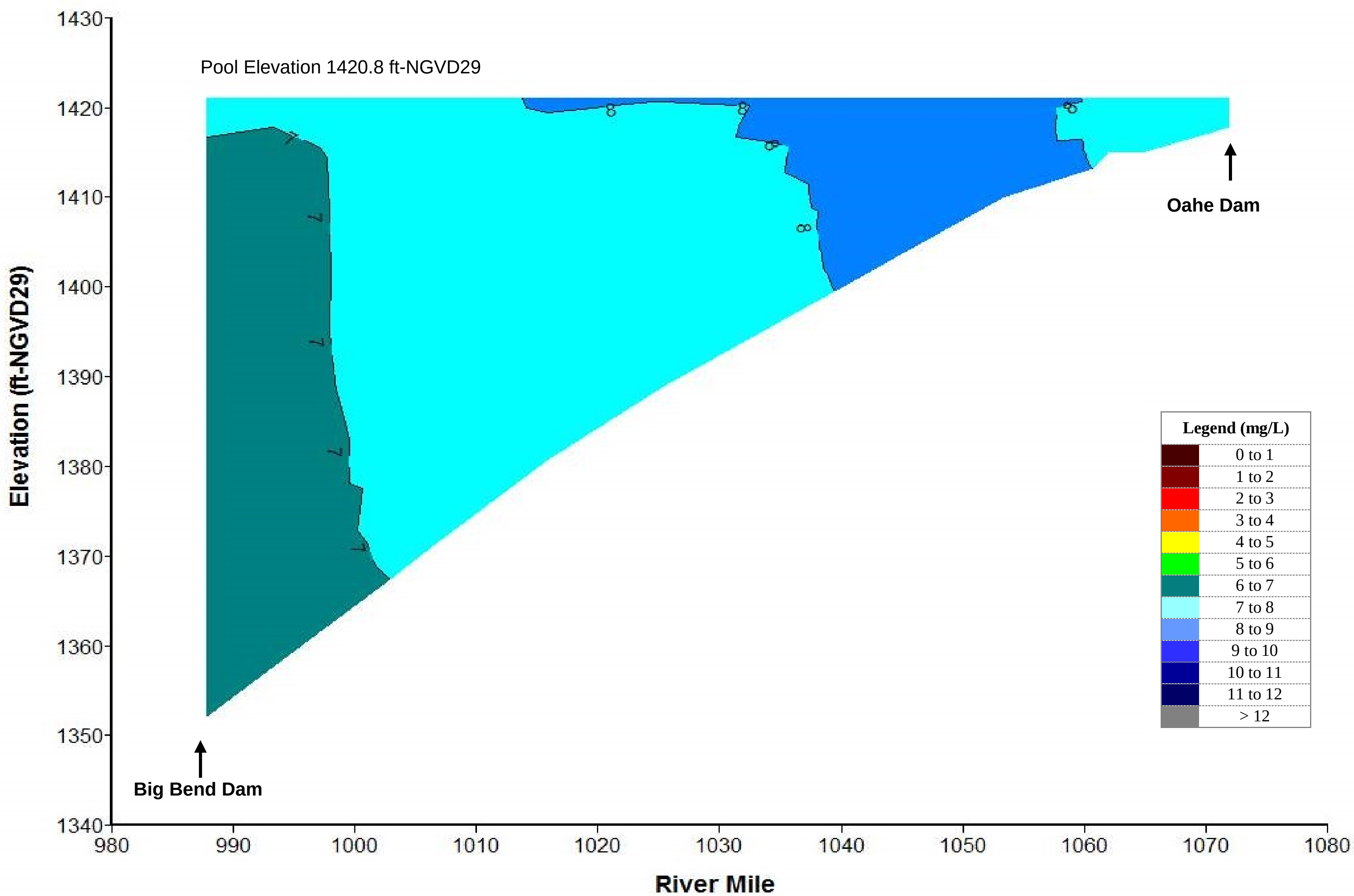


Plate 8-13. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW and OAHPP1 on August 19, 2015.

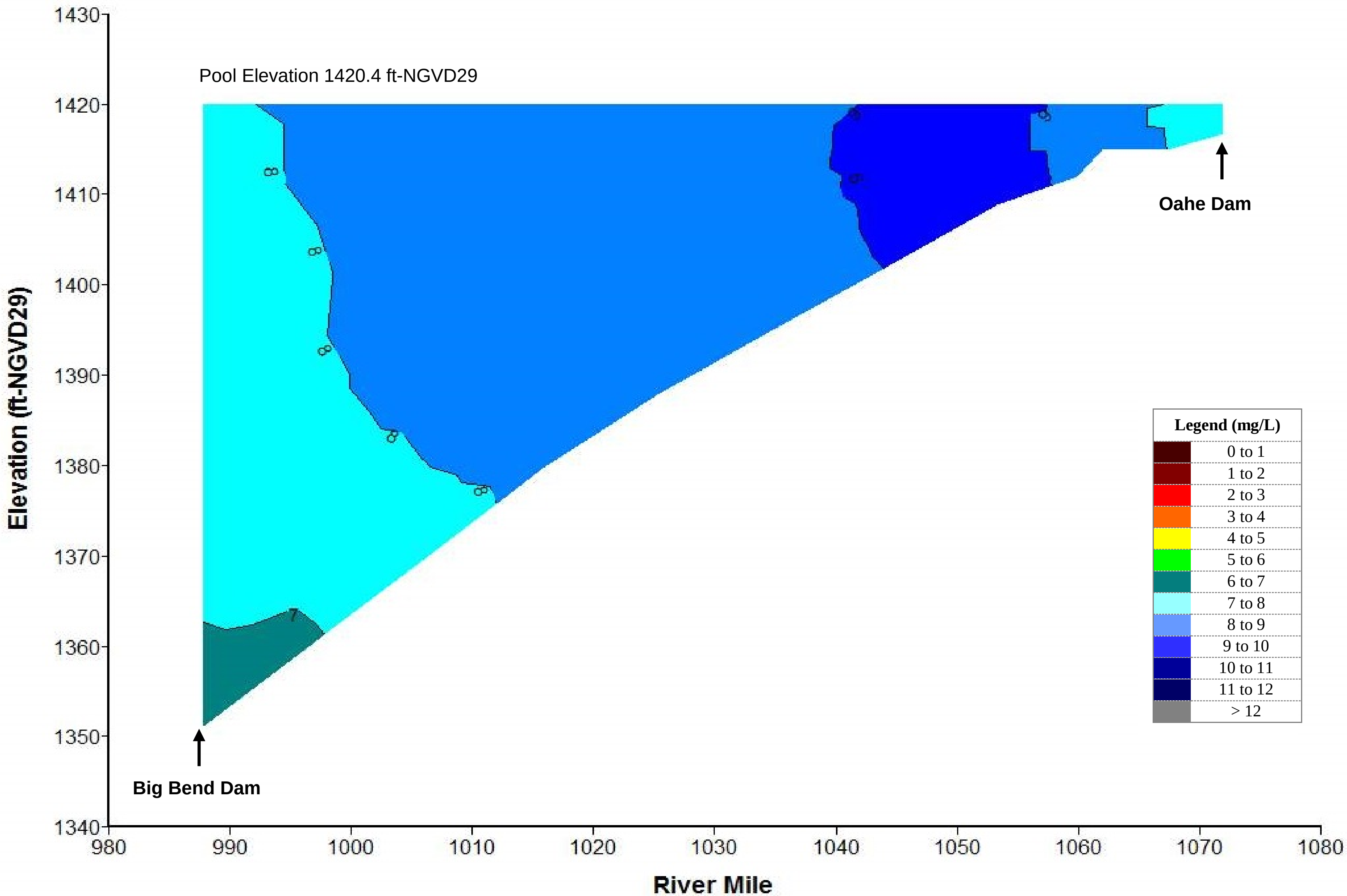


Plate 8-14. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Sharpe based on depth-profile dissolved oxygen concentrations measured at sites BBDLK0987A, BBDLK1020DW, BBDLK1055DW and OAHPP1 on September 16, 2015.

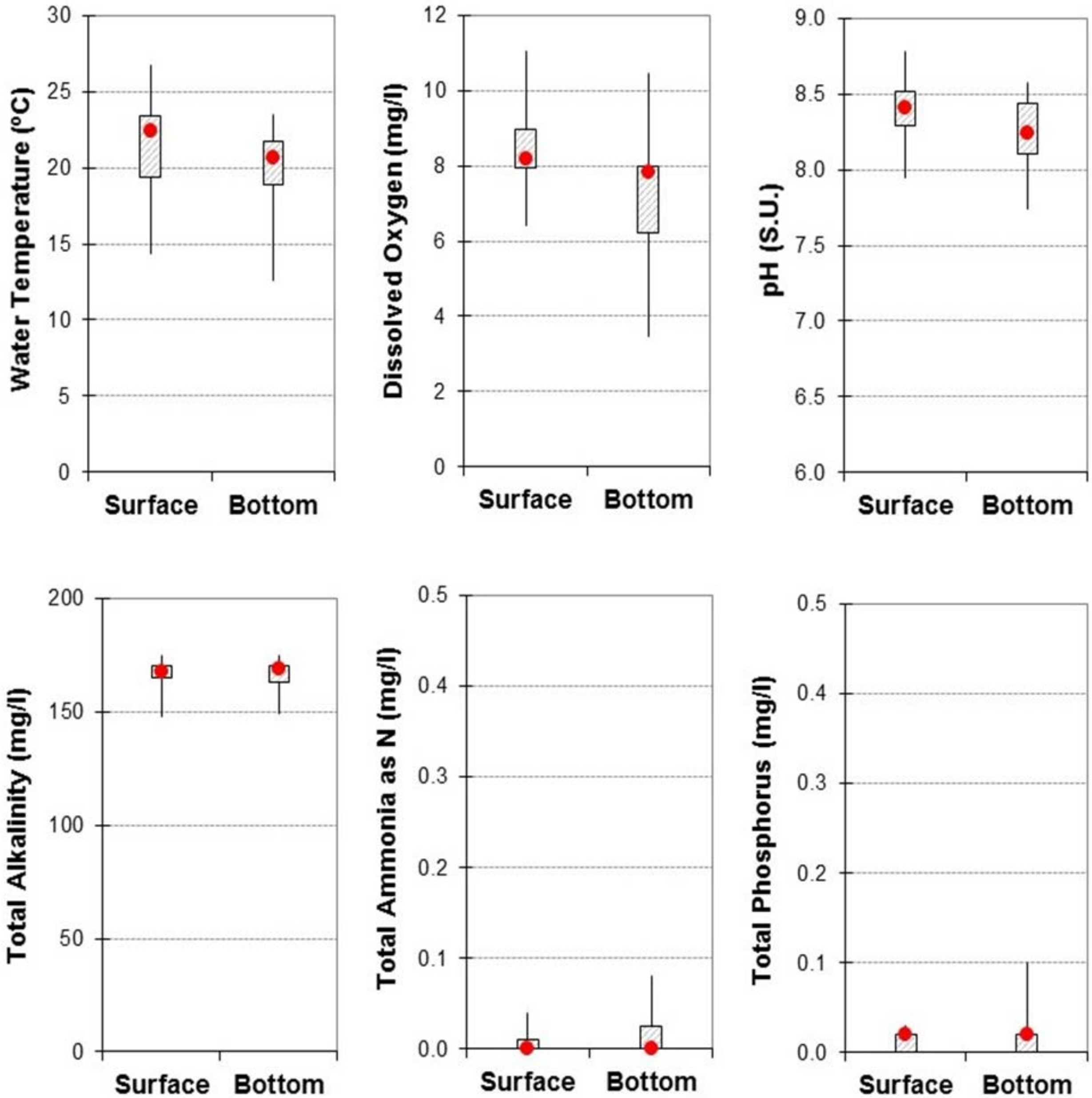


Plate 8-15. Box plots comparing paired surface and bottom water temperature, dissolved oxygen, pH, alkalinity, total ammonia nitrogen, and total phosphorus measurements taken in Lake Sharpe at site BBDLK0987A during the summer months of 2011 through 2015.
(Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

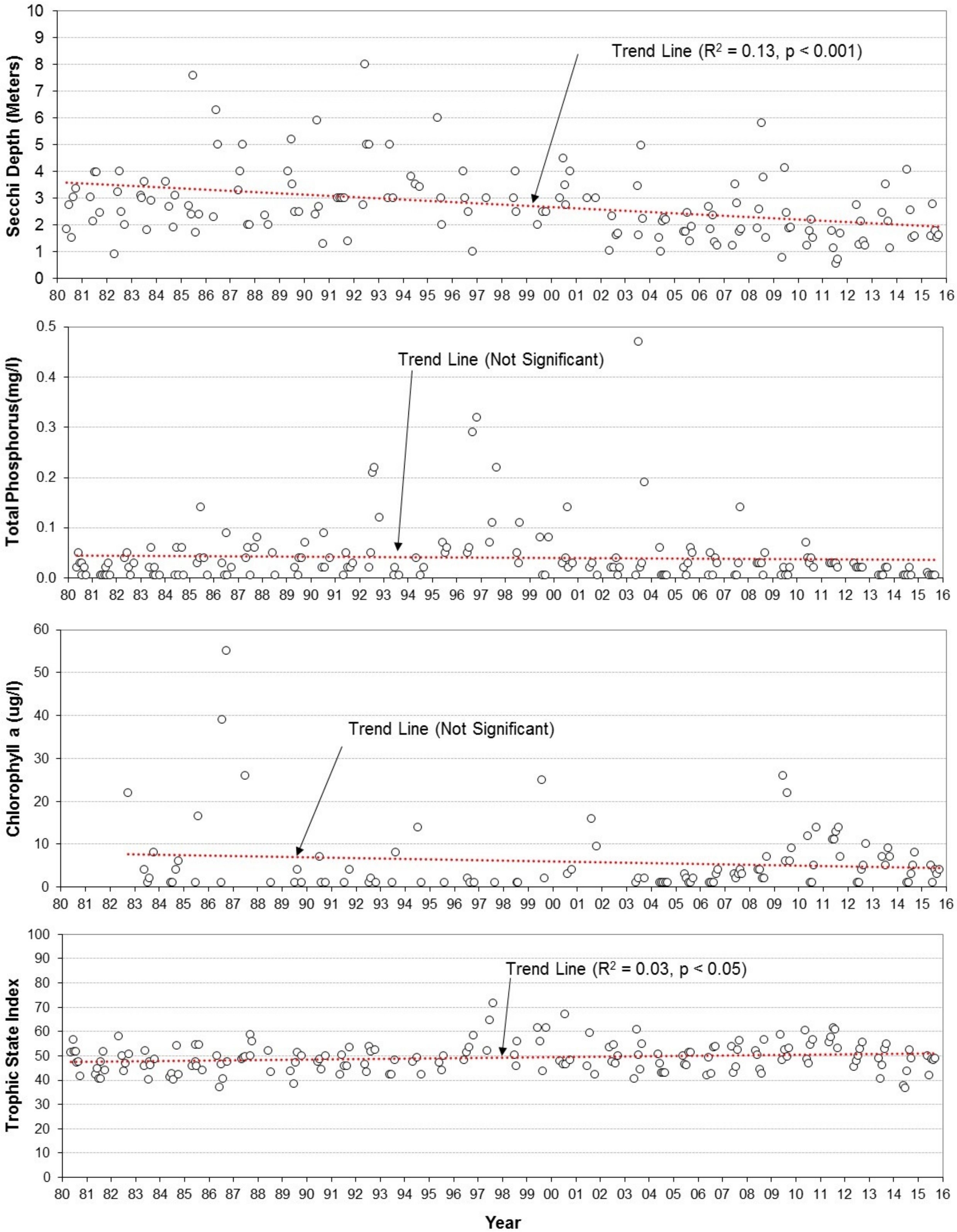


Plate 8-16. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Lake Sharpe at the near-dam, ambient site (i.e. site BBDLK0987A) over the 36-year period of 1980 through 2015.

Plate 8-17. Summary of water quality conditions monitored on water discharged through Big Bend Dam powerplant (i.e. site BBDPP1) during the 5-year period of 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit(A)	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Dam Discharge, Powerplant (Mean Daily, cfs)	1	48	31,408	28,650	2,600	78,100	-----	-----	-----
Dam Discharge, Powerplant + Spillway (Mean Daily, cfs)	1	48	35,383	28,650	2,600	145,900	-----	-----	-----
Water Temperature (°C)	0.1	48	14.5	14.9	1.2	24.9	27(1,2)	0	0%
Dissolved Oxygen (mg/L)	0.1	48	9.5	9.4	3.1	14.4	5(1,3)	1	2%
Dissolved Oxygen (% Sat.)	0.1	48	93.1	94.4	36.9	114.0	-----	-----	-----
pH (S.U.)	0.1	46	8.3	8.3	7.2	9.1	6.5(1,3), 9.0(1,2)	0, 1	0%, 3%
Specific Conductance (uS/cm)	1	48	816	815	642	967	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	46	352	342	162	714	-----	-----	-----
Turbidity (NTU)	1	47	31	4	n.d.	708	-----	-----	-----
Alkalinity, Total (mg/L)	7	48	164	168	116	225	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	48	4.5	4.2	2.7	13.8	-----	-----	-----
Chloride, Dissolved (mg/L)	1	23	12	12	11	14	438(2,4), 250(2,6)	0	0%
Colorized Dissolved Organic Matter (ug/L)	4	39	24	23	15	42	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	48	594	597	378	786	1,750(2,4), 1,000(2,6), 3,500(3,4), 2,000(3,6)	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	48	-----	n.d.	n.d.	0.15	4.7 (1,4,7), 1.4 (1,6,7)	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	47	0.5	0.4	n.d.	3.4	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	48	-----	0.08	n.d.	1.00	10(2,4)	0	0%
Nitrogen, Total (mg/L)	0.1	47	0.6	0.5	n.d.	3.4	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	48	-----	n.d.	n.d.	0.06	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	47	-----	0.02	n.d.	1.77	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	48	-----	n.d.	n.d.	0.06	-----	-----	-----
Sulfate (mg/L)	1	48	248	245	187	314	875(2,4), 500(2,6)	0	0%
Suspended Solids, Total (mg/L)	4	46	-----	6	n.d.	73	158(1,4), 90(1,6)	0	0%

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

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

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

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

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

Plate 8-18. Summary of annual metals and pesticide levels monitored on water discharged through Big Bend Dam (i.e. site BBDPP1) during the 5-year period of 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[B]	Median	Min.	Max.	State WQS Criteria[C]	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/L)	40	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Aluminum, Total (ug/L)	40	5	437	420	180	745	-----	-----	-----
Antimony, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Antimony, Total (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	5.6[3]	0	0%
Arsenic, Dissolved (ug/L)	1	5	1	2	n.d.	2	340[1], 150[2]	0, 0	0%, 0%
Arsenic, Total (ug/L)	1	5	2	2	1	2	0.018[3]	5	100%
Barium, Dissolved (ug/L)	5	5	44	45	37	49	-----	-----	-----
Barium, Total (ug/L)	5	5	52	51	49	54	-----	-----	-----
Beryllium, Dissolved (ug/L)	2	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Beryllium, Total (ug/L)	2	5	-----	n.d.	n.d.	n.d.	4[3]	0	0%
Cadmium, Dissolved (ug/L)	0.2	5	-----	n.d.	n.d.	n.d.	4.5[1], 0.44[2]	0	0%
Cadmium, Total (ug/L)	0.2	5	-----	n.d.	n.d.	n.d.	5[3]	0	0%
Calcium, Dissolved (mg/L)	0.01	5	56.3	53.2	53.0	63.9	-----	-----	-----
Chromium, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	1,123[1], 146[2]	0	0%
Chromium, Total (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Copper, Dissolved (ug/L)	6	5	-----	n.d.	n.d.	n.d.	29[1], 18[2],	0	0%
Copper, Total (ug/L)	6	5	-----	n.d.	n.d.	6	1,300[3]	0	0%
Hardness, Dissolved (mg/L)	0.4	5	235	229	200	275	-----	-----	-----
Iron, Dissolved (ug/L)	7	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Iron, Total (ug/L)	7	5	340	330	150	543	-----	-----	-----
Lead, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	0.6	157[1], 6.1[2]	0	0%
Lead, Total (ug/L)	0.5	5	1.5	0.6	n.d.	6.0	-----	-----	-----
Magnesium, Dissolved (mg/L)	0.01	5	23.8	23.6	18.5	29.0	-----	-----	-----
Manganese, Dissolved (ug/L)	2	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Manganese, Total (ug/L)	2	5	146	80	45	315	-----	-----	-----
Mercury, Dissolved (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[1]	0	0%
Mercury, Total (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[2], 0.05[3]	0	0%
Nickel, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	943[1], 105[2]	0	0%
Nickel, Total (ug/L)	10	5	-----	n.d.	n.d.	n.d.	610[3]	0	0%
Selenium, Dissolved (ug/L)	1	5	2	1	n.d.	4			
Selenium, Total (ug/L)	1	5	1	2	n.d.	4	4.6[2], 170[3]	0	0%
Silver, Dissolved (ug/L)	1	5	-----	n.d.	n.d.	n.d.	14[1]	0	0%
Silver, Total (ug/L)	1	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Sodium, Dissolved (mg/L)	0.01	4	84.4	88.0	63.5	98.3	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Total (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	0.24[3]	b.d.	b.d.
Zinc, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	236[1,2]	0	0%
Zinc, Total (ug/L)	10	5	17	10	n.d.	40	50	0	0%
Pesticide Scan (ug/L)[D]	0.05[E]	5	-----	n.d.	n.d.	n.d.	-----	-----	-----

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

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

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

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

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

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

(3) Criterion for the protection of human health.

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

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

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

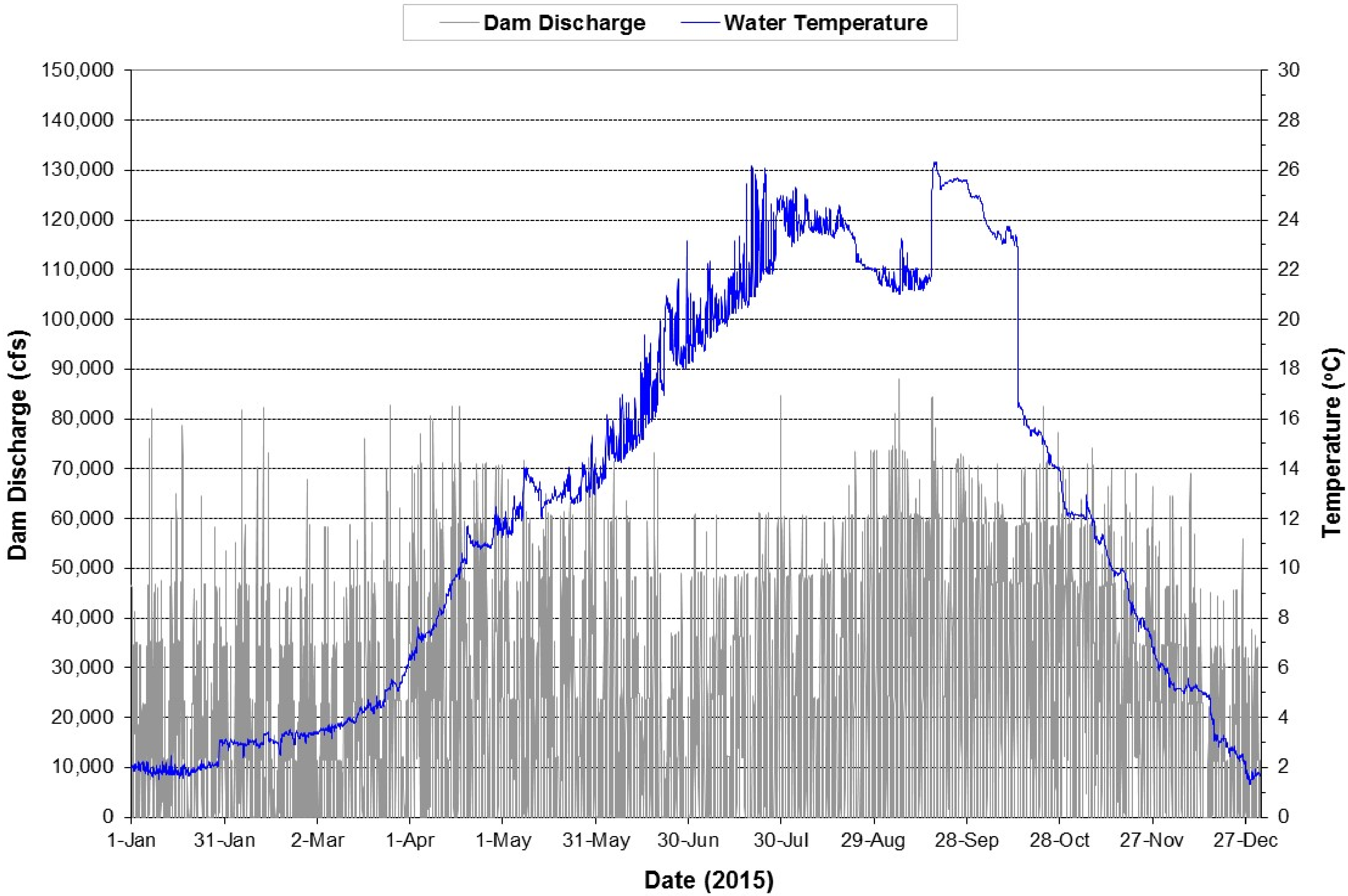


Plate 8-19. Hourly discharge and water temperature monitored at the Big Bend powerplant on water discharged through the dam during 2015.

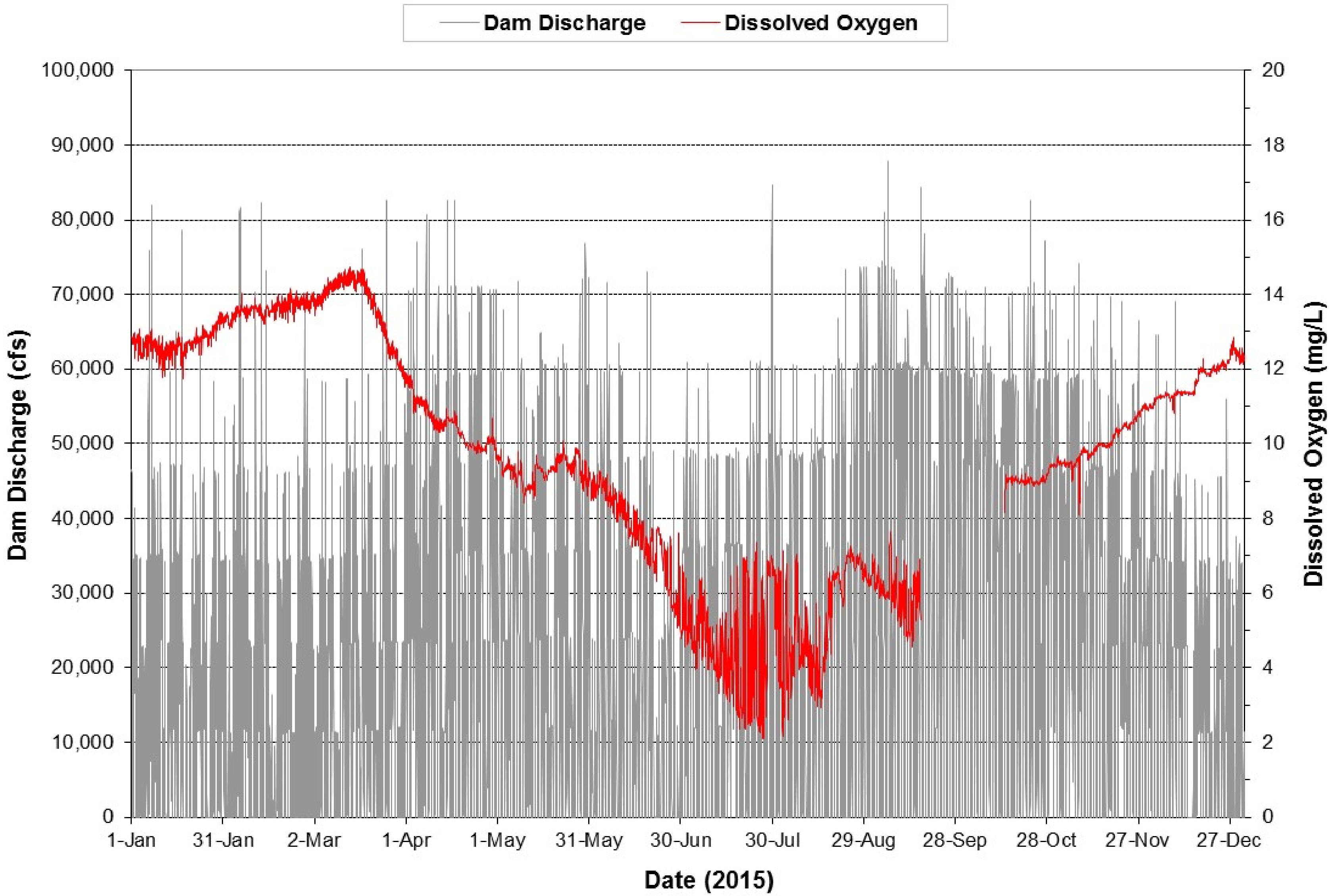


Plate 8-20. Hourly discharge and dissolved oxygen concentrations monitored at the Big Bend powerplant on water discharged through the dam during 2015. (Note: Gaps in dissolved oxygen plot represents periods when monitoring equipment was not operational.

9 FORT RANDALL PROJECT

9.1 BACKGROUND INFORMATION

9.1.1 PROJECT OVERVIEW

Fort Randall Dam is located on the Missouri River at RM 880.0 in southeastern South Dakota, 50 miles southwest of Mitchell, SD. The closing of Fort Randall Dam in 1952 resulted in the formation of Fort Randall Reservoir (Lake Francis Case). When full, the reservoir is 107 miles long, covers 102,000 acres, and has 540 miles of shoreline. Table 9-1 summarizes how the surface area, volume, mean depth, and retention time of Lake Francis Case vary with pool elevations. The reservoir at the end of December 2015 was at pool elevation 1339.8 ft-NGVD29. This is 10.2 feet below the top of the Carryover Multiple Use Zone (1350.0 ft-NGVD29). A "low" pool level is typical for Lake Francis Case 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. Major inflows to Lake Francis Case are the Missouri River and White River. Figure 9-1 shows a schematic drawing and photo of the outlet works at Fort Randall Dam.

Table 9-1. Surface area, volume, mean depth, and retention time of Lake Francis Case at different pool elevations based on 2011 bathymetric survey.

Elevation (Feet-NGVD29)	Surface Area (Acres)	Volume (Acre-Feet)	Mean Depth (Feet)*	Retention Time (Years)**
1370	98,323	4,791,967	48.7	0.263
1365	94,462	4,309,618	45.6	0.237
1360	89,779	3,849,085	42.9	0.212
1355	85,821	3,407,960	39.7	0.187
1350	76,206	3,000,732	39.4	0.165
1345	67,271	2,642,271	39.3	0.145
1340	57,772	2,329,032	40.3	0.128
1335	47,798	2,067,079	43.2	0.114
1330	42,615	1,842,451	43.2	0.101
1325	36,203	1,647,479	45.5	0.091
1320	36,100	1,469,353	40.7	0.081
1315	35,513	1,289,057	36.3	0.071
1310	32,744	1,117,544	34.1	0.061
1305	30,019	961,381	32.0	0.053
1300	28,936	814,716	28.2	0.045
1295	27,866	671,953	24.1	0.037
1290	25,134	538,898	21.4	0.030

Average Annual Inflow (1967 through 2015) = 18.449 Million Acre-Feet.
Average Annual Outflow: (1967 through 2015) = 18.189 Million Acre-Feet.
* Mean Depth = Volume ÷ Surface Area.
** Retention Time = Volume ÷ Average Annual Outflow.
Note: Exclusive Flood Control Zone (elev. 1375-1365 ft-NGVD29), Annual Flood Control and Multiple Use Zone (elev. 1365-1350 ft-NGVD29), Carryover Multiple Use Zone (1350-1320 ft-NGVD29), and Permanent Pool Zone (elev. 1320-1227 ft-NGVD29). All elevations are in the NGVD 29 datum.

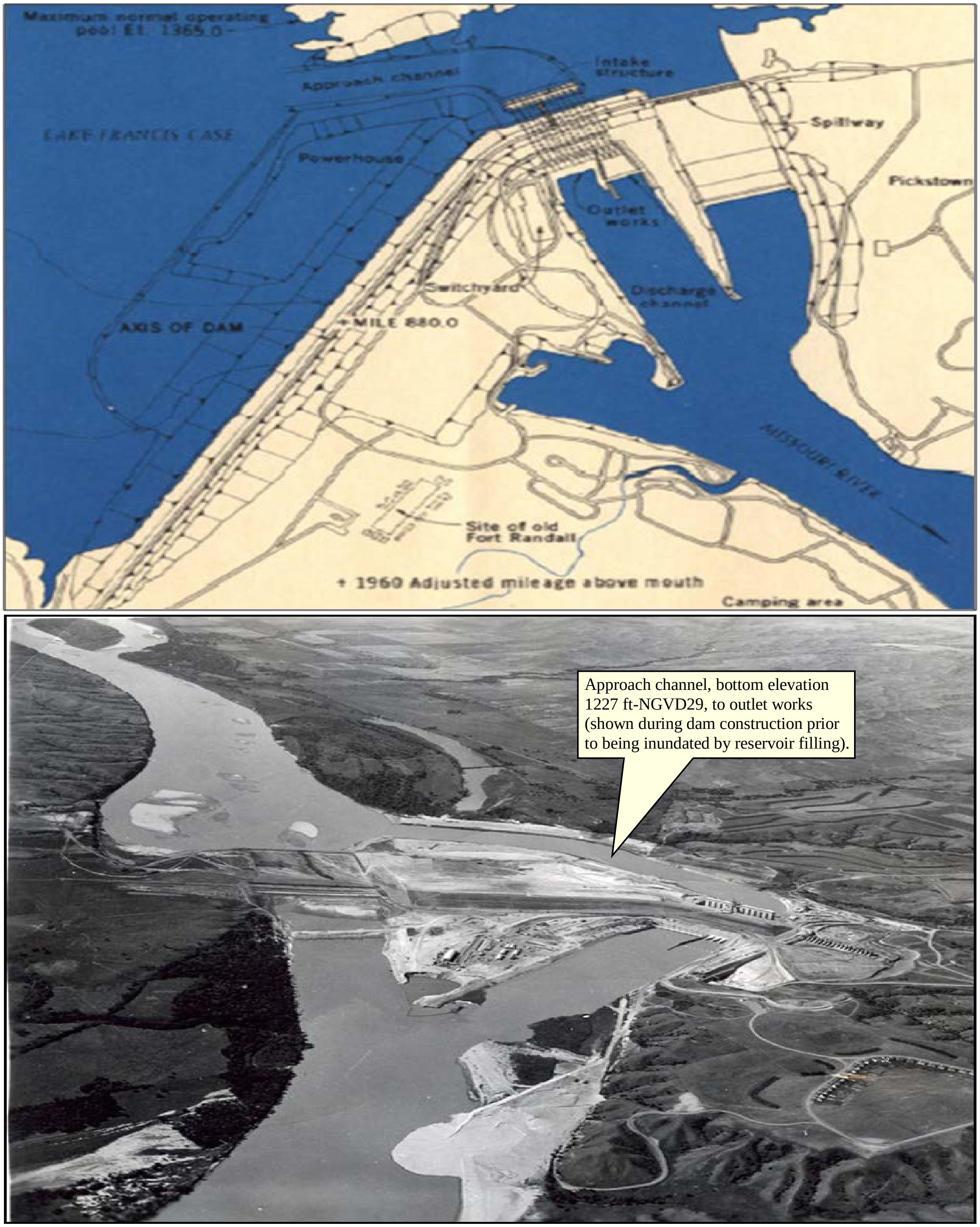


Figure 9-1. Schematic drawing and photo of outlet works at Fort Randall Dam.

Lake Francis Case was authorized for the purposes of flood control, recreation, fish and wildlife, hydroelectric power production, water supply, water quality, navigation, and irrigation. Habitat for two endangered species, pallid sturgeon and interior least tern, and one threatened species, piping plover, occur within the project area. Five surface water intakes are located on Lake Sharpe: 1) Chamberlain, SD (RM967); 2) Aurora-Brule Rural Water System (RM966 – Pukwana, Kimball, White Lake, Stickney, Plankinton, Gann Valley, Aurora Center, SD, and approximately 1,000 farms); 3) Oacoma, SD (RM967); and 4 and 5) Randall Community Water District - Platte and Pickstown (RM912 and RM880 – Pickstown, Davidson, Charles Mix, and Douglas, SD). The reservoir is an important recreational resource and a major visitor destination in South Dakota.

Water discharged through Fort Randall Dam for power production is withdrawn from Lake Francis Case at elevation 1229 ft-NGVD29, approximately 2 feet above the reservoir bottom. Figure 9-2 plots the midnight pool elevation of Lake Sharpe and the mean daily discharge of Fort Randall Dam over the 5-year period 2011 through 2015. The extreme discharges in 2011 reflect additional releases made through the spillway and flood tunnels to manage the high inflows and flood conditions during 2011.

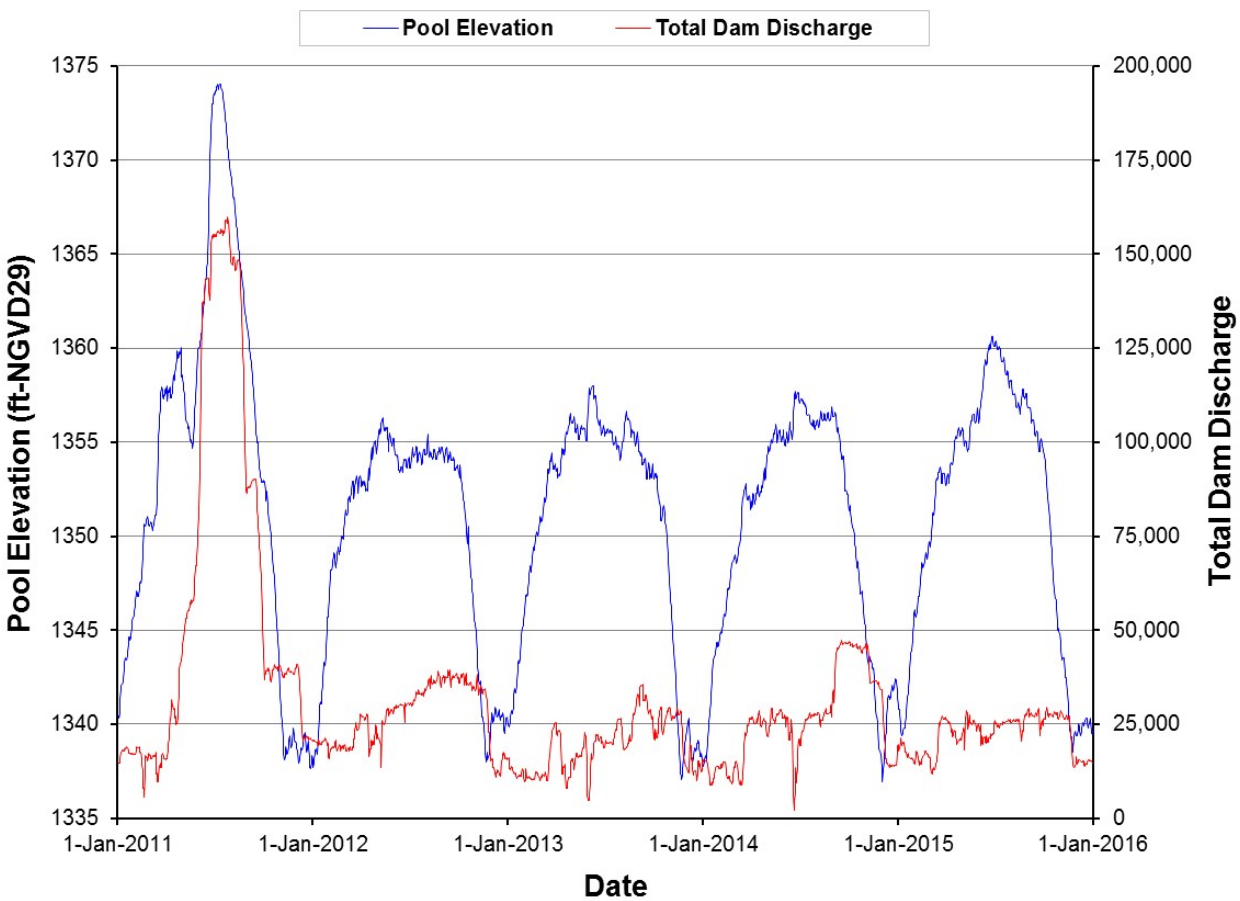


Figure 9-2. Lake Francis Case midnight pool elevation and the mean daily discharge of Fort Randall Dam over the 5-year period 2011 through 2015.

9.1.2 WATER QUALITY STANDARDS CLASSIFICATION AND SECTION 303(D) LISTINGS

9.1.2.1 Lake Francis Case

South Dakota has classified the Missouri River impoundments within the State as flowing streams and not reservoirs (South Dakota Administrative Rules 74:51:01:43). The State of South Dakota has designated the following water quality-dependent beneficial uses for Lake Francis Case 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. The State of South Dakota has not placed Lake Francis Case on the State's Section 303(d) list of impaired waters and has not issued a fish consumption advisory for the reservoir.

9.1.2.2 Fort Randall Dam Tailwaters

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

9.1.2.3 Ambient Water Quality Monitoring

The District has monitored water quality conditions at the Fort Randall Project since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow to and outflow from the reservoir. The water quality conditions of the Big Bend Dam discharge are taken to represent the inflow water quality conditions of the Missouri River to Lake Francis Case. Figure 9-3 shows the location of sites at the Fort Randall Project that have been monitored for water quality during the 5-year period 2011 through 2015. The near-dam location (i.e. site FTRLK0880A) has been continuously monitored since 1980.

9.2 WATER QUALITY IN LAKE FRANCIS CASE

9.2.1 EXISTING WATER QUALITY CONDITIONS

9.2.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Water quality conditions that were monitored in Lake Francis Case at sites FTRLK0880A, FTRLK0911DW, FTRLK0940DW, and FTRLK0968DW from May through September during the 5-year period 2011 through 2015 are summarized in Plate 9-1, Plate 9-2, Plate 9-3, and Plate 9-4. A review of these results indicated a possible water quality concern regarding dissolved oxygen for the support of Warmwater Permanent Fish Life Propagation. Dissolved oxygen levels degrade along the reservoir bottom as summer progresses and fall below 5.0 mg/L in July and August. The lowest dissolved oxygen concentration measured at the four sites was 2.5 mg/L and occurred near the reservoir bottom at site FTRLK0911DW in July 2015.

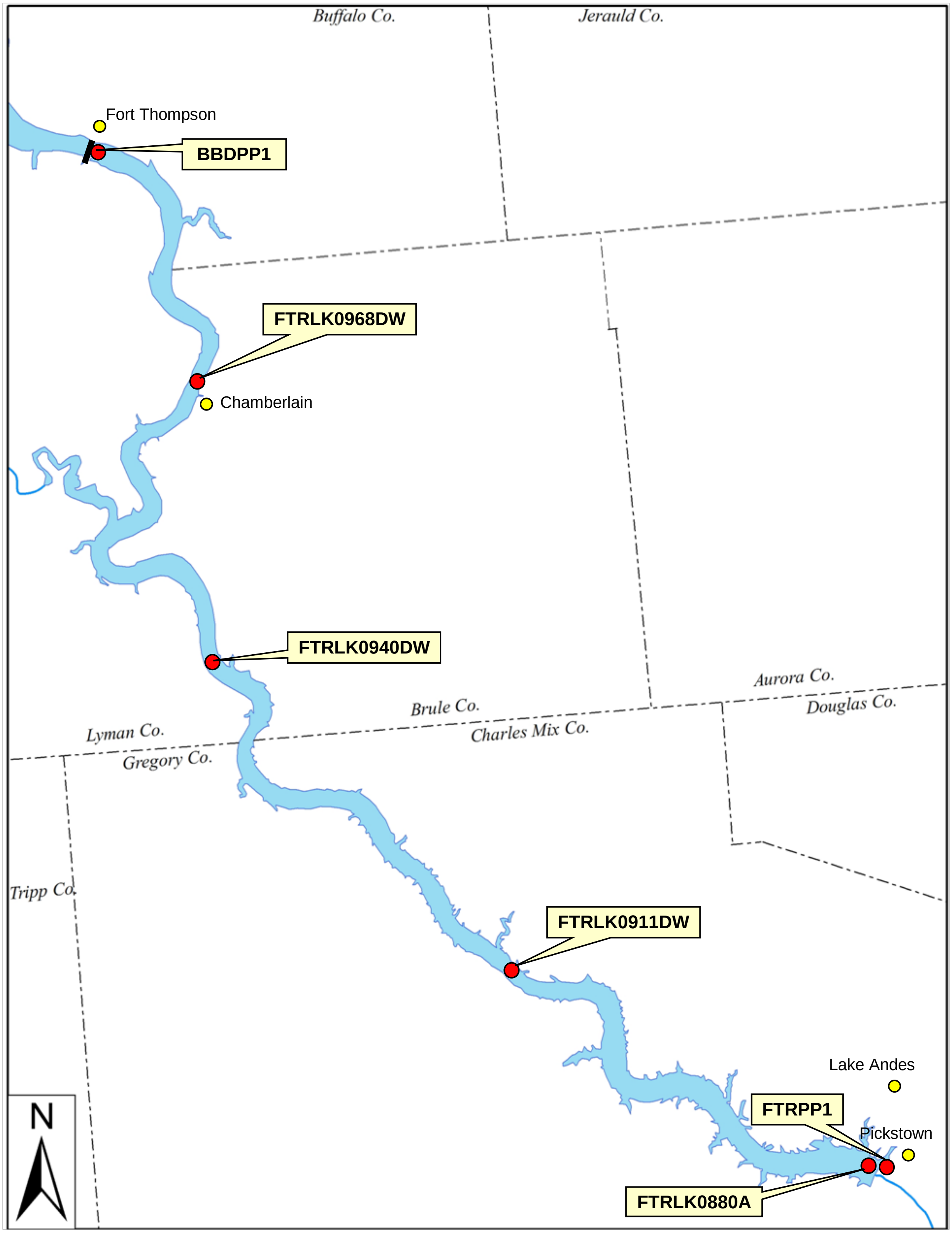


Figure 9-3. Location of sites where water quality monitoring was conducted by the District at the Fort Randall Project during the 5-year period 2011 through 2015.

9.2.1.2 Summer Thermal Stratification and Dissolved Oxygen Conditions during 2015

9.2.1.2.1 Depth-Profile Plots

Depth-profile plots of temperature measurements taken at sites FTRLK0880A, FTRLK0911DW, FTRLK0940DW, and FTRLK0968DW during 2015 are shown in Plate 9-5. Depth-profile plots of dissolved oxygen measurements taken at sites FTRLK0880A, FTRLK0911DW, FTRLK0940DW, and FTRLK0968DW during 2015 are shown in Plate 9-6.

9.2.1.2.2 Longitudinal Temperature Contour Plots

Summer thermal stratification of Lake Francis Case during 2015 is described by the monthly longitudinal temperature contour plots based on depth-profile temperature measurements taken in May, June, July, August, and September (Plate 9-7, Plate 9-8, Plate 9-9, Plate 9-10, and Plate 9-11). The contour plots were constructed along the length of the reservoir. As seen in the contour plots, water temperature in Lake Francis Case varies longitudinally from the dam to the reservoir's upstream reaches and vertically from the reservoir surface to the bottom. Water temperatures in the upstream reaches of the reservoir are influenced by the discharges from Big Bend Dam (RM987) and inflows from the White River (RM956). In late-spring to mid-summer an appreciable vertical thermal gradient typically is present in the lacustrine, downstream region of the reservoir. By late summer this vertical thermal gradient usually diminishes.

9.2.1.2.3 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Lake Francis Case based on depth-profile measurements taken in May, July, August, and September of 2015 (Plate 9-12, Plate 9-13, Plate 9-14, Plate 9-15, and Plate 9-16). During the summer of 2015, dissolved oxygen conditions in Lake Francis Case varied longitudinally from the dam to the reservoir's upstream reaches and vertically from the reservoir surface to the bottom. A small area of low dissolved oxygen (i.e. <5 mg/L) occurred in the downstream area of the reservoir near the dam. The area of low dissolved oxygen occurred along the reservoir bottom in the hypolimnion, during July.

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

Paired near-surface and near-bottom water quality samples collected from Lake Francis Case during the summer were compared. Near-surface conditions were represented by samples collected within 2-meters of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site FTPLK0880A during the 5-year period 2011 through 2015. During the period a total of 19 paired samples were collected monthly from June through September. Box plots were constructed to display the distribution of the paired near-surface and near-bottom measurements for the following parameters: water temperature, dissolved oxygen, pH, alkalinity, total ammonia, and total phosphorus (Plate 9-17). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for water temperature, dissolved oxygen, pH, and total phosphorus. Parameters that were significantly lower in the near-bottom water of Lake Francis Case included: water temperature ($p < 0.001$), dissolved oxygen ($p < 0.001$), and pH ($p < 0.001$). Parameters that were significantly higher in the near-bottom water included: and total phosphorus ($p < 0.05$).

9.2.1.4 Reservoir Trophic Status

Trophic State Index (TSI) values for Lake Francis Case were calculated from monitoring data collected at sites FTRLK0880A, FTRLK0911DW, FTRLK0940DW, and FTRLK0968DW during the 5-year period 2011 through 2015 (Table 9-2). The calculated TSI values indicate that the lacustrine zone of the reservoir near the dam (site FTRLK0880A) is mesotrophic, the area near site FTRLK0911DW is moderately eutrophic, and the upstream transition and riverine zones of the reservoir (sites FTRLK940DW and FTRLK0968DWDW) are eutrophic.

Table 9-2. Mean Trophic State Index (TSI) values calculated for Lake Francis Case. TSI values are based on monitoring at the identified four sites during the 5-year period 2011 through 2015.

Monitoring Site	Mean – TSI (Secchi Depth)	Mean – TSI (Total Phosphorus)	Mean – TSI (Chlorophyll)	Mean – TSI (Average)
FTRLK0880A	47	42	47	45
FTRLK0911DW	55	50	58	55
FTRLK0940DW	70	54	57	59
FTRLK0968DW	69	52	59	59

Note: See Section 4.1.4 for discussion of TSI calculation.

9.2.1.5 Plankton Community

9.2.1.5.1 Phytoplankton

Phytoplankton grab samples collected from Lake Francis Case at sites FTRLK0880A, FTRLK0911DW, FTRLK0940DW, and FTRLK0968DW during 2015. The following seven taxonomic divisions were represented by taxa collected in the phytoplankton samples: Bacillariophyta (Diatoms), Chlorophyta (Green Algae), Chrysophyta (Golden Algae), Cryptophyta (Cryptomonad Algae), Cyanobacteria (Blue-Green Algae), Pyrrophyta (Dinoflagellate Algae), and Euglenophyta (Euglenoid Algae). The relative abundance of phytoplankton in samples collected from Lake Francis Case in May, July, and September 2015, based on biovolume, is shown in Figure 9-4. Diatoms and Cryptomonad algae were the dominant phytoplankton group sampled in Lake Francis Case during 2015. No concentrations of the cyanobacteria toxin microcystin above 1 ug/L were monitored in the reservoir during the 5-year period 2011 through 2015 (Plate 9-1, Plate 9-2, Plate 9-3, and Plate 9-4).

9.2.1.5.2 Zooplankton

Zooplankton vertical-tow samples were collected from Lake Francis Case at sites FTRLK0880A, FTRLK0911DW, FTRLK0940DW, and FTRLK0968DWDW in May, July, and September 2015. The sampled zooplankton included three taxonomic groupings: Cladocerans, Copepods, and Rotifers. The relative abundance of these three taxonomic groupings, based on biomass, shown in Figure 9-5. Cladocerans and copepods dominated the sampled zooplankton community in Lake Francis Case.

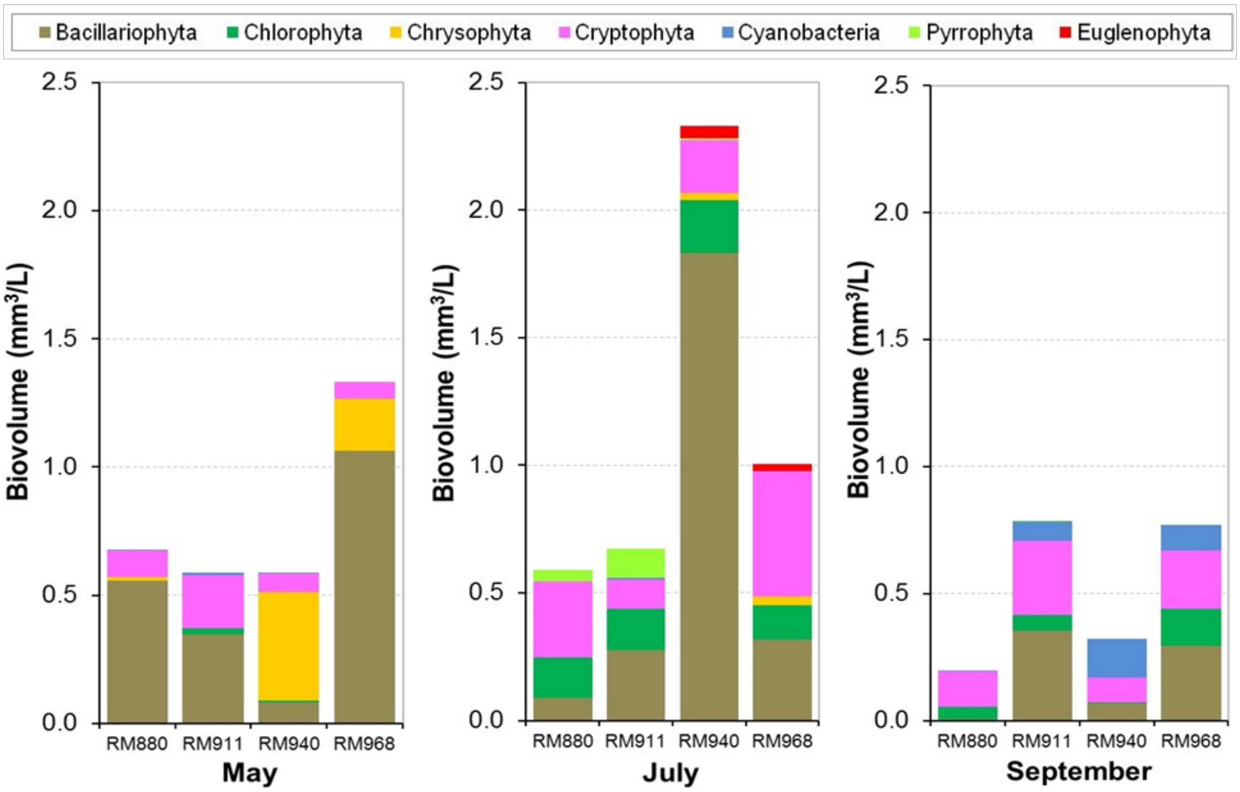


Figure 9-4. Relative abundance of phytoplankton in samples collected along Lake Francis Case during 2015.

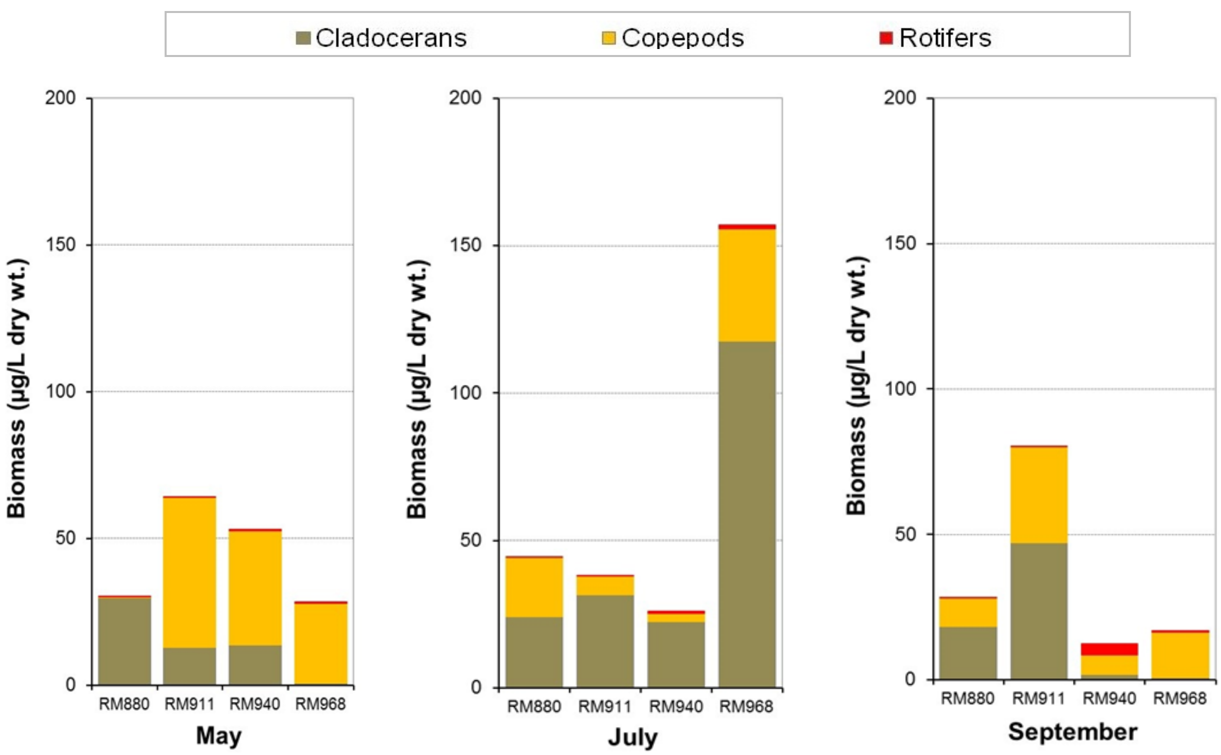


Figure 9-5. Relative abundance of zooplankton in samples collected along Lake Francis Case during 2015**.**

9.2.2 WATER QUALITY TRENDS (1980 THROUGH 2015)

Water quality trends over the 36-year period of 1980 through 2015 were determined for Lake Francis Case for Secchi depth, total phosphorus, chlorophyll *a*, and TSI (i.e. trophic status). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam monitoring site (i.e. site FTRLK0880A). Plate 9-18 displays a scatter-plot of the collected data for the four parameters, a linear regression trend line, and the significance of the trend line (i.e. $\alpha = 0.05$). For the assessment period, Lake Francis Case exhibited a significant decreasing trend for Secchi depth. No significant trends were detected for total phosphorus, chlorophyll *a*., or TSI. Over the 36-year period, the downstream reach of Lake Francis Case has generally remained in a mesotrophic state.

9.3 EXISTING WATER QUALITY CONDITIONS OF THE MISSOURI RIVER INFLOW TO LAKE FRANCIS CASE

The water quality conditions of the Missouri River inflow to Lake Francis Case is taken to be the monitored water quality conditions of the outflow from Big Bend Dam (see Section 8.4).

9.4 WATER QUALITY AT THE FORT RANDALL POWERPLANT

9.4.1 STATISTICAL SUMMARY AND COMPARISON TO APPLICABLE WATER QUALITY STANDARDS CRITERIA

Plate 9-19 and Plate 9-20 summarize the water quality conditions that were monitored on water discharged through the Fort Randall Dam powerplant during the 5-year period 2011 through 2015. A review of these results seemingly found no significant water quality concerns. However, the 0.18 ug/L human health criterion for total arsenic was exceeded on all five occasions. The highest total arsenic concentration measured was 3 ug/L.

9.4.2 TEMPERATURE, DISSOLVED OXYGEN, AND DAM DISCHARGE TIME-SERIES PLOTS

Hourly temperature and dam discharge recorded at the Fort Randall powerplant during 2015 were used to construct an annual time-series plot (Plate 9-21). Monitored water temperatures showed seasonal cooling and warming through each calendar year. Daily water temperatures remained fairly stable during the winter, early spring, and fall and exhibited considerable variability during the late spring and summer. When thermal stratification becomes established in Lake Francis Case during the late spring, the temperature of the water discharged through the powerplant becomes highly dependent upon the discharge rate of the dam. 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 leading to the intake structure. Water is likely drawn from an extended vertical zone in Lake Francis Case year-round, but is only evident in the temperatures monitored at the powerhouse during reservoir thermal stratification during the summer. When thermal stratification breaks down in the summer, the high correlation between dam discharge and the temperature of the discharged water no longer occurs.

Hourly dissolved oxygen and dam discharge recorded at the Fort Randall powerplant during 2015 were used to construct an annual time-series plot (Plate 9-22). Dissolved oxygen levels remained relatively high and stable during the winter, steadily declined through the spring and summer, and steadily increased during the fall. The lowest dissolved oxygen levels occurred during mid-summer. The higher winter, declining spring, and increasing fall dissolved oxygen concentrations are attributed to decreasing dissolved oxygen solubility with warmer water temperatures. The decreasing dissolved oxygen in the summer is attributed to ongoing degradation of dissolved oxygen in the lower hypolimnion as the summer progressed. Water is withdrawn from Lake Francis Case into the dam's power tunnels approximately 2 feet above the reservoir bottom. During the summer when Lake Francis Case is thermally stratified, dissolved oxygen levels degrade near the reservoir bottom. Under such conditions, low dam discharge rates pull water with low dissolved oxygen concentrations from the near-bottom region of the hypolimnion.

As seen in the time series plots, dissolved oxygen levels monitored during the summer go below the 5 mg/L criterion established for the protection of the Warmwater Permanent Fish Life Propagation use. The lower dissolved oxygen levels appear to be associated with lower discharge conditions when water is drawn into the penstocks along the reservoir bottom. Seemingly, the low dissolved oxygen levels are related to oxygen degradation in the reservoir hypolimnion during the summer. During periods of lower discharge, water is drawn along the bottom of the submerged approach channel to the dam's intake tower. This is where low dissolved oxygen would occur in the hypolimnion during mid- to late summer. To further evaluate this situation a Special Water Quality Study was conducted during the summer of 2010 to evaluate how low dissolved oxygen levels in the powerplant discharges impact the Missouri River tailwaters of Fort Randall Dam (see Section 9.6).

9.4.3 Nutrient Flux Conditions of the Fort Randall Dam Discharge to the Missouri River

Nutrient flux rates for the Fort Randall Dam discharge to the Missouri River over the 5-year period 2011 through 2015 were calculated based on samples taken from the Fort Randall powerplant (i.e. site FTRPP1) and the dam discharge at the time of sample collection (Table 9-3). The samples collected in the powerplant are taken from the raw water supply line and are believed to be unbiased regarding particulate-associated constituents. Therefore, the flux rates calculated for the Fort Randall Dam discharge give an unbiased estimate of the flux rates for all the constituents, including total phosphorus and total organic carbon. Fall spillway discharge is typically done at Fort Randall Dam to evacuate volume for storage of winter hydropower generation flows from Oahe and Big Bend. Also, significant summer spillway flows were utilized in 2011 to manage flood conditions. During these periods, water quality conditions monitored in the powerplant discharge were taken to represent the water quality of the total discharge to calculate nutrient flux. The maximum flux rates for all the constituents are believed to be attributed to higher dam discharges.

Table 9-3. Summary of nutrient flux rates (kg/sec) calculated for the Fort Randall Dam discharge to the Missouri River (i.e. site FTRPP1) during January through December over the 5-year period 2011 through 2015.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	60	59	60	60	60	60	60
Mean	28,263	0.0308	0.3503	0.1069	0.0183	0.0097	3.3471
Median	19,700	0.0028	0.2260	0.0291	0.0102	0.0035	2.2881
Minimum	1,600	n.d.	0.0231	n.d.	n.d.	n.d.	0.1993
Maximum	155,500	0.4403	2.6369	1.8122	0.1761	0.1321	20.4147

Note: Nondetectable values set to 0 for flux calculations.

9.5 WATER QUALITY IN THE MISSOURI RIVER DOWNSTREAM OF FORT RANDALL DAM

9.5.1 MISSOURI RIVER REACH – FORT RANDALL DAM TO LEWIS AND CLARK LAKE

The Missouri River downstream from Fort Randall Dam (RM880) flows in a southeasterly direction for approximately 44 miles in an unchannelized river to Lewis and Clark Lake. 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 Lewis and Clark Lake 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).

9.5.1.1 National Recreation River Designation Pursuant to the Federal Wild and Scenic Rivers Act

The 39-mile "natural-channel" reach of the Missouri River from Fort Randall Dam to the headwaters of Lewis and Clark Lake 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.

9.5.1.2 State Designations and Listings Pursuant to the Federal Clean Water Act

Pursuant to the Federal Clean Water Act (CWA), the States of South Dakota and Nebraska have designated water quality-dependent beneficial uses, in their State water quality standards, for the Missouri River from of Fort Randall Dam to Lewis and Clark Lake. South Dakota has designated the following uses for this reach of the Missouri River: 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. Nebraska has designated the following uses to this reach of the Missouri River: primary contact recreation, Class A warmwater aquatic life, agricultural water supply, and aesthetics. It has designated the use of drinking water supply to the river below the confluence of the Niobrara River. Nebraska has also designated the reach between the Nebraska-South Dakota border and Lewis and Clark Lake an Outstanding State Resource Water for "Tier 3" protection under the water quality standard's antidegradation policy. Both of the States have placed this reach of the Missouri River on their Section 303(d) list of impaired waters, and have issued a fish consumption advisory for this reach of the Missouri River. The impairment and fish consumption advisory is attributed to the contamination of fish tissue due to mercury.

The national interpretation with respect to the Outstanding National Resource Waters protected under "Tier 3" of the antidegradation policy is that no new or increased discharges are allowed. The only exception to this is that States (i.e. Nebraska) may allow some limited activities which result in temporary and short-term changes in water quality.

9.5.2 MONITORED WATER QUALITY CONDITIONS

The District, in cooperation with the Nebraska Department of Environmental Quality, conducted fixed-station water quality monitoring at two sites along the Missouri River from Fort Randall Dam to Lewis and Clark Lake. The locations of the two sites were Fort Randall Dam tailwaters (site FTRRRTW1) and the Missouri River near Verdel, NE (site MORRR0851) (see Figure 10-3). During the 5-year period of 2011 through 2015, water quality samples were collected. Plate 9-23 and Plate 9-24 summarize the water quality conditions that were monitored at the two sites. A review of these results indicated no major water quality concerns

9.6 FINDINGS OF THE 2010 SPECIAL WATER QUALITY STUDY OF DISSOLVED OXYGEN CONDITIONS IN THE FORT RANDALL DAM TAILWATERS

Findings of a 2010 Special Water Quality Study are presented in the document, "Low Dissolved Oxygen Levels in Summer Powerplant Discharges from Fort Randall Dam, South Dakota", (USACE, 2010). The following conclusions were taken from that report:

Thermal stratification of Lake Francis Case during the summer results in the development of hypoxic conditions in the reservoir's hypolimnion. Lake Francis Case is a bottom-release reservoir, and hypoxic water is passed through Fort Randall Dam during power production during July and August. Under these conditions, dissolved oxygen levels in areas of the Fort Randall Dam tailwaters fall below South Dakota's water quality standards' minimum dissolved oxygen criterion of 5 mg/L. Monitored conditions indicate that the low dissolved oxygen levels in the tailwaters are not seemingly impairing the designated Warmwater Permanent Fish Life Propagation beneficial use as regions of refugia exist in the impacted area. Also, there is no evidence of past fish kills in the Fort Randall tailwaters attributable to hypoxic conditions. If warranted, dissolved oxygen conditions in the Fort Randall tailwaters during periods of hypoxic dam releases could be mitigated by drawing water from the reservoir surface and releasing it down the spillway into the tailwaters.

Plate 9-1. Summary of monthly (May through September) water quality conditions monitored in Lake Francis Case near Fort Randall Dam (Site FTRLK0880A) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	25	1357.1	1355.7	1353.2	1373.8	-----	-----	-----
Water Temperature (°C)	0.1	884	19.4	21.6	7.7	28.8	27[1,5]	2	<1%
Dissolved Oxygen (mg/L)	0.1	884	8.2	8.2	2.6	11.8	5[1,6]	28	3%
Dissolved Oxygen (% Sat.)	0.1	884	91.8	93.3	30.1	113.1	----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[E]	0.1	788	8.4	8.2	3.9	11.8	5[3,6]	9	1%
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	95	7.3	8.5	2.6	9.4	5[1,6]	19	20%
Specific Conductance (uS/cm)	1	884	842	846	708	951	-----	-----	-----
pH (S.U.)	0.1	883	8.3	8.3	7.3	8.8	6.5[1,2,6], 9.0[1,2,5], 9.5[4,5]	0	0%
Turbidity (NTUs)	1	881	-----	2	n.d.	35	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	844	329	343	121	431	-----	-----	-----
Secchi Depth (M)	0.02	23	2.56	2.29	1.22	4.27	-----	-----	-----
Alkalinity, Total (mg/L)	7	49	164	166	141	175	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	49	4.1	4.0	3.0	5.3	-----	-----	-----
Chloride (mg/L)	1	29	12	12	11	13	438[2,5], 250[2,7]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	810	-----	2	n.d.	23	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	25	-----	2	n.d.	17	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	49	24	24	15	36	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	48	606	593	450	848	1,750[2,5], 1,000[2,7], 3,500[4,5], 2,000[4,7]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	49	-----	n.d.	n.d.	0.12	4.7 [1,5,8], 0.93[1,7,8]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	49	0.3	0.3	n.d.	1.1	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	49	-----	0.07	n.d.	0.40	10[2,5]	0	0%
Nitrogen, Total (mg/L)	0.1	49	0.4	0.4	n.d.	1.5	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	49	-----	n.d.	n.d.	0.03	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	49	-----	0.02	n.d.	0.05	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	49	-----	n.d.	n.d.	0.02	-----	-----	-----
Sulfate (mg/L)	1	49	257	255	201	304	875[2,5], 500[2,7]	0	0%
Suspended Solids, Total (mg/L)	4	49	-----	n.d.	n.d.	39	158[1,5], 90[1,7]	0	0%
Microcystin, Extracellular (ug/L)	0.1	25	-----	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 microcystin are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.

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

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

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

- [1] Criteria for the protection of warmwater permanent fish life propagation waters.
- [2] Criteria for the protection of domestic water supply waters.
- [3] Criteria for the protection of immersion and limited contact recreation waters (applies only to epilimnion and metalimnion if water body stratified).
- [4] Criteria for the protection of commerce and industry waters.
- [5] Daily maximum criterion (monitoring results directly comparable to criterion).
- [6] Daily minimum criterion (monitoring results directly comparable to criterion).
- [7] 30-day average criterion (monitoring results not directly comparable to criterion).
- [8] Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

[E] A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

Plate 9-2. **S**ummary of monthly (May through September) water quality conditions monitored in Lake Francis Case near Platte Creek (Site FTRLK0911DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	24	1357.2	1355.6	1353.2	1373.9	-----	-----	-----
Water Temperature (°C)	0.1	538	20.2	22.3	9.8	28.3	27[1,5]	6	1%
Dissolved Oxygen (mg/L)	0.1	538	8.3	8.4	2.5	10.6	5[1,6]	11	2%
Dissolved Oxygen (% Sat.)	0.1	538	94.9	96.6	28.6	114.7	----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[E]	0.1	489	8.4	8.4	4.6	10.6	5[1,6]	3	1%
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	47	7.5	7.8	2.5	10.2	5[1,6]	8	17%
Specific Conductance (uS/cm)	1	538	8.3	8.4	2.5	10.2	-----	-----	-----
pH (S.U.)	0.1	538	8.3	8.4	7.3	8.9	6.5[1,2,6], 9.0[1,2,5], 9.5[4,5]	0	0%
Turbidity (NTUs)	1	536	4	3	n.d.	40	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	537	338	338	155	448	-----	-----	-----
Secchi Depth (M)	0.02	23	1.68	1.37	0.61	4.98	-----	-----	-----
Alkalinity, Total (mg/L)	7	46	165	168	148	175	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	46	4.1	4.1	2.6	5.6	-----	-----	-----
Chloride (mg/L)	1	28	13	13	11	14	438[2,5], 250[2,7]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	487	5	4	n.d.	23	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	24	5	4	n.d.	12	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	46	25	25	16	37	-----	-----	-----
Dissolved Solids, Total (mg/L)	4	45	616	610	460	840	1,750[2,5], 1,000[2,7], 3,500[4,5], 2,000[4,7]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	46	-----	n.d.	n.d.	0.08	3.9 [1,5,8], 0.75 [1,7,8]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	46	0.4	0.3	n.d.	1.3	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	46	-----	0.04	n.d.	0.28	10[2,5]	0	0%
Nitrogen, Total (mg/L)	0.1	46	0.4	0.4	n.d.	1.3	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	46	-----	n.d.	n.d.	0.07	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	46	0.03	0.02	n.d.	0.37	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	46	-----	n.d.	n.d.	0.06	-----	-----	-----
Sulfate (mg/L)	1	46	260	255	197	306	875[2,5], 500[2,7]	0	0%
Suspended Solids, Total (mg/L)	4	46	-----	5	n.d.	30	158[1,5], 90[1,7]	0	0%
Microcystin, Extracellular (ug/L)	0.1	24	-----	n.d.	n.d.	0.4	-----	-----	-----

n.d. = Not detected.

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

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

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

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

- [1] Criteria for the protection of warmwater permanent fish life propagation waters.
- [2] Criteria for the protection of domestic water supply waters.
- [3] Criteria for the protection of immersion and limited contact recreation waters (applies only to epilimnion and metalimnion if water body stratified).
- [4] Criteria for the protection of commerce and industry waters.
- [5] Daily maximum criterion (monitoring results directly comparable to criterion).
- [6] Daily minimum criterion (monitoring results directly comparable to criterion).
- [7] 30-day average criterion (monitoring results not directly comparable to criterion).
- [8] Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

[E] A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

Plate 9-3. Summary of monthly (May through September) water quality conditions monitored in Lake Francis Case near Elm Creek (Site FTRLK0940DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	22	1356.5	1355.5	1353.1	1367.0	-----	-----	-----
Water Temperature (°C)	0.1	103	20.0	20.5	12.1	28.1	27[1,5]	3	3%
Dissolved Oxygen (mg/L)	0.1	101	9.0	8.7	3.0	11.3	5[1,6]	1	1%
Dissolved Oxygen (% Sat.)	0.1	101	101.8	101.3	37.3	112.7	----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[E]	0.1	101	9.0	8.7	3.0	11.3	5[3,6]	1	1%
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	0	-----	-----	-----	-----	5[1,6]	-----	-----
Specific Conductance (uS/cm)	1	102	856	840	704	981	-----	-----	-----
pH (S.U.)	0.1	103	8.4	8.4	7.69	8.8	6.5[1,2,6], 9.0[1,2,5], 9.5[4,5]	0	0%
Turbidity (NTUs)	1	100	19	13	2	160	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	103	335	335	119	509	-----	-----	-----
Secchi Depth (M)	0.02	17	0.53	0.51	0.25	0.86	-----	-----	-----
Alkalinity, Total (mg/L)	7	24	166	168	153	178	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	24	4.0	4.1	2.5	5.4	-----	-----	-----
Chloride (mg/L)	1	13	13	13	11	17	438[2,5], 250[2,7]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	65	8	7	3	20	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	22	7	5	n.d.	15	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	24	26	25	18	43			
Dissolved Solids, Total (mg/L)	4	24	611	591	464	866	1,750[2,5], 1,000[2,7], 3,500[4,5], 2,000[4,7]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	24	-----	n.d.	n.d.	0.07	3.9 [1,5,8], 0.83 [1,7,8]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	24	0.4	0.4	0.1	0.7	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	24	-----	0.05	n.d.	0.26	10[2,5]	0	0%
Nitrogen, Total (mg/L)	0.1	24	0.4	0.4	0.2	0.7	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	24	-----	n.d.	n.d.	0.03	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	24	0.07	0.04	n.d.	0.49	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	24	-----	n.d.	n.d.	0.03	-----	-----	-----
Sulfate (mg/L)	1	24	257	253	196	306	875[2,5], 500[2,7]	0	0%
Suspended Solids, Total (mg/L)	4	24	49	13	n.d.	568	158[1,5], 90[1,7]	2, 2	8%, 8%
Microcystin, Extracellular (ug/L)	0.1	21	-----	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 microcystin are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.

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

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

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

(E) A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

(F) Depth-profiles did not indicate the presence of a hypolimnion during monitored period. It is assumed that the water column experienced complete mixing due to shallower water depths during the monitored period.

Plate 9-4. **S**ummary of monthly (May through September) water quality conditions monitored in Lake Francis Case near Chamberlain, SD (Site FTRLK0968DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	24	1356.8	1355.7	1353.1	1373.8	-----	-----	-----
Water Temperature (°C)	0.1	147	19.7	20.6	11.4	27.3	27[1,5]	1	1%
Dissolved Oxygen (mg/L)	0.1	146	9.0	8.6	7.4	12.0	5[1,6]	0	0%
Dissolved Oxygen (% Sat.)	0.1	146	100.7	99.6	92.0	119.8	----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[E]	0.1	146	9.0	8.6	7.4	12.0	5[1,6]	0	0%
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	0	-----	-----	-----	-----	5[1,6]	-----	-----
Specific Conductance (uS/cm)	1	146	861	851	693	960	-----	-----	-----
pH (S.U.)	0.1	147	8.4	8.4	7.9	8.9	6.5[1,2,6], 9.0[1,2,5], 9.5[4,5]	0	0%
Turbidity (NTUs)	1	147	15	14	2	133	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	146	341	349	201	468	-----	-----	-----
Secchi Depth (M)	0.02	15	0.57	0.56	0.43	0.79	-----	-----	-----
Alkalinity, Total (mg/L)	7	23	168	170	148	176	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	24	4.0	4.1	2.6	5.3	-----	-----	-----
Chloride (mg/L)	1	15	13	13	11	15	438[2,5], 250[2,7]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	126	10	7	3	39	-----	-----	-----
Chlorophyll *a* (ug/L) – Lab Determined	1	23	9	6	3	39	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	24	23	23	16	34	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	24	625	616	448	884	1,750[2,5], 1,000[2,7], 3,500[4,5], 2,000[4,7]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	24	-----	n.d.	n.d.	0.06	3.9 [1,5,8], 0.83 [1,7,8]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	24	0.4	0.3	0.1	0.8	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	24	-----	0.02	n.d.	0.20	10[2,5]	0	0%
Nitrogen, Total (mg/L)	0.1	24	0.4	0.4	0.1	0.8	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	24	-----	n.d.	n.d.	0.02	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	24	0.02	0.02	n.d.	0.04	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	24	-----	n.d.	n.d.	0.02	-----	-----	-----
Sulfate (mg/L)	1	24	263	254	193	309	875[2,5], 500[2,7]	0	0%
Suspended Solids, Total (mg/L)	4	24	13	11	6	23	158[1,5], 90[1,7]	0	0%
Microcystin, Extracellular (ug/L)	0.1	24	-----	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 microcystin are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.

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

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

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

[E] A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

[F] Depth-profiles did not indicate the presence of a hypolimnion during monitored period. It is assumed that the water column experienced complete mixing due to shallower water depths during the monitored period.

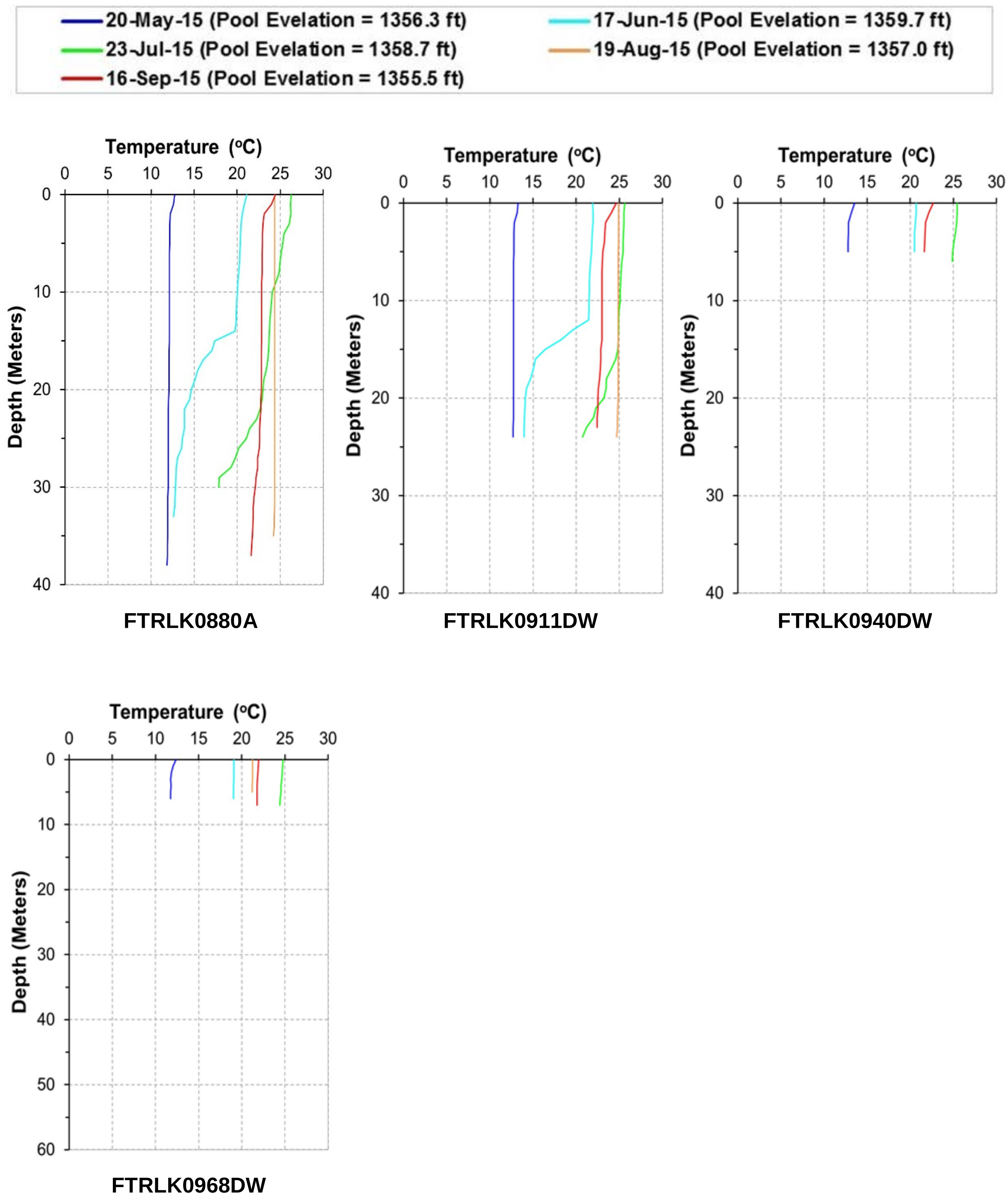


Plate 9-5. Depth-profile plots of temperature conditions of Lake Francis Case measured at sites FTRLK0880A, FTRLK0911DW, FTRLK0940DW, and FTRLK0968DW during 2015**.**

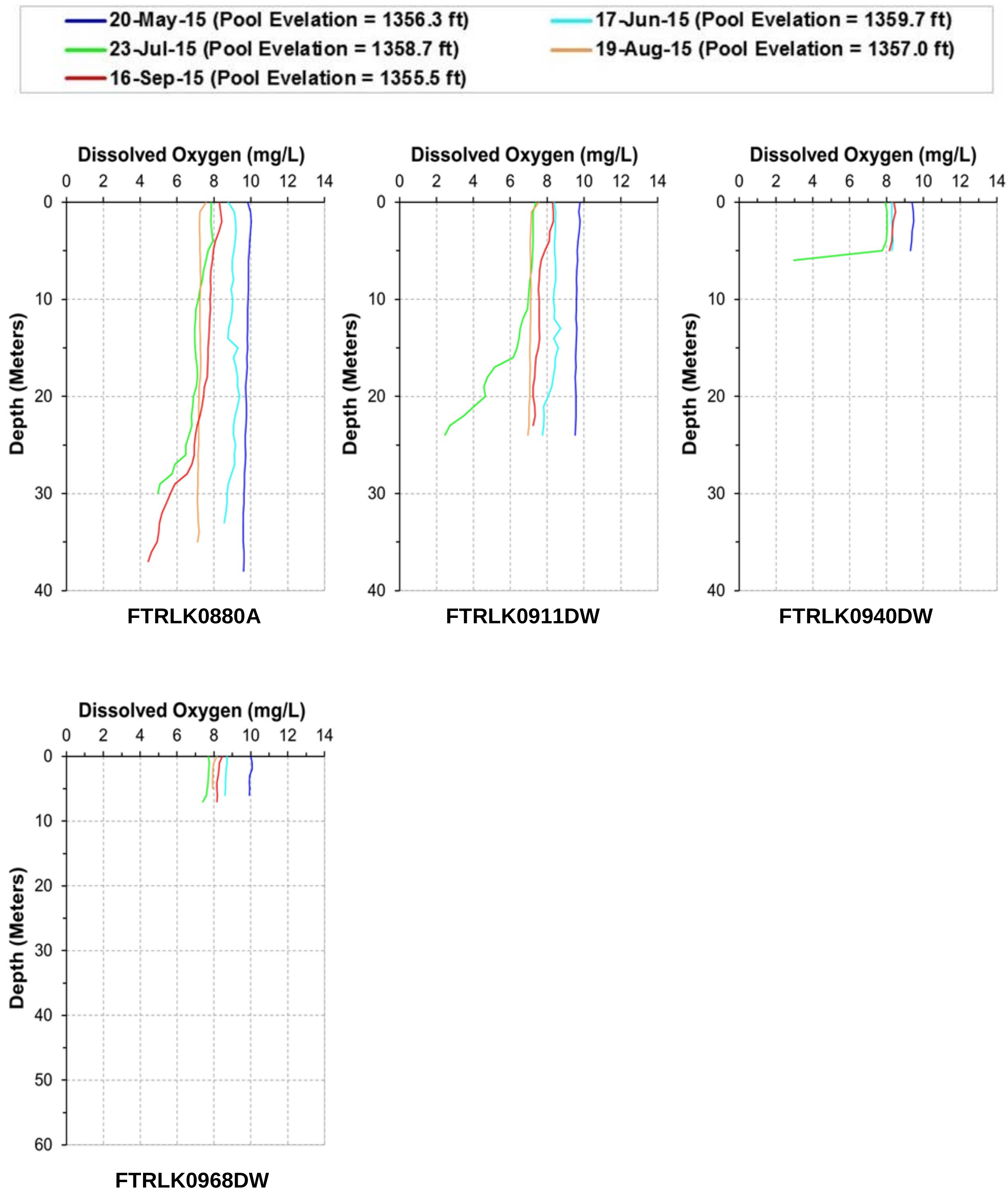


Plate 9-6. Depth-profile plots of dissolved oxygen conditions of Lake Francis Case measured at sites FTRLK0880A, FTRLK0911DW, FTRLK0940DW, and FTRLK0968DW during 2015**.**

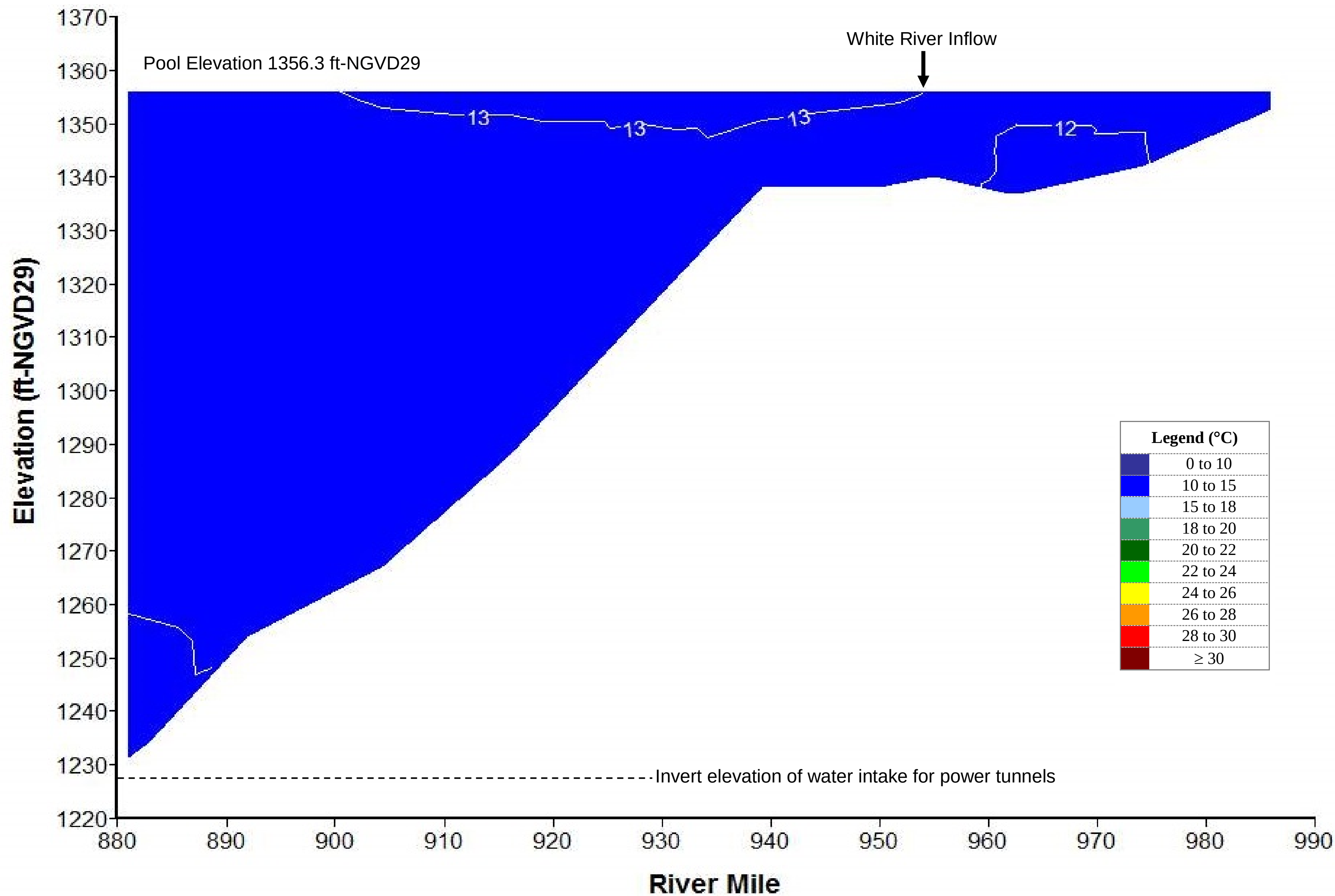


Plate 9-7. Longitudinal water temperature (°C) contour plot of Lake Francis Case based on depth-profile water temperatures measured at sites FTRLK0987A, FTRLK0911DW, FTRLK0940DW, FTRLK0968DW, and BBDPP1 on May 20, 2015.

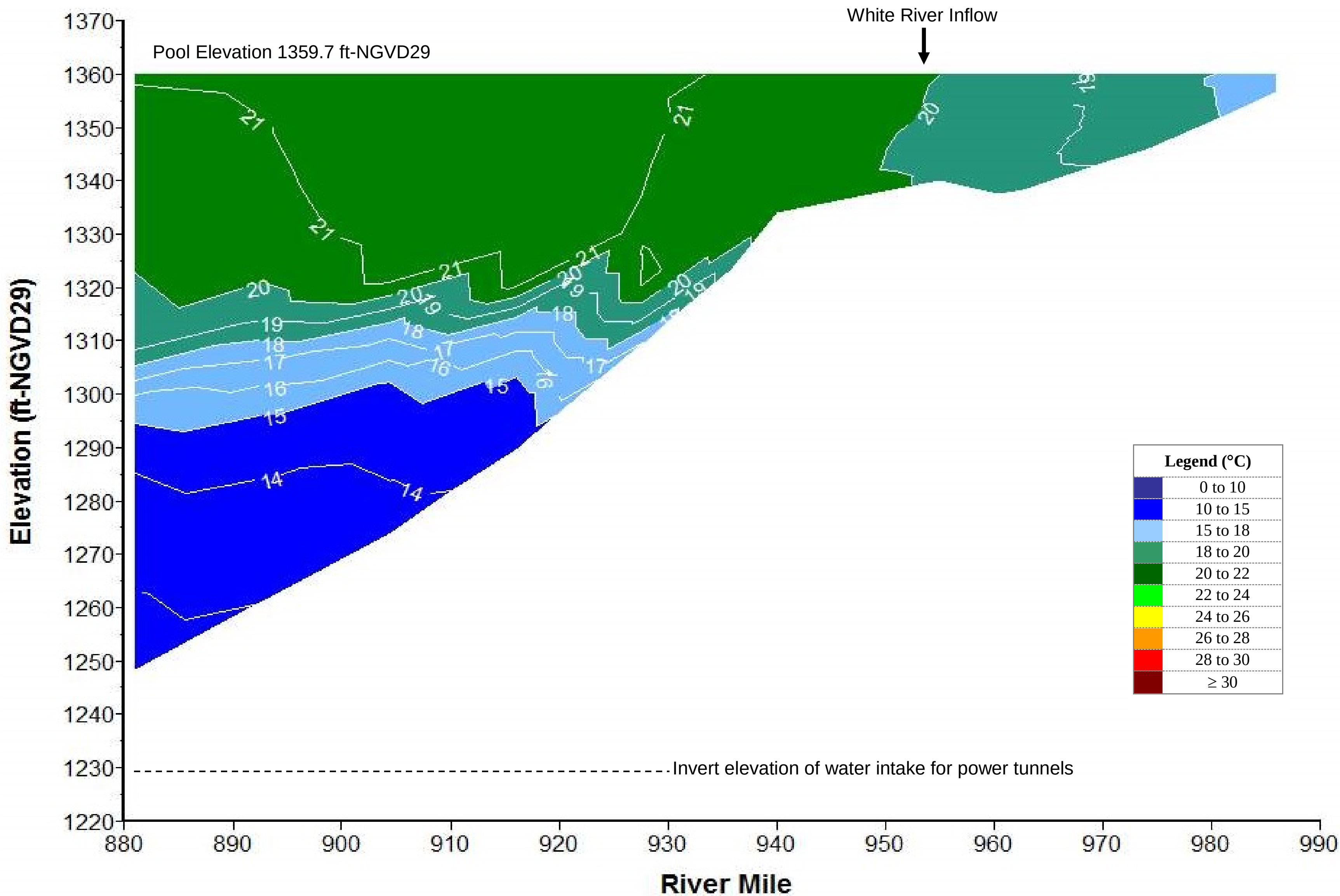


Plate 9-8. Longitudinal water temperature (°C) contour plot of Lake Francis Case based on depth-profile water temperatures measured at sites FTRLK0987A, FTRLK0911DW, FTRLK0968DW, and BBDPP1 on June 17, 2015.

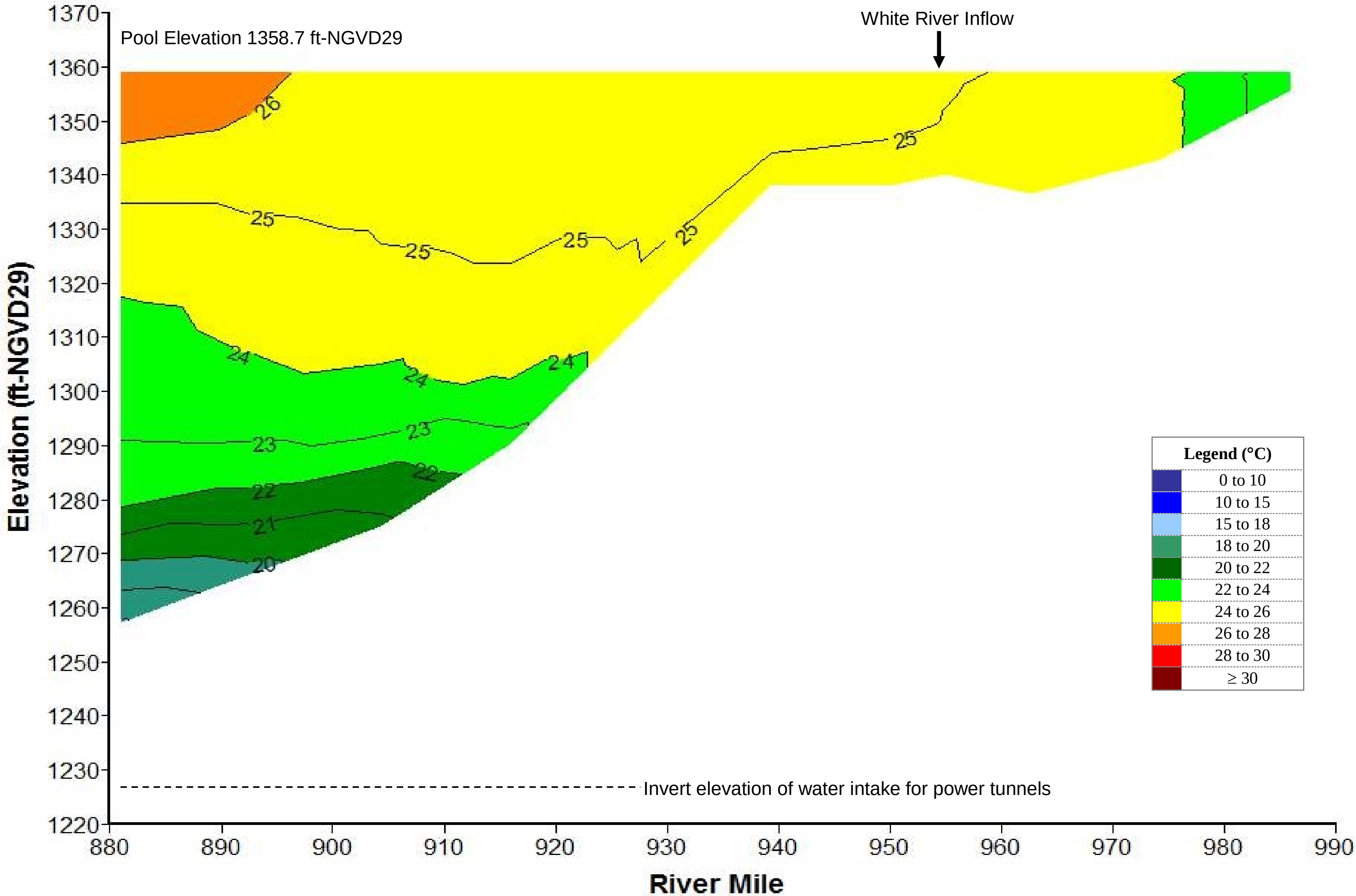


Plate 9-9. Longitudinal water temperature (°C) contour plot of Lake Francis Case based on depth-profile water temperatures measured at sites FTRLK0987A, FTRLK0911DW, FTRLK0968DW, and BBDPP1 on July 21, 2015.

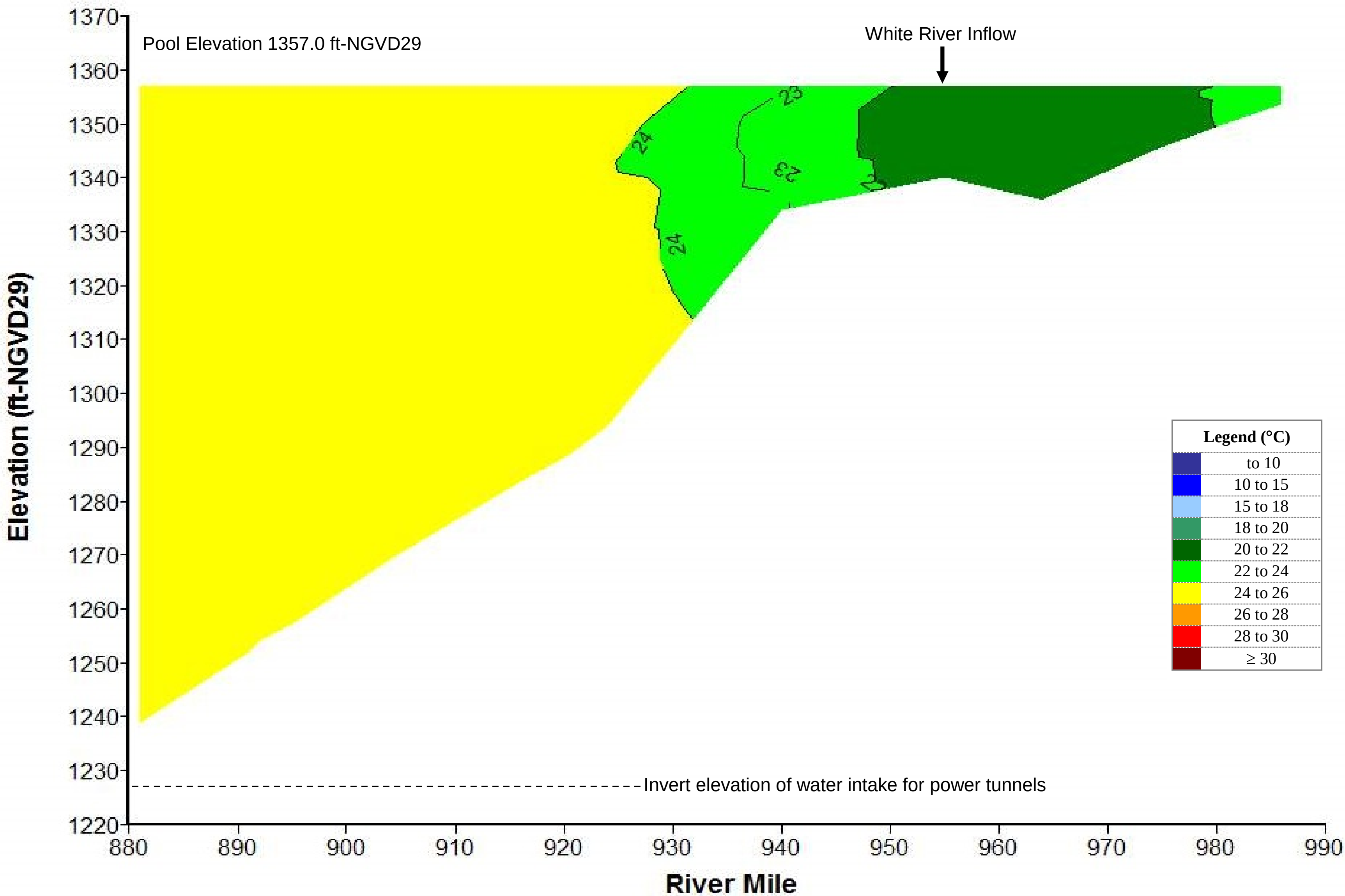


Plate 9-10. Longitudinal water temperature (°C) contour plot of Lake Francis Case based on depth-profile water temperatures measured at sites FTRLK0987A, FTRLK0911DW, and BBDPP1 on August 25, 2015.

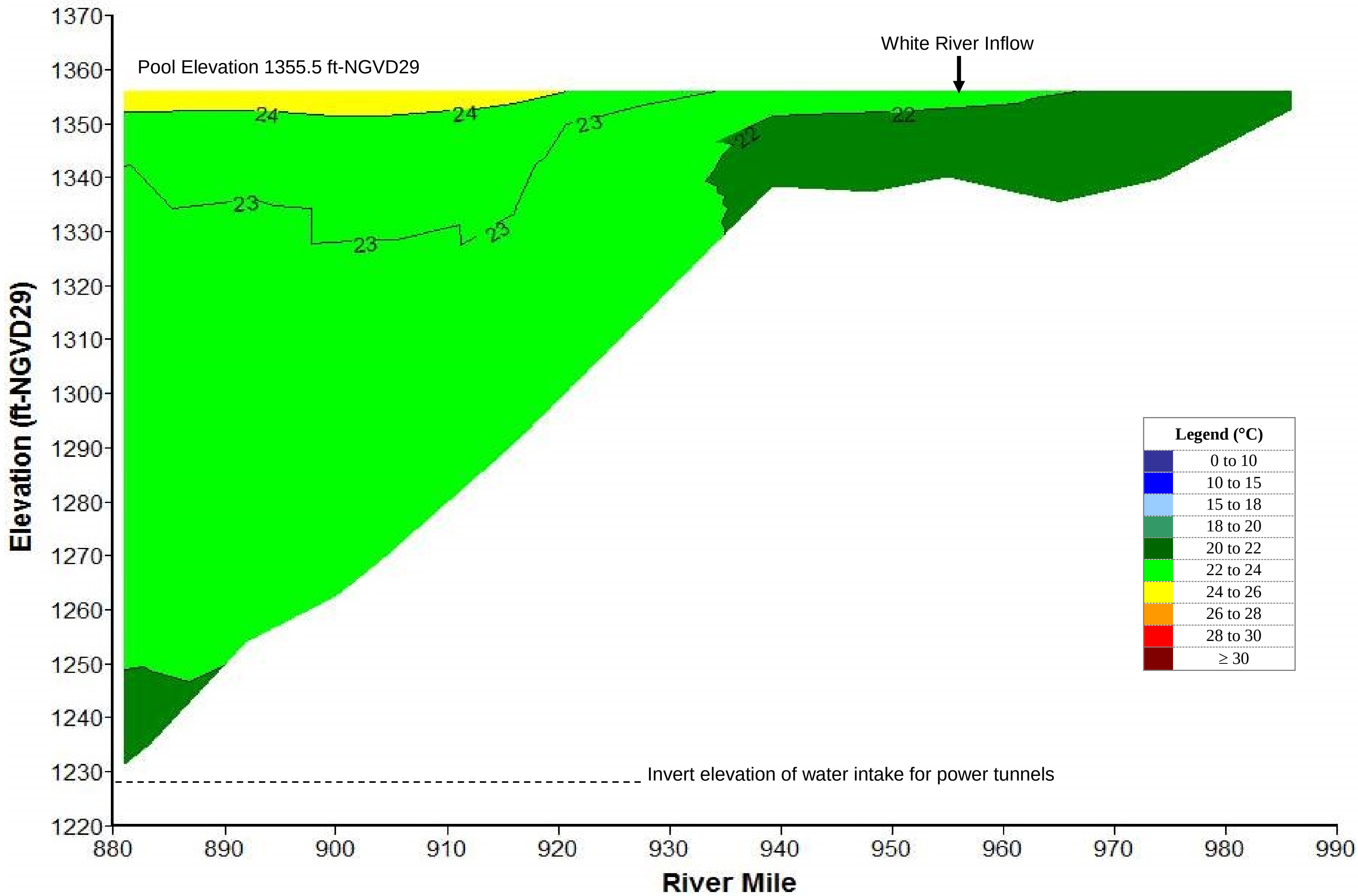


Plate 9-11. Longitudinal water temperature (°C) contour plot of Lake Francis Case based on depth-profile water temperatures measured at sites FTRLK0987A, FTRLK0911DW, FTRLK0968DW, and BBDPP1 on September 16, 2015.

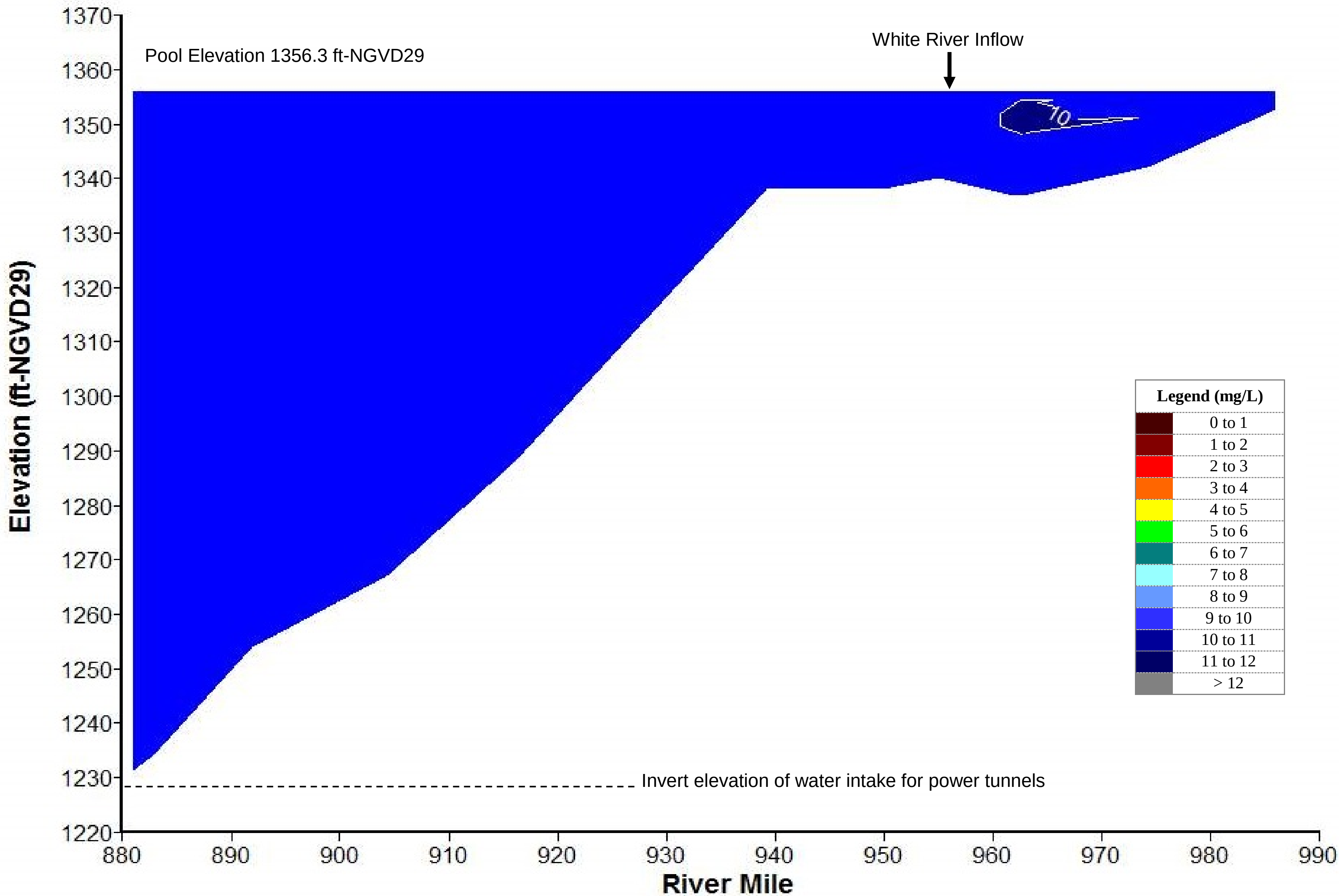


Plate 9-12. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Francis Case based on depth-profile dissolved oxygen concentrations measured at sites FTRLK0987A, FTRLK0911DW, FTRLK0940DW, FTRLK0968DW, and BBDPP1 on May 20, 2015.

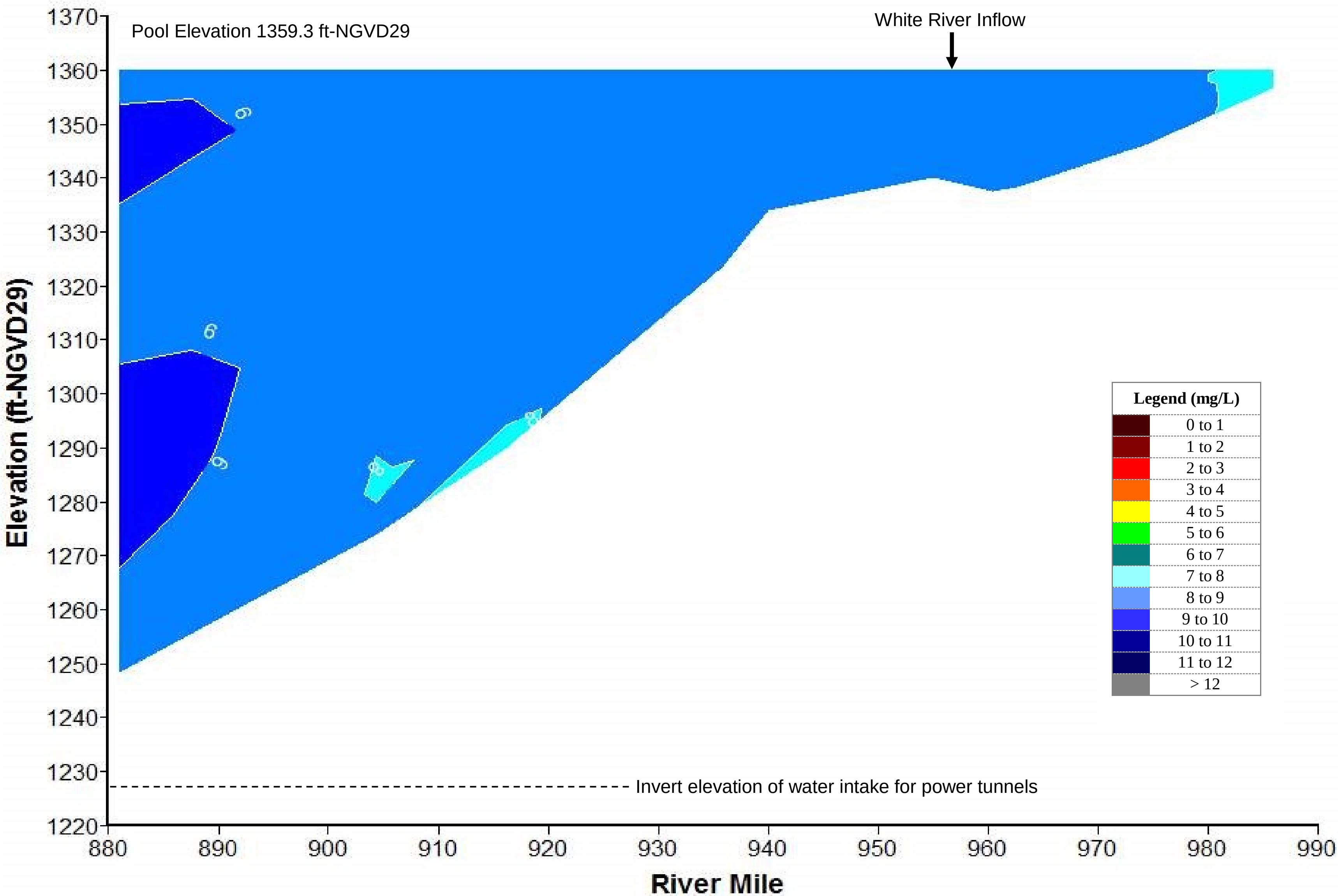


Plate 9-13. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Francis Case based on depth-profile dissolved oxygen concentrations measured at sites FTRLK0987A, FTRLK0911DW, FTRLK0968DW, and BBDPP1 on June 17, 2015.

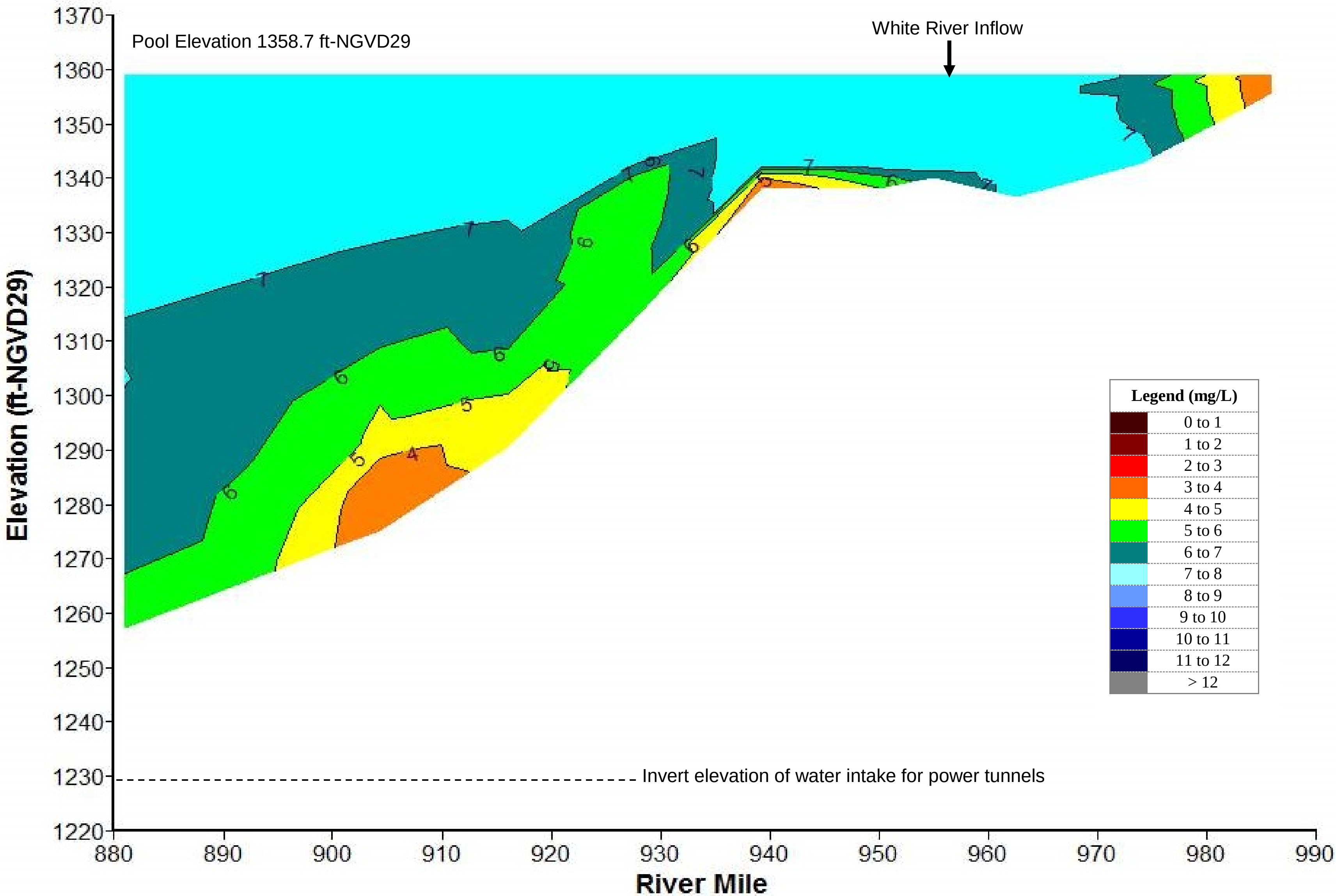


Plate 9-14. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Francis Case based on depth-profile dissolved oxygen concentrations measured at sites FTRLK0987A, FTRLK0911DW, FTRLK0968DW, and BBDPP1 on July 23, 2015.

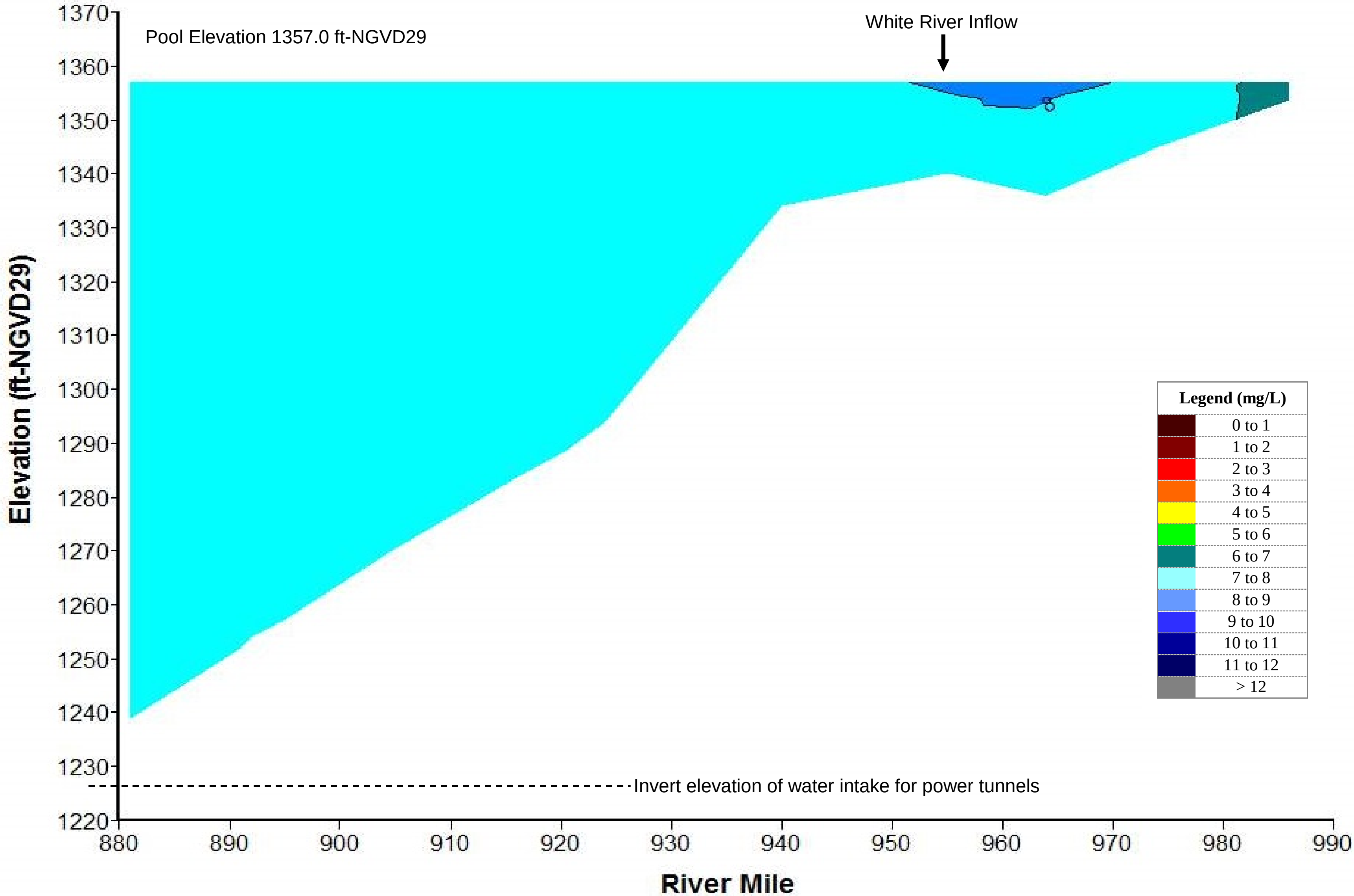


Plate 9-15. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Francis Case based on depth-profile dissolved oxygen concentrations measured at sites FTRLK0987A, FTRLK0911DW, FTRLK0968DW, and BBDPP1 on August 19, 2015.

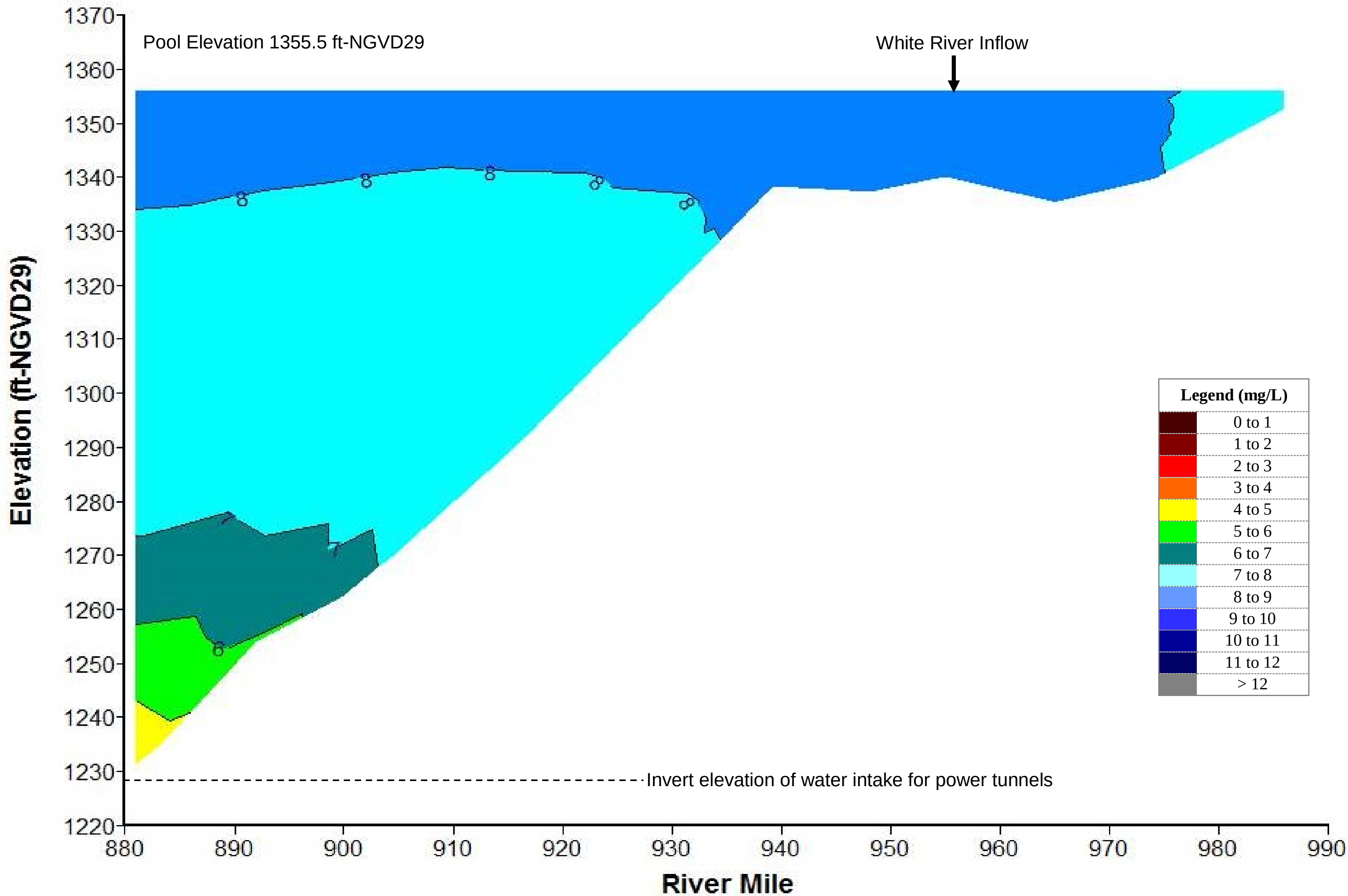


Plate 9-16. Longitudinal dissolved oxygen (mg/L) contour plot of Lake Francis Case based on depth-profile dissolved oxygen concentrations measured at sites FTRLK0987A, FTRLK0911DW, FTRLK0968DW, and BBDPP1 on September 16, 2015.

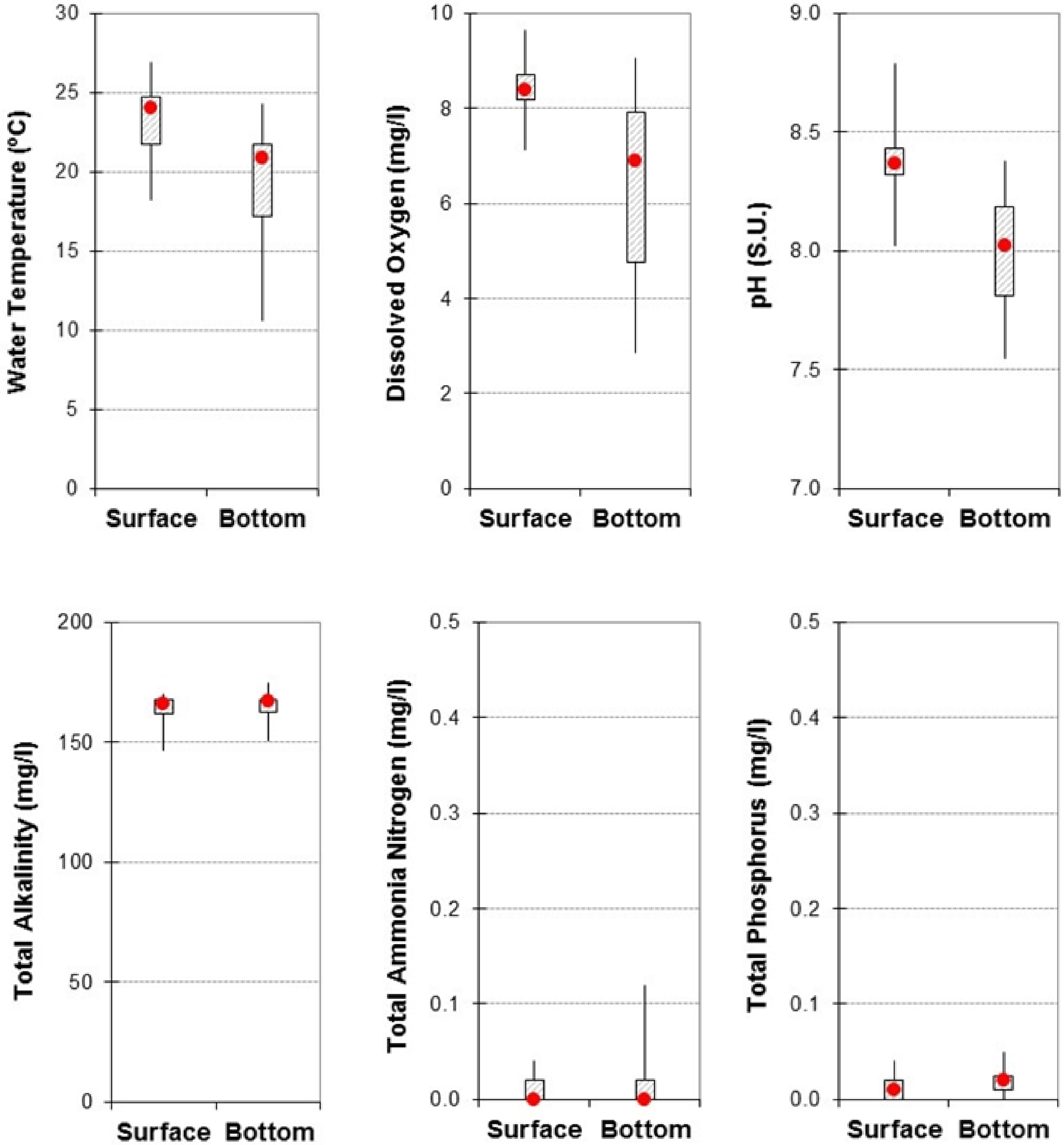


Plate 9-17. Box plots comparing paired surface and bottom water temperature, dissolved oxygen, pH, alkalinity, total ammonia nitrogen, and total phosphorus measurements taken in Lake Francis Case at site FTRLK0880A during the summer months of the 5-year period 2011 through 2015.
(Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

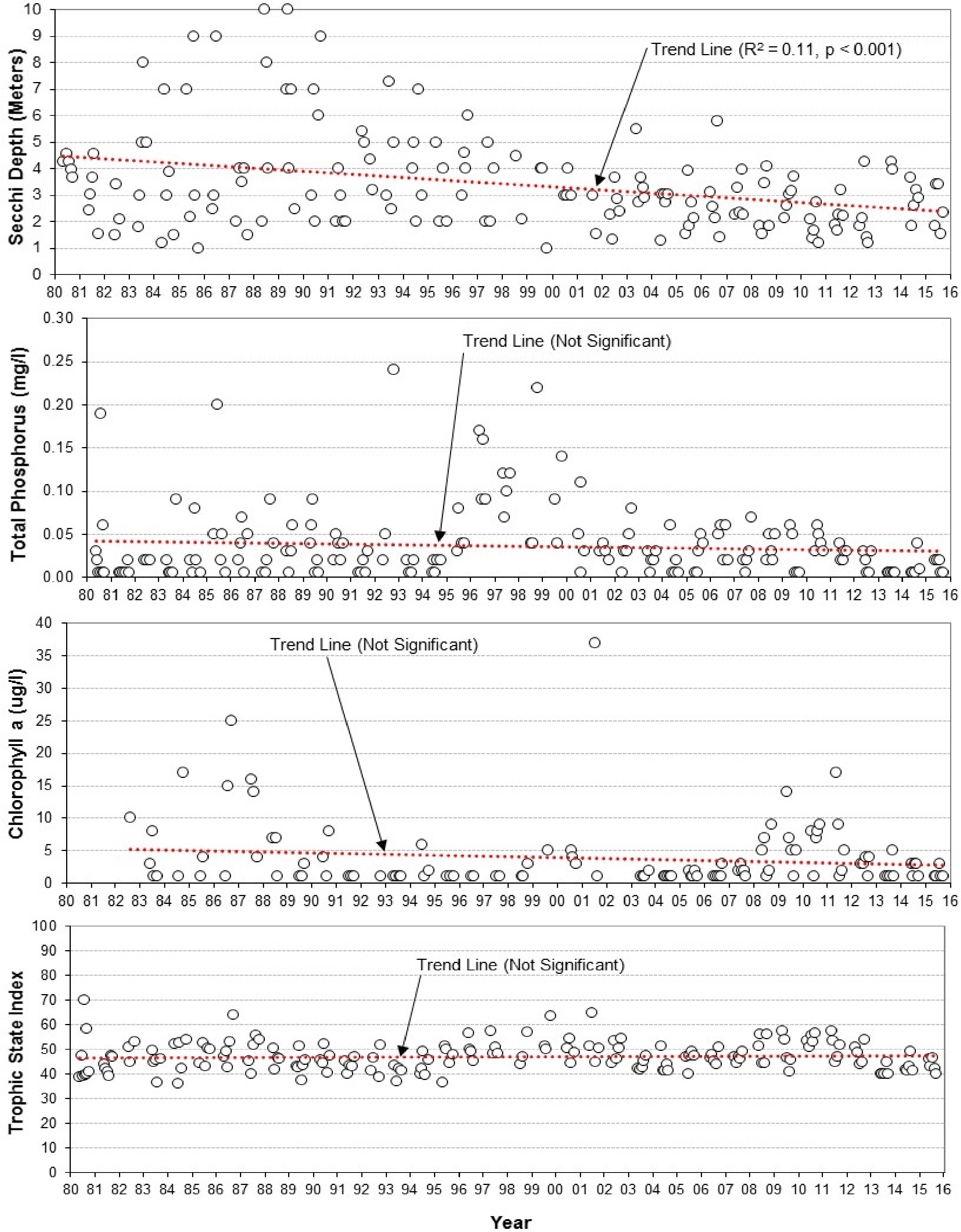


Plate 9-18. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Lake Francis Case at the near-dam, ambient site (i.e. site FTRLK0880A) over the 36-year period of 1980 through 2015.

Plate 9-19. Summary of water quality conditions monitored on water discharged through Fort Randall Dam (i.e. site FTRPP1) during the 5-year period of 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit(A)	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Dam Discharge – Powerplant (Mean Daily, cfs)	1	60	20,717	19,700	1,600	42,300	-----	-----	-----
Dam Discharge – Powerplant + Spillway (Mean Daily, cfs)	1	60	28,263	19,700	1,600	155,500	-----	-----	-----
Water Temperature (°C)	0.1	57	11.2	10.8	1.2	27.1	27(1,4)	1	2%
Dissolved Oxygen (mg/L)	0.1	58	10.6	10.2	6.7	14.4	5(1,5)	0	0%
Dissolved Oxygen (% Sat.)	0.1	58	96.6	96.7	80.7	116.5	-----	-----	-----
pH (S.U.)	0.1	56	8.1	8.2	7.1	8.5	6.5(1,2,5), 9.0(1,2,4), 9.5(3,4)	0	0%
Specific Conductance (uS/cm)	1	58	830	822	701	952	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	57	364	363	242	537	-----	-----	-----
Turbidity (NTU)	1	58	-----	2	n.d.	16	-----	-----	-----
Alkalinity, Total (mg/L)	7	60	167	168	147	182	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	60	4.2	4.3	2.7	5.4	-----	-----	-----
Chloride, Dissolved (mg/L)	1	33	13	13	11	15	438(2,4), 250(2,6)	0	0%
Colorized Dissolved Organic Matter (ug/L)	4	56	23	22	14	31	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	60	597	591	438	770	1,750(2,4), 1,000(2,7), 3,500(3,4), 2,000(3,6)	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	59	-----	n.d.	n.d.	0.18	5.7 (1,4,7), 1.7 (1,6,7)	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	60	0.4	0.4	0.2	0.7	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	60	-----	0.07	n.d.	0.30	10(2,4)	0	0%
Nitrogen, Total (mg/L)	0.1	60	0.5	0.5	0.2	0.9	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	60	-----	n.d.	n.d.	0.06	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	60	-----	0.02	n.d.	0.08	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	60	-----	n.d.	n.d.	0.06	-----	-----	-----
Sulfate (mg/L)	1	60	257	252	200	318	875(2,4), 500(2,6)	0	0%
Suspended Solids, Total (mg/L)	4	59	-----	5	n.d.	30	158(1,4), 90(1,6)	0	0%

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

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

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

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

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

Plate 9-20. Summary of annual metals and pesticide levels monitored on water discharged through Fort Randall Dam (i.e. site FTRPP1) during the 5-year period of 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/L)	40	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Aluminum, Total (ug/L)	40	5	116	110	n.d.	210	-----	-----	-----
Antimony, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	0.8	-----	-----	-----
Antimony, Total (ug/L)	0.5	5	-----	n.d.	n.d.	0.9	5.6[3]	0	0%
Arsenic, Dissolved (ug/L)	1	5	2	2	1	2	340[1], 150[2]	0	0%
Arsenic, Total (ug/L)	1	5	2	2	1	3	0.018[3]	5	100%
Barium, Dissolved (ug/L)	5	5	40	40	36	43	-----	-----	-----
Barium, Total (ug/L)	5	5	42	41	38	46	-----	-----	-----
Beryllium, Dissolved (ug/L)	2	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Beryllium, Total (ug/L)	2	5	-----	n.d.	n.d.	2	4[3]	0	0%
Cadmium, Dissolved (ug/L)	0.2	5	-----	n.d.	n.d.	0.6	4.6[1], 0.45[2]	0, 1	0%, 20%
Cadmium, Total (ug/L)	0.2	5	-----	n.d.	n.d.	0.8	5[3]	0	0%
Calcium, Dissolved (mg/L)	0.01	5	56.7	57.6	45.0	69.0	-----	-----	-----
Chromium, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	1,147[1], 149[2]	0	0%
Chromium, Total (ug/L)	10	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Copper, Dissolved (ug/L)	6	5	-----	n.d.	n.d.	9	30[1], 19[2],	0	0%
Copper, Total (ug/L)	6	5	-----	n.d.	n.d.	10	1,300[3]	0	0%
Hardness, Dissolved (mg/L)	1	5	236	235	188	284	-----	-----	-----
Iron, Dissolved (ug/L)	7	5	-----	n.d.	n.d.	10	-----	-----	-----
Iron, Total (ug/L)	7	5	130	130	60	220	-----	-----	-----
Lead, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	161[1], 6.3[2]	0	0%
Lead, Total (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Magnesium, Dissolved (mg/L)	0.01	5	23.3	23.8	18.9	26.6	-----	-----	-----
Manganese, Dissolved (ug/L)	2	5	9	6	4	19	-----	-----	-----
Manganese, Total (ug/L)	2	5	52	30	10	169	-----	-----	-----
Mercury, Dissolved (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[1]	0	0%
Mercury, Total (ug/L)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[2], 0.05[3]	0	0%
Nickel, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	n.d.	965[1], 107[2]	0	0%
Nickel, Total (ug/L)	10	5	-----	n.d.	n.d.	n.d.	610[3]	0	0%
Selenium, Dissolved (ug/L)	1	5	-----	2	n.d.	2	-----	-----	-----
Selenium, Total (ug/L)	1	5	2	2	n.d.	3	4.6[2], 170[3]	0	0%
Silver, Dissolved (ug/L)	1	5	-----	n.d.	n.d.	n.d.	14[1]	0	0%
Silver, Total (ug/L)	1	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Sodium, Dissolved (mg/L)	0.01	5	85.5	85.5	66.5	98.3	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Thallium, Total (ug/L)	0.5	5	-----	n.d.	n.d.	n.d.	0.24[3]	b.d.	b.d.
Zinc, Dissolved (ug/L)	10	5	-----	n.d.	n.d.	10	242[1,2]	0	0%
Zinc, Total (ug/L)	10	5	-----	n.d.	n.d.	10	7,400[3]	0	0%
Pesticide Scan (ug/L)[C]	0.05[D]	5	-----	n.d.	n.d.	n.d.	-----	-----	-----

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

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

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

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

- [1] Acute (CMC) criterion for the protection of freshwater aquatic life.
- [2] Chronic (CCC) criterion for the protection of freshwater aquatic life.
- [3] Criterion for the protection of human health.

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

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

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

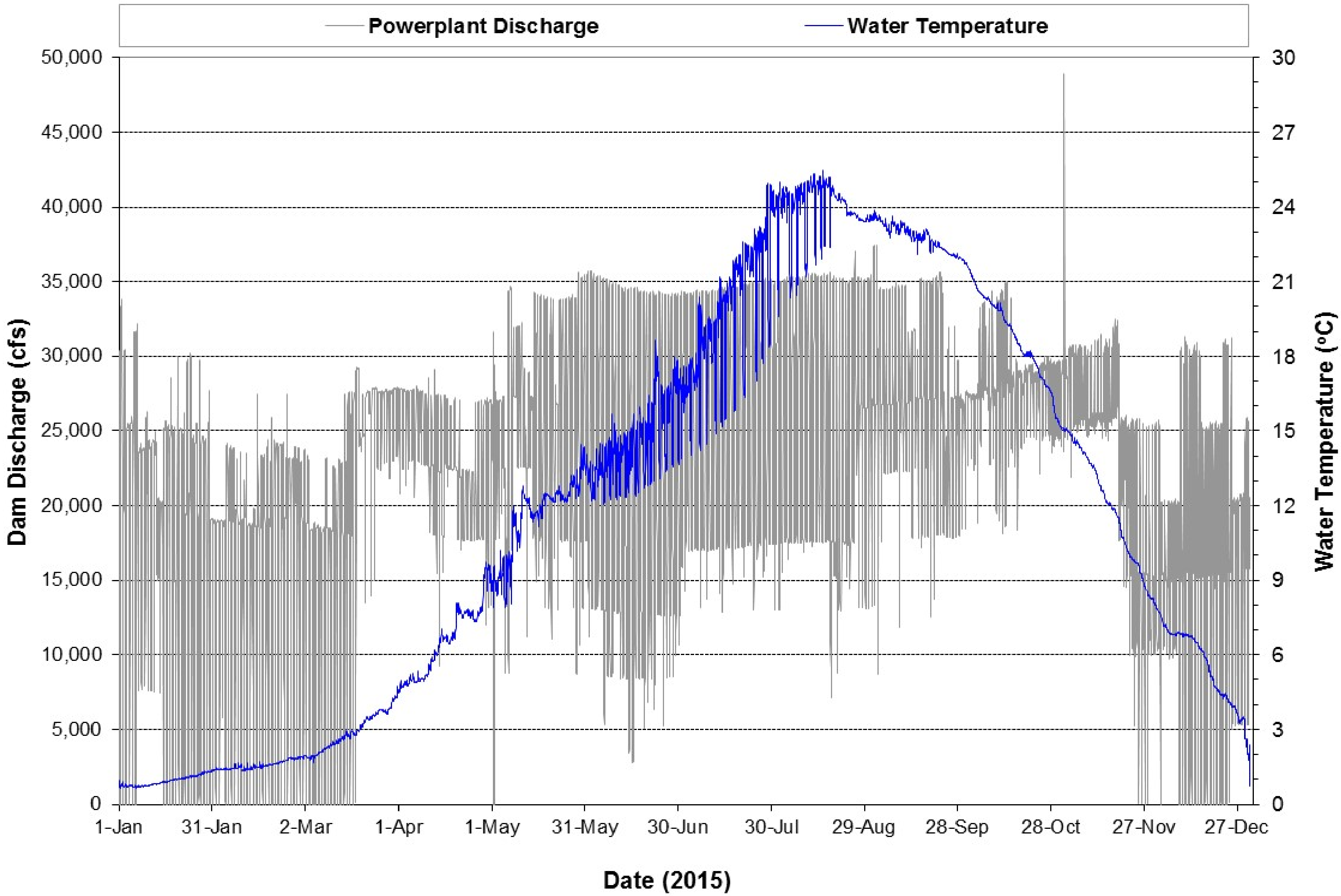


Plate 9-21. Hourly discharge and water temperature monitored at the Fort Randall powerplant on water discharged through the dam during 2015.

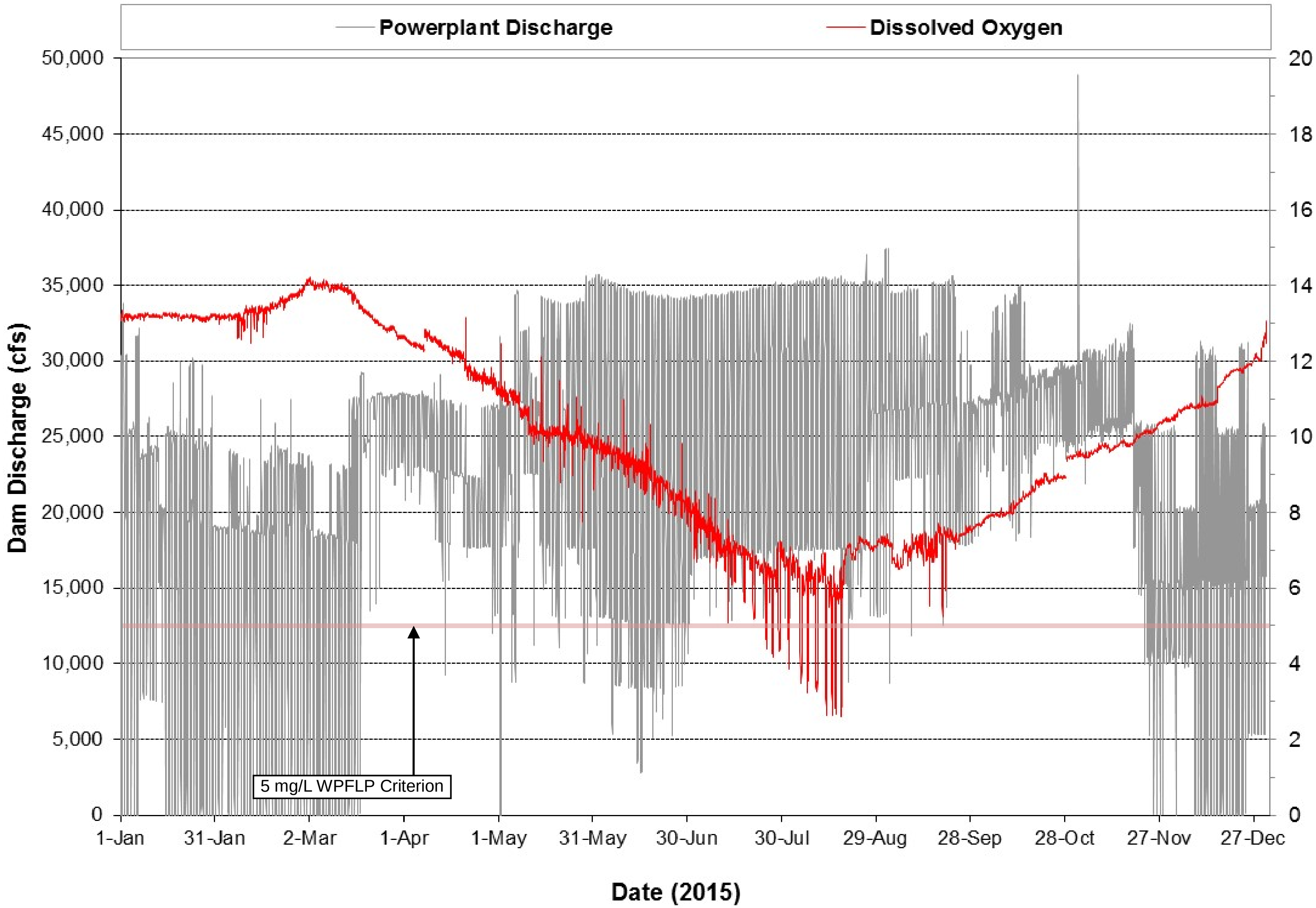


Plate 9-22. Hourly discharge and dissolved oxygen concentrations monitored at the Fort Randall powerplant on water discharged through the dam during 2015.

Plate 9-23. Summary of water quality conditions monitored in the Missouri River at the Fort Randall Dam tailwaters (i.e. site FTRRRTW1) during the 5-year period of 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit(A)	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Streamflow (cfs)	1	59	29,528	22,373	2,118	154,161	-----	-----	-----
Water Temperature (°C)	0.1	58	11.6	10.6	0.1	26.6	27(1,4)	0	0%
Dissolved Oxygen (mg/L)	0.1	58	11.0	11.1	6.3	14.3	≥ 5(1,5)	0	0%
Dissolved Oxygen (% Sat.)	0.1	58	101.8	101.6	79.4	125.2	-----	-----	-----
pH (S.U.)	0.1	57	8.1	8.2	6.9	9.3	6.5(1,2,5), 9.0(1,2,4), 9.5(3,4)	0, 1, 0	0%, 2%, 0%
Specific Conductance (uS/cm)	1	57	838	835	706	959	-----	-----	-----
Oxidation-Reduction Potential	1	57	362	364	230	530	-----	-----	-----
Alkalinity, Total (mg/L)	7	59	167	168	149	182	-----	-----	-----
Carbon, Total Organic (mg/L)	0.3	59	4.2	4.3	n.d.	7.2	-----	-----	-----
Chemical Oxygen Demand (mg/L)	2	50	11	11	2	18	-----	-----	-----
Chloride (mg/L)	1	59	12	12	5	15	438(2,4), 250(2,6)	0	0%
Colorized Dissolved Organic Matter (ug/L)	4	56	23	22	14	43	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	59	597	590	414	750	1,750(2,4), 1,000(2,7), 3,500(3,4), 2,000(3,6)	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	59	-----	0.03	n.d.	0.24	5.7 (1,4,7), 1.7 (1,6,7)	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	59	0.4	0.4	n.d.	2.2	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	59	-----	0.06	n.d.	0.30	10(2,4)	0	0%
Nitrogen, Total (mg/L)	0.1	59	0.5	0.4	n.d.	2.4	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	59	-----	n.d.	n.d.	0.04	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	59	-----	0.02	n.d.	0.09	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	59	-----	n.d.	n.d.	0.04	-----	-----	-----
Suspended Solids, Total (mg/L)	4	58	9	6	n.d.	91	158(1,4), 90(1,6)	0, 1	0%, 2%
Turbidity (NTU)	1	58	4	3	n.d.	21	-----	-----	-----
Acetochlor, Total (ug/L)(D)	0.1	58	-----	n.d.	n.d.	0.4	-----	-----	-----
Atrazine, Total (ug/L)(D)	0.1	58	-----	n.d.	n.d.	0.5	-----	-----	-----
Metolachlor, Total (ug/L)(D)	0.1	58	-----	n.d.	n.d.	0.8	-----	-----	-----

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

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

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

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

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

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

(D) Immunoassay analysis.

Plate 9-24. Summary of water quality conditions monitored in the Missouri River near Verdel, Nebraska (i.e. site MORRR0851) at RM851 during the 5-year period of 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[A]	No. of Obs.	Mean[B]	Median	Min.	Max.	State WQS Criteria[C]	No. of WQS Exceedances	Percent WQS Exceedance
Streamflow (cfs)	1	47	27,317	26,985	3,848	87,963	-----	-----	-----
Water Temperature (°C)	0.1	47	13.0	12.2	0.9	27.0	27[1,2,6], 29[1,2,6]	0	0%
Dissolved Oxygen (mg/L)	0.1	47	10.5	10.3	7.6	13.7	5[1,7]	0	0%
Dissolved Oxygen (% Sat.)	0.1	47	99.9	99.0	91.4	109.6	-----	-----	-----
pH (S.U.)	0.1	46	8.2	8.3	7.2	8.6	6.5[1,3,7], 9.0[1,3,6], 9.5[5,6]	0	0%
Specific Conductance (uS/cm)	1	47	847	846	701	954	2,000[4]	0	0%
Oxidation-Reduction Potential	1	47	355	359	231	443	-----	-----	-----
Alkalinity, Total (mg/L)	7	46	167	168	148	182	-----	0	0%
Carbon, Total Organic (mg/L)	0.05	47	4.3	4.3	2.5	5.2	-----	-----	-----
Chemical Oxygen Demand (mg/L)	2	39	11	10	3	20	-----	-----	-----
Chloride (mg/L)	1	46	12	12	10	15	438[3,6], 250[3,8]	0	0%
Colorized Dissolved Organic Matter (ug/L)	4	46	22	21	14	29			
Dissolved Solids, Total (mg/L)	5	46	595	596	466	848	1,750[3,6], 1,000[3,8], 3,500[5,6], 2,000[5,8]	0	0%
Hardness, Total (mg/L)	1	13	248	254	213	277	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	47	-----	0.02	n.d.	0.13	4.7 [1,6,9], 1.4 [1,8,9]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	47	0.4	0.4	n.d.	1.1	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	47	-----	0.05	n.d.	0.30	10[3,6], 100[4,6]	0	0%
Nitrogen, Total (mg/L)	0.1	47	0.4	0.4	0.1	1.2	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	46	-----	n.d.	n.d.	0.05	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	47	-----	0.02	n.d.	0.07	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	47	-----	n.d.	n.d.	0.04	-----	-----	-----
Sulfate (mg/L)	1	46	263	258	202	317	875[3,6], 500[3,8]	0	0%
Suspended Solids, Total (mg/L)	4	47	-----	6	n.d.	38	158[1,6], 90[1,8]	0	0%
Turbidity (NTU)	1	47	7	3	n.d.	89	-----	-----	-----
Aluminum, Dissolved (ug/L)	40	13	-----	n.d.	n.d.	150	750[10], 87[11], 200[12]	0, 2, 0	0%, 17%, 0%
Antimony, Dissolved (ug/L)	0.5	13	-----	n.d.	n.d.	n.d.	88[10], 30[11], 6[12]	0	0%
Arsenic, Dissolved (ug/L)	1	13	2	2	n.d.	3	340[10], 16.7[11], 10[12]	0	0%
Barium, Dissolved (ug/L)	5	13	41	42	33	46	2,000[11]	0	0%
Beryllium, Dissolved (ug/L)	2	13	-----	n.d.	n.d.	n.d.	130[10], 5.3[11], 4[12]	0	0%
Cadmium, Dissolved (ug/L)	0.2	13	-----	n.d.	n.d.	n.d.	4.7[10], 0.45[11], 5[12]	0, 1, 0	0%, 8%, 0%
Calcium, Dissolved (mg/L)	0.01	13	58.6	59.6	52.0	65.6	-----	-----	-----
Chromium, Dissolved (ug/L)	10	13	-----	n.d.	n.d.	n.d.	1,163[10], 151[11], 100[12]	0	0%
Copper, Dissolved (ug/L)	6	13	-----	n.d.	n.d.	20	31[10], 19[11], 1,000[12]	0, 1, 0	0%, 8%, 0%
Iron, Dissolved (ug/L)	7	13	-----	10	n.d.	120	1,000[11]	0	0%
Lead, Dissolved (ug/L)	0.5	13	-----	n.d.	n.d.	n.d.	164[10], 6.4[11], 15[12]	0	0%
Magnesium, Dissolved (mg/L)	0.01	10	24.6	25.1	20.3	27.8	-----	-----	-----
Manganese, Dissolved (ug/L)	2	13	-----	4	n.d.	20	-----	-----	-----
Mercury, Dissolved (ug/L)	0.05	13	-----	n.d.	n.d.	n.d.	1.4[10]	0	0%
Mercury, Total (ug/L)	0.05	13	-----	n.d.	n.d.	n.d.	0.77[11], 2[12]	0	0%
Nickel, Dissolved (ug/L)	10	13	-----	n.d.	n.d.	20	979[10], 109[11], 100[12]	0	0%
Selenium, Total (ug/L)	1	13	2	2	n.d.	2	20[4,10], 5[11], 50[12]	0	0%
Silver, Dissolved (ug/L)	1	13	2	2	n.d.	2	14[10], 100[12]	0	0%
Sodium, Dissolved (mg/L)	0.01	11	87.7	87.8	69.5	105.0	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	13	-----	n.d.	n.d.	n.d.	1,400[10], 6.3[11], 2[12]	0	0%
Zinc, Dissolved (ug/L)	5	13	-----	n.d.	n.d.	20	245[10,11], 5,000[12]	0	0%
Acetochlor, Total (ug/L)[D]	0.1	47	-----	n.d.	n.d.	0.7	-----	-----	-----
Atrazine, Total (ug/L)[D]	0.1	47	-----	n.d.	n.d.	0.5	330[10], 12[11], 3[12]	0	0%
Metolachlor, Total (ug/L)[D]	0.1	47	-----	n.d.	n.d.	1.0	390[10], 100[11]	0	0%
Pesticide Scan (ug/L)[E]	0.05[F]	5	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

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

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

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

- (1) Criteria for the protection of Warmwater Permanent Fish Life Propagation Waters (South Dakota) or Class I Warmwater Aquatic Life (Nebraska).
- (2) South Dakota's temperature criterion is 27°C and Nebraska's is 29°C.
- (3) Criteria for the protection of domestic water supply waters.
- (4) Criteria for the protection of agricultural water supply waters.
- (5) Criteria for the protection of commerce and industry waters.
- (6) Daily maximum criterion (monitoring results directly comparable to criterion).
- (7) Daily minimum criterion (monitoring results directly comparable to criterion).
- (8) 30-day average criterion (monitoring results not directly comparable to criterion).
- (9) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (10) Acute (CMC) criterion for the protection of freshwater aquatic life.
- (11) Chronic (CCC) criterion for the protection of freshwater aquatic life.
- (12) Criterion for the protection of human health.

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

(D) Immunoassay analysis.

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

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

10 GAVINS POINT PROJECT

10.1 BACKGROUND INFORMATION

10.1.1 PROJECT OVERVIEW

Gavins Point Dam is located on the Missouri River at RM 811.1 on the South Dakota-Nebraska border in southeast South Dakota and northeast Nebraska, 4 miles west of Yankton, SD. The closing of Gavins Point Dam in 1955 resulted in the formation of Gavins Point Reservoir (Lewis and Clark Lake). The reservoir is 25 miles long, covers 31,000 acres, and has 90 miles of shoreline when full. Table 10-1 summarizes how the surface area, volume, mean depth, and retention time of Lewis and Clark Lake vary with pool elevations. Major inflows to Lewis and Clark Lake are the Missouri River and Niobrara River. Figure 10-1 provides an aerial photo of Gavins Point Dam and the surrounding area.

Gavins Point was authorized for the proposes of flood control, recreation, fish and wildlife, hydroelectric power production, water supply, water quality, navigation, and irrigation. Habitat for two endangered species, pallid sturgeon and interior least tern, and one threatened species, piping plover, occur within the project area. Lewis and Clark Lake is a source water supply (drinking water) for Springfield, SD (RM832); Cedar Knox Rural Water District (RM823 – Crofton, Fordice, St. Helena, and Obert, NE); and Bon Homme-Yankton Rural Water District (RM818 – 15 communities). The reservoir is an important recreational resource and a major visitor destination in South Dakota and Nebraska.

Table 10-1. Surface area, volume, mean depth, and retention time of Lewis and Clark Lake at different pool elevations based on 2007 bathymetric survey.

Elevation (Feet-NGVD29)	Surface Area (Acres)	Volume (Acre-Feet)	Mean Depth (Feet)*	Retention Time (Years)**
1210	29,956	450,070	15.0	0.02244
1205	23,029	318,732	13.8	0.01589
1200	18,819	215,126	11.4	0.01073
1195	14,278	132,308	9.3	0.00660
1190	9,921	71,711	7.2	0.00358
1185	5,202	35,027	6.7	0.00175
1180	3,393	14,543	4.3	0.00073
1175	1,067	3,855	3.6	0.00019
1170	371	728	2.0	0.00004

Average Annual Inflow (1967 through 2015) = 20.150 Million Acre-Feet.
Average Annual Outflow: (1967 through 2015) = 20.053 Million Acre-Feet.
* Mean Depth = Volume ÷ Surface Area.
** Retention Time = Volume ÷ Average Annual Outflow.
Note: Exclusive Flood Control Zone (elev. 1210-1208 ft-NGVD29), Annual Flood Control and Multiple Use Zone (elev. 1208-1204.5 ft-NGVD29), Carryover Multiple Use Zone (none), and Permanent Pool Zone (elev. 1204.5-1160 ft-NGVD29). All elevations are in the NGVD 29 datum.

Lewis and Clark Lake is normally regulated near elevation 1206.0 ft-NGVD29 in the spring and early summer with variations day to day due to rainfall runoff. The reservoir level is then increased to elevation 1207.5 ft-NGVD29 following the least tern and piping plover nesting season for reservoir recreation enhancement. Water discharged through Gavins Point Dam for power production is withdrawn from the bottom of Lewis and Clark Lake at an invert elevation of 1139.5 ft-NGVD29. Figure 10-2 plots the midnight pool elevation of Lewis and Clark Lake and the mean daily discharge of Gavins Point Dam over the 5-year period 2011 through 2015. The extreme discharges in 2011 reflect additional releases made through the spillway to manage the high inflows to the reservoir during 2011 flood conditions.

Figure 10-1. Aerial photo of Gavins Point Dam and surrounding area.

10.1.2 WATER QUALITY STANDARDS CLASSIFICATIONS AND SECTION 303(D) LISTINGS

10.1.2.1 Lewis and Clark Lake

Pursuant to the Federal Clean Water Act, the State of South Dakota has designated the following water quality-dependent beneficial uses for Lewis and Clark Lake: 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. The State of Nebraska has designated the following beneficial uses to Lewis and Clark Lake: primary contact recreation, Class A warmwater aquatic life, drinking water supply, agricultural water supply, industrial water supply, and aesthetics. The uses designated by the States of South Dakota and Nebraska to Lewis and Clark Lake are consistent with each other. Both Nebraska and South Dakota have listed Lewis and Clark Lake on the State's 2016 Section 303(d) list of impaired waters. Nebraska has listed the reservoir for impairment to the Aquatic Life use due to chlorophyll-*a*. South Dakota has issued a fish consumption advisory for mercury and listed the reservoir as impaired due to contaminated fish tissue (mercury). Nebraska has not issued a fish consumption advisory for Lewis and Clark Lake.

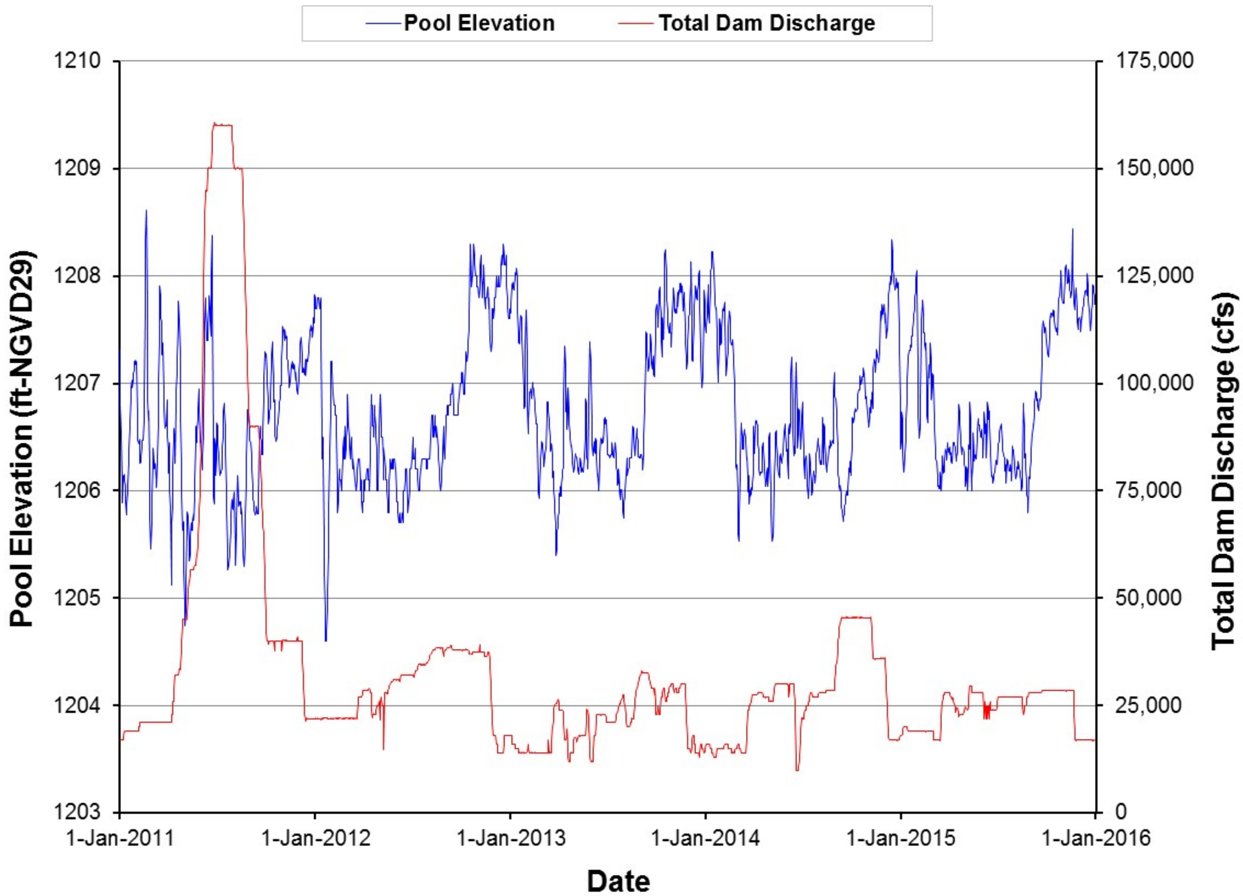


Figure 10-2. Lewis and Clark Lake midnight pool elevation and the mean daily discharge of Gavins Point Dam over the 5-year period 2011 through 2015.

10.1.2.2 <u>Missouri River Downstream of Gavins Point Dam</u>

See Section 11 for a discussion of the Lower Missouri River downstream of Gavins Point Dam.

10.1.3 AMBIENT WATER QUALITY MONITORING

The District has monitored water quality conditions at the Gavins Point Project since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow to and outflow from the reservoir. Figure 10-3 shows the location of sites at the Gavins Point Project that have been monitored by the District for water quality during the 5-year period 2011 through 2015. The near-dam location (i.e. site GPTLK0811A) has been continuously monitored since 1980.

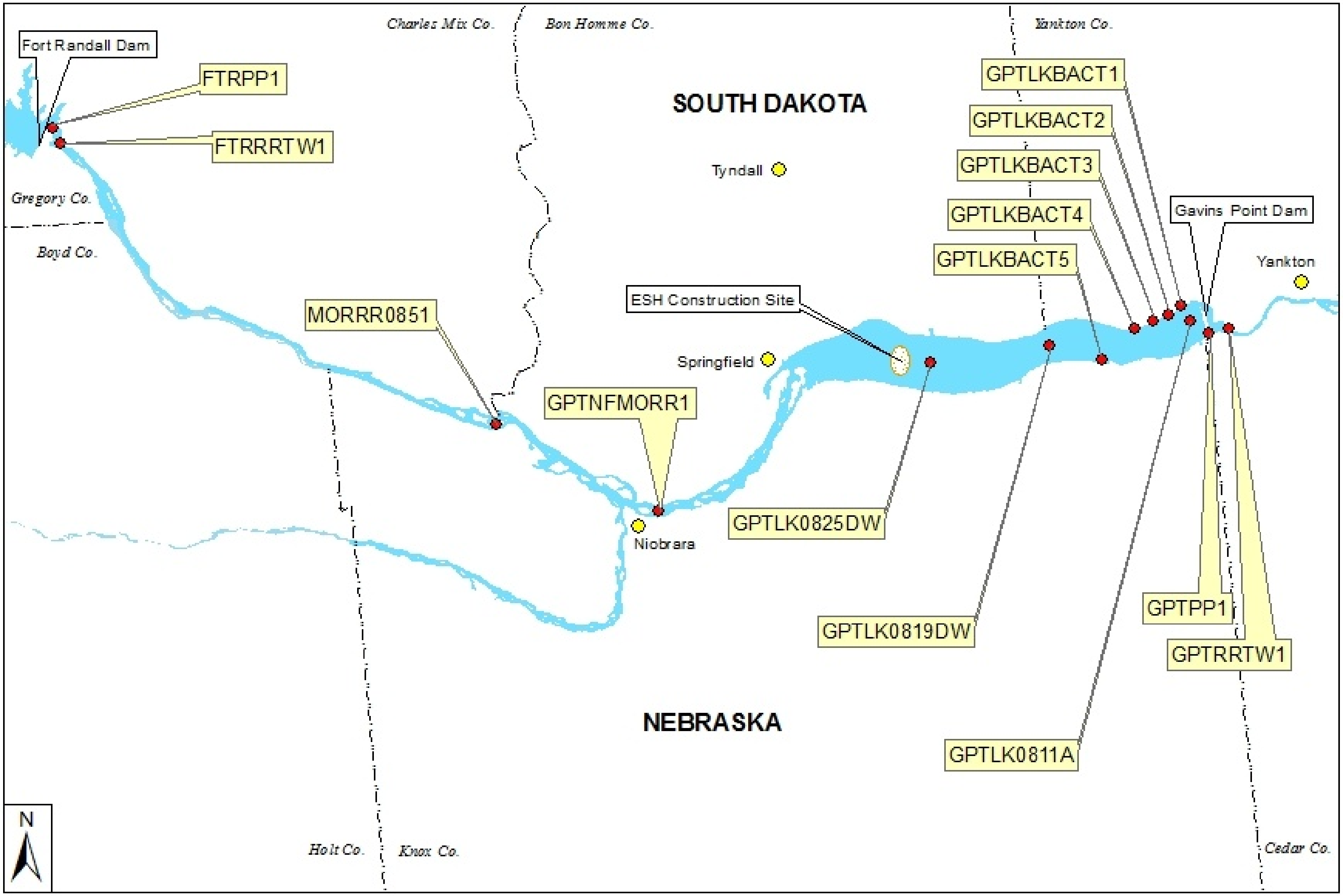


Figure 10-3. Location of sites where water quality monitoring was conducted by the District at the Gavins Point Project during the 5-year period 2011 to 2015.

10.2 WATER QUALITY IN LEWIS AND CLARK LAKE

10.2.1 EXISTING WATER QUALITY CONDITIONS

10.2.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Water quality conditions that were monitored in Lewis and Clark Lake at sites GTPLK0811A, GTPLK0819DW, and GTPLK0825DW from May through September during the 5-year period 2011 through 2015 are summarized in Plate 10-1, Plate 10-2, and Plate 10-3. These results indicate a water quality concern regarding chlorophyll-*a*. The Nebraska water quality standards' criterion for chlorophyll *a* applicable to Lewis and Clark Lake was regularly exceeded throughout the reservoir.

10.2.1.2 Summer Thermal Stratification and Dissolved Oxygen Conditions during 2015

10.2.1.2.1 Depth-Profile Plots

Depth-profile plots of temperature and dissolved oxygen measurements taken at sites GPTLK0811A, GPTLK0819DW, and GPTLK825DW during 2015 are shown in Plate 10-4.

10.2.1.2.2 Longitudinal Temperature Contour Plots

Summer thermal stratification of Lewis and Clark Lake during 2015 is described by the monthly longitudinal temperature contour plots based on depth-profile temperature measurements taken in May, June, July, August, and September (Plate 10-5, Plate 10-6, Plate 10-7, Plate 10-8, and Plate 10-9). The contour plots were constructed along the length of the reservoir. As seen in the contour plots, water temperature in Lewis and Clark Lake varies longitudinally from the dam to the reservoir's upstream reaches and vertically from the reservoir surface to the bottom. Although some summer thermal stratification of Lewis and Clark Lake can occur, the relative shallowness, short retention time, and bottom withdrawal of the reservoir seemingly inhibit the formation of a strong thermocline and long-lasting stratification during the summer.

10.2.1.2.3 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen longitudinal contour plots were constructed along the length of Lewis and Clark Lake based on depth-profile measurements taken in May, June, July, August, and September of 2015 (Plate 10-10, Plate 10-11, Plate 10-12, Plate 10-13, and Plate 10-14). Dissolved oxygen levels below 5 mg/l were measured in June and July near the dam at the bottom of the reservoir.

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

Paired near-surface and near-bottom water quality samples collected from Lewis and Clark Lake during the summer were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site GPTLK0811A during the 5-year period 2011 through 2015. During the period a total of 19 paired samples were collected monthly from June through September. Box plots were constructed to display the distribution of the paired near-surface and near-bottom measurements for the following parameters: water temperature, dissolved oxygen, pH, alkalinity, total ammonia, and total phosphorus (Plate 10-15). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for all assessed parameters except alkalinity. Parameters that were significantly lower in the near-bottom water of Lewis and Clark Lake included: water temperature ($p < 0.001$), dissolved oxygen ($p < 0.001$), and pH ($p < 0.001$). Parameters that were significantly higher in the near-bottom water included: total ammonia ($p <0.05$) and total phosphorus ($p < 0.01$).

10.2.1.4 Reservoir Trophic Status

Trophic State Index (TSI) values for Lewis and Clark Lake were calculated from monitoring data collected during the 5-year period 2011 through 2015 (Table 10-2). The calculated TSI values indicate that the reservoir is eutrophic.

Table 10-2. Mean Trophic State Index (TSI) values calculated for Lewis and Clark Lake. TSI values are based on monitoring at the identified three sites during the 5-year period 2011 through 2015.

Monitoring Site	Mean – TSI (Secchi Depth)	Mean – TSI (Total Phosphorus)	Mean – TSI (Chlorophyll)	Mean – TSI (Average)
GPTLK0811A	61	47	59	56
GPTLK0819DW	71	52	60	61
GPTLK0825DW	74	54	61	63

Note: See Section 4.1.4 for discussion of TSI calculation.

10.2.1.5 Plankton Community

10.2.1.5.1 Phytoplankton

Phytoplankton grab samples were collected from Lewis and Clark Lake at sites GPTLK0811A, GPTLK0819DW, and GPTLK0825DW during the spring and summer of 2015. The following seven taxonomic divisions were represented by taxa collected in the phytoplankton samples: Bacillariophyta (Diatoms), Chlorophyta (Green Algae), Chrysophyta (Golden Algae), Cryptophyta (Cryptomonad Algae), Cyanobacteria (Blue-Green Algae), Pyrrophyta (Dinoflagellate Algae), and Euglenophyta (Euglenoid Algae). The relative abundance of phytoplankton in samples collected from Lewis and Clark Lake in May, July, and September 2015, based on biovolume, is shown in Figure 10-4. Diatoms were the most dominant phytoplankton group present in Lewis and Clark Lake during 2015. No levels of microcystin above 1 ug/L were monitored at sites GPTLK0811A, GPTLK0818DW, or GPTLK0825DW during the 5-year period 2011 through 2015 (Plate 10-1, Plate 10-2, and Plate 10-3).

10.2.1.5.2 Zooplankton

Zooplankton vertical-tow samples were collected from Lewis and Clark Lake at sites GPTLK0811A, GPTLK0819DW, and GPTLK0825DW in May, July, and September of 2015. The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of these four taxonomic groupings, based on biomass of the collected samples, is shown in Figure 10-5. Cladocerans and Copepods were most abundant zooplankton sampled in the 2015.

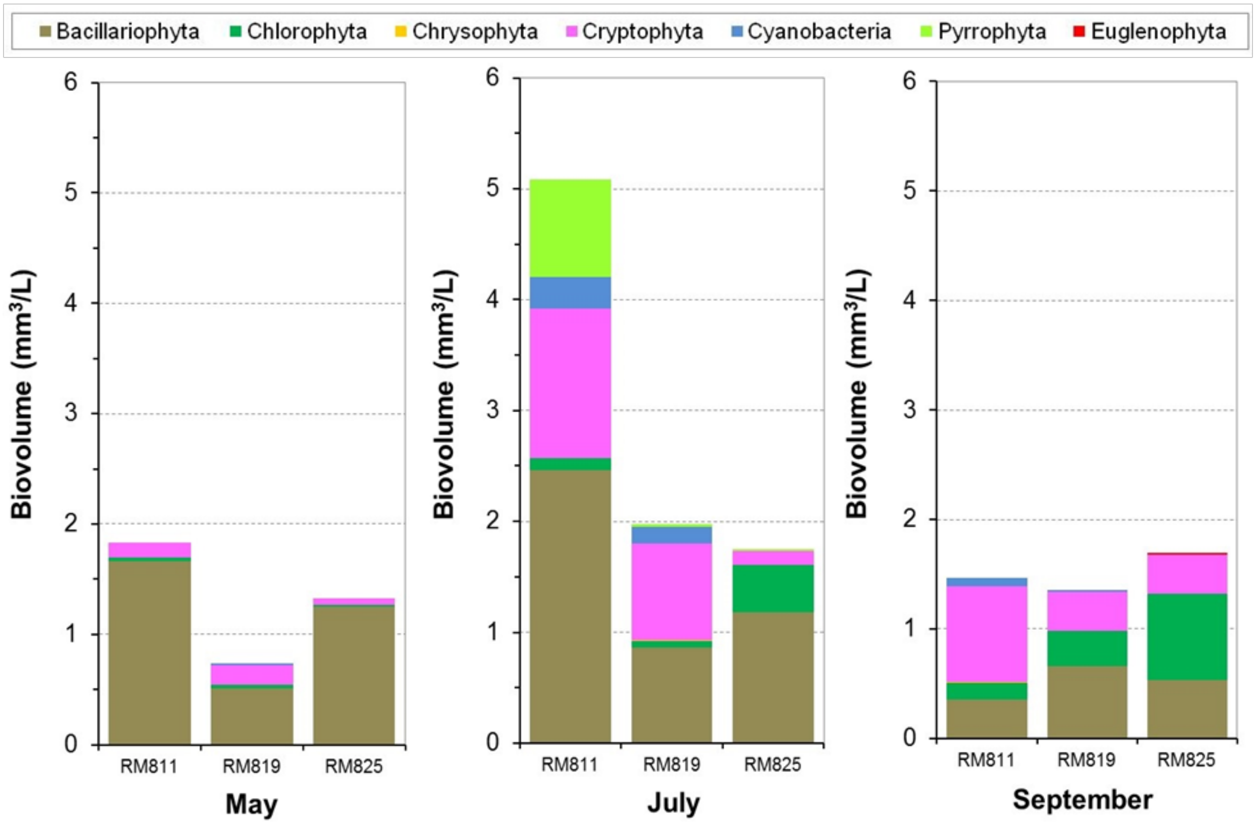


Figure 10-4. Relative abundance of phytoplankton in samples collected from Lewis and Clark Lake during 2015.

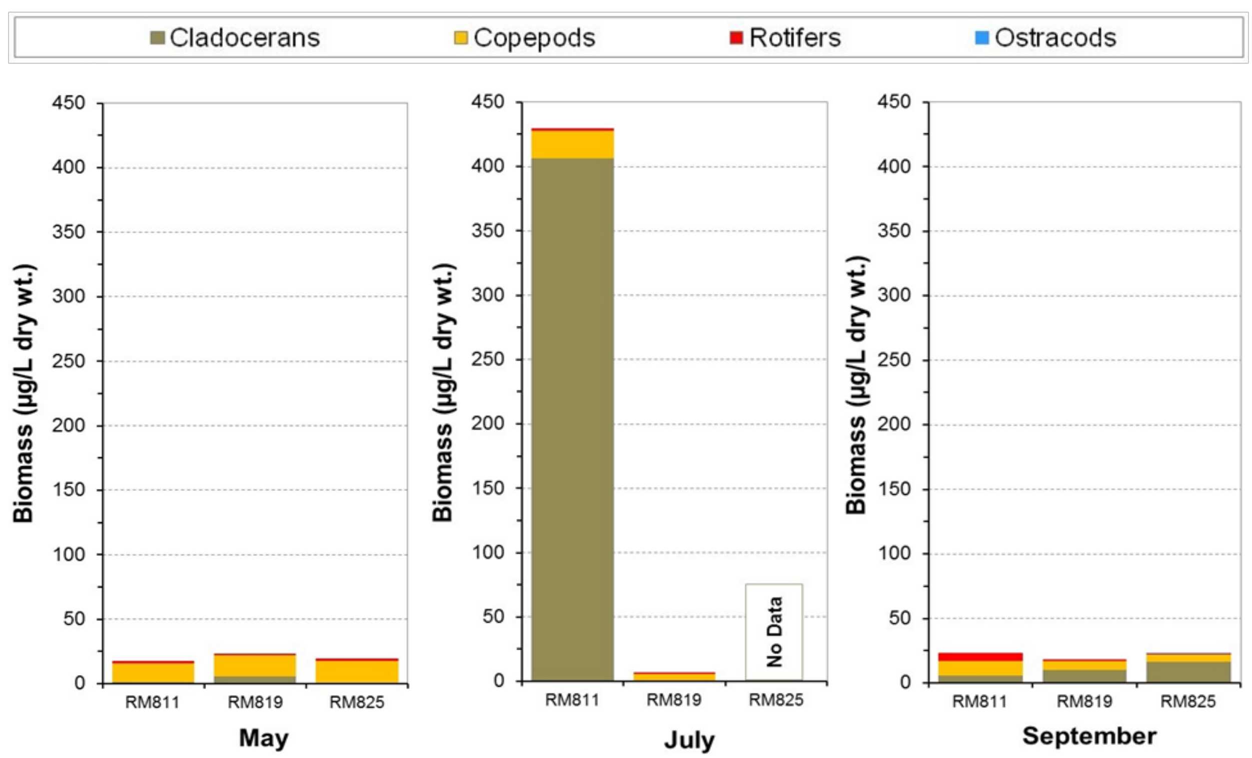


Figure 10-5. Relative abundance of zooplankton in samples collected from Lewis and Clark Lake during 2015**.**

10.2.1.6 Bacteria Monitoring at Swimming Beaches on Lewis and Clark Lake

During the 5-year period 2011 through 2015, bacteria samples were collected weekly from May through September at five swimming beaches located on Lewis and Clark Lake. The five swimming beaches where the bacteria samples were collected were: Weigand Recreation Area (site GPTLKBACT5), Gavins Point Recreation Area (site GPTLKBACT4), Lewis and Clark Recreation Area – Midway West Beach (site GPTLKBACT3) and Midway East Beach (GPTLKBACT2), and the Marina Sailing Boat Area (site GPTLKBACT1) (Figure 10-3). Table 10-3 summarizes the results of the bacteria sampling. The geometric means were calculated as running geometric means for five consecutive weekly bacteria samples and nondetects were set to 1. The bacteria sampling results were compared to the following bacteria criteria for support of "full-body contact" recreation:

> *E. coli*:
> *E. coli* bacteria should not exceed a geometric mean of 126/100ml. For increased confidence of the criteria, the geometric mean should be based on a minimum of five samples taken within a 30-day period. Single sample maximum allowable density for designated bathing beaches is 235/100ml.

Nebraska's recreational impairment assessment methodology defines criteria for "seasonal geomeans" for *E. coli* bacteria. The calculated seasonal *E. coli* geomeans at GPTLKBACT5 for 2011, 2012, 2013, 2014, and 2015 are, respectively, 44, 11, 45, 95, and 26. Based on these criteria, recreation was fully supported at the Nebraska swimming beach on Lewis and Clark Lake during the 5-year period 2011 through 2015. It is noted that 18 percent of the calculated *E. coli* geomeans at site GPTLKBACT5 exceeded the geometric mean criteria of 126/100ml over the 5-year period (Table 10-3).

10.2.2 WATER QUALITY TRENDS (1980 THROUGH 2015)

Water quality trends over the 35-year period of 1980 through 2015 were determined for Lewis and Clark Lake for Secchi depth, total phosphorus, chlorophyll *a*, and TSI (i.e. trophic status). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam monitoring site (i.e. site GPTLK0811A). Plate 10-16 displays a scatter-plot of the collected data for the four parameters, a linear regression trend line, and the significance of the trend line (i.e. $\alpha = 0.05$). For the assessment period, Lewis and Clark Lake exhibited no significant trends for the four parameters. Over the 36-year period, the near-dam area of the reservoir has generally remained in a moderately eutrophic to eutrophic state.

10.3 EXISTING WATER QUALITY CONDITIONS OF THE MISSOURI RIVER INFLOW TO LEWIS AND CLARK LAKE

10.3.1 STATISTICAL SUMMARY AND COMPARISON TO APPLICABLE WATER QUALITY STANDARDS CRITERIA

The water quality conditions that were monitored in the Missouri River near Running Water, SD at site GPTNFMORR1 (Figure 10-3) during the 5-year period 2011 through 2015 are summarized in Plate 10-17. A review of these results indicated no significant water quality concerns.

Table 10-3. Summary of weekly (May through September) bacteria sampling conducted at five swimming beaches on Lewis and Clark Lake over the 5-year period 2011 through 2015.

	Weigand Recreation Area (GPTLKBACT5)	**Gavins Point Recreation Area (GPTLKBACT4)**	**Lewis & Clark Rec. Area Midway West (GPTLKBACT3)**	**Lewis & Clark Rec. Area Midway East (GPTLKBACT2)**	**Marina Sailing Boat Area (GPTLKBACT1)**
Fecal Coliform Bacteria (cfu/100ml):					
Number of Samples	109	108	109	109	109
Mean	369	23	67	31	65
Median	28	6	4	6	5
Minimum	1	1	1	1	1
Maximum	20,500	336	4,800	506	1,568
Percent of samples exceeding 400/100ml	9%	0%	1%	2%	4%
• **Geometric Mean**					
Number of Geomeans	89	89	89	89	89
Average	57	11	12	13	15
Median	37	8	6	8	9
Minimum	1	2	1	2	1
Maximum	515	40	85	67	93
Percent of Geomeans exceeding 200/100ml	3%	0%	0%	0%	0%
***E. coli* Bacteria (MPN/100ml)**					
Number of Samples	109	109	107	109	109
Mean	758	40	60	62	151
Median	32	8	4	6	10
Minimum	1	1	1	1	1
Maximum	36,540	1,159	1,733	1,454	4,352
Percent of samples exceeding 235/100ml	17%	4%	6%	7%	9%
• **Geomean**					
Number of Geomeans	89	89	89	89	89
Average	77	15	19	20	24
Median	44	8	6	9	12
Minimum	2	2	1	1	2
Maximum	745	84	249	195	188
Percent of Geomeans exceeding 126/100ml	18%	0%	1%	2%	3%

n.d. = Not detected.
Note: Not detected values set to 1 to calculate mean and geometric mean.

10.3.2 NUTRIENT FLUX CONDITIONS

Nutrient flux rates of the Missouri River downstream of the Niobrara River and upstream of Lewis and Clark Lake were calculated based on near-surface water quality samples collected from the Missouri River near Running Water, SD (i.e. site GPTNFNIOR1) and the instantaneous flow conditions at the time of sample collection (Table 10-4). It must be recognized that the concentrations of particulate-associated constituents can vary significantly from the river surface to its bottom because of the sinking of particulate matter and its transport nearer the river bottom. Since the instantaneous concentration of particulate-associated constituents (i.e. total phosphorus and total organic carbon) are likely higher nearer the river bottom, near-surface grab samples likely under estimate the "true" water-column composite concentration for these constituents. Thus, the flux rates given for total phosphorus and total organic carbon in Table 10-4 should be considered minimum estimates with the actual flux rates being higher. The maximum nutrient flux rates are attributed to greater nonpoint-source nutrient loadings associated with runoff conditions.

Table 10-4. Summary of nutrient flux rates (kg/sec) calculated for the Missouri River near Running Water, SD (i.e. site GPTNFMORR1) for the 5-year period 2011 through 2015.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	36	36	36	36	36	36	36
Mean	41,214	0.0331	0.4599	0.1131	0.0365	0.0077	4.9718
Median	31,408	n.d.	0.3123	0.0486	0.0202	n.d.	4.0138
Minimum	5,981	n.d.	n.d.	n.d.	n.d.	n.d.	0.7113
Maximum	158,219	0.3278	2.0489	0.7376	0.2688	0.0896	17.9205

Note: Non-detect values set to 0 for flux calculations.

10.4 WATER QUALITY AT THE GAVINS POINT POWERPLANT

10.4.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Plate 10-18 and Plate 10-19 summarize the water quality conditions that were monitored on water discharged through Gavins Point Dam during the 5-year period 2011 through 2015. A review of these results indicated no major water quality concerns. However, the 0.18 ug/L human health criterion for total arsenic was exceeded on all six occasions. The highest total arsenic concentration measured was 4 ug/L.

10.4.2 Temperature, Dissolved Oxygen, and Dam Discharge Time-Series Plots

Hourly temperature, dissolved oxygen, and dam discharge recorded at the Gavins Point powerplant during 2015 were used to construct time-series plots (Plate 10-20 and Plate 10-21). Water temperatures showed seasonal warming and cooling through each calendar year.   Dissolved oxygen levels remained relatively high and stable during the winter, steadily declined through the spring and summer, and steadily increased during the fall. The lowest dissolved oxygen levels occurred during late-June through August. The higher winter, declining spring, and increasing fall dissolved oxygen concentrations are attributed to decreasing dissolved oxygen solubility with warmer water temperatures. The lower dissolved oxygen concentrations in late-June through August may be associated with degradation in the hypolimnion when limited thermal stratification is able to become established. There appeared to be little correlation between discharge rates and measured water temperature and dissolved oxygen concentrations.

10.4.3 NUTRIENT FLUX CONDITIONS OF THE GAVINS POINT DAM DISCHARGE TO THE MISSOURI RIVER

Nutrient flux rates for the Gavins Point Dam discharge to the Missouri River over the 5-year period 2011 through 2015 were calculated based on samples taken from the Gavins Point powerplant (i.e. site GPTPP1) and the total dam discharge at the time of sample collection (Table 10-5). The samples collected in the powerplant are taken from the raw water supply line and are believed to be unbiased regarding particulate-associated constituents. Therefore, the flux rates calculated for the Gavins Point Dam discharge give an unbiased estimate of the flux rates for all the constituents, including total phosphorus and total organic carbon. The maximum flux rates for all the constituents are believed to be attributed to higher dam discharges.

Table 10-5. Summary of nutrient flux rates (kg/sec) calculated for the Gavins Point Dam total discharge to the Missouri River (i.e. site GTPPP1) during January through December over the 5-year period 2011 through 2015.

Statistic	Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	60	59	60	60	60	60	60
Mean	32,887	0.0186	0.4040	0.1171	0.0385	0.0137	3.8358
Median	27,056	n.d.	0.2943	0.0813	0.0200	0.0082	3.0632
Minimum	12,100	n.d.	n.d.	n.d.	n.d.	n.d.	1.1649
Maximum	159,900	0.2616	2.0828	0.9811	0.3169	0.3169	17.6581

Note: Nondetectable values set to 0 for flux calculations.

Plate 10-1. Summary of monthly (May through September) water quality conditions monitored in Lewis and Clark Lake near Gavins Point Dam (Site GPTLK0811A) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[(A)]						Water Quality Standards Attainment		
	Detection Limit[(B)]	No. of Obs.	Mean[(C)]	Median	Min.	Max.	State WQS Criteria[(D)]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	25	1206.5	1206.4	1205.7	1207.6	-----	-----	-----
Water Temperature (°C)	0.1	286	20.9	21.6	11.7	28.9	27[(1,2,6)], 29[(1,2,6)]	4, 0	1%, 0%
Dissolved Oxygen (mg/L)	0.1	286	8.5	8.4	1.2	12.0	5[(1,7)]	10	3%
Dissolved Oxygen (% Sat.)	0.1	286	97.9	98.5	14.5	136.5	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[(E)]	0.1	261	8.7	8.5	6.1	12.0	5[(1,7)]	0	0%
Hypolimnion Dissolved Oxygen (mg/L)[(E)]	0.1	25	5.5	5.3	1.2	9.6	5[(1,7)]	10[(F)]	40%[(F)]
Specific Conductance (uS/cm)	1	286	822	834	713	925	2,000[(4)]	0	0%
pH (S.U.)	0.1	286	8.4	8.4	7.6	9.3	6.5[(1,3,7)], 9.0[(1,3,6)], 9.5[(5,6)]	0, 6, 0	0%, 2%, 0%
Turbidity (NTUs)	1	286	12	9	n.d.	58	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	286	339	348	165	449	-----	-----	-----
Secchi Depth (M)	1	24	1.00	0.89	0.38	1.83	-----	-----	-----
Alkalinity, Total (mg/L)	7	49	162	162	142	173	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	48	4.2	4.2	2.9	5.2	-----	-----	-----
Chloride (mg/L)	1	29	12	12	9	14	438[(3,6)], 250[(3,8)]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	264	10	6	n.d.	191	10[(10)]	96	36%
Chlorophyll *a* (ug/L) – Lab Determined	1	25	11	6	3	85	10[(10)]	5	20%
Colorized Dissolved Organic Matter (ug/L)	4	49	25	25	15	34	-----	-----	-----
Diesel Range Organics	0.5	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	48	590	581	460	830	1,750[(3,6)], 1,000[(3,8)], 3,500[(5,6)], 2,000[(5,8)]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	48	-----	0.02	n.d.	0.28	3.9 [(1,6,9)], 0.78[(1,8,9)]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	49	0.4	0.4	n.d.	1.4	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	49	-----	0.04	n.d.	0.20	10[(3,6)], 100[(4,6)]	0	0%
Nitrogen, Total (mg/L)	0.1	49	0.5	0.4	n.d.	1.5	1[(10)]	1	2%
Phosphorus, Dissolved (mg/L)	0.02	48	-----	n.d.	n.d.	0.06	-----	-----	-----
Phosphorus, Total (mg/L)	0.008	49	0.03	0.03	n.d.	0.08	0.05[(10)]	9	18%
Phosphorus-Orthophosphate (mg/L)	0.02	48	-----	n.d.	n.d.	0.04	-----	-----	-----
Sulfate (mg/L)	1	49	247	248	202	296	875[(3,6)], 500[(3,8)]	0	0%
Suspended Solids, Total (mg/L)	4	49	11	9	n.d.	43	158[(1,6)], 90[(1,8)]	0	0%
Microcystin, Extracellular (ug/L)	0.1	25	-----	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 microcystin are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.

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

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

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

- [(1)] Criteria for the protection of Warmwater Permanent Fish Life Propagation Waters (South Dakota) or Class I Warmwater Aquatic Life (Nebraska).
- [(2)] South Dakota's temperature criterion is 27°C and Nebraska's is 29°C.
- [(3)] Criteria for the protection of domestic water supply waters.
- [(4)] Criteria for the protection of agricultural water supply waters.
- [(5)] Criteria for the protection of commerce and industry waters.
- [(6)] Daily maximum criterion (monitoring results directly comparable to criterion).
- [(7)] Daily minimum criterion (monitoring results directly comparable to criterion).
- [(8)] 30-day average criterion (monitoring results not directly comparable to criterion).
- [(9)] Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- [(10)] Nutrient criteria – Lewis and Clark Lake has been assigned the following nutrient criteria by Nebraska water quality standards: Chlorophyll *a* = 10 ug/L, Total Nitrogen = 1 mg/L, and Total Phosphorus = 50 ug/L. Chlorophyll *a* represents the desired biological condition (response) and is generally influenced by the amount of phosphorus and nitrogen (cause). Thus, if the chlorophyll *a* criterion is met, total phosphorus or total nitrogen values above the listed values will not be considered to violate their respective criteria.

[(E)] A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

[(F)] According to South Dakota's beneficial use support decision criteria, dissolved oxygen levels are not considered impaired if a region exists in the depth profile (i.e. epilimnion) where the dissolved oxygen levels are ≥5 mg/L. Nebraska's dissolved oxygen criteria do not apply to the hypolimnion.

Note: The highlighted values indicate use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 10-2. Summary of monthly (May through September) water quality conditions monitored in Lewis and Clark Lake near the Bloomfield Recreation Area (Site GPTLK0819DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	24	1206.5	1206.4	1205.7	1207.6	-----	-----	-----
Water Temperature (°C)	0.1	174	20.8	20.7	11.5	28.1	27[1,2,6], 29[1,2,6]	4, 0	2%, 0%
Dissolved Oxygen (mg/L)	0.1	174	8.7	8.5	6.7	11.1	5[1,7]	0	0%
Dissolved Oxygen (% Sat.)	0.1	174	100.4	99.5	77.6	127.4	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[E]	0.1	173	8.7	8.5	7.4	11.1	5[1,7]	0	0%
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	1	6.7	6.7	6.7	6.7	5[1,7]	0	0%
Specific Conductance (uS/cm)	1	174	821	823	647	930	2,000[4]	0	0%
pH (S.U.)	0.1	174	8.4	8.4	7.7	9.2	6.5[1,3,7], 9.0[1,3,6], 9.5[5,6]	0, 6, 0	0%, 4%, 0%
Turbidity (NTUs)	1	172	21	18	1	50	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	167	337	347	165	433	-----	-----	-----
Secchi Depth (M)	1	23	0.51	0.48	0.25	1.07	-----	-----	-----
Alkalinity, Total (mg/L)	7	48	163	165	141	171	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	48	4.2	4.2	3.0	5.4	-----	-----	-----
Chloride (mg/L)	1	28	12	12	10	14	438[3,6], 250[3,8]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	152	11	9	1	184	10[10]	56	37%
Chlorophyll *a* (ug/L) – Lab Determined	1	23	10	8	1	54	10[10]	5	22%
Colorized Dissolved Organic Matter (ug/L)	4	48	25	25	16	34	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	47	580	554	468	774	1,750[3,6], 1,000[3,8], 3,500[5,6], 2,000[5,8]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	48	-----	n.d.	n.d.	0.12	3.9 [1,6,9], 0.82[1,8,9]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.08	48	0.4	0.4	n.d.	0.2	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	48	-----	0.07	n.d.	0.21	10[3,6], 100[4,6]	0	0%
Nitrogen, Total (mg/L)	0.1	48	0.5	0.5	n.d.	1.0	1[10]	2	4%
Phosphorus, Dissolved (mg/L)	0.02	47	-----	n.d.	n.d.	0.04	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	48	0.04	0.03	n.d.	0.07	0.05[10]	15	33%
Phosphorus-Orthophosphate (mg/L)	0.02	48	-----	n.d.	n.d.	0.02	-----	-----	-----
Sulfate (mg/L)	1	47	248	246	200	297	875[3,6], 500[3,8]	0	0%
Suspended Solids, Total (mg/L)	4	48	18	17	5	43	158[1,6], 90[1,8]	0	0%
Microcystin, Extracellular (ug/L)	0.1	24	-----	n.d.	n.d.	0.1	-----	-----	-----

n.d. = Not detected.

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

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

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

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

- [1] Criteria for the protection of Warmwater Permanent Fish Life Propagation Waters (South Dakota) or Class I Warmwater Aquatic Life (Nebraska).
- [2] South Dakota's temperature criterion is 27°C and Nebraska's is 29°C.
- [3] Criteria for the protection of domestic water supply waters.
- [4] Criteria for the protection of agricultural water supply waters.
- [5] Criteria for the protection of commerce and industry waters.
- [6] Daily maximum criterion (monitoring results directly comparable to criterion).
- [7] Daily minimum criterion (monitoring results directly comparable to criterion).
- [8] 30-day average criterion (monitoring results not directly comparable to criterion).
- [9] Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- [10] Nutrient criteria – Lewis and Clark Lake has been assigned the following nutrient criteria by Nebraska water quality standards: Chlorophyll *a* = 10 ug/L, Total Nitrogen = 1 mg/L, and Total Phosphorus = 50 ug/L. Chlorophyll *a* represents the desired biological condition (response) and is generally influenced by the amount of phosphorus and nitrogen (cause). Thus, if the chlorophyll *a* criterion is met, total phosphorus or total nitrogen values above the listed values will not be considered to violate their respective criteria.

[E] A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

Note: The highlighted values indicate use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 10-3. Summary of monthly (May through September) water quality conditions monitored in Lewis and Clark Lake near the Charley Creek Area (Site GPTLK0825DW) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results[A]						Water Quality Standards Attainment		
	Detection Limit[B]	No. of Obs.	Mean[C]	Median	Min.	Max.	State WQS Criteria[D]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	26	1206.5	1206.4	1205.7	1207.6	-----	-----	-----
Water Temperature (°C)	0.1	80	20.2	20.2	7.7	25.9	27[1,2,6], 29[1,2,6]	0	0%
Dissolved Oxygen (mg/L)	0.1	80	8.8	8.5	7.4	14.3	5[1,7]	0	0%
Dissolved Oxygen (% Sat.)	0.1	80	100.5	98.9	91.9	148.5	-----	-----	-----
Epilimnion/Metalimnion Dissolved Oxygen (mg/L)[E]	0.1	80	8.8	8.5	7.4	14.3	5[1,7]	0	0%
Hypolimnion Dissolved Oxygen (mg/L)[E]	0.1	0	-----	-----	-----	-----	5[1,7]	-----	-----
Specific Conductance (uS/cm)	1	80	809	814	708	916	2,000[4]	0	0%
pH (S.U.)	0.1	80	8.4	8.3	7.8	9.1	6.5[1,3,7], 9.0[1,3,6], 9.5[5,6]	0, 3, 0	0%, 4%, 0%
Turbidity (NTUs)	1	78	23	23	2	65	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	76	333	341	165	445	-----	-----	-----
Secchi Depth (M)	1	23	0.44	0.41	0.13	0.84	-----	-----	-----
Alkalinity, Total (mg/L)	7	26	162	165	144	170	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	26	4.2	4.2	3.3	7.0	-----	-----	-----
Chloride (mg/L)	1	15	12	12	10	13	438[3,6], 250[3,8]	0	0%
Chlorophyll *a* (ug/L) – Field Probe	1	72	10	9	1	28	10[10]	30	42%
Chlorophyll *a* (ug/L) – Lab Determined	1	26	10	8	1	51	10[10]	10	40%
Colorized Dissolved Organic Matter (ug/L)	4	26	25	26	13	35	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	26	571	567	456	740	1,750[3,6], 1,000[3,8], 3,500[5,6], 2,000[5,8]	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	26	-----	n.d.	n.d.	0.10	4.7 [1,6,9], 1.0[1,8,9]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	26	0.4	0.4	0.1	0.7	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	26	0.11	0.10	n.d.	0.40	10[3,6], 100[4,6]	0	0%
Nitrogen, Total (mg/L)	0.08	26	0.5	0.5	0.1	1.0	1[10]	0	0%
Phosphorus, Dissolved (mg/L)	0.02	26	-----	n.d.	n.d.	0.03	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	26	0.04	0.04	0.01	0.18	0.05[10]	9	36%
Phosphorus-Orthophosphate (mg/L)	0.02	26	-----	n.d.	n.d.	0.02	-----	-----	-----
Sulfate (mg/L)	1	26	245	248	197	289	875[3,6], 500[3,8]	0	0%
Suspended Solids, Total (mg/L)	4	26	29	20	9	148	158[1,6], 90[1,8]	0, 1	0%, 5%
THM Formation Potential, Total	4	26	167	173	14	236	-----	-----	-----
Microcystin, Extracellular (ug/L)	0.1	26	-----	n.d.	n.d.	0.1	-----	-----	-----

n.d. = Not detected.

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

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

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

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

- [1] Criteria for the protection of Warmwater Permanent Fish Life Propagation Waters (South Dakota) or Class I Warmwater Aquatic Life (Nebraska).
- [2] South Dakota's temperature criterion is 27°C and Nebraska's is 29°C.
- [3] Criteria for the protection of domestic water supply waters.
- [4] Criteria for the protection of agricultural water supply waters.
- [5] Criteria for the protection of commerce and industry waters.
- [6] Daily maximum criterion (monitoring results directly comparable to criterion).
- [7] Daily minimum criterion (monitoring results directly comparable to criterion).
- [8] 30-day average criterion (monitoring results not directly comparable to criterion).
- [9] Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- [10] Nutrient criteria – Lewis and Clark Lake has been assigned the following nutrient criteria by Nebraska water quality standards: Chlorophyll *a* = 10 ug/L, Total Nitrogen = 1 mg/L, and Total Phosphorus = 50 ug/L. Chlorophyll *a* represents the desired biological condition (response) and is generally influenced by the amount of phosphorus and nitrogen (cause). Thus, if the chlorophyll *a* criterion is met, total phosphorus or total nitrogen values above the listed values will not be considered to violate their respective criteria.

[E] A hypolimnion is defined to occur when a measured depth-profile of water temperature indicates a decrease of 1.0°C or more over a 1-meter depth increment, or a decrease of at least 0.5°C and a decrease of at least 1 mg/L dissolved oxygen over a 1-meter depth increment. The top of the hypolimnion is delineated as the depth where the above changes occur.

[F] Depth-profiles did not indicate the presence of a hypolimnion during monitored period. It is assumed that the water column experienced complete mixing due to shallower water depths during the monitored period.

Note: The highlighted values indicate use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

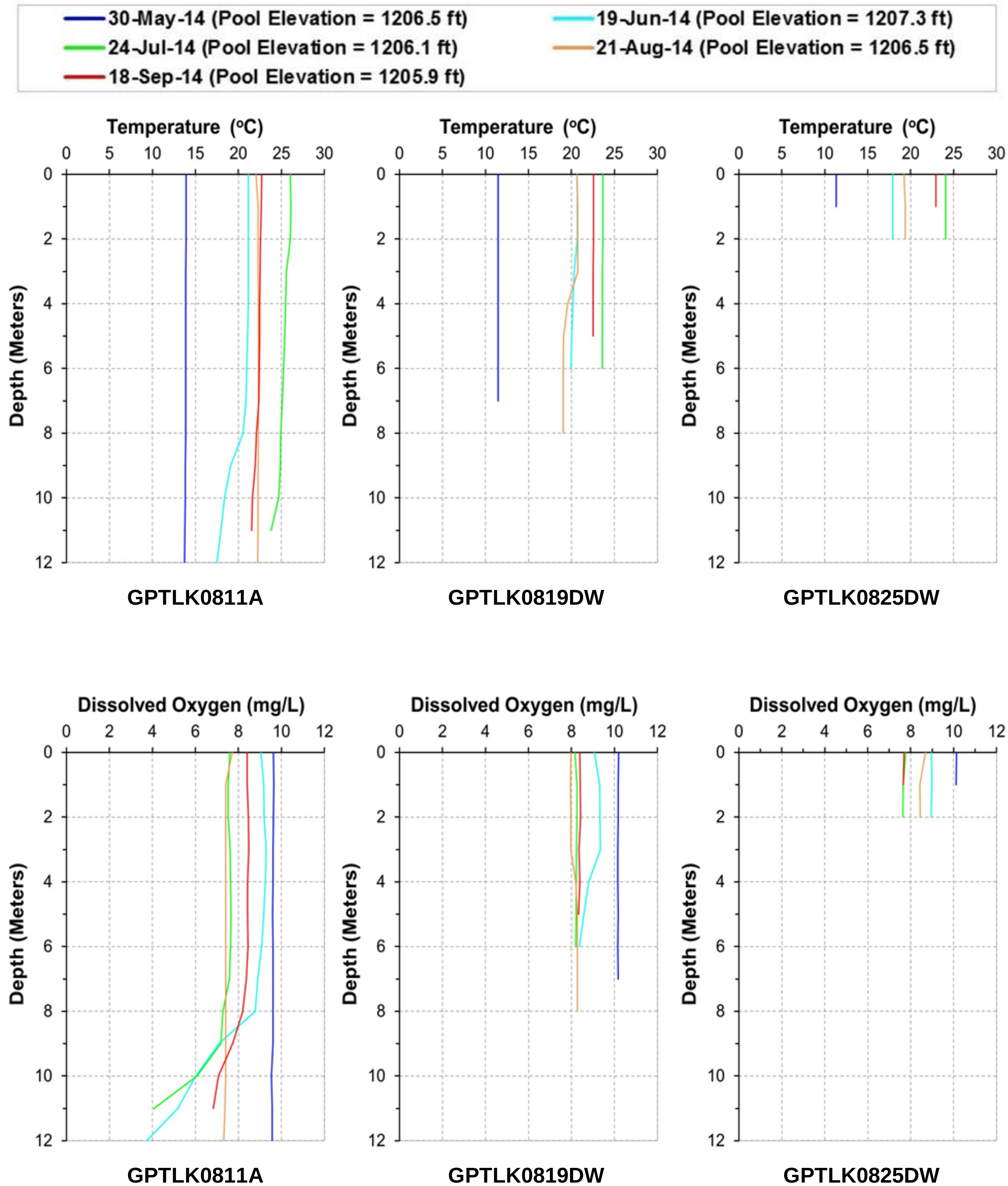


Plate 10-4. Depth-profile plots of temperature and dissolved oxygen conditions of Lewis and Clark Lake measured at sites GPTLK0811A, GPTLK0819DW, and GPTLK0815DW during 2015**.**

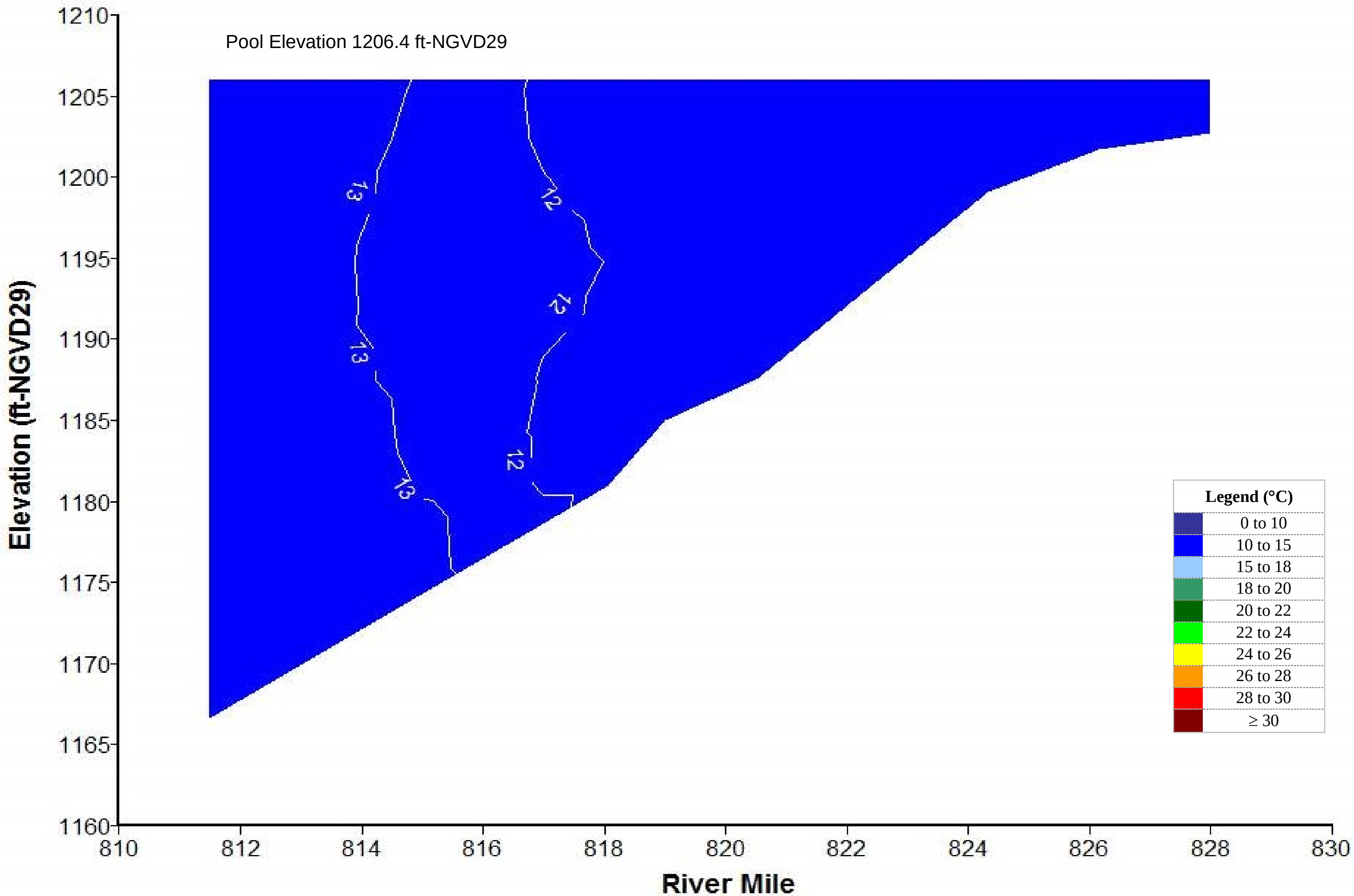


Plate 10-5. Longitudinal water temperature (°C) contour plot of Lewis and Clark Lake based on depth-profile water temperatures measured at sites GPTLK0811A, GPTLK0819DW, GPTLK0825DW, and GPTNFMORR1 on May 21, 2015.

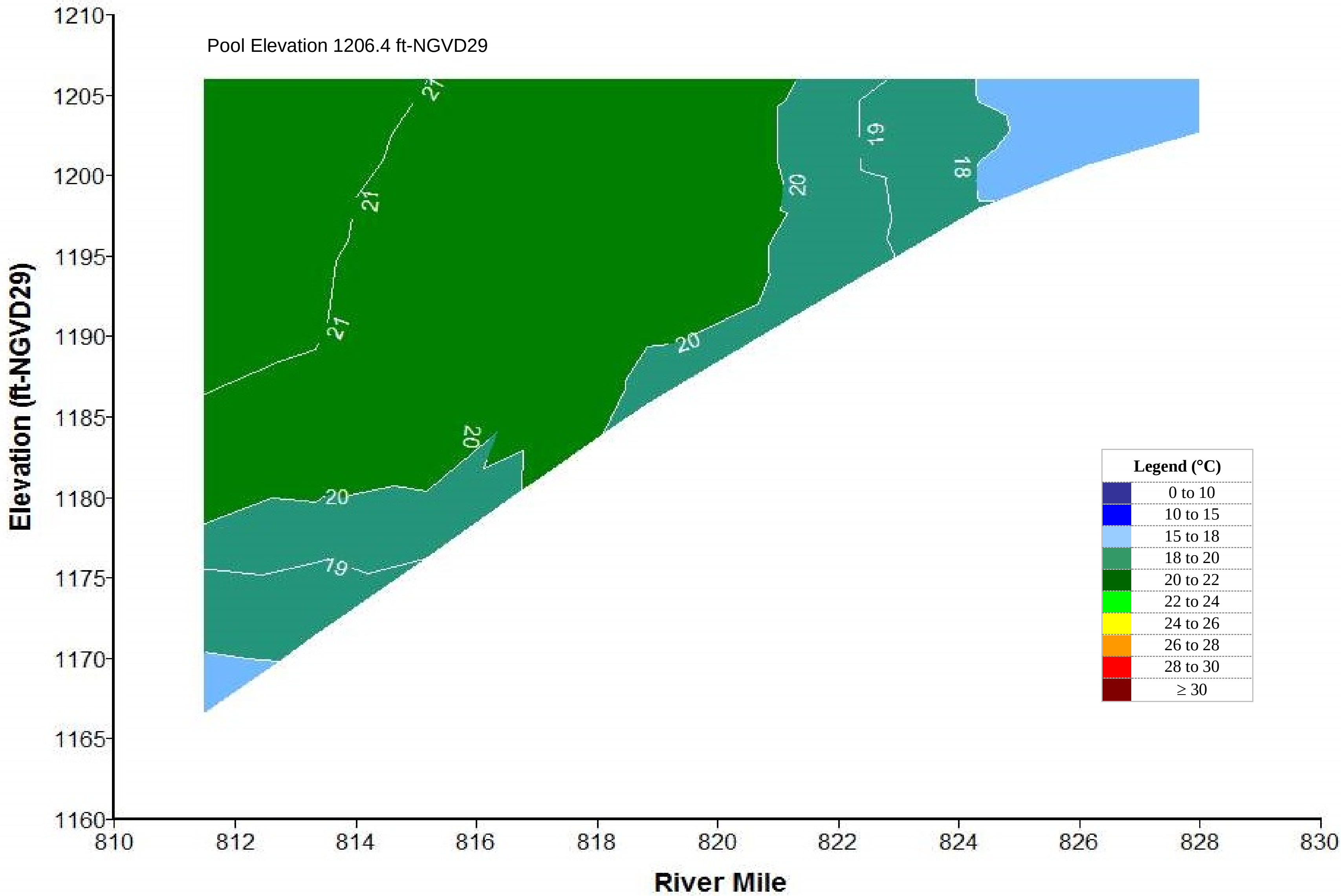


Plate 10-6. Longitudinal water temperature (°C) contour plot of Lewis and Clark Lake based on depth-profile water temperatures measured at sites GPTLK0811A, GPTLK0819DW, GPTLK0825DW, and GPTNFMORR1on June 18, 2015.

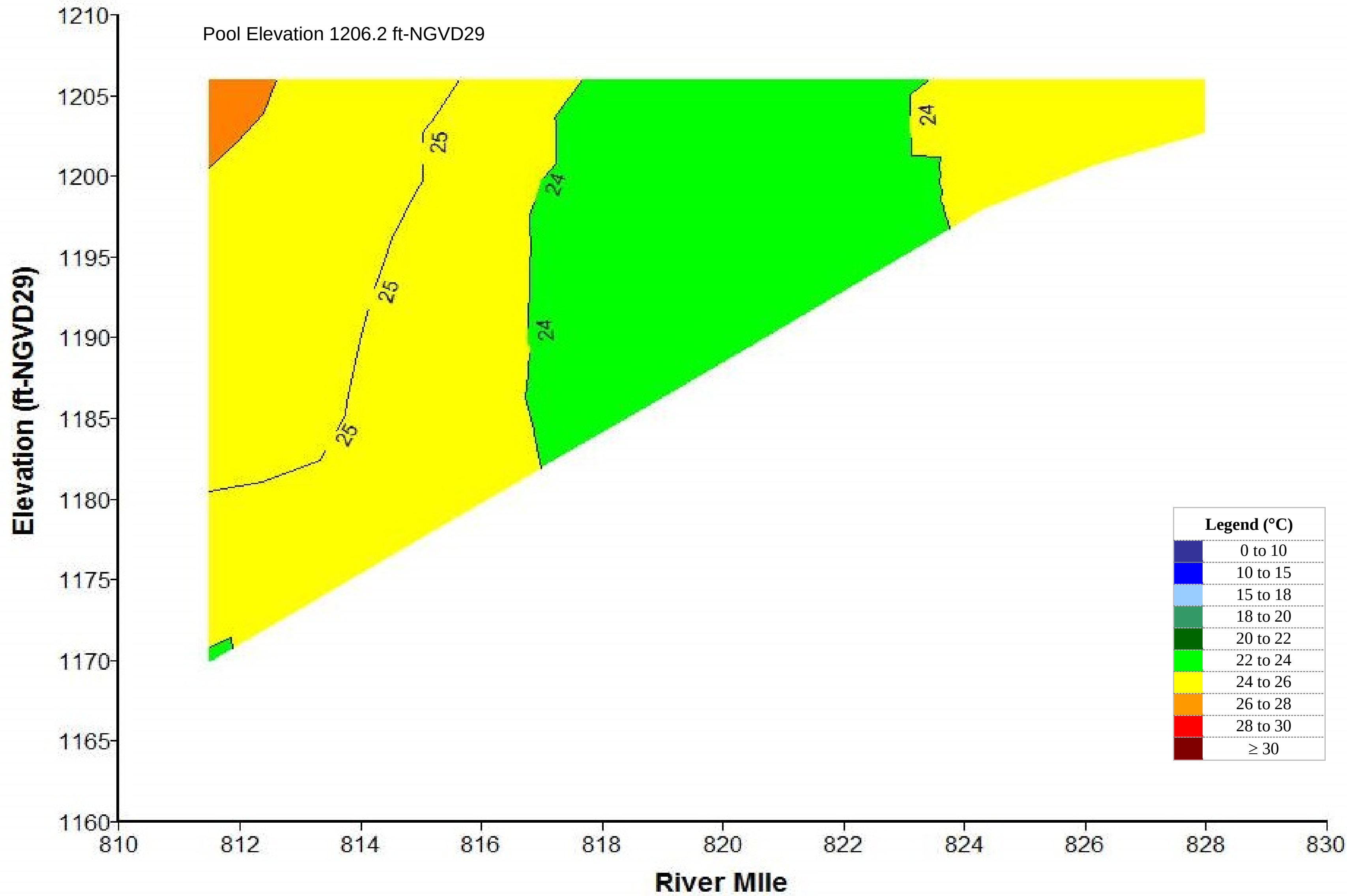


Plate 10-7. Longitudinal water temperature (°C) contour plot of Lewis and Clark Lake based on depth-profile water temperatures measured at sites GPTLK0811A, GPTLK0819DW, GPTLK0825DW, and GPTNFMORR1 on July 24, 2015.

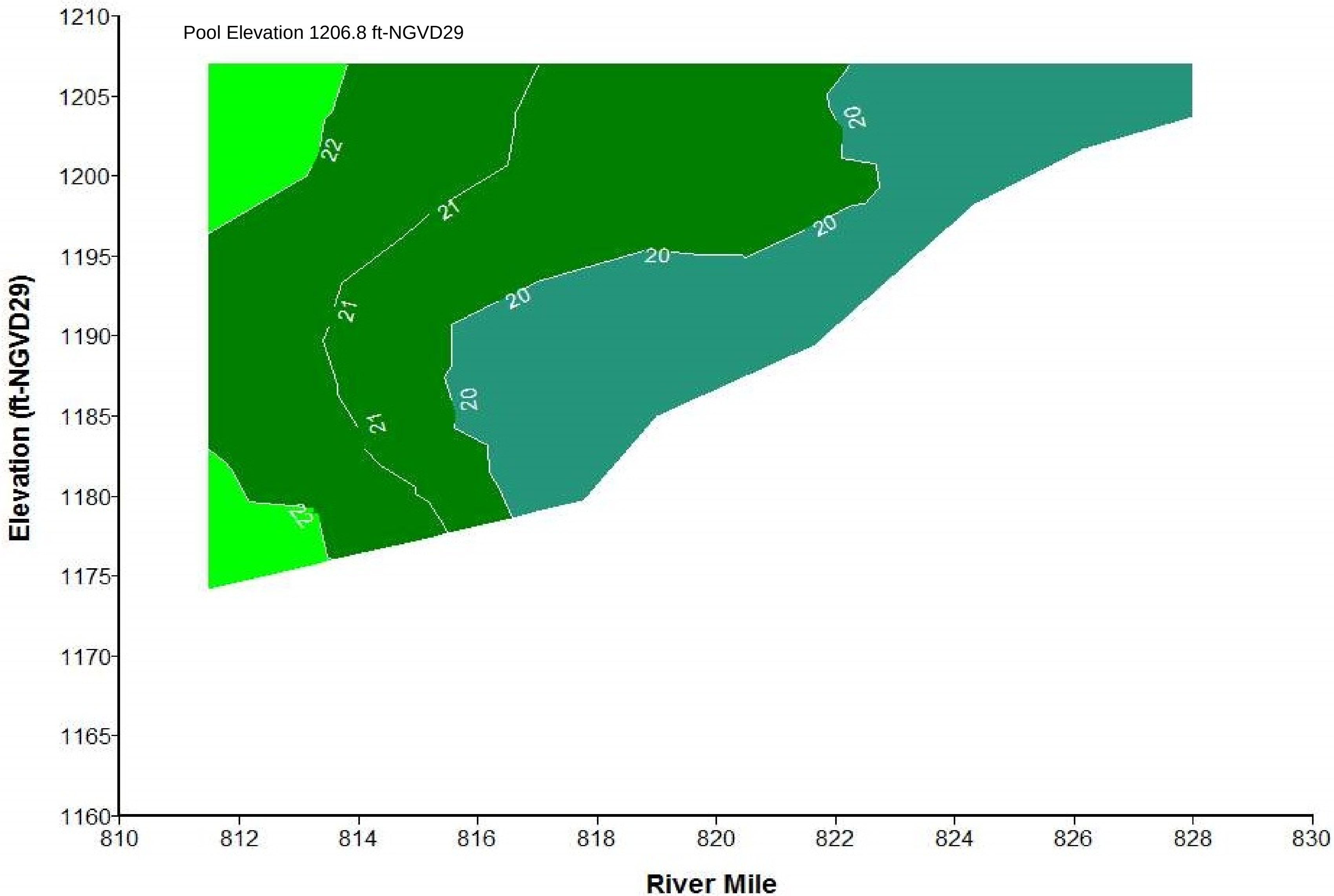


Plate 10-8. Longitudinal water temperature (°C) contour plot of Lewis and Clark Lake based on depth-profile water temperatures measured at sites GPTLK0811A, GPTLK0819DW, GPTLK0825DW, and GPTNFMORR1 on August 20, 2015**.**

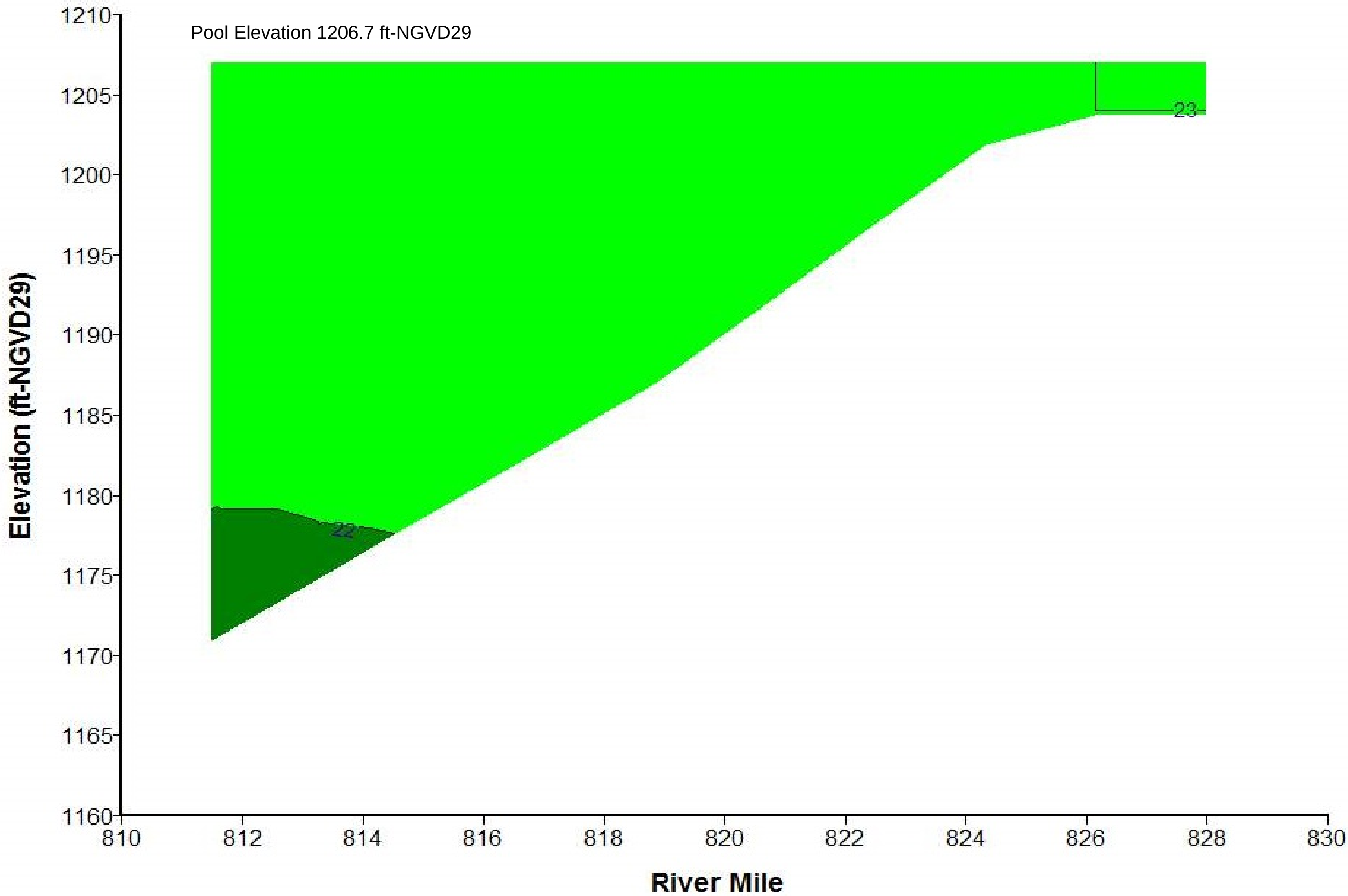


Plate 10-9. Longitudinal water temperature (°C) contour plot of Lewis and Clark Lake based on depth-profile water temperatures measured at sites GPTLK0811A, GPTLK0819DW, GPTLK0825DW, and GPTNFMORR1 on September 17, 2015**.**

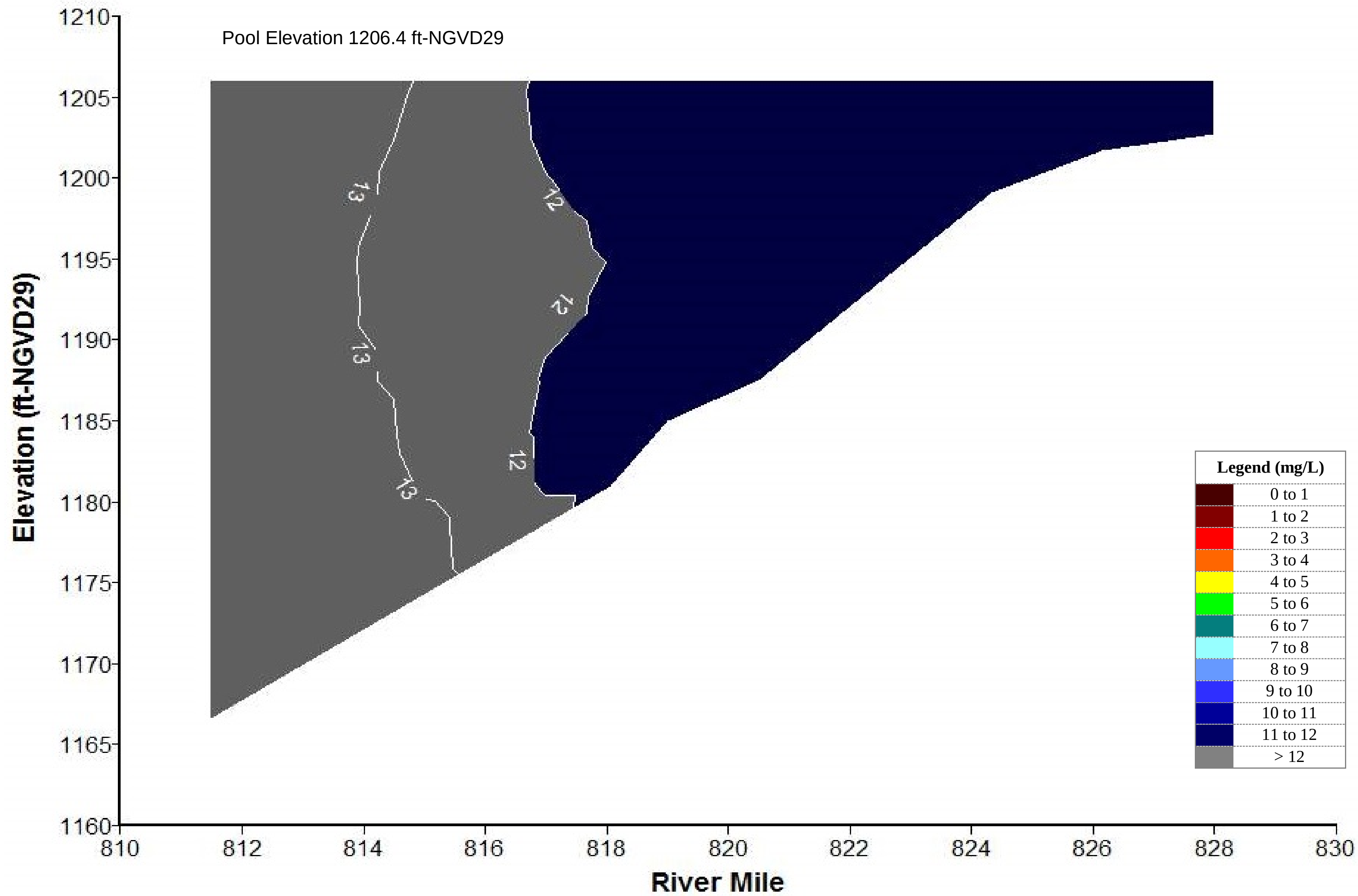


Plate 10-10. Longitudinal dissolved oxygen (mg/L) contour plot of Lewis and Clark Lake based on depth-profile dissolved oxygen concentrations measured at sites GPTLK0811A, GPTLK0819DW, GPTLK0825DW, and GPTNFMORR1 on May 21, 2015.

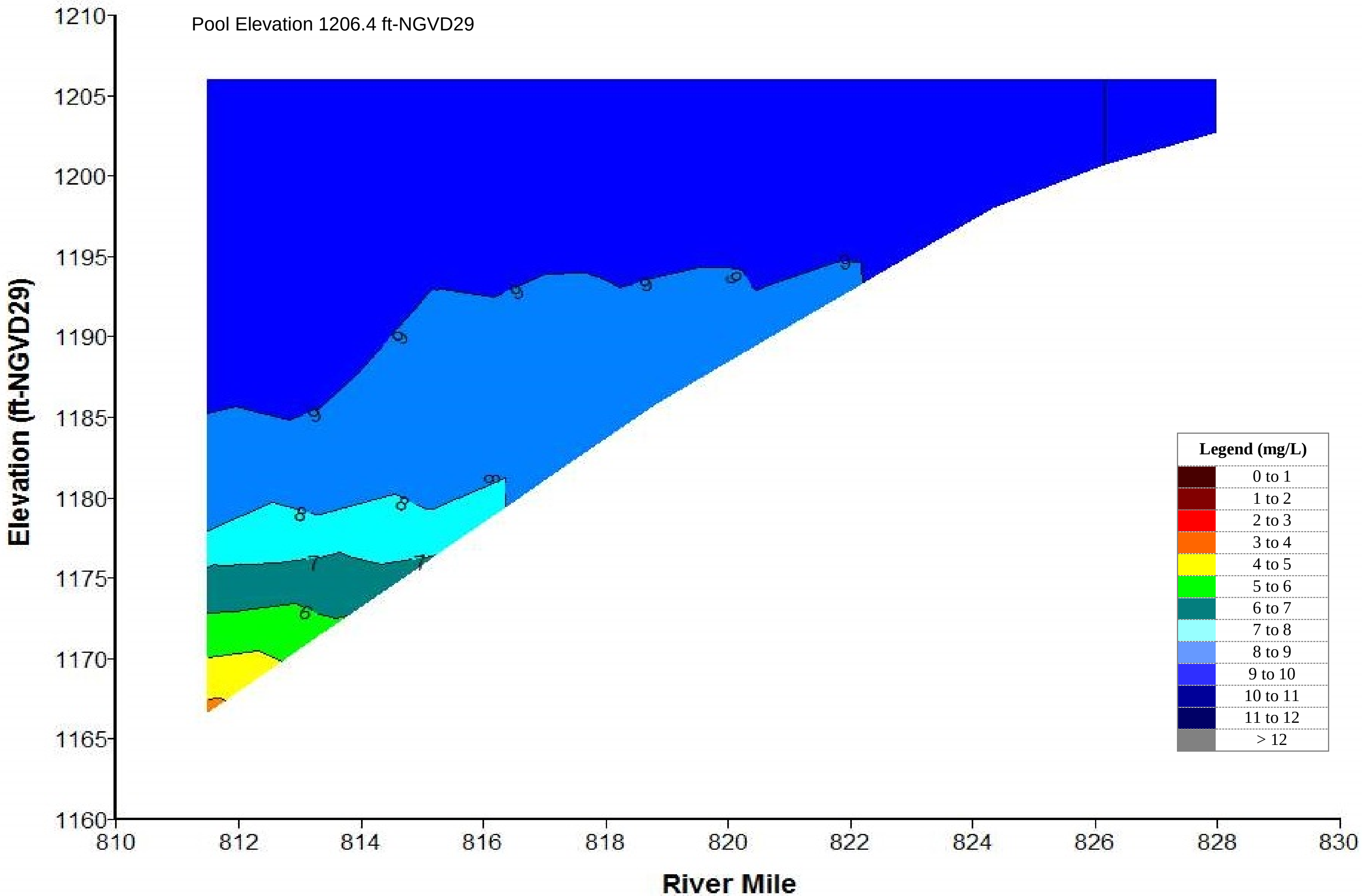


Plate 10-11. Longitudinal dissolved oxygen (mg/L) contour plot of Lewis and Clark Lake based on depth-profile dissolved oxygen concentrations measured at sites GPTLK0811A, GPTLK0819DW, GPTLK0825DW, and GPTNFMORR1 on June 18, 2015.

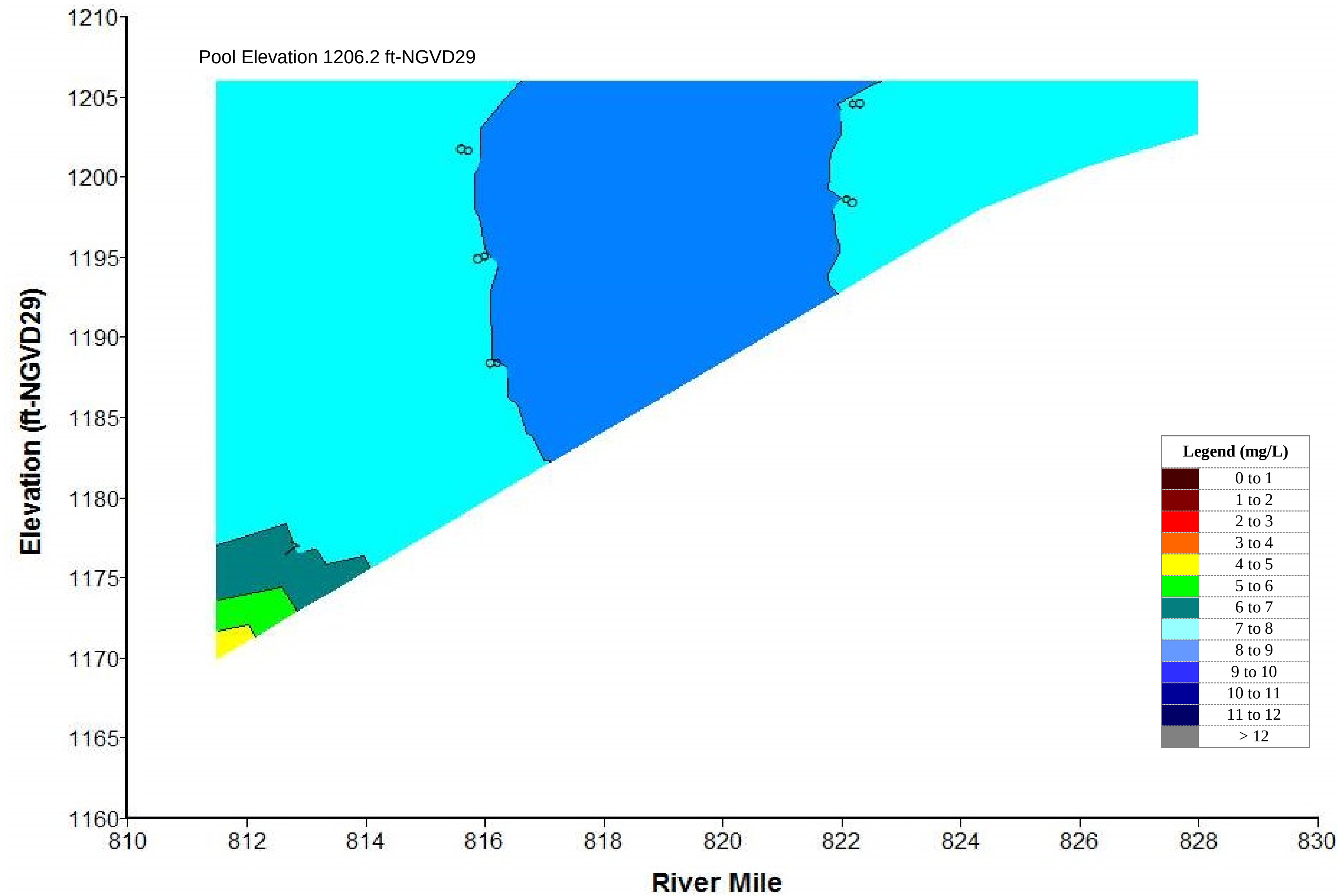


Plate 10-12. Longitudinal dissolved oxygen (mg/L) contour plot of Lewis and Clark Lake based on depth-profile dissolved oxygen concentrations measured at sites GPTLK0811A, GPTLK0819DW, GPTLK0825DW, and GPTNFMORR1 on July 24, 2015.

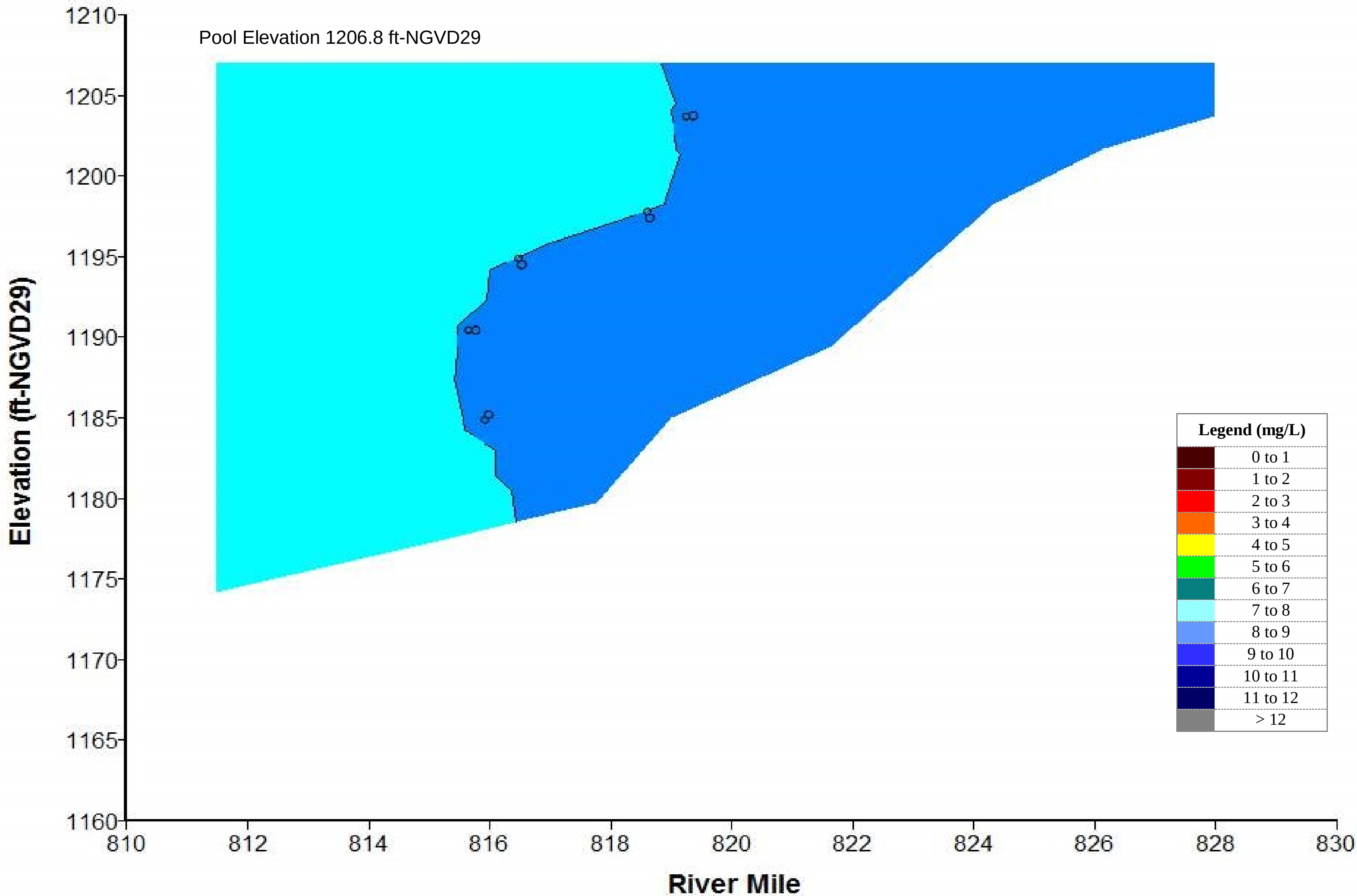


Plate 10-13. Longitudinal dissolved oxygen (mg/L) contour plot of Lewis and Clark Lake based on depth-profile dissolved oxygen concentrations measured at sites GPTLK0811A, GPTLK0819DW, GPTLK0825DW, and GPTNFMORR1 on August 20, 2015**.**

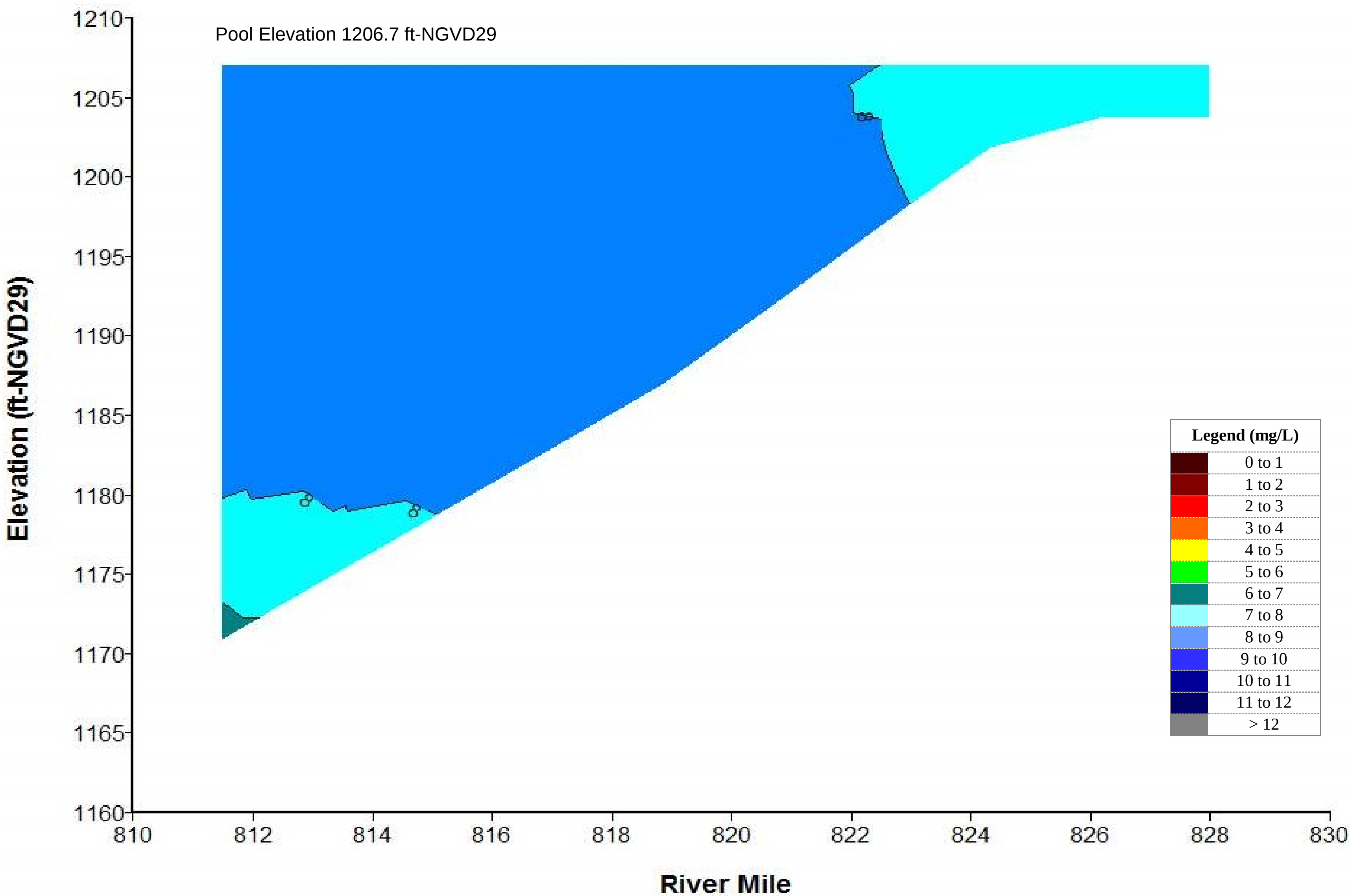


Plate 10-14. Longitudinal dissolved oxygen (mg/L) contour plot of Lewis and Clark Lake based on depth-profile dissolved oxygen concentrations measured at sites GPTLK0811A, GPTLK0819DW, GPTLK0825DW, and GPTNFMORR1 on September, 17 2015**.**

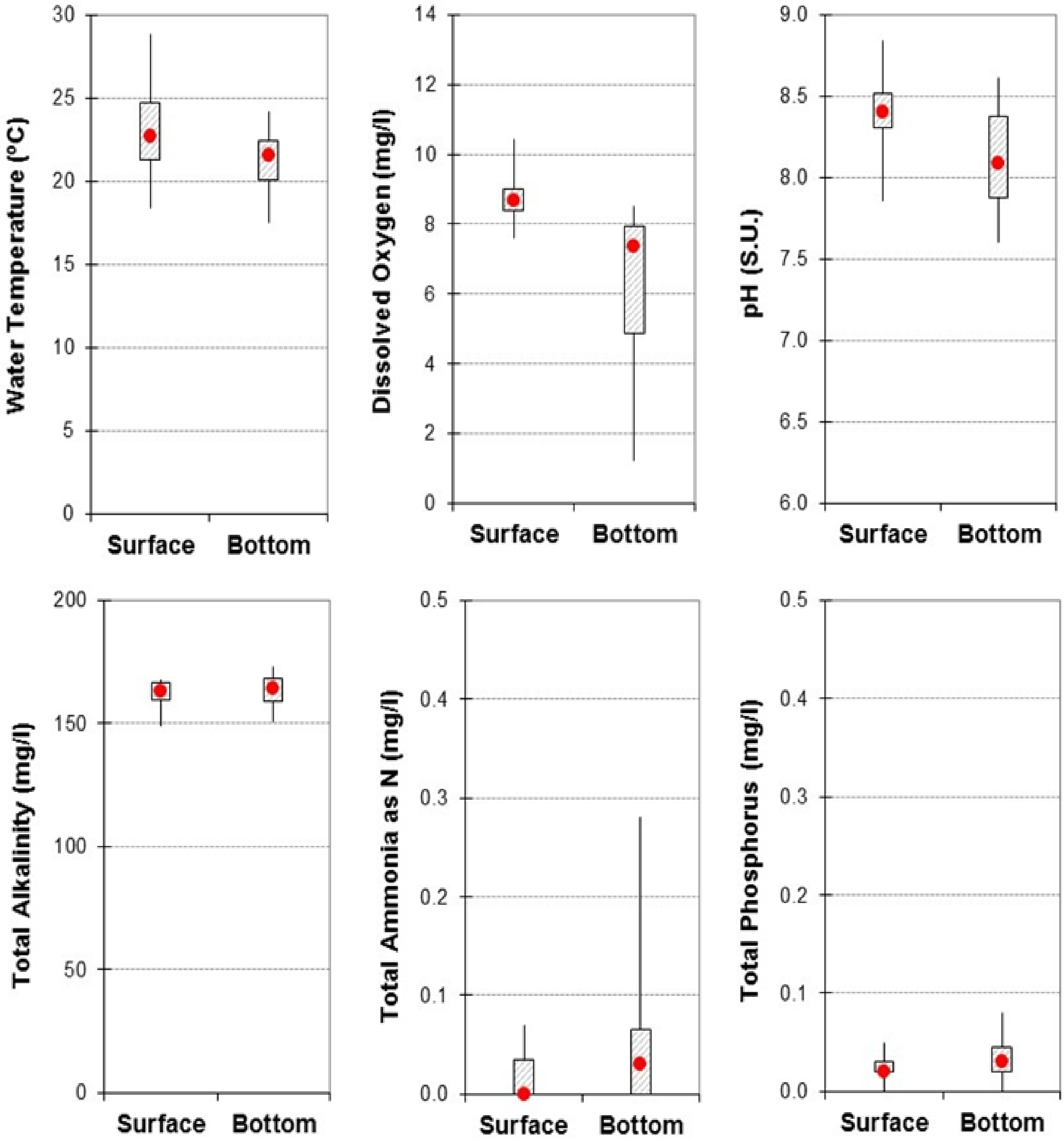


Plate 10-15. Box plots comparing paired surface and bottom water temperature, dissolved oxygen, pH, alkalinity, total ammonia nitrogen, and total phosphorus measurements taken in Lewis and Clark Lake at site GPTLK0811A during the summer months of the 5-year period 2011 through 2015. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

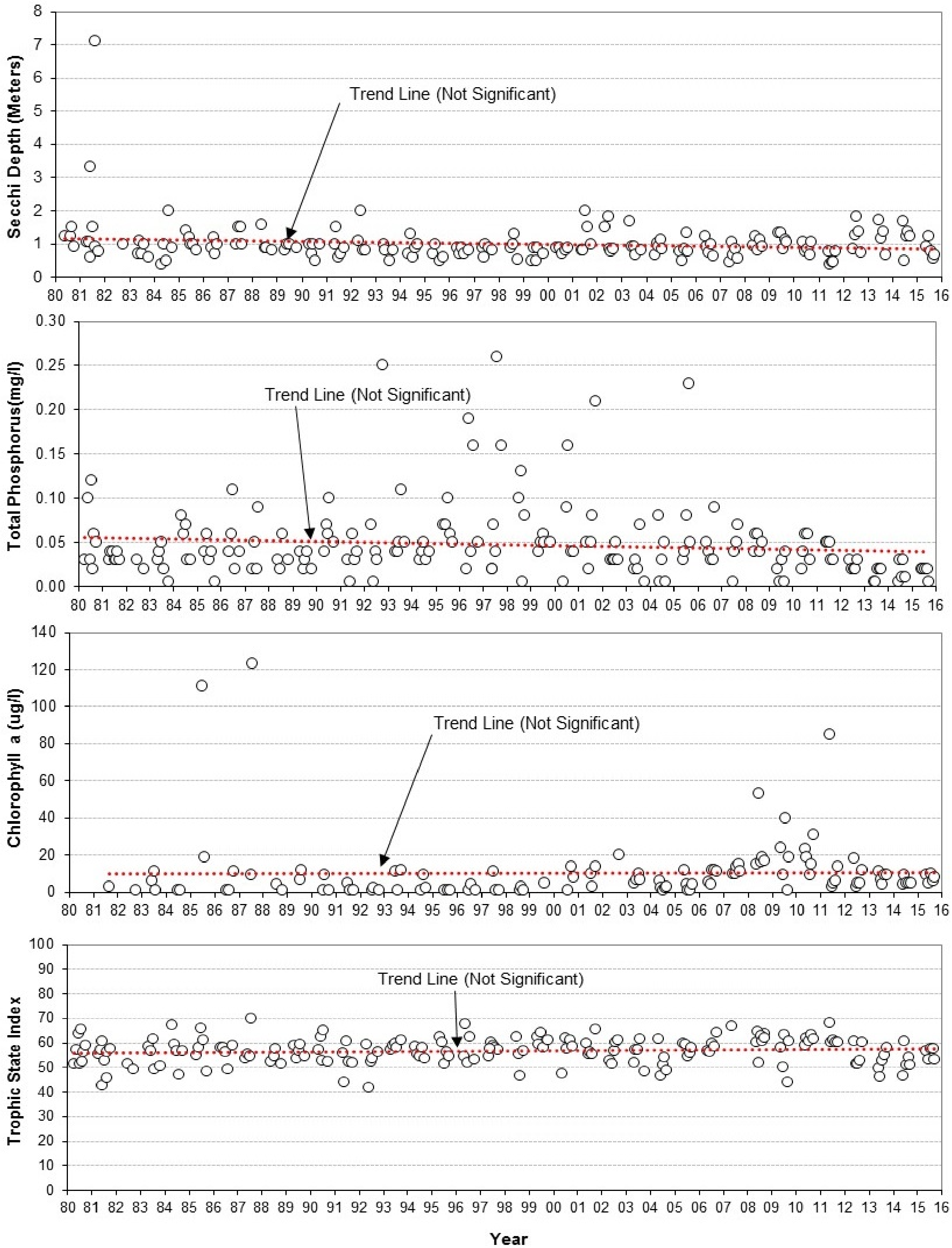


Plate 10-16. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Lewis and Clark Lake at the near-dam, ambient site (i.e. site GTPLK0811A) over the 36-year period of 1980 through 2015.

Plate 10-17. Summary of near-surface water quality conditions monitored in the Missouri River near Running Water, South Dakota (i.e. site GPTNFMORR1) at RM841 during thr 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[A]	No. of Obs.	Mean[B]	Median	Min.	Max.	State WQS Criteria[C]	No. of WQS Exceedances	Percent WQS Exceedance
Streamflow (cfs)	1	36	41,214	31,408	5,981	158,219	-----	-----	-----
Water Temperature (°C)	0.1	36	17.4	19.1	0.8	27.3	27[1,2,6], 29[1,2,6]	1, 0	3%, 0%
Dissolved Oxygen (mg/L)	0.1	36	9.6	9.2	7.5	15.1	5[1,7]	0	0%
Dissolved Oxygen (% Sat.)	0.1	36	101.3	100.2	94.6	113.1	-----	-----	-----
pH (S.U.)	0.1	36	8.3	8.3	7.8	9.0	6.5[1,3,7], 9.0[1,3,6], 9.5[5,6]	0	0%
Specific Conductance (uS/cm)	1	36	833	838	717	953	2,000[4]	0	0%
Oxidation-Reduction Potential	1	35	345	347	155	453	-----	-----	-----
Alkalinity, Total (mg/L)	7	36	165	165	140	178	-----	0	0%
Carbon, Total Organic (mg/L)	0.05	36	4.5	4.2	3.1	13.4	-----	-----	-----
Chloride (mg/L)	1	20	12	12	10	15	438[3,6], 250[3,8]	0	0%
Chlorophyll *a* (ug/L)	1	29	-----	5	n.d.	68	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	36	24	26	15	33	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	36	590	589	438	738	1,750[3,6], 1,000[3,8], 3,500[5,6], 2,000[5,8]	0	0%
Hardness, Total (mg/L)	1	7	245	244	199	281	-----	-----	-----
Nitrogen, Ammonia Total (mg/L)	0.02	36	-----	n.d.	n.d.	0.16	4.7 [1,6,9], 1.3 [1,8,9]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	36	0.4	0.4	n.d.	0.8	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	36	-----	0.07	n.d.	0.30	10[3,6], 100[4,6]	0	0%
Nitrogen, Total (mg/L)	0.1	36	0.5	0.4	n.d.	1.04	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	36	-----	n.d.	n.d.	0.05	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	36	0.03	0.02	n.d.	0.08	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	36	-----	n.d.	n.d.	0.04	-----	-----	-----
Suspended Sediment (mg/L)	4	35	22	18	n.d.	63	-----	-----	-----
Suspended Solids, Total (mg/L)	4	36	19	16	n.d.	59	158[1,6], 90[1,8]	1, 2	3%, 6%
THM Formation Potential, Total	4	33	164	160	68	220	-----	-----	-----
Turbidity (NTU)	1	36	27	9	n.d.	389	-----	-----	-----
Aluminum, Dissolved (ug/L)	40	6	-----	n.d.	n.d.	72	750[10], 87[11], 200[12]	0	0%
Antimony, Dissolved (ug/L)	0.5	6	-----	n.d.	n.d.	0.6	88[10], 30[11], 6[12]	0	0%
Arsenic, Dissolved (ug/L)	1	6	2	2	n.d.	2	340[10], 16.7[11], 10[12]	0	0%
Barium, Dissolved (ug/L)	5	6	43	43	40	45	2,000[11]	0	0%
Beryllium, Dissolved (ug/L)	2	6	-----	n.d.	n.d.	2	130[10], 5.3[11], 4[12]	0	0%
Cadmium, Dissolved (ug/L)	0.2	6	-----	n.d.	n.d.	0.2	4.3[10], 0.42[11], 5[12]	0	0%
Chromium, Dissolved (ug/L)	10	6	-----	n.d.	n.d.	n.d.	1071[10], 139[11], 100[12]	0	0%
Copper, Dissolved (ug/L)	6	6	-----	n.d.	n.d.	7	28[10], 17[11], 1,000[12]	0	0%
Iron, Dissolved (ug/L)	7	6	-----	n.d.	n.d.	10	1,000[11]	0	0%
Lead, Dissolved (ug/L)	0.5	6	-----	n.d.	n.d.	n.d.	148[10], 5.870[11], 15[12]	0	0%
Manganese, Dissolved (ug/L)	2	6	6	5	3	10	-----	-----	-----
Mercury, Dissolved (ug/L)	0.05	6	-----	n.d.	n.d.	n.d.	1.4[10]	0	0%
Mercury, Total (ug/L)	0.05	6	-----	n.d.	n.d.	n.d.	0.77[11], 2[12]	0	0%
Nickel, Dissolved (ug/L)	10	6	-----	n.d.	n.d.	n.d.	898[10], 100[11], 100[12]	0	0%
Selenium, Total (ug/L)	1	6	2	2	n.d.	3	20[4,10], 5[11], 50[12]	0	0%
Silver, Dissolved (ug/L)	1	6	-----	n.d.	n.d.	n.d.	13[10], 100[12]	0	0%
Thallium, Dissolved (ug/L)	0.5	6	-----	n.d.	n.d.	n.d.	1,400[10], 6.3[11], 2[12]	0	0%
Zinc, Dissolved (ug/L)	5	6	-----	n.d.	n.d.	n.d.	225[10,11], 5,000[12]	0	0%
Pesticide Scan (ug/L)[D]	0.05[E]	5	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

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

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

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

- (1) Criteria for the protection of Warmwater Permanent Fish Life Propagation Waters (South Dakota) or Class I Warmwater Aquatic Life (Nebraska).
- (2) South Dakota's temperature criterion is 27°C and Nebraska's is 29°C.
- (3) Criteria for the protection of domestic water supply waters.
- (4) Criteria for the protection of agricultural water supply waters.
- (5) Criteria for the protection of commerce and industry waters.
- (6) Daily maximum criterion (monitoring results directly comparable to criterion).
- (7) Daily minimum criterion (monitoring results directly comparable to criterion).
- (8) 30-day average criterion (monitoring results not directly comparable to criterion).
- (9) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (10) Acute (CMC) criterion for the protection of freshwater aquatic life.
- (11) Chronic (CCC) criterion for the protection of freshwater aquatic life.
- (12) Criterion for the protection of human health.

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

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

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

Plate 10-18. Summary of water quality conditions monitored on water discharged through Gavins Point Dam (i.e. site GPTPP1) during the 5-year period of 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit(A)	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Dam Discharge – Powerplant (Mean Daily, cfs)	1	69	23,003	21,000	4,200	34,000	-----	-----	-----
Dam Discharge – Powerplant + Spillway (Mean Daily, cfs)	1	69	32,506	27,044	12,100	159,000	-----	-----	-----
Water Temperature (°C)	0.1	66	12.0	11.2	0.3	26.5	27(1,2,6), 29(1,2,6)	0	0%
Dissolved Oxygen (mg/L)	0.1	66	10.7	10.8	7.1	14.6	5(1,7)	0	0%
Dissolved Oxygen (% Sat.)	0.1	66	99.4	99.3	83.0	116.9	-----	-----	-----
pH (S.U.)	0.1	64	8.2	8.3	6.3	10.0	6.5(1,3,7), 9.0(1,3,6), 9.5(5,6)	1, 2, 1	2%, 4%, 2%
Specific Conductance (uS/cm)	1	65	784	776	665	926	2,000(4)	-----	-----
Oxidation-Reduction Potential (mV)	1	66	354	353	148	643	-----	-----	-----
Turbidity (NTU)	1	66	19	10	n.d.	217	-----	-----	-----
Alkalinity, Total (mg/L)	7	69	164	164	135	208	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	69	4.2	4.0	2.9	5.9	-----	-----	-----
Chloride, Dissolved (mg/L)	1	22	12	12	5	15	438(3,6), 250(3,8)	0	0%
Colorized Dissolved Organic Matter (ug/L)	4	56	23	22	14	32	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	69	550	540	406	764	1,750(2,4), 1,000(2,7), 3,500(3,4), 2,000(3,6)	0	0%
Nitrogen, Ammonia Total (mg/L)	0.02	68	-----	n.d.	n.d.	0.18	4.7(1,6,9), 1.4 (1,8,9)	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	69	0.4	0.5	n.d.	0.8	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total(mg/L)	0.02	69	0.15	0.12	n.d.	0.50	10(3,6), 100(4,6)	0	0%
Nitrogen, Total (mg/L)	0.1	69	0.6	0.6	n.d.	1.0	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	69	-----	n.d.	n.d.	0.07	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	69	0.04	0.03	n.d.	0.11	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	69	-----	n.d.	n.d.	0.05	-----	-----	-----
Sulfate (mg/L)	1	69	236	232	186	298	875(3,6), 500(3,8)	0	0%
Suspended Solids, Total (mg/L)	4	68	20	10	n.d.	217	158(1,6), 90(1,8)	1, 1	2%, 2%

n.d. = Not detected.

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

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

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

(1) Criteria for the protection of Warmwater Permanent Fish Life Propagation Waters (South Dakota) or Class I Warmwater Aquatic Life (Nebraska).
(2) South Dakota's temperature criterion is 27°C and Nebraska's is 29°C.
(3) Criteria for the protection of domestic water supply waters.
(4) Criteria for the protection of agricultural water supply waters.
(5) Criteria for the protection of commerce and industry waters.
(6) Daily maximum criterion (monitoring results directly comparable to criterion).
(7) Daily minimum criterion (monitoring results directly comparable to criterion).
(8) 30-day average criterion (monitoring results not directly comparable to criterion).
(9) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.

Plate 10-19. Summary of annual metals and pesticide levels monitored on water discharged through Gavins Point Dam (i.e. site GPTPP1) during the 5-year period of 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Aluminum, Dissolved (ug/L)	40	6	-----	n.d.	n.d.	n.d.	750(1), 87(2), 200(3)	0	0%
Aluminum, Total (ug/L)	40	6	488	430	200	1,090	-----	-----	-----
Antimony, Dissolved (ug/L)	0.5	6	-----	n.d.	n.d.	0.7	88(1), 30(2), 6(3)	0	0%
Antimony, Total (ug/L)	0.5	6	-----	n.d.	n.d.	1.0	5.6(4)	0	0%
Arsenic, Dissolved (ug/L)	1	6	3	3	2	4	340(1), 16.7(2)	0	0%
Arsenic, Total (ug/L)	1	6	3	3	2	4	10(3), 0.018(4)	0, 6	0%, 100%
Barium, Dissolved (ug/L)	5	6	50	49	47	54	-----	-----	-----
Barium, Total (ug/L)	5	6	55	54	49	64	2,000(3)	0	0%
Beryllium, Dissolved (ug/L)	2	6	-----	n.d.	n.d.	n.d.	130(1), 5.3(2)	0	0%
Beryllium, Total (ug/L)	2	6	-----	n.d.	n.d.	n.d.	4(4)	0	0%
Cadmium, Dissolved (ug/L)	0.2	6	-----	n.d.	n.d.	0.2	4.6(1), 0.44(2)	0	0%
Cadmium, Total (ug/L)	0.2	6	-----	n.d.	n.d.	0.7	5(3,4)	0	0%
Calcium, Dissolved (mg/L)	0.01	6	56.2	57.9	44.0	65.4	-----	-----	-----
Chromium, Dissolved (ug/L)	10	6	-----	n.d.	n.d.	n.d.	1,139(1), 148(2)	0	0%
Chromium, Total (ug/L)	10	6	-----	n.d.	n.d.	n.d.	100(3)	-----	-----
Copper, Dissolved (ug/L)	6	6	8	10	n.d.	11	30(1), 18(2),	0	0%
Copper, Total (ug/L)	6	6	11	10	9	16	1,300(3,4)	0	0%
Hardness, Dissolved (mg/L)	1	6	230.7	233.1	186.0	270.4	-----	-----	-----
Iron, Dissolved (ug/L)	10	6	-----	n.d.	n.d.	30	1,000(2)	0	0%
Iron, Total (ug/L)	10	6	429	305	160	1,131	-----	-----	-----
Lead, Dissolved (ug/L)	0.5	6	-----	n.d.	n.d.	n.d.	160(1), 6.2(2)	0	0%
Lead, Total (ug/L)	0.5	6	-----	n.d.	n.d.	0.9	-----	-----	-----
Magnesium, Dissolved (mg/L)	0.01	6	22.5	23.0	18.7	26.0	-----	-----	-----
Manganese, Dissolved (ug/L)	2	6	7	7	2	10	1,000(2)	0	0%
Manganese, Total (ug/L)	2	6	63	55	30	111	-----	-----	-----
Mercury, Dissolved (ug/L)	0.05	6	-----	n.d.	n.d.	n.d.	1.4(1)	0	0%
Mercury, Total (ug/L)	0.05	6	-----	n.d.	n.d.	0.5	0.77(2), 0.05(3), 2(3)	0, 1, 0	0%, 17%, 0%
Nickel, Dissolved (ug/L)	10	6	-----	n.d.	n.d.	n.d.	958(1), 106(2)	0	0%
Nickel, Total (ug/L)	10	6	-----	n.d.	n.d.	n.d.	610(4)	0	0%
Selenium, Dissolved (ug/L)	1	6	3	3	n.d.	5	-----	-----	-----
Selenium, Total (ug/L)	1	6	3	3	n.d.	5	20(1), 5(2), 50(3), 170(4)	0	0%
Silver, Dissolved (ug/L)	1	6	-----	n.d.	n.d.	n.d.	14(1)	0	0%
Silver, Total (ug/L)	1	6	-----	n.d.	n.d.	n.d.	10(3)	0	0%
Sodium, Dissolved (mg/L)	0.01	5	82.6	81.2	65.5	94.3	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	6	-----	n.d.	n.d.	n.d.	1,400(1), 6.3(2), 2(3), 0.24(3)	0	0%
Thallium, Total (ug/L)	0.5	6	-----	n.d.	n.d.	n.d.	0.24(3)	b.d.	b.d.
Zinc, Dissolved (ug/L)	10	6	-----	n.d.	n.d.	10	240(1,2)	0	0%
Zinc, Total (ug/L)	10	6	-----	n.d.	n.d.	20	5,000(4), 7,400(4)	0	0%
Pesticide Scan (ug/L)(D)	0.05(E)	6	-----	n.d.	n.d.	n.d.	-----	-----	-----

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

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

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

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

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

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

(3) Criterion for the protection of domestic water supply waters.

(4) Criterion for the protection of human health.

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

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

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

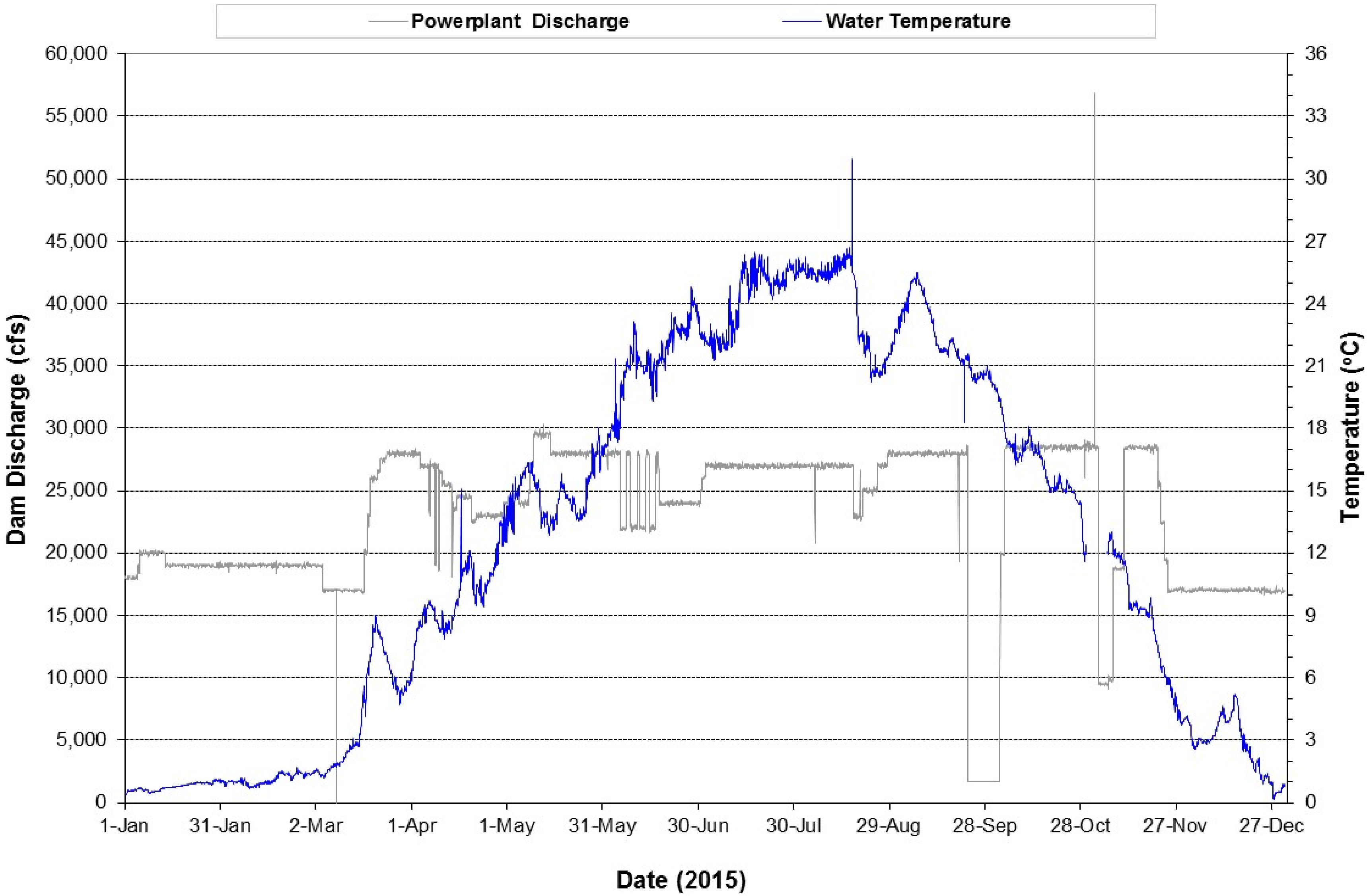


Plate 10-20. Hourly discharge and water temperature monitored at the Gavins Point powerplant on water discharged through the powerplant during 2015.

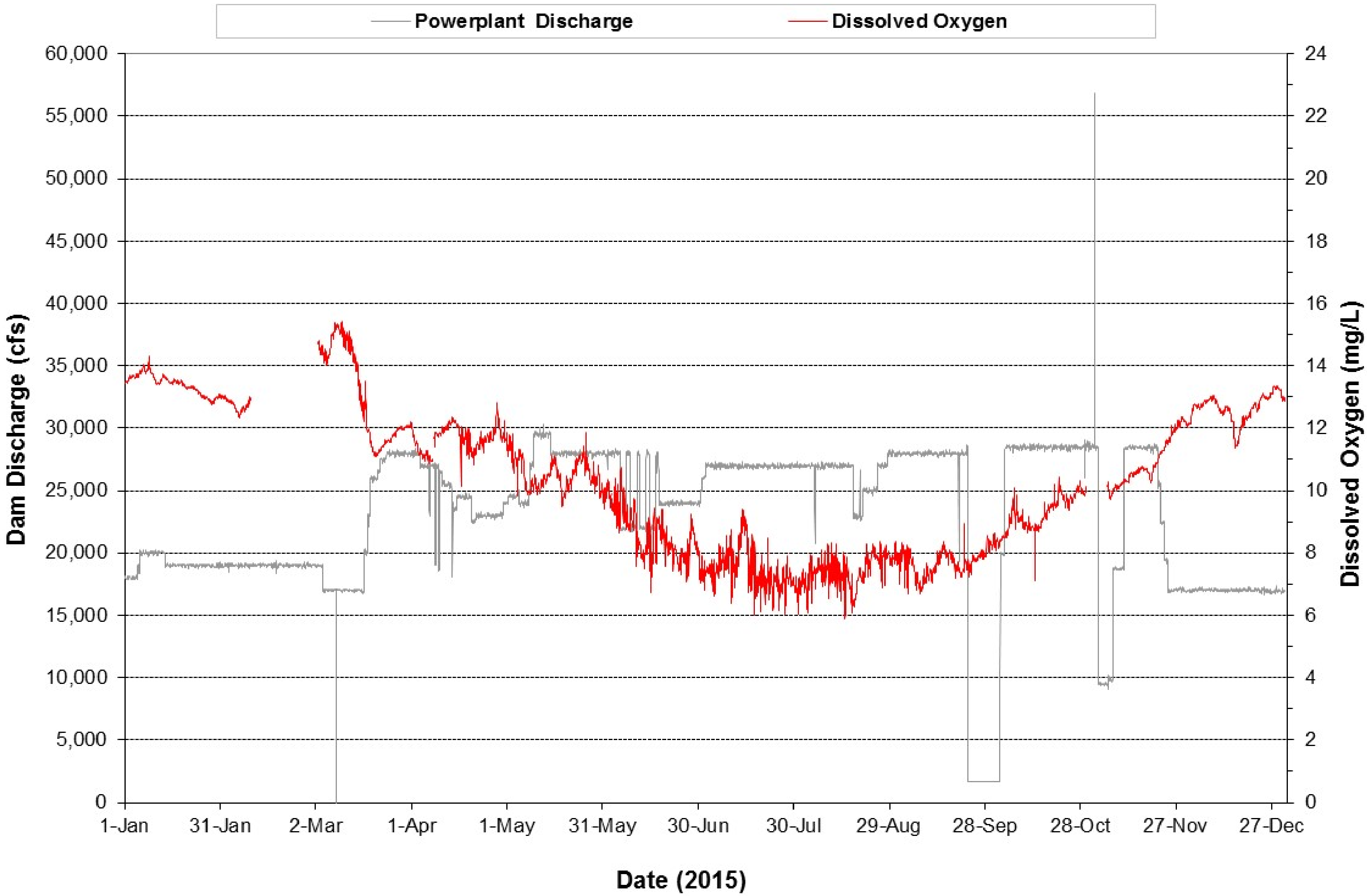


Plate 10-21. Hourly discharge and dissolved oxygen monitored at the Gavins Point powerplant on water discharged through the powerplant during 2015.

11 LOWER MISSOURI RIVER: GAVINS POINT DAM TO RULO, NE

11.1 CHANNEL CHARACTERISTICS AND TRIBUTARIES

The Missouri River between Gavins Point Dam (RM 811) and Rulo, NE (RM498) flows in an east-southeasterly to south-southeasterly direction. Major tributaries to the Missouri River below Gavins Point Dam, moving downstream, include: James River (South Dakota) at RM 801, Vermillion River (South Dakota) at RM 772, Big Sioux River (South Dakota and Iowa) at RM 734, Floyd River (Iowa) at RM 731, Little Sioux River (Iowa) at RM 669, Soldier River (Iowa) at RM664, Boyer River (Iowa) at RM 635, Platte River (Nebraska) at RM 595, Nishnabotna River (Iowa) at RM 542, and Tarkio River (Missouri) at RM 508. Extensive bed degradation has occurred in the upper areas of this Missouri River reach because river sediment is captured above Gavins Point Dam. Another factor is the substantial Missouri River channel shortening that occurred as part of the downstream Missouri River Bank Stabilization and Navigation Project. Gradual armoring of the riverbed has reduced the rate of channel degradation. Since 1965, approximately 10 feet of stage reduction has occurred for a discharge of 30,000 cfs in the Sioux City, IA area. During this period channel degradation of the Missouri River downstream in the Omaha, NE (RM 615.9) area has been non-existent. This reach of the Missouri River can be separated into three distinct sub reaches: the Missouri River National Recreational River, Kensler's Bend, and the Missouri River Navigation Channel reaches.

11.1.1 MISSOURI RIVER NATIONAL RECREATION RIVER REACH

The 59-mile reach of the Missouri River downstream of Gavins Point Dam starting at RM 811 down to Ponca, NE (RM 752) has been designated a National Recreational River under the Federal Wild and Scenic Rivers Act. This reach of the river has not been channelized by construction of dikes and revetments, and has a meandering channel with many chutes, backwater marshes, sandbars, islands, and variable current velocities. Snags and deep pools are also common. Although this portion of the river includes some bank stabilization structures, the river remains fairly wide.

11.1.2 KENSLER'S BEND REACH

The Kensler's Bend reach of the Missouri River extends from Ponca, Nebraska (RM 752) to above Sioux City, IA (RM 735). The Missouri River banks have been stabilized with dikes and revetments through this reach, but it has not been channelized.

11.1.3 MISSOURI RIVER NAVIGATION CHANNEL REACH

The reach of the Missouri River from the end of the Kensler's Bend reach (RM 735) to Rulo, NE (RM 498) has been modified over its entire length by an intricate system of dikes and revetments designed to provide a continuous navigation channel without the use of locks and dams. This reach is managed by the Corps under the Missouri River Bank Stabilization and Navigation Project. In addition to the primary authorization to maintain a navigation channel (9 ft deep by 300 ft wide) downstream from Sioux City, IA to the mouth of the Missouri River, there are authorizations to stabilize the river's banks.

11.2 FLOW REGULATION

Releases from Gavins Point Dam follow the same pattern as those from Fort Randall Dam because there is little active storage in Lewis and Clark Lake. Releases from both dams are based on the amount of water in Mainstem System storage, which governs how much water will be released to meet service demands in the portion of the lower Missouri River from Sioux City, IA to St. Louis, MO. Constraints for flood control, threatened and endangered bird nesting, and fish spawning also are factors governing releases. Releases from Gavins Point Dam generally fall into three categories: navigation, flood evacuation, and non-navigation releases.

11.2.1 MAINSTEM SYSTEM SERVICE LEVEL

To facilitate appropriate application of multipurpose regulation criteria to the Mainstem System, a numeric "service level" has been adopted since the Mainstem System was first filled in 1967. Quantitatively, a full service level approximates the water release rate necessary to achieve a normal 8-month navigation season with average downstream tributary flow contributions. For "full-service" and "minimum service" levels, the numeric service level values are, 35,000 cfs (cubic feet per second) and 29,000 cfs, respectively. This service level is used for selection of appropriate flow target values at previously established downstream control locations on the Missouri River. There are four flow target locations selected below Gavins Point Dam to assure that the Missouri River has adequate water available for the entire downstream reach to achieve regulation objectives. The four flow target locations and their flow target discharge deviation from service levels are: Sioux City (-4,000 cfs); Omaha (-4,000 cfs); Nebraska City (+2,000 cfs); and Kansas City (+6,000 cfs). A full-service level of 35,0000 cfs results in target discharges of 31,000 cfs at Sioux City and Omaha; 37,000 cfs at Nebraska City; and 41,000 cfs at Kansas City. Similarly, a minimum-service level of 29,000 cfs results in target values of 6,000 cfs less than the full-service levels at the four target locations. The relation of service levels to the volume of water in Mainstem System storage is as follows:

Date	Water in Mainstem System Storage (MAF)	Service Level (cfs)
March 15	54.5 or more*	35,000 (full-service)
March 15	31.0 to 49.0*	29,000 (minimum-service)
March 15	31.0 or less	No Service
July 1	57.0 or more*	35,000 (full-service)
July 1	50.5 or less*	29,000 (minimum-service)
* Straight-line interpolation defines intermediate service levels between full and minimum service.		

The length of the navigation season is determined by the volume of water in storage as follows:

Date	Water in Mainstem System Storage (MAF)	Season Closure Date at Mouth of Missouri River
March 15	Less than 31.0	No season
July 1	51.5 or more*	December 1 (8-month season)
July 1	41.0 to 46.8*	November 1 (7-month season)
July 1	36.5 or less*	October 1 (6-month season)
* Straight-line interpolation defines intermediate closure date between given values.		

11.2.2 HISTORIC FLOW RELEASES

In the navigation season, which generally runs from April 1 through November 30, releases from Gavins Point Dam are generally 25,000 to 35,000 cfs. In the winter, releases are in the 10,000- to 20,000-

cfs range. In wet years with above-normal upstream inflows, releases are higher to evacuate flood control storage space in upstream reservoirs. Maximum winter releases are generally kept below 24,000 cfs to minimize downstream flooding problems caused by ice jams in the lower river. During the 1987 to 1993 and the 2000 to 2008 droughts, non-navigation releases were generally in the 8,000- to 9,000- cfs range immediately following the end and preceding the start of the navigation season. During cold weather, releases were increased up to 15,000 cfs, but generally averaged 12,000 cfs over the 3-month winter period from December through February.

11.2.3 FLOW RELEASES FOR WATER QUALITY MANAGEMENT

Generally, Mainstem System release levels necessary to meet downstream water supply purposes exceed the minimum release levels necessary to meet minimum downstream water quality requirements. Tentative flow requirements for satisfactory water quality were first established by the U.S. Public Health Service and presented in the 1951 Missouri Basin Inter-Agency Committee Report on Adequacy of Flows in the Missouri River. These requirements were used in Mainstem System regulation until revisions were made in 1969 by the Federal Water Pollution Control Administration. The Missouri River minimum daily flow requirements for water quality (i.e. dissolved oxygen) that are given below were initially established by the Federal Water Pollution Control Administration in 1969. They were reaffirmed by the U.S. Environmental Protection Agency in 1974 after consideration of: 1) the current status of PL 92-500 programs for managing both point and non-point sources discharging into the river, and 2) the satisfactory adherence to the dissolved-oxygen concentration of 5.0 mg/L. The minimum daily flow requirements listed below are used for Mainstem System regulation purposes.

Location	Dec, Jan, Feb	Mar, Apr	May	Jun, Jul, Aug, Sep	Oct, Nov
Sioux City, IA	1,800 cfs	1,370 cfs	1,800 cfs	3,000 cfs	1,350 cfs
Omaha, NE	4,500 cfs	3,375 cfs	4,500 cfs	7,500 cfs	3,375 cfs
Kansas City, MO	5,400 cfs	4,050 cfs	5,400 cfs	9,000 cfs	4,050 cfs

Low flows in the Missouri River downstream from Gavins Point Dam may affect the ability of powerplants on this reach to meet National Pollutant Discharge Elimination System (NPDES) permit thermal limits for discharging cooling water back into the Missouri River.

11.2.4 FLOW TRAVEL TIMES

For purposes of scheduling releases, approximate open water travel times from Gavins Point Dam are 1.5 days to Sioux City; 3 days to Omaha; 3.5 days to Nebraska City; 5.5 days to Kansas City; and 10 days to the mouth of the Missouri River near St. Louis.

11.3 HISTORIC FLOW CONDITIONS (1967 TO 2015)

Historic flow conditions for the period 1967 through 2015 were determined from Corps and USGS gaging sites along the Missouri River from Gavins Point Dam to Rulo, NE. The gaging sites include: Gavins Point Dam; Omaha (USGS 06610000); Nebraska City (USGS 06807000); and Rulo (06813500). Box plots showing the distribution of the mean daily flows measured over the 48-year period are shown in Figure 11-1. The noted maximum values all occurred in 2011.

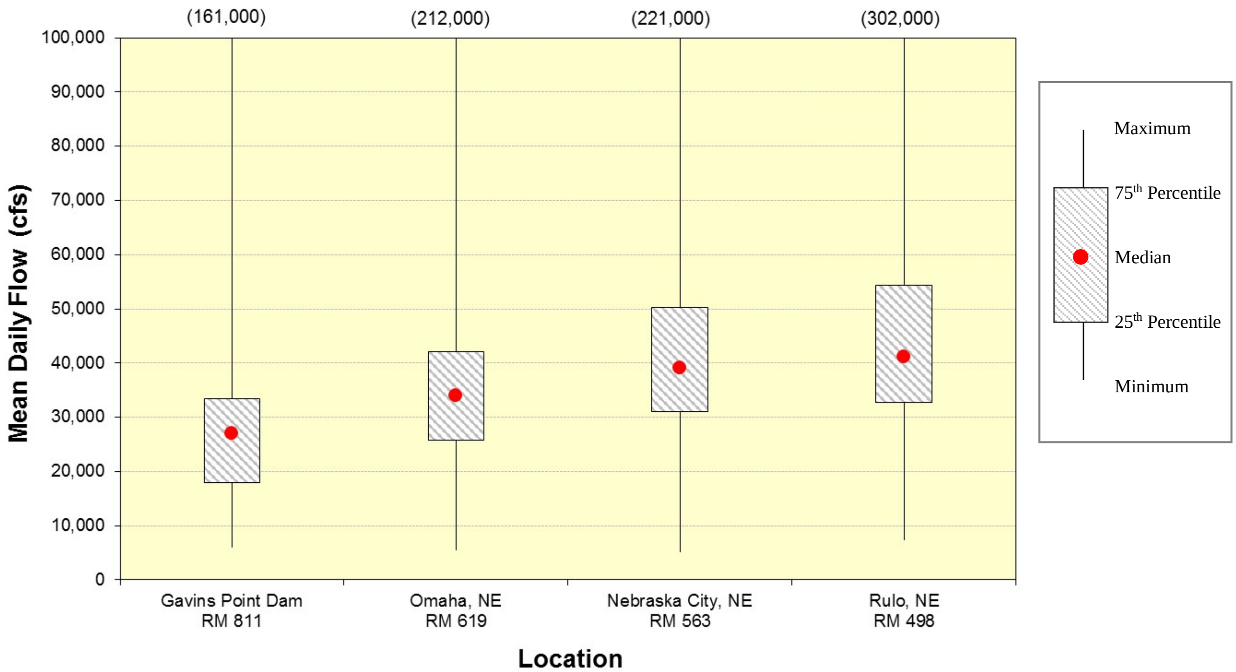


Figure 11-1. Distribution of mean daily flows recorded at gaging sites on the Missouri River at Gavins Point Dam, Omaha, NE, Nebraska City, NE, and Rulo, NE during the 49-year period of 1967 through 2015.

11.4 NATIONAL RECREATION RIVER DESIGNATION PURSUANT TO THE FEDERAL WILD AND SCENIC RIVERS ACT

The 59-mile "natural-channel" reach from Gavins Point Dam to Ponca State Park, NE has been designated as a National Recreational River under the Federal Wild and Scenic Rivers Act (WSRA). The National Park Service (NPS) manages the reach under 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.

11.5 STATE WATER QUALITY STANDARDS DESIGNATIONS

Pursuant to State water quality standards, the States of South Dakota, Nebraska, Iowa, and Missouri have designated water quality-dependent beneficial uses for appropriate reaches of the Missouri River downstream of Gavins Point Dam to Rulo, NE. South Dakota has designated the following uses for all of the Missouri River within the state downstream of Gavins Point Dam: primary contact recreation, warmwater fishery, drinking water supply, and industrial water supply. Nebraska has designated the following uses to the entire length of the Missouri River in Nebraska: primary contact recreation, warmwater aquatic life, agricultural water supply, and aesthetics. It has designated the use of drinking water supply to the river downstream of the confluence of the Niobrara River, and industrial water supply to the river downstream of the confluence of the Big Sioux River. Nebraska has also designated the reach between Gavins Point Dam and Ponca State Park as Outstanding State Resource Waters for "Tier 3" protection under the State's water quality standards' antidegradation policy. Iowa has designated the following uses to all of the Missouri River in the state: primary contact recreation, warmwater fishery, and high quality state resource water. It has also designated the use of drinking water supply to the river in the area of Council Bluffs, IA. Missouri has designated the following uses to the river: primary contact recreation, warmwater fishery, drinking water supply, agricultural water supply, and industrial water supply.

11.6 EXISTING WATER QUALITY CONDITIONS ALONG THE LOWER MISSOURI RIVER FROM GAVINS POINT DAM TO RULO, NEBRASKA

The Omaha District, in cooperation with the Nebraska Department of Environmental Quality (NDEQ), conducted fixed-station water quality monitoring at seven sites along the Missouri River from Gavins Point Dam to Rulo, NE during the 5-year period of 2011 through 2015. The location of the seven sites were Gavins Point Dam tailwaters (site GPTRRTW1); near Maskell, NE (site MORRR0774); near Ponca, NE (site MORRR0753); at Decatur, NE (site MORRR0691); at Omaha, NE (site MORRR0619); at Nebraska City, NE (site MORRR0563); and at Rulo, NE (site MORRR0498) (Figure 11-2).

11.6.1 GAVINS POINT DAM TAILWATERS (SITE GPTRRTW1) – RM810

Water quality samples at site GPTRRTW1 were collected monthly year-round during the 5-year period 2011 through 2015. Sampling during the period March through October was targeted from a boat in the thalweg of the river; otherwise (i.e. November through February), samples were collected from the bank in an area of faster current. When sampling was done from a boat depth-discrete samples were collected and depth-profile measurements were taken from the water surface to river bottom.

11.6.1.1 Near Surface Water Quality Conditions

11.6.1.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Plate 11-1 summarizes the near-surface water quality conditions that were monitored at site GPTRRTW1 during the 5-year period 2011 through 2015. A review of these results indicated no major water quality concerns.

11.6.1.1.2 Nutrient Flux Conditions

Nutrient flux rates for the Missouri River at the Gavins Point Dam tailwaters were calculated for the 5-year period 2011 through 2015. The calculated flux rates were based on near-surface water quality samples collected at site GPTRRTW1 and the instantaneous flow conditions at the time of sample collection (Table 11-1). It must be recognized that the concentrations of particulate-associated constituents can vary significantly from the river surface to its bottom because of the sinking of particulate matter and its transport nearer the river bottom. Since the instantaneous concentration of particulate-associated constituents (i.e. total phosphorus) could seemingly be higher nearer the river bottom, near-surface grab samples likely under estimate the “true” water-column composite concentration for this constituent. Thus, the given flux rate for total phosphorus should be considered a minimum estimate with the actual flux rate being potentially higher.

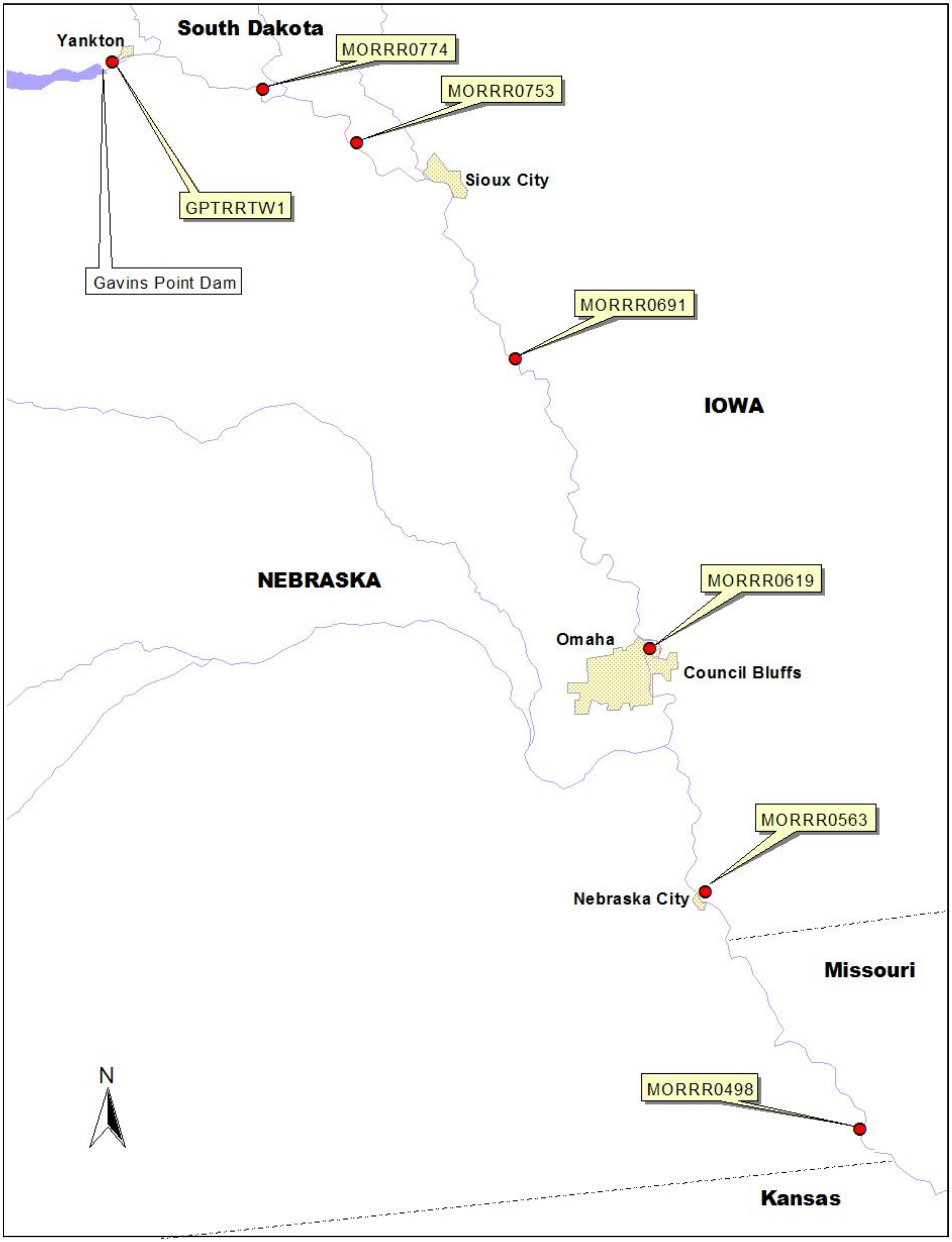


Figure 11-2. Locations of water quality monitoring sites along the Missouri River from Gavins Point Dam to Rulo, NE.

Table 11-1. Summary of near-surface nutrient flux rates (kg/sec) calculated for the Missouri River at the Gavins Point tailwaters (i.e. site GTPRRTW1) over the 5-year period 2011 through 2015.

Statistic	Missouri River Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	58	58	58	58	58	57
Mean	33,317	0.0231	0.4107	0.1316	0.0356	4.0931
Median	27,086	0.0039	0.2885	0.0861	0.0176	2.9702
Minimum	11,895	n.d.	0.0662	n.d.	n.d.	1.0778
Maximum	159,760	0.2755	2.5480	0.6886	0.3167	20.3569

n.d. = Nondetectable.
Note: Non-detect values set to 0 for flux calculations.

11.6.1.2 Vertical Water Quality Variation

Depth discrete water quality monitoring of the Missouri River at site GPTRRTW1 was conducted in 2015. Depth-profiles for water temperature, dissolved oxygen, pH, conductivity, and turbidity were measured in ½-meter increments while drifting in a boat along the river thalweg. Near-surface, mid-depth, and near-bottom grab samples were also collected from the thalweg of the river. The near-surface sample was collected by dipping a plastic churn bucket just below the water surface. The mid-depth and near-bottom samples were collected by triggering a finned-Van Dorn sampler at the appropriate depth while the boat was drifting in the current.

11.6.1.2.1 Depth-Profile Plots

Depth-profile plots were constructed for water temperature, dissolved oxygen, pH, conductivity, and turbidity for 2015 (Plate 11-2). The depth-profile plots indicate minimal variation in the five parameters with depth. The plots do indicate appreciable differences for selected parameters between monitoring dates.

11.6.1.2.2 Comparison of Near-Surface, Mid-Depth and Near-Bottom Water Quality Conditions

Paired near-surface, mid-depth, and near-bottom water quality samples collected at site GPTRRTW1 during the 5-year period 2011 through 2015 were compared. Box plots were constructed to display the distribution of the paired near-surface, mid-depth, and near-bottom measurements for particulate-associated constituents (i.e. total suspended solids, total suspended sediment, total Kjeldahl nitrogen, total phosphorus, and total organic carbon) (Plate 11-3). The box plots of the particulate-associated constituents exhibited vertical variation. 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 found to be significantly different for TKN ($p < 0.01$), with higher TKN concentrations near the bottom.

11.6.2 MISSOURI RIVER NEAR MASKELL, NEBRASKA (SITE MORRR0774) – RM774

Water quality samples at site MORRR0774 were collected monthly year-round during the 5-year period 2011 through 2015. A near-surface grab sample was collected from the bank in an area of faster current.

11.6.2.1 Near-Surface Water Quality Conditions

11.6.2.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Plate 11-4 summarizes the near-surface water quality conditions that were monitored at site MORRR0744 during the 5-year period 2011 through 2015. A review of these results indicated no major water quality concerns.

11.6.2.1.2 Nutrient Flux Conditions

Nutrient flux rates for the Missouri River near Maskell, Nebraska at RM774 were calculated for the 5-year period 2011 through 2015. The calculated flux rates were based on near-surface water quality samples collected at site MORRR0774 and the instantaneous flow conditions at the time of sample collection (Table 11-2). It must be recognized that the concentrations of particulate-associated constituents can vary significantly from the river surface to its bottom because of the sinking of particulate matter and its transport nearer the river bottom. Since the instantaneous concentration of particulate-associated constituents (i.e. total phosphorus and total organic carbon) could seemingly be higher nearer the river bottom, near-surface grab samples likely under estimate the "true" water-column composite concentration for these constituents. Thus, the given flux rates for total phosphorus and total organic carbon should be considered minimum estimates with the actual flux rates likely being higher.

Table 11-2. Summary of nutrient flux rates (kg/sec) calculated for the Missouri River near Maskell, Nebraska at RM774 over the 5-year period 2011 through 2015.

Statistic	Missouri River Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	47	47	47	47	47	47
Mean	39,209	0.0262	0.6298	0.1807	0.0697	5.1367
Median	29,265	n.d.	0.4113	0.0977	0.0331	3.8883
Minimum	14,088	n.d.	0.1668	n.d.	n.d.	1.3650
Maximum	160,801	0.3443	3.2682	1.0330	0.5919	26.4088

n.d. = Nondetectable.
Note: Non-detect values set to 0 for flux calculations.

11.6.3 MISSOURI RIVER NEAR PONCA, NEBRASKA (SITE MORRR0753) – RM753

Water quality samples at site MORRR0753 were collected monthly year-round during the 5-year period 2011 through 2015. In 2011, 2012, 2014, and 2015 sampling during the period March through October was conducted from a boat in the thalweg of the river; otherwise, samples were collected from the bank in an area of faster current. When sampling was done from a boat depth-discrete samples were collected and depth-profile measurements were taken from the water surface to river bottom.

11.6.3.1 Statistical Summary of Near-Surface Water Quality Conditions and Comparison to Applicable Water Quality Standards Criteria

Plate 11-5 summarizes the near-surface water quality conditions that were monitored at site MORRR0753 during the 5-year period 2011 through 2015. A review of these results indicated no major water quality concerns.

11.6.3.2 Nutrient Flux Conditions

Nutrient flux rates for the Missouri River near Ponca, Nebraska at RM753 were calculated for the 5-year period 2011 through 2015. The calculated flux rates were based on near-surface water quality samples collected at site MORRR0753 and the instantaneous flow conditions at the time of sample collection (Table 11-3). It must be recognized that the concentrations of particulate-associated constituents can vary significantly from the river surface to its bottom because of the sinking of particulate matter and its transport nearer the river bottom. Since the instantaneous concentration of particulate-associated constituents (i.e. total phosphorus and total organic carbon) could seemingly be higher nearer the river bottom, near-surface grab samples likely under estimate the "true" water-column composite concentration for these constituents. Thus, the given flux rates for total phosphorus and total organic carbon should be considered minimum estimates with the actual flux rates being potentially higher.

Table 11-3. Summary of nutrient flux rates (kg/sec) calculated for the Missouri River near Ponca, Nebraska at RM753 over the 5-year period 2011 through 2015.

Statistic	Missouri River Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	43	43	43	43	43	42
Mean	39,984	0.0320	0.6969	0.1733	0.0926	5.6762
Median	29,385	n.d.	0.4255	0.0778	0.0393	4.1281
Minimum	8,631	n.d.	0.1137	n.d.	n.d.	1.2464
Maximum	161,302	0.4976	2.8775	1.1264	0.5024	23.7506

n.d. = Nondetectable.
Note: Non-detect values set to 0 for flux calculations.

11.6.4 MISSOURI RIVER AT DECATUR, NEBRASKA (SITE MORRR0691) – RM691

Water quality samples at site MORRR0691 were collected monthly year-round during the 5-year period 2011 through 2015. Sampling during the period March through October was conducted from a boat in the thalweg of the river; otherwise (i.e. November through February), samples were collected from the bank in an area of faster current. When sampling was done from a boat depth-discrete samples were collected and depth-profile measurements were taken from the water surface to river bottom.

11.6.4.1 Near-Surface Water Quality Conditions

11.6.4.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Plate 11-6 summarizes the near-surface water quality conditions that were monitored at site MORRR0691 during the 5-year period 2011 through 2015. A review of these results indicated no major water quality concerns.

11.6.4.1.2 Nutrient Flux Conditions

Nutrient flux rates for the Missouri River at Decatur, Nebraska at RM691 were calculated for the 5-year period 2011 through 2015. The calculated flux rates were based on near-surface water quality samples collected at site MORRR0691 and the instantaneous flow conditions at the time of sample collection (Table 11-4). It must be recognized that the concentrations of particulate-associated constituents can vary significantly from the river surface to its bottom because of the sinking of particulate matter and its transport nearer the river bottom. Since the instantaneous concentration of particulate-associated constituents (i.e. total phosphorus) could seemingly be higher nearer the river bottom, near-surface grab samples likely under estimate the "true" water-column composite concentration for this constituent. Thus, the given flux rates for total phosphorus should be considered minimum estimate with the actual flux rate being potentially higher.

Table 11-4. Summary of nutrient flux rates (kg/sec) calculated for the Missouri River at Decatur, Nebraska at RM691 over the 5-year period 2011 through 2015.

Statistic	Missouri River Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	52	52	52	52	52	51
Mean	40,659	0.0418	0.8238	0.5338	0.1642	6.0250
Median	32,157	n.d.	0.5367	0.2684	0.0749	4.3925
Minimum	14,777	n.d.	0.1201	n.d.	0.0258	1.4177
Maximum	182,527	0.5401	4.7551	2.6235	1.3869	27.3927

n.d. = Nondetectable.
Note: Non-detect values set to 0 for flux calculations.

11.6.4.2 Vertical Water Quality Variation

Depth discrete water quality monitoring of the Missouri River at site MORRR0691 was conducted in 2015. Depth-profiles for water temperature, dissolved oxygen, pH, conductivity, and turbidity were measured in ½-meter increments while drifting in a boat along the river thalweg. Near-surface, mid-depth, and near-bottom grab samples were also collected from the thalweg of the river. The near-surface sample was collected by dipping a plastic churn bucket just below the water surface. The mid-depth and near-bottom samples were collected by triggering a finned-Van Dorn sampler at the appropriate depth while the boat was drifting in the current.

11.6.4.2.1 Depth-Profile Plots

Depth-profile plots were constructed for water temperature, dissolved oxygen, pH, conductivity, and turbidity for 2015 (Plate 11-7). The depth-profile plots indicate minimal variation in the five parameters with depth. The plots do indicate appreciable differences for selected parameters between monitoring dates.

11.6.4.2.2 Comparison of Near-Surface, Mid-Depth and Near-Bottom Water Quality Conditions

Paired near-surface, mid-depth, and near-bottom water quality samples collected at site MORRR0691 during the 5-year period 2011 through 2015 were compared. Box plots were constructed to display the distribution of the paired near-surface, mid-depth, and near-bottom measurements for selected particulate-associated constituents (i.e. total suspended solids, total suspended sediment, total Kjeldahl nitrogen, total phosphorus, and total organic carbon) (Plate 11-8). 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-bottom conditions were significantly higher for total phosphorus ($p < 0.01$). Total suspended solids, turbidity, total Kjeldahl nitrogen, and total organic carbon showed no significant difference between near-surface and near-bottom paired samples.

11.6.5 MISSOURI RIVER AT OMAHA, NEBRASKA (SITE MORRR0619) – RM619

Water quality samples at site MORRR0619 were collected monthly year-round during the 5-year period 2011 through 2015. Sampling during the period March through October was conducted from a boat in the thalweg of the river; otherwise, samples were collected from the bank in an area of faster current. When sampling was done from a boat depth-discrete samples were collected and depth-profile measurements were taken from the water surface to river bottom.

11.6.5.1 Near-Surface Water Quality Conditions

11.6.5.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Plate 11-9 summarizes the near-surface water quality conditions that were monitored at site MORRR0619 during the 5-year period 2011 through 2015. A review of these results indicated no major water quality concerns. There was one detection of the pesticide chlorpyrifos above acute and chronic water quality standards criteria for the protection of aquatic life.

11.6.5.1.2 Nutrient Flux Conditions

Nutrient flux rates for the Missouri River at Omaha, Nebraska at RM619 were calculated for the 5-year period 2011 through 2015. The calculated flux rates were based on near-surface water quality samples collected at site MORRR0619 and the instantaneous flow conditions at the time of sample collection (Table 11-5). It must be recognized that the concentrations of particulate-associated constituents can vary significantly from the river surface to its bottom because of the sinking of particulate matter and its transport nearer the river bottom. Since the instantaneous concentration of particulate-associated constituents (i.e. total phosphorus) could seemingly be higher nearer the river bottom, near-surface grab samples likely under estimate the “true” water-column composite concentration for this constituent. Thus, the given flux rate for total phosphorus should be considered minimum estimate with the actual flux rate being potentially higher.

Table 11-5. Summary of nutrient flux rates (kg/sec) calculated for the Missouri River at Omaha, Nebraska at RM619 over the 5-year period 2011 through 2015.

Statistic	Missouri River Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	58	58	58	57	58	57
Mean	40,957	0.0466	0.9284	1.2345	0.1954	6.4960
Median	34,281	0.0126	0.6217	0.6241	0.0954	4.4170
Minimum	15,144	n.d	0.0770	n.d	0.0185	1.4431
Maximum	193,284	0.4177	4.4332	5.8444	1.8797	40.5318

n.d. = Nondetectable.
Note: Non-detect values set to 0 for flux calculations.

11.6.5.2 <u>Vertical Water Quality Variation</u>

Depth discrete water quality monitoring of the Missouri River at site MORRR0619 was conducted during the 5-year period 2011 through 2015. Depth-profiles for water temperature, dissolved oxygen, pH, conductivity, and turbidity were measured in ½-meter increments while drifting in a boat along the river thalweg. Near-surface, mid-depth, and near-bottom grab samples were also collected from the thalweg of the river. The near-surface sample was collected by dipping a plastic churn bucket just below the water surface. The mid-depth and near-bottom samples were collected by triggering a finned-Van Dorn sampler at the appropriate depth while the boat was drifting in the current.

11.6.5.2.1 Depth-Profile Plots

Depth-profile plots were constructed for water temperature, dissolved oxygen, pH, conductivity, and turbidity for 2015 (Plate 11-10). The depth-profile plots indicate minimal variation in the five parameters with depth. The plots do indicate appreciable differences for selected parameters between monitoring dates.

11.6.5.2.2 Comparison of Near-Surface, Mid-Depth and Near-Bottom Water Quality Conditions

Paired near-surface, mid-depth, and near-bottom water quality samples collected at site MORRR0619 during the 5-year period 2011 through 2015 were compared. Box plots were constructed to display the distribution of the paired near-surface, mid-depth, and near-bottom measurements for selected particulate-associated constituents (i.e. total suspended solids, total suspended sediment, total Kjeldahl nitrogen, total phosphorus, and total organic carbon) (Plate 11-11). 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-bottom conditions were significantly higher for total suspended sediment ($p < 0.01$) and total phosphorus ($p < 0.001$), and significantly lower for total organic carbon ($p < 0.05$).

11.6.6 MISSOURI RIVER AT NEBRASKA CITY, NEBRASKA (SITE MORRR0563) – RM563

Water quality samples at site MORRR0563 were collected monthly year-round during the 5-year period 2011 through 2015. Sampling during the period March through October was conducted from a boat in the thalweg of the river; otherwise, samples were collected from the bank in an area of faster current. When sampling was done from a boat depth-discrete samples were collected and depth-profile measurements were taken from the water surface to river bottom.

11.6.6.1 <u>Near-Surface Water Quality Conditions</u>

11.6.6.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Plate 11-12 summarizes the near-surface water quality conditions that were monitored at site MORRR0563 during the 5-year period 2011 through 2015. A review of these results indicated no major water quality concerns.

11.6.6.1.2 Nutrient Flux Conditions

Nutrient flux rates for the Missouri River at Nebraska City, Nebraska at RM563 were calculated for the 5-year period 2011 through 2015. The calculated flux rates were based on near-surface water quality samples collected at site MORRR0563 and the instantaneous flow conditions at the time of sample collection (Table 11-6). It must be recognized that the concentrations of particulate-associated constituents can vary significantly from the river surface to its bottom because of the sinking of particulate matter and its transport nearer the river bottom. Since the instantaneous concentration of particulate-associated constituents (i.e. total phosphorus) could seemingly be higher nearer the river bottom, near-surface grab samples likely under estimate the "true" water-column composite concentration for this constituent. Thus, the given flux rate for total phosphorus should be considered a minimum estimate with the actual flux rate likely being higher.

Table 11-6. Summary of nutrient flux rates (kg/sec) calculated for the Missouri River at Nebraska City, Nebraska at RM563 over the 5-year period 2011 through 2015.

Statistic	Missouri River Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	60	60	60	60	60	60
Mean	48,274	0.1059	1.3732	1.6517	0.3995	8.6961
Median	40,064	0.0884	0.9564	1.2648	0.2038	5.2878
Minimum	17,910	n.d.	0.3094	0.0761	0.0422	1.7750
Maximum	198,043	0.6225	6.1079	9.5711	3.5262	53.5237

n.d. = Nondetectable.
Note: Non-detect values set to 0 for flux calculations.

11.6.6.2 Vertical Water Quality Variation

Depth discrete water quality monitoring of the Missouri River at site MORRR0563 was conducted during the 5-year period 2011 through 2015. Depth-profiles for water temperature, dissolved oxygen, pH, conductivity, and turbidity were measured in ½-meter increments while drifting in a boat along the river thalweg. Near-surface, mid-depth, and near-bottom grab samples were also collected from the thalweg of the river. The near-surface sample was collected by dipping a plastic churn bucket just below the water surface. The mid-depth and near-bottom samples were collected by triggering a finned-Van Dorn sampler at the appropriate depth while the boat was drifting in the current.

11.6.6.2.1 Depth-Profile Plots

Depth-profile plots were constructed for water temperature, dissolved oxygen, pH, conductivity, and turbidity for 2015 (Plate 11-13). The depth-profile plots indicate minimal variation in the five parameters with depth. The plots do indicate appreciable differences for selected parameters between monitoring dates.

11.6.6.2.2 Comparison of Near-Surface, Mid-Depth and Near-Bottom Water Quality Conditions

Paired near-surface, mid-depth, and near-bottom water quality samples collected at site MORRR0563 during the 5-year period 2011 through 2015 were compared. Box plots were constructed to display the distribution of the paired near-surface, mid-depth, and near-bottom measurements for selected particulate-associated constituents (i.e. total suspended solids, total suspended sediment, total Kjeldahl nitrogen, total phosphorus, and total organic carbon) (Plate 11-14). 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-bottom conditions were significantly higher for total suspended sediment ($p < 0.05$) and total phosphorus ($p < 0.001$), and significantly lower for total organic carbon ($p < 0.05$).

11.6.7 MISSOURI RIVER AT RULO, NEBRASKA (SITE MORRR0498) – RM498

Water quality samples at site MORRR0498 were collected monthly year-round during the 5-year period 2011 through 2015. Sampling during the period March through October was conducted from a boat in the thalweg of the river; otherwise, samples were collected from the bank in an area of faster current. When sampling was done from a boat depth-discrete samples were collected and depth-profile measurements were taken from the water surface to river bottom.

11.6.7.1 Near-Surface Water Quality Conditions

11.6.7.1.1 Statistical Summary and Comparison to Applicable Water Quality Standards Criteria

Plate 11-15 summarizes the near-surface water quality conditions that were monitored at site MORRR0498 during the 5-year period 2011 through 2015. A review of these results indicated no major water quality concerns.

11.6.7.1.2 Nutrient Flux Conditions

Nutrient flux rates for the Missouri River at Rulo, Nebraska at RM498 were calculated for the 5-year period 2011 through 2015. The calculated flux rates were based on near-surface water quality samples collected at site MORRR0498 and the instantaneous flow conditions at the time of sample collection (Table 11-7). It must be recognized that the concentrations of particulate-associated constituents can vary significantly from the river surface to its bottom because of the sinking of particulate matter and its transport nearer the river bottom. Since the instantaneous concentration of particulate-associated constituents (i.e. total phosphorus) could seemingly be higher nearer the river bottom, near-surface grab samples likely under estimate the "true" water-column composite concentration for this constituent. Thus, the given flux rate for total phosphorus should be considered a minimum estimate with the actual flux rate likely being somewhat higher.

Table 11-7. Summary of nutrient flux rates (kg/sec) calculated for the Missouri River at Rulo, Nebraska at RM498 over the 5-year period 2011 through 2015.

Statistic	Missouri River Flow (cfs)	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	60	60	60	60	60	59
Mean	51,584	0.0896	1.6111	2.0351	0.4740	10.4647
Median	40,807	0.0723	1.0606	1.2580	0.2227	6.1785
Minimum	18,883	n.d.	0.1620	0.1022	0.0656	1.7558
Maximum	245,917	0.4757	8.1472	13.5284	3.1517	58.4924

n.d. = Nondetectable.
Note: Non-detect values set to 0 for flux calculations.

11.6.7.2 Vertical Water Quality Variation

Depth discrete water quality monitoring of the Missouri River was conducted at site MORRR0498 during the 5-year period 2011 through 2015. Depth-profiles for water temperature, dissolved oxygen, pH, conductivity, and turbidity were measured in ½-meter increments while drifting in a boat along the river thalweg. Near-surface, mid-depth, and near-bottom grab samples were also collected from the thalweg of the river. The near-surface sample was collected by dipping a plastic churn bucket just below the water surface. The mid-depth and near-bottom samples were collected by triggering a finned-Van Dorn sampler at the appropriate depth while the boat was drifting in the current.

11.6.7.2.1 Depth-Profile Plots

Depth-profile plots were constructed for water temperature, dissolved oxygen, pH, conductivity, and turbidity for 2015 (Plate 11-16). The depth-profile plots indicate minimal variation in the five parameters with depth. The plots do indicate appreciable differences for selected parameters between monitoring dates.

11.6.7.2.2 Comparison of Near-Surface, Mid-Depth and Near-Bottom Water Quality Conditions

Paired near-surface, mid-depth, and near-bottom water quality samples collected at site MORRR0498 during the 5-year period 2011 through 2015 were compared. Box plots were constructed to display the distribution of the paired near-surface, mid-depth, and near-bottom measurements for selected particulate-associated constituents (i.e. total suspended solids, total suspended sediment, turbidity, total Kjeldahl nitrogen, total phosphorus, and total organic carbon) (Plate 11-17). 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-bottom conditions were significantly higher for total phosphorus ($p < 0.05$) and suspended sediment ($p < 0.05$). The sampled near-bottom conditions were significantly lower for total organic carbon ($p <0.01$).

11.6.8 Longitudinal Variation in Water Quality Along the Lower Missouri River

The levels of selected parameters measured in near-surface samples collected at each of the seven monitoring sites along the lower Missouri River over the 5-year period 2011 through 2015 are depicted as box plots. The parameters plotted include flow, dissolved oxygen, pH, specific conductance, chloride, turbidity, total suspended solids, total organic carbon, total nitrogen, total nitrate-nitrite nitrogen, total ammonia nitrogen, total phosphorus, and dissolved phosphorus (Plate 11-18). For comparison purposes, box plots for the individual parameters measured at each of the seven sites are arranged relative to their respective location in an upstream to downstream order (i.e. GPTRRTW1 = RM811, MORRR0774 = RM774, MORRR0753 = RM753, MORR0691 = RM691, MORR0619 = RM619, MORR0563 = RM563, and MORR0498 = RM498).

11.6.1 Water Temperatures Monitored Along the Lower Missouri River during 2015

Mean daily water temperatures where determined for the Missouri River at Gavins Point Dam and the St. Joseph, Mo USGS gage (06818000). Mean daily water temperatures for the two sites for 2015 are plotted in Plate 11-19. In the spring and summer, mean daily water temperatures in the Missouri River are generally about 2 to 4° C warmer at St. Joseph, MO as compared to the discharges from Gavins Point Dam.

Plate 11-1. Summary of near-surface water quality conditions monitored in the Missouri River at the Gavins Point Dam tailwaters (i.e. site GPTRRTW1) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[(A)]	No. of Obs.	Mean[(B)]	Median	Min.	Max.	State WQS Criteria[(C)]	No. of WQS Exceedances	Percent WQS Exceedance
Gavins Point Dam Discharge:									
Streamflow (cfs)	1	57	33,569	27,117	11,895	159,760	-----	-----	-----
Field Measurements:									
Water Temperature (°C)	0.1	56	12.1	10.3	0.0	26.2	27[(1,2,6)], 29[(1,2,6)]	0, 0	0%, 0%
Dissolved Oxygen (mg/L)	0.1	56	11.0	11.1	7.1	14.6	5[(1,7)]	0	0%
Dissolved Oxygen (% Sat.)	0.1	56	102.1	100.4	91.5	132.6	-----	-----	-----
Oxidation-Reduction Potential	1	56	355	356	158	434	-----	-----	-----
pH (S.U.)	0.1	55	8.3	8.3	7.0	9.4	6.5[(1,3,7)], 9.0[(1,3,6)], 9.5[(5,6)]	0, 1, 0	0%, 2%, 0%
Specific Conductance (uS/cm)	1	54	806	812	681	928	2,000[(4)]	0	0%
Turbidity (NTU)	1	56	14	10	n.d.	80	-----	-----	-----
Laboratory Results:									
Alkalinity, Total (mg/L)	7	57	166	166	153	184	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	56	4.2	4.3	3.0	6.4	-----	-----	-----
CBOD 5-day (mg/L)	2	39	-----	n.d.	n.d.	7.0	-----	-----	-----
Chemical Oxygen Demand (mg/L)	2	54	10	10	n.d.	19	-----	-----	-----
Chloride (mg/L)	1	37	12	12	10	14	438[(3,6)], 250[(3,8)]	0	0%
Chlorophyll *a* (ug/L)	1	31	12	7	n.d.	48	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	64	23	23	16	32	-----	----	-----
Dissolved Solids, Total (mg/L)	5	57	562	546	458	774	1,750[(3,6)], 1,000[(3,8)], 3,500[(5,6)], 2,000[(5,8)]	0	0%
Nitrogen, Ammonia Total	0.02	57	-----	n.d.	n.d.	0.20	4.7 [(1,6,9)], 1.4 [(1,8,9)]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	57	0.4	0.4	0.1	0.9	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	57	0.15	0.11	n.d.	1.06	10[(3,6)], 100[(4,6)]	0	0%
Nitrogen, Total (mg/L)	0.1	57	0.6	0.5	0.1	1.4	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	57	-----	n.d.	n.d.	0.07	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	57	0.03	0.02	n.d,	0.19	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	57	-----	n.d.	n.d.	0.09	-----	-----	-----
Sulfate (mg/L)	1	57	243	243	198	297	-----	-----	-----
Suspended Sediment, Total (mg/L)	4	40	15	11	n.d.	61	-----	-----	-----
Suspended Solids, Total (mg/L)	4	57	12	10	n.d.	38	158[(1,6)], 90[(1,8)]	0	0%
THM Formation Potential, Total (mg/L)	4	33	156	165	13	406	-----	-----	-----
Acetochlor, Total (ug/L)[(D)]	0.05	55	-----	n.d.	n.d.	0.3	-----	-----	-----
Atrazine, Total (ug/L)[(D)]	0.05	55	-----	n.d.	n.d.	0.5	330[(10)], 12[(11)], 3[(3)]	0	0%
Metolachlor, Total (ug/L)[(D)]	0.05	55	-----	n.d.	n.d.	0.4	390[(10)], 100[(11)]	0	0%

n.d. = Not detected.

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

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

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

- (1) Criteria for the protection of Warmwater Permanent Fish Life Propagation Waters (South Dakota) or Class I Warmwater Aquatic Life (Nebraska).
- (2) South Dakota's temperature criterion is 27°C and Nebraska's is 29°C.
- (3) Criteria for the protection of domestic water supply waters.
- (4) Criteria for the protection of agricultural water supply waters.
- (5) Criteria for the protection of commerce and industry waters.
- (6) Daily maximum criterion (monitoring results directly comparable to criterion).
- (7) Daily minimum criterion (monitoring results directly comparable to criterion).
- (8) 30-day average criterion (monitoring results not directly comparable to criterion).
- (9) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (10) Acute (CMC) criterion for the protection of freshwater aquatic life.
- (11) Chronic (CCC) criterion for the protection of freshwater aquatic life.
- (12) Criterion for the protection of human health.

(D) Immunoassay analysis.

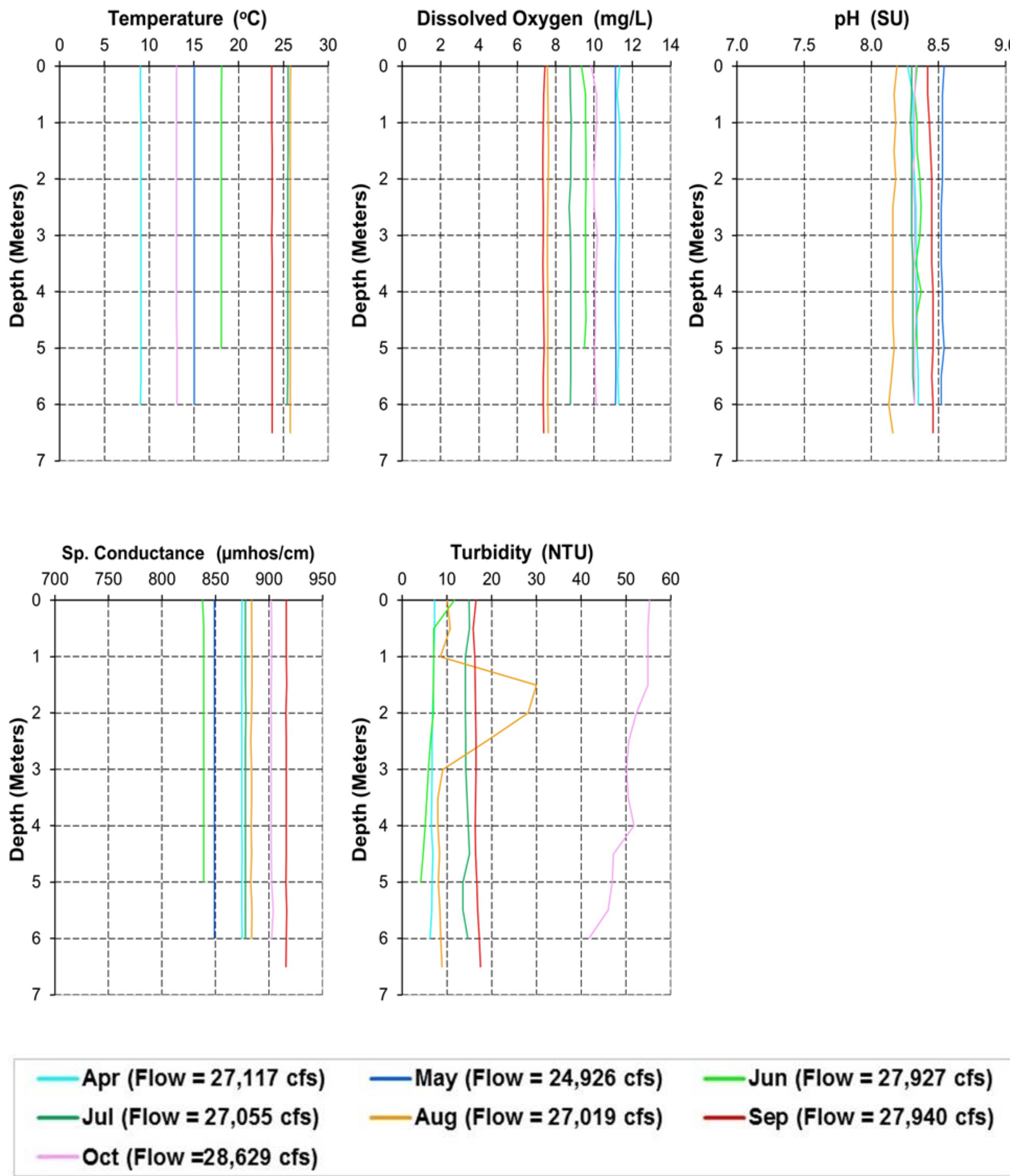


Plate 11-2. Water temperature, dissolved oxygen, pH, specific conductance, and turbidity depth profiles for the Missouri River compiled from data collected at the Gavins Point Dam tailwaters site (i.e. GPTPRRTW1) during 2015.

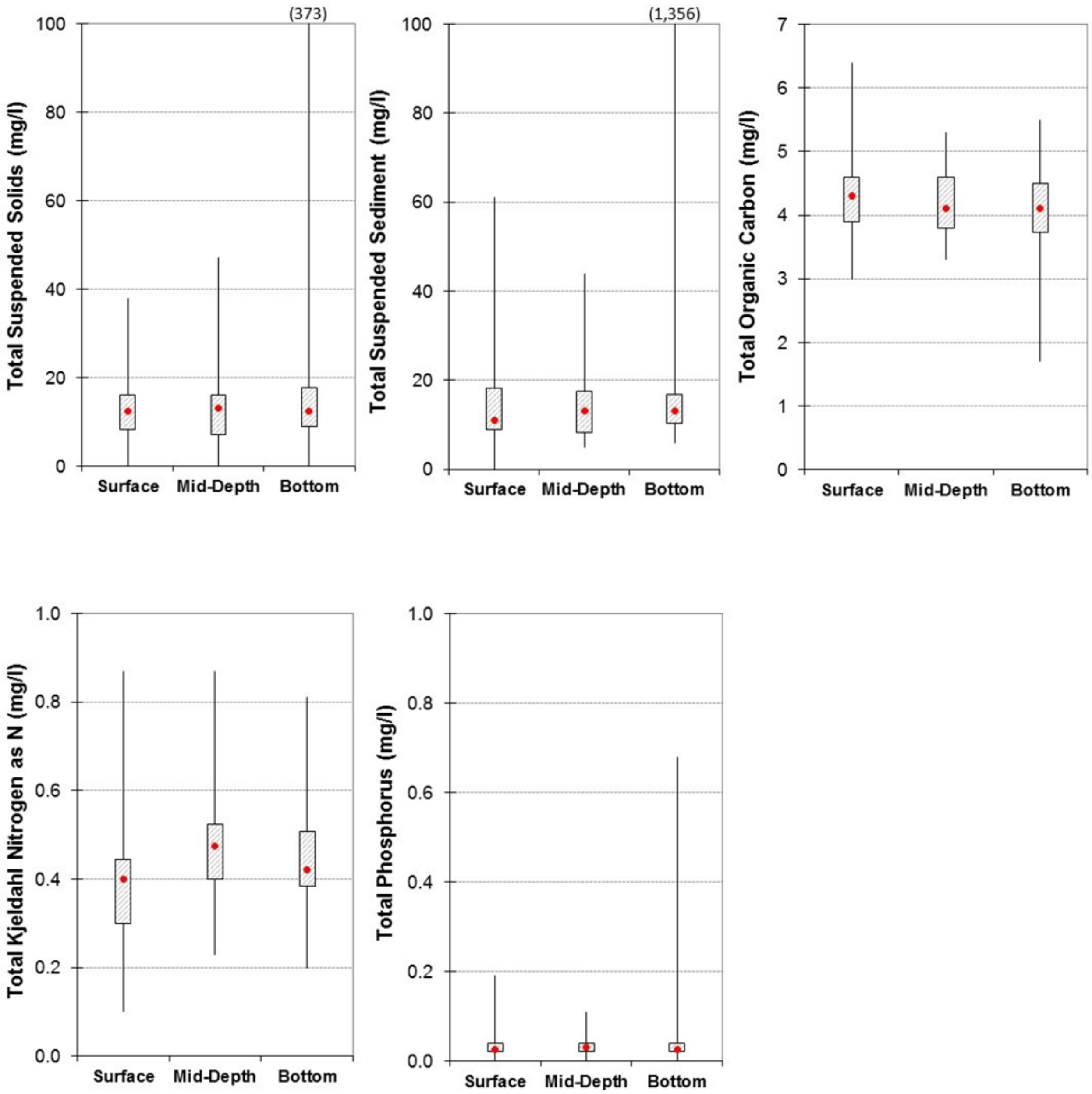


Plate 11-3. Box plots comparing paired surface, mid-depth, and bottom total suspended solids, total suspended sediment, turbidity, total Kjeldahl nitrogen, total phosphorus, and total organic carbon measurements taken in the Missouri River at site GPTRRTW1 during the 5-year period 2011 through 2015. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

Plate 11-4. Summary of near-surface water quality conditions monitored in the Missouri River near Maskell, Nebraska (i.e. site MORRR0774) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit(A)	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Estimated Discharge:									
Streamflow (cfs)	1	54	37,340	30,792	14,088	160,801	-----	-----	-----
Field Measurements:									
Water Temperature (°C)	0.1	56	15.1	14.4	0.1	28.9	27(1,2,6), 29(1,2,6)	4, 0	7%, 0%
Dissolved Oxygen (mg/L)	0.1	56	10.2	9.9	7.7	13.8	5(1,7)	0	0%
Dissolved Oxygen (% Sat.)	0.1	56	103.3	102.4	94.9	116.0	-----	-----	-----
Oxidation-Reduction Potential	1	56	345	358	118	445	-----	-----	-----
pH (S.U.)	0.1	56	8.3	8.4	7.8	8.6	6.5(1,3,7), 9.0(1,3,6), 9.5(5,6)	0	0%
Specific Conductance (uS/cm)	1	56	809	814	690	921	2,000(4)	0	0%
Turbidity (NTU)	1	56	23	18	n.d.	29	-----	-----	-----
Laboratory Results:									
Alkalinity, Total (mg/L)	7	55	166	168	142	190	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	56	4.6	4.7	2.7	7.2	-----	-----	-----
CBOD 5-day (mg/L)	2	31	-----	2.0	n.d.	25	-----	-----	-----
Chemical Oxygen Demand (mg/L)	2	45	12	13	n.d.	19	-----	-----	-----
Chloride (mg/L)	1	55	13	13	10	16	438(3,6), 250(3,8)	0	0%
Colorized Dissolved Organic Matter (ug/L)	4	45	25	25	16	33	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	55	558	553	420	784	1,750(3,6), 1,000(3,8), 3,500(5,6), 2,000(5,8)	0	0%
Nitrogen, Ammonia Total	0.02	56	-----	n.d.	n.d.	0.16	3.9(1,6,9), 1.2(1,8,9)	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	56	0.5	0.5	n.d.	0.9	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	56	0.17	0.15	n.d.	0.60	10(3,6), 100(4,6)	0	0%
Nitrogen, Total (mg/L)	0.1	56	0.7	0.7	0.3	1.3	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	55	-----	0.02	n.d.	0.07	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	56	0.05	0.05	n.d.	0.15	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	56	-----	n.d.	n.d.	0.05	-----	-----	-----
Sulfate (mg/L)	1	55	243	244	193	316	-----	-----	-----
Suspended Solids, Total (mg/L)	4	55	32	27	6	120	158(1,6), 90(1,8)	0, 1	0%, 2%

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Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[A]	No. of Obs.	Mean[B]	Median	Min.	Max.	State WQS Criteria[C]	No. of WQS Exceedances	Percent WQS Exceedance
Laboratory Results (Metals and Pesticides):									
Aluminum, Dissolved (ug/L)	40	16	-----	n.d.	n.d.	110	750[10], 87[11], 200[12]	0, 2, 0	0%, 13%, 0%
Antimony, Dissolved (ug/L)	0.5	16	-----	n.d.	n.d.	0.8	88[10], 30[11], 6[12]	0	0%
Arsenic, Dissolved (ug/L)	1	16	2	2	1	5	340[10], 16.7[11], 10[12]	0	0%
Barium, Dissolved (ug/L)	5	16	53	52	46	62	2,000[11]	0	0%
Beryllium, Dissolved (ug/L)	2	16	-----	n.d.	n.d.	2	130[10], 5.3[11], 4[12]	0	0%
Cadmium, Dissolved (ug/L)	0.2	16	-----	n.d.	n.d.	0.3	4.9[10], 0.46[11], 5[12]	0	0%
Calcium, Dissolved (mg/L)	0.01	16	59.8	60.6	51.0	65.8	-----	-----	-----
Chromium, Dissolved (ug/L)	10	16	-----	n.d.	n.d.	10	1,199[10], 156[11], 100[12]	0	0%
Copper, Dissolved (ug/L)	6	16	-----	n.d.	n.d.	30	32[10], 19[11], 1,000[12]	0, 2, 0	0%, 15%, 0%
Hardness, Total (mg/L)	0.4	16	247	248	214	276	-----	-----	-----
Iron, Dissolved (ug/L)	10	16	-----	n.d.	n.d.	30	1,000[11]	0	0%
Lead, Dissolved (ug/L)	0.5	16	-----	n.d.	n.d.	0.6	171[10], 6.7[11], 15[12]	0	0%
Magnesium, Dissolved (mg/L)	0.01	14	23.4	24.2	19.2	27.3	-----	-----	-----
Manganese, Dissolved (ug/L)	2	16	10	9	n.d.	20	1,000[10]	0	0%
Mercury, Dissolved (ug/L)	0.05	16 16	-----	n.d.	n.d.	n.d.	1.4[10]	0	0%
Mercury, Total (ug/L)	0.05	5	-----	n.d.	n.d.	0.1	0.77[11], 2[12]	0	0%
Nickel, Dissolved (ug/L)	10	16	-----	n.d.	n.d.	20	1,010[10], 112[11], 100[12]	0	0%
Selenium, Dissolved (ug/L)	1	16	2	2	n.d.	4	-----	-----	-----
Selenium, Total (ug/L)	1	16	2	2	1	4	20[4,10], 5[11], 50[12]	0	0%
Silver, Dissolved (ug/L)	1	16	-----	n.d.	n.d.	n.d.	15[10], 100[12]	0	0%
Sodium, Dissolved (mg/L)	0.01	13	81.1	82.0	65.8	99.9	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	16	-----	n.d.	n.d.	n.d.	1,400[10], 6.3[11], 2[12]	0	0%
Zinc, Dissolved (ug/L)	10	16	-----	n.d.	n.d.	10	253[10,11], 5,000[12]	0	0%
Acetochlor, Total (ug/L)[D]	0.05	56	-----	n.d.	n.d.	0.5	-----	-----	-----
Atrazine, Total (ug/L)[D]	0.05	56	-----	n.d.	n.d.	0.6	330[10], 12[11], 3[3]	0	0%
Metolachlor, Total (ug/L)[D]	0.05	56	-----	n.d.	n.d.	0.2	390[10], 100[11]	0	0%
Pesticide Scan (ug/L)[E]	0.05	6	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

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

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

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

- (1) Criteria for the protection of Warmwater Permanent Fish Life Propagation Waters (South Dakota) or Class I Warmwater Aquatic Life (Nebraska).
- (2) South Dakota's temperature criterion is 27°C and Nebraska's is 29°C.
- (3) Criteria for the protection of domestic water supply waters.
- (4) Criteria for the protection of agricultural water supply waters.
- (5) Criteria for the protection of commerce and industry waters.
- (6) Daily maximum criterion (monitoring results directly comparable to criterion).
- (7) Daily minimum criterion (monitoring results directly comparable to criterion).
- (8) 30-day average criterion (monitoring results not directly comparable to criterion).
- (9) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (10) Acute (CMC) criterion for the protection of freshwater aquatic life.
- (11) Chronic (CCC) criterion for the protection of freshwater aquatic life.
- (12) Criterion for the protection of human health.

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

(D) Immunoassay analysis.

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

Plate 11-5. Summary of near-surface water quality conditions monitored in the Missouri River at near Ponca, Nebraska (i.e. site MORRR0753) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit(A)	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
Estimated Discharge:									
Streamflow (cfs)	1	51	39,878	31,493	8,631	161,302	-----	-----	-----
Field Measurements:									
Water Temperature (°C)	0.1	51	15.7	17.1	0.1	28.8	27(1,2,6), 29(1,2,6)	1, 1	4%, 2%
Dissolved Oxygen (mg/L)	0.1	51	9.9	9.4	7.6	14.1	5(1,7)	0	0%
Dissolved Oxygen (% Sat.)	0.1	51	100.6	100.3	88.9	113.7	-----	-----	-----
Oxidation-Reduction Potential	1	51	349	362	121	439	-----	-----	-----
pH (S.U.)	0.1	51	8.3	8.3	7.8	8.7	6.5(1,3,7), 9.0(1,3,6), 9.5(5,6)	0	0%
Specific Conductance (uS/cm)	1	50	830	829	732	977	2,000(4)	0	0%
Turbidity (NTU)	1	51	35	23	n.d.	329	-----	-----	-----
Laboratory Results:									
Alkalinity, Total (mg/L)	7	52	168	170	141	227	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	51	5.0	4.8	3.0	9.5	-----	-----	-----
CBOD 5-day (mg/L)	2	44	-----	n.d.	n.d.	4.0	-----	-----	-----
Chemical Oxygen Demand (mg/L)	2	49	13	12	n.d.	34	-----	-----	-----
Chloride (mg/L)	1	52	14	14	11	24	438(3,6), 250(3,8)	0	0%
Chlorophyll *a* (ug/L)	1	37	17	13	n.d.	52	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	41	28	27	18	54	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	52	582	565	418	910	1,750(3,6), 1,000(3,8), 3,500(5,6), 2,000(5,8)	0	0%
Nitrogen, Ammonia Total	0.02	52	-----	n.d.	n.d.	0.41	4.7 (1,6,9), 1.5 (1,8,9)	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	52	0.6	0.5	n.d.	1.6	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	52	-----	0.10	n.d.	0.80	10(3,6), 100(4,6)	0	0%
Nitrogen, Total (mg/L)	0.1	52	0.7	0.7	n.d.	2.1	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	52	-----	0.02	n.d.	0.14	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	52	0.08	0.05	n.d.	0.33	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	52	-----	n.d.	n.d.	0.13	-----	-----	-----
Sulfate (mg/L)	1	52	251	247	203	326	-----	-----	-----
Suspended Sediment, Total (mg/L)	4	45	42	30	11	159	-----	-----	-----
Suspended Solids, Total (mg/L)	4	52	41	30	9	159	158(1,6), 90(1,8)	2, 3	4%, 7%
Acetochlor (ug/L)(D)	0.05	52	-----	n.d.	n.d.	0.7	-----	-----	-----
Atrazine, Total (ug/L)(D)	0.05	52	-----	n.d.	n.d.	0.9	330(10), 12(11), 3(3)	0	0%
Metolachlor, Total (ug/L)(D)	0.05	52	-----	n.d.	n.d.	0.4	390(10), 100(11)	0	0%

n.d. = Not detected.

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

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

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

- (1) Criteria for the protection of Warmwater Permanent Fish Life Propagation Waters (South Dakota) or Class I Warmwater Aquatic Life (Nebraska).
- (2) South Dakota's temperature criterion is 27°C and Nebraska's is 29°C.
- (3) Criteria for the protection of domestic water supply waters.
- (4) Criteria for the protection of agricultural water supply waters.
- (5) Criteria for the protection of commerce and industry waters.
- (6) Daily maximum criterion (monitoring results directly comparable to criterion).
- (7) Daily minimum criterion (monitoring results directly comparable to criterion).
- (8) 30-day average criterion (monitoring results not directly comparable to criterion).
- (9) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (10) Acute (CMC) criterion for the protection of freshwater aquatic life.
- (11) Chronic (CCC) criterion for the protection of freshwater aquatic life.
- (12) Criterion for the protection of human health.

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

(D) Immunoassay analysis.

Plate 11-6. Summary of near-surface water quality conditions monitored in the Missouri River at Decatur, Nebraska (i.e. site MORRR0691) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit(A)	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
USGS Gage 06601200 Discharge:									
Streamflow (cfs)	1	52	40,659	32,157	14,777	182,527	-----	-----	-----
Field Measurements:									
Water Temperature (°C)	0.1	52	13.5	12.5	0.3	27.1	32(1,5)	0	0%
Dissolved Oxygen (mg/L)	0.1	52	10.2	10.1	7.5	14.3	5(1,6)	0	0%
Dissolved Oxygen (% Sat.)	0.1	52	98.2	97.9	90.4	111.2	-----	-----	-----
Oxidation-Reduction Potential	1	52	361	372	155	454	-----	-----	-----
pH (S.U.)	0.1	52	8.2	8.3	7.5	8.9	6.5(1,6), 9.0(1,5)	0	0%
Specific Conductance (uS/cm)	1	51	845	845	679	958	2,000(3)	0	0%
Turbidity (NTU)	1	52	64	29	1	1,459	-----	-----	-----
Laboratory Results:									
Alkalinity, Total (mg/L)	7	51	178	176	160	212	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	51	5.0	4.6	2.7	12.2	-----	-----	-----
CBOD 5-day (mg/L)	2	38	-----	n.d.	n.d.	4.0	-----	-----	-----
Chemical Oxygen Demand (mg/L)	2	49	14	14	n.d.	51	-----	-----	-----
Chloride (mg/L)	1	52	15	15	6	22	-----	-----	-----
Chlorophyll *a* (ug/L)	1	34	23	21	n.d.	88	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	49	29	26	18	55	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	51	605	586	502	826	-----	-----	-----
Nitrogen, Ammonia Total	0.02	52	-----	n.d.	n.d.	0.35	5.7 (1,5,8), 1.8 (1,7,8)	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	52	0.7	0.5	0.3	4.3	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	52	0.48	0.35	n.d.	1.91	10(2,5), 100(3,5)	0	0%
Nitrogen, Total (mg/L)	0.1	52	1.2	0.9	0.3	4.6	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	51	0.03	0.03	n.d.	0.17	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	52	0.13	0.09	0.03	1.26	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	52	-----	0.02	n.d.	0.15	-----	-----	-----
Sulfate (mg/L)	1	51	251	248	209	301	-----	-----	-----
Suspended Sediment, Total (mg/L)	4	38	72	53	26	409	-----	-----	-----
Suspended Solids, Total (mg/L)	4	52	78	44	11	398	-----	-----	-----

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	Monitoring Results						Water Quality Standards Attainment		
Parameter	**Detection Limit**[A]	**No. of Obs.**	**Mean**[B]	**Median**	**Min.**	**Max.**	**State WQS Criteria**[C]	**No. of WQS Exceedances**	**Percent WQS Exceedance**
Aluminum, Dissolved (ug/L)	40	17	-----	n.d.	n.d.	70	750[9], 87[10], 200[11]	0	0%
Antimony, Dissolved (ug/L)	0.5	17	-----	n.d.	n.d.	0.6	88[9], 30[10], 6[11]	0	0%
Arsenic, Dissolved (ug/L)	1	17	2	2	1	4	340[9], 16.7[10], 10[11]	0	0%
Barium, Dissolved (ug/L)	5	17	56	52	47	77	2,000[2]	0	0%
Beryllium, Dissolved (ug/L)	2	17	-----	n.d.	n.d.	n.d.	130[9], 5.3[10], 4[11]	0	0%
Cadmium, Dissolved (ug/L)	0.2	17	-----	n.d.	n.d.	n.d.	16[9], 0.50[10], 5[11]	0	0%
Calcium, Dissolved (mg/L)	0.01	17	66.0	65.9	54.7	81.1	-----	-----	-----
Chromium, Dissolved (ug/L)	10	17	-----	n.d.	n.d.	n.d.	1,352[9], 176[10], 100[11]	0	0%
Copper, Dissolved (ug/L)	6	17	-----	n.d.	n.d.	20	35[9], 21[10], 1,000[11]	0	0%
Hardness, Dissolved (mg/L)	0.4	17	275.2	274.3	237.0	339.3	-----	-----	-----
Iron, Dissolved (ug/L)	7	17	-----	10	n.d.	50	1,000[10]	0	0%
Lead, Dissolved (ug/L)	0.5	17	-----	n.d.	n.d.	0.5.	190[9], 7.4[10], 15[11]	0	0%
Magnesium, Dissolved (mg/L)	0.01	17	26.9	27.3	23.0	33.2	-----	-----	-----
Manganese, Dissolved (ug/L)	2	17	-----	4	n.d.	30	1,000[10]	0	0%
Mercury, Dissolved (ug/L)	0.05	17	-----	n.d.	n.d.	n.d.	1.4[9]	0	0%
Mercury, Total (ug/L)	0.05	16	-----	n.d.	n.d.	n.d.	0.77[10], 2[11]	0	0%
Nickel, Dissolved (ug/L)	10	17	-----	n.d.	n.d.	10	1,099[9], 122[10], 100[11]	0	0%
Selenium, Dissolved (ug/L)	1	17	2	2	n.d.	3	-----	-----	-----
Selenium, Total (ug/L)	1	16	2	2	1	3	20[3,9], 5[10], 50[11]	0	0%
Silver, Dissolved (ug/L)	1	17	-----	n.d.	n.d.	n.d.	19[9], 100[11]	0	0%
Sodium, Dissolved (mg/L)	0.01	15	81.4	81.0	64.6	100.6	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	17	-----	n.d.	n.d.	0.5	1,400[9], 6.3[10], 2[11]	0	0%
Zinc, Dissolved (ug/L)	10	17	-----	n.d.	n.d.	20	275[9,10], 5,000[11]	0	0%
Acetochlor, Total (ug/L)[D]	0.05	51	-----	n.d.	n.d.	1.1	-----	-----	-----
Atrazine, Total (ug/L)[D]	0.05	51	-----	n.d.	n.d.	1.3	330[9], 12[10], 3[2]	0	0%
Metolachlor, Total (ug/L)[D]	0.05	51	-----	n.d.	n.d.	0.6	390[9], 100[10]	0	0%
Pesticide Scan (ug/L)[E]	0.05						-----	-----	-----
Acetochlor, Total (ug/L)	0.02	5	-----	n.d.	n.d.	1.0	-----	-----	-----
Atrazine, Total (ug/L)	0.02	5	-----	n.d.	n.d.	0.3	330[9], 12[10], 3[2]	0	0%

n.d. = Not detected.

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

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

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

- [1] Criteria for the protection of Class I Warmwater Aquatic Life (Nebraska).
- [2] Criteria for the protection of domestic water supply waters.
- [3] Criteria for the protection of agricultural water supply waters.
- [4] Criteria for the protection of commerce and industry waters.
- [5] Daily maximum criterion (monitoring results directly comparable to criterion).
- [6] Daily minimum criterion (monitoring results directly comparable to criterion).
- [7] 30-day average criterion (monitoring results not directly comparable to criterion).
- [8] Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- [9] Acute criterion for aquatic life.
- [10] Chronic criterion for aquatic life.
- [11] Criterion for the protection of human health.

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

[D] Immunoassay analysis.

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

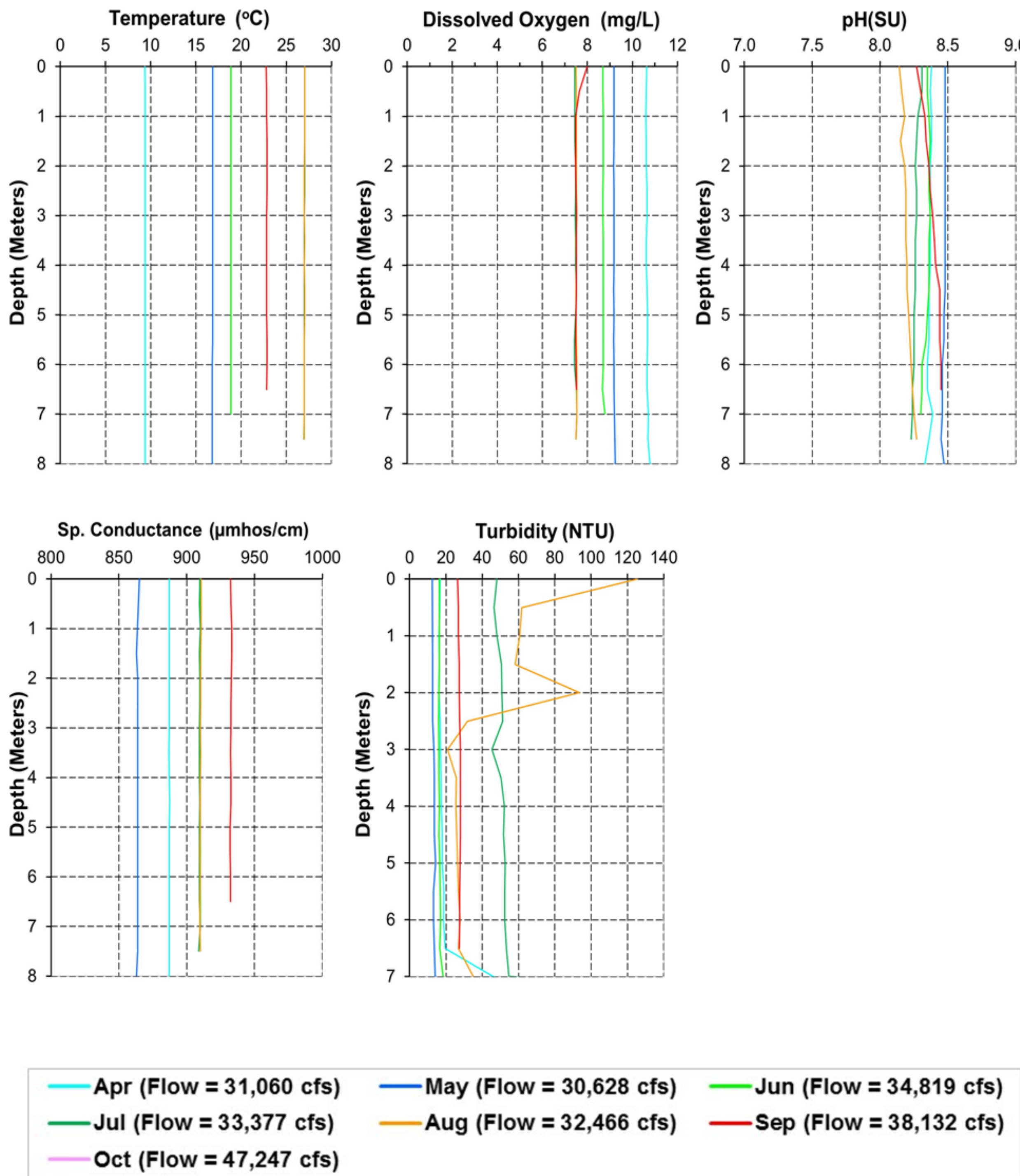

Plate 11-7. Water temperature, dissolved oxygen, pH, specific conductance, and turbidity depth profiles for the Missouri River compiled from data collected at RM691 (i.e. MORRR0691) during 2015.

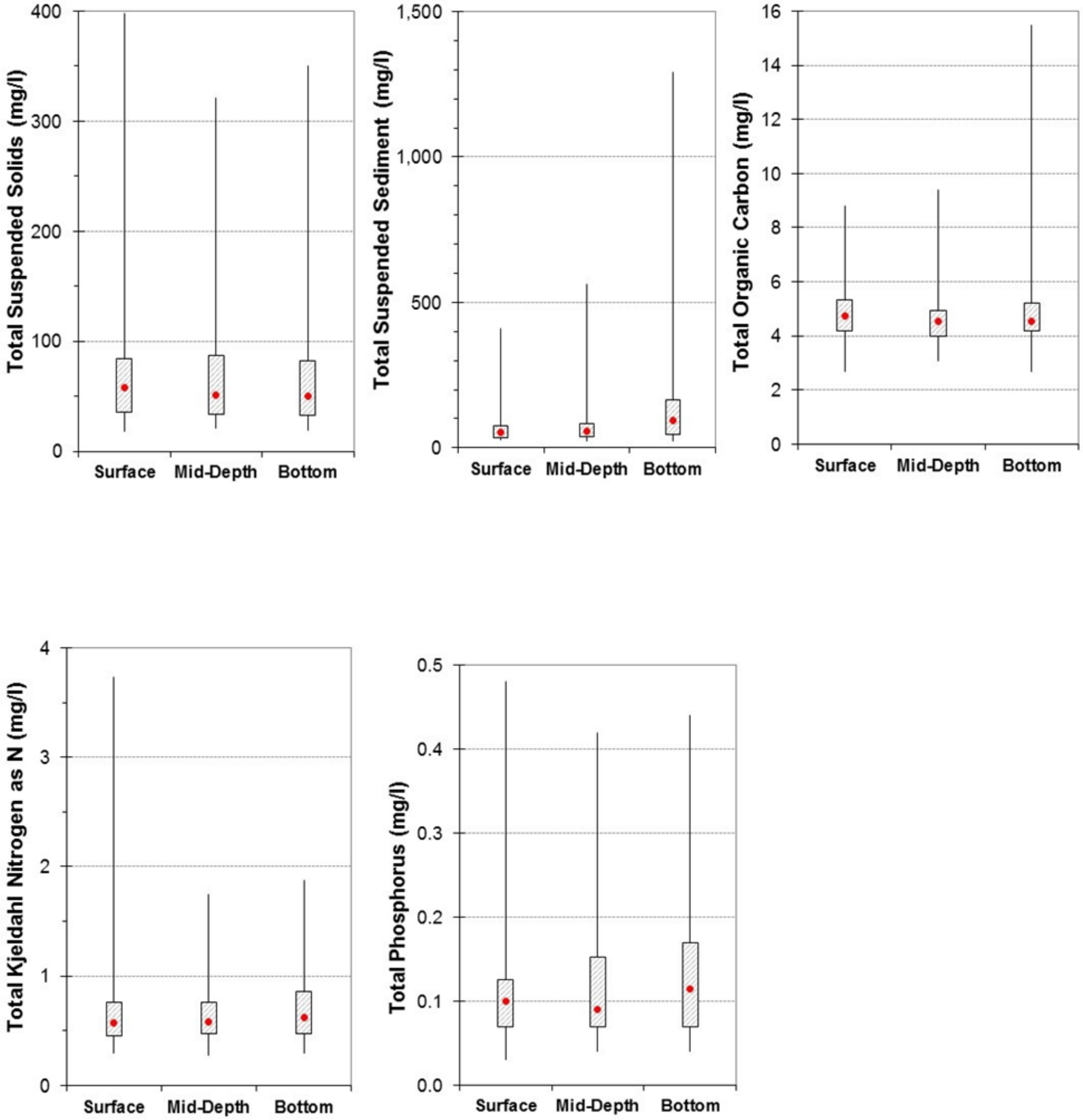

Plate 11-8. Box plots comparing paired surface, mid-depth, and bottom total suspended solids, total suspended sediment, turbidity, total Kjeldahl nitrogen, total phosphorus, and total organic carbon measurements taken in the Missouri River at site MORRR0691 during the 5-year period 2011 through 2015. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

Plate 11-9. Summary of near-surface water quality conditions monitored in the Missouri River at Omaha, Nebraska (i.e. site MORRR0619) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[(A)]	No. of Obs.	Mean[(B)]	Median	Min.	Max.	State WQS Criteria[(C)]	No. of WQS Exceedances	Percent WQS Exceedance
USGS Gage 06610000 Discharge:									
Streamflow (cfs)	1	58	40,957	34,281	15,144	193,284	-----	-----	-----
Field Measurements:									
Water Temperature (°C)	0.1	58	12.8	12.2	0.0	28.0	32[(1,5)]	0	0%
Dissolved Oxygen (mg/L)	0.1	58	10.4	10.3	6.7	15.7	5[(1,6)]	0	0%
Dissolved Oxygen (% Sat.)	0.1	58	97.5	97.9	80.6	111.4	-----	-----	-----
Oxidation-Reduction Potential	1	58	369	372	206	481	-----	-----	-----
pH (S.U.)	0.1	56	8.3	8.2	7.7	10.0	6.5[(1,6)], 9.0[(1,5)]	0, 2	0%, 4%
Specific Conductance (uS/cm)	1	57	825	831	593	949	2,000[(3)]	0	0%
Turbidity (NTU)	1	58	85	37	1	1,426	-----	-----	-----
Laboratory Results:									
Alkalinity, Total (mg/L)	7	57	187	186	164	242	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	57	5.3	4.4	3.0	33.1	-----	-----	-----
CBOD 5-day (mg/L)	2	39	-----	n.d.	n.d.	27	-----	-----	-----
Chemical Oxygen Demand (mg/L)	2	54	14	13	2	35	-----	-----	-----
Chloride (mg/L)	1	58	18	17	13	35	-----	-----	-----
Chlorophyll *a* (ug/L)	1	36	25	26	n.d.	56	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	54	30	27	18	58	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	57	588	582	450	828	-----	-----	-----
Nitrogen, Ammonia Total	0.02	58	-----	0.02	n.d.	0.39	5.7[(1,5,8)], 1.8[(1,7,8)]	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	58	0.8	0.6	0.2	3.3	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	57	1.18	0.80	n.d.	6.34	10[(2,5)], 100[(3,5)]	0	0%
Nitrogen, Total (mg/L)	0.1	57	2.0	1.4	0.4	8.0	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	57	0.05	0.04	n.d.	0.15	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	58	0.18	0.13	0.02	1.74	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	58	0.05	0.04	n.d.	0.14	-----	-----	-----
Sulfate (mg/L)	1	57	229	233	149	288	-----	-----	-----
Suspended Sediment, Total (mg/L)	4	40	159	80	15	1,920	-----	-----	-----
Suspended Solids, Total (mg/L)	4	58	106	63	12	764	-----	-----	-----

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Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[(A)]	No. of Obs.	Mean[(B)]	Median	Min.	Max.	State WQS Criteria[(C)]	No. of WQS Exceedances	Percent WQS Exceedance
Laboratory Results (Metals and Pesticides):									
Aluminum, Dissolved (ug/L)	40	19	-----	n.d.	n.d.	2,760	750[(9)], 87[(10)], 200[(11)]	0	0%
Antimony, Dissolved (ug/L)	0.5	19	-----	n.d.	n.d.	1.0	88[(9)], 30[(10)], 6[(11)]	0	0%
Arsenic, Dissolved (ug/L)	1	19	2	2	1	5	340[(9)], 16.7[(10)], 10[(11)]	0	0%
Barium, Dissolved (ug/L)	5	19	71	65	52	115	2,000[(2)]	0	0%
Beryllium, Dissolved (ug/L)	2	19	-----	n.d.	n.d.	n.d.	130[(9)], 5.3[(10)], 4[(11)]	0	0%
Cadmium, Dissolved (ug/L)	0.2	19	-----	n.d.	n.d.	0.2	16[(9)], 0.50[(10)], 5[(11)]	0, 2, 0	0%, 12%, 0%
Calcium, Dissolved (mg/L)	0.01	19	69.1	67.8	56.1	92.0	-----	-----	-----
Chromium, Dissolved (ug/L)	10	19	-----	n.d.	n.d.	n.d.	1,388[(9)], 181[(10)], 100[(11)]	0	0%
Copper, Dissolved (ug/L)	6	19	-----	n.d.	n.d.	10	36[(9)], 22[(10)], 1,000[(11)]	0	0%
Hardness, Dissolved (mg/L)	0.4	19	283	283	242	349	-----	-----	-----
Iron, Dissolved (ug/L)	10	20	-----	10	n.d.	2,740	1,000[(10)]	0	0%
Lead, Dissolved (ug/L)	0.5	19	-----	n.d.	n.d.	1.8	196[(9)], 7.7[(10)], 15[(11)]	0	0%
Magnesium, Dissolved (mg/L)	0.01	19	27.2	27.6	23.4	31.9	-----	-----	-----
Manganese, Dissolved (ug/L)	2	19	-----	5	n.d.	210	1,000[(10)]	0	0%
Mercury, Dissolved (ug/L)	0.05	19	-----	n.d.	n.d.	n.d.	1.4[(9)]	0	0%
Mercury, Total (ug/L)	0.05	19	-----	n.d.	n.d.	0.1	0.77[(10)], 2[(11)]	0	0%
Nickel, Dissolved (ug/L)	10	19	-----	n.d.	n.d.	10	1,122[(9)], 125[(10)], 100[(11)]	0	0%
Selenium, Dissolved (ug/L)	1	19	2	2	1	4	-----	-----	-----
Selenium, Total (ug/L)	1	19	2	2	1	4	20[(3,9)], 5[(10)], 50[(11)]	0, 1, 0	0%, 6%, 0%
Silver, Dissolved (ug/L)	1	19	-----	n.d.	n.d.	n.d.	21[(9)], 100[(11)]	0	0%
Sodium, Dissolved (mg/L)	0.01	16	75.5	78.2	50.4	93.4	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	19	-----	n.d.	n.d.	n.d.	1,400[(9)], 6.3[(10)], 2[(11)]	0	0%
Zinc, Dissolved (ug/L)	10	19	-----	n.d.	n.d.	10	283[(9,10)], 5,000[(11)]	0	0%
Acetochlor, Total (ug/L)[(D)]	0.05	57	-----	n.d.	n.d.	1.4	-----	-----	-----
Atrazine, Total (ug/L)[(D)]	0.05	57	-----	n.d.	n.d.	0.3	330[(9)], 12[(10)], 3[(2)]	0	0%
Metolachlor, Total (ug/L)[(D)]	0.05	57	-----	n.d.	n.d.	0.7	390[(9)], 100[(10)]	0	0%
Pesticide Scan (ug/L)[(E)]	0.05	5	-----	n.d.	n.d.	n.d.	-----	-----	------
Acetochlor, Total (ug/L)	0.07	5	-----	n.d.	n.d.	0.9	-----	-----	-----
Atrazine, Total (ug/L)	0.06	5	-----	n.d.	n.d.	0.3	330[(9)], 12[(10)], 3[(2)]	0	0%
Metolachlor, Total (ug/L)	0.05	5	-----	n.d.	n.d.	0.1	390[(9)], 100[(10)]	0	0%

n.d. = Not detected.

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

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

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

- (1) Criteria for the protection of Class I Warmwater Aquatic Life (Nebraska).
- (2) Criteria for the protection of domestic water supply waters.
- (3) Criteria for the protection of agricultural water supply waters.
- (4) Criteria for the protection of commerce and industry waters.
- (5) Daily maximum criterion (monitoring results directly comparable to criterion).
- (6) Daily minimum criterion (monitoring results directly comparable to criterion).
- (7) 30-day average criterion (monitoring results not directly comparable to criterion).
- (8) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (9) Acute criterion for aquatic life.
- (10) Chronic criterion for aquatic life.
- (11) Criterion for the protection of human health.

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

(D) Immunoassay analysis.

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

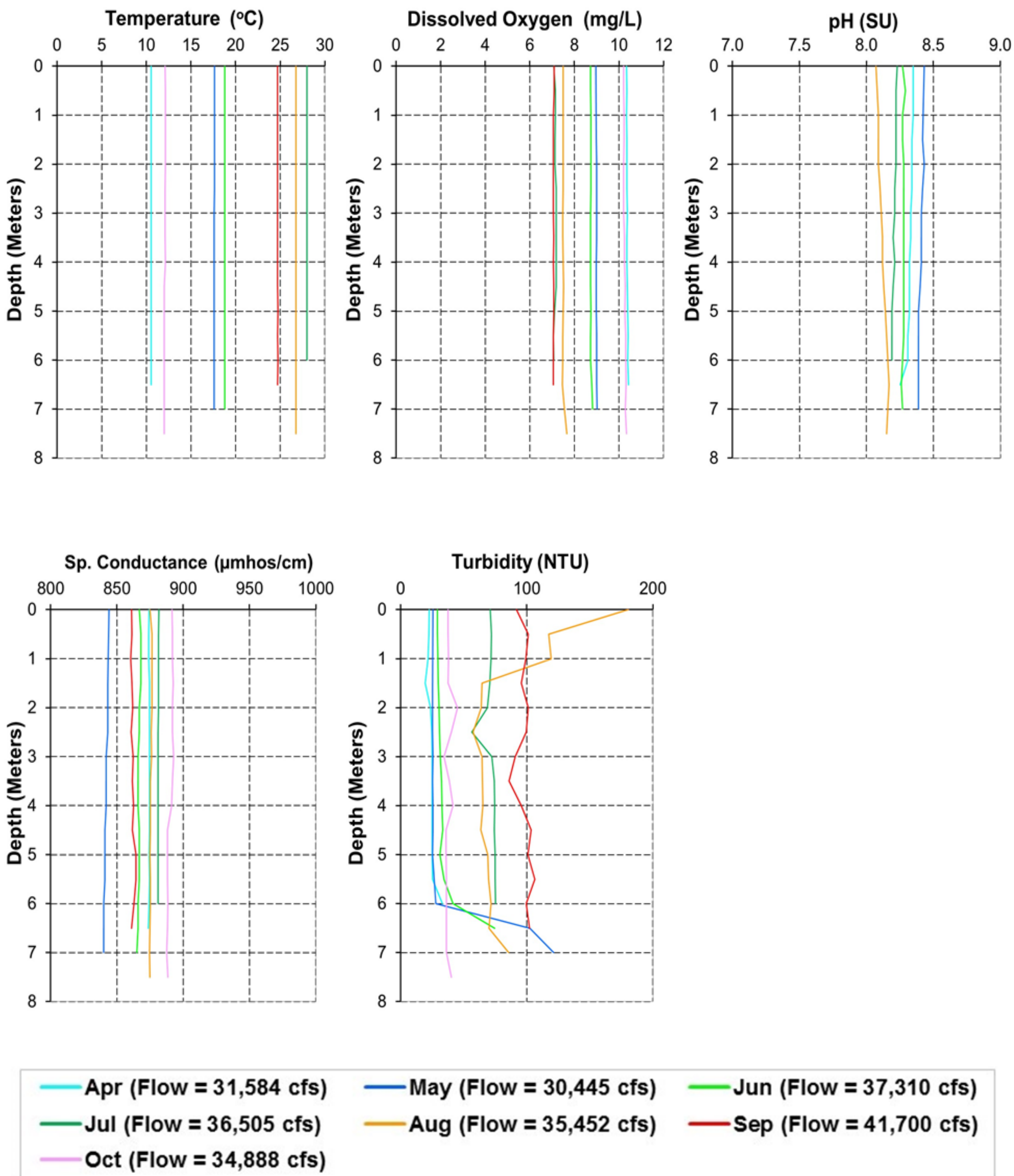

Plate 11-10. Water temperature, dissolved oxygen, pH, specific conductance, and turbidity depth profiles for the Missouri River compiled from data collected at RM619 (i.e. MORRR0619) during 2015.

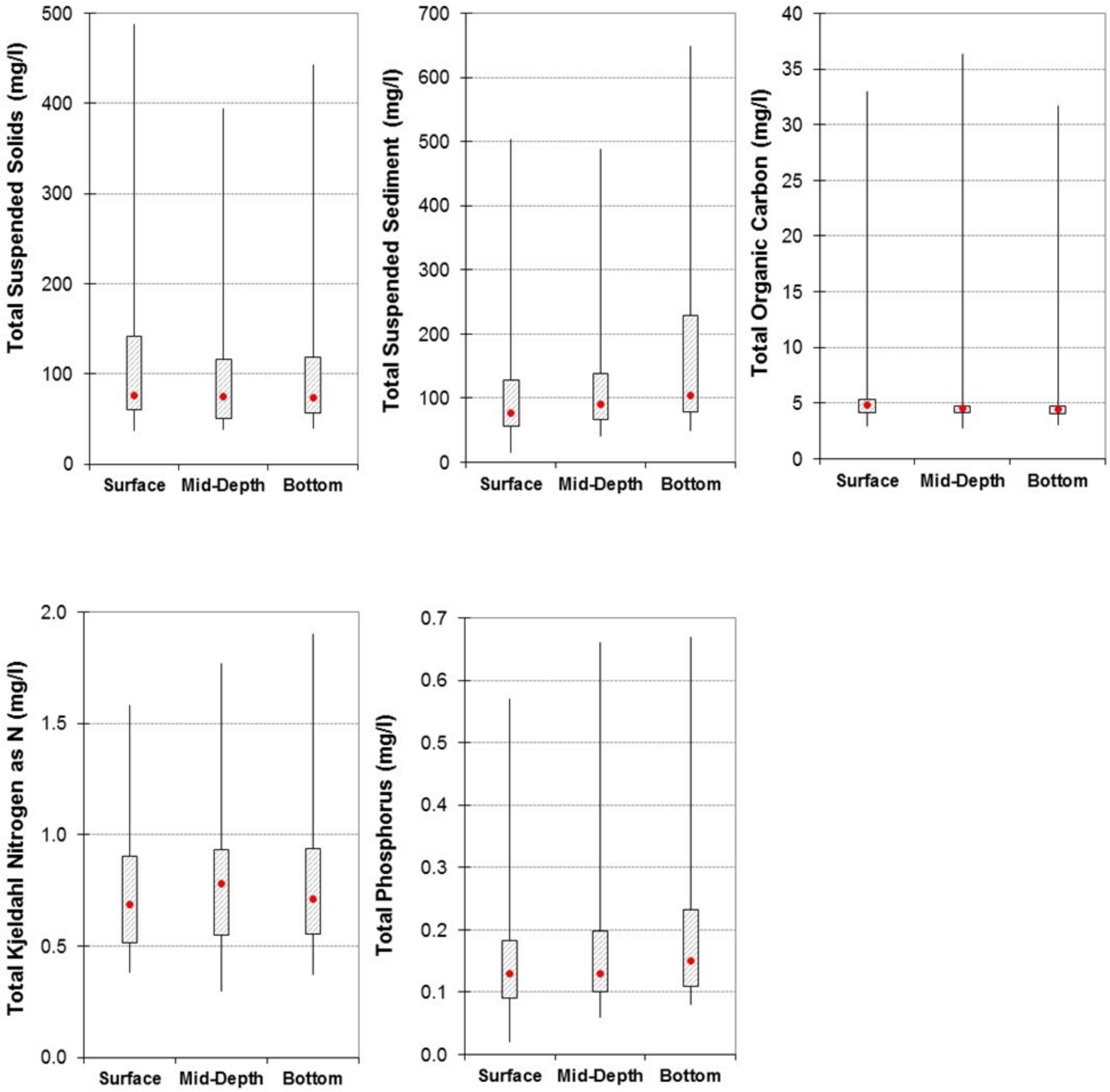

Plate 11-11. Box plots comparing paired surface, mid-depth, and bottom total suspended solids, total suspended sediment, turbidity, total Kjeldahl nitrogen, total phosphorus, and total organic carbon measurements taken in the Missouri River at site MORRR0619 during the 5-year period 2011 through 2015. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

Plate 11-12. Summary of near-surface water quality conditions monitored in the Missouri River at Nebraska City, Nebraska (i.e. site MORRR0563) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit(A)	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
USGS Gage 06807000 Discharge:									
Streamflow (cfs)	1	60	48,274	40,064	17,910	198,043	-----	-----	-----
Field Measurements:									
Water Temperature (°C)	0.1	59	12.5	12.0	0.0	28.5	32(1,5)	0	0%
Dissolved Oxygen (mg/L)	0.1	59	10.2	10.2	5.6	14.3	5(1,6)	0	0%
Dissolved Oxygen (% Sat.)	0.1	59	94.8	96.0	64.9	107.0	-----	-----	-----
Oxidation-Reduction Potential	1	59	375	387	224	465	-----	-----	-----
pH (S.U.)	0.1	58	8.2	8.2	7.4	9.1	6.5(1,6), 9.0(1,5)	0	0%
Specific Conductance (uS/cm)	1	59	805	811	621	933	2,000(3)	0	0%
Turbidity (NTU)	1	59	105	43	2	1,272	-----	-----	-----
Laboratory Results:									
Alkalinity, Total (mg/L)	7	59	186	185	144	237	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	60	5.9	4.6	2.8	38.9	-----	-----	-----
CBOD 5-day (mg/L)	2	38	-----	2	n.d.	9	-----	-----	-----
Chloride (mg/L)	1	60	24	22	15	36	-----	-----	-----
Chlorophyll *a* (ug/L)	1	34	34	34	n.d.	63	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	55	32	29	18	56	-----	-----	-----
Dissolved Solids, Total (mg/L)	5	59	562	538	240	790	-----	-----	-----
Nitrogen, Ammonia Total	0.02	60	0.10	0.07	n.d.	0.39	5.7 (1,5,8), 1.8 (1,7,8)	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	60	1.0	0.8	0.4	2.9	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	60	1.23	1.04	0.07	5.08	10(2,5), 100(3,5)	0	0%
Nitrogen, Total (mg/L)	0.1	60	2.18	1.81	0.57	7.47	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	59	0.08	0.08	0.02	0.18	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	60	0.28	0.18	0.04	2.03	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	60	0.08	0.08	n.d.	0.19	-----	-----	-----
Sulfate (mg/L)	1	59	207	203	109	250	-----	-----	-----
Suspended Sediment, Total (mg/L)	4	40	274	108	50	2,740	-----	-----	-----
Suspended Solids, Total (mg/L)	4	60	165	82	11	2,300	-----	-----	-----

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Parameter	**Monitoring Results**						**Water Quality Standards Attainment**		
	Detection Limit[A]	**No. of Obs.**	**Mean**[B]	**Median**	**Min.**	**Max.**	**State WQS Criteria**[C]	**No. of WQS Exceedances**	**Percent WQS Exceedance**
Laboratory Results (Metals and Pesticides):									
Aluminum, Dissolved (ug/L)	40	19	-----	n.d.	n.d.	n.d.	750[9], 87[10], 200[11]	0	0%
Antimony, Dissolved (ug/L)	0.5	19	-----	n.d.	n.d.	1.3	88[9], 30[10], 6[11]	0	0%
Arsenic, Dissolved (ug/L)	1	19	3	3	2	4	340[9], 16.7[10], 10[11]	0	0%
Barium, Dissolved (ug/L)	5	19	78	75	54	111	2,000[2]	0	0%
Beryllium, Dissolved (ug/L)	2	19	-----	n.d.	n.d.	n.d.	130[9], 5.3[10], 4[11]	0	0%
Cadmium, Dissolved (ug/L)	0.2	19	-----	n.d.	n.d.	0.3	16[9], 0.50[10], 5[11]	0	0%
Calcium, Dissolved (mg/L)	0.01	19	68.4	68.4	56.6	87.0	-----	-----	-----
Chromium, Dissolved (ug/L)	10	19	-----	n.d.	n.d.	n.d.	1,356[9], 177[10], 100[11]	0	0%
Copper, Dissolved (ug/L)	6	19	-----	n.d.	n.d.	10	35[9], 21[10], 1,000[11]	0	0%
Hardness, Total (mg/L)	0.4	19	276.3	274.7	243.8	336.0	-----	-----	-----
Iron, Dissolved (ug/L)	7	19	-----	n.d.	n.d.	440	1,000[10]	0	0%
Lead, Dissolved (ug/L)	0.5	19	-----	n.d.	n.d.	1.0	190[9], 7.4[10], 15[11]	0	0%
Magnesium, Dissolved (mg/L)	0.01	19	25.8	25.9	21.2	28.9	-----	-----	-----
Manganese, Dissolved (ug/L)	2	19	-----	2	n.d.	10	1,000[10]	0	0%
Mercury, Dissolved (ug/L)	0.05						1.4[9]	0	0%
Mercury, Total (ug/L)	0.05						0.77[10], 2[11]	0	0%
Nickel, Dissolved (ug/L)	10	19	-----	n.d.	n.d.	n.d.	1,101[9], 122[10], 100[11]	0	0%
Selenium, Dissolved (ug/L)	1	19	2	2	n.d.	4	-----	-----	-----
Selenium, Total (ug/L)	1	19	3	3	1	4	20[3,9], 5[10], 50[11]	0	0%
Silver, Dissolved (ug/L)	1	19	-----	n.d.	n.d.	2	20[9], 100[11]	0	0%
Sodium, Dissolved (mg/L)	0.01	16	74.7	77.9	44.7	85.4	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	19	-----	n.d.	n.d.	0.5	1,400[9], 6.3[10], 2[11]	0	0%
Zinc, Dissolved (ug/L)	10	19	-----	n.d.	n.d.	n.d.	276[9,10], 5,000[11]	0	0%
Acetochlor, Total (ug/L)[D]	0.05	59	-----	n.d.	n.d.	2.9	-----	-----	-----
Atrazine, Total (ug/L)[D]	0.05	59	-----	n.d.	n.d.	3.9	330[9], 12[10], 3[2]	0, 0, 1	0%, 0%, 2%
Metolachlor, Total (ug/L)[D]	0.05	59	-----	n.d.	n.d.	1.0	390[9], 100[10]	0	0%
Pesticide Scan (ug/L)[E]	0.05								
Acetochlor, Total (ug/L)	0.02	5	-----	n.d.	n.d.	0.9	-----	-----	-----
Atrazine, Total (ug/L)	0.02	5	-----	n.d.	n.d.	0.6	330[9], 12[10], 3[2]	0	0%
Metolachlor, Total (ug/L)	0.03	5	-----	n.d.	n.d.	0.2	390[9], 100[10]	0	0%

n.d. = Not detected.

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

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

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

- (1) Criteria for the protection of Class I Warmwater Aquatic Life (Nebraska).
- (2) Criteria for the protection of domestic water supply waters.
- (3) Criteria for the protection of agricultural water supply waters.
- (4) Criteria for the protection of commerce and industry waters.
- (5) Daily maximum criterion (monitoring results directly comparable to criterion).
- (6) Daily minimum criterion (monitoring results directly comparable to criterion).
- (7) 30-day average criterion (monitoring results not directly comparable to criterion).
- (8) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (9) Acute criterion for aquatic life.
- (10) Chronic criterion for aquatic life.
- (11) Criterion for the protection of human health.

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

(D) Immunoassay analysis.

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

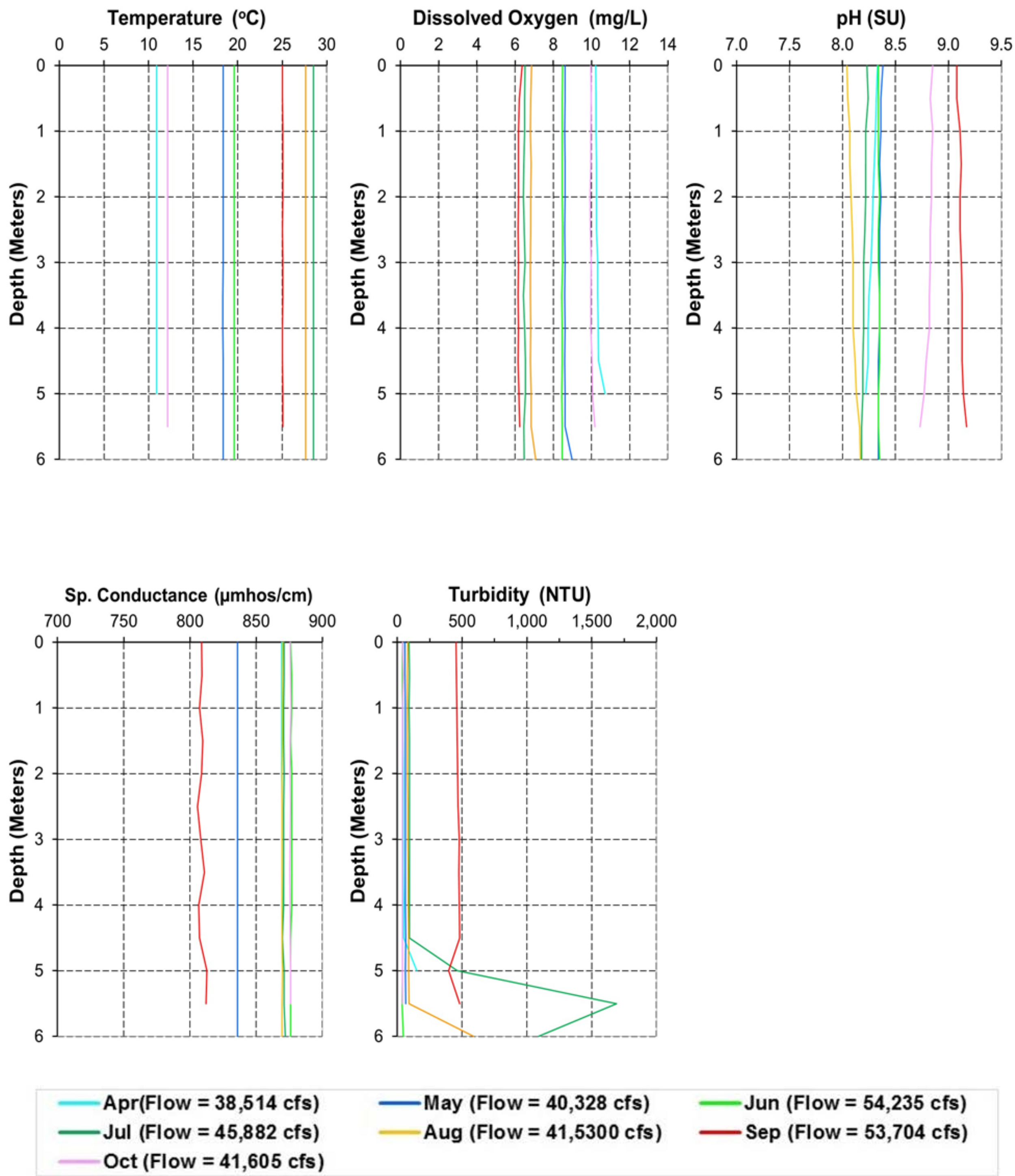

Plate 11-13. Water temperature, dissolved oxygen, pH, specific conductance, and turbidity depth profiles for the Missouri River compiled from data collected at RM563 (i.e. MORRR0563) during 2015.

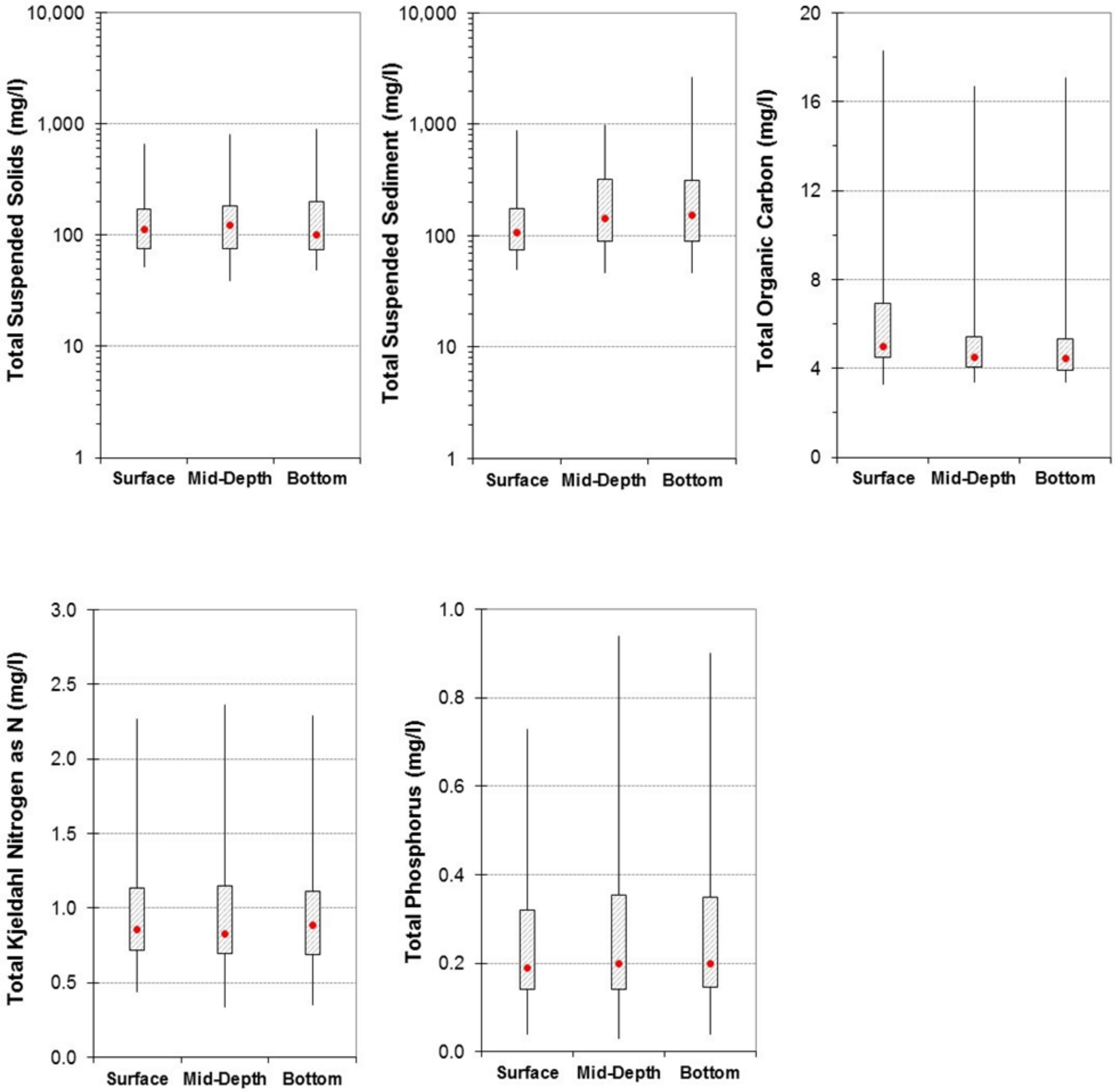

Plate 11-14. Box plots comparing paired surface, mid-depth, and bottom total suspended solids, total suspended sediment, turbidity, total Kjeldahl nitrogen, total phosphorus, and total organic carbon measurements taken in the Missouri River at site MORRR0563 during the 5-year period 2011 through 2015. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

Plate 11-15. Summary of near-surface water quality conditions monitored in the Missouri River at Rulo, Nebraska (i.e. site MORRR0498) during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit(A)	No. of Obs.	Mean(B)	Median	Min.	Max.	State WQS Criteria(C)	No. of WQS Exceedances	Percent WQS Exceedance
USGS Gage 06813500 Discharge:									
Streamflow (cfs)	1	60	51,584	40,807	18,883	245,917	-----	-----	-----
Field Measurements:									
Water Temperature (°C)	0.1	58	13.6	12.7	0.0	29.1	32(1,5)	0	0%
Dissolved Oxygen (mg/L)	0.1	58	9.9	10.1	5.2	13.9	5(1,6)	0	0%
Dissolved Oxygen (% Sat.)	0.1	58	93.7	96.3	66.5	110.2	-----	-----	-----
Oxidation-Reduction Potential	1	58	371	381	249	450	-----	-----	-----
pH (S.U.)	0.1	57	8.2	8.2	7.5	8.9	6.5(1,6), 9.0(1,5)	0	0%
Specific Conductance (uS/cm)	1	58	797	802	699	926	2,000(3)	0	0%
Turbidity (NTU)	1	58	120	46	1	965	-----	-----	-----
Laboratory Results:									
Alkalinity, Total (mg/L)	7	59	186	184	156	237	-----	-----	-----
Carbon, Total Organic (mg/L)	0.05	60	5.8	4.6	3.0	22.0	-----	-----	-----
CBOD 5-day (mg/L)	2	38	-----	2	n.d.	35	-----	-----	-----
Chemical Oxygen Demand (mg/L)	2	57	17	15	n.d.	49	-----	-----	-----
Chloride (mg/L)	1	59	23	22	14	35	-----	-----	-----
Chlorophyll *a* (ug/L)	1	35	35	32	n.d.	74	-----	-----	-----
Colorized Dissolved Organic Matter (ug/L)	4	55	33	30	19	56	-----	-----	-----
Diesel Range Organics (mg/L)	0.05	6	-----	n.d.	n.d.	n.d.			
Dissolved Solids, Total (mg/L)	5	59	554	536	407	810	-----	-----	-----
Nitrogen, Ammonia Total	0.02	60	-----	0.06	n.d.	0.41	5.7 (1,5,8), 1.8 (1,7,8)	0	0%
Nitrogen, Kjeldahl Total (mg/L)	0.1	60	1.0	0.8	0.2	2.9	-----	-----	-----
Nitrogen, Nitrate-Nitrite Total (mg/L)	0.02	60	1.38	1.12	0.09	5.48	10(2,5), 100(3,5)	0	0%
Nitrogen, Total (mg/L)	0.1	60	2.4	1.9	0.6	7.6	-----	-----	-----
Phosphorus, Dissolved (mg/L)	0.02	59	0.09	0.09	0.03	0.18	-----	-----	-----
Phosphorus, Total (mg/L)	0.02	60	0.32	0.21	0.06	1.95	-----	-----	-----
Phosphorus-Orthophosphate (mg/L)	0.02	60	0.09	0.08	n.d.	0.21	-----	-----	-----
Sulfate (mg/L)	1	59	199	198	111	245	-----	-----	-----
Suspended Sediment, Total (mg/L)	4						-----	-----	-----
Suspended Solids, Total (mg/L)	4	60	194	99	9	1,470	-----	-----	-----

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Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit[A]	**No. of Obs.**	**Mean[B]**	**Median**	**Min.**	**Max.**	**State WQS Criteria[C]**	**No. of WQS Exceedances**	**Percent WQS Exceedance**
Laboratory Results (Metals and Pesticides):									
Aluminum, Dissolved (ug/L)	40	19	-----	n.d.	n.d.	40	750[9], 87[10], 200[11]	0	0%
Antimony, Dissolved (ug/L)	0.5	19	-----	n.d.	n.d.	1.0	88[9], 30[10], 6[11]	0	0%
Arsenic, Dissolved (ug/L)	1	19	3	3	2	5	340[9], 16.7[10], 10[11]	0	0%
Barium, Dissolved (ug/L)	5	85	81	56	126		2,000[2]	0	0%
Beryllium, Dissolved (ug/L)	2	19	-----	n.d.	n.d.	2	130[9], 5.3[10], 4[11]	0	0%
Cadmium, Dissolved (ug/L)	0.2	19	-----	n.d.	n.d.	0.2	16[9], 0.49[10], 5[11]	0	0%
Calcium, Dissolved (mg/L)	0.01	19	68.0	67.0	54.9	88.0	-----	-----	-----
Chromium, Dissolved (ug/L)	10	19	-----	n.d.	n.d.	n.d.	1,340[9], 174 [10], 100[11]	0	0%
Copper, Dissolved (ug/L)	6	19	-----	n.d.	n.d.	10	34[9], 21[10], 1,000[11]	0	0%
Hardness, Total (mg/L)	0.4	19	273.4	271.2	237.1	338.0	-----	-----	-----
Iron, Dissolved (ug/L)	7	19	-----	9	n.d.	90	1,000[10]	0	0%
Lead, Dissolved (ug/L)	0.5	19	-----	n.d.	n.d.	0.5	188[9], 7.3[10], 15[11]	0	0%
Magnesium, Dissolved (mg/L)	0.01	19	25.3	25.4	21.4	28.9	-----	-----	-----
Manganese, Dissolved (ug/L)	2	19	-----	3	n.d.	50.	1,000[10]	0	0%
Mercury, Dissolved (ug/L)	0.05	19	-----	n.d.	n.d.	n.d.	1.4[9]	0	0%
Mercury, Total (ug/L)	0.05	19	-----	n.d.	n.d.	n.d.	0.77[10], 2[11]	0	0%
Nickel, Dissolved (ug/L)	10	19	-----	n.d.	n.d.	n.d.	1,088[9], 121[10], 100[11]	0	0%
Selenium, Dissolved (ug/L)	1	19	2	2	n.d.	4	-----	-----	-----
Selenium, Total (ug/L)	1	19	3	3	n.d.	5	20[3,9], 5[10], 50[11]	0	0%
Silver, Dissolved (ug/L)	1	19	-----	n.d.	n.d.	n.d.	19[9], 100[11]	0	0%
Sodium, Dissolved (mg/L)	0.01	16	71.4	74.0	38.8	83.6	-----	-----	-----
Thallium, Dissolved (ug/L)	0.5	19	-----	n.d.	n.d.	n.d.	1,400[9], 6.3[10], 2[11]	0	0%
Zinc, Dissolved (ug/L)	10	19	-----	n.d.	n.d.	20	272[9,10], 5,000[11]	0	0%
Acetochlor, Total (ug/L)[D]	0.05	59	-----	n.d.	n.d.	3.7	-----	-----	-----
Atrazine, Total (ug/L)[D]	0.05	59	-----	n.d.	n.d.	28.5	330[9], 12[10], 3[2]	0, 1, 2	0%, 2%, 3%
Metolachlor, Total (ug/L)[D]	0.05	58	-----	n.d.	n.d.	1.6	390[9], 100[10]	0	0%
Pesticide Scan (ug/L)[E]	0.05								
Acetochlor, Total (ug/L)	0.02	5	-----	n.d.	n.d.	0.7	-----	-----	-----
Atrazine, Total (ug/L)	0.02	5	-----	n.d.	n.d.	4	330[9], 12[10], 3[2]	0, 0, 1	0%, 0%, 20%
Metolachlor, Total (ug/L)	0.03	5	-----	n.d.	n.d.	1.6	390[9], 100[10]	0	0%

n.d. = Not detected.

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

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

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

- (1) Criteria for the protection of Class I Warmwater Aquatic Life (Nebraska).
- (2) Criteria for the protection of domestic water supply waters.
- (3) Criteria for the protection of agricultural water supply waters.
- (4) Criteria for the protection of commerce and industry waters.
- (5) Daily maximum criterion (monitoring results directly comparable to criterion).
- (6) Daily minimum criterion (monitoring results directly comparable to criterion).
- (7) 30-day average criterion (monitoring results not directly comparable to criterion).
- (8) Total ammonia criteria pH and temperature dependent. Criteria listed are for the median pH and temperature conditions.
- (9) Acute criterion for aquatic life.
- (10) Chronic criterion for aquatic life.
- (11) Criterion for the protection of human health.

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

(D) Immunoassay analysis.

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

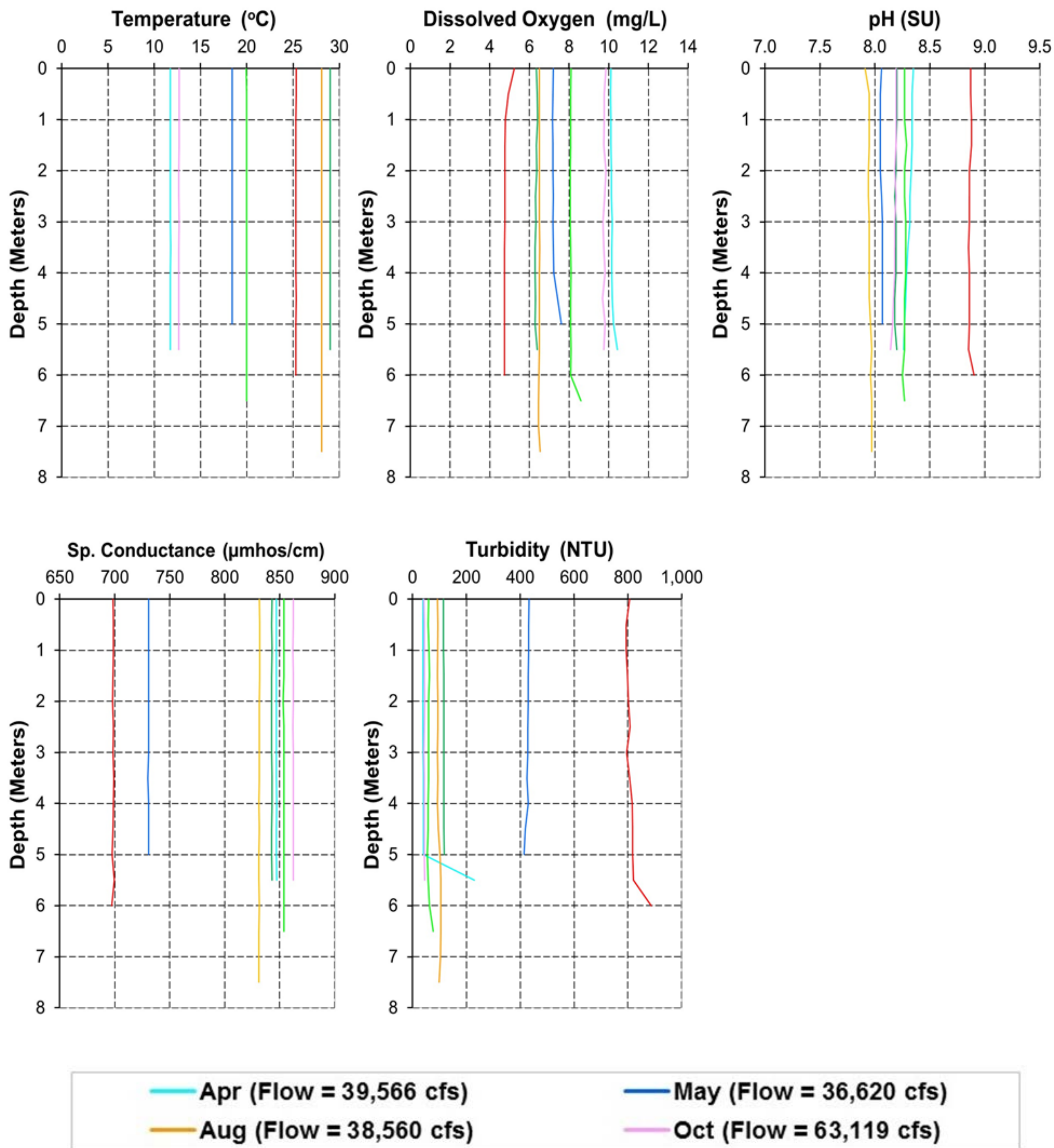


Plate 11-16. Water temperature, dissolved oxygen, pH, specific conductance, and turbidity depth profiles for the Missouri River compiled from data collected at RM498 (i.e. MORRR0498) during 2015.

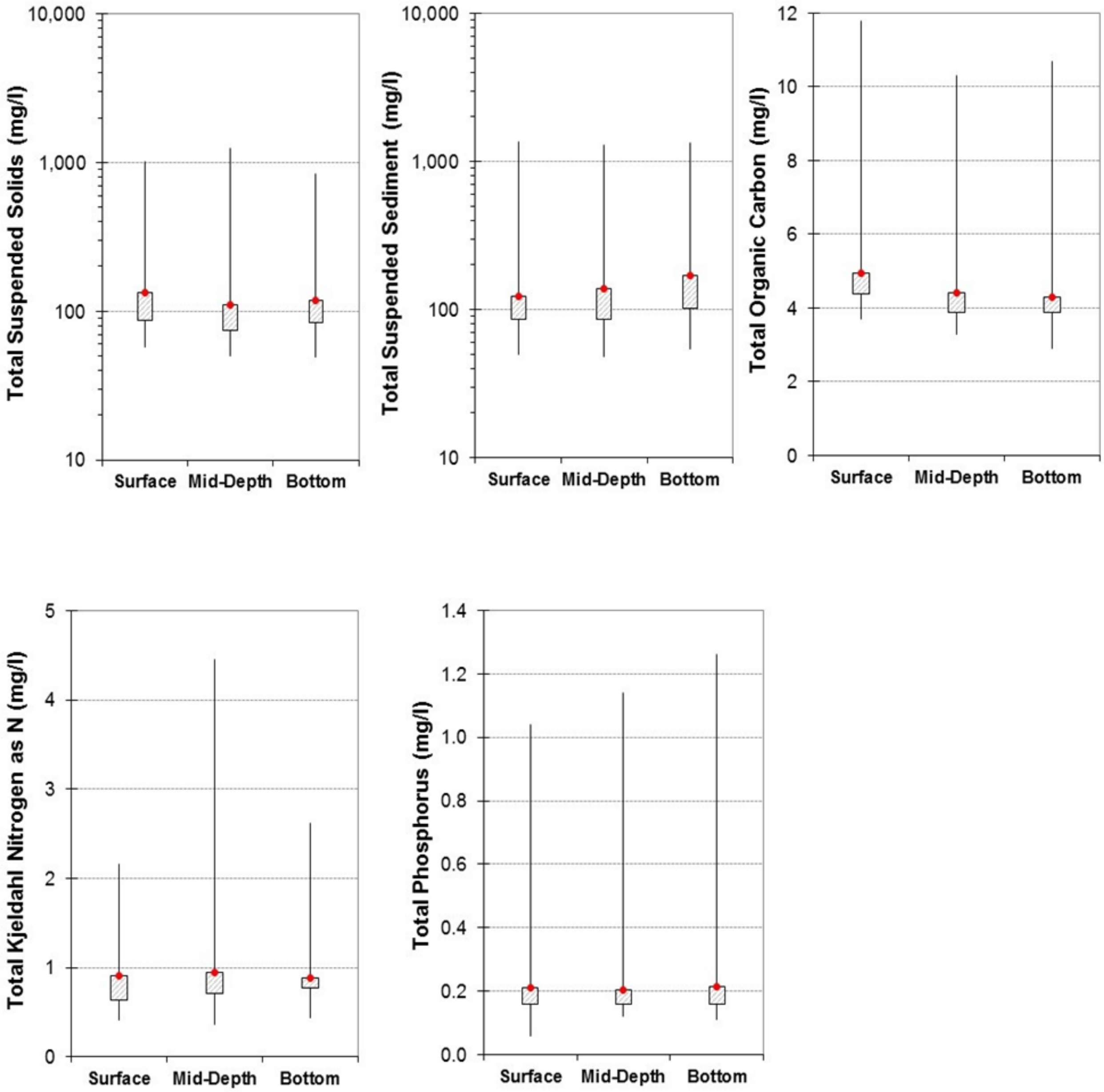
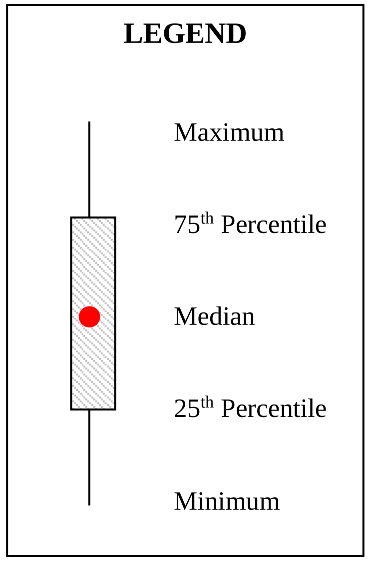
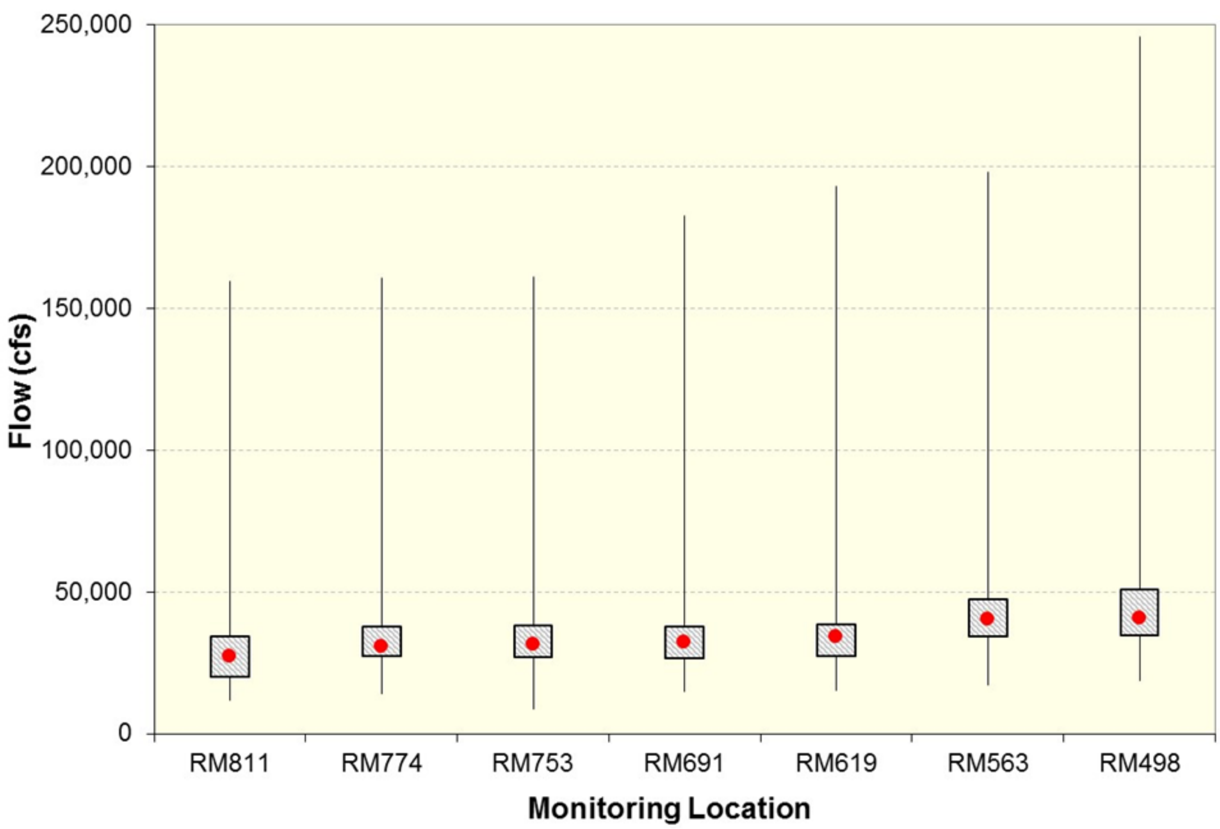


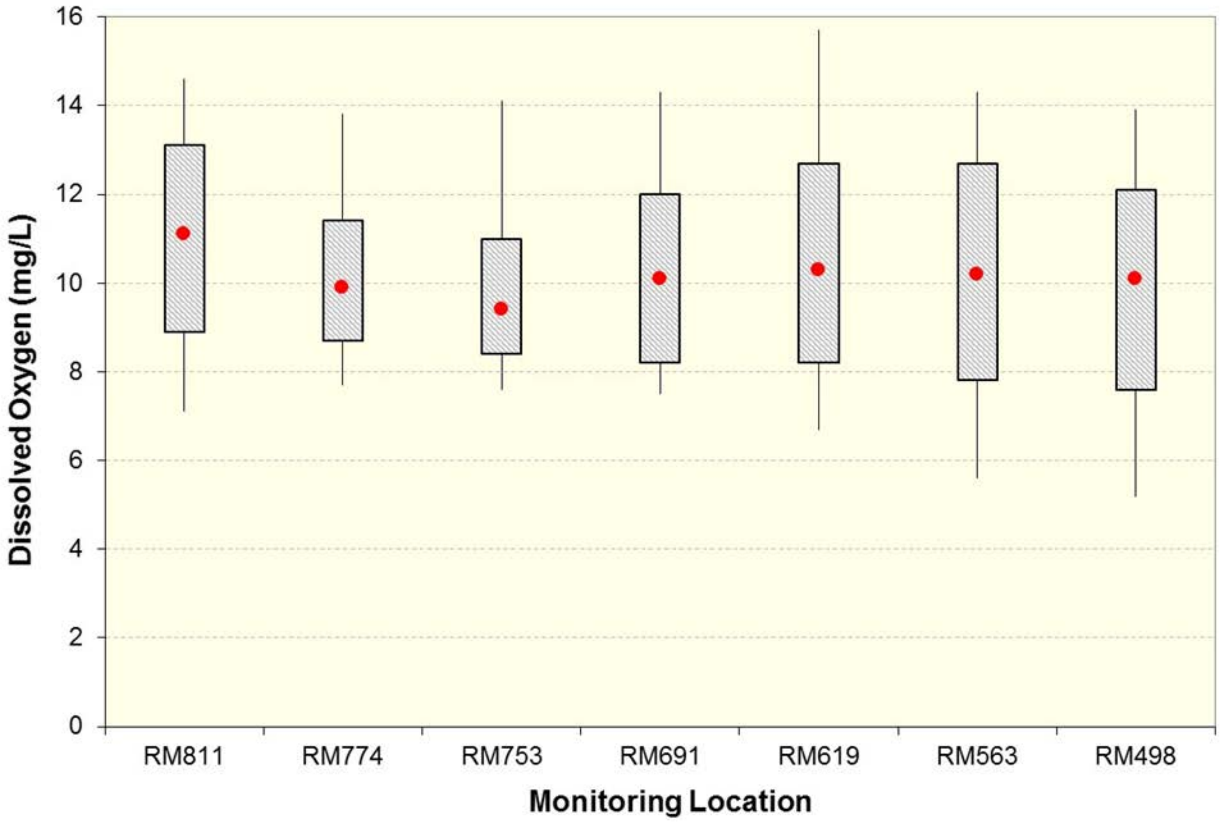
Plate 11-17. Box plots comparing paired surface, mid-depth, and bottom total suspended solids, total suspended sediment, turbidity, total Kjeldahl nitrogen, total phosphorus, and total organic carbon measurements taken in the Missouri River at site MORRR0498 during the 5-year period 2011 through 2015. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

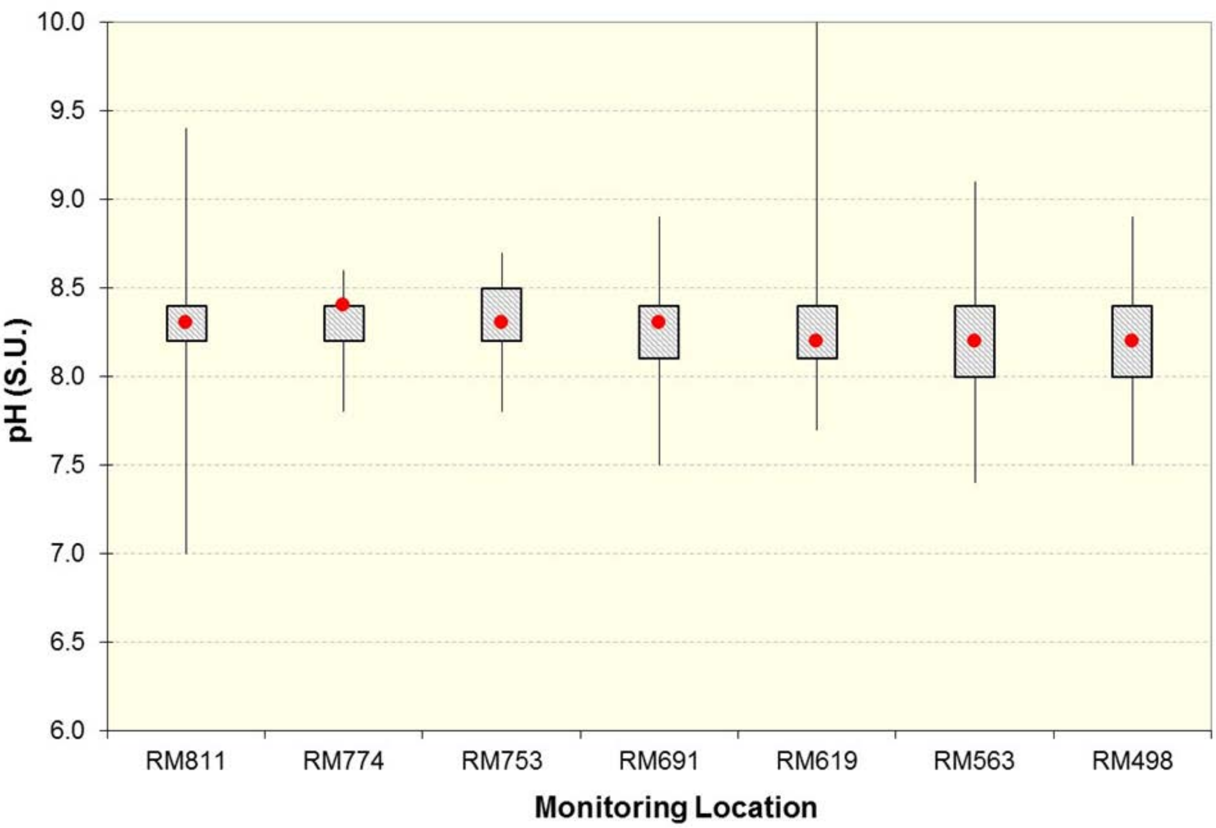
Plate 11-18. Distribution plots (i.e. box plots) for selected parameters monitored at locations along the lower Missouri River from the Gavins Point Dam tailwaters to Rulo, Nebraska during the 5-year period of 2011 through 2015.

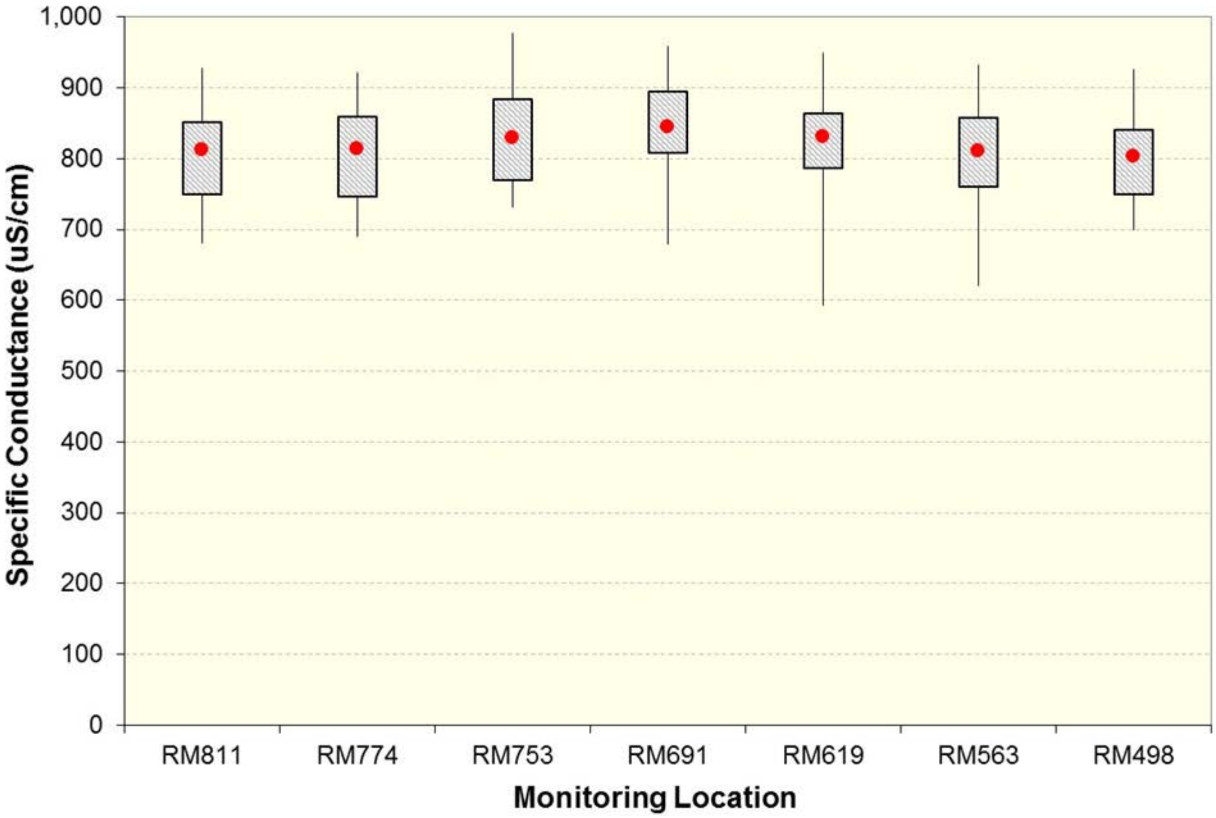


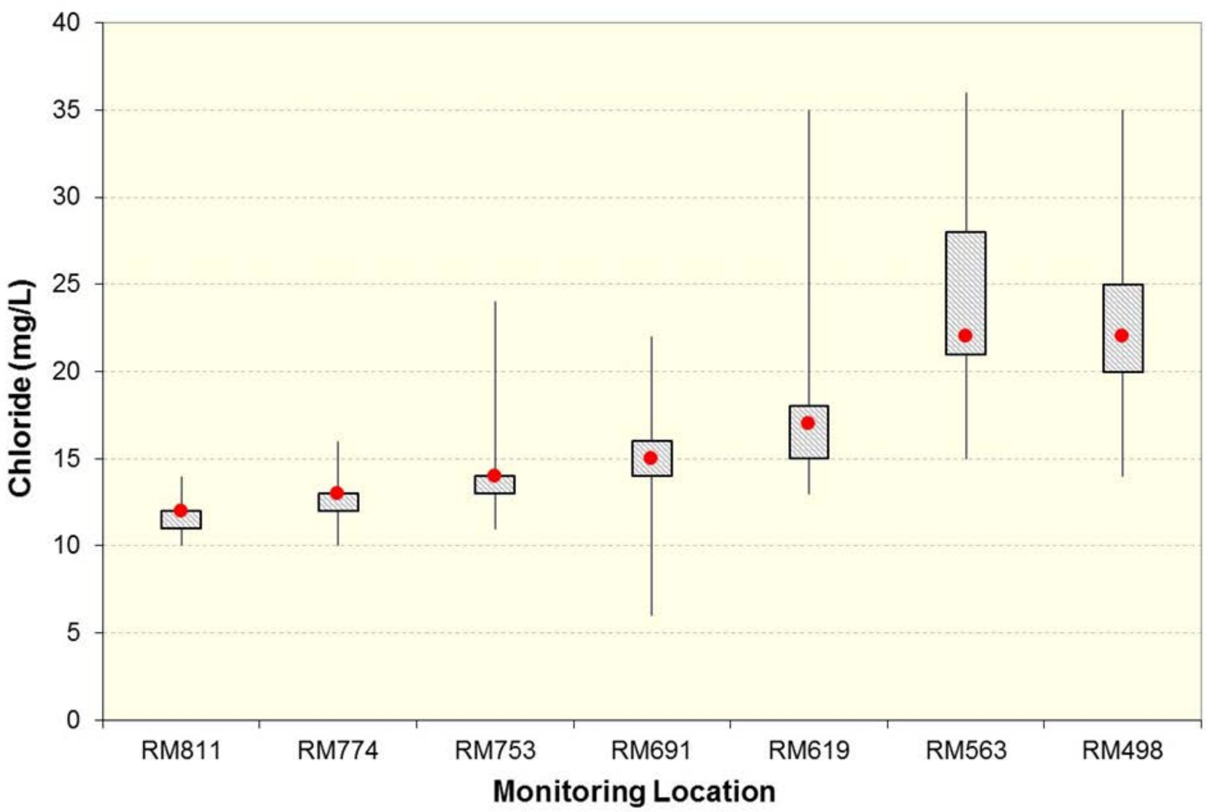
Note: Monitoring location refers to the River Mile (RM) along the Missouri River where the monitoring site was located.

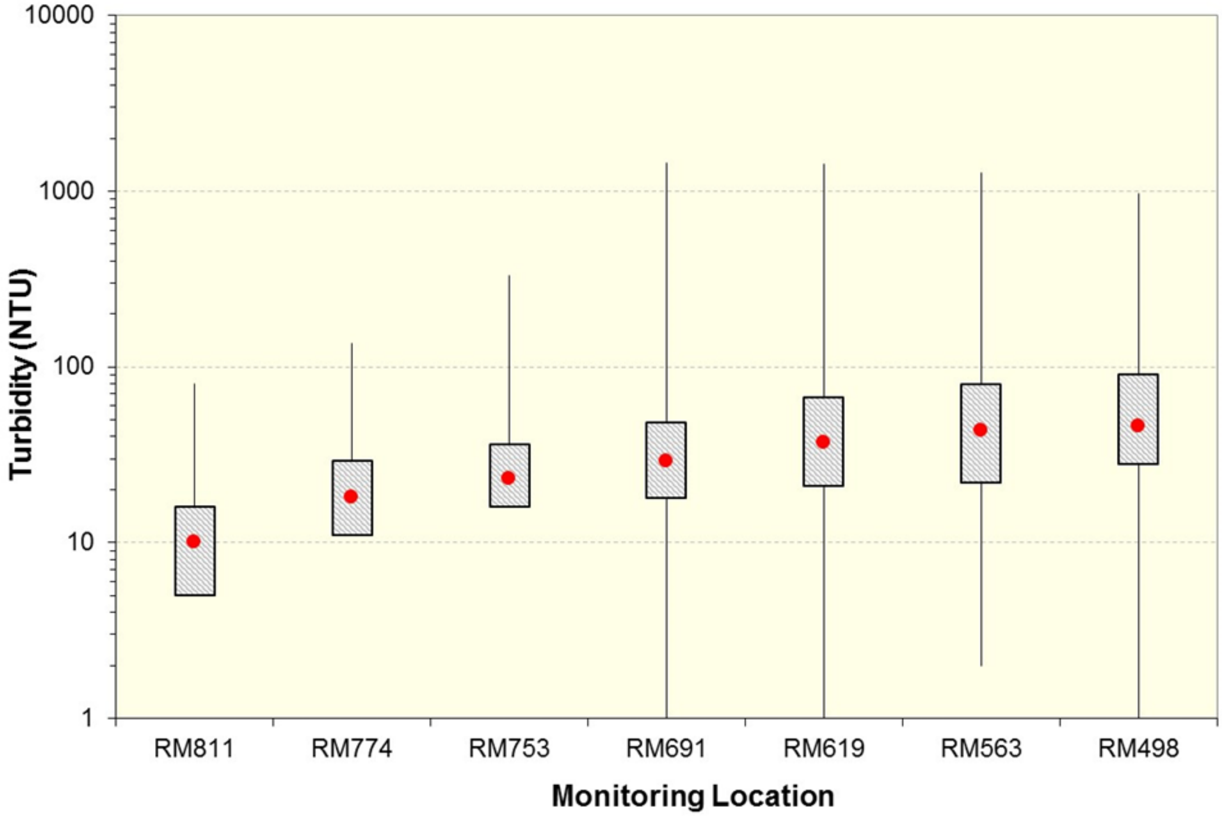


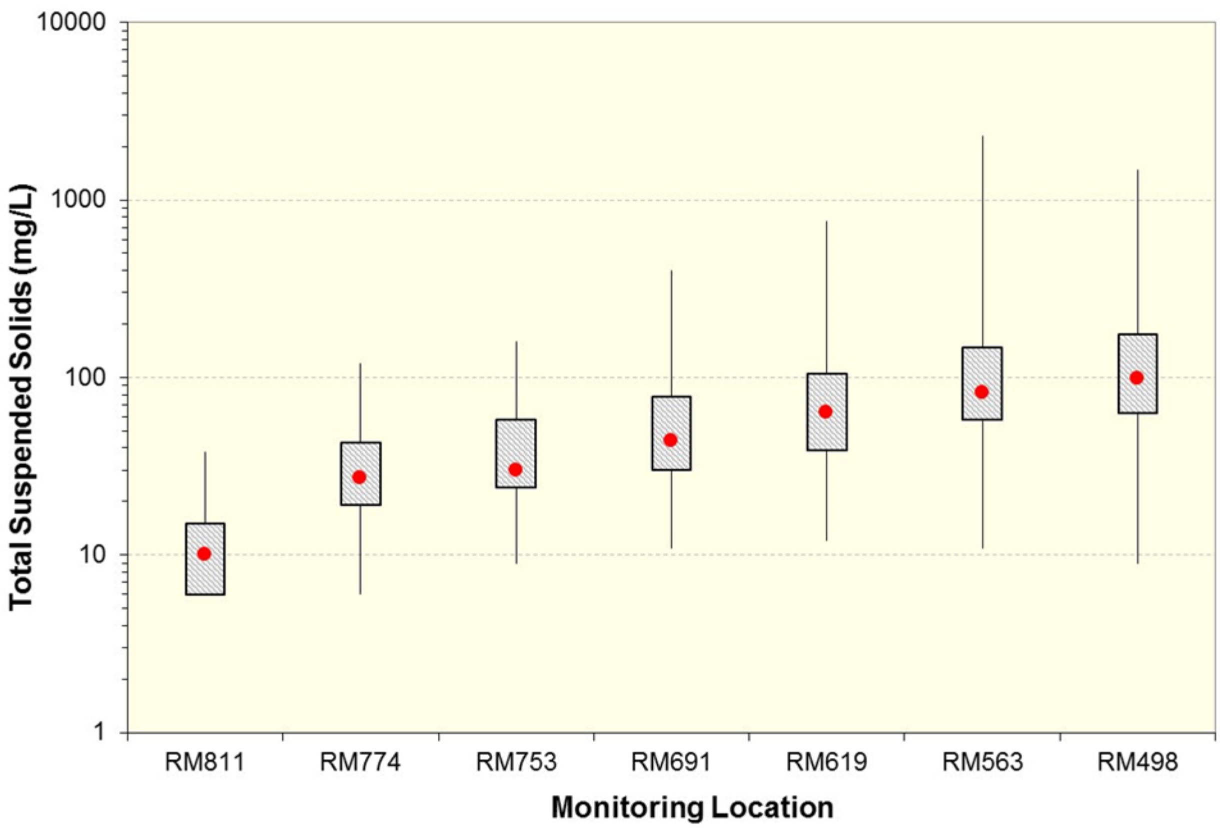

16
14
12
10
8
6
4
2
0
Dissolved Oxygen (mg/L)
RM811
RM774
RM753
RM691
RM619
RM563
RM498
Monitoring Location

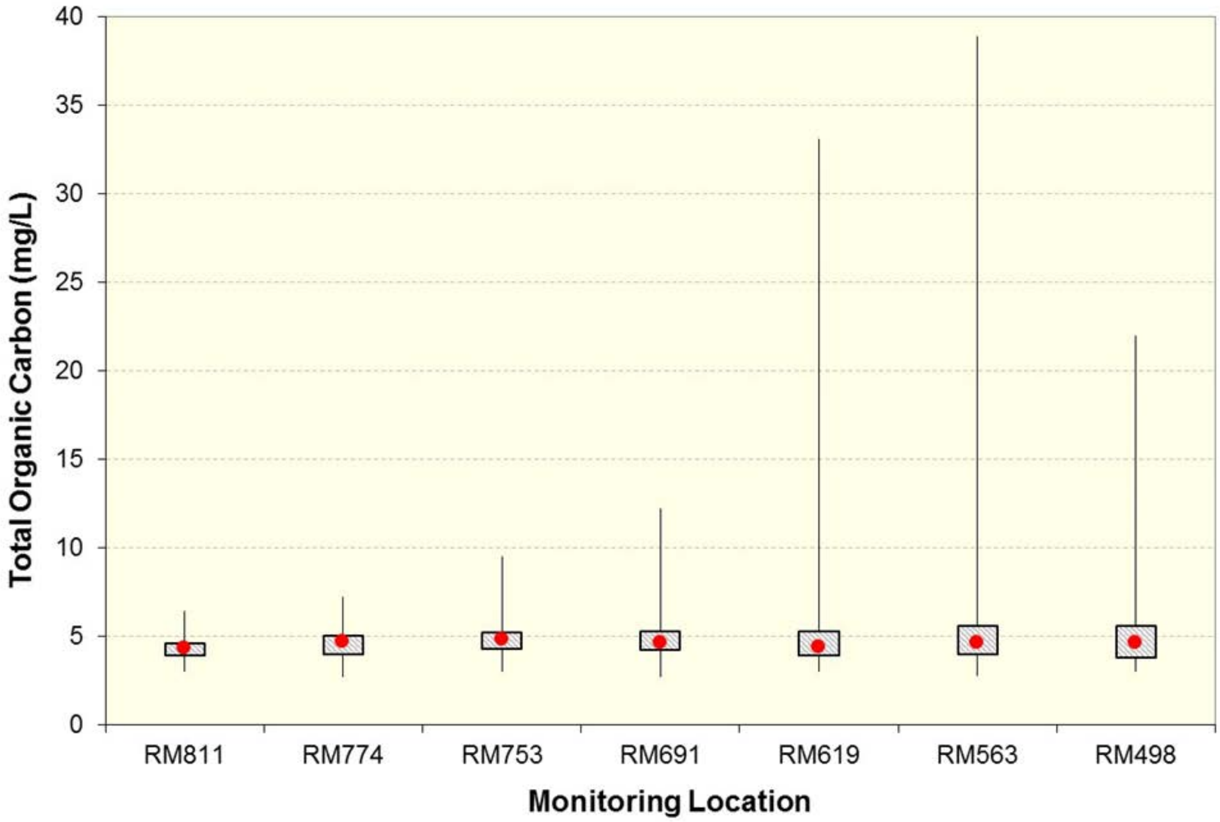

10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
pH (S.U.)
RM811
RM774
RM753
RM691
RM619
RM563
RM498
Monitoring Location

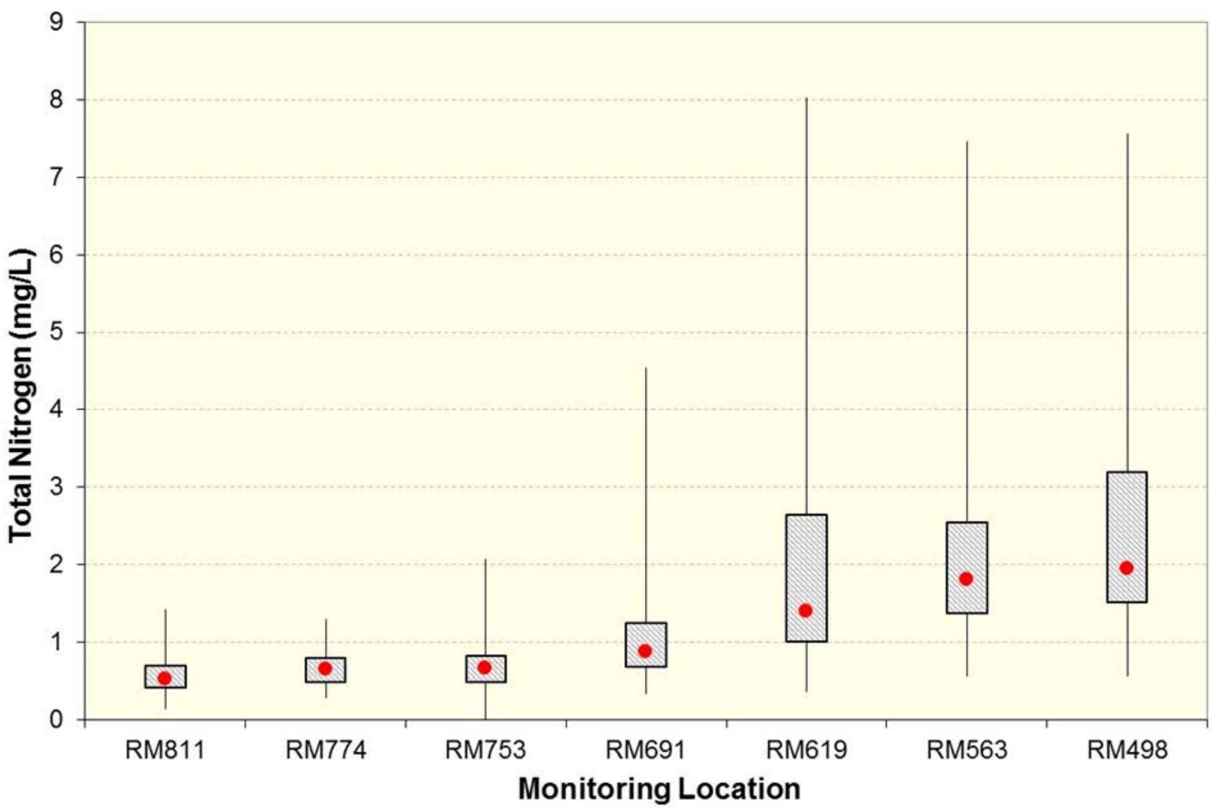

Specific Conductance (uS/cm)
1,000
900
800
700
600
500
400
300
200
100
0
RM811
RM774
RM753
RM691
RM619
RM563
RM498
Monitoring Location

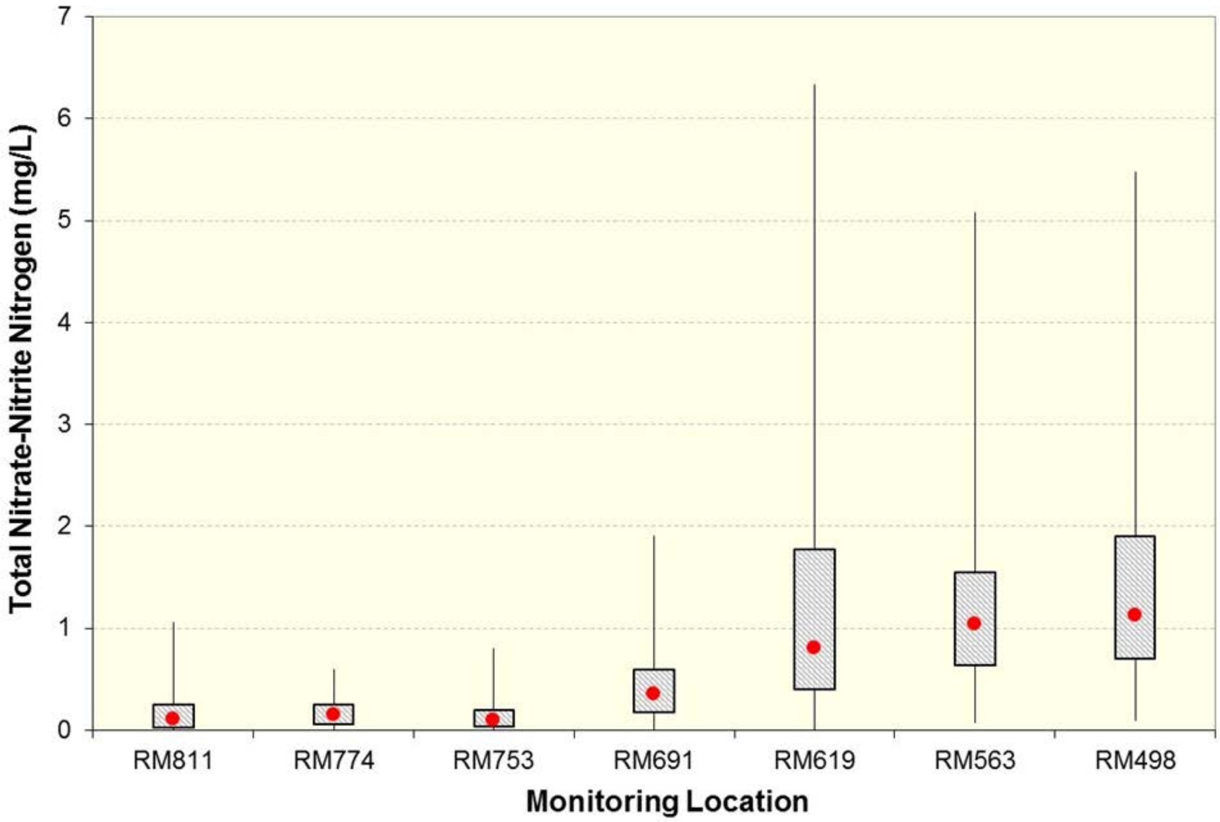

Chloride (mg/L)
40
35
30
25
20
15
10
5
0
RM811
RM774
RM753
RM691
RM619
RM563
RM498
Monitoring Location

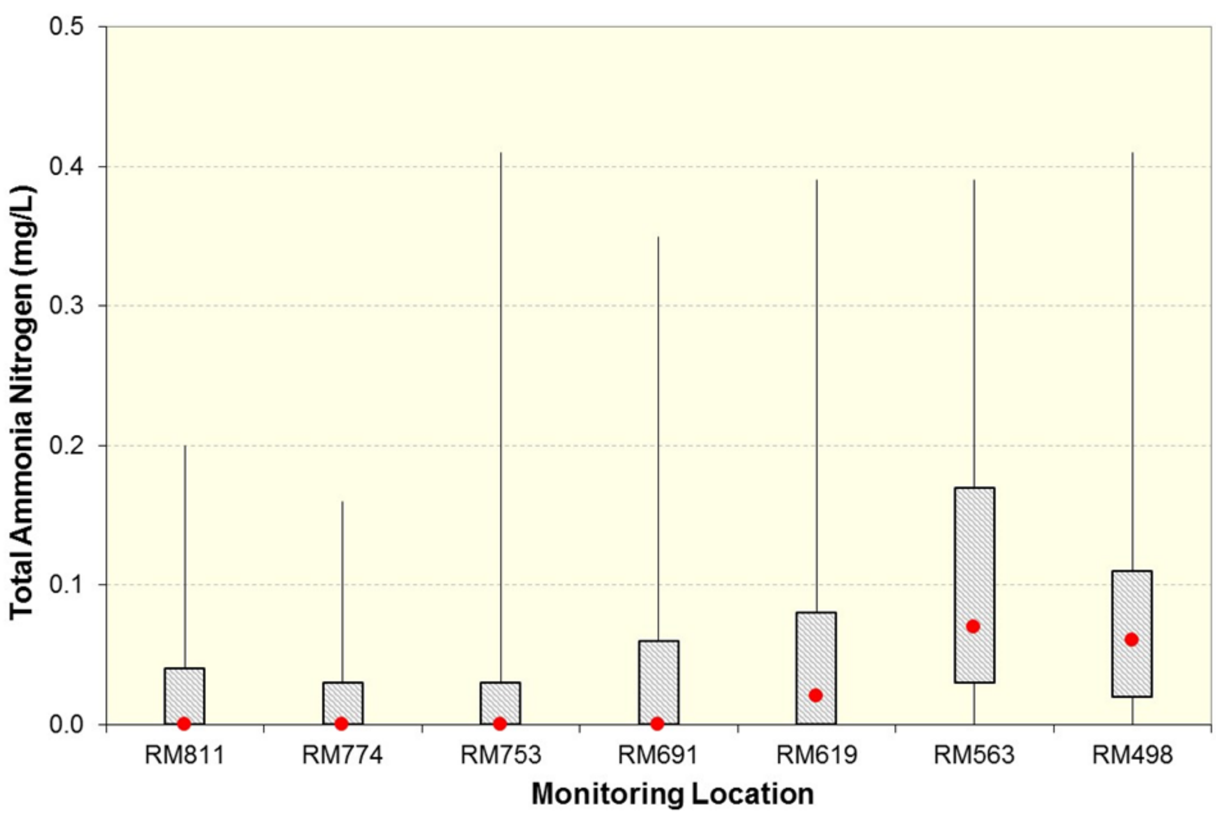

10000
1000
100
10
1
Turbidity (NTU)
RM811
RM774
RM753
RM691
RM619
RM563
RM498
Monitoring Location

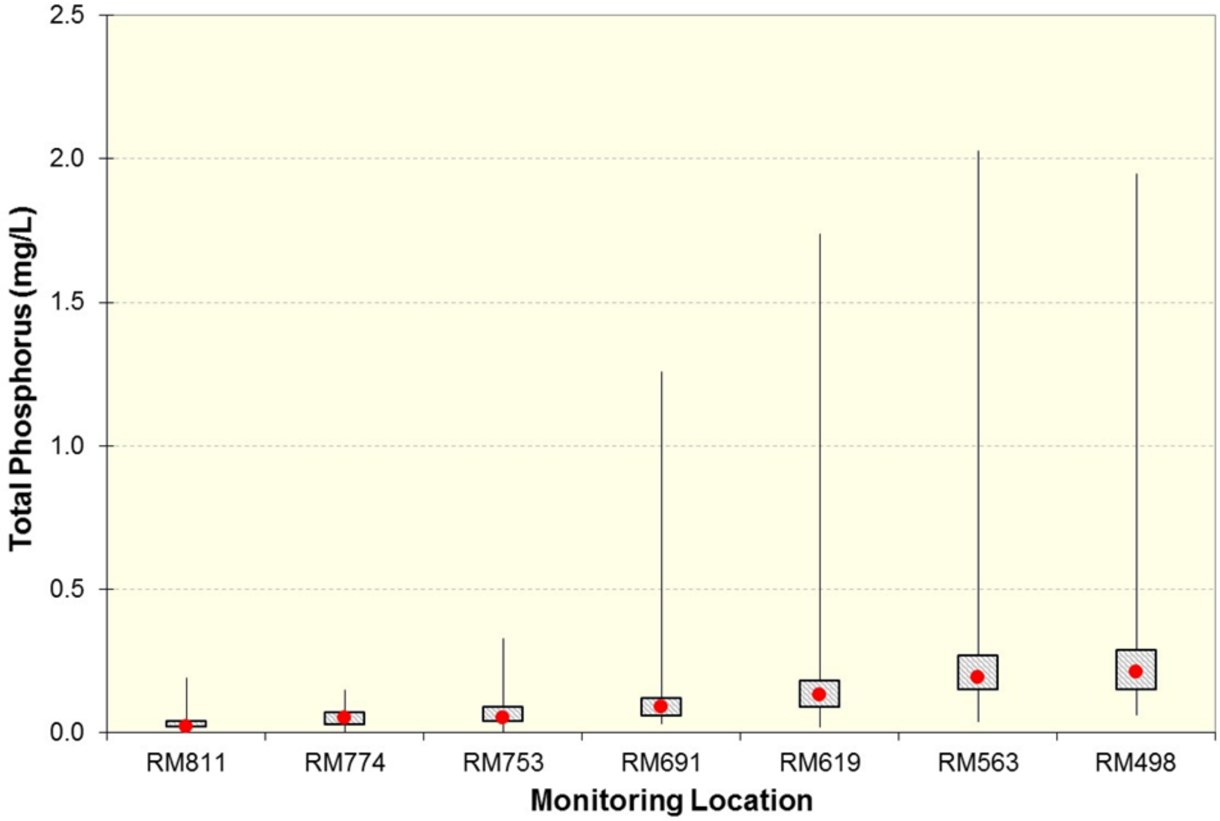

10000
1000
100
10
1
Total Suspended Solids (mg/L)
RM811
RM774
RM753
RM691
RM619
RM563
RM498
Monitoring Location

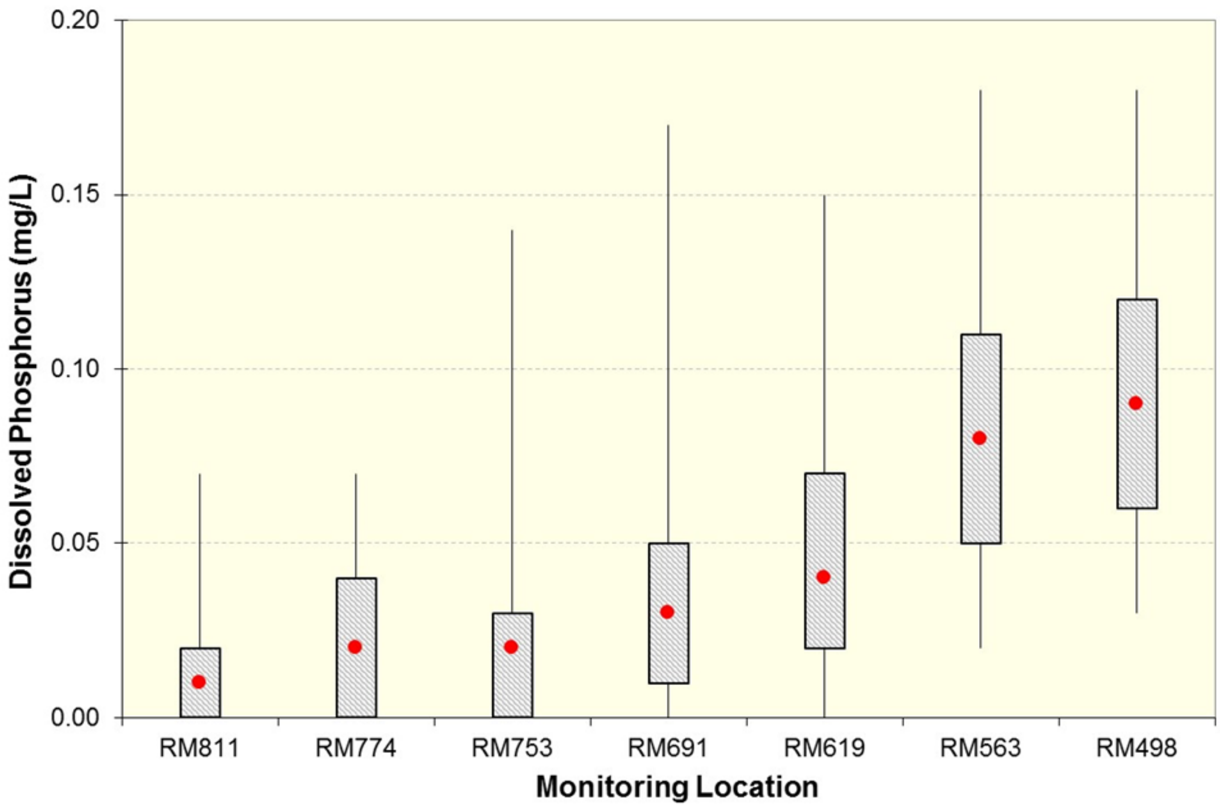

40
35
30
25
20
15
10
5
0
Total Organic Carbon (mg/L)
RM811
RM774
RM753
RM691
RM619
RM563
RM498
Monitoring Location


9
8
7
6
5
4
3
2
1
0
Total Nitrogen (mg/L)
RM811
RM774
RM753
RM691
RM619
RM563
RM498
Monitoring Location


7
6
5
4
3
2
1
0
Total Nitrate-Nitrite Nitrogen (mg/L)
RM811
RM774
RM753
RM691
RM619
RM563
RM498
Monitoring Location


0.5
0.4
0.3
0.2
0.1
0.0
Total Ammonia Nitrogen (mg/L)
RM811
RM774
RM753
RM691
RM619
RM563
RM498
Monitoring Location


Total Phosphorus (mg/L)
2.5
2.0
1.5
1.0
0.5
0.0
RM811
RM774
RM753
RM691
RM619
RM563
RM498
Monitoring Location


Dissolved Phosphorus (mg/L)
0.20
0.15
0.10
0.05
0.00
RM811
RM774
RM753
RM691
RM619
RM563
RM498
Monitoring Location

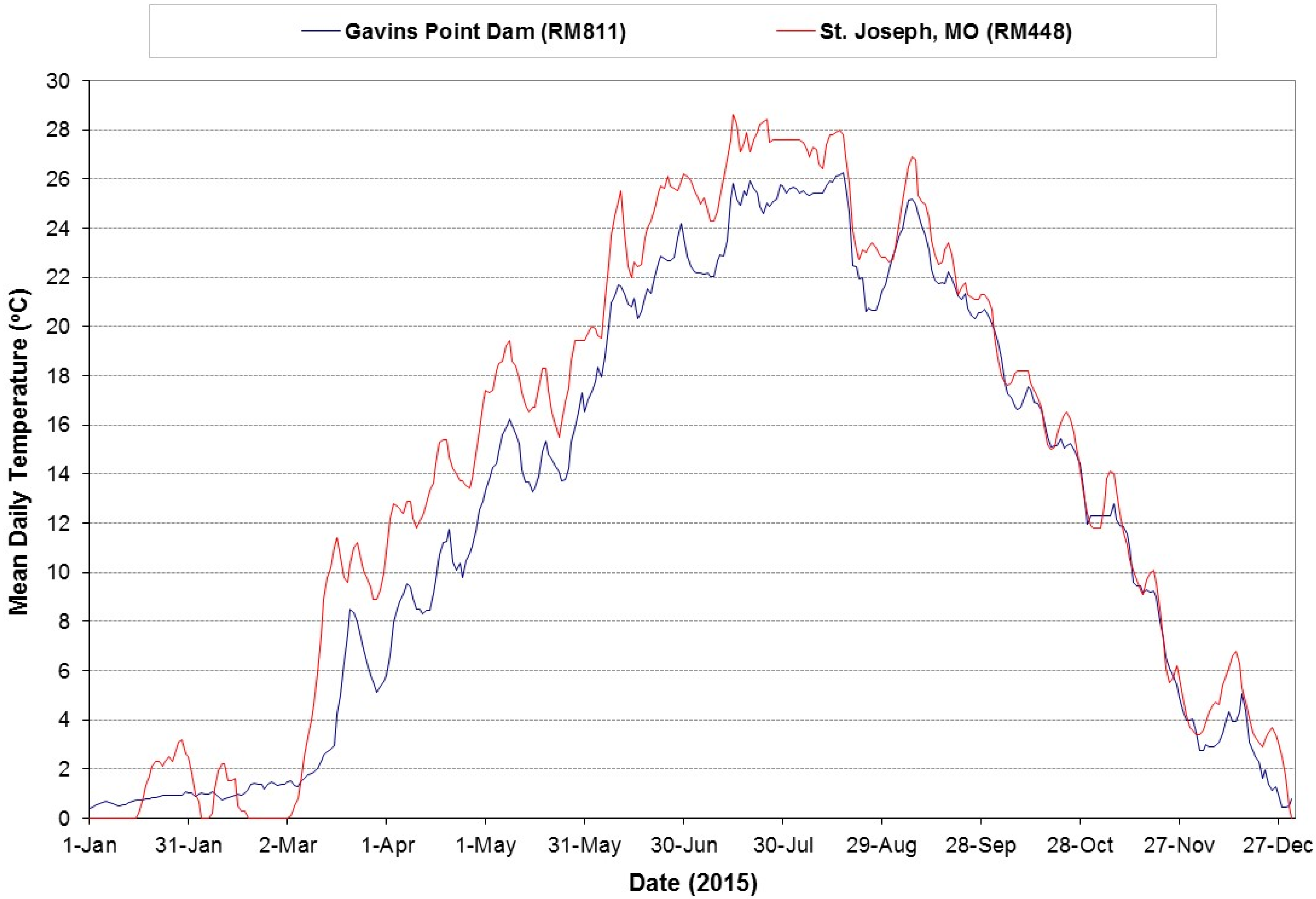


Plate 11-19. Mean daily water temperature determined for the lower Missouri River during 2015 at Gavins Point Dam and St. Joseph, MO.

12 NUTRIENT CONDITIONS ALONG THE MISSOURI RIVER IN THE OMAHA DISTRICT

Nutrient (i.e. nitrate-nitrite nitrogen, total nitrogen, and total phosphorus) concentrations and mean daily loads for the Missouri River at selected locations in the Omaha District were compiled from monitoring conducted during the 5-year period of 2011 through 2015. The monitored locations along the Missouri River included the following 17 sites (listed in an upstream to downstream order with the river mile given): 1) near Landusky, MT (RM 1921); 2) at Fort Peck Dam (RM 1771); 3) Near Williston, ND (RM 1553); 4) at Garrison Dam (RM 1389); 5) at Bismarck, ND (RM 1315); 6) at Oahe Dam (RM 1072); 7) at Big Bend Dam (RM 986); 8) at Fort Randall Dam (RM 879); 9) near Verdel, NE (RM 851); 10) at Running Water SD (RM840); 11) at Gavins Point Dam (RM 811); 12) near Maskell, NE (RM 774); 13) near Ponca, NE (RM 753); 14) at Decatur, NE (RM 691); 15) at Omaha, NE (RM 619); 16) at Nebraska City, NE (RM 563); and 17) at Rulo, NE (RM 498). The samples collected at the mainstem dams were collected at the respective powerplants and are representative of the water discharged from the dams. The other samples collected along the Missouri River were grab samples representative of near-surface conditions.

12.1 EXISTING NUTRIENT CONCENTRATIONS

Box plots were constructed from the total nitrate-nitrite nitrogen, total nitrogen, and total phosphorus concentrations measured along the Missouri River at the 17 locations during the 5-year period 2011 through 2015 (Figure 12-1). As seen in Figure 12-1, there is a significant increase in nitrate-nitrite nitrogen levels downstream of Gavins Point Dam; especially downstream of Ponca, NE (RM753). Large cities (i.e. Sioux City, IA and Omaha, NE) and tributary streams draining areas of intensive agriculture are located downstream of Gavins Point Dam. An increase in total phosphorus levels is also seen downstream of Gavins Point Dam (Figure 12-1). Higher levels of total phosphorus were also measured in the Missouri River near Landusky, MT (RM1921 – inflow to Fort Peck Lake) and Williston, ND (RM1553 – inflow to Lake Sakakawea). It is noted that the Yellowstone River enters the Missouri River downstream of Fort Peck Dam and upstream from Williston, ND.

12.2 ESTIMATED NUTRIENT LOADINGS

Loadings for total nitrate-nitrite nitrogen, total nitrogen, and total phosphorus were estimated for the Missouri River at 16 locations based on the powerplant and near-surface sampling data collected over the 5-year period 2011 through 2015. Daily loadings were calculated from the instantaneous flux rates determined for the sites. It is recognized that the concentrations of particulate-associated constituents can vary significantly from the river surface to its bottom because of the sinking of particulate matter and its transport nearer the river bottom. Thus, the calculated flux rates from the near-surface sampling likely under estimate the total phosphorus loadings. The powerplant samples are representative of the water discharged from the dams and give an unbiased estimate of total phosphorus loadings. Loadings for nitrate-nitrite nitrogen are believed to be unbiased in this regard as nitrate-nitrite nitrogen does not tend to be particulate associated.

Figure 12-2 plots the estimated mean daily loads in tons per day at the 15 sites along the Missouri River. The six mainstem reservoirs trap nutrients along the Missouri River and function as nutrient sinks; thus, nutrient loadings are appreciably reduced immediately downstream of the six Missouri River mainstem reservoirs (Figure 12-2). The increased loading in the Missouri River at Williston, ND is attributed to the inflow of the Yellowstone River which has no major reservoirs along its entire reach to Yellowstone National Park. The greatly increasing nutrient loads in the Missouri River downstream of Gavins Point Dam are attributed to point and nonpoint source nutrient input to the river.

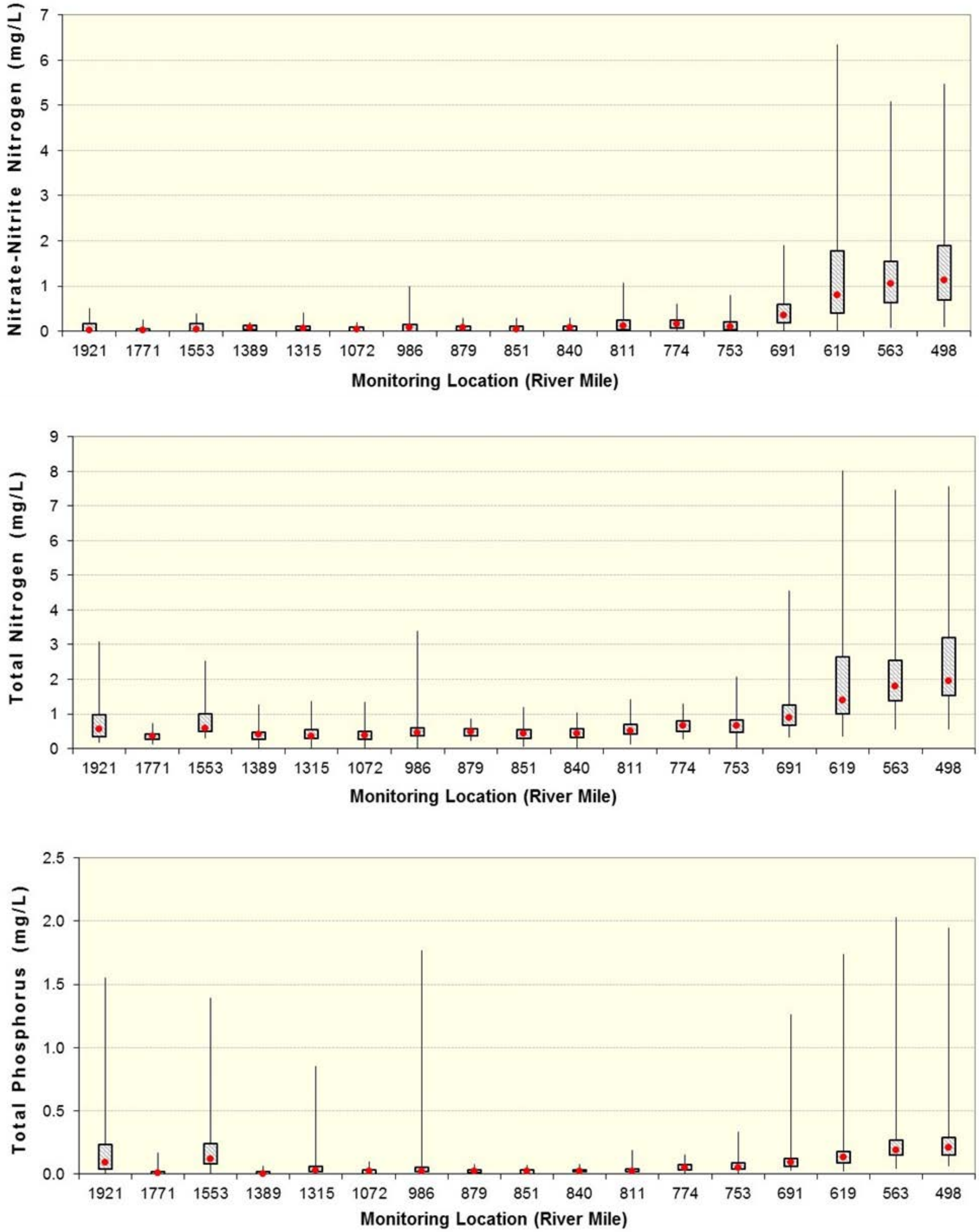


Figure 12-1. Distribution of measured concentrations of nitrate-nitrite nitrogen, total nitrogen, and total phosphorus at 17 locations along the Missouri River from Landusky, MT (RM1921) to Rulo, NE (RM498) during the 5-year period 2011 through 2015. (Box plots represent minimum, 25th percentile, 75th percentile, and maximum. Red dot is the median value).

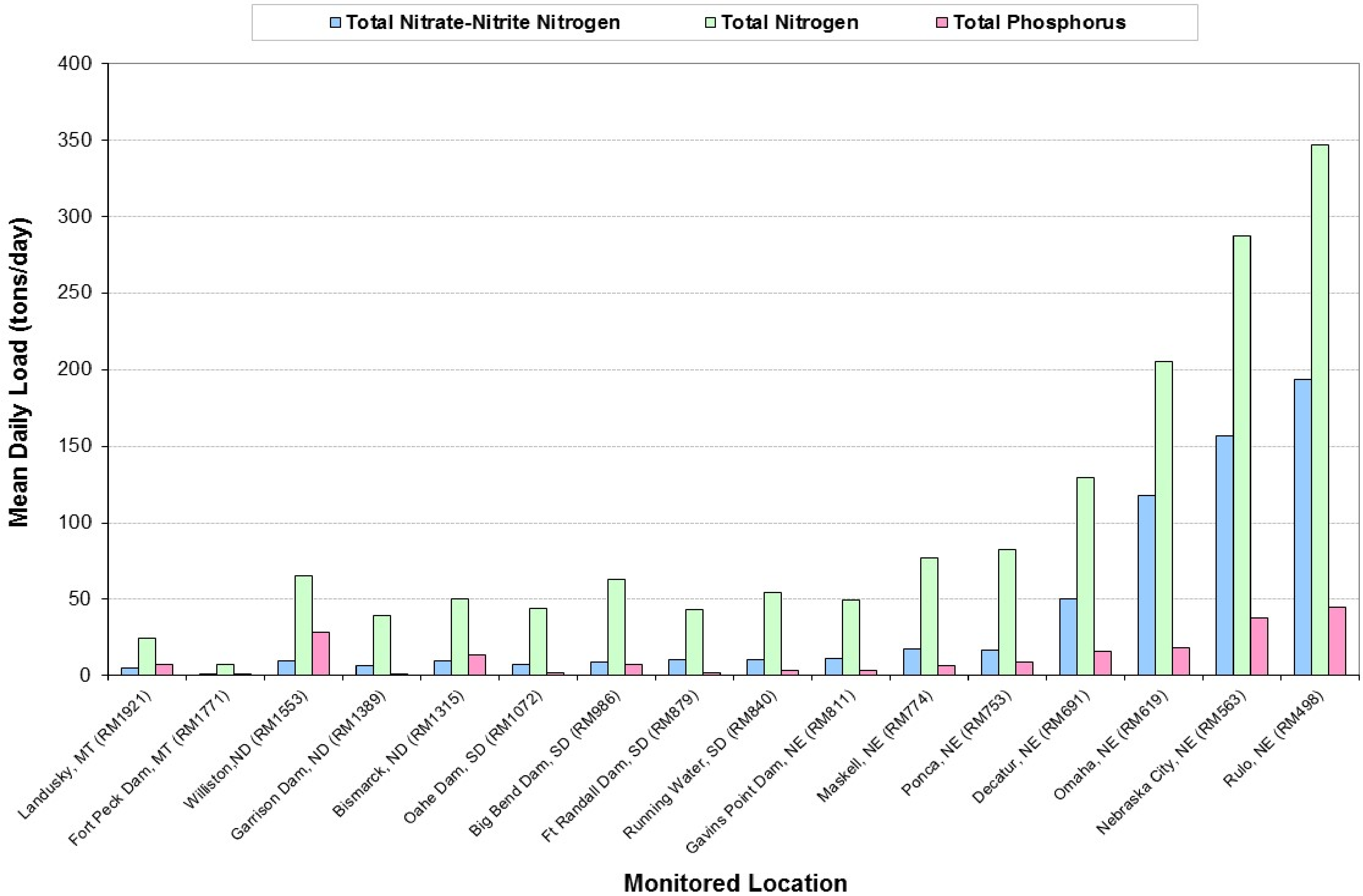


Figure 12-2. Estimated mean daily loads (tons/day) for total nitrate-nitrite nitrogen, total nitrogen, and total phosphorus along the Missouri River from near Landusky, MT (RM1921) to Rulo, NE (RM498) for the 5-year period 2011 through 2015.

13 REFERENCES

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography, March 1977, Vol 22(2), pp. 361-369.

Hydrogeologic, Inc. 2012. Data Management and Analysis System for Lakes, Estuaries, and Rivers – Professional Version (DASLER-X). Version 6.2. HydroGeoLogic, Inc. Maryville, TN.

South Dakota Department of Environment and Natural Resources. 2016. The 2016 South Dakota Integrated Report Surface Water Quality Assessment. South Dakota Department of Environment and Natural Resources. Pierre, South Dakota.

U.S. Army Corps of Engineers. 1995. Engineer Regulation (ER) 1110-2-8154, Engineering and design – Water quality and environmental management for Corps civil works projects. Department of the Army, U.S. Army Corps of Engineers, Washington, D.C.

_______. 2006. Missouri River mainstem reservoir system, master water control manual, Missouri River Basin (Revised March 2006). Reservoir Control Center, Northwestern Division – Missouri River Basin, U.S. Army Corps of Engineers. Omaha, Nebraska.

_______. **2010.** Low dissolved oxygen levels in summer powerplant discharges from Fort Randall Dam, South Dakota. Water Quality Unit, Water Control and Water Quality Section, Hydrologic Engineering Branch, Engineering Division, Omaha District, U.S. Army Corps of Engineers. Omaha, Nebraska.

_______. **2012.** Final Situation Report – Low Dissolved Oxygen Levels in Discharges from Fort Peck Dam. Water Quality Unit, Water Control and Water Quality Section, Hydrologic Engineering Branch, Engineering Division, Omaha District, U.S. Army Corps of Engineers. Omaha, Nebraska.

_______. **2016.** Program management plan for implementing the Omaha District's water quality management program. Water Quality Unit, Water Control and Water Quality Section, Hydrologic Engineering Branch, Engineering Division, Omaha District, U.S. Army Corps of Engineers. Omaha, Nebraska.

U.S. Fish and Wildlife Service. 1993. Recovery plan for the pallid sturgeon (*Scaphirhynchus albus*). Pallid sturgeon recovery team. Region 6, U.S. Fish and Wildlife Service, Denver, Colorado.

_______. 2003. U.S. Fish and Wildlife Service 2003 Amendments to the 2000 Biological Opinion on the Operation of the Missouri River Main Stem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project, and Operation of the Kansas River Reservoir System. December 16, 2003.