U.S. Army Corps of Engineers
Omaha District

2015 Report

Water Quality Conditions at Omaha District Tributary Projects in Colorado, North Dakota, and South Dakota

June 2016

2015 Report

Water Quality Conditions at Omaha District Tributary Projects in Colorado, North Dakota, and South Dakota

Prepared by:

Water Quality Unit
Water Control and Water Quality Section
Hydrologic Engineering Branch
Engineering Division
Omaha District
U.S. Army Corps of Engineers

June 2016

TABLE OF CONTENTS

List of Tables

List of Figures

Page

List of Plates

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 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). The following four goals have been established 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, and 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 water quality management objectives, allows for the characterization of 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.

Water quality data collection and assessment are of paramount importance to the implementation of the District's WQMP.

The District prepares periodic reports to regularly assess and document surface water quality conditions present at Corps civil works tributary projects in the District. These reports describe existing surface water quality conditions, identify surface water quality trends, and identify any evident surface water quality management issues. The periodic reporting of surface water quality conditions provides information to facilitate water quality management decisions regarding the operation and regulation of the Corps Tributary Projects.

1.2 CORPS CIVIL WORKS TRIBUTARY PROJECTS WITHIN THE OMAHA DISTRICT

The locations of Corps tributary civil works project areas within the District are shown on Figure 1.1These are the Tributary Projects under the purview of the District's WQMP. Table 1-1 provides background information on the Colorado, North Dakota, and South Dakota projects. The Nebraska Tributary Projects are covered in a separate Tributary Projects water quality report.

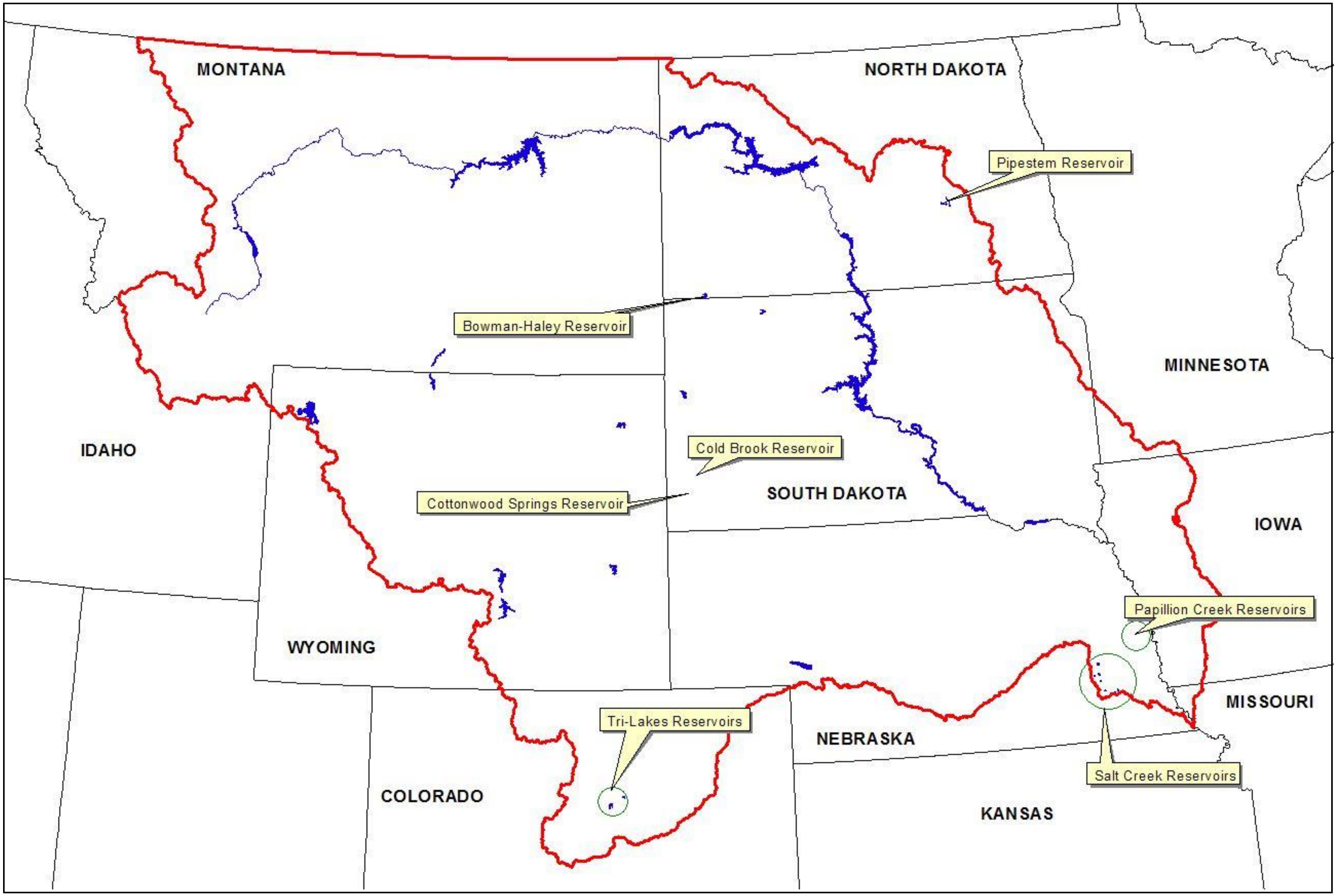


Figure 1.1. Tributary Projects in the Omaha District. (Refer to Table 1.1 for project background information on the Colorado, Nirth Dakota, and South Dakota projects.)

Table 1-1. Background information for the Colorado, North Dakota, and South Dakota Tributary Projects located in the Omaha District.

Project	Location	Dam Closure	Reservoir Size (1)	Authorized Proposes(2)	Water Quality Designated Beneficial Uses(3)
Tri-Lakes Reservoirs (Colorado):					
Bear Creek	Denver, CO	1977	107 A (mp)	FC, Rec, FW	Rec, CAL, DWS, AWS
Chatfield	Denver, CO	1973	1,423 A (mp)	FC, Rec, FW, WS	Rec, CAL, DWS, AWS
Cherry Creek	Denver, CO	1948	844 A (mp)	FC, Rec, FW	Rec, WAL, DWS, AWS
North Dakota Reservoirs:					
Bowman-Haley	Bowman, ND	1966	1,732 A (mp)	FC, Rec, FW, WQ, WS	Rec, WAL, FW, AWS
Pipestem	Jamestown, ND	1973	840 A (mp)	FC, Rec, FW, WQ	Rec, WAL, AWS, Aes
South Dakota Reservoirs:					
Cold Brook	Hot Springs, SD	1952	36 A (mp)	FC, Rec, FW, WQ	Rec, FW, CAL, AWS, DWS
Cottonwood Springs	Hot Springs, SD	1969	41 A (mp)	FC, Rec, FW, WQ	Rec, FW, WAL, AWS, DWS

(1) A = acres and mp = top of multipurpose pool.
(2) Purposes authorized under Federal laws for the operation of the Corps projects.
FC = Flood Control, Rec = Recreation, FW = Fish & Wildlife, WS = Water Supply, WQ = Water Quality.
(3) Water quality dependent beneficial uses designated to the reservoir in State water quality standards pursuant to the Federal Clean Water Act.
Rec = Recreation, CAL = Coldwater Aquatic Life, DWS = Domestic Water Supply, AWS = Agricultural Water Supply, WAL = Warmwater Aquatic Life, Aes = Aesthetics, and FW = Fish and Wildlife.

1.3 PROJECT-SPECIFIC WATER QUALITY MANAGEMENT ISSUES AT THE TRIBUTARY PROJECTS

1.3.1 SECTION 303(D) LISTINGS OF IMPAIRED WATERS

Under Section 303(d) of the Federal Clean Water Act (CWA), Tribes and States, with the delegated authority from the U.S. Environmental Protection Agency (EPA), are required to prepare a periodic list of impaired waters [i.e., Section 303(d) list]. Impaired waters refer to those waterbodies where it has been determined that technology-based effluent limitations required by Section 301 of the CWA are not stringent enough to attain and maintain applicable water quality standards. Tribes and States, as appropriate, are required to establish and implement Total Maximum Daily Loads (TMDLs) for waterbodies on their Section 303(d) lists.

1.3.2 FISH CONSUMPTION ADVISORIES

Fish are capable of accumulating many toxic substances in excess of 1,000 times the concentrations found in surface waters. The public has expressed concerns on whether fish caught from District Project waters are safe to consume. It is important that answers to public health concerns be based on substantiated knowledge of toxicants in fish fillets and the public health risks associated with measured toxicant concentrations. This type of information can be used by States when considering the issuance of fish consumption advisories. Fish consumption advisories have been issued for fish caught from certain District Project waters. Mercury is the most prevalent contaminant leading to the issuance of fish consumption advisories at District Projects.

1.3.3 SUMMARY OF PROJECT-SPECIFIC TMDL CONSIDERATIONS, FISH CONSUMPTION ADVISORIES, AND OTHER WATER QUALITY MANAGEMENT ISSUES

Table 1.3 summarizes TMDL considerations, fish consumption advisories, and other water quality management issues applicable to District's Colorado, North Dakota, and South Dakota Tributary Projects. The impaired uses and pollutant/stressors (i.e., TMDL considerations) and identified contamination (i.e., Fish Consumption Advisories) identified in Table 1.3 are taken directly from the appropriate State 303(d) impaired waters listings and issued fish consumption advisories. They are provided for information purposes and are not based on water quality monitoring conducted by the District. The listed other water quality management issues in Table 1.3 were identified by the District based on District water quality monitoring and water quality management concerns. Water quality management issues at specific Tributary Projects are assessed in further detail in any Project-Specific Reports prepared by the District or State-prepared TMDL plans developed for any State-listed impaired waterbody.

Table 1-2. Summary of project-specific water quality management issues and concerns at District Tributary Projects.

Project Area	TMDL Considerations*				Fish Consumption Advisories		Other Water Quality Management Issues
	On 303(d) List	Impaired Uses	Pollutant/Stressor	TMDL Completed	Advisory in Effect	Identified Contamination	
Colorado Tributary Projects:							
Bear Creek Reservoir	Yes	Aquatic Life	Chlorophyll-a, Total Phosphorus	No	No		Site specific phosphorus and chlorophyll-a water quality criteria
Chatfield Reservoir	No	-----	-----	-----	No		Site specific phosphorus and chlorophyll-a water quality criteria
Cherry Creek Reservoir	Yes	Aquatic Life	Chlorophyll-a, Dissolved Oxygen	No	No		Site specific phosphorus and chlorophyll-a water quality criteria
North Dakota Tributary Projects:							
Bowman-Haley Reservoir	No	-----	-----	-----	Yes	Mercury	Algal blooms
Pipestem Reservoir	Yes	Recreation	Nutrients/Eutrophication Biological Indicators	No	Yes	Mercury	Fully Supported But Threatened
South Dakota Tributary Projects:							
Cold Brook	Yes	Coldwater Fishery	Water Temperature	No	No		Natural Condition

* Colorado tributary information taken from published State Total Maximum Daily Load (TMDL) Section 303(d) reports and listings as of May 1, 2016. North and South Dakota tributary information taken from published State Total Maximum Daily Load (TMDL) Section 303(d) reports and listings as of October 1, 2014.

COLORADO, NORTH DAKOTA, AND SOUTH DAKOTA TRIBUTARY PROJECTS WATER QUALITY MONITORING

1.4 COLORADO TRIBUTARY PROJECTS

The District has not conducted water quality monitoring at the three District Tributary Projects in Colorado since 2002. At each reservoir (i.e., Bear Creek, Chatfield, and Cherry Creek) local watershed authorities have been established to improve and protect water quality. As part of their efforts they have established water quality monitoring networks at each of the three reservoirs. After reviewing the water quality monitoring efforts of the three watershed authorities, the District determined that its water quality information needs can be met though the use of data collected by the local Watershed Authorities.

1.5 NORTH DAKOTA TRIBUTARY PROJECTS

The District has monitored ambient water quality conditions over the past 30 years at the two Tributary Projects in North Dakota – Bowman-Haley and Pipestem. During the past 5 years, ambient monitoring of the reservoirs was conducted in 2012 and 2015. During 2015 an intensive water quality survey of Pipestem Reservoir was completed. This data is currently being used to facilitate application of the CE-QUAL-W2 hydrodynamic and water quality model. Ambient water quality monitoring at Bowman-Haley and Pipestem Reservoirs is on a 3-year rotating cycle with the next ambient monitoring scheduled for 2018. The ambient monitoring included monthly sampling (May through September) at near-dam, mid-reservoir, and up-reservoir deepwater locations. Water quality monitoring at the near-dam location included field measurements for depth profiling and water transparency and collecting near-surface and near-bottom water samples for laboratory physicochemical analysis. Water quality monitoring at the mid-reservoir and up-reservoir locations included field measurements for depth profiling and water transparency. Depth profiles in 1/2-meter increments were determined for temperature, dissolved oxygen, pH, conductivity, oxidation-reduction potential (ORP), turbidity, and chlorophyll *a*. Near-surface grab samples were analyzed for alkalinity, nitrate/nitrite, total ammonia, Kjeldahl nitrogen, total phosphorus, orthophosphorus, total suspended solids, total organic carbon, chlorophyll a, pesticides, and various metals. Except for chlorophyll a, pesticides, and various metals, near-bottom samples grab samples were analyzed for the same parameters.

1.6 SOUTH DAKOTA TRIBUTARY PROJECTS

The District has monitored ambient water quality conditions at the two Tributary Projects in South Dakota – Cold Brook and Cottonwood Springs. Ambient water quality monitoring at the two reservoirs is now on a 3-year rotating cycle with the next monitoring scheduled for 2018. Over the past five years monitoring has been conducted in 2012 and 2015. Scheduled ambient water quality monitoring includes monthly sampling (May through September) at near-dam, mid-reservoir, and up-reservoir locations. Water quality monitoring at the near-dam location includes field measurements for depth profiling and water transparency and collecting near-surface and near-bottom water samples for laboratory physicochemical analysis. Water quality monitoring at the mid-reservoir and up-reservoir locations include field measurements for depth profiling and water transparency. Depth profiles in ½-meter increments are determined for temperature, dissolved oxygen, pH, conductivity, ORP, turbidity, and chlorophyll *a*. Near-surface grab samples are analyzed for alkalinity, nitrate/nitrite, total ammonia, Kjeldahl nitrogen, total phosphorus, orthophosphorus, total suspended solids, total organic carbon, chlorophyll a, pesticides, and various metals. Except for chlorophyll _a_, pesticides, and various metals, near-bottom samples grab samples are analyzed for the same parameters.

2 WATER QUALITY ASSESSMENT METHODS

2.1 EXISTING WATER QUALITY

In this report existing water quality is based on the "Sufficient and Credible Data Requirements" identified by the appropriate States in their methodologies for water quality assessment for development of the State's integrated water quality reports. The State integrated water quality reports follow the U.S. Environmental Protection Agency's Consolidated Assessment and Listing Methodology (CALM) guidance provided to the States for preparing their water quality reports pursuant to Sections 305(b) and 303(d) of the Federal Clean Water Act (CWA). States have identified "age restrictions" for data to insure credible assessment of existing water quality conditions. The four States where District Tributary Projects are located have identified the following data age restrictions for credible assessment of existing water quality conditions: Colorado (not applicable), Nebraska (5 years), North Dakota (10 years), and South Dakota (9 years). With the exception of trend analysis, a time period of 6 years was used for analyses in this report.

2.1.1 STATISTICAL SUMMARY AND COMPARISON TO APPLICABLE NUMERIC WATER QUALITY STANDARDS CRITERIA

Statistical analyses were performed on the water quality monitoring data collected at the Colorado, North Dakota, and South Dakota Tributary Projects. Descriptive statistics were calculated to describe central tendencies and the range of observations in existing water quality. Monitoring results were compared to applicable water quality standards criteria established by the appropriate States pursuant to the Federal CWA. Tables were constructed that list the parameters measured; number of observations; and the mean, median, minimum, and maximum of the data collected. The constructed tables also list the water quality standards criteria applicable to the individual parameters and the frequency that these criteria were not met.

2.1.2 SPATIAL VARIATION IN RESERVOIR WATER QUALITY CONDITIONS

2.1.2.1 Longitudinal Variation

Depending on their length, shape, mixing characteristics, and residence time, reservoirs can experience significant longitudinal variation in water quality. The longitudinal variation in smaller reservoirs is greatly influenced by the water quality characteristics of inflow water during significant runoff events.

2.1.2.1.1 Contour Plots

Longitudinal contour plots were constructed when adequate depth-profile measurements were collected along the length of a reservoir. At these reservoirs longitudinal contour plots were constructed for water temperature and dissolved oxygen. ORP and pH longitudinal contour plots were also constructed where significant hypoxic dissolved oxygen conditions were present. For this report hypoxic conditions are defined as dissolved oxygen concentrations ≤ 2.5 mg/l and anoxic conditions are defined as dissolved oxygen concentrations ≤ 0.5 mg/l. 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) software developed by HydroGeoLogic, Inc. (Hydrogeologic Inc., 2005).

2.1.2.1.2 Box Plots

Longitudinal box plots were constructed from Secchi depth measurements collected within reservoirs. Box plots for monitored sites within a reservoir were plotted relative to their location within the reservoir.

2.1.2.2 Vertical Variation in Water Quality

Depending on their depth and bathymetry, reservoirs can experience thermally-induced density stratification in the summer. The denser water near the reservoir bottom inhibits mixing of the hypolimnion with the less dense water near the reservoir surface. This, coupled with the decomposition of organic matter at the reservoir bottom, can lead to the development of hypoxic conditions in the hypolimnion. Under hypoxic conditions anaerobic processes begin to occur that result in the reduction of oxidized compounds (e.g., denitrification, etc.). Strongly reduced conditions can develop if hypoxic conditions become anoxic and persist. This can lead to significant vertical variation in water quality conditions.

2.1.2.2.1 Depth Profile Plots

Measured water temperature and dissolved oxygen depth profiles were plotted for measurements taken during the summer at the near-dam, deepwater ambient monitoring locations. Depth profiles measured within the the past 5 years were included. The plots were reviewed to assess the occurrence of thermal stratification and hypolimnetic dissolved oxygen degradation. Depth profiles were also plotted for ORP and pH if hypoxic conditions were present.

2.1.2.2.2 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 when hypoxia was present. The paired samples compared were collected at sites for a reservoir were hypoxic conditions were monitored near the reservoir bottom. The parameters compared included water temperature, dissolved oxygen, ORP, pH, total ammonia, nitrate-nitrite, alkalinity, total phosphorus, and orthophosphorus.

2.1.3 TROPHIC STATUS

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

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

Accurate TSI values from total phosphorus depend on the assumptions that phosphorus is the major limiting factor for algal growth and that the concentrations of all forms of phosphorus present are a function of algal biomass. Accurate TSI values from Secchi depth transparency depend on the assumption that water clarity is primarily limited by phytoplankton biomass. Carlson indicates that the chlorophyll TSI value may be a better indicator of a lake's trophic conditions during mid-summer when algal productivity is at its maximum, while the total phosphorus TSI value may be a better indicator in the spring and fall when algal biomass is below its potential maximum. Calculation of TSI values from data collected from a lake's epilimnion during summer stratification provide the best agreement between all of the index parameters and facilitate comparisons between lakes. A TSI average value, calculated as the average of the three individually determined TSI values, is used by the District as an overall indicator of a reservoir's trophic state. The District uses the criteria defined in Table 3.1 for determining lake trophic status from TSI values.

Table 2-1. 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

2.1.4 IMPAIRMENT OF DESIGNATED WATER QUALITY-DEPENDENT BENEFICIAL USES

Water quality-dependent beneficial uses are designated to waterbodies in State water quality standards and criteria are defined to protect these uses. Water quality data collected by the District within the past five years were assessed to determine if water quality conditions were impairing the designated beneficial uses. These data were assessed using the methodologies defined by the appropriate States in developing their 2014 Integrated Reports pursuant to the Federal Clean Water Act. It is noted that the "official" determination of whether water quality-dependent beneficial uses are impaired, pursuant to the Federal CWA, is by the States pursuant to their Section 305(b) and Section 303(d) assessments compiled in their biennial Integrated Water Quality Reports (See Table 1.3).

2.1.4.1 Assessment Methodologies Used for North Dakota Reservoirs

As previously discussed (Section 3.1), water quality assessment, other than trends, was limited to data collected during 2010, 2012, and 2015. Allow more restrictive, the 6-year period of data assessment meets the sufficient and credible data requirements identified by the State of North Dakota. North Dakota's sufficient and credible data requirements include:

- Data collection and analysis followed known and documented quality assurance/quality control procedures.
- Water column data are 10 years old or less.
- There should be a minimum of two samples collected from lakes or reservoirs during the growing season, May through September. The samples may consist of two samples collected in the same year or samples collected in separate years.

2.1.4.1.1 Assessment of Physicochemical Data

The following are the decision criteria that the State of North Dakota uses to determine if aquatic life use is impaired based on physicochemical data:

- For dissolved oxygen and pH, one or more standards were exceeded in more than 25 percent of the measurements taken during the previous 10 years. The temperature standard is exceeded in more than 10 percent of the measurements taken during the previous 10 years.

- For ammonia and other toxic pollutants (i.e., trace elements and organics), the acute or chronic standard was exceeded three or more times during any consecutive 3-year period during the past 10 years.

2.1.4.1.2 Assessment of Trophic Data

Trophic status is the primary indicator used to assess whether a lake is impaired. Under North Dakota protocols, it is assumed hypereutrophic lakes do not fully support a sustainable sport fishery and are limited in recreational uses, whereas mesotrophic lakes fully support both aquatic life and recreation use. Eutrophic lakes may be assessed as fully supporting, fully supporting but threatened, or not supporting their uses for aquatic life or recreation. North Dakota further assesses eutrophic lakes based on: 1) the lake's water quality standards fishery classification; 2) information provided by North Dakota Game and Fish Department Fisheries Division staff, local water resource managers, and the public; 3) the knowledge of land use in the lake's watershed; and/or 4) the relative degree of eutrophication. For example, a eutrophic lake, which has a well-balanced sport fishery and experiences infrequent algal blooms, is assessed as fully supporting with respect to aquatic life and recreation use. A eutrophic lake, which experiences periodic algal blooms and limited swimming use, would be assessed as not supporting recreation use. A lake fully supporting its aquatic life and/or recreation use, but for which monitoring has shown a decline in its trophic status (i.e., increasing phosphorus concentrations over time), would be assessed as fully supporting but threatened.

Carlson's Trophic State Index (TSI) is used to assess lake trophic status. When conducting an aquatic life and recreation use assessment for a lake, the average TSI score should be calculated for each indicator (i.e., chlorophyll *a*, Secchi depth, and total phosphorus). If TSI scores for each indicator result in a different trophic status assessment, the assessment should be based first on the chlorophyll *a*, followed by the Secchi depth transparency. Only when there are not adequate chlorophyll *a* and/or Secchi depth data available to make an assessment should total phosphorus concentration data be used.

2.1.4.2 <u>Assessment Methodologies Used for South Dakota Reservoirs</u>

As previously discussed (Section 3.1), water quality assessment, other than trends, was limited to data collected during 2010, 2012, and 2015. Although more restrictive, the 6-year period of data assessment meets the sufficient and credible data requirements identified by the State of South Dakota. Sufficient and credible data requirements identified by South Dakota include:

- Data meets QA/QC requirements similar to those outlined in South Dakota Department of Environment and Natural Resources protocols.
- Data age (for both conventional and toxic parameters) for assessing existing water quality conditions of lakes should be from 2005 through 2015.
- For assessing lakes, 2 separate years of samples for conventional and Trophic State Index (TSI) parameters. Data must include at least one Secchi disk and chlorophyll *a* value. Samples dates must be between May 1st and September 30th.

The following are the decision criteria that the State of South Dakota uses to determine if aquatic life use is impaired based on conventional water quality parameters:

- Required percentage of samples exceeding water quality standards in order to consider lake water quality impaired:
  - Greater than 10 percent of surface samples when 20 or more samples collected
  - Greater than 25 percent of surface samples if less than 20 samples collected.

- If one surface exceedence observed for water temperature, dissolved oxygen, or pH; lake profile data is used to make listing determinations. Lakes are considered fully supporting the aquatic life beneficial use if profile data indicate a region within the water column where temperature, pH, and dissolved oxygen meet numeric water quality standards. If a region does not exist the lake is considered impaired due to the parameter in exceedence.

2.2 WATER QUALITY TRENDS

Surface water quality trends were assessed by evaluating water clarity (i.e. Secchi depth), total phosphorus, chlorophyll *a*, and calculated average TSI values from monitoring results obtained at long-term, fixed-station ambient monitoring sites for the period 1980 to 2015.

3 COLORADO TRIBUTARY PROJECTS

Three District Tributary Projects are located in north-central Colorado: Bear Creek, Chatfield, and Cherry Creek (Figure 1.1). The three projects are commonly referred to as the Colorado Tri-Lakes Project. All three reservoirs are located in the Denver, Colorado metropolitan area (Figure 3.1). Table 3-1 gives selected engineering data for the Colorado Tri-Lakes Tributary Projects.

3.1 BEAR CREEK RESERVOIR

3.1.1 BACKGROUND INFORMATION

3.1.1.1 Project Overview

The dam forming Bear Creek Reservoir is located on Bear Creek, 3 miles southwest of Denver, Colorado (Figure 3.1). The dam was completed in July 1977 and the reservoir reached its initial fill in May 1979. The Bear Creek Reservoir watershed is 236 square miles. The watershed was rangeland, forested, and residential/acreage development when the dam was built in 1974. Urbanization of the watershed is occurring with the growth of the Denver metropolitan area. The authorized project purposes for Bear Creek Reservoir are: flood control, recreation, and fish and wildlife. An aeration system was initially installed in Bear Creek Reservoir in 2002 to improve water quality. During 2013 flooding at the reservoir, the aeration system was damaged but has been repaired and upgraded.

3.1.1.2 Bear Creek Dam Intake Structure

The outlet works at Bear Creek Dam consist of a reinforced concrete intake structure with high-level drop inlets and a low-level 36-inch diameter reinforced concrete pipe and intake upstream of the intake structure. The gate structure is contained in the dam just upstream of the impervious core. The high-level drop inlets have two weirs at elevation 5558.0 ft-msl (multipurpose pool level). Two lower-level gated inlets are located at invert elevations of 5538.0 and 5528.0 ft-msl. The low-level intake at elevation 5528.0 ft-msl is 135 feet upstream from the main intake structure.

3.1.1.3 Reservoir Storage Zones

Figure 3.2 depicts the current storage zones of Bear Creek Reservoir based on the 2009 survey data and estimated sedimentation. It is estimated that 9 percent of the Multipurpose Pool has been lost to sedimentation as of 2015.

3.1.1.4 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

The State of Colorado's water quality standards designate the following beneficial uses to Bear Creek Reservoir: primary contact recreation, domestic water supply, Class 1 coldwater aquatic life, and agriculture. Pursuant to Section 303(d) of the CWA, the State of Colorado has placed Bear Creek Reservoir on the State's 303(d) monitoring and evaluation list (Table 1-2). Bear Creek Reservoir is listed for impairment to aquatic life due to elevated chlorophyll *a* levels resulting from high phosphorus loadings to the reservoir. A TMDL for chlorophyll *a* and phosphorus is targeted to complete in 2017.

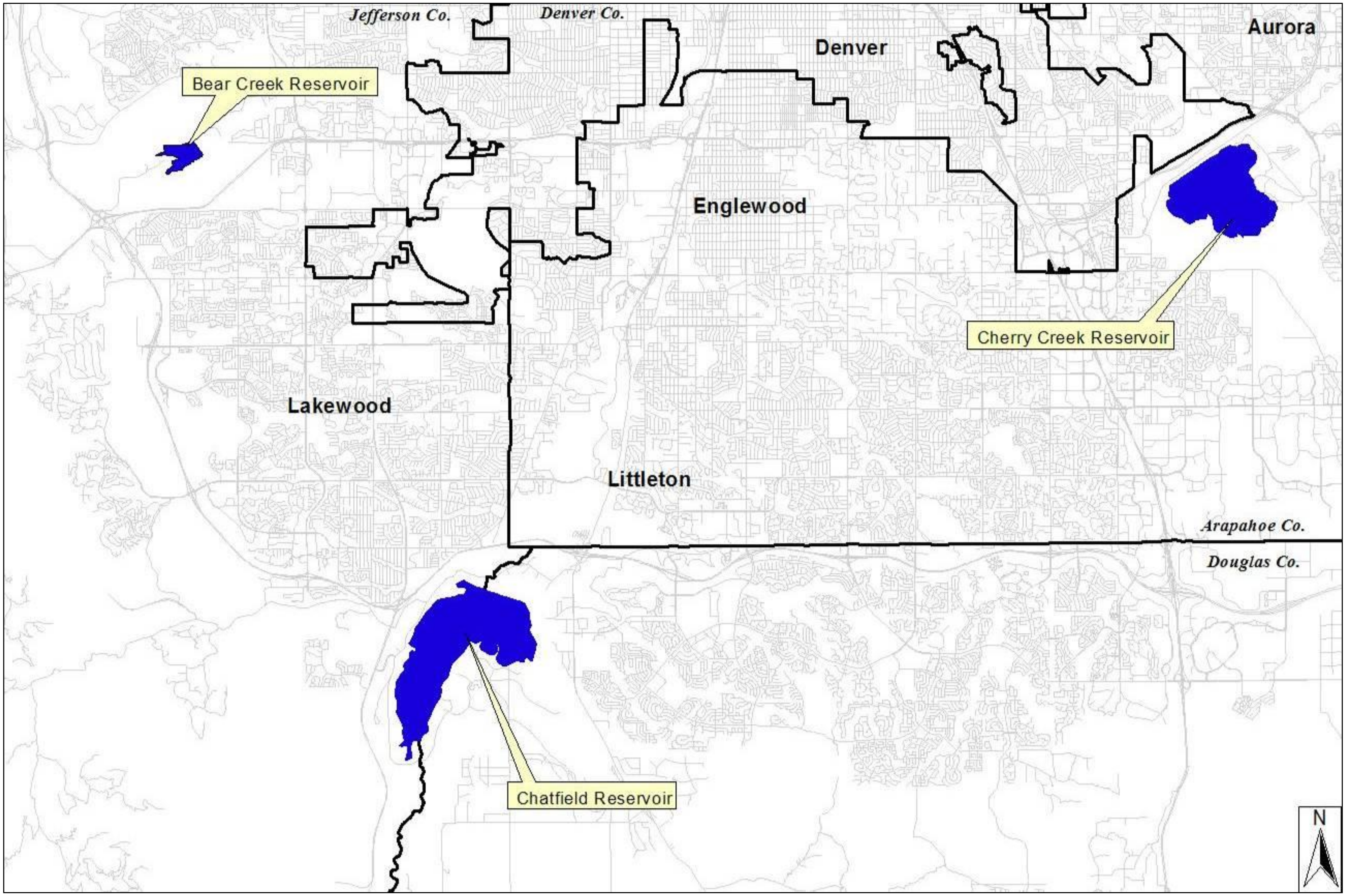


Figure 3.1. Locations of Bear Creek, Chatfield, and Cherry Creek Reservoirs in the Denver, Colorado metropolitan area.

Table 3-1. Summary of selected engineering data for the Colorado Tri-Lakes Tributary Projects.

	Beak Creek Reservoir	Chatfield Reservoir	Cherry Creek Reservoir
General			
Dammed Stream	Bear Creek	South Platte River	Cherry Creek
Drainage Area	236 sq. mi.	3,018 sq. mi.	386 sq. mi.
Reservoir Length[1]	0.5 miles	2.0 miles	1.5 miles
Multipurpose Pool Elevation (Top)	5558.0 ft-msl	5,432.0 ft-msl	5550.0 ft-msl
Date of Dam Closure	July 1977	August 1973	October 1948
Date of Initial Fill[2]	May 1979	June 1979	March 1960
"As-Built" Conditions[3]	(1980 Survey Data)	(1977 Survey Data)	(1950 Survey Data)
Lowest Reservoir Bottom Elevation	5522 ft-msl	5379 ft-msl	5504 ft-msl
Surface Area at top of Multipurpose Pool	109 ac	1,444 ac	886 ac
Capacity of Multipurpose Pool	1,964 ac-ft	28,076 ac-ft	15,155 ac-ft
Mean Depth at top of Multipurpose Pool[4]	18.0 ft	19.4 ft	17.1 ft
Latest Surveyed Conditions	(2009 Survey Data)	(2010 Survey Data)	(2007 Survey Data)
Lowest Reservoir Bottom Elevation	5523 ft-msl	5382 ft-msl	5525 ft-msl
Surface Area at top of Multipurpose Pool	107 ac	1,412 ac	840 ac
Capacity of Multipurpose Pool	1,824 ac-ft	27,076 ac-ft	12,558 ac-ft
Mean Depth at top of Multipurpose Pool[4]	17.0 ft	19.2 ft	15.1 ft
Sediment Deposition in Multipurpose Pool			
Historic Sediment Deposition[5]	140 ac-ft	1000 ac-ft	2,597 ac-ft
Annual Sedimentation Rate[6]	1980-2009 4.8 ac-ft/yr	1977-2010 30.3 ac-ft/yr	1950-2007 45.6 ac-ft/yr
Current Estimated Sediment Deposition[7]	169 ac-ft	1,151 ac-ft	2,964 ac-ft
Current capacity of Multipurpose Pool[8]	1,795 ac-ft	26,925 ac-ft	12,191 ac-ft
Percent of "As-Built" Multipurpose Pool capacity lost to current estimated sediment deposition	9%	4%	20%
Operational Details – Historic	(1980 – 2015)	(1980 – 2015)	(1958 – 2015)
Maximum Recorded Pool Elevation	5607.8 ft-msl 21-Sep-13	5448.5 ft-msl 19-Jun-15	5565.8 ft-msl 3-Jun-73
Minimum Recorded Pool Elevation	5549.2ft-msl 18-Oct-99	5422.9 ft-msl 31-Oct-06	5543.5 ft-msl 29-Jan-65
Maximum Recorded Daily Inflow	1183 cfs 10-May-15	3,896 cfs 12-Jun-15	6,150 cfs 16-Jun-65
Maximum Recorded Daily Outflow	800 cfs 11-Jun-79	3,350 cfs 06-Jul-95	560 cfs 7-Aug-65
Average Annual Pool Elevation	5556.9 ft-msl	5428.5 ft-msl	5548.9 ft-msl
Average Annual Inflow	34,174 ac-ft	154,303 ac-ft	11,744 ac-ft
Average Annual Outflow	33,808 ac-ft	143,403 ac-ft	10,841 ac-ft
Estimated Retention Time[10]	0.05 Years	0.19 Years	1.12 Years
Operational Details – Current[11]			
Maximum Recorded Pool Elevation	5602.7 ft-msl 26-May-15	5448.5 ft-msl 19-Jun-15	5555.3 ft-msl 17-Jun-15
Minimum Recorded Pool Elevation	5558.3 ft-msl 29-Sep-15	5426.9 ft-msl 30-Aug-15	5549.7 ft-msl 02-Sep-15
Maximum Recorded Daily Inflow	1183 cfs 10-May-15	3,896 cfs 12-Jun-15	1231 cfs 12-Jun-15
Maximum Recorded Daily Outflow	509 cfs 15-Jun-15	3,067 cfs 19-Jun-15	262 cfs 14-May-15
Total Inflow (% of Average)	84,135 ac-ft (241%)	398,692 ac-ft (265%)	27,689 ac-ft (233%)
Total Outflow (% of Average)	83,738 ac-ft (242%)	400,621 ac-ft (275%)	25,070 ac-ft (279%)
Outlet Works			
Ungated Outlets	Drop Inlet 5558.0 ft-msl		2) 1.0'x2.5' 5504.0 ft-msl 2) 2.0'x6.0' 5509.0 ft-msl
Gated Outlets (Mid-depth)	2) 3' x 6' hydraulic slide 1) 36" Dia. 5538.0 ft-msl	2) 6' x 13.5' hydraulic slide 2) 2' x 2' slide gate on gate 1) 6' butterfly	5) 6' x 9' hydraulic slide
Gated Outlets (Low-level)	1) 36" Dia. 5528.0 ft-msl	none	2) 18" by-pass gates

[1] Reservoir length at top of conservation pool.
[2] First occurrence of reservoir pool elevation to top of multipurpose pool elevation.
[3] "As-Built" conditions taken to be the conditions present when the reservoir was first surveyed.
[4] Mean Depth = Volume ÷ Surface Area.
[5] Difference in reservoir storage capacity to top of Multipurpose Pool between "as-built" and latest survey.
[6] Annualized rate based on historic accumulated sediment.
[7] Current accumulated sediment estimated from historic annual sedimentation rate.
[8] Current capacity of Multipurpose Pool = "As-Built" Multipurpose Pool capacity - Estimated Current Sedimentation.
[9] Reservoir drawn down for lake restoration project.
[10] Estimated Retention Time = Multipurpose Pool Volume ÷ Average Annual Outflow.
[11] Current operational details are for the water year 1-Oct-2014 through 30-Sep-2015.

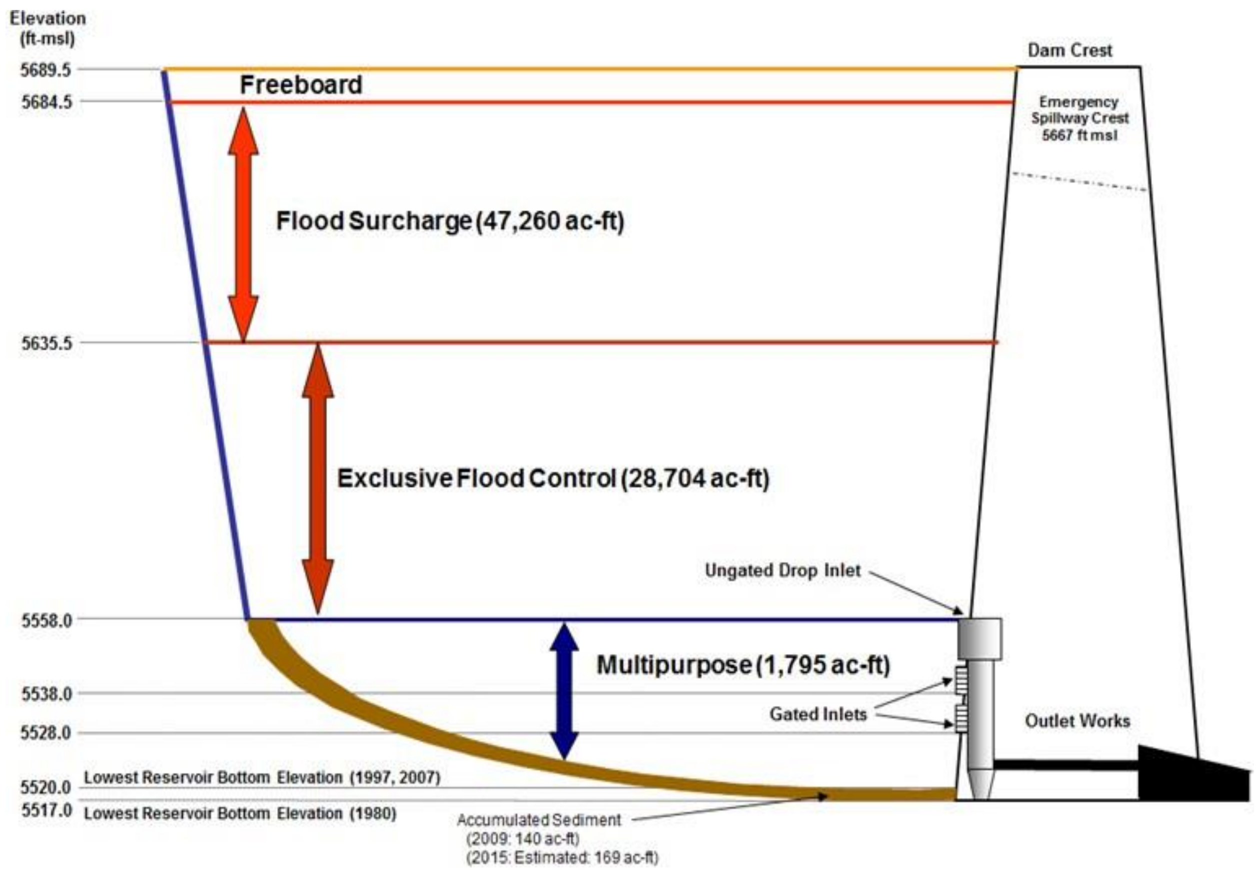


Figure 3.2. Current storage zones of Bear Creek Reservoir based on the 2009 survey data and estimated sedimentation.

3.1.1.5 Ambient Water Quality Monitoring

A Local Watershed Authority has been established for Bear Creek Reservoir to protect and improve water quality. The Bear Creek Watershed Authority has adopted local water quality regulations and a water quality management plan to protect and manage water quality in Bear Creek Reservoir. As part of its water quality management plan, the Bear Creek Watershed Authority is implementing a comprehensive water quality monitoring program. In an agreement with the District's Tri-Lakes Project Office and the Bear Crerk Watershed Authoruty, the District ceased its water quality monitoring activities at Bear Creek Reservoir in 2002. The Bear Creek Watershed Authority shared their collected water quality data with the District, and assessment of water quality conditions at Bear Creek Reservoir is currently deferred to the Authority. Prior to 2002, the District had monitored water quality at Bear Creek Reservoir since the 1970's.

3.1.2 EXISTING WATER QUALITY CONDITIONS

Persons interested in existing water quality conditions at Bear Creek Reservoir can visit the website maintained by the Bear Creek Watershed Association (http://www.bearcreekwatershed.org).

3.2 CHATFIELD RESERVOIR

3.2.1 BACKGROUND INFORMATION

3.2.1.1 Project Overview

The dam forming Chatfield Reservoir is located on the South Platte River, 2 miles south of Denver, Colorado (Figure 3.1). The dam was completed in August 1973 and the reservoir reached its initial fill in June 1979. The Chatfield Reservoir watershed is 3,018 square miles. The watershed was rangeland, forested, and residential/acreage development when the dam was built in 1973. Urbanization of the watershed is occurring with the growth of the Denver metropolitan area. The authorized project purposes for Chatfield Reservoir are: flood control, recreation, fish and wildlife, and water supply.

3.2.1.2 Chatfield Reservoir Storage Reallocation

In order to supply renewable surface water resources to the expanding Denver metropolitan area the Colorado Water Conservation Board requested that the Omaha District consider reallocating space within Chatfield Reservoir for water supply purposes. The Chatfield Reservoir Storage Reallocation Study was tasked with assessing the feasibility of storage reallocation. The Feasability Report and Environmental Impact Statement (FR/EIS) addressed potential reservoir water quality concerns regarding the effect of increased hypolimnetic volume on internal nutrient loading and metals concentrations. The record of decision approving the Chatfield Reservoir Storage Reallocation Study FR/EIS was signed on May 29, 2014.

Annual Water Quality Monitoring Reports and supporting data are currently provided to the Omaha District by the Chatfield Reservoir Mitigation Company (CRMC). The CRMC is currently working with the Chatfield Watershed Authority to collect water quality data pursuant to the requirements of the Adaptive Management Plan (Appendix GG) of the Final Chatfield Reservoir Storage Reallocation FR/EIS.

3.2.1.3 Chatfield Dam Intake Structure

The intake structure has three gated passageways which conduct water to a twin conduit. The two right passageways have a service and emergency gate which are controlled by hydraulic hoists. In each gate a 2-foot x 2-foot auxiliary gate is provided to facilitate regulation of normal flows to the river. In the left passageway of the intake structure a 6-foot diameter penstock, equipped with a butterfly valve near the upstream end, is provided to conduct releases to satisfy the downstream water rights.

3.2.1.4 Reservoir Storage Zones

Figure 3.3 depicts the current storage zones of Chatfield Reservoir based on the 2010 survey data and estimated sedimentation. It is estimated that 4 percent of the Multipurpose Pool has been lost to sedimentation as of 2015.

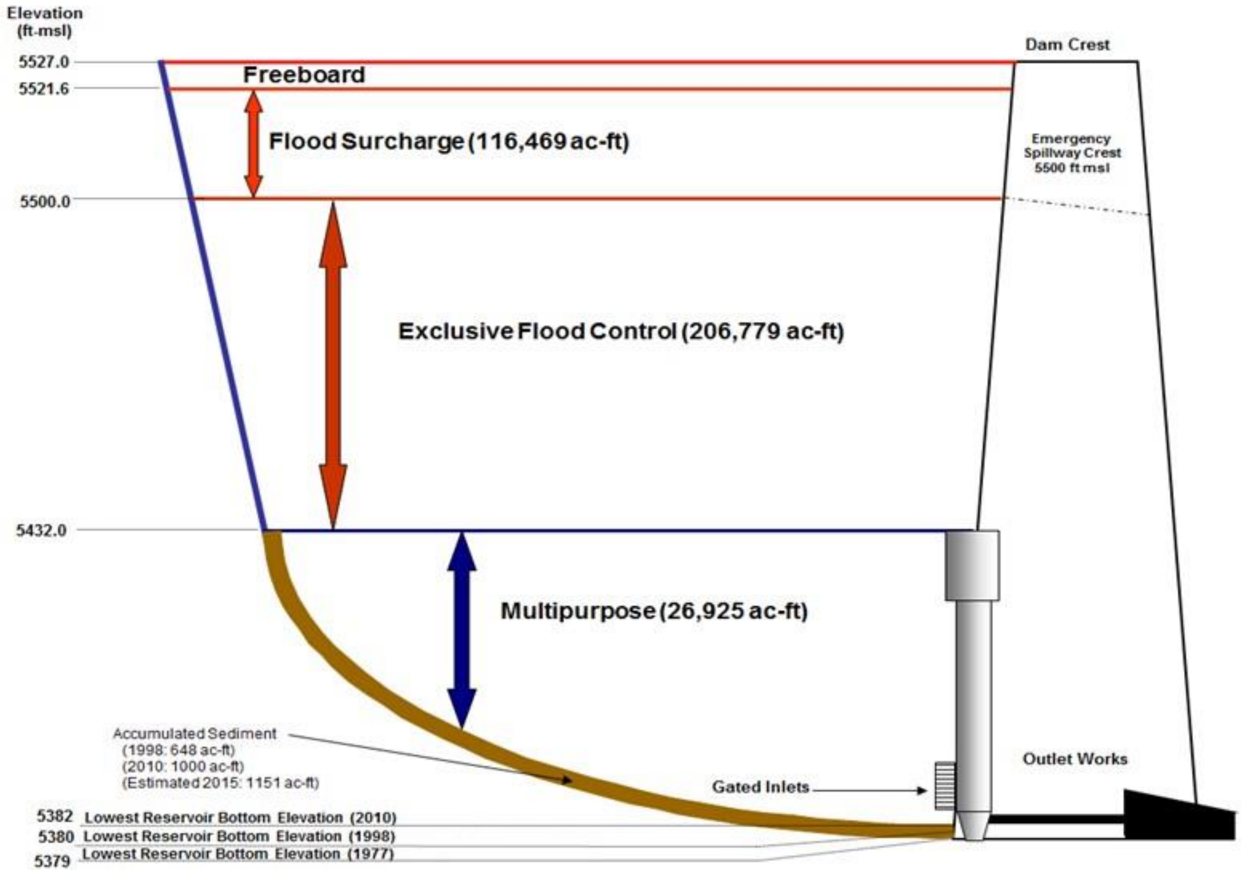


Figure 3.3. Current storage zones of Chatfield Reservoir based on the 2010 survey data and estimated sedimentation.

3.2.1.5 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

The State of Colorado's water quality standards designate the following beneficial uses to Chatfield Reservoir: primary contact recreation, domestic water supply, Class 1 coldwater aquatic life, and agriculture. Chatfield Reservoir is a source of public drinking water for the Cities of Denver, Englewood, and Littleton, Colorado. Pursuant to Section 303(d) of the CWA, the State of Colorado has not placed Chatfield Reservoir on the State's 303(d) list of impaired waters. The State of Colorado has not issued a fish consumption advisory for Chatfield Reservoir.

3.2.1.6 Ambient Water Quality Monitoring

A Local Watershed Authority has been established for Chatfield Reservoir to protect and improve water quality at the reservoir. The Chatfield Watershed Authority has adopted local water quality regulations and a water quality management plan to protect and manage water quality in Chatfield Reservoir. As part of its water quality management plan, the Chatfield Watershed Authority is implementing a comprehensive water quality monitoring program. In an agreement with the District's Tri-Lakes Project Office and the Chatfield Watershed Authoruty, the District ceased its water quality monitoring activities at Chatfield Reservoir in 2002. The District now defers to the Chatfield Watershed Authority for assessment of water quality conditions at Chatfield Reservoir. Prior to 2002, the District had monitored water quality at Chatfield Reservoir since the 1970's.

3.2.2 EXISTING WATER QUALITY CONDITIONS

Persons interested in existing water quality conditions at Chatfield Reservoir can visit the website maintained by the Chatfield Watershed Association (http://www.chatfieldwatershedauthority.org).

3.3 CHERRY CREEK RESERVOIR

3.3.1 BACKGROUND INFORMATION

3.3.1.1 Project Overview

The dam forming Cherry Creek Reservoir is located on Cherry Creek, southeast of Denver, Colorado (Figure 3.1). The dam was completed in October 1948 and the reservoir reached its initial fill in March 1960. The Cherry Creek Reservoir watershed is 386 square miles. The watershed was rangeland and agricultural when the dam was built in 1948. Extensive urbanization of the watershed has occurred with the growth of the Denver metropolitan area. The authorized project purposes for Cherry Creek Reservoir are: flood control, recreation, and fish and wildlife. An aeration system to de-stratify the reservoir to improve water quality was installed in 2007 and became operational on April 4, 2008.

3.3.1.2 Cherry Creek Dam Intake Structure

The Cherry Creek Dam intake tower contains five rectangular water passages with a 6' x 9' slide gate in each to control water flow. Two emergency gates have also been added to the intake structure. These gates can be installed while water is flowing thru a water passage, but are not to be used for regulating flow. A low-flow by-pass was installed in February 1988 to allow finer regulation of flow to downstream water rights users. The low-flow by-pass consists of two 18" knife valves.

3.3.1.3 Cherry Creek Dam Safety Modification Study

The Cherry Creek Dam Safety Modification Study is currently underway to assess options for reducing the potential for life loss and property damage from detailed risks associated with the dam. The most significant safety concern at Cherry Creek Dam is the potential for overtopping during an extreme precipitation event. Although the chances for overtopping and/or failure are extraordinarily low, should high operational releases or a dam failure occur, a high urgency for action exists because of the potential for impacts to a large population that includes much of downtown Denver.

3.3.1.4 Cherry Creek Dam Water Control Plan Modification Study

The Water Control and Water Quality Section of the Hydrologic Engineering Branch in the USACE's Omaha District is studying potential modifications to the water control plan for Cherry Creek Dam. The goal of the study is to establish a timeline for increased releases from Cherry Creek Dam in an extreme flooding event to reduce the potential for overtopping and failure as well as the overall flood extent. The following will be considered in the study: (1) removing the 5,000 cfs Denver maximum flow target to ensure releases can be made from Cherry Creek, (2) increasing Cherry Creek Dam releases above the 5,000 cfs limit (up to 13,300 cfs), and (3) evaluating added impacts of Cherry Creek Dam releases to existing uncontrolled drainage flooding. Results from this study will be incorporated into the Cherry Creek Dam Safety Modification Study.

3.3.1.5 Reservoir Storage Zones

Error! Reference source not found. depicts the current storage zones of Cherry Creek Reservoir ased on the 2007 survey data and estimated sedimentation. It is estimated that 19 percent of the Multipurpose Pool has been lost to sedimentation as of 2015.

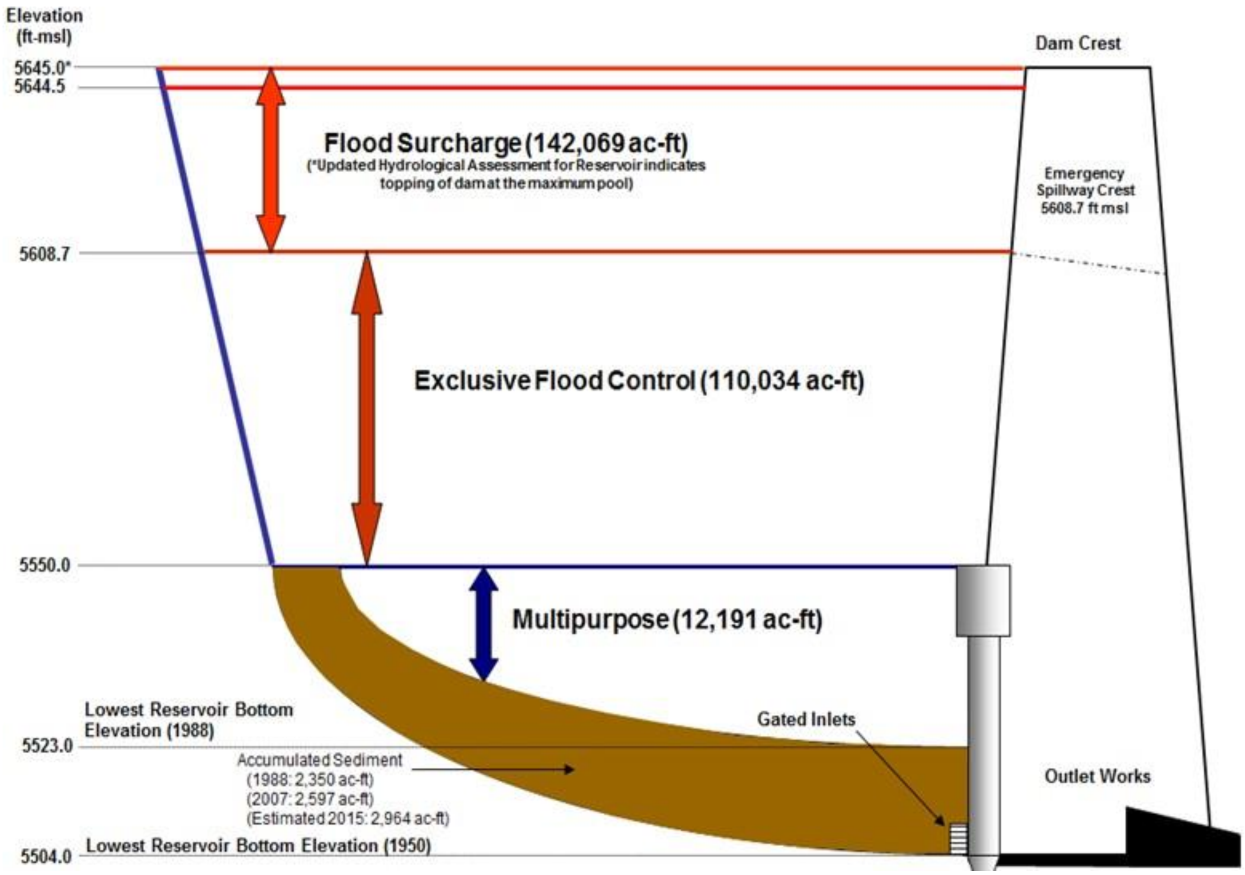


Figure 3.4. Current storage zones of Cherry Creek Reservoir based on the 2007 survey data and estimated sedimentation.

3.3.1.6 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

The State of Colorado's water quality standards designate the following beneficial uses to Cherry Creek Reservoir: primary contact recreation, domestic water supply, Class 1 warmwater aquatic life, and agriculture. State Regulation No. 38 defines Class 1 warm water aquatic life classification as "capable of sustaining a wide variety a warm water biota, including some sensitive species, and biota where physical habitat, water flows or levels, and water quality conditions result in no substantial impairment of the abundance and diversity of aquatic life." Cherry Creek Reservoir is currently on the State of Colorado 2016 303(d) list of impaired waters. In 2016 the reservoir was listed as impaired due to exceedence of the chlorophyll *a* and dissolved oxygen water quality standards. The State of Colorado has not issued a fish consumption advisory for Cherry Creek Reservoir.

3.4 AMBIENT WATER QUALITY MONITORING

A Local Watershed Authority has been established for Cherry Creek Reservoir to protect and improve water quality at the reservoir. The Cherry Creek Basin Water Quality Authority (CCBWQA) is the designated water quality management agency for the Cherry Creek watershed, including Cherry Creek Reservoir. The CCBWQA manages a water quality monitoring program and routinely monitors inflows and outflows, sediment loading and export, surface and groundwater quality, and the effectiveness of pollutant reduction facilities (PRFs) in the watershed. Under the State of Colorado Regulation No. 72, the CCBWQA is also responsible for implementing control regulations and monitoring water quality conditions with an emphasis on stream and reservoir phosphorus concentrations. Based on the comprehensive water quality monitoring being implemented by the CCBWQA, the District ceased its water quality monitoring activities at at Cherry Creek Reservoir in 2002, and now defers to the CCBWQA for assessment of water quality conditions at Cherry Creek Reservoir. Prior to 2002, the District had monitored water quality at Cherry Reservoir since the 1970's.

3.4.1 CHERRY CREEK RESERVOIR WATER QUALITY CONDITIONS SUMMARY

In 2016 the reservoir was listed as impaired due to exceedence of the chlorophyll *a* and dissolved oxygen water quality standards. Chlorophyll *a* is a surrogate measurement used to assess algal abundance within a lake. Historically, the reservoir has not consistently met the 18 ug/l seasonal mean chlorophyll *a* standard. To help control algal growth and limit internal nutrient loading a reservoir destratification system was installed in 2008. A full evaluation of the effectiveness of the destratification system has not been completed due the inability to directly compare algal data between two laboratories utilizing different methodologies. Algal growth within Cherry Creek Reservoir is limited by phosphorus and/or nitrogen. To better understand the dynamics between algal growth and nutrient availability the CCBWQA has implemented a monitoring program to facilitate application of the CE-QUAL-W2 (W2) hydrodynamic and water quality model. Once completed the W2 model will provide scenario testing to better evaluate the reservoir response to different nutrient conditions.

The CCBWQA did not operate the destratification system in 2014 to assess nutrients without mixing as well as other factors potentially contributing to algal production in the reservoir. During 2014 the seasonal mean chlorophyll *a* concentration of 24.4 ug/l exceeded the 18 ug/l seasonal mean standard and was not significantly different from values observed in 2010-2013 (CCWQBA, 2015). In 2014 the reservoir experienced a Hazardous Algal Bloom (HAB). HABs occur when cyanobacteria dominate the algal assemblage, reach high densities, and subsequently die-off releasing cyanotoxins into the water column. Cherry Creek Reservoir is polymictic; it is possible that calm weather conditions lead to weak transient thermal stratification in the reservoir, and then with the absence of reservoir mixing cyanobacteria dominated the algal assemblage.

A cursory nutrient analysis (Table 4-2) was conducted on data collected from 1992 to 2014 at the Cherry Creek Reservoir near dam sampling location, CCR-1. Data was obtained from the CCBWQA via online database; mean values from photic zone depths were used to characterize water quality in the reservoir. Chlorophyll *a* values collected outside the July to September time period were excluded. The analysis indicates potential difficulties achieving the in-reservoir standards for chlorophyll *a* and total phosphorus. The overall mean seasonal chlorophyll *a* concentration was 22.3 ug/l, exceeding the 18 ug/l standard. The overall mean total phosphorus concentration in the photic zone exceeded the 0.035 mg/l (35 ug/l) total phosphorus standard (Colorado Regulation No. 38; 5 CCR 1002-72) with a mean concentration of 81 ug/l. All other mean values examined met state water quality standards.

Table 3-2. Nutrient Analysis Table for Location CCR-1

Parameter	Obs.	Units	Mean	Min	Max	Med
Ammonia, Total as N	103	ug/l	31	n.d.	313	22
Chlorophyll a	173	ug/l	22.3	n.d.	65.1	21.5
Conductivity, Total	462	uS/cm	999	432	1623	1021
NO_3/NO_2, Total as N	371	ug/l	16	n.d.	650	2
Nitrogen, Total	339	ug/l	831	68	1620	840
Oxygen, Dissolved	330	mg/l	9.4	3.8	22.0	9.0
Phosphorus, Total	394	ug/l	81	n.d.	270	78
Soluble Reactive Phophorus, Total as P	394	ug/l	19	n.d.	102	13
Temperature, water	503	°C	17.2	0.6	26.5	19.5
Total Suspended Solids	53	mg/l	13.2	n.d.	24.8	12.5
pH	459	SU	8.1	5.8	9.0	8.1

* n.d. = laboratory non-detect, non-detect values set to zero to calculate mean.

Water quality conditions monitored at location CCR-1 indicate concerns regarding chlorophyll *a* and total phosphorus concentrations exist despite substantial effort to limit influent phosphorus concentrations; further analysis of the reservoir internal nutrient load will be conducted by the CCBWQA. It is noted that the “official” determination of whether water quality-dependent beneficial uses are impaired, pursuant to the Federal Clean Water Act, is by the States pursuant to their Section 305(b) and Section 303(d) assessments compiled in their biennial Integrated Water Quality Reports.

3.4.2 EXISTING WATER QUALITY CONDITIONS

Persons interested in existing water quality conditions at Cherry Creek Reservoir can visit the website maintained by the Cherry Creek Basin Watershed Authority (http://www.cherrycreekbasin.org).

4 NORTH DAKOTA TRIBUTARY PROJECTS

Two District Tributary Projects are located in North Dakota: Bowman-Haley and Pipestem. Bowman-Haley Reservoir is located in southwest North Dakota along the South Dakota border (Figure 1.1). Pipestem Reservoir is located in southeast North Dakota (Figure 1.1). Table 4-1 gives selected engineering data for the Bowman-Haley and Pipestem Projects.

4.1 BOWMAN-HALEY RESERVOIR

4.1.1 BACKGROUND INFORMATION

4.1.1.1 Project Overview

The dam forming Bowman-Haley Reservoir is located on the North Fork of the Grand River, 6 miles west of Haley, North Dakota. The dam was completed in August 1966 and the reservoir reached its initial fill in March 1969. The Bowman-Haley Reservoir watershed is 446 square miles. The watershed was largely agricultural and rangeland when the dam was built in 1966 and has remained so to the present time. The authorized project purposes of Bowman-Haley Reservoir are flood control, recreation, fish and wildlife, water quality, and water supply.

4.1.1.2 Bowman-Haley Dam Intake Structure

The intake structure at Bowman-Haley Dam is a shaft with a fixed weir for automatic release of water when the reservoir level rises above elevation 2754.8 ft-msl. The ungated glory hole has a crest elevation of 2754.8 ft-msl. Provision for low-level release of water is by means of a 30-inch gated pipe located in the dry well part of the intake. A 30-inch diameter slide gate is provided in the wet well as an emergency closure of the 30-inch pipe. The invert elevation for the low-level gate is 2740.0 ft-msl.

4.1.1.3 Reservoir Storage Zones

Two storage zones are provided in the reservoir, a multiple-purpose zone and a flood control zone. The multipurpose zone of 18,765 ac-ft includes storage for water supply, fish and wildlife, and recreation. In addition this zone contains space for storing an estimated 100 years of sediment deposition. The water supply storage was developed for maximum possible yield from the contributing drainage areas. Figure 4.1 depicts the current storage zones of Bowman-Haley Reservoir based on the 1984 survey data.

4.1.1.4 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

The State of North Dakota has designated Bowman-Haley Reservoir as a Class 3 lake in the State's water quality standards. The beneficial uses designated for Class I streams are also applicable to all classified lakes in North Dakota. As such, the beneficial uses designated for Bowman-Haley Reservoir are: primary contact recreation, warmwater fishery, wildlife, and agricultural water supply. Water quality is also to be suitable for municipal or domestic use after appropriate treatment. The reservoir is not directly used as a municipal or domestic water supply. Pursuant to the Federal CWA, the State of North Dakota has not listed Bowman-Haley Reservoir on the State's Section 303(d) list. The State of North Dakota has issued a statewide fish consumption advisory for mercury. As such, the advisory applies to Bowman-Haley Reservoir.

Table 4-1. Summary of selected engineering data for the Bowman-Haley and Pipestem Projects.

	Bowman-Haley Reservoir	**Pipestem Reservoir**
General		
Dammed Stream	North Fork Grand River	Pipestem Creek
Drainage Area	446 sq. mi.	594 sq. mi.
Reservoir Length[1]	2.5 miles	5.5 miles
Multipurpose Pool Elevation (Top)	2754.8 ft-msl	1442.4 ft-msl
Date of Dam Closure	August 1966	July 1973
Date of Initial Fill[2]	March 1969	May 1974
"As-Built" Conditions[3]	(Project Operation and Maintenance Manual)	(1973 Survey Data)
Lowest Reservoir Bottom Elevation	2715 ft-msl	1407 ft-msl
Surface Area at top of Multipurpose Pool	1750 ac	817
Capacity to top of Multipurpose Pool	24,060 ac-ft	9,106 ac-ft
Mean Depth at top of Multipurpose Pool[4]	13.7 ft	10.8 ft
Latest Surveyed Conditions	(1984 Survey Data)	(2014 Survey Data)
Lowest Reservoir Bottom Elevation	2721 ft-msl	1416.8 ft-msl
Surface Area at top of Multipurpose Pool	1750 ac	845 ac
Capacity of Multipurpose Pool	18,765	8,272ac-ft
Mean Depth at top of Multipurpose Pool[4]	10.7	9.8 ft
Sediment Deposition in Multipurpose Pool		
Historic Sediment Deposition[5]	Unknown[9]	834 ac-ft
Annual Sedimentation Rate[6]	Unknown[9]	1973-2014 20.3 ac-ft/yr
Current Estimated Sediment Deposition[7]	Unknown[9]	854 ac-ft
Current capacity of Multipurpose Pool[8]	Unknown[9]	8,252 ac-ft
Percent of "As-Built" Multipurpose Pool capacity lost to current estimated sediment deposition	Unknown[9]	9.3%
Operational Details – Historic	(1970 – 2012)	(1975 – 2012)
Maximum Recorded Pool Elevation	2762.7 ft-msl 28-Mar-78	1492.2 ft-msl 24-Apr-09
Minimum Recorded Pool Elevation	2746.3 ft-msl 06-May-13	1439.7 ft-msl 17-Feb-93
Maximum Recorded Daily Inflow	5,310 cfs 27-Mar-78	9,232 cfs 15-Apr-09
Maximum Recorded Daily Outflow	2,390 cfs 28-Mar-78	1,422 cfs 10-May-09
Average Annual Pool Elevation	2752.7 ft-msl	1447.6 ft-msl
Average Annual Inflow	24,171 ac-ft	55,933 ac-ft
Average Annual Outflow	19,070 ac-ft	52,159 ac-ft
Estimated Retention Time[10]	0.98 Years	0.16 Years
Operational Details – Current[11]		
Maximum Recorded Pool Elevation	2757.3 ft-msl 26-Jun-15	1452.4 ft-msl 31-May-15
Minimum Recorded Pool Elevation	2751.0 ft-msl 29-Sep-15	1442.0 ft-msl 11-June-15
Maximum Recorded Daily Inflow	211 cfs 26-Jul-15	557 cfs 19-May-15
Maximum Recorded Daily Outflow	119 cfs 01-Oct-14	161 cfs 11-June-15
Total Inflow (% of Average Annual)	32,811 ac-ft (134%)	27,132 ac-ft (48%)
Total Outflow (% of Average Annual)	30,099 ac-ft (156%)	24,756 ac-ft
Outlet Works		
Ungated Outlets	Glory Hole 2754.8 ft-msl	Drop Inlet 1442.5 ft-msl
Gated Outlets (Mid-depth)		2) 4'x 7' Service Gates
Gated Outlets (Low-level)	1) 30" Dia. Gate Valve 2740.0 ft-msl	1) 3'x 3' Slide Gate 1433.0 ft-msl 1) 3' Dia. Gate Valve 1415.0 ft-msl

(1) Reservoir length at top of conservation pool.
(2) First occurrence of reservoir pool elevation to top of multipurpose pool elevation.
(3) "As-Built" conditions taken to be the conditions present when the reservoir was first surveyed.
(4) Mean Depth = Volume ÷ Surface Area.
(5) Difference in reservoir storage capacity to top of Multipurpose Pool between "as-built" and latest survey.
(6) Annualized rate based on historic accumulated sediment.
(7) Current accumulated sediment estimated from historic annual sedimentation rate.
(8) Current capacity of Multipurpose Pool = "As-Built" Multipurpose Pool capacity - Estimated Current Sedimentation.
(9) Estimating "as-built" conditions from O&M manual not deemed reliable.
(10) Estimated Retention Time = Multipurpose Pool Volume ÷ Average Annual Outflow.
(11) Current operational details are for the water year 1-Oct-2014 through 30-Sep-2015.

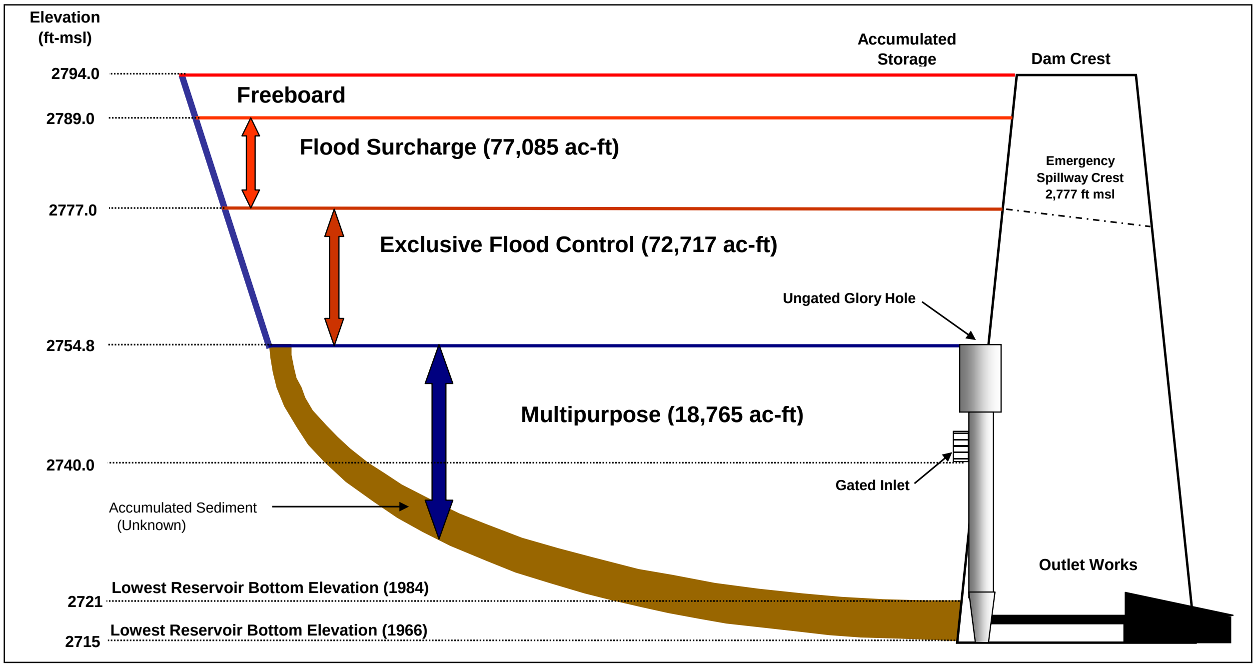


Figure 4.1. Storage zones of Bowman-Haley Reservoir based on the 1984 survey data**.**

4.1.1.5 Historic Water Quality Concerns

Historic water quality data collection indicated that Bowman-Haley had extremely poor water quality with numerous exceedences of State water quality standards. Some authorized project purposes could not be met because of poor water quality. Due to the documented poor water quality, a public meeting was held in Bowman, North Dakota on April 8, 1985 to discuss procedures that might be employed to improve water quality in the reservoir. In 1990 the Bowman-Slope Soil Conservation District initiated a water quality improvement project focused on implementation of BMPs in the watershed.

4.1.1.6 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Bowman-Haley Reservoir since the 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Recently, the District has scaled back water quality monitoring at Bowman-Haley Reservoir, and is currently monitoring the reservoir every 3 years. Figure 4.2 shows the location of the sites that are currently targeted for water quality monitoring. During the past 6 years, the District conducted water quality monitoring at Bowman-Haley Reservoir in 2010, 2012, and 2015.

4.1.2 Existing Water Quality Conditions

4.1.2.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Bowman-Haley Reservoir at sites BOWLKND1, BOWLKMLN1, and BOWLKMLS1 from May through September during 2010, 2012, and 2015 are summarized, respectively, in Plate 4-1 through Plate 4-3.

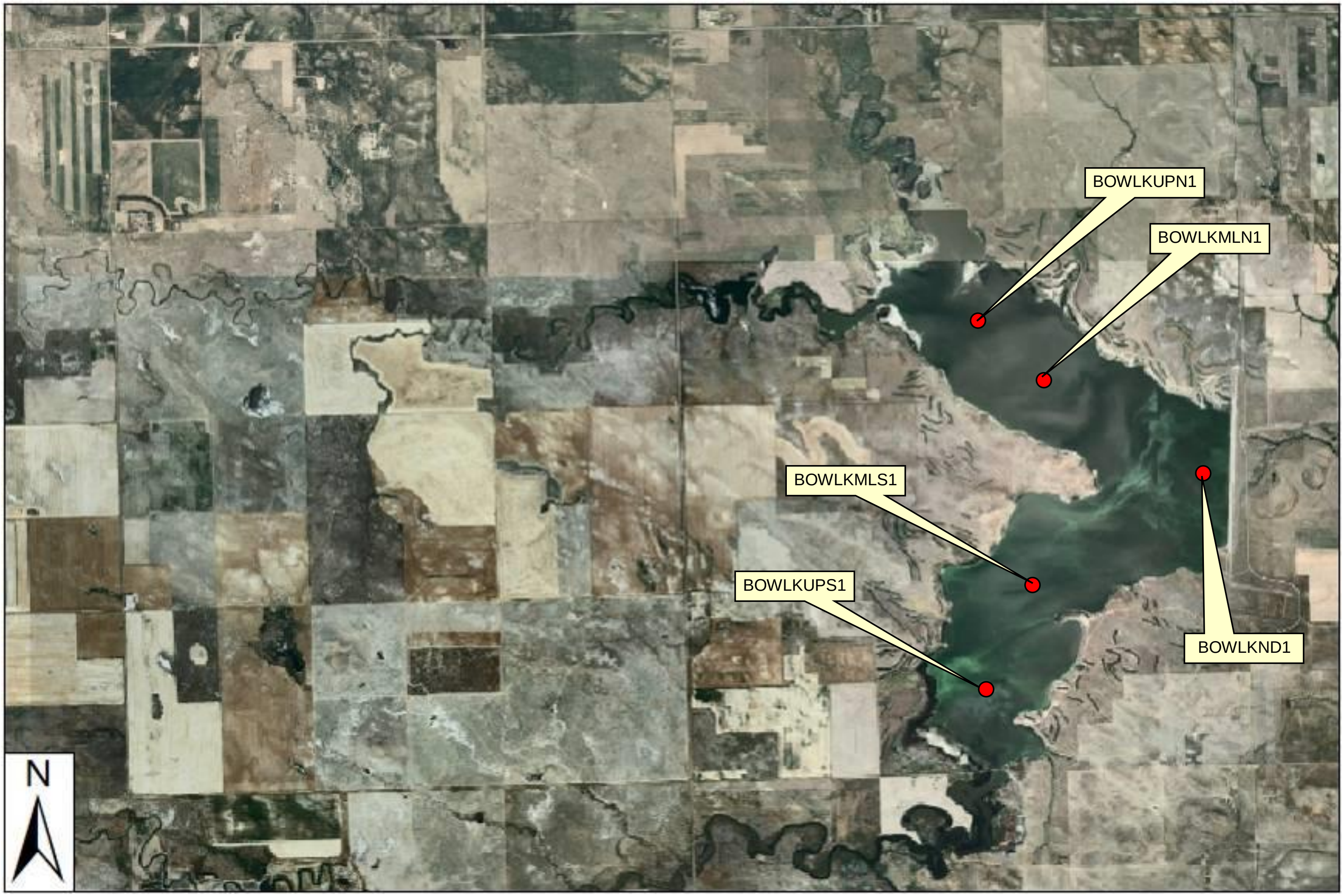


Figure 4.2. Location of sites where water quality monitoring was conducted at Bowman-Haley Reservoir during the period 2010 through 2015.

North Dakota's water quality standards define a criterion of 250 mg/l for sulfates (total as SO_4) which is applicable to Class I Streams including lakes. As such this criterion is applicable to Bowman-Haley Reservoir. The sulfate criterion was exceeded in all 29 samples collected from Bowman-Haley Reservoir for which sulfate was measured. The high sulfate levels are a natural condition attributable to the soils of the region.

4.1.2.2 Thermal Stratification

4.1.2.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal conditions measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 4-4 shows longitudinal temperature contour plots based on depth-profile temperature measurements taken at sites BOWLKND1, BOWLKMLN1, and BOWLKUPN1. The plots indicate Bowman-Haley Reservoir did not exhibit significant thermal stratification.

4.1.2.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of Bowman-Haley Reservoir, at the deep water area near the dam, is described by the depth-profile temperature plots measured over the past 5 years. Depth-profile temperature plots measured during the summer were compiled (Plate 4-5). The plotted depth-profile temperature measurements indicate that the reservoir seldom exhibits significant summer thermal stratification. Since Bowman-Haley Reservoir ices over in the winter and exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

4.1.2.3 Summer Dissolved Oxygen Conditions

4.1.2.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen conditions measured during 2015 are depicted by longitudinal contour plots constructed along the length of the reservoir. Plate 4-6 shows longitudinal dissolved oxygen contour plots based on depth-profile temperature measurements taken at sites BOWLKND1, BOWLKMLN1, and BOWLKUPN1. The plots indicate Bowman-Haley Reservoir exhibited only minor hypoxic conditions during 2015.

4.1.2.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in Bowman-Haley Reservoir at the deep water area near the dam are described by dissolved oxygen depth-profiles measured over the past 6 years. Dissolved oxygen depth-profiles measured during the summer were compiled and plotted (Plate 4-7). A significant vertical gradient in summer dissolved oxygen levels rarely occurred.

4.1.2.4 Water Clarity

Figure 4.3 displays a box plot of the Secchi depth transparencies measured at the five in-reservoir monitoring sites during the 2010 through 2015 period (note: the monitoring sites are oriented in an upstream to downstream direction). Water clarity in the reservoir was slightly higher in the north arm than in the south arm with the area near the dam similar to the north arm.

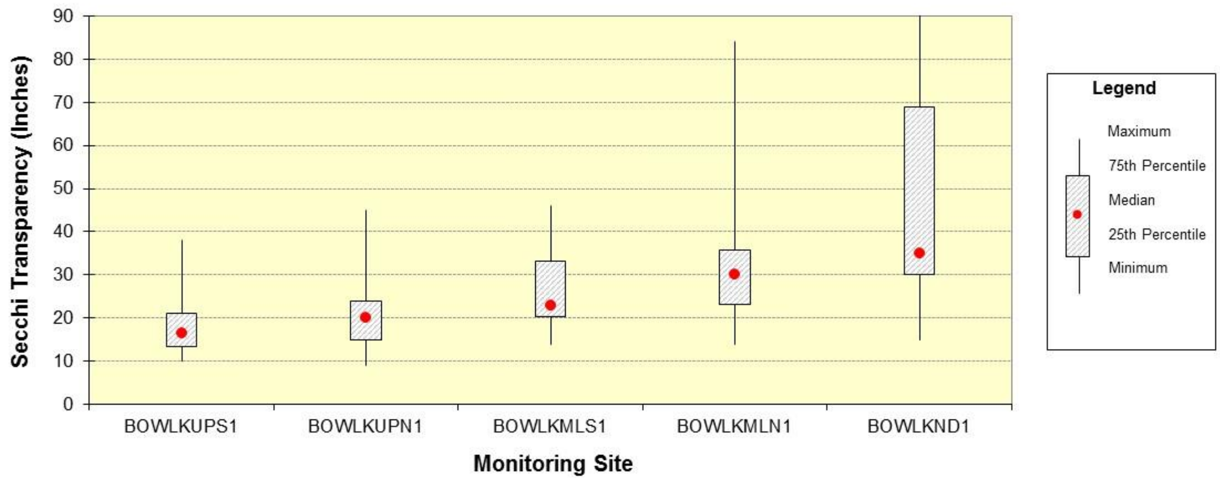


Figure 4.3. Box plot of Secchi depth transparencies measured in Bowman-Haley Reservoir during the period 2010 through 2015.

4.1.2.1 Phytoplankton Assemblage

Phytoplankton samples were collected at the near dam station (BOWLKND1) in May, July, and September of 2015. Total and relative group biovolume are shown in Figure 5.4. The May sample indicated relatively little algal production within the reservoir. July and September results show dominance by the blue green algae *Aphanizomenon flos-aquae*.

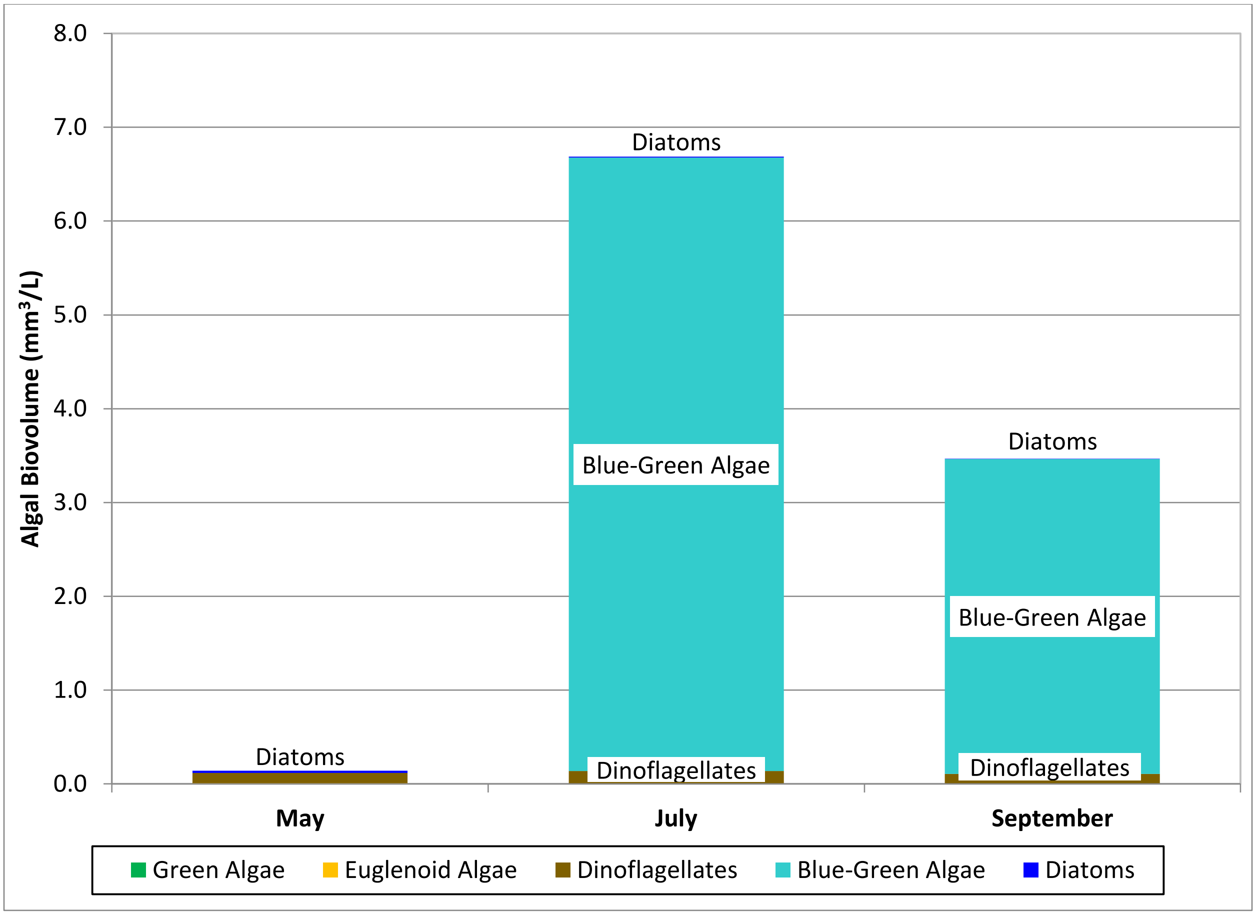


Figure 4.4. Graph showing total and relative phytoplankton biovolume at the near dam station of Bowman-Haley Reservoir in 2015.

4.1.2.2 Reservoir Trophic Status

Trophic State Index (TSI) values for Bowman-Haley Reservoir were calculated from monitoring data collected during 2010, 2012, and 2015 at the near-dam ambient monitoring site (i.e., BOWLKND1). Table 4-2 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Bowman-Haley Reservoir is in a eutrophic condition. Based on the State of North Dakota's impairment assessment methodology, the TSI values indicated that the trophic conditions of Bowman-Haley Reservoir fully support aquatic life and recreation.

Table 4-2. Summary of Trophic State Index (TSI) values calculated for Bowman-Haley Reservoir based on data collected in 2010, 2012, and 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	13	60	62	47	74
TSI(TP)	15	60	60	41	90
TSI(Chl)	15	56	53	40	74
TSI(Avg)	15	59	58	46	81

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.

Note: See Section 2.1.3 for discussion of TSI calculation.

4.1.1 **WATER QUALITY TRENDS (1980 THROUGH 2015)**

Water quality trends from 1980 to 2015 were determined for Bowman-Haley Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). 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 monitoring site (i.e., BOWLKND1). Plate 4-8 displays a scatter-plot of the collected data for the four parameters and a regression line. For the assessment period, Bowman-Haley Reservoir exhibited no significant trends in total phosphorus, and chlorophyll *a*. Over the 36-year period since 1980, Bowman-Haley Reservoir has exhibited an increasing trends in transparency and a decreasing trend in average TSI, seemingly indicating a change from a borderline hypereutrophic to eutrophic condition (Plate 4-8).

4.1.1.1.1 Existing Water Quality Conditions in the Upper Reaches of Bowman-Haley Reservoir

Existing water quality conditions in the upper reaches of Bowman-Haley Reservoir were monitored at sites BOWLKUPN1 and BOWLKUPS1 (Figure 4.2). Plate 4-9 and Plate 4-10, respectively, summarize water quality conditions that were monitored at sites BOWLKUPN1 and BOWLKUPS1 during 2010, 2012, and 2015 (Plate 4-9 and Plate 4-10).

4.2 PIPESTEM RESERVOIR

4.2.1 **BACKGROUND INFORMATION**

4.2.1.1 Project Overview

The dam forming Pipestem Reservoir is located on Pipestem Creek, 3 miles northwest of Jamestown, North Dakota. The dam was completed in July 1973 and the reservoir reached its initial fill in May 1974. The Pipestem Reservoir watershed is 594 square miles. The watershed was largely agricultural and rangeland when the dam was built in 1974 and has remained so to the present time. The authorized project purposes of Pipestem Reservoir are flood control, recreation, fish and wildlife, and water quality.

4.2.1.2 Pipestem Dam Intake Structure

The intake at Pipestem Dam is an ungated drop inlet with a weir elevation of 1442.4 ft-msl. The intake structure has two 4 feet x 7 feet hydraulic slide service gates and two low-level gates. The two low-level gates are a 3 foot x 3 foot slide gate at invert elevation 1433.0 ft-msl, and a 3 foot diameter slide gate at invert elevation 1415.0 ft-msl. Since the top of the multipurpose pool is also the crest of the ungated weir, no specific regulation of water levels of the multipurpose pool is required. Regulation for conservation will normally be automatic in that the incoming water will flow over the weir crest. The two low-level gates allow for the release of water from the multipurpose pool. The higher outlet is designed to meet water quality and downstream requirements. The lower outlet is provided for emergency drainage of the reservoir but may also be used for other purposes.

4.2.1.3 Reservoir Storage Zones

Figure 4.5 depicts the current storage zones of Pipestem Reservoir based on the 2014 survey data and estimated sedimentation. It is estimated that 9.3 percent of the "as-built" volume to the top of the Multipurpose Pool has been lost to sedimentation as of 2015. The annual volume loss is estimated to be 0.23 percent.

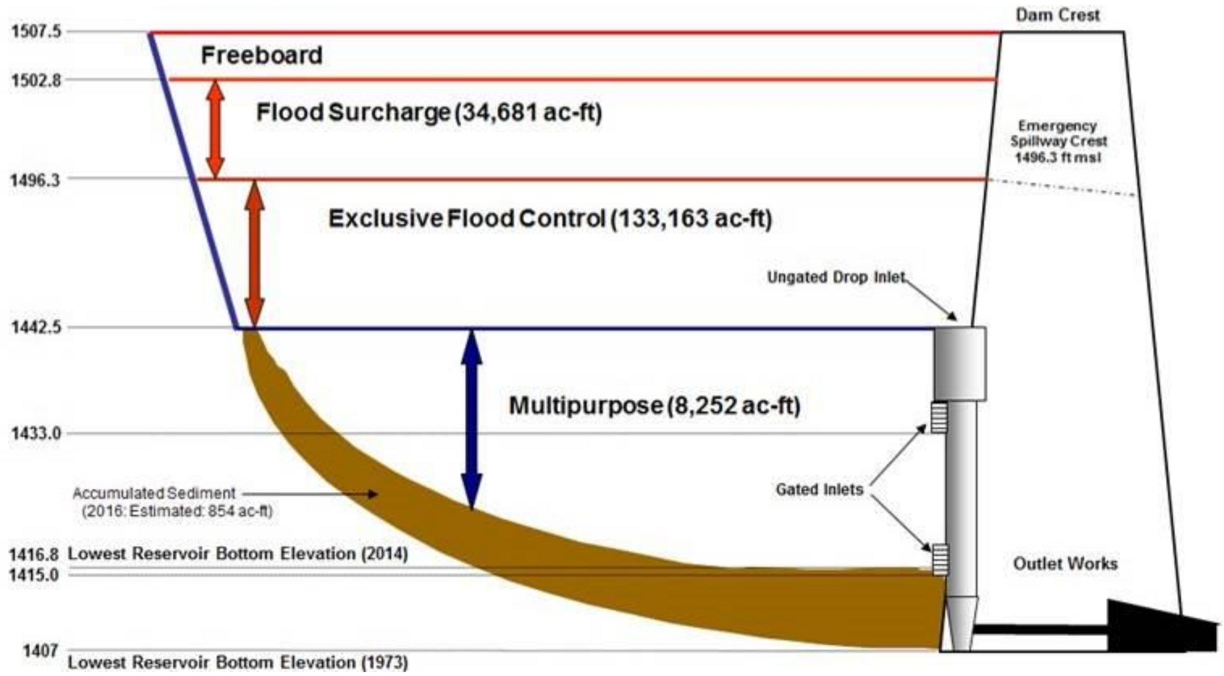


Figure 4.5. Current storage zones of Pipestem Reservoir based on the 2014 survey data and estimated sedimentation**.**

4.2.1.4 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

The State of North Dakota has designated Pipestem Reservoir as a Class 3 lake in the State's water quality standards. The beneficial uses designated for Class I streams are also applicable to all classified lakes in North Dakota. As such, the beneficial uses designated for Pipestem Reservoir are: primary contact recreation, warmwater fishery, wildlife, and agricultural water supply. Water quality is also to be suitable for municipal or domestic use after appropriate treatment. The reservoir is not directly used as a municipal or domestic water supply.

Pursuant to the Federal CWA, the State of North Dakota has listed Pipestem Reservoir on the State's 2014 Section 303(d) list (see Table 1-2). The beneficial use identified as fully supported but threatened is recreation. The impairment of the use is attributed to nutrients and eutrophication. The development of a TDML for Pipestem Reservoir has been given a high priority rating. The State of North Dakota has issued a statewide fish consumption advisory for mercury. As such, the mercury advisory applies to Pipestem Reservoir.

4.2.1.5 Water Quality Concerns

Following the initial fill of the multipurpose pool in 1974 and prior to the spring runoff in 1975, water quality measurements indicated severe oxygen depletion existed in the reservoir under ice cover. Further investigations confirmed that elevated levels of nitrogen, phosphorus, and organic matter occurred near the bottom of the reservoir. In an effort to improve the recreational and fish and wildlife quality of the reservoir, a deepwater water withdrawal operation was conducted using the lower low-level outlet to draw off the poor quality water near the reservoir bottom. The decision was made to proceed with this operation after it was determined that the impending snowmelt runoff would fill the reservoir to the multipurpose pool. The low-level releases were monitored during the operation and it was found that the released water was rapidly oxygenated and did not cause any adverse affects downstream.

Severe oxygen depletion beneath the ice cover occurred once again in 2013; this resulted in a winter fishkill in the reservoir. Dissolved oxygen measurements below ice cover indicated almost the entire length of the reservoir was hypoxic with only a small area of refugia in the upper reaches of the reservoir. The low-level gate was again utilized to to draw off the poor quality water near the reservoir bottom and "pull" influent oxygenated water towards the dam.

To investigate the potential effects of utilizing the low-level gate for water quality management the CE-QUAL-W2 (W2) hydrodynamic and water quality model is being applied at Pipestem Reservoir. To facilitate W2 model application an intensive water quality survey was conducted during 2015. The survey included additional samples and parameters collected from locations PIPLKND1, PIPLKML1, PIPLKUP1, PIPRL1, and PIPNF1 (Figure 4.6). The additional sample results are included in this report for analysis; however, a more detailed report documents model application will be released in the near future.

Current operations at Pipestem dam include keeping the lower low-level gate open during periods when water is flowing over the crest of the drop inlet structure in an effort to draw some water from the reservoir bottom and improve the water quality in the reservoir. It appears this may also be facilitating the passage of sediment through the dam and reducing sedimentation within the reservoir.

4.2.1.6 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Pipestem Reservoir since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Recently, the District has scaled back water quality monitoring at Pipestem Reservoir, and is currently monitoring the reservoir every 3 years. Figure 4.6 shows the location of the sites that were monitored during 2010, 2012, and 2015. During the past 6 years, the District conducted water quality monitoring at Pipestem Reservoir in 2010, 2012, and 2015.

4.2.2 EXISTING WATER QUALITY CONDITIONS

4.2.2.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Pipestem Reservoir at sites PIPLKND1, PIPLKML1, and PIPLKUP1 from May through September during the 6-year period 2010 through 2015 are summarized, respectively, in Plate 4-11 through Plate 4-13. A review of these results indicated possible water quality concerns regarding dissolved oxygen.

North Dakota's water quality standards define a criterion of 250 mg/l for sulfates (total as SO_4) which is applicable to Class I Streams including lakes. As such this criterion is applicable to Pipestem Reservoir. The sulfate criterion was exceeded throughout Pipestem Reservoir (Plate 4-11 through Plate 4-13). The high sulfate levels are a natural condition attributable to the soils of the region.

An appreciable number (22%) of dissolved oxygen measurements taken throughout Pipestem Reservoir were Leass than 5 mg/l. Most of the low dissolved oxygen measurements occurred near the bottom of the reservoir and were associated with thermal stratification. The chronic ammonia criteria was seemingly exceeded in one sample collected near the reservoir bottom at location PIPLKND1; however, because ammonia criteria are pH and temperature dependant this exceedence may be an artifact of utilizing median temperature and pH values for ammonia criteria calculation. The upper pH standard of 9 SU was exceeded at all in-reservoir monitoring locations. These exceedences were due to high levels of algal production in the photic waters of the reservoir.

4.2.2.2 Thermal Stratification

4.2.2.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal conditions of Pipestem Reservoir measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 4-14 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites PIPLKND1, PIPLKML1, and PIPLKUP1 in 2015. These temperature plots indicate that Pipestem Reservoir exhibited significant thermal stratification. The maximum difference monitored between the surface and bottom water temperatures was 11°C in July.

4.2.2.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of Pipestem Reservoir, at the deep water area near the dam, measured in 2010, 2012, and 2015 is depicted by depth-profile temperature plots (Plate 4-15). The depth-profile temperature plots indicate that the reservoir has regularly exhibited significant summer thermal stratification. Since Pipestem Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer (infrequently), it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

Figure 4.6. Location of sites where water quality monitoring was conducted at Pipestem Reservoir during the period 2010, 2012, and 2015.

4.2.2.3 Summer Dissolved Oxygen Conditions

4.2.2.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Pipestem Reservoir based on depth-profile measurements taken at sites PIPLKND1, PIPLKML1, and PIPLKUP1 in 2015. Plate 4-16 provides longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2015. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored along the reservoir bottom extending from the dam towards the upper reaches of the reservoir in in June through August of 2015.

4.2.2.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in Pipestem Reservoir are described by the dissolved oxygen depth-profiles measured near the dam in 2010, 2012, and 2015. Summer dissolved oxygen depth-profiles were compiled and plotted for 2010, 2012, and 2015 (Plate 4-17). On most occasions there was a significant vertical gradient in summer dissolved oxygen levels. Hypoxic to anoxic conditions were monitored near the reservoir bottom on several occasions. Very high super saturated dissolved oxygen conditions were monitored in August of 2010 and 2015. These conditions are due to high rates of algal photosynthesis during the day. Although Pipestem Reservoir is likely polymictic based on the potential for high winds to break down thermal stratification, there is enough resistance to mixing to allow degraded dissolved oxygen conditions to develop and persist near the reservoir bottom.

4.2.2.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Pipestem Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2015 and the District's Area-Capacity Tables (2014 Survey) for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The August 2015 contour plot indicates a pool elevation of 1444.2 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1431.0 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1430 ft-msl (Plate 4-16). The District's Area-Capacity Tables give storage capacities of 9,836 ac-ft for elevation 1444.2 ft-msl, 1,945 ac-ft for elevation 1431.0 ft-msl, and 1,637 ac-ft for elevation 1430.0 ft-msl. On August 11, 2015 it is estimated that 20 percent of the volume of Pipestem Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of aquatic life, and 17 percent of the reservoir volume was hypoxic.

4.2.2.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Pipestem Reservoir indicated hypoxic conditions were present during the summer of 2015, longitudinal contour and depth-profile plots were constructed for ORP and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared.

4.2.2.4.1 Oxidation-Reduction Potential

Plate 4-18 shows longitudinal ORP contour plots based on depth-profile measurements taken in 2015. The contour plots indicate lower ORP conditions occurred near the reservoir bottom when hypoxic conditions were monitored (Plate 4-18). Plate 4-19 plots depth profiles for ORP measured during the summer during 2010, 2012, and 2015 in the deep water area of Pipestem Reservoir near the dam. The depth profiles indicate that appreciable lower ORP conditions occasionally occurred in Pipestem Reservoir during the summer (Plate 4-19).

4.2.2.4.2 pH

Longitudinal contour plots for pH conditions measured in 2015 are shown in Plate 4-20. Plate 4-21 plots depth profiles for pH measured during the summers of 2010, 2012, and 2015 in the deep water area of Pipestem Reservoir near the dam. An appreciable vertical gradient in pH occasionally occurred in the reservoir during the summer (Plate 4-20). It appears reduced conditions in the deeper water of Pipestem Reservoir lead to lower pH levels near the reservoir bottom. The lowest measured pH levels near the reservoir bottom were 6.9; this is just below the lower pH criterion of 7.0 for the protection of aquatic life. In August of 2015 measured pH was unusually high in the hypolimnion, the high values were also observed at locations PIPLKML1 and PIPRL1.

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

Paired near-surface and near-bottom water quality samples collected from Pipestem Reservoir 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 PIPLKND1 during 2010, 2012, and 2015. During 2010, 2012, and 2015 a total of 9 paired samples were collected during hypoxic conditions in the hypolimnion. Box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature (8), dissolved oxygen (8), oxidation-reduction potential (8), pH (8), total ammonia (9), nitrate-nitrate nitrogen (9), total phosphorus (9), dissolved phosphorus (9), and orthophosphorus (9) (Plate 4-22) *[Note: the number in parentheses is the number of paired observations available for each parameter]*. A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different (α = 0.05). The sampled near-surface and near-bottom conditions were not significantly different for nitrate-nitrite nitrogen. Parameters that were significantly lower in the near-bottom water of Pipestem Reservoir included: water temperature ($p < 0.01$), dissolved oxygen ($p < 0.001$) oxidation-reduction potential ($p < 0.05$). Parameters that were significantly higher in the near-bottom water of Pipestem Reservoir when hypoxia was present included: total ammonia ($p <0.05$), total phosphorus ($p <0.05$), dissolved phosphorus ($p <0.05$), and orthophosphorus ($p<0.05$).

4.2.2.5 <u>Water Clarity</u>

4.2.2.5.1 Secchi Transparency

Figure 4.7 displays a box plot of the Secchi depth transparencies measured at the three in-reservoir monitoring sites (i.e., PIPLKUP1, PIPLKML1, and PIPLKND1) during 2010, 2012, and 2015 (note: the monitoring sites are oriented in an upstream to downstream direction). Water clarity in the reservoir was noticeably higher near the dam as compared to sites farther upstream (Figure 4.7)

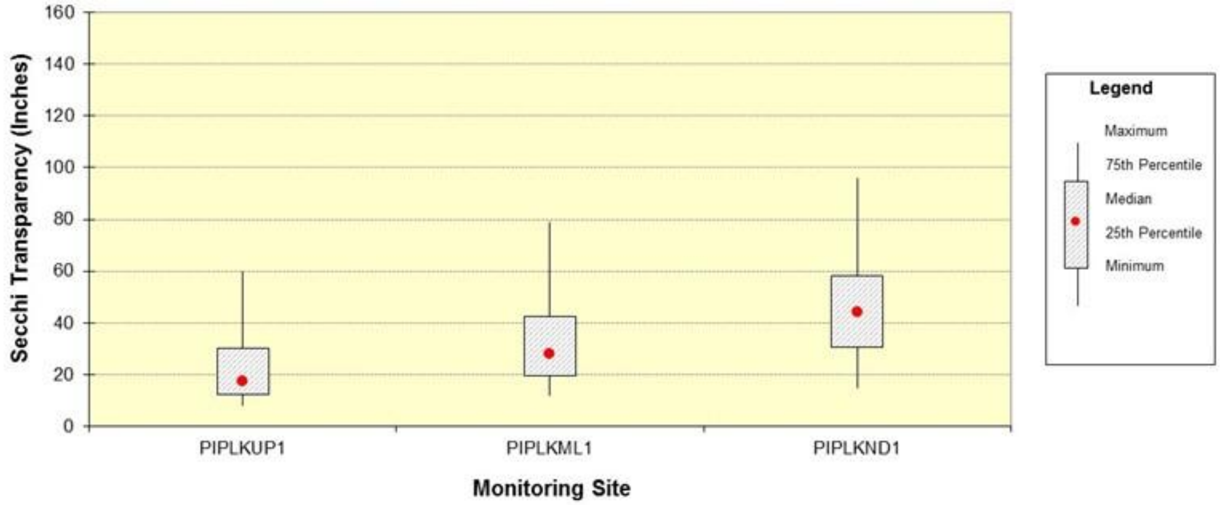


Figure 4.7. Box plot of Secchi depth transparencies measured in Pipestem Reservoir during 2010, 2012, and 2015.

4.2.2.5.2 Turbidity

Turbidity contour plots were constructed along the length of Pipestem Reservoir based on depth-profile measurements taken during 2015. Plate 4-23 shows longitudinal turbidity contour plots based on depth-profile measurements taken from May through September at sites PIPLKND1, PIPLKML1, and PIPLKUP1. Pipestem Reservoir occasionally exhibited appreciable longitudinal and depth variability in turbidity.

4.2.2.6 <u>Phytoplankton Assemblage</u>

Phytoplankton samples were collected at the near dam station (PIPLKND1) in May, July, and September of 2015. Total and relative group biovolume are shown in Figure 5.8. The May sample was dominated by the diatom *Aulacoseira granulata*, which is often found in water bodies where eutrophic conditions exist. The July results show the blue green algae *Aphanizomenon flos-aquae* was dominant; however, the total biovolume shown in figure 5.8 does not reflect the observed algal bloom in the reservoir. This could potentially be the result of sampling error or an artifact of algal buoyancy. *Aphanizomenon flos-aquae* likely played a key role in the in the nitrogen cycle at Pipestem Reservoir in 2015 through nitrogen fixation and release into the water column. Diatom growth and observed biovolume in September could have been accelerated by this increased nitrogen availability.

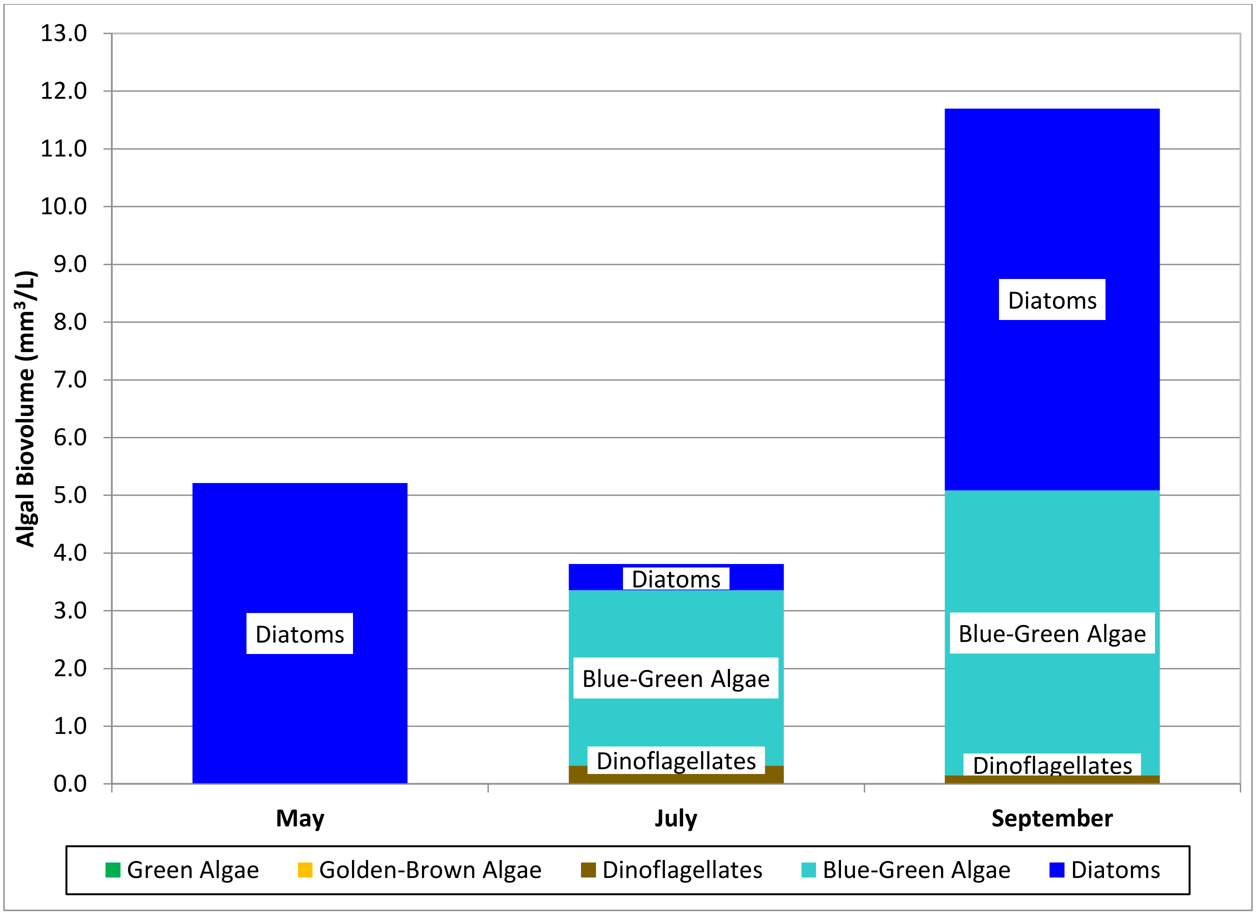


Figure 4.8. Graph showing total and relative phytoplankton biovolume at the near dam station of Pipestem Reservoir in 2015.

4.2.2.7 <u>Reservoir Trophic Status</u>

Trophic State Index (TSI) values for Pipestem Reservoir were calculated from monitoring data collected during the 6-year period 2010 through 2015 at the near-dam ambient monitoring site (i.e., PIPLKND1). **Error! Reference source not found.** summarizes the TSI values calculated for the reservoir. he TSI values indicate that the near-dam lacustrine area of Pipestem Reservoir is in a eutrophic to hypereutrophic condition. Based on the State of North Dakota's impairment assessment criteria, the TSI values indicate that the aquatic life and recreation uses of Pipestem Reservoir are likely impaired.

Table 4-3. Summary of Trophic State Index (TSI) values calculated for Pipestem Reservoir for 2010, 2012, and 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	15	59	58	47	74
TSI(TP)	15	70	74	41	83
TSI(Chl)	15	68	73	46	87
TSI(Avg)	15	66	67	51	80

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.

Note: See Section 4.1.3 for discussion of TSI calculation.

4.2.3 WATER QUALITY TRENDS (1980 THROUGH 2015)

Water quality trends from 1980 to 2015 were determined for Pipestem Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). 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 monitoring site (i.e., PIPLKND1). Plate 4-24 displays a scatter-plot of the collected data for the four parameters and a linear regression line. Pipestem Reservoir exhibited an increasing trend in total phosphorus ($p < 0.001$) and no significant trend in transparency and chlorophyll *a*. Over the 36-year period since 1980, Pipestem Reservoir has remained in a eutrophic to hypereutrophic condition (Plate 4-24).

4.2.4 EXISTING WATER QUALITY CONDITIONS OF INFLOWS TO PIPESTEM RESERVOIR AND RESERVOIR RELEASES

Existing water quality conditions in Pipestem Creek, the main tributary inflow to Pipestem Reservoir and the reservoir releases were monitored in 2015 as part of the intensive survey of Pipestem Reservoir. Descriptive statistics for the water quality conditions monitored at station PIPNF1 and PIPRL1 in 2015 are given in Plate 4-25 and Plate 4-26.

4.3 CHAPTER 4 PLATES

Plate 4-1. Summary of water quality conditions monitored in Bowman-Haley Reservoir at the near-dam location (i.e., site BOWLKND1) from May to September of 2010, 2012, and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for “grab samples” collected at ½ the Secchi depth. Results for other parameters are for “grab samples” collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Lake Depth (m)	0.1	13	6.3	6.2	5.0	7.3	-----	-----	-----
Water Temperature (°C)	0.1	187	19.0	20.1	10.8	24.3	29.4	0	0%
Pool Elevation (ft-msl)		15	2751.4	2751.7	2747.5	2753.6	-----	-----	-----
Secchi Depth (in.)	1	13	45.5	35.0	15.0	94.0	-----	-----	-----
Turbidity (NTUs)	0.1	187	12.1	8.1	n.d.	147.2	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	187	334	364	82	432	-----	-----	-----
Specific Conductance (umho/cm)	1	187	2436	2600	1429	3382	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	187	8	8	3	9	≥ 5	7	4%
Dissolved Oxygen (% Sat.)	0.1	187	85.0	86.1	38.5	100.9	-----	-----	-----
Chemical Oxygen Demand (mg/l)	0.8	12	29.7	31.0	15.0	41.0	-----	-----	-----
pH (S.U.)	0.1	187	8.6	8.6	8.1	9.3	≥7.0 & ≤9.0	0,1	1%
Alkalinity, Total (mg/l)	0.6	29	290	330	53	363	-----	-----	-----
Dissolved Solids, Total (mg/l)	10	29	1821	1960	1098	2590	-----	-----	-----
Suspended Solids, Total (mg/l)	4	29	19	12	n.d.	185	-----	-----	-----
Ammonia, Total (mg/l)	0.02	29	0.16	0.14	n.d.	0.40	2.7 [1,2], 0.6 [1,3]	0, 0	0%, 0%
Kjeldahl N, Total (mg/l)	0.08	29	1.83	1.44	0.39	12.30	-----	-----	-----
Nitrogen, Total (mg/l)	0.08	29	1.86	1.45	0.39	12.30	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	29	-----	n.d.	n.d.	0.13	1.0	0	0%
Phosphorus, Total (mg/l)	0.005	29	0.119	0.080	0.010	1.410	-----	-----	-----
Phosphorus, Dissolved (mg/l)	0.01	29	0.07	0.05	0.01	0.82	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.003	29	0.033	0.030	0.004	0.080	-----	-----	-----
Chlorophyll a (ug/l) – Lab Determined	3	15	8	4	2	34	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	3	174	8	4	2	41	-----	-----	-----
Total Organic Carbon (mg/l)	0.2	29	15.6	13.8	5.0	47.7	-----	-----	-----
Hardness, Total (mg/l)	0.32	3	409.00	394.40	249.00	583.60	-----	-----	-----
Calcium, Total	0.05	3	56.05	50.29	40.20	77.66	-----	-----	-----
Magnesium, Total (mg/l)	0.05	3	65.08	65.80	34.80	94.64	1.0	0	0%
Sodium, Total (mg/l)	0.01	2	504.70	504.70	449.10	560.30	-----	-----	-----
Sulfate, Dissolved (mg/l)	0.4	29	990.9	1070.0	506.0	1510.0	250	29	100%
Arsenic, Total (ug/l)	8	3	-----	n.d.	n.d.	4.00	-----	-----	-----
Cadmium, Total (ug/l)	0.007	3	-----	n.d.	n.d.	0.03	21[2], 7[3]	0	0%
Copper, Dissolved (ug/l)	6	3	-----	n.d.	n.d.	9.00	51[2], 30[3]	0	0%
Iron, Total (ug/l)	10	3	239	220	110	386	-----	-----	-----
Lead, Total (ug/l)	0.008	3	-----	n.d.	n.d.	0.20	468 [2], 8[3]	0	0%
Manganese, Total (ug/l)	3	3	121	100	43	220	-----	-----	-----
Zinc, Total (ug/l)	6	3	-----	4.00	n.d.	16.00	383[2,3]	0	0%
Aluminum, Total (ug/l)	40	3	315	280	140	524	-----	-----	-----
Selenium, Total (ug/l)	0.06	3	2.00	2.00	2.00	2.00	-----	-----	-----
Mercury, Dissolved (ug/l)	0.002	3	-----	n.d.	n.d.	0.02	-----	-----	-----
Mercury, Total (ug/l)	0.002	3	-----	n.d.	n.d.	0.02	1.7[2], 0.012[3], 0.05[4]	0, 0, 0	0%, 0%, 0%
Atrazine, Tot	0.07	3	-----	n.d.	n.d.	n.d.	3[c]	0	0%
Metolachlor, Tot	0.05	3	-----	n.d.	n.d.	n.d.	3[c]	0	0%
Acetochlor, Tot	0.07	3	-----	n.d.	n.d.	n.d.	3[c]	0	0%
Microcystin, Total (ug/l)	0.1	15	-----	0.10	n.d.	0.40	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, 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) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

(2) Acute criterion for aquatic life.

(3) Chronic criterion for aquatic life.

Note: North Dakota’s chronic WQS criterion for Mercury was below the detection limit during the reporting period.

(4) Human health criterion for surface waters.

Note: North Dakota’s WQS criteria for metals are based on total recoverable, some analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, metolachlor, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted percent exceedence indicates use impairment based on State of North Dakota’s 2016 Section 303(d) impairment assessment criteria.

Plate 4-2. Summary of water quality conditions monitored in Bowman-Haley Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site BOWLKMLN1) from May to September of 2010, 2012, and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean*	Median	Min.	Max.	State WQS Criteria	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	9	2751.3	2751.5	2749.0	2753.7	-----	-----	-----
Water Temperature (°C)	0.1	138	19.1	20.0	10.7	24.6	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	138	8.1	8.1	5.7	11.0	≥ 5	0	0%
Dissolved Oxygen (% Sat.)	0.1	138	91.5	88.9	68.4	136.7	-----	-----	-----
Specific Conductance (umho/cm)	1	138	2426	2545	1447	3382	-----	-----	-----
pH (S.U.)	0.1	138	8.6	8.7	8.4	8.8	≥7.0 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	137	14.6	9.8	0.0	119.0	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	138	332	368	95	421	-----	-----	-----
Secchi Depth (in.)	1	14	35	30	14	84	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	128	9	4	3	47	-----	-----	-----

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

Plate 4-3. Summary of water quality conditions monitored in Bowman-Haley Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site BOWLKMLS1) from May to September of 2010, 2012, and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean*	Median	Min.	Max.	State WQS Criteria	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)		9	2751.3	2751.5	2749.0	2753.6	-----	-----	-----
Water Temperature (°C)	0.1	92	19.5	21.5	10.9	24.4	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	92	8.0	7.6	5.4	10.8	≥ 5	0	0%
Dissolved Oxygen (% Sat.)	0.1	92	90.8	88.3	65.6	126.7	-----	-----	-----
Specific Conductance (umho/cm)	1	92	2479	2621	1426	3400	-----	-----	-----
pH (S.U.)	0.1	92	8.6	8.7	8.4	8.8	≥7.0 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	92	23.5	16.0	3.3	425.0	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	92	352	374	105	438	-----	-----	-----
Secchi Depth (in.)	1	14	26	23	14	46	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	87	10	5	2	63	-----	-----	-----

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

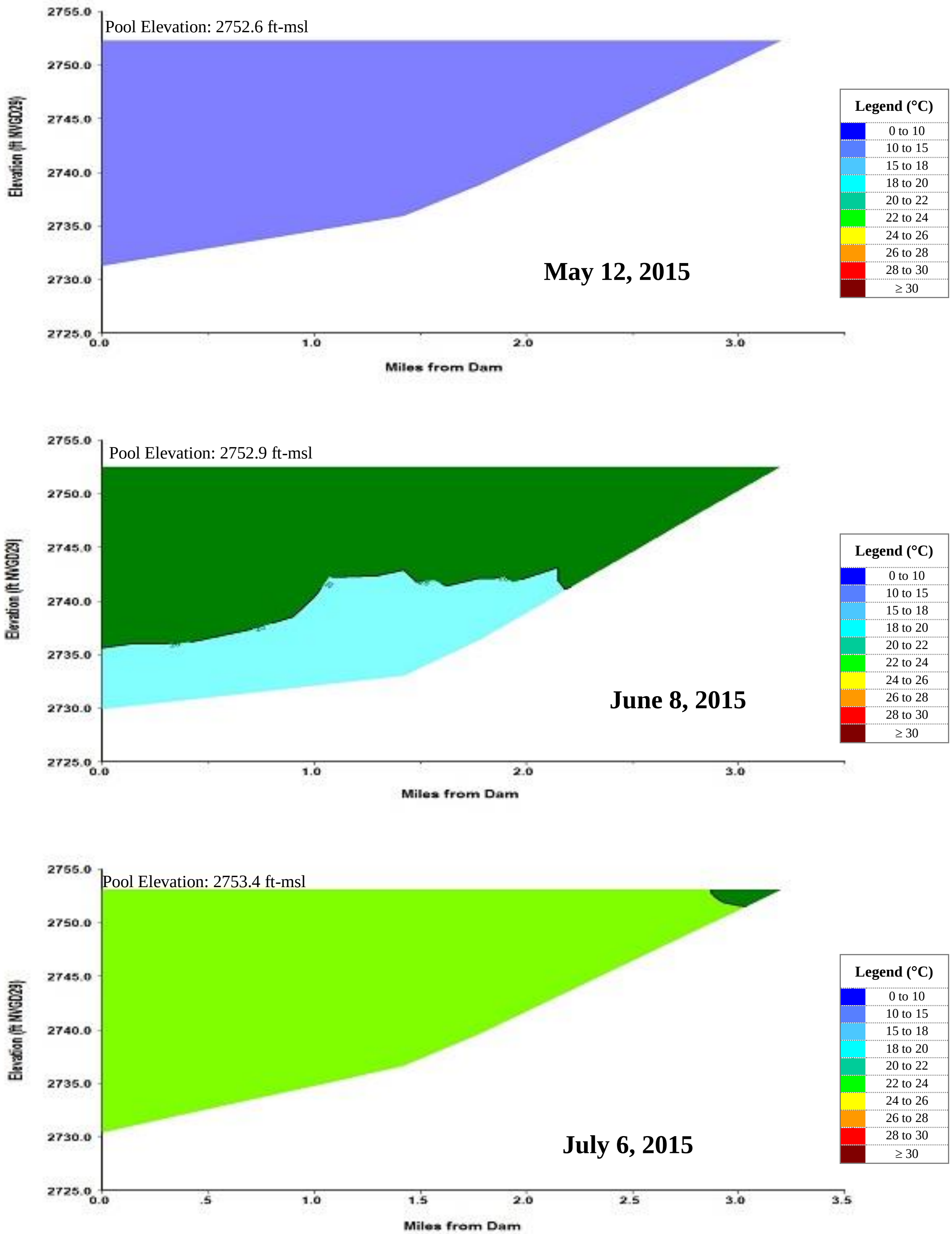
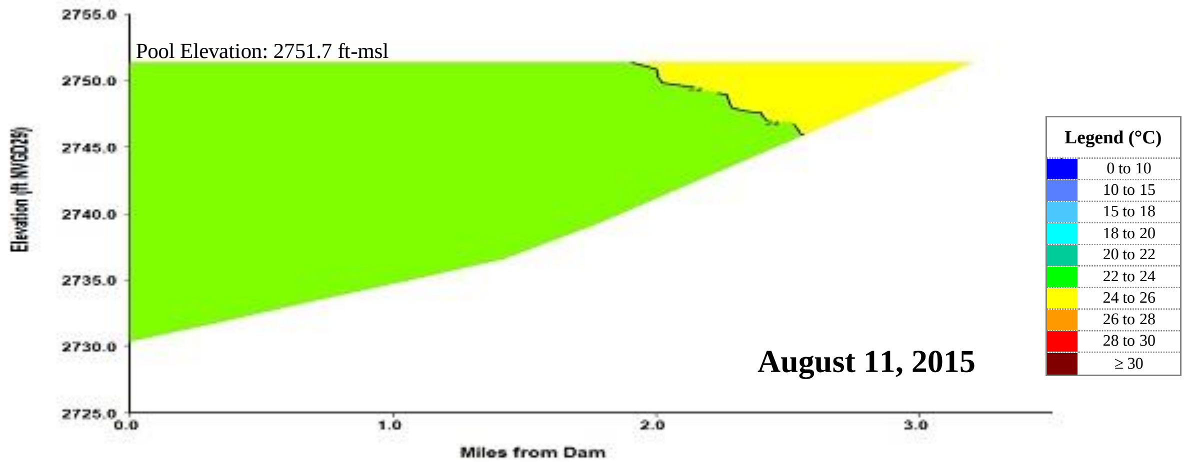
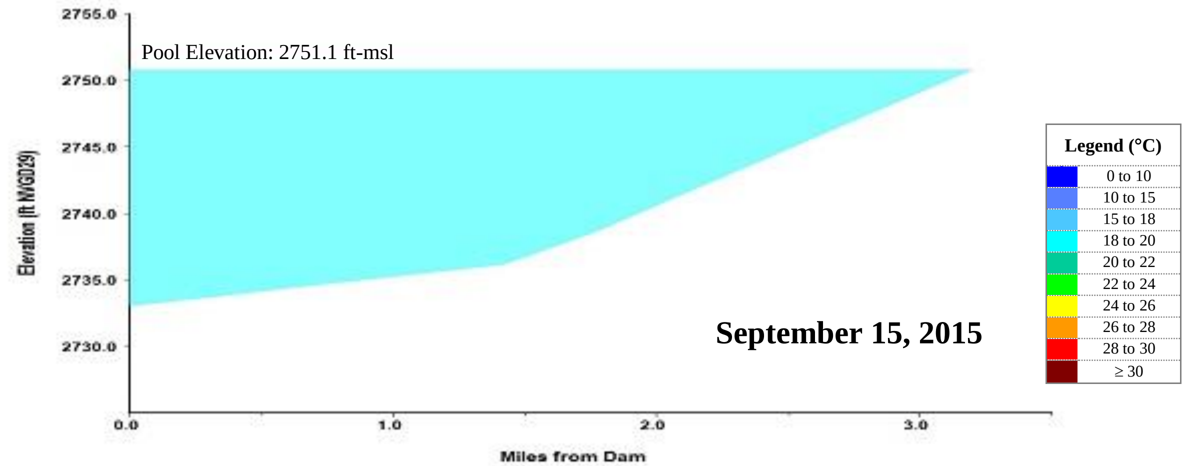


Plate 4-4. Longitudinal water temperature (°C) contour plots of Bowman Haley Reservoir based on depth-profile water temperatures measured at sites BOWLKND1, BOWLKMLN1, and BOWLKUPN1 in 2015.


Pool Elevation: 2751.7 ft-msl
August 11, 2015
Legend (°C)
0 to 10
10 to 15
15 to 18
18 to 20
20 to 22
22 to 24
24 to 26
26 to 28
28 to 30
≥ 30
Elevation (ft NVGD29)
2755.0
2750.0
2745.0
2740.0
2735.0
2730.0
2725.0
0.0
1.0
2.0
3.0
Miles from Dam


Pool Elevation: 2751.1 ft-msl
September 15, 2015
Legend (°C)
0 to 10
10 to 15
15 to 18
18 to 20
20 to 22
22 to 24
24 to 26
26 to 28
28 to 30
≥ 30
Elevation (ft NVGD29)
2755.0
2750.0
2745.0
2740.0
2735.0
2730.0
0.0
1.0
2.0
3.0
Miles from Dam

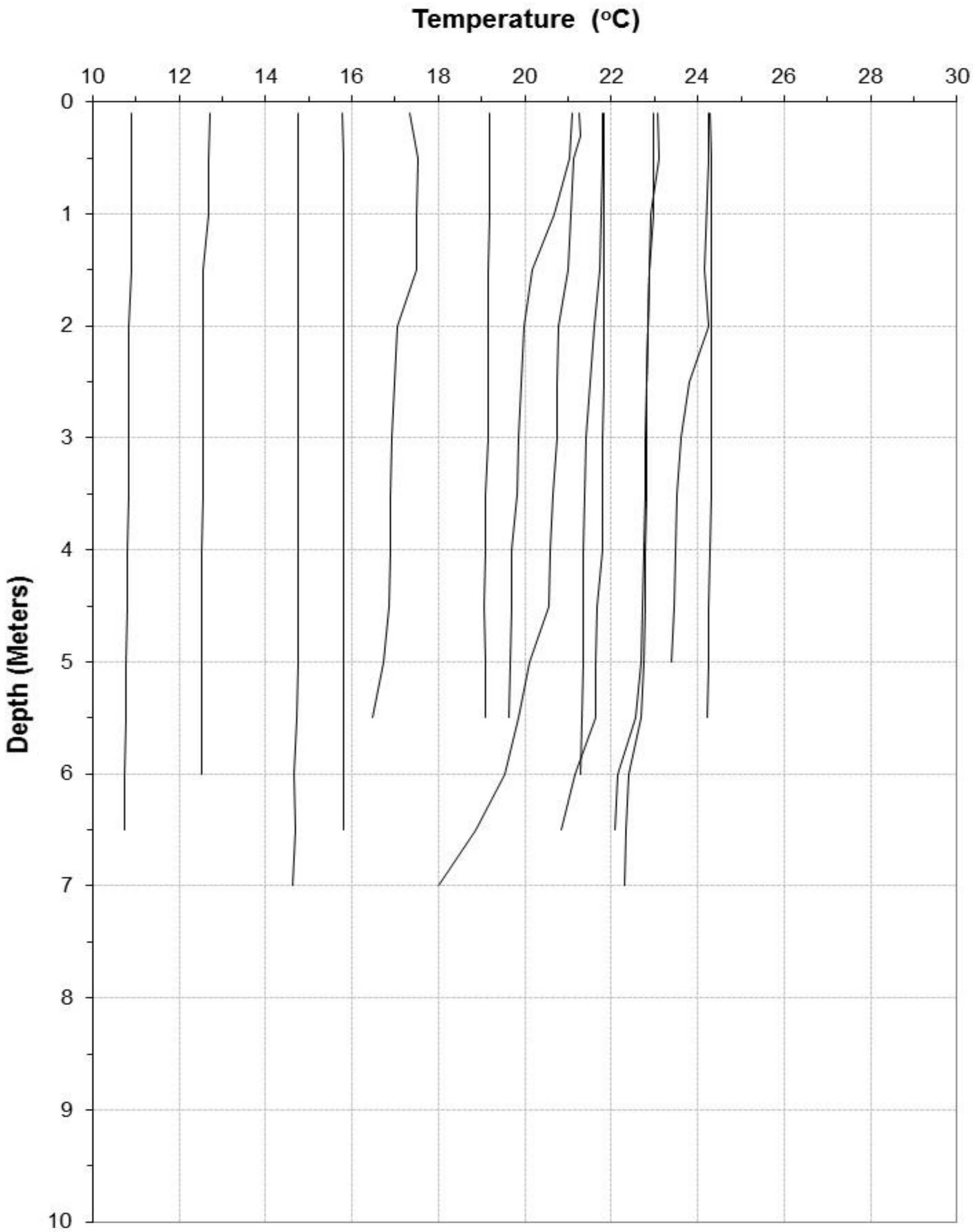


Plate 4-5. Temperature depth profiles for Bowman-Haley Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BOWLKND1) during the summers of 2010, 2012, and 2015.

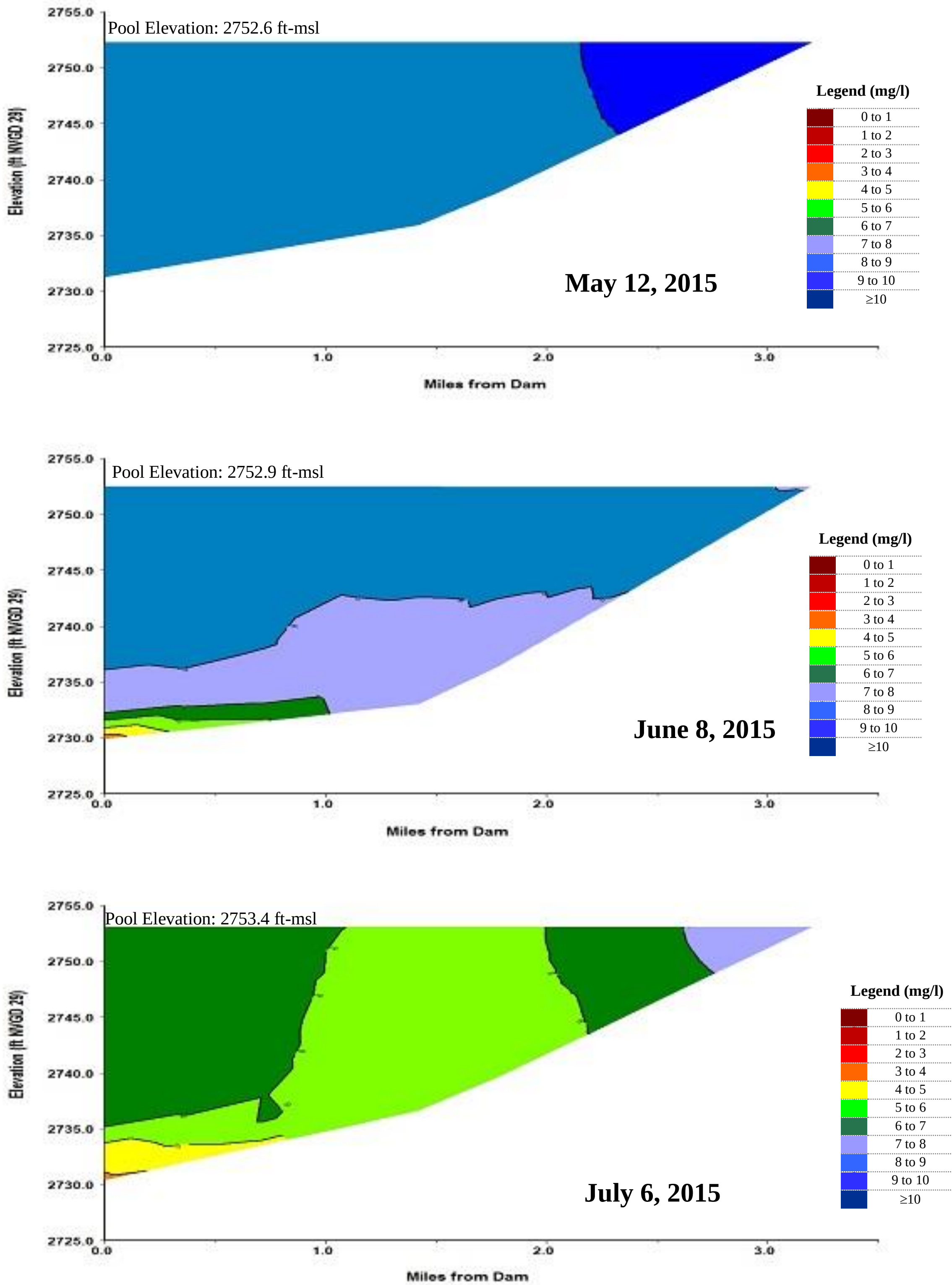
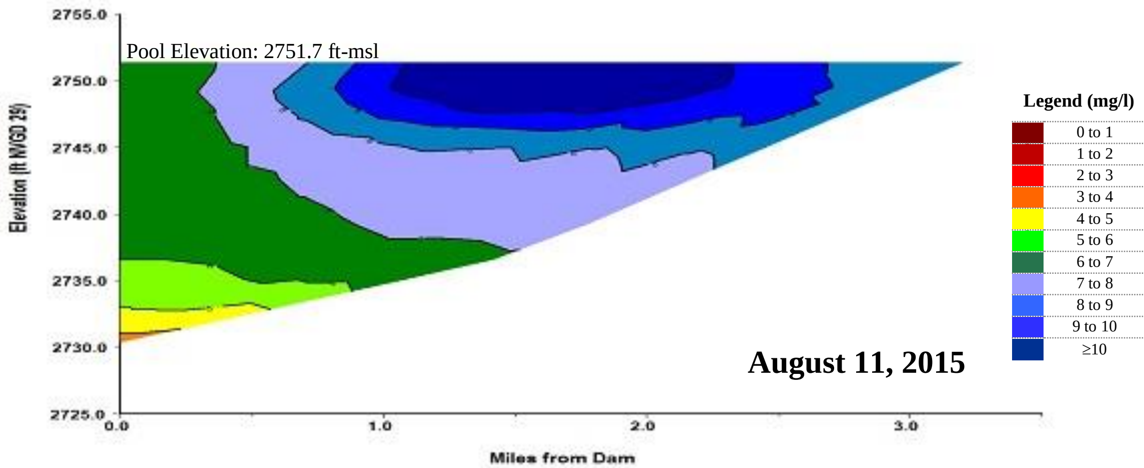


Plate 4-6. Longitudinal Dissolved Oxygen (mg/l) contour plots of Bowman Haley Reservoir based on depth-profile measurements at sites BOWLKND1, BOWLKMLN1, and BOWLKUPN1 in 2015.



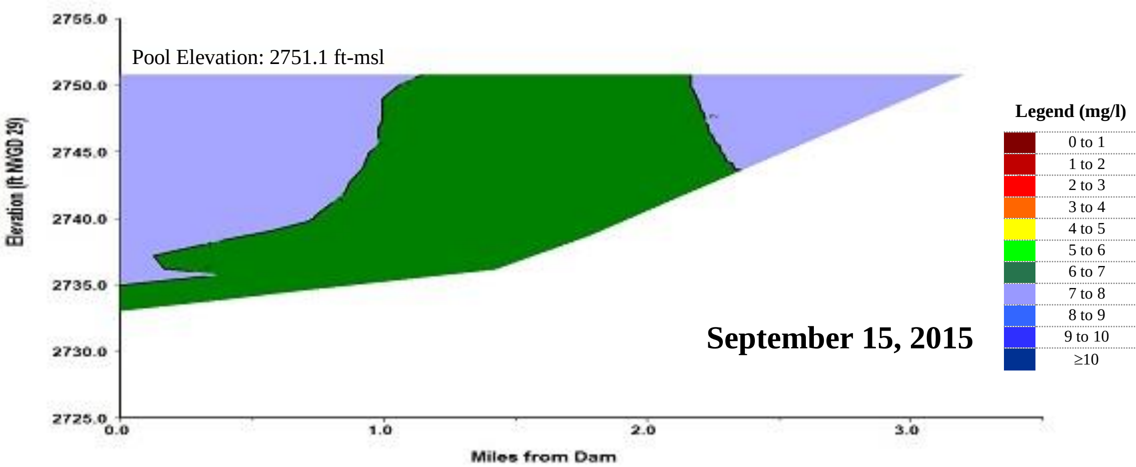


Plate 4-6. (Continued)

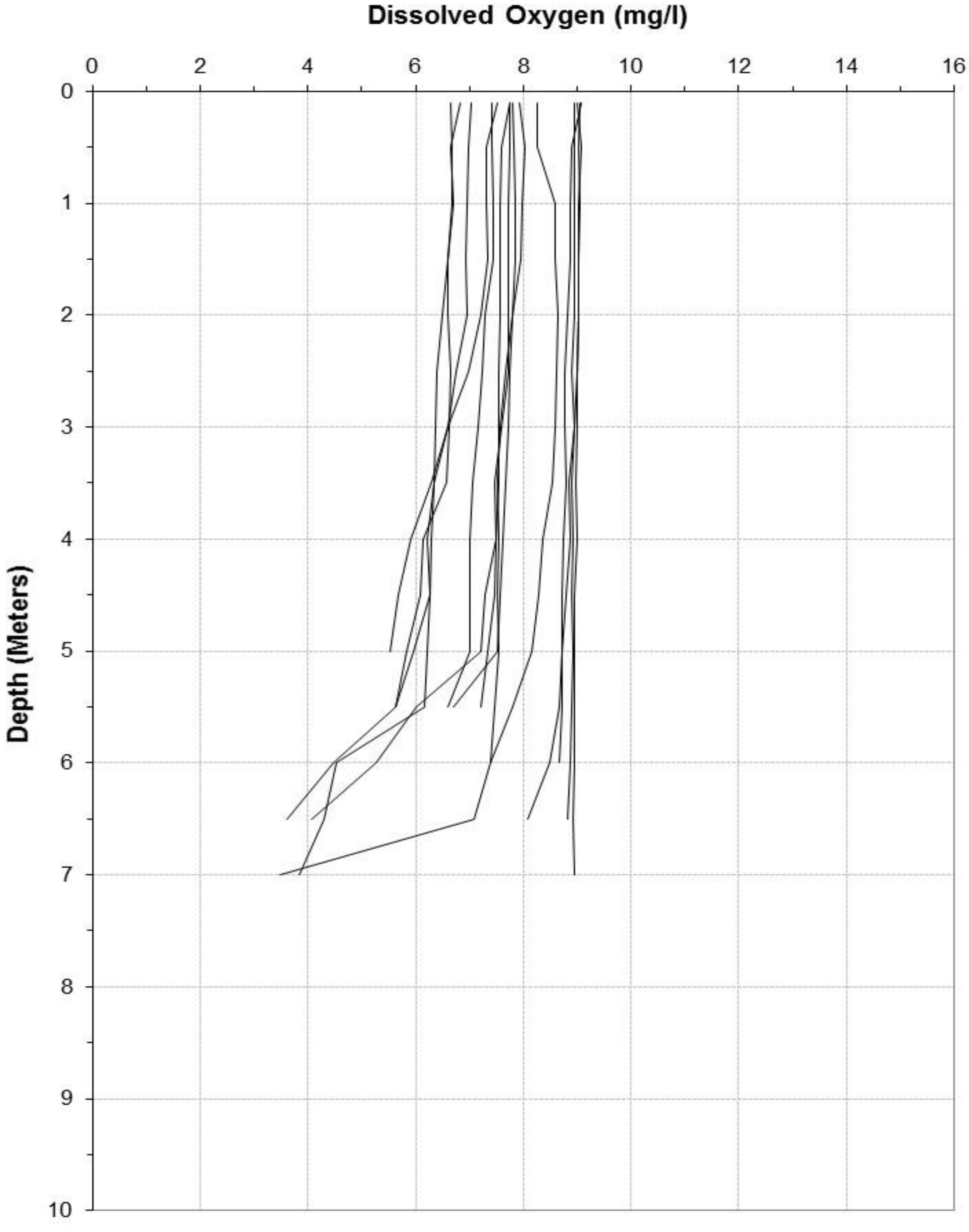


Plate 4-7. Dissolved Oxygen depth profiles for Bowman-Haley Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BOWLKND1) during the summers of 2010, 2012, and 2015.

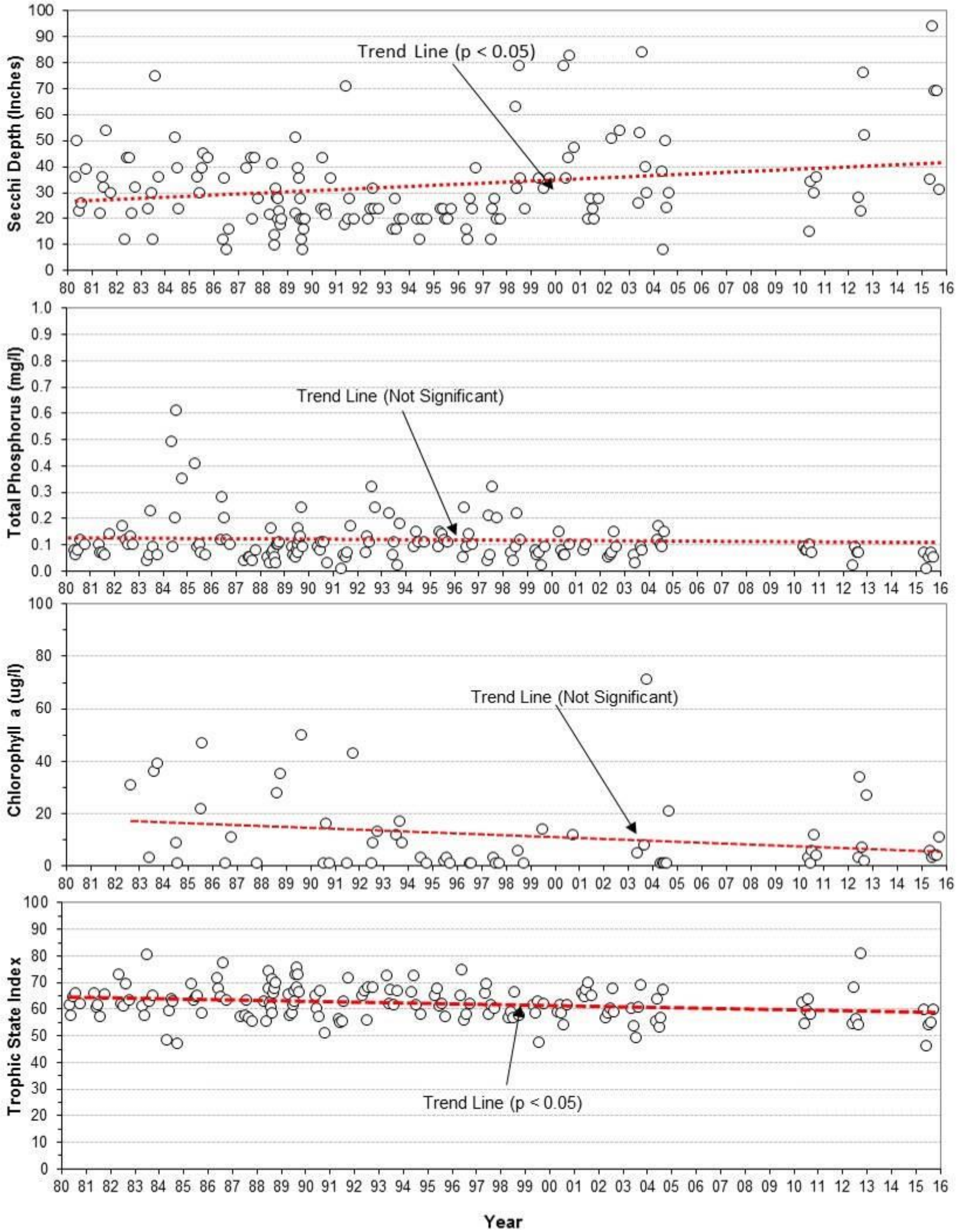


Plate 4-8. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Bowman-Haley Reservoir at the near-dam, ambient site (i.e., site BOWLKND1) over the 36-year period of 1980 through 2015.

Plate 4-9. Summary of water quality conditions monitored in Bowman-Haley Reservoir at the up-lake, ambient monitoring location (i.e., site BOWLKUPN1) from May to September during 2010, 2012, and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[(A)]	Median	Min.	Max.	State WQS Criteria[(B)]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	8	2751.4	2751.7	2749.0	2753.6	-----	-----	-----
Water Temperature (°C)	0.1	31	19.6	19.0	11.1	24.8	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	31	8.6	8.7	6.2	12.3	≥ 5	0	0%
Dissolved Oxygen (% Sat.)	0.1	31	98.0	96.8	76.5	148.1	-----	-----	-----
Specific Conductance (umho/cm)	1	31	2084	1783	1588	3398	-----	-----	-----
pH (S.U.)	0.1	31	8.7	8.7	8.5	8.9	≥7.0 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	31	35.1	21.5	7.0	102.6	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	31	291	253	92	422	-----	-----	-----
Secchi Depth (in.)	1	13	20	20	9	45	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	31	15	14	3	35	-----	-----	-----

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

Plate 4-10. Summary of water quality conditions monitored in Bowman-Haley Reservoir at the up-lake, ambient monitoring location (i.e., site BOWLKUPS1) from May to September during during 2010, 2012, and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[(A)]	Median	Min.	Max.	State WQS Criteria[(B)]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	8	2751.4	2751.7	2749.0	2753.6	-----	-----	-----
Water Temperature (°C)	0.1	21	19.9	21.8	10.9	24.2	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	20	8.6	8.3	6.9	14.8	≥ 5	0	0%
Dissolved Oxygen (% Sat.)	0.1	21	94.4	91.1	2.2	182.0	-----	-----	-----
Specific Conductance (umho/cm)	1	21	2234	1847	1419	3413	-----	-----	-----
pH (S.U.)	0.1	21	8.7	8.7	8.4	8.9	≥7.0 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	21	24.9	20.2	3.7	74.1	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	21	346	377	104	438	-----	-----	-----
Secchi Depth (in.)	1	12	18	17	10	38	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	20	14	7	3	59	-----	-----	-----

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

Plate 4-11. Summary of water quality conditions monitored in Pipestem Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site PIPLKND1) from May to September during during 2010, 2012, and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at ½ the measured Secchi depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	15	1449.6	1446.1	1442.1	1470.1	-----	-----	-----
Water Temperature (°C)	0.1	277	18.6	19.7	9.3	27.8	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	277	6.9	7.3	0.0	21.3	≥ 5	79	29%
Dissolved Oxygen (% Sat.)	0.1	277	78.0	74.6	0.0	282.2	-----	-----	-----
Specific Conductance (umho/cm)	1	277	1149	1292	523	1646	-----	-----	-----
pH (S.U.)	0.1	277	8.2	8.2	6.9	9.9	≥7.0 & ≤9.0	1, 7	0%, 3%
Turbidity (NTUs)	0.1	276	9.4	4.2	0.0	150.6	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	277	334	371	-70	491	-----	-----	-----
Secchi Depth (in.)	1	15	47	44	15	96	-----	-----	-----
Alkalinity, Total (mg/l)	0.6	30	262.5	255.0	146.0	383.0	-----	-----	-----
Ammonia, Total (mg/l)	0.02	30	0.42	0.37	n.d.	2.04	5.7[1,2], 1.2 [1,3]	0, 1	0%, 3%
Carbon, Total Organic (mg/l)	0.2	30	13.3	13.8	2.1	27.1	-----	-----	-----
Carbon, Dissolved Organic (mg/l)	0.2	10	13.5	13.6	11.5	15.5	-----	-----	-----
Biological Oxygen Demand 5 (mg/l)	0.8	10	5.1	4.0	n.d.	13.0	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	3	277	0	0	0	0	-----	-----	-----
Chlorophyll a (ug/l) – Lab Determined	3	15	34	29	n.d.	127	-----	-----	-----
Dissolved Solids, Total (mg/l)	10	30	820	940	350	1250	-----	-----	-----
Hardness, Total (mg/l)	0.32	3	492.93	495.30	386.00	597.50	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.08	28	2.11	2.03	1.20	-----		-----	-----
Nitrogen, Total (mg/l)	0.03	28	2.18	2.12	1.54	3.19	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	30	-----	0.00	n.d.	0.40	1.0	0	0%
Phosphorus, Total (mg/l)	0.005	30	0.397	0.385	0.010	1.120	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.003	30	0.308	0.295	n.d.	1.140	-----	-----	-----
Sulfate, Total (mg/l)	0.4	30	350.2	431.5	117.0	511.0	250	20	67%
Suspended Solids, Total (mg/l)	4	30	11	11	n.d.	31	-----	-----	-----
Arsenic, Total (ug/l)	8	3	9	7	7	13	340[2], 150[3], 10[4]	1	33%
Beryllium, Total (ug/l)	1	3	-----	n.d.	n.d.	n.d.	4[4]	0	0%
Cadmium, Total (ug/l)	0.007	3	-----	n.d.	n.d.	0.060	30[2], 9[3]	0	0%
Chromium, Total (ug/l)	4	3	-----	n.d.	n.d.	n.d.	7,120[2], 340[3]	0	0%
Copper, Total (ug/l)	6	3	-----	n.d.	n.d.	n.d.	67[2], 38[3]	0	0%
Lead, Total (ug/l)	0.008	3	-----	n.d.	n.d.	0.200	674[2], 26[3]	0	0%
Mercury, Total (ug/l)	0.002	3	-----	0.010	n.d.	0.020	1.7[2], 0.012[3], 0.05[4]	1	33%
Zinc, Total (ug/l)	6	3	-----	n.d.	n.d.	4	496[2,3]	0	0%
Microcystin (ug/l)	0.1	15	-----	n.d.	n.d.	0.3	-----	-----	-----
Acetochlor, Total (ug/l)(C)	0.07	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Atrazine, Total (ug/l)(C)	0.07	3	-----	n.d.	n.d.	0.25	3[4]	0	0%
Metolachlor, Total (ug/l)(C)	0.05	3	-----	n.d.	n.d.	n.d.	40[4]	0	0%
Pesticide Scan (ug/l)(D)	0.05	3	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, 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) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

(2) Acute criterion for aquatic life.

(3) Chronic criterion for aquatic life.

Note: North Dakota's chronic WQS criterion for Mercury was below the detection limit during the reporting period.

(4) Human health criterion for surface waters.

Note: North Dakota's WQS criteria for metals are based on total recoverable, some analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, metolachlor, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted percent exceedence indicates use impairment based on State of North Dakota's 2016 Section 303(d) impairment assessment criteria.

Plate 4-12. Summary of water quality conditions monitored in Pipestem Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site PIPLKML1) from May to September during during 2010, 2012, and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column profile measurements.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	9	1450.1	1444.8	1442.4	1470.1	-----	-----	-----
Water Temperature (°C)	0.1	173	19.2	19.1	9.6	27.7	29.0	0	0%
Secchi Depth (in.)	1	14	33	28	12	79	-----	-----	-----
Turbidity (NTUs)	0.1	173	14.3	9.0	0.0	241.7	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	173	347	376	142	422	-----	-----	-----
Specific Conductance (umho/cm)	1	173	1140	1312	544	1728	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	173	8.4	8.7	0.0	17.3	≥ 5	20	12%
Dissolved Oxygen (% Sat.)	0.1	173	95.0	93.7	0.0	222.3	-----	-----	-----
CBOD, 5-Day (mg/l)	0.8	10	-----	5.5	n.d.	14.0	-----	-----	-----
pH (S.U.)	0.1	173	8.3	8.4	7.5	9.8	≥7.0 & ≤9.0	0,8	0%,5%
Alkalinity, Total (mg/l)	0.6	10	264.8	262.5	247.0	286.0	-----	-----	-----
Dissolved Solids, Total (mg/l)	10	10	972	964	864	1070	-----	-----	-----
Suspended Solids, Total (mg/l)	0.02	10	22.20	21.50	9.00	47.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	10	-----	0.25	n.d.	0.77	5.7[1,2], 1.2 [1,3]	0,0	0%, 0%
Kjeldahl N, Total (mg/l)	0.08	10	2.25	2.20	1.56	3.06	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	10	-----	n.d.	n.d.	0.38	-----	-----	-----
Phosphorus, Total (mg/l)	0.005	10	0.229	0.220	0.050	0.460	-----	-----	-----
Phosphorus, Dissolved (mg/l)	0.01	10	0.16	0.12	n.d.	0.39	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.003	10	0.142	0.115	n.d.	0.390	-----	-----	-----
Total Organic Carbon (mg/l)	0.2	10	14.3	14.6	10.9	16.6	-----	-----	-----
Dissolved Organic Carbon (mg/l)	0.2	10	13.7	14.3	11.1	15.2	-----	-----	-----
Sulfate, Total (mg/l)	0.4	10	447.5	455.5	411.0	464.0	≥ 250	5	100%
Silica, Total (mg/l)	0.02	5	2.88	2.84	1.47	4.44	-----	-----	-----
Iron, Total (ug/l)	10	9	414	360	80	1080	-----	-----	-----
Manganese, Total (ug/l)	3	9	846	730	480	1240	-----	-----	-----
CDOM (ug/l)	10	10	101	109	69	119	-----	-----	-----
Chlorophyll a (ug/l) – Lab Determined	3	5	39	41	3	70	-----	-----	-----
Nitrogen, Total (mg/l)	0.03	10	2.33	2.22	1.83	3.06	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, 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) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

(2) Acute criterion for aquatic life.

(3) Chronic criterion for aquatic life.

* A highlighted percent exceedence indicates use impairment based on State of North Dakota's 2016 Section 303(d) impairment assessment criteria.

Plate 4-13. Summary of water quality conditions monitored in Pipestem Reservoir at the up-lake ambient monitoring location (i.e., site PIPLKUP1) from May to September during during 2010, 2012, and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column profile measurements.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[(A)]	Median	Min.	Max.	State WQS Criteria[(B)]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	10	1450.9	1446.4	1442.4	1470.1	-----	-----	-----
Water Temperature (°C)	0.1	96	18.5	18.0	7.4	27.6	29.0	0	0%
Secchi Depth (in.)	1	14	23	18	8	60	-----	-----	-----
Turbidity (NTUs)	0.1	96	30.2	14.5	0.0	715.0	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	96	367	389	126	458	-----	-----	-----
Specific Conductance (umho/cm)	1	96	1107	1141	586	1590	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	96	8.5	8.9	0.4	13.4	≥ 5	20	12%
Dissolved Oxygen (% Sat.)	0.1	96	93.5	93.5	4.3	142.8	-----	-----	-----
CBOD, 5-Day (mg/l)	0.8	4	-----	5.0	n.d.	15.0	-----	-----	-----
pH (S.U.)	0.1	96	8.3	8.3	7.6	9.3	≥7.0 & ≤9.0	0,8	0%, 5%
Alkalinity, Total (mg/l)	0.6	4	274.3	268.5	260.0	300.0	-----	-----	-----
Dissolved Solids, Total (mg/l)	10	5	976	1010	852	1020	-----	-----	-----
Suspended Solids, Total (mg/l)	0.02	5	26.40	20.00	15.00	41.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	5	-----	0.29	n.d.	0.68	5.7[(1,2)], 1.2[(1,3)]	0,0	0%, 0%
Kjeldahl N, Total (mg/l)	0.08	5	2.18	2.24	1.50	3.19	-----	-----	-----
Nitrogen, Total (mg/l)	0.03	5	2.25	2.27	1.53	3.19	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	5	-----	0.03	n.d.	0.32	-----	-----	-----
Phosphorus, Total (mg/l)	0.005	5	0.276	0.290	0.080	0.550	-----	-----	-----
Phosphorus, Dissolved (mg/l)	0.01	5	0.2	0.2	n.d.	0.4	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.003	5	0.182	0.170	n.d.	0.420	-----	-----	-----
Total Organic Carbon (mg/l)	0.2	5	14.4	15.3	11.0	15.7	-----	-----	-----
Dissolved Organic Carbon (mg/l)	0.2	5	14.2	14.4	11.9	15.7	-----	-----	-----
Sulfate, Total (mg/l)	0.4	5	451.4	450.0	414.0	491.0	≥ 250	5	100%
Silica, Total (mg/l)	0.02	5	4.48	4.05	3.31	5.98	-----	-----	-----
Iron, Total (ug/l)	10	4	-----	235	n.d.	740	-----	-----	-----
Manganese, Total (ug/l)	3	4	735	695	640	910	-----	-----	-----
CDOM (ug/l)	10	5	108	108	69	144	-----	-----	-----
Chlorophyll a (ug/l) – Lab Determined	3	5	38	19	12	107	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, 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) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

(2) Acute criterion for aquatic life.

(3) Chronic criterion for aquatic life.

* A highlighted percent exceedence indicates use impairment based on State of North Dakota's 2016 Section 303(d) impairment assessment criteria.

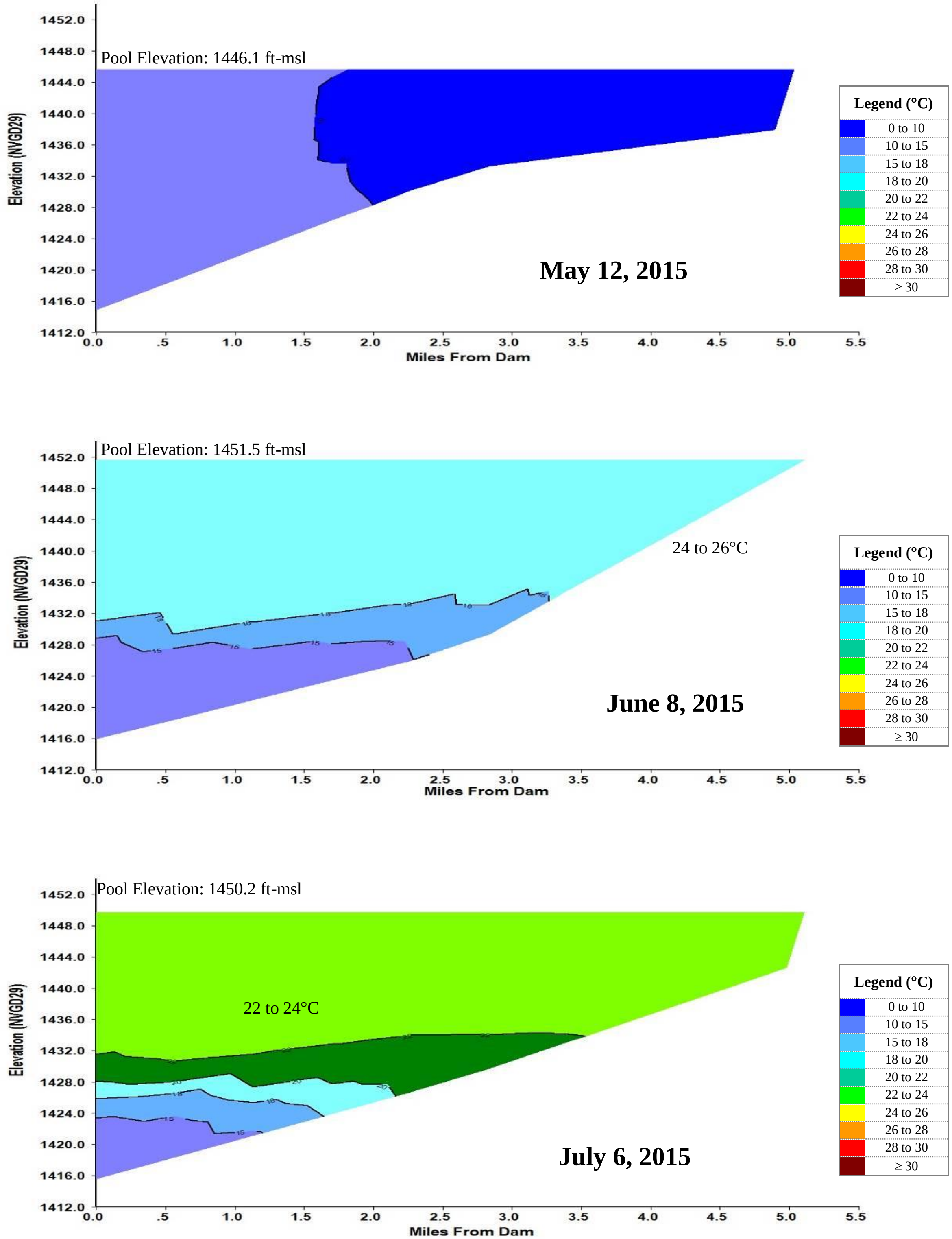
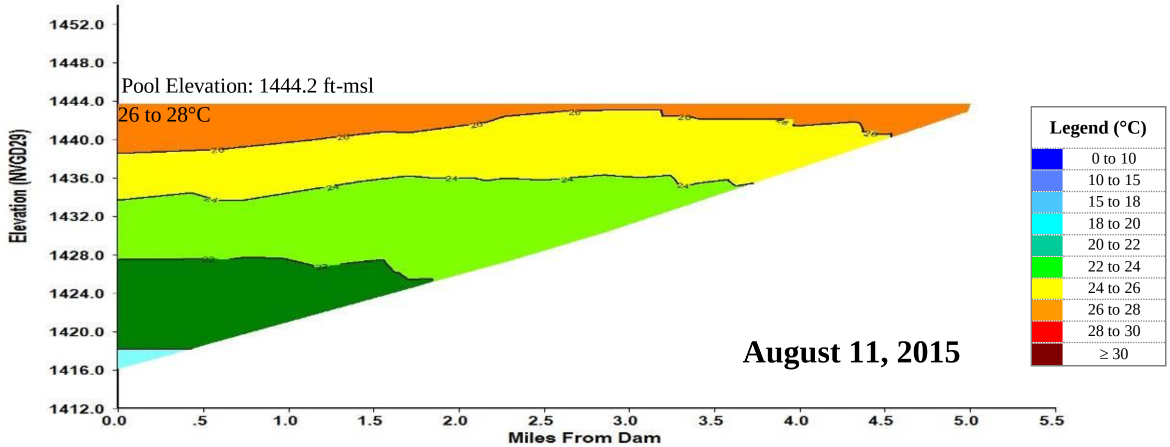


Plate 4-14. Longitudinal water temperature (°C) contour plots of Pipestem Reservoir based on depth-profile water temperatures measured at sites PIPLKND1, PIPLKML1, and PIPLKUP1 in 2015.



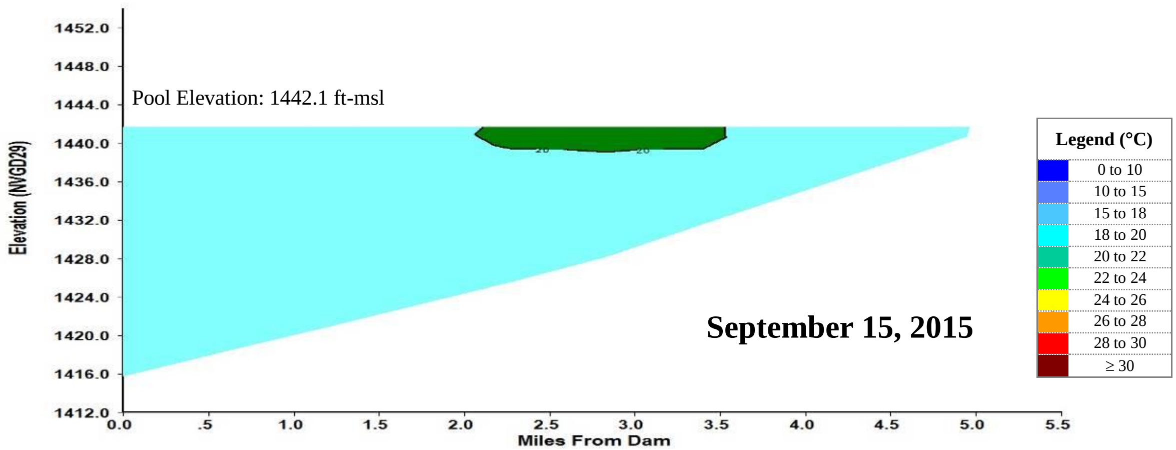


Plate 4-14. (Continued).

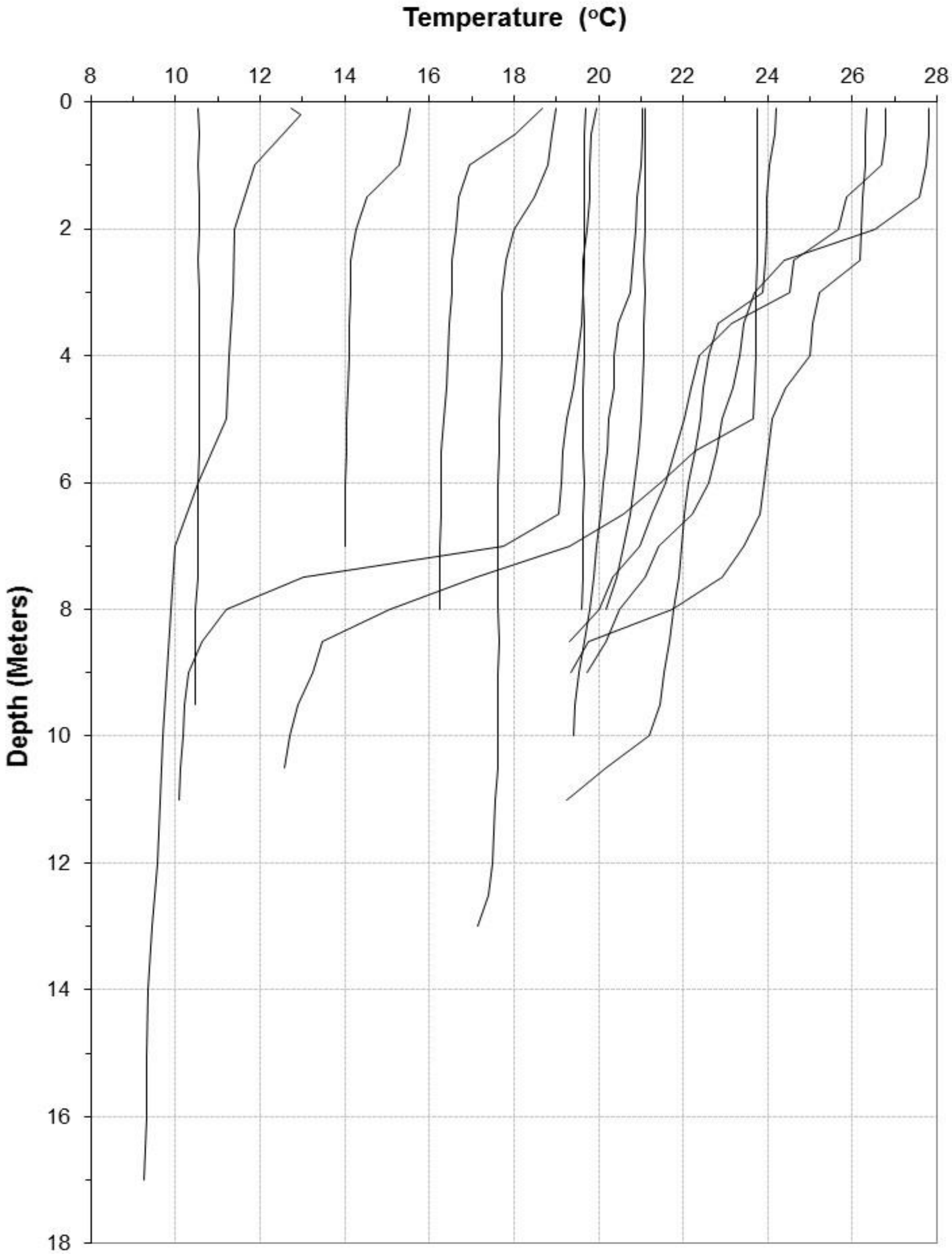


Plate 4-15. Temperature depth profiles for Pipestem Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PIPLKND1) during the summers of 2010, 2012, and 2015.

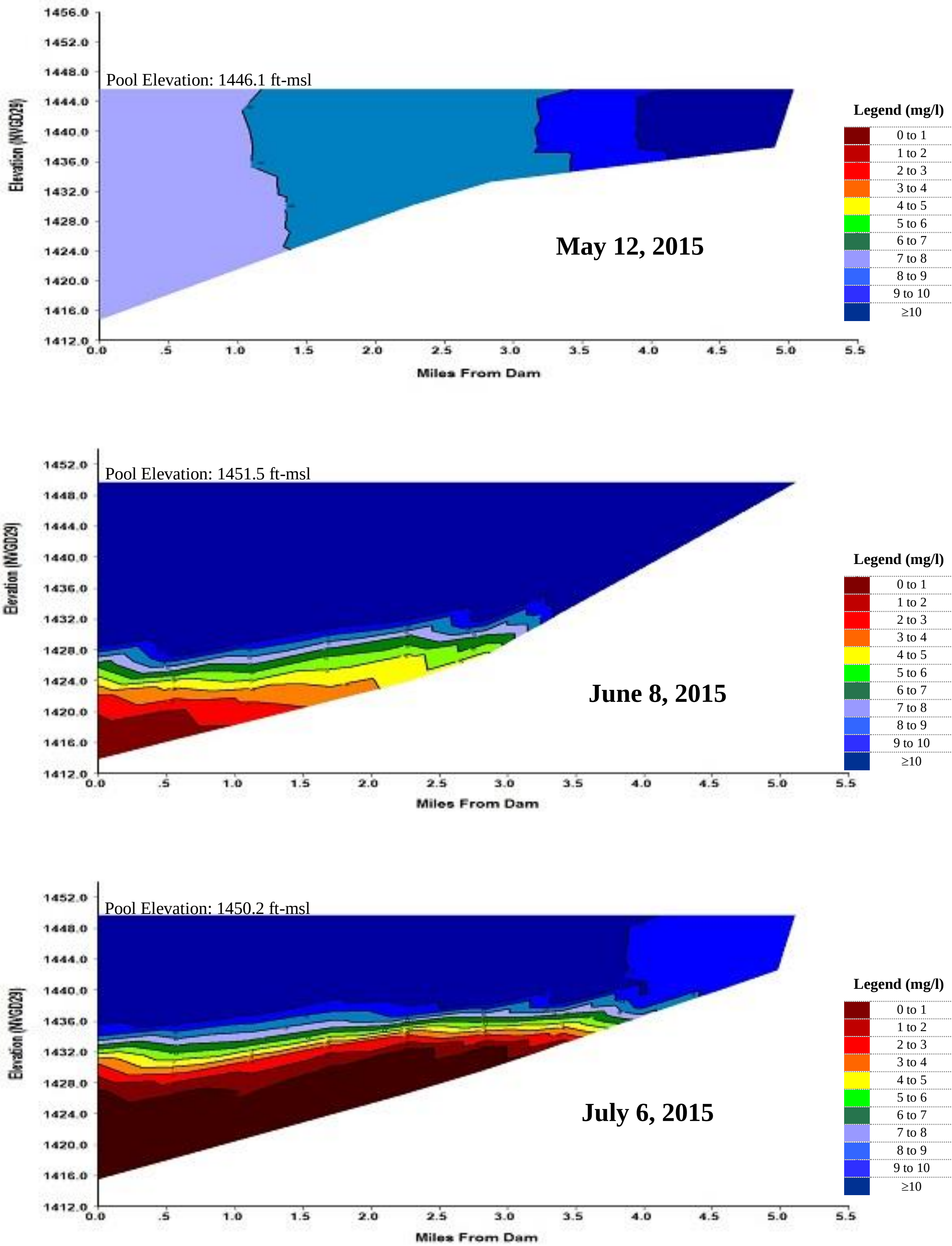
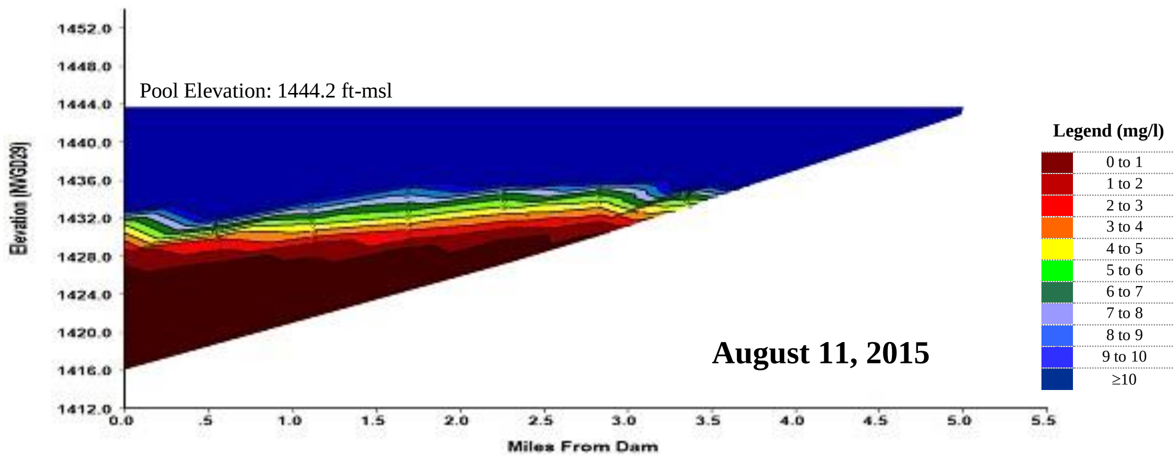


Plate 4-16. Longitudinal dissolved oxygen (mg/l) contour plots of Pipestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PIPLKND1, PIPLKML1, and PIPLKUP1 in 2015.



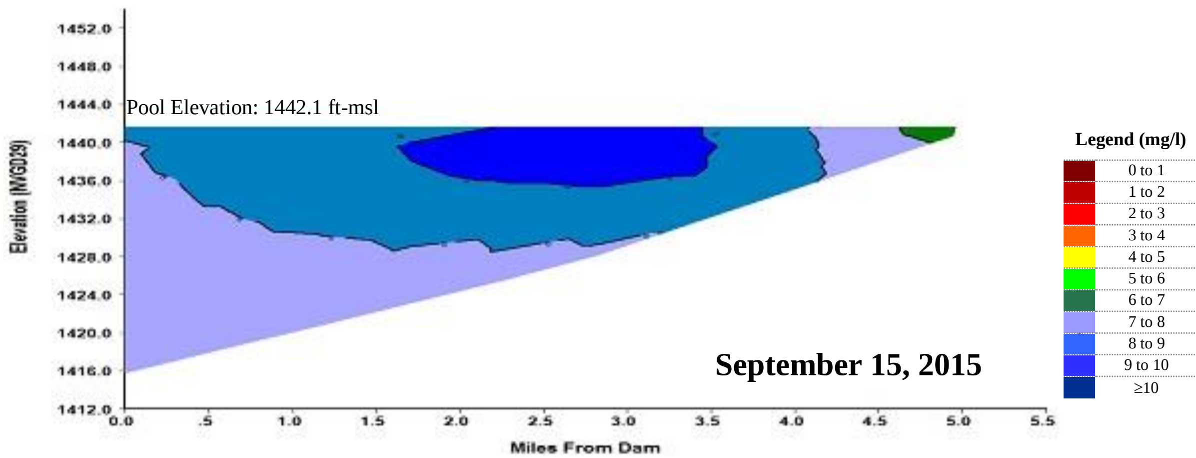


Plate 4-16. (Continued).

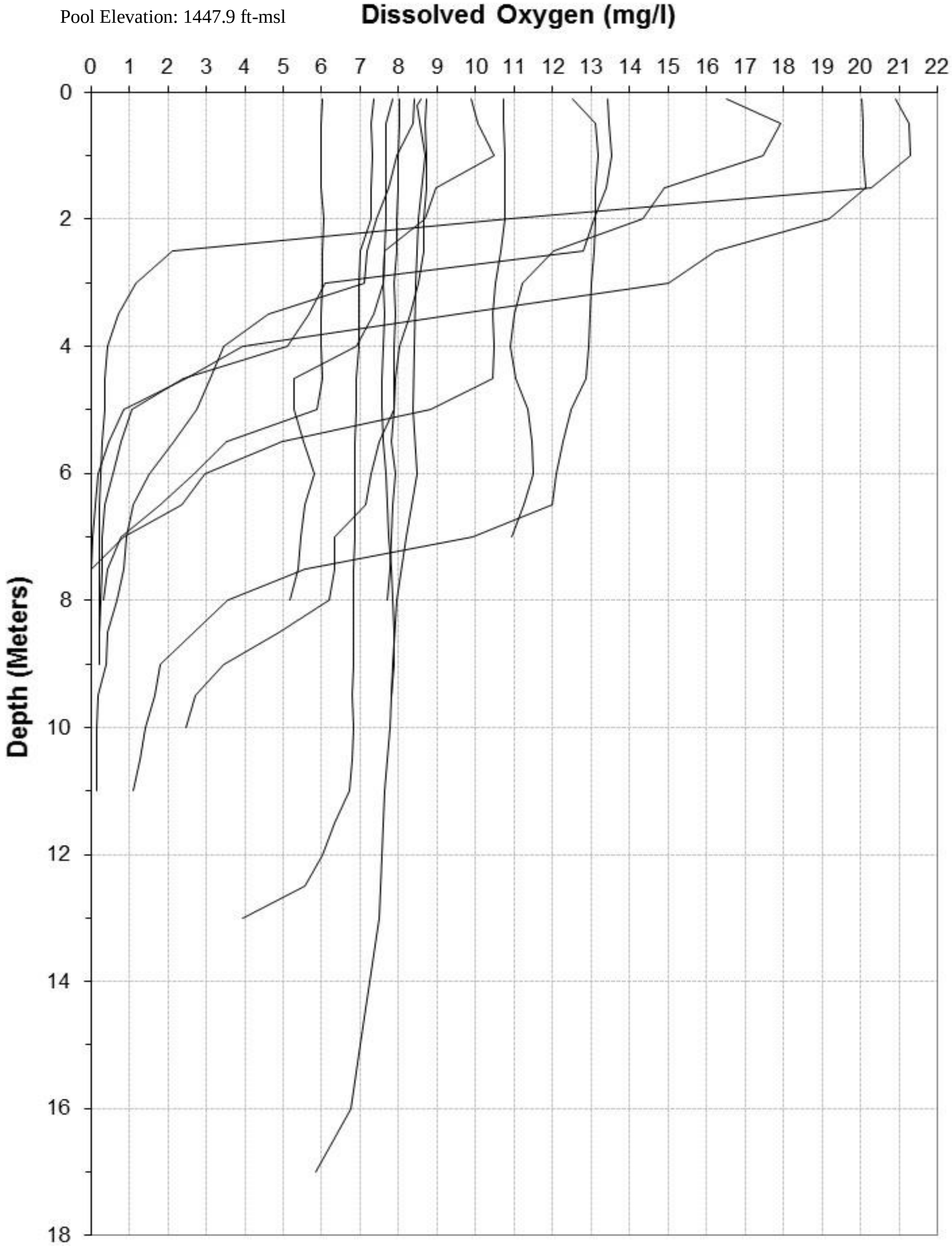


Plate 4-17. Dissolved oxygen depth profiles for Pipestem Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PIPLKND1) during the summers of 2010, 2012, and 2015.

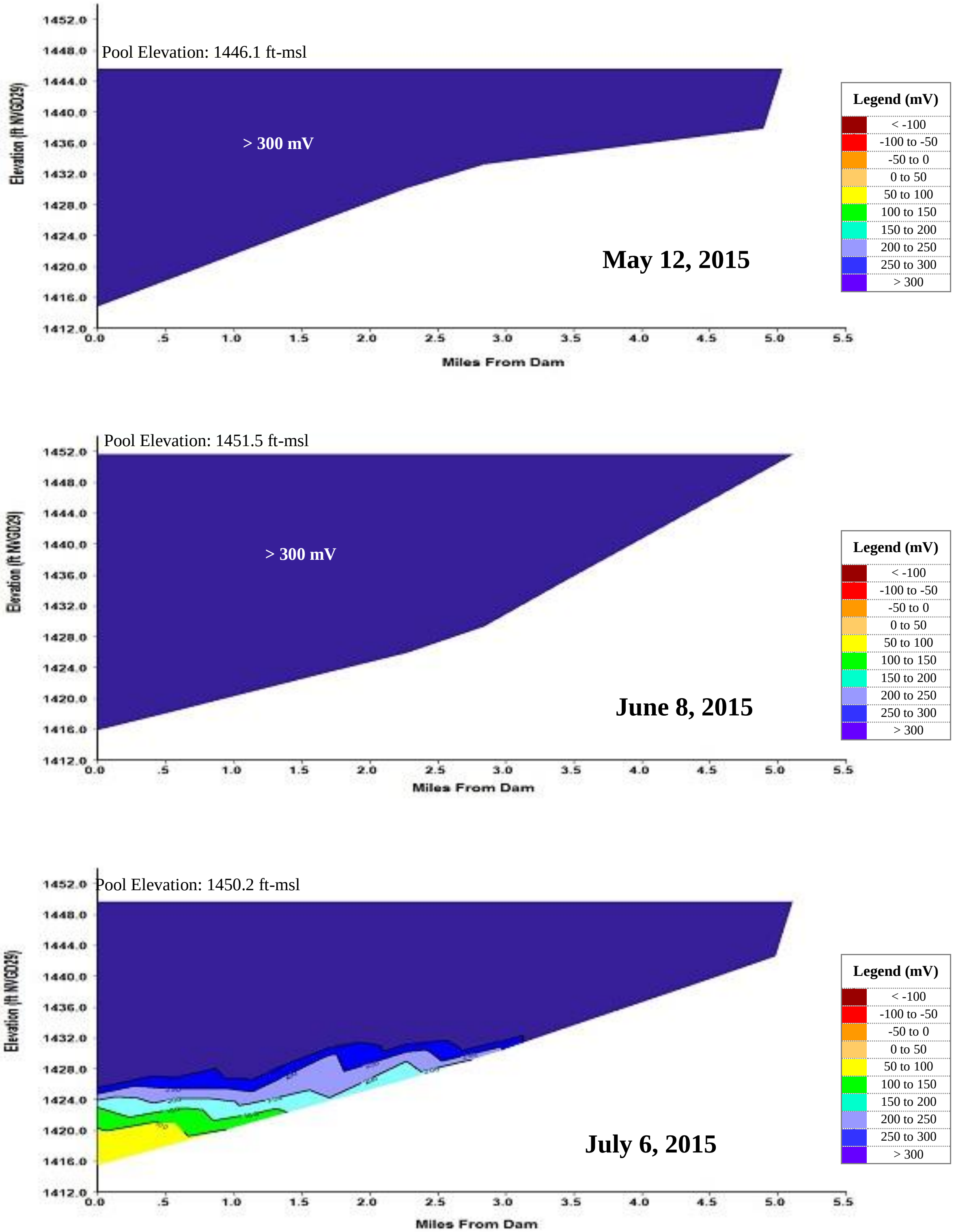
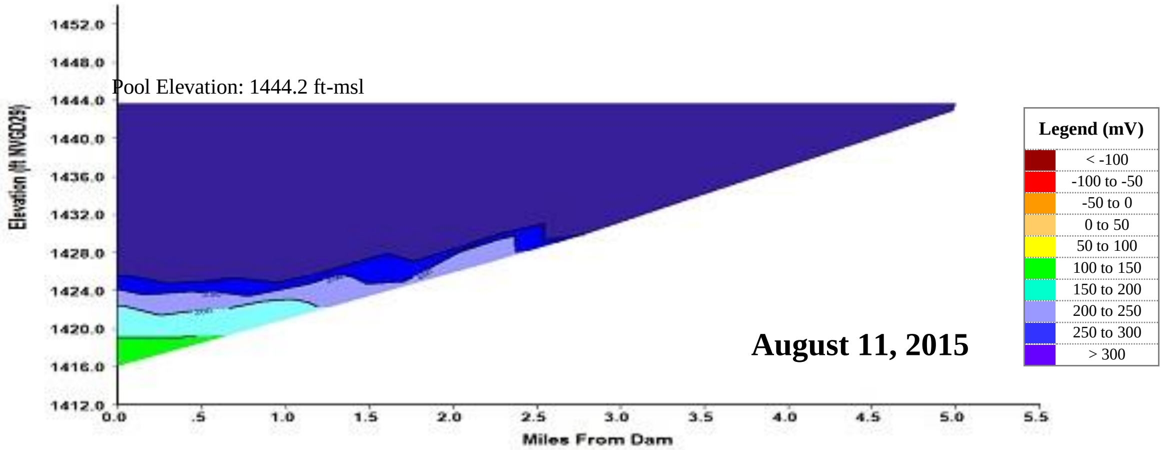


Plate 4-18. Longitudinal oxidation-reduction potential (mV) contour plots of Pipestem Reservoir based on depth-profile measurements at sites PIPLKND1, PIPLKML1, and PIPLKUP1 in 2015.



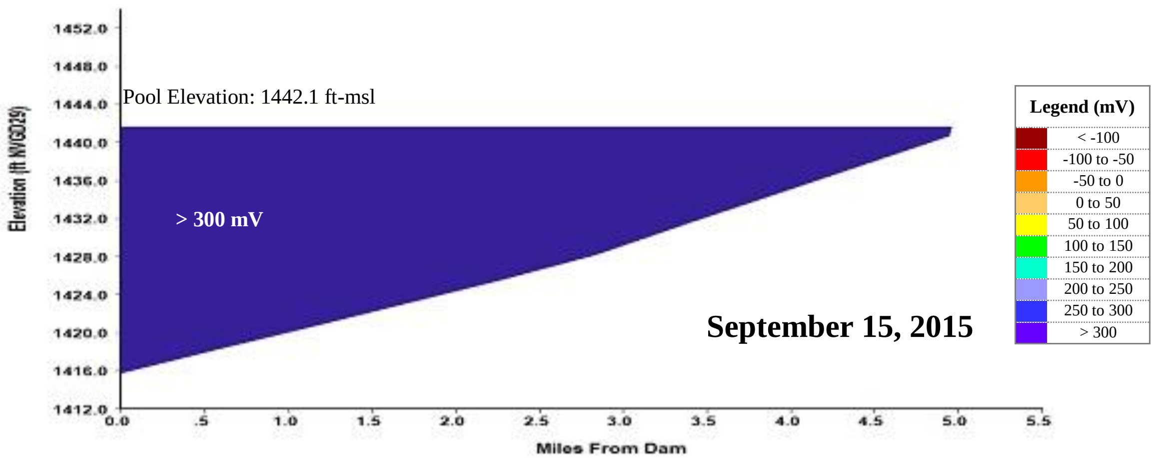


Plate 4-18. (Continued)

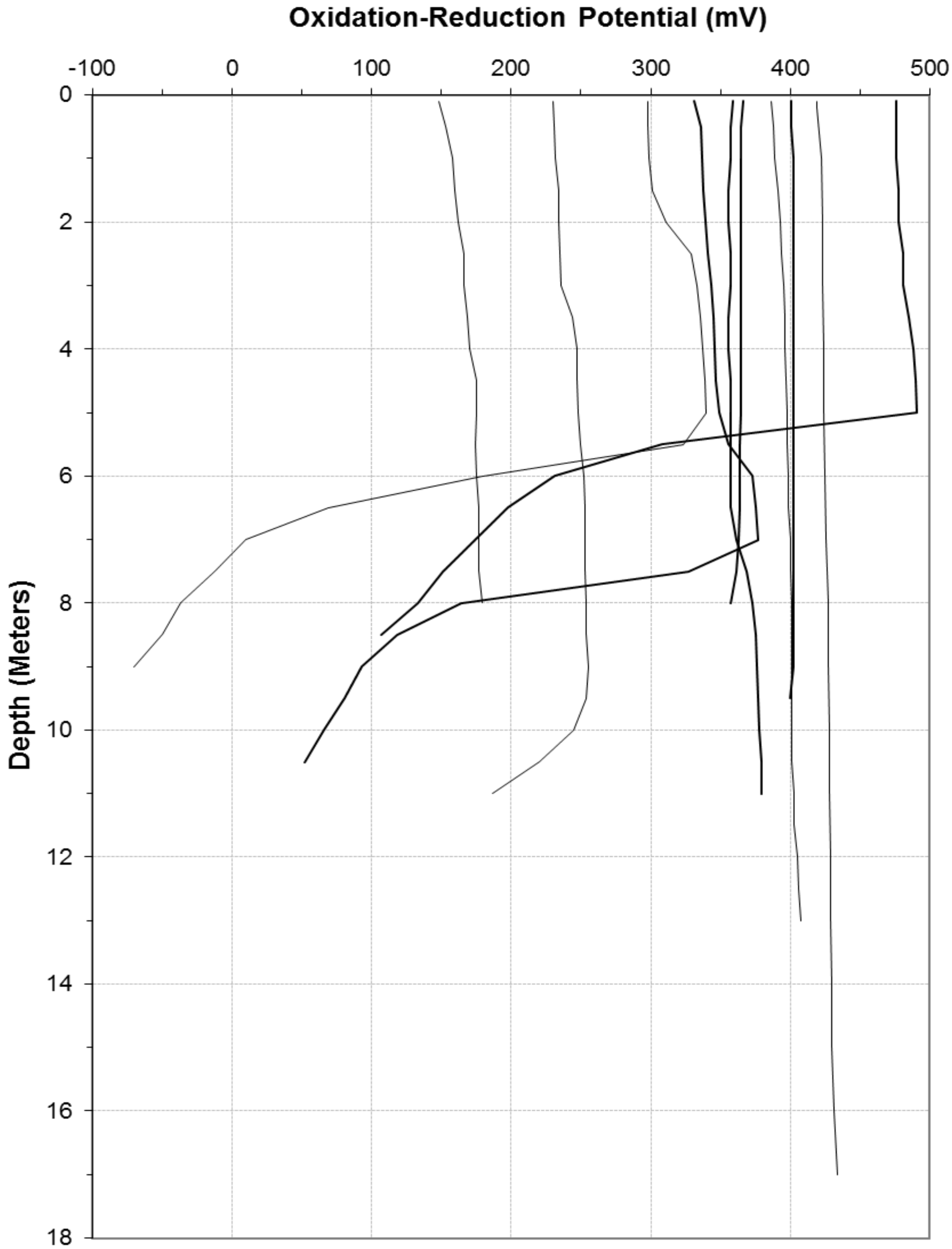
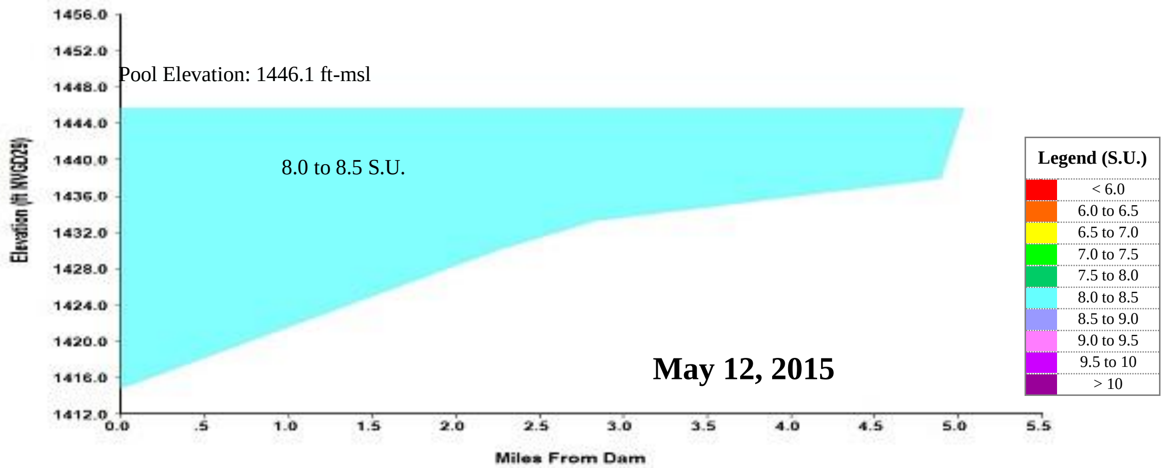
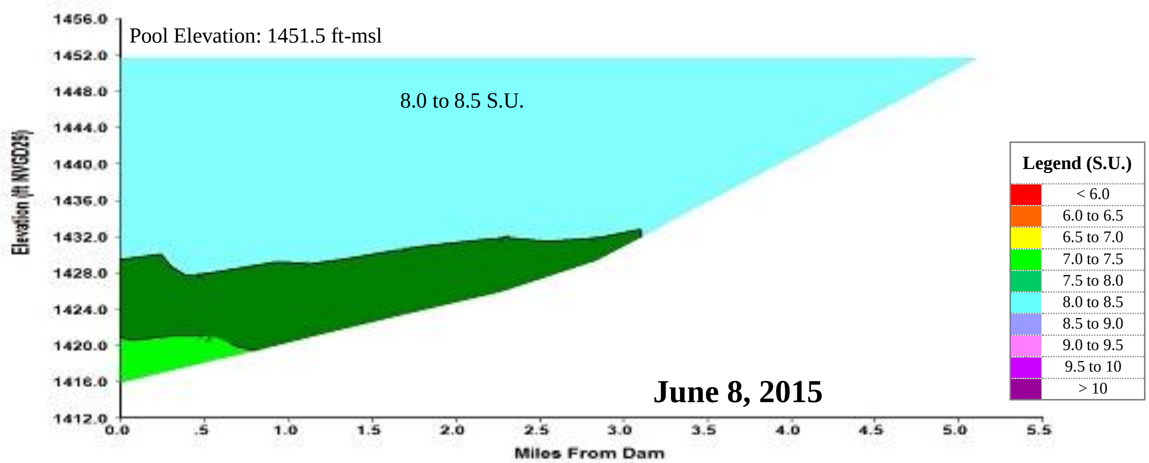


Plate 4-19. Oxidation-reduction potential depth profiles for Pipestem Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PIPLKND1) during the summers of 2010, 2012, and 2015.





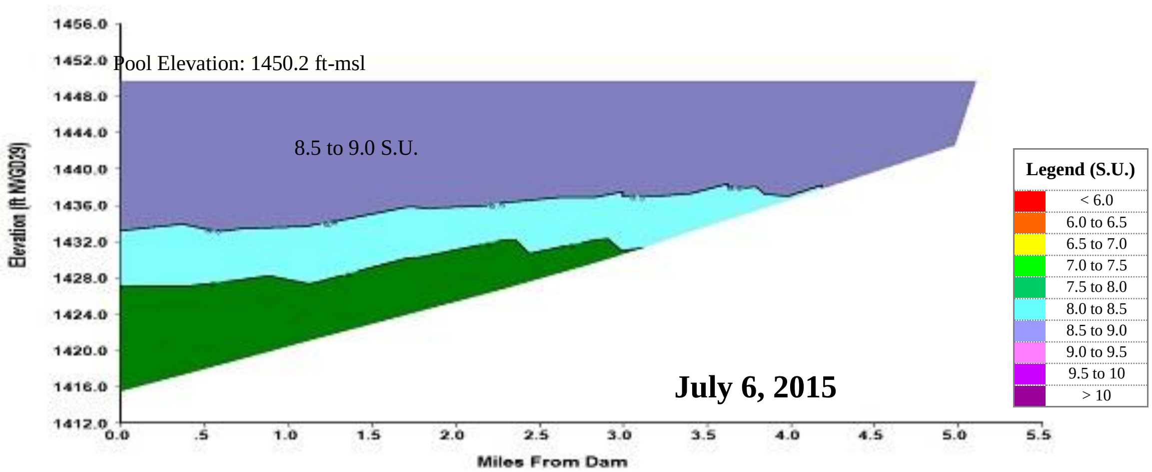
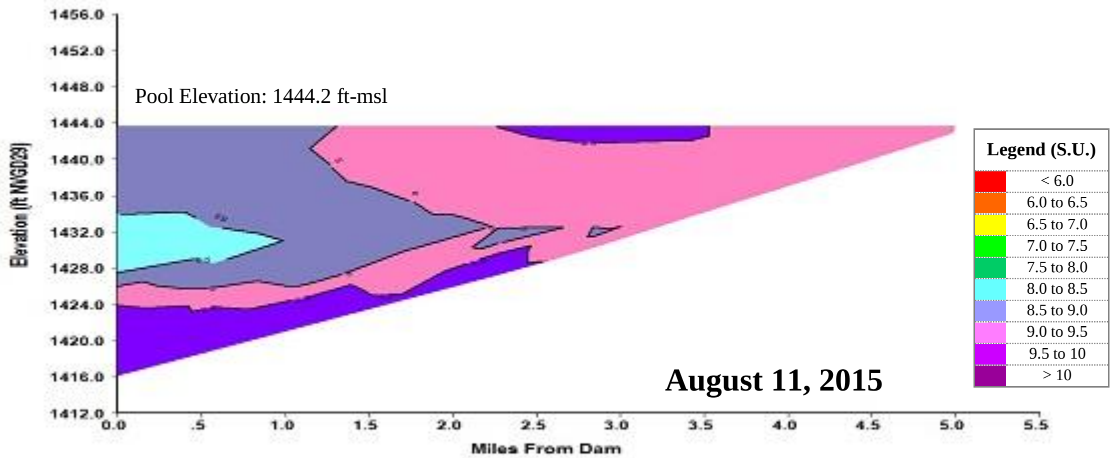


Plate 4-20. Longitudinal pH (S.U.) contour plots of Pipestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PIPLKND1 and PIPLKML1 in 2015.



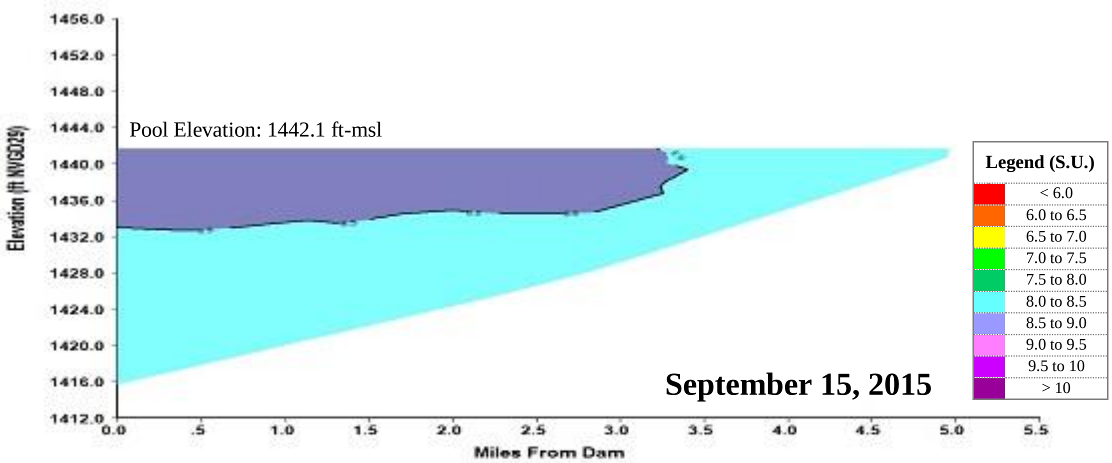


Plate 4-20. (Continued).

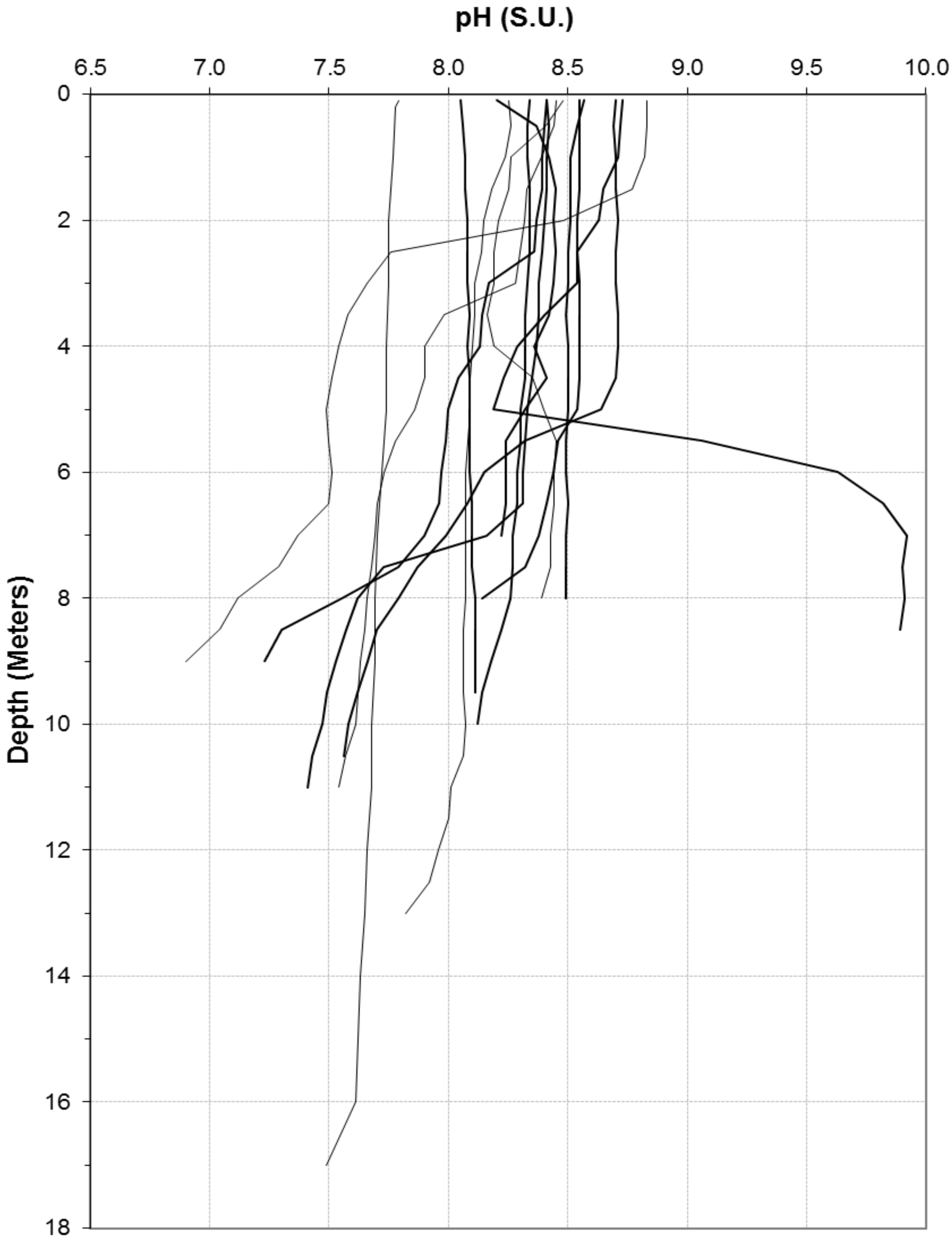


Plate 4-21. pH depth profiles for Pipestem Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PIPLKND1) during the summers of 2010, 2012, and 2015.

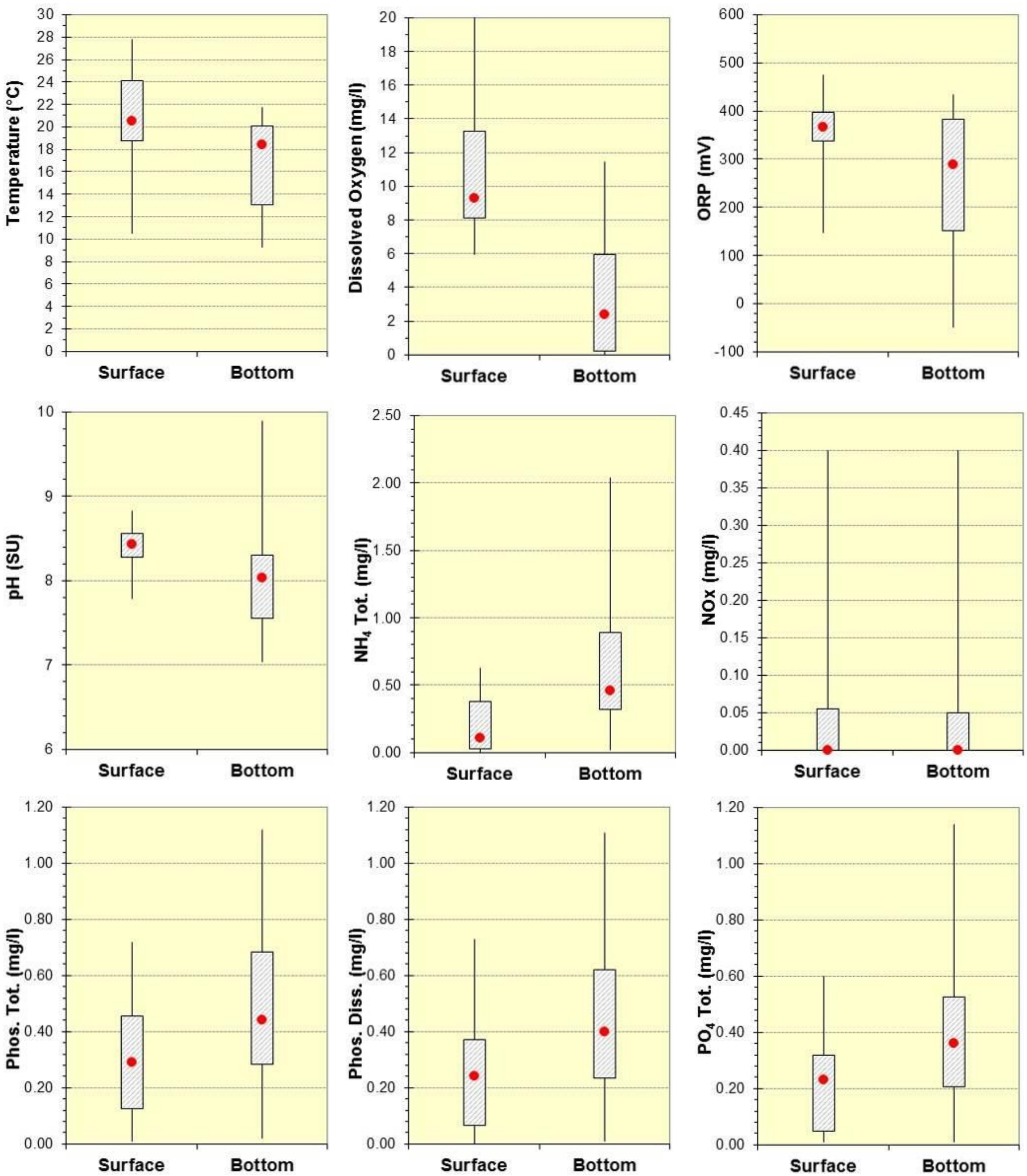
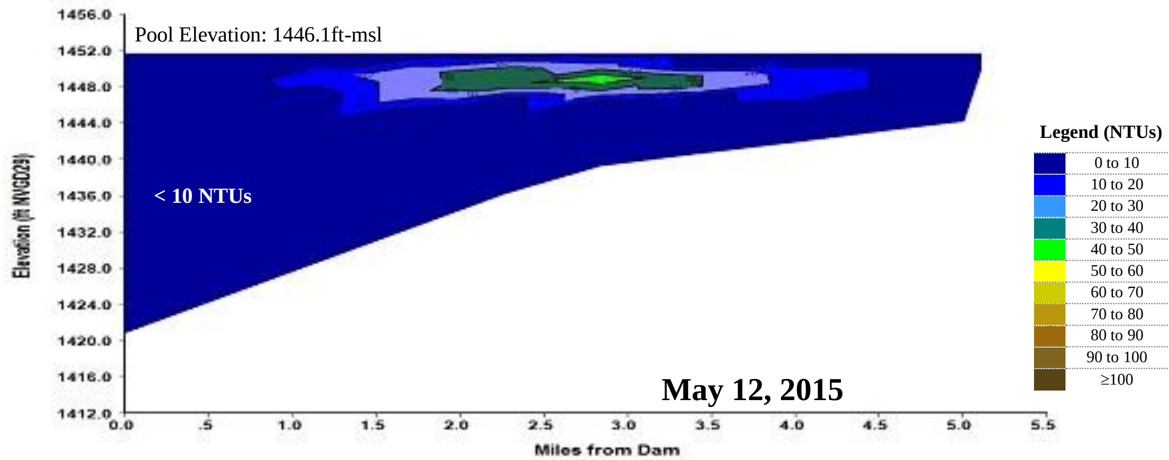
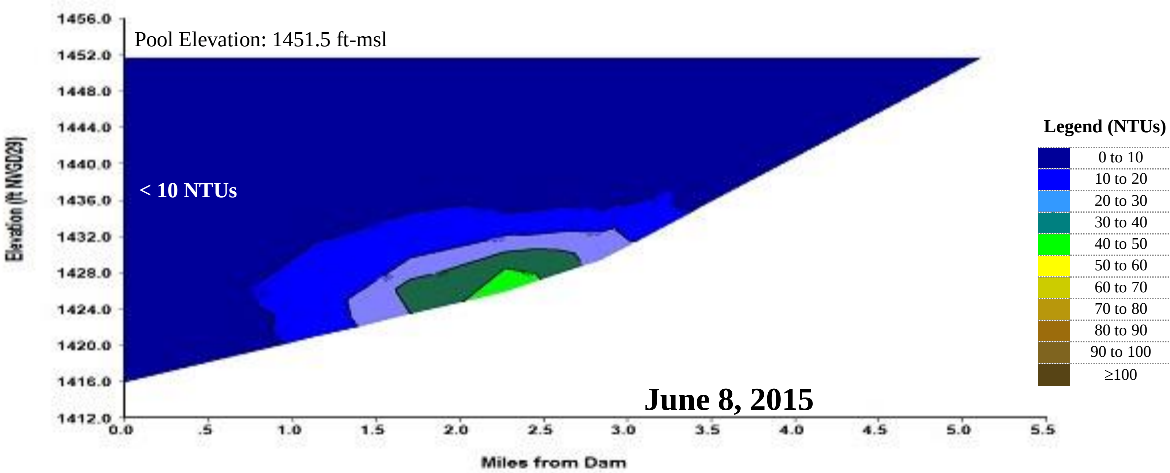


Plate 4-22. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, total ammonia nitrogen, nitrate-nitrite nitrogen, total phosphorus, dissolved phosphorus, and ortho-phosphorus measured in Pipestem Reservoir during 2010, 2012, and 2015. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)





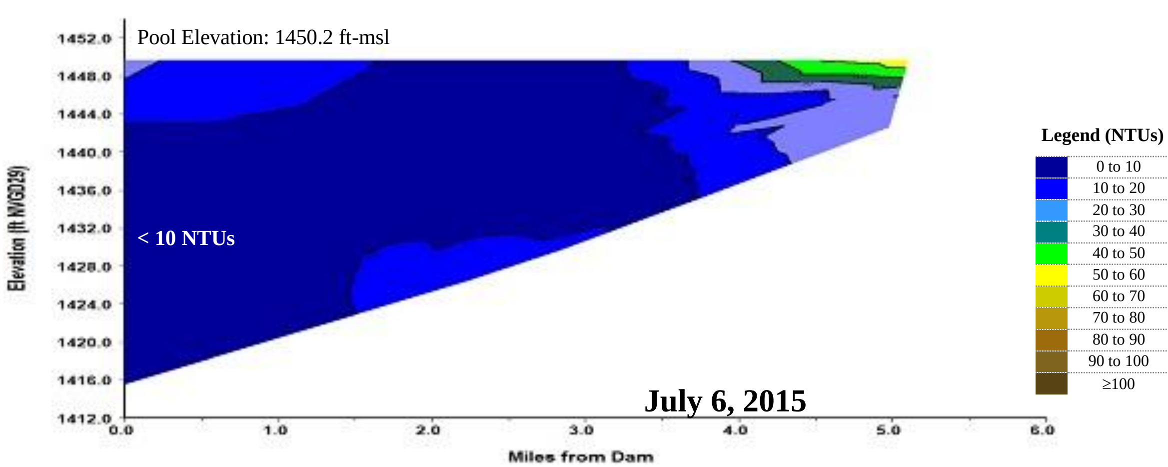
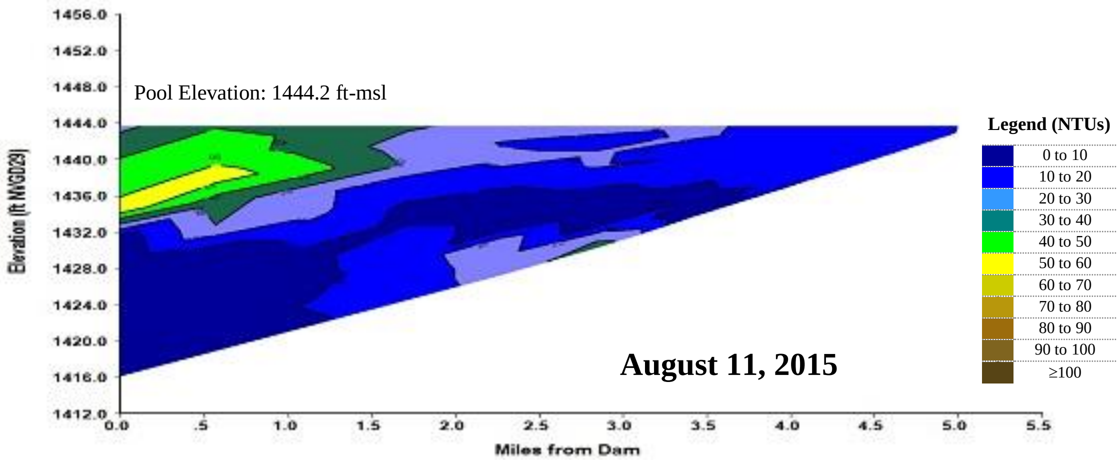


Plate 4-23. Longitudinal turbidity (NTU) contour plots of Pipestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PIPLKND1 and PIPLKML1 in 2015.



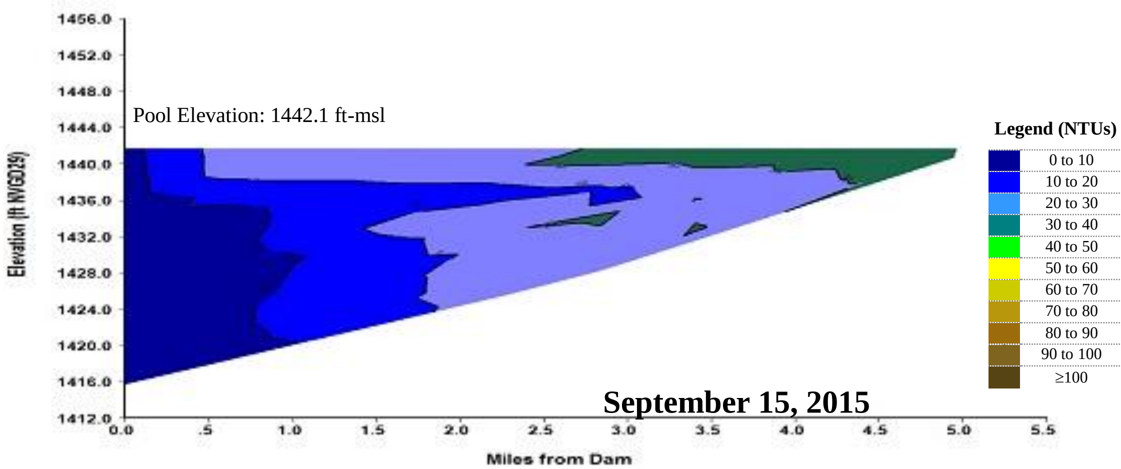


Plate 4-23. (Continued).

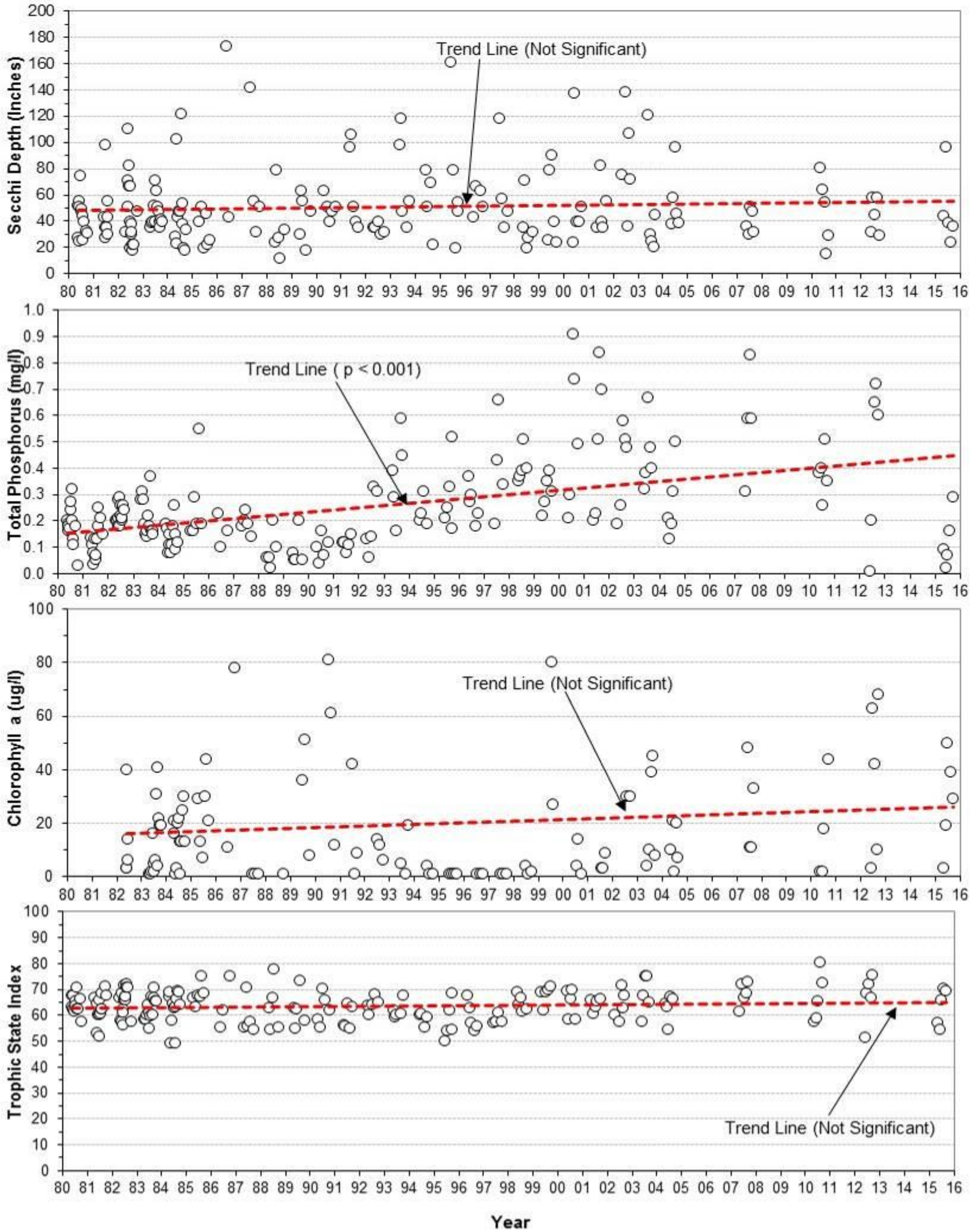


Plate 4-24. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Pipestem Reservoir at the near-dam, ambient site (i.e., site PIPLKND1) over the 36-year period 1980 through 2015.

Plate 4-25. Summary of runoff water quality conditions monitored in Pipestem Creek upstream from Pipestem Reservoir at monitoring site PIPNF1 during 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 Exceedences**	**Percent WQS Exceedence**
Stream Flow (cfs)	0.01	7	11.74	6.20	0.04	37.00	-----	-----	-----
Water Temperature (°C)	0.1	7	19.2	19.7	6.7	30.0	29.0	1	14%
Turbidity (NTUs)	0.1	7	32.5	24.1	12.2	82.2	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	7	408	395	334	495	≥ 5	0	0%
Specific Conductance (umho/cm)	0.1	7	1443.7	1405.0	1334.0	1652.0	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	7	10.3	10.6	6.3	12.7	≥ 5	0	0%
Dissolved Oxygen (% Sat.)	0.1	7	116.7	120.0	71.1	151.3	-----	-----	-----
CBOD, 5-Day (mg/l)	0.1	8	-----	4.0	n.d.	7.0	-----	-----	-----
pH (S.U.)	0.1	7	8.3	8.3	8.2	8.4	≥7.0 & ≤9.0	0, 0	0%, 0%
Alkalinity, Total (mg/l)	0.6	8	335.5	340.5	285.0	358.0	-----	-----	-----
Dissolved Solids, Total (mg/l)	4	7	1066	1050	954	1240	-----	-----	-----
Suspended Solids, Total (mg/l)	4	7	52	39	27	119	-----	-----	-----
Ammonia, Total (mg/l)	0.02	7	-----	n.d.	n.d.	n.d.	2.6 [1,2], 1.2[1,3]	0	0%
Kjeldahl N, Total (mg/l)	0.03	7	1.69	1.69	1.21	2.69	-----	-----	-----
Nitrogen, Total (mg/l)	0.03	7	1.71	1.69	1.21	2.69	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	7	-----	n.d.	n.d.	0.11	1.0	0	0%
Phosphorus, Total (mg/l)	0.005	7	0.239	0.230	0.090	0.430	-----	-----	-----
Phosphorus, Dissolved (mg/l)	0.01	7	0.1	0.1	0.0	0.2	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.003	7	0.071	0.060	0.009	0.180	-----	-----	-----
Total Organic Carbon (mg/l)	0.2	7	12.6	12.6	9.2	15.1	-----	-----	-----
Dissolved Organic Carbon (mg/l)	0.2	7	12.0	12.5	8.0	15.1	-----	-----	-----
Sulfate, Dissolved (mg/l)	0.4	7	448.14	434.00	375.00	556.00	250	7	100%
Silica, Total (mg/l)	0.02	7	9.11	9.35	6.76	10.95	-----	-----	-----
Iron, Total (ug/l)	10	7	1203	950	640	2650	-----	-----	-----
Manganese, Total (ug/l)	3	7	666	620	270	960	-----	-----	-----
CDOM (ug/l)	10	7	90	96	48	132	-----	-----	-----
Chlorophyll a (ug/l) – Lab Determined	3	7	27	23	17	49	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, 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) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

(2) Acute criterion for aquatic life.

(3) Chronic criterion for aquatic life.

Note: North Dakota's chronic WQS criterion for Mercury was below the detection limit during the reporting period.

Plate 4-26. Summary of runoff water quality conditions monitored in The releases from from Pipestem Reservoir at monitoring site PIPRL1 during 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 Exceedences	Percent WQS Exceedence
Stream Flow (cfs)	0.01	4	94.45	105.30	11.20	156.00	-----	-----	-----
Water Temperature (°C)	0.1	4	22.5	22.0	20.0	25.9	29.0	0	0%
Turbidity (NTUs)	0.1	4	13.9	8.3	0.0	39.0	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	4	344	350	308	370	-----	-----	-----
Specific Conductance (umho/cm)	1	4	1317	1313	1301	1343	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	4	8.9	8.7	8.2	10.1	≥ 5	0	0%
Dissolved Oxygen (% Sat.)	0.1	4	108.1	108.6	96.5	118.9	-----	-----	-----
CBOD, 5-Day (mg/l)	0.8	4	6.3	5.0	4.0	11.0	-----	-----	-----
pH (S.U.)	0.1	4	8.8	8.5	8.4	9.7	≥7.0 & ≤9.0	0, 1	0%, 25%
Alkalinity, Total (mg/l)	0.6	4	251.5	246.0	242.0	272.0	-----	-----	-----
Dissolved Solids, Total (mg/l)	10	4	947	954	912	968	-----	-----	-----
Suspended Solids, Total (mg/l)	0.02	4	26.75	27.00	14.00	39.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	4	0.20	0.20	0.10	0.30	2.1 (1,2), 1(1,3)	0	0%
Kjeldahl N, Total (mg/l)	0.08	4	2.27	2.19	1.64	3.05	-----	-----	-----
Nitrogen, Total (mg/l)	0.03	4	2.38	2.38	1.68	3.09	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	4	-----	0.04	n.d.	0.38	1.0	0	0%
Phosphorus, Total (mg/l)	0.005	4	0.21	0.18	0.05	0.44	-----	-----	-----
Phosphorus, Dissolved (mg/l)	0.01	4	0.13	0.11	n.d.	0.29	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.003	4	0.12	0.09	0.02	0.27	-----	-----	-----
Total Organic Carbon (mg/l)	0.2	4	14.6	14.4	13.7	15.8	-----	-----	-----
Dissolved Organic Carbon (mg/l)	0.2	4	14.3	14.3	13.2	15.6	-----	-----	-----
Sulfate, Total (mg/l)	0.4	4	459.5	462.0	448.0	466.0	250	4	100%
Iron, Total (ug/l)	10	4	230	165	80	510	-----	-----	-----
Manganese, Total (ug/l)	3	4	700	610	470	1110	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, 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) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

(2) Acute criterion for aquatic life.

(3) Chronic criterion for aquatic life.

Note: North Dakota's chronic WQS criterion for Mercury was below the detection limit during the reporting period.

5 SOUTH DAKOTA TRIBUTARY PROJECTS

Two District Tributary Projects are located in South Dakota: Cold Brook and Cottonwood Springs. Cold Brook and Cottonwood Springs reservoirs are located in southwest South Dakota in the Black Hills area near Hot Springs, South Dakota (Figure 1.1). Table 5-1 gives selected engineering data for the Cold Brook and Cottonwood Springs Projects.

5.1 COLD BROOK RESERVOIR

5.1.1 BACKGROUND INFORMATION

5.1.1.1 Project Overview

The dam forming Cold Brook Reservoir is located on Cold Brook Creek, approximately 1-mile upstream from its confluence with the Fall River, and 2 miles north of Hot Springs, South Dakota. The dam was completed in September 1952 and the reservoir reached its initial fill in June 1963. The Cold Brook Reservoir watershed is 70.5 square miles. The watershed was largely rangeland and forested when the dam was built in 1952 and has remained so to the present time. The authorized project purposes of Cold Brook Reservoir are flood control, recreation, fish and wildlife, and water quality.

5.1.1.2 Cold Brook Dam Intake Structure

The intake structure at Cold Brook Dam is a circular (6.67 ft inside diameter) freestanding tower of reinforced concrete having an ungated bell-mouthed entrance. Supported on four buttress-type spread footings, the tower stands in the deepest part of the reservoir, about 70 feet upstream from the toe of the dam. The crest of the bell-mouthed entrance is at elevation 3600.0 ft-msl. Four port openings, each 1.2 feet high by 3.0 feet wide, are spaced evenly around the periphery of the vertical tower at elevation 3585.0 ft-msl, which is the upper limit of the conservation pool. Lowering of the surface of the conservation pool to a minimum elevation of 3548 ft-msl is accomplished by manual control of three 12-inch gate values located in the footings of the tower which discharge through the openings into the conduit.

Three 8-inch diameter inlets were originally provided at elevations 3580.0, 3560.0, and 3548.0 ft-msl as intakes for the Larvie Lake supply line. The inlets were modified in 1978 to enhance the water supply to Larvie Lake. The lowest inlet (i.e., elevation 3548.0 ft-msl) was located on the bottom of the reservoir and was abandoned due to the excessive amount of silts that were captured by the inlet and passed to Larvie Lake. Inlet covers were placed on both faces of the inlet at this elevation to seal the opening. Similar inlet covers were placed on the left side of the structure legs over the inlets at 3580.0 and 3560.0 ft-msl. Slide gates were placed over the right side of the inlet openings. A gate stem was extended from the gates to the grating deck where a gate lift mechanism was constructed to the structure leg.

5.1.1.3 Reservoir Storage Zones

Figure 5.1 depicts the current storage zones of Cold Brook Reservoir based on 1972 computations. The District has not conducted sediment surveys at Cold Brook Reservoir; therefore, the current amount of sedimentation has not been estimated and is unknown.

Table 5-1. Summary of selected engineering data for the Cold Brook and Cottonwood Springs Projects.

	Cold Brook Reservoir	Cottonwood Springs Reservoir
General		
Dammed Stream	Cold Brook Creek	Cottonwood Springs Creek
Drainage Area	70.5 sq. mi.	26 sq. mi.
Reservoir Length[1]	1.2 miles	0.6 miles
Multipurpose Pool Elevation (Top)	3585.0 ft-msl	3875.0 ft-msl
Date of Dam Closure	September 1952	May 1969
Date of Initial Fill[2]	June 1963	Not yet reached
"As-Built" Conditions[3]	(1972 Computations)	(1971 Computations)
Lowest Reservoir Bottom Elevation	3539 ft-msl	3839 ft-msl
Surface Area at top of Multipurpose Pool	36 ac	44 ac
Capacity to top of Multipurpose Pool	520 ac-ft	655
Mean Depth at top of Multipurpose Pool[4]	14.4 ft	14.9 ft
Latest Surveyed Conditions	(1972 Computations)	(1971 Computations)
Lowest Reservoir Bottom Elevation	3539 ft-msl	3839 ft-msl
Surface Area at top of Multipurpose Pool	36 ac	44 ac
Capacity of Multipurpose Pool	520 ac-ft	655
Mean Depth at top of Multipurpose Pool[4]	14.4 ft	14.9 ft
Sediment Deposition in Multipurpose Pool		
Historic Sediment Deposition[5]	Unknown[9]	Unknown[9]
Annual Sedimentation Rate[6]	Unknown[9]	Unknown[9]
Current Estimated Sediment Deposition[7]	Unknown[9]	Unknown[9]
Current capacity of Multipurpose Pool[8]	Unknown[9]	Unknown[9]
Percent of "As-Built" Multipurpose Pool capacity lost to current estimated sediment deposition	Unknown[9]	Unknown[9]
Operational Details – Historic	(1964 – 2012)	(1973 – 2012)
Maximum Recorded Pool Elevation	3585.8 ft-msl 10-Aug-14	3872.7 ft-msl 23-Mar-00
Minimum Recorded Pool Elevation	3576.6 ft-msl 22-Oct-77	3832.4 ft-msl 30-Sep-89
Maximum Recorded Daily Inflow	74 cfs 14-Jul-62	52 cfs 20-Aug-93
Maximum Recorded Daily Outflow	19 cfs 4-Jul-99	No Outflow
Average Annual Pool Elevation	3581.0 ft-msl	3848.7 ft-msl
Average Annual Inflow	759 ac-ft	38 ac-ft
Average Annual Outflow	658 ac-ft	No Outflow
Estimated Retention Time[10]	0.79 Years	-----
Operational Details – Current[11]		
Maximum Recorded Pool Elevation	3585.7 ft-msl 27-Jul-15	3859.3 ft-msl 30-Sep-15
Minimum Recorded Pool Elevation	3584.1 ft-msl 04-Jul-15	3856.9 ft-msl 01-May-15
Maximum Recorded Daily Inflow	7 cfs 07-Jul-15	2 cfs 25-May-15
Maximum Recorded Daily Outflow	7 cfs 19-Jun-15	No Outflow
Total Inflow (% of Normal)	1,954 ac-ft (257%)	81 ac-ft (208%)
Total Outflow (% of Normal)	1,856 ac-ft (283%)	No Outflow
Outlet Works		
Ungated Outlets	Drop Inlet 3585.0 ft-msl	Drop Inlet 3875.0 ft-msl
Gated Outlets (Mid-depth)	1) 8" Dia. Slide Gate 3580.0 ft-msl 1) 8" Dia. Slide Gate 3560.0 ft-msl	1) 3'x 3' Slide Gate 3868.0 ft-msl
Gated Outlets (Low-level)	3) 12" Gate Valves 3548.0 ft-msl	

(1) Reservoir length at top of conservation pool.
(2) First occurrence of reservoir pool elevation to top of multipurpose pool elevation.
(3) "As-Built" conditions taken to be the conditions present when the reservoir was first surveyed.
(4) Mean Depth = Volume ÷ Surface Area.
(5) Difference in reservoir storage capacity to top of Multipurpose Pool between "as-built" and latest survey.
(6) Annualized rate based on historic accumulated sediment.
(7) Current accumulated sediment estimated from historic annual sedimentation rate.
(8) Current capacity of Multipurpose Pool = "As-Built" Multipurpose Pool capacity - Estimated Current Sedimentation.
(9) Unable to calculate accumulated sediment and sediment deposition rates because no bathymetric surveys conducted on either reservoir.
(10) Estimated Retention Time = Multipurpose Pool Volume ÷ Average Annual Outflow.
(11) Current operational details are for the water year 1-Oct-2014 through 30-Sep-2015.

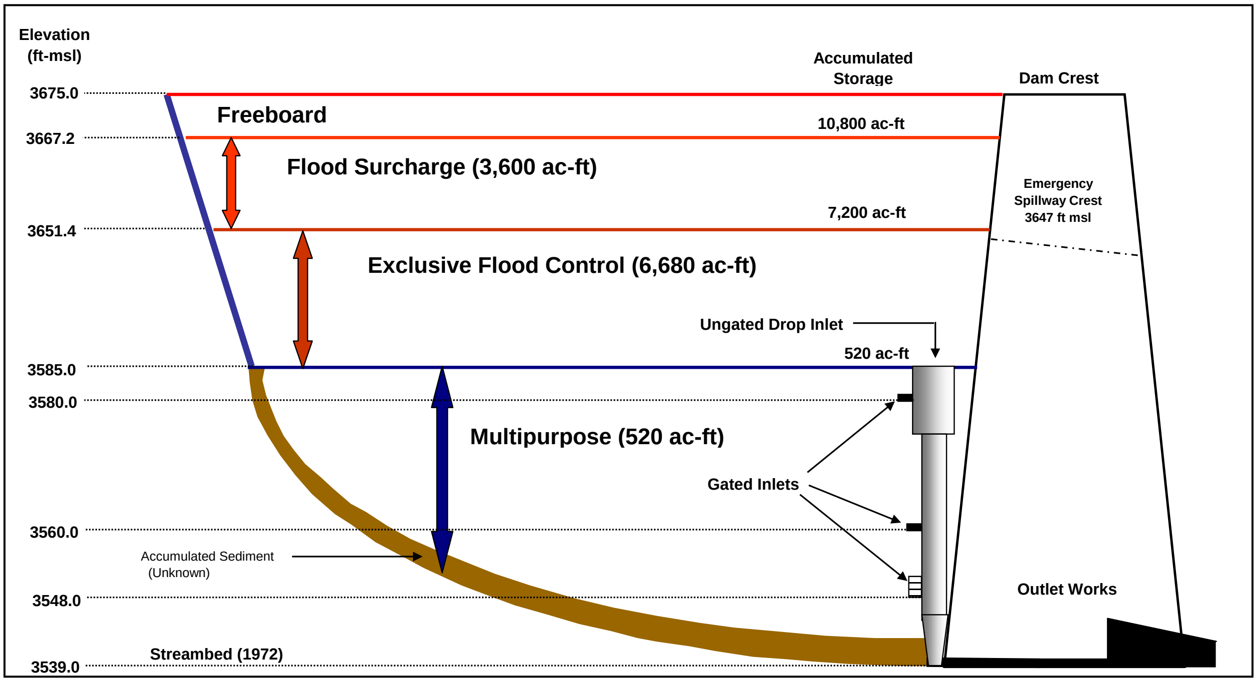


Figure 5.1. Current storage zones of Cold Brook Reservoir based on the 1972 computations**.**

5.1.1.4 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

As identified in the State of South Dakota's water quality standards, the following beneficial uses are designated for Cold Brook Reservoir: recreation (immersion and limited contact), coldwater permanent fish life propagation, fish and wildlife propagation, and stock watering. The reservoir is not directly used as a municipal or domestic water supply. Pursuant to the Federal CWA, the State of South Dakota has listed Cold Brook Reservoir on the State's 2014 Section 303(d) list (see Table 1-2). The beneficial use identified as impaired is coldwater permanent fish life. The impairment of the use is attributed to natural warming of water temperatures. The State of South Dakota has not issued a fish consumption advisory for the reservoir.

5.1.1.5 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Cold Brook Reservoir since the 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Recently, the District has scaled back water quality monitoring at Cold Brook Reservoir and is monitoring the reservoir every 3 years. Cold Brook Reservoir was last monitored in 2015. Figure 8.2 shows the location of the sites that monitored during 2012 and 2015.

Figure 5.2. Location of sites where water quality monitoring was conducted at Cold Brook Reservoir during 2012 and 2015.

5.1.2 EXISTING WATER QUALITY CONDITIONS

5.1.2.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Cold Brook Reservoir at sites CODLKND1, CODLKML1, and CODLKUP1 from May through September during 2012 and 2015 are summarized, respectively, in Plate 5-1 through Plate 5-3. A review of these results indicated possible water quality concerns regarding water temperature, dissolved oxygen, and ammonia.

The temperature criterion of 65° F (18.3°C) for the protection of coldwater permanent fish life propagation was exceeded by 38 percent of measurements taken in Cold Brook Reservoir at the near dam location. It is noted that if the reservoir were classified for the protection of coldwater marginal fish life propagation the criterion of 75°F (23.9°C) would have been exceeded by only 16% of the measurements. The temperature criterion of 80°F (26.6°C) for the protection of warmwater permanent fish life propagation would not have been exceeded at any time. Ambient water temperatures in Cold Brook Reservoir do not appear to be cold enough to fully support coldwater permanent fish life propagation as defined by state water quality standards criteria. Consideration should be given to reclassify Cold Brook Reservoir for either coldwater marginal fish life propagation or warmwater permanent fish life propagation use based on a use attainability assessment of "natural conditions" regarding ambient water temperatures.

Dissolved oxygen criteria were exceeded by 8 percent of the dissolved oxygen measurements taken in Cold Brook Reservoir. The lower dissolved oxygen concentrations occurred in the deeper part of the measured depth profile and were associated with a temperature gradient. The lower dissolved oxygen concentrations in the deeper water of Cold Brook Reservoir may be a concern if a coldwater fishery is to be supported. Water temperatures appear marginal in Cold Brook Reservoir for supporting a coldwater fishery, and the colder water that occurs in the reservoir during the summer is in the deeper portions where lower dissolved oxygen levels occur.

The chronic ammonia criteria for surface waters is temperature and pH dependant. The exceedence of the chronic ammonia criterion, which was calculated based on seasonal median temperature and pH, is not believed to be of concern at this time.

5.1.2.2 Thermal Stratification

5.1.2.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal conditions of Cold Brook Reservoir measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 5-4 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites CODLKND1, CODLKML1, and CODLKUP1. In comparison to thermal conditions monitored in 2012, Cold Brook Reservoir exhibited far more thermal stratification during 2015. The maximum difference monitored between the surface and bottom water temperatures during 2012 was 2°C in late June, in July of 2015 the maximum difference was 8.7°C (Plate 5-4).

5.1.2.2.2 Near-Dam Temperature Depth-Profile Plots

Summer thermal stratification of Cold Brook Reservoir, at the deep water area near the dam, measured during 2012 and 2015 is depicted by depth-profile temperature plots (Plate 5-5). The depth-profile temperature plots indicate that the reservoir does exhibit significant summer thermal stratification. It appears that the deepwater area near the dam may remained stratified through the middle of the summer.

Since Cold Brook Reservoir ices over in the winter and seemingly exhibits extended stratification during the summer, it appears to fit the definition of a dimictic lake (Wetzel, 2001).

5.1.2.3 Summer Dissolved Oxygen Conditions

5.1.2.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Cold Brook Reservoir based on depth-profile measurements taken during 2015 at sites CODLKND1, CODLKML1, and CODLKUP1. Plate 5-6 provides longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored along the reservoir bottom in June through September (Plate 5-6).

5.1.2.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in Cold Brook Reservoir are described by the dissolved oxygen depth-profiles measured near the dam during 2012 and 2015. Summer dissolved oxygen depth-profiles were compiled and plotted (Plate 5-7). On several occasions there were significant vertical gradients in summer dissolved oxygen levels. Hypoxic conditions were monitored near reservoir bottom on a few occasions (Plate 5-7). Enough "sediment" oxygen demand and inhibition to mixing exists to allow degraded dissolved oxygen conditions to develop near the reservoir bottom.

5.1.2.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Cold Brook Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2015 and the District's current Area-Capacity Tables (1972 Computations) for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 6 mg/l and 2.5 mg/l dissolved oxygen isopleths. The August 12, 2015 contour plot indicates a pool elevation of 3585.5 ft-msl, a 6 mg/l dissolved oxygen isopleth elevation of about 3565.0 ft-msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 3562.5 ft-msl (Plate 5-6). The District's Area-Capacity Tables give storage capacities of 538.5 ac-ft for elevation 3585.5 ft-msl, 108.0 ac-ft for elevation 3565.0 ft-msl, and 90.5 ac-ft for elevation 3562.5 ft-msl. On August 12, 2015 it is estimated that 20 percent of the volume of Cold Brook Reservoir was less than the 6 mg/l dissolved oxygen criterion for the protection of aquatic life, and 16.8 percent of the reservoir volume was hypoxic.

5.1.2.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Cold Brook Reservoir indicated some hypoxic conditions occurred during the summer of 2015, longitudinal contour and depth-profile plots were constructed for ORP and pH. The number of paired samples collected when hypoxia was present was insufficient to statistically compare near-surface and near-bottom water quality conditions.

5.1.2.4.1 Oxidation-Reduction Potential

Plate 5-8 provides longitudinal ORP contour plots based on depth-profile measurements taken in 2015. The monitored values indicated "slightly" lower ORP conditions were monitored near the reservoir bottom in a small area near the dam in early August (Plate 5-8). Plate 5-9 plots depth profiles for ORP measured during the summer in 2012 and 2015 in the deepwater area of Cold Brook Reservoir near the dam

(Plate 5-9). The depth profiles indicate that slightly lower ORPconditions occasionally occurred near the bottom of Cold Brook Reservoir during the summer.

5.1.2.4.2 pH

Longitudinal contour plots for pH conditions measured in 2015 are provided in Plate 5-10. Plate 5-11 plots depth profiles for pH measured during the summer in 2012 and 2015 at the deepwater area of Cold Brook Reservoir near the dam. An appreciable vertical gradient in pH occasionally occurred in the reservoir during the summer (Plate 5-10 and Plate 5-11). It appears occasional reduced conditions in the deeper water of Cold Brook Reservoir seemingly lead to in lower pH levels near the reservoir bottom. The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 7.0 for the protection of aquatic life.

5.1.2.5 Water Clarity

Figure 6.3 displays a box plot of the Secchi depth transparencies measured at the three in-reservoir monitoring sites (i.e., CODLKND1, CODLKML1, CODLKUP1) in 2012 and 2015 (note: the monitoring sites are oriented in an upstream to downstream direction). Water clarity measured at the three sites was high and seemingly increased in a downstream direction (Figure 5.3).

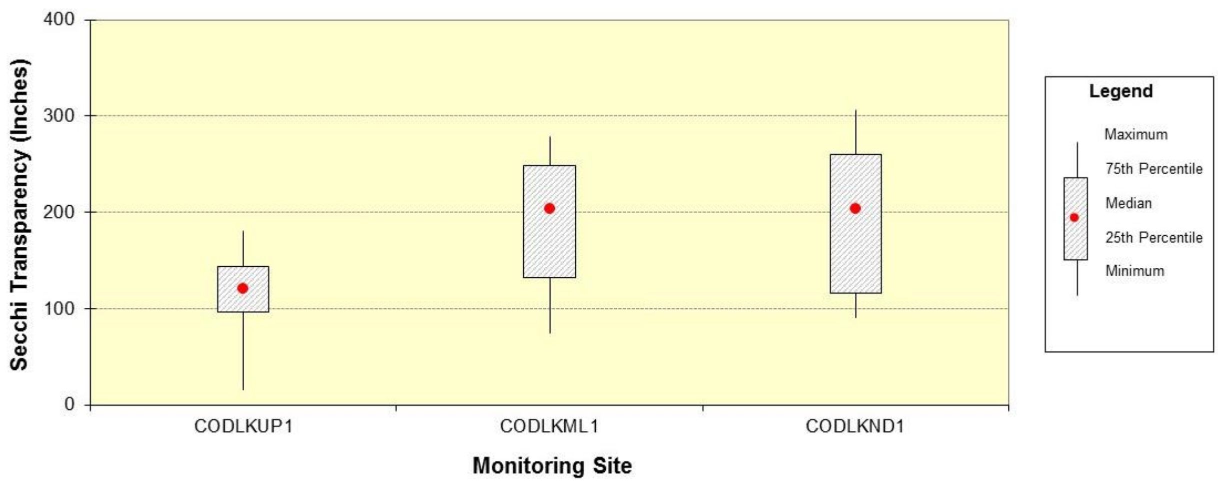


Figure 5.3. Box plot of Secchi depth transparencies measured in Cold Brook Reservoir from 2012 and 2015.

5.1.2.6 Phytoplankton Assemblage

Phytoplankton samples were collected at the near dam station (CODLKND1) in May, July, and September of 2015. Total and algal group biovolume are shown in Figure 6.4. The sample results indicate that Coldbrook reservoir appears to a relatively healthy algal assemblage with an abundance of Golden-Brown algae (Chrysophyta).

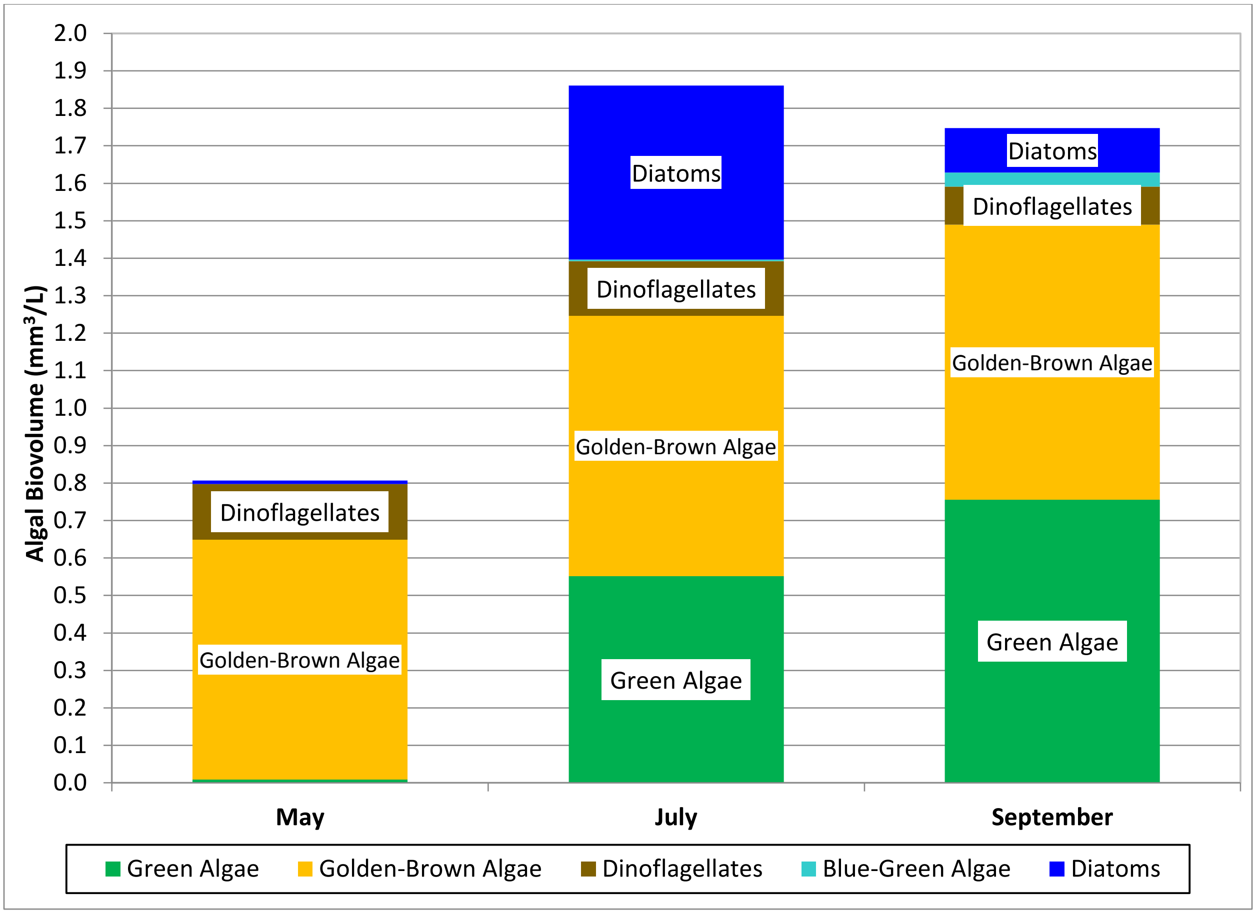


Figure 5.4. Graph showing phytoplankton biovolume and relative dominance at the near dom station of Cold Brook Reservoir in 2015.

5.1.2.7 Reservoir Trophic State

Trophic State Index (TSI) values for Cold Brook Reservoir were calculated from monitoring data collected during 2012 and 2015 at the near-dam ambient monitoring site (i.e., CODLKND1). Table 6.2 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Cold Brook Reservoir is in a mesotrophic condition.

Table 5-2. Summary of Trophic State Index (TSI) values calculated for Cold Brook Reservoir during 2012, and 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	10	33	32	30	39
TSI(TP)	10	50	48	41	65
TSI(Chl)	10	51	50	40	65
TSI(Avg)	10	45	42	39	54

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.

Note: See Section 2.1.3 for discussion of TSI calculation.

5.1.3 WATER QUALITY TRENDS (1980 THROUGH 2015)

Water quality trends from 1980 to 2015 were determined for Cold Brook Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). 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., CODLKND1). Plate 5-12 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, Cold Brook Reservoir exhibited no significant trends in transparency, total phosphorus, or chlorophyll *a*. Over the 36-year period since 1980, Cold Brook Reservoir has remained in a mesotrophic condition (Plate 5-12).

5.2 COTTONWOOD SPRINGS RESERVOIR

5.2.1 BACKGROUND INFORMATION

5.2.1.1 Project Overview

The dam forming Cottonwood Springs Reservoir is located on Cottonwood Springs Creek, approximately 5 miles west of Hot Springs, South Dakota. The dam was completed in May 1969 and the reservoir has not reached an initial fill. The Cottonwood Springs Reservoir watershed is 26 square miles. The watershed was largely rangeland and forested when the dam was built in 1952 and has remained so to the present time. The authorized project purposes of Cottonwood Springs Reservoir are flood control, recreation, fish and wildlife, and water quality.

5.2.1.2 Cottonwood Springs Dam Intake Structure

The intake at Cottonwood Springs Dam is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 4 feet by 8 feet. The structure was designed and constructed so that normal and flood period pool regulation is automatic. The intake structure has two ungated openings, each 42" x 96", with a weir crest elevation of 3875.0 ft-msl. The weir crest elevation of 3875.0 ft-msl is the water surface elevation of the multipurpose pool. A 36" x 36" gated opening with a crest elevation of 3868.0 ft-msl was constructed into the upstream face of the intake structure. The gated outlet may be used to release water for downstream needs.

5.2.1.3 Reservoir Storage Zones

Figure 5.5 depicts the current storage zones of Cottonwood Springs Reservoir based on the 1971 "as-built" conditions. The District has not conducted sediment surveys at Cottonwood Springs Reservoir; therefore, the current amount of sedimentation has not been estimated and is unknown.

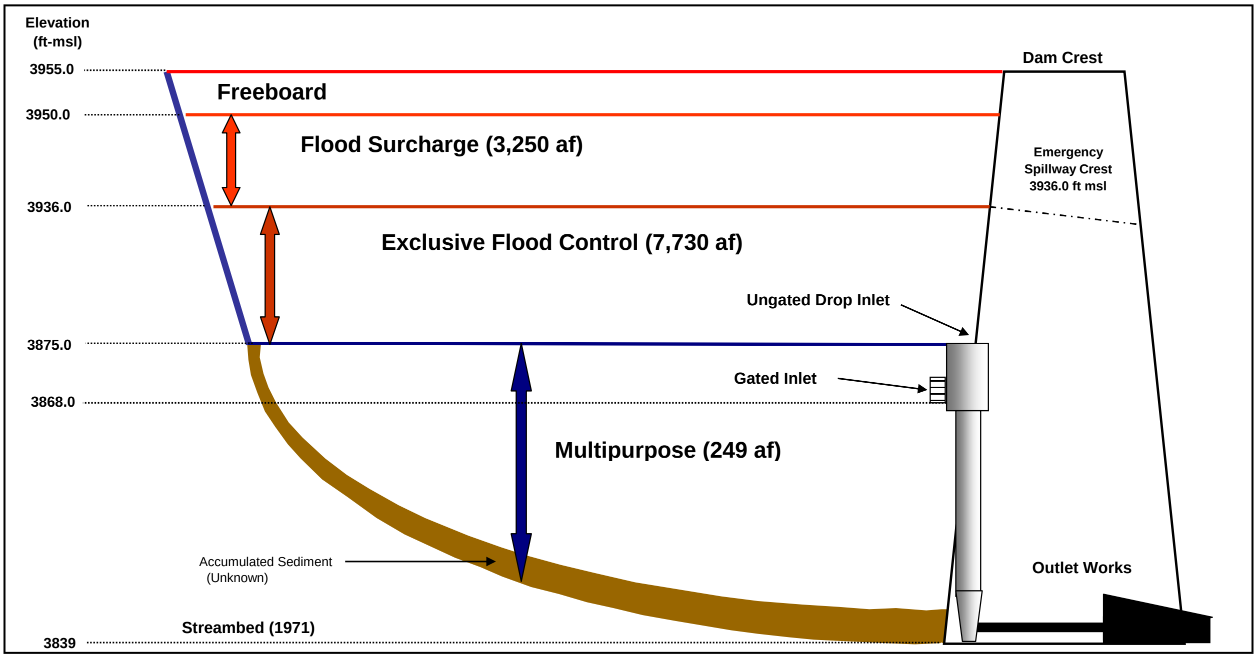


Figure 5.5. Current storage zones of Cottonwood Springs Reservoir based on the 1971 "as-built" conditions**.**

5.2.1.4 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

As identified in the State of South Dakota's water quality standards, the following beneficial uses are designated for Cottonwood Springs Reservoir: recreation (immersion and limited contact), warmwater permanent fish life propagation, fish and wildlife propagation, stock watering, and domestic water supply. The reservoir is not directly used as a municipal or domestic water supply. Pursuant to the Federal CWA, the State of South Dakota has not listed Cottonwood Springs Reservoir on the State's 2014 Section 303(d) list. The State of South Dakota also has not issued a fish consumption advisory for the reservoir.

5.2.1.5 Ambient Water Quality Monitoring

The District has irregularly monitored water quality conditions at Cottonwood Reservoir since the 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Recently, the District has scaled back water quality monitoring at Cottonwood Springs Reservoir, and is monitoring the reservoir every 3 years. Monitoring was scheduled for 2005 and 2008, but was not conducted because low water conditions restricted access. On September 30, 2008, the pool elevation of the reservoir was 3840.3. Based on the District's Area Capacity Tables (1971) for the reservoir this equates to a surface area of 1.6 acres and storage of 1.64 ac-ft. Figure 6.5 shows the location of the sites where water quality monitoring has occurred. Since 2010, the District conducted water quality monitoring at Cottonwood Springs Reservoir during 2012 and 2015.

Figure 5.6. Location of sites where water quality monitoring was conducted at Cottonwood Springs Reservoir during 2012 and 2015.

5.2.2 EXISTING WATER QUALITY CONDITIONS

5.2.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions monitored in Cottonwood Springs Reservoir at sites COTLKND1, COTLKML1, and COTLKUP1 from May through September during 2012 and 2015 are summarized in Plate 5-13 to Plate 5-15. A review of these results indicated possible water quality concerns regarding dissolved oxygen (Plate 5-13).

Dissolved oxygen criteria were exceeded by about 7 percent of the dissolved oxygen measurements taken in Cottonwood Springs Reservoir. The lower dissolved oxygen concentrations occurred in the deeper part of the measured depth profile and were associated with a temperature gradient.

5.2.2.2 Thermal Stratification

5.2.2.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal conditions of Cottonwood Reservoir measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 5-16 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites COTLKND1, COTLKML1, and COTLKUP1. These temperature plots indicate that Cottonwood Reservoir seldom exhibited strong thermal stratification during 2015. The maximum difference monitored between the surface and bottom water temperatures during 2015 was around 6°C (Plate 5-16).

5.2.2.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of Cottonwood Springs Reservoir, in the deep water area near the dam, is described by the depth-profile temperature plots measured during 2012 and 2015. Temperature depth-profiles measured during the summer were compiled and plotted (Plate 5-17). The plotted depth-profile temperature measurements indicate occasional thermal stratification during the summer.

5.2.2.3 Summer Dissolved Oxygen Conditions

5.2.2.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Cottonwood Reservoir based on depth-profile measurements taken during 2015 at sites COTLKND1, COTLKML1, and COTLKUP1. Plate 5-18 provides longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored along the reservoir bottom in July, but had significantly receded by August (Plate 5-18).

5.2.2.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in Cottonwood Springs Reservoir, in the deep water area near the dam, are described by the depth-profile dissolved oxygen plots for 2012 and 2015 (Plate 5-19). Significant vertical gradients in dissolved oxygen levels occurred during the summer when thermal stratification was present. Three profiles indicated anoxic conditions (i.e., dissolved oxygen concentrations < 2.5 mg/l) near the reservoir bottom (Plate 5-19).

5.2.2.4 Water Clarity

Figure 5.7 displays a box plot of the Secchi depth transparencies measured at the in-reservoir monitoring sites (i.e., COTLKND1, COTLKML1, and COTLKUP1) during 2012 and 2015 (note: the monitoring sites are oriented in an upstream to downstream direction). Water clarity measured at the two downstream sites were similar with lower water transparencies at the upstream site.

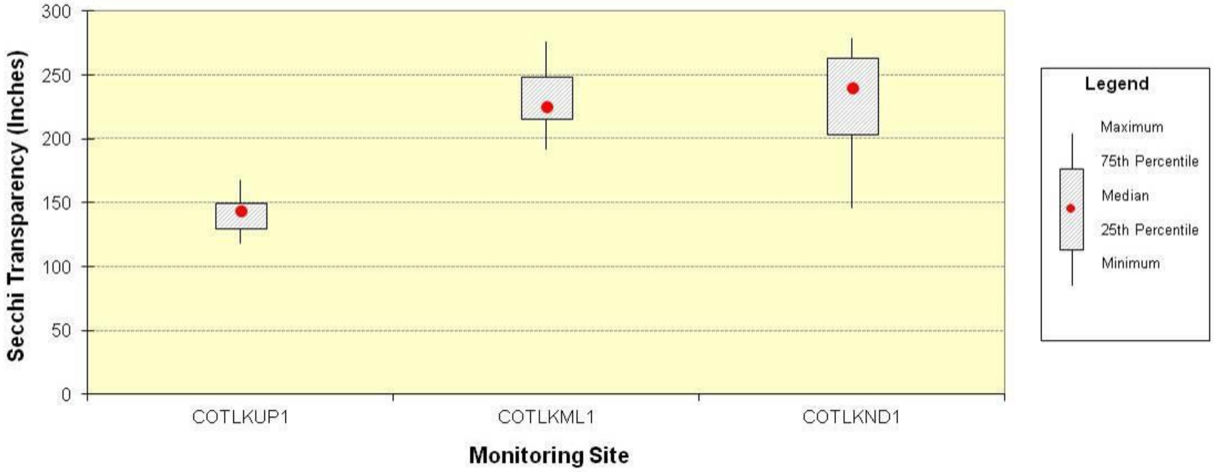


Figure 5.7. Box plot of Secchi depth transparencies measured in Cottonwood Springs Reservoir during 2012 and 2015.

5.2.2.1 Phytoplankton Assemblage

Phytoplankton samples were collected at the near dam station (COTLKND1) in May, July, and September of 2015. Total and relative algal group biovolume are shown in Figure 6.8. The results show the largest component of the algal biomass at Cottonwood Reservoir was comprised of Dinoflagellates. *Rhodomonas* occurred in the greatest volume in May followed by *Chryptomonas erosa* in July and September. It is worth noting that zooplankton samples collected concurrently with the phytoplankton samples indicated an abundance of *Ceriodaphnia spp*. biomass which coincided with the observed increases in *Chryptomonas erosa* biovolume. These results likely illustrate selective grazing preferences by *Ceriodaphnia* species.

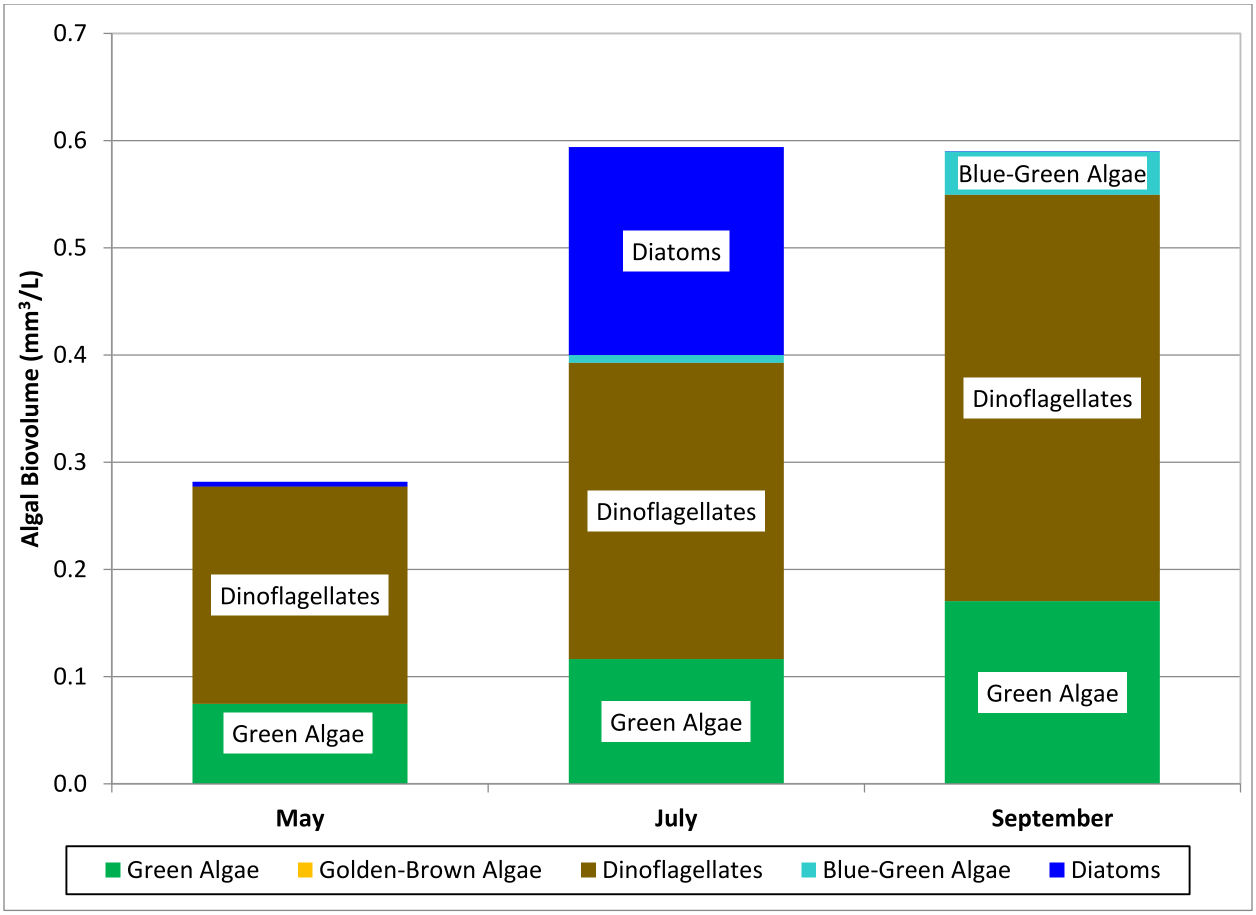


Figure 5.8. Graph showing phytoplankton biovolume and relative dominance at the near dam station of Cottonwood Reservoir in 2015.

5.2.2.2 Reservoir Trophic State

Trophic State Index (TSI) values for Cottonwood Springs Reservoir were calculated from monitoring data collected during 2012 and 2015 at the near-dam ambient monitoring site (i.e., COTLKND1). Table 6.3 summarizes the TSI values calculated for the reservoir. The TSI values indicate that Cottonwood Springs Reservoir is in a mesotrophic condition.

Table 5-3. Summary of Trophic State Index (TSI) values calculated for Cottonwood Springs Reservoir during 2012 and 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	10	32	37	35	50
TSI(TP)	10	34	43	44	59
TSI(Chl)	10	40	49	50	55
TSI(Avg)	10	34	40	40	48

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.
Note: See Section 4.1.3 for discussion of TSI calculation.

5.3 CHAPTER 5 PLATES

Plate 5-1. Summary of water quality conditions monitored in Cold Brook Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site CODLKND1) from May to September during 2012 and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at ½ the measured Secchi depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	**No. of Obs.**	**Mean[A]**	**Median**	**Min.**	**Max.**	**State WQS Criteria[B]**	**No. of WQS Exceedences**	**Percent WQS Exceedence**
Pool Elevation (ft-msl)	0.1	10	3583.2	3583.8	3579.9	3585.5	-----	-----	-----
Water Temperature (°C)	0.1	192	19.6	20.2	12.1	25.0	18.3[1], 23.9[2], 26.6[3]	73, 31, 0	38%, 16%, 0%
Dissolved Oxygen (mg/l)	0.1	192	9.1	9.5	0.0	16.0	≥6, ≥7	16, 24	8%, 13%
Dissolved Oxygen (% Sat.)	0.1	192	103.4	105.5	0.0	190.2	-----	-----	-----
Secchi Depth (in.)	1	10	194	204	91	306	-----	-----	-----
pH (S.U.)	0.1	192	8.1	8.1	7.2	8.8	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	192	1.7	0.5	0.0	105.8	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	192	381	400	191	455	-----	-----	-----
Specific Conductance (umho/cm)	1	192	716	611	540	1558	-----	-----	-----
Chemical Oxygen Demand (mg/l)	0.8	2	36.5	36.5	35.0	38.0	-----	-----	-----
Ammonia, Total (mg/l)	0.02	20	-----	n.d.	n.d.	0.08	4.6 [4,5], 1.4 [4,6]	0, 1	0%, 4%
Chlorophyll a (ug/l) – Lab Determined	3	10	4	3	3	13	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	3	171	7	4	2	30	-----	-----	-----
Alkalinity, Total (mg/l)	0.6	20	178.7	181.0	36.0	344.0	-----	-----	-----
Dissolved Solids, Total (mg/l)	10	20	585	416	324	1330	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	20	-----	n.d.	n.d.	0.16	10[8]	0	0%
Phosphorus, Total (mg/l)	0.005	20	-----	0.01	n.d.	0.12	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.003	20	-----	0.01	n.d.	0.05	-----	-----	-----
Suspended Solids, Total (mg/l)	4	20	-----	4	n.d.	17	53[5], 30[6]	0	0%
Antimony, Dissolved (ug/l)	0.03	2	-----	0.10	n.d.	0.20	6[7]	0	0%
Arsenic, Dissolved (ug/l)	0.008	2	5.00	5.00	5.00	5.00	340[5], 150[6], 0.018[7]	0, 0, 4	0%, 0%, 100%
Beryllium, Dissolved (ug/l)	1	2	-----	n.d.	n.d.	0	4[7]	0	0%
Cadmium, Dissolved (ug/l)	0.007	2	-----	0.02	n.d.	0.04	9.3[5], 1.9[6]	0	0%
Chromium, Dissolved (ug/l)	4	2	-----	n.d.	n.d.	0	1,101[5], 357[6]	0	0%
Copper, Dissolved (ug/l)	6	2	-----	n.d.	n.d.	0	38[5], 23[6], 1,300[7]	0	0%
Lead, Dissolved (ug/l)	0.008	2	-----	2.70	n.d.	5.40	160[5], 6.3[6]	0	0%
Mercury, Dissolved (ug/l)	0.002	2	0.12	0.12	0.03	0.20	1.4[5]	0	0%
Mercury, Total (ug/l)	0.002	2	0.12	0.12	0.03	0.20	0.012[6]	2	100%
Nickel, Dissolved (ug/l)	8	2	-----	n.d.	n.d.	0	2,906 [5], 323[6]	0	0%
Silver, Dissolved (ug/l)	0.005	2	-----	n.d.	n.d.	0.00	15[5]	0	0%
Zinc, Dissolved (ug/l)	6	2	-----	1	n.d.	2	235[5], 215[6],7,400[7]	0	0%
Microcystin, Total (ug/l)	0.1	10	-----	n.d.	n.d.	0.1	-----	-----	-----
Atrazine, Total (ug/l)[C]	0.07	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Metolachlor, Total (ug/l)[C]	0.05	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Acetochlor, Total (ug/l)©	0.07	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Selenium, Dissolved (ug/l)	0.06	2	2.00	2.00	2.00	2.00	-----	-----	-----
Barium, Dissolved (ug/l)	1	2	96	96	85	107	-----	-----	-----
Total Organic Carbon (mg/l)	0.2	20	5.0	3.6	2.1	17.2	-----	-----	-----
Hardness, Dissolved (mg/l)	0.32	2	330.20	330.20	237.60	422.80	-----	-----	-----
Sulfate, Dissolved (mg/l)	0.4	20	256.2	140.0	107.0	911.0	-----	-----	-----
CDOM (ug/l)	10	20	-----	n.d.	n.d.	85	-----	-----	-----
Pesticide Scan (ug/l)[D]	0.05	3	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected., b.d. = Below detection limit

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

[B] [1] Water temperature criterion for protection of coldwater permanent fish life propagation.
[2] Water temperature criterion for protection of coldwater marginal fish life propagation.
[3] Water temperature criterion for protection of warmwater permanent fish life propagation.
[4] Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values of 8.1 and 20.2 respectively.
[5] Acute criterion for aquatic life.
[6] Chronic criterion for aquatic life.
[7] Human health criterion for surface waters.

[C] Immunoassay analysis.

[D] The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, metolachlor, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

Plate 5-2. Summary of water quality conditions monitored in Cold Brook Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site CODLKML1) from May to September during 2012 and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	5	3581.1	3581.0	3579.9	3582.7	-----	-----	-----
Water Temperature (°C)	0.1	190	19.7	20.6	10.3	25.5	18.3[1], 23.9[2], 26.6[3]	66, 26, 0	35%, 14%, 0%
Dissolved Oxygen (mg/l)	0.1	190	8.8	9.1	0.1	14.8	≥6, ≥7	12, 32	6%, 17%
Dissolved Oxygen (% Sat.)	0.1	190	100.5	100.8	0.7	154.0	-----	-----	-----
pH (S.U.)	0.1	190	8.0	8.1	7.0	8.7	≥6.5 & ≤9.0	0	0%
Secchi Depth (in.)	1	10	191	203	74	278	-----	-----	-----
Turbidity (NTUs)	0.1	190	1.4	0.8	0.0	26.6	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	190	371	384	165	482	-----	-----	-----
Specific Conductance (umho/cm)	1	190	769	611	540	1596	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	175	6	5	1	21	-----	-----	-----

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

(B) (1) Water temperature criterion for protection of coldwater permanent fish life propagation.
(2) Water temperature criterion for protection of coldwater marginal fish life propagation.
(3) Water temperature criterion for protection of warmwater permanent fish life propagation.

Plate 5-3. Summary of water quality conditions monitored in Cold Brook Reservoir at the up-lake, deepwater ambient monitoring location (i.e., site CODLKUP1) from May to September during 2012 and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	5	3581.1	3581.0	3579.9	3582.7	-----	-----	-----
Water Temperature (°C)	0.1	60	19.3	18.6	12.6	25.9	18.3[1], 23.9[2], 26.6[3]	30, 10, 0	50%, 17%, 0%
Dissolved Oxygen (mg/l)	0.1	60	9.2	9.4	6.3	11.5	≥6, ≥7	0, 4	0%, 7%
Dissolved Oxygen (% Sat.)	0.1	60	103.2	99.5	73.9	133.9	-----	-----	-----
pH (S.U.)	0.1	60	8.2	8.1	7.3	8.6	≥6.5 & ≤9.0	0	0%
Secchi Depth (in.)	1	10	117	121	15	180	-----	-----	-----
Turbidity (NTUs)	0.1	60	1.0	0.6	0.0	7.7	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	60	361	359	286	482	-----	-----	-----
Specific Conductance (umho/cm)	1	60	735	596	539	1533	-----	-----	-----

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

(B) (1) Water temperature criterion for protection of coldwater permanent fish life propagation.
(2) Water temperature criterion for protection of coldwater marginal fish life propagation.
(3) Water temperature criterion for protection of warmwater permanent fish life propagation.

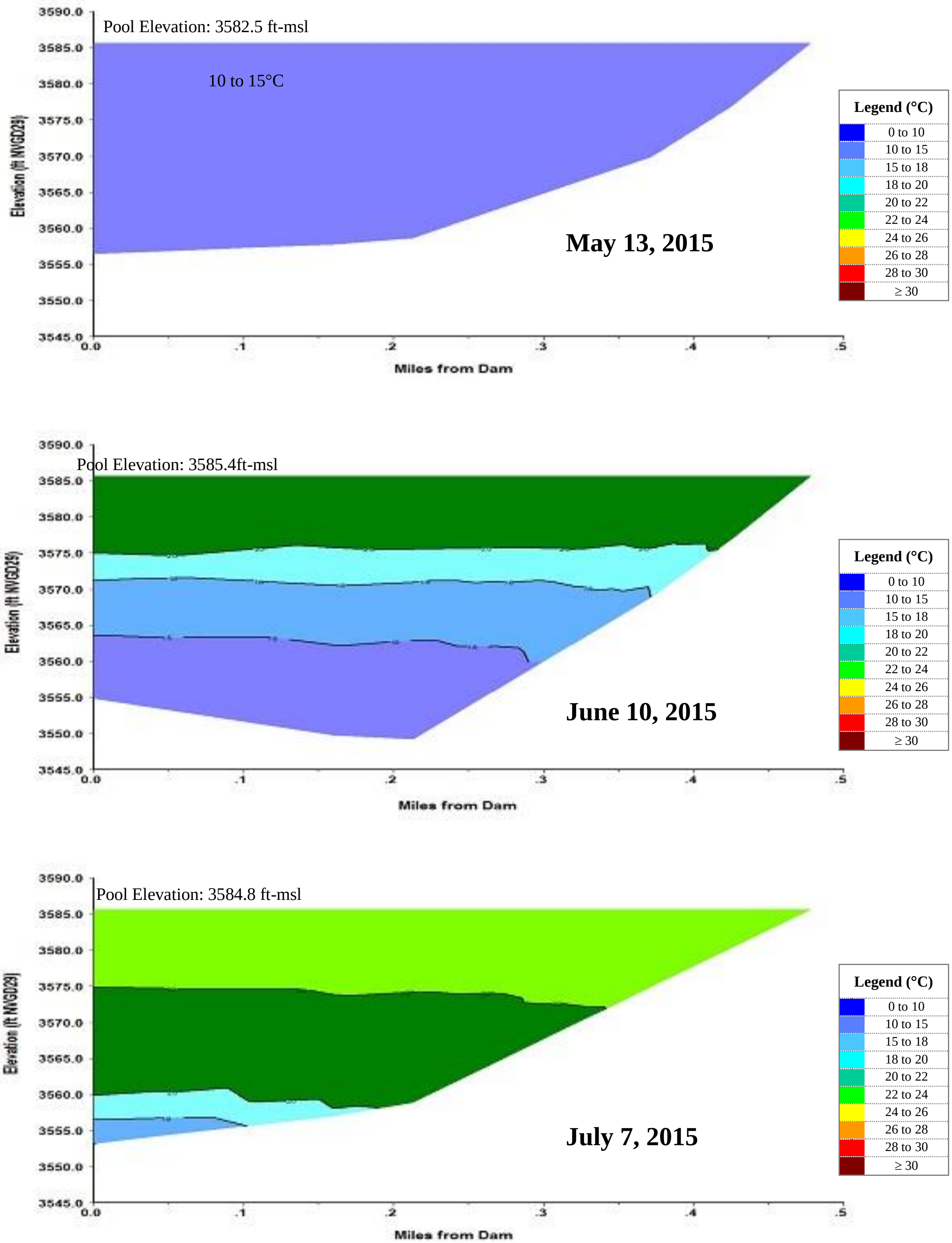
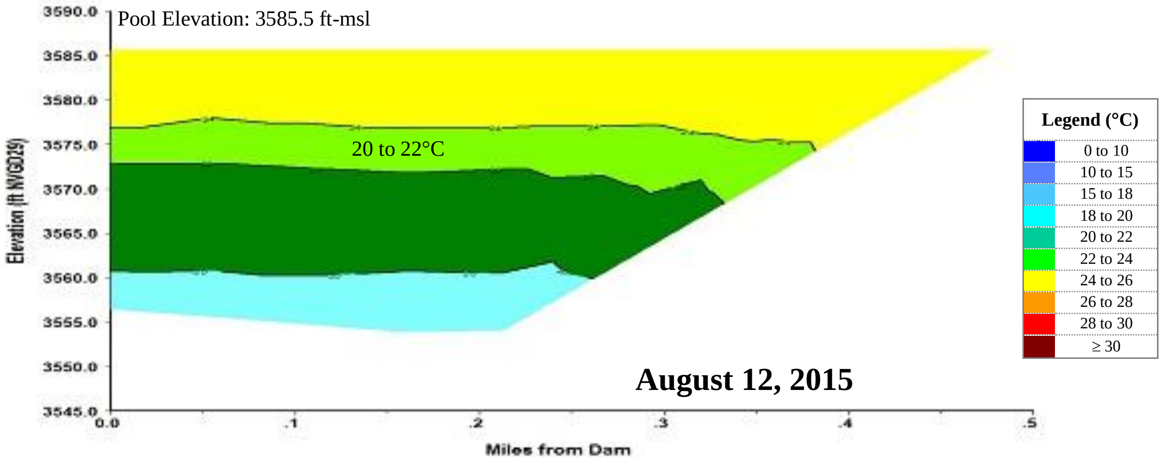


Plate 5-4. Longitudinal water temperature (°C) contour plots of Cold Brook Reservoir based on depth-profile water temperatures measured at sites CODLKND1, CODLKML1, and CODLKUP1 in 2015.



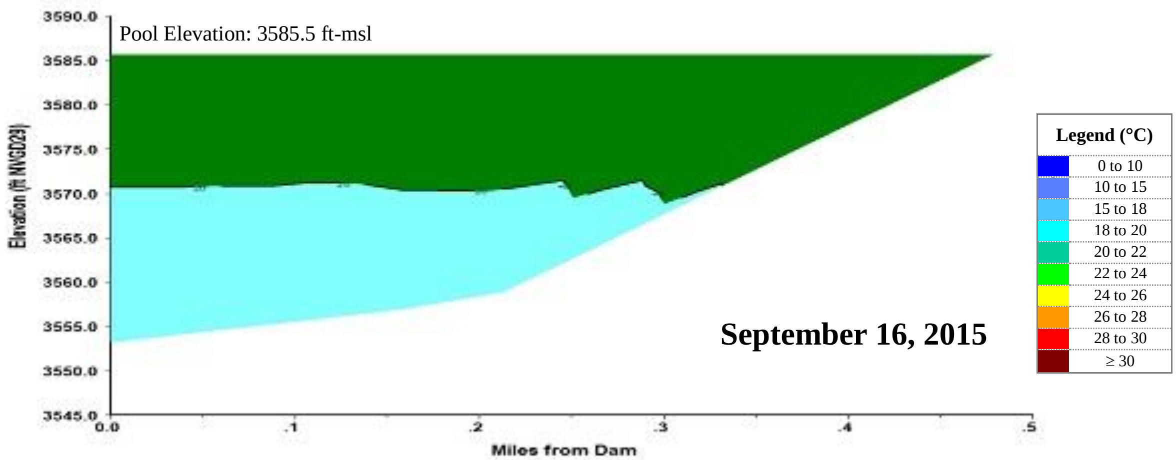


Plate 5-4 **(Continued).**

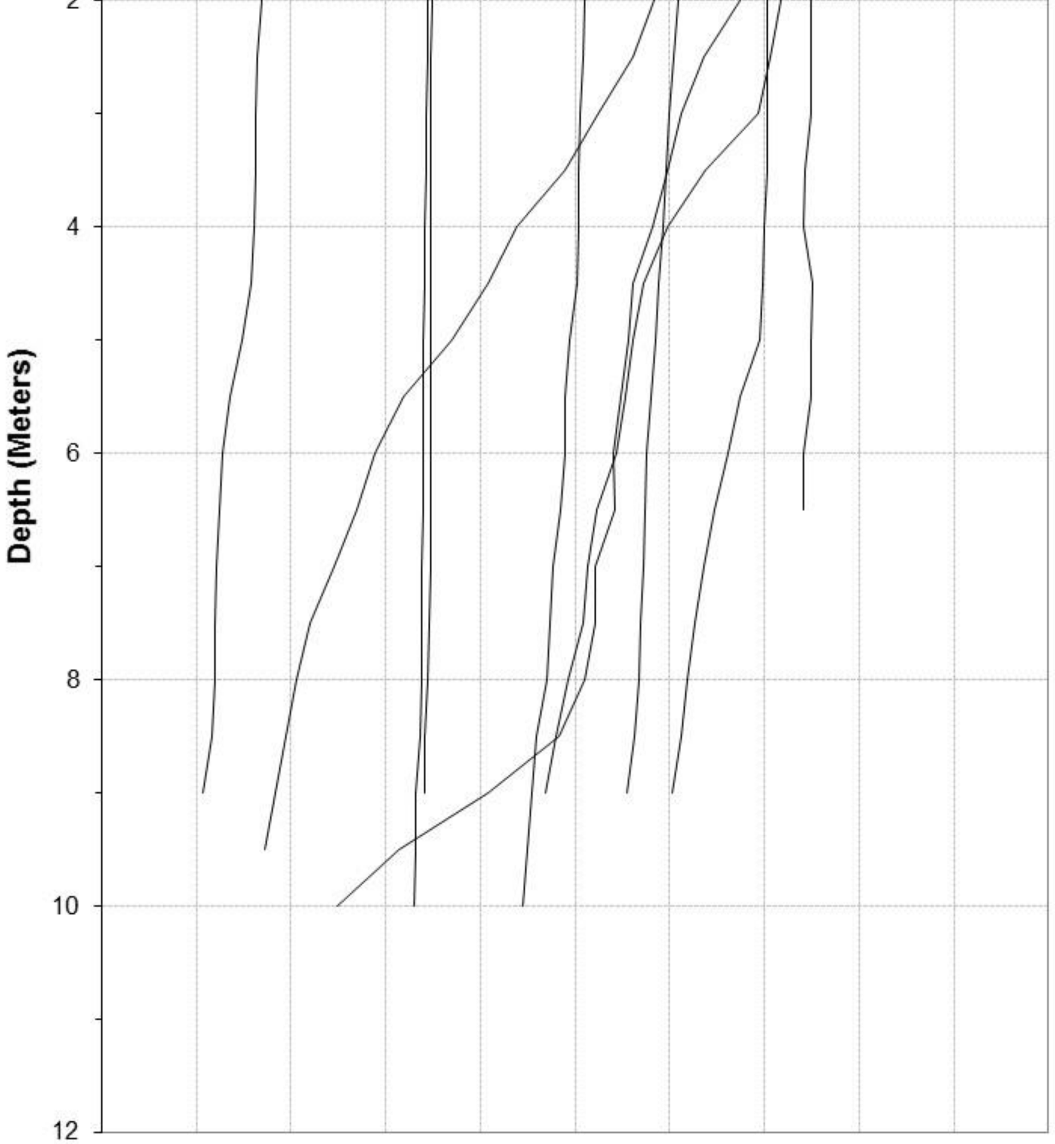


Plate 5-5. Temperature depth profiles for Cold Brook Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., CODLKND1) during the summers of 2012 and 2015.

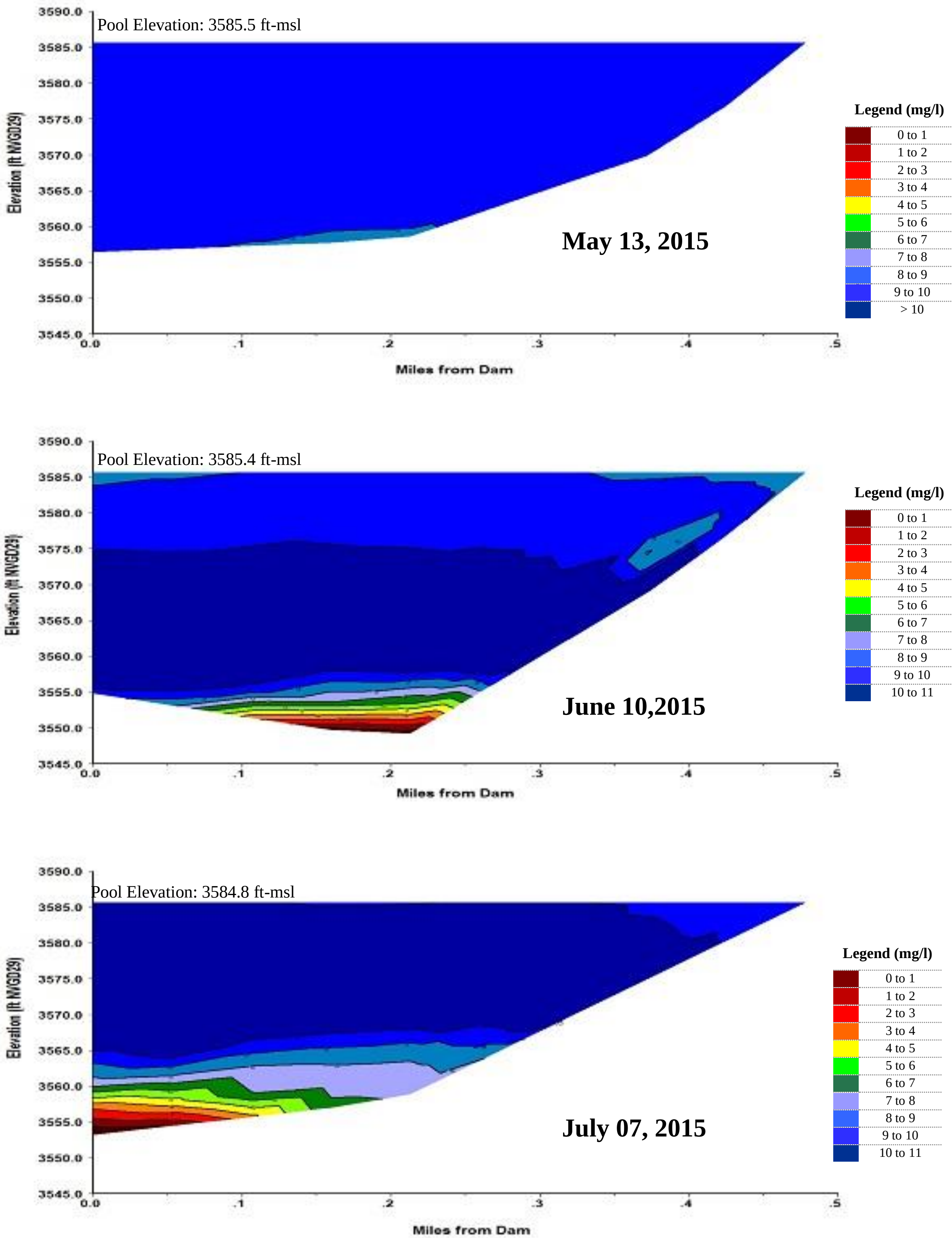
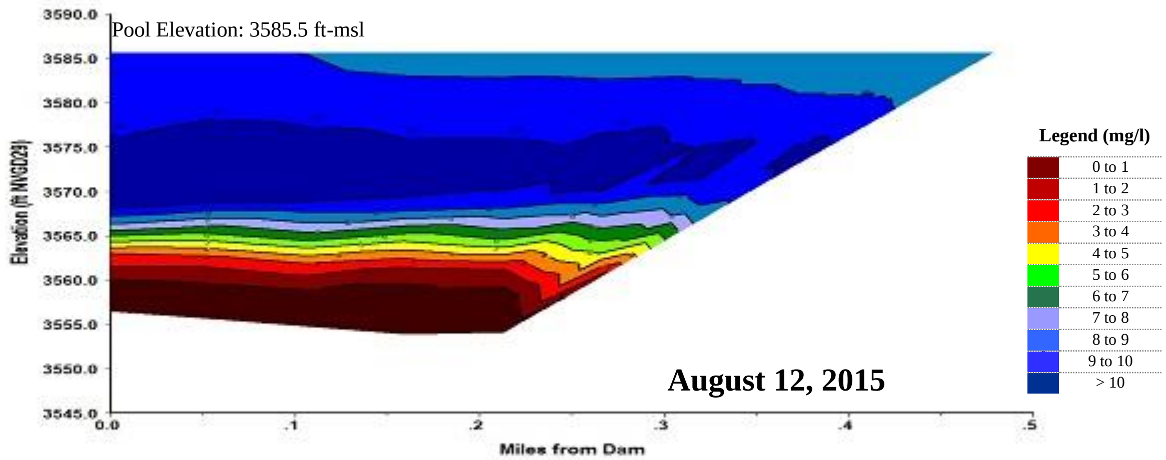


Plate 5-6. Longitudinal dissolved oxygen (mg/l) contour plots of Cold Brook Reservoir based on depth-profile dissolved oxygen concentrations measured at sites CODLKND1, CODLKML1, and CODLKUP1 in 2015.



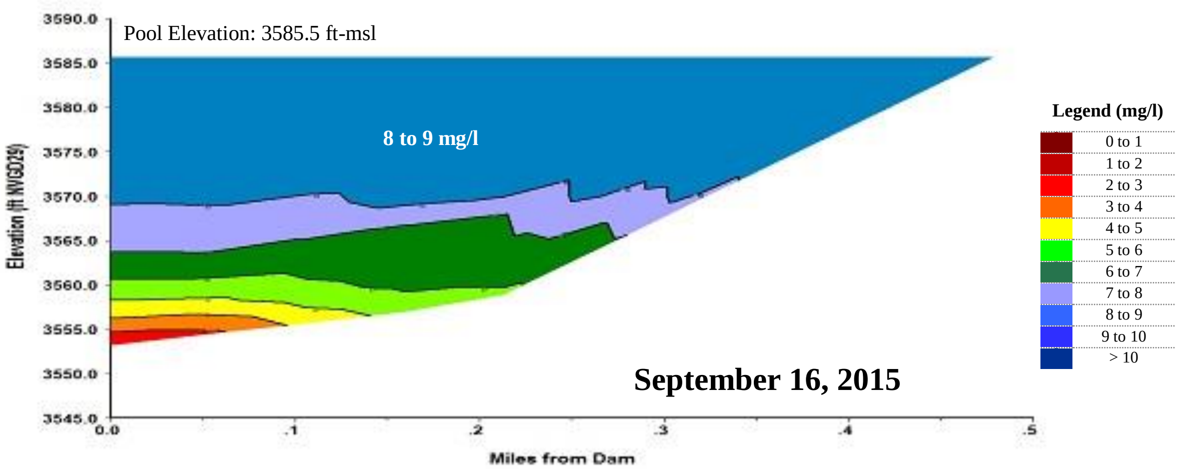


Plate 5-6 **(Continued).**

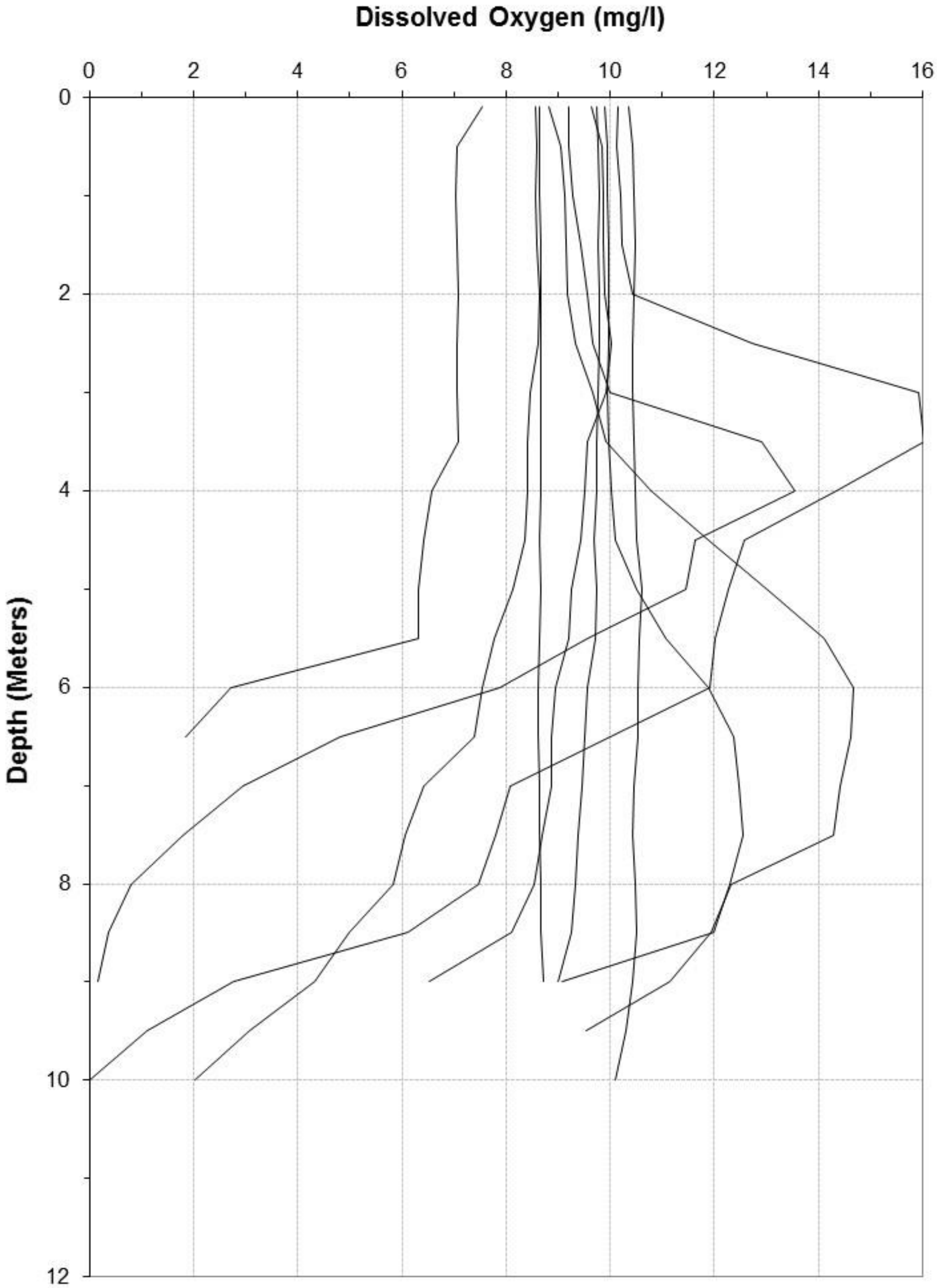
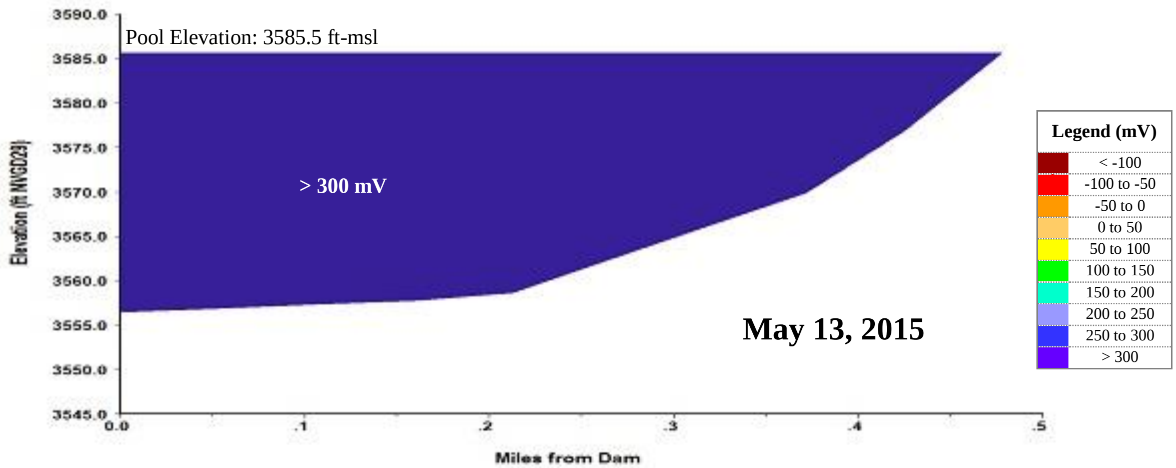
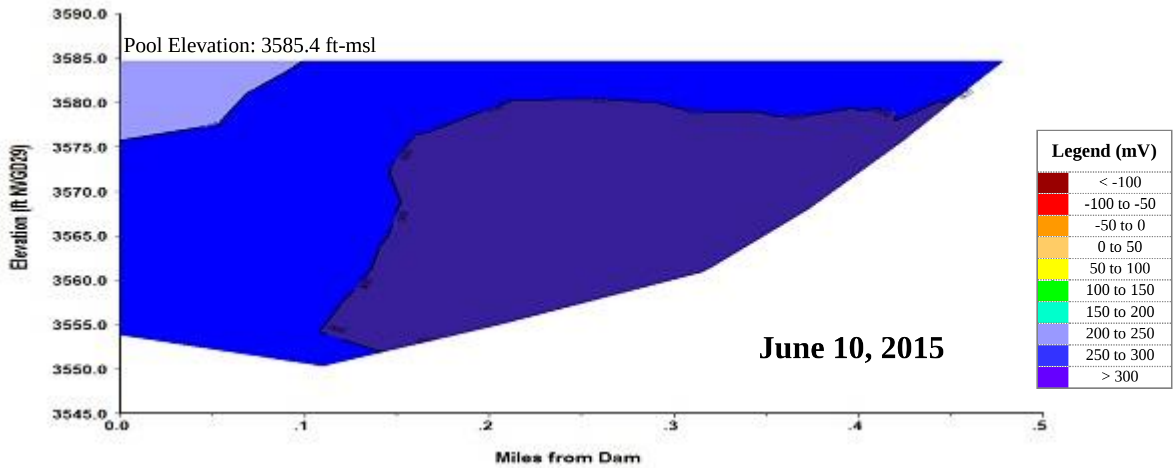


Plate 5-7. Dissolved oxygen depth profiles for Cold Brook Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., CODLKND1) during the summers of 2012 and 2015.





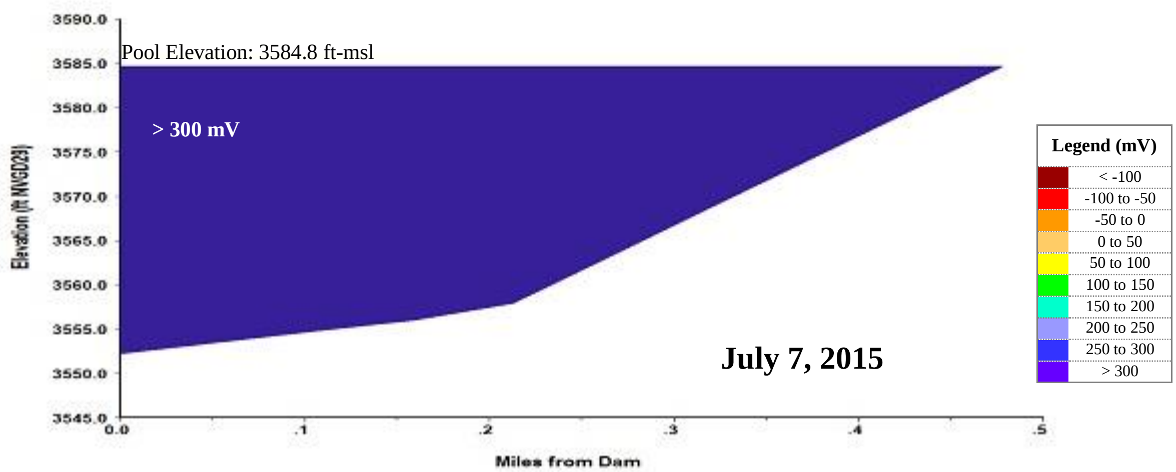
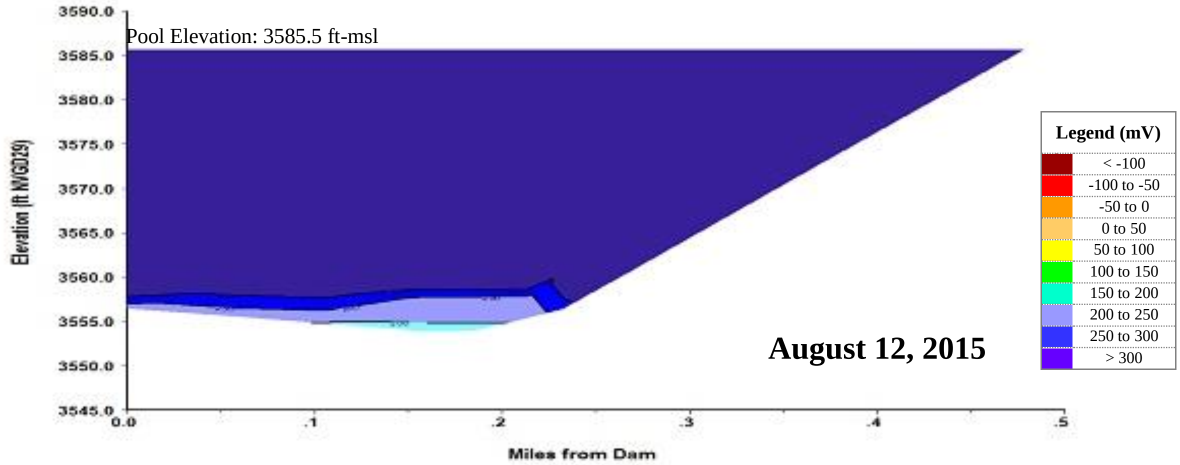


Plate 5-8. Longitudinal oxidation-reduction potential (mV) contour plots of Coldbrook Reservoir based on depth-profile measurements at sites CODLKND1, CODLKML1, and CODLKUP1 in 2015.



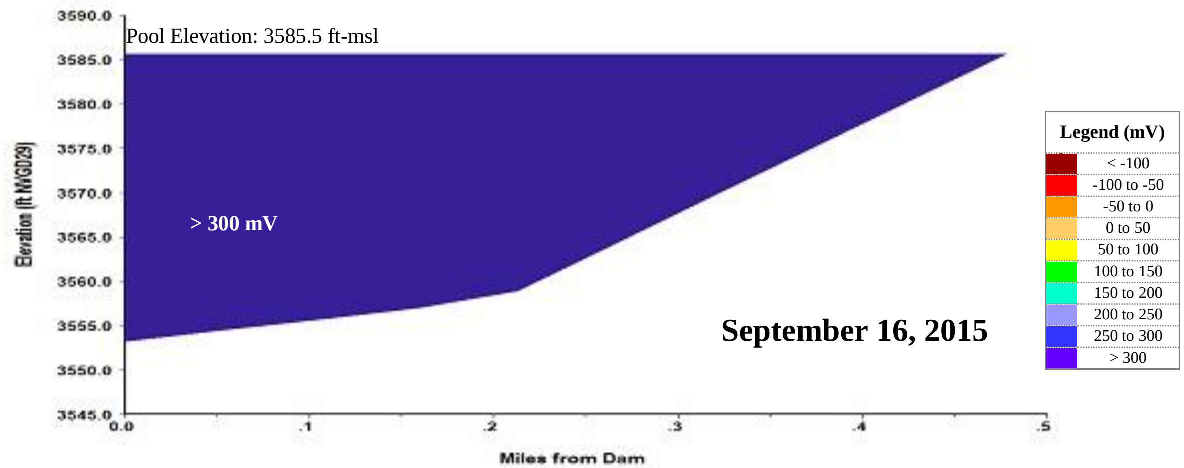


Plate 5-8 (Continued)

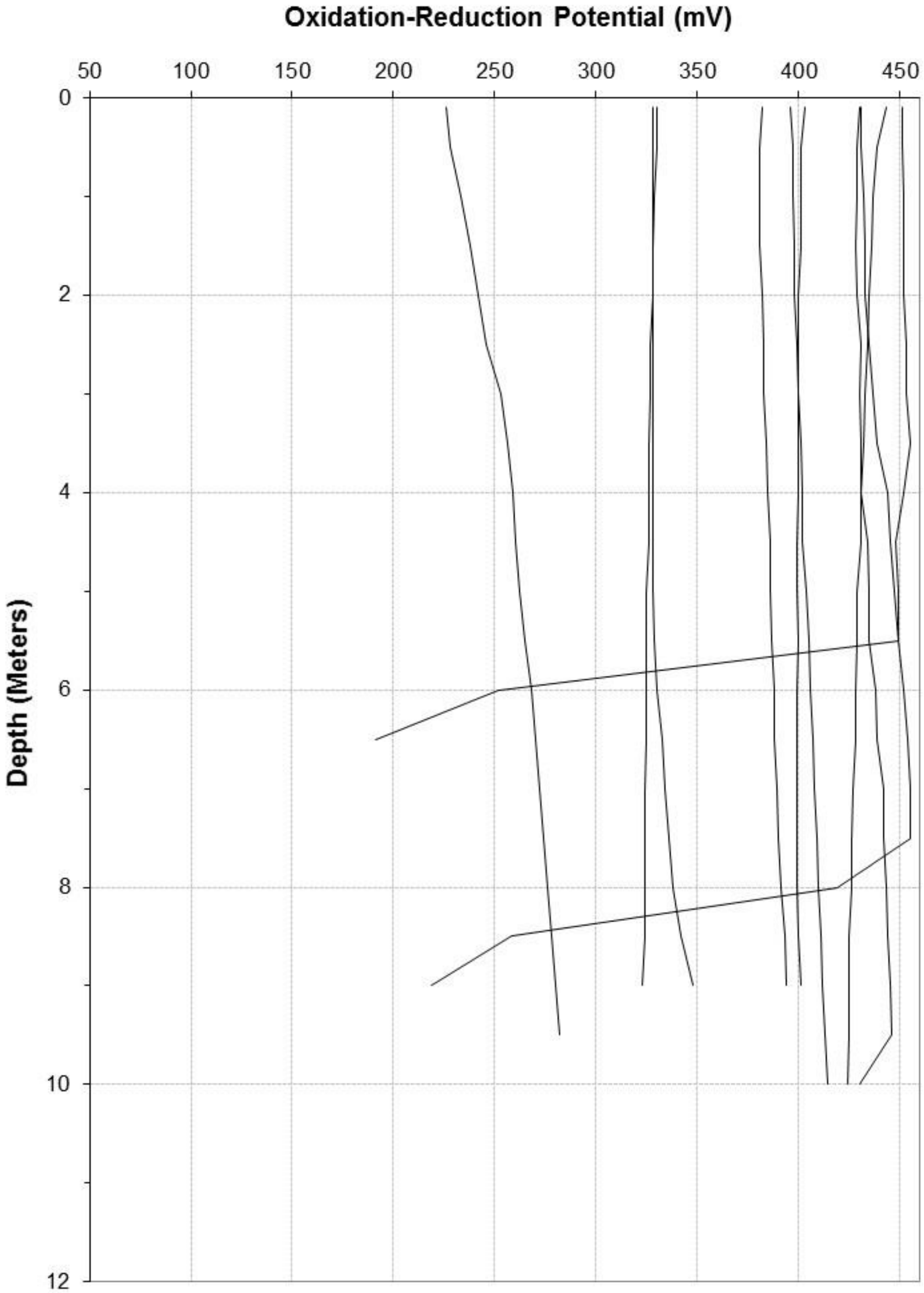


Plate 5-9. ORP depth profiles for Cold Brook Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., CODLKND1) during 2012 and 2015.

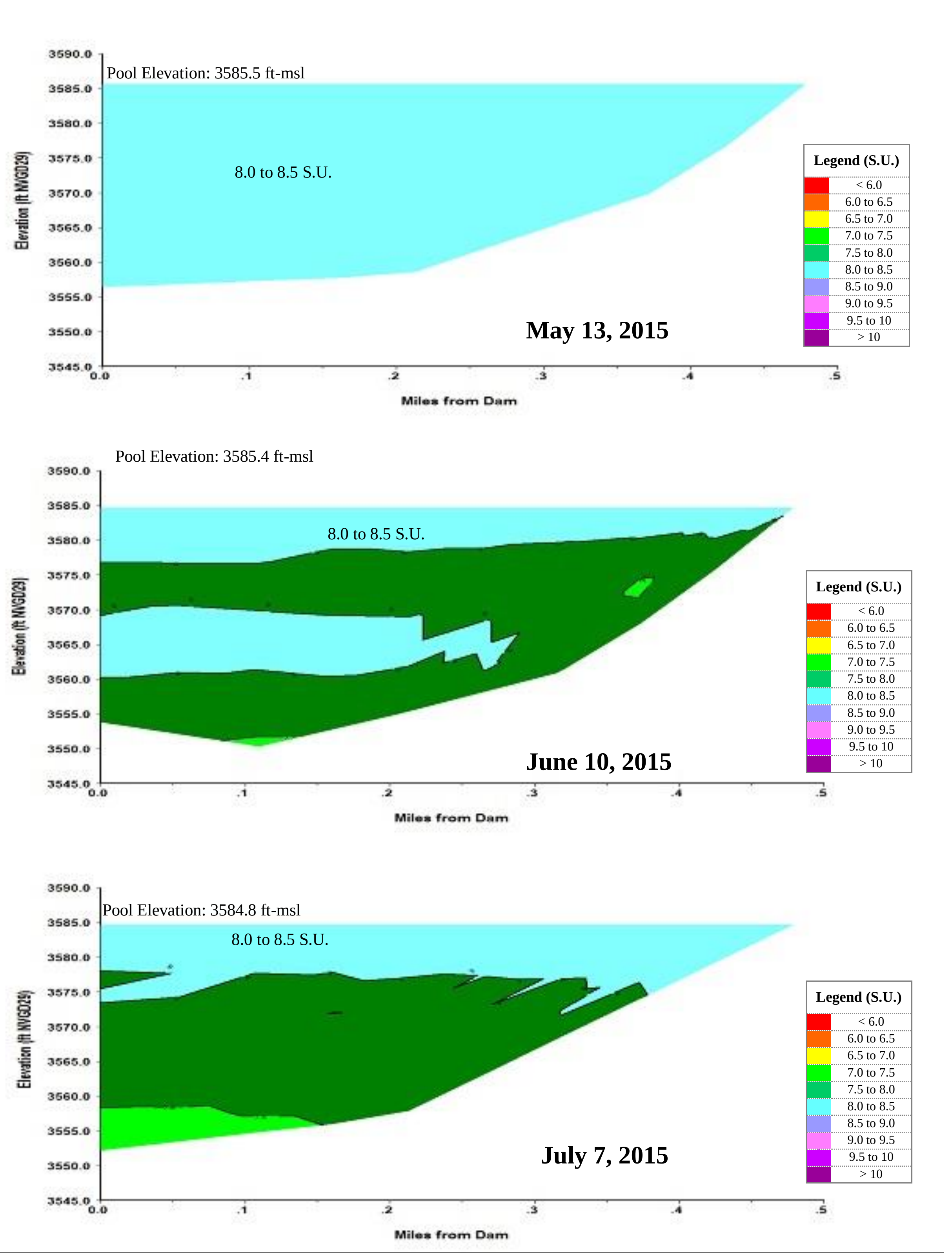
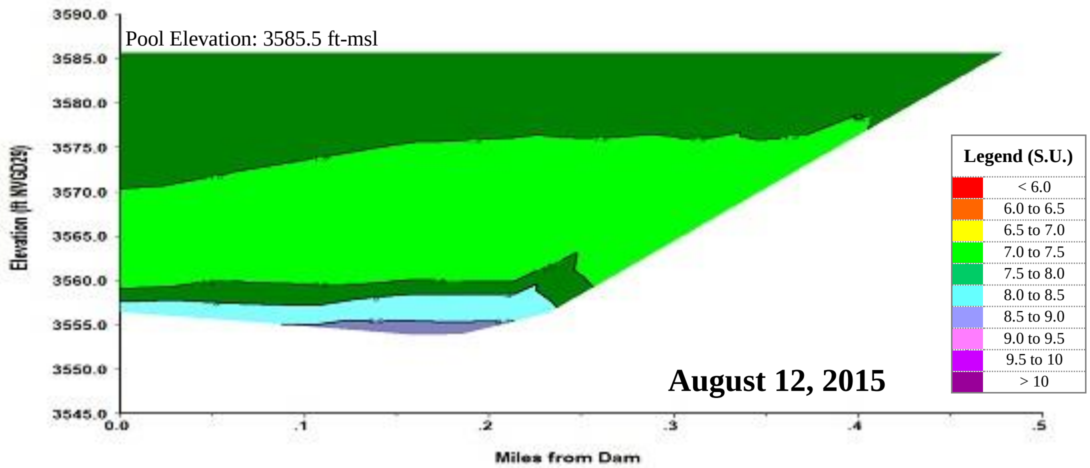


Plate 5-10. Longitudinal pH (S.U.) contour plots of Coldbrook Reservoir based on depth-profile dissolved oxygen concentrations measured at sites CODLKND1, CODLKML1, and CODLKUP1 in 2015.



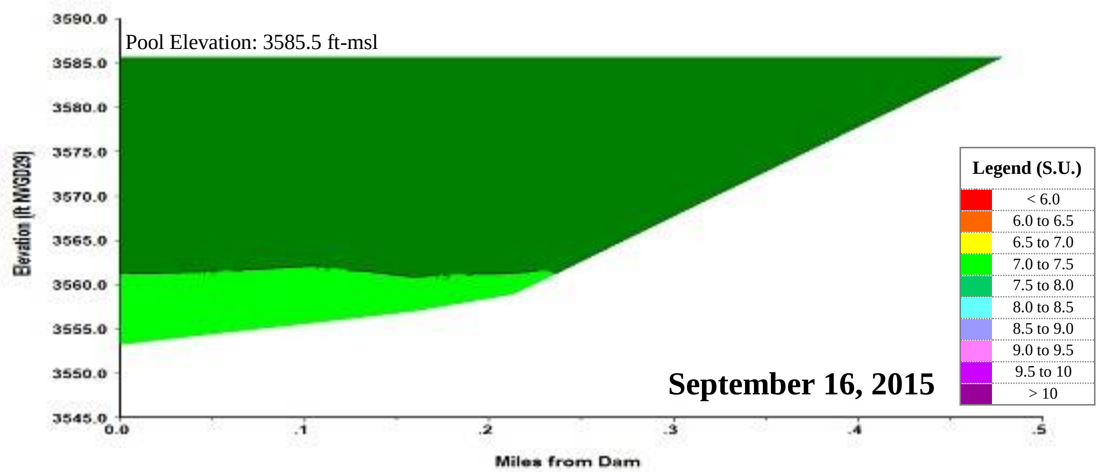


Plate 5-10 (Continued).

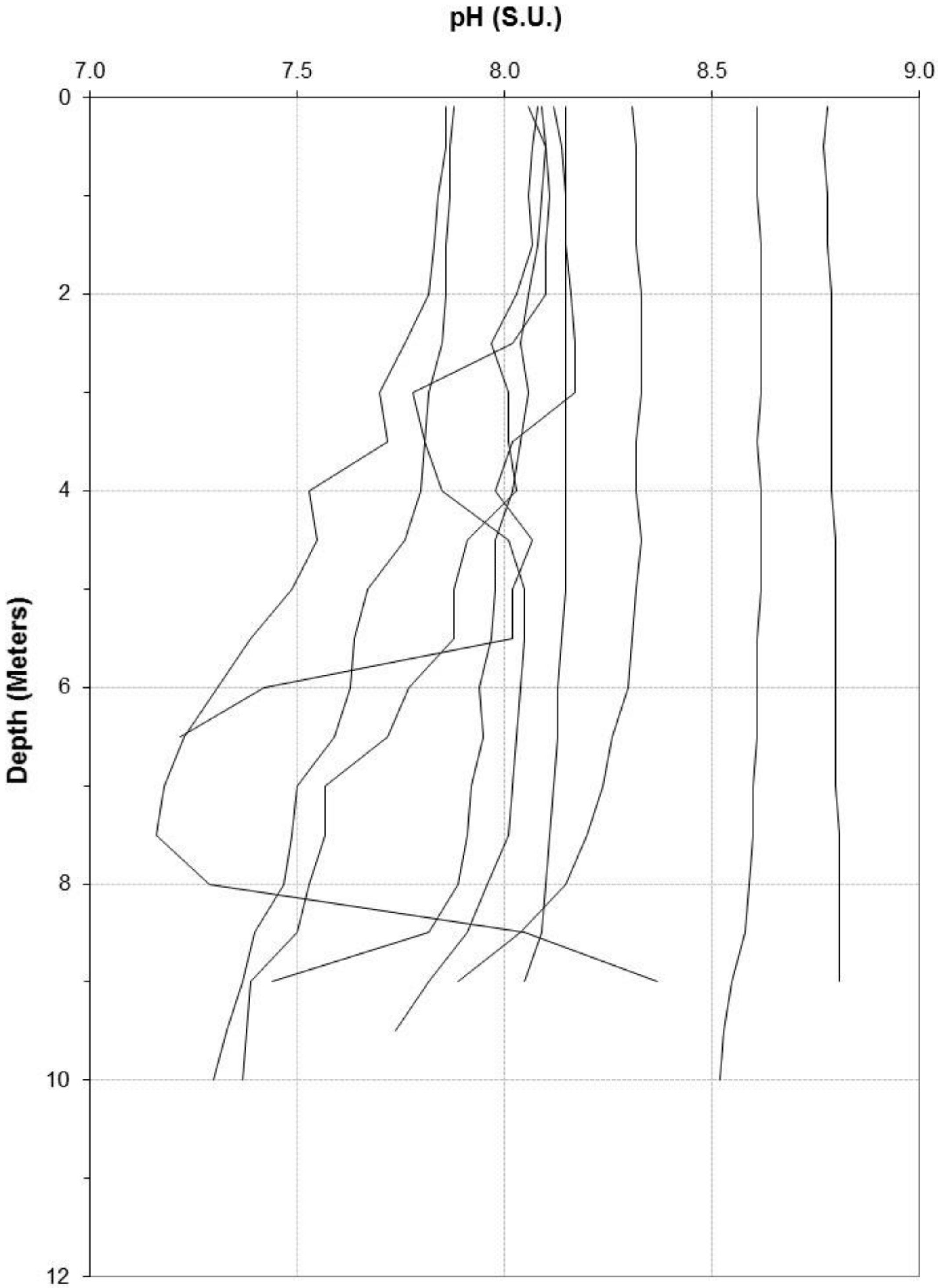


Plate 5-11. pH depth profiles for Cold Brook Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., CODLKND1) during the summers of 2012 and 2015.

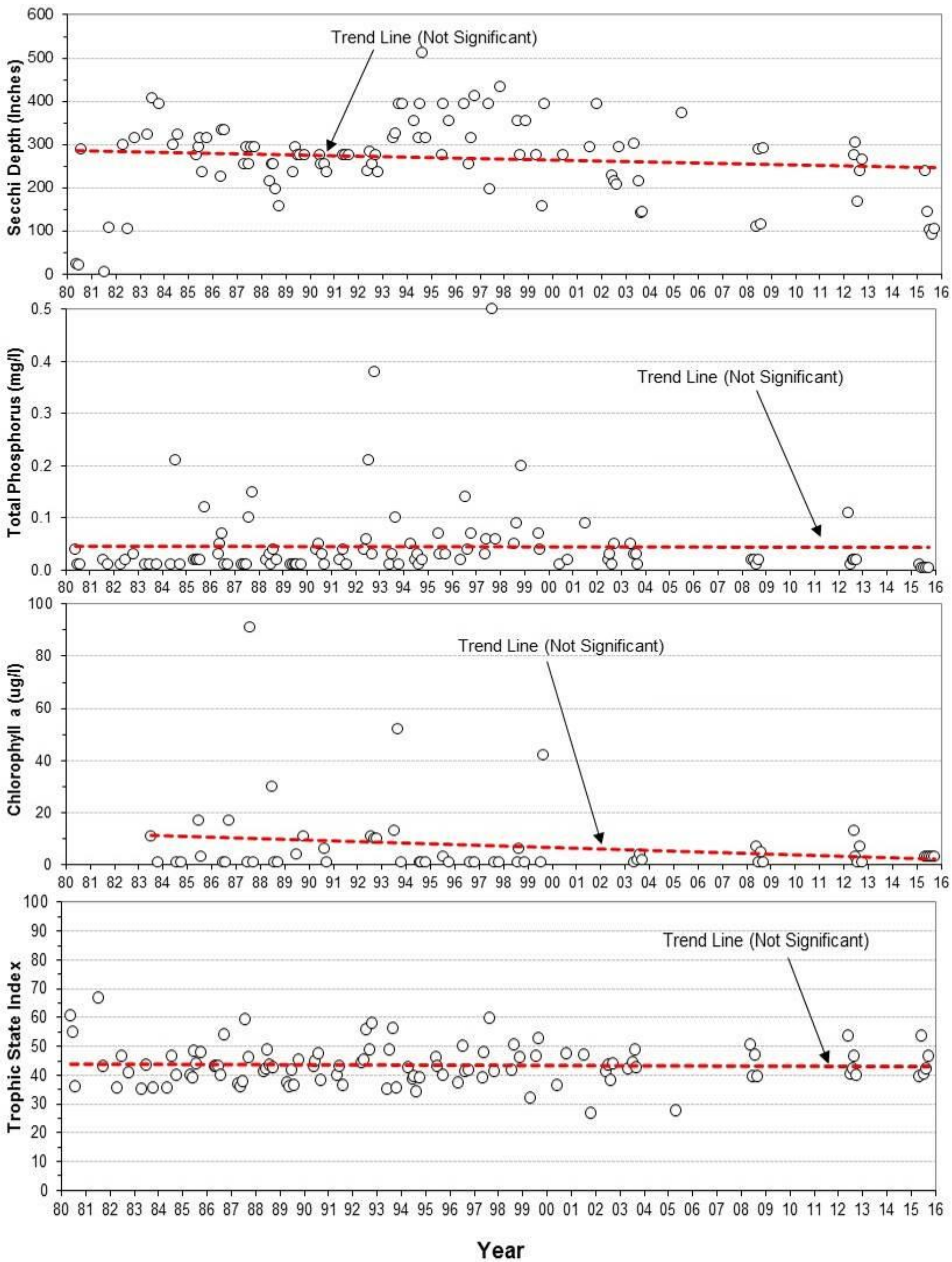


Plate 5-12. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Cold Brook Reservoir at the near-dam, ambient site (i.e., site CODLKND1) over the 36-year period of 1980 through 2015.

Plate 5-13. Summary of water quality conditions monitored in Cottonwood Springs Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site COTLKND1) from May to September 2012 and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, and pH are for water column profile measurements. Results for hardness, metals, and pesticides are for "grab samples" collected at ½ the measured Secchi depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	10	3830.5	3858.2	3581.0	3859.7	-----	-----	-----
Water Temperature (°C)	0.1	150	20.2	21.4	12.1	25.7	26.6	0	0%
Dissolved Oxygen (mg/l)	0.1	150	8.1	8.4	0.0	12.6	≥ 6, ≥ 5	12, 11	8%, 7%
Dissolved Oxygen (% Sat.)	0.1	150	93.0	100.6	0.0	143.7	-----	-----	-----
Specific Conductance (umho/cm)	1	150	1305	1308	538	1637	-----	-----	-----
pH (S.U.)	0.1	150	8.1	8.1	7.0	8.7	≥6.5 & ≤9.0	0	0%
Oxidation-Reduction Potential (mV)	1	150	343	343	13	446	-----	-----	-----
Secchi Depth (in.)	1	10	207	227	80	279	-----	-----	-----
Alkalinity, Total (mg/l)	0.6	20	86.8	51.0	32.0	329.0	-----	-----	-----
Ammonia, Total (mg/l)	0.02	20	-----	n.d.	n.d.	0.18	4.6 (1), 1.3(2)	0	0%
Chlorophyll a (ug/l) – Lab	3	10	3	3	3	5			
Chlorophyll a (ug/l) – Field Probe	3	127	-----	3	3	7			
Hardness, Total (mg/l)	0.3	2	825.6	825.6	745.7	905.4	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.08	20	0.77	0.73	0.26	1.52	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	20	-----	n.d.	n.d.	0.03	10(4)	0	0%
Phosphorus, Total (mg/l)	0.005	20	-----	0.02	n.d.	0.07	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.003	20	-----	n.d.	n.d.	0.03	-----	-----	-----
Suspended Solids, Total (mg/l)	4	20	-----	5	n.d.	20	158(1), 90(2)	0	0%
Dissolved Solids, Total (mg/l)	10	20	1191	1150	322	1830			
Total Organic Carbon (mg/l)	0.2	20	7.7	6.7	3.4	16.0			
Sulfate, Dissolved (mg/l)	0.4	20	724.0	714.5	117.0	972.0			
Antimony, Dissolved (ug/l)	0.03	2	-----	0.10	n.d.	0.20	6(4)	0	0%
Arsenic, Dissolved (ug/l)	0.008	2	3.50	3.50	3.00	4.00	340(1), 150(2), 0.018(3)	0, 0, b.d.	0%
Barium, Dissolved (ug/l)	1	2	32	32	27	36			
Beryllium, Dissolved (ug/l)	1	2	-----	n.d.	n.d.	n.d.	4(3)	0	0%
Cadmium, Dissolved (ug/l)	0.007	2	-----	0.05	n.d.	0.10	36(1), 4.9(2)	0	0%
Chromium, Dissolved (ug/l)	4	2	-----	n.d.	n.d.	n.d.	3091(1), 1,002(2)	0	0%
Copper, Dissolved (ug/l)	6	2	-----	n.d.	n.d.	n.d.	124(1), 68(2), 1,300(3)	0	0%
Lead, Dissolved (ug/l)	0.008	2	-----	n.d.	n.d.	n.d.	577(1), 22(2)	0	0%
Mercury, Dissolved (ug/l)	0.002	2	0.13	0.13	0.06	0.20	1.4(1)	0	0%
Nickel, Dissolved (ug/l)	8	2	-----	n.d.	n.d.	n.d.	8,442(1), 937(2)	0	0%
Silver, Dissolved (ug/l)	0.005	2	-----	n.d.	n.d.	n.d.	130(1)	0	0%
Selenium, Dissolved (ug/l)	0.06	2	0.95	0.95	0.90	1.00			
Zinc, Dissolved (ug/l)	6	2	-----	3	n.d.	6	684(1), 622(2),7,400(3)	0	0%
Acetochlor, Tot	0.07	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Atrazine, Tot	0.07	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Metolachlor, Tot	0.05	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Pesticide Scan (ug/l)(D)	0.05	3	-----	n.d.	n.d.	n.d.	-----	-----	-----
Microcystin, Total (ug/l)	0.1	10	-----	0.1	n.d.	0.1	-----	-----	-----

n.d. = Not detected. b.d. = Below detection.

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

(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(3) Human health criterion for surface waters.
(4) Daily maximum criterion for domestic water supply.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, metolachlor, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

Plate 5-14. Summary of water quality conditions monitored in Cottonwood Springs Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site COTLKML1) from May to September during 2012 and 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, and pH are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	5	3802.9	3858.2	3581.0	3859.7	-----	-----	-----
Water Temperature (°C)	0.1	124	20.4	21.1	12.2	25.7	26.6	0	0%
Dissolved Oxygen (mg/l)	0.1	124	8.1	8.3	0.0	12.0	≥ 6, ≥ 5	11, 10	9%, 8%
Dissolved Oxygen (% Sat.)	0.1	124	93.0	100.2	0.0	142.6	-----	-----	-----
Specific Conductance (umho/cm)	1	124	1258	1300	539	1635	-----	-----	-----
pH (S.U.)	0.1	124	8.1	8.2	7.1	8.8	≥6.5& ≤9.0	0	0%
Oxidation-Reduction Potential (mV)	1	124	355	390	45	448	-----	-----	-----
Turbidity (NTUs)	0.1	124	-----	0.4	0.0	147.5	-----	-----	-----
Secchi Depth (in.)	1	10	199	223	80	258	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	3	110	3	3	3	13	-----	-----	-----

n.d. = Not detected.

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

Plate 5-15. Summary of water quality conditions monitored in Cottonwood Springs Reservoir at the up-lake, monitoring location (i.e., site COTLKUP1) from May to September during 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, and pH are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	5	3803	3858	3581	3860	-----	-----	-----
Water Temperature (°C)	0.1	43	20.6	21.5	13.8	26.8	26.6	1	2%
Dissolved Oxygen (mg/l)	0.1	42	8.8	8.9	7.2	11.3	≥ 6, ≥ 5	0, 0	0%,0%
Dissolved Oxygen (% Sat.)	0.1	42	101.4	100.7	83.5	118.1	-----	-----	-----
Specific Conductance (umho/cm)	1	42	1293.1	1487.0	538.0	1634.0	-----	-----	-----
pH (S.U.)	0.1	42	8	8	8	9	≥6.5& ≤9.0	0	0%
Oxidation-Reduction Potential (mV)	1	42	355	360	291	420	-----	-----	-----
Turbidity (NTUs)	0.1	41	1	1	0	10	-----	-----	-----
Secchi Depth (in.)	1	10	114.3	114.0	73.0	168.0	6(4)	0	0%

n.d. = Not detected.

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

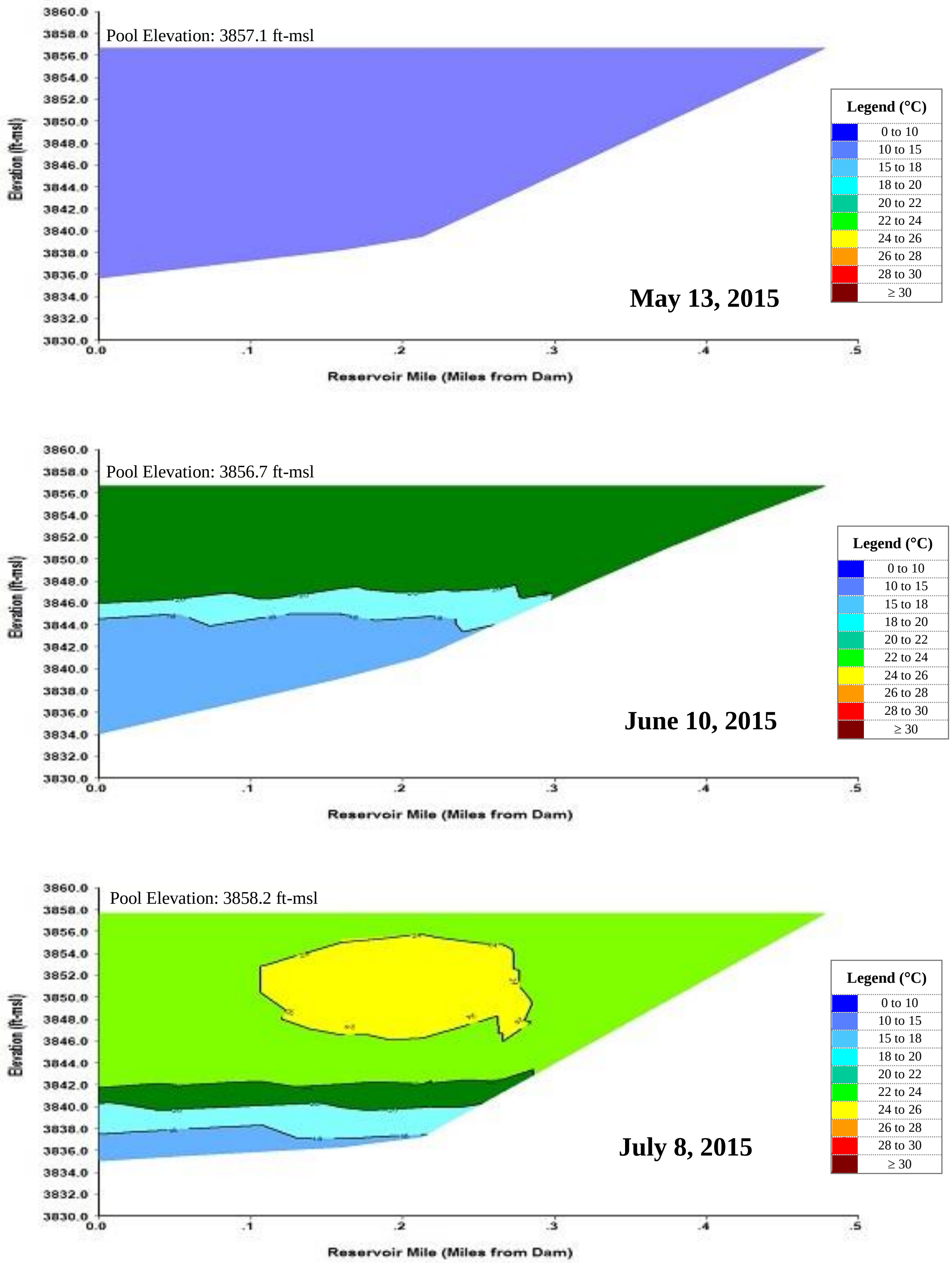
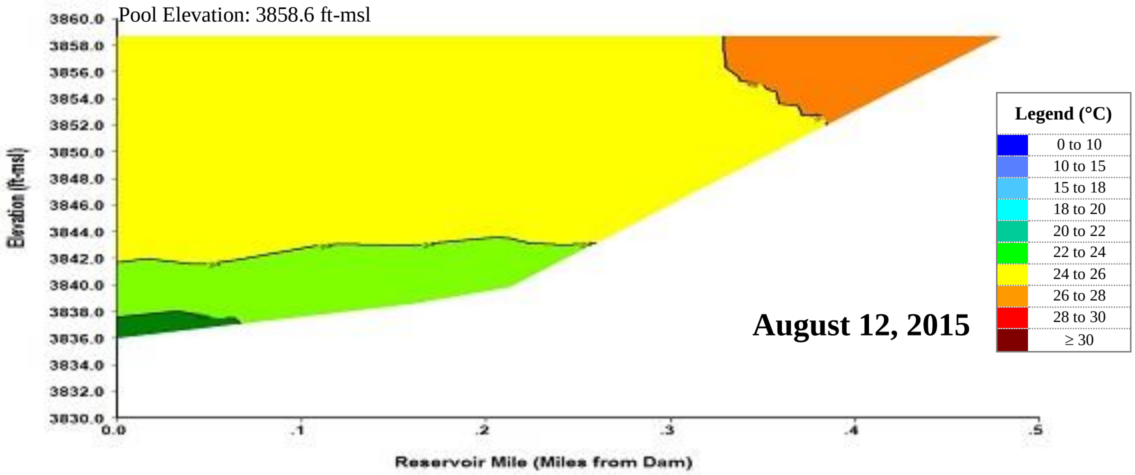


Plate 5-16. Longitudinal water temperature (°C) contour plots of Cottonwood Reservoir based on depth-profile water temperatures measured at sites COTLKND1, COTLKML1, and COTLKUP1 in 2015.



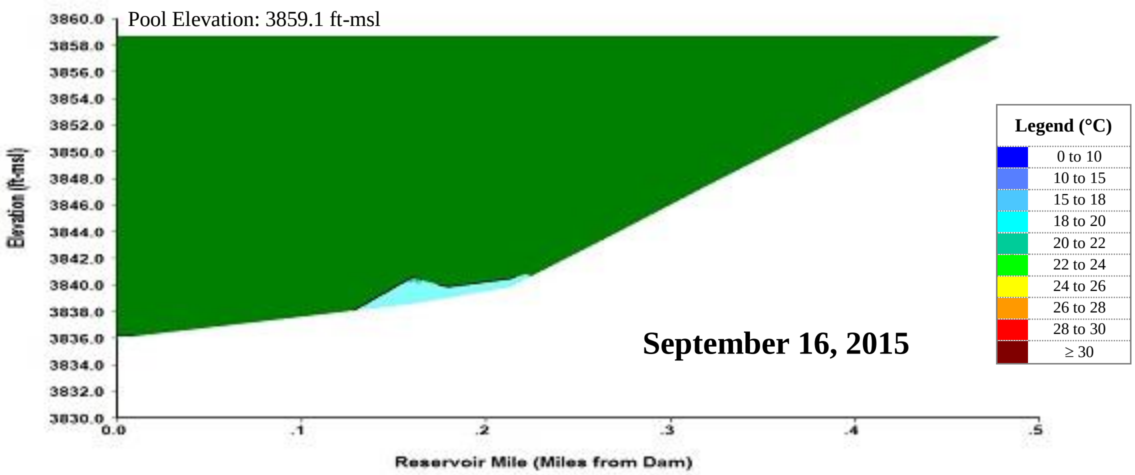


Plate 5-16 (Continued).

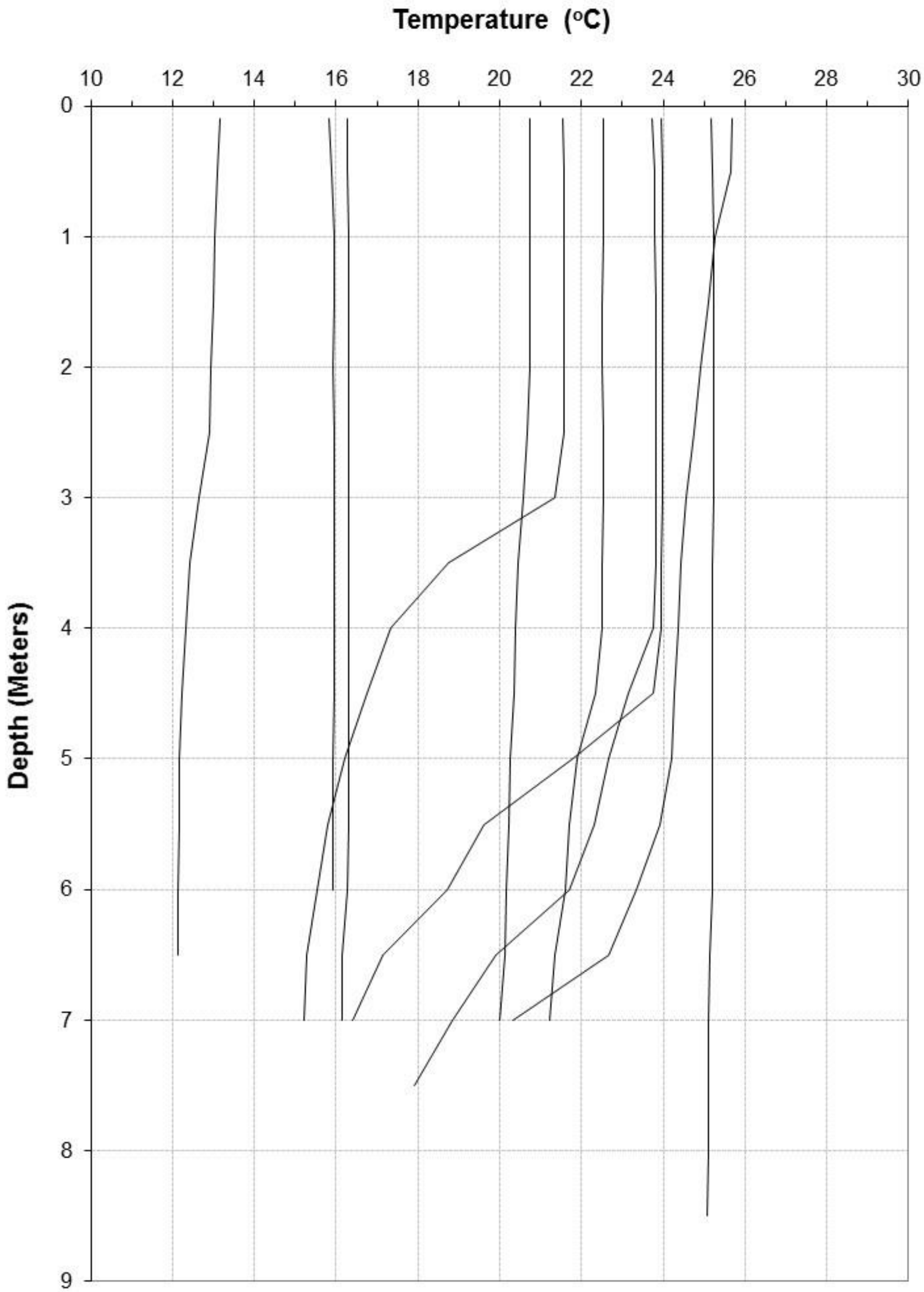


Plate 5-17. Temperature depth profiles for Cottonwood Springs Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., COTLKND1) during the summers of 2012 and 2015.

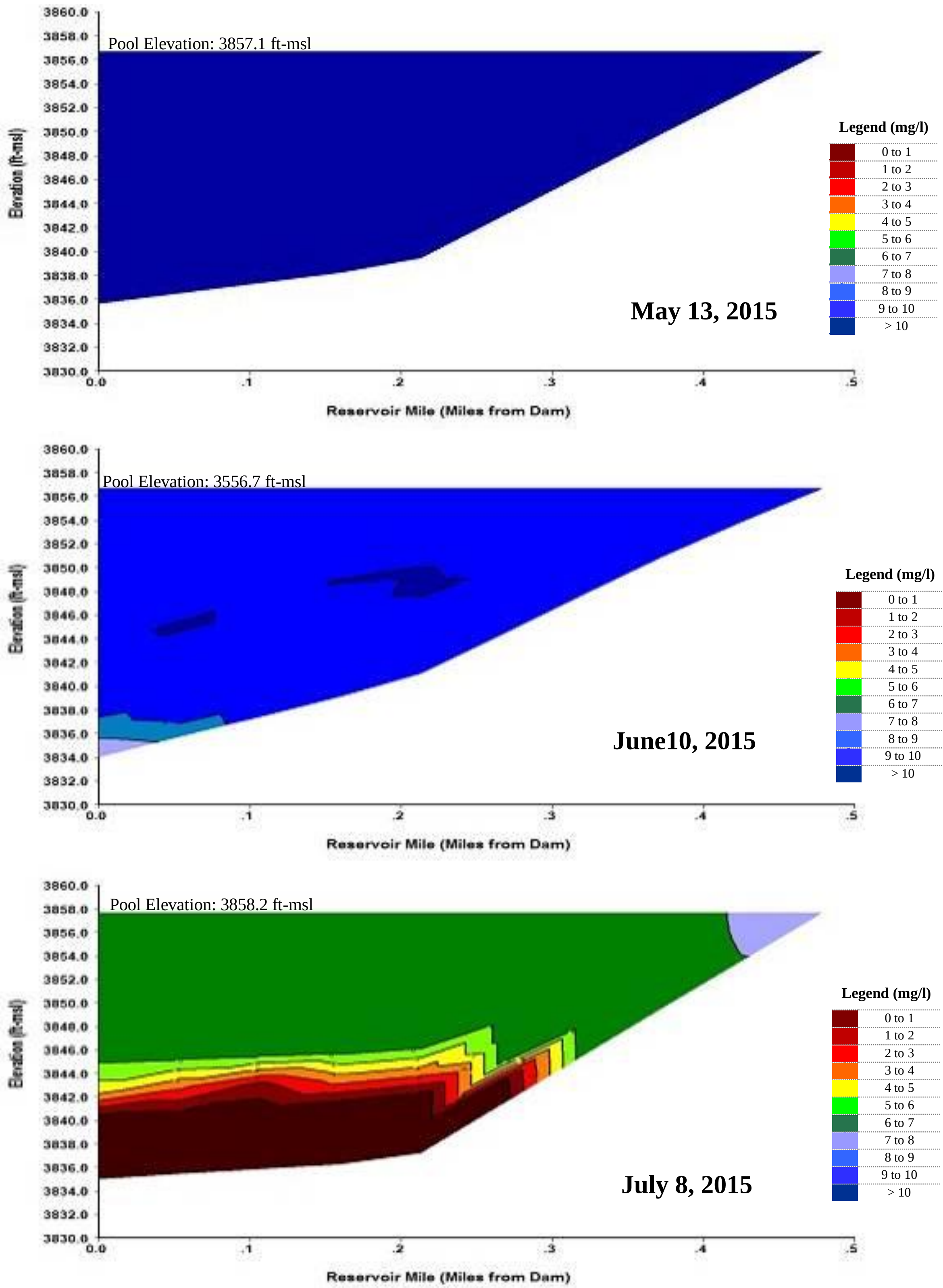
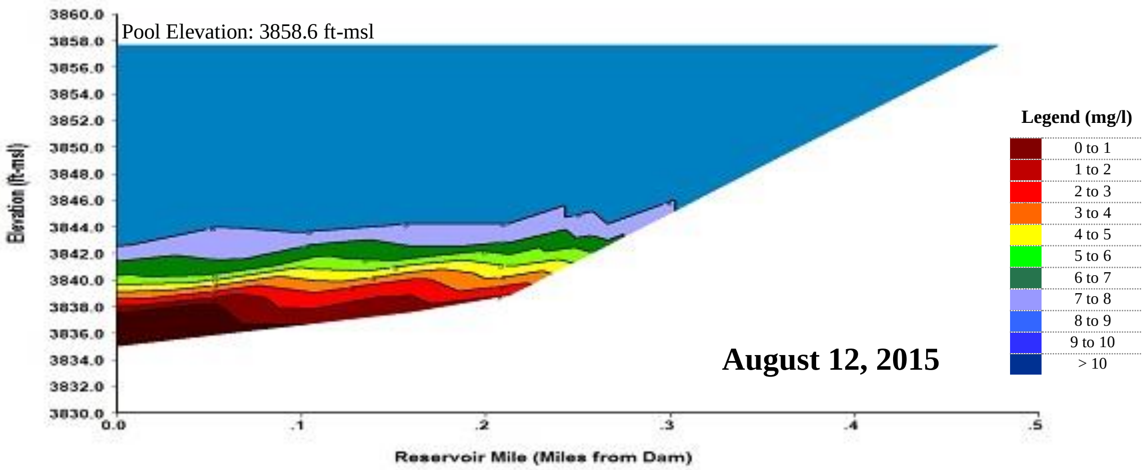


Plate 5-18. Longitudinal dissolved oxygen (mg/l) contour plots of Cottonwood Reservoir based on depth-profile measurments at sites COTLKND1, COTLKML1, and COTLKUP1 in 2015.



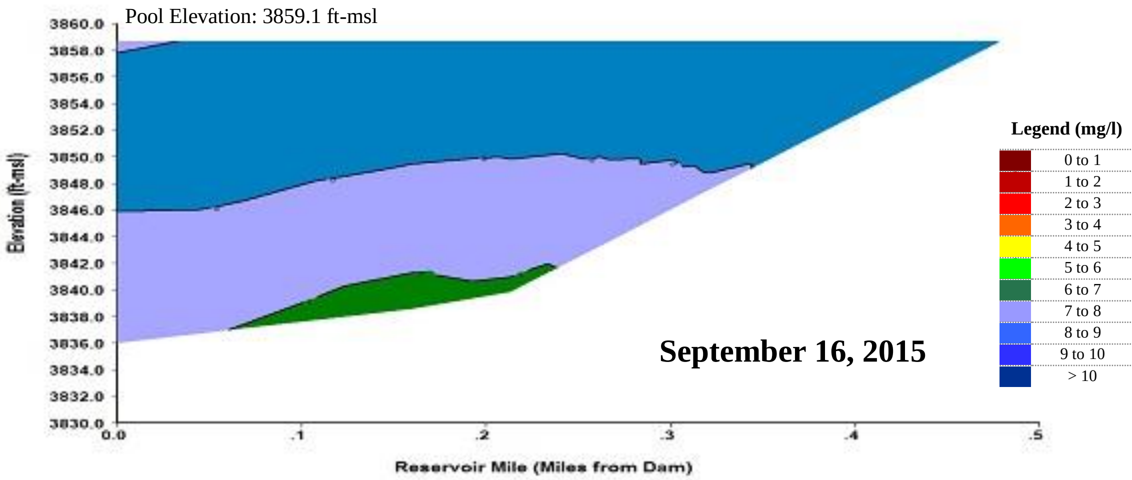


Plate 5-18 (Continued).

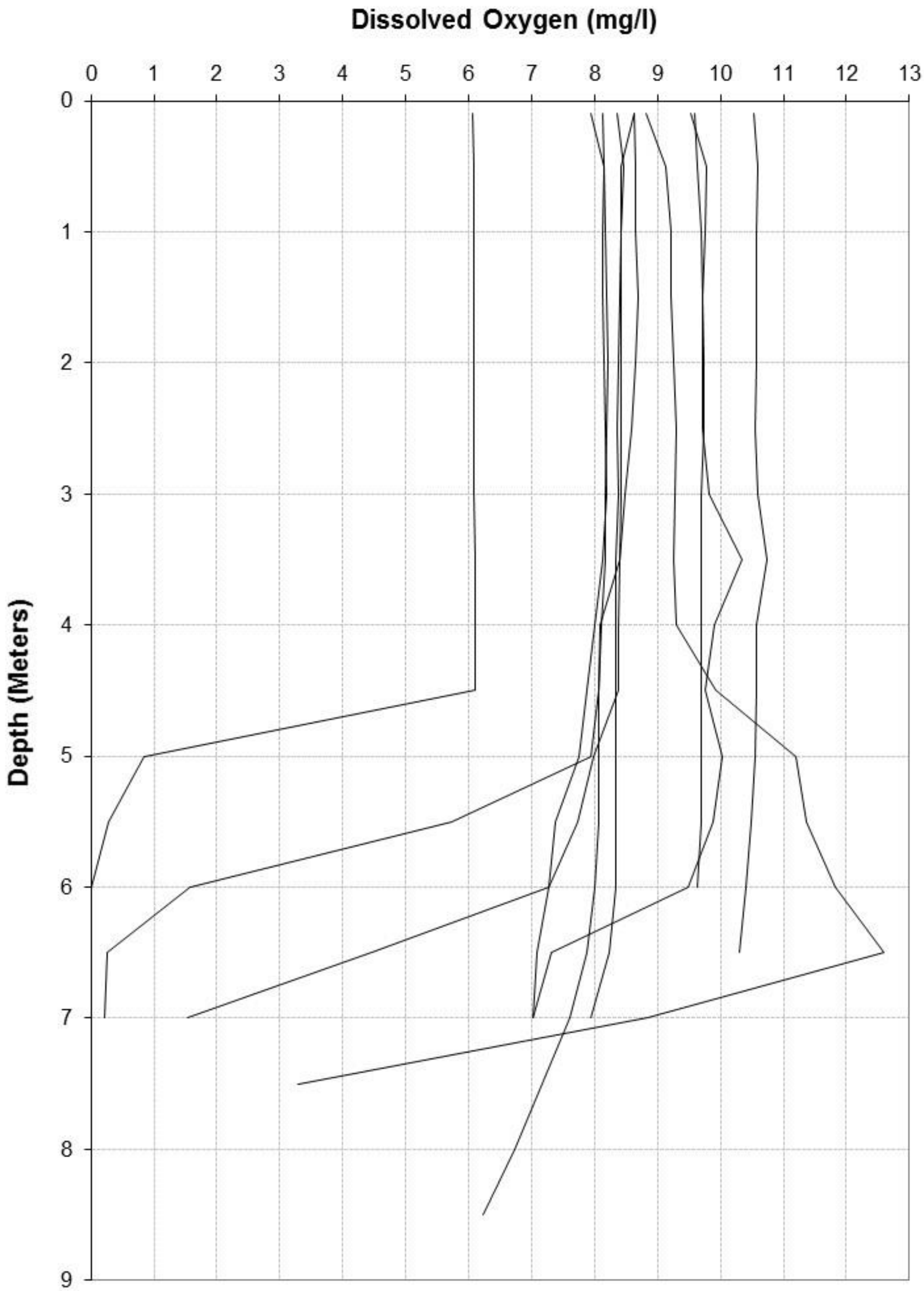


Plate 5-19. Dissolved oxygen depth profiles for Cottonwood Springs Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., COTLKND1) during the summers of 2012 and 2015.

6 WATER QUALITY MONITORING AND MANAGEMENT ACTIVITIES PLANNED FOR FUTURE YEARS

6.1 WATER QUALITY DATA COLLECTION

A tentative schedule of water quality monitoring targeted for implementation over the next 5 years at the District's Tributary Projects is given in Table 6-1. The identified data collection activities are considered the minimum needed to allow for the periodic assessment of water quality conditions. The actual monitoring activities that are implemented will be dependent upon the availability of future resources.

6.2 TOTAL MAXIMUM DAILY LOADS (TMDLS)

The District will provide water quality information to the States for 303(d) listing consideration and participate, as appropriate, as a stakeholder in the development and implementation of TMDLs on waterbodies that involve Tributary Projects.

Table 6-1. Water quality monitoring planned for District Tributary Projects over the next 5 years and the intended data collection approach. Actual monitoring activities implemented will be dependent upon available resources.

Waterbodies to be Monitored	Long-Term Fixed Station Monitoring	Intensive Surveys	Special Studies	Investigative Monitoring
Colorado Tributary Project Areas:				
• Bear Creek, Chatfield, and Cherry Creek Reservoirs	2018 2021[a]			
North Dakota Tributary Project Areas:				
• Bowman-Haley and Pipestem Reservoirs	2018 2021			
South Dakota Tributary Project Areas:				
• Cold Brook and Cottonwood Springs Reservoirs	2018 2021			

[a] The District will also utilize water quality data collected by the Local Watershed Management Authorities.

7 REFERENCES

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography, March 1977, Vol 22(2), pp. 361-369.

Health Canada. 2006. Blue-Green Algae (Cyanobacteria) and their toxins. http://www.hc-sc.gc.ca/ewh-semt/water-eau/drink-potab/cyanobacteria-cyanobacteries_e.html.

Hydrogeologic, Inc. 2005. Data Management and Analysis System for Lakes, Estuaries, and Rivers – Generic Version (DASLER-X). Version 4.5. HydroGeoLogic, Inc. Maryville, TN.

U.S. Army Corps of Engineers. 1987. Engineer Manual (EM) 1110-2-1201, Engineering and design – Reservoir Water Quality Analysis. U.S. Army Corps of Engineers, Department of the Army, Washington, DC.

_______. 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.

_______. 2015. 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.

Wetzel, R.G. 2001. Limnology – Lake and River Ecosystems. Third Edition. Academic Press, San Diego, CA