U.S. Army Corps of Engineers
Omaha District

2015 Report

Water Quality Conditions at the Omaha District Tributary Projects in Nebraska

December 2016

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Water Quality Conditions at Nebraska Tributary Projects in the Omaha District

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1 INTRODUCTION

1.1 OMAHA DISTRICT WATER QUALITY MANAGEMENT PROGRAM

The Omaha District (District) of the U.S. Army Corps of Engineers (Corps) is implementing a Water Quality Management Program (WQMP) as part of the operation and maintenance 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, 2015):

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 1.1. Table 2.1 provides background information on the projects. These are the Tributary Projects under the purview of the District's WQMP.

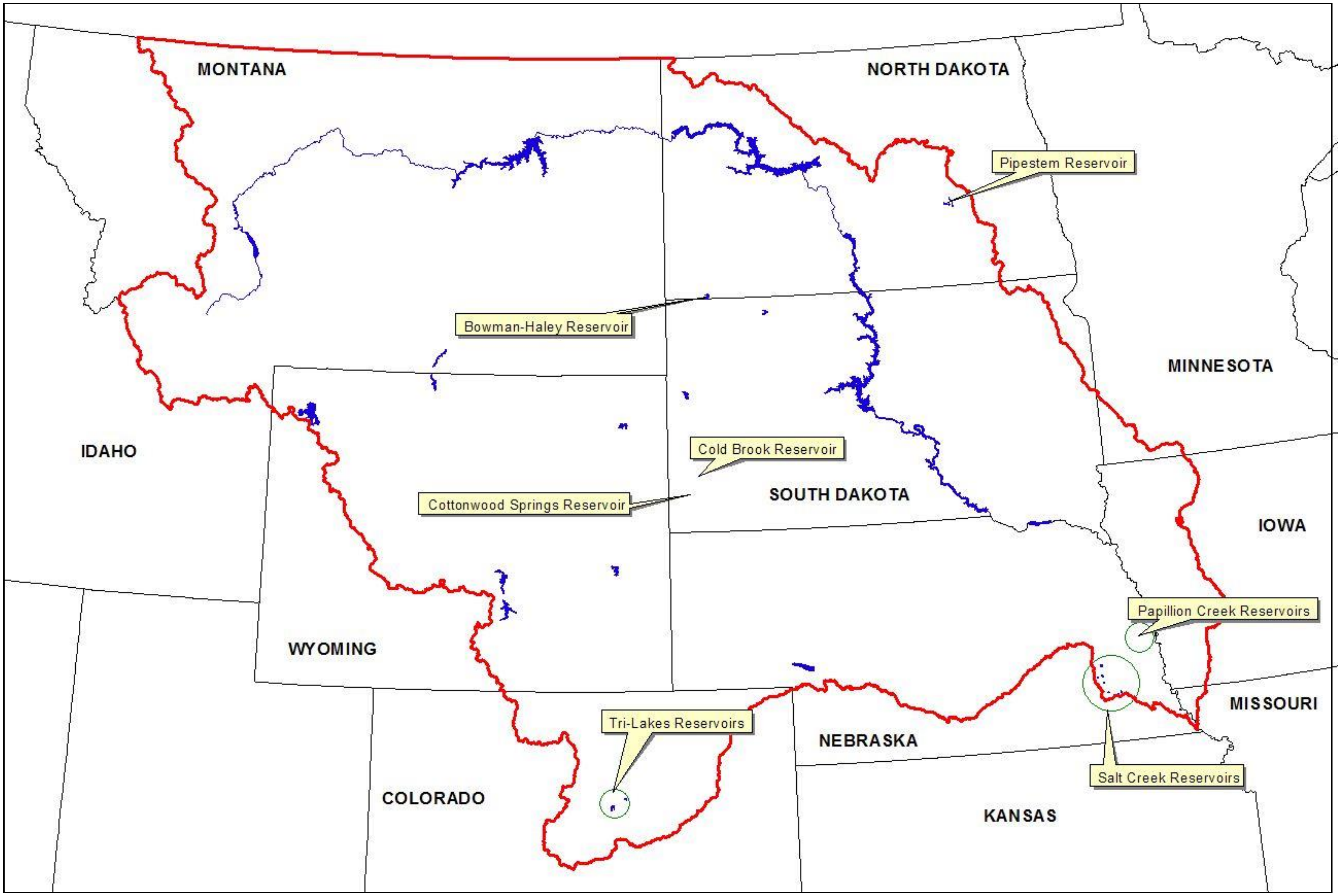


Figure 1.1. Tributary Projects in the Omaha District.

1.3 WATER QUALITY MONITORING PURPOSES AND OBJECTIVES

The District has established 4 purposes and 12 monitoring objectives for surface water quality monitoring under its WQMP. These monitoring purposes and objectives were established to meet the water quality information needs of the WQMP and the water quality management objectives, data collection rules and objectives, data application guidance, and reporting requirements identified in ER 1110-2-8154. The monitoring purposes and objectives that have been established are:

Purpose 1: Determine surface water quality conditions at District Projects.

Monitoring Objectives:

1. For new District water resource projects establish baseline surface water quality conditions as soon as possible and appropriate.
2. Characterize the spatial and temporal distribution of surface water quality conditions at District Projects.
3. Identify pollutants and their sources that are affecting surface water quality and the aquatic environment at District Projects.
4. Evaluate water/sediment interactions and their effects on overall surface water quality at District Projects.
5. Identify the presence and concentrations of contaminants in indicator and human-consumed fish species at District Projects.
6. Investigate unique events (e.g., fish kills, hazardous waste spills, operational emergencies, health emergencies, public complaints, etc.) at District Projects that may have degraded surface water quality or impacted the aquatic environment.

Purpose 2: Document surface water concerns that are due to the operation and reservoir regulation of District Projects.

Monitoring Objectives:

7. Determine if surface water quality conditions at District Projects or attributable to District operations or reservoir regulation (i.e., downstream conditions resulting from reservoir discharges) meets applicable Federal, Tribal, and State water quality standards.
8. Determine if surface water quality conditions at District Projects or attributable to District operations or reservoir regulation are improving, degrading, or staying the same over time.
9. Apply water quality models to assess surface water quality conditions at District Projects.

Purpose 3: Provide data to support project operations and reservoir regulation for effective management and enhancement of surface water quality and the aquatic environment.

Monitoring Objectives:

10. Provide surface water quality data required for real-time regulation of District Projects.
11. Collect the information needed to design, engineer, and implement measures or modifications at District Projects to enhance surface water quality and the aquatic environment.

Purpose 4: Evaluate the effectiveness of structural or regulation measures implemented at District Projects to enhance surface water quality and the aquatic environment.

Monitoring Objective:

12. Evaluate the effectiveness of implemented measures at District Projects to improve surface water quality and the aquatic environment.

1.4 PRIORITIZATION OF DISTRICT-WIDE WATER QUALITY MANAGEMENT ISSUES

The District has identified four priority issues for water quality management that are relevant to the Nebraska Tributary Projects. These priority issues and their relative ranking are listed in Table 1.1.

Table 1.1. Priority water quality management issues for the District's 2015 Water Quality Management Program.

	District-Wide Water Quality Management Issues
➢	Provide water quality information to support Corps reservoir regulation elements for effective surface water quality and aquatic habitat management.
➢	Provide water quality information and technical support to the Tribes and States in the development of their Section 303(d) lists and development and implementation of TMDLs at District Projects.
➢	Identify existing and potential surface water quality problems at District Projects and develop and implement appropriate solutions.
➢	Evaluate surface water quality conditions and trends at District Projects.

1.5 DATA COLLECTION APPROACHES

The District has identified four approaches to surface water quality data collection (USACE, 2015). These four surface water quality data collection approaches are:

- Long-term fixed-station ambient monitoring,
- Intensive surveys,
- Special studies, and
- Investigative monitoring.

Long-term fixed-station ambient monitoring is intended to provide information that will allow the District to determine the status and trends of surface water quality at District Projects. This type of sampling consists of systematically collecting samples at the same location over a long period of time (e.g., collecting monthly water samples at the same site for several years).

Intensive surveys are intended to provide more detailed information regarding surface water quality conditions at District Projects. They typically will include more sites sampled over a shorter timeframe than long-term fixed-station monitoring. Intensive surveys will provide the detailed water quality information needed to thoroughly understand surface water quality conditions at a project.

Special studies are conducted to address specific information needs. Special studies may be undertaken to collect the information needed to "scope-out" a specific surface water quality problem, apply water quality models, design and engineer modifications at projects, or evaluate the effectiveness of implemented surface water quality management measures.

Investigative monitoring is typically initiated in response to an immediate need for surface water quality information at a District Project. This may be in response to an operational situation, the occurrence of a significant pollution event, public complaint, or a report of a fish kill. Any District response to a pollution event or fish kill would need to be coordinated with the appropriate Tribal, State, and Local agencies. The type of sampling that is done for investigative purposes is highly specific to the situation under investigation.

2 NEBRASKA TRIBUTARY PROJECTS

2.1 OMAHA DISTRICT CIVIL WORKS TRIBUTARY PROJECTS WITHIN NEBRASKA

The locations of Corps Omaha District tributary civil works project areas within Nebraska are shown on Figure 2.1 and Figure 2.2. Table 2.1 provides background information on the projects. These Tributary Projects are under the purview of the District's WQMP.

Table 2.1. Background information for the Nebraska Tributary Projects located in the Omaha District.

Project	Location	Dam Closure	Reservoir Size (1)	Authorized Proposes(2)	Water Quality Designated Beneficial Uses(3)
Salt Creek Reservoirs:					
Bluestem (Dam #4)	Lincoln, NE	1962	309 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Branched Oak (Dam #18)	Lincoln, NE	1967	1,847 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Conestoga (Dam #12)	Lincoln, NE	1963	217 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Holmes (Dam #17)	Lincoln, NE	1962	123 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Olive Creek (Dam #2)	Lincoln, NE	1963	162 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Pawnee (Dam #14)	Lincoln, NE	1964	739 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Stagecoach (Dam #9)	Lincoln, NE	1963	195 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Twin Lakes (East and West) (Dam #13)	Lincoln, NE	1965	236 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Wagon Train (Dam #8)	Lincoln, NE	1962	277 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Yankee Hill (Dam #10)	Lincoln, NE	1965	211 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Papillion Creek Reservoirs:					
Ed Zorinsky (Dam #18)	Omaha, NE	1984	259 A (mp)	FC, Rec, FW, WQ	Rec, WAL, AWS, Aes
Glenn Cunningham (Dam #11)	Omaha, NE	1974	377 A (mp)	FC, Rec, FW, WQ	Rec, WAL, AWS, Aes
Standing Bear (Dam #16)	Omaha, NE	1972	125 A (mp)	FC, Rec, FW, WQ	Rec, WAL, AWS, Aes
Wehrspann (Dam #20)	Omaha, NE	1982	239 A (mp)	FC, Rec, FW, WQ	Rec, WAL, AWS, Aes

(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.

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

Table 2.2 summarizes TMDL considerations, fish consumption advisories, and other water quality management issues applicable to District Tributary Projects. The impaired uses and pollutant/stressors (i.e., TMDL considerations) and identified contamination (i.e., Fish Consumption Advisories) identified in Table 3.2 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 3.2 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.

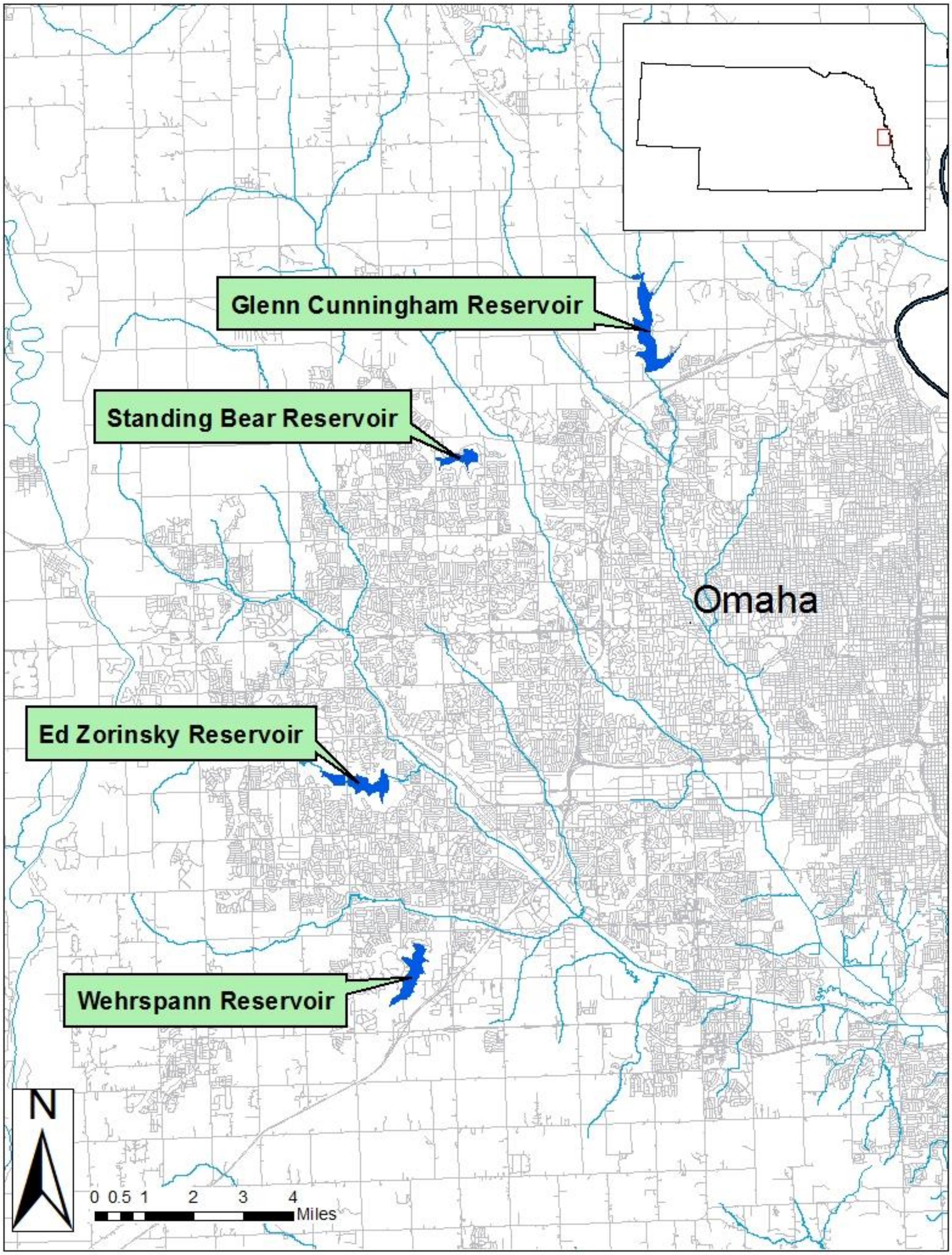


Figure 2.1. Location of Papio Creek Tributary Projects in the Omaha District.

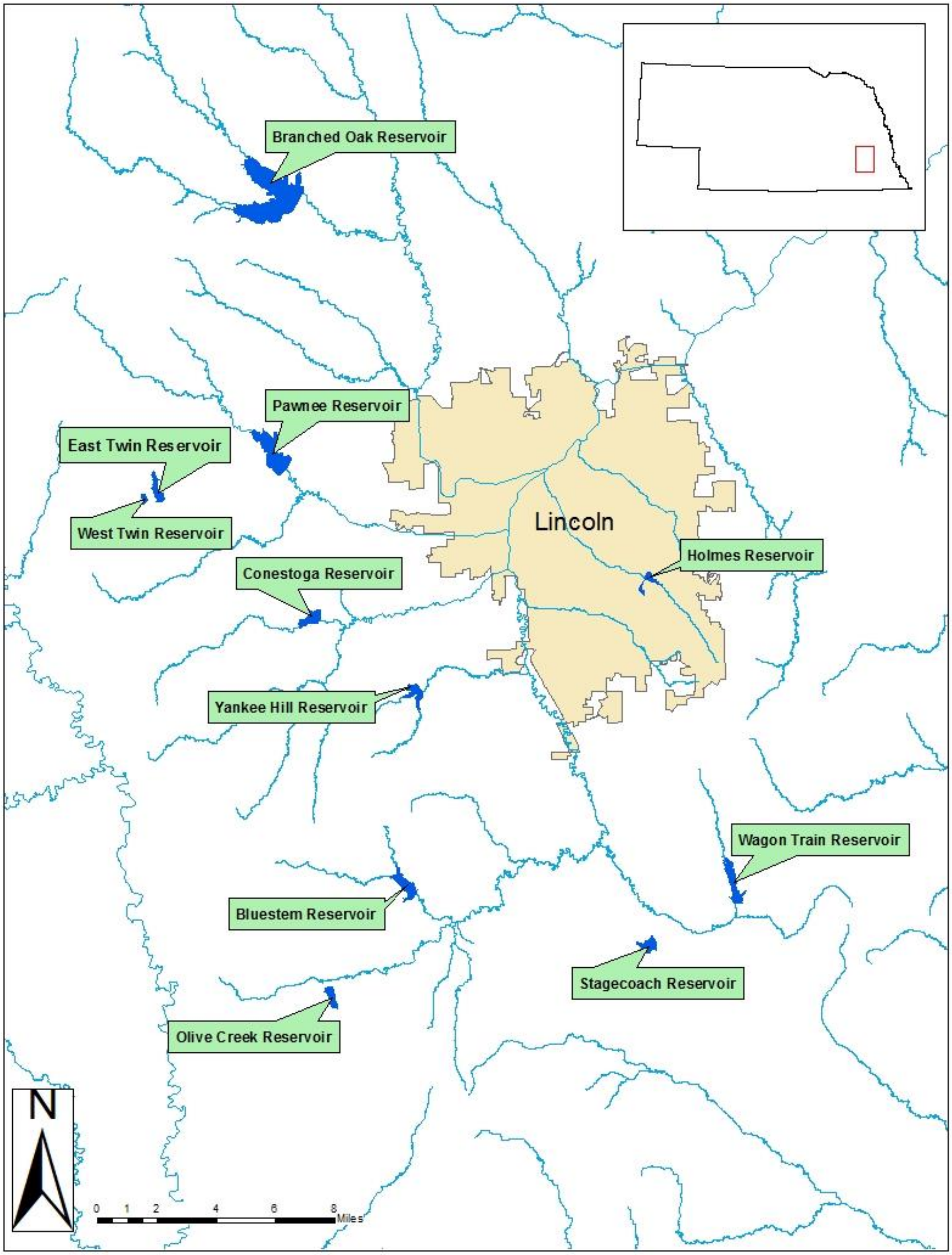


Figure 2.2. Location of the Salt Creek Tributary Projects in the Omaha District.

Table 2.2. Summary of project-specific water quality management issues and concerns at District Nebraska Tributary Projects.

Nebraska Tributary Project	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	
Bluestem Reservoir	Yes	Aquatic Life, Aesthetics	Sediment, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Mercury (Fish Tissue)	No	Yes	Mercury	TMDL to be developed
Branched Oak Reservoir	Yes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	No	No		TMDL to be developed
Conestoga Reservoir	Yes	Aquatic Life, Aesthetics	Sediment, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	No	No		Renovation project to begin in late 2013
East Twin Reservoir	Yes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	No	No		TMDL to be developed
Ed Zorinsky Reservoir	Yes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen) Mercury (Fish Tissue)	Yes	Yes	Mercury	TMDLs for nutrients and sediment approved (2002)
Glenn Cunningham Reservoir	No**	Aquatic Life	High pH, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	No	No		Renovation project completed in 2009
Holmes Reservoir	Yes	Aquatic Life	High pH, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Mercury (Fish Tissue)	Yes	Yes	Mercury	TMDLs for sediment and phosphorus approved (2003) Renovation project completed in 2005
Olive Creek Reservoir	Yes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen, Ammonia), High pH	No	No		TMDL to be developed
Pawnee Reservoir	Yes	Aquatic Life, Aesthetics, Recreation	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Algae Toxins, Sediment	Yes	No		TMDL for sediment approved (2001)
Stagecoach Reservoir	Yes	Aesthetics, Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Sediment	No	Yes	Mercury	TMDL to be developed
Standing Bear Reservoir	Yes	Aesthetics, Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Mercury (Fish Tissue), Sediment	Yes	Yes	Mercury	TMDLs for phosphorus and sediment approved (2003)
Wagon Train Reservoir	Yes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), DO, Mercury (Fish Tissue)	Yes	Yes	Mercury	TMDLs for phosphorus and sediment approved (2002)
Wehrspann Reservoir	Yes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Mercury (Fish Tissue)	No	Yes	Mercury	TMDL to be developed
West Twin Reservoir	Yes	Aquatic Life	Ammonia, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen, ammonia)	No	No		TMDL to be developed
Yankee Hill Reservoir	No**	Aquatic Life	High pH, Nutrient (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	Yes	No		TMDLs for phosphorus and sediment approved (2002) Renovation project completed in 2006

* Information taken from Nebraska Department of Environmental Quality 2016 Water Quality Integrated Report published State Total Maximum Daily Load (TMDL) Section 303(d) reports and listings.

** Category 4R – Waterbody data exceeds the impairment threshold however a TMDL may not be needed. The category will only be used for nutrient assessments in new or renovated lakes and reservoirs. Newly filled reservoirs usually go through a period of trophic instability – a trophic upsurge followed by the trophic decline. Erroneous water quality assessments are likely to occur during this period. To account for this, all new or renovated reservoirs will be placed in this category for a period not to exceed eight years following the fill or re-fill process. After the eighth year monitoring data will be assessed and the waterbody will be appropriately placed into category 1, 2, or 5.

3 WATER QUALITY MONITORING

3.1 AMBIENT RESERVOIR WATER QUALITY MONITORING

The District has conducted fixed-station ambient surface water quality monitoring at all the Nebraska tributary reservoirs. Some reservoirs have been monitored for the past 30 years. Since 2003, the District has cooperated with the Nebraska Department of Environmental Quality (NDEQ) to monitor ambient surface water quality conditions at all the Papillion and Salt Creek tributary reservoirs.

Ambient surface water quality monitoring at the Nebraska tributary reservoirs included monthly sampling (May through September) at three longitudinal locations on the reservoirs: 1) near-dam, 2) middle reaches, and 3) upstream reaches. Where a discrete submerged creek channel still existed, the monitoring site was located in the deepwater area over the submerged creek channel. Water quality monitoring at the near-dam location included field measurements for depth profiling and water transparency, and collection of near-surface and near-bottom grab samples for laboratory analysis. Water quality monitoring at the mid-reservoir and up-reservoir locations included field measurements for depth profiling and water transparency. Depth profiles in ½-meter increments were determined for temperature, dissolved oxygen, pH, conductivity, 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, chlorophyll *a*, pesticides, extracellular microcystin, and various metals. Except for chlorophyll *a*, pesticides, and various metals, near-bottom samples grab samples were analyzed for the same parameters.

3.2 MONITORING AT SWIMMING BEACHES

The District has cooperated with the NDEQ to monitor bacteria (i.e. *E. coli*) and cyanobacteria toxin levels present at swimming beaches and major recreational use areas at the Nebraska tributary reservoirs over the past 14 years. Reservoirs that were sampled include: Glenn Cunningham, Bluestem, Branched Oak, Conestoga, Pawnee, and Wagon Train. Weekly grab samples were collected from May to September and analyzed for *E. coli* bacteria and the cyanobacteria toxin total microcystin. The bacteria monitoring was conducted to meet a 6-hour holding time for collected samples.

E. coli bacteria are primarily associated with animal and human waste. Animal sources of *E. coli* bacteria commonly enter waterbodies from livestock and wildlife wastes that runoff the landscape during significant rainfall events. Human sources of contamination can include improperly maintained septic systems and wastewater treatment facilities that discharge untreated wastewater. *E. coli* bacteria are monitored to provide an “indirect” indication of potentially harmful bacteria. While not all *E. coli* bacteria are considered a threat to human health, some strains are. The larger the population of *E. coli* measured, the greater the odds of having harmful pathogenic bacteria. The state of Nebraska uses the value of 235 colonies of *E. coli* bacteria per 100 mL as the upper limit for supporting full body contact recreation.

Cyanobacteria toxins are naturally produced substances of certain species of cyanobacteria (i.e., bluegreen algae). These toxins can be harmful to animals, including humans. Cyanobacteria toxins are known to attack the liver (hepatotoxins) or the nervous system (neurotoxins), others simply irritate the skin. These toxins are usually released into the water when the cyanobacteria cell ruptures or dies. Cyanotoxins can be either free or cell bound (extracellular or intracellular respectively). In terms of monitoring for human health, total cyanotoxin levels (intra- and extracellular) is often measured to account for accidental human consumption or mass die-off a cyanobacterial bloom. One group of toxins produced and released by cyanobacteria is called microcystin because they were isolated from the cyanobacterium *Microcystis aeruginosa.* Microcystin are the most common of the cyanobacteria toxins found in water, as well as being the ones most often responsible for poisoning animals and humans who come into contact with toxic blooms

(Health Canada, 2006). Microcystin toxins are a hepatotoxin and are extremely stable in water because of their chemical structure. They can survive in both warm and cold water and can tolerate radical changes in water chemistry, including pH. Over 50 different variants of the microcystin toxin have been identified. Due to human health and other environmental concerns, the NDEQ began monitoring total microcystin in 2004. The State of Nebraska issues health advisories and closes swimming beaches if monitored total microcystins levels exceed 20 ug/l.

3.3 PLANKTON MONITORING

Plankton community data has been collected since 2011 in May, July, and September at the near-dam deepwater sites for all of the Salt Creek and Papio Creek Reservoirs. Phytoplankton was sampled by taking a 500-ml grab aliquot from the collected near-dam, near-surface sample. Zooplankton samples were collected by towing a 64-um with mesh plankton net with a front aperture of 706 cm^2 vertically from the lake bottom to surface. The contents of the net were then washed into a 250-ml plastic sample bottle using lake water. Plankton samples were preserved with 5ml of Lugol's solution and placed on ice in a cooler.

3.4 ZEBRA MUSSEL MONITORING

The European freshwater zebra mussel (*Dreissena polymorpha*) and a congener species, quagga mussel (*Dreissena bugensis)* are invasive species that were introduced to North America in the mid-1980s. These mussels produce a planktonic veliger larval stage (veliger) that eventually settles to the bottom and then uses byssal threads for attachment to firm substrates. They are the only calcareous-shelled invertebrates that attach to firm substratum in freshwater. Their ability to occupy a unique niche makes them an environmental threat and especially problematic as attached biofoulers.

In 2010, zebra mussels were identified in Ed Zorinsky reservoir. The reservoir was treated for the mussels, but the incident resulted in increased monitoring efforts from the District. Since 2012, the District has sampled for zebra mussel veligers. Once a year, veligers were sampled with a 64-µm plankton net with a front aperture of 706 cm^2. The plankton net was obliquely towed through the water column at depths of 2 to 10 feet along the reservoir dam in the area of rock riprap. The tows were as close to the dam face as possible. The plankton net was manually towed from a boat to achieve the specified oblique tow through the water column. A series of tows were made until the targeted area of the dam was covered. Samples were then concentrated into a 250-ml plastic sample bottle, preserved with 5ml of Lugol's solution, and placed on ice in a cooler.

3.5 INFLOW MONITORING DURING RUNOFF CONDITIONS

Since 2003, the District has cooperated with the NDEQ to monitor water quality conditions of major inflows under runoff conditions at all the Nebraska tributary reservoirs. Up to six runoff events from April through September were sampled annually at each of the reservoirs. Near-surface runoff grab samples were collected from a bridge or stream bank and analyzed for suspended solids, total Kjeldahl nitrogen, nitrate/nitrate, total ammonia, total phosphorus, acetochlor, alachlor, atrazine, and metolachlor.

4 WATER QUALITY ASSESSMENT METHODS

4.1 EXISTING WATER QUALITY

In this report, existing water quality is based on the "Sufficient and Credible Data Requirements" identified by the State of Nebraska in their methodologies for water quality assessment for development of Nebraska's integrated water quality reports. Nebraska's 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). Nebraska has identified five years as an appropriate "age restriction" for data to insure credible assessment of existing water quality conditions.

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

Statistical analyses were performed on the water quality monitoring data collected at the Nebraska 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 State of Nebraska 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.

4.1.2 SPATIAL VARIATION IN RESERVOIR WATER QUALITY CONDITIONS

4.1.2.1 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.

4.1.2.1.1 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. Oxidation-reduction potential (ORP) and pH longitudinal contour plots were also constructed where 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).

4.1.2.2 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 results 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.

4.1.2.2.1 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 State defined 5-year "age restrictions" 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 greater then twenty-five percent of the past 5-year depth profiles exhibited hypoxic conditions.

4.1.2.2.2 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 in more than twenty-five percent of the near dam depth profiles. 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.

4.1.3 RESERVOIR PLANKTON COMMUNITY

4.1.3.1 Phytoplankton Community

Assessment of the phytoplankton communities was based on grab samples collected at the near-surface, near-dam sampling sites. Laboratory analyses consisted of identification of phytoplankton taxa to the lowest practical level and quantification of taxa biovolume and density. Results were used to determine the relative abundance of phytoplankton taxa, for ten taxanomic groups, based on measured biovolumes across the 2015 growing season and across growing seasons between 2011 and 2015. Taxonomic groups consist of Divisions Charophyta (green algae), Chlorophyta (green algae), Chrysophyta (golden-brown algae), Cryptophycota (dinoflagellates), Ochrophyta (brown algae), Pyrrophycophyta (dinoflagellates), and Xanthophyta (yellow-green algae) and Phylums Cyanobacteria (blue-green algae) and Euglenophycota (euglenoid algae). Phytoplankton abundance across growing seasons was analyzed by averaging each years three sampling event's (May, July, September) biovolumes into a single biovolume measurement for each group for the given year. Years missing a complete data set were excluded from analysis.

Cyanobacteria have the potential to develop into dense blooms that produce potentially harmful cyanotoxins. Table 4.1 summarizes the World Health Organizations guidelines in regards to potential health risks of varying cyanobacterial densities for recreational surface waters. Cyanobacterial cell densities were analyzed and compared to these standards in order to identify reservoirs with the potential to become hazardous to human health.

Table 4.1. World Health Organization's guidelines to the monitoring of cyanobacteria in recreational surface waters.

Relative Probability of Acute Health Effects	Cyanobacteria Density (Cells/mL)	Microcystin-LR (µg/L)	Chlorophyll-a (µg/L)
Low	<20,000	<10	<10
Moderate	20,000-100,000	10-20	10-50
High	100,000-10,000,000	20-2,000	50-5,000
Very High	>10,000,000	>2,000	>5,000

4.1.3.2 <u>Zooplankton Community</u>

Assessment of the zooplankton communities was based on vertical-tow samples collected at the near-dam sampling sites. Laboratory analyses consisted of identification of zooplankton taxa to the lowest practical level and quantification of taxa biomass and density. These results were used to determine the relative abundance of zooplankton taxa for four different taxonomic groups, Cladocerans, Copepods, Rotifers, and Ostracods, based on measured biomasses during the 2015 growing season.

4.1.4 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:

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

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. However, this is often not the case at the Omaha District Tributary Reservoirs in Nebraska where suspended sediment often limits light penetration. Carlson indicates that the chlorophyll TSI value may be a better indicator of a lake's trophic conditions during mid-summer when algal productivity is at its maximum, while the total phosphorus TSI value may be a better indicator in the spring and fall when algal biomass is below its potential maximum. Calculation of TSI values from data collected from a lake's epilimnion during summer stratification provide the best agreement between all of the index parameters and facilitate comparisons between lakes. A TSI average value, calculated as the average of the three individually determined TSI values, is used by the District as an overall indicator of a reservoir's trophic state. The District uses the criteria defined in Table 4.2 for determining lake trophic status from TSI values.

Table 4.2. 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

4.2 IMPAIRMENT OF DESIGNATED WATER QUALITY-DEPENDENT BENEFICIAL USES

Water quality-dependent beneficial uses are designated to waterbodies in Nebraska. Water quality standards and criteria are defined to protect these uses. Water quality data collected by the District within the appropriate State defined "age restrictions" were assessed to determine if water quality conditions were impairing the designated beneficial uses. These data were assessed using the methodologies defined by Nebraska in developing their 2016 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 3.2).

4.2.1 ASSESSMENT METHODOLOGIES USED FOR NEBRASKA RESERVOIRS

4.2.1.1 Assessment of Reservoir Sedimentation

It is the State of Nebraska's position that excess sediment delivered to a lake can cause several problems including "objectionable colors, turbidity, and deposits." Deposition of sediment can displace or eliminate fish spawning and rearing and other aquatic habitats. Also, the recreation area of a lake can be reduced or rendered undesirable. Nebraska uses two measurements to assess lake sedimentation regarding the use of aesthetics: impoundment volume loss and sedimentation rate. Both the lake volume loss and sedimentation rate are based on the "as-built" conditions of the lake. Table 4.3 summarizes the Nebraska measures for the assessment of lakes regarding sedimentation.

Table 4.3. State of Nebraska measures for the assessment of lake sedimentation data.

Minimum Assessment Period	Supported	Impaired
≥5 Years	Volume loss < 25%, and Annual sedimentation rate ≤0.75%	Volume loss ≥ 25%, and Annual sedimentation rate >0.75%

4.2.1.2 Assessment of Reservoir Nutrient Data

Excessive nutrient concentrations can promote adverse effects to water quality and biological populations within lakes. Some of these effects include reductions in dissolved oxygen, water clarity, biodiversity, and fish and wildlife habitat; and increases in bacteria concentrations, toxin mobility, ammonia toxicity, and in-lake filling. Nebraska uses the term "nutrients" to refer specifically to total nitrogen and total phosphorus. The presence of nitrogen and phosphorus do not directly impair uses; rather, the nutrients spur algal and other vegetative growth that causes use impairment from algal toxins, extreme diurnal pH fluctuations, and dissolved oxygen depletion. Table 4.4 summarizes the Nebraska measures for the assessment of lakes regarding nutrients. Nutrient data for a reservoir must represent a minimum of two years of data for epilimnotic conditions during growing season conditions (May 1 through September 30).

Table 4.4. State of Nebraska measures for the assessment of lakes regarding nutrients.

Beneficial Use	Parameter	Criteria	Impaired
Aquatic Life	Chlorophyll *a*	<10 ug/l	Growing Season Average > 10 ug/l
Aquatic Life	Total Nitrogen	<1.0 mg/l	Growing Season Average > 1.0 mg/l
Aquatic Life	Total Phosphorus	< 0.05 mg/l	Growing Season Average > 0.05 mg/l

4.2.1.1 Assessment of Reservoir Physiochemical Data

Nebraska water quality standards define acute and chronic numeric criteria for the protection of aquatic life and maximum criteria for the protection of public drinking and agricultural water supplies. Nebraska deems a designated use to be impaired if measured water quality conditions indicate that numeric criteria are exceeded more than 10 percent of the time over an assessed period (i.e., 5 years). To address the uncertainty associated with water quality data, the application of the 10 percent exceedance criterion is based on the number of measurements for the appropriate water quality criteria. Table 4.5 summarizes the Nebraska assessment measures regarding sample size and the number of exceedances that indicate an impaired use (i.e., 10% exceedance) at a 90% confidence level (i.e., $\alpha= 0.10$).

4.2.1.2 Assessment of Fecal Coliform Bacteria, *E. Coli* Bacteria, and Cyanobacterial Toxins

Table 4.6 summarizes the Nebraska impairment criteria for the assessment of the Primary Contact Recreation Beneficial Use using fecal coliform bacteria, *E. coli* bacteria, and cyanobacterial toxin data.

Recreational data must be represented by a minimum of five years of data during growing season conditions.

Table 4.5. State of Nebraska Assessment Measures for Sample Size and Number of Exceedances Required to Determine an Impaired Use (i.e., 10% Exceedance).

Sample Size (n)	Number of Observations Exceeding a Criterion Required to Define an Impaired Use	Sample Size (n)	Number of Observations Exceeding a Criterion Required to Define an Impaired Use
<12	3	56 - 63	10
12 – 18	4	64 - 71	11
19 - 25	5	72 - 79	12
26 - 32	6	80 - 88	13
33 - 40	7	89 - 96	14
41 - 47	8	97 - 100	15
48 - 55	9	>100	>10% of Sample Size

Table 4.6. State of Nebraska impairment criteria for the assessment of the Primary Contact Recreation Beneficial Use using fecal coliform, *E. coli* bacteria, and total microcystin toxin data.

Beneficial Use	Parameter	Criteria	Impaired
Recreation	Fecal Coliform	≤ 200cfu/100ml	Season geometric mean > 200cfu/100ml
Recreation	*E. coli*	≤ 126cfu/100ml	Season geometric mean > 126cfu/100ml
Recreation	Total Microcystin	≤ 20 ug/l	>10% of samples exceed 20 ug/l

4.3 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.

5 PAPILION CREEK TRIBUTARY PROJECTS

5.1 BACKGROUND INFORMATION

5.1.1 PAPILLION CREEK WATERSHED HYDROLOGY

Streamflow in the Papillion Creek watershed follows a characteristic pattern. Flows are generally low except for brief periods of rise caused by runoff from rainfall events. A snowpack over the basin in early spring can produce a significant rise in flow as a result of snowmelt runoff. During the winter months streams in the basin are generally frozen over.

5.1.2 TRIBUTARY RESERVOIRS

Four District tributary reservoirs (i.e., Ed Zorinsky, Glenn Cunningham, Standing Bear, and Wehrspann) are located in the Papillion Creek watershed in the vicinity of Omaha, Nebraska (Figure 2.1). The authorized purposes for the four reservoirs are flood control, recreation, fish and wildlife, and water quality. Table 5.1 gives selected engineering data for each of the four reservoirs. A low-level outlet is installed at each dam to permit draining of the multipurpose pools in approximately a 1-month time period. This outlet may also be used to hasten the evacuation of flood storage so as to avoid damage to shoreline grasses and recreational facilities. The low and mid-level outlets may also be used for water quality management purposes by providing: 1) downstream flow augmentation releases during low-flow periods, and 2) targeted withdrawal from the bottom of the reservoir.

5.1.2.1 Water Quality Standards Classifications and Section 303(d) Listings

The State of Nebraska's water quality standards designates the following beneficial uses to all the Papillion Creek tributary project reservoirs: recreation, warmwater aquatic life, agricultural water supply, and aesthetics. None of the reservoirs are used as a public drinking water supply or have designated swimming beaches. The State's water quality standards also identify nutrient criteria for lakes and impounded waters based on their geographic location. Under this categorization, Ed Zorinsky, Standing Bear, and Wehrspann Reservoirs have been included in group "E" for eastern lakes or impounded waters. Glenn Cunningham Reservoir is currently listed as "Category 4R" due to the recent lake renovation.

Pursuant to the Federal CWA, the State of Nebraska has listed all the Papillion Creek Tributary project reservoirs on the State's 2014 Section 303(d) list (see Table 2.2). The beneficial use of aquatic life is identified as impaired in all four reservoirs, and aesthetics is identified as impaired in Standing Bear Reservoir. The identified pollutants/stressors include: chlorophyll a and nutrients (all four reservoirs), high pH (Glen Cunningham), sediment (Standing Bear), and mercury (Ed Zorinsky, Standing Bear, and Wehrspann Reservoirs). The State of Nebraska has issued fish consumption advisories for Ed Zorinsky, Standing Bear, and Wehrspann Reservoirs due to mercury concerns. TMDLs have been completed for Ed Zorinsky and Standing Bear Reservoirs.

Table 5.1. Summary of selected engineering data for the Papillion Creek Tributary Projects.

	Ed Zorinsky Reservoir (Dam Site No. 18)		Glenn Cunningham Reservoir (Dam Site No. 11)		Standing Bear Reservoir (Dam Site No. 16)		Wehrspan Reservoir (Dam Site No. 20)	
General								
Dammed Stream	Boxelder Creek		Knight Creek		Trib. Big Papillion CK		Trib. So Br Papillion Ck	
Drainage Area	16.4 sq. mi.		17.8 sq. mi.		6.0 sq. mi.		13.1 sq. mi.	
Reservoir Length[1]	1.5 miles		2.5 miles		1.0 miles		1.5 miles	
Designated Water Quality Storage	620 ac-ft		820 ac-ft		0 ac-ft		490 ac-ft	
Multipurpose Pool Elevation (Top)	1110.0 ft-msl		1121.0 ft-msl		1104.0 ft-msl		1095.8 ft-msl	
Date of Dam Closure	7-Dec-1989		5-Aug-1974		3-Oct-1972		21-Sep-1982	
Date of Initial Fill[2]	22-Apr-1992		2-Sep-1977		24-Oct-1977		26-May-1987	
"As-Built" Conditions[3]	(1985)		(1976)		(1976)		(1984)	
Lowest Reservoir Bottom Elevation	1074 ft-msl		1090 ft-msl		1073 ft-msl		1060 ft-msl	
Surface Area at top of Multipurpose Pool	259 ac		395 ac		135 ac		239 ac	
Capacity of Multipurpose Pool	3037 ac-ft		3705 ac-ft		1504 ac-ft		2640 ac-ft	
Mean Depth at top of Multipurpose Pool[4]	11.7 ft		9.4 ft		11.1 ft		11.0 ft	
Surveyed Conditions	2007:USACE	2002:USGS	2009:USACE	2001:NGPC	2009:USACE	2005:USGS	2009:USACE	2002:NGPC
Lowest Reservoir Bottom Elevation	1080 ft-msl	1077 ft-msl	1101 ft-msl	1100 ft-msl	1086 ft-msl	1082 ft-msl	1070 ft-msl	1068 ft-msl
Surface Area at top of Multipurpose Pool	247 ac	246 ac	337 ac	348 ac	123 ac	116 ac	236 ac	227 ac
Capacity of Multipurpose Pool	2781 ac-ft	2870 ac-ft	3015 ac-ft	2879 ac-ft	1141 ac-ft	1278 ac-ft	2309 ac-ft	2274 ac-ft
Mean Depth at top of Multipurpose Pool[4]	11.3 ft	11.7 ft	8.9 ft	8.3 ft	9.3 ft	11.0 ft	9.8 ft	10.0 ft
Sediment Deposition in Multipurpose Pool	2007:USACE	2002:USGS	2009:USACE	2001:NGPC	2009:USACE	2005:USGS	2009:USACE	2002:NGPC
Surveyed Sediment Deposition[5]	256 ac-ft	167 ac-ft	690 ac-ft	826 ac-ft	363 ac-ft	226 ac-ft	331 ac-ft	366 ac-ft
Annual Sedimentation Rate[6][12]	11.6 ac-ft/yr	9.8 ac-ft/yr	20.9 ac-ft/yr	33.0 ac-ft/yr	11.0 ac-ft/yr	7.8 ac-ft/yr	13.2 ac-ft/yr	20.3 ac-ft/yr
Current Estimated Sediment Deposition[7][11]	349 ac-ft	295 ac-ft	540 ac-ft	1014 ac-ft	429 ac-ft	304 ac-ft	410 ac-ft	630 ac-ft
Current capacity of Multipurpose Pool[8][11]	2688 ac-ft	2742 ac-ft	3165 ac-ft	2691 ac-ft	1075 ac-ft	1200 ac-ft	2230 ac-ft	2010 ac-ft
Annual Percent of Multipurpose Pool Capacity Lost to Sedimentation	0.38%	0.32%	0.56%	0.89%	0.73%	0.52%	0.50%	0.77%
Percent of "As-Built" Multipurpose Pool capacity lost to current estimated sediment deposition[11]	11%	10%	15%	27%	29%	20%	16%	24%
Operational Details – Historic	(1991-2015)		(1978-2015)		(1978-2015)		(1987-2015)	
Maximum Recorded Pool Elevation	1116.8 ft-msl	24-Jul-1993	1125.3 ft-msl	7-Aug-1999	1108.6 ft-msl	12-Jun-2008	1103.2 ft-msl	24-Jul-1993
Minimum Recorded Pool Elevation	1091.7 ft-msl	6-Apr-2011	1100.9 ft-msl	9-Jun-2006	1096.0 ft-msl	28-Feb-1991	1085.4 ft-msl	2-May-1990
Maximum Recorded Daily Inflow	684 cfs	8-May-2015	931 cfs	7-Aug-1999	277 cfs	8-May-2015	678 cfs	28-Jun-1993
Maximum Recorded Daily Outflow	142 cfs	25-Jul-1993	157 cfs	8-Aug-1999	65 cfs	16-Jun-1984	124 cfs	25-Jul-1993
Average Annual Pool Elevation	1109.4 ft-msl		1119.9 ft-msl		1103.0 ft-msl		1093.7 ft-msl	
Average Annual Inflow	5068 ac-ft		6795 ac-ft		1768 ac-ft		2498 ac-ft	
Average Annual Outflow	4269 ac-ft		5671 ac-ft		1323 ac-ft		1403 ac-ft	
Estimated Retention Time[9]	0.63 Years		0.56 Years		0.81 Years		1.59 Years	
Operational Details – Current[10]	(2011-2015)		(2011-2015)		(2011-2015)		(2011-2015)	
Maximum Recorded Pool Elevation	1115.2 ft-msl	7-May-2015	1123.1 ft-msl	11-Sep-2014	1108.2 ft-msl	8-May-2015	1098.3 ft-msl	22-Jun-2014
Minimum Recorded Pool Elevation	1091.7 ft-msl	6-Apr-2011	1118.1 ft-msl	13-Feb-2011	1101.3 ft-msl	8-Mar-2013	1091.2 ft-msl	8-Mar-2013
Maximum Recorded Daily Inflow	684 cfs	8-May-2015	253 cfs	11-Sep-2014	277 cfs	8-May-2015	249 cfs	8-May-2015
Maximum Recorded Daily Outflow	117 cfs	9-May-2015	93 cfs	12-Sep-2014	53 cfs	9-May-2015	66 cfs	22-Jun-2014
Average Annual Inflow (% of Historical Average Annual)	5769 ac-ft	(114%)	5139 ac-ft	(76%)	2740 ac-ft	(155%)	2668 ac-ft	(107%)
Average Annual Outflow (% of Historical Average Annual)	4887 ac-ft	(114%)	3889 ac-ft	(69%)	2214 ac-ft	(167%)	1270 ac-ft	(90%)
Outlet Works								
Ungated Outlets	2) 1.5'x3.5'	1110.0 ft-msl	2) 2.0'x4.0'	1121.0 ft-msl	2) 1.0'x2.5'	1104.0 ft-msl	2) 1.3'x3.5'	1095.8 ft-msl
	2) 3.2'x8.0'	1117.6 ft-msl	2) 2.5'x9.0'	1127.5 ft-msl	2) 2.0'x6.0'	1109.0 ft-msl	2) 3.7'x8.0'	1103.4 ft-msl
Gated Outlets (Mid-depth)	1) 6" Dia.	1104.3 ft-msl	None		None		1) 6" Dia.	1090.0 ft-msl
Gated Outlets (Low-level)	1) 30"x30"	1090.0 ft-msl	1) 30"x30"	1100.0 ft-msl	1) 24"x36"	1080.0 ft-msl	1) 30"x30"	1077.0 ft-msl

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

(1) Reservoir length at top of multipurpose 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) Surveyed sediment deposition is the difference in reservoir storage capacity to top of Multipurpose Pool between "as-built" and 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) Estimated Retention Time = Current Estimated Multipurpose Pool Volume ÷ Average Annual Outflow.

(10) Current operational details are for the last five water years, 1-Oct-2011 through 30-Sep-2015

(11) A lake restoration project for Glen Cunningham Reservoir was finished in 2008 that included dredging and removal of 275 ac-ft of sediment

(12) Estimated rate before completion of Wehrspan Reservoir restoration project in 1999. Estimated rate after 1999 is $^1/_2$ of this rate.

* A highlighted percent indicates impairment based on the State of Nebraska's assessment of lake sedimentation data.

5.1.2.1 <u>Reservoir Regulation for Water Quality Management</u>

5.1.2.1.1 Downstream Water Quality Management

When the Papillion Creek Tributary Projects were authorized, water quality management was identified as a concern within the Papillion Creek basin. At that time, studies by the Federal Water Pollution Control Administration (FWPCA) indicated that a need existed for water quality storage within the basin. The FWPCA identified the need for 3 cfs water quality flow in the Big Papillion Creek, Little Papillion Creek, and West Branch Papillion Creek. The FWPCA's studies indicated 8 of the proposed 21 reservoirs would collectively have sufficient storage to provide the identified 3 cfs water quality flows. Based on the costs of an alternative groundwater pumping project at that time, the storage was estimated to have an annual value of $10,700. Dam sites 11 (i.e., Glenn Cunningham), 18 (i.e., Ed Zorinsky), and 20 (i.e., Wehrspann) were included in the eight reservoirs potentially identified for having a water quality component in the multipurpose pool. Originally, Dam site 11 was to have a multipurpose pool of 4,600 ac-ft, of which 820 ac-ft was indicated as the water quality storage component. The 1976 survey of Glenn Cunningham Reservoir determined the multipurpose storage of the reservoir at that time was 3,705 ac-ft. Originally, Dam site 18 was to have a multipurpose pool of 4,700 ac-ft with a water quality component of 620 ac-ft. The 1984 survey of Ed Zorinsky Reservoir established the "as-built" multipurpose storage of the reservoir at 3,037 ac-ft. Originally, Dam site 20 was to have a multipurpose storage of 3,700 ac-ft with a water quality storage component 490 ac-ft. The 1984 survey of Wehrspann Reservoir determined the multipurpose storage of the reservoir at that time was 2,640 ac-ft. The multipurpose pools at the four Papillion Creek reservoirs were projected to fill with sediment in 100 years. To date, releases for downstream water quality management have not been necessary because seepage, releases, and/or tributary inflows at Dam sites 11, 18, and 20 have provided adequate flow for water quality purposes.

5.1.2.1.2 Reservoir Water Quality Management

Since authorized water quality storage has not been required for downstream water quality management, it is available for reservoir water quality management. The Papillion Creek tributary reservoirs are dimictic to polymictic and near-bottom areas of the reservoirs become anoxic during the summer and winter. Releases could be made from the reservoirs through the low-level outlet to potentially discharge excess phosphorus released from anoxic sediments during reservoir stratification.

5.2 ED ZORINSKY RESERVOIR

5.2.1 BACKGROUND INFORMATION

5.2.1.1 <u>Project Overview</u>

The dam forming Ed Zorinsky Reservoir is located on Boxelder Creek, a tributary of the South Papillion Creek in the West Branch Papillion Creek basin. The Ed Zorinsky Reservoir watershed is 16.4 square miles. The watershed was largely agricultural when the dam was built in 1984; however since then, the watershed has undergone extensive urbanization with the growth of Omaha.

The dam was completed on July 20, 1984; however, potential water quality problems delayed closure. Two wastewater treatment facilities occasionally discharged to upstream tributaries of the reservoir and it was decided to delay final closure until the situation was addressed. The situation was corrected by constructing a diversion pipeline to the Elkhorn River in the fall of 1989. The low-level gate at the dam was closed on December 7, 1989 and the reservoir reached its initial fill in April 1992.

5.2.1.2 <u>Zebra Mussels at Zorinsky Lake</u>

As part of the District's routine maintenance at Zorinsky Lake, the reservoir was lowered 3 feet in the fall of 2010 to pool elevation 1107 ft-NGVD29. This was done to facilitate the placement of additional riprap along the reservoir shoreline for erosion control. On 18-Nov-2010 a Boy Scout was picking up litter along the reservoir shoreline and picked up an aluminum can with a suspected zebra mussel attached. The can and attached suspected zebra mussel were provided to Nebraska Game and Parks Commission (NGPC) officials who confirmed it as a zebra mussel.

5.2.1.2.1 Measures Implemented to Control Zebra Mussels

The District's Missouri River Project Office held an interagency meeting on 2-Dec-2010 which was followed by a public meeting lead by the Nebraska Invasive Species Project on 7-Dec-2010. Both meetings discussed the potential impacts to Zorinsky Lake and addressed possible zebra mussel transmission to other area lakes. With input from the public and participating agencies it was concluded that this was likely an initial infestation of zebra mussels and measures should be implemented to control their potential spread and protect public infrastructure. An initial measure identified for controlling the zebra mussel population at Zorinsky Lake was drawing the reservoir down over the winter. It is generally believed that a rapid drop in water level (i.e., reservoir drawdown) during the winter months, and the subsequent exposure of zebra mussels to sub-freezing temperatures, can result in the mortality of emerged zebra mussels due to freezing and desiccation (McMahon, Ussery, & Clarke, 1993). It was also recommended that Zorinsky Lake remain drawn down until zebra mussel veliger sampling could be completed in the summer of 2011 and chemical treatment pursued if warranted.

An additional seven foot drawdown of Lake Zorinsky began on 10-Dec-2010 with the reservoir reaching a pool elevation of 1100 ft-NVGD29 on 18-Dec-2010. The drawdown to pool elevation 1100 ft-NGVD29 was deemed within the Districts normal operation and regulation of the reservoir. All of the participating agencies recommended that a complete drawdown of Zorinsky Lake should be pursued, and an Environmental Assessment (EA) was completed by the District to evaluate this recommendation. On 23-Dec-2010, the low-level outlet gates were opened to draw down Zorinsky Lake to the maximum extent possible. On 4-Jan-2011 Zorinsky Lake reached an elevation of 1092.4 ft-NGVD29 which was the maximum drawdown possible without the removal of accreted sediment in front of the low-level outlet.

5.2.1.2.2 Survey of Emerged Zebra Mussel Shells after the Zorinsky Lake Drawdown

Preliminary inspections before and after the reservoir drawdown indicated a very low abundance of zebra mussels relative to levels reported in the literature for infested waters. To gain a better understanding of the zebra mussel population in Zorinsky Lake at the time of the 2010/2011 winter drawdown, in was decided to survey the exposed bottom of the reservoir for the occurrence of emerged adult zebra mussel shells. The survey methodology and results are documented in the report "Assessment of the Water Quality Conditions at Ed Zorinsky Reservoir and the Zebra Mussel (Dreissena polymorpha) Population Emerged after the Drawdown of the Reservoir and Management Implications for the District's Papillion and Salt Creek Reservoirs" (USACE, 2012).

5.2.1.3 <u>Ed Zorinsky Dam Intake Structure</u>

The reinforced concrete intake structure at Ed Zorinsky Dam has four upper-level intakes (two at invert elevation 1110.0 ft-msl and two at invert elevation 1117.6 ft-msl), an intermediate-level intake (invert elevation 1104.3 ft-msl), and a low-level intake (invert elevation 1090 ft-msl). The upper-level intakes are uncontrolled. The intermediate-level intake has a 6-inch diameter slide gate for flow augmentation releases for water quality management. The low-level intake is provided with a slide gate to permit draining of the reservoir below elevation 1110.0 ft-msl in the event drawdown is desirable. The low-level inlet is constructed 240 feet upstream of the intake tower. The inlet is provided with a trash rack and emergency bulkhead to allow closure with the gate open. A 30-inch reinforced concrete pipe connects the low-level inlet to the intake structure.

5.2.1.4 Reservoir Storage Zones

Figure 5.1 depicts the current storage zones of Ed Zorinsky Reservoir based on the 2007 Corps survey data and estimated sedimentation. It is estimated that 10 to 11 percent of the "as-built" Multipurpose Pool has been lost to sedimentation as of 2015 with the annual volume loss estimated to be 0.38 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Ed Zorinsky Reservoir's water quality dependent uses are not impaired due to sedimentation.

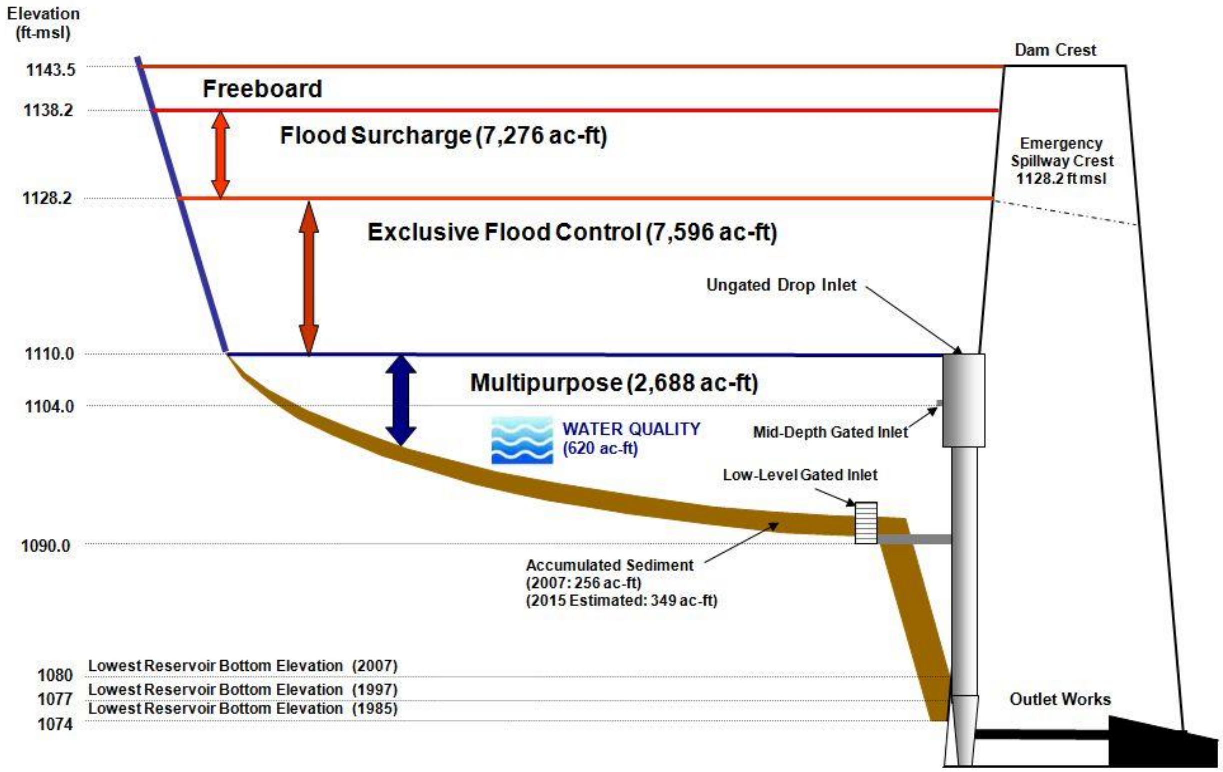


Figure 5.1. Current storage zones of Ed Zorinsky Reservoir based on the 2007 Corps survey data and estimated sedimentation.

5.2.1.5 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Ed Zorinsky Reservoir since the reservoir was initially filled in the early 1990's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 5.2 shows the location of sites that have been monitored for water quality during the 5-year sampling period (i.e., 2011 through 2015). The near-dam location (i.e., EZRLKND1) was been continuously monitored since 1993.

Figure 5.2. Location of sites where water quality monitoring was conducted by the District at Ed Zorinsky Reservoir during the period 2011 through 2015.

5.2.2 WATER QUALITY IN ED ZORINSKY RESERVOIR

5.2.2.1 <u>Existing Water Quality Conditions</u>

5.2.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Ed Zorinsky Reservoir at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 from May through September during the 5-year period 2011 through 2015 are summarized in

Plate 5-1 through Plate 5-5. A review of these results indicated possible water quality concerns regarding dissolved oxygen, ammonia, nutrients, and chlorophyll a.

A significant number of dissolved oxygen measurements throughout Ed Zorinsky Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (

Plate **5-1-**Plate 5-5) All of the exceeded criteria occurred near the bottom of the reservoir and were associated with thermal stratification (Plate 5-8). The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen and high ammonia and dissolved manganese levels measured in Ed Zorinsky Reservoir. Therefore, the criteria are not considered exceedances of the water quality standards criteria. However, dissolved oxygen measurements on September 12, 2014 were below the 5 mg/l criterion for the protection of warmwater aquatic life from the reservoirs surface to bottom.

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September). The near-surface total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 35, 30, and 70 percent of the samples collected at site EZRLKND1 (i.e., near-dam) (

Plate 5-1). At site EZRLKUP1 (i.e., upper reaches), the near-surface total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 70, 55, and 80 percent of the collected samples (Plate 5-4). All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values represent the growing season average for the 5-year period 2011 through 2015. The near-surface chlorophyll *a* mean values were 20 ug/l and 33.1 ug/l respectively at site EZRLKND1 and EZRLKUP1. The near-surface total nitrogen mean values were 0.94 mg/l and 1.14 mg/l respectively and near-surface total phosphorus values were 0.05 mg/l ad 0.09 mg/l respectively. Based on the State of Nebraska's impairment assessment methodology, these mean values indicate impairment of the Aquatic Life beneficial use of Ed Zorinsky Reservoir due to nutrients.

5.2.2.1.2 Thermal Stratification

5.2.2.1.2.1 ***Longitudinal Temperature Contour Plots***

Late-spring and summer thermal stratification of Ed Zorinsky Reservoir measured during 2015 is depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 5-6 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2015. Significant thermal stratification occurred in Ed Zorinsky Reservoir from late-spring through most of the summer during 2015.

5.2.2.1.2.2 ***Near-Dam Temperature Depth-Profile Plots***

The depth-profile temperature measurements collected during the summer over the 5-year sampling period at the deep water area near the dam were compiled and plotted to describe the existing summer thermal stratification of Ed Zorinsky Reservoir (Plate 5-7). The plotted depth-profile temperature measurements indicate that the reservoir exhibits significant thermal stratification during the summer. The deeper areas of the reservoir, in the area of the old creek channel, do not appear to mix with the upper column of water during the summer. Since Ed Zorinsky Reservoir ices over in the winter, it appears to be a dimictic lake based on the measured thermal stratification in the summer (Wetzel, 2001). Wetzel (2001) identifies lakes as dimictic if they circulate freely twice a year in the spring and fall and are directly stratified in the summer and inversely stratified under ice cover in winter.

5.2.2.1.3 Dissolved Oxygen Conditions

5.2.2.1.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of Ed Zorinsky Reservoir based on depth-profile measurements taken during 2015. Plate 5-8 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 near the reservoir bottom throughout the summer with the exception of May 2015.

5.2.2.1.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

The depth-profile dissolved oxygen measurements collected during the summer over the 5-year sampling period at the deep water area near the dam were compiled and plotted to describe the existing summer dissolved oxygen conditions of Ed Zorinsky Reservoir (Plate 5-9). Most of the plotted profiles indicate a significant vertical gradient in dissolved oxygen levels with most tending towards a clinograde distribution. Seventy-five percent of the profiles showed hypoxic conditions near the reservoir bottom. A few of the plotted profiles indicate dissolved oxygen concentrations above 5 mg/l from the reservoir surface to the bottom. These profiles were measured in early spring or fall and are believed to be a result of thermal stratification breaking down to the depth the profile was measured as "spring turnover" ended or "fall turnover" of the reservoir approached.

5.2.2.1.3.3 ***Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of Ed Zorinsky 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 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 July 30, 2015 contour plot indicates a pool elevation of 1110.4 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1100 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1098 ft-msl (Plate 5-8). The current District Area-Capacity Tables (2007 Survey) give storage capacities of 2,883 ac-ft for elevation 1110.4 ft-msl, 939 ac-ft for elevation 1100 ft-msl, and 703 ac-ft for elevation 1098 ft-msl. On July 30, 2015 it is estimated that 33 percent of the volume of Ed Zorinsky Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 24 percent of the reservoir volume was hypoxic.

5.2.2.1.4 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in Ed Zorinsky reservoir indicated hypoxic conditions during the months of June through September 2015. As a result, longitudinal contour plots where constructed for ORP and pH during these months. Depth profiles and near-surface/near-bottom sample comparisons were constructed for periods of hypoxic conditions from 2011 through 2015.

5.2.2.1.4.1 ***Oxidation-Reduction Potential***

Plate 5-10 provides longitudinal ORP contour plots based on measurements taken in 2015. ORP values present during June and July 2015 indicated somewhat reduced conditions present near the reservoir bottom. Plate 5-11 plots depth profiles for ORP measured during the summer over the 5-year sampling period in the deep water area of Ed Zorinsky Reservoir near the dam when hypoxic conditions are present. A significant vertical gradient in ORP regularly occurred in the reservoir during the summer.

5.2.2.1.4.2 ***pH***

Longitudinal contour plots for pH conditions measured in 2015 are provided in Plate 5-12. Lower pH levels near the bottom of the reservoir could be attributable to reservoir stratification and ongoing decomposition/respiration near the reservoir bottom. This would lead to an increase in CO_2 and decrease in pH. All pH levels were within the pH criteria for the protection of warmwater aquatic life. Plate 5-13 plots depth profiles for pH measured during the summer over the 5-year sampling period in the deep water area of Ed Zorinsky Reservoir near the dam when hypoxic conditions were present. A significant vertical gradient in pH regularly occurred in the reservoir during the summer, but all pH levels were within the criteria for the protection of warmwater aquatic life.

5.2.2.1.4.3 ***Comparison of Near-Surface and Near-Bottom Water Quality Conditions***

Paired near-surface and near-bottom water quality samples collected from Ed Zorinsky Reservoir during the summer when hypoxia was present 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 EZRLKND1 during the 5-year period 2011 through 2015. During the 5-year period a total of 20 paired samples were collected monthly from May through September. Of the 20 paired samples collected, 15 (75%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 5-14). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for all the assessed parameters except nitrate-nitrite nitrogen ($p=0.28$). Parameters that were significantly lower in the near-bottom water of Ed Zorinsky Reservoir when hypoxia was present included: water temperature, dissolved oxygen, ORP, and pH ($p < 0.05$). Parameters that were significantly higher in the near-bottom water included: total ammonia nitrogen, total alkalinity, total phosphorus, and ortho-phosphorus ($p < 0.05$).

5.2.2.1.5 Reservoir Trophic Status

Trophic State Index (TSI) values for Ed Zorinsky Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., EZRLKND1). Table 5.2 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Ed Zorinsky Reservoir is in a eutrophic condition.

Table 5.2. Summary of Trophic State Index (TSI) values calculated for Ed Zorinsky Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	20	63	63	49	76
TSI(TP)	20	53	55	34	71
TSI(Chl)	20	67	67	57	79
TSI(Avg)	20	61	62	51	74

* 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 for the individual parameters.
Note: See Section 4.1.3 for discussion of TSI calculation.

5.2.2.1.6 Reservoir Plankton Community

5.2.2.1.6.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at Ed Zorinsky Reservoir near-surface, near-dam sampling sites during the spring and summer of the 4-year period 2012 through 2015 (Plate 5-15). No samples were collected in 2011 due to the reservoir drawdown. The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 5-16. The highest phytoplankton total biovolume was observed in May and the lowest in July. Ochrophyta and Cryptophycophyta were the dominate taxa in May, Cyanobacteria in July, and Ochrophyta in September. This dominance pattern follows successional patterns commonly observed in eutrophic reservoirs. Cool water taxa such as Ochrophyta tend to dominate in spring and late fall while warm water taxa such as Cyanobacteria dominate the summer and early fall. Dominant and major phytoplankton genera sampled in Ed Zorinsky Reservoir during 2015 are provided in Table 5.3.

Annual variation in phytoplankton community composition is displayed in Plate 5-17. During the 4-year period 2012 through 2015, Cyanobacteria, Ochrophyta, and Cryptophycophyta were the dominant groups in Ed Zorinsky Reservoir. The highest Cyanobacteria levels were observed in 2012 with two sampled densities being greater than the World Health Organizations high level of health risk (>100,000

Cells/ml) (Plate 5-15). 2012 was a particularily warm and dry year. The long reservoir residence time, decreased mixing, and warm water could have lead to a longer Cyanobacterial growing season which lead to the large observed biovolumes and densities. The maximum extracellular microcystin level measured during the 5-year period was 0.2 µg/L (
Plate 5-1).

Table 5.3. Listing of Major and Dominant Phytoplankton Genera Sampled in Ed Zorinsky Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1)

Division	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Chrysophyta	*Mallomonas*	-----
Cryptophycophyta	*Cryptomonas*	-----
Ochrophyta	*Stephanodiscus*	*Cyclotella*, *Aulacoseira*
Cyanobacteria	*Anabaena*	*Aphanizomenon*
Pyrrophycophyta	*Ceratium*	-----

5.2.2.1.6.2 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at Ed Zorinsky Reservoir near-dam sampling sites during the spring and summer of the 4-year period 2012 through 2015 (Plate 5-18). No samples were collected in 2011 due to the reservoir drawdown. The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in Plate 5-19. Zooplankton total biomass stayed relatively consistent through the 2015 growing season with Copepods and Cladocerans dominating Ed Zorinsky Reservoir. Dominant and major zooplankton genera sampled in Ed Zorinsky Reservoir during 2015 are provided in Table 5.5.

Table 5.4. Listing of Major and Dominant Phytoplankton Genera Sampled in Ed Zorinsky Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1)

Taxonomic Group	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cladocerans	-----	*Daphnia*
Copepods	-----	*Leptodiaptomus*
Rotifers	*Asplanchna*	-----

5.2.2.1.7 Zebra Mussel Monitoring

Since the 2010/2011 drawdown of Ed Zorinsky Reservoir to control the spread of zebra mussels in and from the lake, once yearly sampling for zebra mussel veligers have been implemented. During the sampling period (2012-2015) no veligers have been identified.

5.2.2.2 Water Quality Trends (1993-2015)

Ed Zorinsky Reservoir reached initial fill in 1992 and water quality monitoring of the reservoir began in 1993. Water quality trends from 1993 to 2015 were determined for Ed Zorinsky 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., EZRLKND1). Plate 5-20 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, it appears that Ed Zorinsky Reservoir exhibited decreasing levels of total phosphorus ($p<0.05$, $R^2=0.04$). No significant trend in transparency or chlorophyll *a* is observable. Since 1993, Ed Zorinsky

Reservoir has generally remained in a eutrophic condition. However, if the current trend continues, the reservoir appears to be moving towards a hypereutrophic condition ($p<0.05$, $R^2=0.04$).

5.2.2.3 Existing Water Quality Conditions of Runoff Inflows to Ed Zorinsky Reservoir

Existing water quality in Box Elder Creek, above Ed Zorinsky Reservoir, was monitored under runoff conditions during the period of April through September at site EZRNF1. The site is approximately 1½ miles upstream from the reservoir (Figure 5.2). Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from “base-flow” conditions. Plate 5-21 summarizes water quality conditions that were monitored at site EZRNF1 under runoff conditions during the 5-year period 2011 through 2015.

5.2.3 Plates

Plate 5-1. Summary of water quality conditions monitored in Ed Zorinsky Reservoir at site EZRLKND1 from May to September during the 5-year period 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1110.43	1110.40	1108.70	1111.71	-----	-----	-----
Water Temperature (°C)	0.1	347	20.47	20.37	10.18	29.16	32(1)	0	0%
Secchi Depth (in.)	1	20	37.00	33.00	13.00	85.00	-----	-----	-----
Turbidity (NTUs)	1	328	10.07	7.75	n.d.	28.70	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	347	225.84	229.00	-59.00	411.00	-----	-----	-----
Specific Conductance (umho/cm)	1	347	517.70	528.00	303.50	740.00	2,000(3)	0	0%
Dissolved Oxygen (mg/l)	0.1	347	4.39	5.04	n.d.	11.98	≥5(2)	173	50%
Dissolved Oxygen, Near-Surface (mg/l)(C)	0.1	20	8.49	8.49	4.04	11.91	≥5(2)	1	5%
Dissolved Oxygen (% Sat.)	0.1	347	52.23	56.80	n.d.	151.50	-----	-----	-----
pH (S.U.)	0.1	347	7.83	7.85	6.51	8.76	≥6.5 & ≤9.0 (1)	0	0%
Alkalinity, Total (mg/l)	1	38	153.50	150.50	97.00	238.00	>20(1)	0	0%
Ammonia, Total (mg/l)	0.02	40	-----	0.27	n.d.	6.50	6.39(4,5), 1.13 (4,6)	0,7	0%,18%
Ammonia, Total, Near-Surface (mg/l)(C)	0.02	20	-----	0.02	0.01	0.30	1.00(4,5), 0.25(4,6)	0,1	0%,5%
Kjeldahl N, Total (mg/l)	0.08	40	1.73	1.12	0.47	7.15	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	40	-----	n.d.	n.d.	0.36	100(3)	0	0%
Nitrogen, Total (mg/l)	0.08	40	1.79	1.19	0.50	7.18	1(7)	26	65%
Nitrogen, Total, Near-Surface (mg/l)(C)	0.08	20	0.94	0.95	0.50	1.36	>1	7	35%
Phosphorus, Total (mg/l)	0.005	40	0.25	0.07	n.d.	1.47	0.05(7)	24	60%
Phosphorus, Total, Near-Surface (mg/l) (C)	0.005	20	0.05	0.04	0.01	0.20	0.05(7)	6	30%
Phosphorus-Ortho, Dissolved (mg/l)	0.005	40	-----	0.02	n.d.	0.98	-----	-----	-----
Hardness, Total (mg/l)	0.4	4	134.28	137.70	113.70	148.00	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	4	6.50	6.00	5.00	9.00	340(5), 16.7(6)	0	0%
Beryllium, Dissolved (ug/l)	1	4	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.007	4	-----	0.05	n.d.	0.08	8.1(5), 0.3(6)	0	0%
Chromium, Dissolved (ug/l)	4	4	-----	n.d.	n.d.	n.d.	769.4(5), 100.2(6)	0	0%
Copper, Dissolved (ug/l)	6	4	-----	n.d.	n.d.	n.d.	18.2(5), 11.8(6)	0	0%
Iron, Dissolved (ug/l)	10	23	-----	20.00	n.d.	410.00	1000(6)	0	0%
Lead, Dissolved (ug/l)	0.09	4	-----	0.15	n.d.	0.80	91.3(5), 3.6(6)	0	0%
Manganese, Dissolved (ug/l)	3	23	-----	20.00	n.d.	6440.00	1000(6)	5	22%
Manganese, Dissolved (ug/l)(C)	3	18	-----	9.50	2.00	230.00	>1000	0	0%
Nickel, Dissolved (ug/l)	8	4	-----	n.d.	n.d.	n.d.	613.8(5), 68.2(6)	0	0%
Silver, Dissolved (ug/l)	0.005	4	-----	0.02	n.d.	0.03	5.98(5)	0	0%
Zinc, Dissolved (ug/l)	6	4	-----	9.00	n.d.	30.00	153.7(5), 154.9(6)	0	0%
Antimony, Dissolved (ug/l)	0.03	4	0.73	0.75	0.60	0.80	88(5), 30(6)	0	0%
Aluminum, Dissolved (ug/l)	40	4	-----	n.d.	n.d.	50.00	750(5), 87(6)	0	0%
Mercury, Dissolved (ug/l)	0.008	4	-----	n.d.	n.d.	0.01	1.4(5)	0	0%
Chlorophyll a (ug/l) – Lab Determined(C)	6	20	20	16	n.d.	56	10(7)	14	70%
Chlorophyll a (ug/l) – Field Probe	6	347	19	12	n.d.	343	10(7)	202	58%
Atrazine, Total (ug/l) (D)	0.1	20	0.82	0.80	n.d.	2.20	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l) (D)	0.1	20	-----	0.20	n.d.	0.40	390(5), 100(6)	0	0%
Microcystin, Extracellular (ug/l)	0.1	20	-----	n.d.	n.d.	0.20	20(9)	0	0%
Pesticide Scan (ug/l)(E)									
Acetochlor, Tot	0.08	5	0.09	n.d.	n.d.	0.19	-----	-----	-----
Atrazine, Tot	0.13	5	0.51	0.45	0.21	0.99	330(5), 12(6)	0	0%
Metolachlor, Tot	0.05	5	-----	0.14	n.d.	0.20	390(5), 100(6)	0	0%

n.d. = Not detected.

(A) Nondetect values set to detection limit value 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria

Plate 5-2. Summary of water quality conditions monitored in Ed Zorinsky Reservoir at site EZRLKML1A from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	15	1110.31	1110.10	1108.70	1111.71	-----	-----	-----
Water Temperature (°C)	0.1	325	20.50	20.39	10.28	29.43	32(1)	0	0%
Dissolved Oxygen (% Sat.)	0.1	325	53.15	55.40	0.00	157.00	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	325	4.48	4.79	0.00	11.57	≥5(2)	169	52%
Specific Conductance (umho/cm)	1	325	520.36	530.20	287.40	741.00	2,000(3)	0	0%
pH (S.U.)	0.1	325	7.83	7.78	6.61	8.80	≥6.5 & ≤9.0 (1)	0	0%
Turbidity (NTUs)	1	308	12.03	7.80	0.00	249.20	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	325	255.19	258.00	-45.00	435.00	-----	-----	-----
Secchi Depth (in.)	1	20	38.00	33.00	11.00	96.00	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	325	19	13	1	204	10(4)	194	60%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria

Plate 5-3. Summary of water quality conditions monitored in Ed Zorinsky Reservoir at site EZRLKML2 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	15	1110.31	1110.10	1108.70	1111.71	-----	-----	-----
Water Temperature (°C)	0.1	224	22.39	22.42	11.81	29.93	32(1)	0	0%
Dissolved Oxygen (% Sat.)	0.1	224	71.59	77.05	0.00	155.40	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	224	5.89	6.72	0.00	13.18	≥5(2)	73	33%
Specific Conductance (umho/cm)	1	224	489.96	514.00	269.30	721.00	2,000(3)	0	0%
pH (S.U.)	0.1	224	8.03	8.08	6.92	8.93	≥6.5 & ≤9.0 (1)	0	0%
Turbidity (NTUs)	1	214	19.66	12.05	0.00	119.90	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	224	316.42	333.00	6.00	509.00	-----	-----	-----
Secchi Depth (in.)	1	20	33.80	30.50	9.00	113.00	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	224	28	18	1	440	10(7)	160	71%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-4. Summary of water quality conditions monitored in Ed Zorinsky Reservoir at site EZRLKUP1 from May to September during the 5-year period 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for other parameters are for "grab samples" collected at near-surface.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	15	1110.31	1110.10	1108.70	1111.71	-----	-----	-----
Water Temperature (°C)	0.1	120	23.55	24.15	15.84	30.71	32(1)	0	0%
Secchi Depth (in.)	1	20	18.90	20.00	4.00	37.00	-----	-----	-----
Turbidity (NTUs)	1	113	46.05	24.30	n.d.	243.50	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	120	355.59	348.00	179.00	499.00	-----	-----	-----
Specific Conductance (umho/cm)	1	120	466.49	481.15	248.00	661.40	2,000(3)	0	0%
Dissolved Oxygen (mg/l)	0.1	120	7.09	7.04	0.13	13.00	≥5(2)	24	20%
Dissolved Oxygen, Near-Surface (mg/l)(C)	0.1	20	8.661	8.135	5.23	13	≥5(2)	0	0%
Dissolved Oxygen (% Sat.)	0.1	120	87.06	84.15	1.70	169.80	-----	-----	-----
pH (S.U.)	0.1	120	8.12	8.22	7.22	8.80	≥6.5 & ≤9.0 (1)	0	0%
Alkalinity, Total (mg/l)	1	19	130.21	134.00	19.00	197.00	>20(1)	1	5%
Suspended Solids, Total (mg/l)	4	19	22.58	17.00	n.d.	80.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	20	-----	n.d.	n.d.	0.38	1.27(4,5), 0.31(4,6)	0	0%
Kjeldahl N, Total (mg/l)	0.08	20	1.04	1.02	0.60	1.66	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	20	0.10	n.d.	n.d.	0.54	100(3)	0	0%
Nitrogen, Total, Near-Surface (mg/l)(C)	0.08	20	1.14	1.07	0.64	1.72	1(7)	11	55%
Phosphorus, Total, Near-Surface (mg/l) (C)	0.005	20	0.09	0.07	0.03	0.24	0.05(7)	14	70%
Phosphorus-Ortho, Dissolved (mg/l)	0.005	20	-----	0.01	n.d.	0.07	-----	-----	-----
Hardness, Total (mg/l)	0.4	3	128.47	128.60	118.30	138.50	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	3	5.67	6.00	4.00	7.00	340(5), 16.7(8)	0	0%
Beryllium, Dissolved (ug/l)	1	3	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.01	3	-----	n.d.	n.d.	0.05	7.5(5), 0.29(6)	0	0%
Chromium, Dissolved (ug/l)	4	3	-----	n.d.	n.d.	n.d.	727.5(5), 94.71(6)	0	0%
Copper, Dissolved (ug/l)	6	3	-----	n.d.	n.d.	8.00	17.0(5), 11.1(6)	0	0%
Iron, Dissolved (ug/l)	10	18	104.83	25.00	n.d.	530.00	1000(6)	0	0%
Lead, Dissolved (ug/l)	0.09	3	-----	n.d.	n.d.	0.30	84.8(5), 3.3(6)	0	0%
Manganese, Dissolved (ug/l)	3	18	66.50	40.00	n.d.	250.00	1000(6)	0	0%
Thallium (ug/l)	0.005	3	-----	n.d.	n.d.	n.d.	1400(5),0.47(8)	0	0%
Nickel, Dissolved (ug/l)	8	3	-----	n.d.	n.d.	n.d.	579.3(5), 64.3(6)	0	0%
Silver, Dissolved (ug/l)	0.005	3	-----	n.d.	n.d.	0.01	5.3(5)	0	0%
Zinc, Dissolved (ug/l)	6	3	-----	8.00	n.d.	10.00	145.0(5), 146.2(6)	0	0%
Antimony, Dissolved (ug/l)	0.03	3	0.83	0.80	0.80	0.90	88(5), 30(6)	0	0%
Aluminum, Dissolved (ug/l)	40	3	-----	n.d.	n.d.	50.00	750(5), 87(6)	0	0%
Selenium, Total (ug/l)	0.4	4	-----	0.95	n.d.	11.00	20(3,5), 5(6)	0, 1	0%,25%
Chlorophyll a (ug/l) – Lab Determined	6	20	33	29	n.d.	109	10(7)	16	80%
Chlorophyll a (ug/l) – Field Probe	6	120	42	27	n.d.	478	10(7)	96	80%
Atrazine, Total (ug/l)(D)	0.1	20	1.28	1.00	n.d.	6.50	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(D)	0.1	20	-----	0.20	n.d.	1.50	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l)(D)	0.1	20	0.55	0.40	n.d.	3.30	-----	-----	-----
Mercury, Dissolved (ug/l)	0.008	3	-----	0.01	n.d.	0.02	1.4(5)	0	0%
Mercury, Total (ug/l)	0.008	4	-----	n.d.	n.d.	0.01	0.77(6)	0	0%
Microcystin, Extracellular (ug/l)	0.1	19	-----	n.d.	n.d.	0.20	20(9)	0	0%
Pesticide Scan (ug/l)(E)									
Acetochlor, Tot	0.08	4	-----	0.12	n.d.	1.41	-----	-----	-----
Atrazine, Tot	0.13	4	0.77	0.41	0.21	2.05	330(5), 12(6)	0	0%
Metolachlor, Tot	0.05	4	-----	0.11	n.d.	0.66	390(5), 100(6)	0	0%

n.d. = Not detected.

(A) Nondetect values set to detection limit value 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-5. Summary of water quality conditions monitored in Ed Zorinsky Reservoir at site EZRLKUP2 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances**	**Percent WQS Exceedance**
Pool Elevation (ft-msl)	0.1	15	1110.31	1110.10	1108.70	1111.71	-----	-----	-----
Water Temperature (°C)	0.1	28	24.22	25.46	15.80	30.92	32(1)	0	0%
Dissolved Oxygen (% Sat.)	0.1	28	104.68	97.55	59.50	163.10	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	28	8.43	7.56	5.36	13.36	$\geq$5(2)	0	0%
Specific Conductance (umho/cm)	1	28	443.05	443.75	246.00	660.00	2,000(3)	0	0%
pH (S.U.)	0.1	28	8.31	8.33	7.48	8.94	$\geq$6.5 & $\leq$9.0 (1)	0	0%
Turbidity (NTUs)	1	27	49.32	30.00	3.90	211.30	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	28	373.82	380.50	262.00	498.00	-----	-----	-----
Secchi Depth (in.)	1	20	13.85	11.50	4.00	31.00	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	28	30	23	4	174	10(4)	20	71%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

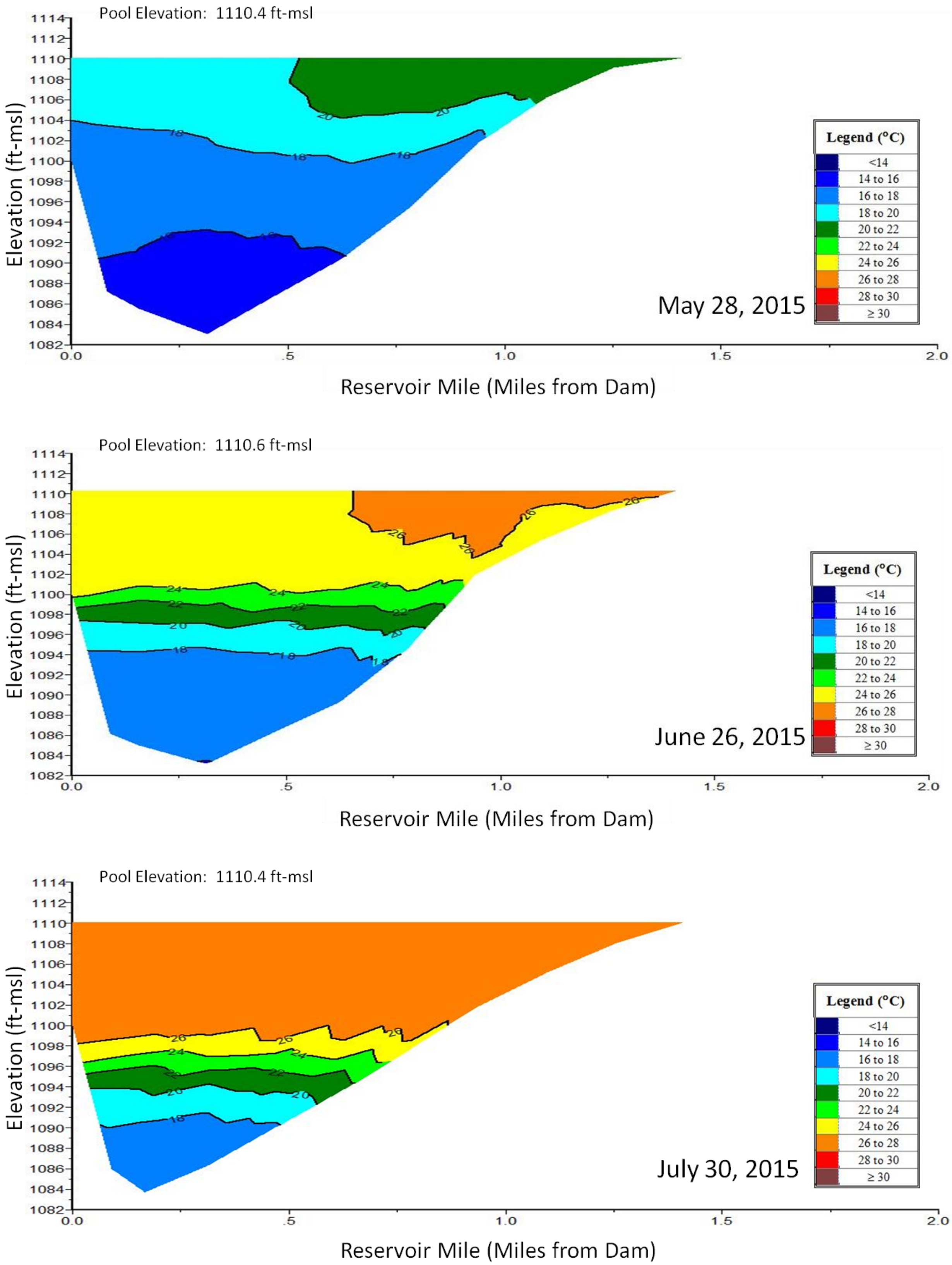
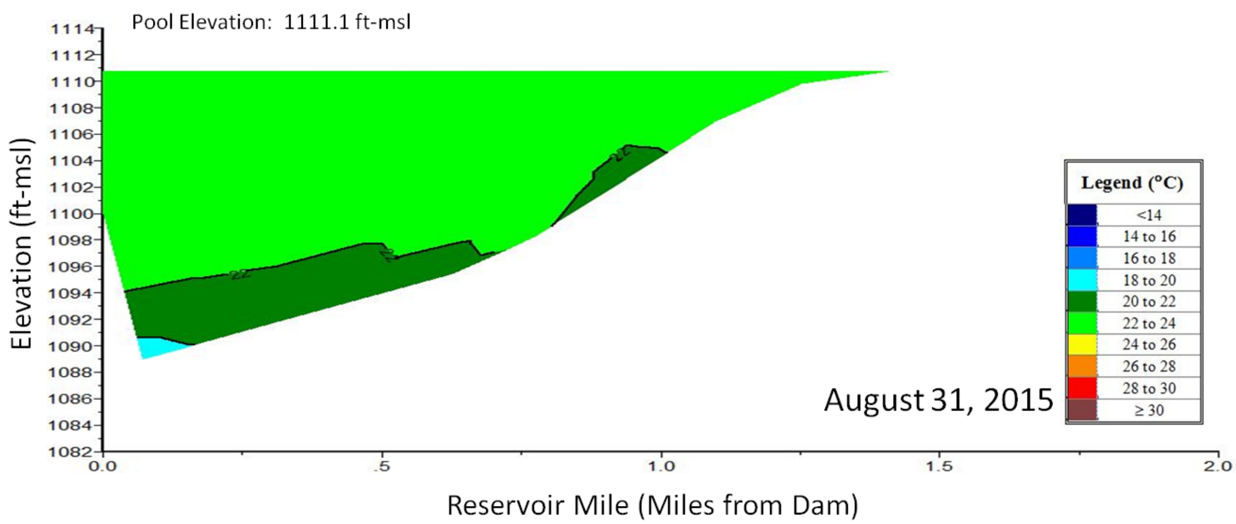


Plate 5-6. Longitudinal water temperature contour plots of Ed Zorinsky Reservoir based on depth-profile water temperatures (°C) measured from May to September 2015.



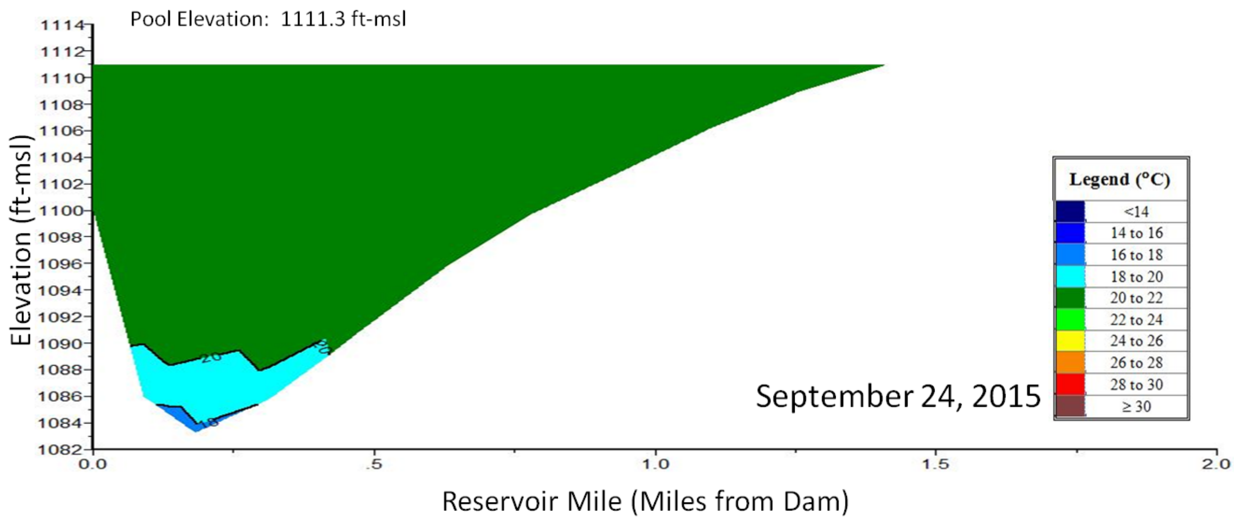


Plate 5-6. (Continued).

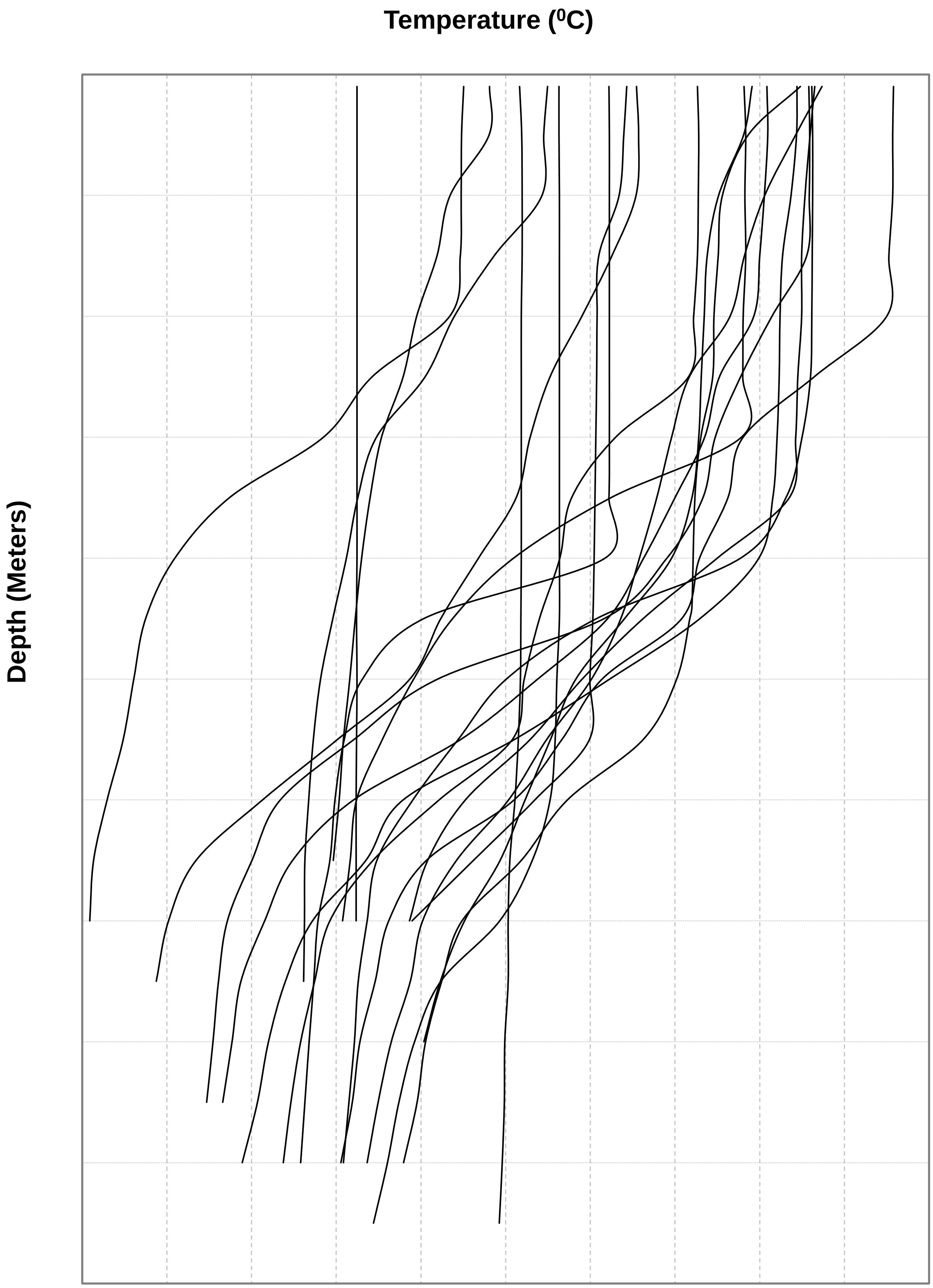


Plate 5-7. Temperature depth profiles for Ed Zorinsky Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2011 through 2015.

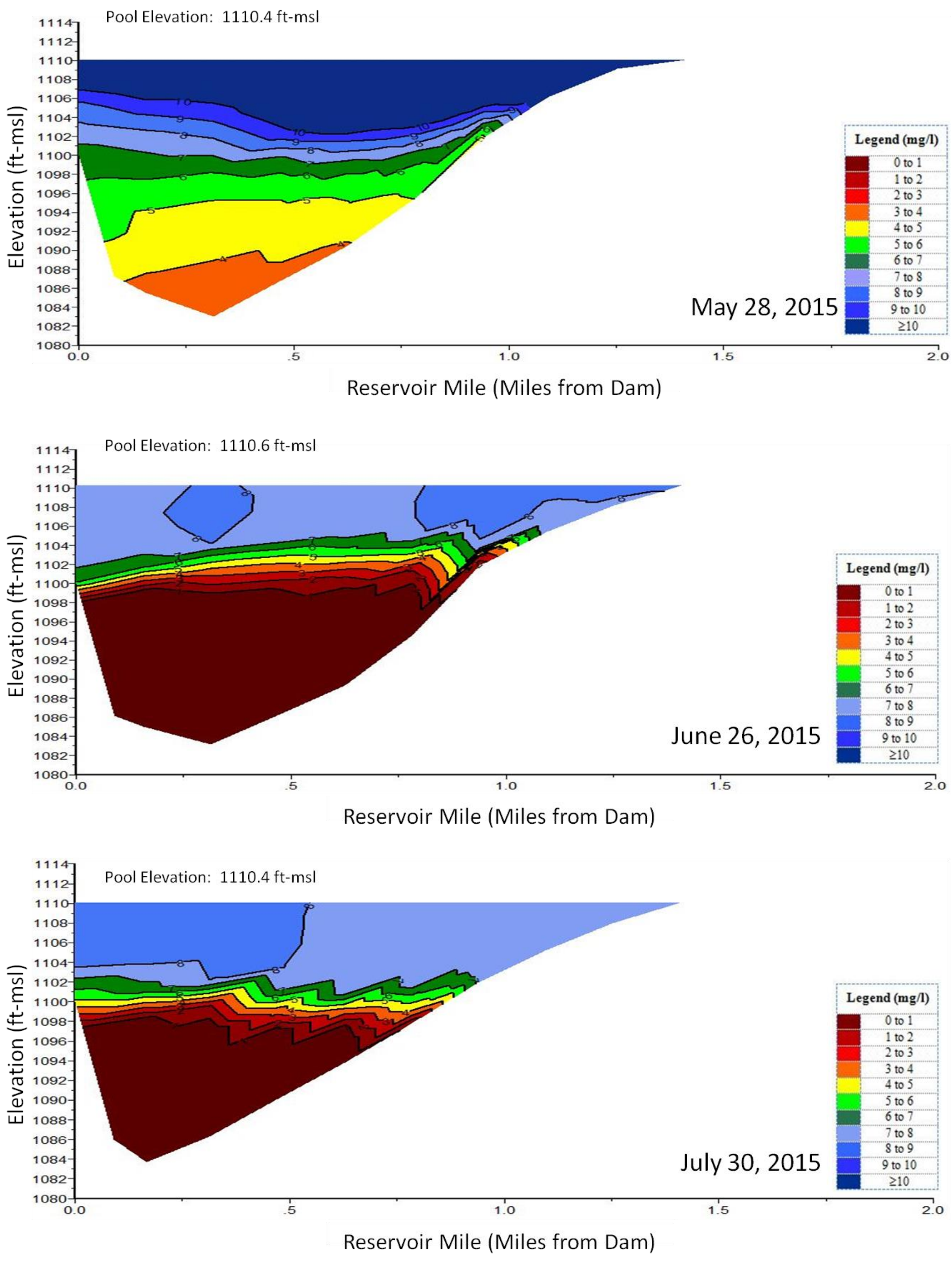
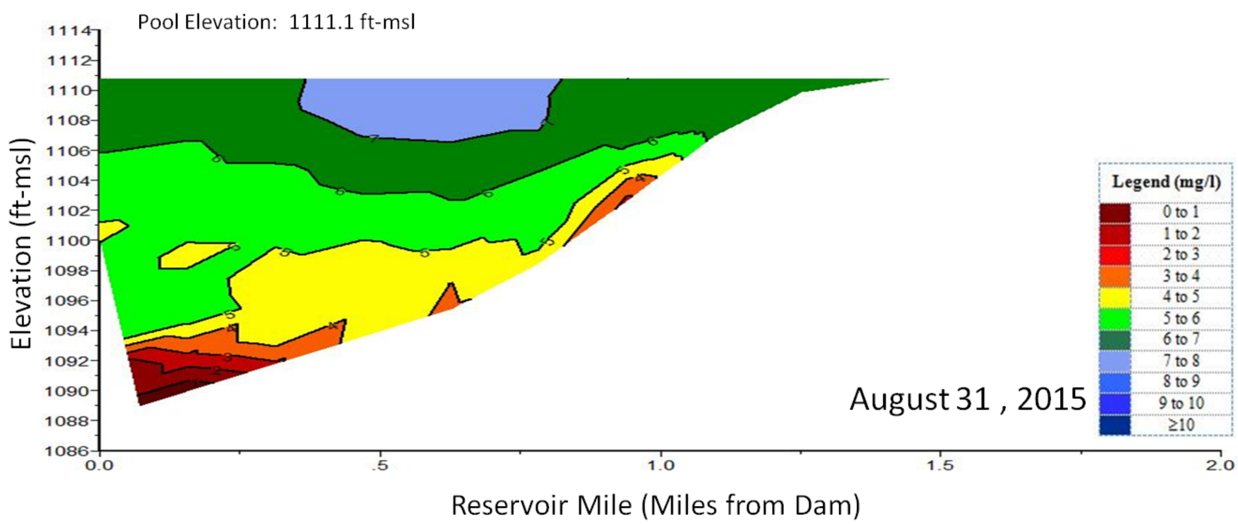


Plate 5-8. Longitudinal dissolved oxygen contour plots of Ed Zorinsky Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2015.



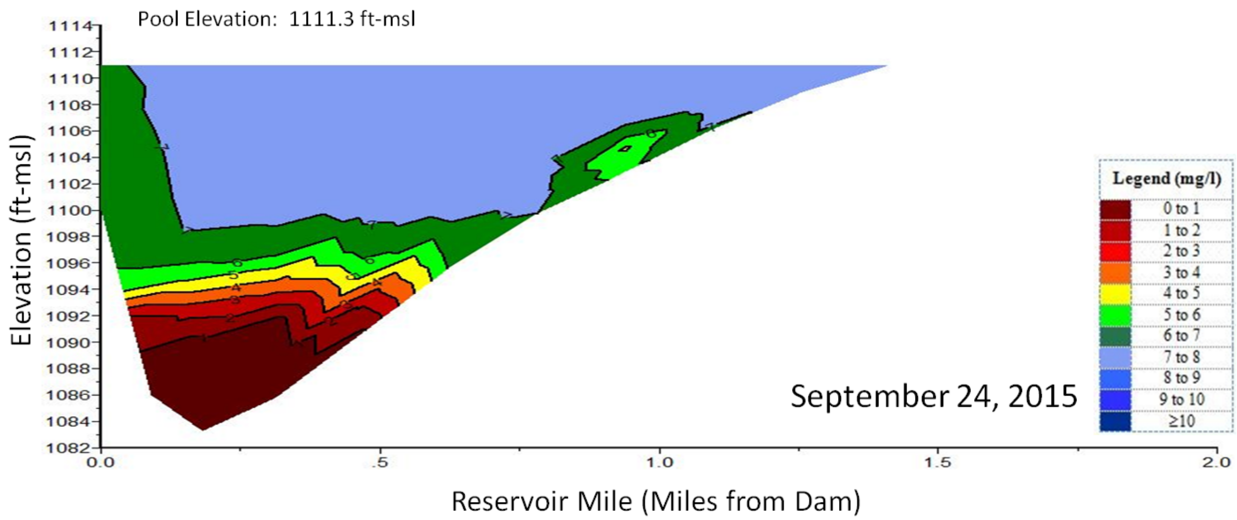


Plate 5-8. (Continued).

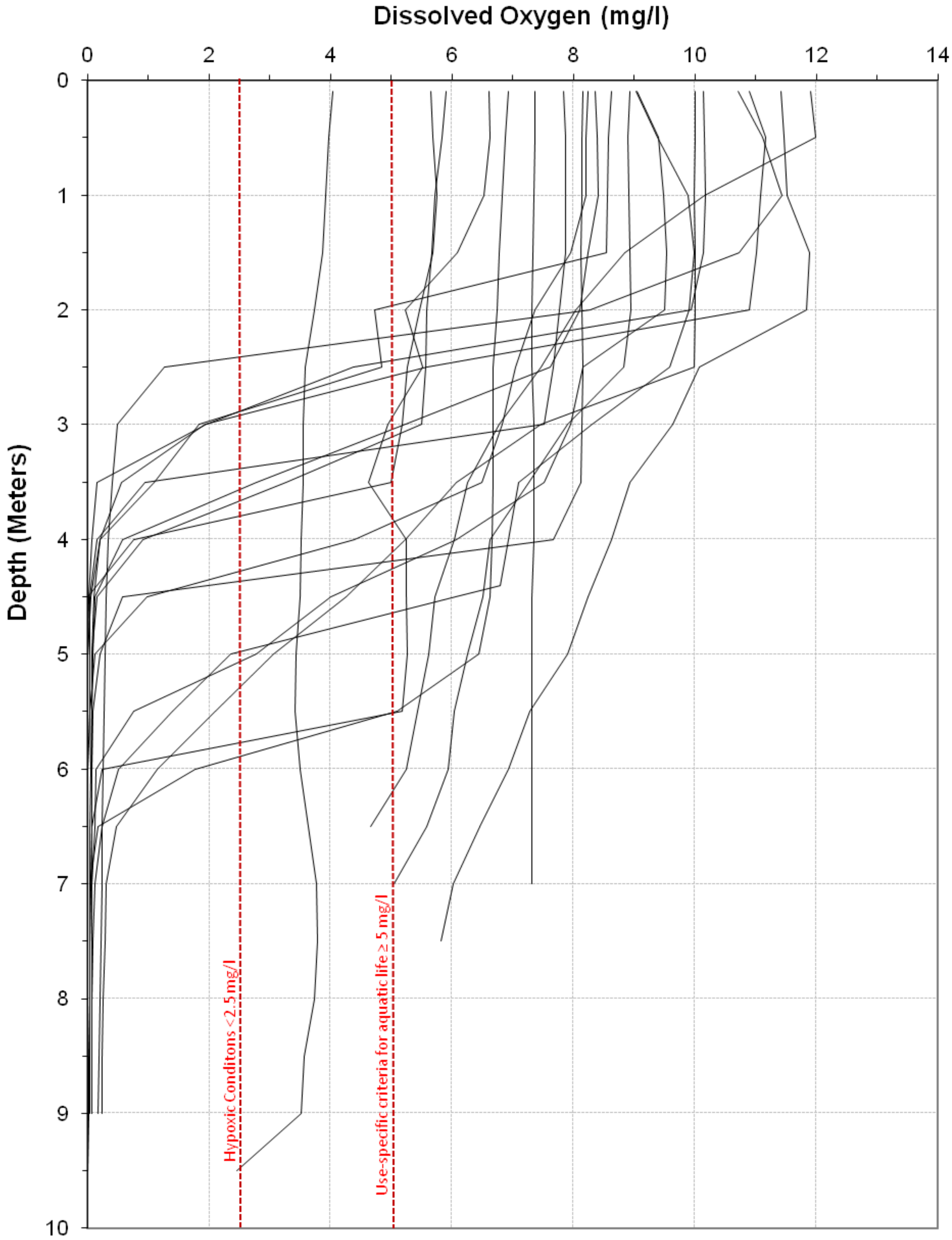
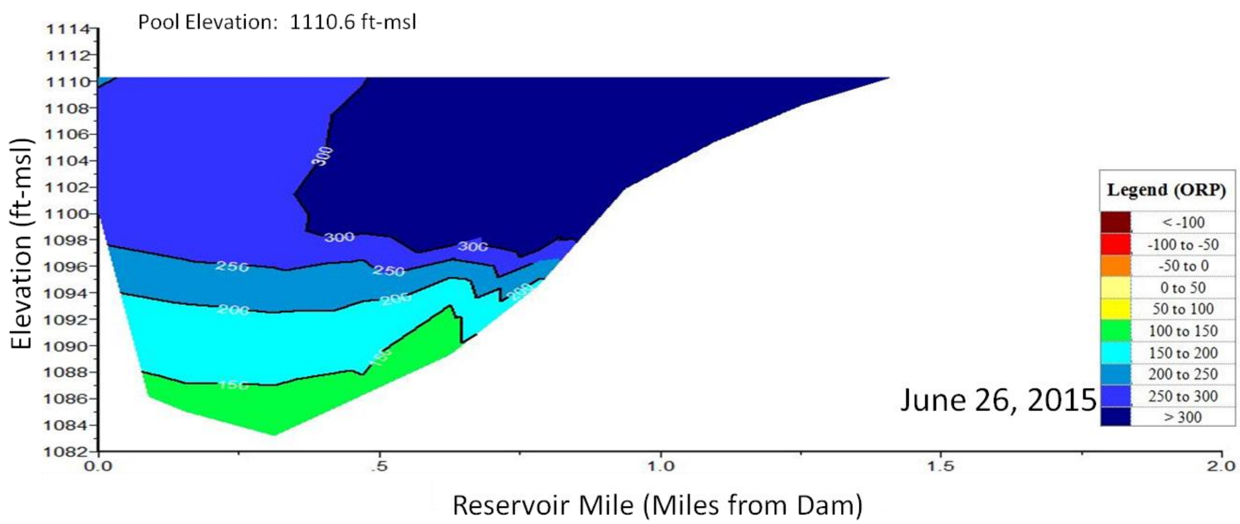
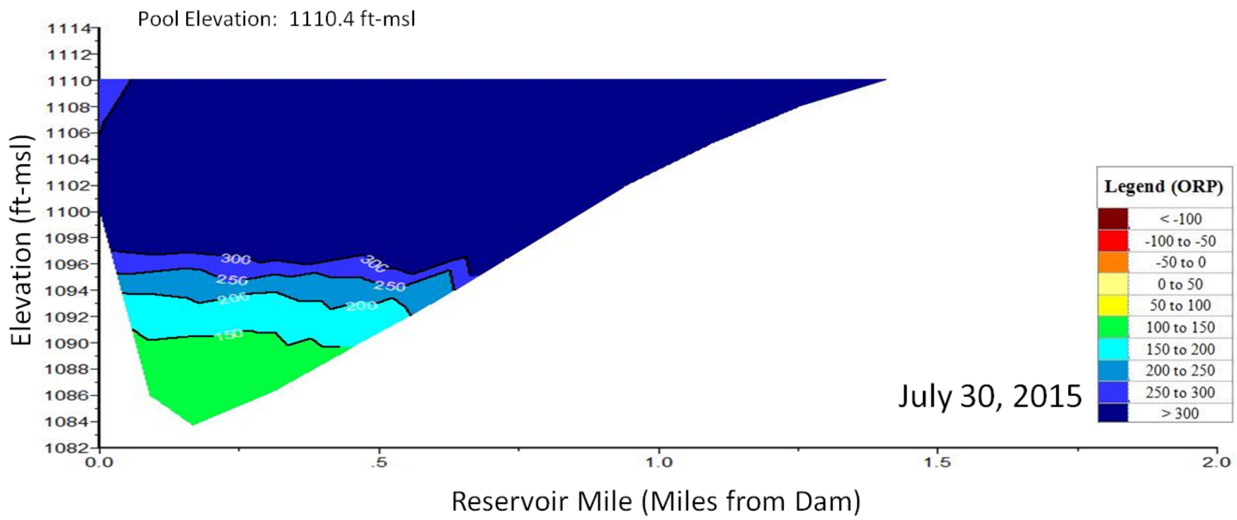


Plate 5-9. Dissolved oxygen depth profiles for Ed Zorinsky Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2011 through 2015.





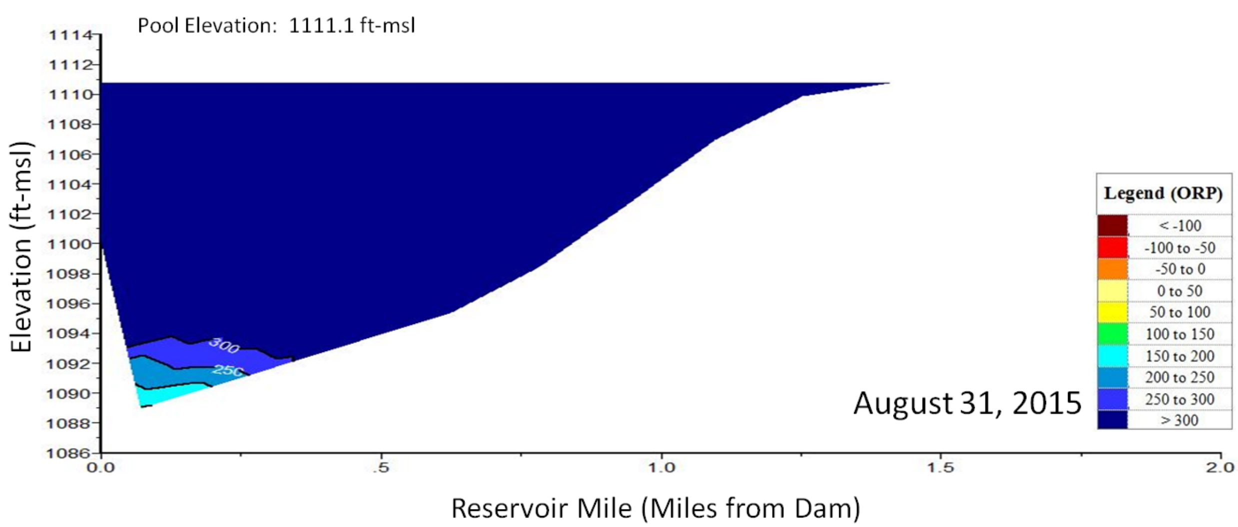


Plate 5-10. Longitudinal oxidation-reduction potential (ORP) contour plots of Ed Zorinsky Reservoir based on depth-profile ORP levels (mV) measured at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2015.

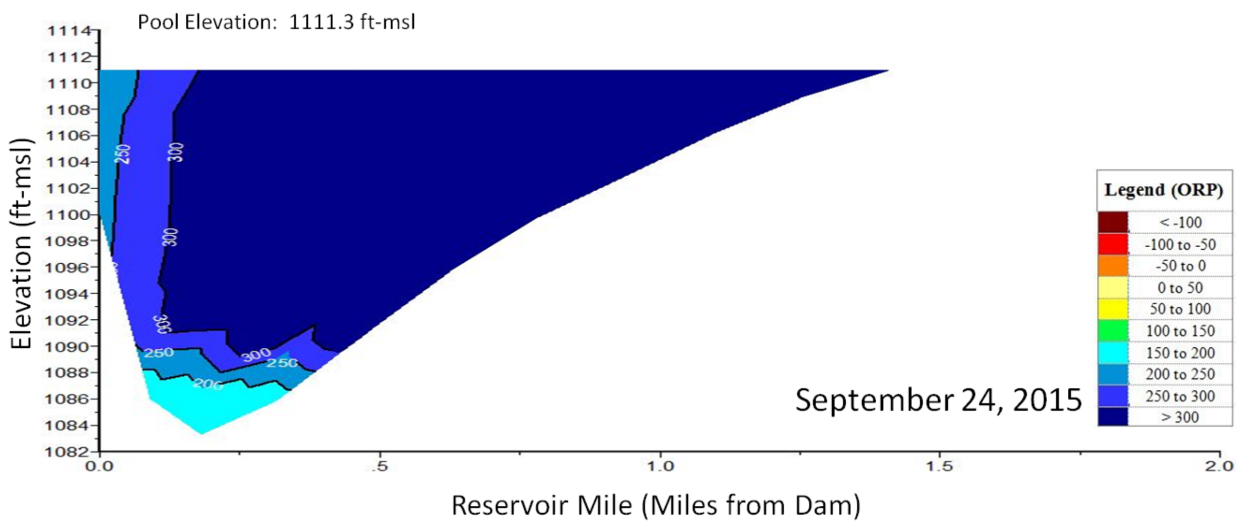


Plate 5-10. (Continued).

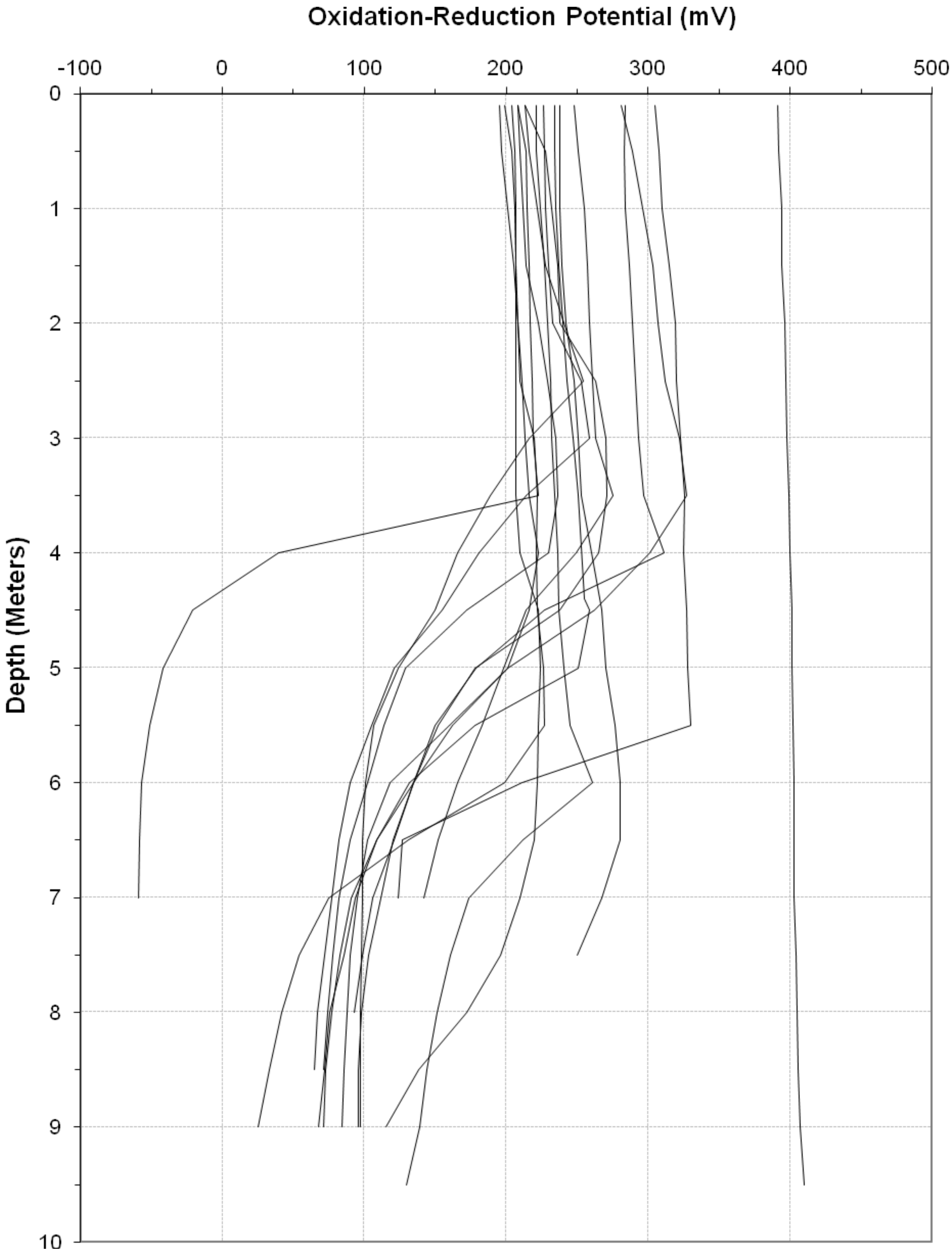


Plate 5-11. Oxidation-reduction potential depth profiles for Ed Zorinsky Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2011 through 2015

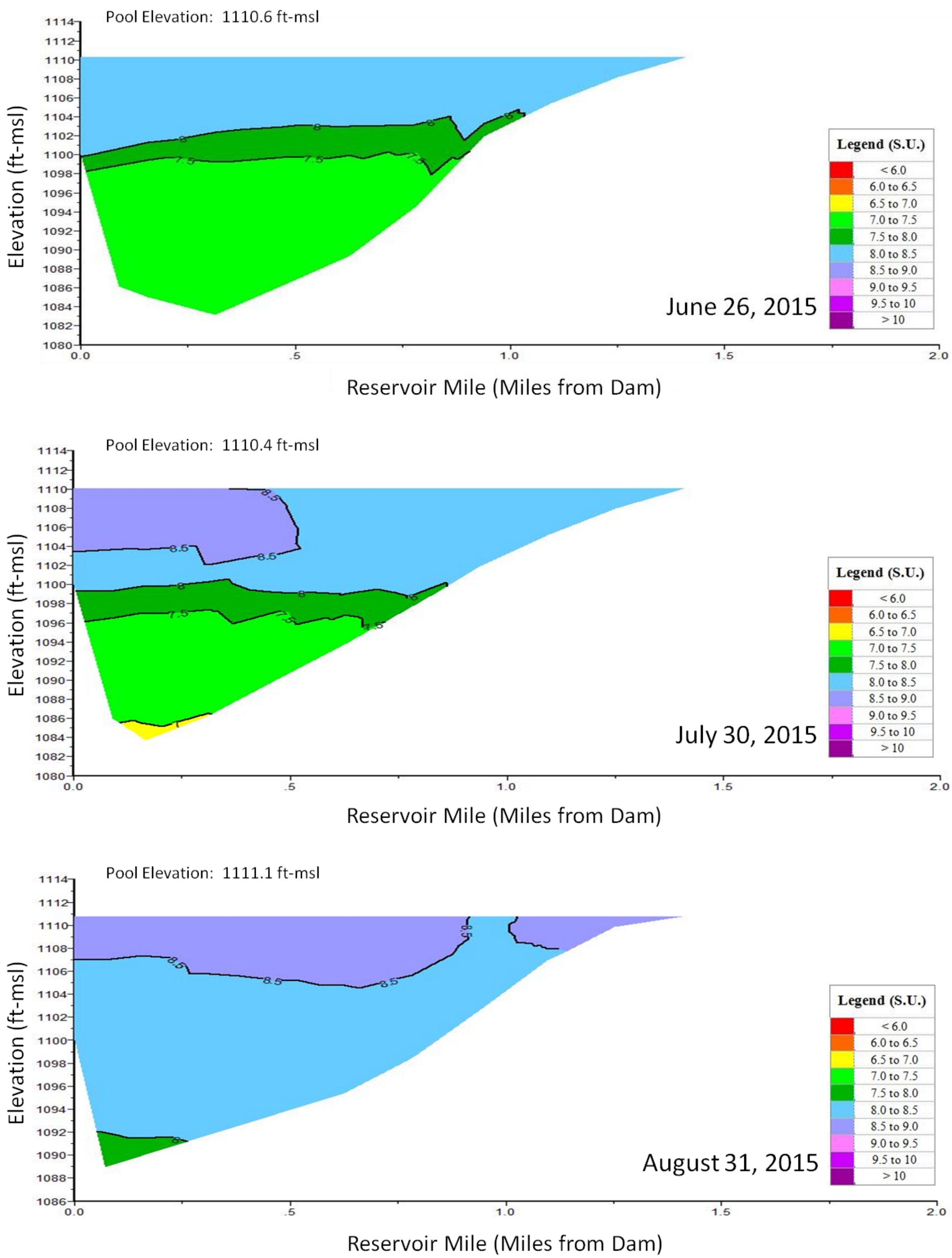


Plate 5-12. Longitudinal pH contour plots of Ed Zorinsky Reservoir based on depth-profile pH levels (S.U.) measured at sites EZRLKND1, EZRLKML1A, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2015.

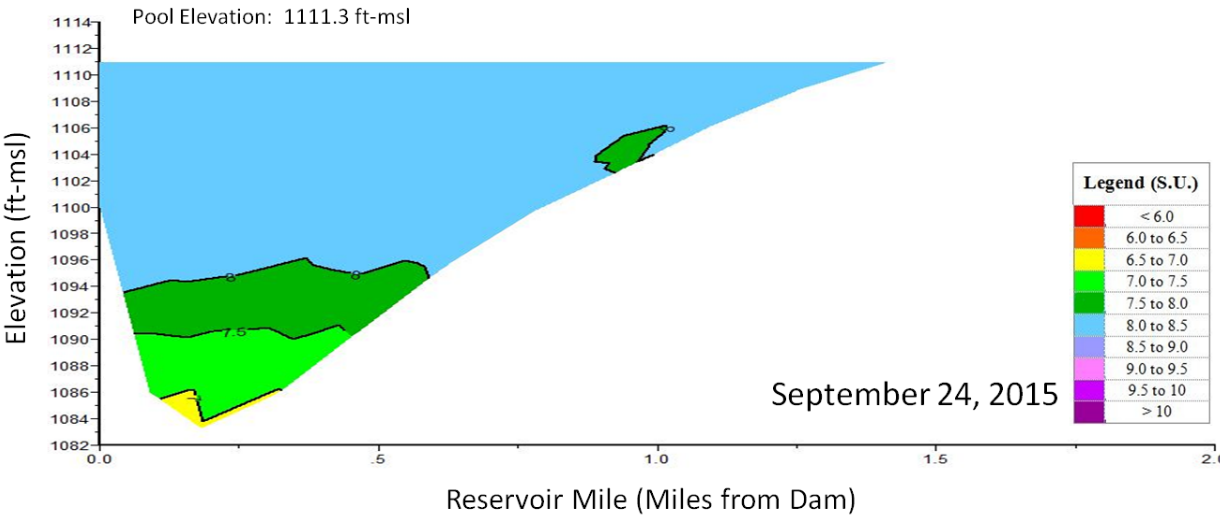


Plate 5-12. (Continued).

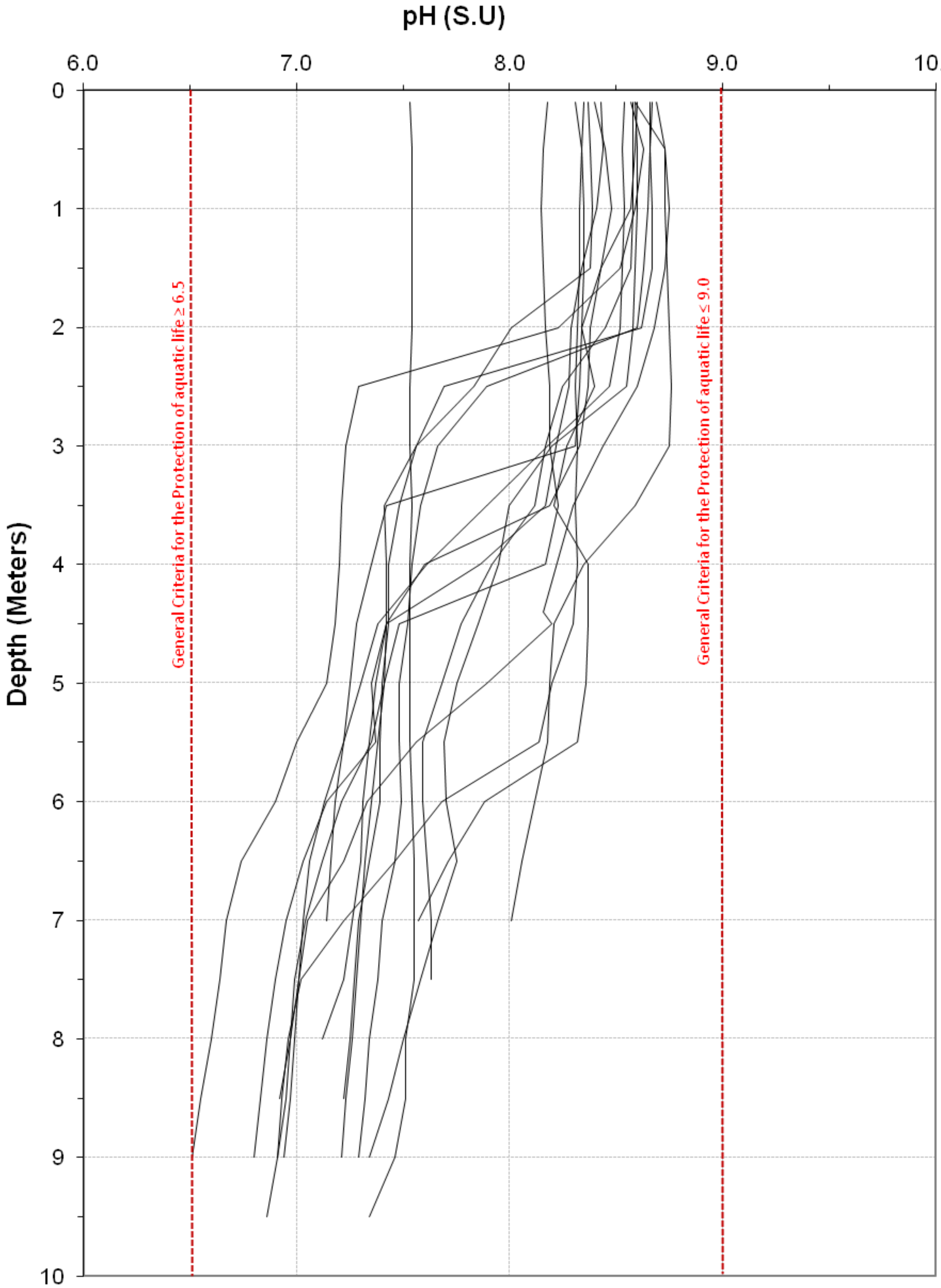


Plate 5-13. pH depth profiles for Ed Zorinsky Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2011 through 2015.

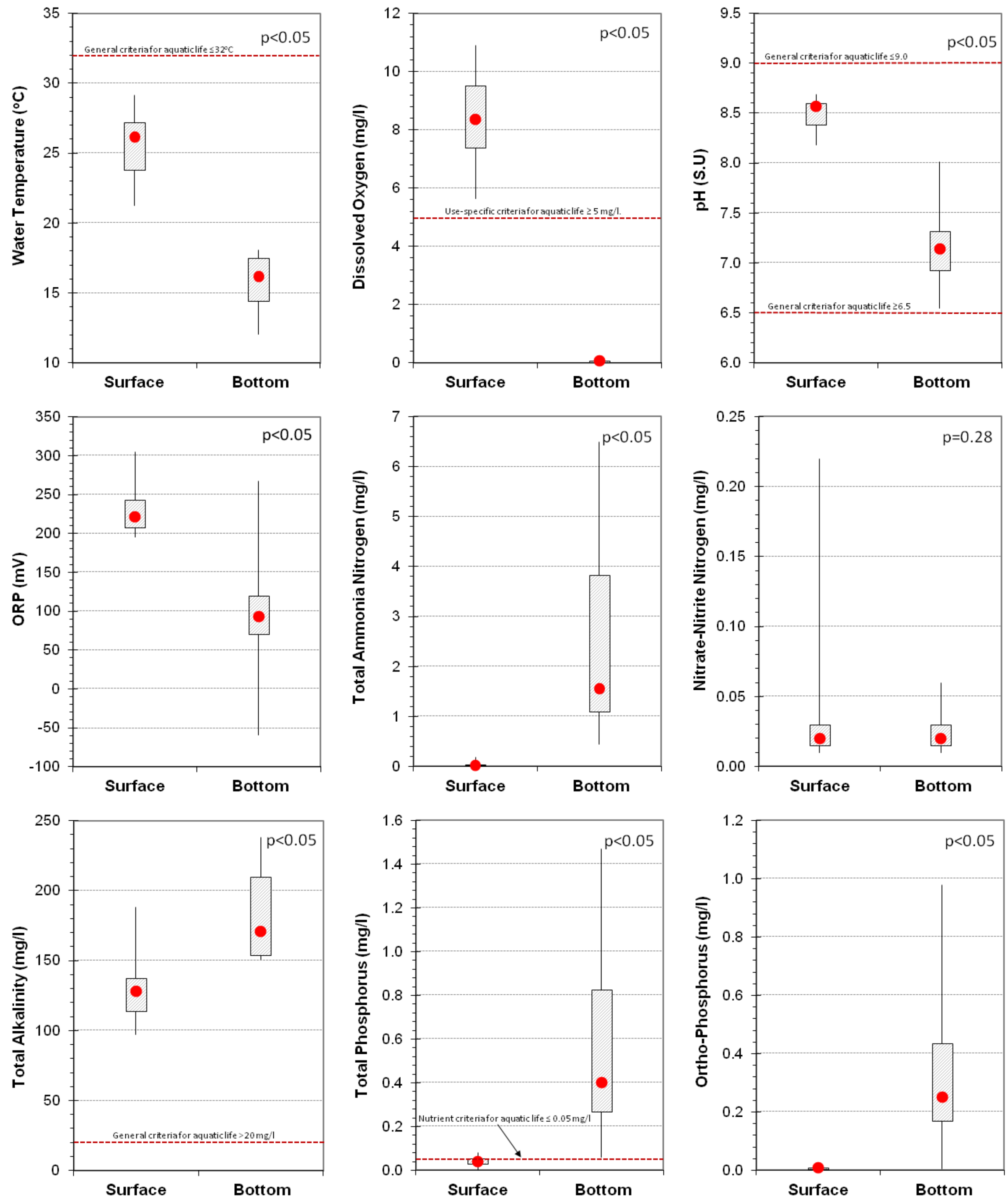


Plate 5-14. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, total ammonia nitrogen, nitrate-nitrite nitrogen, alkalinity, total phosphorus, and ortho-phosphorus measured in Ed Zorinsky Reservoir when summer hypoxic conditions were present during the 5-year period of 2011 through 2015 (n=15). P-values indicate significant differences between the near-surface and near-bottom samples via a paired two-tailed t-test (α = 0.05). (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot. Water quality criteria marked with red line when applicable)

Plate 5-15. Total biovolume and density by taxonomic Phylum for phytoplankton grab samples from Ed Zorinsky Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**
04-May-12	1,877	0	320,122	1,842	1,245,243	8,745	1,212,132	1,032	20,904	986	-----	-----	947,022	1,618	25,908,580	223
02-Jul-12	355,015	6,716	-----	-----	-----	-----	357,866	535	13,986,030	1,274,972	-----	-----	4,244,629	9,262	20,776	1
04-Sep-12	4,855,483	21,466	74,366	2,172	838	1	10,800	764	11,563,325	929,347	159,994	382	23,775	96	122,690	154
16-May-13	-----	-----	176,088	344	25,217	10	15,724	185	-----	-----	13,996	2	421,180	1,143	-----	-----
11-Jul-13	264	0	818,520	5,269	278,747	117	919,015	10,150	7,643,445	37,840	9,698	7	1,839,516	4,122	760,587	29
11-Sep-13	-----	-----	334,803	1,833	168,202	57	311,482	3,522	2,682,021	15,850	1,239	0	128,675	707	348,037	14
15-May-14	4,055	1	161,895	552	-----	-----	23,223	274	-----	-----	-----	-----	237,957	346	-----	-----
16-Jul-14	-----	-----	1,674,988	3,285	82,055	6	11,134,510	2,512	3,651,933	11,860	-----	-----	1,439,671	951	-----	-----
12-Sep-14	48,379	97	583,038	677	-----	-----	280,246	106	211,058	1,142	361,773	73	175,170	648	-----	-----
28-May-15	3,403	0	205,585	1,261	2,704,377	941	3,879,343	10,695	124,758	862	-----	-----	7,271,774	25,627	356,382	15
30-Jul-15	-----	-----	56,520	685	28,223	107	309,780	1,818	2,912,561	71,628	1,046	4	1,099,313	3,020	589,704	36
24-Sep-15	-----	-----	4,264	61	-----	-----	150,644	544	2,057,937	14,247	-----	-----	8,668,204	14,389	12,789	0

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

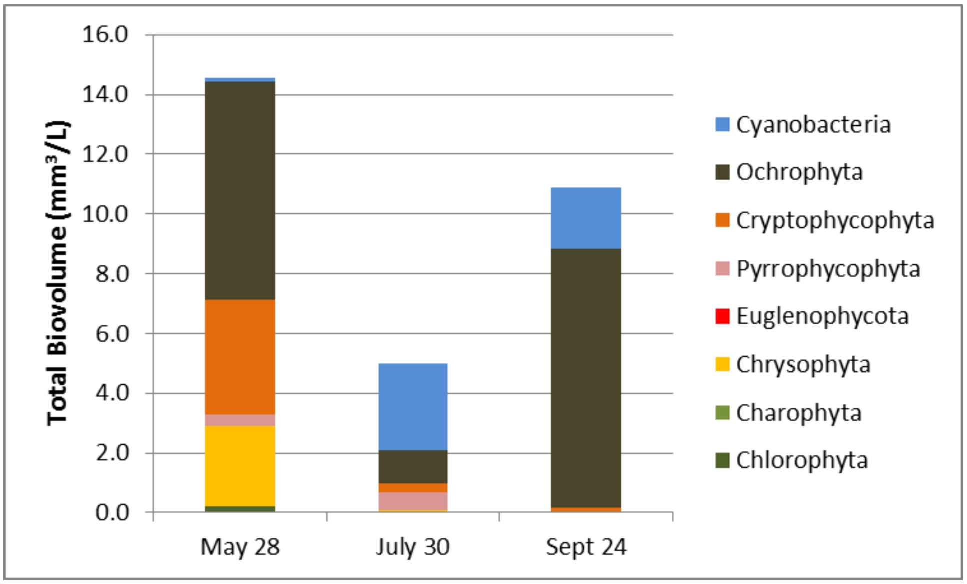


Plate 5-16. Relative abundance of phytoplankton in samples collected from Ed Zorinsky Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1).

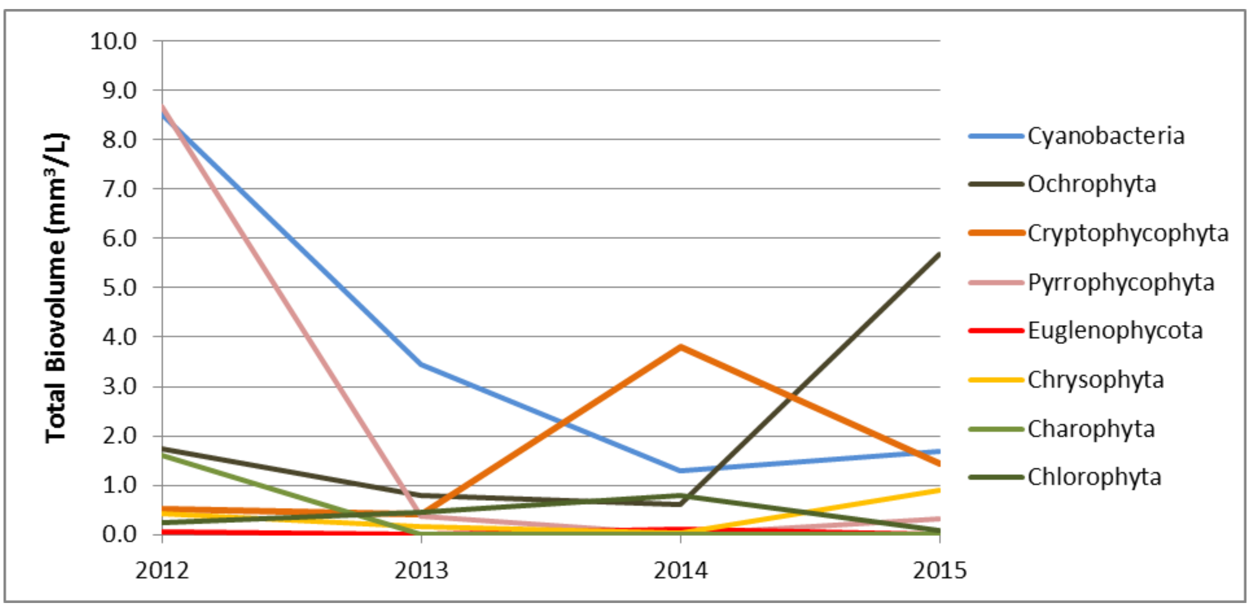


Plate 5-17. Relative abundance of phytoplankton in samples collected from Ed Zorinsky Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are a seasonal average of three summer samples (i.e. May, July, and September)

Plate 5-18. Total Biomass and density by taxonomic grouping for zooplankton vertical-tow samples from Ed Zorinsky Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)
04-May-12	15	196.46	62	19.05	-----	-----	195	2.02
02-Jul-12	8	52.99	9	15.26	0	0.35	69	0.44
04-Sep-12	1	1.73	6	10.67	0	0.01	15	0.07
16-May-13	43	154.49	46	47.01	-----	-----	117	4.97
11-Jul-13	2	1.81	31	39.60	0	0.35	45	0.95
11-Sep-13	16	35.29	28	32.90	-----	-----	66	0.75
15-May-14	71	218.13	133	145.17	-----	-----	1	2.25
16-Jul-14	77	119.93	128	89.72	-----	-----	826	80.33
12-Sep-14	18	104.34	56	56.27	-----	-----	147	6.31
28-May-15	4	15.19	24	42.44	-----	-----	43	11.16
30-Jul-15	11	22.36	40	23.11	-----	-----	11	0.22
24-Sep-15	16	40.14	11	11.06	-----	-----	54	0.47

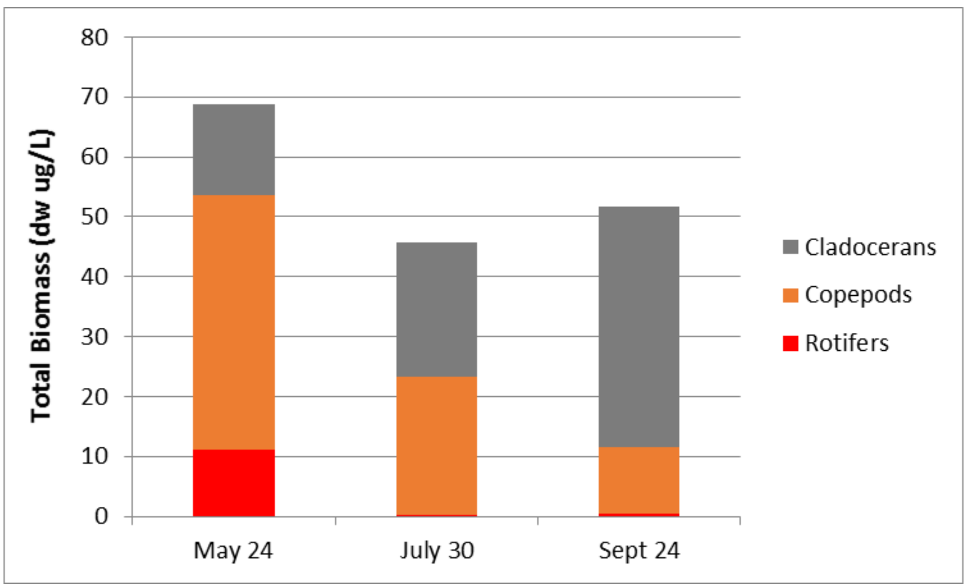


Plate 5-19. Relative abundance of zooplankton in samples collected from Ed Zorinsky Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1).

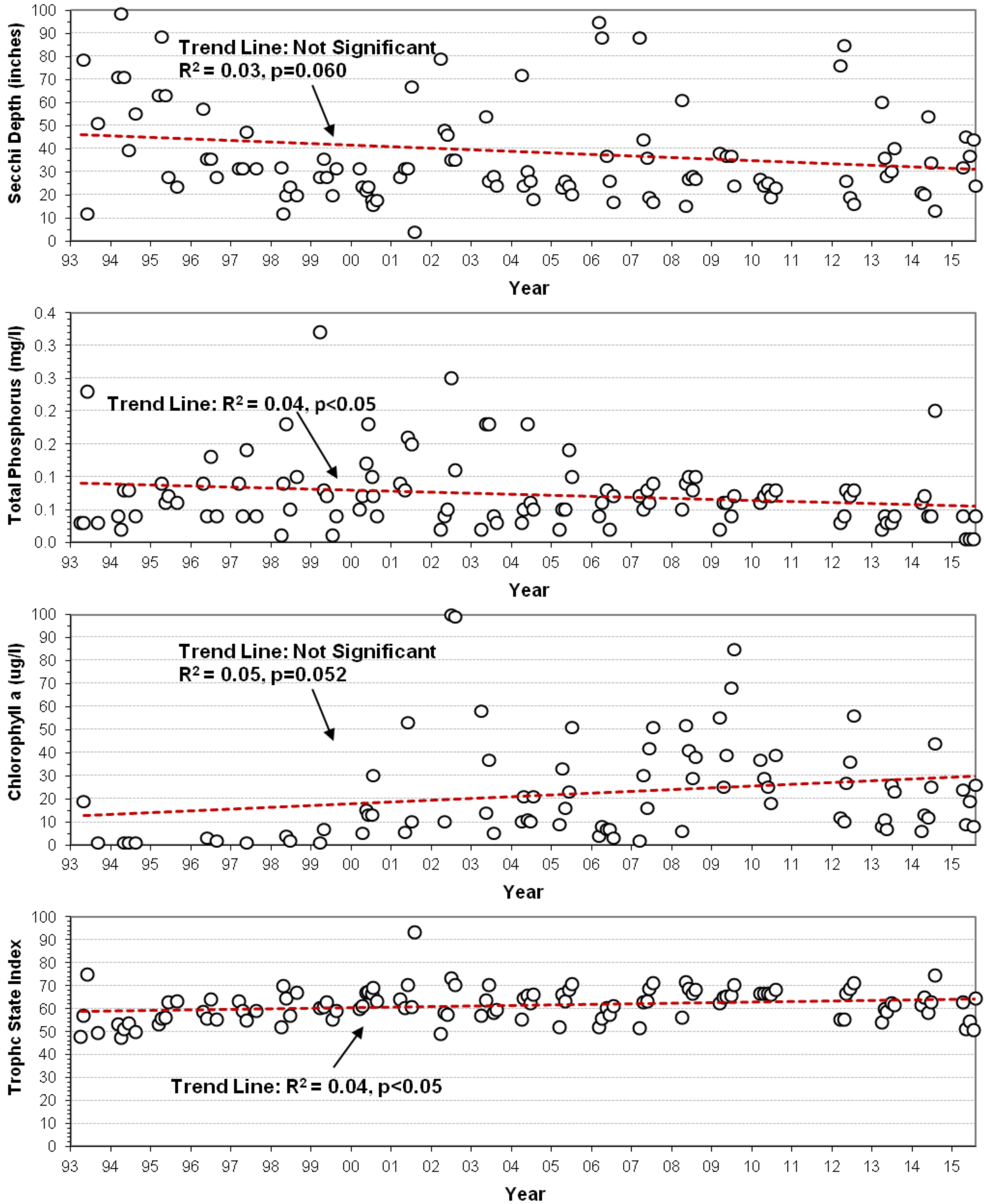


Plate 5-20. Historic trends for Secchi depth, total phosphorus, chlorophyll a, and Trophic State Index (TSI) monitored in Ed Zorinsky Reservoir at the near-dam, ambient site (i.e., site EZRLKND1) over the period of 1993 through 2015.

Plate 5-21. Summary of runoff water quality conditions monitored in the Boxelder Creek inflow to Ed Zorinsky Reservoir at monitoring site EZRNF1 during the 5-year period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	**No. of Obs.**	**Mean(A)**	**Median**	**Min.**	**Max.**	**State WQS Criteria(B)**	**No. of WQS Exceedances**	**Percent WQS Exceedance**
Water Temperature (°C)	0.10	24.00	20.57	21.17	9.73	27.18	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.10	24.00	8.36	8.03	6.87	11.52	≥5(2)	0	0%
Dissolved Oxygen (% Sat.)	0.10	24.00	96.16	93.60	81.90	148.20	-----	-----	-----
Turbidity (NTUs)	1.00	23.00	224.19	92.60	12.40	1092.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1.00	24.00	333.17	315.00	206.00	522.00	-----	-----	-----
Specific Conductance (umho/cm)	1.00	24.00	504.86	538.45	216.20	729.40	2,000(3)	0	0%
pH (S.U.)	0.10	23.00	8.20	8.17	7.53	9.70	≥6.5 & ≤9.0 (1)	0,1	0%,4%
Suspended Solids, Total (mg/l)	10.00	25.00	548.04	140.00	18.00	5950.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	26.00	0.13	0.10	n.d.	0.43	2.90(4,5), 0.61(4,6)	1,5	4%,19%
Kjeldahl N, Total (mg/l)	0.80	26.00	1.89	1.58	n.d.	5.58	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	26.00	1.43	0.98	0.37	3.98	100(3)	0	0%
Nitrogen, Total (mg/l)	0.80	26.00	3.32	2.99	2.01	9.56	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	26.00	0.66	0.31	0.10	6.11	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.01	21.00	0.12	0.12	0.02	0.18	-----	-----	-----
Iron, Dissolved (ug/l)	10.00	11.00	729.09	40.00	n.d.	4940.00	1000(6)	2	18%
Manganese, Dissolved (ug/l)	3.00	11.00	110.36	100.00	4.00	230.00	1000(6)	0	0%
Atrazine, Total (ug/l)(C)	0.05	16.00	1.36	0.90	n.d.	3.50	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(C)	0.10	16.00	-----	0.40	n.d.	1.70	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l)(C)	0.10	16.00	1.33	0.90	n.d.	3.80	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

5.3 GLENN CUNNINGHAM RESERVOIR

5.3.1 BACKGROUND INFORMATION

5.3.1.1 Project Overview

The dam forming Glenn Cunningham Reservoir is located on Knight Creek, a tributary to Little Papillion Creek. The dam was completed on August 5, 1974 and the reservoir reached its initial fill on September 2, 1977. The Glenn Cunningham Reservoir watershed is 17.8 square miles. The watershed has remained largely agricultural since the dam was built in 1974; however, widespread acreage development is presently occurring.

5.3.1.2 Aquatic Habitat Restoration Project

An aquatic habitat restoration project was initiated at Glenn Cunningham Reservoir in 2006. To facilitate implementation of the project, the reservoir was drained in the spring of 2006. The project consisted of two phases: 1) construction of in-reservoir habitat structures and modification of the outlet structure, and 2) rehabilitation and creation of wetland habitat in the reservoir and floodplain immediately upstream of the Nebraska Hwy 36 Bridge. The project was completed in December 2008 and water quality monitoring resumed in June 2009.

5.3.1.3 Reservoir Storage Zones

Figure 5.3 depicts the storage zones of Glenn Cunningham Reservoir based on 2009 survey data and estimated sedimentation. These storage zones reflect the 275 ac-ft of sediment removed during the habitat restoration project. The dam intake structure was also modified as part of the ongoing aquatic habitat restoration project. It is estimated that 15 percent of the "as-built" Multipurpose Pool has been lost to sedimentation with an annual volume loss estimate of 0.56 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Glenn Cunningham Reservoir's water quality dependent uses are not impaired due to sedimentation.

5.3.1.3.1 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Glenn Cunningham Reservoir since the reservoir was initially filled in the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 5.4 shows the location of the sites that have been monitored for water quality during the 5-year sampling period (2011-2015). The near-dam location (GCRLKND1) was continuously monitored from 1980 through 2005, and resumed in 2009 to the present.

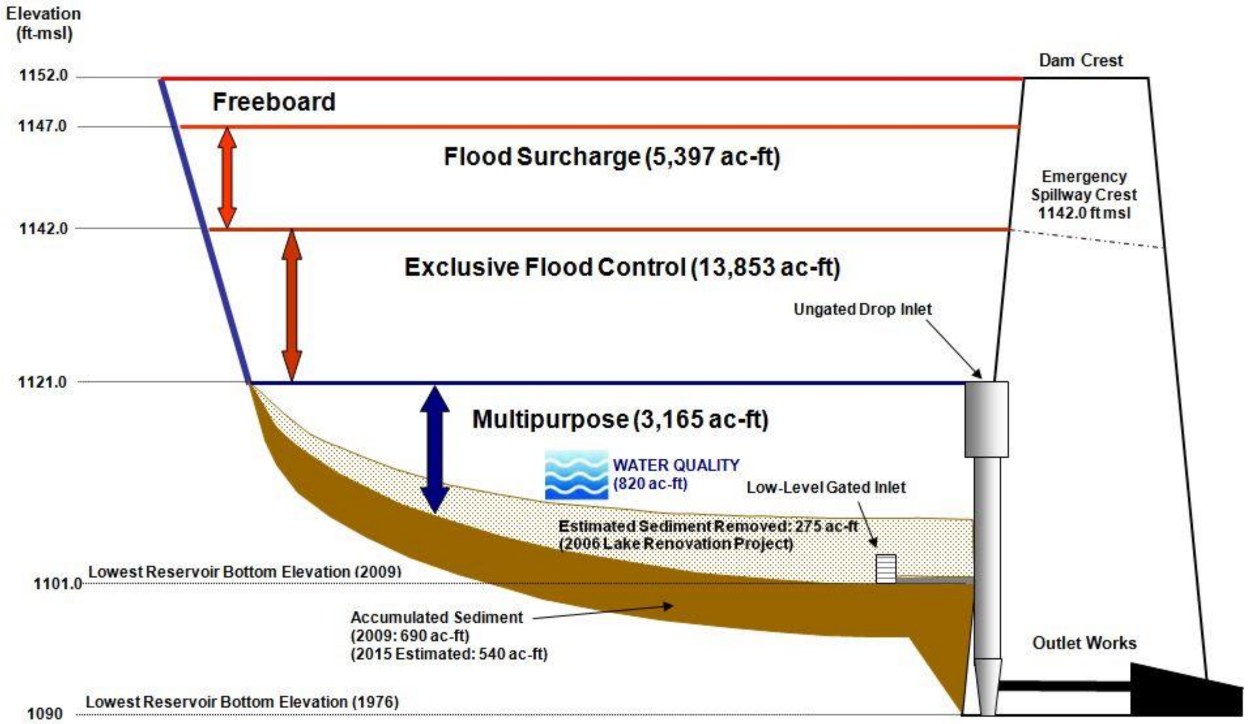


Figure 5.3. Current storage zones of Glenn Cunningham Reservoir based on the Corps 2009 survey data and estimated sedimentation.

5.3.2 WATER QUALITY IN GLENN CUNNINGHAM RESERVOIR

5.3.2.1 <u>Existing Water Quality Conditions</u>

5.3.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Glenn Cunningham Reservoir at sites GCRLKND1, GCRLKML1 and GCRLKUP1 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 5-22, Plate 5-23, and Plate 5-24 . A review of the results indicated possible water quality concerns regarding dissolved oxygen, chlorophyll *a*, and nutrients.

A significant number of dissolved oxygen measurements throughout Glenn Cunningham Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 5-22 and Plate 5-23). All of the low dissolved oxygen measurements occurred near the reservoir bottom and were associated with thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen levels measured in Glenn Cunningham Reservoir. Therefore, the measured dissolved oxygen levels below 5 mg/l are not considered exceedances of the water quality standards criteria.

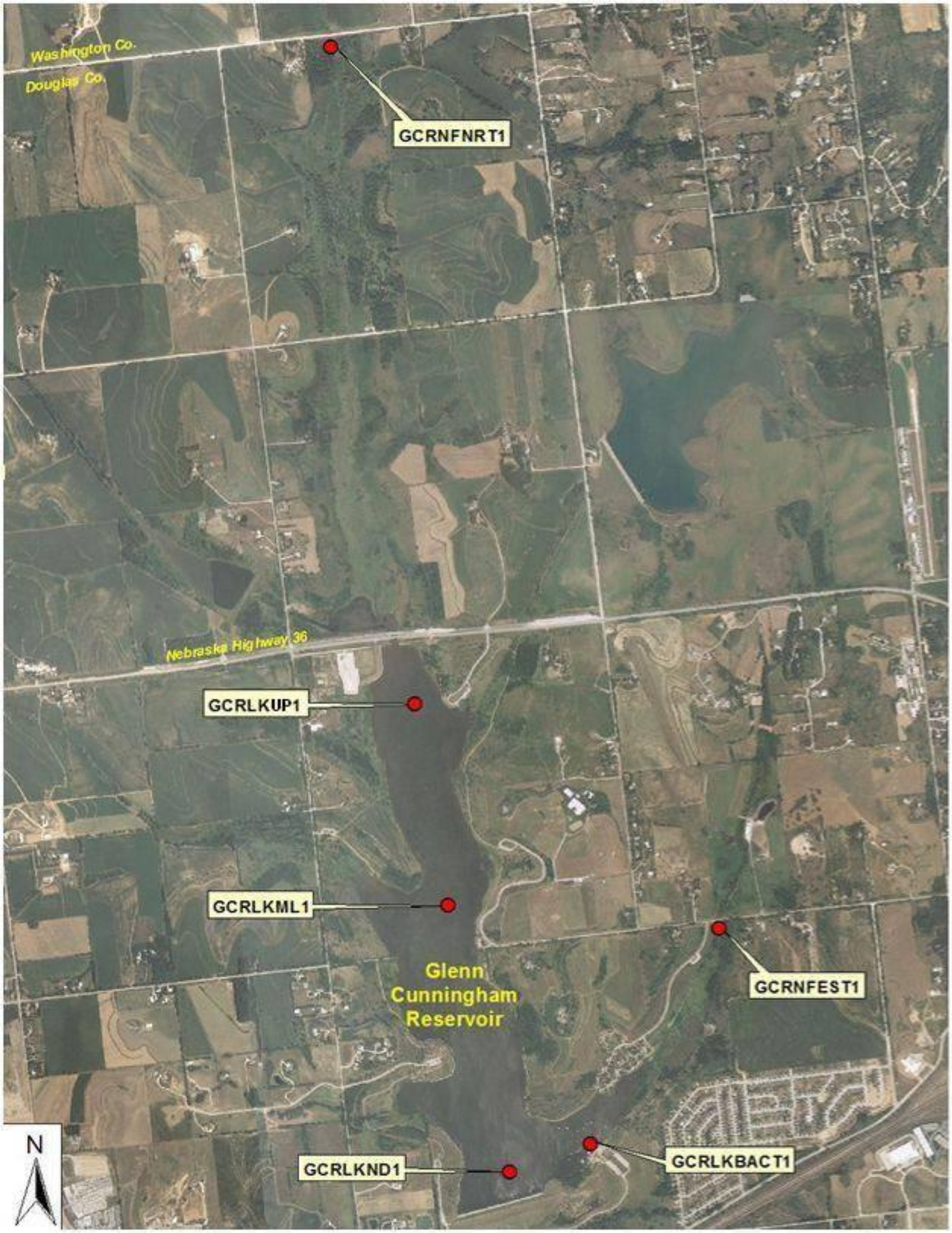


Figure 5.4. Location of sites where water quality monitoring was conducted by the District at Glenn Cunningham Reservoir during the 5-year period 2011 through 2015.

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September). All three of these criteria were exceeded Glenn Cunningham Reservoir (Plate 5-22). The near-surface chlorophyll *a* criterion was exceeded by 92 percent of the "lab analyzed" samples taken in the reservoir at site GCRLKND1. The total phosphorus and total nitrogen criteria were exceeded by 36 and 68 percent of samples, respectively. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values (Plate 5-22) represent the growing season average for the 5-year period 2011 through 2015. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.05 mg/l), total nitrogen (1.17 mg/l), and chlorophyll *a* (29 ug/l) values at GCRLKND1 indicate impairment of the aquatic life use.

Due to the recent habitat restoration project Nebraska's water quality standards place Glenn Cunningham Reservoir in category 4R. Nutrient assessment of category 4R designated waters may be misleading due to a trophic upsurge upon refill which is typically followed by a period of decline. Reservoirs may be placed in the category for a period of up to 8 years (Nebraska Department of Environmental Quality, 2016).

5.3.2.1.2 Thermal Stratification

5.3.2.1.2.1 ***Longitudinal Temperature Contour Plots***

Late-spring and summer thermal stratification of Glenn Cunningham Reservoir measured during 2015 is depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 5-25 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites GCRLKND1, GCRLKML1 and GCRLKUP1 in 2015. Thermal stratification persisted from late-spring through August. A maximum difference of about 10°C was measured between surface and bottom water temperatures.

5.3.2.1.2.2 ***Near-Dam Temperature Depth-Profile Plots***

The depth-profile temperature measurements collected over the 5-year period of 2011 through 2015 at the deep water area near the dam were compiled and plotted to describe the existing summer thermal stratification of Glenn Cunningham Reservoir (Plate 5-26). The plotted depth-profile temperature measurements indicate that the reservoir exhibits periodic thermal stratification during the summer. Since Glenn Cunningham Reservoir ices over in the winter, it appears to be a dimictic lake based on the measured thermal stratification in the summer (Wetzel, 2001). Wetzel (2001) identifies lakes as dimictic if they circulate freely twice a year in the spring and fall and are directly stratified in the summer and inversely stratified under ice cover in winter.

5.3.2.1.3 Dissolved Oxygen Conditions

5.3.2.1.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of Glenn Cunningham Reservoir based on depth-profile measurements taken during 2015. Plate 5-27 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 near the reservoir bottom from late-spring through mid-summer.

5.3.2.1.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

The depth-profile dissolved oxygen measurements collected during the summers of 2011 through 2015 at the deep water area near the dam were compiled and plotted to describe the existing summer dissolved oxygen conditions of Glenn Cunningham Reservoir (Plate 5-28). Most of the plotted profiles indicate a significant vertical gradient in dissolved oxygen levels with most tending towards a clinograde distribution. Sixty-eight percent of the profiles showed hypoxic conditions near the reservoir bottom. A few of the plotted profiles indicate dissolved oxygen concentrations above 5 mg/l from the reservoir surface to the bottom. These profiles were measured in early spring or fall and are believed to be a result of thermal stratification breaking down to the depth the profile was measured as “spring turnover” ended or “fall turnover” of the reservoir approached.

5.3.2.1.3.3 ***Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of Glenn Cunningham 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 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 June 23, 2015 contour plot indicates a pool elevation of 1121.8 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1111 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1110 ft-msl (Plate 5-27). The current District Area-Capacity Tables (2007 Survey) give storage capacities of 3,291 ac-ft for elevation 1121.8 ft-msl, 646 ac-ft for elevation 1111 ft-msl, and 523 ac-ft for elevation 1110 ft-msl. On June 23, 2015 it is estimated that 20 percent of the volume of Glenn Cunningham Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 16 percent of the reservoir volume was hypoxic.

5.3.2.1.4 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in Glenn Cunningham reservoir indicated hypoxic conditions May through July 2015. As a result, longitudinal contour plots where constructed for ORP and pH during these months. Depth profiles and near-surface/near-bottom sample comparisons were constructed for periods of hypoxic conditions from 2011 through 2015.

5.3.2.1.4.1 ***Oxidation-Reduction Potential***

Plate 5-29 provides longitudinal ORP contour plots based on measurements taken in 2015. ORP values present during June and July 2015 indicated somewhat reduced conditions near the reservoir bottom. Plate 5-30 plots depth profiles for ORP measured during the summer over the 5-year sampling period in the deep water area of Glenn Cunningham Reservoir near the dam when hypoxic conditions are present. Significant vertical gradients in ORP occurred occasionally during the 5-year period, however, most ORP readings remained above 250 mV.

5.3.2.1.4.2 ***pH***

Longitudinal contour plots for pH conditions measured in 2015 are provided in Plate 5-31. Lower pH levels near the bottom of the reservoir could be attributable to reservoir stratification and ongoing decomposition/respiration near the reservoir bottom. This would lead to an increase in CO_2 and decrease in pH. All pH levels were within the pH criteria for the protection of warmwater aquatic life. Plate 5-32 plots depth profiles for pH measured during the summer over the 5-year sampling period in the deep water area of Glenn Cunningham Reservoir near the dam when hypoxic conditions were present. A significant vertical gradient in pH regularly occurred in the reservoir during the summer, but all pH levels remained within Nebraska’s criterion for the protection of warmwater aquatic life.

5.3.2.1.4.3 ***Comparison of Near-Surface and Near-Bottom Water Quality Conditions***

Paired near-surface and near-bottom water quality samples collected from Glenn Cunningham Reservoir during the summer when hypoxia was present 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 GCRLKND1 during the 5-year period 2011 through 2015. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 17 (68%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 5-33). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for all the assessed parameters except nitrate-nitrite nitrogen. Parameters that were significantly lower in the near-bottom water of Ed Zorinsky Reservoir when hypoxia was present included: water temperature, dissolved oxygen, ORP, and pH ($p < 0.05$). Parameters that were significantly higher in the near-bottom water included: total ammonia nitrogen, total alkalinity, total phosphorus, and ortho-phosphorus ($p<0.05$).

5.3.2.1.4.4 ***Reservoir Trophic Status***

Trophic State Index (TSI) values for Glenn Cunningham Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., GCRLKND1). Table 5.5 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Glenn Cunningham Reservoir is in a eutrophic condition.

Table 5.5. Summary of Trophic State Index (TSI) values calculated for Glenn Cunningham Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	20	63	63	49	76
TSI(TP)	20	53	55	34	71
TSI(Chl)	20	67	67	57	79
TSI(Avg)	20	61	62	51	74

* 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 for the individual parameters.

Note: See Section 4.1.3 for discussion of TSI calculation.

5.3.2.1.4.1 ***Bacteria Monitoring***

A designated swimming beach is not located on Glenn Cunningham Reservoir; however, the reservoir is used extensively for sailing and wind surfing. Since these recreational uses can lead to direct contact with water, bacteria monitoring was conducted at the reservoir. During the 5-year period 2011 through 2015, bacteria samples were collected weekly from May through September near the marina boat ramp on Glenn Cunningham Reservoir (i.e., site GCRLKBACT1) (Figure 5.4). Table 5.6 summarizes the results of the bacteria sampling. The "running 5-week" geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The "pooled" geomeans were determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for bacteria:

Fecal Coliform:

Bacteria of the fecal coliform group should not exceed a geometric mean of 200/100ml, nor equal or exceed 400/100ml, in more than 10% of the samples. These criteria are based on a minimum of five samples taken within a 30-day period.

E. coli:

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

Table 5.6. Summary of weekly (May through September) bacteria samples collected at Glenn Cunningham Reservoir (i.e., site GCRLKBACT1) during the 4-year period 2011 through 2015.

Fecal Coliform Bacteria – Individual Samples		***E. coli* – Individual Samples**	
Number of Samples	108	Number of Samples	108
Mean (cfu/100ml)	63.61	Mean (cfu/100ml)	71.46
Median (cfu/100ml)	19	Median (cfu/100ml)	16.4
Minimum (cfu/100ml)	1	Minimum (cfu/100ml)	1
Maximum (cfu/100ml)	1000	Maximum (cfu/100ml)	1961
Percent of samples exceeding 400/100ml	4%	Percent of samples exceeding 235/100ml	6%
Fecal Coliform Bacteria – Running 5-Week Geomean		***E. coli* – Running 5-Week Geomean**	
Number of Geomeans	88	Number of Geomeans	88
Average	32	Average	25
Median	22	Median	19
Minimum	4	Minimum	5
Maximum	112	Maximum	78
Percent of Geomeans exceeding 200/100ml	0%	Percent of Geomeans exceeding 126/100ml	0%
Fecal Coliform Bacteria – Pooled Geomean		***E. coli* – Pooled Geomean**	
Pooled Geomean (cfu/100ml)	12	Pooled Geomean (cfu/100ml)	13

n.d. = non-detected.

Note: Non-detected values set to 1 to calculate mean and geomean.

The pooled geomeans were compared to the State of Nebraska's impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using fecal coliform and *E. coli* bacteria data. Based on those criteria, a Primary Contact Recreation use in Glenn Cunningham Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

5.3.2.1.5 Reservoir Plankton Community

5.3.2.1.5.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at the Glenn Cunningham Reservoir near-surface, near-dam sampling site during the spring and summer of the 5-year period 2011 through 2015 (Plate 5-34). The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 5-35. During the 2015 growing season, the phytoplankton community exhibited seasonal changes but the total phytoplankton biovolume stayed relatively stable. May was dominated by Chrysophyta, July by Pyrrrophycophyta, and September by Cryptophycophyta. Plate 5-35 shows that Glenn Cunningham Reservoir had a relatively healthy and diverse phytoplankton population. 2015 showed some seasonal successional patterns commonly observed in eutrophic reservoirs with Cyanobacteria densities being their greatest during the warm summer months. Major and dominant phytoplankton genera sampled in 2015 at Glenn Cunningham Reservoir are provided in Table 5.7.

Annual variation in phytoplankton community composition is displayed in Plate 5-36. During the 5-year period 2011 through 2015, Cyanobacteria, predominantly dominated Glenn Cunningham Reservoir from 2011 through 2013. Cryptophycophyta, Chrysophyta and Ochrophyta became more dominant in 2014 and 2015. The highest Cyanobacteria levels were observed in 2012. 2012 was a particularily warm and dry year. The resulting long residence times, decreased mixing, and warm waters could have created a longer Cyanobacterial growing season resulting in the large biovolumes and densities observed. Cyanobacteria density levels were above World Health Organization's high health risk standard in 2012, 2013, and 2015 though the 5-year period (Plate 5-34). The maximum extracellular microcystin level measured during the 5-year period was 0.3 µg/L (Plate 5-22).

Table 5.7. Listing of Major and Dominant Phytoplankton Genera Sampled in Glenn Cunningham Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1)

Division	**Major Genera** (>10% Total Biovolume in a single sample)	**Dominant Genera** (>25% Total Biovolume in a single sample)
Chrysophyta	-----	*Mallomonas*
Cryptophycophyta	*Cryptomonas*	*Rhodomonas*
Cyanobacteria	*Planktothrix, Anabaena*	-----
Pyrrophycophyta	*Ceratium*	*Peridinium*

5.3.2.1.5.2 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at Glenn Cunningham Reservoir near-dam sampling sites during the spring and summer of the 5-year period 2011 through 2015 (Plate 5-37). The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in Plate 5-38. Zooplankton total biomass was the greatest in September. Copepods and Cladocerans dominating Glenn Cunningham Reservoir in 2015. Dominant and major zooplankton genera sampled in Glenn Cunningham Reservoir during 2015 are provided in Table 5.8.

Table 5.8. Listing of major and dominant zooplankton genera sampled in Glenn Cunningham Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1)

Taxonomic Group	**Major Genera** (>10% Total Biovolume in a single sample)	**Dominant Genera** (>25% Total Biovolume in a single sample)
Cladocerans	-----	*Daphnia*
Copepods	*Leptodiaptomus, Acanthocyclops, Cyclopodoida*	*Mesocyclops*
Rotifers	*Asplanchna*	-----

5.3.2.1.6 Zebra Mussel Monitoring

Zebra mussel veliger sampling has been conducted once yearly since 2012. During the sampling period (2012-2015) no veligers have been identified.

5.3.2.2 <u>Water Quality Trends (1980 through 2015)</u>

Water quality trends from 1980 to 2015 were determined for Glenn Cunningham 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., GCRLKND1). Plate 5-39 displays a scatter-plot of the collected data for the four parameters and a linear regression line for data collected before and after the habitat restoration project. The trends indicated that prior to the lake renovation project Glenn Cunningham Reservoir exhibited decreasing transparency ($p < 0.05$, R^2=0.05) increasing levels of total phosphorus ($p < 0.05$, R^2=0.07) and an increasing TSI ($p<0.05$, R^2=0.10). Due to the recent habitat restoration project Nebraska's water quality standards place Glenn Cunningham Reservoir in category 4R. Nutrient assessment of category 4R designated waters may be misleading due to a trophic upsurge upon refill which is typically followed by a period of decline. Once the reservoir category has changed and the more "post-project" water quality data is collected, further analyses will be pursued to test for water quality changes from "pre-project" conditions.

5.3.2.3 Existing Water Quality Conditions of Runoff Inflows to Glenn Cunningham Reservoir

Existing water quality in the north and east inflows to Glenn Cunningham Reservoir were monitored under runoff conditions, during the period of April through September, respectively at sites GCRNFNRT1, GCRNFNRT2, and GCRNFEST1. Site GCRNFNRT1 is 2 miles upstream from the reservoir, GCRNFNRT2 is located at the Nebraska Highway 36 bridge, right before inflow water enters the reservoir, and site GCRNFEST1 is approximately ½ mile upstream of the reservoir (Figure 5.4). Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plate 5-40, 31, and 32, respectively summarize water quality conditions that were monitored at sites GCRNFNRT1 GCRNFNRT2 and GCRNFEST1 under runoff conditions during the 5-year monitoring period of 2011 through 2015.

5.3.3 PLATES

Plate 5-22. Summary of water quality conditions monitored in Glenn Cunningham Reservoir at site GCRLKND1 from May to September during the 5-year period 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	24	1130.48	1121.40	1120.30	1339.22	-----	-----	-----
Water Temperature (°C)	0.1	311	22.44	22.23	12.68	29.96	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	311	6.34	6.98	n.d.	10.98	≥5(2)	77	25%
Dissolved Oxygen, Near-Surface (mg/l)(C)	0.1	25	8.72	9.37	5.43	10.89	≥5(2)	0	0%
Dissolved Oxygen (% Sat.)	0.1	311	75.83	84.80	n.d.	139.40	-----	-----	-----
Secchi Depth (in.)	1	25	33.00	33.00	14.00	54.00	-----	-----	-----
Turbidity (NTUs)	1	299	12.32	10.60	1.70	315.70	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	311	336.88	327.00	90.00	487.00	-----	-----	-----
Specific Conductance (umho/cm)	1	311	433.13	426.00	357.40	573.60	2,000(3)	0	0%
pH (S.U.)	0.1	311	8.25	8.31	7.16	9.60	≥6.5 & ≤9.0 (1)	0,2	0%,1%
Alkalinity, Total (mg/l)	1	50	189.14	183.00	146.00	238.00	20(1)	0	0%
Suspended Solids, Total (mg/l)	4	50	-----	10.00	n.d.	38.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	50	-----	0.09	n.d.	2.41	1.96(4,5), 0.45(4,6)	1,4	2%,8%
Ammonia, Total, Near-Surface (mg/l) (C)	0.02	25	-----	n.d.	n.d.	0.27	1.25(4,5), 0.31(4,6)	0	0%
Kjeldahl N, Total (mg/l)	0.08	50	1.18	1.05	0.51	3.50	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	50	0.20	0.04	n.d.	0.81	100(3)	0	0%
Nitrogen, Total (mg/l)	0.03	50	1.38	1.28	0.61	3.53	1(7)	40	80%
Nitrogen, Total, Near-Surface (mg/l) (C)	0.03	25	1.17	1.11	0.61	1.84	1(7)	17	68%
Phosphorus, Total (mg/l)	0.005	50	0.08	0.06	0.01	0.50	0.05(7)	26	52%
Phosphorus, Total, Near-Surface (mg/l) (C)	0.005	25	0.05	0.05	0.01	0.10	0.05(7)	9	36%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	n.d.	n.d.	0.25	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	164.66	166.30	154.00	171.90	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	5	9.00	8.00	6.00	15.00	340(5), 16.7(8)	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	n.d.	9.67(5), 0.35(6)	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	898.01(5), 116.91(6)	0	0%
Copper, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	21.70(5), 13.83(6)	0	0%
Iron, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	40.00	1000(6)	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	0.70	111.84(5), 4.36(6)	0	0%
Manganese, Dissolved (ug/l)	3	5	-----	8.00	n.d.	50.00	1000(6)	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	720.01(5), 79.97(6)	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	8.27(5)	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	30.00	180.31(5), 181.78(6)	0	0%
Antimony, Dissolved (ug/l)	0.03	5	0.98	0.90	0.90	1.20	88(5), 30(6)	0	0%
Aluminum, Dissolved (ug/l)	40	5	-----	n.d.	n.d.	50.00	750(5), 87(6)	0	0%
Selenium, Total (ug/l)	0.06	5	3.00	2.00	2.00	6.00	20(3,5), 5(6)	1	20%
Chlorophyll a (ug/l) – Lab Determined(C)	6	25	29	24	n.d.	71	10(7)	23	92%
Chlorophyll a (ug/l) – Field Probe	6	298	32	26	n.d.	271	10(7)	258	87%
Mercury, Dissolved (ug/l)	0.008	5	-----	n.d.	n.d.	0.05	1.4(5)	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77(6)	0	0%
Atrazine, Total (ug/l)(D)	0.1	25	1.27	1.10	0.20	4.20	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(D)	0.1	25	-----	n.d.	n.d.	0.40	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l)(D)	0.1	25	-----	0.30	n.d.	0.80	-----	-----	-----
Microcystin, Extracellular (ug/l)	0.1	24	-----	n.d.	n.d.	0.30	20(9)	0	0%
Pesticide Scan (ug/l)(E)									
Atrazine, Tot	0.13	5	-----	0.28	n.d.	0.73	330(5), 12(6)	0	0%
Acetochlor, Tot	0.08	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Metolachlor, Tot	0.13	5	-----	n.d.	n.d.	n.d.	390(5), 100(6)	0	0%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-23. Summary of water quality conditions monitored in Glenn Cunningham Reservoir at site GCRLKML1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1132.26	1121.39	1120.30	1339.22	-----	-----	-----
Water Temperature (°C)	0.1	203	23.17	24.30	15.17	31.04	32$^{(1)}$	0	0%
Dissolved Oxygen (% Sat.)	0.1	203	93.37	94.30	1.00	184.20	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	203	7.70	7.71	0.08	13.22	≥5$^{(2)}$	21	10%
Specific Conductance (umho/cm)	1	203	423.48	414.80	331.20	523.40	2,000$^{(3)}$	0	0%
pH (S.U.)	0.1	203	8.37	8.39	7.40	9.07	≥6.5 & ≤9.0$^{(1)}$	0,8	0%,4%
Turbidity (NTUs)	1	195	19.09	17.90	4.60	62.80	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	203	351.61	335.00	146.00	478.00	-----	-----	-----
Secchi Depth (in.)	1	23	24.52	25.00	12.00	43.00	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	195	48	37	4	446	10$^{(4)}$	186	95%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-24. Summary of water quality conditions monitored in Glenn Cunningham Reservoir at site GCRLKUP1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1132.26	1121.39	1120.30	1339.22	-----	-----	-----
Water Temperature (°C)	0.1	57	24.00	25.11	14.92	32.01	32(1)	1	2%
Dissolved Oxygen (% Sat.)	0.1	57	106.99	100.80	48.90	214.30	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	57	8.61	8.24	3.91	15.08	≥5$^{(2)}$	3	5%
Specific Conductance (umho/cm)	1	57	428.79	414.20	287.10	547.80	2,000(3)	0	0%
pH (S.U.)	0.1	57	8.43	8.40	7.71	9.16	≥6.5 & ≤9.0 (1)	0,5	0%,9%
Turbidity (NTUs)	1	56	47.16	28.10	8.40	630.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	57	344.26	318.00	261.00	508.00	-----	-----	-----
Secchi Depth (in.)	1	24	15.08	16.00	5.00	21.00	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	52	50	36	4	165	10(4)	48	92%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

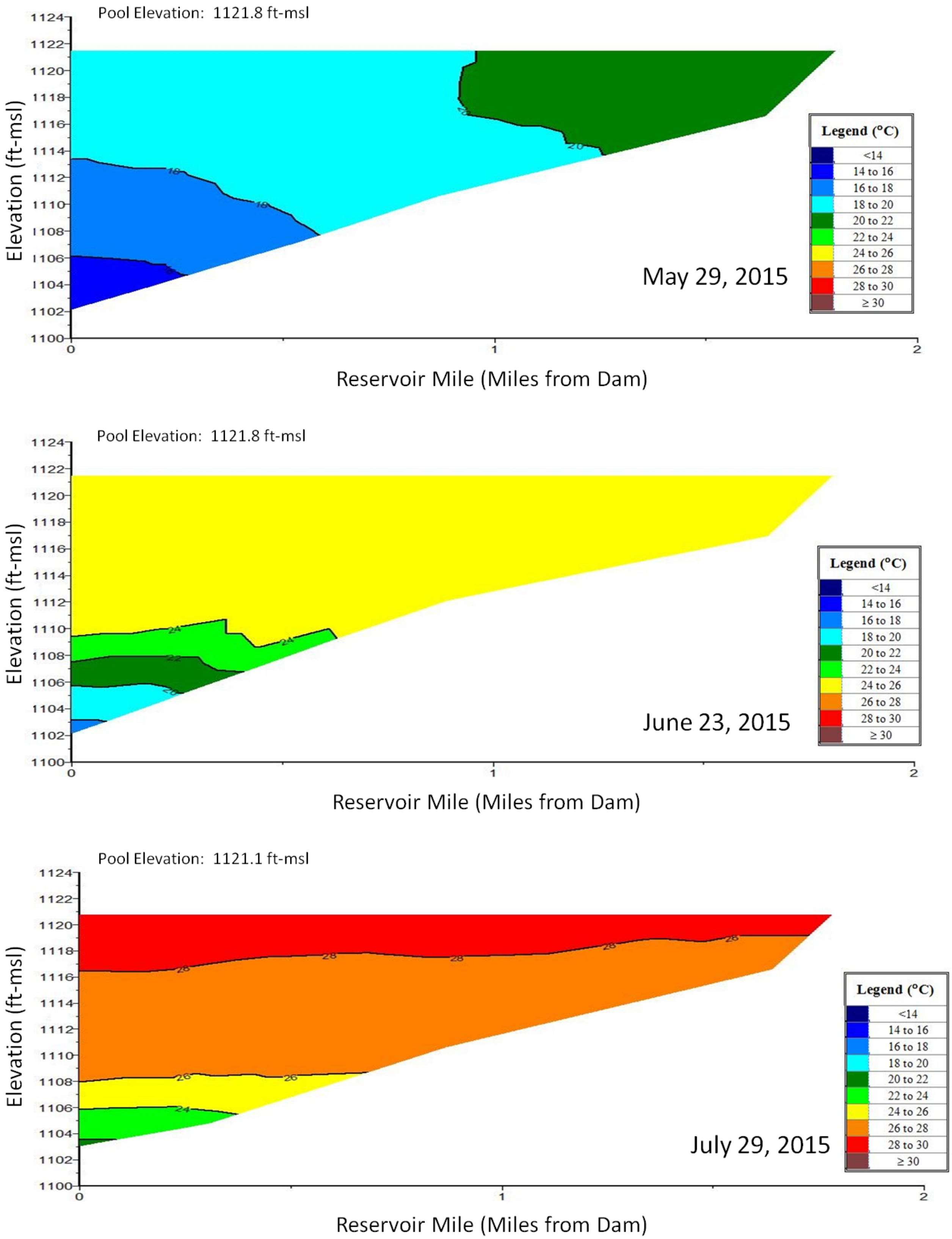
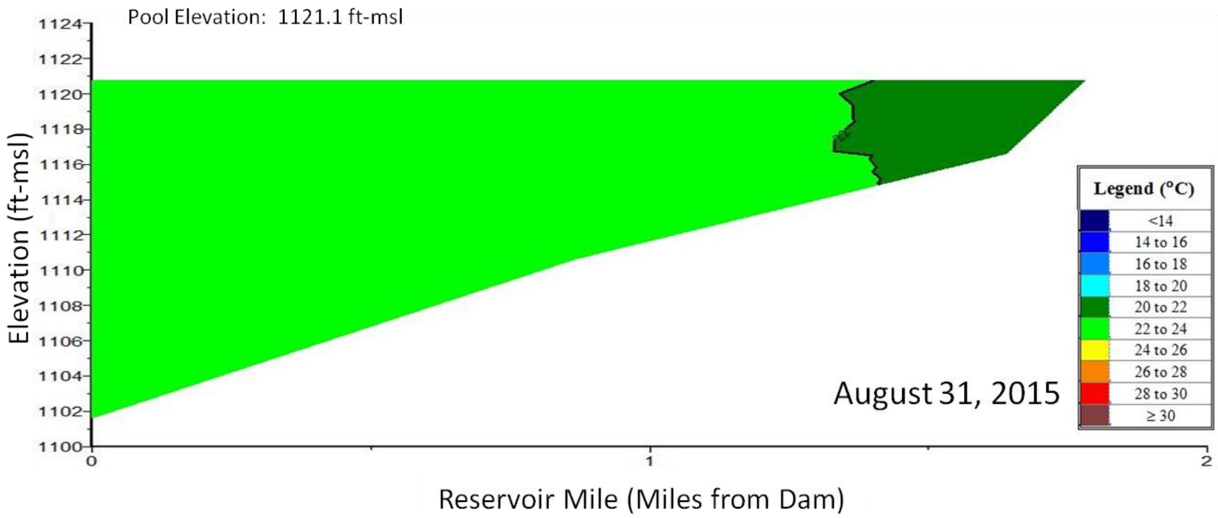


Plate 5-25. Longitudinal water temperature contour plots of Glenn Cunningham Reservoir based on depth-profile water temperatures (°C) measured from May to September 2015.



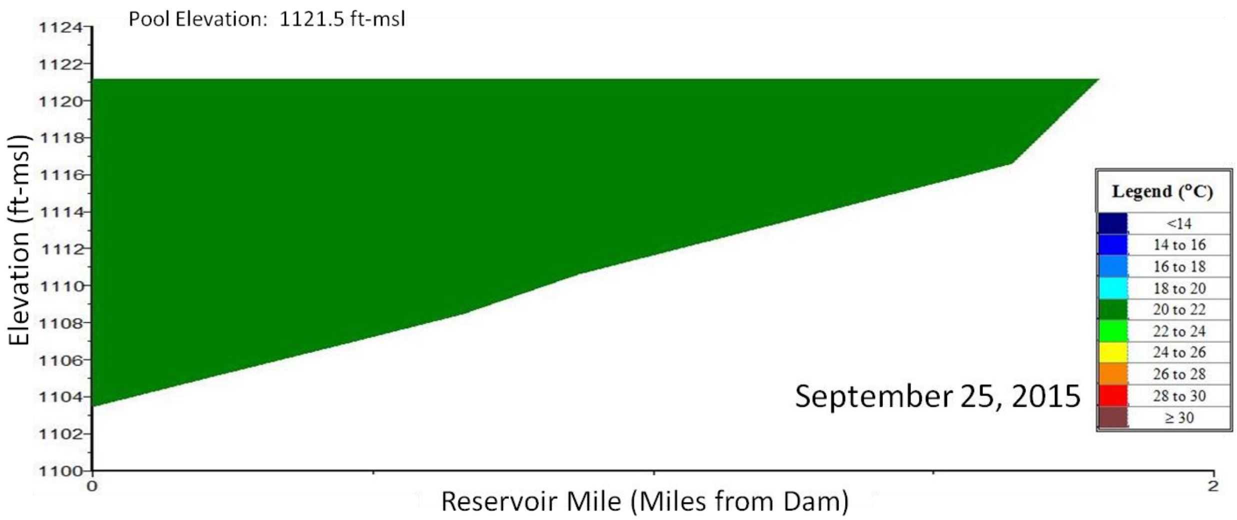


Plate 5-25. (Continued).

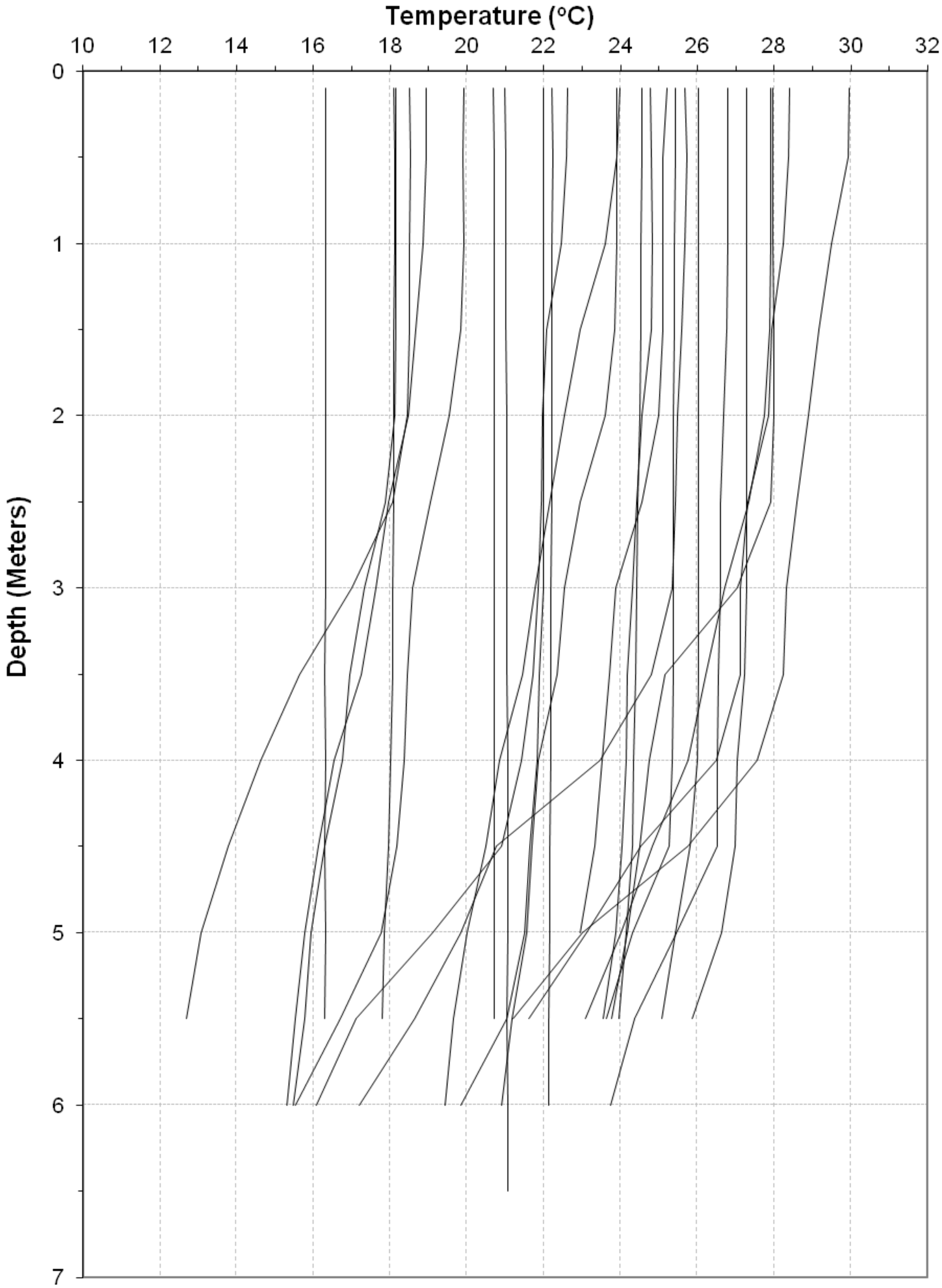


Plate 5-26. Temperature depth profiles for Glen Cunningham Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1) during the summer over the 5-year period of 2011 through 2015.

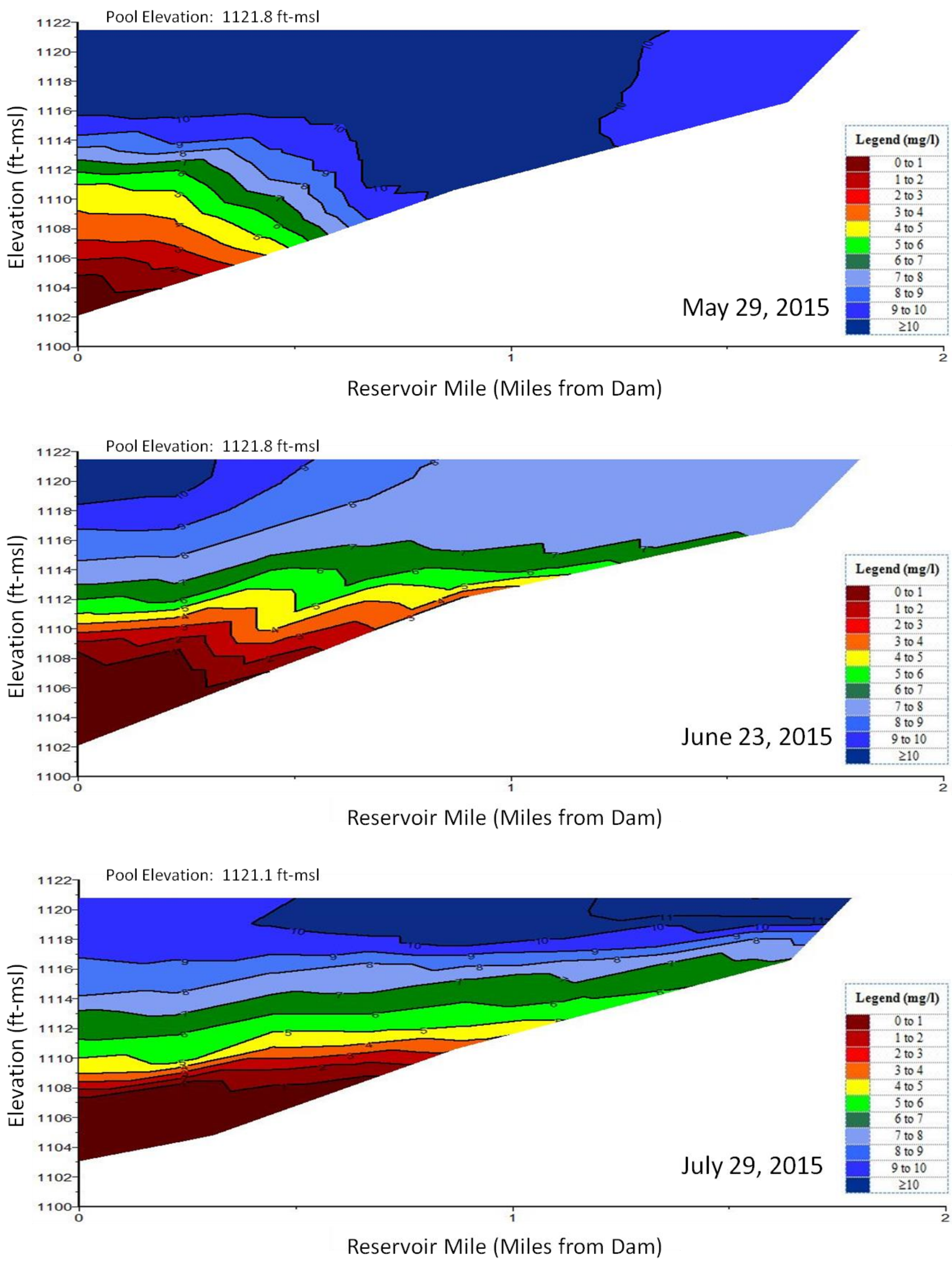
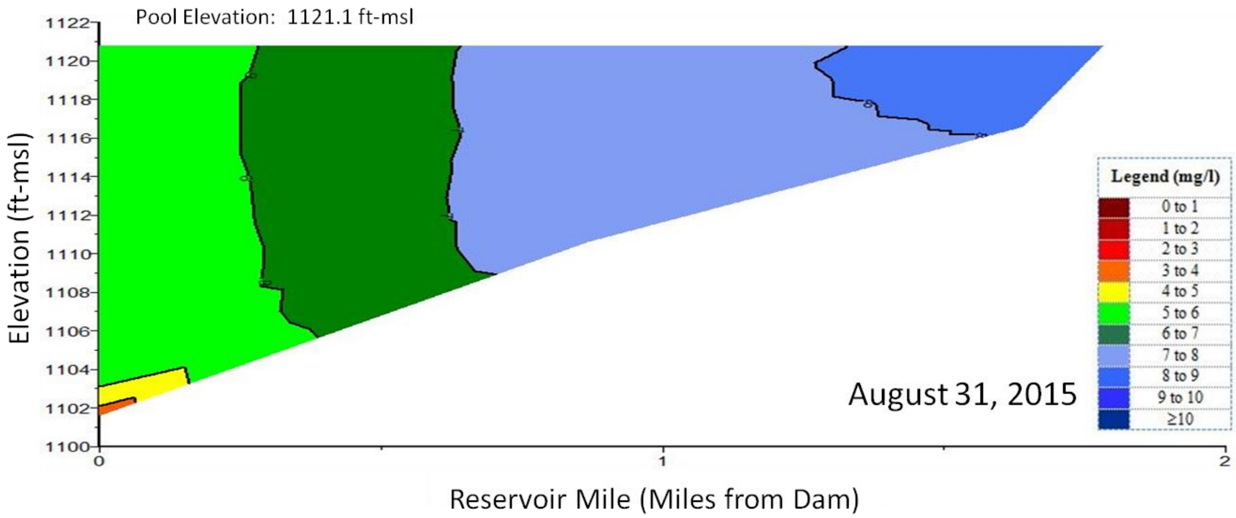


Plate 5-27. Longitudinal dissolved oxygen contour plots of Cunningham Reservoir based on depth-profile water temperatures (°C) measured from May to September in 2015.



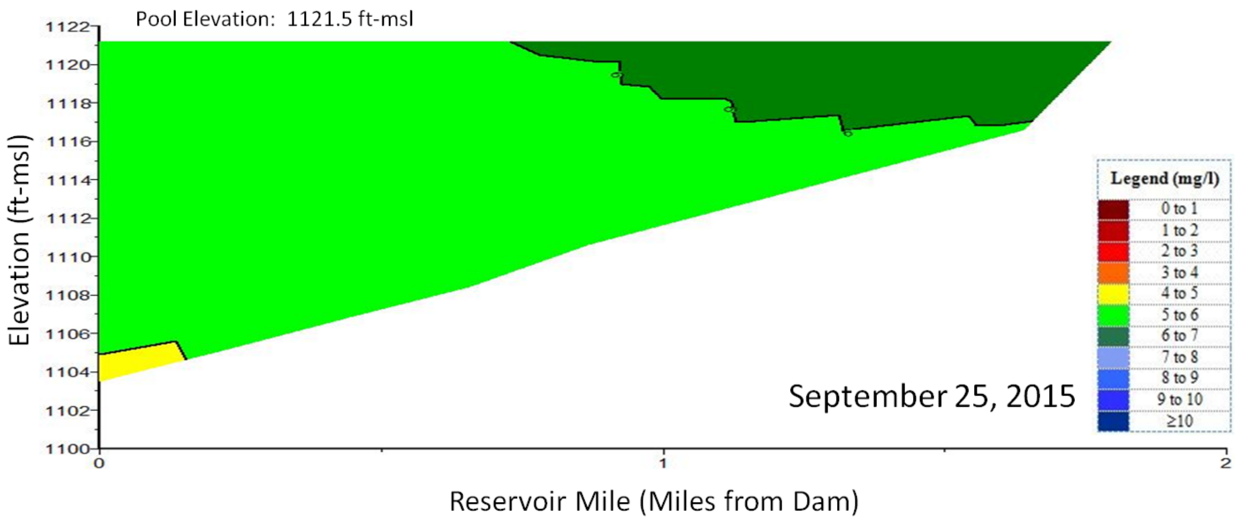


Plate 5-27. (Continued).

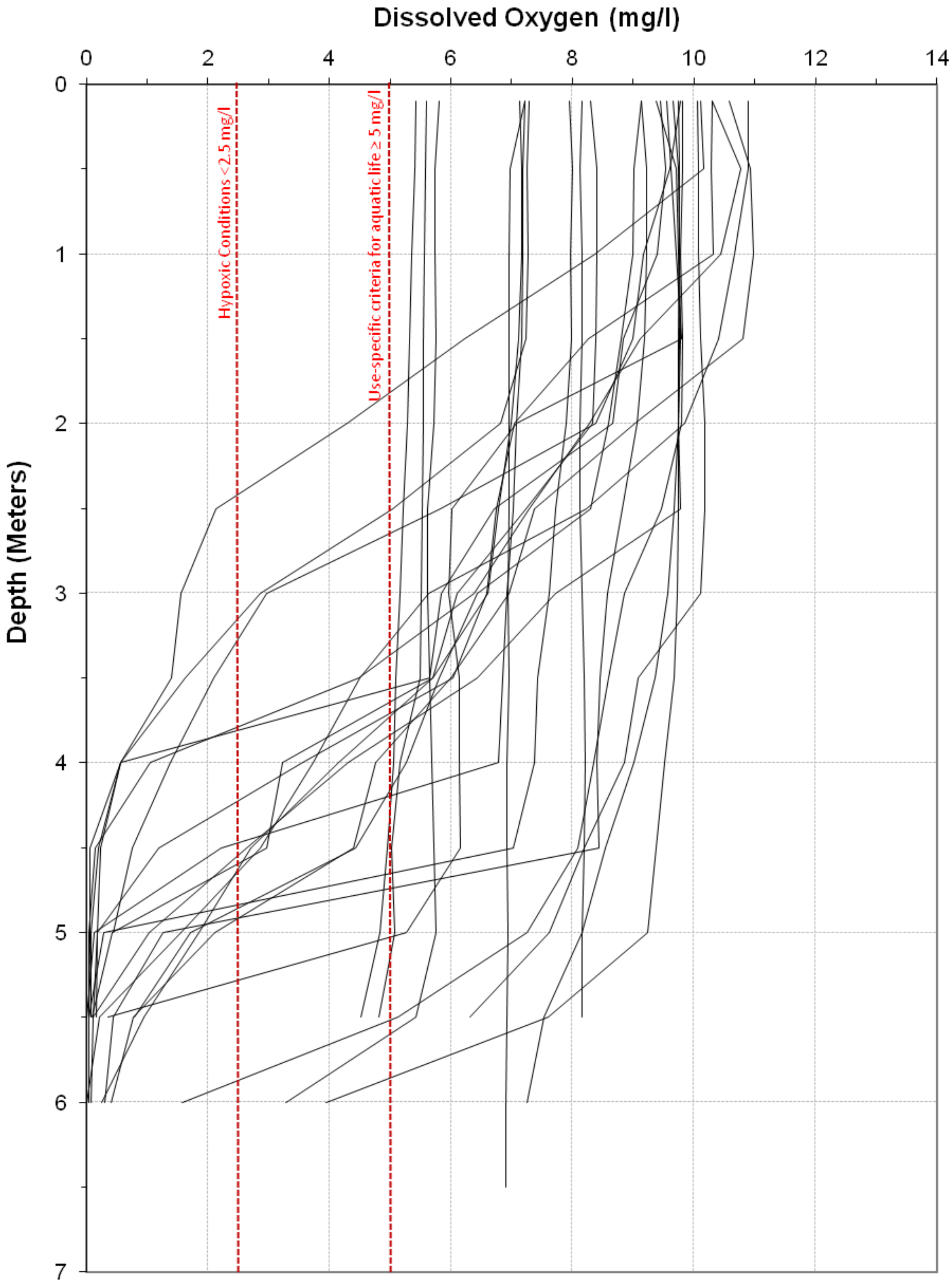


Plate 5-28. Dissolved oxygen depth profiles for Glen Cunningham Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1) during the summer over the 5-year period of 2011 through 2015.

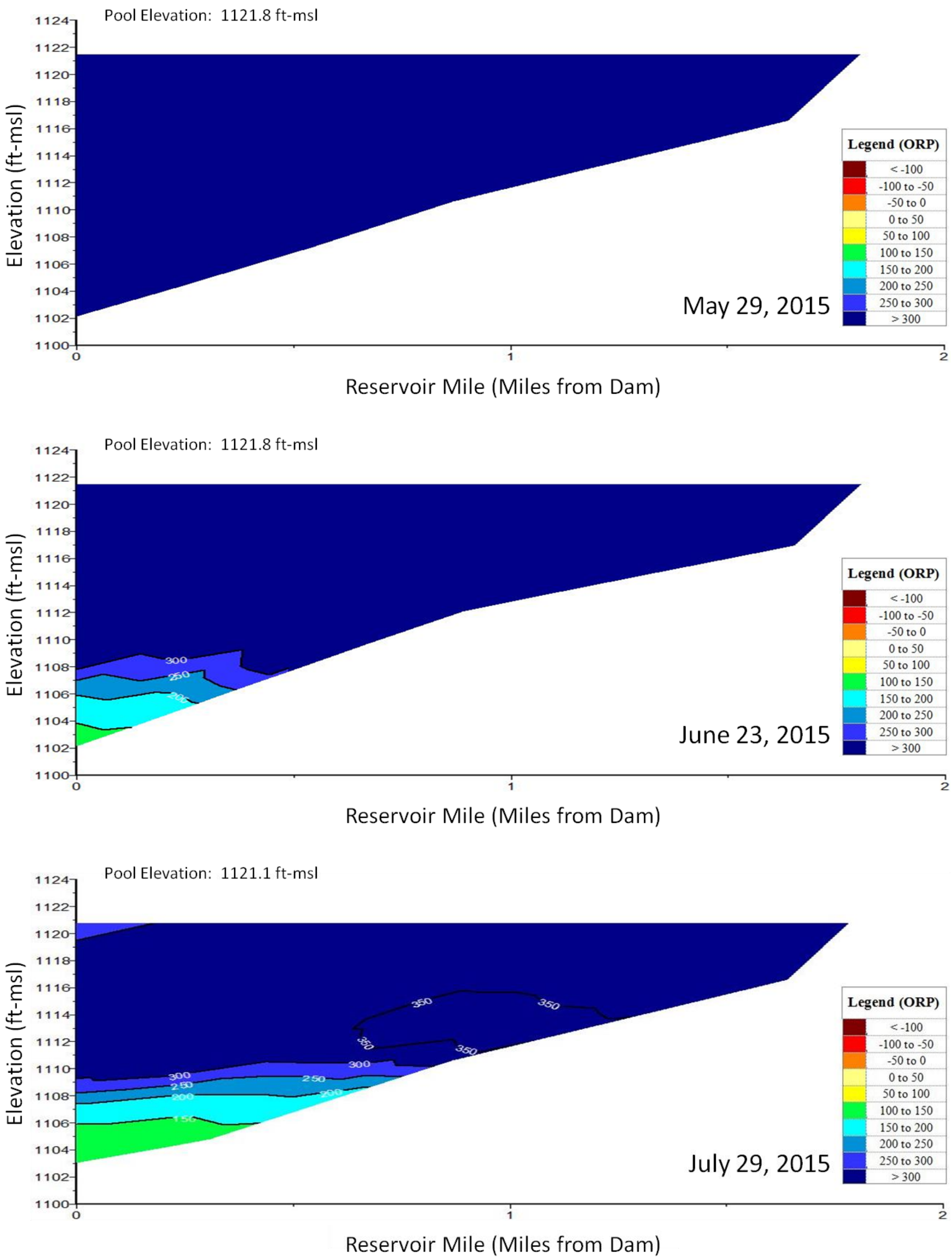


Plate 5-29. Longitudinal oxidation-reduction potential contour plots of Glenn Cunningham Reservoir based on depth-profile ORP levels (mV) measured at sites GCRLKND1, GCRLKML1, and GCRLKUP1 in 2011.

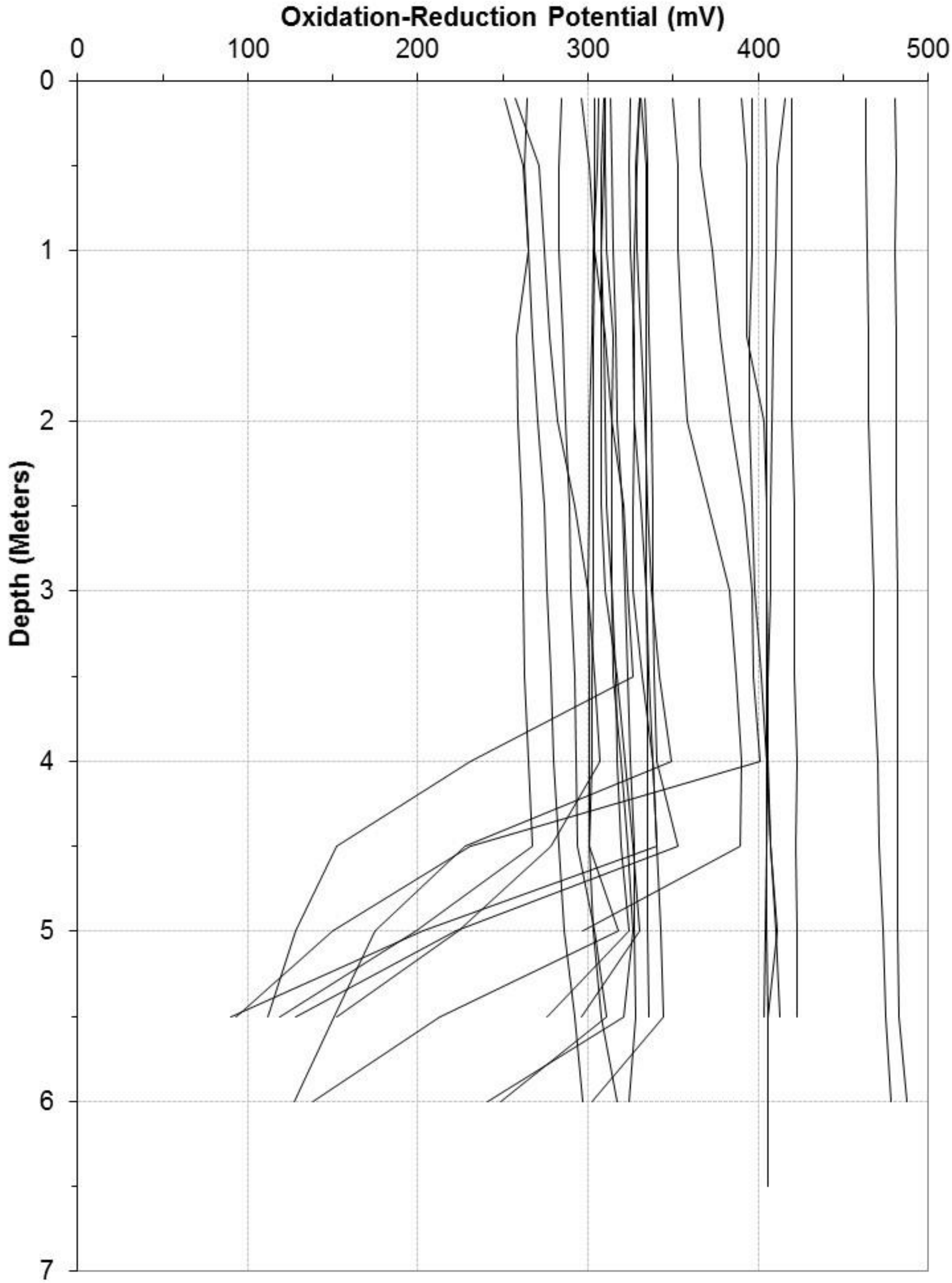


Plate 5-30. Oxidation-reduction potential depth profiles for Glenn Cunningham Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1) when hypoxic conditions were present, during the summer over the 5-year period of 2011 through 2015.

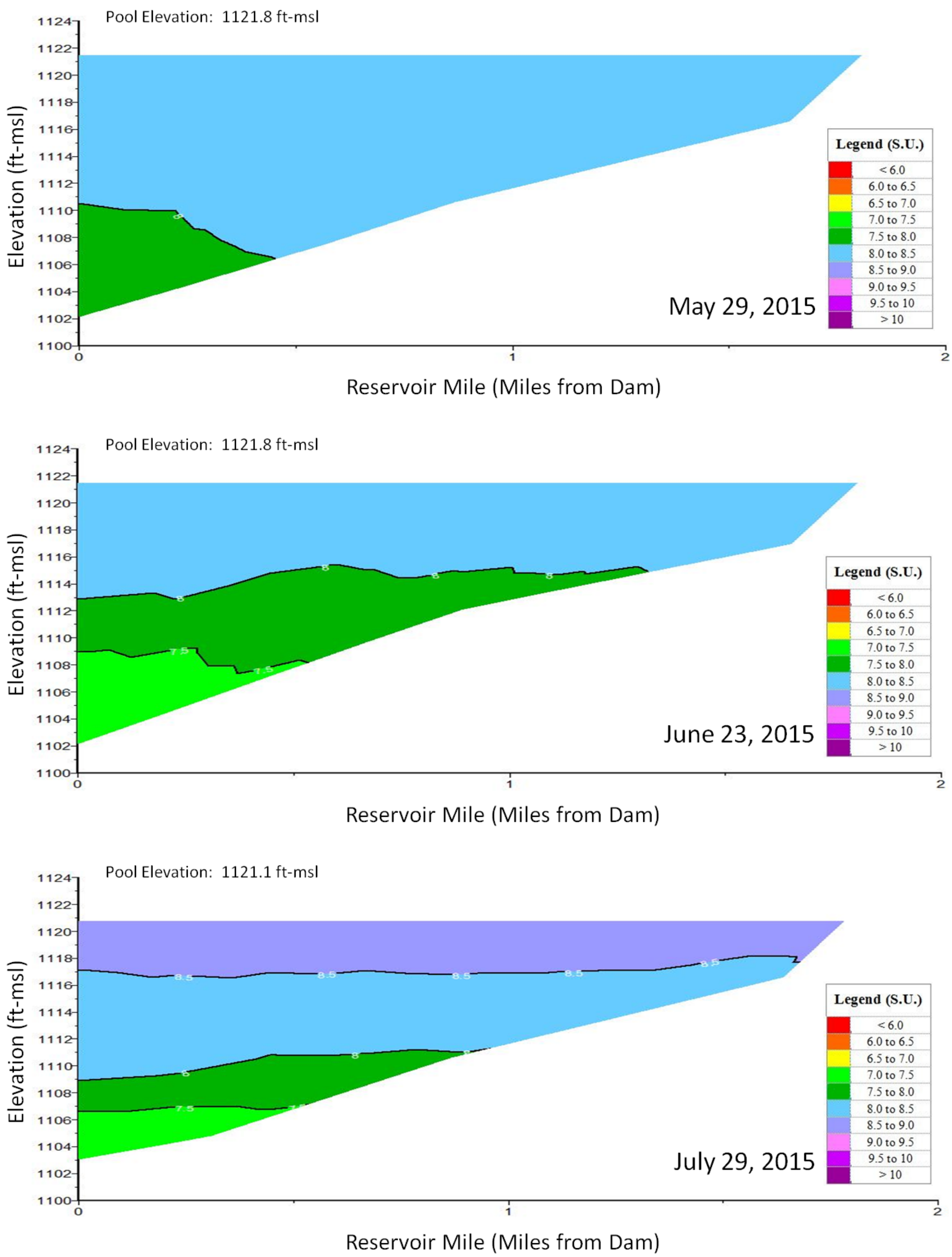


Plate 5-31. Longitudinal pH contour plots of Glenn Cunningham Reservoir based on depth-profile pH levels (S.U.) measured at sites GCRLKND1, GCRLKML1 and GCRLKUP1 in 2015.

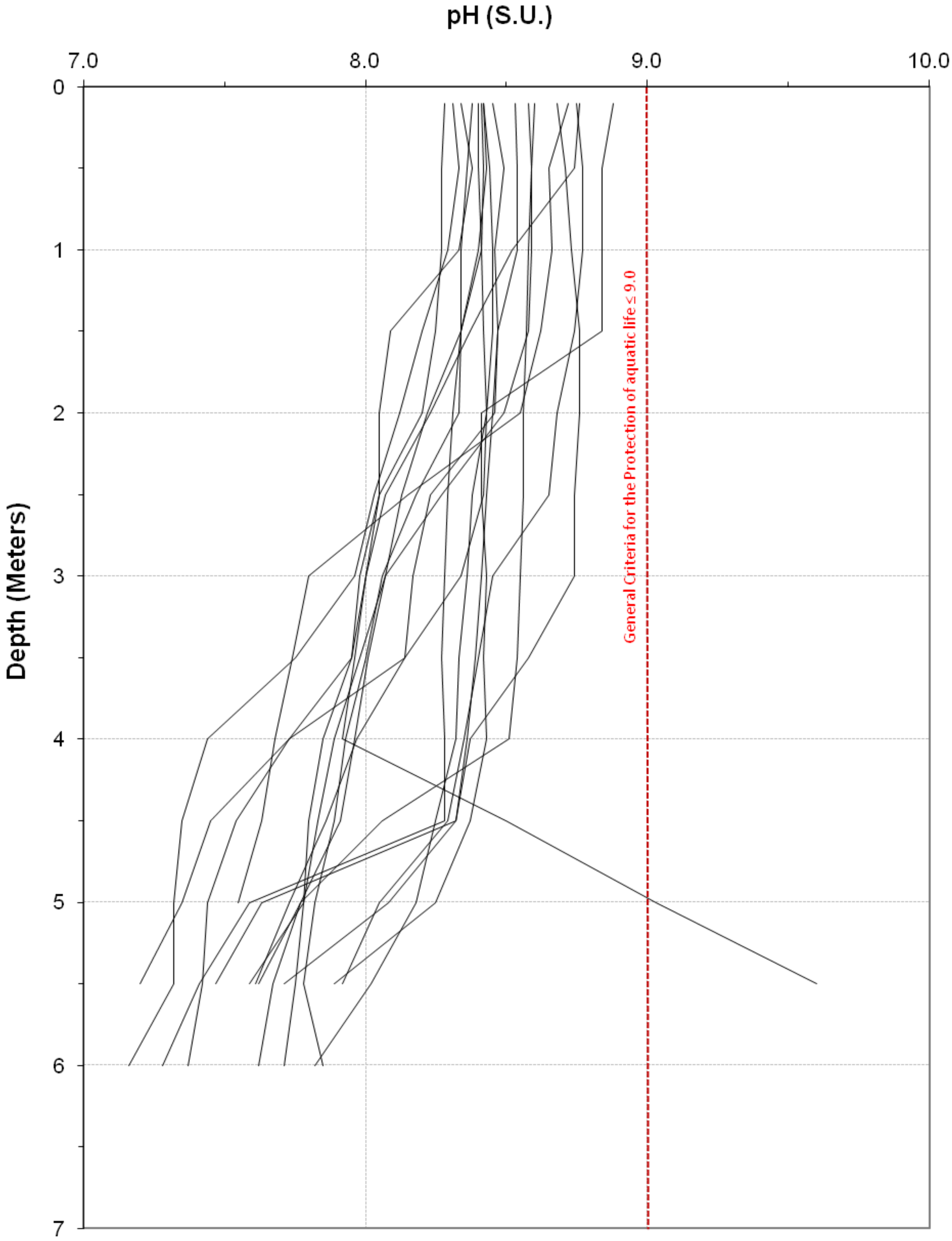


Plate 5-32. pH depth profiles for Glenn Cunningham Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1) when hypoxic conditions were present, during the summer over the 5-year period of 2011 through 2015.

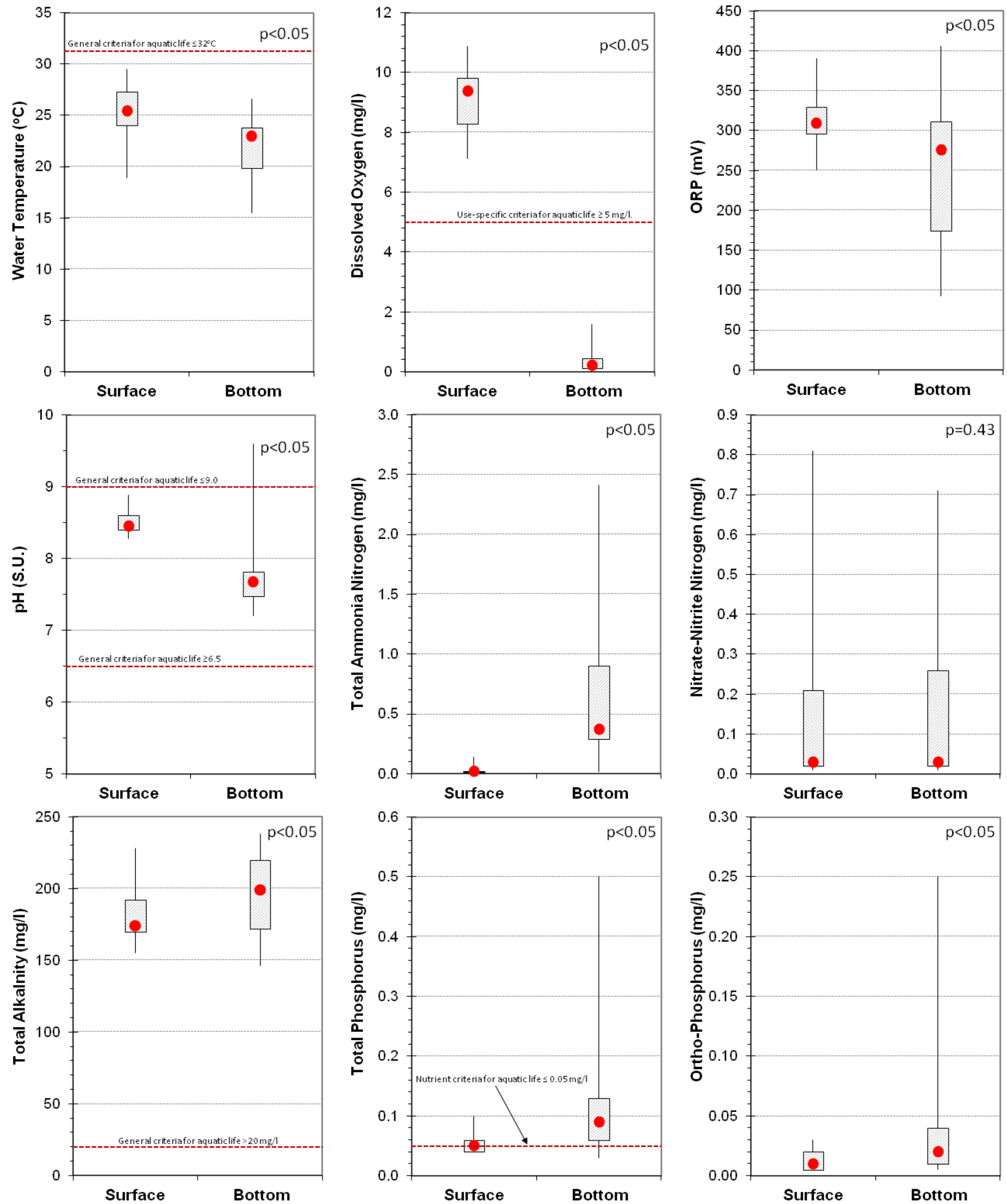


Plate 5-33. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, total ammonia nitrogen, nitrate-nitrite nitrogen, alkalinity, total phosphorus, and ortho-phosphorus measured in Glenn Cunningham Reservoir when summer hypoxic conditions were present during the 5-year period of 2011 through 2015 (n=17). P-values indicate significant differences between the near-surface and near-bottom samples via a paired two-tailed t-test ($\alpha = 0.05$). (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot. Water quality criteria marked with red line when applicable)

Plate 5-34. Total biovolume and density by taxonomic group for phytoplankton grab samples from Glenn Cunningham Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**
26-May-11	5,879	20	219,180	4,365	743	3	82,867	1,763	5,952	509	2,069	3	1,170,758	3,695	5,195	3
26-Jul-11	5,396	76	112,046	1,919	3,284	66	17,984	225	694,861	45,357	2,919	6	141,962	202	-----	-----
19-Sep-11	3,024	6	61,261	714	-----	-----	22,453	357	191,052	10,783	9,865	26	43,646	110	-----	-----
03-May-12	21,785	8	638,664	5,358	350,668	84	375,833	4,087	9,088	643	3,860	0	110,480	86	-----	-----
02-Jul-12	670	1	484,630	6,315	127,003	27	295,738	134	4,754,403	251,454	-----	-----	74,841	158	116,545	4
04-Sep-12	71,198	18	22,924	46	-----	-----	1,193,312	1,413	16,628,480	796,189	-----	-----	12,038	56	3,618,543	38
16-May-13	64,689	17	514,989	3,636	-----	-----	380,086	4,381	-----	-----	-----	-----	531,484	1,906	-----	-----
10-Jul-13	17,693	8	377,868	2,176	-----	-----	179,543	2,117	404,001	8,257	-----	-----	178,044	280	-----	-----
11-Sep-13	276,801	29	261,131	724	120,418	43	105,231	1,241	15,107,322	101,258	1,441	1	1,061,301	1,377	26,944	1
15-May-14	469,628	56	38,597	311	-----	-----	48,261	569	-----	-----	-----	-----	5,011,455	602	-----	-----
17-Jul-14	-----	-----	1,101,224	558	-----	-----	4,096,464	1,175	2,527,475	21,494	-----	-----	62,816	335	143,226	6
11-Sep-14	-----	-----	14,930	29	254,794	53	371,889	317	5,684,453	65,659	52,255	11	502,165	160	313,934	40
29-May-15	-----	-----	55,445	330	7,759,872	2,501	2,568,762	3,801	371,885	2,272	-----	-----	280,983	513	425,109	16
29-Jul-15	1,542	2	558,299	3,294	57,217	48	468,776	713	3,814,876	105,031	139,647	31	162,200	298	5,579,091	285
25-Sep-15	-----	-----	57,188	240	121,375	32	10,660,928	199	227,549	2,400	-----	-----	7,136	13	1,771,273	66

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

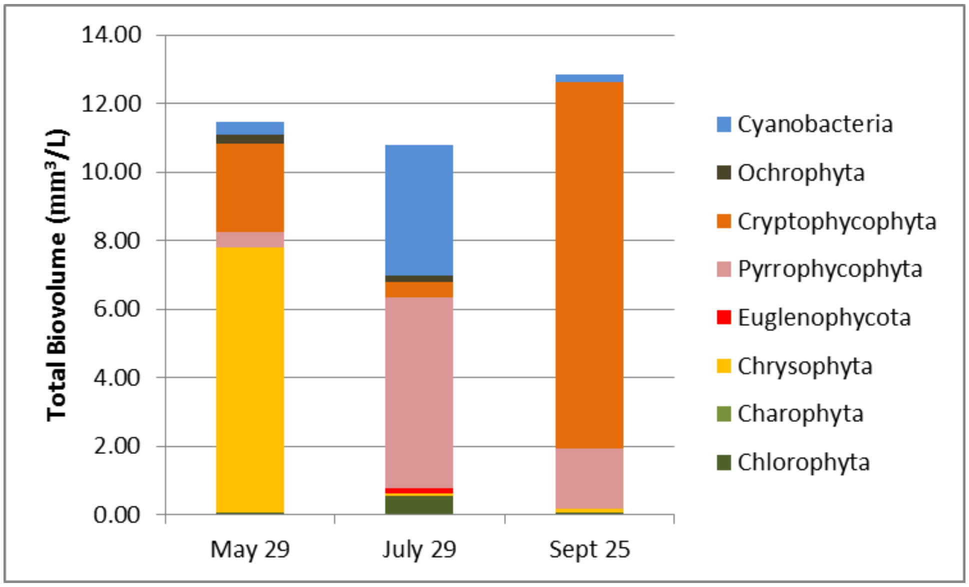


Plate 5-35. Relative abundance of phytoplankton in samples collected from Glenn Cunningham Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1).

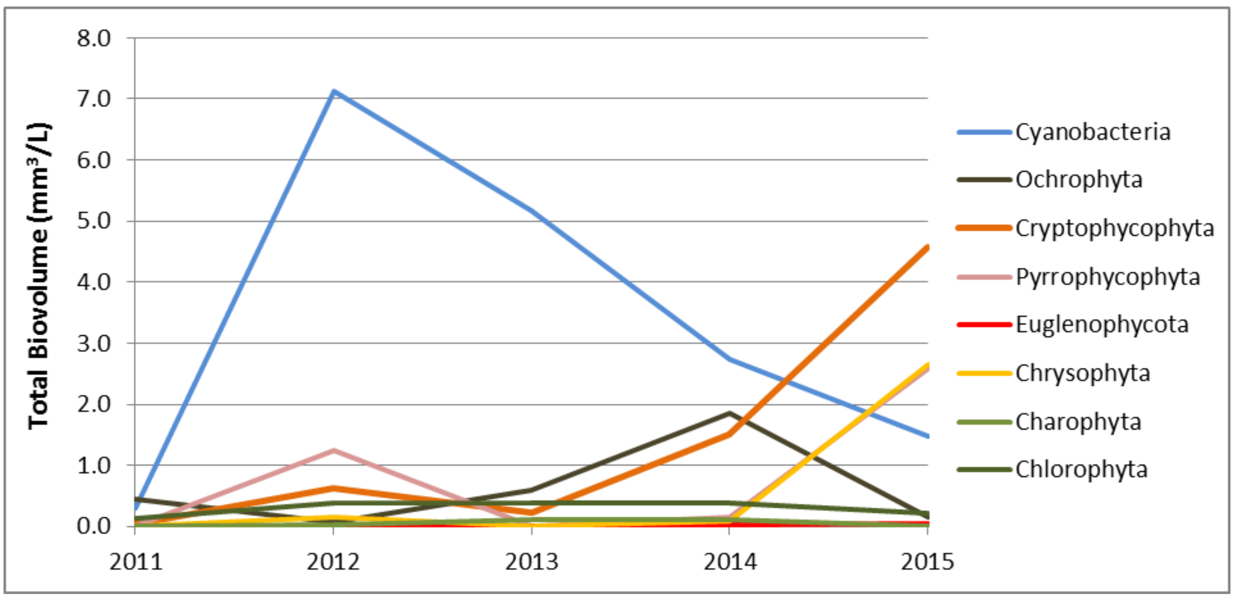


Plate 5-36. Relative abundance of phytoplankton in samples collected from Glenn Cunningham Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are a seasonal average of three summer samples (i.e. May, July, and September)

Plate 5-37. Total biomass and density by taxonomic grouping for zooplankton vertical-tow samples from Glenn Cunningham Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)
26-May-11	23	40.96	118	75.94	-----	-----	118	4.73
26-Jul-11	31	54.75	85	24.16	-----	-----	127	1.50
19-Sep-11	59	139.45	203	147.97	-----	-----	80	1.66
03-May-12	10	83.75	57	42.17	-----	-----	83	7.33
02-Jul-12	43	98.97	126	40.45	1	10.79	68	4.18
04-Sep-12	72	197.37	105	25.65	-----	-----	129	1.79
16-May-13	108	143.23	99	90.74	-----	-----	384	20.39
10-Jul-13	26	103.08	49	39.97	1	0.07	121	8.15
11-Sep-13	113	267.46	46	11.52	-----	-----	217	2.14
15-May-14	347	719.65	324	199.57	-----	-----	91	12.29
17-Jul-14	101	439.51	346	1,286.41	-----	-----	405	6.05
11-Sep-14	35	65.49	118	133.70	-----	-----	132	1.71
29-May-15	27	95.31	166	148.04	-----	-----	37	29.05
29-Jul-15	7	29.96	90	169.14	-----	-----	10	4.07
25-Sep-15	85	307.40	421	298.57	-----	-----	266	144.44

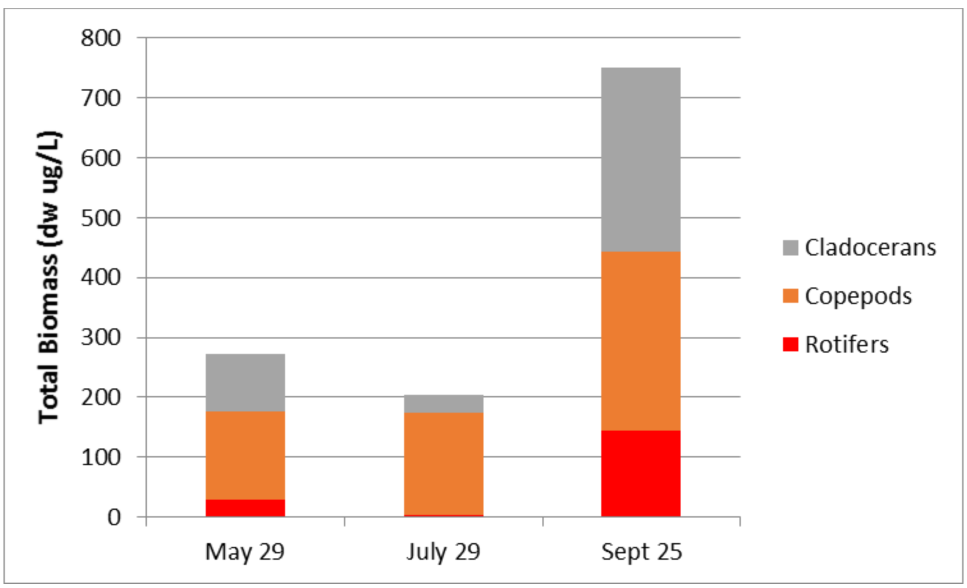


Plate 5-38. Relative abundance of zooplankton in samples collected from Glenn Cunningham Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1).

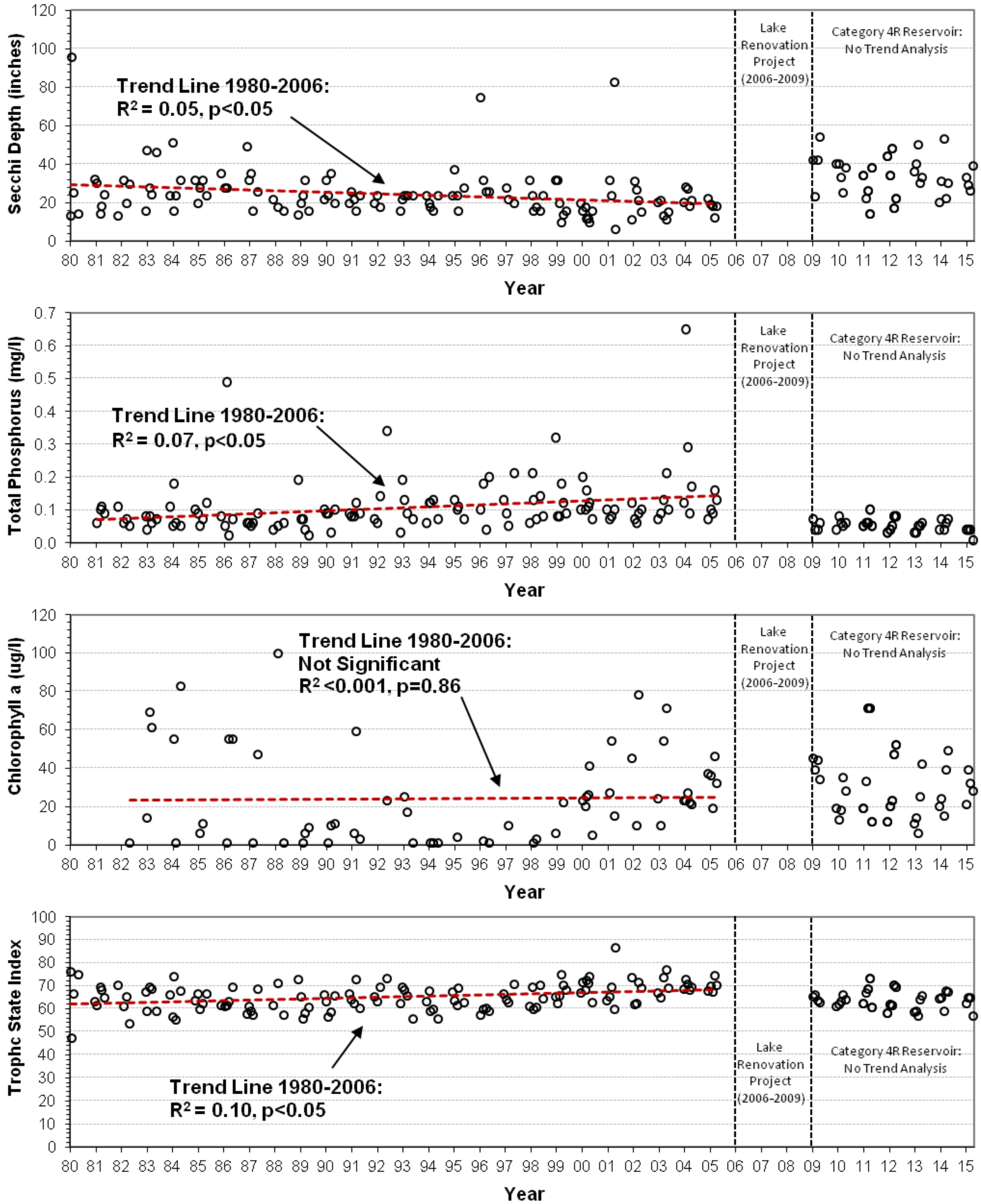


Plate 5-39. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Glenn Cunningham Reservoir at the near-dam, ambient site (i.e., site GCRLKND1) over the 35-year period of 1980 through 2015.

Plate 5-40. Summary of runoff water quality conditions monitored in the Knight Creek inflow to Glenn Cunningham Reservoir at monitoring site GCRNFNRT1 during the period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedances	Percent WQS Exceedance
Water Temperature (°C)	0.1	9	14.48	14.64	6.68	18.21	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	9	7.90	7.83	4.97	10.50	≥5[2]	1	11%
Dissolved Oxygen (% Sat.)	0.1	9	79.51	83.00	51.70	90.00	-----	-----	-----
Turbidity (NTUs)	1	9	650.61	391.50	142.00	3000.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	9	338.11	359.00	222.00	450.00	-----	-----	-----
Specific Conductance (umho/cm)	1	9	581.53	648.40	329.00	698.00	2,000[3]	0	0%
pH (S.U.)	0.1	8	7.61	7.50	7.12	8.70	≥6.5 & ≤9.0 [1]	0	0%
Suspended Solids, Total (mg/l)	10	11	1242.64	544.00	80.00	7860.00	-----	-----	-----
Ammonia, Total (mg/l)	10	11	-----	n.d.	n.d.	n.d.	11.91[4,5], 1.73[4,6]	0,2	0%,18%
Kjeldahl N, Total (mg/l)	0.02	11	6.83	3.72	0.71	29.60	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.8	11	6.32	6.13	1.14	9.50	100[3]	0	0%
Nitrogen, Total (mg/l)	0.8	11	13.15	11.98	3.52	33.50	-----	-----	-----
Phosphorus, Total (mg/l)	0.008	11	1.82	1.04	0.24	8.50	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.008	1	0.29	0.29	0.29	0.29	-----	-----	-----
Atrazine, Total (ug/l)[C]	0.1	11	-----	2.70	n.d.	7.70	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[C]	0.1	11	0.72	0.50	n.d.	3.50	390[5], 100[6]	0	0%
Acetochlor, Total (ug/l)[C]	0.1	11	3.51	2.30	n.d.	16.60	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-41. Summary of runoff water quality conditions monitored in the east Knight Creek inflow to Glenn Cunningham Reservoir at monitoring site GCRNFNRT2 over the 5-year period 2011-2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedances	Percent WQS Exceedance
Water Temperature (°C)	0.1	6	17.95	17.91	13.34	22.71	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	6	6.73	7.02	4.78	8.32	≥5[2]	1	17%
Dissolved Oxygen (% Sat.)	0.1	6	72.78	75.00	52.00	83.70	-----	-----	-----
Turbidity (NTUs)	1	6	575.70	386.00	39.50	1415.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	6	327.67	309.50	260.00	436.00	-----	-----	-----
Specific Conductance (umho/cm)	1	6	460.92	513.75	206.00	607.00	2,000[3]	0	0%
pH (S.U.)	0.1	6	7.75	7.64	7.45	8.40	≥6.5 & ≤9.0 [1]	0	0%
Suspended Solids, Total (mg/l)	10	7	315.86	231.00	74.00	789.00	-----	-----	-----
Ammonia, Total (mg/l)	10	7	-----	n.d.	n.d.	n.d.	9.00[4,5], 1.40[4,6]	0	0%
Kjeldahl N, Total (mg/l)	0.02	7	2.45	1.82	1.23	4.83	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.8	7	-----	1.93	n.d.	4.00	100[3]	0	0%
Nitrogen, Total (mg/l)	0.8	7	4.45	4.84	1.50	6.48	-----	-----	-----
Phosphorus, Total (mg/l)	0.008	7	0.64	0.55	0.24	1.30	-----	-----	-----
Atrazine, Total (ug/l)[C]	0.1	7	-----	1.80	n.d.	15.40	330[5], 12[6]	0,1	0%,14%
Metolachlor, Total (ug/l)[C]	0.1	7	-----	0.20	n.d.	0.40	390[5], 100[6]	0	0%
Acetochlor, Total (ug/l)[C]	0.1	7	-----	0.30	n.d.	4.40	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-42. Summary of runoff water quality conditions monitored in the unnamed inflow to Glenn Cunningham Reservoir at monitoring site GCRNFEST1 during the period 2011 through 2015**.**

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Water Temperature (°C)	0.1	8	15.31	15.42	8.03	18.76	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	8	8.63	8.41	7.94	10.55	≥5(2)	0	0%
Dissolved Oxygen (% Sat.)	0.1	8	88.36	88.50	80.70	92.60	-----	-----	-----
Turbidity (NTUs)	1	8	179.03	141.85	48.70	399.70	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	8	356.75	366.50	229.00	504.00	-----	-----	-----
Specific Conductance (umho/cm)	1	8	577.00	576.60	436.00	730.80	2,000(3)	0	0%
pH (S.U.)	0.1	7	7.58	7.50	7.10	8.30	≥6.5 & ≤9.0 (1)	0	0%
Suspended Solids, Total (mg/l)	10	9	440.89	325.00	96.00	1600.00	-----	-----	-----
Ammonia, Total (mg/l)	10	9	-----	n.d.	n.d.	n.d.	13.91(4,5), 1.92(4,6)	0	0%
Kjeldahl N, Total (mg/l)	0.02	9	2.19	1.91	0.62	5.45	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.8	9	-----	n.d.	n.d.	1.94	100(3)	0	0%
Nitrogen, Total (mg/l)	0.8	9	3.11	3.32	0.85	6.55	-----	-----	-----
Phosphorus, Total (mg/l)	0.008	9	0.79	0.59	0.24	2.46	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.008	1	0.02	0.02	0.02	0.02	-----	-----	-----
Atrazine, Total (ug/l)(C)	0.1	9	-----	0.40	n.d.	12.40	330(5), 12(6)	0,1	0%,11%
Metolachlor, Total (ug/l)(C)	0.1	9	-----	n.d.	n.d.	0.30	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l)(C)	0.1	9	-----	0.20	n.d.	1.50	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

5.4 STANDING BEAR RESERVOIR

5.4.1 BACKGROUND INFORMATION

5.4.1.1 Project Overview

The dam forming Standing Bear Reservoir is located on an unnamed tributary of Big Papillion Creek. The Standing Bear Reservoir watershed is 6.0 square miles. The watershed was largely agricultural when the dam was built in 1972; however since then, the watershed has undergone extensive urbanization with the growth of Omaha. The reservoir reached its initial fill in October 1977.

5.4.1.2 Standing Bear Dam Intake Structure

The reinforced concrete intake structure at Standing Bear dam has uncontrolled openings at two levels in addition to a low-level gate. Uncontrolled flood control weirs are at elevation 1109 ft-msl and smaller openings for the conservation pool are at elevation 1104 ft-msl. The inlet to the low-level gate is located 302 feet upstream of the intake structure at elevation 1080 ft-msl. The ungated openings and the low-level inlet are protected with metal trash racks.

5.4.1.3 Reservoir Storage Zones

Figure 5.5 depicts the current storage zones of Standing Bear Reservoir based on 2009 survey data and estimated sedimentation. It is estimated that 20 to 29 percent of the "as-built" Multipurpose Pool had been lost to sedimentation as of 2015. Annual volume loss is estimated to be 0.52 to 0.73 percent. According to the State of Nebraska's impairment assessment methodology, Standing Bear Reservoir's water quality dependent uses may be marginally impaired due to sedimentation.

5.4.1.4 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Standing Bear Reservoir since the reservoir was initially filled in the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 5.6 shows the location of the sites that have been monitored for water quality during the 5-year sampling period (i.e., 2011 through 2015). The near-dam location (STBLKND1) has been continuously monitored since 1980.

5.4.2 WATER QUALITY IN STANDING BEAR RESERVOIR

5.4.2.1 Existing Water Quality Conditions

5.4.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Standing Bear Reservoir at sites STBLKND1 STBLKML1, STBLKUPN1, and STBLKUPS1 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 5-43 through Plate 5-46. A review of these results indicated possible water quality concerns regarding nutrients and dissolved oxygen.

A significant number of dissolved oxygen measurements throughout Standing Bear Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 5-43-Plate 5-46). All of the low dissolved oxygen measurements occurred near the reservoir bottom and were associated with thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."

This provision seemingly applies to the low dissolved oxygen levels measured in Standing Bear Reservoir. Therefore, the measured dissolved oxygen levels below 5 mg/l are not considered exceedances of the water quality standards criteria.

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September). All three of these criteria were exceeded Standing Bear Reservoir (Plate 5-43). The near-surface chlorophyll *a* criterion was exceeded by 80 percent of the "lab analyzed" samples taken STBLKND1. The total phosphorus and total nitrogen criteria were exceeded by 32 and 52 percent of samples, respectively. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values (Plate 5-43) represent the growing season average for the 5-year period 2011 through 2015. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.06 mg/l), total nitrogen (1.06 mg/l), and chlorophyll *a* (37 ug/l) values at STBLKND1 indicate impairment of the aquatic life use.

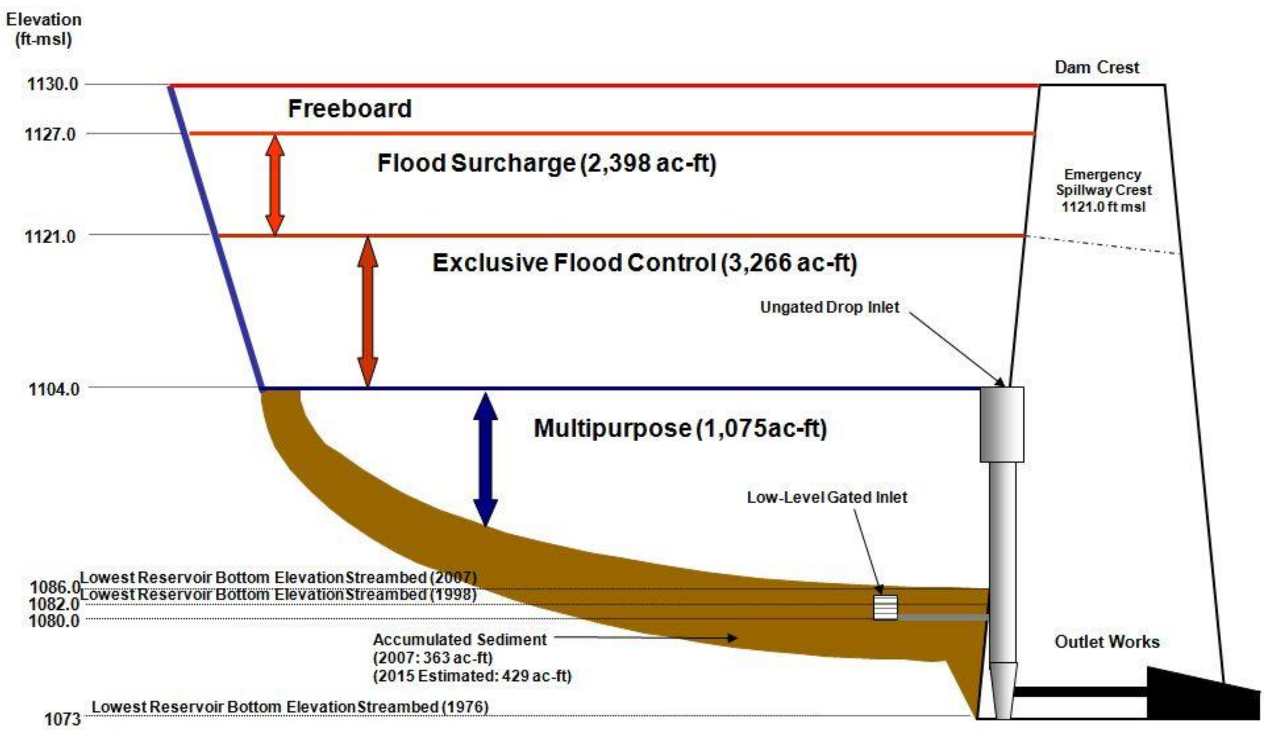


Figure 5.5. Current storage zones of Standing Bear Reservoir based on the Corps 2009 survey data and estimated sedimentation.

Figure 5.6. Location of sites where water quality monitoring was conducted by the District at Standing Bear Reservoir during the period 2011 through 2015.

5.4.2.1.2 Thermal Stratification

*5.4.2.1.2.1 **Longitudinal Temperature Contour Plots***

Late-spring and summer thermal stratification of Standing Bear Reservoir measured during 2015 is depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 5-47 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites STBLKND1, STBLKML1, and STBLKUPN1 in 2015. Thermal stratification persisted from late-spring through July. A maximum difference of about 12°C was measured between surface and bottom water temperatures.

*5.4.2.1.2.2 **Near-Dam Temperature Depth-Profile Plots***

The depth-profile temperature measurements collected over the 5-year period of 2011 through 2015 at the deep water area near the dam were compiled and plotted to describe the existing summer thermal stratification of Standing Bear Reservoir (Plate 5-48). The plotted depth-profile temperature measurements indicate that the reservoir exhibits regular thermal stratification during the summer. The deeper areas of the reservoir in the area of the old creek channel do not appear to mix with the upper column of water in the summer. Since Standing Bear Reservoir ices over in the winter, it appears to be a cold dimictic lake based on the measured thermal stratification in the summer (Wetzel, 2001).

5.4.2.1.3 Dissolved Oxygen Conditions

*5.4.2.1.3.1 **Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of Standing Bear Reservoir based on depth-profile measurements taken during 2015. Plate 5-49 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 near the reservoir bottom through the entire sampling period.

*5.4.2.1.3.2 **Near-Dam Dissolved Oxygen Depth-Profile Plots***

The depth-profile dissolved oxygen measurements collected during the summer over the 5-year sampling period at the deep water area near the dam were compiled and plotted to describe the existing summer dissolved oxygen conditions of Standing Bear Reservoir (Plate 5-50). Most of the plotted profiles indicate a significant vertical gradient in dissolved oxygen levels with most tending towards a clinograde distribution. Seventy-six percent of the profiles showed hypoxic conditions near the reservoir bottom. A few of the plotted profiles indicate dissolved oxygen concentrations above 5 mg/l from the reservoir surface to the bottom. These profiles were measured in early spring or fall and are believed to be a result of thermal stratification breaking down to the depth the profile was measured as “spring turnover” ended or “fall turnover” of the reservoir approached.

*5.4.2.1.3.3 **Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of Standing Bear 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 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 June 23, 2015 contour plot indicates a pool elevation of 1104.3 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1097.5 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1096.5 ft-msl (Plate 5-49). The current District Area-Capacity Tables (2007 Survey) give storage capacities of 1,179 ac-ft for elevation 1,104.3 ft-msl, 490 ac-ft for elevation 1097.5 ft-msl, and 418 ac-ft for elevation 1096.5 ft-msl. On June 23, 2015 it is estimated that 42 percent of the volume of Standing Bear Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 35 percent of the reservoir volume was hypoxic.

5.4.2.1.4 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in Standing Bear reservoir indicated hypoxic conditions May through September 2015. As a result, longitudinal contour plots where constructed for ORP and pH during these months. Depth profiles and near-surface/near-bottom sample comparisons were constructed for periods of hypoxic conditions during the sampling periods from 2011 through 2015.

*5.4.2.1.4.1 **Oxidation-Reduction Potential***

Plate 5-51 provides longitudinal ORP contour plots based on measurements taken in 2015. ORP values measured in June and July 2015 indicated somewhat reduced conditions present near the reservoir bottom. Plate 5-52 plots depth profiles for ORP measured during the summer over the 5-year sampling period in the deep water area of Standing Bear Reservoir near the dam when hypoxic conditions were present. A significant vertical gradient in ORP regularly occurred in the reservoir. ORP levels were frequently under 250 mV, even at the surface. Several levels were below 100 mV near the bottom during the summer.

5.4.2.1.4.2 ***pH***

Longitudinal contour plots for pH conditions measured in 2015 are provided in Plate 5-53. Lower pH levels near the bottom of the reservoir could be attributable to reservoir stratification and ongoing decomposition/respiration near the reservoir bottom. This would lead to an increase in CO_2 and decrease in pH. The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 6.5 for the protection of warmwater aquatic life. pH levels near the surface where above the upper pH criterion of 9.0 in August at the upper site (STBLKUPN1). Plate 5-54 plots depth profiles for pH measured during the summer over the 5-year sampling period in the deep water area of Standing Bear Reservoir when hypoxic conditions were present. A significant vertical gradient in pH regularly occurred in the reservoir during the summer. The upper pH criterion for the protection of warmwater aquatic life was exceeded several times during the sampling period near the reservoir surface.

5.4.2.1.4.3 ***Comparison of Near-Surface and Near-Bottom Water Quality Conditions***

Paired near-surface and near-bottom water quality samples collected from Standing Bear Reservoir during the summer when hypoxia was present 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 STBLKND1 during the 5-year period 2011 through 2015. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 19 (76%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 5-55). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for all the assessed parameters except nitrate-nitrite nitrogen. Parameters that were significantly lower in the near-bottom water of Standing Bear Reservoir when hypoxia was present included: water temperature, dissolved oxygen, ORP, and pH ($p < 0.05$). Parameters that were significantly higher in the near-bottom water included: total ammonia nitrogen, total alkalinity, total phosphorus, and ortho-phosphorus ($p<0.05$).

5.4.2.1.4.4 ***Reservoir Trophic Status***

Trophic State Index (TSI) values for Standing Bear Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., STBLKND1). Table 5.9 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Standing Bear Reservoir is in a eutrophic condition.

Table 5.9. Summary of Trophic State Index (TSI) values calculated for Standing Bear Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	65	67	41	77
TSI(TP)	25	56	55	34	68
TSI(Chl)	25	72	71	57	84
TSI(Avg)	25	64	65	51	75

* 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 for the individual parameters.

Note: See Section 4.1.3 for discussion of TSI calculation.

5.4.2.1.5 Reservoir Plankton Community

5.4.2.1.5.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at the Standing Bear Reservoir near-surface, near-dam sampling site during the spring and summer of the 5-year period 2011 through 2015 (Plate 5-56). The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 5-57. The highest phytoplankton total biovolume was observed in September and the lowest in May. Cyanobacteria dominated most of the 2015 growing season and made up 96% of the total biovolume in September. The high cyanobacteria biovolume observed in September corresponds with seasonal successional patterns commonly observed in eutrophic reservoirs. Early in the season cool water taxa such as Ochrophyta dominate. As the water warms, Cyanobacteria have a competitive advantage over most other algal taxa until the water begins to cool in late fall. Major and dominant phytoplankton genera sampled at Standing Bear Reservoir in 2015 are provided in Table 5.10.

Annual variation in phytoplankton community composition is displayed in Plate 5-58. During the 5-year period 2011 through 2015, Cyanobacteria, Ochrophyta, and Pyrrophycophyta were the dominant groups in Standing Bear Reservoir. Cyanobacteria density levels were greater than the World Health Organizations high level of health risk (>100,000 Cells/ml) in 2012 and 2015 (Plate 5-56). 2012 was a particularily warm and dry year. The long reservoir residence time, decreased mixing, and warm waters could have provided a longer Cyanobacterial growing season which lead to the highest cyanobacteria densities during the 5-year sampling period. 2015 was a wetter year but spring water temperatures were still higher compared to years of low density Cyanobacterial blooms. The maximum extracellular microcystin level measured during the 5-year period was 0.3 µg/L (Plate 5-43).

Table 5.10. Listing of Major and Dominant Phytoplankton Genera Sampled in Standing Bear Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1)

Division	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cyanobacteria	*Cylindrospermopsis*	*Anabaena, Aphanizomenon*
Pyrrophycophyta	-----	*Ceratium*

5.4.2.1.5.2 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at Standing Bear Reservoir near-dam sampling sites during the spring and summer of the 5-year period 2011 through 2015 (Plate 5-59). The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in Plate 5-60. Zooplankton total biomass was the greatest in May and September. Rotifers dominated Standing Bear Reservoir in May, Copepods in July, and Cladocerans and Copepods in September. Dominant and major zooplankton genera sampled in Standing Bear Reservoir during 2015 are provided in Table 5.11.

Table 5.11. Listing of major and dominant zooplankton genera sampled in Standing Bear Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1)

Taxonomic Group	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cladocerans	-----	*Daphnia*
Copepods	*Cyclopoida*	*Mesocyclops, Acanthocyclops*
Rotifers	-----	*Asplanchna*

5.4.2.1.6 Zebra Mussel Monitoring

Zebra mussel veliger sampling has been conducted once yearly since 2012 at Standing Bear Reservoir. During sampling period (2012-2015) no veligers have been identified.

5.4.2.2 Water Quality Trends (1980 through 2015)

Water quality trends from 1980 to 2015 were determined for Standing Bear 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., STBLKND1). Plate 5-61 displays a scatter-plot of the collected data for the four parameters and a linear regression line. The determined trend indicates that Standing Bear Reservoir exhibited increasing chlorophyll *a* levels ($p<0.05$, $R^2=0.07$). No trend in total phosphorus, water transparency, or TSI was significant. Over the 36-year period since 1980, Standing Bear Reservoir has remained in a eutrophic to hypereutrophic condition.

5.4.2.3 Existing Water Quality Conditions of Runoff Inflows to Standing Bear Reservoir

Existing water quality in the north and south inflows to Standing Bear Reservoir were monitored, respectively, at sites STBNFNRT1 and STBNFSTH1 under runoff conditions during the period of April through September. Both sites are approximately ¼ mile upstream of the reservoir (Figure 5.6). Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plate 5-62 and Plate 5-63, respectively, summarize water quality conditions that were monitored at sites STBNFNRT1 and STBNFSTH1 under runoff conditions during the 5-year period 2011 through 2015.

5.4.3 PLATES

Plate 5-43. Summary of water quality conditions monitored in Standing Bear Reservoir at site STBLKND1 from May to September during the 5-year period 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

	Monitoring Results						Water Quality Standards Attainment		
Parameter	**Detection Limit**	**No. of Obs.**	**Mean[A]**	**Median**	**Min.**	**Max.**	**State WQS Criteria[B]**	**No. of WQS Exceedances**	**Percent WQS Exceedance**
Pool Elevation (ft-msl)	0.1	24	1104.20	1104.30	1102.30	1105.80	-----	-----	-----
Water Temperature (°C)	0.1	301	21.96	21.97	9.94	32.23	32[1]	2	1%
Dissolved Oxygen (mg/l)	0.1	301	5.57	5.66	n.d.	16.43	≥5[2]	130	43%
Dissolved Oxygen, Near-Surface (mg/l)[C]	0.1	25	9.57	9.47	5.29	16.23	≥5[2]	0	0%
Dissolved Oxygen (% Sat.)	0.1	301	67.02	64.40	n.d.	232.90	-----	-----	-----
Secchi Depth (in.)	1	25	34.24	25.00	12.00	148.00	-----	-----	-----
Turbidity (NTUs)	1	290	16.39	12.50	n.d.	55.50	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	301	253.74	242.00	10.00	474.00	-----	-----	-----
Specific Conductance (umho/cm)	1	301	429.45	432.90	267.10	622.30	2,000[3]	0	0%
pH (S.U.)	0.1	301	8.13	8.11	6.81	9.60	≥6.5 & ≤9.0 [1]	0,24	0%,8%
Alkalinity, Total (mg/l)	1	50	129.16	121.50	79.00	535.00	20[1]	0	0%
Suspended Solids, Total (mg/l)	4	50	15.10	15.00	n.d.	60.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	50	-----	0.10	n.d.	3.64	4.34[4,5], 0.84[4,6]	1,7	2%,14%
Ammonia, Total, Near-Surface (mg/l)[C]	0.02	25	-----	0.02	0.01	0.26	0.70[4,5], 0.18[4,6]	0,1	0%,4%
Kjeldahl N, Total (mg/l)	0.08	50	1.55	1.25	0.52	4.63	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	50	-----	n.d.	n.d.	0.18	100[3]	0	0%
Nitrogen, Total (mg/l)	0.03	50	1.58	1.27	0.55	4.66	1[7]	34	68%
Nitrogen, Total, Near-Surface (mg) [C]	0.03	25	1.06	1.04	0.55	1.64	1[7]	13	52%
Phosphorus, Total (mg/l)	0.005	50	0.14	0.08	n.d.	0.69	0.05[7]	28	56%
Phosphorus, Total, Near-Surface (mg/l)[C]	0.005	25	0.06	0.04	0.01	0.15	0.05[7]	8	32%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	n.d.	n.d.	0.29	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	96.26	90.94	85.78	124.60	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	5	8.00	7.00	6.00	11.00	340[5], 16.7[8]	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	n.d.	5.38[5], 0.23[6]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	547.76[5], 71.31[6]	0	0%
Copper, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	8.00	12.29[5], 8.26[6]	0	0%
Iron, Dissolved (ug/l)	10	5	-----	20.00	n.d.	90.00	1000[6]	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	58.23[5], 2.27[6]	0	0%
Manganese, Dissolved (ug/l)	3	5	-----	6.00	n.d.	30.00	1000[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	432.09[5], 47.99[6]	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	2.93[5]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	108.12[5], 109.00[6]	0	0%
Antimony, Dissolved (ug/l)	0.03	5	0.70	0.70	0.60	0.80	88[5], 30[6]	0	0%
Aluminum, Dissolved (ug/l)	25	5	-----	30.00	n.d.	110.00	750[5], 87[6]	0,1	0%,20%
Selenium, Total (ug/l)	1	5	-----	n.d.	n.d.	5.00	20[3,5], 5[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Chlorophyll a (ug/l) – Lab Determined[C]	6	25	37	25	n.d.	89	10[7]	20	80%
Chlorophyll a (ug/l) – Field Probe	6	288	47	31	n.d.	663	10[7]	244	85%
Atrazine, Total (ug/l)[D]	0.1	25	-----	0.40	n.d.	0.80	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[D]	0.1	25	-----	n.d.	n.d.	0.40	390[5], 100[6]	0	0%
Microcystin, Extracellular (ug/l)	0.1	24	-----	n.d.	n.d.	0.30	20[9]	0	0%
Pesticide Scan (ug/l)[E]									
Atrazine, Tot	0.07	4	-----	0.14	n.d.	0.23	330[5], 12[6]	0	0%

n.d. = Not detected.

[A] Nondetect values set to detection limit 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] General criteria for aquatic life.
[2] Use-specific criteria for aquatic life.
[3] Agricultural criteria for surface waters.
[4] Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
[5] Acute criteria for aquatic life.
[6] Chronic criteria for aquatic life.
[7] Nutrient criteria for aquatic life.
[8] Human health criteria.
[9] Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

[C] Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

[D] Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-44. Summary of water quality conditions monitored in Standing Bear Reservoir at site STBLKML1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1104.08	1104.10	1102.30	1105.60	-----	-----	-----
Water Temperature (°C)	0.1	280	22.34	22.26	10.04	32.15	32(1)	2	1%
Dissolved Oxygen (% Sat.)	0.1	280	71.44	73.35	0.00	242.10	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	280	5.93	6.48	0.00	17.05	$\geq$5(2)	100	36%
Specific Conductance (umho/cm)	1	280	424.18	427.65	264.40	615.60	2,000(3)	0	0%
pH (S.U.)	0.1	280	8.18	8.20	6.99	9.61	$\geq$6.5 & $\leq$9.0 (1)	0,26	0%,9%
Turbidity (NTUs)	1	269	19.50	13.80	0.60	109.30	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	280	309.34	319.50	26.00	486.00	-----	-----	-----
Secchi Depth (in.)	1	25	30.72	27.00	10.00	72.00	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	6	268	77	34	3	6601	10(4)	231	86%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-45. Summary of water quality conditions monitored in Standing Bear Reservoir at site STBLKUPN1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1104.08	1104.10	1102.30	1105.60	-----	-----	-----
Water Temperature (°C)	0.1	56	24.27	25.88	16.12	32.51	32(1)	2	4%
Dissolved Oxygen (% Sat.)	0.1	56	113.34	103.30	40.30	237.70	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	56	9.08	8.70	3.14	16.87	$\geq$5(2)	2	4%
Specific Conductance (umho/cm)	1	56	376.26	357.70	259.40	557.50	2,000(3)	0	0%
pH (S.U.)	0.1	56	8.60	8.63	7.55	9.54	$\geq$6.5 & $\leq$9.0 (1)	0,8	0%,14%
Turbidity (NTUs)	1	55	34.37	23.10	5.20	197.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	56	332.55	322.00	249.00	480.00	-----	-----	-----
Secchi Depth (in.)	1	24	19.71	17.50	7.00	39.00	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	1	52	79	47	5	719	10(4)	45	87%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-46. Summary of water quality conditions monitored in Standing Bear Reservoir at site STBLKUPS1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances**	**Percent WQS Exceedance**
Pool Elevation (ft-msl)	0.1	20	1104.08	1104.10	1102.30	1105.60	-----	-----	-----
Water Temperature (°C)	0.1	40	24.02	25.53	15.94	32.13	32[(1)]	1	3%
Dissolved Oxygen (% Sat.)	0.1	40	109.67	104.55	61.20	211.80	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	40	8.84	8.75	5.10	15.07	≥5[(2)]	0	0%
Specific Conductance (umho/cm)	1	40	384.17	368.95	232.40	559.30	2,000[(3)]	0	0%
pH (S.U.)	0.1	40	8.53	8.67	7.43	9.27	≥6.5 & ≤9.0 [(1)]	0,4	0%,10%
Turbidity (NTUs)	1	39	32.92	24.20	3.00	86.60	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	40	333.23	322.50	268.00	471.00	-----	-----	-----
Secchi Depth (in.)	1	25	17.58	15.00	7.00	39.00	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	6	37	94	32	7	762	10[(4)]	35	95%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

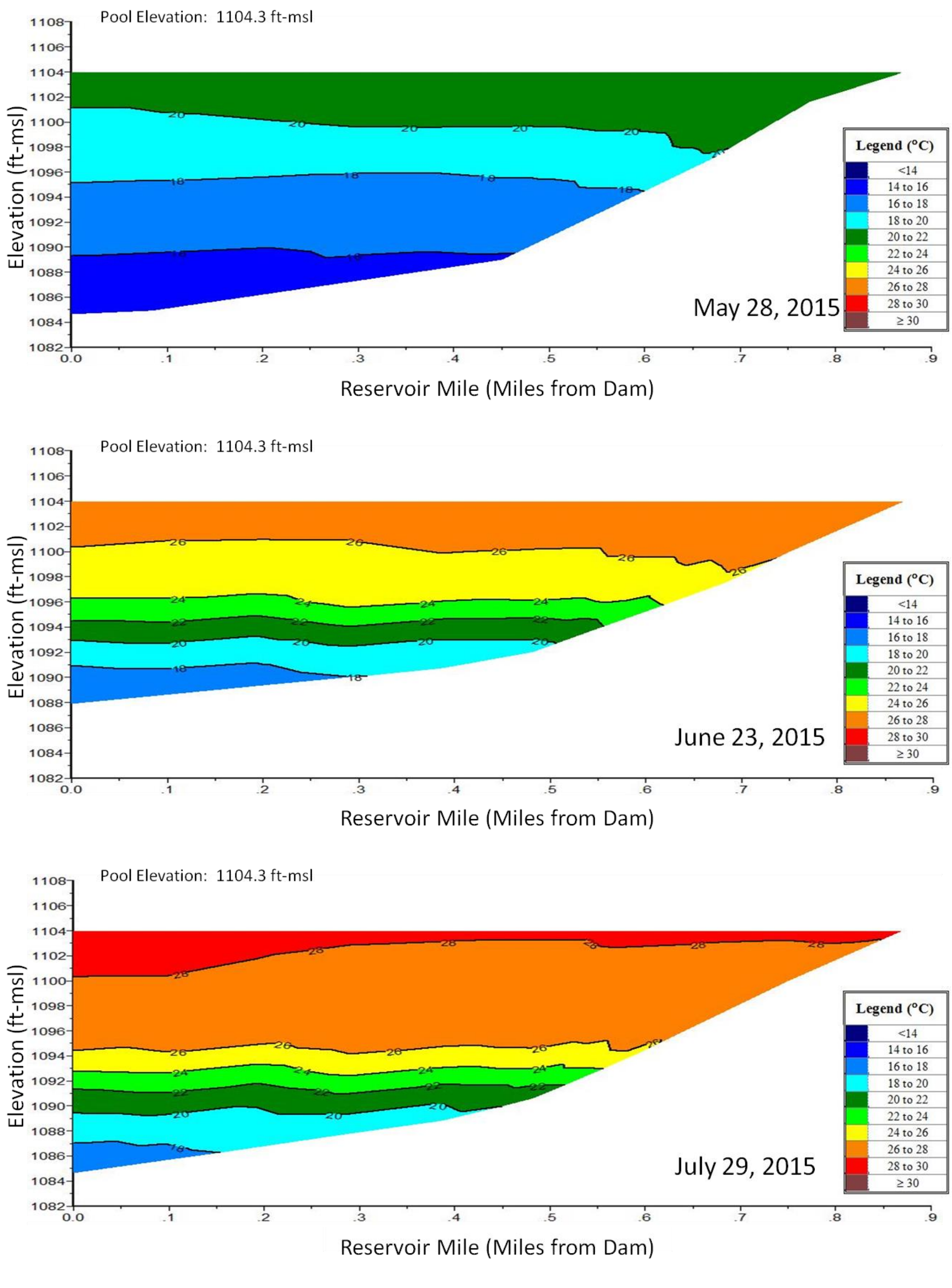
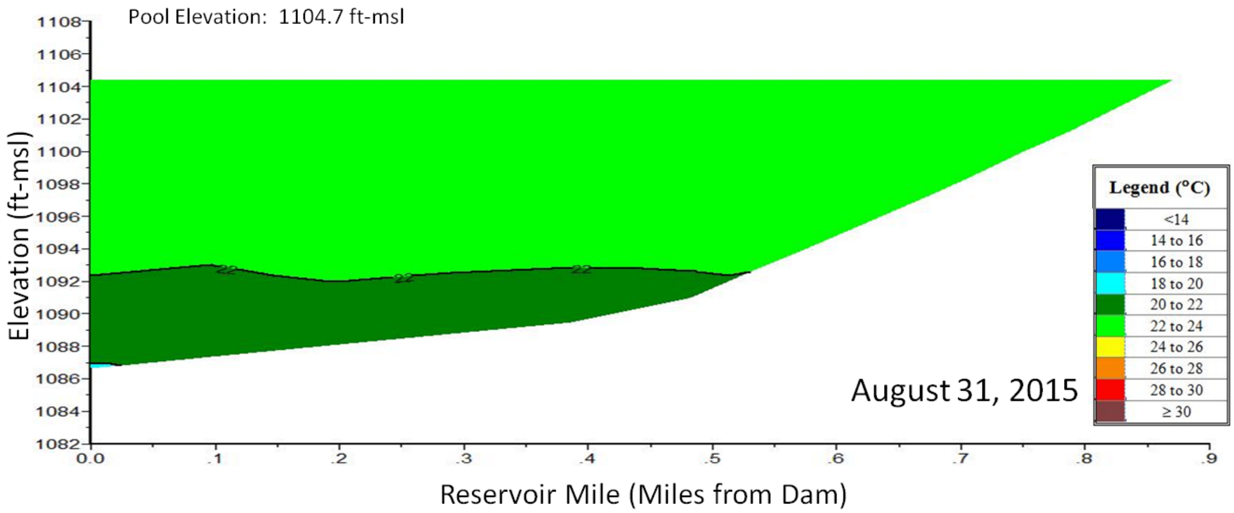


Plate 5-47. Longitudinal water temperature contour plots of Standing Bear Reservoir based on depth-profile water temperatures (°C) measured at sites STBLKND1, STBLKML1, and STBLKUPN1 in 2015.



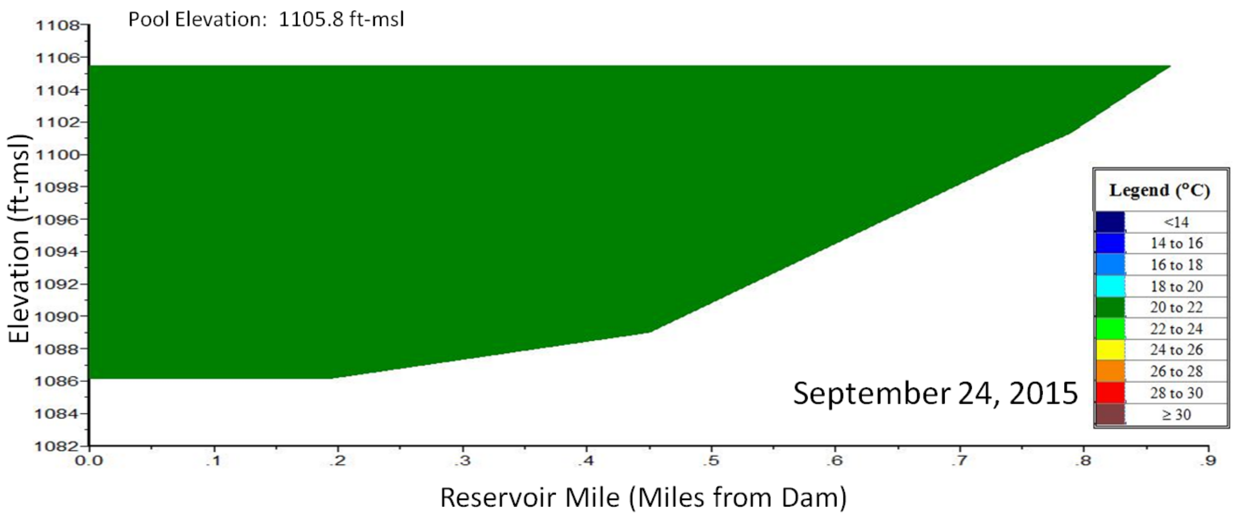


Plate 5-47. (Continued).

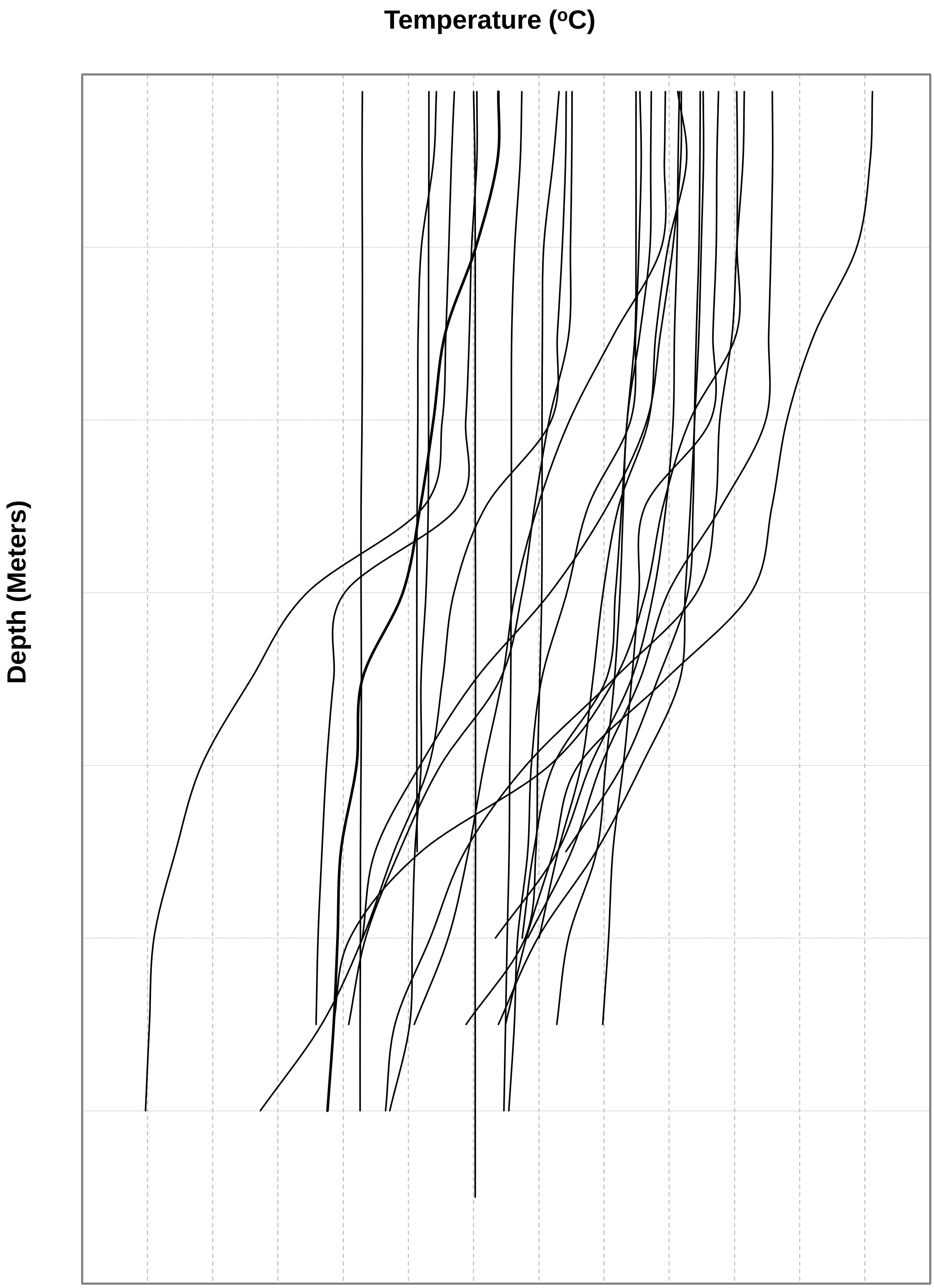


Plate 5-48. Temperature depth profiles for Standing Bear Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1) during the summer over the 5-year period of 2011 through 2015.

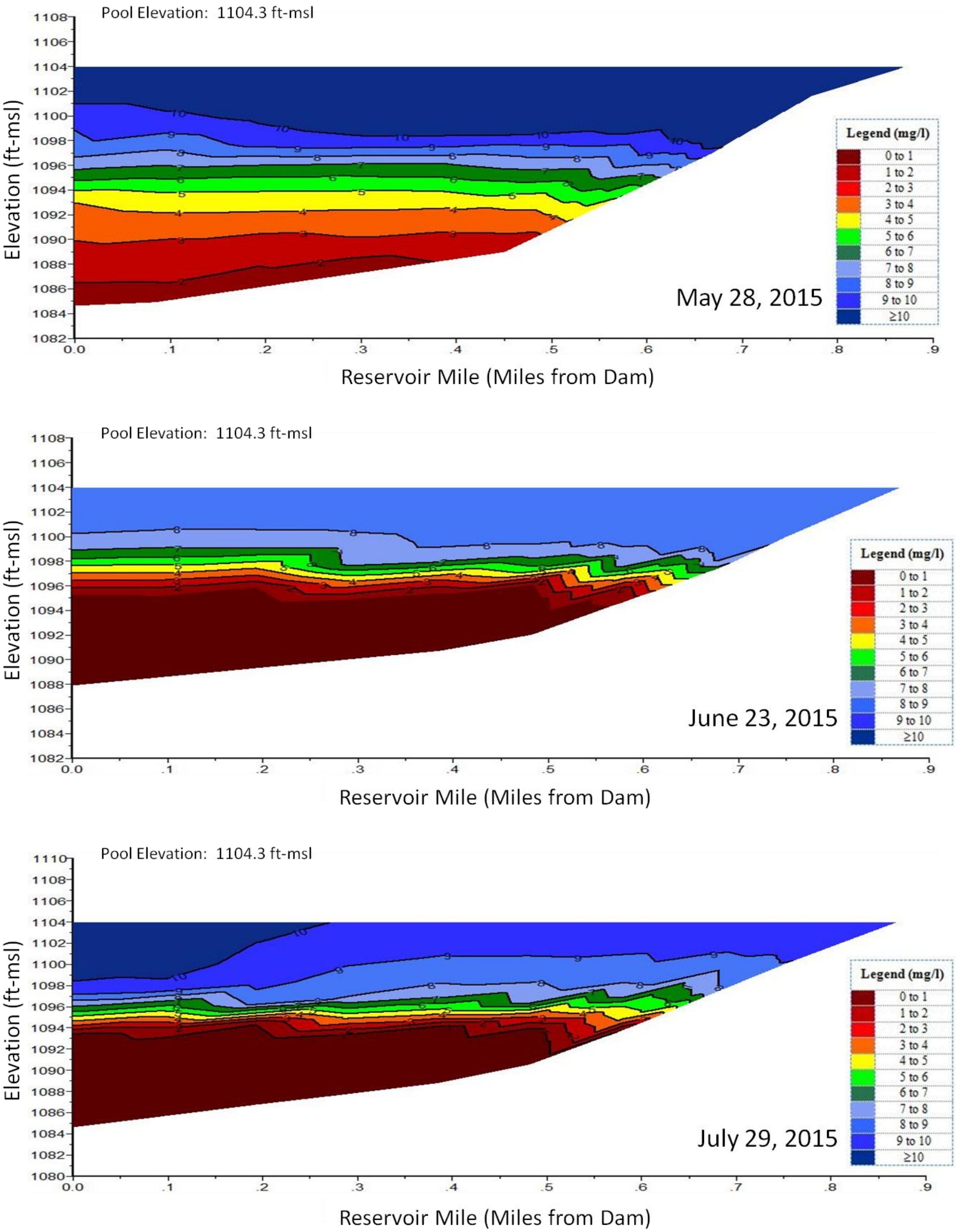
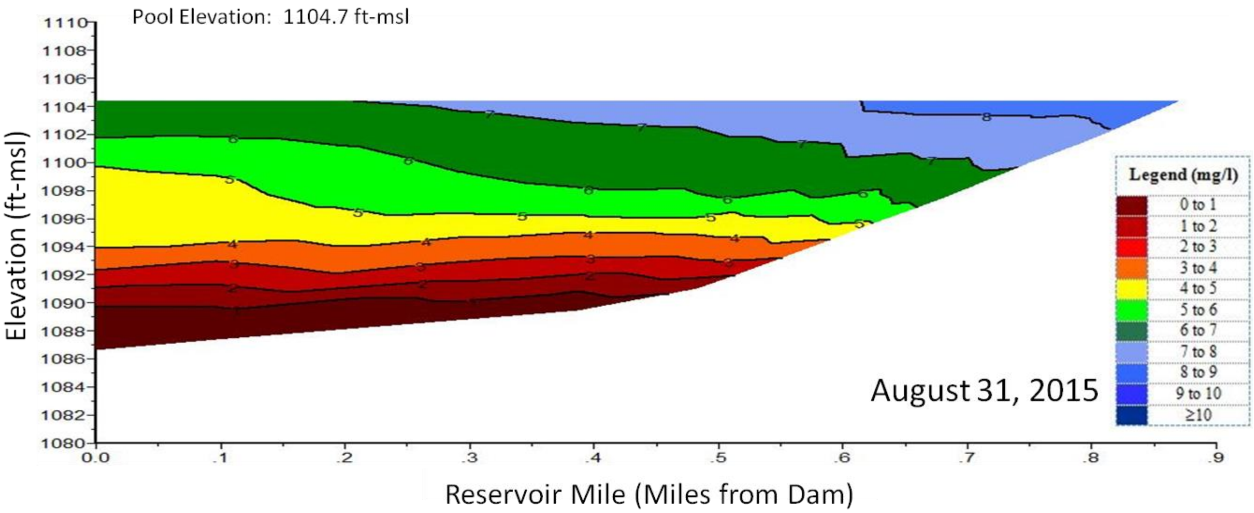


Plate 5-49. Longitudinal dissolved oxygen contour plots of Standing Bear Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites STBLKND1, STBLKML1, and STBLKUPN1 in 2015.



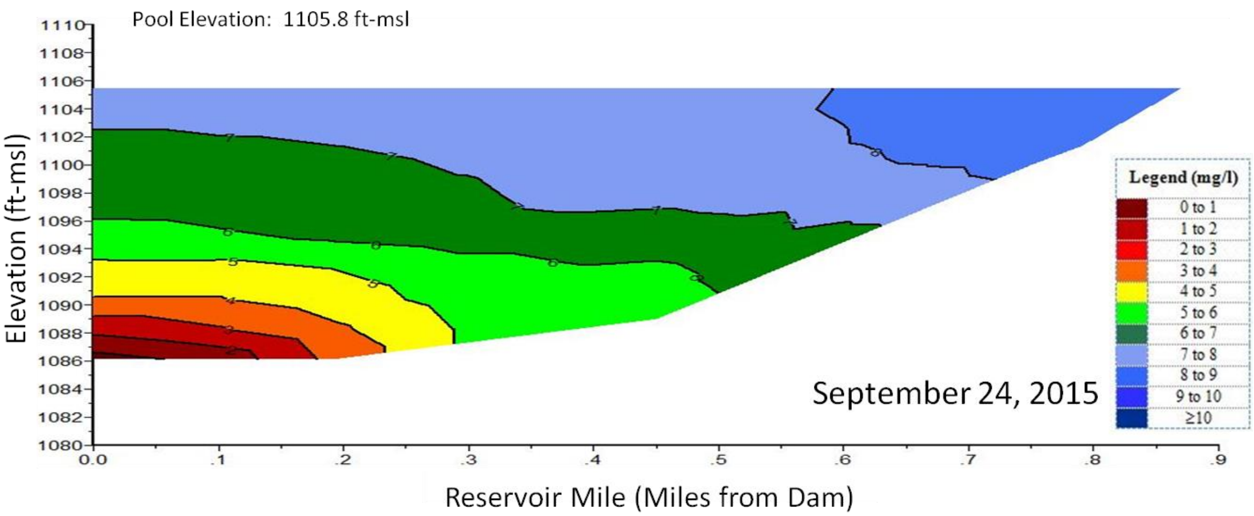


Plate 5-49. (Continued).

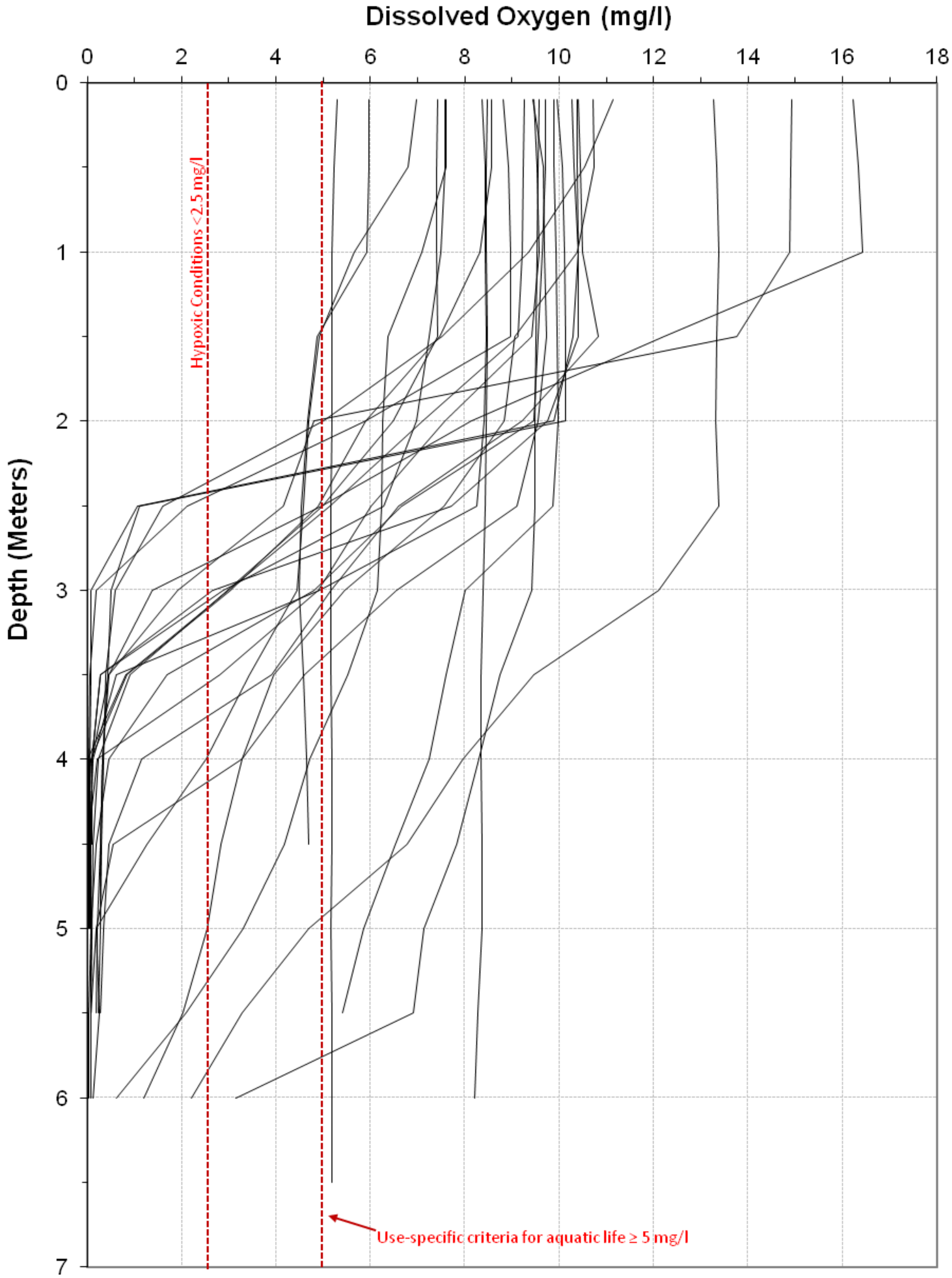
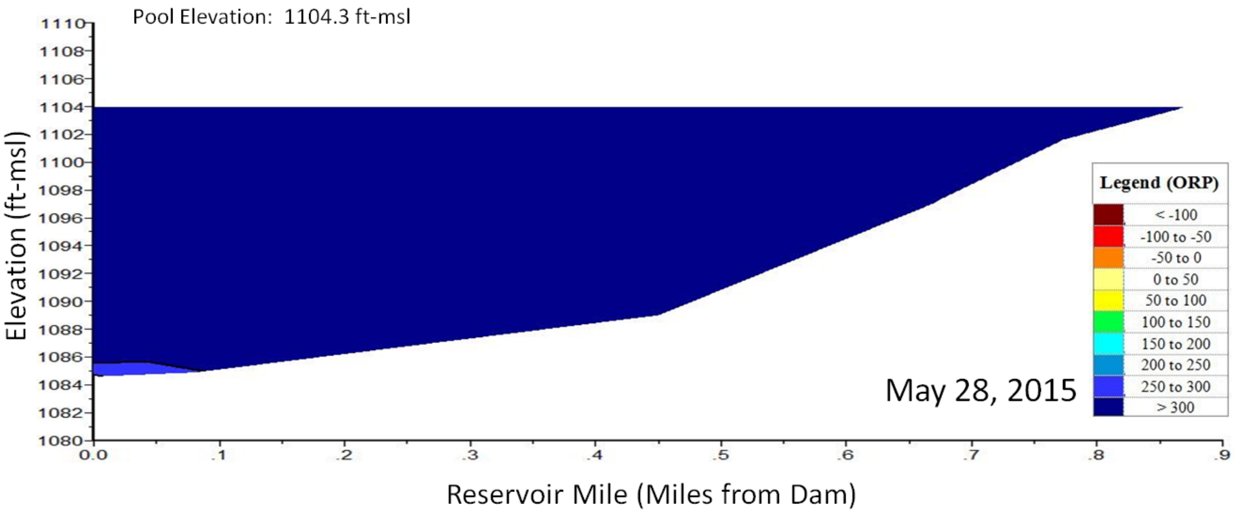
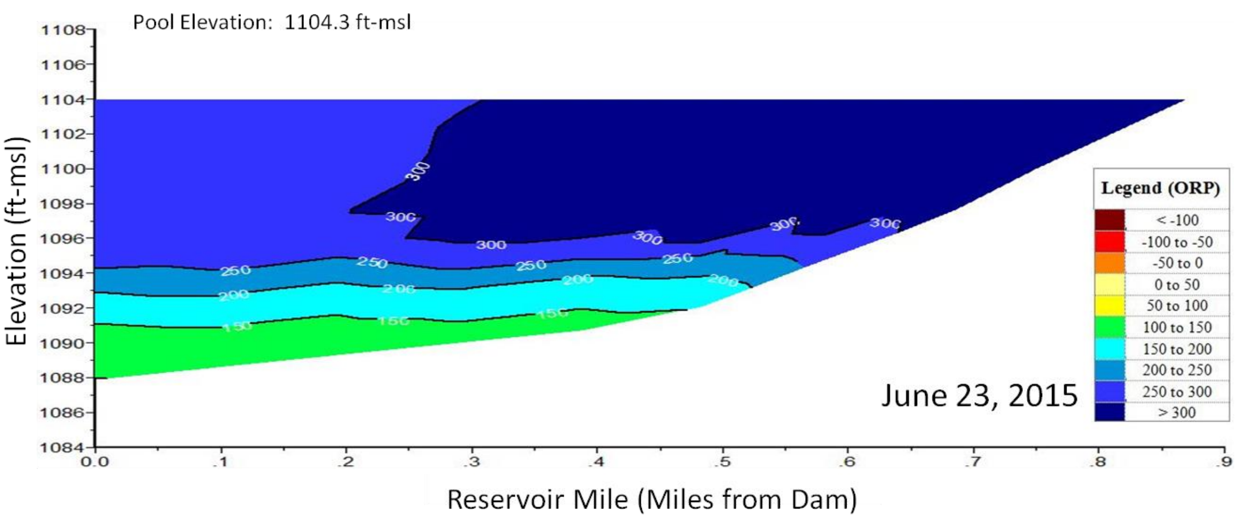


Plate 5-50. Dissolved oxygen depth profiles for Standing Bear Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1) during the summer over the 5-year period of 2011 through 2015.





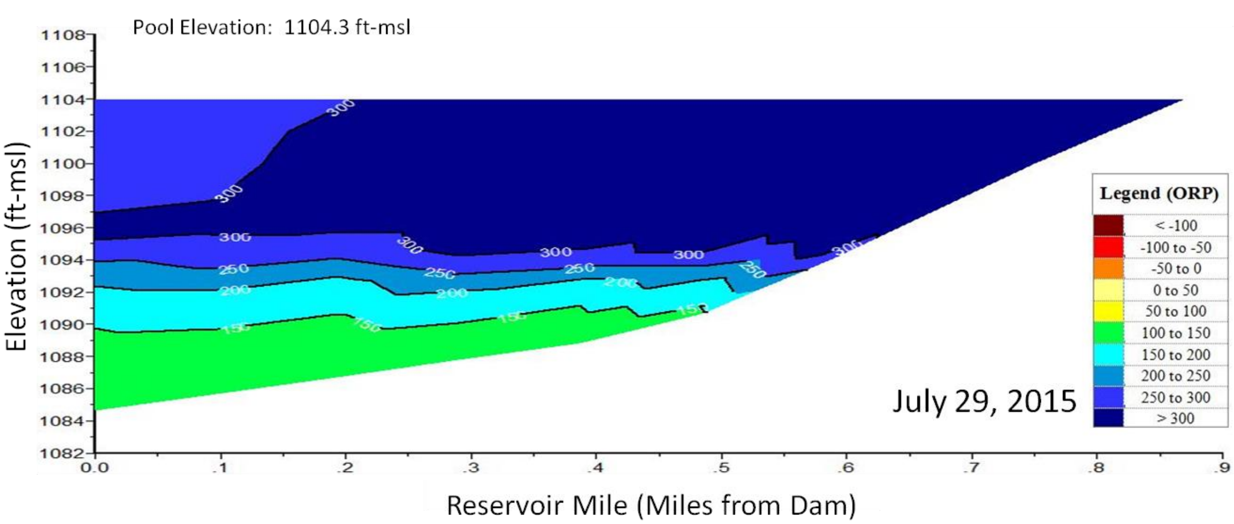


Plate 5-51. Longitudinal oxidation-reduction potential contour plots of Standing Bear Reservoir based on depth-profile ORP levels (mV) measured at sites STBLKND1, STBLKML1, and STBLKUPN1 in 2015.

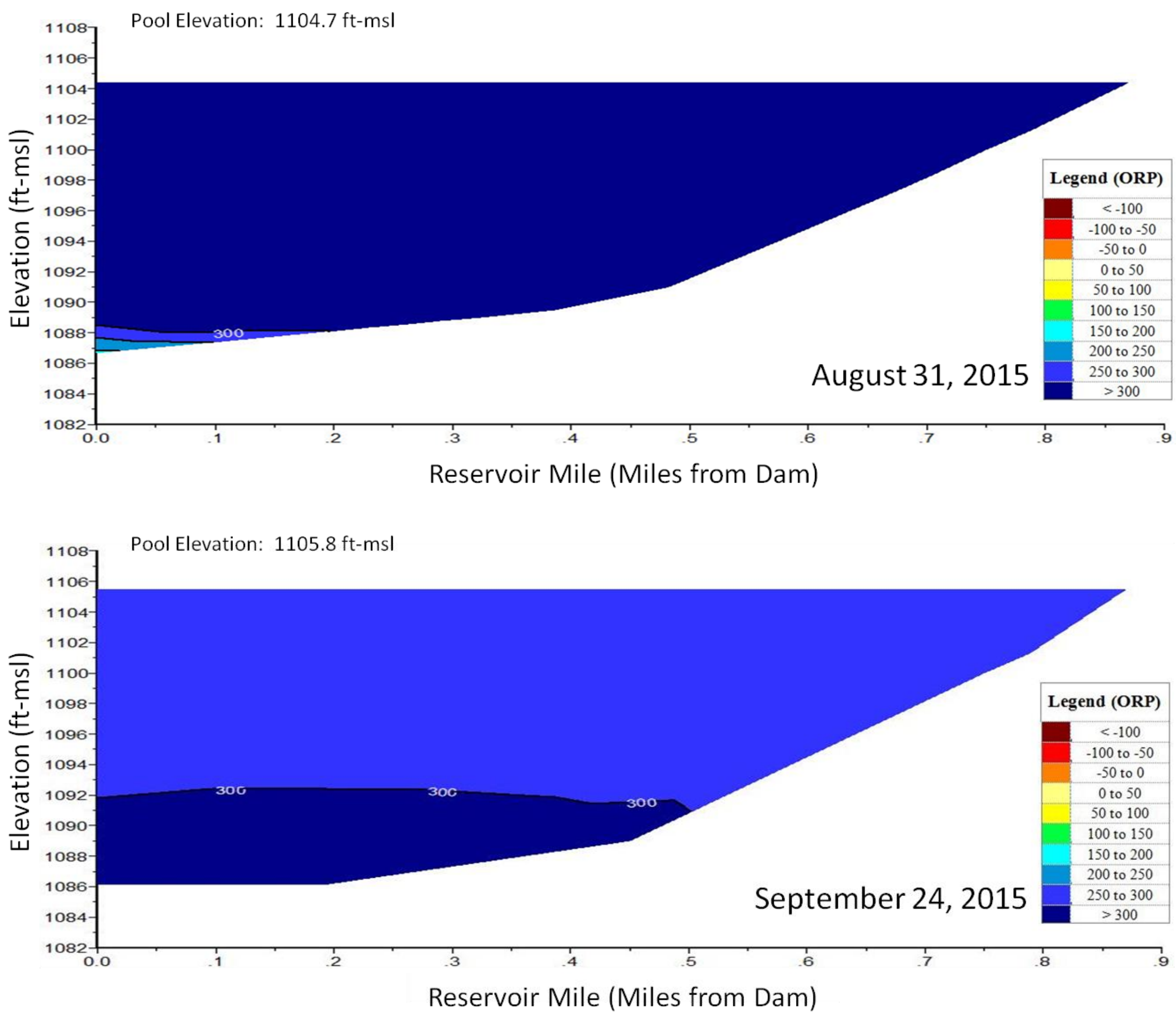


Plate 5-51. (Continued)

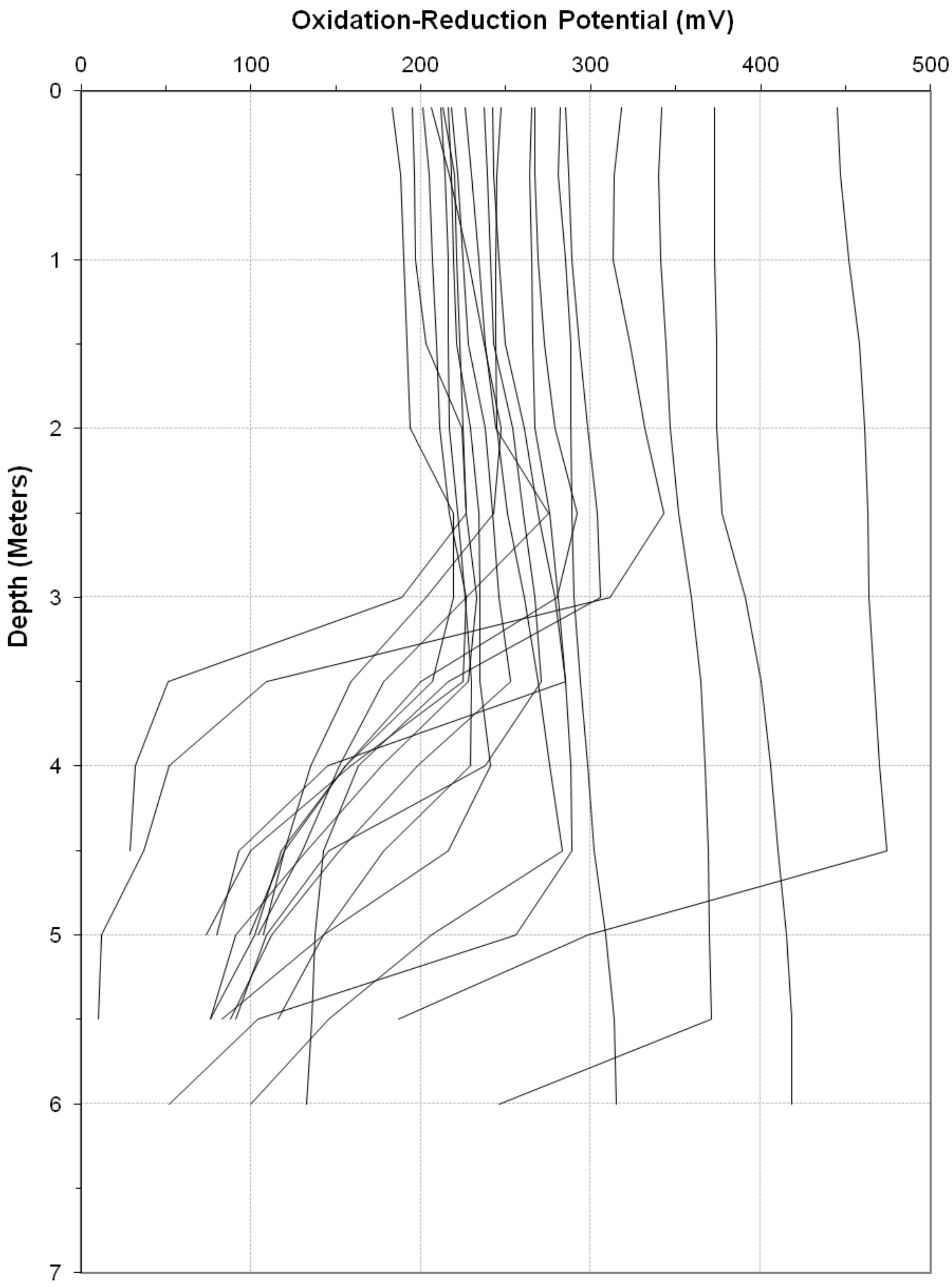
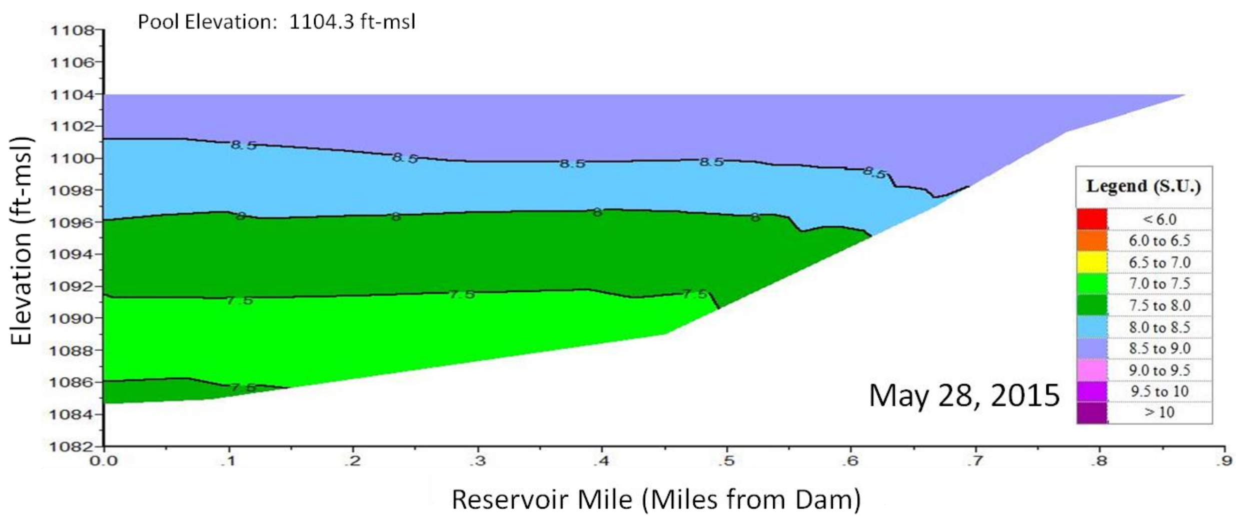
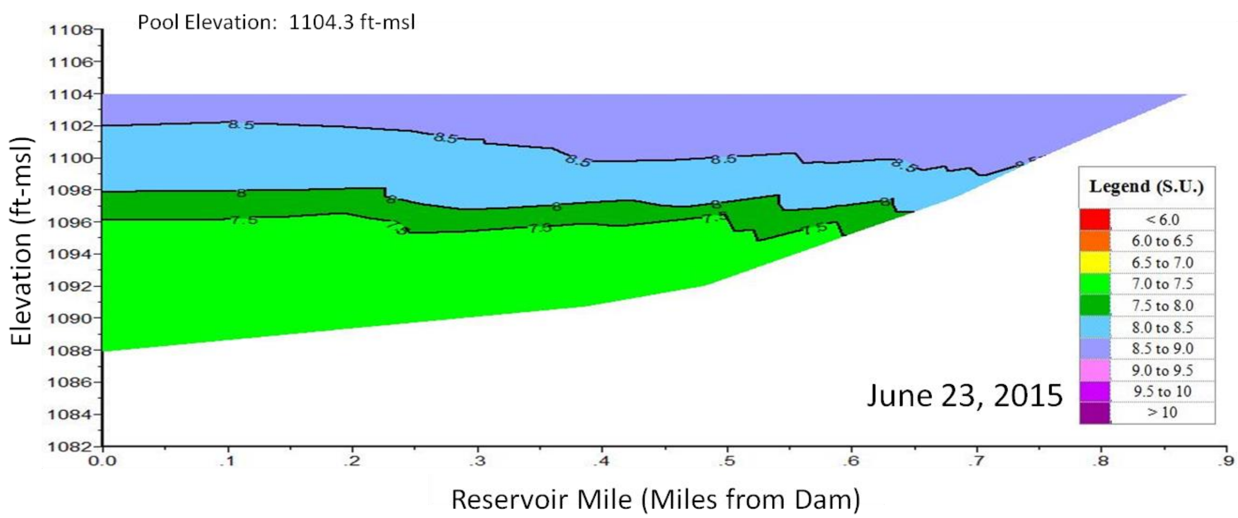


Plate 5-52. Oxidation-reduction potential depth profiles for Standing Bear Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1) when hypoxic conditions were present, during the summer over the 5-year period of 2011 through 2015.





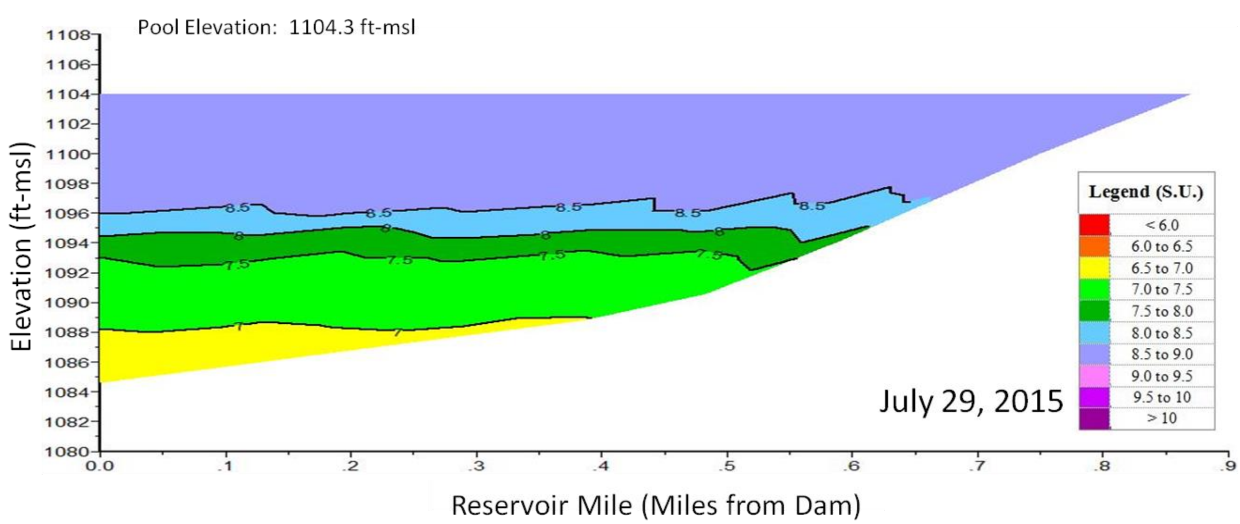
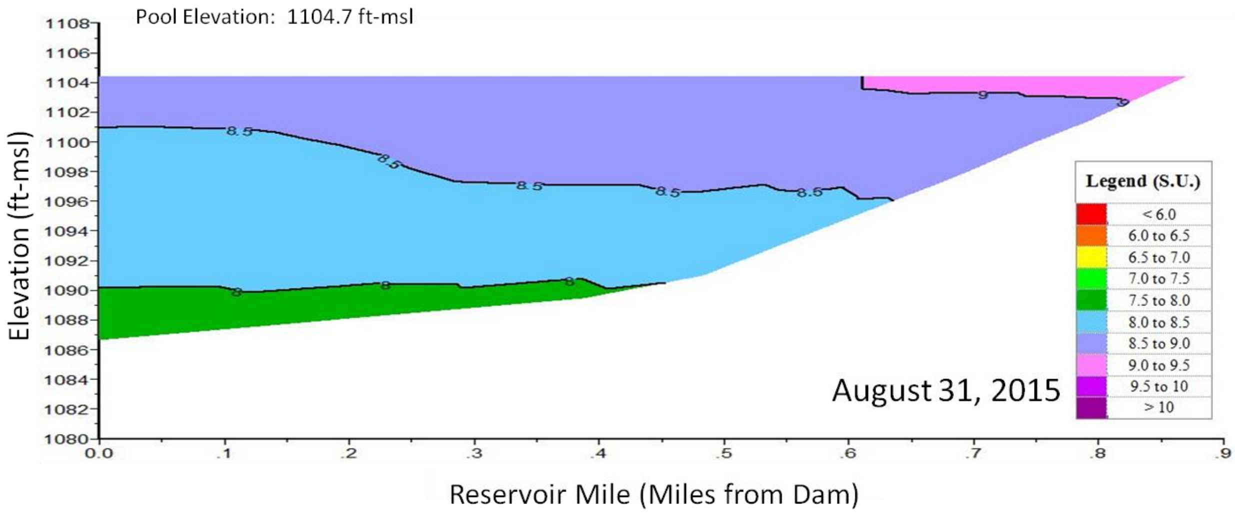


Plate 5-53. Longitudinal pH contour plots of Standing Bear Reservoir based on depth-profile pH levels (S.U.) measured at sites STBLKND1, STBLKML1, and STBLKUPN1 in 2015.



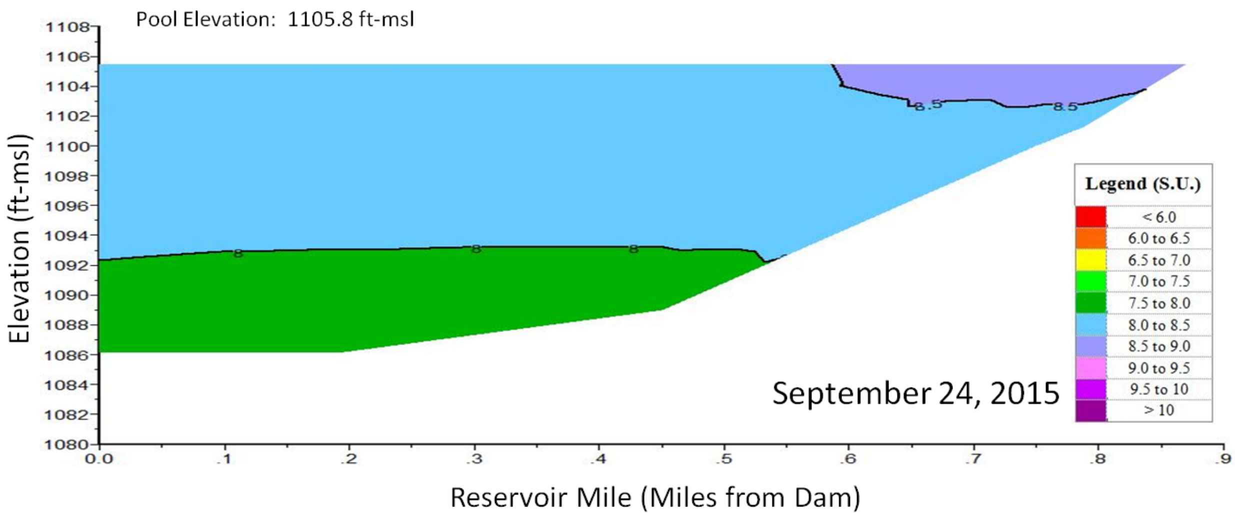


Plate 5-53. (Continued).

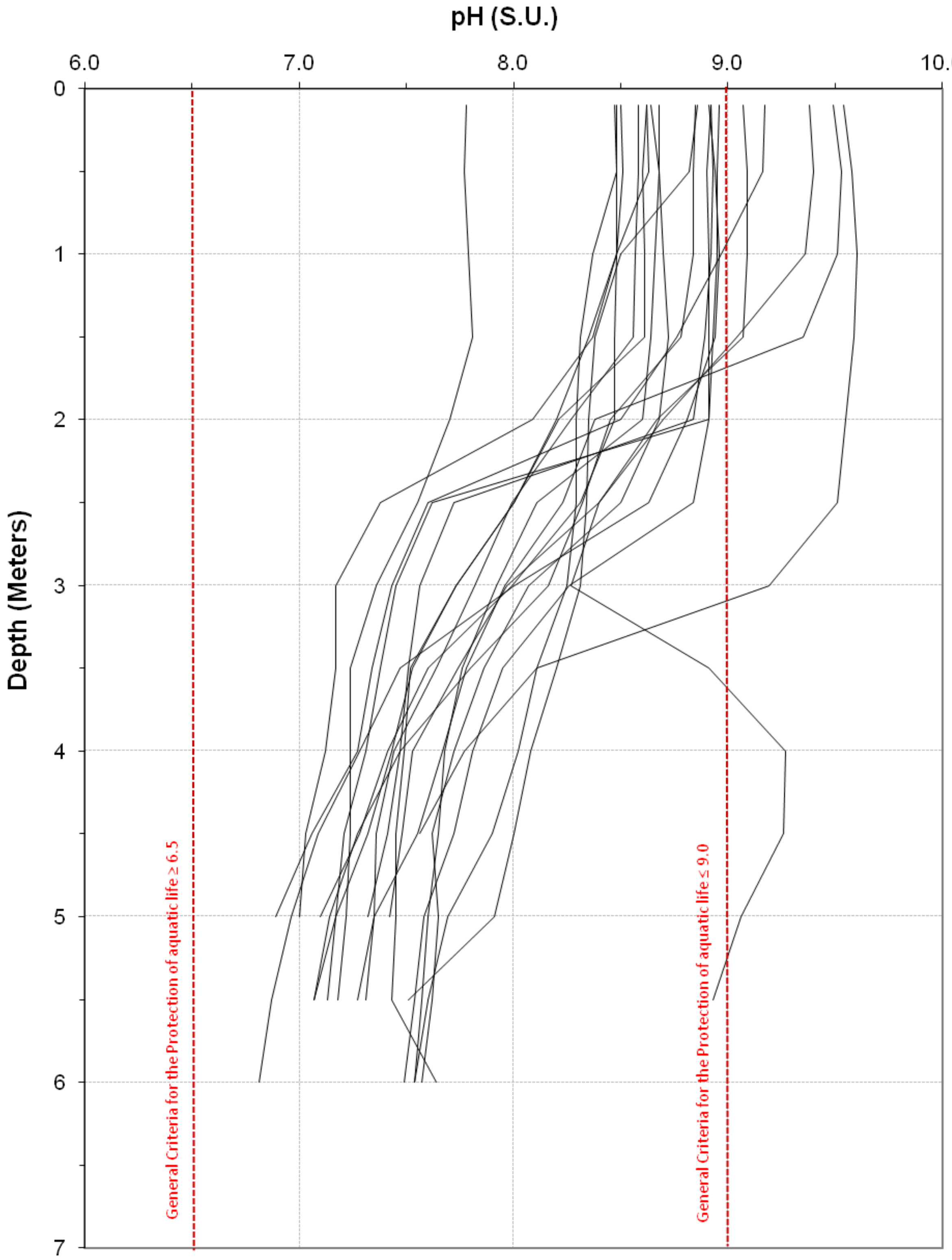


Plate 5-54. pH depth profiles for Standing Bear Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1) during the summer over the 5-year period of 2011 through 2015, when hypoxic conditions were present.

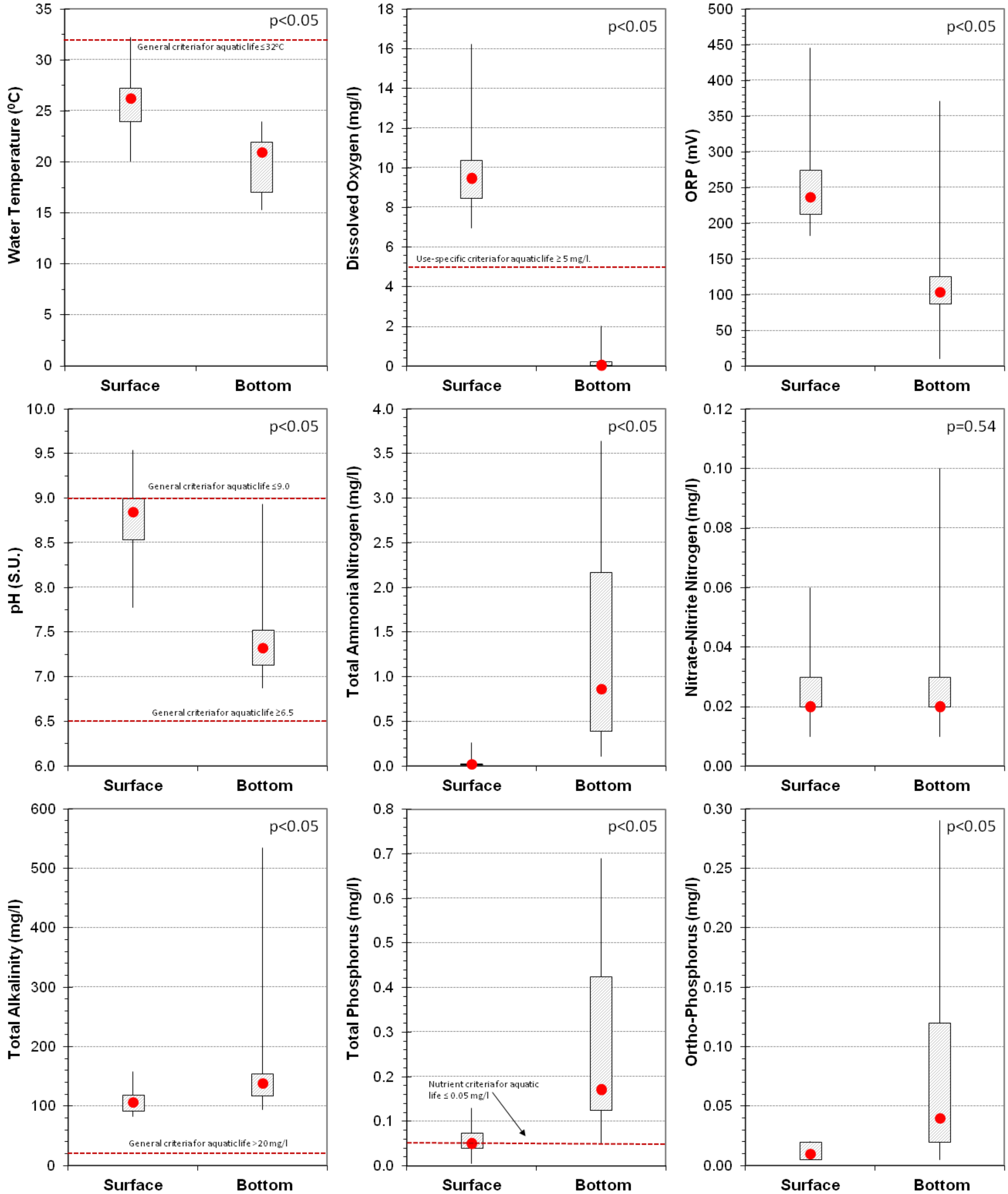


Plate 5-55. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, total ammonia nitrogen, nitrate-nitrite nitrogen, alkalinity, total phosphorus, and ortho-phosphorus measured in Standing Bear Reservoir when summer hypoxic conditions were present during the 5-year period of 2011 through 2015 (n=19). P-values indicate significant differences between the near-surface and near-bottom samples via a paired two-tailed t-test (α = 0.05). (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot. Water quality criteria marked with red line when applicable)

Plate 5-56. Total biovolume and density by taxonomic group for phytoplankton grab samples from Standing Bear Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	Biovolume (µm³/ml)	Density (Cells/ml)	Biovolume (µm³/ml)	Density (Cells/ml)	Biovolume (µm³/ml)	Density (Cells/ml)	Biovolume (µm³/ml)	Density (Cells/ml)	Biovolume (µm³/ml)	Density (Cells/ml)	Biovolume (µm³/ml)	Density (Cells/ml)	Biovolume (µm³/ml)	Density (Cells/ml)	Biovolume (µm³/ml)	Density (Cells/ml)
27-May-11	2,406	8	96,168	986	2,428	38	14,907	238	147,448	7,754	27	0	333,311	552	2,029	1
26-Jul-11	-----	-----	2,734	170	-----	-----	16,040	251	564,578	77,955	1,414	2	19,202	22	3,423	3
19-Sep-11	16	0	11,691	208	29	0	14,876	198	372,328	36,671	24,178	34	102,310	119	3,795	4
03-May-12	1,406	6	177,576	2,047	58,044	950	616,915	588	121,952	1,905	1,899	0	703,670	130	-----	-----
02-Jul-12	-----	-----	917,465	21,735	27,306	102	656,613	5,500	7,088,166	390,039	99,143	102	1,347,356	1,845	3,106,632	103
04-Sep-12	-----	-----	58,419	291	-----	-----	1,239,510	2,005	16,059,381	2,484,563	-----	-----	-----	-----	-----	-----
16-May-13	-----	-----	920,558	2,689	-----	-----	58,058	684	-----	-----	-----	-----	12,242,848	17,929	-----	-----
10-Jul-13	676	0	185,101	687	-----	-----	173,519	1,878	172,579	1,118	7,549	8	504,733	1,085	866,193	31
11-Sep-13	-----	-----	221,712	489	48,167	17	242,394	2,858	2,230,524	12,264	381	0	2,101,797	3,131	10,855,260	479
15-May-14	-----	-----	228,359	494	47,813	18	90,131	1,063	98,785	870	-----	-----	8,209,170	584	36,204	1
15-Jul-14	1,424	0	831,745	1,037	-----	-----	456,137	807	1,044,382	6,785	-----	-----	420,618	159	11,605,010	463
12-Sep-14	-----	-----	248,068	366	77,420	6	191,428	159	1,493,807	22,974	588,650	85	57,244	227	-----	-----
28-May-15	-----	-----	336,421	1,398	-----	-----	344,596	2,012	1,520,239	7,311	22,679	13	193,172	226	-----	-----
29-Jul-15	11,520	22	237,410	8,336	23,519	89	416,063	1,426	2,728,856	374,296	217,279	375	519,867	1,547	3,035,269	196
24-Sep-15	-----	-----	458,848	1,089	-----	-----	1,238,782	2,032	43,102,434	252,290	-----	-----	135,856	555	27,444	1

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

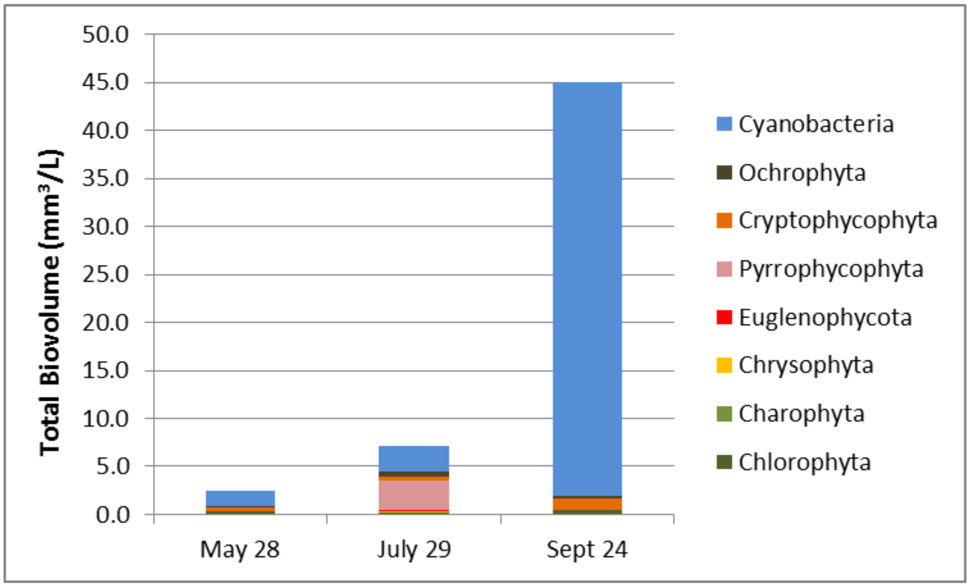


Plate 5-57. Relative abundance of phytoplankton in samples collected from Standing Bear Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1).

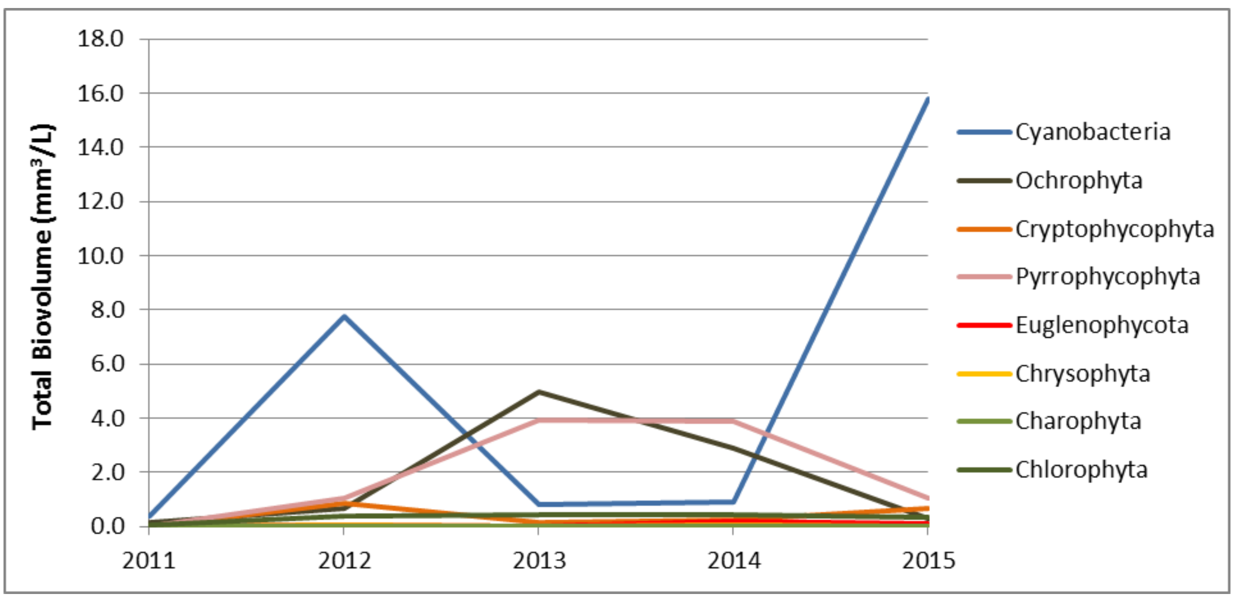


Plate 5-58. Relative abundance of phytoplankton in samples collected from Standing Bear Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are a seasonal average of three summer samples (i.e. May, July, and September)

Plate 5-59. Total biomass and density by taxonomic grouping for zooplankton vertical-tow samples from Standing Bear Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)
27-May-11	31	213.66	165	46.45	2	0	257	11.07
26-Jul-11	9	47.16	111	14.42	-----	-----	42	1.80
19-Sep-11	15	102.17	64	50.00	-----	-----	17	0.41
03-May-12	38	417.57	80	72.17	-----	-----	22	34.55
02-Jul-12	4	2.38	45	130.37	-----	-----	286	2.88
04-Sep-12	4	10.16	32	14.59	-----	-----	23	0.27
16-May-13	12	89.74	94	91.78	-----	-----	232	3.03
10-Jul-13	23	743.70	77	106.23	-----	-----	106	2.30
11-Sep-13	25	65.86	89	66.83	2	0	165	1.72
15-May-14	89	159.00	163	262.33	2	0	20	3.66
17-Jul-14	89	586.81	157	1,019.21	-----	-----	1,173	13.15
12-Sep-14	38	412.00	73	54.33	-----	-----	233	3.69
28-May-15	41	109.54	44	37.10	-----	-----	323	432.47
29-Jul-15	7	14.15	47	142.26	-----	-----	3	0.05
24-Sep-15	66	307.64	313	321.00	-----	-----	22	0.30

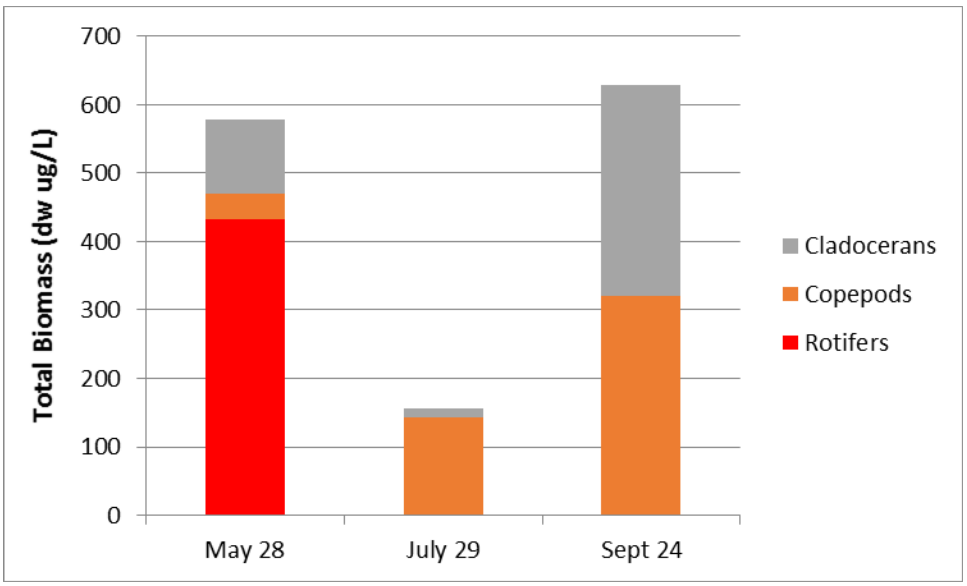


Plate 5-60. Relative abundance of zooplankton in samples collected from Standing Bear Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1).

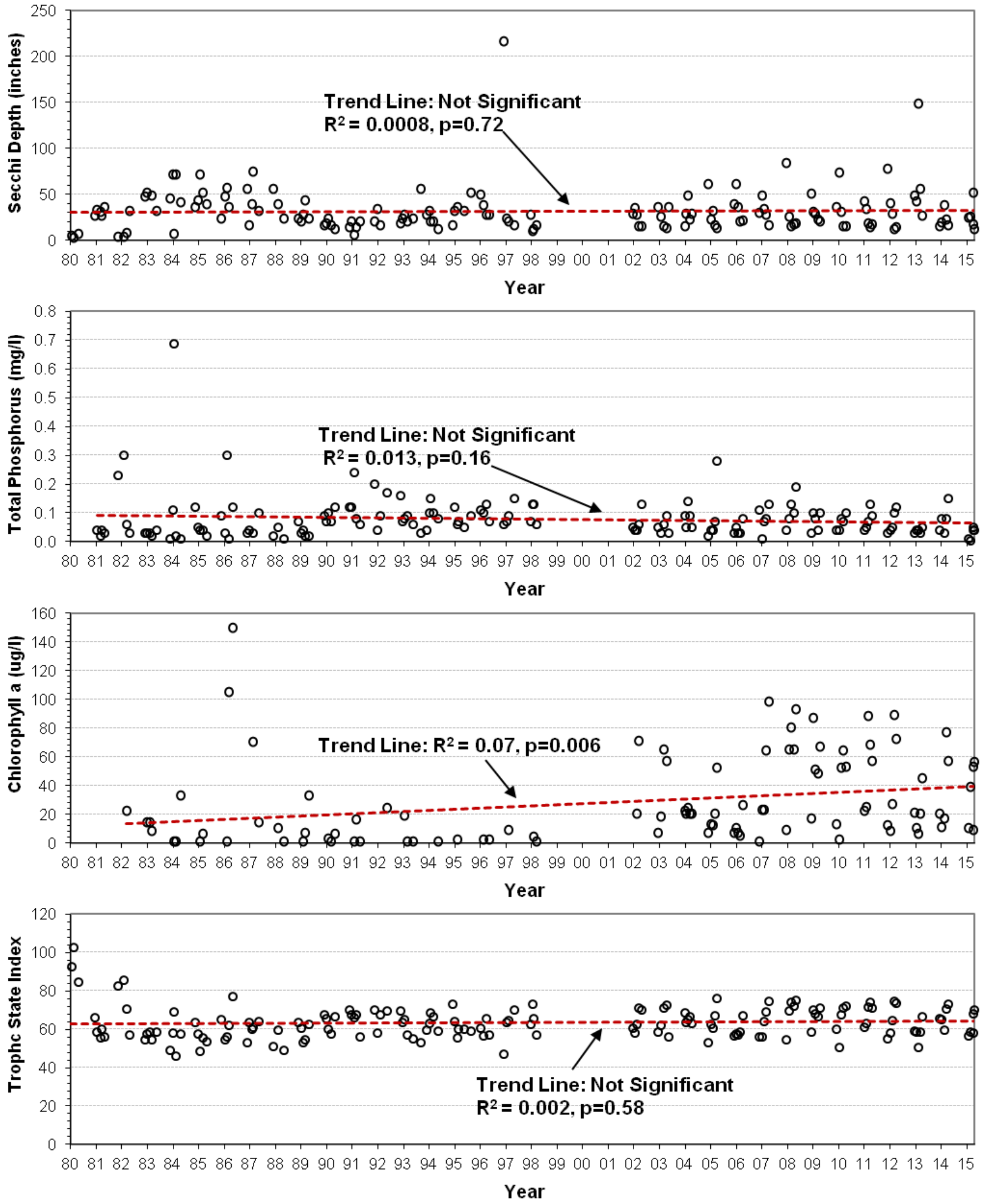


Plate 5-61. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Standing Bear Reservoir at the near-dam, ambient site (i.e., site STBLKND1) over the 35-year period of 1980 through 2015.

Plate 5-62. Summary of runoff water quality conditions monitored in the north tributary inflow to Standing Bear Reservoir at monitoring site STBNFNRT1 during the period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Water Temperature (°C)	0.1	8	19.18	20.65	10.95	24.57	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	8	8.05	8.16	5.10	10.42	≥5(2)	0	0%
Dissolved Oxygen (% Sat.)	0.1	8	89.36	94.85	54.80	99.00	-----	-----	-----
Turbidity (NTUs)	1	8	257.81	152.65	32.90	680.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	8	329.00	331.50	228.00	419.00	-----	-----	-----
Specific Conductance (umho/cm)	1	8	359.54	271.80	193.00	725.00	2,000(3)	0	0%
pH (S.U.)	0.1	7	8.09	8.01	7.60	8.70	≥6.5 & ≤9.0 (1)	0	0%
Suspended Solids, Total (mg/l)	10	10	181.10	62.50	18.00	533.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	10	0.15	0.12	n.d.	0.34	4.74(4,5), 0.89(4,6)	0	0%
Kjeldahl N, Total (mg/l)	0.02	10	1.71	1.78	1.03	2.18	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.8	10	-----	n.d.	n.d.	n.d.	100(3)	0	0%
Nitrogen, Total (mg/l)	0.8	10	1.91	1.85	1.15	2.68	-----	-----	-----
Phosphorus, Total (mg/l)	0.008	10	0.36	0.33	0.10	0.72	-----	-----	-----
Atrazine, Total (ug/l)(C)	0.05	10	0.78	0.70	n.d.	2.00	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(C)	0.1	10	-----	0.20	n.d.	0.60	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l)(C)	0.05	10	0.68	0.45	n.d.	1.70	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-63. Summary of runoff water quality conditions monitored in the south tributary inflow to Standing Bear Reservoir at monitoring site STBNFSTH1 during the period 2011 through 2015.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Water Temperature (°C)	0.1	8	18.67	19.55	7.95	23.78	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	8	8.99	8.51	8.04	11.06	≥5(2)	0	0%
Dissolved Oxygen (% Sat.)	0.1	8	98.31	97.60	91.30	103.00	-----	-----	-----
Turbidity (NTUs)	1	8	181.66	103.20	46.80	665.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	8	349.38	352.50	268.00	433.00	-----	-----	-----
Specific Conductance (umho/cm)	1	8	284.58	289.50	147.00	429.40	2,000(3)	0	0%
pH (S.U.)	0.1	7	8.03	7.84	7.50	8.77	≥6.5 & ≤9.0 (1)	0	0%
Suspended Solids, Total (mg/l)	10	9	94.67	73.00	28.00	208.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	9	0.16	0.14	n.d.	0.33	3.87(4,5), 0.76(4,6)	0	0%
Kjeldahl N, Total (mg/l)	0.02	9	1.57	1.57	1.22	1.92	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.8	9	-----	n.d.	n.d.	n.d.	100(3)	0	0%
Nitrogen, Total (mg/l)	0.8	9	1.89	2.01	1.37	2.19	-----	-----	-----
Phosphorus, Total (mg/l)	0.008	9	0.27	0.29	0.09	0.41	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.003	1	-----	n.d.	n.d.	n.d.	-----	-----	-----
Atrazine, Total (ug/l)(C)	0.05	9	0.78	0.70	0.10	2.40	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(C)	0.1	9	-----	n.d.	n.d.	0.60	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l)(C)	0.05	9	0.48	0.40	0.10	1.20	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

5.5 WEHRSPANN RESERVOIR

5.5.1 BACKGROUND INFORMATION

5.5.1.1 Project Overview

The dam forming Wehrspann Reservoir is located on a tributary to the South Branch Papillion Creek. The dam was completed on September 21, 1982 and the reservoir reached its initial fill on May 26, 1987. The Wehrspann Reservoir watershed is 13.1 square miles. The watershed was largely agricultural when the dam was built in 1982. Recently however, the watershed has undergone increased urbanization with the growth of Gretna and rural acreage development.

5.5.1.2 Aquatic Habitat Improvement and Water Quality Management Project

A Corps Section 1135 aquatic habitat improvement and water quality management project was completed at Wehrspann Reservoir in 1999. The project consisted of a sediment control structure, sediment detention pond/wetlands, and tree and shrub mitigation plantings. The sediment control structure dam was located approximately ½ mile upstream of the reservoir (see Figure 5.8). A detention area was formed upstream of the sediment dam to capture and store sediments that would enter Wehrspann Reservoir. The natural detention area was further excavated and graded to maximize retention volume and wetlands creation. The sediment storage area will ultimately become a wet meadow-scrub wetland-grassland mosaic, unless sediment that collects is periodically removed. The detention area was designed to ultimately fill with sediment to the top of the spillway crest elevation of 1117 ft-msl. The detention area has a design capacity of 469 ac-ft with a maximum surface area of approximately 76 acres. A nonpoint source water quality management project to educate landowners and implement best management practices (BMPs) was also implemented in the watershed when the Section 1135 project was constructed.

5.5.1.3 Wehrspann Dam Intake Structure

The reinforced concrete intake structure has two upper level intakes (invert elevations 1096.0 and 1103.4 ft-msl), an intermediate intake (invert elevation 1090.0 ft-msl), and also a low-level intake (invert elevation 1074.0 ft-msl). The upper level intakes are uncontrolled. The low-level intake is provided with a slide gate to allow draining of the reservoir. The intermediate intake is a 6-inch diameter slide gate for flow augmentation releases. A low-level inlet is constructed 130 feet upstream of the intake tower. The inlet is provided with a trash rack and emergency bulkhead to allow closure with the gate open. A 30-inch reinforced concrete pipe connects the low-level inlet to the intake structure.

5.5.1.4 Reservoir Storage Zones

Figure 5.7 depicts the current storage zones of Wehrspann Reservoir based on the 2009 Corps survey data and estimated sedimentation. It is estimated that 16 to 24 percent of the "as-built" Multipurpose Pool had been lost to sedimentation as of 2015 with the annual volume loss estimated to be 0.50 to 0.77 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Wehrspann Reservoir's water quality dependent uses are not currently impaired due to sedimentation. However, these rates of sedimentation suggest possible impairment in the near future.

5.5.1.5 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Wehrspann Reservoir since the reservoir was initially filled in the late 1980's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 5.8 shows the location of the sites that have been monitored for water quality during the 5-year sampling period (i.e., 2011 through 2015). The near-dam location (WEHLKND1) has been continuously monitored since 1986.

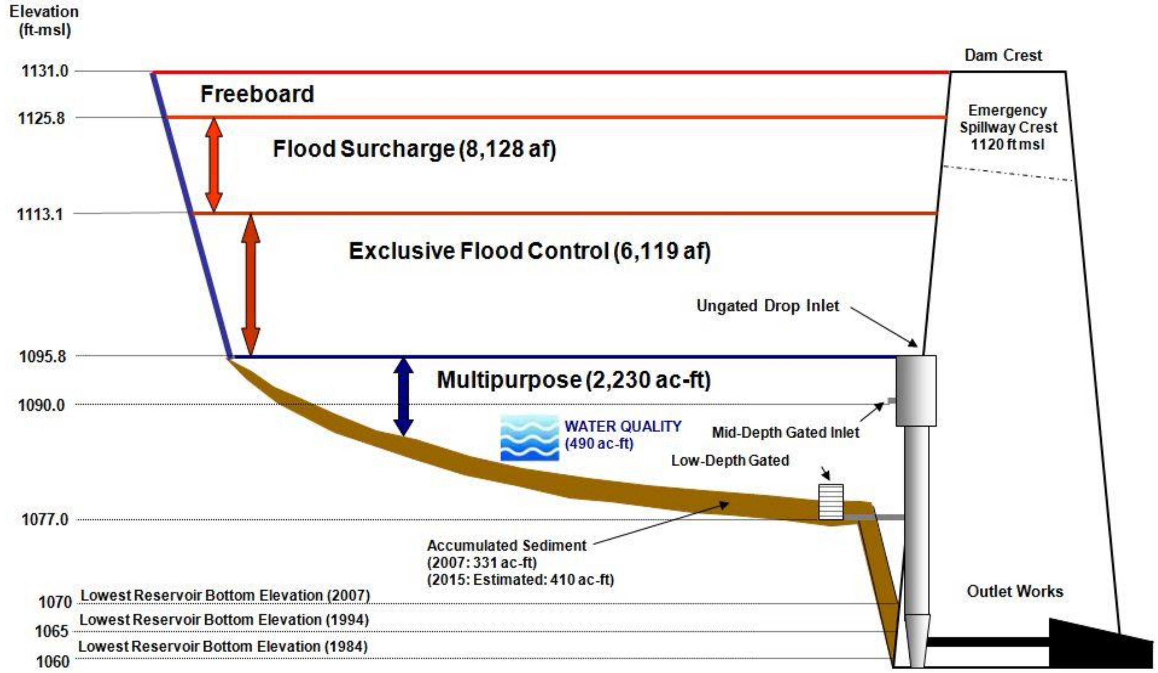


Figure 5.7. Current storage zones of Wehrspann Reservoir based on the 2009 Corps survey data and estimated sedimentation**.**

Figure 5.8. Location of sites where water quality monitoring was conducted by the District at Wehrspann Reservoir during the period 2011 through 2015.

5.5.2 WATER QUALITY IN WEHRSPANN RESERVOIR

5.5.2.1 Existing Water Quality Conditions

5.5.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Wehrspann Reservoir at sites WEHLKND, WEHLKML1 and WEHLKUP1 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 5-64 through Plate 5-66. A review of these results indicated possible water quality concerns regarding dissolved oxygen, pH, and nutrients.

A significant number of dissolved oxygen measurements throughout Wehrspann Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 5-64-Plate 5-66). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and appeared to be associated with a slight thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Wehrspann Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation.

The upper pH general criterion (9 S.U.) for the protection of aquatic life was seemingly exceeded multiple times during the 5-year sampling period at Wehrspann Reservoir in the area near the dam (i.e. WEHLKND1). Ten percent of the measurements taken during the sampling period near the dam exceeded the criteria (Plate 5-64). The greatest pH value was measured at 9.8 SU. pH measurements greater than 9.0 SU did not exceed 10 percent of the measurements taken at either WEHLKML1 or WEHLKUP1 (Plate 5-65 and Plate 5-66). Based on the State of Nebraska's impairment assessment criteria, the percent exceedance of the upper pH criterion indicates possible impairment concern for the Aquatic Life beneficial use of Wehrspan Reservoir. It is believed the high pH values may be associated with periods of high algal production and CO_2 uptake during photosynthesis.

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September) to be considered for impairment assessment. All three of these criteria were exceeded Wehrspan Reservoir (Plate 5-64). The near-surface chlorophyll *a* criterion was exceeded by 88 percent of the "lab analyzed" samples taken in the reservoir at site WEHLKND1. The total phosphorus and total nitrogen criteria were exceeded by 52 and 64 percent of samples, respectively. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values represent the growing season average for the 5-year period 2011 through 2015. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.06 mg/l), total nitrogen (1.11 mg/l), and chlorophyll *a* (34 ug/l) values at WEHLKND1 indicate impairment of the aquatic life use due to nutrients.

5.5.2.1.2 Thermal Stratification

5.5.2.1.2.1 ***Longitudinal Temperature Contour Plots***

Late-spring and early summer thermal stratification of Wehrspann Reservoir measured during 2015 is depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 5-67 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites WEHLKND1, WEHLKML1, and WEHLKUP1 in 2015. These temperature plots indicate that thermal stratification was present in Wehrspann Reservoir during the late spring and early summer. The extent of the stratification appeared to weaken in July and no thermal stratification was present from August through September. The greatest monitored difference between surface and bottom water temperatures was about 8°C.

5.5.2.1.2.2 ***Near-Dam Temperature Depth-Profile Plots***

The depth-profile temperature measurements collected during the summer over the 5-year sampling period at the deep water area near the dam were compiled and plotted to describe the existing summer thermal stratification of Wehrspann Reservoir (Plate 5-68). The plotted depth-profile temperature measurements indicate that the reservoir exhibits regular thermal stratification during the summer. The deeper portions of the reservoir in the area of the old creek channel appear to resist mixing with the upper column of water through mid-summer. Since Wehrspann Reservoir ices over in the winter and based on the occurrence of thermal stratification in the summer it appears to fit the definition of a discontinuous cold polymictic to a dimictic lake (Wetzel, 2001).

5.5.2.1.3 Dissolved Oxygen Conditions

5.5.2.1.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of Wehrspann Reservoir based on depth-profile measurements taken during 2015. Plate 5-69 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 near the reservoir bottom from May through July 2015.

5.5.2.1.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

The depth-profile dissolved oxygen measurements collected during the summer over the 5-year sampling period at the deep water area near the dam were compiled and plotted to describe the existing summer dissolved oxygen conditions of Wehrspann Reservoir (Plate 5-70). Several of the plotted profiles indicate a significant vertical gradient in dissolved oxygen levels tending towards a clinograde distribution. Fifty-two percent of the profiles showed hypoxic conditions near the reservoir bottom. Two of the those profiles indicated dissolved oxygen levels below Nebraska's criteria for the protection of aquatic life (<5.0 mg/l) through the entire profile. Some profiles show a fairly constant dissolved oxygen concentration from the reservoir surface to the bottom. These profiles were measured in early spring or late summer and are believed to be a result of thermal stratification breaking down and the water column mixing as "turnover" of the reservoir occurred.

5.5.2.1.3.3 ***Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of Wehrspan 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 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 July 29, 2015 contour plot indicates a pool elevation of 1095.8 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1089.0 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1079.5 ft-msl (Plate 5-69). The current District Area-Capacity Tables (2007 Survey) give storage capacities of 2,302 ac-ft for elevation 1,095.8 ft-msl, 970 ac-ft for elevation 1089.0 ft-msl, and 154 ac-ft for elevation 1079.5 ft-msl. On July 29, 2015 it is estimated that 42 percent of the volume of Wehrspan Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 7 percent of the reservoir volume was hypoxic.

5.5.2.1.4 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in Wehrspan reservoir indicated hypoxic conditions May through July 2015. As a result, longitudinal contour plots for ORP and pH were constructed during these months. Depth profiles and near-surface/near-bottom sample comparisons were constructed for periods of hypoxic conditions during the sampling periods from 2011 through 2015.

5.5.2.1.4.1 ***Oxidation-Reduction Potential***

Plate 5-71 provides longitudinal ORP contour plots based on measurements taken in 2015. Slightly reduced conditions were measured in June and July, but most conditions stayed above 250 mV through the entire depth of the reservoir. Plate 5-72 plots depth profiles for ORP measured during the summer over the 5-year sampling period in the deep water area of Wehrspan Reservoir near the dam when hypoxic conditions were present. A vertical gradient in ORP occasionally occurred in the reservoir during the summer, especially near the bottom. The most reduced condition was -31 mV.

5.5.2.1.4.2 ***pH***

Longitudinal contour plots for pH conditions measured in 2015 are provided in Plate 5-73. Lower pH levels near the bottom of the reservoir could be attributable to reservoir stratification and ongoing decomposition/respiration near the reservoir bottom. This would lead to an increase in CO_2 and decrease in pH. All pH levels were within the pH criteria for the protection of warmwater aquatic life. Plate 5-74 plots depth profiles for pH measured during the summer over the 5-year sampling period in the deep water area of Wehrspan near the dam when hypoxic conditions were present. A significant vertical gradient in pH regularly occurred in the reservoir during the summer. The upper pH criterion for the protection of aquatic life (9.0 SU) was exceeded several times during the 5-year period near the reservoir surface.

5.5.2.1.4.3 ***Comparison of Near-Surface and Near-Bottom Water Quality Conditions***

Paired near-surface and near-bottom water quality samples collected from Wehrspan Reservoir during the summer when hypoxia was present 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 WEHLKND1 during the 5-year period 2011 through 2015. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 13 (52%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 5-75). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for all the assessed parameters except nitrate-nitrite nitrogen ($p=1.0$) and ortho-phosphorus ($p=0.06$). Parameters that were significantly lower in the near-bottom water of Wehrspann Reservoir when hypoxia was present included: water temperature, dissolved oxygen, ORP, and pH ($p<0.05$). Parameters that were significantly higher in the near-bottom water included: total ammonia nitrogen, total alkalinity, and total phosphorus ($p<0.05$).

5.5.2.1.4.4 ***Reservoir Trophic Status***

Trophic State Index (TSI) values for Wehrspan Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., WEHLKND1). Table 5.12 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Wehrspan Reservoir is in a eutrophic condition.

Table 5.12. Summary of Trophic State Index (TSI) values calculated for Wehrspan Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	67	68	51	93
TSI(TP)	25	56	59	34	68
TSI(Chl)	25	72	72	57	83
TSI(Avg)	25	65	66	52	75

* 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 for the individual parameters.
Note: See Section 4.1.3 for discussion of TSI calculation.

5.5.2.1.1 Reservoir Plankton Community

5.5.2.1.1.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at the Wehrspan Reservoir near-surface, near-dam sampling site during the spring and summer of the 5-year period 2011 through 2015 (Plate 5-76). The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 5-77. The highest phytoplankton total biovolume was observed in September and the lowest in July. Ochrophyta and Cryptophycophyta dominated most of the 2015 growing season. Plate 5-77 shows that the phytoplankton population in 2015 was relatively healthy and diverse. Major and dominant phytoplankton genera sampled in 2015 at Wehrspan Reservoir are provided in Table 5.13.

Annual variation in phytoplankton community composition is displayed in Plate 5-78. Dominant groups varied during the 5-year period 2011 through 2015. Cyanobacteria dominated most of the sampling years but other dominant groups included Pyrrophycophyta, Chlorophyta, Ochrophyta, and Cryptophyta. Cyanobacteria density levels were greater than the World Health Organizations high level of health risk (>100,000 Cells/ml) in 2011, 2012, and 2014 (Plate 5-76). Maximum average Cyanobacteria density was observed 2012. 2012 was a particularily warm and dry year. The resulting long reservoir residence time, decreased mixing, and and warm waters could have lead to a longer Cyanbacterial growing season, causing the observed large densities and biovolumes. The maximum extracellular microcystin level measured during the 5-year period was 0.3 µg/L (Plate 5-64).

Table 5.13. Listing of Major and Dominant Phytoplankton Genera Sampled in Wehrspan Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1)

Division	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Chrysophyta	Mallomonas	-----
Cryptophycophyta	Cryptomonas, Rhodomonas	-----
Ochrophyta	*Cyclotella, Stephanodiscus*	*Asterionella, Aulacoseira*
Pyrrophycophyta	*Ceratium*	-----

5.5.2.1.1.2 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at Wehrspann Reservoir near-dam sampling sites during the spring and summer of the 5-year period 2011 through 2015 (Plate 5-79). The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in

Plate 5-80. Wehrspan Reservoir was dominated by Cladocerans and Copepods in 2015 with the greatest total zooplankton biomass in May. Dominant and major zooplankton genera sampled in Wehrspan Reservoir during 2015 are provided in Table 5.14.

Table 5.14. Listing of major and dominant zooplankton genera sampled in Wehrspan Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1)

Taxonomic Group	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cladocerans	-----	*Daphnia*
Copepods	*Cyclopoida, Mesocyclops*	*Skistodiaptomus, Calanoida, Leptodiaptomus*

5.5.2.1.2 Zebra Mussel Monitoring

Zebra mussel veliger sampling has been conducted once yearly since 2012 at Wehrspan Reservoir. During the sampling period (2012-2015) no veligers have been identified.

5.5.2.2 Water Quality Trends (1986 through 2015)

Water quality trends from 1986 to 2015 were determined for Wehrspan 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., WEHLKND1). Plate 5-81 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, it appears that Wehrspann Reservoir exhibited decreasing transparency ($p<0.05$; $R^2=0.08$), decreasing total phosphorus concentrations ($p<0.05$; $R^2=0.09$), and increasing chlorophyll *a* levels ($p<0.05$, $R^2=0.09$). Over the 30-year period since 1986, Wehrspann Reservoir has moved from a eutrophic to hypereutrophic condition.

5.5.2.3 Existing Water Quality Conditions of Runoff Inflows to Wehrspan Reservoir

5.5.2.3.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Existing water quality conditions in the main tributary inflow to Wehrspann Reservoir was monitored under runoff conditions, during the period of April through September, at two sites WEHNFUSB1 and WEHNFDSB1 (Figure 5.8). Site WEHNFUSB1 was about 1½ miles above the constructed sediment basin/wetland and site WEHNFDSB1 was at the sediment basin/wetland outflow. Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from “base-flow” conditions. Plate 5-82 and Plate 5-83, respectively, summarize water quality conditions that were monitored at sites WEHNFUSB1 and WEHNFDSB1 under runoff conditions during the period 2011 through 2015.

5.5.2.3.2 Impact of Constructed Sediment Basin/Wetland on Water Quality Conditions of Runoff Inflow

Runoff water quality conditions monitored upstream and downstream of the constructed sediment basin/wetland over the 14-year period 2002 through 2015 were compared. Paired runoff samples collected at sites WEHNFUSB1 (i.e., upstream) and WEHNFDSB1 (i.e., downstream) were compared for the following parameters: turbidity, total suspended solids, total phosphorus, total Kjeldahl nitrogen, total ammonia nitrogen, nitrate-nitrite nitrogen, atrazine, metolachlor, and alachlor. Box plots were constructed for each parameter to display the distribution of the paired runoff samples collected upstream and downstream of the constructed sediment basin/wetland (Plate 5-84). A paired two-tailed t-test was used to determine if the sampled upstream and downstream runoff conditions were significantly different. The sampled paired runoff conditions upstream and downstream of the constructed sediment basin/wetland were not significantly different (α = 0.05) for turbidity (p=0.15) total ammonia nitrogen (p=0.39), atrazine (p=0.35), alachlor (p=0.35), and metolachlor (p=0.11). Parameters that were significantly lower downstream of the constructed sediment basin wetland included: total suspended solids, total Kjeldahl nitrogen, nitrate-nitrite nitrogen, and total phosphorus ($p < 0.05$).

5.5.3 PLATES

Plate 5-64. Summary of water quality conditions monitored in Wehrspan Reservoir at site WEHLKND1 from May to September during the 5-year period 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	24	1095.68	1095.80	1093.50	1096.75	-----	-----	-----
Water Temperature (°C)	0.1	334	23.23	24.21	13.65	30.82	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	334	6.29	6.80	n.d.	15.12	≥5(2)	115	34%
Dissolved Oxygen, Near-Surface (mg/l)(C)	0.1	25.00	9.26	9.28	4.67	13.95	≥5(2)	1	4%
Dissolved Oxygen (% Sat.)	0.1	334	76.49	77.50	n.d.	202.90	-----	-----	-----
Secchi Depth (in.)	1	25	28.00	22.00	4.00	72.00	-----	-----	-----
Turbidity (NTUs)	1	321	19.90	13.10	n.d.	159.70	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	334	295.69	289.50	-31.00	432.00	-----	-----	-----
Specific Conductance (umho/cm)	1	334	453.56	454.50	298.70	584.40	2,000(3)	0	0%
pH (S.U.)	0.1	334	8.20	8.14	7.02	9.84	≥6.5 & ≤9.0 (1)	0,33	0%,10%
Alkalinity, Total (mg/l)	1	50	140.30	136.00	96.00	475.00	20(1)	0	0%
Suspended Solids, Total (mg/l)	4	50	13.82	13.00	n.d.	40.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	50	-----	0.07	n.d.	2.08	2.48(4,5), 0.54(4,6)	1,2	2%,4%
Ammonia, Total, Near-Surface (mg/)(C)	0.02	25	-----	n.d.	n.d.	0.4	0.83(4,5), 0.22(4,6)	0	0%
Kjeldahl N, Total (mg/l)	0.08	50	1.21	1.15	0.42	3.26	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	50	-----	n.d.	n.d.	0.39	100(3)	0	0%
Nitrogen, Total (mg/l)	0.03	50	1.27	1.18	0.46	3.28	1(7)	36	72%
Nitrogen, Total, Near-Surface (mg/)(C)	0.03	25	1.11	1.05	0.46	2.09	1(7)	16	64%
Phosphorus, Total (mg/l)	0.005	50	0.09	0.07	n.d.	0.55	0.05(7)	30	60%
Phosphorus, Total, Near-Surface (mg/l)(C)	0.005	25	0.06	0.06	0.01	0.16	0.05(7)	13	52%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	n.d.	n.d.	0.37	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	124.66	122.00	104.60	148.40	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	5	6.00	4.00	3.00	12.00	340(5), 16.7(8)	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	n.d.	7.16(5), 0.28(6)	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	696.79(5), 90.71(6)	0	0%
Copper, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	16.21(5), 10.61(6)	0	0%
Iron, Dissolved (ug/l)	10	5	-----	15.00	n.d.	40.00	1000(6)	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	80.14(5), 3.12(6)	0	0%
Manganese, Dissolved (ug/l)	3	5	-----	4.00	n.d.	8.00	1000(6)	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	554.02(5), 61.53(6)	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	4.86(5)	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	40.00	138.68(5), 139.82(6)	0	0%
Antimony, Dissolved (ug/l)	0.03	5	0.66	0.70	0.50	0.80	88(5), 30(6)	0	0%
Aluminum, Dissolved (ug/l)	40	5	-----	n.d.	n.d.	80.00	750(5), 87(6)	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77(6)	0	0%
Chlorophyll a (ug/l) – Lab Determined(C)	6	25	34	26	n.d.	80	10(7)	22	88%
Chlorophyll a (ug/l) – Field Probe	6	322	42	34	n.d.	372	10(7)	293	91%
Atrazine, Total (ug/l)(D)	0.1	25	1.95	1.50	0.20	5.80	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(D)	0.1	25	-----	0.30	n.d.	1.50	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l)(D)	0.1	25	0.88	0.60	n.d.	5.40	-----	-----	-----
Microcystin, Extracellular (ug/l)	0.1	24	-----	n.d.	n.d.	0.30	20(9)	0	0%
Pesticide Scan (ug/l)(E)									
Atrazine, Tot	0.13	5	-----	0.55	n.d.	4.08	330(5), 12(6)	0	0%
Acetochlor, Tot	0.08	5	-----	n.d.	n.d.	2.19	-----	-----	-----
Metolachlor, Tot	0.13	5	-----	n.d.	n.d.	0.55	390(5), 100(6)	0	0%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-65. Summary of water quality conditions monitored in Wehrspan Reservoir at site WEHLKML1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	19	1095.56	1095.70	1093.50	1096.75	-----	-----	-----
Water Temperature (°C)	0.1	289	23.23	24.10	15.53	30.53	32(1)	0	0%
Dissolved Oxygen (% Sat.)	0.1	289	77.08	79.40	0.00	213.10	-----	-----	-----
Dissolved Oxygen (mg/l)	0.1	289	6.35	6.89	0.00	16.18	≥5(2)	75	26%
Specific Conductance (umho/cm)	1	289	451.93	449.90	297.00	580.60	2,000(3)	0	0%
pH (S.U.)	0.1	289	8.19	8.18	7.04	9.81	≥6.5 & ≤9.0 (1)	0,12	0%,4%
Turbidity (NTUs)	1	275	20.53	14.10	0.00	88.40	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	289	304.20	299.00	-28.00	432.00	-----	-----	-----
Secchi Depth (in.)	1	25	26.12	24.00	7.00	52.00	-----	-----	-----
Chlorophyll a (ug/l) – Field Probe	6	280	41	34	5	318	10(4)	259	93%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-66. Summary of water quality conditions monitored in Wehrspan Reservoir at site WEHLKUP1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	19	1095.56	1095.70	1093.50	1096.75	-----	-----	-----
Water Temperature (°C)	0.1	66	23.69	23.85	16.64	29.65	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	66	7.76	7.23	2.02	12.90	≥5(2)	7	11%
Dissolved Oxygen (% Sat.)	0.1	66	94.62	90.05	26.40	175.70	-----	-----	-----
Secchi Depth (in.)	1	25	15.96	17.00	4.00	27.00	-----	-----	-----
Turbidity (NTUs)	1	65	27.52	23.30	8.90	151.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	66	315.98	294.00	208.00	433.00	-----	-----	-----
Specific Conductance (umho/cm)	1	66	443.96	442.85	299.20	581.40	2,000(3)	0	0%
pH (S.U.)	0.1	66	8.28	8.30	7.53	10.11	≥6.5 & ≤9.0 (1)	0,2	0%,3%
Chlorophyll a (ug/l) – Field Probe	6	62	64	50	8	519	10(4)	61	98%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

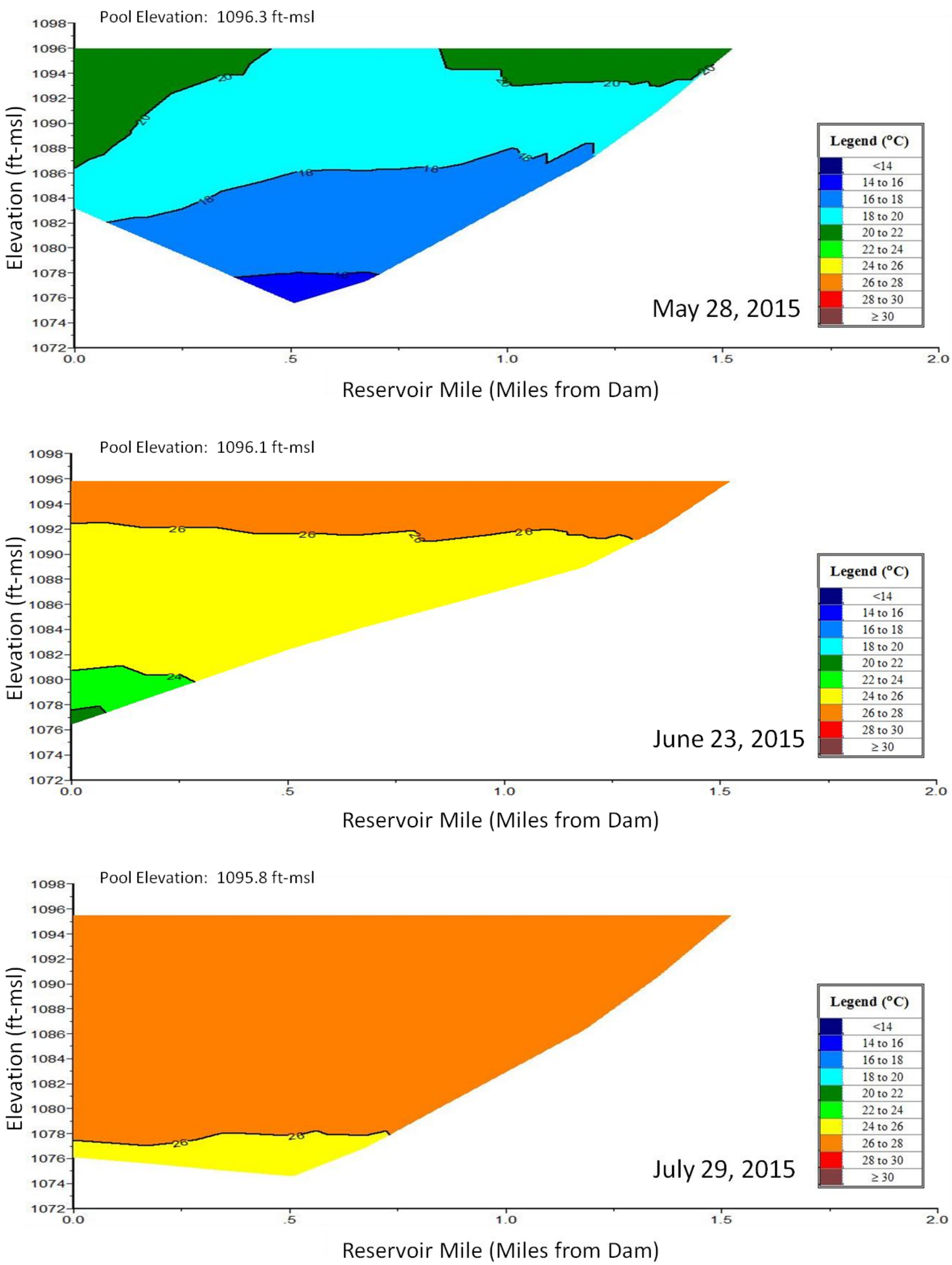
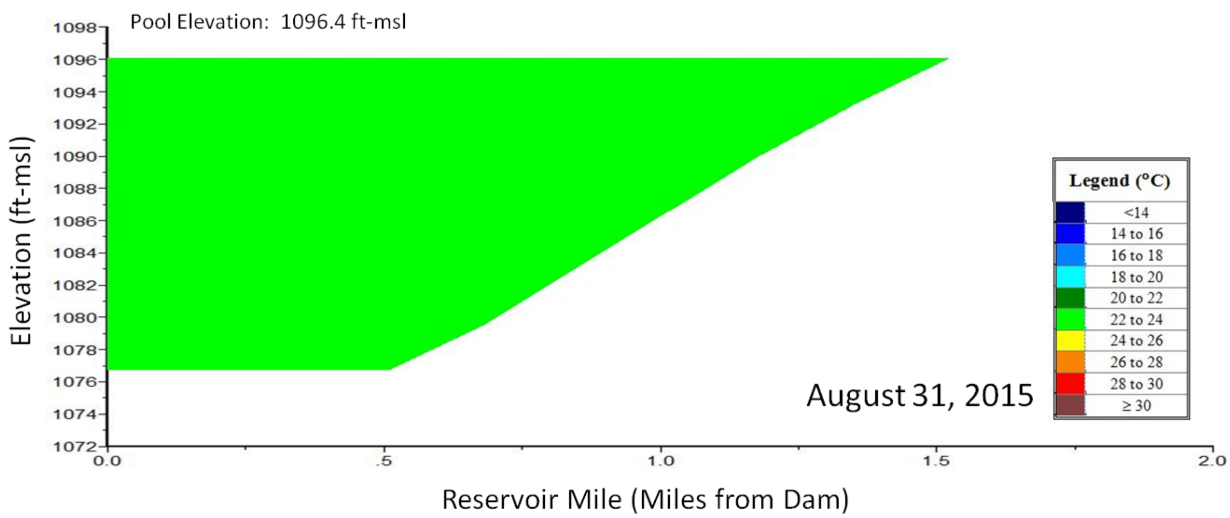


Plate 5-67. Longitudinal water temperature contour plots of Wehrspan Reservoir based on depth-profile water temperatures (°C) measured at sites WEHLKND1, WEHLKML1, and WEHLKUP1 in 2015.



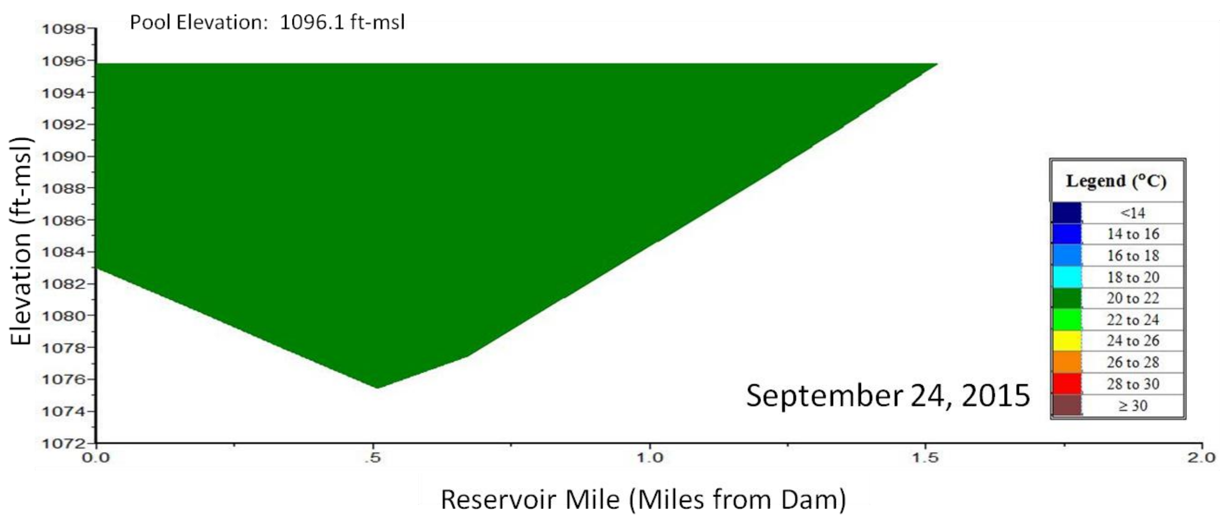


Plate 5-67. (Continued).

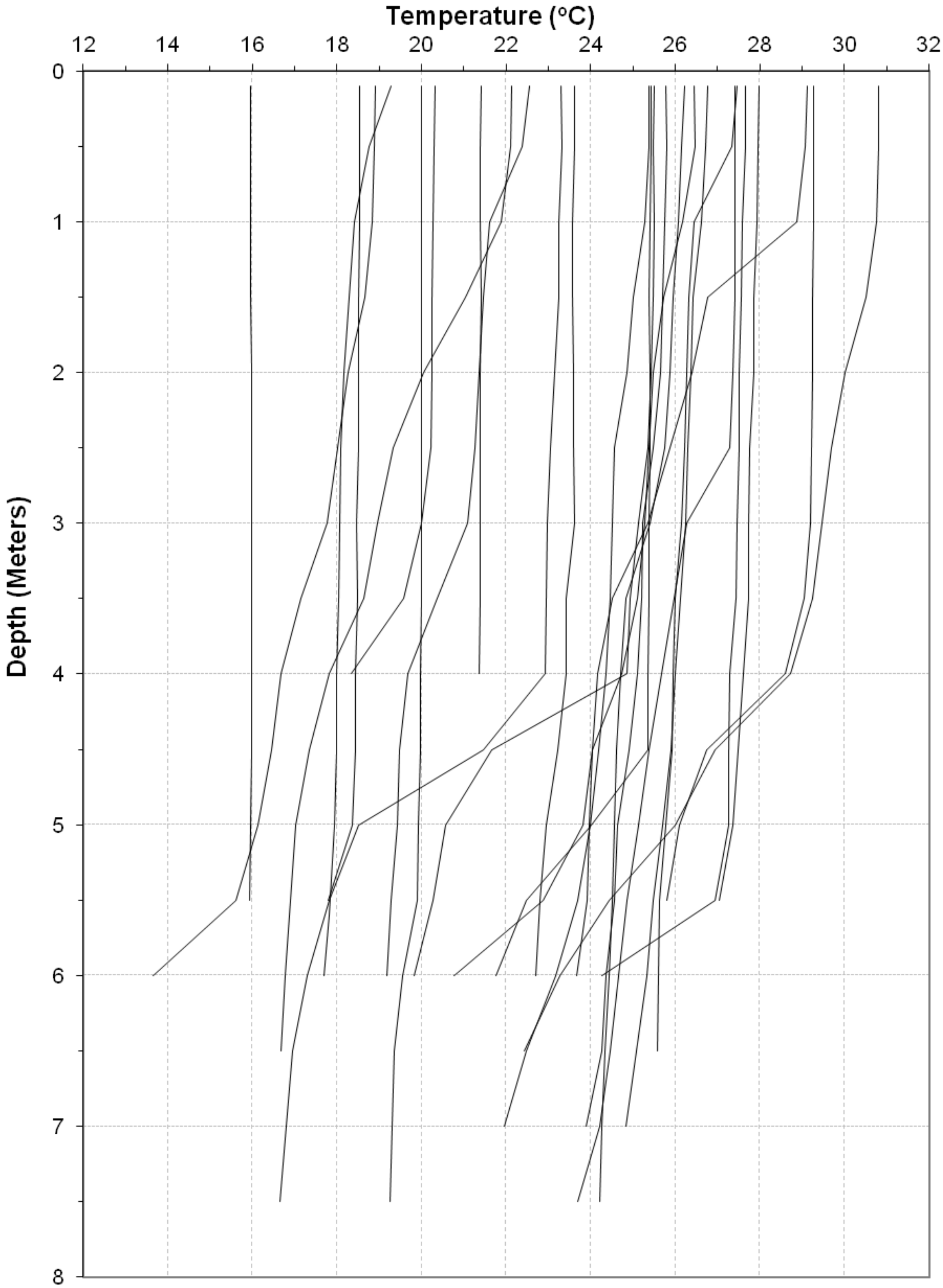


Plate 5-68. Temperature depth profiles for Wehrspan Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1) during the summer over the 5-year period of 2011 through 2015.

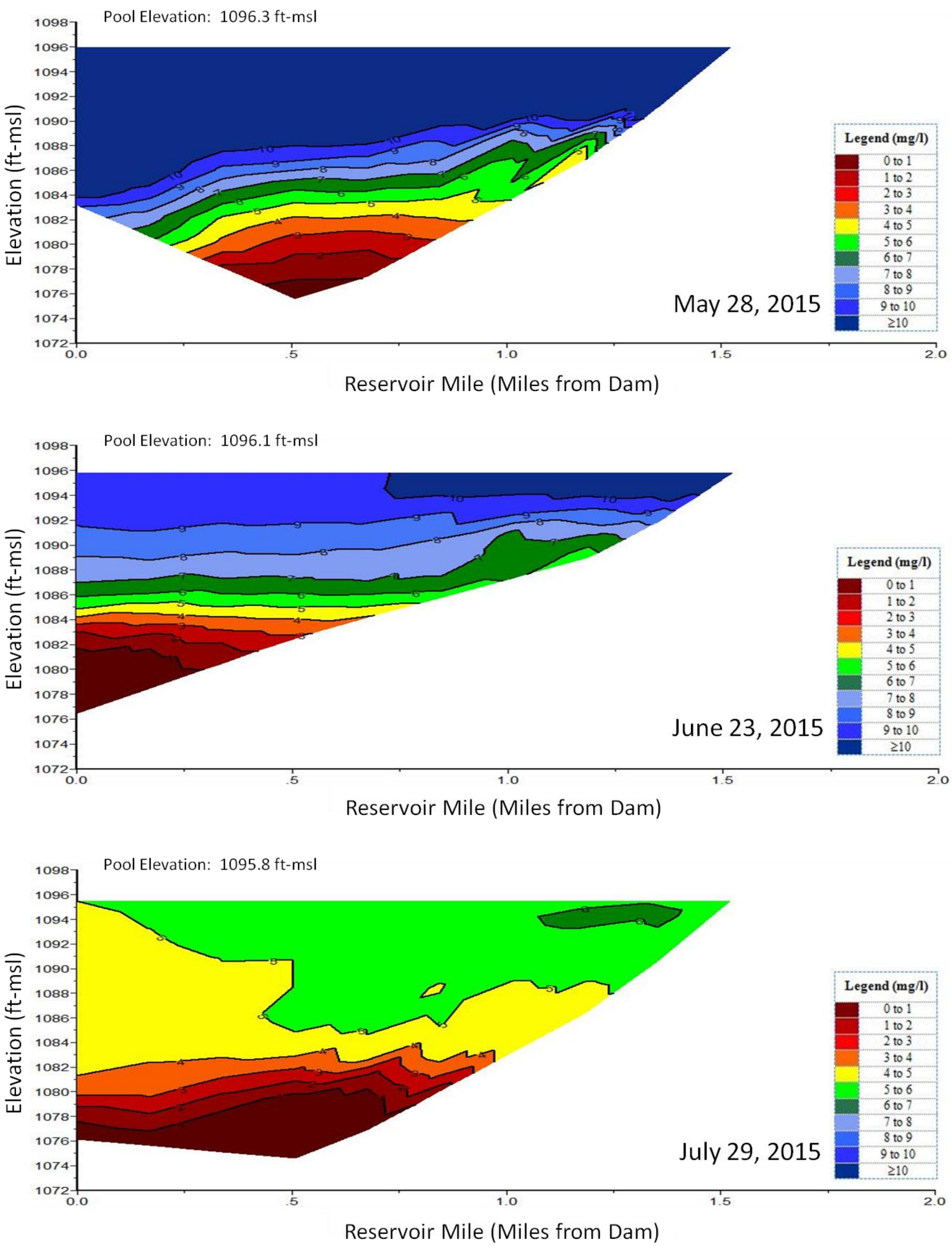
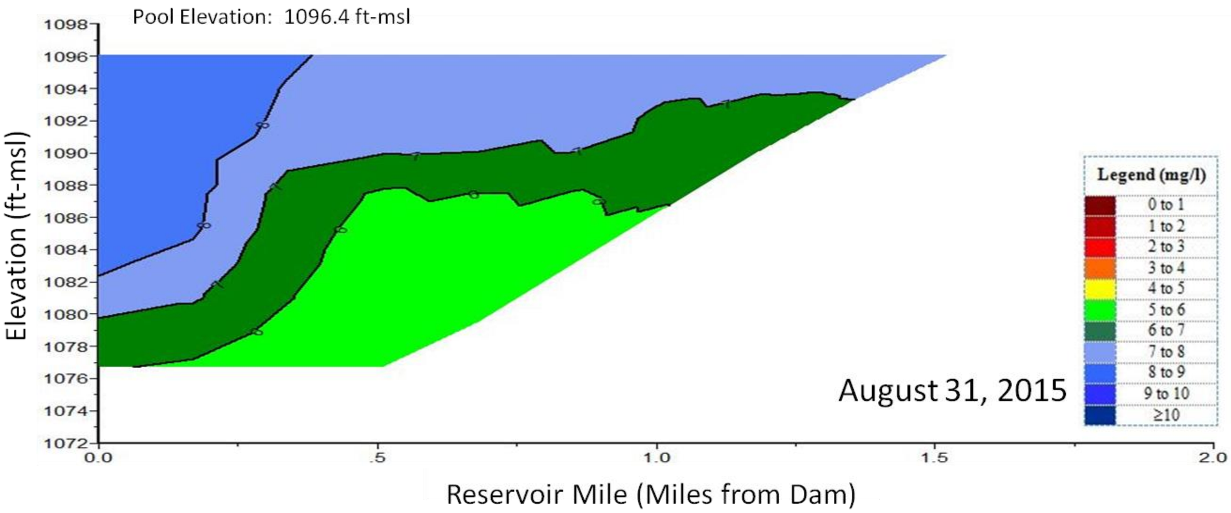


Plate 5-69. Longitudinal dissolved oxygen contour plots of Wehrspan Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites WEHLKND1, WEHLKML1, and WEHLKUP1 in 2015.



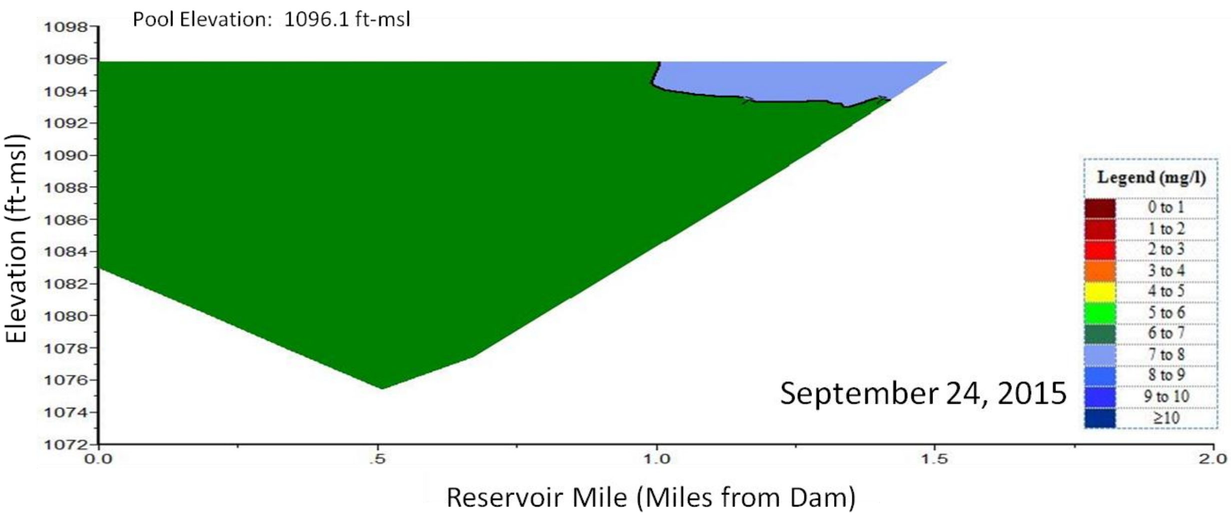


Plate 5-69. (Continued).

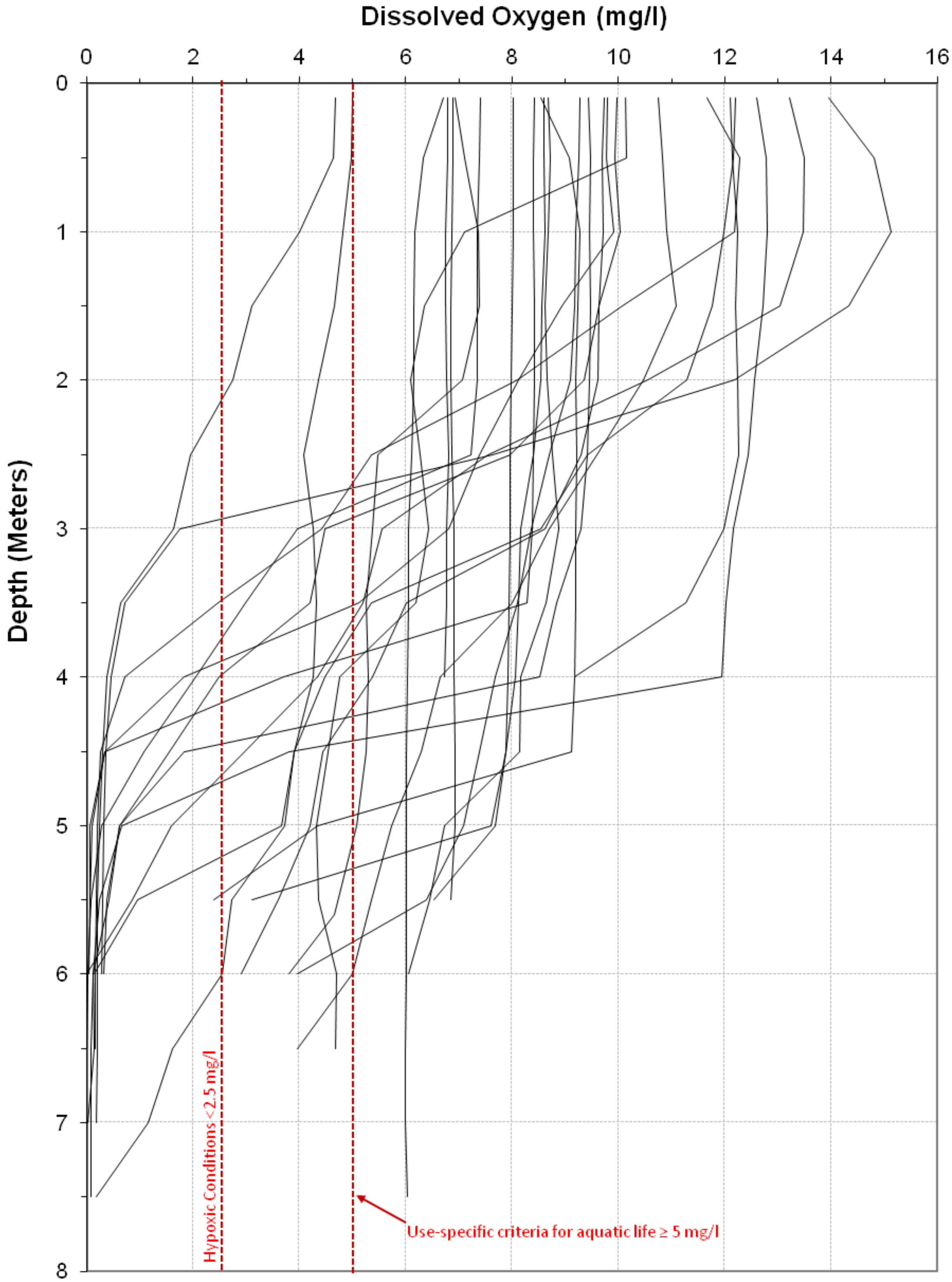


Plate 5-70. Dissolved oxygen depth profiles for Wehrspan Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1) during the summer over the 5-year period of 2011 through 2015.

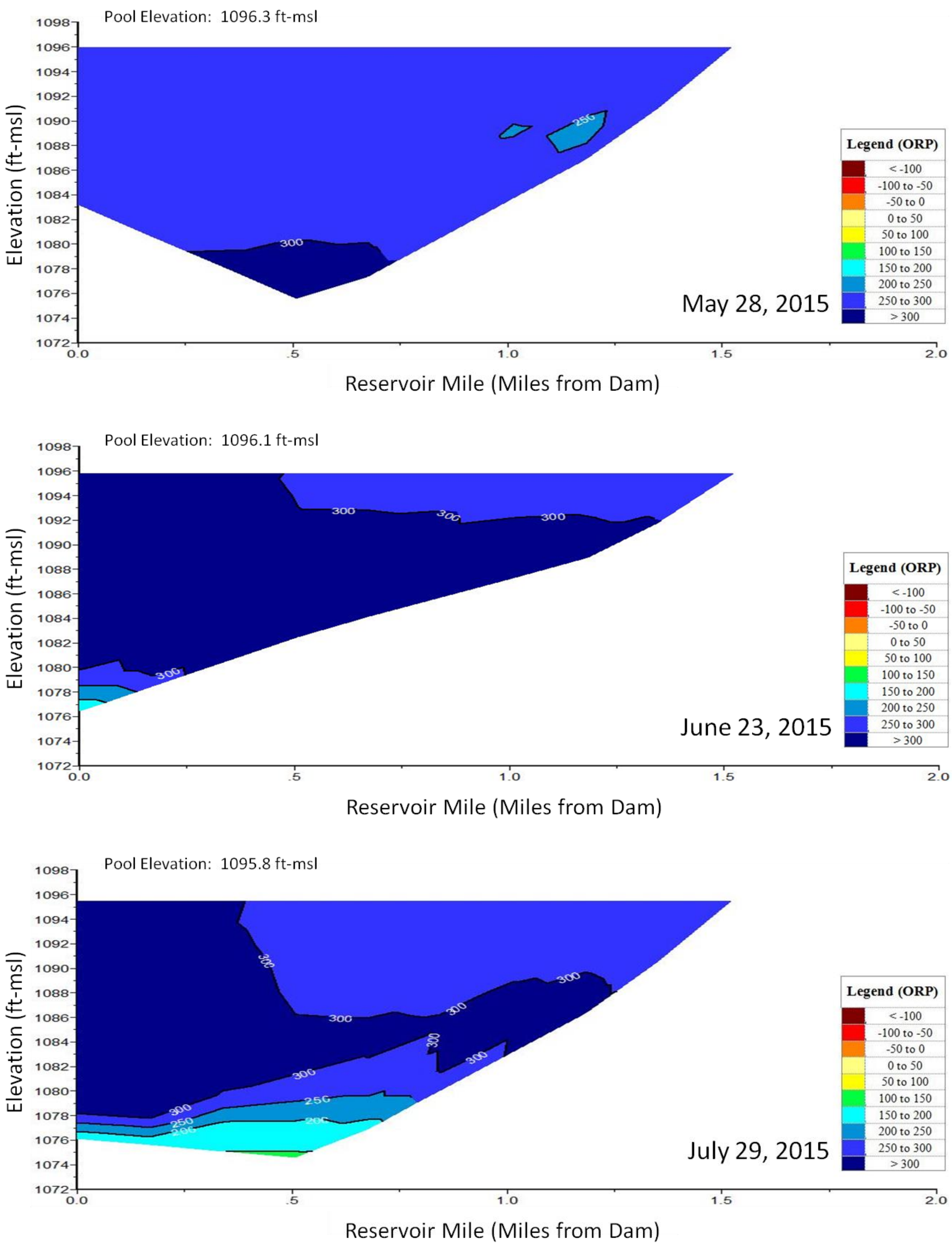


Plate 5-71. Longitudinal oxidation-reduction potential contour plots of Wehrspan Reservoir based on depth-profile ORP levels (mV) measured at sites WEHLKND1, WEHLKML1, and WEHLKUP1 in 2015.

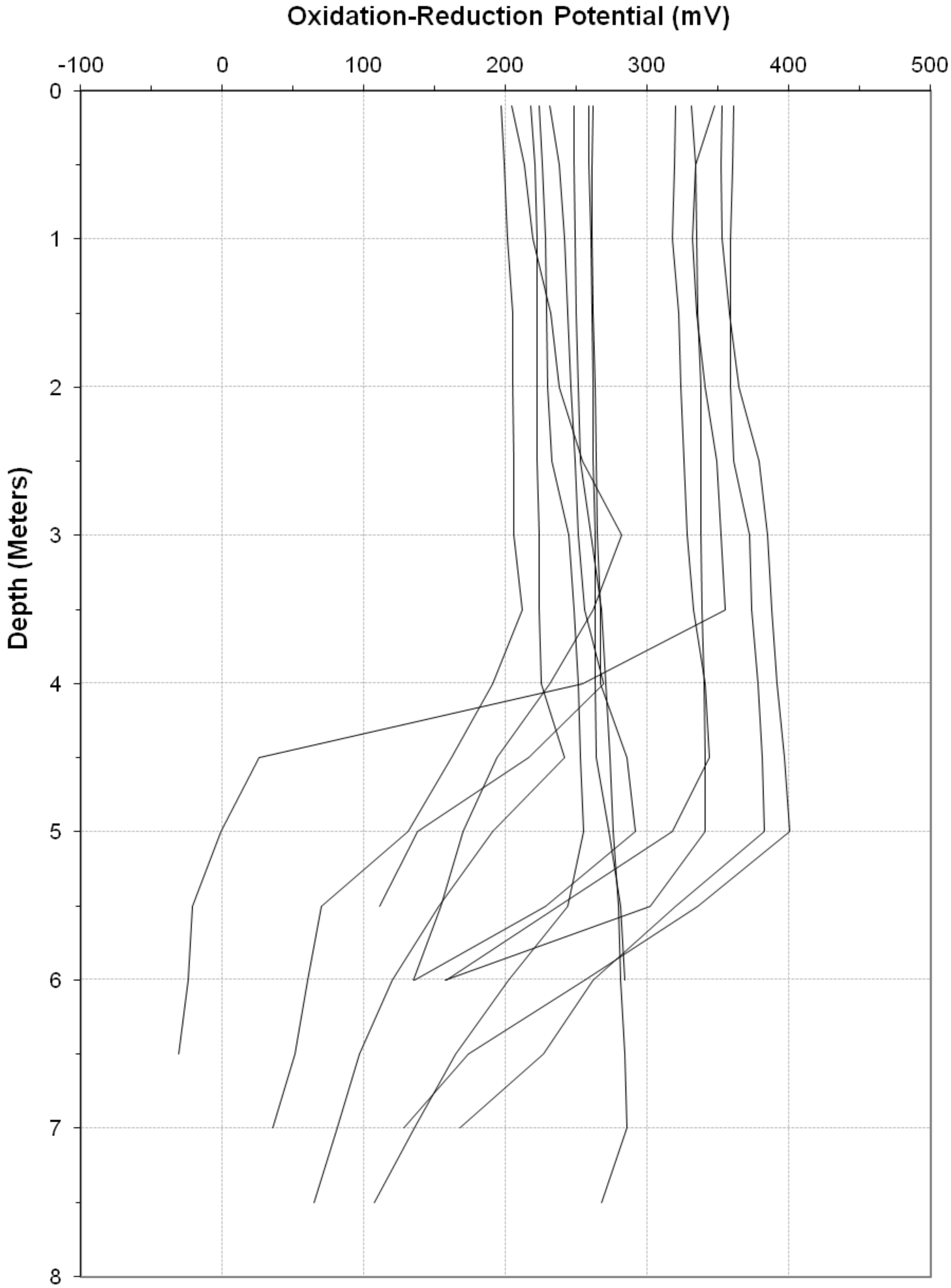


Plate 5-72. Oxidation-reduction potential depth profiles for Wehrspan Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1) when hypoxic conditions were present, during the summer, over the 5-year period of 2011 through 2015.

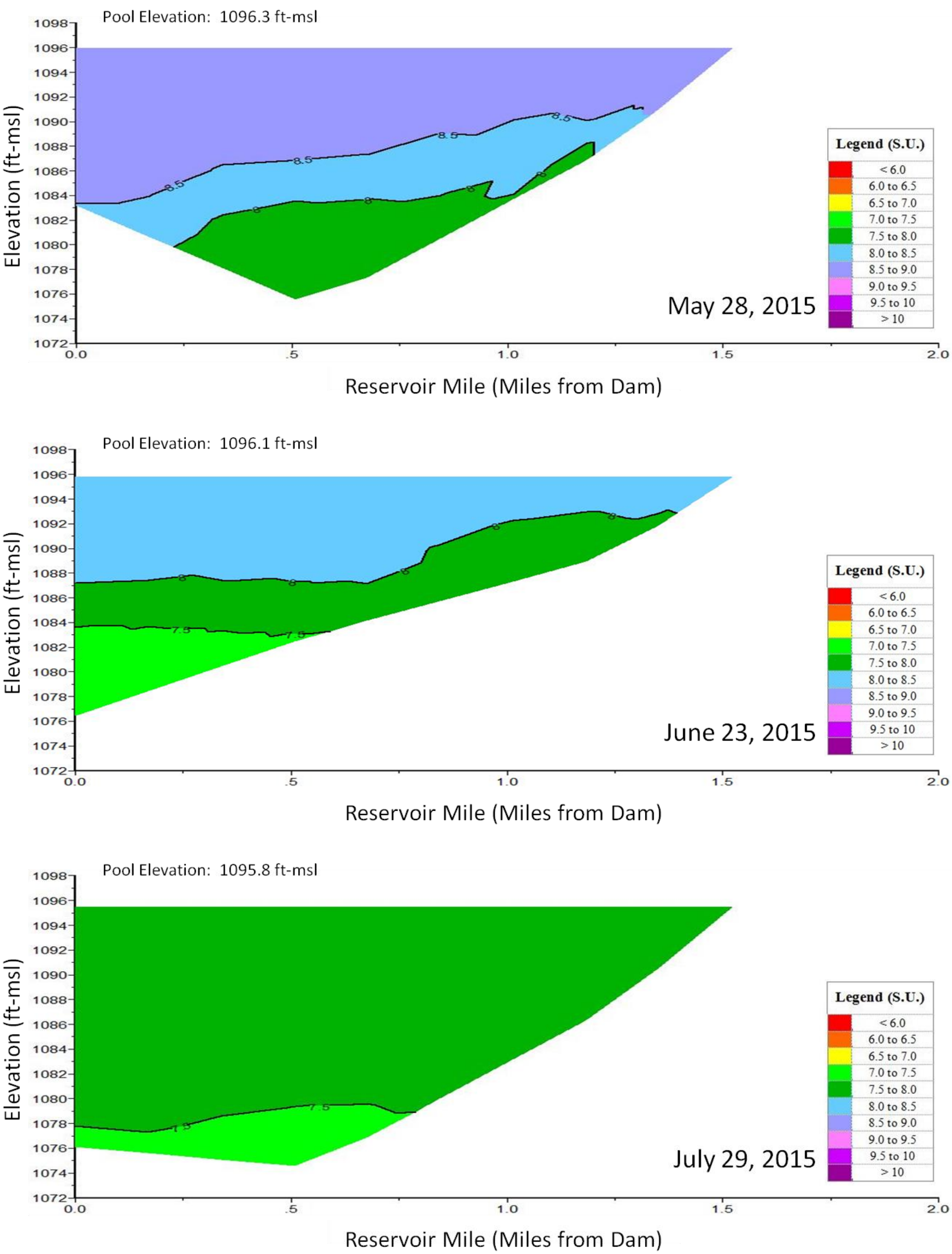


Plate 5-73. Longitudinal pH contour plots of Wehrspan Reservoir based on depth-profile pH levels (S.U.) measured at sites WEHLKND1, WEHLKML1, and WEHLKUP1 in 2015.

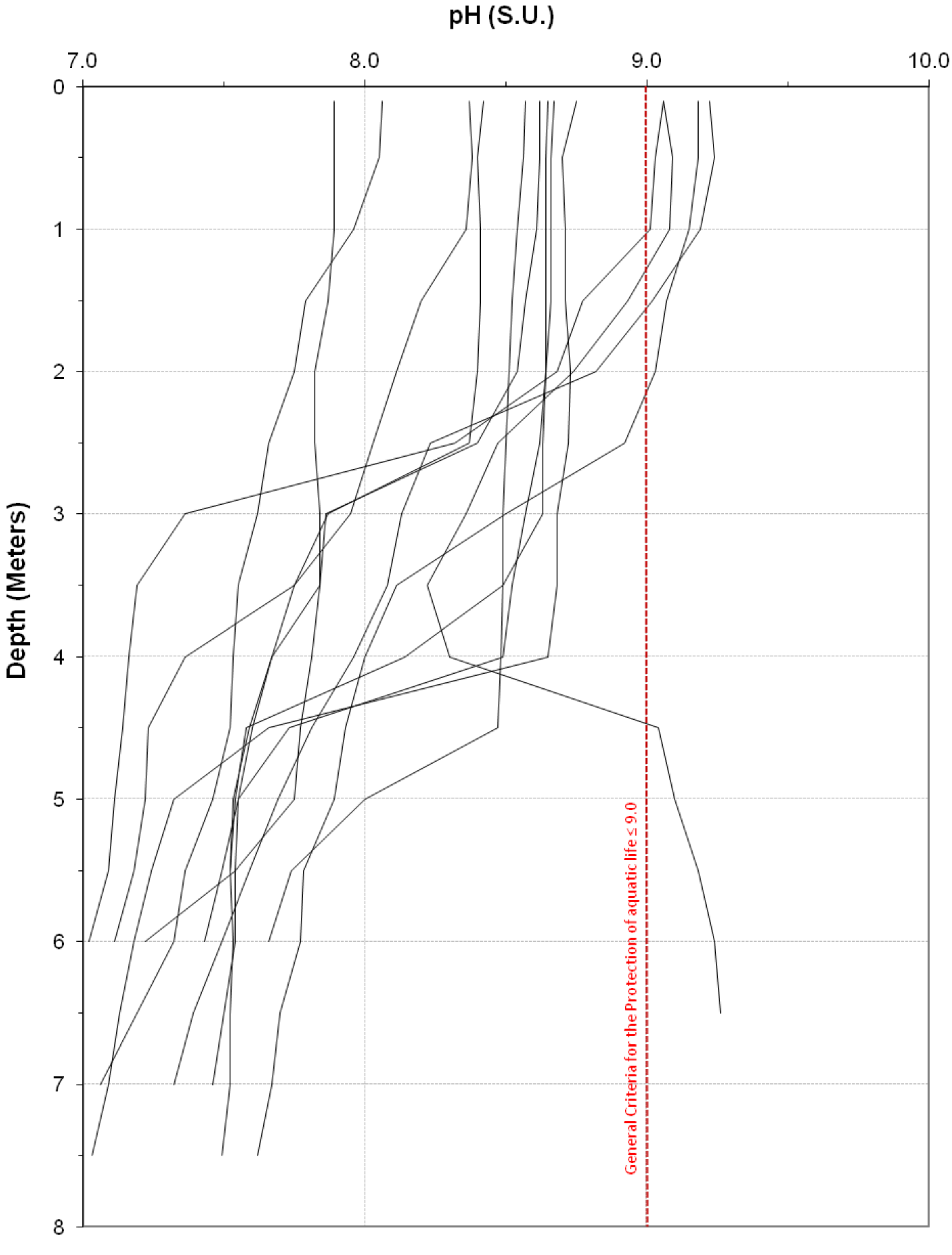


Plate 5-74. pH depth profiles for Wehrspan Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1) during the summer over the 5-year period of 2011 through 2015, when hypoxic conditions were present.

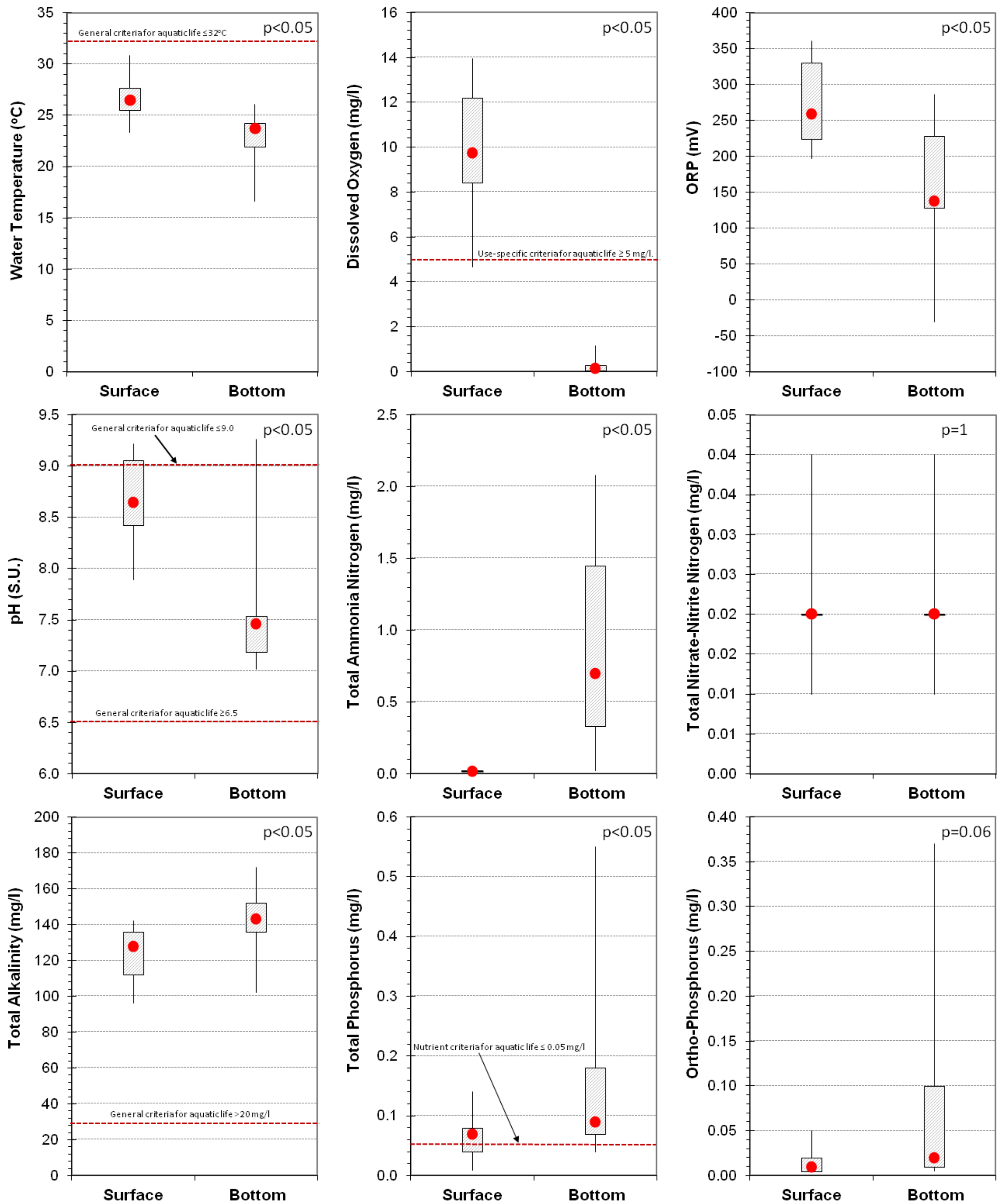


Plate 5-75. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, total ammonia nitrogen, nitrate-nitrite nitrogen, alkalinity, total phosphorus, and ortho-phosphorus measured in Wehrspan Reservoir when summer hypoxic conditions were present during the 5-year period of 2011 through 2015 (n=13). P-values indicate significant differences between the near-surface and near-bottom samples via a paired two-tailed t-test (α = 0.05). (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot. Water quality criteria marked with red line when applicable)

Plate 5-76. Total biovolume and density by taxonomic group for phytoplankton grab samples from Wehrspan Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)
28-May-11	6,875	166	88,583	1,743	682	3	6,406	123	10,310	492	6,875	166	280,455	411	1,346	1
26-Jul-11	-----	-----	99,220	1,875	1,622	6	11,266	159	1,196,130	158,456	7,288	11	2,502,868	2,407	21,660	11
19-Sep-11	540	3	11,384	212	-----	-----	-----	-----	284,838	40,942	51	0	305,741	411	2,682	1
04-May-12	77,664	237	6,786,538	4,490	88,700	58	1,587,994	3,636	347	67	828	0	680,814	3,139	5,392	0
03-Jul-12	3,831	4	1,533,696	1,340	26,469	40	273,689	3,088	5,776,110	110,654	129,564	75	266,963	429	5,878,615	348
04-Sep-12	56,331	8	700,669	2,297	-----	-----	2,168,321	13,518	14,566,714	810,066	227,221	244	376,528	73	40,292,290	1,112
16-May-13	48,196	7	360,102	2,125	-----	-----	119,141	1,405	65,450	1,000	115,469	22	2,258,950	1,198	-----	-----
11-Jul-13	8,026	16	141,790	459	-----	-----	205,297	2,304	436,670	4,000	5,491	5	380,258	582	39,106	0
11-Sep-13	10,954	7	456,963	787	-----	-----	184,154	2,171	7,038,546	60,265	20,966	32	527,231	759	10,388	1
15-May-14	-----	-----	261,061	891	-----	-----	28,666	338	51,769	458	1,565	0	229,352	144	-----	-----
17-Jul-14	224,542	11	1,664,032	2,896	169,877	23	12,704,042	4,337	42,915,358	210,548	108,476	11	610,891	652	286,452	11
12-Sep-14	38,160	29	1,845,641	1,825	9,425	1	107,491	110	1,550,959	16,339	294,029	88	2,314,131	936	3,142	1
28-May-15	1,947	0	74,198	417	-----	-----	882,495	3,251	19,453	1,411	-----	-----	1,138,842	1,594	309,855	11
29-Jul-15	-----	-----	131,975	2,041	338,674	57	441,990	2,460	95,617	3,628	120,744	298	841,562	3,544	409,844	51
24-Sep-15	965	0	1,080,788	2,567	16,127	53	3,069,168	19,850	222,477	1,881	86,432	87	3,780,545	14,023	220,269	7

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

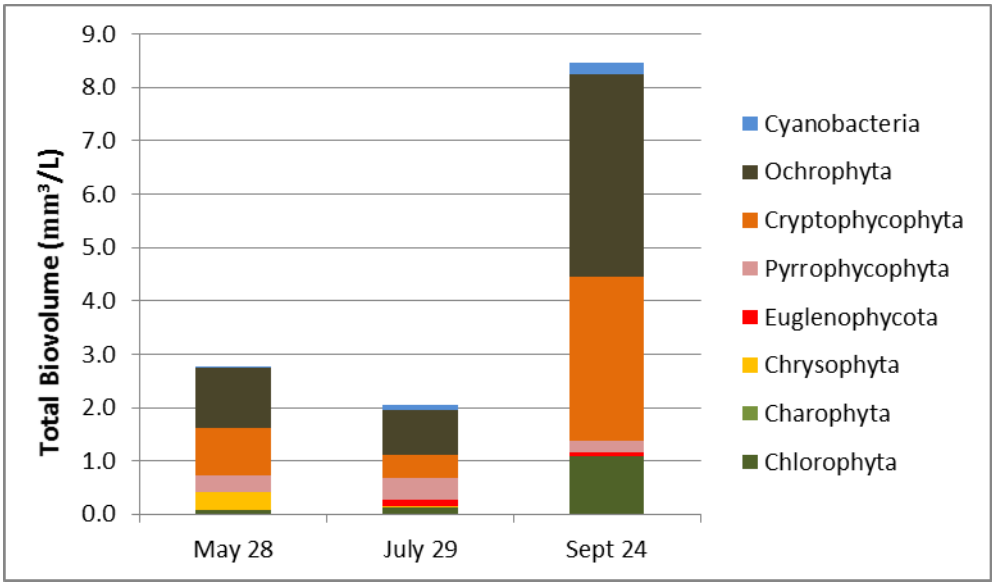


Plate 5-77. Relative abundance of phytoplankton in samples collected from Wehrspan Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1).

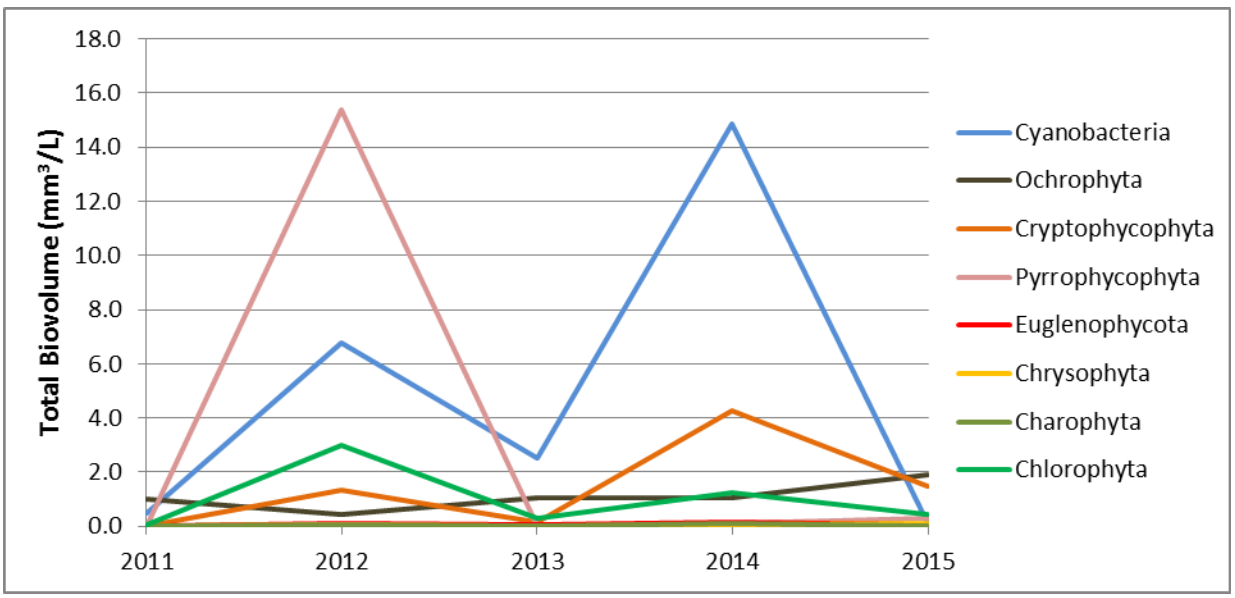


Plate 5-78. Relative abundance of phytoplankton in samples collected from Wehrspan Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are seasonal average of three summer samples (i.e. May, July, and September)

Plate 5-79. Total biomass and density by taxonomic grouping for zooplankton vertical-tow samples from Wehrspan Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	**Density (Count/L)**	**Biomass (dw µg/L)**	**Density (Count/L)**	**Biomass (dw µg/L)**	**Density (Count/L)**	**Biomass (dw µg/L)**	**Density (Count/L)**	**Biomass (dw µg/L)**
27-May-11	67	125.55	204	130.86	-----	-----	184	6.98
26-Jul-11	40	70.53	107	99.38	-----	-----	113	0.47
19-Sep-11	25	77.89	122	86.09	-----	-----	242	0.48
04-May-12	19	235.40	77	50.92	-----	-----	63	31.50
03-Jul-12	9	67.03	43	26.07	-----	-----	34	0.46
04-Sep-12	4	8.39	29	42.29	1	0.91	48	0.10
16-May-13	50	106.35	83	62.40	-----	-----	83	3.13
11-Jul-13	27	618.70	73	100.28	-----	-----	771	9.60
11-Sep-13	26	29.41	49	65.65	-----	-----	21	0.53
15-May-14	73	247.10	225	87.33	3	0.29	13	0.30
14-Jul-14	20	254.55	129	127.71	1	0.97	34	0.67
12-Sep-14	40	125.96	122	74.98	-----	-----	84	2.41
28-May-15	21	124.78	66	80.01	-----	-----	119	7.40
29-Jul-15	1	8.64	58	81.45	-----	-----	5	0.23
24-Sep-15	11	14.30	54	91.72	-----	-----	53	1.01

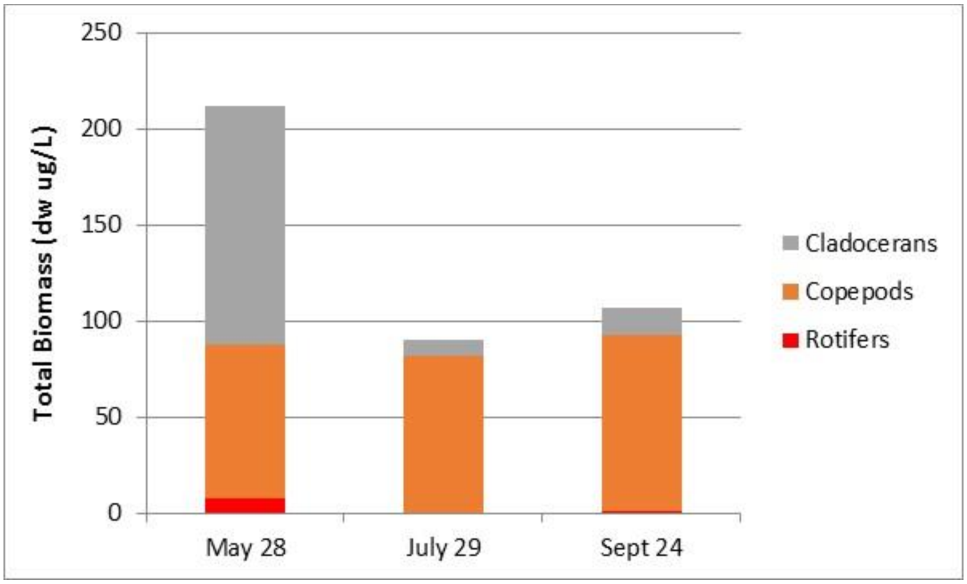


Plate 5-80. Relative abundance of zooplankton in samples collected from Wehrspan Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1).

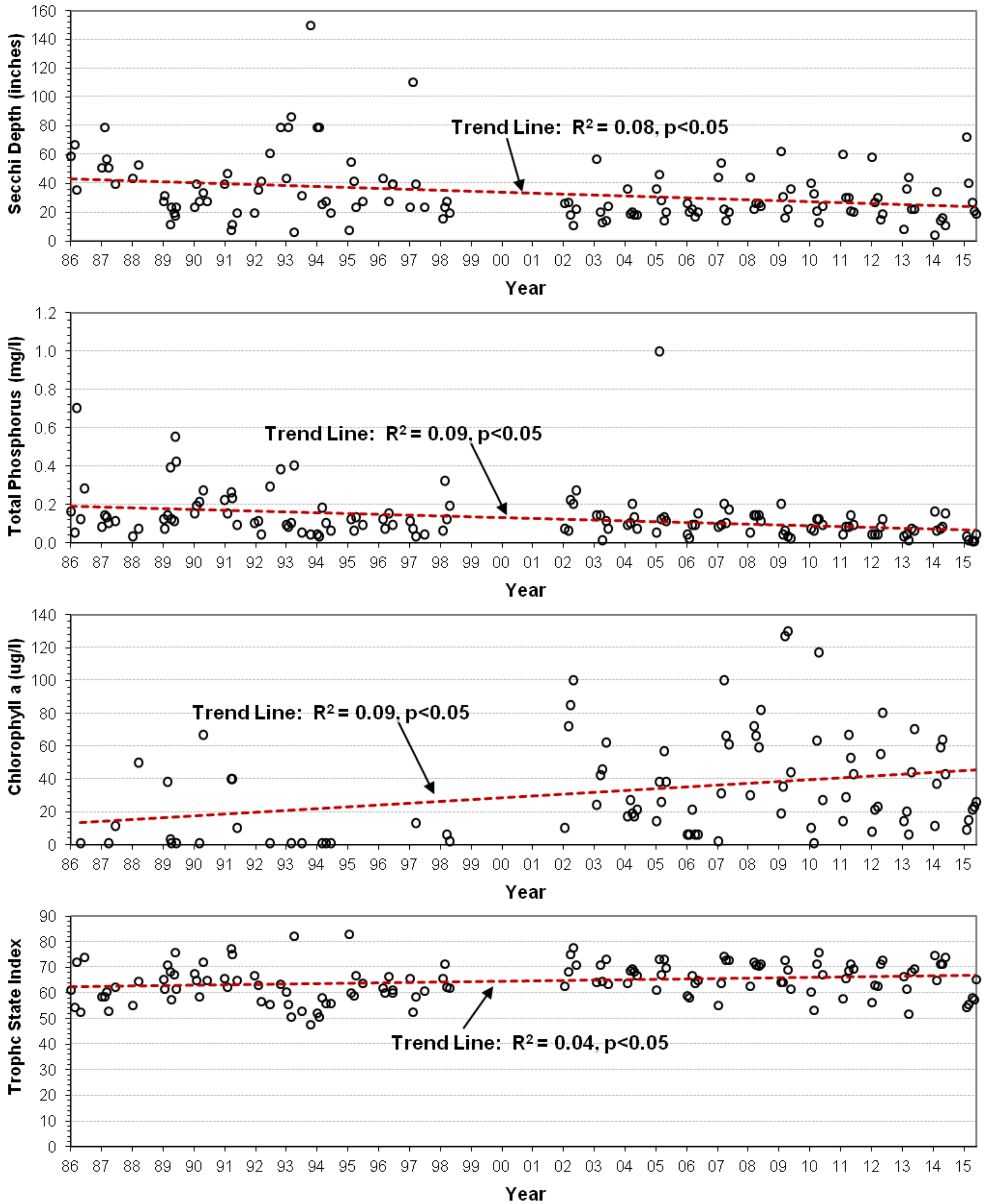


Plate 5-81. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Wehrspan Reservoir at the near-dam, ambient site (i.e., site WEHLKND1) over the 30-year period of 1986 through 2015.

Plate 5-82. Summary of runoff water quality conditions monitored in the main tributary inflow to Wehrspann Reservoir, upstream of the constructed sediment basin/wetland, at monitoring site WEHNFUSB1 during the period 2011 through 2015**.**

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedances	Percent WQS Exceedance
Water Temperature (°C)	0.1	7	16.70	18.60	7.47	20.58	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	7	8.58	8.50	7.20	11.08	≥5[2]	0	0%
Dissolved Oxygen (% Sat.)	0.1	7	92.63	93.00	82.10	101.50	-----	-----	-----
Turbidity (NTUs)	1	6	476.17	363.75	183.30	999.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	7	336.29	331.00	220.00	476.00	-----	-----	-----
Specific Conductance (umho/cm)	1	7	363.83	345.00	268.80	608.00	2,000[3]	0	0%
pH (S.U.)	0.1	6	7.89	7.82	7.44	8.40	≥6.5 & ≤9.0 [1]	0	0%
Suspended Solids, Total (mg/l)	10	8	516.25	381.00	80.00	1816.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	8	0.22	0.18	0.07	0.48	5.63[4,5], 1.02[4,6]	0	0%
Kjeldahl N, Total (mg/l)	0.02	8	2.23	1.92	0.96	3.86	-----		
Nitrate-Nitrite N, Total (mg/l)	0.8	8	1.61	1.65	n.d.	3.16	100[3]	0	0%
Nitrogen, Total (mg/l)	0.8	8	3.85	3.64	2.65	4.70	-----	-----	-----
Phosphorus, Total (mg/l)	0.008	8	0.72	0.61	0.37	1.72	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.008	1	0.09	0.09	0.09	0.09	-----	-----	-----
Atrazine, Total (ug/l)[C]	0.1	8	-----	1.55	n.d.	3.10	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[C]	0.1	8	-----	0.45	n.d.	1.50	390[5], 100[6]	0	0%
Acetochlor, Total (ug/l)[C]	0.05	8	0.89	0.80	n.d.	2.10	-----	-----	-----

n.d. = Not detected.

[A] Nondetect values set to detection limit 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] General criteria for aquatic life.
[2] Use-specific criteria for aquatic life.
[3] Agricultural criteria for surface waters.
[4] Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
[5] Acute criteria for aquatic life.
[6] Chronic criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 5-83. Summary of runoff water quality conditions monitored in the main tributary inflow to Wehrspann Reservoir, immediately below the constructed sediment basin/wetland, at monitoring site WEHNFDSB1 during the period 2011 through 2015**.**

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedances	Percent WQS Exceedance
Water Temperature (°C)	0.1	9	19.59	19.91	9.17	28.61	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	9	8.49	8.10	7.05	11.08	≥5[2]	0	0%
Dissolved Oxygen (% Sat.)	0.1	9	96.28	95.00	86.00	111.00	-----	-----	-----
Turbidity (NTUs)	1	8	339.28	267.15	43.00	916.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	9	350.22	358.00	222.00	481.00	-----	-----	-----
Specific Conductance (umho/cm)	1	9	378.12	326.00	202.20	709.00	2,000[3]	0	0%
pH (S.U.)	0.1	8	8.09	7.87	7.71	8.90	≥6.5 & ≤9.0 [1]	0	0%
Suspended Solids, Total (mg/l)	10	11	222.36	178.00	39.00	687.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	11	0.14	0.10	n.d.	0.41	3.76[4,5], 0.74[4,6]	0	0%
Kjeldahl N, Total (mg/l)	0.02	11	1.88	1.74	1.11	2.79	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.8	11	-----	n.d.	n.d.	1.80	100[3]	0	0%
Nitrogen, Total (mg/l)	0.8	11	2.81	2.69	1.20	4.25	-----	-----	-----
Phosphorus, Total (mg/l)	0.008	11	0.43	0.36	0.15	0.94	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.003	1	-----	n.d.	n.d.	n.d.	-----	-----	-----
Atrazine, Total (ug/l)[C]	0.05	11	2.81	1.60	n.d.	10.30	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[C]	0.05	11	0.73	0.50	n.d.	2.10	390[5], 100[6]	0	0%
Acetochlor, Total (ug/l)[C]	0.05	11	2.57	1.60	n.d.	8.90	-----	-----	-----

n.d. = Not detected.

[A] Nondetect values set to detection limit 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] General criteria for aquatic life.
[2] Use-specific criteria for aquatic life.
[3] Agricultural criteria for surface waters.
[4] Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
[5] Acute criteria for aquatic life.
[6] Chronic criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

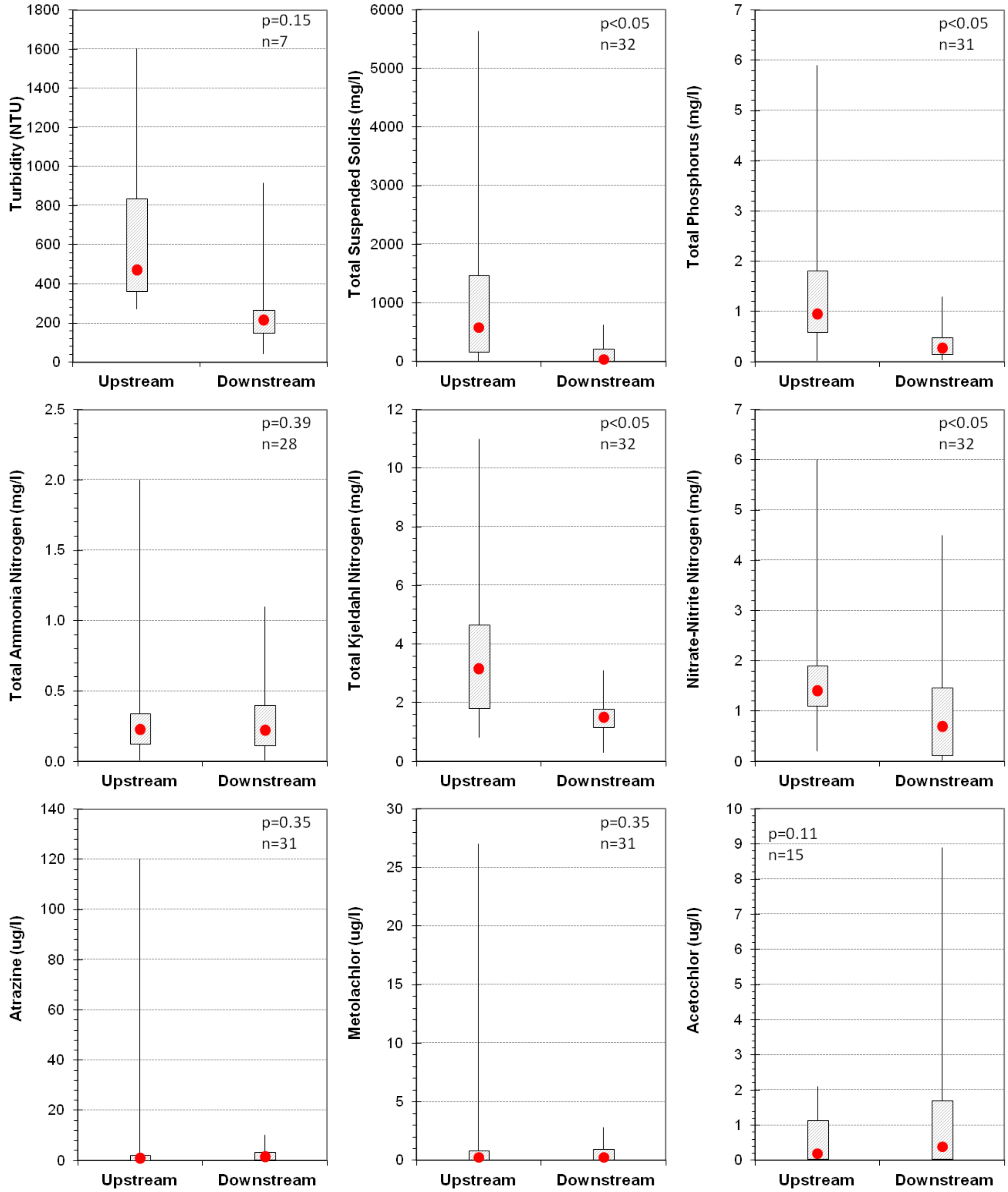


Plate 5-84. Box plots comparing paired runoff samples collected upstream (i.e., site WEHNFUSB1) and downstream (i.e., WEHNFDSB1) of the constructed sediment basin/wetland at Wehrspann Reservoir during the period 2002 through 2015. P-values indicate significant differences between the near-surface and near-bottom samples via a paired two-tailed t-test (α = 0.05). (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

6 SALT CREEK WATERSHED PROJECTS

6.1 BACKGROUND INFORMATION

6.1.1 SALT CREEK WATERSHED HYDROLOGY

Streamflow in the Salt Creek watershed follows a characteristic pattern. Flows are generally low except for brief periods of rise caused by runoff from rainfall events. A snowpack over the basin in early spring can produce a significant rise in flow as a result of snowmelt runoff. Streams in the basin generally freeze over during the winter months.

6.1.1.1 Tributary Project Reservoirs

Ten Tributary Projects [Bluestem, Branched Oak, Conestoga, Holmes, Olive Creek, Pawnee, Stagecoach, Twin Lakes (East and West Twin Reservoirs), Wagon Train, and Yankee Hill are located in the Salt Creek watershed in southeast Nebraska in the vicinity of the City of Lincoln (Figure 2.2). The authorized purposes for all the reservoirs are flood control, recreation, and fish and wildlife management. Table 6.1 gives selected engineering data for the Salt Creek Tributary Project reservoirs. Lake restoration projects have recently been completed on Holmes (2006) and Yankee Hill Reservoirs (2002). Conestoga Reservoir is currently being renovated.

6.1.1.2 Water Quality Standards Classifications and Section 303(d) Listings

The State of Nebraska's water quality standards designates the following beneficial uses to all the Salt Creek Tributary Project reservoirs: recreation, warmwater aquatic life, agricultural water supply, and aesthetics. None of the reservoirs are used as a public drinking water supply. Designated swimming beaches are present at Branched Oak, Pawnee, Bluestem, and Wagon Train Reservoirs. The State's water quality standards also identify nutrient criteria for lakes and impounded waters based on their geographic location. Under this categorization, Bluestem, Branched Oak, Conestoga, Holmes, Olive Creek, Pawnee, Stagecoach, Twin Lakes (East and West Twin Reservoirs), Wagon Train, and Yankee Hill have been included in group "E" for eastern lakes or impounded waters.

Pursuant to the Federal CWA, the State of Nebraska has listed several of the Salt Creek reservoirs as "Category 5" waters on the State's 2012 Section 303(d) list (see Table 2.2). A "Category 5" listing infers that at least one beneficial use is impaired and a TMDL is required. Salt Creek reservoirs listed as "Category 5" waters include: Bluestem, Branched Oak, Conestoga, East Twin, Olive Creek, Pawnee, Stagecoach, Wagon Train, and West Twin. The beneficial uses impaired include aquatic life, aesthetics, and recreation. The identified pollutants/stressors include: High pH, dissolved oxygen, mercury (fish tissue), algae toxins, ammonia, nutrients, and sediment. TMDLs have been completed for Holmes, Pawnee, Wagon Train, and Yankee Hill Reservoirs.

Table 6.1. Summary of selected engineering for the Salt Creek Tributary Projects.

	Bluestem Reservoir (Dam Site No. 4)		Branched Oak Reservoir (Dam Site No. 18)		Conestoga Reservoir (Dam Site No. 12)		Holmes Reservoir (Dam Site No. 17)	
General								
Dammed Stream	N. Trib. of Olive Branch		Oak Creek		Holmes Creek		Antelope Creek	
Drainage Area	16.6 sq. mi.		89.0 sq. mi.		15.1 sq. mi.		5.4 sq. mi.	
Reservoir Length(1)	1.6 miles		3.7 miles		1.4 miles		0.7 miles	
Conservation Pool Elevation (Top)	1307.4 ft-msl		1284.0 ft-msl		1232.9 ft-msl		1242.4 ft-msl	
Date of Dam Closure	12-Sep-1962		21-Aug-1967		24-Sep-1963		17-Sep-1962	
Date of Initial Fill(2)	6-Jul-1963		18-Jan-1973		1-May-1965		2-Jun-1965	
"As-Built" Conditions(3)	(1964)		(1967)		(1964)		(1963)	
Lowest Reservoir Bottom Elevation	1281 ft-msl		1244 ft-msl		1207 ft-msl		1224 ft-msl	
Surface Area at top of Conservation Pool	316 ac		1798 ac		227 ac		123 ac	
Capacity of Conservation Pool	3057 ac-ft		26385 ac-ft		2472 ac-ft		1059 ac-ft	
Mean Depth at top of Conservation Pool(4)	9.7 ft		14.7 ft		10.9 ft		8.6 ft	
Surveyed Conditions	1993:USACE	2002:USGS	1991:USACE	2003:NGPC	1996:USACE	2002:USGS	1993:USACE	2006:NGPC
Lowest Reservoir Bottom Elevation	1288 ft-msl	1291 ft-msl	1252 ft-msl	1252 ft-msl	1216 ft-msl	1214 ft-msl	1228 ft-msl	1226 ft-msl
Surface Area at top of Conservation Pool	309 ac	290 ac	1847 ac	1761 ac	217 ac	211 ac	123 ac	108 ac
Capacity of Conservation Pool	2531 ac-ft	2102 ac-ft	25088 ac-ft	24526 ac-ft	1808 ac-ft	1846 ac-ft	783 ac-ft	931 ac-ft
Mean Depth at top of Conservation Pool(4)	8.2 ft	7.2 ft	13.6 ft	13.9 ft	8.3 ft	8.7 ft	6.4 ft	8.6 ft
Sediment Deposition in Multipurpose Pool	1993:USACE	2002:USGS	1991:USACE	2003:NGPC	1996:USACE	2002:USGS	1993:USACE	2006:NGPC
Surveyed Sediment Deposition(5)	526 ac-ft	955 ac-ft	1297 ac-ft	1859 ac-ft	664 ac-ft	626 ac-ft	276 ac-ft	128 ac-ft
Annual Sedimentation Rate(6)(11)	18.1 ac-ft/yr	25.1 ac-ft/yr	54.0 ac-ft/yr	51.6 ac-ft/yr	20.8 ac-ft/yr	16.5 ac-ft/yr	9.2 ac-ft/yr	-----
Current Estimated Sediment Deposition(7)(11)	925 ac-ft	1282 ac-ft	2594 ac-ft	2479 ac-ft	1058 ac-ft	840 ac-ft	278 ac-ft	211 ac-ft
Current capacity of Multipurpose Pool(8)(11)	2132 ac-ft	1775 ac-ft	23791 ac-ft	23906 ac-ft	1414 ac-ft	1632 ac-ft	781 ac-ft	848 ac-ft
Annual Percent of Multipurpose Pool Capacity Lost to Sedimentation	0.59%	0.82%	0.20%	0.20%	0.84%	0.67%	0.87%	-----
Percent of "As-Built" Multipurpose Pool capacity lost to current estimated sediment deposition(11)	30%	42%	10%	9%	43%	34%	26%	20%
Operational Details – Historic	(1964-2015)		(1973-2015)		(1966-2015)		(1966-2015)	
Maximum Recorded Pool Elevation	1316.5 ft-msl	11-Oct-1973	1287.9 ft-msl	26-Aug-1987	1241.1 ft-msl	24-Mar-1987	1250.0 ft-msl	24-Jul-1993
Minimum Recorded Pool Elevation	1299.1 ft-msl	28-Oct-1991	1277.6 ft-msl	30-Sep-2006	1224.9 ft-msl	22-Apr-2007	1231.0 ft-msl	1-Oct-2003
Maximum Recorded Daily Inflow	1501 cfs	8-May-2015	3700 cfs	25-Aug-1987	1401 cfs	8-May-2015	604 cfs	24-Jul-1993
Maximum Recorded Daily Outflow	342 cfs	12-Oct-1973	774 cfs	25-Jul-1993	678 cfs	16-Jun-2015	187 cfs	29-Jun-1983
Average Annual Pool Elevation	1305.9 ft-msl		1283.2 ft-msl		1231.9 ft-msl		1241.0 ft-msl	
Average Annual Inflow	4427 ac-ft		25857 ac-ft		4891 ac-ft		3333 ac-ft	
Average Annual Outflow	3394 ac-ft		20014 ac-ft		4155 ac-ft		2912 ac-ft	
Estimated Retention Time(9)	0.63 Years		1.19 Years		0.34 Years		0.27 Years	
Operational Details – Current(10)	(2011-2015)		(2011-2015)		(2011-2015)		(2011-2015)	
Maximum Recorded Pool Elevation	1316.3 ft-msl	8-May-2015	1286.7 ft-msl	31-Aug-2014	1239.9 ft-msl	12-Jun-2015	1249.2 ft-msl	8-May-2015
Minimum Recorded Pool Elevation	1303.3 ft-msl	30-Mar-2013	1281.9 ft-msl	14-Nov-2012	1227.6 ft-msl	26-Aug-2014	1238.8 ft-msl	12-Sep-2012
Maximum Recorded Daily Inflow	1501 cfs	8-May-2015	1568 cfs	8-May-2015	1401 cfs	8-May-2015	300 cfs	12-Jun-2015
Maximum Recorded Daily Outflow	277 cfs	9-May-2015	348 cfs	31-Aug-2014	678 cfs	16-Jun-2015	115 cfs	8-May-2015
Average Annual Inflow (% of Historical Average Annual)	3276 ac-ft	(74%)	17112 ac-ft	(66%)	7001 ac-ft	(143%)	3339 ac-ft	(100%)
Average Annual Outflow (% of Historical Average Annual)	1888 ac-ft	(56%)	10340 ac-ft	(52%)	6375 ac-ft	(153%)	2769 ac-ft	(95%)
Outlet Works								
Ungated Outlets	2) 30" x 96" 2) 12" x 54"	1313.5 ft-msl 1307.4 ft-msl	2) 42" x 144"	1284.0 ft-msl	2) 30" x 96" 2) 12" x 54"	1242.3 ft-msl 1232.9 ft-msl	2) 30" x 96" 2) 12" x 36"	1249.0 ft-msl 1242.5 ft-msl
Gated Outlets (Low-level) (12)	1) 36" x 36"	1303.0 ft-msl	1) 48" x 72" 1) 10" Dia.	1274.0 ft-msl 1276.3 ft-msl	1) 36" x 36"	1228.0 ft-msl	1) 36" x 36" 1) 45" x 45"	1239.0 ft-msl 1230.6 ft-msl

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

(1) Reservoir length at top of multipurpose 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) Surveyed sediment deposition is the difference in reservoir storage capacity to top of Multipurpose Pool between "as-built" and 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) Estimated Retention Time = Current Estimated Multipurpose Pool Volume ÷ Average Annual Outflow.

(10) Current operational details are for the last five water years, 1-Oct-2011 through 30-Sep-2015

(11) A lake renovation project was completed at Holmes Reservoir in 2005 and an estimated 200 ac-ft of sediment was removed from the bottom of the reservoir. Values given are estimates for conditions after the removal of the sediment based on the NGPC survey.

(12) A new gate was installed in the Holmes Dam outlet works as part of the 2004 Lake renovation Project to allow the reservoir to be drawn down to lower pool elevations.

* A highlighted percent indicates impairment based on the State of Nebraska's assessment of lake sedimentation data.

Table 7.1. Summary of selected engineering for the Salt Creek Tributary Projects.

	Olive Creek Reservoir (Dam Site No. 2)		Pawnee Reservoir (Dam Site No. 14)		Stagecoach Reservoir (Dam Site No. 9)		Twin Lakes East and West Twin Res. (Dam Site No. 13)	
General								
Dammed Stream	S. Trib of Olive Branch		North Middle Creek		S. Trib. Of Hickman Branch		Middle Creek	
Drainage Area	8.2 sq. mi.		35.9 sq. mi.		9.7 sq. mi.		11.0 sq. mi.	
Reservoir Length(1)	1.2 miles		3.0 miles		1.4 miles		1.5 miles	
Conservation Pool Elevation (Top)	1335.0 ft-msl		1244.3 ft-msl		1271.1 ft-msl		1341.0 ft-msl	
Date of Dam Closure	20-Sep-1963		16-Jul-1964		27-Aug-1963		26-Sep-1965	
Date of Initial Fill(2)	30-Jun-1965		21-Jun-1967		1-May-1965		18-Mar-1969	
"As-Built" Conditions(3)	(1964)		(1966)		(1964)		(1966)	
Lowest Reservoir Bottom Elevation	1316 ft-msl		1209 ft-msl		1252 ft-msl		1316 ft-msl	
Surface Area at top of Conservation Pool	169 ac		734 ac		201 ac		245 ac	
Capacity of Conservation Pool	1298 ac-ft		8695 ac-ft		1770 ac-ft		2561 ac-ft	
Mean Depth at top of Conservation Pool(4)	7.7 ft		11.8 ft		8.8 ft		10.5 ft	
Surveyed Conditions	1993:USACE	2005:USGS	1991:USACE	2002:NGPC	1990:USACE	2002:USGS	1994:USACE	2002:USGS
Lowest Reservoir Bottom Elevation	1322 ft-msl	1320 ft-msl	1219 ft-msl	1220 ft-msl	1256 ft-msl	1256 ft-msl	1320 ft-msl	1320 ft-msl
Surface Area at top of Conservation Pool	162 ac	120 ac	725 ac	604 ac	195 ac	196 ac	236 ac	232 ac
Capacity of Conservation Pool	1100 ac-ft	1060 ac-ft	7500 ac-ft	6924 ac-ft	1451 ac-ft	1422 ac-ft	2161 ac-ft	1808 ac-ft
Mean Depth at top of Conservation Pool(4)	6.8 ft	8.8 ft	10.3 ft	11.5 ft	7.4 ft	7.3 ft	9.2 ft	7.8 ft
Sediment Deposition in Multipurpose Pool	1993:USACE	2005:USGS	1991:USACE	2002:NGPC	1990:USACE	2002:USGS	1994:USACE	2002:USGS
Surveyed Sediment Deposition(5)	198 ac-ft	238 ac-ft	1195 ac-ft	1771 ac-ft	319 ac-ft	348 ac-ft	400 ac-ft	753 ac-ft
Annual Sedimentation Rate(6)(11)	6.8 ac-ft/yr	-----	47.8 ac-ft/yr	49.2 ac-ft/yr	12.3 ac-ft/yr	9.2 ac-ft/yr	14.3 ac-ft/yr	20.9 ac-ft/yr
Current Estimated Sediment Deposition(7)(11)	263 ac-ft	306 ac-ft	2342 ac-ft	2411 ac-ft	626 ac-ft	467 ac-ft	700 ac-ft	1025 ac-ft
Current capacity of Multipurpose Pool(8)(11)	1035 ac-ft	992 ac-ft	6353 ac-ft	6284 ac-ft	1144 ac-ft	1303 ac-ft	1861 ac-ft	1536 ac-ft
Annual Percent of Multipurpose Pool Capacity Lost to Sedimentation	0.53%	-----	0.55%	0.57%	0.69%	0.52%	0.56%	0.82%
Percent of "As-Built" Multipurpose Pool capacity lost to current estimated sediment deposition(11)	20%	24%	27%	28%	35%	26%	27%	40%
Operational Details – Historic	(1966-2015)		(1968-2015)		(1965-2015)		(1969-2015)	
Maximum Recorded Pool Elevation	1345.3 ft-msl	8-May-2015	1249.1 ft-msl	25-Jul-1993	1279.7 ft-msl	5-Jun-2008	1346.9 ft-msl	29-Jun-1983
Minimum Recorded Pool Elevation	1324.3 ft-msl	1-Dec-1999	1240.2 ft-msl	14-Oct-1979	1259.6 ft-msl	31-Oct-1991	1332.1 ft-msl	31-Oct-1991
Maximum Recorded Daily Inflow	920 cfs	23-May-2004	1381 cfs	24-Mar-1987	1030 cfs	23-May-2004	632 cfs	14-Jun-2001
Maximum Recorded Daily Outflow	188 cfs	24-May-2004	420 cfs	25-Jul-1993	193 cfs	6-Jun-2008	168 cfs	30-Jun-1983
Average Annual Pool Elevation	1332.1 ft-msl		1243.7 ft-msl		1270.4 ft-msl		1339.3 ft-msl	
Average Annual Inflow	2207 ac-ft		6784 ac-ft		3259 ac-ft		3558 ac-ft	
Average Annual Outflow	1623 ac-ft		4364 ac-ft		2573 ac-ft		2719 ac-ft	
Estimated Retention Time(9)	0.64 Years		1.46 Years		0.44 Years		0.68 Years	
Operational Details – Current(10)	(2011-2015)		(2011-2015)		(2011-2015)		(2011-2015)	
Maximum Recorded Pool Elevation	1345.3 ft-msl	8-May-2015	1246.2 ft-msl	16-Jun-2015	1278.9 ft-msl	8-May-2015	1345.1 ft-msl	16-Jun-2015
Minimum Recorded Pool Elevation	1330.7 ft-msl	7-Apr-2013	1241.1 ft-msl	14-Dec-2012	1269.2 ft-msl	13-Dec-2012	1338.4 ft-msl	14-Dec-2012
Maximum Recorded Daily Inflow	813 cfs	8-May-2015	577 cfs	8-May-2015	897 cfs	8-May-2015	515 cfs	8-May-2015
Maximum Recorded Daily Outflow	133 cfs	9-May-2015	139 cfs	16-Jun-2015	133 cfs	9-May-2015	134 cfs	16-Jun-2015
Average Annual Inflow (% of Historical Average Annual)	1767 ac-ft	(80%)	3961 ac-ft	(58%)	3008 ac-ft	(92%)	2006 ac-ft	(56%)
Average Annual Outflow (% of Historical Average Annual)	971 ac-ft	(60%)	1183 ac-ft	(27%)	2164 ac-ft	(84%)	1069 ac-ft	(39%)
Outlet Works								
Ungated Outlets	2) 24" x 72" 2) 12" x 30"	1340.9 ft-msl 1335.0 ft-msl	2) 34" x 120"	1244.3 ft-msl	2) 24" x 72" 2) 12" x 30"	1277.1 ft-msl 1271.1 ft-msl	2) 24" x 63"	1341.0 ft-msl
Gated Outlets (Low-level)	1) 36" x 36"	1330.0 ft-msl	1) 42" x 60"	1236.0 ft-msl	1) 36" x 36"	1261.0 ft-msl	1) 42" x 54"	1333.0 ft-msl

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

(1) Reservoir length at top of multipurpose 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) Surveyed sediment deposition is the difference in reservoir storage capacity to top of Multipurpose Pool between "as-built" and 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) Estimated Retention Time = Current Estimated Multipurpose Pool Volume ÷ Average Annual Outflow.

(10) Current operational details are for the last five water years, 1-Oct-2011 through 30-Sep-2015

(11) A lake renovation project was completed at Olive Creek Reservoir in 2000 and an estimated 85 ac-ft of sediment was removed from the bottom of the reservoir. Values given are estimates for conditions after the removal of the sediment. The USGS 2005 survey was conducted after the lake renovation project was completed.

* A highlighted percent indicates impairment based on the State of Nebraska's assessment of lake sedimentation data.

Table 7.1. Summary of selected engineering for the Salt Creek Tributary Projects.

	Wagon Train Reservoir (Dam Site No. 8)		Yankee Hill Reservoir (Dam Site No. 10)					
General								
Dammed Stream	N. Trib. Of Hickman Branch		Cardwell Branch					
Drainage Area	15.6 sq. mi.		9.7 sq. mi.					
Reservoir Length[1]	1.8 miles		1.4 miles					
Conservation Pool Elevation (Top)	1287.8 ft-msl		1244.9 ft-msl					
Date of Dam Closure	24-Sep-1962		27-Aug-1963					
Date of Initial Fill[2]	24-Jun-1963		1-May-1965					
“As-Built” Conditions[3]	(1963)		(1966)					
Lowest Reservoir Bottom Elevation	1261 ft-msl		1226 ft-msl					
Surface Area at top of Conservation Pool	279 ac		216 ac					
Capacity of Conservation Pool	2272 ac-ft		1907 ac-ft					
Mean Depth at top of Conservation Pool[4]	8.1 ft		8.8 ft					
Surveyed Conditions	1993:USACE	2005:USGS	1994:USACE	2005:USGS				
Lowest Reservoir Bottom Elevation	1272 ft-msl	1273 ft-msl	1231 ft-msl	1228 ft-msl				
Surface Area at top of Conservation Pool	277 ac	293 ac	211 ac	192 ac				
Capacity of Conservation Pool	2053 ac-ft	2012 ac-ft	1627 ac-ft	1680 ac-ft				
Mean Depth at top of Conservation Pool[4]	7.4 ft	6.9 ft	7.7 ft	8.8 ft				
Sediment Deposition in Multipurpose Pool	1993:USACE	2005:USGS	1994:USACE	2005:USGS				
Surveyed Sediment Deposition[5]	219 ac-ft	260 ac-ft	280 ac-ft	227 ac-ft				
Annual Sedimentation Rate[6][11][12]	7.3 ac-ft/yr	-----	10.0 ac-ft/yr	-----				
Current Estimated Sediment Deposition[7][11][12]	335 ac-ft	333 ac-ft	273 ac-ft	327 ac-ft				
Current capacity of Multipurpose Pool[8][11][12]	1937 ac-ft	1939 ac-ft	1634 ac-ft	1580 ac-ft				
Annual Percent of Multipurpose Pool Capacity Lost to Sedimentation	0.32%	-----	0.52%	-----				
Percent of “As-Built” Multipurpose Pool capacity lost to current estimated sediment deposition[11][12]	15%	15%	14%	17%				
Operational Details – Historic	(1964-2015)		(1968-2015)					
Maximum Recorded Pool Elevation	1295.5 ft-msl	5-Jun-2008	1253.5 ft-msl	8-May-2015				
Minimum Recorded Pool Elevation	1273.1 ft-msl	5-Apr-2000	1232.0 ft-msl	25-Oct-2003				
Maximum Recorded Daily Inflow	1237 cfs	8-May-2015	896 cfs	8-May-2015				
Maximum Recorded Daily Outflow	334 cfs	25-Jul-1993	145 cfs	12-Oct-1973				
Average Annual Pool Elevation	1286.3 ft-msl		1243.0 ft-msl					
Average Annual Inflow	5227 ac-ft		4669 ac-ft					
Average Annual Outflow	4266 ac-ft		4004 ac-ft					
Estimated Retention Time[9]	0.45 Years		0.41 Years					
Operational Details – Current[10]	(2011-2015)		(2011-2015)					
Maximum Recorded Pool Elevation	1294.9 ft-msl	8-May-2015	1253.5 ft-msl	8-May-2015				
Minimum Recorded Pool Elevation	1285.6 ft-msl	29-Mar-2013	1242.3 ft-msl	14-Dec-2012				
Maximum Recorded Daily Inflow	1237 cfs	8-May-2015	896 cfs	8-May-2015				
Maximum Recorded Daily Outflow	249 cfs	9-May-2015	138 cfs	9-May-2015				
Average Annual Inflow (% of Historical Average Annual)	5182 ac-ft	(99%)	3079 ac-ft	(66%)				
Average Annual Outflow (% of Historical Average Annual)	3934 ac-ft	(92%)	2194 ac-ft	(55%)				
Outlet Works								
Ungated Outlets	2) 30” x 96” 2) 12” x 54”	1292.4 ft-msl 1287.8 ft-msl	2) 18” x 63” 2) 12” x 30”	1250.0 ft-msl 1244.9 ft-msl				
Gated Outlets (Low-level)	1) 36” x 36”	1283.5 ft-msl	1) 36” x 36”	1237.0 ft-msl				

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

(1) Reservoir length at top of multipurpose 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) Surveyed sediment deposition is the difference in reservoir storage capacity to top of Multipurpose Pool between “as-built” and 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) Estimated Retention Time = Current Estimated Multipurpose Pool Volume ÷ Average Annual Outflow.

(10) Current operational details are for the last five water years, 1-Oct-2011 through 30-Sep-2015

(11) A lake renovation project was completed at Wagon Train Reservoir in 2003 and an estimated 45 ac-ft of sediment was removed from the bottom of the reservoir. Values given are estimates for conditions after the removal of the sediment. The USGS 2005 survey was conducted after the lake renovation project was completed.

(12) A lake renovation project was completed at Yankee Hill Reservoir in 2005 and an estimated 217 ac-ft of sediment was removed from the bottom of the reservoir. Values given are estimates for conditions after the removal of the sediment. The USGS 2005 survey was conducted after the lake renovation project was completed.

* A highlighted percent indicates impairment based on the State of Nebraska's assessment of lake sedimentation data.

6.2 BLUESTEM RESERVOIR

6.2.1 BACKGROUND INFORMATION

6.2.1.1 Project Overview

The dam forming Bluestem Reservoir is located on a tributary to the Olive Branch. The dam was completed on September 12, 1962 and the reservoir reached its initial fill on July 6, 1963. The Bluestem Reservoir watershed is 16.6 square miles. The watershed was largely agricultural when the dam was built in 1962 and has remained so to the present time.

6.2.1.2 Bluestem Dam Intake Structure

The intake structure at Bluestem Dam is a single reinforced concrete box shaft commonly called a two-way drop inlet. Its inside dimensions are 5 feet by 8 feet. The intake structure has four ungated openings – two 30” x 96” openings with a crest elevation at 1313.5 ft-msl and two 12” x 54” openings with a crest elevation of 1307.4. A 36” x 36” gated opening with a crest elevation at 1303.0 ft-msl was constructed into the upstream wall. The purpose of the gated opening is to lower the level of the conservation pool in order to inspect the conduit, make shoreline repairs, and manage fish populations. It may also be used to release water for downstream needs when the reservoir is below conservation pool.

6.2.1.2.1 Reservoir Storage Zones

Figure 6.1 depicts the current storage zones of Bluestem Reservoir based on the 1993 survey data and estimated sedimentation. It is estimated that 30 to 42 percent of the “as-built” volume to the top of the Conservation Pool has been lost to sedimentation as of 2015. The annual volume loss is estimated to be 0.59 to 0.82 percent. Based on the State of Nebraska’s impairment assessment methodology, these values indicate that Bluestem Reservoir’s water quality dependent uses are impaired due to sedimentation.

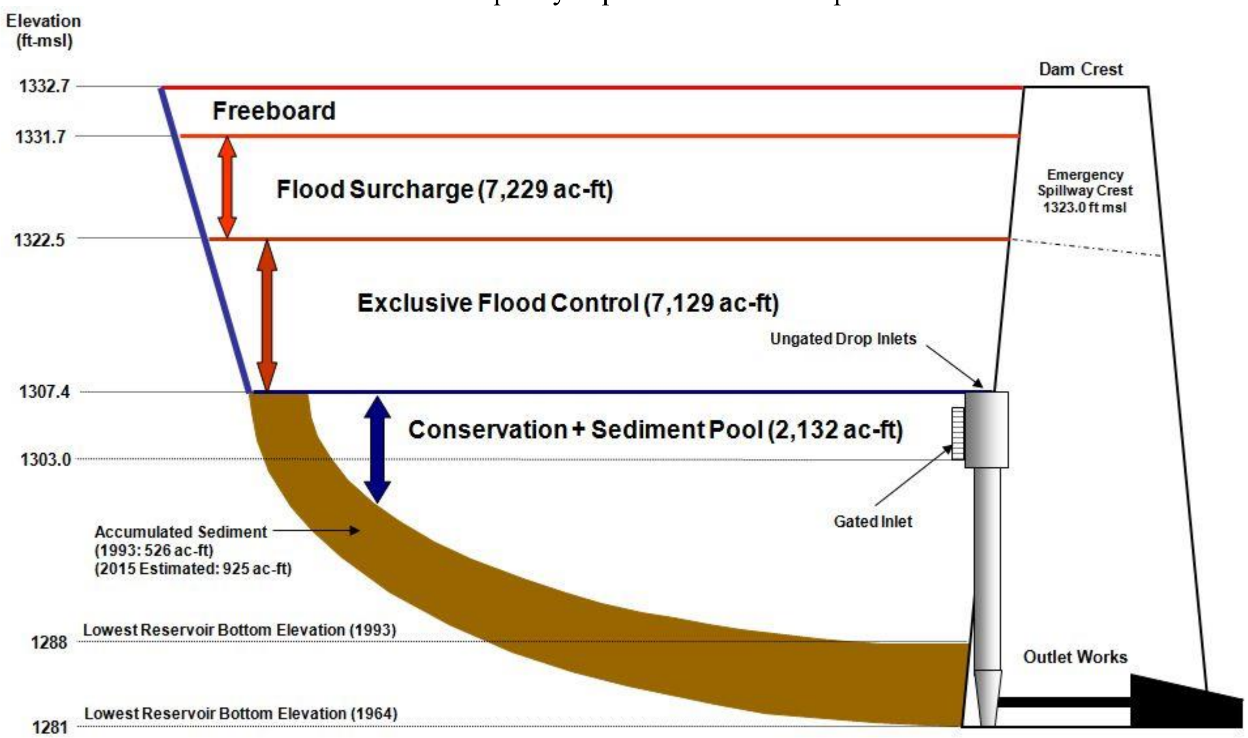


Figure 6.1. Current storage zones of Bluestem Reservoir based on the 1993 survey data and estimated sedimentation**.**

6.2.1.3 <u>Ambient Water Quality Monitoring</u>

The District has monitored water quality conditions at Bluestem Reservoir since the late 1970's. Water quality monitoring locations have included sites in the reservoir and on the inflow and outflow of the reservoir. Figure 6.2 shows the location of the sites that have been monitored for water quality during the 5-year sampling period (i.e., 2011 through 2015). The inflow runoff sites (BLUNFNRT1 and BLUNFWST1) and the in-reservoir bacteria site (BLULKBACT1) were sampled by the Nebraska Department of Environmental Quality (NDEQ). The other in-reservoir sites (BLULKND1, BLULKML1, and BLULKUP1) were sampled by the District. The near-dam location (BLULKND1) has been continuously monitored since 1980.

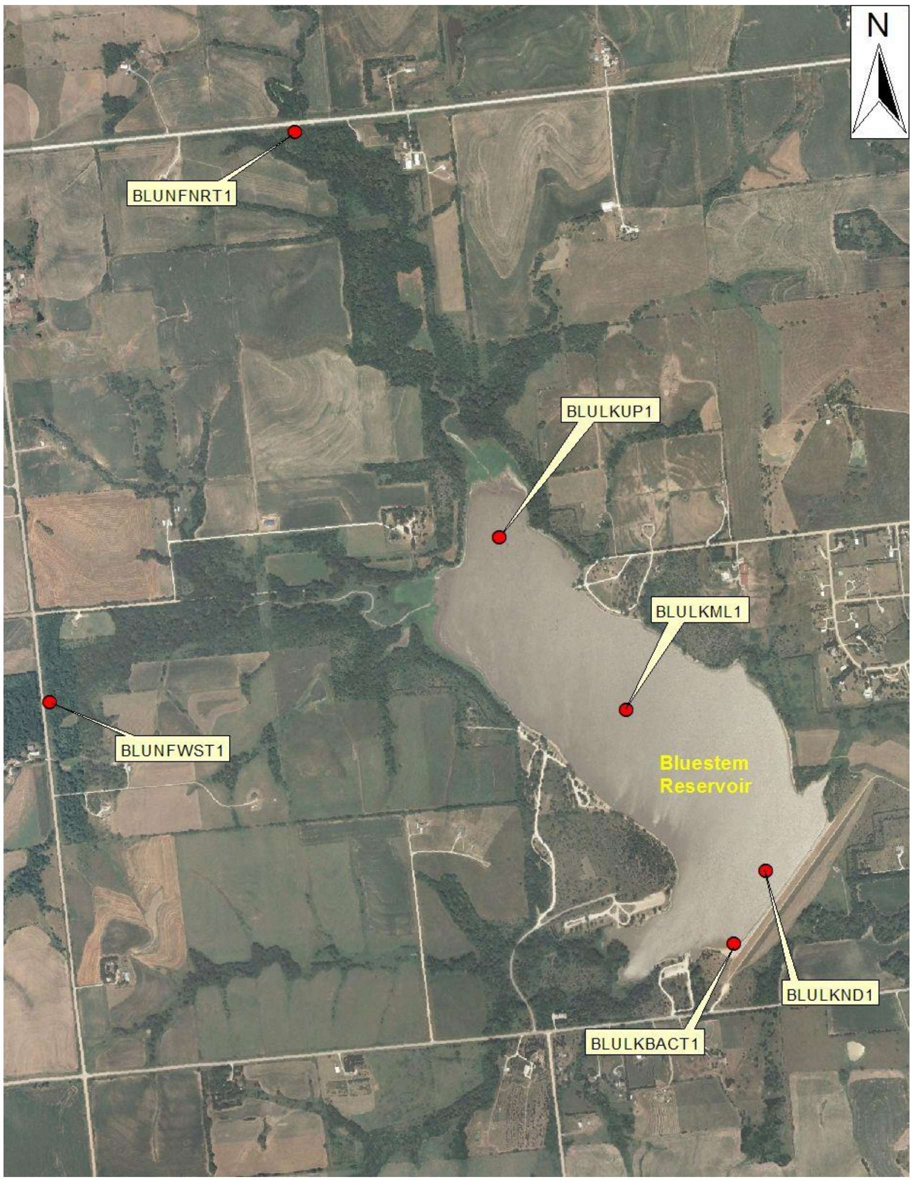


Figure 6.2. Location of sites where water quality monitoring was conducted at Bluestem Reservoir during the period 2008 through 2012.

6.2.2 Water Quality in Bluestem Reservoir

6.2.2.1 <u>Existing Water Quality Conditions</u>

6.2.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Bluestem Reservoir at sites BLULKND1, BLULKML1, and BLULKUP1 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 6-1 through Plate 6-3. A review of these results indicated possible water quality concerns regarding dissolved oxygen and nutrients.

A significant number of dissolved oxygen measurements throughout Bluestem Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 6-1-Plate 6-3). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and appeared to be associated with a slight thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Bluestem Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation. However, thermal stratification in Bluestem Reservoir was relatively limited during the 5-year sampling period of 2011 through 2015 (Plate 6-5). This limited stratification could lead to the above provision not applying to the reservoir and possible impairment for dissolved oxygen for the protection of aquatic life in Bluestem Reservoir. In addition, dissolved oxygen measurements on June 24, 2015 were below the5 mg/l criterion for the protection of warmwater aquatic life from the reservoirs surface to bottom.

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September) to be considered for impairment assessment. All three of these criteria were exceeded Bluestem Reservoir (Plate 6-1). The near-surface chlorophyll *a* criterion was exceeded by 80 percent of the "lab analyzed" samples taken in the reservoir at site BLULKND1. The total phosphorus and total nitrogen criteria were exceeded by 100 and 92 percent of samples, respectively. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values represent the growing season average for the 5-year period 2011 through 2015. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.25 mg/l), total nitrogen (1.95 mg/l), and chlorophyll *a* (28 ug/l) values at BLULKND1 indicate impairment of the aquatic life use due to nutrients.

6.2.2.1.2 Thermal Stratification

6.2.2.1.2.1 ***Longitudinal Temperature Contour Plots***

Late-spring and summer thermal conditions of Bluestem Reservoir measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 6-4 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites BLULKND1, BLULKML1, and BLULKUP1 in 2015. These temperature plots indicate that appreciable thermal variation was rarely present in Bluestem Reservoir during late-spring and summer. Significant thermal stratification was only observed in June 2015, when a 4°C difference was monitored between the surface and bottom water temperatures.

6.2.2.1.2.2 ***Near-Dam Temperature Depth-Profile Plots***

Existing summer thermal stratification of Bluestem Reservoir is depicted by the depth-profile temperature plots measured in the deep water area near the dam over the 5-year period 2011 through 2015 (Plate 6-5). The plotted depth-profile temperature measurements indicate that the reservoir rarely exhibited significant summer thermal stratification over the 5-year sampling period. Since Bluestem Reservoir ices over in the winter and seemingly exhibits frequent or continuous circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.2.2.1.3 Dissolved Oxygen Conditions

6.2.2.1.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of Bluestem Reservoir based on depth-profile measurements taken during 2015 at sites BLULKND1, BLULKML1, and BLULKUP1. Plate 6-6 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 only observed in June, near the reservoir bottom.

6.2.2.1.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

The depth-profile dissolved oxygen measurements collected during the summer over the 5-year sampling period at the deep water area near the dam were compiled and plotted to describe the existing summer dissolved oxygen conditions of Bluestem Reservoir (Plate 6-7). Some of the plotted profiles indicate an appreciable vertical gradient in dissolved oxygen levels, but most profiles show a fairly constant dissolved oxygen concentration from the reservoir surface to the bottom. Sixteen percent of the profiles showed hypoxic conditions near the reservoir bottom. One of the profiles indicated dissolved oxygen levels below Nebraska's criteria for the protection of aquatic life (<5.0 mg/l) through the entire profile.

6.2.2.1.3.3 ***Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of Bluestem 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 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 June 24, 2015 contour plot indicates a pool elevation of 1309.7 ft-msl, a 5 mg/l dissolved oxygen isopleth at the surface elevation of about 1309.7 ft-msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1,299.0 ft-msl (Plate 6-6). The current District Area-Capacity Tables (1993 Survey) give storage capacities of 3,300 ac-ft for elevation 1309.7 ft-msl and 619 ac-ft for elevation 1299.0 ft-msl. On June 24, 2015 it is estimated that 100 percent of the volume of Bluestem Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 19 percent of the reservoir volume was hypoxic.

6.2.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Bluestem Reservoir indicated hypoxic conditions were not prevalent during 2015 (Plate 6-6) and during the 5-year sampling period of 2011 through 2015 (Plate 6-7), additional water quality assessment of hypoxic conditions was not conducted.

6.2.2.1.4.1 ***Reservoir Trophic Status***

Trophic State Index (TSI) values for Bluestem Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., BLULKND1). Table 6.2 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Bluestem Reservoir is in a hypereutrophic condition. It is noted that the TSI(SD) and TSI(AVG) values are seemingly skewed due to the high turbidity of the reservoir.

Table 6.2. Summary of Trophic State Index (TSI) values calculated for Bluestem Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	23	84	85	71	97
TSI(TP)	25	72	71	63	82
TSI(Chl)	25	70	72	50	79
TSI(Avg)	25	75	75	67	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 for the individual parameters.
Note: See Section 4.1.3 for discussion of TSI calculation.

6.2.2.1.4.2 ***Monitoring at Swimming Beaches***

A designated swimming beach is located on Bluestem Reservoir. Bacteria (i.e., *E. coli*) and the cyanobacteria toxin microcystin were monitored at the swimming beach on the reservoir at site BLULKBACT1 by the NDEQ (Figure 6.2). Bacteria were monitored from May through September over the 5-year period 2011 through 2015, and microcystin was monitored from May through September during the 5-year period 2011 through 2015.

6.2.2.1.4.2.1 <u>Bacteria Monitoring</u>

Table 6.3 summarizes the results of the *E. coli* bacteria monitoring. The “running 5-week” geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The “pooled” geomean was determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for *E. coli* bacteria:

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

The 5-year pooled geomean was compared to the State of Nebraska’s impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using *E. coli* bacteria data. Based on that methodology a Primary Contact Recreation, Bluestem Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

6.2.2.1.4.2.2 <u>Microcystin Monitoring</u>

Table 6.4 summarizes the microcystin monitoring conducted at the Bluestem Reservoir swimming beach during the 5-year period 2011 through 2015. These results were compared to the 20 ug/l criterion for issuing health advisories and the posting of swimming beaches. Four samples, 4 percent of the collected samples, exceeded the criterion. The monitored levels of total microcystin do not indicate a significant cyanobacteria toxin concern at Bluestem Reservoir.

Table 6.3. Summary of weekly (May through September) *E. coli* bacteria samples collected at Bluestem Reservoir (i.e., site BLULKBACT1) during the 5-year period 2011 through 2015.

***E. coli* – Individual Samples**		***E. coli* – Geomeans (Running 5-Week)**	
Number of Samples	108	Number of Geomeans	88
Mean (cfu/100ml)	181	Average	49
Median (cfu/100ml)	14	Median	9
Minimum (cfu/100ml)	1	Minimum	2
Maximum (cfu/100ml)	4106	Maximum	424
Percent of samples exceeding 235/100ml	14%	Percent of Geomeans exceeding 126/100ml	13%
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	16

Table 6.4. Summary of weekly (May through September) total microcystin samples collected at the Bluestem Reservoir swimming beach (i.e., site BLULKBACT1) during the 5-year period 2008 through 2012.

Summary Statistic	**Swimming Beach (Site BLULKBACT1)**
Number of Samples	109
Minimum (ug/l)	n.d.
25th percentile (ug/l)	n.d.
Median (ug/l)	0.31
75th Percentile (ug/l)	2.73
Maximum (ug/l)	43.89
Number of samples exceeding 20 ug/l	4
Percent of samples exceeding 20 ug/l	4%

6.2.2.1.5 Reservoir Plankton Community

6.2.2.1.5.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at the Bluestem Reservoir near-surface, near-dam sampling site during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-8). The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 6-9. Phytoplankton was significantly more abundant in September when compared to May and July. Ochrophyta and Cyanobacteria were the most dominant phytoplankton in 2015. Phytoplankton populations show some seasonal successional patterns commonly observed in eutrophic reservoirs. Ochrophyta and other cool water taxa tend to dominate spring and late fall while Cyanobacteria tend to dominate summer and early fall when the water is warmer. Major and dominant phytoplankton genera sampled in 2015 at Bluestem Reservoir are provided in Table 6.7.

Annual variation in phytoplankton community composition is displayed in Plate 6-10. During the 5-year period 2011 through 2015 Cyanobacteria, Ochrophyta and Chlorophyta dominated Bluestem Reservoir. Cyanobacteria density levels were greater than the World Health Organizations high level of health risk (>100,000 Cells/ml) in 2012 (Plate 6-8). 2012 was a particularily warm dry year. The resulting longer reservoir residence time, decreased mixing, and warmer waters could have resulted in a longer Cyanbacterial growing season which lead to the large densities and biovolumes observed. The maximum extracellular microcystin level measured during the 5-year period at the near-dam site was 0.3 µg/L (Plate 6-1).

Table 6.5. Listing of Major and Dominant Phytoplankton Genera Sampled in Bluestem Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., BLULKND1)

Division	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cryptophycophyta	*Rhodomonas*	-----
Cyanobacteria	-----	*Aphanizomenon*
Ochrophyta	*Stephanodiscus, Aulacoseira*	*Cyclotella, Stephanodiscus*

6.2.2.1.5.2 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at Bluestem Reservoir near-dam sampling sites during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-11). The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in Plate 6-12. Bluestem Reservoir was dominated by Cladocerans and Copepods in 2015 with the greatest total zooplankton biomass in May. Dominant and major zooplankton genera sampled in Bluestem Reservoir during 2015 are provided in Table 6.6.

Table 6.6. Listing of major and dominant zooplankton genera sampled in Bluestem Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., BLULKND1)

Taxonomic Group	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cladocerans	-----	*Daphnia, Diaphanosoma*
Copepods	*Acanthocyclops, Aglaodiaptomus*	*Leptodiaptomus, Calanoida*

6.2.2.1.6 Mussel Monitoring

Zebra mussel veliger sampling has been conducted once yearly since 2012 at Bluestem Reservoir. During the sampling period (2012-2015) no veligers have been identified.

6.2.2.2 <u>Water Quality Trends (1980 through 2015)</u>

Water quality trends from 1980 to 2015 were determined for Bluestem 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., BLULKND1). Plate 6-13 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, it appears that Bluestem Reservoir exhibited decreasing transparency ($p<0.05$, $R^2=0.09$), increasing total phosphorus concentrations ($p<0.05$, $R^2=0.07$), and an increasing TSI ($p<0.05$, $R^2=0.05$). Over the 36-year period since 1980, Bluestem Reservoir remained in a hypereutrophic condition.

6.2.3 PLATES

Plate 6-1. Summary of water quality conditions monitored in Bluestem Reservoir at site BLULKND1 from May to September during the 5-year period 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

	Monitoring Results						Water Quality Standards Attainment		
Parameter	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	25	1306.34	1306.60	1303.50	1309.70	-----	-----	-----
Water Temperature (°C)	0.1	190	22.97	23.41	15.13	30.57	32[(1)]	0	0%
Dissolved Oxygen (mg/l)	0.1	190	6.87	7.11	0.30	11.11	≥5(2)	27	14%
Dissolved Oxygen, Near-Surface (mg/l)[(C)]	0.1	25	7.55	7.53	4.27	10.99	≥5(2)	1	4%
Dissolved Oxygen (% Sat.)	0.1	190	82.72	88.05	3.50	129.40	-----	-----	-----
Secchi Depth (in.)	1	23	8.35	7.00	3.00	19.00	-----	-----	-----
Turbidity (NTUs)	1	182	100.84	87.20	13.70	407.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	190	354.96	369.50	100.00	484.00	-----	-----	-----
Specific Conductance (umho/cm)	1	190	339.34	353.00	185.90	419.50	2,000[(3)]	0	0%
pH (S.U.)	0.1	190	8.26	8.28	6.71	9.10	≥6.5 & ≤9.0 [(1)]	0,5	0%,3%
Alkalinity, Total (mg/l)	1	50	130.96	134.00	71.00	166.00	20[(1)]	0	0%
Suspended Solids, Total (mg/l)	4	50	38.92	31.00	14.00	157.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	50	-----	0.03	n.d.	0.64	1.65[(4,5)], 0.40[(4,6)]	0	0%
Kjeldahl N, Total (mg/l)	0.08	50	1.45	1.43	0.57	2.57	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	50	-----	0.31	n.d.	1.83	100[(3)]	0	0%
Nitrogen, Total (mg/l)	0.08	50	1.98	1.88	0.88	3.40	1[(7)]	47	94%
Nitrogen, Total, Near-Surface (mg/)[(C)]	0.08	25	1.95	1.85	0.88	3.31	1[(7)]	23	92%
Phosphorus, Total (mg/l)	0.005	50	0.27	0.22	0.09	0.75	0.05[(7)]	50	100%
Phosphorus, Total, Near-Surface (mg/l)[(C)]	0.005	25	0.25	0.21	0.09	0.64	0.05[(7)]	25	100%
Phosphorus-Ortho, Dissolved (mg/l)	0.005	50	0.11	0.10	n.d.	0.41	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	118.82	119.00	104.80	129.80	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	5	6.60	6.00	5.00	11.00	340[(5)], 16.7[(8)]	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130[(5)], 5.3[(6)]	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	n.d.	6.99[(5)], 0.28[(6)]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	682.72[(5)], 88.89[(6)]	0	0%
Copper, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	15.83[(5)], 10.39[(6)]	0	0%
Iron, Dissolved (ug/l)	10	5	35.00	20.00	15.00	80.00	1000[(6)]	0	0%
Lead, Dissolved (ug/l)	0.09	5	-----	n.d.	n.d.	0.50	78.01[(5)], 3.04[(6)]	0	0%
Manganese, Dissolved (ug/l)	3	5	32.60	9.00	6.00	130.00	1000[(6)]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	542.47[(5)], 60.25[(6)]	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	4.65[(5)]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	135.79[(5)], 136.90[(6)]	0	0%
Antimony, Dissolved (ug/l)	0.03	5	-----	0.60	n.d.	1.10	88[(5)], 30[(6)]	0	0%
Aluminum, Dissolved (ug/l)	25	5	-----	50.00	n.d.	110.00	750[(5)], 87[(6)]	0,1	0%,20%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[(5)]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[(6)]	0	0%
Chlorophyll a (ug/l) – Lab Determined [(C)]	6	25	28	27	n.d.	58	10[(7)]	20	80%
Chlorophyll a (ug/l) – Field Probe	6	182	32	27	n.d.	558	10[(7)]	150	82%
Atrazine, Total (ug/l)[(D)]	0.1	25	2.74	2.20	n.d.	14.40	330[(5)], 12[(6)]	0,1	0%,4%
Metolachlor, Total (ug/l)[(D)]	0.1	25	1.40	1.20	0.20	4.70	390[(5)], 100[(6)]	0	0%
Acetochlor, Total (ug/l)[(D)]	0.5	25	1.65	1.50	n.d.	4.10	-----	-----	-----
Microcystin, Extracellular (ug/l)	0.1	24	-----	n.d.	n.d.	0.30	20[(9)]	0	0%
Pesticide Scan (ug/l)[(E)]									
Atrazine, Tot	0.13	4	3.08	1.97	0.28	8.09	330[(5)], 12[(6)]	0	0%
Acetochlor, Tot	0.08	4	-----	0.29	n.d.	0.71	-----	-----	-----
Metolachlor, Tot	0.05	4	-----	0.82	n.d.	1.36	390[(5)], 100[(6)]	0	0%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-2. Summary of water quality conditions monitored in Bluestem Reservoir at site BLULKML1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1306.03	1306.25	1303.50	1308.30	-----	-----	-----
Water Temperature (°C)	0.1	151	22.99	23.85	15.45	29.86	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	151	7.31	7.57	0.24	12.31	≥5(2)	15	10%
Dissolved Oxygen (% Sat.)	0.1	151	88.15	87.80	2.80	150.90	-----	-----	-----
Secchi Depth (in.)	1	24	7.78	7.00	0.80	22.00	-----	-----	-----
Turbidity (NTUs)	1	145	98.95	84.80	13.10	348.90	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	151	363.26	374.00	206.00	473.00	-----	-----	-----
Specific Conductance (umho/cm)	1	151	337.18	354.00	175.20	419.40	2,000(3)	0	0%
pH (S.U.)	0.1	151	8.28	8.30	6.71	9.08	≥6.5 & ≤9.0 (1)	0,7	0%,5%
Chlorophyll a (ug/l) – Field Probe	6	144	30	26	3	133	10(4)	115	80%

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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-3. Summary of water quality conditions monitored in Bluestem Reservoir at site BLULKUP1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	19	1306.16	1306.50	1304.30	1308.30	-----	-----	-----
Water Temperature (°C)	0.1	43	23.69	23.70	15.55	29.61	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	43	7.52	7.29	3.11	13.29	≥5(2)	4	9%
Dissolved Oxygen (% Sat.)	0.1	43	92.07	89.80	37.80	170.30	-----	-----	-----
Secchi Depth (in.)	1	23	7.17	6.00	0.80	24.00	-----	-----	-----
Turbidity (NTUs)	1	42	114.65	84.05	15.00	297.20	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	43	341.84	351.00	207.00	471.00	-----	-----	-----
Specific Conductance (umho/cm)	1	43	320.02	324.00	215.10	404.50	2,000(3)	0	0%
pH (S.U.)	0.1	43	8.30	8.42	6.97	9.09	≥6.5 & ≤9.0 (1)	0,2	0%,5%
Chlorophyll a (ug/l) – Field Probe	6	41	29	30	3	74	10(4)	31	76%

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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

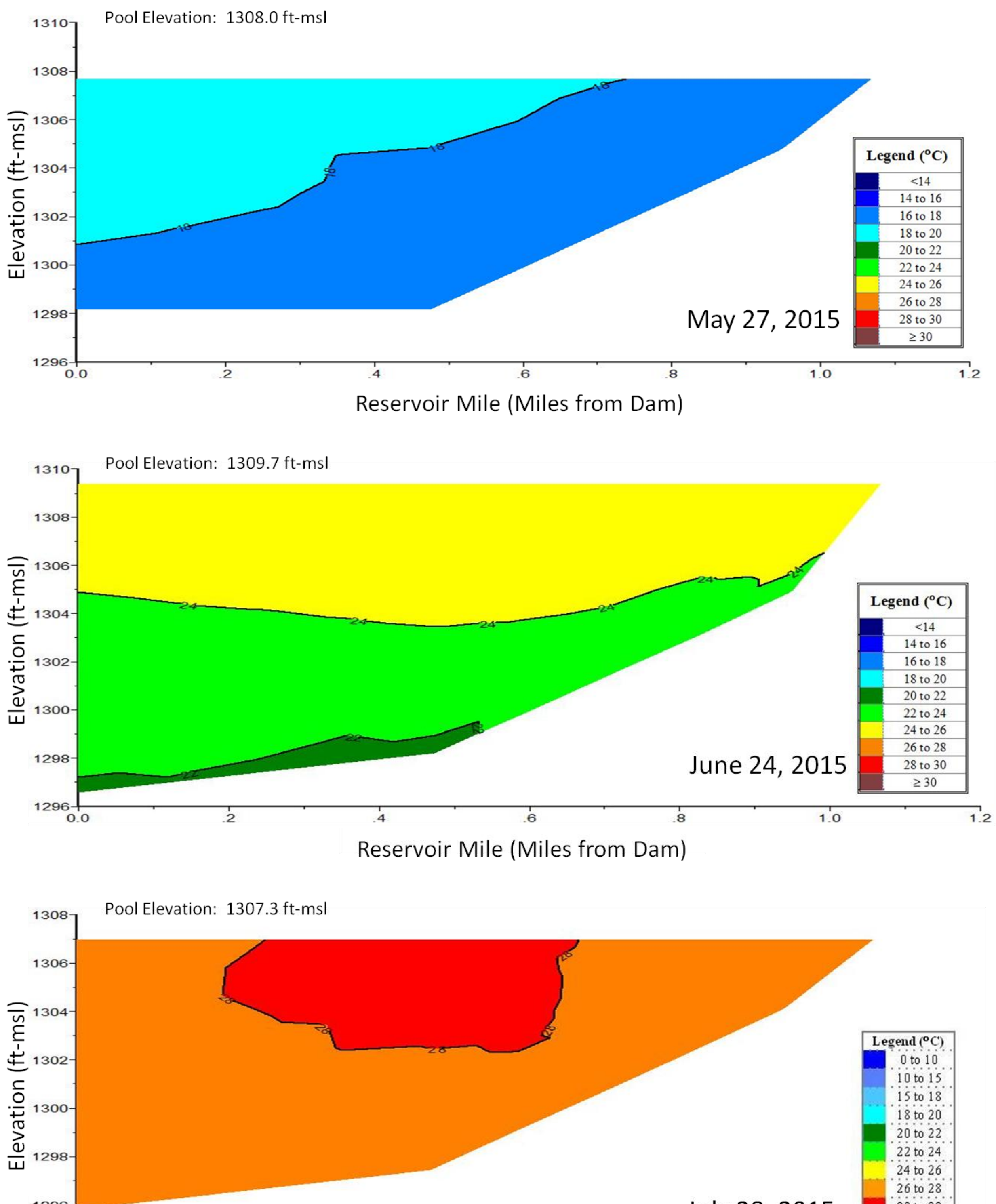
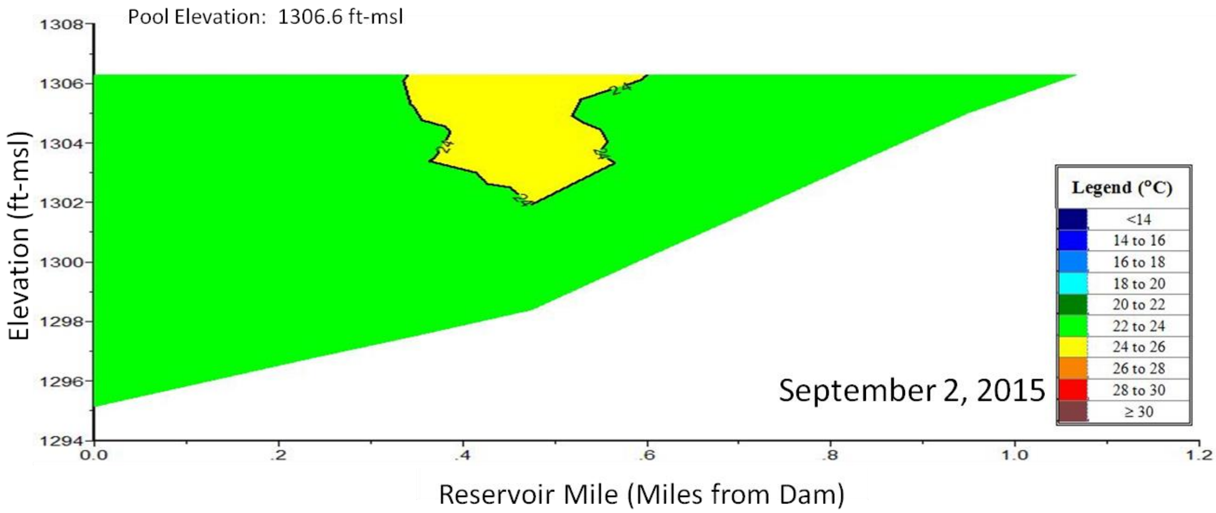


Plate 6-4. Longitudinal water temperature contour plots of Bluestem Reservoir based on depth-profile water temperatures (°C) measured at sites BLULKND1, BLULKML1, and BLULKUP1 in 2015.



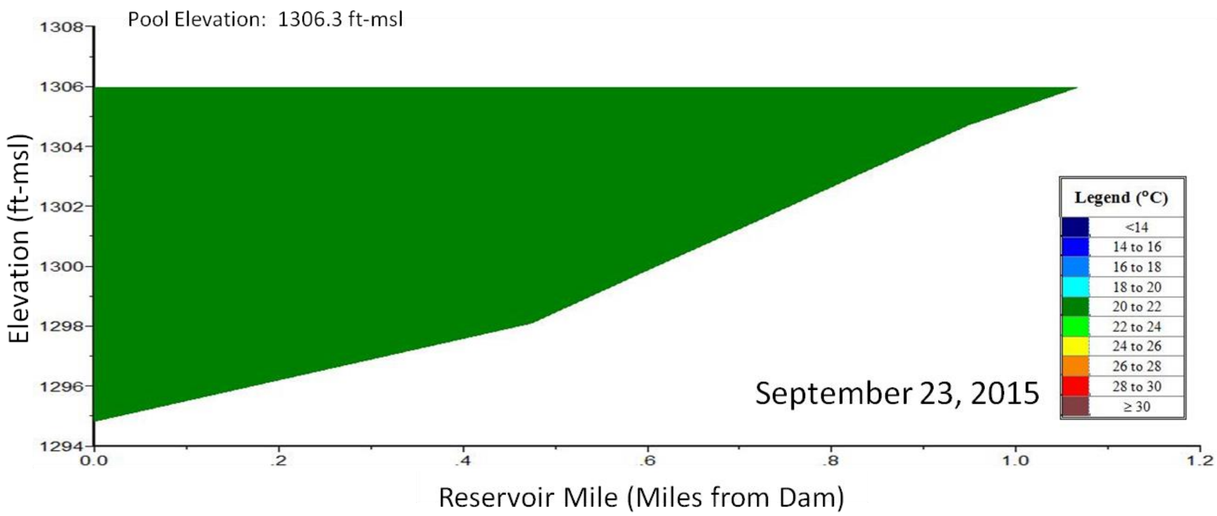


Plate 6-4. (Continued).

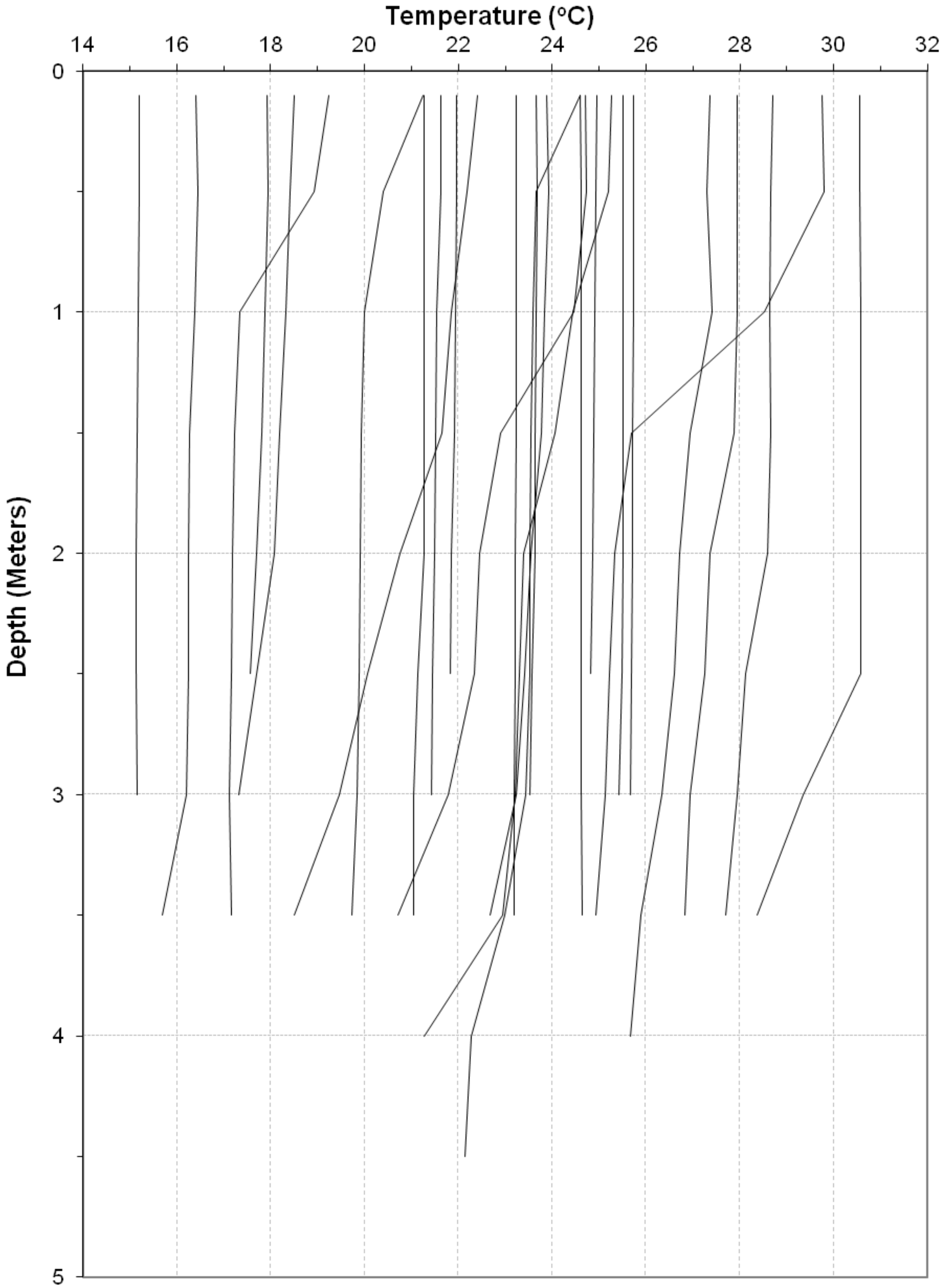


Plate 6-5. Temperature depth profiles for Bluestem Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BLULKND1) during the summer over the 5-year period of 2011 through 2015.

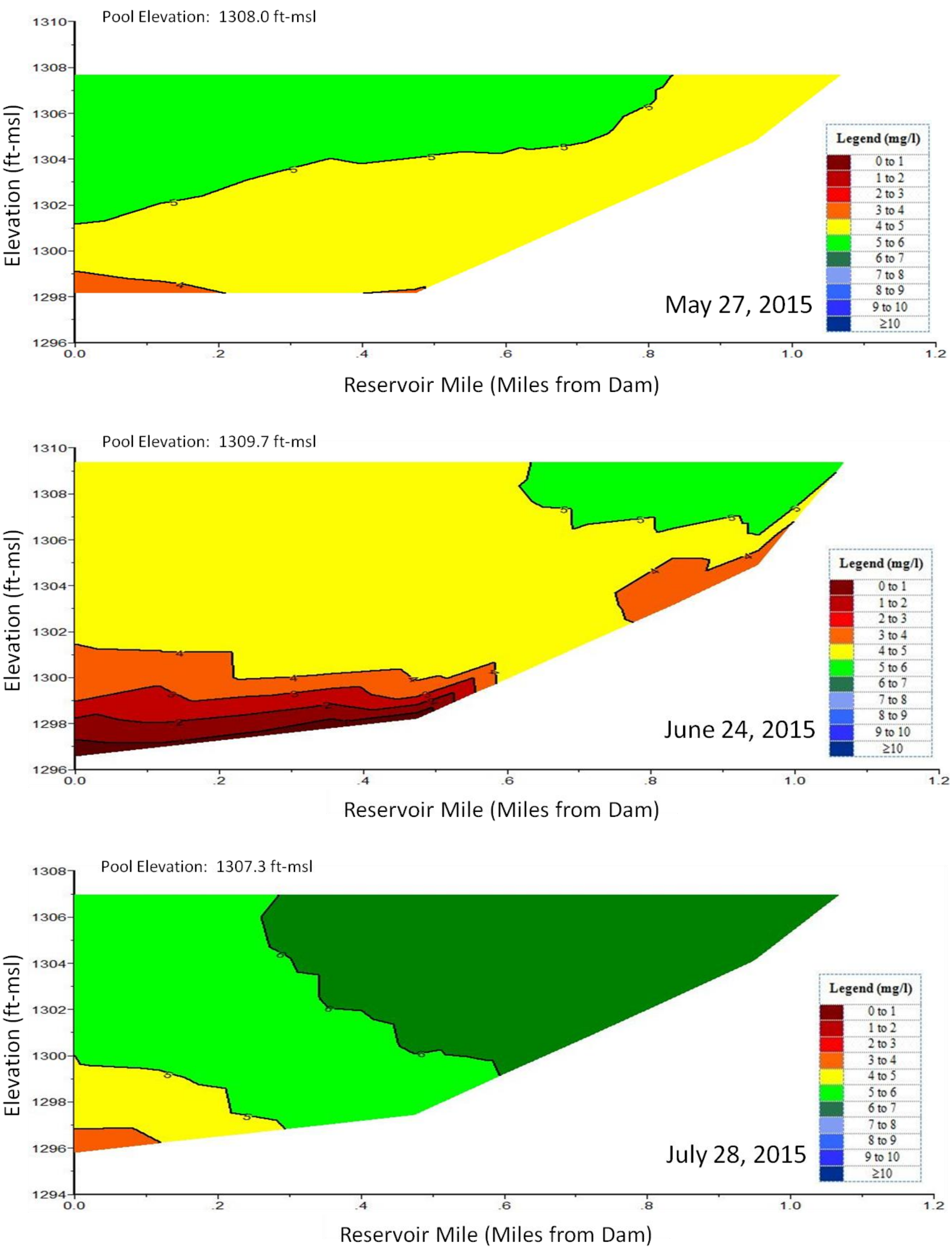
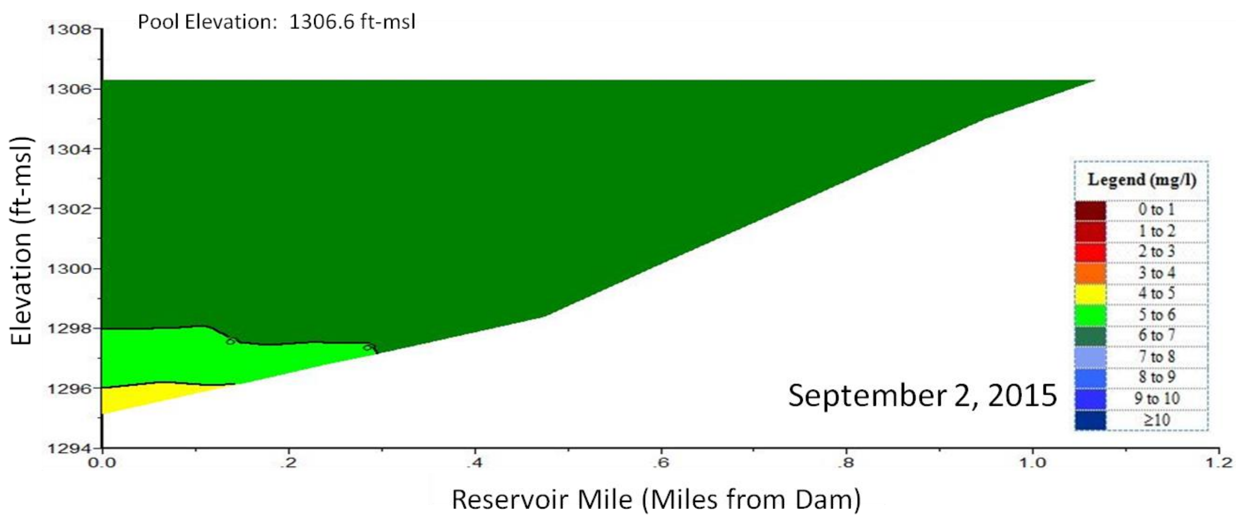


Plate 6-6. Longitudinal dissolved oxygen contour plots of Bluestem Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites BLULKND1, BLULKML1, and BLULKUP1 in 2015.



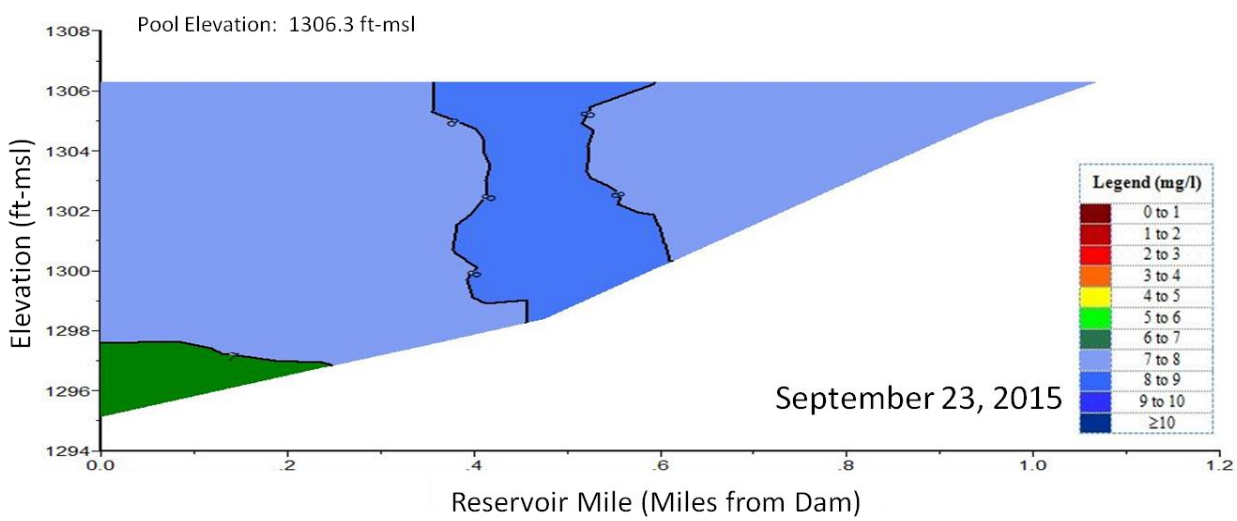


Plate 6-6. (Continued).

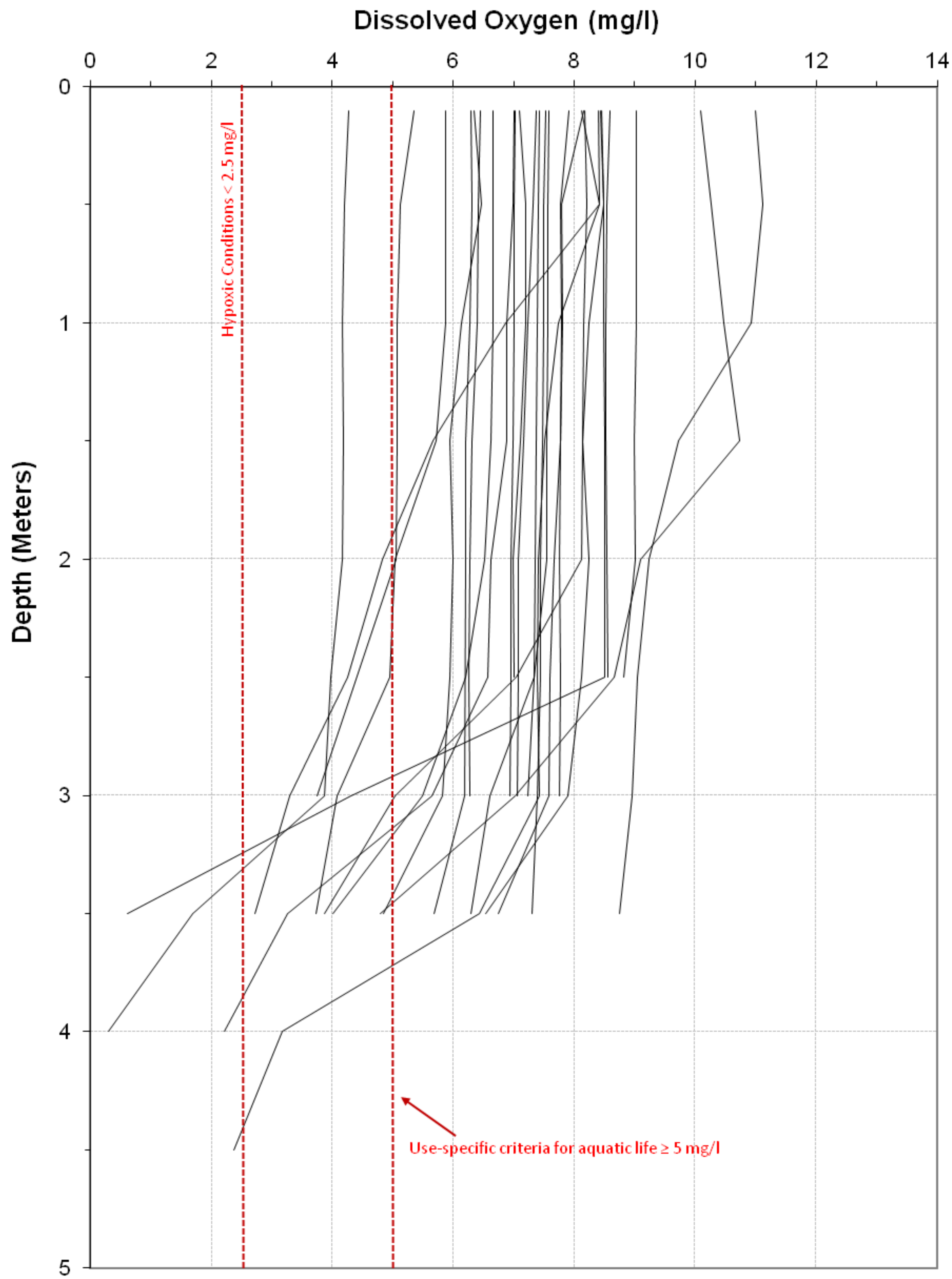


Plate 6-7. Dissolved oxygen depth profiles for Bluestem Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BLULKND1) during the summer over the 5-year period of 2011 through 2015.

Plate 6-8. Total biovolume and density by taxonomic group for phytoplankton grab samples from Bluestem Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., BLULKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**
23-May-11	40,790	221	42,419	824	120	0	40,146	582	28,686	925	7,962	15	235,994	591	10,539	6
28-Jul-11	3,776	3	25,180	561	48	0	17,138	238	1,147,560	29,308	5,620	9	1,799,897	1,752	4,809	11
22-Sep-11	1,005	6	76,079	928	-----	-----	7,934	106	939,300	37,784	3,472	6	87,290	90	5,426	11
01-May-12	8,895	4	53,280	492	26,091	7	15,814	13	-----	-----	1,511	5	1,095,204	166	115,579	4
06-Jul-12	6,371	7	5,861,158	1,107	152	0	191,624	78	2,267,699	215,087	-----	-----	2,261,693	2,897	-----	-----
07-Sep-12	194,172	134	705,120	1,285	-----	-----	110,313	916	14,038,465	232,023	61,006	68	13,198,221	7,615	-----	-----
14-May-13	555,941	1,506	-----	-----	-----	-----	418,944	4,939	37,630	428	-----	-----	1,264,566	10,538	-----	-----
09-Jul-13	67,912	7	443,072	419	-----	-----	76,927	907	1,352,188	7,957	40,049	22	1,120,541	2,071	9,236	0
12-Sep-13	-----	-----	86,509	117	-----	-----	48,026	566	8,434,791	62,317	7,416	7	2,695,437	4,001	29,459	1
13-May-14	82,830	9	79,813	535	1,629	0	-----	-----	-----	-----	9,082	1	2,430,918	1,575	-----	-----
15-Jul-14	552,238	206	-----	-----	-----	-----	6,169	73	15,601,888	51,095	-----	-----	2,503,566	4,928	-----	-----
10-Sep-14	-----	-----	24,497	105	-----	-----	250,813	185	18,213,269	92,962	70,762	19	383,333	927	-----	-----
27-May-15	6,720	7	-----	-----	35,700	12	33,956	110	1,532	9	-----	-----	220,381	191	-----	-----
28-Jul-15	-----	-----	8,387	97	-----	-----	24,155	120	4,512	42	1,217	7	70,302	95	-----	-----
23-Sep-15	-----	-----	41,750	296	-----	-----	173,011	977	4,309,025	24,384	-----	-----	5,979,680	5,847	-----	-----

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

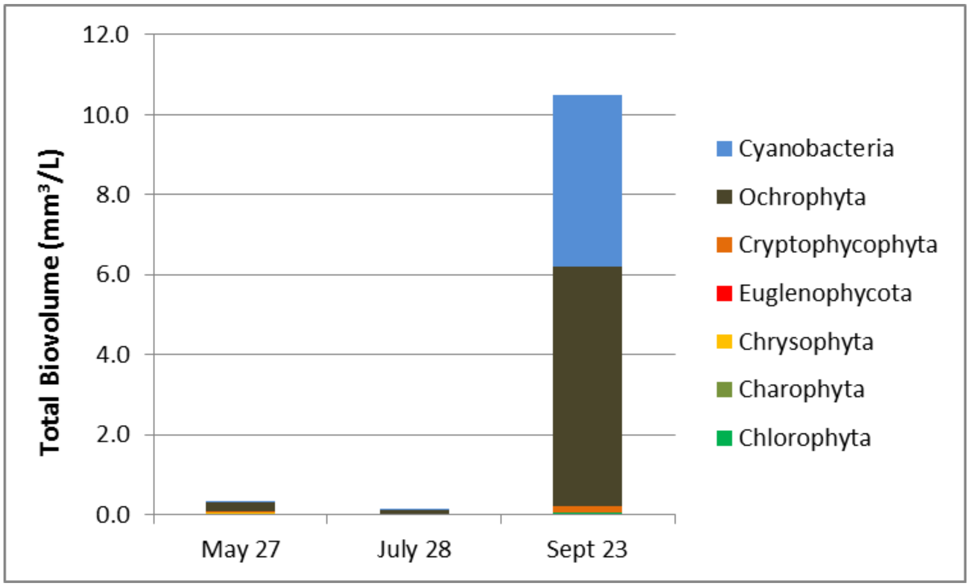


Plate 6-9. Relative abundance of phytoplankton in samples collected from Bluestem Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., BLULKND1).

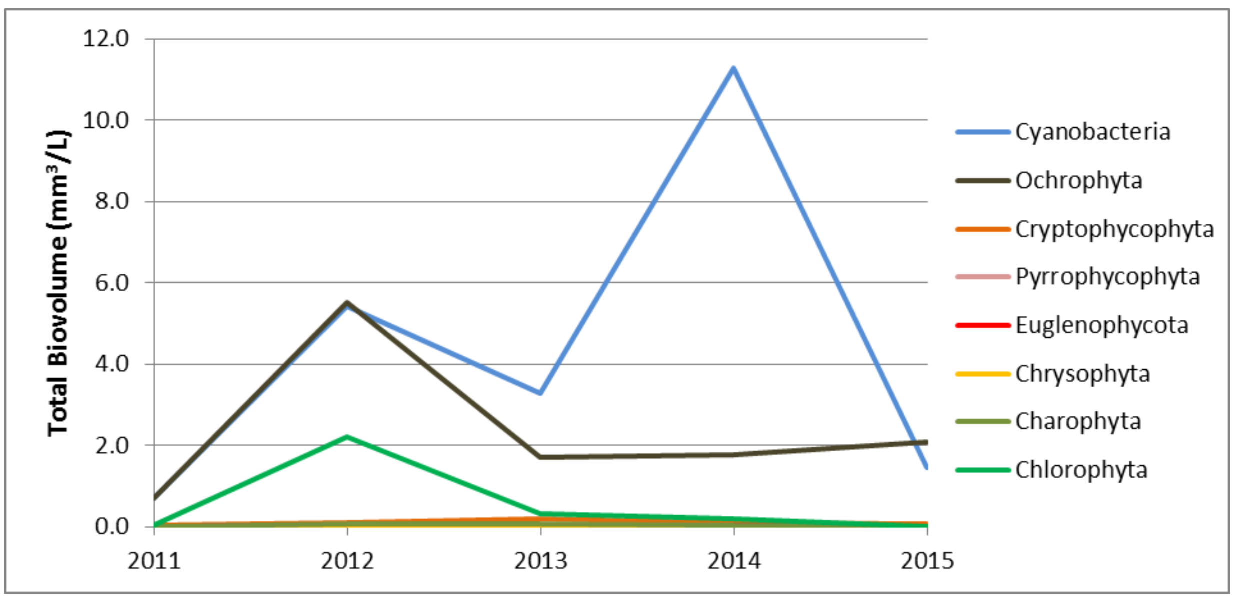


Plate 6-10. Relative abundance of phytoplankton in samples collected from Bluestem Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., BLULKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are a yearly average three summer samples (i.e. May, July, September)

Plate 6-11. Total biomass and density by taxonomic grouping for zooplankton vertical-tow samples from Bluestem Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., BLULKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	**Density (Count/L)**	**Biomass (dw µg/L)**	**Density (Count/L)**	**Biomass (dw µg/L)**	**Density (Count/L)**	**Biomass (dw µg/L)**	**Density (Count/L)**	**Biomass (dw µg/L)**
23-May-11	6	9.36	17	16.31	-----	-----	4	0.05
28-Jul-11	35	62.23	75	43.24	2	1.92	112	5.44
22-Sep-11	157	278.37	70	13.78	-----	-----	47	6.74
01-May-12	7	167.04	168	108.20	1	0.04	19	0.03
06-Jul-12	73	87.76	234	191.50	-----	-----	438	5.62
07-Sep-12	126	164.18	66	39.61	-----	-----	9	0.21
14-May-13	99	166.06	231	375.65	4	11.66	185	1.52
09-Jul-13	4	6.62	26	26.35	-----	-----	101	8.55
12-Sep-13	22	45.31	79	125.67	-----	-----	4	0.04
13-May-14	115	231.10	104	111.40	-----	-----	3	1.19
15-Jul-14	23	34.53	44	35.15	1	2.95	82	18.85
10-Sep-14	20	105.91	560	506.39	-----	-----	559	5.59
27-May-15	50	162.74	154	200.41	1	0.44	40	0.46
28-Jul-15	11	31.36	38	85.87	-----	-----	-----	-----
23-Sep-15	9	12.02	79	83.29	-----	-----	219	3.41

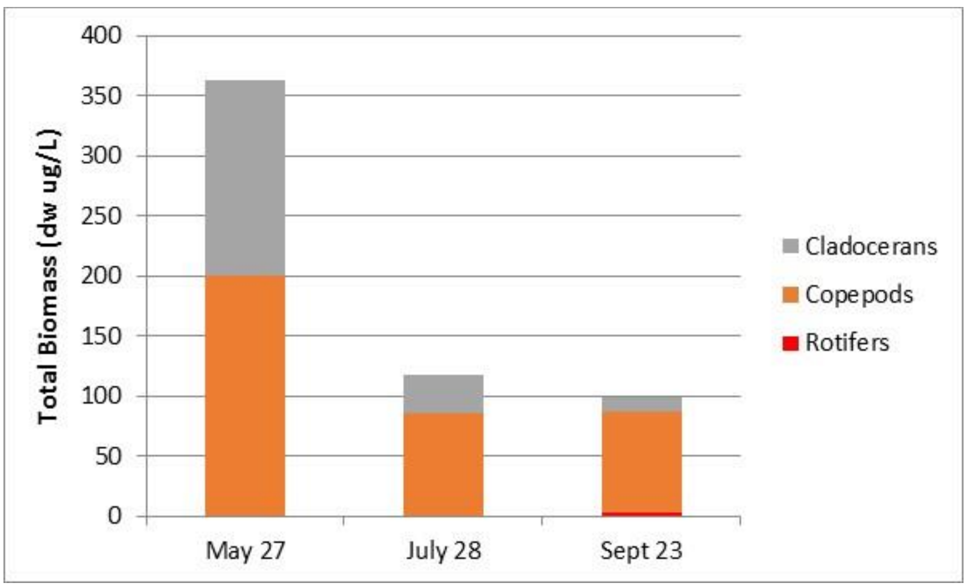


Plate 6-12. Relative abundance of zooplankton in samples collected from Bluestem Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., BLULKND1).

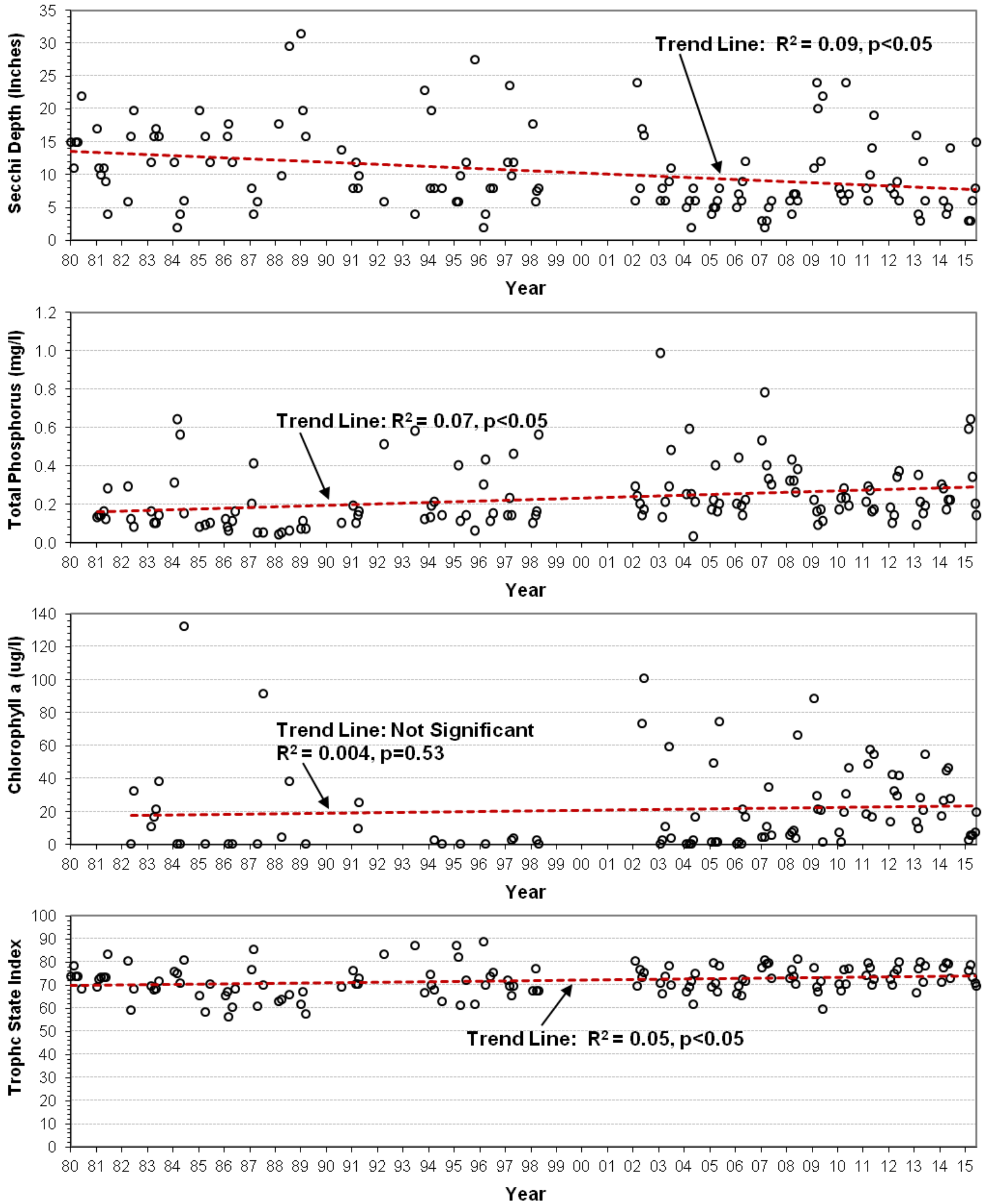


Plate 6-13. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Bluestem Reservoir at the near-dam, ambient site (i.e., site BLULKND1) over the 36-year period of 1980 through 2015.

6.3 BRANCHED OAK RESERVOIR

6.3.1 BACKGROUND INFORMATION

6.3.1.1 Project Overview

The dam forming Branched Oak Reservoir is located on Oak Creek. The dam was completed on August 21, 1967 and the reservoir reached its initial fill on January 18, 1973. The Branched Oak Reservoir watershed is 89.0 square miles. The watershed was largely agricultural when the dam was built in 1967 and has remained so to the present time.

6.3.1.2 Branched Oak Dam Intake Structure

The Branched Oak Dam intake structure is a single reinforced concrete box shaft commonly called a drop inlet structure. Its inside dimensions are 6 feet by 12 feet. The intake structure has two ungated openings, each 42" x 144" with crest elevations at 1284.0 ft-msl. A 48" x 72" gated opening was constructed into the upstream wall of the inlet structure at a crest elevation of 1274.0 ft-msl. The purpose of the gated opening is to lower the level of the conservation pool in order to inspect the conduit, make shoreline repairs, and manage fish populations. A 10" diameter gated opening is located below the weir on the right side wall of the inlet structure at an elevation of 1276.3 ft-msl. This gate may be used to provide water for downstream requirements.

6.3.1.3 Reservoir Storage Zones

Figure 6.3 depicts the current storage zones of Branched Oak Reservoir based on the 1991 survey data and estimated sedimentation. It is estimated that 9 to 10 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2015. The annual volume loss is estimated to be 0.20 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Branched Oak Reservoir's water quality dependent uses are not impaired due to sedimentation.

6.3.1.4 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Branched Oak 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. Figure 6.4 shows the location of the sites that have been monitored for water quality during the 5-year sampling period (i.e., 2011 through 2012). The inflow runoff sites (BOKNFNRT1 and BOKNFWST1) and the in-reservoir bacteria sites (BOKLKBACT1 and BOKLKBACT2) were sampled by the NDEQ. The other in-reservoir sites (BOKLKND1, BOKLKMLN1, BOKLKMLS1, BOKLKUPN1, and BOKLKUPS1) were monitored by the District. The near-dam location (BOKLKND1) has been continuously monitored since 1980.

6.3.2 WATER QUALITY IN BRANCHED OAK RESERVOIR

6.3.2.1 Existing Water Quality Conditions

6.3.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Branched Oak Reservoir at sites BOKLKND1, BOKLKML1, and BOKLKUP1 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 6-14 through Plate 6-18. A review of these results indicated possible water quality concerns regarding dissolved oxygen and nutrients.

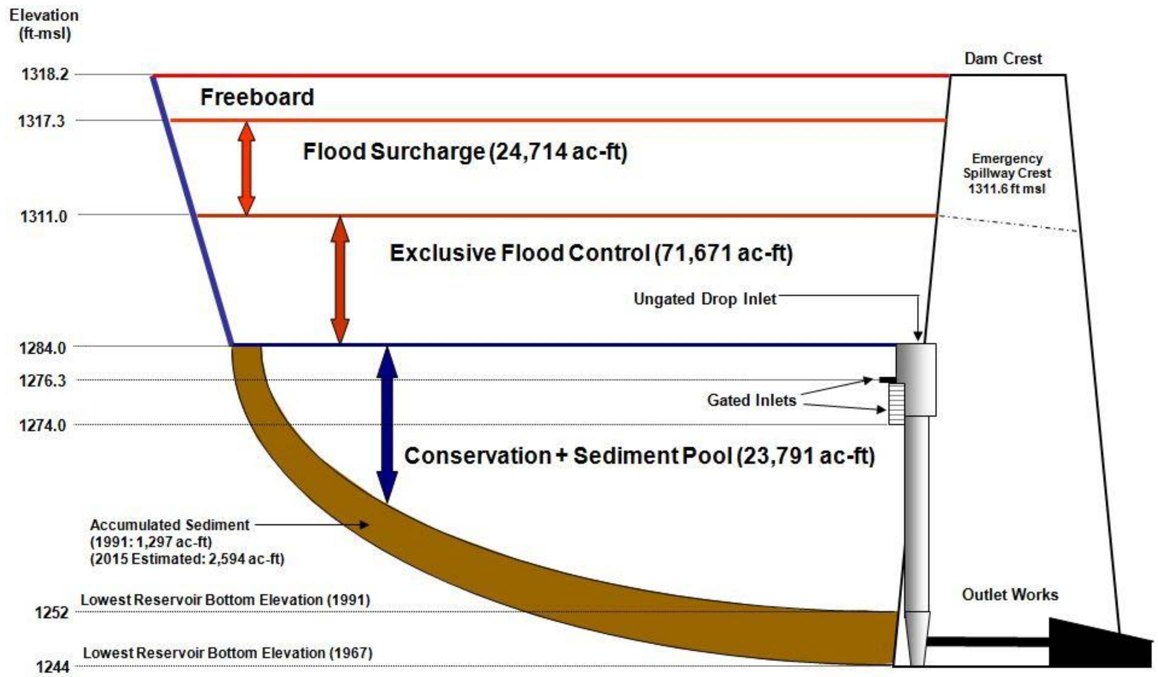


Figure 6.3. Current storage zones of Branched Oak Reservoir based on the 1991 survey data and estimated sedimentation**.**

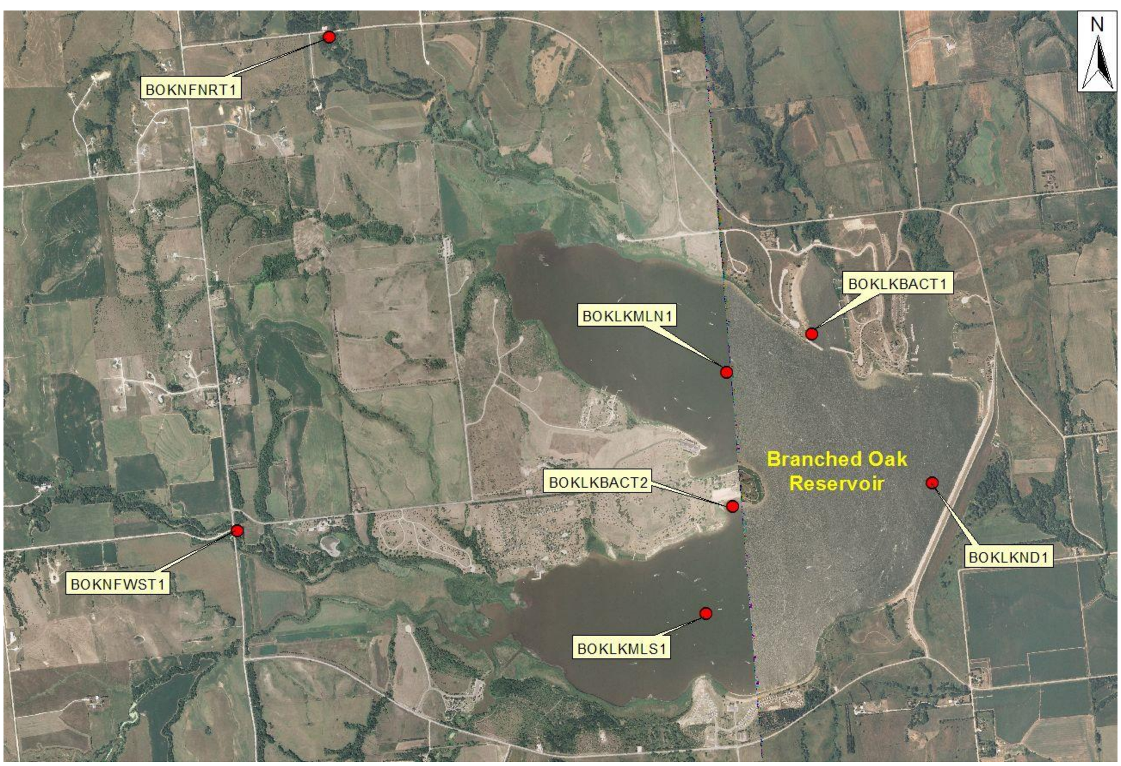


Figure 6.4. Location of sites where water quality monitoring was conducted at Branched Oak Reservoir during the period 2011 through 2015.

A significant number of dissolved oxygen measurements throughout Branched Oak Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 6-14-Plate 6-18). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and appeared to be associated with a slight thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Branched Oak Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation.

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September) to be considered for impairment assessment. All three of these criteria were exceeded Branched Oak Reservoir (Plate 6-14). The near-surface chlorophyll *a* criterion was exceeded by 92 percent of the "lab analyzed" samples taken in the reservoir at site BOKLKND1. The total phosphorus and total nitrogen criteria were exceeded by 92 and 84 percent of samples, respectively. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values represent the growing season average for the 5-year period 2011 through 2015. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.11 mg/l), total nitrogen (1.24 mg/l), and chlorophyll *a* (40 ug/l) values at BOKLKND1 indicate impairment of the aquatic life use due to nutrients.

6.3.2.1.2 Thermal Stratification

6.3.2.1.2.1 ***Longitudinal Temperature Contour Plots***

Late-spring and summer thermal conditions of Branched Oak Reservoir measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 6-19 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites BOKLKND1, BOKLKMLN1, and BOKLKUPN1. These temperature plots indicate that Branched Oak Reservoir only occasionally exhibits appreciable thermal variation during late-spring and summer. The maximum difference monitored between the surface and bottom water temperatures during the 2015 was 8°C in July.

6.3.2.1.2.2 ***Near-Dam Temperature Depth-Profile Plots***

Existing summer thermal stratification of Branched Oak Reservoir, at the deep water area near the dam, measured over the 5-year period 2011 through 2015 is depicted by depth-profile temperature plots (Plate 6-20). The depth-profile temperature plots indicate that the reservoir occasionally exhibited slight summer thermal stratification over the 5-year sampling period. Since Branched Oak Reservoir ices over in the winter and seemingly exhibits frequent or continuous circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.3.2.1.3 Dissolved Oxygen Conditions

6.3.2.1.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of Branched Oak Reservoir based on depth-profile measurements taken during 2015. Plate 6-21 provides longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September at sites BOKLKND1, BOKLKMLN1, and BOKLKUPN1. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored along the reservoir bottom near the dam June through July.

6.3.2.1.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

Existing summer dissolved oxygen conditions in Branched Oak Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2011 through 2015 (Plate 6-22). On several occasions there was a significant vertical gradient in summer dissolved oxygen levels. Thirty-two percent of the profiles showed hypoxic conditions near the reservoir bottom. Although Branched Oak Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition of mixing to allow hypoxic conditions to develop near the reservoir bottom in the area near the dam.

6.3.2.1.3.3 ***Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of Branched Oak 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 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 June 24, 2015 contour plot indicates a pool elevation of 1284.8 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1273.0 ft-msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1270.0 ft-msl (Plate 6-21). The current District Area-Capacity Tables (1993 Survey) give storage capacities of 26,593 ac-ft for elevation 1284.8 ft-msl, 9,294 ac-ft for elevation 1273.0 ft-msl, and 6,439 ac-ft for elevation 1270.0 ft-msl. On June 24, 2015 it is estimated that 35 percent of the volume of Branched Oak Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 24 percent of the reservoir volume was hypoxic.

6.3.2.1.4 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in Branched Oak Reservoir indicated hypoxic conditions June and July 2015. As a result, longitudinal contour plots for ORP and pH were constructed during these months. Depth profiles and near-surface/near-bottom sample comparisons were also constructed for periods of hypoxic conditions during the sampling periods from 2011 through 2015.

6.3.2.1.4.1 ***Oxidation-Reduction Potential***

Plate 6-23 provides longitudinal ORP contour plots based on depth-profile measurements taken in 2015 when hypoxic conditions were present in Branched Oak Reservoir. The ORP values indicated significantly reduced conditions present near the bottom of the reservoir in July 2015 with measurements below 100 mV. Plate 6-24 plots depth profiles for ORP measured during the summer over the 5-year sampling period in the deep water area of Branched Oak Reservoir near the dam when hypoxic conditions were present. Over the 5-year period reduced conditions at the bottom of the reservoir were limited. Only three of the hypoxic profiles exhibited ORP values below 200mV and the minimum measurement was 66 mV. Given the polymictic nature of the reservoir reduced conditions seemingly are not long-term.

6.3.2.1.4.2 ***pH***

Longitudinal contour plots for pH conditions measured in 2015 when hypoxic conditions were present are provided in Plate 6-25. Lower pH levels near the bottom of the reservoir could be attributable to reservoir stratification and ongoing decomposition/respiration near the reservoir bottom. This would lead to an increase in CO_2 and decrease in pH. All pH levels were however within the pH criteria for the protection of warmwater aquatic life. Plate 6-26 plots depth profiles for pH measured during the summer over the 5-year sampling period in the deep water area of Branched Oak Reservoir near the dam when hypoxic conditions were present. A slight vertical gradient in pH regularly occurred in the reservoir during the summer, however, all pH measurements were within the criteria for the protection of aquatic life.

6.3.2.1.4.3 ***Comparison of Near-Surface and Near-Bottom Water Quality Conditions***

Paired near-surface and near-bottom water quality samples collected from Branched Oak Reservoir during the summer when hypoxia was present 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 BOKLKND1 during the 5-year period 2011 through 2015. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 8 (32%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 6-27). 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 ORP (p=0.08), alkalinity (p=0.12), and nitrate-nitrite nitrogen (p=0.24). Parameters that were significantly lower in the near-bottom water of Branched Oak Reservoir when hypoxia was present included: water temperature, dissolved oxygen, and pH (p<0.05). Parameters that were significantly higher in the near-bottom water included: total ammonia nitrogen, total phosphorus, and ortho-phosphorus (p<0.05).

6.3.2.1.4.4 ***Reservoir Trophic Status***

Trophic State Index (TSI) values for Branched Oak Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., BOKLKND1). Table 6.7 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Branched Oak Reservoir is in a hypereutrophic condition.

Table 6.7. Summary of Trophic State Index (TSI) values calculated for Branched Oak Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	69	69	59	73
TSI(TP)	25	64	65	57	70
TSI(Chl)	25	73	75	57	84
TSI(Avg)	25	69	70	61	74

* 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 for the individual parameters.
Note: See Section 4.1.3 for discussion of TSI calculation.

6.3.2.1.4.5 ***Monitoring at Swimming Beaches***

Two designated swimming beaches are located on Branched Oak Reservoir. Bacteria (i.e., *E. coli*) and the cyanobacterial toxin microcystin were monitored at the two swimming beaches (i.e., sites BOKLKBACT1 and BOKLKBACT2) by the NDEQ during the 5-year sampling period. Bacteria and cyanobacterial toxins were monitored from May through September over the 5-year period 2011 through 2015.

6.3.2.1.4.5.1 Bacteria Monitoring

Table 6.8 summarizes the results of the bacteria sampling. The "running 5-week" geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The "pooled" geomean was determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for *E. coli* bacteria:

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

The pooled geomeans were compared to the State of Nebraska's impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using *E. coli* bacteria data. Based on those criteria a Primary Contact Recreation use in Branched Oak Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

Table 6.8. Summary of weekly (May through September) bacteria samples collected at Branched Oak Reservoir (i.e., sites BOKLKBACT1 and BOKLKBACT2) during the 5-year period 2011 through 2015.

North Swimming Beach Site: BOKLKBACT1			
***E. coli* Bacteria – Individual Samples**		***E. coli* Bacteria – Geomeans**	
Number of Samples	108	Number of Geomeans	89
Mean (cfu/100ml)	47	Average	20
Median (cfu/100ml)	13	Median	11
Minimum (cfu/100ml)	1	Minimum	4
Maximum (cfu/100ml)	461	Maximum	122
Percent of samples exceeding 235/100ml	6%	Percent of Geomeans exceeding 126/100ml	0%
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	14
South Swimming Beach Site: BOKLKBACT2			
***E. coli* Bacteria – Individual Samples**		***E. coli* Bacteria – Geomeans**	
Number of Samples	108	Number of Geomeans	89
Mean (cfu/100ml)	209	Average	33
Median (cfu/100ml)	15	Median	20
Minimum (cfu/100ml)	1	Minimum	2
Maximum (cfu/100ml)	9804	Maximum	545
Percent of samples exceeding 235/100ml	8%	Percent of Geomeans exceeding 126/100ml	4%
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	18

6.3.2.1.4.5.2 Microcystin Monitoring

Table 6.9 summarizes the total microcystin monitoring conducted at the Branched Oak Reservoir swimming beaches during the 5-year period 2011 through 2015. These results were compared to the 20 ug/l criterion for issuing health advisories and the posting of swimming beaches. No samples exceeded the criterion. The monitored levels of total microcystin do not indicate a significant cyanobacteria toxin concern at Branched Oak Reservoir.

Table 6.9. Summary of weekly (May through September) total microcystin samples collected at Branched Oak Reservoir (i.e., sites BOKLKBACT1 and BOKLKBACT2) during the 5-year period 2011 through 2015.

Summary Statistic	North Swimming Beach (Site BOKLKBACT1)	South Swimming Beach (Site BOKLKBACT2)
Number of Samples	109	109
Minimum (ug/l)	n.d.	n.d.
25th percentile (ug/l)	n.d.	n.d.
Median (ug/l)	n.d.	1
75th Percentile (ug/l)	1	2
Maximum (ug/l)	6	5
Percent of samples exceeding 20 ug/l	0%	0%

6.3.2.1.5 Reservoir Plankton Community

6.3.2.1.5.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at the Branched Oak Reservoir near-surface, near-dam sampling site during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-28). The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 6-29. The highest phytoplankton total biovolume was observed in September. Ochrophyta and Cyanobacteria dominated most of the 2015 growing season. The phytoplankton populations followed successional patterns commonly observed in eutrphic reservoirs. Cool water taxa such as Ochrophyta tend to dominate in spring and late fall while warm water taxa such as Cyanbacteria tend to dominate the summer and early fall. Major and dominant phytoplankton genera sampled in 2015 at Branched Oak Reservoir are provided in Table 6.10.

Annual variation in phytoplankton community composition is displayed in Plate 6-30. The phytoplankton community was relatively mixed through the 5-year period with no single group appearing to be most dominant. Cyanobacteria density levels were greater than the World Health Organizations high level of health risk (>100,000 Cells/ml) in 2012, 2013, and 2015 (Plate 6-28). The greatest average Cyanobacterial density was observed in 2015. Spring 2015 water temperatures were greater than all other years during the 5-year sampling period. This warmer water early in the year could have lead to a longer Cyanobacterial growing season which resulted in the high biovolumes and densities observed. The maximum extracellular microcystin level measured at the near-dam site during the 5-year period was 0.4 µg/L (Plate 6-14).

Table 6.10. Listing of Major and Dominant Phytoplankton Genera Sampled in Branched Oak Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1)

Division	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cyanobacteria	*Anabaena*	*Microcystis*
Ochrophyta	*Stephanodiscus, Aulacoseira*	*Aulacoseira*

Table 6.11. Listing of major and dominant zooplankton genera sampled in Branched Oak Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1)

Taxonomic Group	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cladocerans	-----	*Daphnia, Leptodora*
Copepods	*Calanoida, Skistodiaptomus*	*Leptodiaptomus*

6.3.2.1.5.2 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at Branched Oak Reservoir near-dam sampling sites during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-31). The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in Plate 6-32. Branched Oak Reservoir was dominated by Cladocerans and Copepods in 2015 with the greatest total zooplankton biomass in September. Dominant and major zooplankton genera sampled in Branched Oak Reservoir during 2015 are provided in Table 6.11.

6.3.2.1.6 Zebra Mussel Monitoring

Zebra mussel veliger sampling has been conducted once yearly since 2012 at Branched Oak Reservoir. During the sampling period (2012-2015) no veligers have been identified.

6.3.2.2 Water Quality Trends (1980 through 2015)

Water quality trends from 1980 to 2015 were determined for Branched Oak 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., BOKLKND1). Plate 6-33 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, it appears that Branched Oak Reservoir exhibited decreasing transparency ($p<0.05$, $R^2=0.06$) and increasing total phosphorus ($p<0.05$, $R^2=0.04$) and chlorophyll *a* ($p<0.05$, $R^2=0.18$) levels. Over the 36-year period since 1980, Branched Oak Reservoir moved from a eutrophic to hypereutrophic condition ($p<0.05$, $R^2=0.25$).

6.3.3 Plates

Plate 6-14. Summary of water quality conditions monitored in Branched Oak Reservoir at site BOKLKND1 from May to September during the 5-year period 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	25	1284.10	1284.10	1282.50	1285.30	-----	-----	-----
Water Temperature (°C)	0.1	426	22.44	23.05	14.75	29.63	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	426	6.45	6.91	n.d.	11.71	≥5(2)	77	18%
Dissolved Oxygen, Near-Surface (mg/l)(C)	0.1	25	7.87	7.65	5.59	11.71	≥5(2)	0	0%
Dissolved Oxygen (% Sat.)	0.1	426	76.48	81.40	n.d.	139.00	-----	-----	-----
Secchi Depth (in.)	1	25	21.92	21.00	16.00	43.00	-----	-----	-----
Turbidity (NTUs)	1	392	14.95	13.45	5.50	105.70	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	426	372.09	368.00	66.00	520.00	-----	-----	-----
Specific Conductance (umho/cm)	1	426	398.55	407.75	327.30	453.40	2,000(3)	0	0%
pH (S.U.)	0.1	426	8.22	8.26	7.27	8.86	≥6.5 & ≤9.0 (1)	0	0%
Alkalinity, Total (mg/l)	1	50	168.42	172.00	138.00	196.00	<20(1)	0	0%
Suspended Solids, Total (mg/l)	4	50	18.86	15.50	n.d.	156.00	-----		
Ammonia, Total (mg/l)	0.02	50	-----	0.06	n.d.	1.17	2.13(4,5), 0.47(4,6)	0,1	0%,2%
Kjeldahl N, Total (mg/l)	0.08	50	1.27	1.19	0.82	2.38	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	50	-----	0.04	n.d.	0.32	100(3)	0	0%
Nitrogen, Total (mg/l)	0.08	50	1.35	1.28	0.84	2.41	1(7)	43	86%
Nitrogen, Total, Near-Surface (mg/)(C)	0.08	25	1.24	1.20	0.84	1.78	1(7)	21	84%
Phosphorus, Total (mg/l)	0.005	50	0.13	0.12	0.05	0.39	0.05(7)	48	96%
Phosphorus, Total, Near-Surface (mg/l)(C)	0.005	25	0.11	0.11	0.05	0.18	0.05(7)	23	92%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	0.04	n.d.	0.20	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	144.72	142.40	127.00	163.30	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	5	8.00	9.00	6.00	9.00	340(5), 16.7(8)	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	0.70	8.32(5), 0.31(6)	0,1	0%,20%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	790.85(5), 102.96(6)	0	0%
Copper, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	18.75(5), 12.11(6)	0	0%
Iron, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	90.00	1000(6)	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	94.69(5), 3.69(6)	0	0%
Manganese, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	30.00	1000(6)	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	631.44(5), 70.13(6)	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	6.34(5)	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	158.10(5), 159.40(6)	0	0%
Antimony, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	2.40	88(5), 30(6)	0	0%
Aluminum, Dissolved (ug/l)	40	5	-----	n.d.	n.d.	90.00	750(5), 87(6)	0,1	0%,20%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77(6)	0	0%
Chlorophyll a (ug/l) – Lab Determined (C)	6	25	40	37	n.d.	88	10(7)	23	92%
Chlorophyll a (ug/l) – Field Probe	6	408	52	51	n.d.	203	10(7)	371	91%
Atrazine, Total (ug/l)(D)	0.1	25	1.94	1.50	0.50	4.40	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(D)	0.1	25	-----	0.40	n.d.	2.00	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l)(D)	0.1	25	0.53	0.40	n.d.	1.80	-----	-----	-----
Microcystin, Extracellular (ug/l)	0.1	24	-----	n.d.	n.d.	0.40	20(9)	0	0%
Pesticide Scan (ug/l)(E)									
Atrazine, Tot	0.13	5	0.90	0.68	0.50	2.01	330(5), 12(6)	0	0%
Acetochlor, Tot	0.08	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Metolachlor, Tot	0.13	5	-----	n.d.	n.d.	0.69	390(5), 100(6)	0	0%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-15. Summary of water quality conditions monitored in Branched Oak Reservoir at site BOKLKMLN1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1284.05	1284.15	1282.50	1285.30	-----	-----	-----
Water Temperature (°C)	0.1	298	22.79	23.38	15.45	29.55	32[(1)]	0	0%
Dissolved Oxygen (mg/l)	0.1	298	7.25	7.27	0.00	11.77	$\geq$5[(2)]	40	13%
Dissolved Oxygen (% Sat.)	0.1	298	86.60	88.40	0.00	128.10	-----	-----	-----
Secchi Depth (in.)	1	23	19.76	17.00	12.00	37.00	-----	-----	-----
Turbidity (NTUs)	1	272	16.48	14.60	4.60	117.40	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	298	371.58	368.00	120.00	536.00	-----	-----	-----
Specific Conductance (umho/cm)	1	298	395.79	399.80	327.70	453.00	2,000[(3)]	0	0%
pH (S.U.)	0.1	298	8.30	8.34	7.51	8.72	$\geq$6.5 & $\leq$9.0 [(1)]	0	0%
Chlorophyll a (ug/l) – Field Probe	6	285	55	51	5	181	10[(4)]	262	92%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-16. Summary of water quality conditions monitored in Branched Oak Reservoir at site BOKLKMLS1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1284.05	1284.15	1282.50	1285.30	-----	-----	-----
Water Temperature (°C)	0.1	263	22.72	23.07	15.37	29.22	32[(1)]	0	0%
Dissolved Oxygen (mg/l)	0.1	263	7.33	7.52	0.14	11.67	$\geq$5[(2)]	20	8%
Dissolved Oxygen (% Sat.)	0.1	263	87.59	89.70	1.80	130.10	-----	-----	-----
Secchi Depth (in.)	1	25	18.68	17.00	9.00	32.00	-----	-----	-----
Turbidity (NTUs)	1	243	18.43	16.10	4.60	234.10	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	263	377.13	366.00	241.00	528.00	-----	-----	-----
Specific Conductance (umho/cm)	1	263	395.27	398.00	328.30	444.20	2,000[(3)]	0	0%
pH (S.U.)	0.1	263	8.29	8.35	7.47	8.83	$\geq$6.5 & $\leq$9.0 [(1)]	0	0%
Chlorophyll a (ug/l) – Field Probe	6	253	58	53	5	632	10[(4)]	229	91%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-17. Summary of water quality conditions monitored in Branched Oak Reservoir at site BOKLKUPN1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1284.05	1284.15	1282.50	1285.30	-----	-----	-----
Water Temperature (°C)	0.1	68	22.97	22.69	15.68	30.64	32[(1)]	0	0%
Dissolved Oxygen (mg/l)	0.1	68	8.31	7.94	4.79	11.63	≥5[(2)]	1	1%
Dissolved Oxygen (% Sat.)	0.1	68	100.12	95.70	64.80	144.10	-----	-----	-----
Secchi Depth (in.)	1	25	14.42	14.50	5.00	25.00	-----	-----	-----
Turbidity (NTUs)	1	62	27.36	22.10	11.60	132.40	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	68	362.79	352.50	226.00	544.00	-----	-----	-----
Specific Conductance (umho/cm)	1	68	383.09	385.45	328.40	451.20	2,000[(3)]	0	0%
pH (S.U.)	0.1	68	8.44	8.50	7.90	8.69	≥6.5 & ≤9.0 [(1)]	0	0%
Chlorophyll a (ug/l) – Field Probe	6	62	59	61	6	161	10[(4)]	60	97%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-18. Summary of water quality conditions monitored in Branched Oak Reservoir at site BOKLKUPS1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1284.05	1284.15	1282.50	1285.30	-----	-----	-----
Water Temperature (°C)	0.1	78	22.61	22.48	15.57	29.56	32[(1)]	0	0%
Dissolved Oxygen (mg/l)	0.1	78	7.79	7.91	0.34	11.43	≥5[(2)]	6	8%
Dissolved Oxygen (% Sat.)	0.1	78	92.75	94.45	4.50	122.70	-----	-----	-----
Secchi Depth (in.)	1	25	14.32	14.00	4.00	25.00	-----	-----	-----
Turbidity (NTUs)	1	67	27.86	23.70	6.00	169.90	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	78	375.15	372.50	242.00	520.00	-----	-----	-----
Specific Conductance (umho/cm)	1	78	383.19	379.45	330.90	452.80	2,000[(3)]	0	0%
pH (S.U.)	0.1	78	8.34	8.39	7.20	8.82	≥6.5 & ≤9.0 [(1)]	0	0%
Chlorophyll a (ug/l) – Field Probe	6	73	61	48	5	428	10[(4)]	72	99%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria

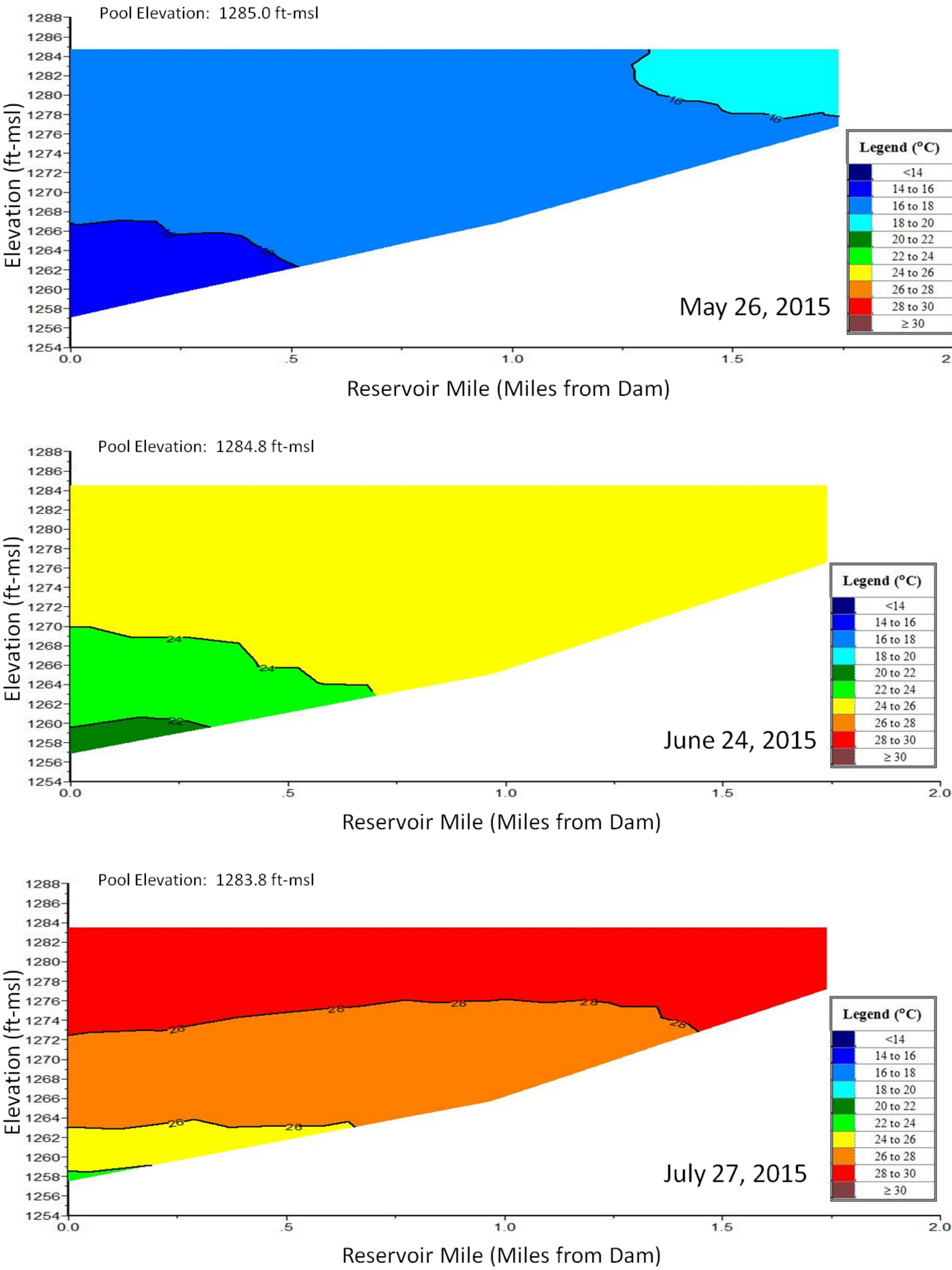
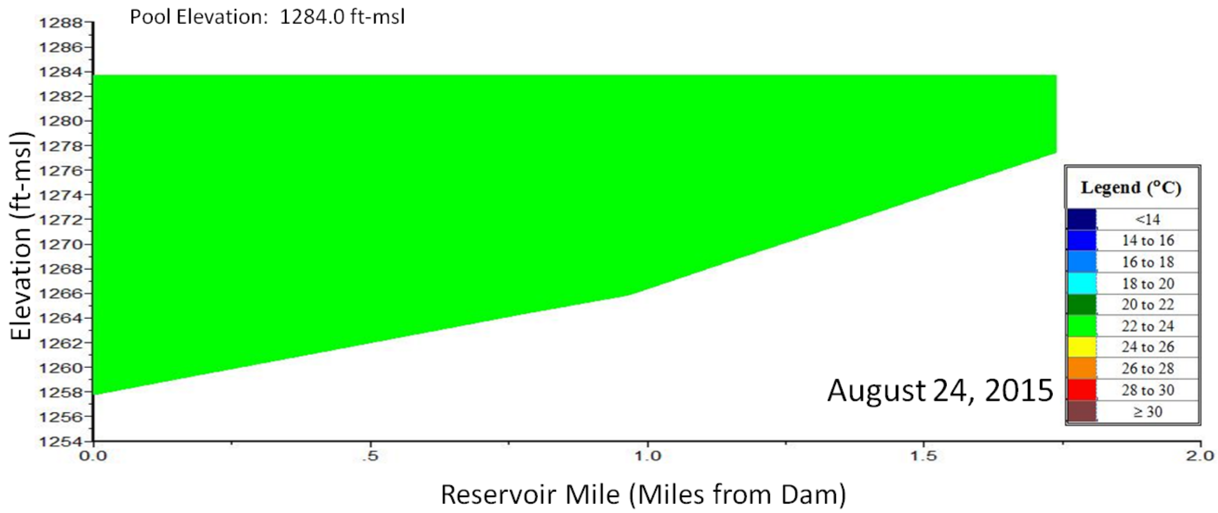


Plate 6-19. Longitudinal water temperature contour plots of Branched Oak Reservoir based on depth-profile water temperatures (°C) measured at sites BOKLKND1, BOKLKMLN1, and BOKLKUPN1 in 2015.



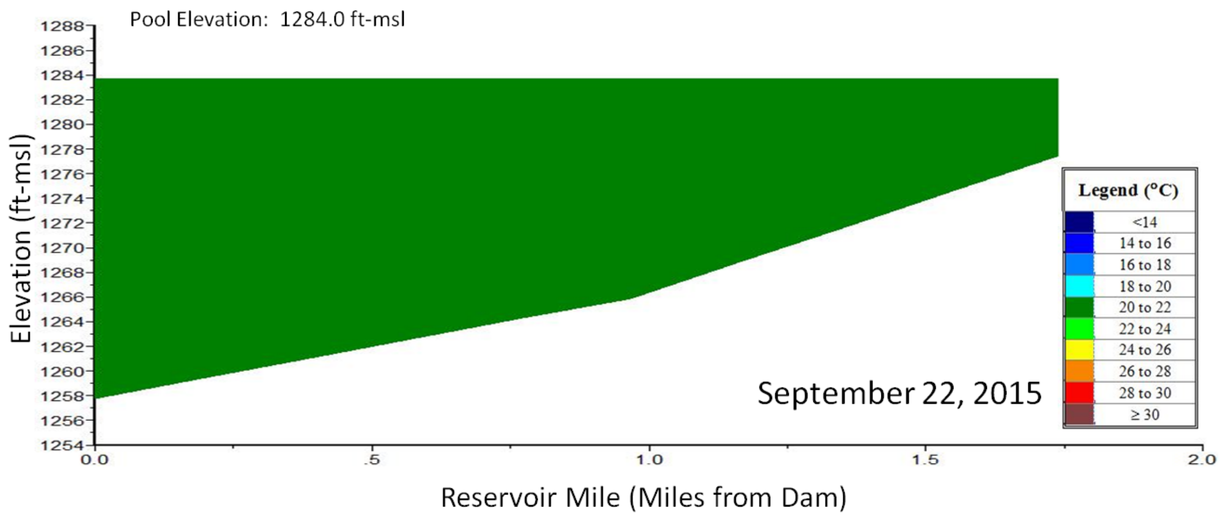


Plate 6-19. (Continued)

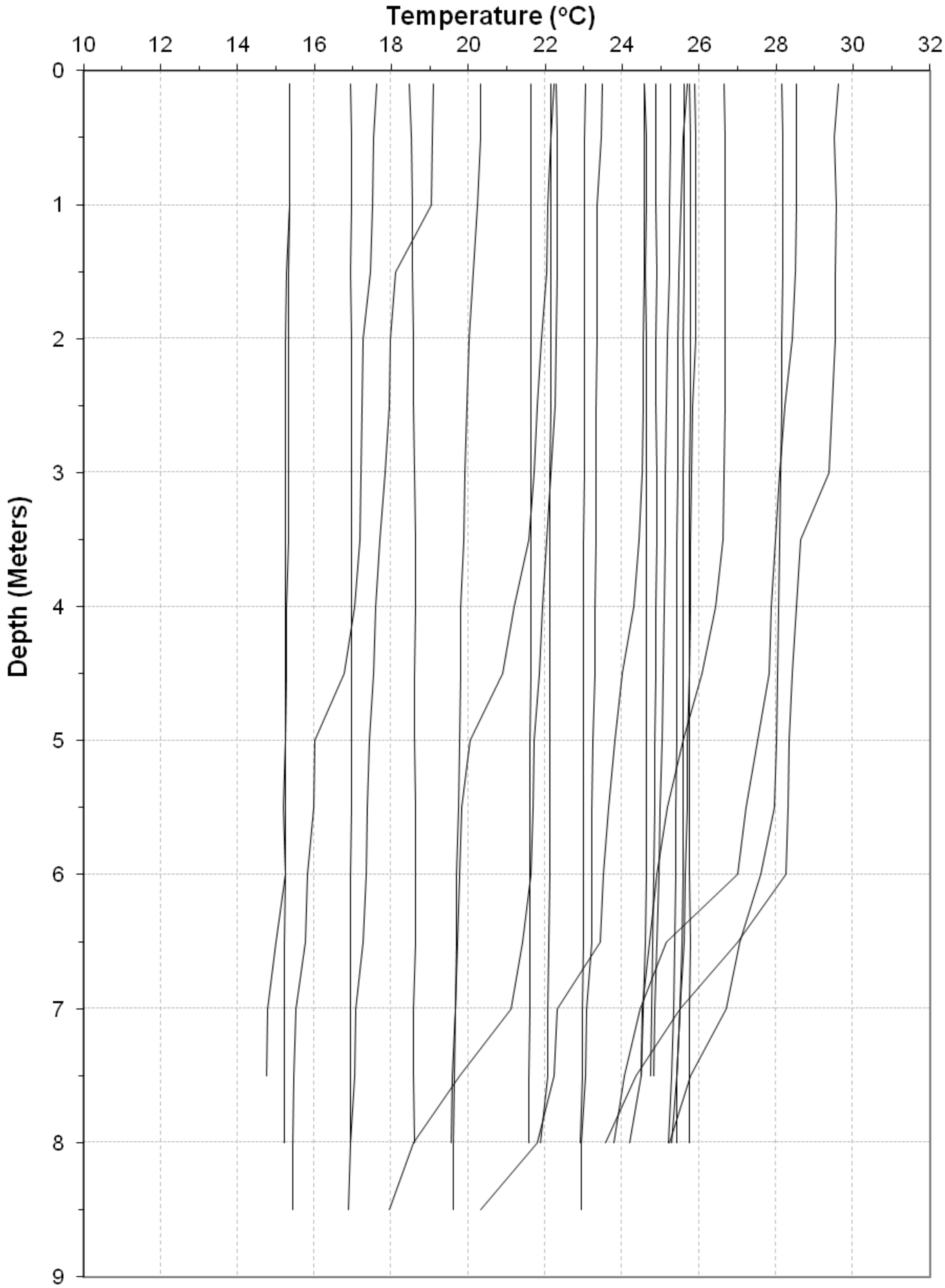


Plate 6-20. Temperature depth profiles for Branched Oak Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1) during the summer over the 5-year period of 2011 through 2015.

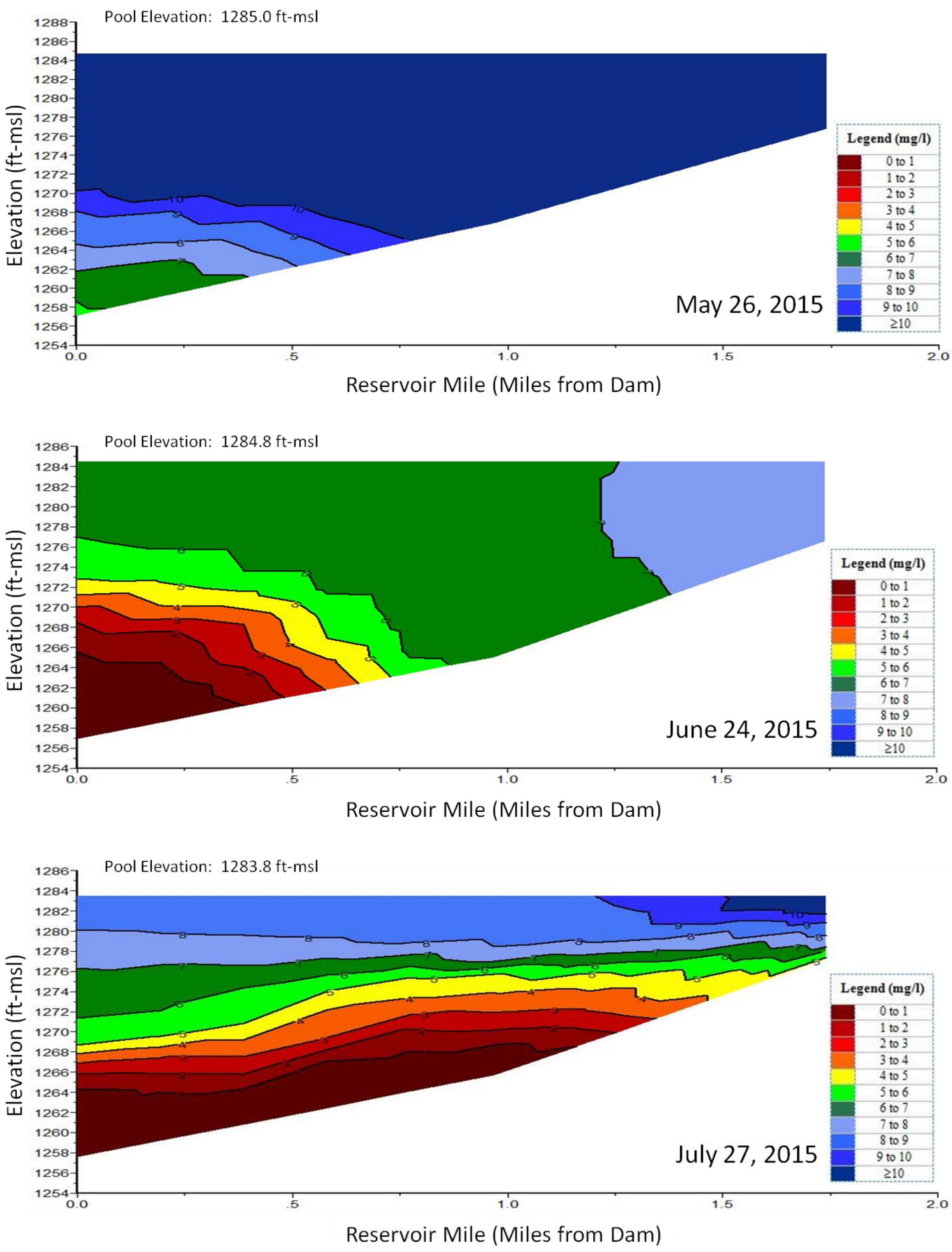
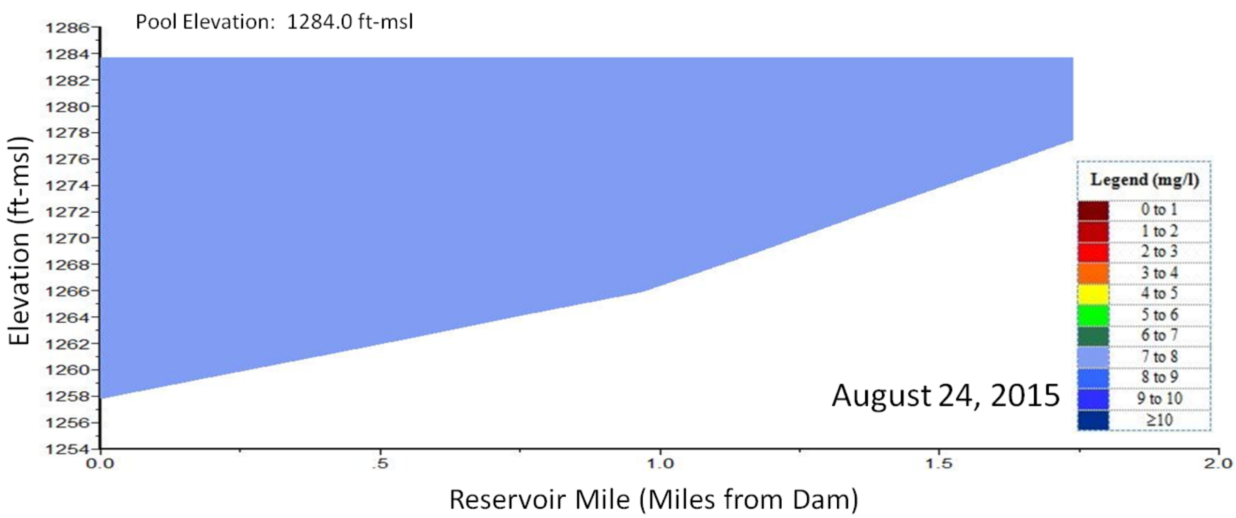


Plate 6-21. Longitudinal dissolved oxygen contour plots of Branched Oak Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites BOKLKND1, BOKLKMLN1, and BOKLKUPN1 in 2015.



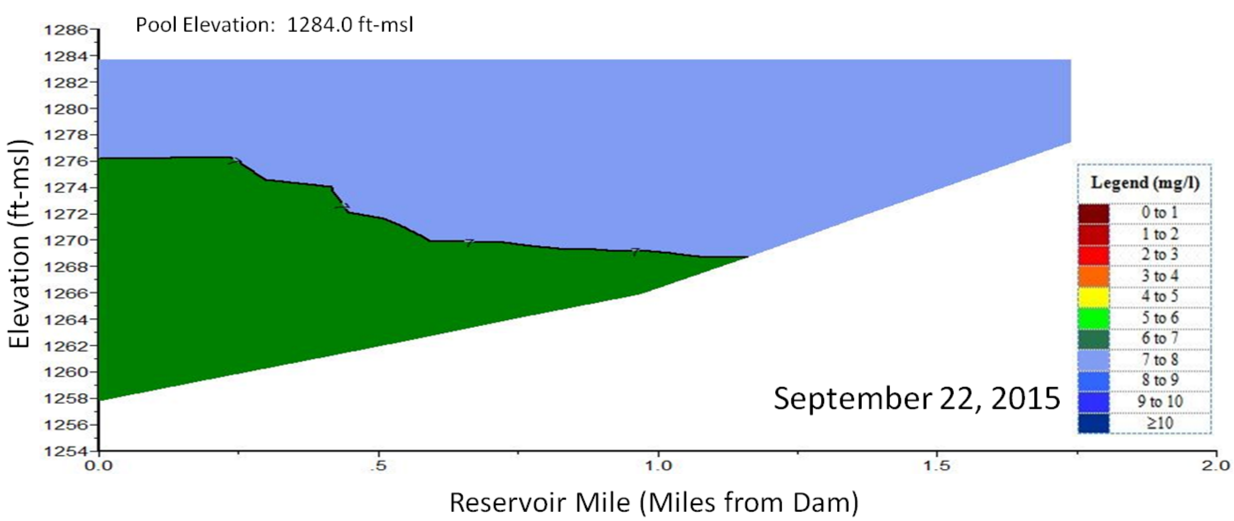


Plate 6-21. (Continued).

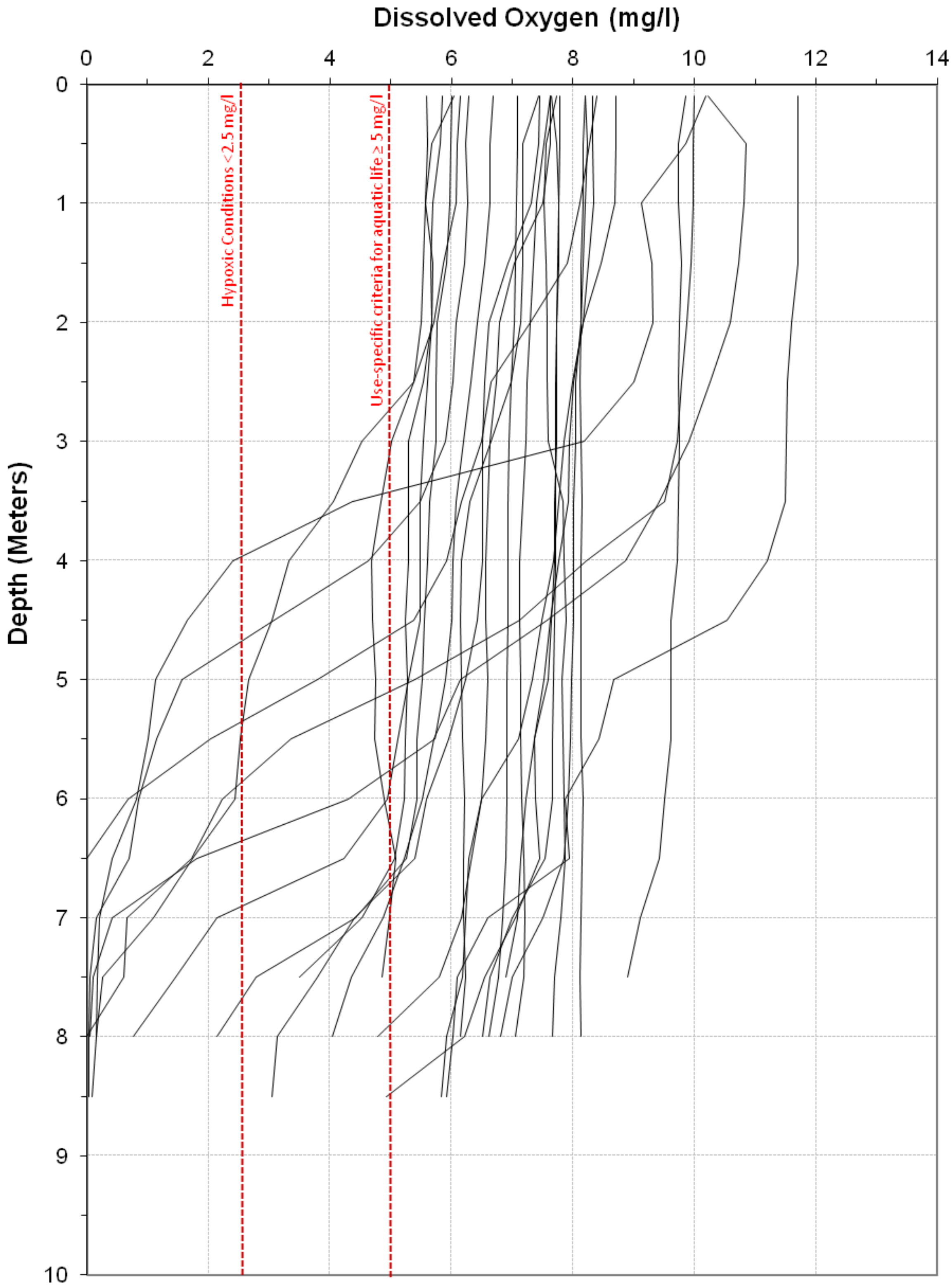
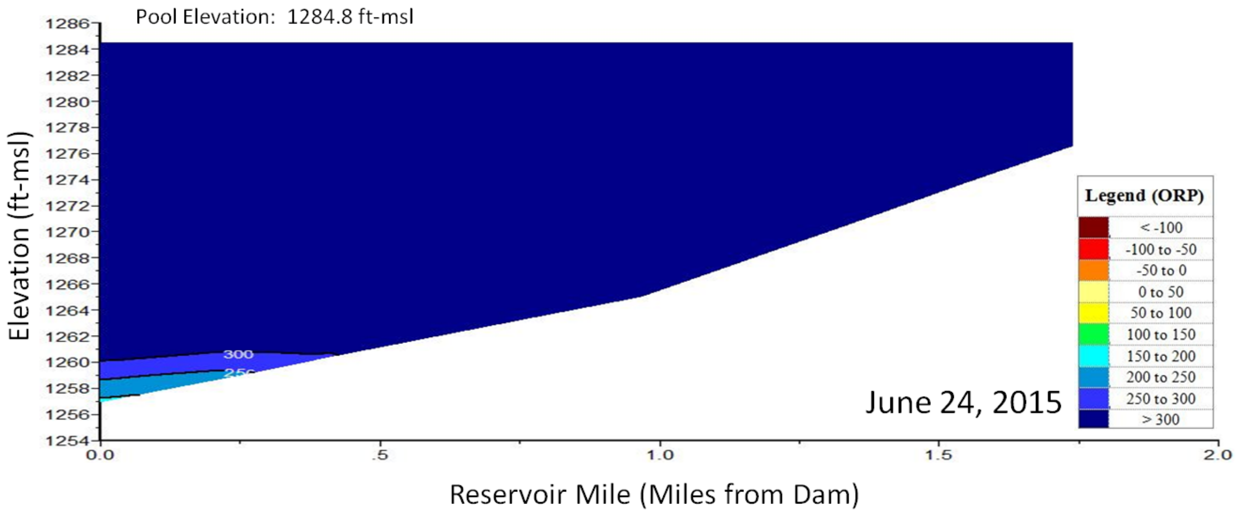


Plate 6-22. Dissolved oxygen depth profiles for Branched Oak Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1) during the summer over the 5-year period of 2011 through 2015.



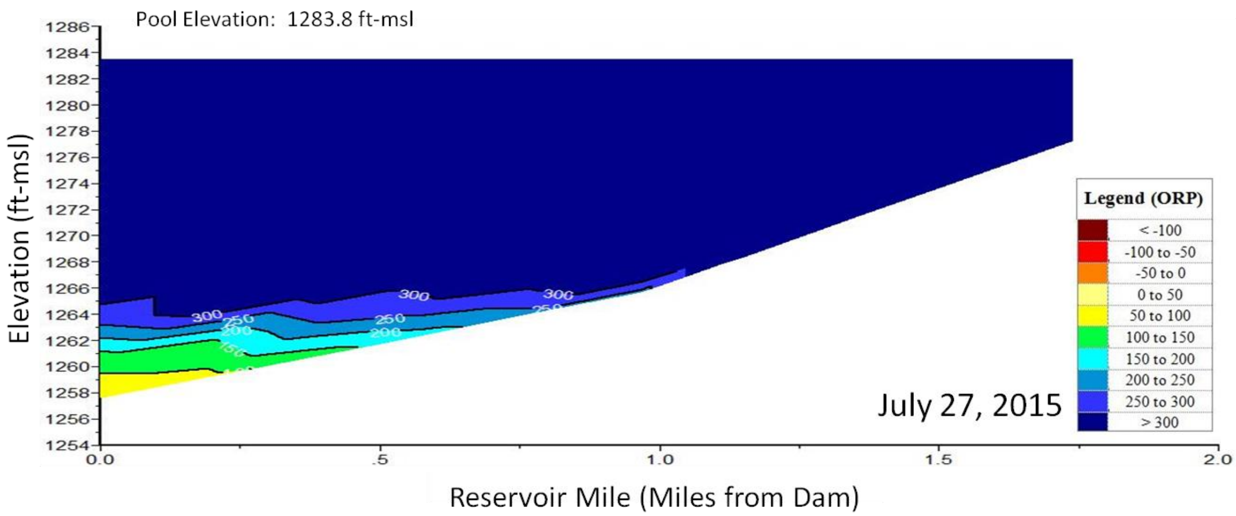


Plate 6-23. Longitudinal oxidation-reduction potential contour plots of Branched Oak Reservoir based on depth-profile ORP levels (mV) measured at sites BOKLKND1, BOKLKMLN1, and BOKLKUPN1 in 2015.

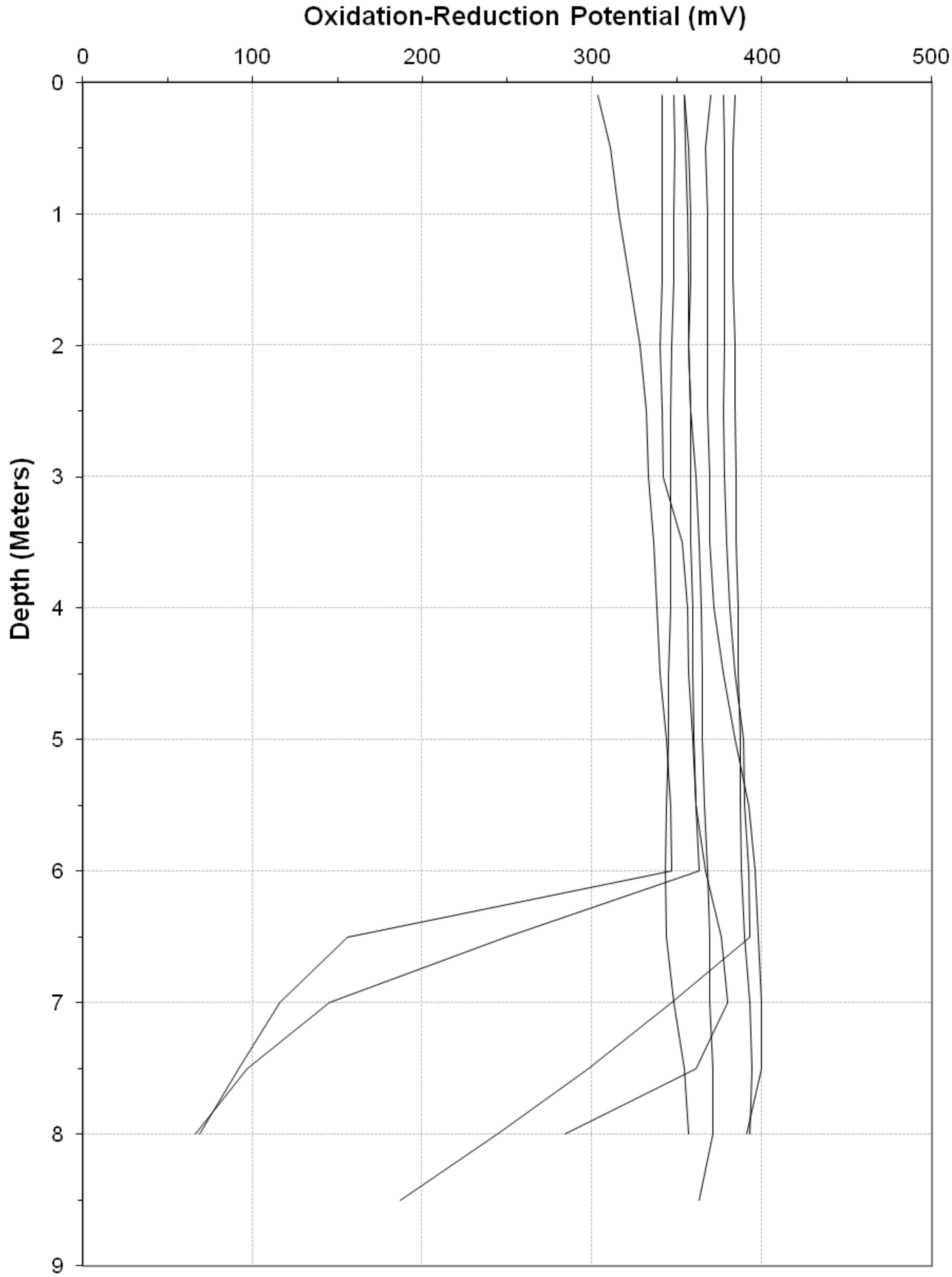
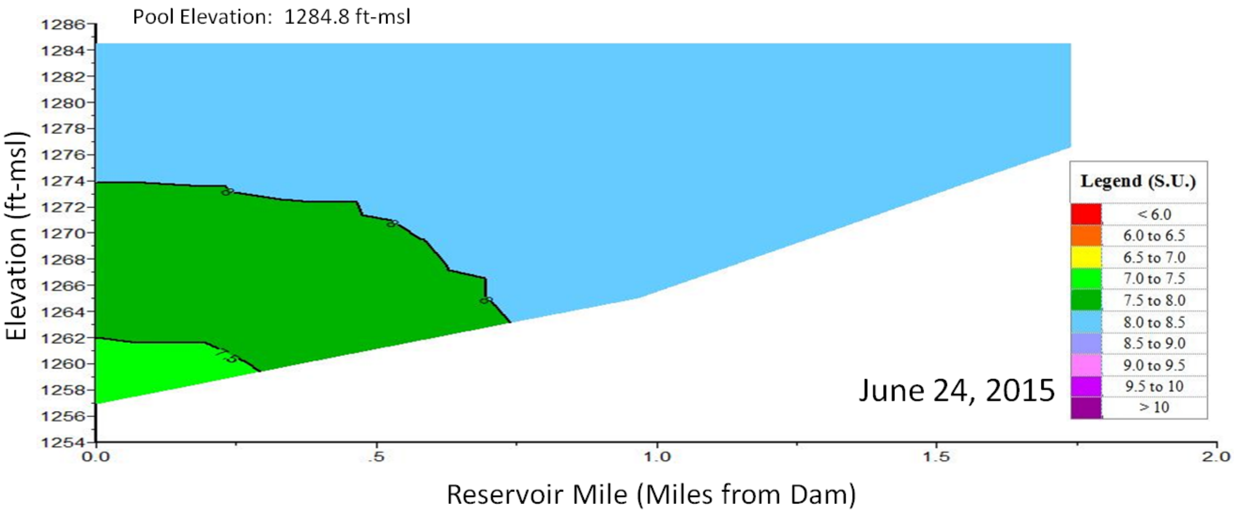


Plate 6-24. Oxidation-reduction potential depth profiles for Branched Oak Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1) when hypoxic conditions were present, during the summer, over the 5-year period of 2011 through 2015.



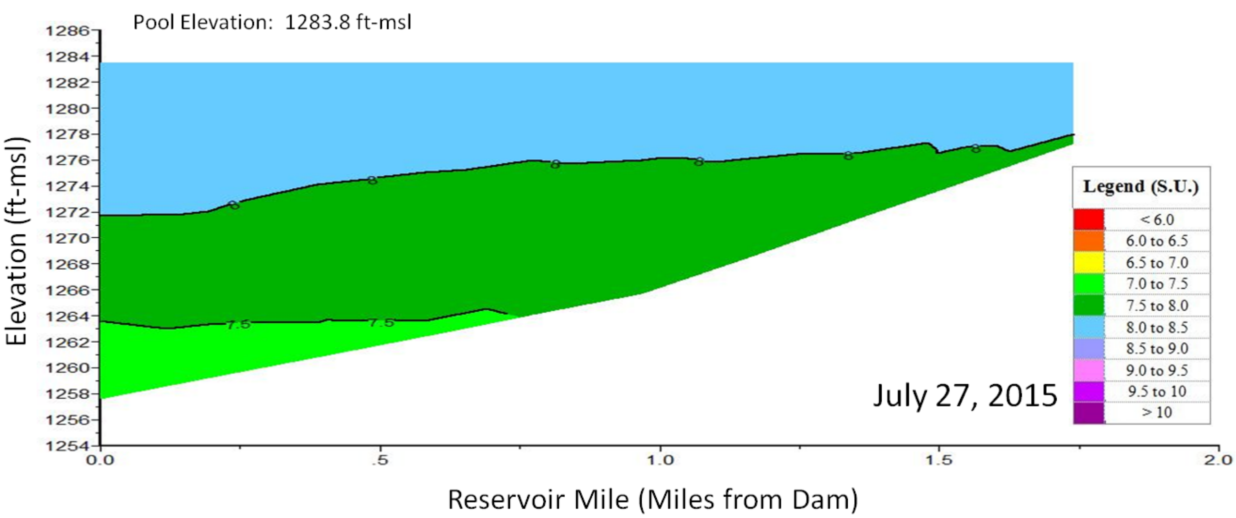


Plate 6-25. Longitudinal pH contour plots of Branched Oak Reservoir based on depth-profile pH levels (S.U.) measured at sites BOKLKND1, BOKLKMLN1, and BOKLKUPN1 in 2015.

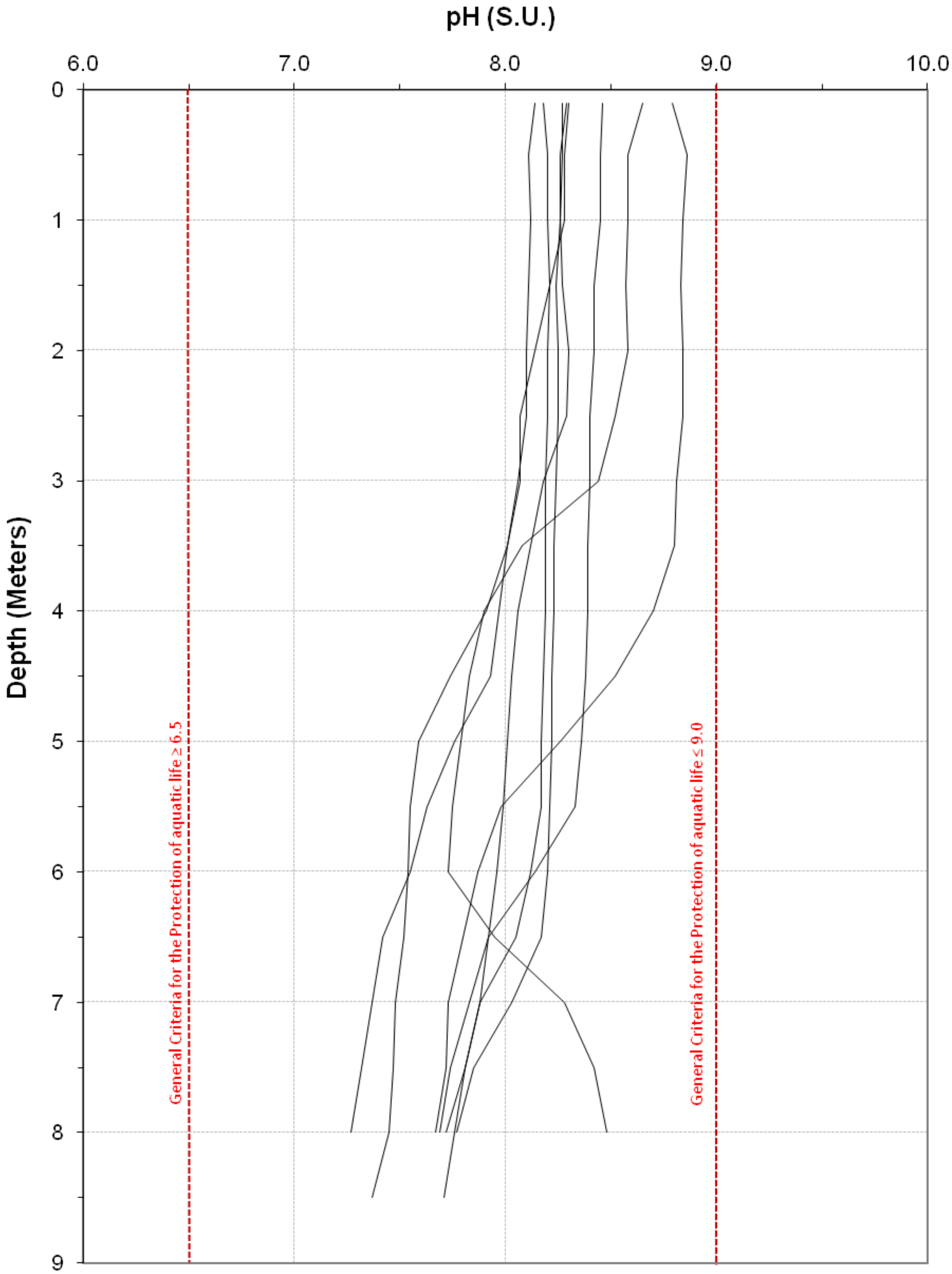


Plate 6-26. pH depth profiles for Branched Oak Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1) during the summer over the 5-year period of 2011 through 2015, when hypoxic conditions were present.

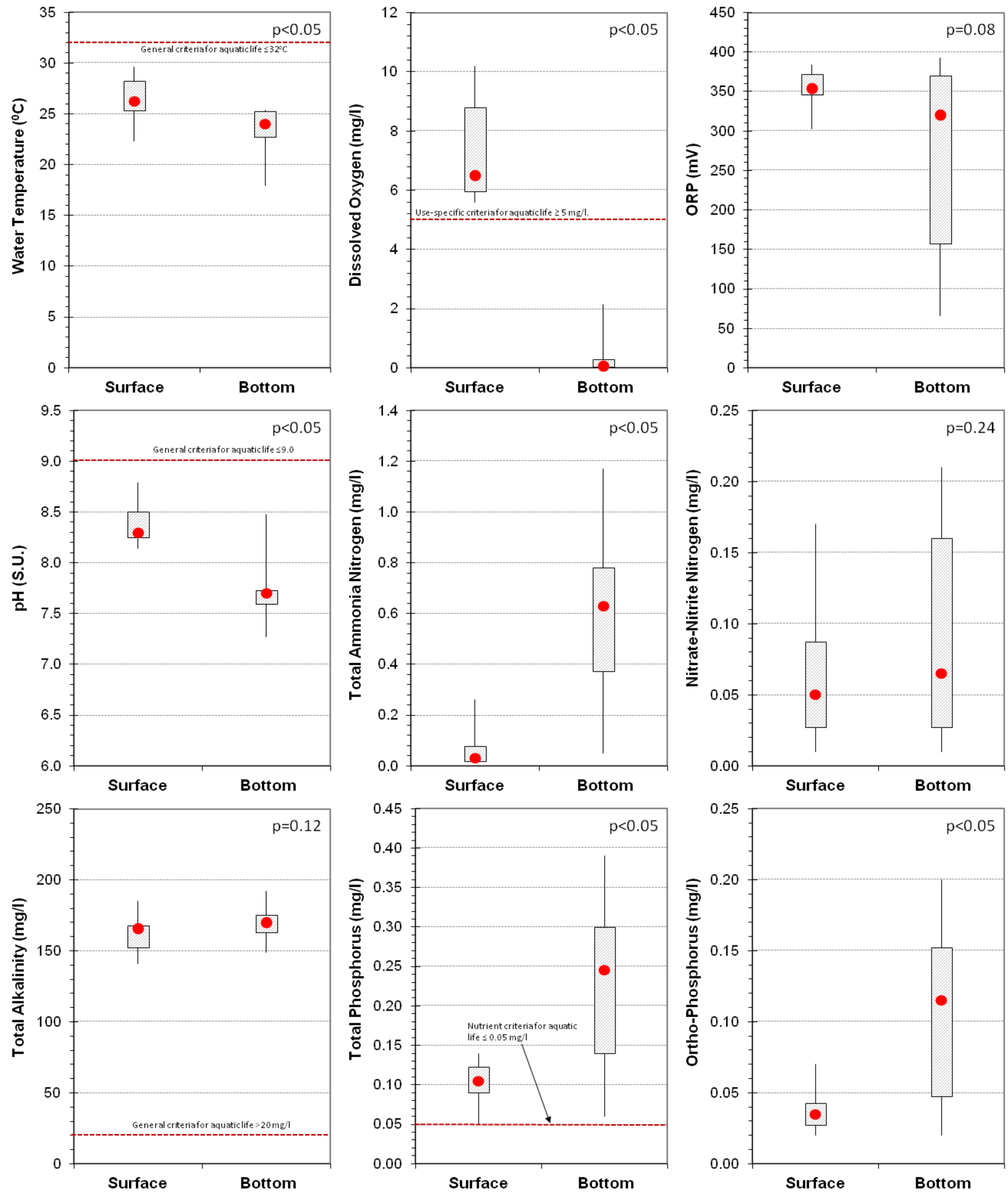


Plate 6-27. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, total ammonia nitrogen, nitrate-nitrite nitrogen, alkalinity, total phosphorus, and ortho-phosphorus measured in Branched Oak Reservoir when summer hypoxic conditions were present during the 5-year period of 2011 through 2015 (n=8). P-values indicate significant differences between the near-surface and near-bottom samples via a paired two-tailed t-test ($\alpha = 0.05$). (Box plots display minimum, 25^{th} percentile, 75^{th} percentile, and maximum. Median value is indicated by the red dot. Water quality criteria marked with red line when applicable)

Plate 6-28. Total biovolume and density by taxonomic group for phytoplankton grab samples from Branched Oak Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)
24-May-11	1,909	9	74,307	1,944	18	0	220	3	94,746	1,873	-----	-----	49,003	198	-----	-----
27-Jul-11	2,631	29	49,411	1,186	-----	-----	52,171	723	2,627,792	42,423	76	0	4,099,401	3,979	3,793	2
21-Sep-11	9,650	55	204,618	3,927	6,189	26	76,907	1,481	997,518	80,733	-----	-----	1,173,082	1,207	11,887	6
30-Apr-12	56,068	47	236,916	3,055	82,752	83	48,724	475	18,452	6,845	-----	-----	664,565	890	493,670	857
05-Jul-12	-----	-----	2,309,742	4,717	127	0	230,823	3,886	125,893	40,379	39,707	7	3,436,903	8,920	434,076	71
06-Sep-12	-----	-----	361,496	9,972	-----	-----	237,850	1,248	2,664,047	232,695	-----	-----	4,123,392	20,588	8,960	89
15-May-13	52,060	15	1,198,204	18,319	840,190	107	2,748,704	32,405	52,918	29,945	-----	-----	4,754,881	15,304	-----	-----
08-Jul-13	4,411	1	656,074	4,320	-----	-----	730,300	7,044	994,774	47,656	18,393	15	2,735,215	3,309	179,472	8
10-Sep-13	193,194	29	3,590,094	8,573	-----	-----	1,812,714	20,021	3,074,267	110,969	1,102	1	5,264,255	12,770	2,294,304	93
12-May-14	135,459	22	58,660	900	1,453	0	269,125	3,173	12,782	4,397	-----	-----	1,483,688	1,283	-----	-----
14-Jul-14	267,550	180	1,171,005	1,943	5,702	0	837,201	2,342	7,537,997	22,832	25,039	6	387,858	2,191	291,871	17
09-Sep-14	119,431	17	1,028,145	1,963	4,141	0	6,863,900	1,777	640,047	3,499	91,574	18	148,458	1,430	46,062	11
26-May-15	8,615	7	99,898	308	-----	-----	464,484	1,856	25,683	578	-----	-----	3,306,683	266	111,002	4
27-Jul-15	-----	-----	237,726	8,220	-----	-----	512,227	5,117	2,478,296	142,726	-----	-----	1,075,951	4,493	263,341	18
22-Sep-15	142,309	143	785,837	3,893	-----	-----	854,190	4,706	7,680,351	429,763	10,474	7	7,316,719	13,918	198,446	7

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

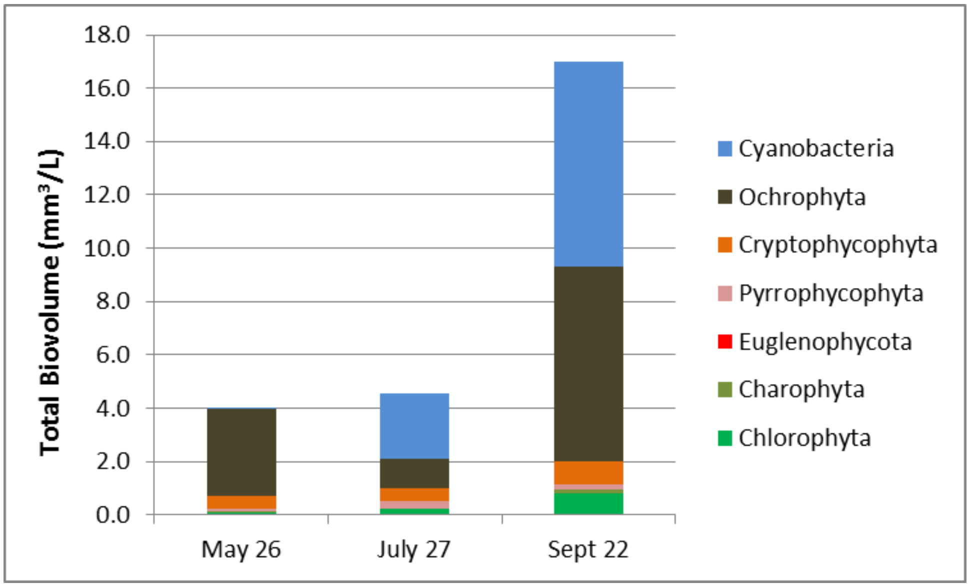


Plate 6-29. Relative abundance of phytoplankton in samples collected from Branched Oak Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1).

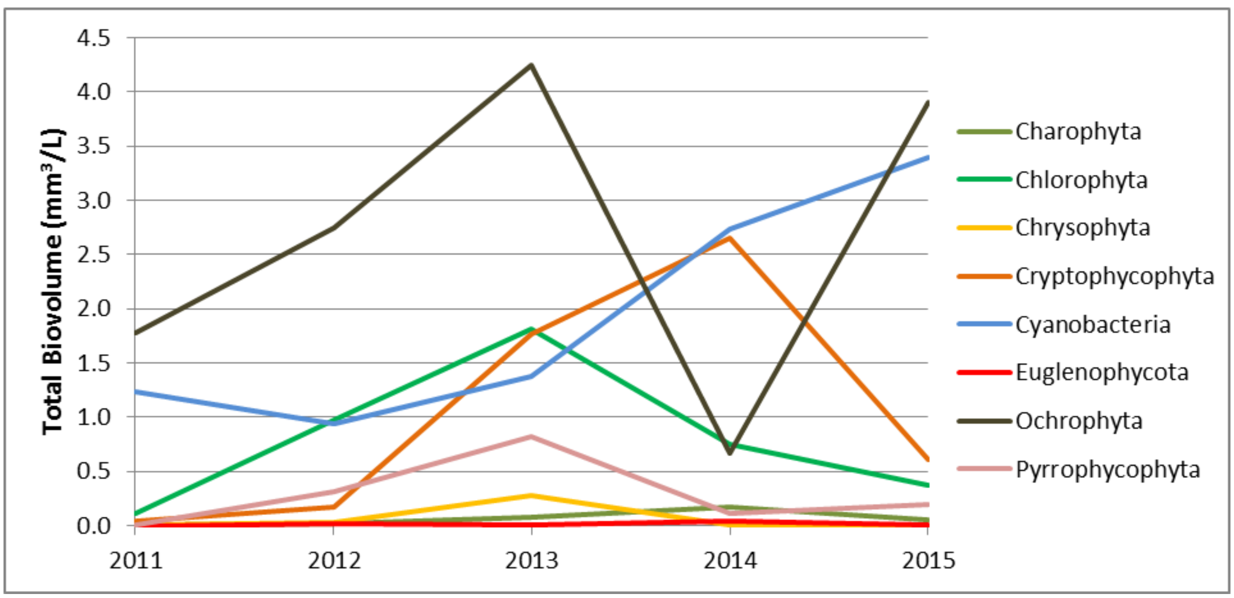


Plate 6-30. Relative abundance of phytoplankton in samples collected from Branched Oak Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are a yearly average of three summer samples (i.e. May, July, and September)

Plate 6-31. Total biomass and density by taxonomic grouping for zooplankton vertical-tow samples from Branched Oak Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)
24-May-11	12	42.94	65	36.63	-----	-----	1	0.01
27-Jul-11	29	31.33	116	47.71	1	0.08	99	0.82
21-Sep-11	1	3.66	49	67.19	-----	-----	9	0.05
30-Apr-12	8	124.28	30	30.16	-----	-----	25	0.11
05-Jul-12	13	55.66	160	70.73	-----	-----	77	0.86
06-Sep-12	4	8.48	61	83.99	-----	-----	-----	-----
15-May-13	7	75.38	315	388.92	-----	-----	225	7.43
18-Jul-13	10	93.19	29	21.10	-----	-----	22	0.32
10-Sep-13	14	44.66	64	86.08	-----	-----	6	0.06
12-May-14	51	264.59	155	145.96	-----	-----	19	0.24
14-Jul-14	46	180.84	311	238.73	-----	-----	1,569	25.88
09-Sep-14	27	147.71	167	232.49	1	5.47	46	0.72
26-May-15	22	80.13	53	69.75	-----	-----	15	0.24
27-Jul-15	34	133.81	157	127.57	-----	-----	121	8
22-Sep-15	19	222.71	179	282.01	-----	-----	11	0.13

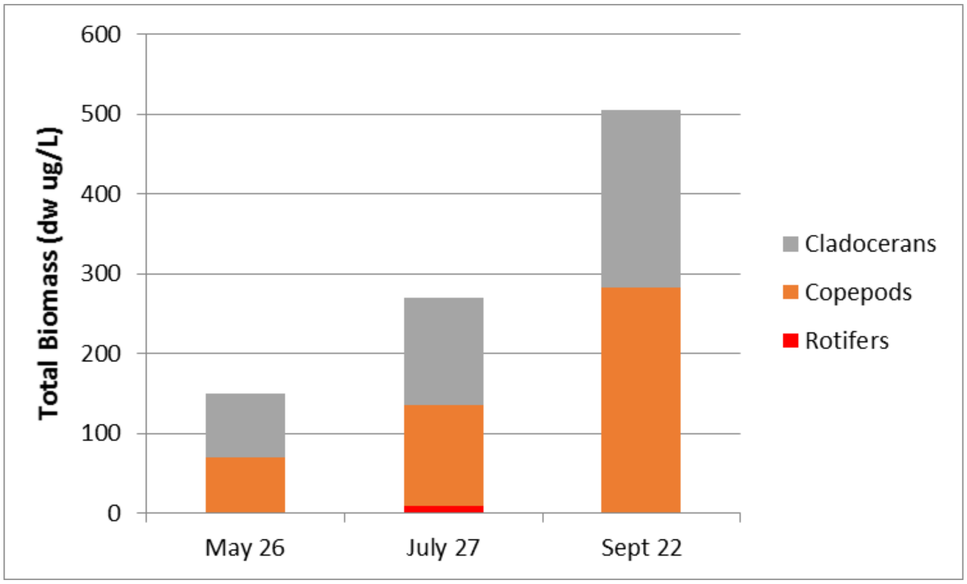


Plate 6-32. Relative abundance of zooplankton in samples collected from Branched Oak Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1).

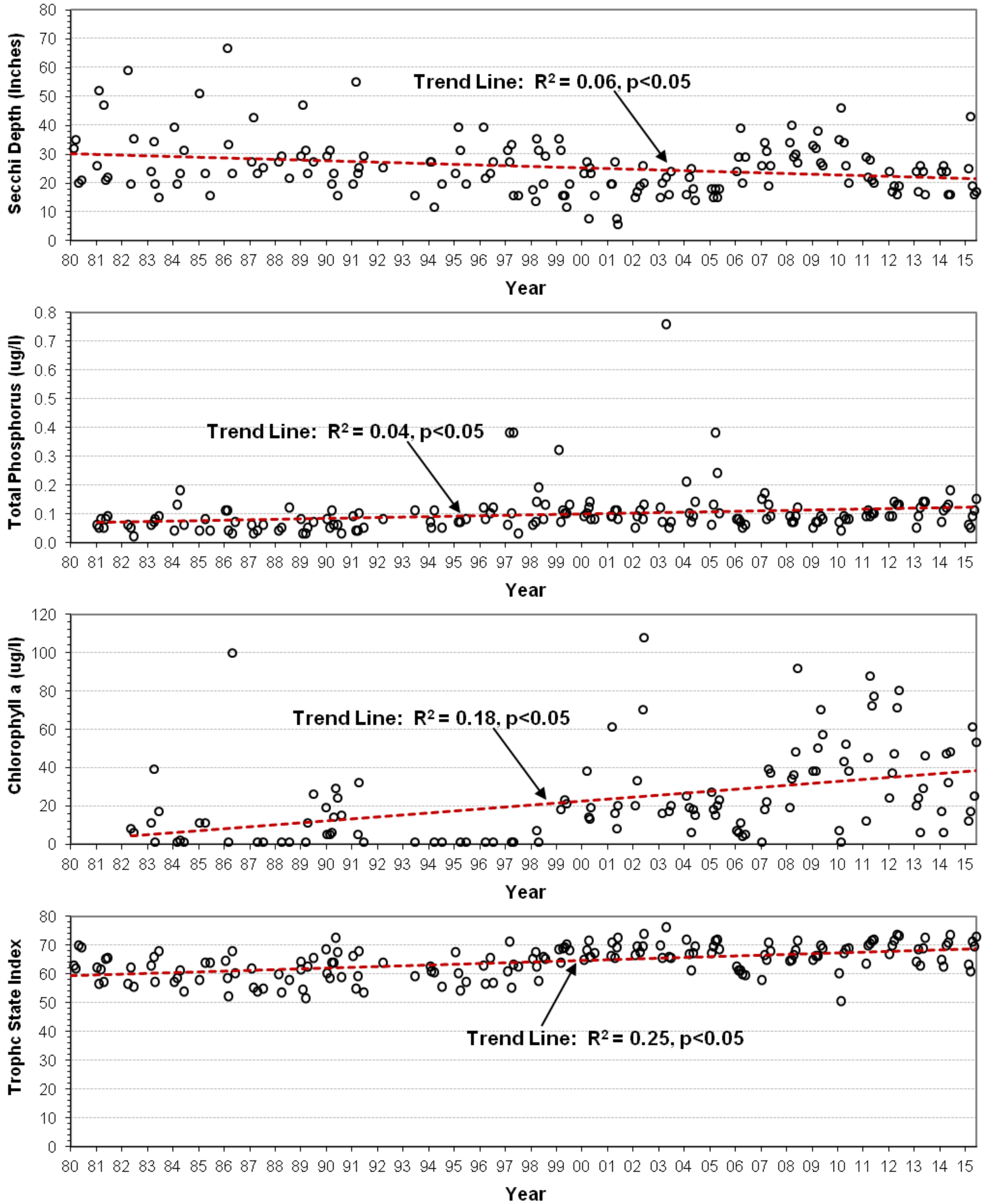


Plate 6-33. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Branched Oak Reservoir at the near-dam, ambient site (i.e., site BOKLKND1) over the 36-year period of 1980 through 2015.

6.4 CONESTOGA RESERVOIR

6.4.1 BACKGROUND INFORMATION

6.4.1.1 Project Overview

The dam forming Conestoga Reservoir is located on Holmes Creek. The dam was completed on September 24, 1963 and the reservoir reached its initial fill in May 1965. The Conestoga Reservoir watershed is 15.1 square miles. The watershed was largely agricultural when the dam was built in 1963 and has remained so to the present time.

6.4.1.2 Conestoga Reservoir Renovation Project

Conestoga reservoir is listed as impaired by the State of Nebraska for Aquatic Life, Aesthetics, and Recreation with the primary stressors being high levels of nutrients and algal toxins along with sedimentation. Conestoga Reservoir has been undergoing a renovation project since late 2013. No water quality data has been collected since the initiation of the renovation project. All data in this report will represent the 5-year period prior to the renovation project (2009 through 2013).

6.4.1.3 Conestoga Dam Intake Structure

The dam intake at Conestoga Dam is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 5 feet by 8 feet. The intake structure has four ungated openings – two 30" x 96" openings with a crest elevation at 1242.3 ft-msl and two 12" x 54" openings with a crest elevation at 1232.9. A 36" x 36" gated opening with a crest elevation of 1228.0 ft-msl was constructed into the upstream wall. The purpose of the gated opening is to lower the level of the conservation pool in order to inspect the conduit, make shoreline repairs, and manage fish populations. It may also be used to release water for downstream needs.

6.4.1.4 Reservoir Storage Zones

Figure 6.5 depicts the current storage zones of Conestoga Reservoir based on the 1996 survey data and estimated sedimentation. All estimates do not account for the present renovation project at Conestoga Reservoir. It is estimated that 34 to 44 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2015. The annual volume loss is estimated to be 0.67 to 0.84 percent. Based on the State of Nebraska's impairment assessment criteria, these values indicate that Conestoga Reservoir's water quality dependent uses are impaired due to sedimentation.

6.4.1.5 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Conestoga 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. Figure 6.6 shows the location of the sites that have been monitored for water quality during the 5-years prior to the current renovation project (i.e., 2009 through 2013). The in-reservoir sites (CONLKND1, CONLKML1, and CONLKUP1) were sampled by the District. The near-dam location (CONLKND1) has been continuously monitored by the District since 1980.

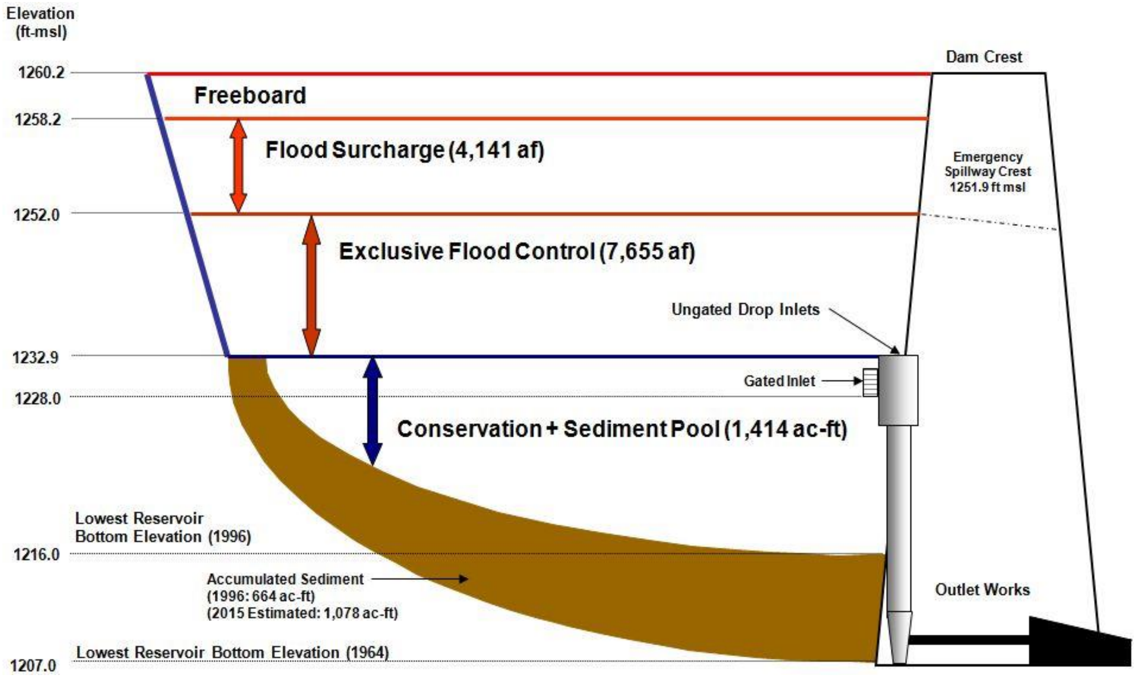


Figure 6.5. Current storage zones of Conestoga Reservoir based on the 1996 survey data and estimated sedimentation (estimations do not include any effects of current renovation project)**.**

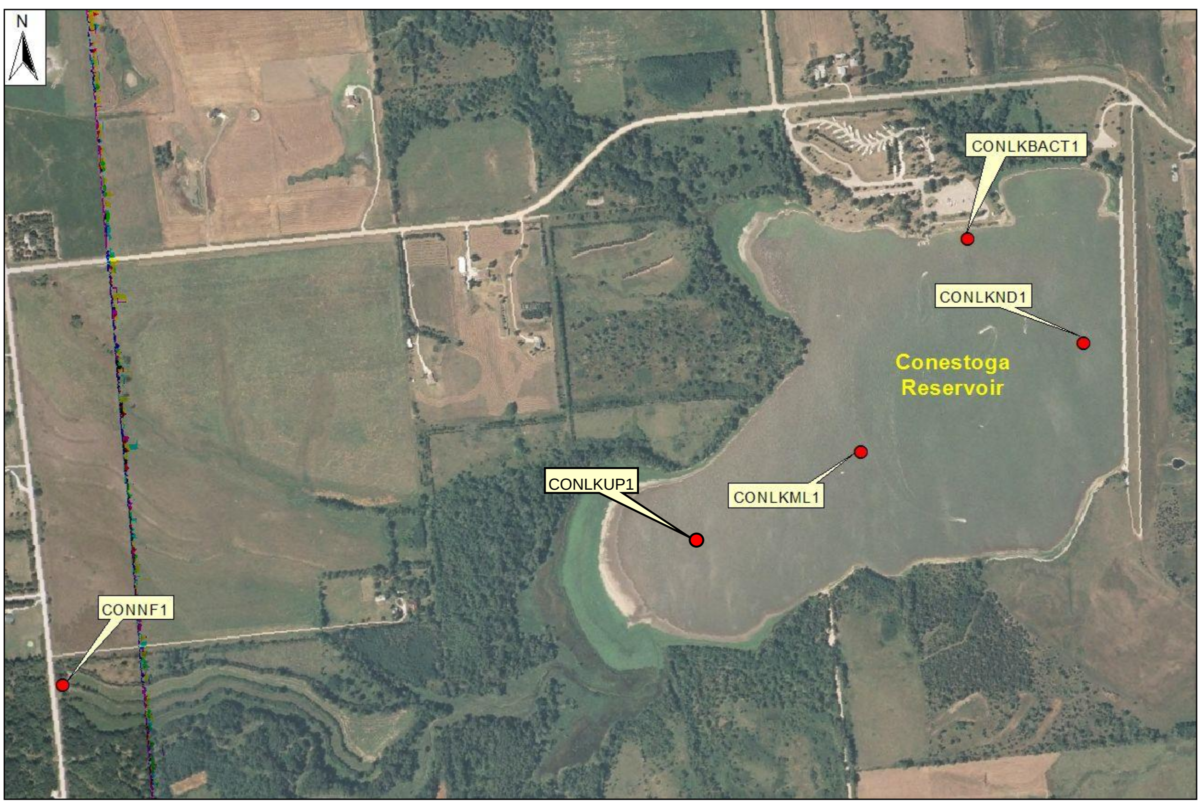


Figure 6.6. Location of sites where water quality monitoring was conducted at Conestoga Reservoir during the period 2009 through 2013.

6.4.1.5.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Conestoga Reservoir at sites CONLKND1, CONLKML1, and CONLKUP1 from May through September during the 5-year period prior to the current renovation project (2009 through 2013) are summarized, respectively, in Plate 6-34 through Plate 6-36. A review of these results indicated possible water quality concerns regarding dissolved oxygen and nutrients.

A significant number of dissolved oxygen measurements throughout Conestoga Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 6-34-Plate 6-36). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and appeared to be associated with a slight thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Conestoga Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation. However, thermal stratification in Conestoga Reservoir was relatively limited during the 5-year sampling period of 2009 through 2013 (Plate 6-37). This limited stratification could lead to the above provision not applying to the reservoir and possible impairment for dissolved oxygen for the protection of aquatic life in Conestoga Reservoir. In addition, dissolved oxygen measurements on September 26, 2012 were below the 5 mg/l criterion for the protection of warmwater aquatic life from the reservoirs surface to bottom.

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September) to be considered for impairment assessment. All three of these criteria were exceeded Conestoga Reservoir (Plate 6-34). The near-surface chlorophyll *a* criterion was exceeded by 92 percent of the "lab analyzed" samples taken in the reservoir at site CONLKND1. The total phosphorus and total nitrogen criteria were exceeded by 100 percent of the samples for both parameters. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values (Plate 6-34) represent the growing season average for the 5-year period 2009 through 2013. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.12 mg/l), total nitrogen (1.84 mg/l), and chlorophyll *a* (67 ug/l) values at CONLKND1 indicate impairment of the aquatic life use due to nutrients.

6.4.1.5.2 Thermal Stratification

6.4.1.5.2.1 ***Longitudinal Temperature Contour Plots***

Due to the current renovation project at Conestoga Reservoir, water quality data has not been collected since late summer 2013. As a result, no current longitudinal temperature contour plots were constructed.

6.4.1.5.2.2 ***Near-Dam Temperature Depth-Profile Plots***

Summer thermal stratification of Conestoga Reservoir, at the deep water area near the dam, measured over the 5-year period prior to the current renovation project (2009 through 2013) is depicted by depth-profile temperature plots (Plate 6-37). The plotted depth-profile temperature measurements indicate that the reservoir rarely exhibits significant summer thermal stratification. Since Conestoga Reservoir ices over in the winter and seemingly exhibits frequent or continuous circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.4.1.5.3 Dissolved Oxygen Conditions

6.4.1.5.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Due to the current renovation project at Conestoga Reservoir, water quality data has not been collected since late summer 2013. As a result, no current longitudinal dissolved oxygen contour plots were constructed.

6.4.1.5.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

The depth-profile dissolved oxygen measurements collected during the summer over the 5 years prior to the current renovation project at the deep water area near the dam were plotted and compiled to describe summer dissolved oxygen conditions of Conestoga Reservoir (Plate 6-38). Several of the profiles showed an appreciable vertical gradient in dissolved oxygen levels. Twenty percent of the profiles showed hypoxic conditions near the reservoir bottom. For one of the profiles, dissolved oxygen levels were below the state criteria for the protection of aquatic life through the entire depth of the profile (>5ug/l). Although Conestoga Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition of mixing to allow hypoxic conditions to develop near the reservoir bottom in the area near the dam.

6.4.1.5.4 Water Quality Conditions Based on Hypoxia

Due to the current renovation project at Conestoga Reservoir, water quality data has not been collected since late summer 2013. As a result, no current longitudinal pH or ORP contour plots were constructed. During the 5-year sampling period prior to the current renovation project (2009 through 2013) only twenty percent of the depth profiles at the near dam site showed hypoxic conditions near the reservoir bottom (Plate 6-38). Due to this further analysis was not performed.

6.4.1.5.4.1 ***Reservoir Trophic Status***

Trophic State Index (TSI) values for Conestoga Reservoir were calculated from monitoring data collected during the 5-year period prior to the current renovation project for years 2009 through 2013 at the near-dam ambient monitoring site (i.e., CONLKND1). Table 6.12 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Conestoga Reservoir was in a hypereutrophic condition prior to the current renovation project.

Table 6.12. Summary of Trophic State Index (TSI) values calculated for Conestoga Reservoir for the 5-year period prior to the current renovation project for years 2009 through 2013.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	24	71	71	61	90
TSI(TP)	25	64	65	59	74
TSI(Chl)	24	78	76	61	90
TSI(Avg)	25	71	70	60	84

* 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 for the individual parameters.

Note: See Section 4.1.3 for discussion of TSI calculation.

6.4.1.5.5 Monitoring at Swimming Beaches

A designated swimming beach is located on Conestoga Reservoir. Bacteria (i.e., *E. coli*) and the cyanobacteria toxin microcystin were monitored at the swimming beach on the reservoir at site CONLKBACT1 by the NDEQ prior to the current renovation project (Figure 6.2).

6.4.1.5.5.1 ***Bacteria Monitoring***

Table 6.13 summarizes the results of the *E. coli* bacteria monitoring during the 5-year period prior to the current renovation project. The "running 5-week" geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The "pooled" geomean was determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for *E. coli* bacteria:

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

The pooled geomean was compared to the State of Nebraska's impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using *E. coli* bacteria data. Based on these criteria a Primary Contact Recreation use in Conestoga Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

Table 6.13. Summary of weekly (May through September) *E. coli* bacteria samples collected at Conestoga Reservoir (i.e., site CONLKBACT1) during the 5-year period prior to the current renovation project (2009-2013).

E. coli **– Individual Samples**		***E. coli*** **– Geomeans (Running 5-Week)**	
Number of Samples	108	Number of Geomeans	88
Mean (cfu/100ml)	35	Average	14
Median (cfu/100ml)	5	Median	5
Minimum (cfu/100ml)	1	Minimum	1
Maximum (cfu/100ml)	613	Maximum	160
Percent of samples exceeding 235/100ml	6%	Percent of Geomeans exceeding 126/100ml	1%
		E. coli **– Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	6

6.4.1.5.5.2 ***Microcystin Monitoring***

Table 6.14 summarizes the total microcystin monitoring conducted at the Conestoga Reservoir swimming beach during the 5-year period prior to the current renovation project 2009 through 2013. These results were compared to the 20 ug/l criterion for issuing health advisories and the posting of swimming beaches. No samples exceeded the criterion.

6.4.1.6 <u>Water Quality Trends Prior to Current Renovation Project (1980 through 2013)</u>

Water quality trends prior to the current renovation project from 1980 to 2013 were determined for Conestoga 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., CONLKND1). Plate 6-39 displays a scatter-plot of the collected data for the four parameters and a linear regression line.

For the assessment period, it appears that Conestoga Reservoir exhibited no noticeable change in transparency ($p=0.86$, $R^2=0.0002$) and increases in total phosphorus ($p<0.05$, $R^2=0.05$) concentrations and chlorophyll *a* levels ($p<0.05$, $R^2=0.07$). Over the 34-year period before the renovation project, Conestoga Reservoir moved from a eutrophic to hypereutrophic condition ($p < 0.05$, $R^2=0.15$).

Table 6.14. Summary of weekly (May through September) total microcystin samples collected at the Conestoga Reservoir swimming beach (i.e., site CONLKBACT1) during the 4-year period 2008 through 2012.

Summary Statistic	**Swimming Beach (Site CONLKBACT1)**
Number of Samples	109
Minimum (ug/l)	n.d.
25th percentile (ug/l)	0.1
Median (ug/l)	0.49
75th Percentile (ug/l)	2.28
Maximum (ug/l)	9.56
Number of samples exceeding 20 ug/l	0
Percent of samples exceeding 20 ug/l	0%

6.4.2 PLATES

Plate 6-34. Summary of water quality conditions monitored in Conestoga Reservoir at site CONLKND1 from May to September during the 5-year period prior to current restoration project 2009 through 2013. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	24	1232.82	1232.90	1230.00	1234.10	-----	-----	-----
Water Temperature (°C)	0.1	218	23.78	24.25	15.76	32.97	32(1)	2	1%
Dissolved Oxygen (mg/l)	0.1	218	8.08	8.19	0.23	14.43	≥5(2)	32	15%
Dissolved Oxygen, Near-Surface (mg/l)(C)	0.1	24	9.58	9.73	4.31	14.30	≥5(2)	1	4%
Dissolved Oxygen (% Sat.)	0.1	210	99.14	104.05	3.00	190.00	-----	-----	-----
Secchi Depth (in.)	1	24	19.50	18.00	5.00	36.00	-----	-----	-----
Turbidity (NTUs)	1	201	29.16	23.60	6.70	421.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	210	316.17	322.50	-104.00	466.00	-----	-----	-----
Specific Conductance (umho/cm)	1	210	471.68	450.25	89.40	636.20	2,000(3)	0	0%
pH (S.U.)	0.1	210	8.40	8.41	7.34	9.31	≥6.5 & ≤9.0 (1)	0,11	0%,5%
Alkalinity, Total (mg/l)	1	50	138.46	131.00	95.00	212.00	<20(1)	0	0%
Suspended Solids, Total (mg/l)	4	50	21.50	21.00	6.00	49.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	50	-----	0.08	n.d.	0.92	1.28(4,5), 0.32(4,6)	0,3	0%,6%
Ammonia, Total, Near-Surface (mg/)(C)	0.02	25	-----	0.04	n.d.	0.60	0.84(4,5), 0.22(4,6)	0	0%
Kjeldahl N, Total (mg/l)	0.08	50	1.80	1.70	0.96	3.84	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	50	-----	n.d.	n.d.	0.30	100(3)	0	0%
Nitrogen, Total (mg/l)	0.08	50	1.85	1.76	0.98	3.85	1(7)	49	98%
Nitrogen, Total, Near-Surface (mg/)(C)	0.08	25	1.84	1.73	1.04	3.85	1(7)	25	100%
Phosphorus, Total (mg/l)	0.005	50	0.13	0.12	0.06	0.38	0.05(7)	50	100%
Phosphorus, Total, Near-Surface (mg/l)(C)	0.005	25	0.12	0.11	0.06	0.27	0.05(7)	25	100%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	n.d.	n.d.	0.11	-----	-----	-----
Hardness, Total (mg/l)	0.4	6	137.43	135.00	117.00	157.00	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	6	6.33	6.00	4.00	9.00	340(5), 16.7(8)	0	0%
Beryllium, Dissolved (ug/l)	2	6	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.2	6	-----	n.d.	n.d.	0.50	7.90(5), 0.30(6)	0,1	0%,17%
Chromium, Dissolved (ug/l)	10	6	-----	n.d.	n.d.	n.d.	757.03(5), 98.55(6)	0	0%
Copper, Dissolved (ug/l)	10	6	-----	n.d.	n.d.	n.d.	17.83(5), 11.57(6)	0	0%
Iron, Dissolved (ug/l)	10	10	-----	28.00	n.d.	40.00	1000(6)	0	0%
Lead, Dissolved (ug/l)	0.5	6	-----	n.d.	n.d.	n.d.	89.40(5), 3.48(6)	0	0%
Manganese, Dissolved (ug/l)	3	10	29.30	11.50	4.00	100.00	1000(6)	0	0%
Nickel, Dissolved (ug/l)	10	6	-----	n.d.	n.d.	n.d.	603.57(5), 67.04(6)	0	0%
Silver, Dissolved (ug/l)	1	6	-----	n.d.	n.d.	n.d.	5.78(5)	0	0%
Zinc, Dissolved (ug/l)	10	6	-----	n.d.	n.d.	n.d.	151.11(5), 152.34(6)	0	0%
Antimony, Dissolved (ug/l)	0.5	6	-----	n.d.	n.d.	1.00	88(5), 30(6)	0	0%
Aluminum, Dissolved (ug/l)	25	6	-----	n.d.	n.d.	40.00	750(5), 87(6)	0	0%
Mercury, Dissolved (ug/l)	0.05	6	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.05	6	-----	n.d.	n.d.	n.d.	0.77(6)	0	0%
Chlorophyll a (ug/l) – Lab Determined(C)	6	24	68	43	9	171	10(7)	22	92%
Chlorophyll a (ug/l) – Field Probe	6	196	71	54	7	191	10(7)	179	91%
Atrazine, Total (ug/l)(D)	0.05	25	1.14	1.10	n.d.	2.30	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(D)	0.1	25	-----	0.20	n.d.	2.40	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l)(D)	0.08	25	0.31	0.20	n.d.	0.90	-----	-----	-----
Microcystin, Extracellular (ug/l)	0.1	24	-----	n.d.	n.d.	3.00	20(9)	0	0%
Pesticide Scan (ug/l)(E)									
Atrazine, Tot	0.13	5	0.52	0.57	n.d.	0.70	330(5), 12(6)	0	0%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-35. Summary of water quality conditions monitored in Conestoga Reservoir at site CONLKML1 from May to September during the 5-year period prior to current renovation project (2009 through 2013). [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	24	1232.83	1232.90	1230.00	1234.10	-----	-----	-----
Water Temperature (°C)	0.1	164	23.95	24.65	15.86	33.48	32(1)	2	1%
Dissolved Oxygen (mg/l)	0.1	164	8.45	8.31	0.68	17.00	$\geq$5(2)	10	6%
Dissolved Oxygen (% Sat.)	0.1	160	103.61	101.05	8.50	242.20	-----	-----	-----
Secchi Depth (in.)	1	25	17.56	17.00	5.00	32.00	-----	-----	-----
Turbidity (NTUs)	1	154	28.11	23.75	6.40	90.10	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	160	327.72	326.00	130.00	465.00	-----	-----	-----
Specific Conductance (umho/cm)	1	160	472.81	448.95	350.00	636.60	2,000(3)	0	0%
pH (S.U.)	0.1	160	8.43	8.43	7.26	9.30	$\geq$6.5 & $\leq$9.0 (1)	0,10	0%,6%
Chlorophyll a (ug/l) – Field Probe	6	149	68	50	8	201	10(4)	146	98%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-36. Summary of water quality conditions monitored in Conestoga Reservoir at site CONLKUP1 from May to September during the 5-year period prior to current renovation project (2009 through 2013). [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	24	1232.83	1232.90	1230.00	1234.10	-----	-----	-----
Water Temperature (°C)	0.1	50	24.06	24.77	17.24	33.63	32(1)	2	4%
Dissolved Oxygen (mg/l)	0.1	50	9.98	9.85	5.80	17.70	$\geq$5(2)	0	0%
Dissolved Oxygen (% Sat.)	0.1	50	124.22	123.20	75.20	252.10	-----	-----	-----
Secchi Depth (in.)	1	25	15.24	16.00	5.00	27.00	-----	-----	-----
Turbidity (NTUs)	1	49	39.07	25.80	8.80	141.40	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	50	317.10	311.00	113.00	460.00	-----	-----	-----
Specific Conductance (umho/cm)	1	50	469.49	444.85	343.00	637.30	2,000(3)	0	0%
pH (S.U.)	0.1	50	8.58	8.61	7.74	9.35	$\geq$6.5 & $\leq$9.0 (1)	0,4	0%,8%
Chlorophyll a (ug/l) – Field Probe	6	48	1080	1099	587	2332	10(4)	48	100%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

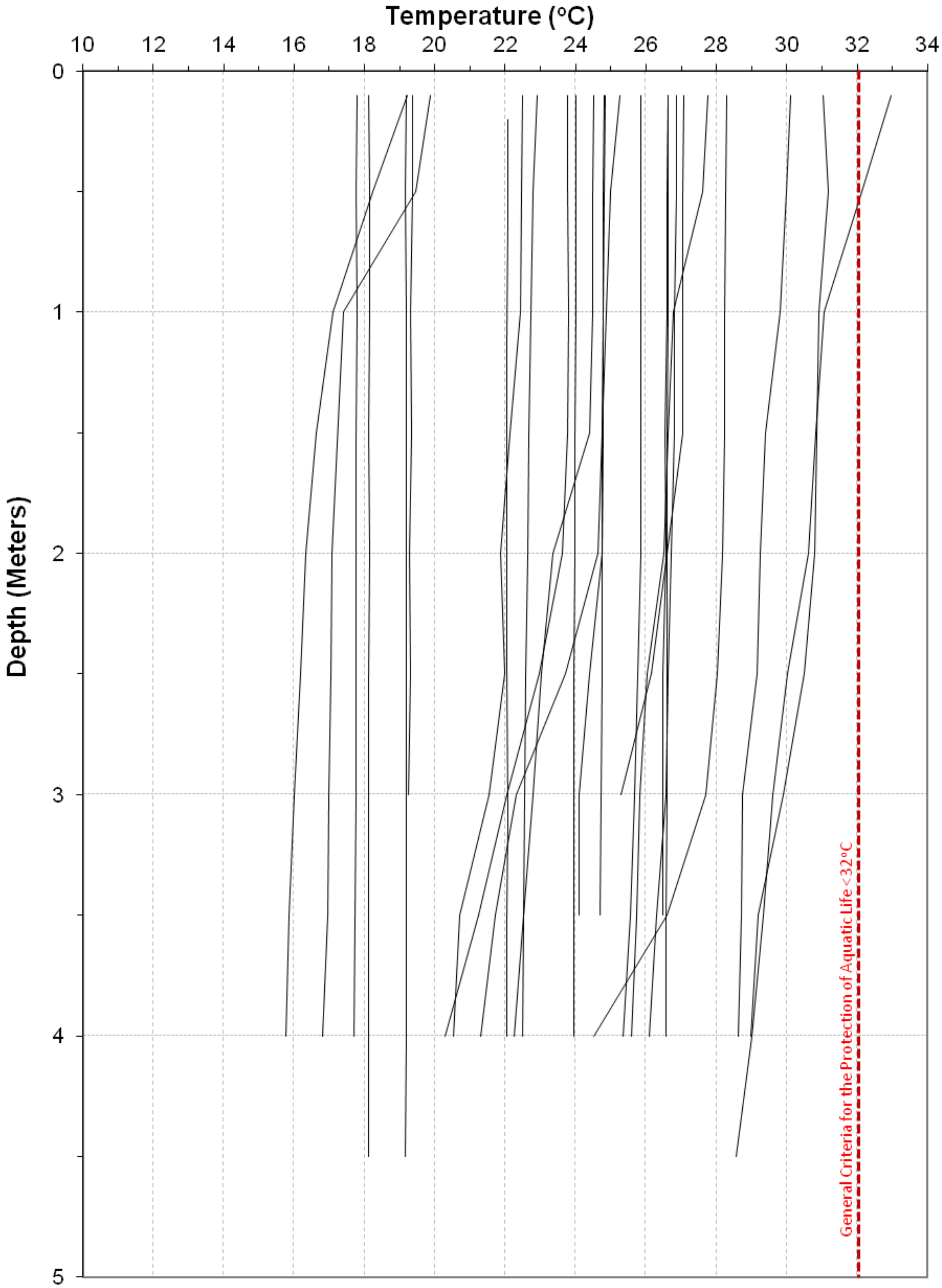


Plate 6-37. Temperature depth profiles for Conestoga Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., CONLKND1) during the summer over the 5-year period prior to the current renovation project (2009 through 2013).

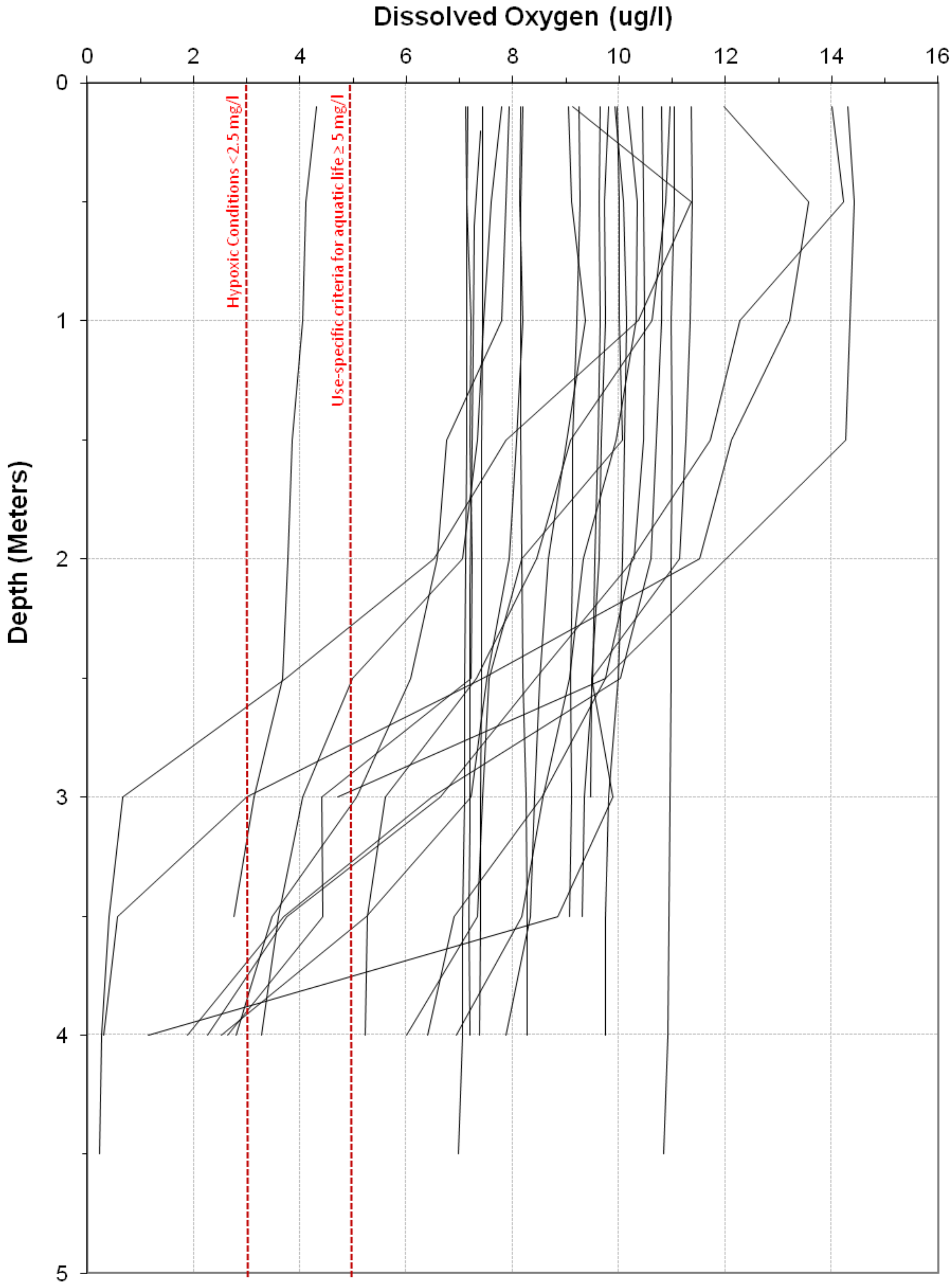


Plate 6-38. Dissolved oxygen depth profiles for Conestoga Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., CONLKND1) during the summer over the 5-year period prior to the current renovation project (2009 through 2013).

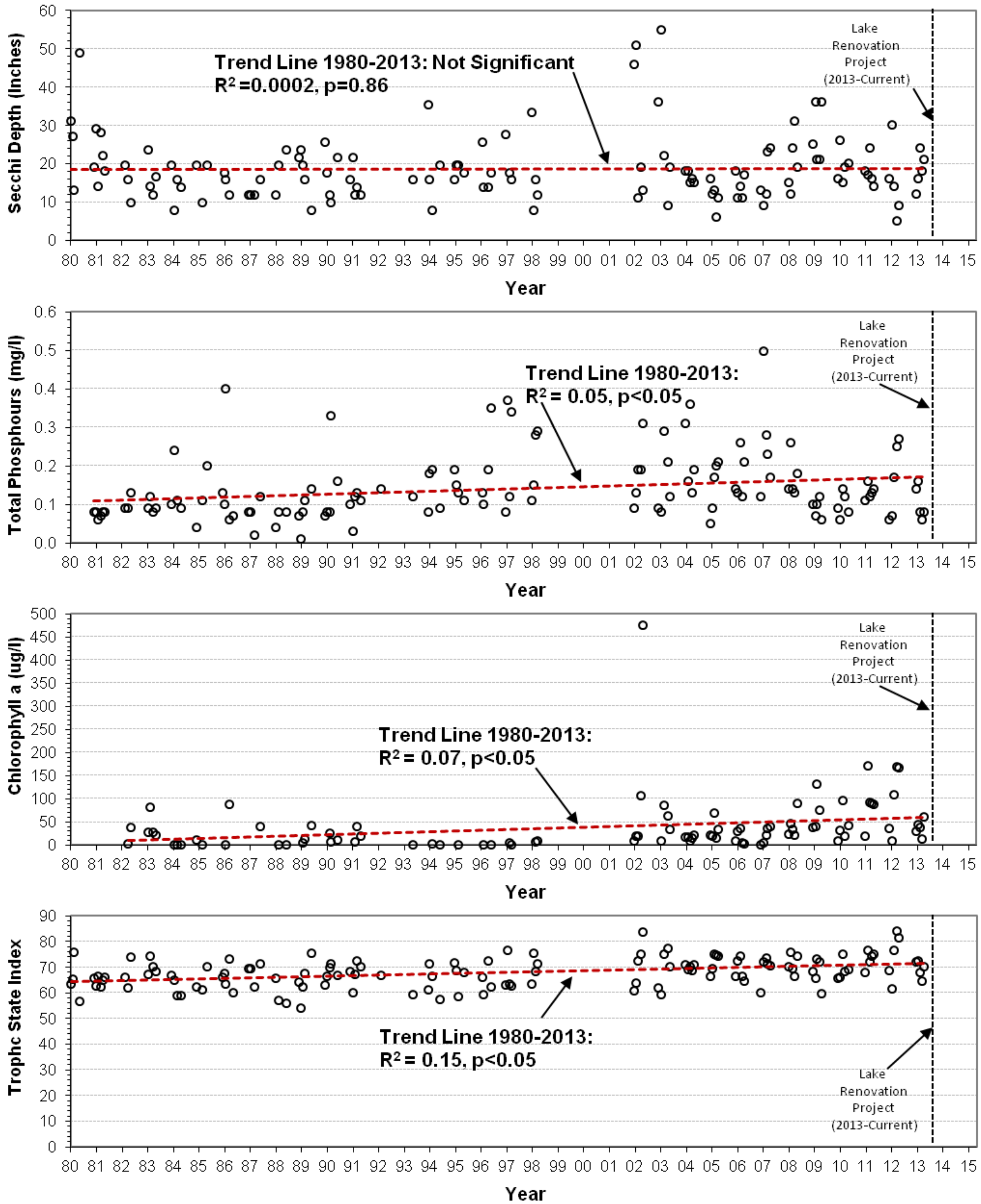


Plate 6-39. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Conestoga Reservoir at the near-dam, ambient site (i.e., site CONLKND1) over the 34-year period of 1980 through 2013, prior to the current reservoir renovation project.

6.5 HOLMES RESERVOIR

6.5.1 BACKGROUND INFORMATION

6.5.1.1 Project Overview

The dam forming Holmes Reservoir is located on Antelope Creek in the City of Lincoln. The dam was completed on September 17, 1962 and the reservoir reached its initial fill on June 2, 1965. The Holmes Reservoir watershed is 5.4 square miles. The watershed was largely agricultural when the dam was built in 1962; however since then, the watershed has undergone extensive urbanization with the growth of Lincoln.

6.5.1.2 Aquatic Habitat Improvement and Water Quality Management Project

Over $5.5 million in State and Federal funds were used to by the State of Nebraska to implement a lake restoration project at Holmes Reservoir. The project, completed in 2005, implemented numerous measures to improve the aquatic habitat, water quality, and the fishery of the reservoir. Implemented measures included off-line wetlands east of 70th Street, headwater wetlands north of Pioneers Boulevard, outlet modifications, construction of four jetties, two offshore breakwaters, a wooden fishing pier, three bridges, offset sediment dikes on each reservoir arm, and excavation of the reservoir basin. Approximately 320,750 cubic yards (CY) of sediment was excavated from the reservoir basin; 240,000 CY was completely removed, 61,000 CY was used in jetties and breakwaters, and 20,000 CY was incorporated into wetland construction. The excavation restored an estimated 52 percent of the original conservation pool volume and increased deep water (i.e. over 10 feet) by 111 percent. Existing and newly constructed wetlands are expected to reduce sediment loading from 21,877 tons to below 5,000 tons annually. Shoreline features such as jetties and breakwaters have added over 5,000 feet of new, productive shoreline while protecting against erosion. This represents a 21 percent increase in shoreline length. Collectively, basin excavation, shoreline stabilization features, sediment retention structures, and wetlands are expected to add 87 years to the recreational life of the reservoir. The fish community was also renovated and restocked. To increase recreational fishing opportunities, rainbow trout are annually scheduled for stocking into the south arm of the reservoir each fall and spring.

6.5.1.3 Holmes Dam Intake Structure

The dam intake at Holmes Dam is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 5 feet by 8 feet. The intake structure has four ungated openings – two 30” x 96” openings with a crest elevation at 1249.0 ft-msl and two 12” x 36” openings with a crest elevation at 1242.5 ft-msl. A 36” x 36” gated opening with a crest elevation of 1239.0 ft-msl was constructed into the upstream wall. As part of the lake renovation project a new low-level gated opening was installed in the drop inlet structure. The new low-level gated opening is 45” x 45” with a crest elevation of 1230.6 ft-msl. The purpose of the new low-level gated opening is to allow for better management of pool elevations for water quality and fishery management. It may also be used to release water for downstream needs.

6.5.1.4 Reservoir Storage Zones

Figure 6.7 depicts the current storage zones of Holmes Reservoir based on NGPC survey data, results of the lake renovation project, and estimated sedimentation. After accounting for the sediment removed from the reservoir basin as part of the lake renovation project, it is estimated that 20 to 26 percent of the “as-built” volume to the top of the Conservation Pool has been lost to sedimentation as of 2012. The annual volume loss, prior to the implementation of the lake renovation project, is estimated to be 0.87 percent. However, measures implemented as part of, or in conjunction with, the lake renovation project (e.g., off-line wetlands, headwater wetlands, Antelope Commons wetlands, riparian vegetative plantings, storm water management, etc.) are believed to have significantly reduced the annual volume loss below

0.87 percent. Based on the State of Nebraska's impairment assessment criteria, these values indicate that Holmes Reservoir's water quality dependent uses are not impaired due to sedimentation.

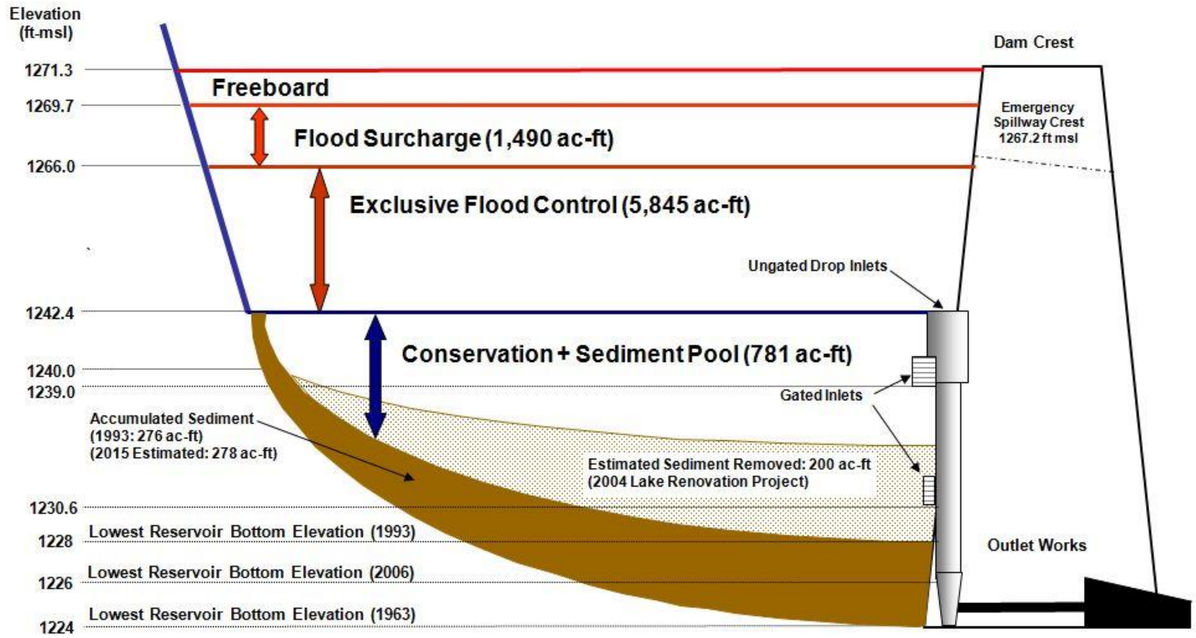


Figure 6.7. Current storage zones of Holmes Reservoir based on the 2006 NGPC survey data, recently implemented lake renovation project, and estimated sedimentation.

6.5.1.1 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Holmes 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. Figure 6.8 shows the location of the sites that have been monitored for water quality during the 5-year sampling period (i.e., 2011 through 2015). The inflow runoff sites (HOLNFEST1 and HOLNFWST1) and the in-reservoir bacteria site (HOLLKBACT1) were sampled by the NDEQ. The other in-reservoir sites (HOLLKND1, HOLLKMLN1, HOLLKMLS1, and HOLLKUP1) were sampled by the District. The near-dam location (HOLLKND1) has been continuously monitored by the District since 1980.

6.5.2 WATER QUALITY IN HOLMES RESERVOIR

6.5.2.1 Existing Water Quality Conditions

6.5.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Holmes Reservoir at sites HOLLKND1, HOLLKMLN1, HOLLKMLS1, and HOLLKUP1 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 6-40 through Plate 6-43. A review of these results indicated possible water quality concerns regarding dissolved oxygen, pH, and nutrients.

Figure 6.8. Location of sites where water quality monitoring was conducted at Holmes Reservoir during the period 2011 through 2015.

A significant number of dissolved oxygen measurements throughout Holmes Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life. All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and appeared to be associated with a slight thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Holmes Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation. However, thermal stratification in Holmes Reservoir was relatively limited during the 5-year sampling period of 2011 through 2015 (Plate 6-45). This limited stratification could lead to the above provision not applying to the reservoir and possible impairment for dissolved oxygen for the protection of aquatic life in Holmes Reservoir.

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September) to be considered for impairment assessment. All three of these criteria were exceeded Holmes Reservoir (Plate 6-40 - Plate 6-43). The near-surface chlorophyll *a* criterion was exceeded by 96 percent of the "lab analyzed" samples taken in the reservoir at site HOLLKND1. The total phosphorus and total nitrogen criteria were exceeded by 96 and 64 percent of samples, respectively. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values represent the growing season average for the 5-year period 2011 through 2015. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.17 mg/l), total nitrogen (1.42 mg/l), and chlorophyll *a* (44 ug/l) values at HOLLKND1 indicate impairment of the aquatic life use due to nutrients.

An appreciable number (43-45%) of pH readings throughout Holmes Reservoir were above the numeric pH criteria of 9.0 for the protection of warmwater aquatic life (Plate 6-40 through Plate 6-43). The measured pH values also exhibited a substantial range (i.e., 7.03 - 9.68). It is believed the highly variable pH values are associated with periods of high algal production and CO_2 uptake and release during photosynthesis and respiration. The initial high water clarity in Holmes Reservoir, attributed to the newly completed lake restoration project (completed in 2005), has allowed for extensive algal production due to the depth of the photic zone and the availability of nutrients.

6.5.2.1.2 Thermal Stratification

6.5.2.1.2.1 ***Longitudinal Temperature Contour Plots***

Late-spring and summer thermal conditions of Holmes Reservoir measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 6-44 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1. These temperature plots indicate that Holmes Reservoir exhibited significant thermal stratification during most of the summer. The maximum difference monitored between the surface and bottom water temperatures during the 2-year period was around 10°C in May.

6.5.2.1.2.2 ***Near-Dam Temperature Depth-Profile Plots***

Existing summer thermal stratification of Holmes Reservoir, at the deep water area near the dam, measured over the 5-year period 2011 through 2015 is depicted by depth-profile temperature plots (Plate 6-45). The depth-profile temperature plots indicate that the reservoir periodically exhibited significant summer thermal stratification over the 5-year sampling period. Since Holmes Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.5.2.1.3 Dissolved Oxygen Conditions

6.5.2.1.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of Holmes Reservoir through the north arm based on depth-profile measurements taken during 2015 at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1. Plate 6-46 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 near the dam May through early September. Super saturation of dissolved oxygen was also monitored through the length of the reservoir at the near surface through much of 2015. The initial high water clarity in Holmes Reservoir, attributed to the newly completed lake restoration project (completed in 2005), has allowed for extensive algal production due to the depth of the photic zone and the availability of nutrients. Dissolved oxygen supersaturation is attributed to the high rates of photosynthesis by aquatic vegetation in the reservoir during the day.

6.5.2.1.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

Existing summer dissolved oxygen conditions in Holmes Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2011 through 2015 (Plate 6-47). Most of the depth-profiles indicate a significant vertical gradient in summer dissolved oxygen, with most tending towards a clinograde distribution. Forty-six percent of the profiles showed hypoxic conditions near the reservoir bottom. Although Holmes Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition to mixing to allow hypoxic conditions to develop near the reservoir bottom in the area near the dam.

6.5.2.1.3.3 ***Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of Holmes 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 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 July 28, 2015 contour plot indicates a pool elevation of 1243.1 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1236.5 ft-msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1235.7 ft-msl (Plate 6-46). The current District Area-Capacity Tables (1993 Survey) give storage capacities of 895 ac-ft for elevation 1243.1 ft-msl, 211 ac-ft for elevation 1236.5 ft-msl, and 150 ac-ft for elevation 1235.7 ft-msl. On July 28, 2015 it is estimated that 24 percent of the volume of Holmes Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 17 percent of the reservoir volume was hypoxic.

6.5.2.1.4 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in Holmes reservoir indicated hypoxic conditions May through August 2015. As a result, longitudinal contour plots for ORP and pH were constructed during these months. Depth profiles and near-surface/near-bottom sample comparisons were also constructed for periods of hypoxic conditions during the sampling periods from 2011 through 2015.

6.5.2.1.4.1 ***Oxidation-Reduction Potential***

Plate 6-48 provides longitudinal ORP contour plots based on depth-profile measurements taken in 2015 when hypoxic conditions were present in Holmes Reservoir. The ORP values indicated somewhat reduced conditions occurred near the bottom of Holmes Reservoir in June and July, with measurements below 150 mV. Plate 6-49 plots depth profiles for ORP measured during the summer over the 5-year sampling period in the deep water area of Holmes Reservoir near the dam when hypoxic conditions were present. Over the 5-year period reduced conditions at the bottom of the reservoir were limited. Only three of the hypoxic profiles exhibited ORP values below 200mV and the minimum measurement was 64 mV. Given the polymictic nature of the reservoir, reduced conditions seemingly are not long-term.

6.5.2.1.4.2 ***pH***

Longitudinal contour plots for pH conditions measured in 2015 when hypoxic conditions were present are provided in Plate 6-50. Plate 6-51 plots depth profiles for pH measured during the summer over the 5-year sampling period in the deep water area of Holmes Reservoir near the dam when hypoxic conditions were present. An appreciable vertical gradient in pH regularly occurred in the reservoir during the summer. Lower pH levels near the bottom of the reservoir could be attributable to reservoir stratification and ongoing decomposition/respiration near the reservoir bottom. This would lead to an increase in CO_2 and decrease in pH. The lowest measured pH levels near the reservoir bottom were however above the lower pH criterion of 6.5 for the protection of warmwater aquatic life. A more significant concern appears to be high the pH near the surface of the reservoir. Measured surface pH levels are frequently above the upper pH criterion of 9.0 for the protection of warmwater aquatic life. In May 2015, roughly half of the reservoir exceeded the criterion of 9.0 for the protection of warmwater aquatic life and in early September 2015 roughly two thirds of the reservoir exceeded the criterion. The high pH levels are attributed to high rates of photosynthesis by aquatic vegetation and the associated uptake of carbon dioxide in the reservoir during the day.

6.5.2.1.4.3 ***Comparison of Near-Surface and Near-Bottom Water Quality Conditions***

Paired near-surface and near-bottom water quality samples collected from Holmes Reservoir during the summer when hypoxia was present 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 HOLLKND1 during the 5-year period 2011 through 2015. During the 5-year period a total of 24 paired samples were collected monthly from May through September. Of the 24 paired samples collected, 11 (46%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 6-52). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were not significantly different for ORP ($p=0.24$) and nitrate-nitrite nitrogen ($p=0.34$). Parameters that were significantly lower in the near-bottom water of Holmes Reservoir when hypoxia was present included: water temperature, dissolved oxygen, and pH ($p<0.05$). Parameters that were significantly higher in the near-bottom water included: total ammonia nitrogen, total alkalinity, total phosphorus, and ortho-phosphorus ($p<0.05$).

6.5.2.1.4.4 ***Reservoir Trophic Status***

Table 6.15. Summary of Trophic State Index (TSI) values calculated for Holmes Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	69	70	52	93
TSI(TP)	25	67	69	48	79
TSI(Chl)	25	74	75	50	85
TSI(Avg)	25	70	70	51	83

* 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 for the individual parameters.
Note: See Section 4.1.3 for discussion of TSI calculation.

Trophic State Index (TSI) values for Holmes Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., HOLLKND1). Table 6.15 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Holmes Reservoir is in a hypereutrophic condition.

6.5.2.1.4.5 ***Monitoring at Swimming Beaches***

A designated swimming beach is not located on Holmes Reservoir; however, the reservoir is used extensively for recreation (e.g., canoeing, kayaking, paddle-boating, wind surfing, etc.). Since these recreational uses can lead to direct contact with water, bacteria (i.e., *E. coli*) and microcystin monitoring were conducted by the NDEQ at the reservoir. During the 5-year period 2011 through 2015, bacteria and total microcystin samples were collected weekly from May through September. The samples were collected from the reservoir near the marina on the north shore at site HOLLKBACT1 (Figure 6.8).

6.5.2.1.4.5.1 Bacteria Monitoring

Table 6.16 summarizes the results of the *E. coli* bacteria monitoring. The "running 5-week" geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The "pooled" geomean was determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for *E. coli* bacteria:

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

The pooled geomean was compared to the State of Nebraska's impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using *E. coli* bacteria data. Based on those criteria a Primary Contact Recreation use in Homes Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

Table 6.16. Summary of weekly (May through September) *E. coli* bacteria samples collected at Holmes Reservoir (i.e., site HOLLKBACT1) during the 5-year period 2011 through 2015**.**

***E. coli* – Individual Samples**		***E. coli* – Geomeans (Running 5-Week)**	
Number of Samples	109	Number of Geomeans	89
Mean (cfu/100ml)	95	Average	24
Median (cfu/100ml)	12	Median	18
Minimum (cfu/100ml)	1	Minimum	2
Maximum (cfu/100ml)	1553	Maximum	130
Percent of samples exceeding 235/100ml	9%	Percent of Geomeans exceeding 126/100ml	1%
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	13

6.5.2.1.4.5.2 Microcystin Monitoring

Table 6.17 summarizes the total microcystin monitoring conducted at site HOLLKBACT1 on Holmes Reservoir during the 5-year period 2011 through 2015 These results were compared to the 20 ug/l criterion for issuing health advisories and the posting of swimming beaches. No samples exceeded the criterion. The monitored levels of total microcystin do not indicate a significant cyanobacteria toxin concern at Holmes Reservoir.

Table 6.17. Summary of weekly (May through September) total microcystin samples collected at Holmes Reservoir (i.e., site HOLLKBACT1) during the 5-year period 2008 through 2015

Summary Statistic	Site HOLLKBACT1
Number of Samples	109
Minimum (ug/l)	n.d.
25th percentile (ug/l)	n.d.
Median (ug/l)	0.15
75th Percentile (ug/l)	0.34
Maximum (ug/l)	4.41
Percent of samples exceeding 20 ug/l	0%

6.5.2.1.5 Reservoir Plankton Community

6.5.2.1.5.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at the Holmes Reservoir near-surface, near-dam sampling site during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-53). The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 6-54. The highest phytoplankton total biovolume was observed in May. May was dominated by Cryptophycophyta and Ochrophyta, July by Cyanobacteria, and September by Cyanobacteria as well. This population pattern follows successional patterns commonly found in eutrophic reservoirs. Cool water taxa such as Ochrophyta dominate in the sping and late fall while warm water taxa such as Cyanobacteria dominate summer and early fall. Dominant and major phytoplankton genera sampled in 2015 at Holmes Reservoir are provided in Table 6.18.

Annual variation in phytoplankton community composition during the 5-year period 2011 through 2015 is displayed in Plate 6-55. Holmes Reservoir was mostly dominated by Cyanobacteria through the 5-year period, however, Cryptophycophyta and Ochrophyta were close in abundance in 2015. Cyanobacteria density levels were greater than the World Health Organizations high level of health risk (>100,000 Cells/ml) in 2011, 2012, and 2015 (Plate 6-53). The greatest average cyanobacterial density was observed in 2012. 2012 was a particularily warm and dry year. The resulting long reservoir residence times, decreased mixing, and warmer water could have lead to a longer Cyanobacterial growing season, which resulted in the large densities and biovolumes observed. The maximum extracellular microcystin level measured at the near-dam site during the 5-year period was 0.2 µg/L (Plate 6-40).

Table 6.18. Listing of Major and Dominant Phytoplankton Genera Sampled in Holmes Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1)

Division	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cryptophycophyta	-----	*Cryptomonas*
Cyanobacteria	Aphanizomenon	*Anabaena, Microcystis*
Ochrophyta	-----	*Stephanodiscus*

6.5.2.1.5.2 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at Holmes Reservoir near-dam sampling sites during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-56). The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in Plate 6-57. Holmes Reservoir was dominated by Cladocerans and Copepods in 2015 with the greatest total zooplankton biomass in May. Dominant and major zooplankton genera sampled in Holmes Reservoir during 2015 are provided in Table 6.19.

Table 6.19. Listing of major and dominant zooplankton genera sampled in Holmes Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1)

Taxonomic Group	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cladocerans	*Ceriodaphnia, Chydorus*	*Calanoida, Ceriodaphnia, Daphnia, Diaphanosoma*
Copepods	*Leptodiaptomus, Mesocyclops*	-----

6.5.2.1.6 Zebra Mussel Monitoring

Zebra mussel veliger sampling has been conducted once yearly since 2012 at Holmes Reservoir. During the sampling period (2012-2015) no veligers have been identified.

6.5.2.2 Water Quality Trends (1980 through 2015)

Water quality trends from 1980 to 2015 were determined for Holmes 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., HOLLKND1). Plate 6-58 displays a scatter-plot of the collected data for the four parameters and linear regression lines for the period 1980 through 2002 and 2006 through 2015. The data gap of 2002 through 2005 is the period when the lake renovation project was implemented at Holmes Reservoir. Prior to the renovation project there were no significant trends in transparency ($p=0.93$, $R^2<0.0001$), total phosphorus ($p=0.06$, $R^2=0.04$), chlorophyll a ($p=0.75$, $R^2=0.002$) and TSI ($p=0.91$, $R^2=0.0001$). Due to the recent renovation project, Nebraska's water quality standards placed Holmes Reservoir in category 4R from 2005 through 2012. Nutrient assessment of category 4R designated waters may be misleading due to a trophic upsurge upon refill which is typically followed by a period of decline. Due to this trophic instability, no further analysis was performed. Once more post category 4R water quality data is collected, further analyses will be pursued to test for water quality changes from "pre-project" conditions. Prior to the renovation project, Holmes Reservoir was in a hypereutrophic condition and has remained so post renovation.

6.5.3 PLATES

Plate 6-40. Summary of water quality conditions monitored in Holmes Reservoir at site HOLLKND1 from May to September during the 5-year 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	25	1242.45	1242.70	1238.80	1244.70	-----	-----	-----
Water Temperature (°C)	0.1	197	22.64	22.55	15.39	29.73	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	197	8.18	8.72	n.d.	21.48	$\geq$5[2]	31	16%
Dissolved Oxygen, Near-Surface (mg/l)[C]	0.1	25	10.47	9.48	6.54	21.48	$\geq$5[2]	0	0%
Dissolved Oxygen (% Sat.)	0.1	197	98.97	99.20	0.50	293.60	-----	-----	-----
Secchi Depth (in.)	1	25	26.20	20.00	4.00	70.00	-----	-----	-----
Turbidity (NTUs)	1	196	44.90	19.80	n.d.	736.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	197	320.13	320.00	64.00	427.00	-----	-----	-----
Specific Conductance (umho/cm)	1	197	375.59	352.50	225.80	602.80	2,000[3]	0	0%
pH (S.U.)	0.1	197	8.75	8.96	7.03	9.68	$\geq$6.5 & $\leq$9.0 [1]	0,88	0%,45%
Alkalinity, Total (mg/l)	1	49	119.12	116.00	81.00	160.00	>20[1]	0	0%
Suspended Solids, Total (mg/l)	4	49	19.41	17.00	n.d.	82.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	49	-----	n.d.	n.d.	0.88	0.62[4,5], 0.16[4,6]	0,1	0%,2%
Kjeldahl N, Total (mg/l)	0.08	49	1.38	1.19	0.57	3.16	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	49	-----	n.d.	n.d.	0.18	100[3]	0	0%
Nitrogen, Total (mg/l)	0.08	49	1.41	1.21	0.59	3.17	1[7]	38	78%
Nitrogen, Total, Near-Surface (mg/)[C]	0.08	25	1.42	1.17	0.62	3.17	1[7]	16	64%
Phosphorus, Total (mg/l)	0.005	49	0.20	0.18	0.02	0.50	0.05[7]	47	96%
Phosphorus, Total, Near-Surface (mg/l)[C]	0.005	25	0.17	0.17	0.02	0.47	0.05[7]	24	96%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	49	-----	0.09	n.d.	0.40	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	103.04	104.60	86.00	116.70	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	5	9.00	8.00	7.00	14.00	340[5], 16.7[8]	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	n.d.	6.16[5], 0.25[6]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	614.28[5], 79.97[6]	0	0%
Copper, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	14.02[5], 9.31[6]	0	0%
Iron, Dissolved (ug/l)	10	5	-----	30.00	n.d.	78.00	1000[6]	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	67.82[5], 2.64[6]	0	0%
Manganese, Dissolved (ug/l)	3	5	-----	10.00	n.d.	43.00	1000[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	486.39[5], 54.02[6]	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	3.72[5]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	121.73[5], 122.72[6]	0	0%
Antimony, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	88[5], 30[6]	0	0%
Aluminum, Dissolved (ug/l)	40	5	-----	n.d.	n.d.	60.00	750[5], 87[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Chlorophyll a (ug/l) – Lab Determined [C]	6	25	44	36	n.d.	98	10[7]	24	96%
Chlorophyll a (ug/l) – Field Probe	6	188	49	37	n.d.	188	10[7]	180	96%
Atrazine, Total (ug/l)[D]	0.1	25	-----	0.30	n.d.	5.50	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[D]	0.1	25	-----	n.d.	n.d.	2.30	390[5], 100[6]	0	0%
Acetochlor, Total (ug/l)[D]	0.1	25	-----	0.20	n.d.	3.00	-----	-----	-----
Microcystin, Extracellular (ug/l)	0.1	24	-----	n.d.	n.d.	0.20	20[9]	0	0%
Pesticide Scan (ug/l)[E]									
Atrazine, Tot	0.13	5	-----	n.d.	n.d.	0.20	330[5], 12[6]	0	0%
Acetochlor, Tot	0.08	5	-----	n.d.	n.d.	0.16	-----	-----	-----
Metolachlor, Tot	0.13	5	-----	n.d.	n.d.	0.19	390[5], 100[6]	0	0%

n.d. = Not detected.

[A] Nondetect values set to detection limit 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] General criteria for aquatic life.
[2] Use-specific criteria for aquatic life.
[3] Agricultural criteria for surface waters.
[4] Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
[5] Acute criteria for aquatic life.
[6] Chronic criteria for aquatic life.
[7] Nutrient criteria for aquatic life.
[8] Human health criteria.
[9] Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

[C] Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

[D] Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-41. Summary of water quality conditions monitored in Holmes Reservoir at site HOLLKMLN1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	18	1242.52	1242.65	1238.80	1244.70	-----	-----	-----
Water Temperature (°C)	0.1	168	22.89	23.24	14.79	29.56	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	168	7.99	8.45	0.04	17.89	≥5(2)	29	17%
Dissolved Oxygen (% Sat.)	0.1	168	96.87	97.25	0.40	239.90	-----	-----	-----
Secchi Depth (in.)	1	23	25.22	21.00	6.00	60.00	-----	-----	-----
Turbidity (NTUs)	1	168	39.94	19.80	2.80	588.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	168	321.37	318.50	78.00	417.00	-----	-----	-----
Specific Conductance (umho/cm)	1	168	368.45	343.05	237.50	602.40	2,000(3)	0	0%
pH (S.U.)	0.1	168	8.74	8.94	7.06	9.71	≥6.5 & ≤9.0 (1)	0,73	0%,43%
Chlorophyll a (ug/l) – Field Probe	6	160	52	36	3	749	10(4)	153	96%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-42. Summary of water quality conditions monitored in Holmes Reservoir at site HOLLKMLS1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	19	1242.54	1242.70	1238.80	1244.70	-----	-----	-----
Water Temperature (°C)	0.1	167	22.67	23.12	13.64	29.86	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	167	7.76	8.16	0.06	18.16	≥5(2)	31	19%
Dissolved Oxygen (% Sat.)	0.1	167	93.40	97.60	0.80	239.00	-----	-----	-----
Secchi Depth (in.)	1	24	26.13	20.00	6.00	78.00	-----	-----	-----
Turbidity (NTUs)	1	166	26.96	21.25	1.60	357.60	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	167	325.61	323.00	77.00	443.00	-----	-----	-----
Specific Conductance (umho/cm)	1	167	363.58	337.20	154.40	604.00	2,000(3)	0	0%
pH (S.U.)	0.1	167	8.74	8.90	6.92	9.81	≥6.5 & ≤9.0 (1)	0,74	0%,44%
Chlorophyll a (ug/l) – Field Probe	6	158	51	41	4	134	10(4)	151	96%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-43. Summary of water quality conditions monitored in Holmes Reservoir at site HOLLKUP1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	19	1242.54	1242.70	1238.80	1244.70	-----	-----	-----
Water Temperature (°C)	0.1	77	23.25	22.93	16.95	33.05	32(1)	1	1%
Dissolved Oxygen (mg/l)	0.1	77	8.90	8.81	0.10	23.84	≥5(2)	11	14%
Dissolved Oxygen (% Sat.)	0.1	77	108.56	103.70	1.20	306.60	-----	-----	-----
Secchi Depth (in.)	1	24	24.00	20.50	6.00	60.00	-----	-----	-----
Turbidity (NTUs)	1	77	29.32	21.20	4.70	386.80	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	77	315.96	321.00	73.00	412.00	-----	-----	-----
Specific Conductance (umho/cm)	1	77	349.13	333.20	252.70	608.30	2,000(3)	0	0%
pH (S.U.)	0.1	77	8.85	8.96	7.34	9.67	≥6.5 & ≤9.0 (1)	0,35	0%,45%
Chlorophyll a (ug/l) – Field Probe	6	71	61	49	2	219	10(4)	69	97%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

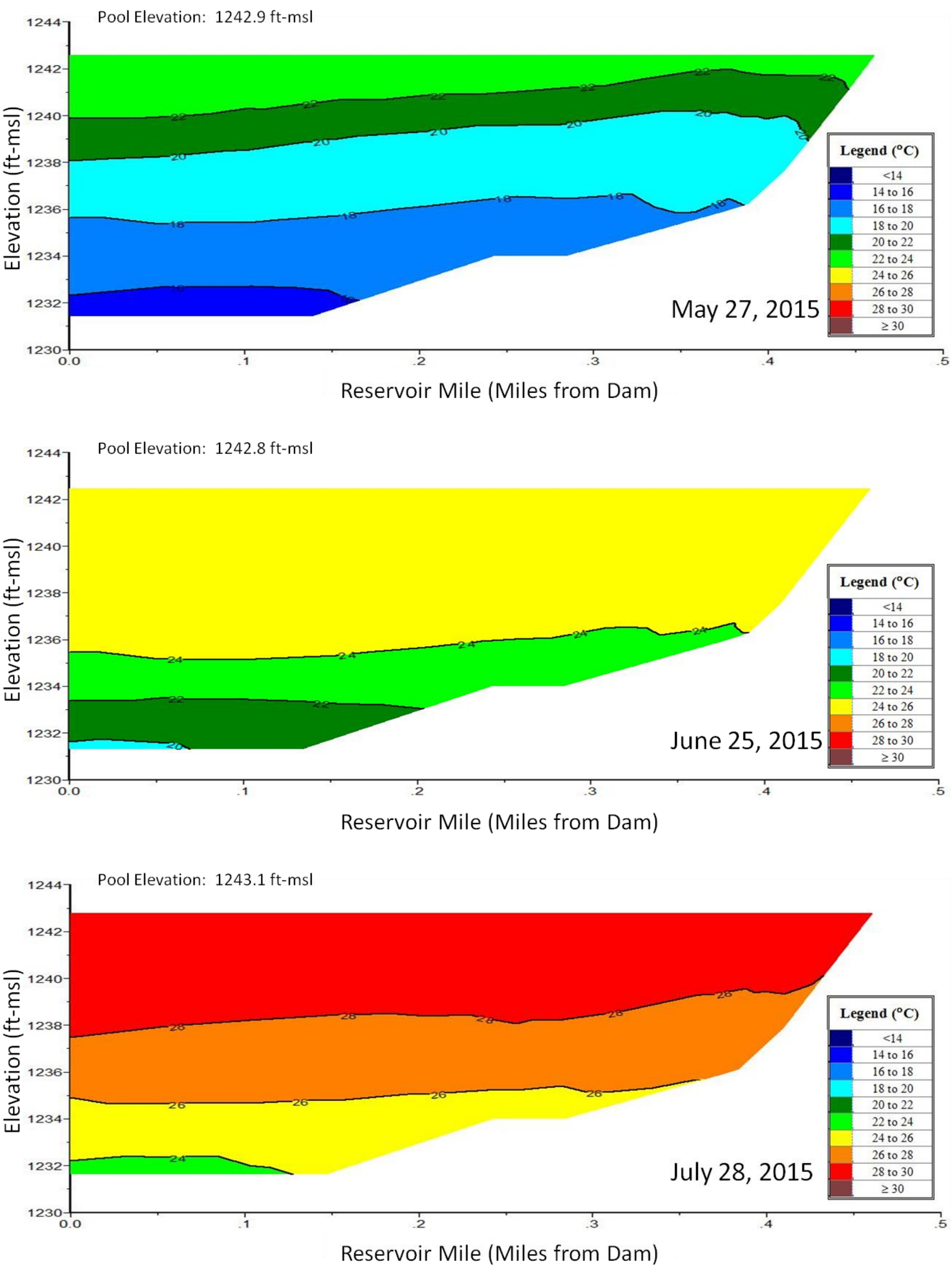
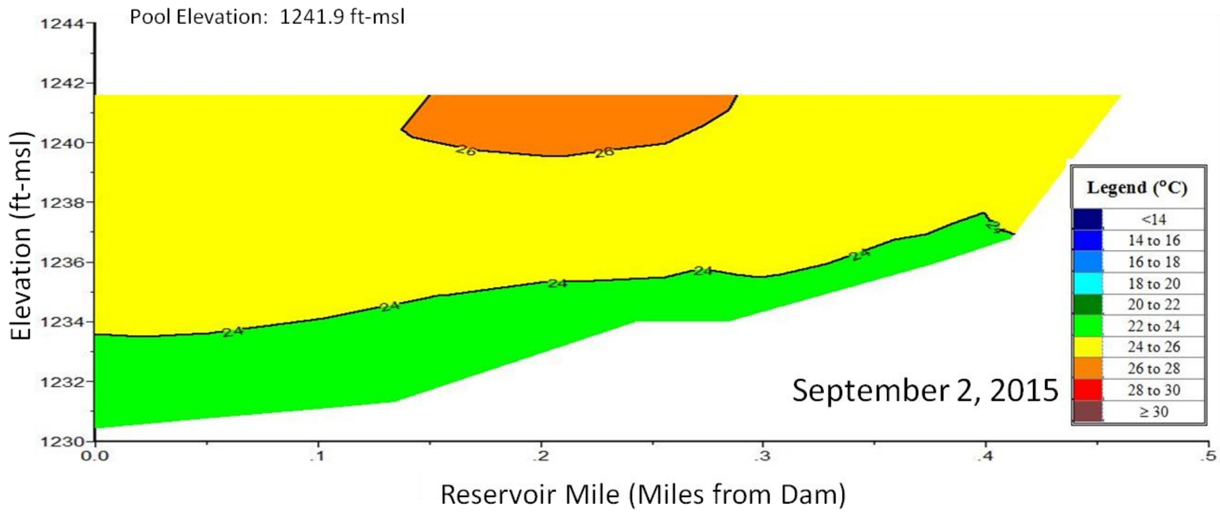


Plate 6-44. Longitudinal water temperature contour plots of Holmes Reservoir based on depth-profile water temperatures (°C) measured at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1 in 2015.



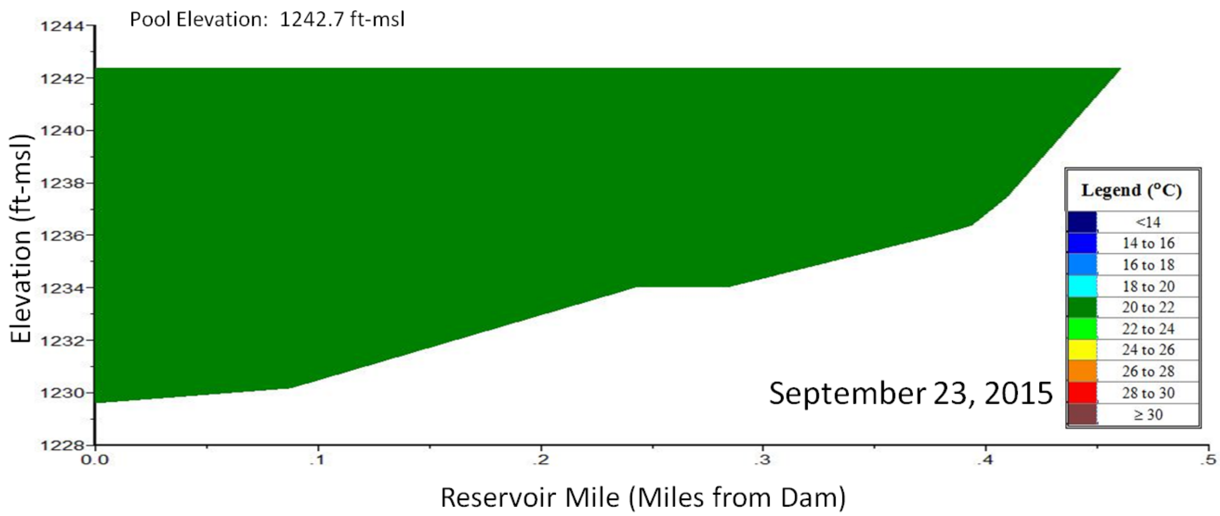


Plate 6-44. (Continued).

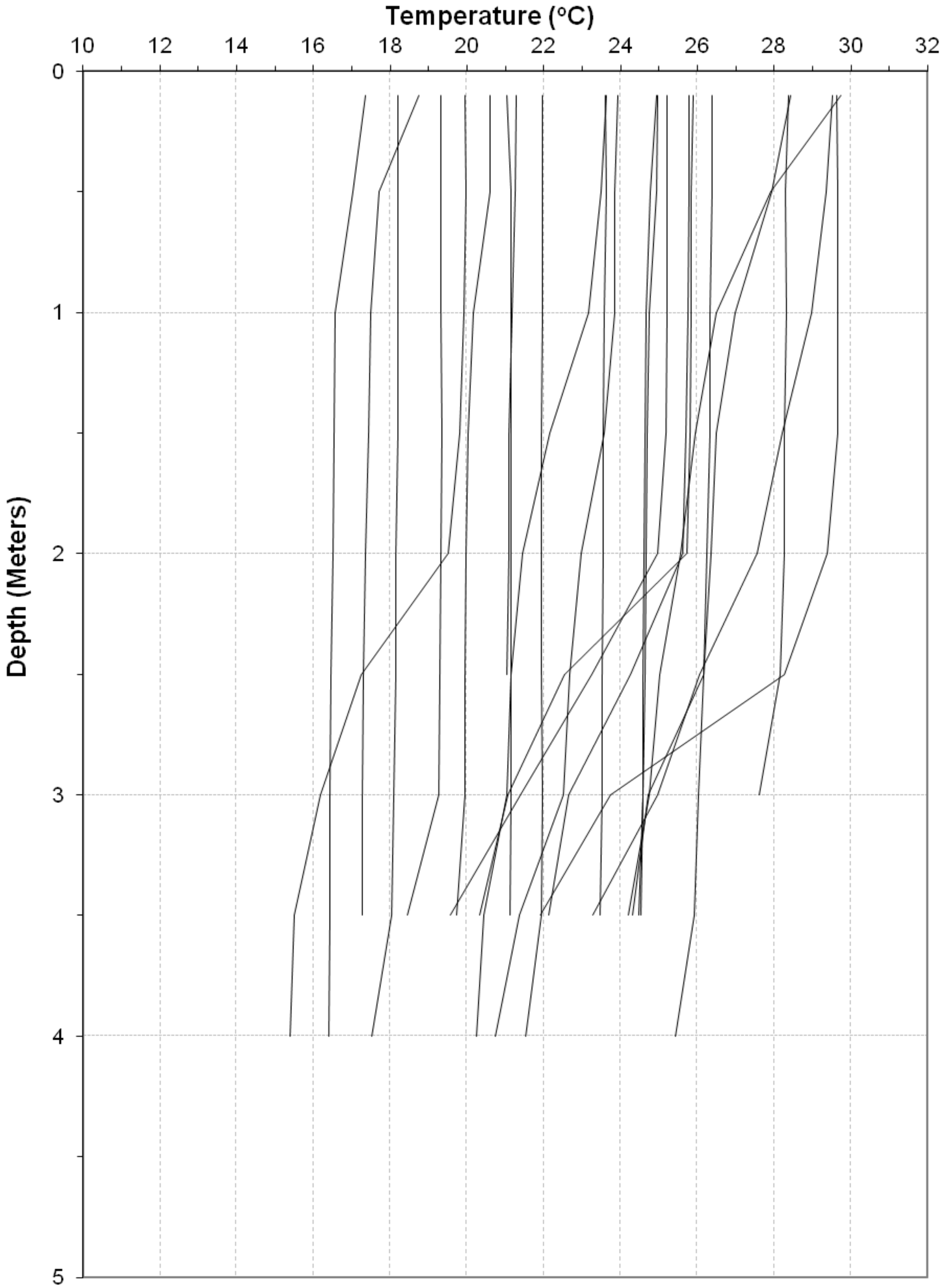


Plate 6-45. Temperature depth profiles for Holmes Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1) during the summer over the 5-year period of 2011 through 2015.

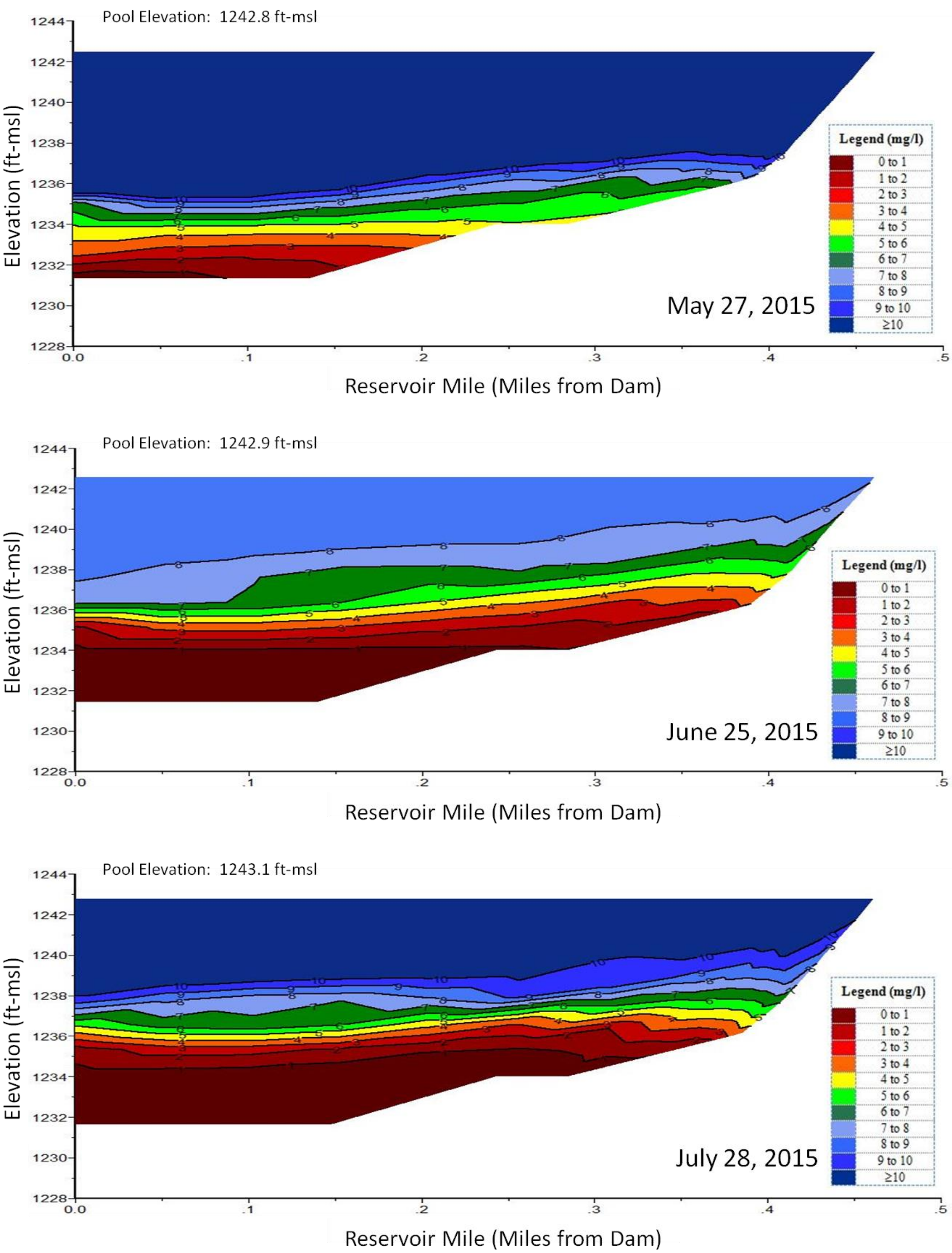
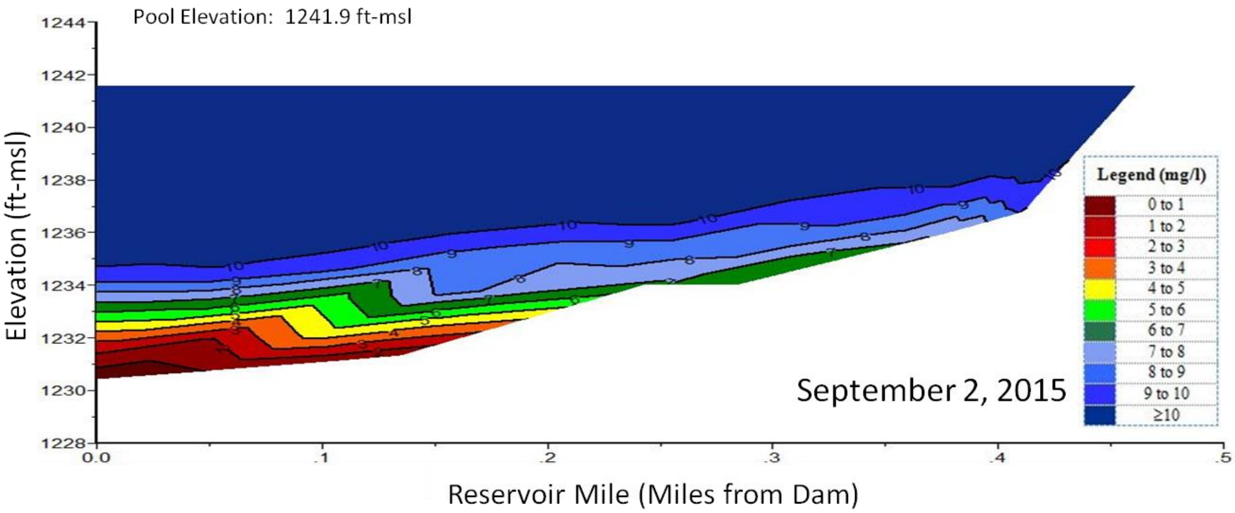


Plate 6-46. Longitudinal dissolved oxygen contour plots of Holmes Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1 in 2015.



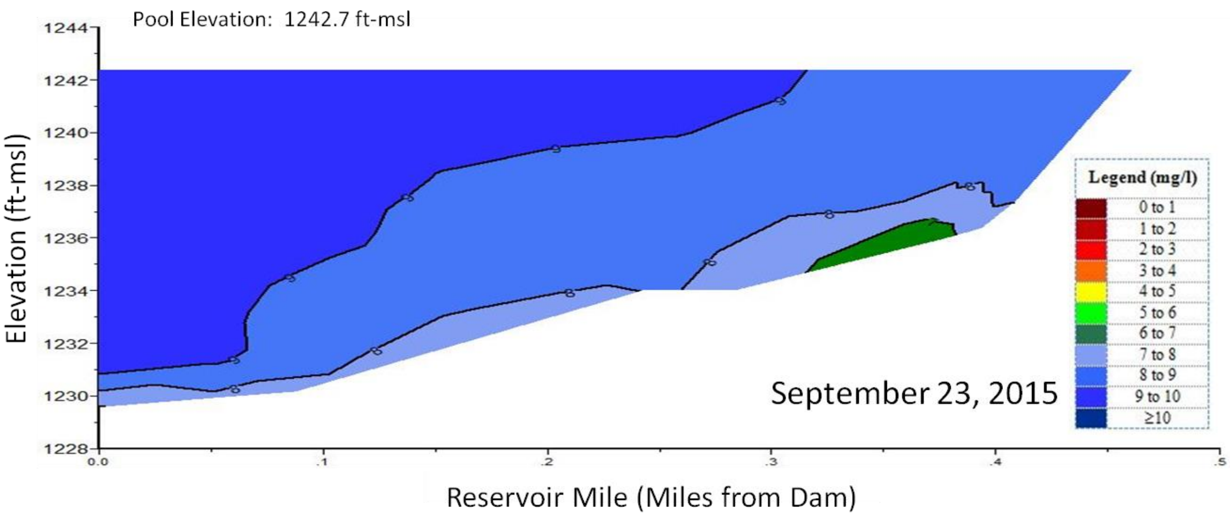


Plate 6-46. (Continued).

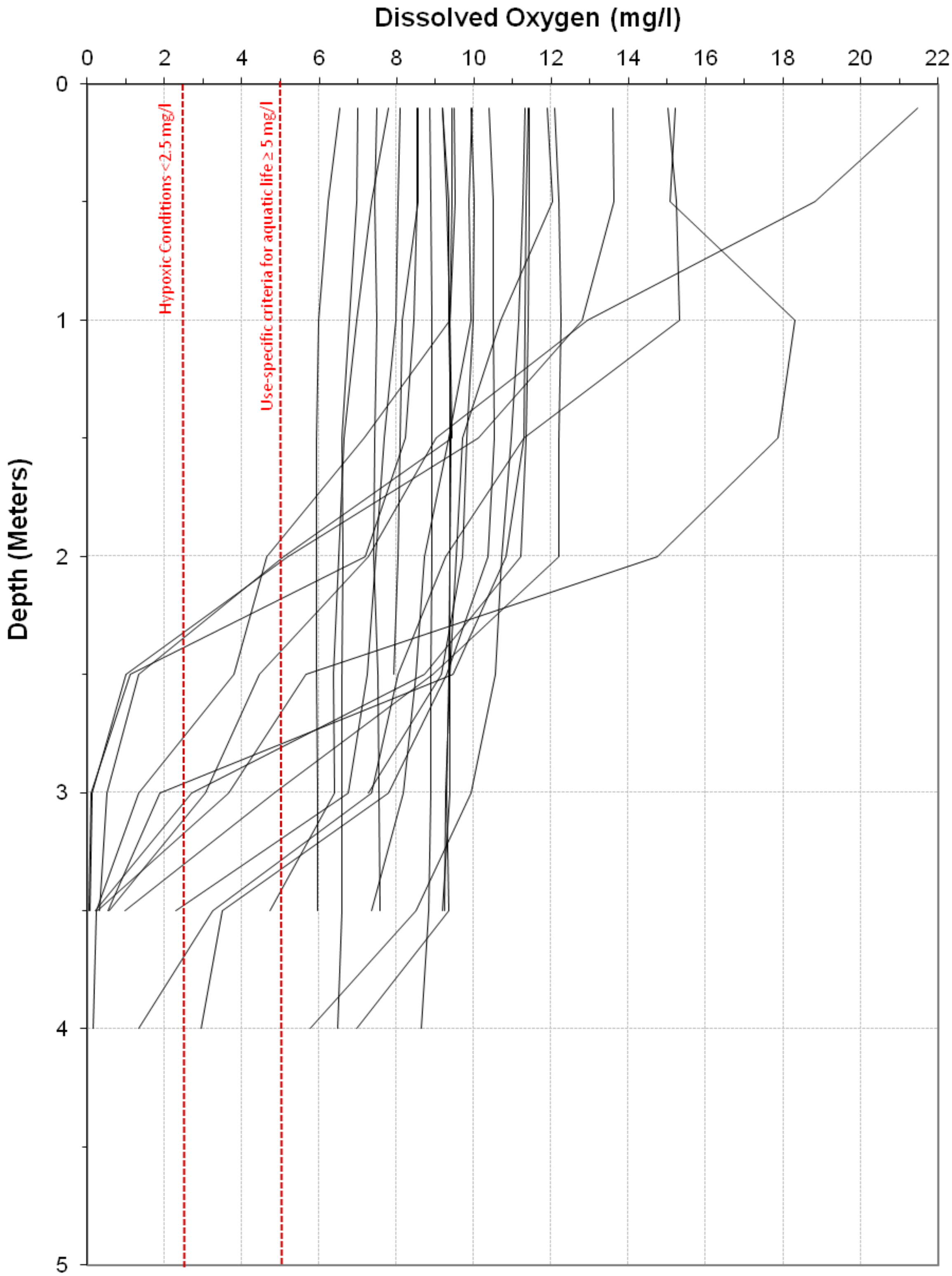


Plate 6-47. Dissolved oxygen depth profiles for Holmes Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1) during the summer over the 5-year period 2011 through 2015.

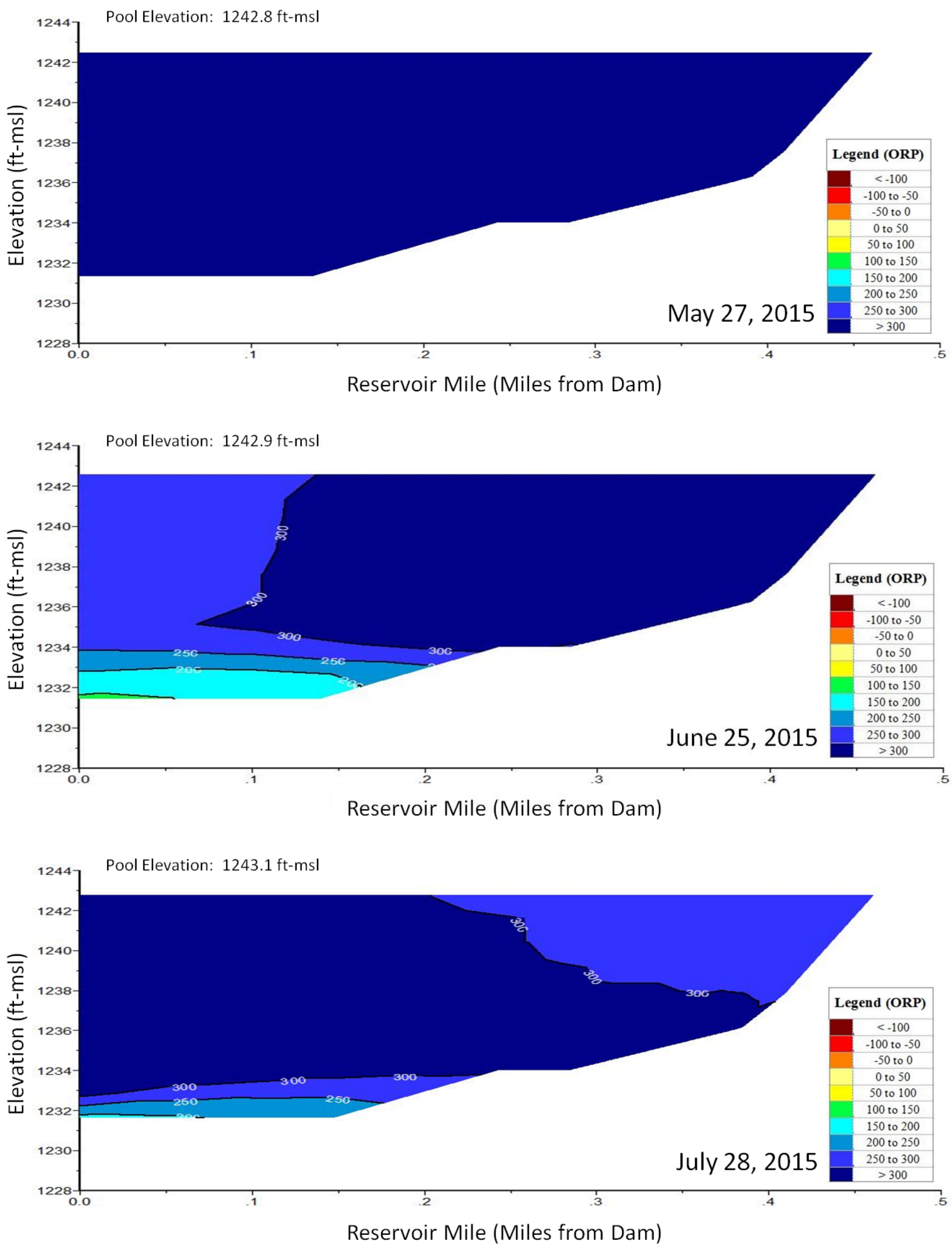


Plate 6-48. Longitudinal oxidation-reduction potential contour plots of Holmes Reservoir based on depth-profile ORP levels (mV) measured at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1 in 2015.

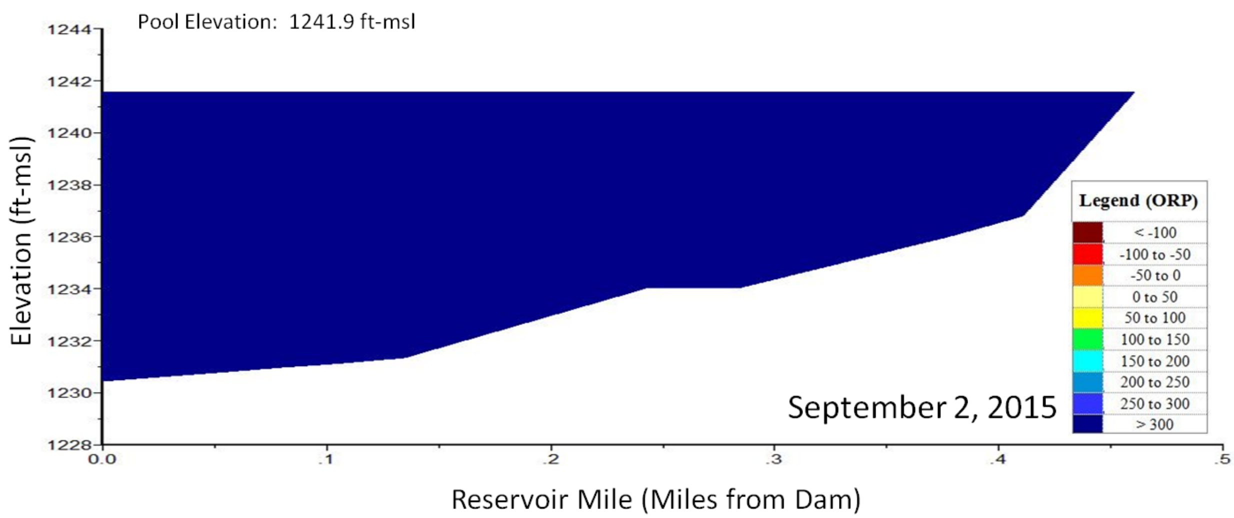


Plate 6-48. (Continued).

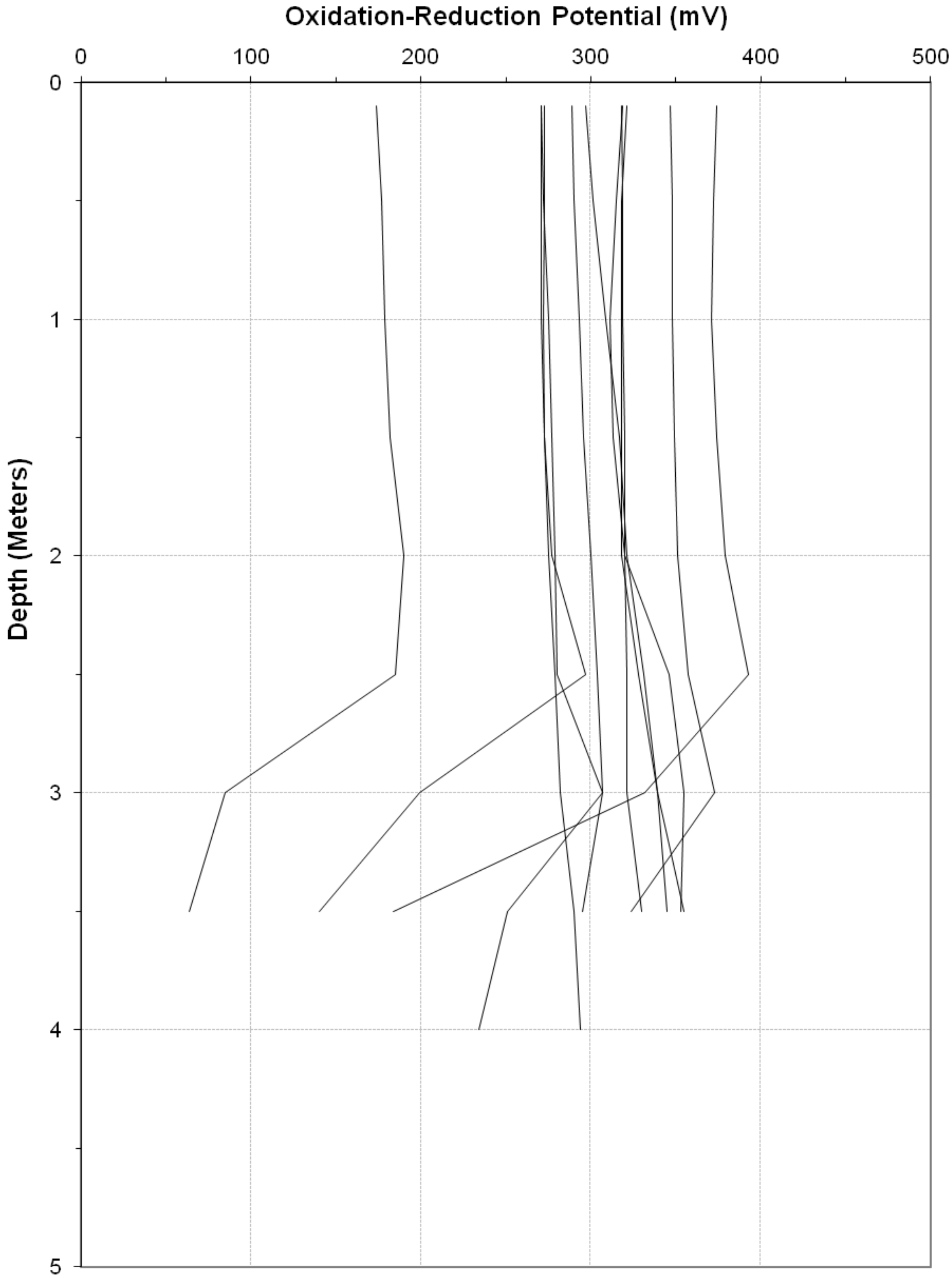


Plate 6-49. Oxidation-reduction potential depth profiles for Holmes Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1) when hypoxic conditions were present, during the summer, over the 5-year period of 2011 through 2015.

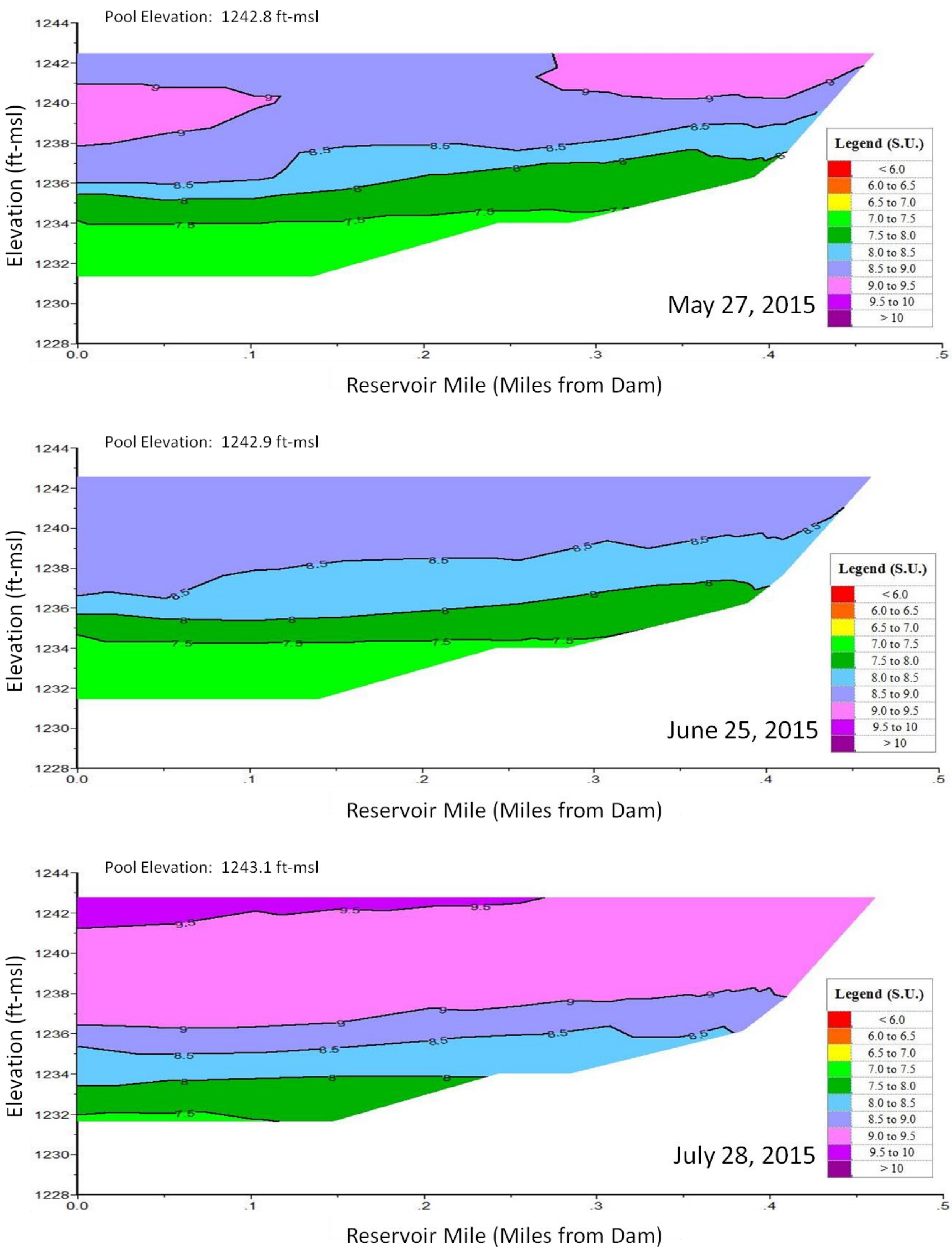


Plate 6-50. Longitudinal pH contour plots of Holmes Reservoir based on depth-profile pH levels (S.U.) measured at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1 in 2015.

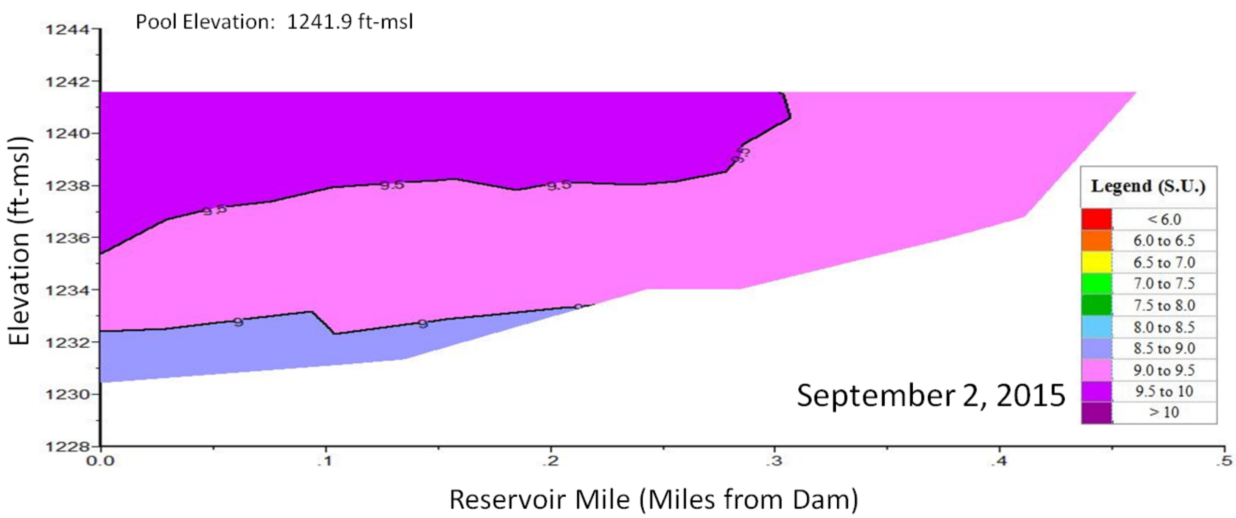


Plate 6-50. (Continued).

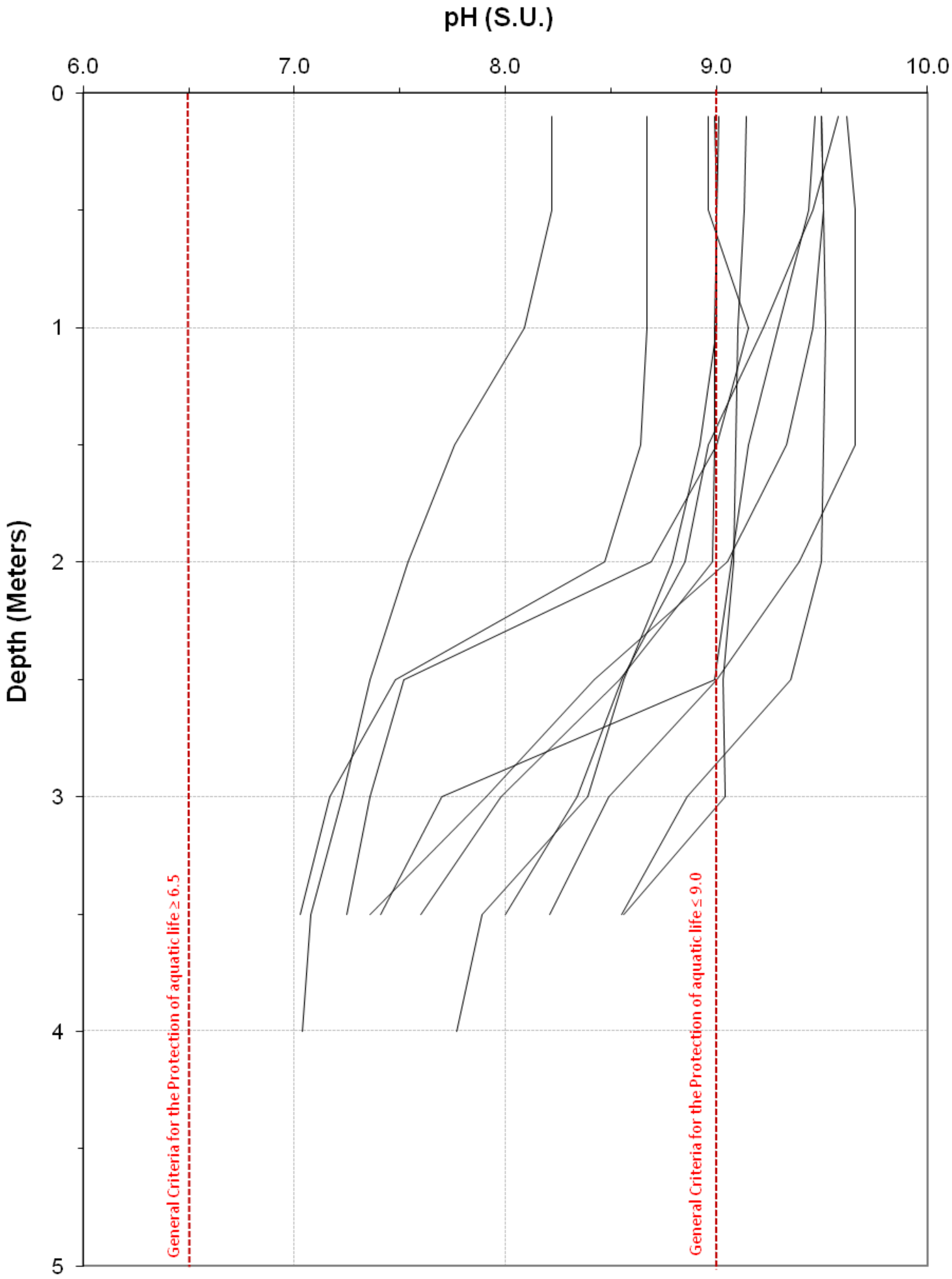


Plate 6-51. pH depth profiles for Holmes Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1) during the summer over the 5-year period of 2011 through 2015, when hypoxic conditions were present.

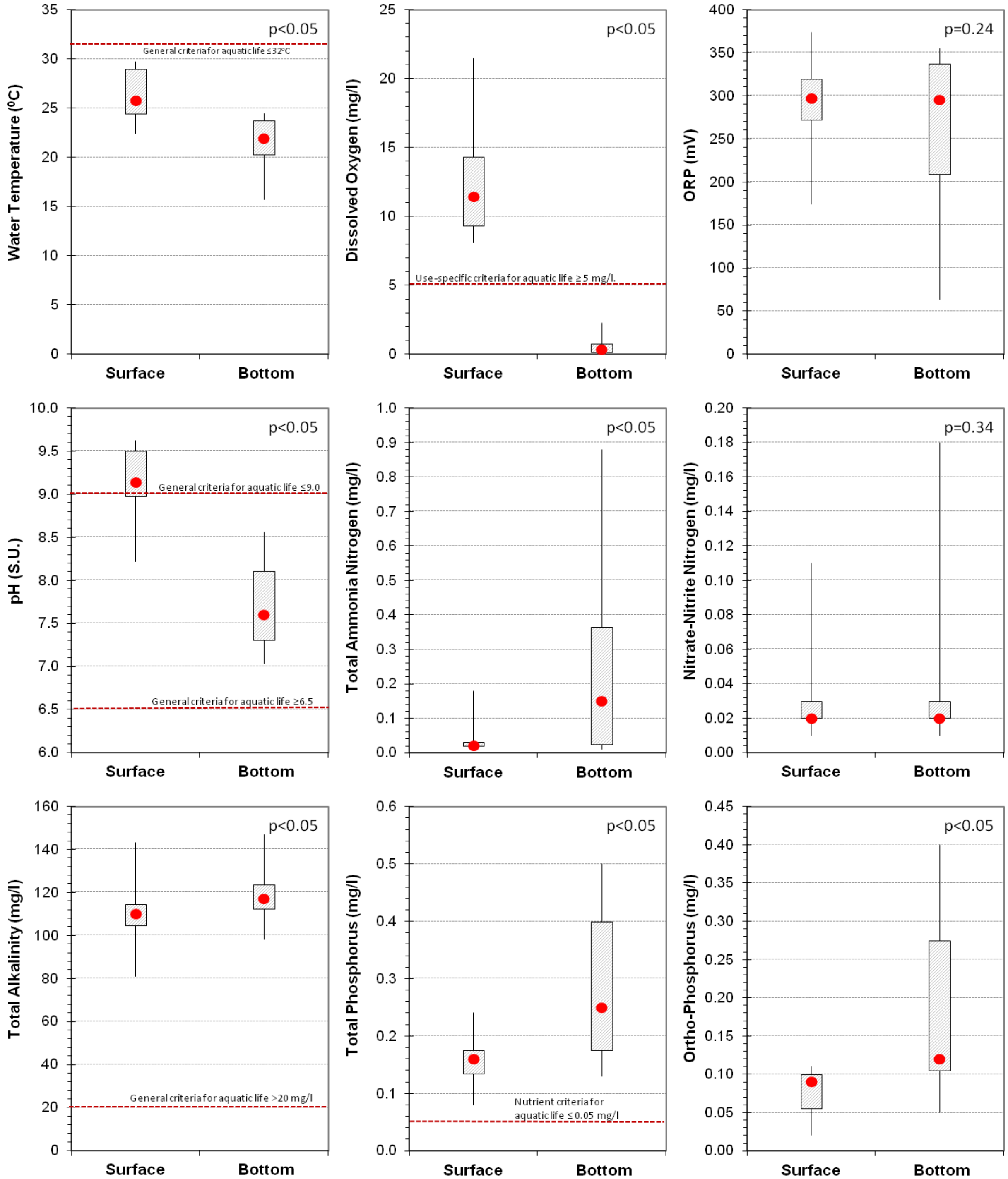


Plate 6-52. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, total ammonia nitrogen, nitrate-nitrite nitrogen, alkalinity, total phosphorus, and ortho-phosphorus measured in Holmes Reservoir when summer hypoxic conditions were present during the 5-year period of 2011 through 2015 (n=11). P-values indicate significant differences between the near-surface and near-bottom samples via a paired two-tailed t-test (α = 0.05). (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot. Water quality criteria marked with red line when applicable)

Plate 6-53. Total biovolume and density by taxonomic group for phytoplankton grab samples from Holmes Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)
26-May-11	-----	-----	88,803	1,429	1,354	25	9,107	159	94,433	3,665	1,685	5	2,274,782	3,098	3,998	2
29-Jul-11	4,493	6	18,341	1,165	57	0	96,161	1,507	1,059,796	78,646	3,204	6	4,234	5	11,982	14
22-Sep-11	8,533	11	18,058	553	-----	-----	35,756	529	1,901,196	123,210	6,694	11	1,125,063	1,387	-----	-----
03-May-12	158,443	93	15,842,690	11,636	-----	-----	110,579	1,560	499,324	20,259	-----	-----	765,382	2,378	-----	-----
09-Jul-12	-----	-----	802,195	2,799	-----	-----	87,805	392	26,695,719	623,150	222,124	178	1,505,673	4,195	-----	-----
12-Sep-12	-----	-----	38,376	476	-----	-----	305,535	406	44,305,701	709,449	129,389	18	2,992,742	2,035	765,332	43
15-May-13	3,024	1	71,974	264	13,902	7	213,486	2,517	14,843	207	122,382	272	-----	-----	-----	-----
09-Jul-13	-----	-----	304,687	347	-----	-----	44,995	530	9,120,211	69,431	191,554	299	-----	-----	-----	-----
14-May-14	167,724	21	701,605	1,769	699,599	335	99,863	1,048	174,920	1,549	-----	-----	1,331,006	1,326	-----	-----
16-Jul-14	419,028	23	1,700	12	-----	-----	89,724	17	3,667,483	32,981	65,008	6	23,296	94	-----	-----
11-Sep-14	-----	-----	147,593	355	1,570	0	1,268,285	467	405,188	4,053	44,265	9	700,377	507	-----	-----
27-May-15	-----	-----	845,290	3,289	507,129	187	13,102,067	7,593	928,336	10,257	1,673	4	8,442,744	2,140	251,631	7
28-Jul-15	-----	-----	120,343	2,926	-----	-----	263,893	1,283	4,947,163	225,082	126	0	203,439	667	274,837	7
23-Sep-15	4,580	0	1,865	47	-----	-----	480,477	1,166	14,359,198	82,634	-----	-----	593,126	393	-----	-----

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

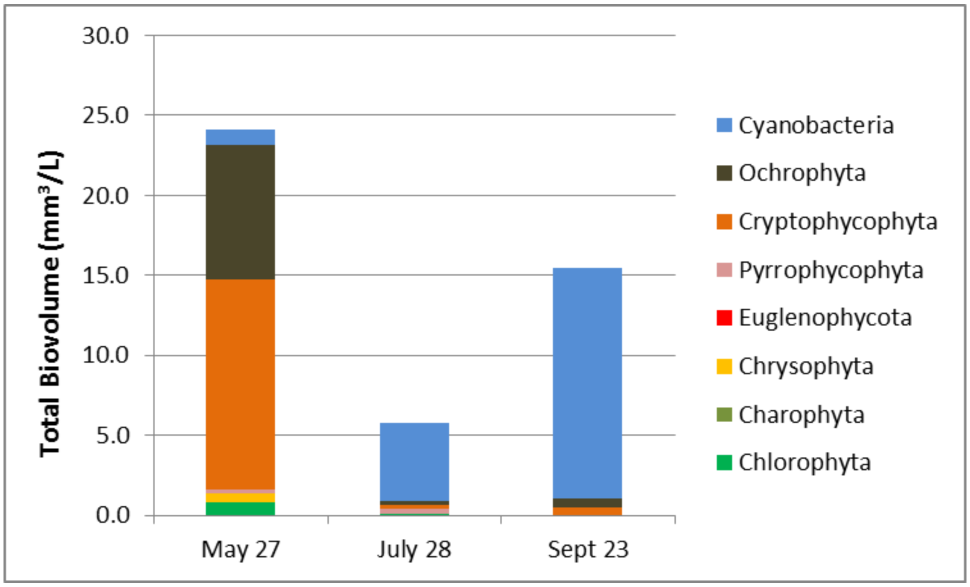


Plate 6-54. Relative abundance of phytoplankton in samples collected from Holmes Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1).

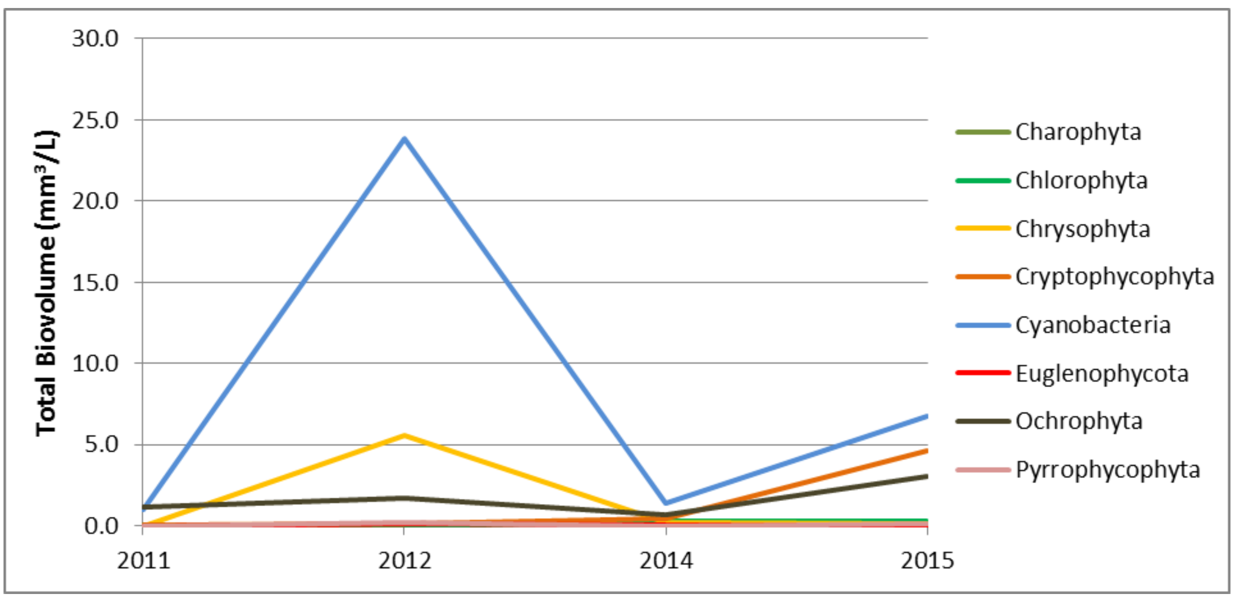


Plate 6-55. Relative abundance of phytoplankton in samples collected from Holmes Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are a yearly average of three summer samples (i.e. May, July, and September). Note: Analysis did not include 2013 due to an incomplete data set.

Plate 6-56. Total biomass and density by taxonomic grouping for zooplankton vertical-tow samples from Holmes Oak Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)
26-May-11	53	315.42	37	24.60	-----	-----	56	0.42
29-Jul-11	499	385.54	100	33.41	-----	-----	37	0.79
22-Sep-11	58	53.46	31	11.40	-----	-----	17	6.12
03-May-12	83	287.72	66	87.61	-----	-----	153	20.66
09-Jul-12	370	301.20	80	16.83	2	1.26	10	0.40
12-Sep-12	12	16.74	2	5.24	-----	-----	3	0.03
15-May-13	116	222.49	104	100.50	-----	-----	191	0.89
09-Jul-13	130	1,199.50	40	59.88	12	54.19	52	1.23
12-Sep-13	92	337.13	28	118.66	-----	-----	1	0.01
14-May-14	165	412.14	147	43.81	2	2.00	68	7.44
16-Jul-14	175	198.17	79	10.37	5	0.71	18	0.40
11-Sep-14	226	366.77	123	83.10	-----	-----	1,374	19.27
27-May-15	81	262.89	204	187.82	17	2.04	528	13.95
28-Jul-15	14	18.71	7	8.79	-----	-----	-----	-----
23-Sep-15	48	80.07	12	5.56	-----	-----	13	3.27

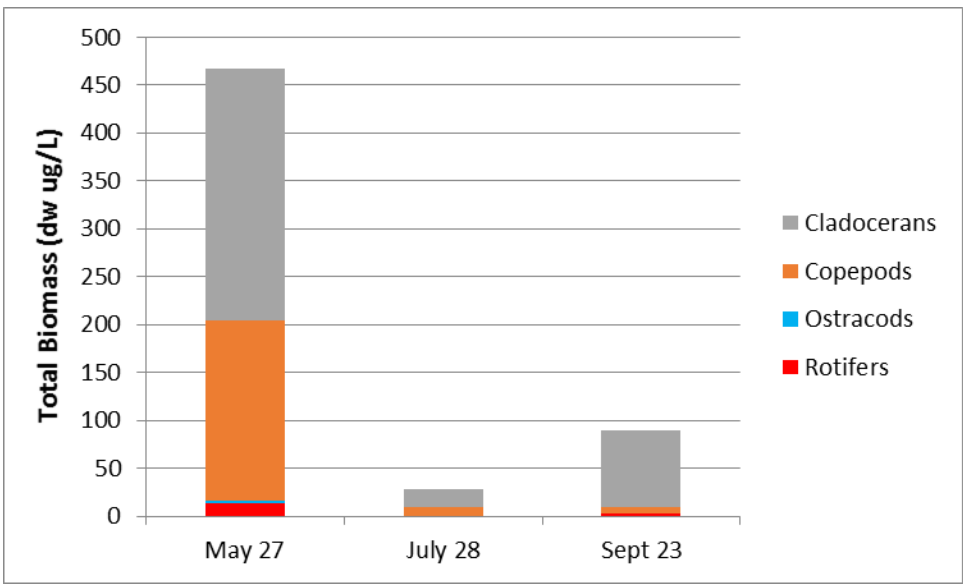


Plate 6-57. Relative abundance of zooplankton in samples collected from Holmes Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1).

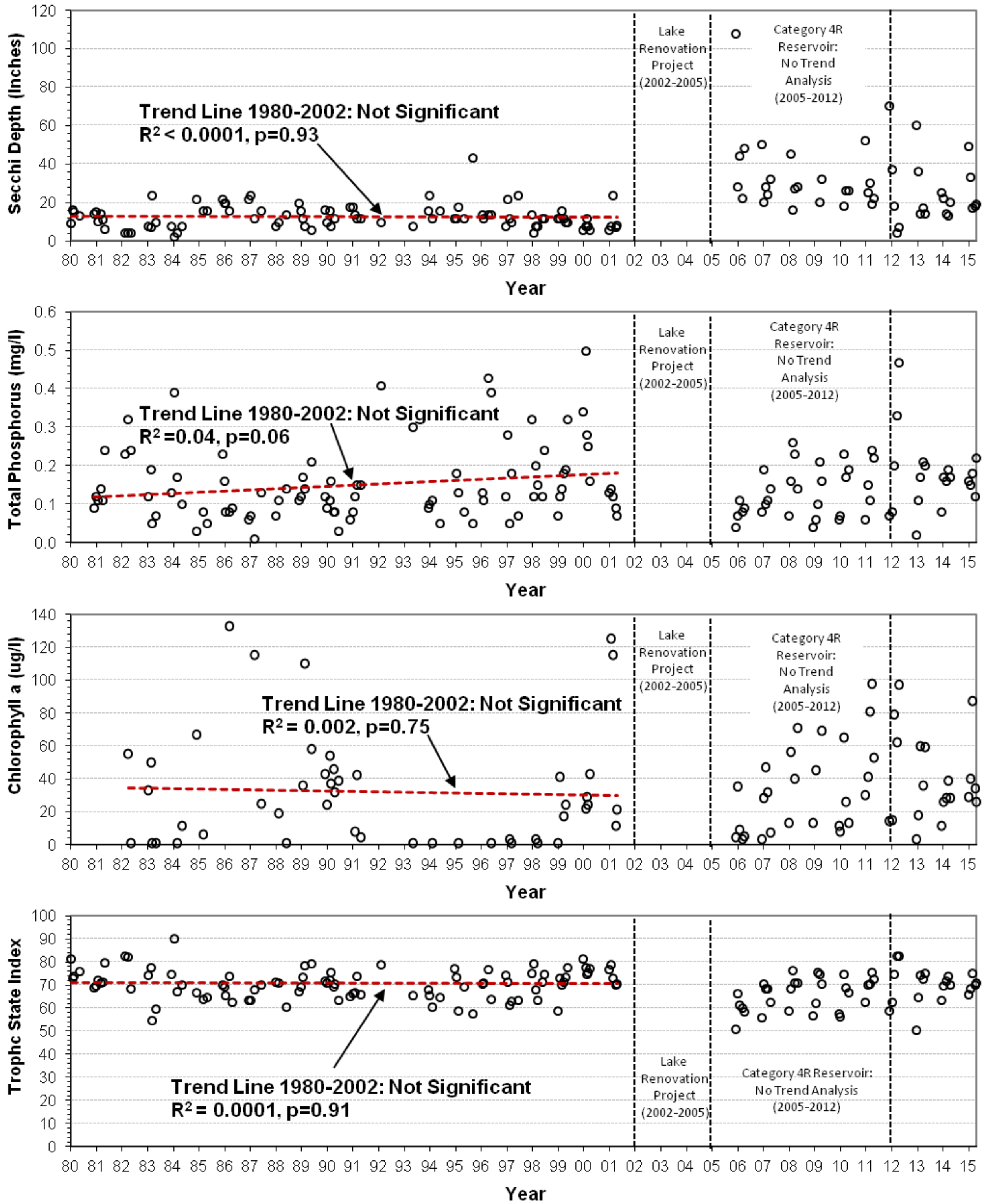


Plate 6-58. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Holmes Reservoir at the near-dam, ambient site (i.e., site HOLLKND1) over the 36-year period of 1980 through 2015.

6.6 OLIVE CREEK RESERVOIR

6.6.1 BACKGROUND INFORMATION

6.6.1.1 Project Overview

The dam forming Olive Creek Reservoir is located on a south tributary of Olive Branch of Salt Creek. The dam was completed on September 20, 1963 and the reservoir reached its initial fill on June 30, 1965. The Olive Creek Reservoir watershed is 8.2 square miles. The watershed was largely agricultural when the dam was built in 1963 and has remained so to the present time.

6.6.1.2 Aquatic Habitat Improvement and Water Quality Management Project

A lake renovation project was completed at Olive Creek Reservoir in 2002. The goal of the project was to reduce the quantity of both sediment and nutrients entering the reservoir; to reduce the likelihood of winter fish kills (oxygen depletion); to replace the rough fish dominated community with largemouth bass, bluegill, channel catfish and walleye; and to increase the quantity and quality of shoreline habitat for fish. Approximately $2 million in Federal, State, and Local funding was spent on the lake renovation project.

The lake renovation project consisted of two phases. Phase 1 included excavating approximately 138,000 cubic yards of sediment from the reservoir basin to construct six jetties, three islands, and two offshore breakwaters (see Figure 6.10). The structures collectively added 4,700 feet of shoreline, a 43 percent increase to the reservoir. In addition, shorelines and bays were reshaped and the outlet structure was modified to allow for minor water level manipulation, all as a means of enhancing aquatic vegetation. Phase 2 was the construction of four sediment basins, two spanning each of the two main inflowing streams (See Figure 6.10). The basins were created to intercept and slow silt laden runoff following rain events, thus allowing some of the sediment load to settle out before the water reached the main reservoir. Since these basins were located in the flood pool, they occupied flood storage space which had to be mitigated. This was accomplished by excavating an amount of material from behind the basins equal to the amount of space they and their impounded water occupied. The mitigation requirement reduced the reservoir basin excavation by a comparable amount. In addition to the work on the reservoir, other funding was utilized to help implement BMPs (best management practices) in the Olive Creek Reservoir watershed.

6.6.1.3 Olive Creek Dam Intake Structure

The dam intake at Olive Creek Dam is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 4 feet by 6 feet. The intake structure has four ungated openings – two 24” x 72” openings with a crest elevation at 1340.9 ft-msl and two 12” x 30” openings with a crest elevation at 1335.0 ft-msl. A 36” x 36” gated opening with a crest elevation of 1330.0 ft-msl was constructed into the upstream wall. As part of the recent lake renovation project a “stop-log” structure was attached to the concrete box shaft over the 36” x 36” gated opening. The 36” x 36” gate is permanently left open and pool levels are managed with the external stop-log structure. The purpose of the gate modification is to allow for better management of pool elevations for water quality and fishery management. The gated outlet may also be used to release water for downstream needs.

6.6.1.4 Reservoir Storage Zones

Figure 6.9 depicts the current storage zones of Olive Creek Reservoir based on the 1993 survey data, results of the recent lake renovation project, and estimated sedimentation. After accounting for the sediment removed from the reservoir basin as part of the recent lake renovation project, it is estimated that 20 to 24 percent of the “as-built” volume to the top of the Conservation Pool has been lost to sedimentation as of 2015. The annual volume loss is estimated to be 0.53 percent. Based on the State of Nebraska’s impairment assessment methodology, these values indicate that Olive Creek Reservoir's water quality dependent uses are not at this time impaired due to sedimentation.

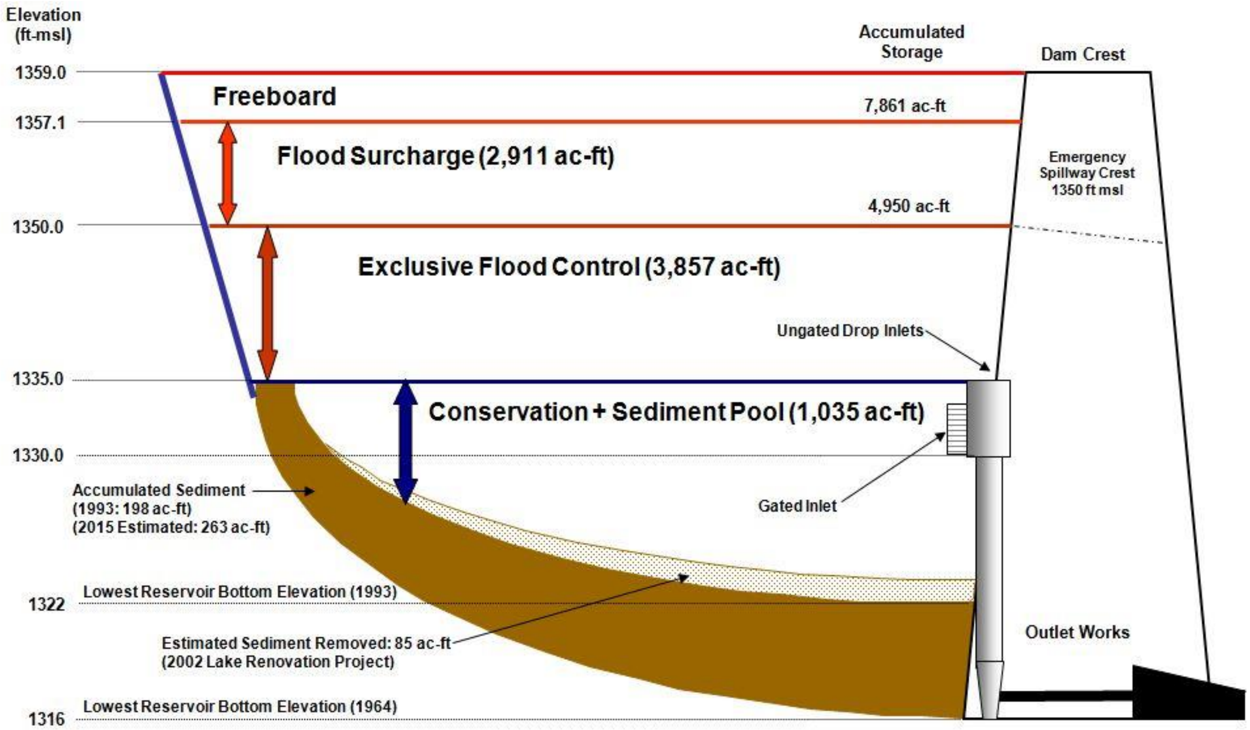


Figure 6.9. Current storage zones of Olive Creek Reservoir based on the 1993 survey data, recently implemented lake renovation project, and estimated sedimentation**.**

6.6.1.5 <u>Ambient Water Quality Monitoring</u>

The District has monitored water quality conditions at Olive Creek 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. Figure 6.10 shows the location of the sites that have been monitored for water quality during the 5-year sampling period (i.e., 2008 through 2012). The inflow runoff sites (OCRNFWST1 and OCRNFEST1) were sampled by the NDEQ. The other in-reservoir sites (OCRLKND1, OCRLKML1, and OCRLKUP1) were sampled by the District. The near-dam location (OCRLKND1) has been continuously monitored by the District since 1980.

6.6.2 Water Quality in Olive Creek Reservoir

6.6.2.1 <u>Existing Water Quality Conditions</u>

6.6.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Olive Creek Reservoir at sites OCRLKND1, OCRLKML1, and OCRLKUP1 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 6-59 through Plate 6-61. A review of these results indicated possible water quality concerns regarding dissolved oxygen, ammonia, arsenic, pH, and nutrients.

A significant number of dissolved oxygen measurements throughout Olive Creek Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 6-59-Plate 6-61). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and appeared to be associated with a slight thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Olive Creek Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation. However, thermal stratification in Olive Creek Reservoir was relatively limited during the 5-year sampling period of 2011 through 2015 (Plate 6-63). This limited stratification could lead to the above provision not applying to the reservoir and possible impairment for dissolved oxygen for the protection of aquatic life in Olive Creek Reservoir. In addition, dissolved oxygen measurements were below the 5 mg/l criterion for the protection of warmwater aquatic life from the reservoirs surface to bottom several times during the 5-year sampling period (Plate 6-65).

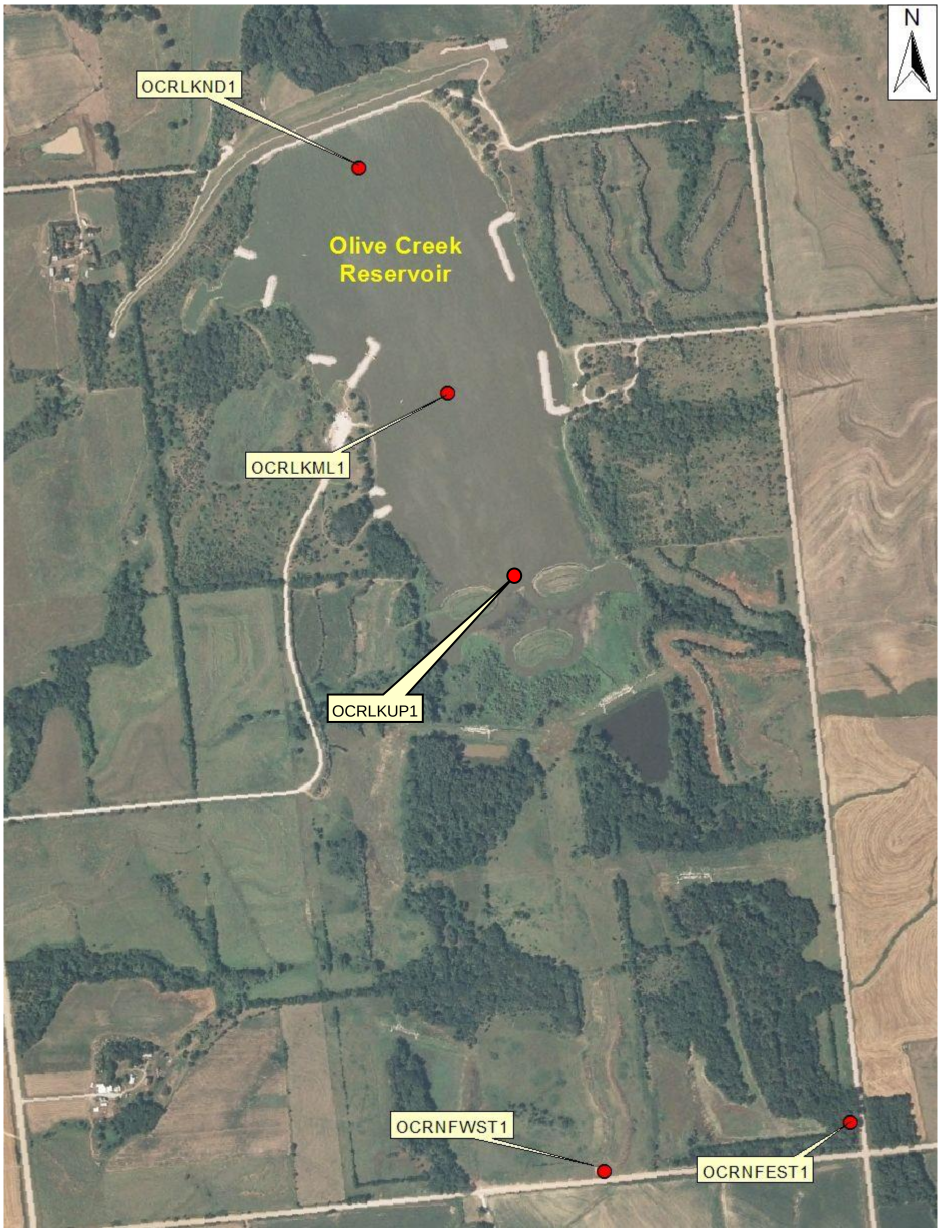


Figure 6.10. Location of sites where water quality monitoring was conducted at Olive Creek Reservoir during the period 2011 through 2015.

The above provision also seemingly applies to total ammonia and dissolved arsenic. Ammonia criteria are pH and temperature dependent. Acute and chronic criteria were determined for each ammonia sample using near-surface temperature and pH measurements at time of collection. Median acute and chronic criteria during the 5-year sampling period of 2011 through 2015were 0.57 and 0.14 mg/l respectively (Plate 6-59). Twenty-eight percent of the 25 near-surface samples exceeded the chronic ammonia criteria. Based on the State of Nebraska's impairment assessment criteria (Table 4.5), the percent exceedance of the chronic ammonia criterion indicates impairment of the Aquatic Life beneficial use of Olive Creek Reservoir.

The State of Nebraska's acute and chronic criteria for dissolved arsenic is 340 and 16.7 ug/l respectively. Eighty percent of the 5 near-surface dissolved arsenic samples exceeded the states chronic criteria for dissolved arsenic (Plate 6-59). Based on the State of Nebraska's impairment assessment criteria (Table 4.5), the percent exceedance of the chronic dissolved arsenic criterion indicates impairment of the Aquatic Life beneficial use of Olive Creek Reservoir.

A large number (>40%) of pH readings throughout Olive Creek Reservoir were above the numeric pH criteria of 9.0 for the protection of warmwater aquatic life (Plate 6-59-Plate 6-61). The greatest pH value measured was 10.02 SU. The magnitude and number of pH criterion exceedances indicate a noteworthy water quality concern. Based on the State of Nebraska's impairment assessment criteria, the percent exceedance of the upper pH criterion indicates impairment of the Aquatic Life beneficial use of Olive Creek Reservoir. It is believed the high pH values may be associated with periods of high algal production and CO_2 uptake during photosynthesis.

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September) to be considered for impairment assessment. All three of these criteria were exceeded Olive Creek Reservoir (Plate 6-59). The near-surface chlorophyll *a* criterion was exceeded by 92 percent of the "lab analyzed" samples taken in the reservoir at site OCRLKND1. The total phosphorus and total nitrogen criteria were exceeded in all samples collected. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values represent the growing season average for the 5-year period 2011 through 2015. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.42 mg/l), total nitrogen (2.34 mg/l), and chlorophyll *a* (64 ug/l) values at OCRLKND1 indicate impairment of the aquatic life use due to nutrients.

6.6.2.1.2 Thermal Stratification

6.6.2.1.2.1 ***Longitudinal Temperature Contour Plots***

Late-spring and summer thermal conditions of Olive Creek Reservoir measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 6-62 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites OCRLKND1, OCRLKML1, and OCRLKUP1. These temperature plots indicate that Olive Creek Reservoir rarely exhibited significant thermal stratification during 2015. The maximum difference monitored between the surface and bottom water temperatures was around 6.0°C in June 2015 (Plate 6-62).

6.6.2.1.2.2 ***Near-Dam Temperature Depth-Profile Plots***

Existing summer thermal stratification of Olive Creek Reservoir, at the deep water area near the dam, measured over the 5-year period 2011 through 2015 is depicted by depth-profile temperature plots (Plate 6-63). The depth-profile temperature plots indicate that the reservoir rarely exhibited significant summer thermal stratification over the 5-year sampling period. Since Olive Creek Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.6.2.1.3 Dissolved Oxygen Conditions

6.6.2.1.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of Olive Creek Reservoir based on depth-profile measurements taken in 2015 at sites OCRLKND1, OCRLKML1, and OCRLKUP1. Plate 6-64 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 May through June near the reservoir bottom near the dam (Plate 6-64). In late June, close to a third of Olive Creek Reservoir was hypoxic.

6.6.2.1.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

Existing summer dissolved oxygen conditions in Olive Creek Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2011 through 2015 (Plate 6-65). On several occasions there was a significant vertical gradient in summer dissolved oxygen levels. Sixteen percent of the profiles showed hypoxic conditions near the reservoir bottom and four of the 25 profiles showed dissolved oxygen levels below the Nebraska's dissolved oxygen criterion for the protection of warmwater aquatic life (≥ 5 mg/l) through the entire depth of the profile. Although Olive Creek Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition to mixing to allow hypoxic conditions to occasionally develop near the reservoir bottom.

6.6.2.1.3.3 ***Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of Olive Creek 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 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 June 25, 2015 contour plot indicates a pool elevation of 1335.6 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1333.0 ft-msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1330.0 ft-msl (Plate 6-64). The current District Area-Capacity Tables (1993 Survey) give storage capacities of 1,201 ac-ft for elevation 1335.6 ft-msl, 800 ac-ft for elevation 1333.0 ft-msl, and 439 ac-ft for elevation 1330.0 ft-msl. On June 25, 2015 it is estimated that 67 percent of the volume of Olive Creek Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 37 percent of the reservoir volume was hypoxic.

6.6.2.1.4 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in Olive Creek Reservoir indicated hypoxic conditions May and June 2015. As a result, longitudinal contour plots for ORP and pH were constructed during these months. During the last 5-years (2011 through 2015) only sixteen percent of the depth profiles at the near dam site have showed hypoxic conditions near the reservoir bottom (Plate 6-65). Due to this, further analysis was not performed

6.6.2.1.4.1 ***Oxidation-Reduction Potential***

Plate 6-66 provides longitudinal ORP contour plots based on depth-profile measurements taken in 2015 when hypoxic conditions were present in Olive Creek Reservoir. The longitudinal contour plots showed that no appreciable reduced conditions occurred in 2015 at Olive Creek Reservoir, with all measurements being greater than 300 mV. Given the polymictic nature of the reservoir, reduced conditions seemingly are not long-term.

6.6.2.1.4.2 ***pH***

Longitudinal contour plots for pH conditions measured in 2015 when hypoxic conditions were present are provided in Plate 6-67. Only slight pH differences were observed during hypoxic conditions at Olive Creek Reservoir in 2015.

6.6.2.1.4.3 ***Reservoir Trophic Status***

Trophic State Index (TSI) values for Olive Creek Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., OCRLKND1). Table 6.20 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Olive Creek Reservoir is in a hypereutrophic condition.

Table 6.20. Summary of Trophic State Index (TSI) values calculated for Olive Creek Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	75	74	64	90
TSI(TP)	25	76	76	61	86
TSI(Chl)	25	76	76	50	92
TSI(Avg)	25	76	75	66	85

* 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 for the individual parameters.
Note: See Section 4.1.3 for discussion of TSI calculation.

6.6.2.1.5 Reservoir Plankton Community

6.6.2.1.5.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at the Olive Creek Reservoir near-surface, near-dam sampling site during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-68). The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 6-69. The highest phytoplankton total biovolume was observed in July and the lowest in May. Olive Creek Reservoir was mostly dominated by Cyanobacteria in 2015 and had little phytoplankton diversity. The greatest cyanobacterial densities being observed in July and September correspond with Cyanobacteria growing best in warm water conditions. Major and dominant phytoplankton genera sampled in 2015 at Olive Creek Reservoir are provided in Table 6.21.

Table 6.21. Listing of Major and Dominant Phytoplankton Genera Sampled in Olive Creek Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1)

Division	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cryptophycophyta	-----	*Cryptomonas*
Cyanobacteria	*Microcystis, Planktothrix*	*Anabaena*
Ochrophyta	-----	*Aulacoseira*
Pyrrophycophyta	*Ceratium*	-----

Annual variation in phytoplankton community composition during the 5-year period 2011 through 2015 is displayed in Plate 6-70. Olive Creek Reservoir was mostly dominated by Cyanobacteria through the 5-year period, however, Ochrophyta, Cryptophycophyta, and Chlorophyta were also abundant. Cyanobacteria density levels were greater than the World Health Organizations high level of health risk (>100,000 Cells/ml) in 2011 and 2012 (Plate 6-68). The greatest average Cyanobacteria density was observed in 2012. 2012 was a particularily warm and dry year. The longer reservoir residence time, decreased mixing, and warmer waters could have lead to a longer Cyanobacterial growing season, resulting in the observed large densities and biovolumes. The maximum extracellular microcystin level measured at the near-dam site during the 5-year period was 1.1 µg/L (Plate 6-59).

6.6.2.1.5.2 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at Olive Creek Reservoir near-dam sampling sites during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-71). The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in Plate 6-72. Olive Creek Reservoir was dominated largely by Cladocerans in 2015 with the greatest total zooplankton biomass in September. Dominant and major zooplankton genera sampled in Olive Creek Reservoir during 2015 are provided in Table 6.22.

Table 6.22. Listing of major and dominant zooplankton genera sampled in Olive Creek Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1)

Taxonomic Group	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cladocerans	*Leydigia*	*Ceriodaphnia, Daphnia*
Copepods	-----	*Mesocyclops, Skistodiaptomus*
Ostracods	*Ostracoda*	-----

6.6.2.1.6 Zebra Mussel Monitoring

Zebra mussel veliger sampling has been conducted once yearly since 2012 at Olive Creek Reservoir. During the sampling period (2012-2015) no veligers have been identified.

6.6.2.1 Water Quality Trends (1980 through 2015)

Water quality trends from 1980 to 2015 were determined for Olive Creek 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., OCRLKND1). Plate 6-73 displays a scatter-plot of the collected data for the four parameters and linear regression lines for the period 1980 through 1998 and 2003 through 2015. The data gap of 1999 through 2002 is the period when the lake renovation project was implemented at Olive Creek Reservoir. Prior to the renovation project (1980-1998) there were no significant trends in transparency ($p=0.16$, $R^2=0.03$), total phosphorus ($p=0.45$, $R^2=0.01$), chlorophyll a ($p=0.10$, $R^2=0.11$) and TSI ($p=0.07$, $R^2=0.05$). Post renovation analysis of years 2002 through 2015 also showed no significant trends in transparency ($p=0.25$, $R^2=0.02$), total phosphorus ($p=0.19$, $R^2=0.03$), chlorophyll a ($p=0.09$, $R^2=0.05$) and TSI ($p=0.20$, $R^2=0.03$). Further regression analysis was then used to determine if the renovation project at Olive Creek Reservoir had any affect on observed trends. No significant changes in trends were observed in transparency ($p=0.60$), total phosphorus ($p=0.27$), or chlorophyll a ($p=0.09$). Average TSI trends increased post renovation ($p=0.04$). Olive Creek was in a hypereutrophic condition prior to the renovation project and has remained so post renovation. The apparent negative impacts of the renovation project may be attributed to Olive Creek entering a period of trophic instability due to the renovation project. More time my be needed in order for those trend changes to be observed.

6.6.3 Plates

Plate 6-59. Summary of water quality conditions monitored in Olive Creek Reservoir at site OCRLKND1 from May to September during the 5-year 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	25	1334.48	1333.90	1330.80	1353.30	-----	-----	-----
Water Temperature (°C)	0.1	161	23.22	24.28	16.32	29.96	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	161	7.39	7.82	n.d.	15.17	≥5[2]	37	23%
Dissolved Oxygen, Near-Surface (mg/l)[C]	0.1	25	8.38	8.66	2.67	14.65	≥5[2]	4	16%
Dissolved Oxygen (% Sat.)	0.1	161	90.16	88.00	0.50	186.50	-----	-----	-----
Secchi Depth (in.)	1	25	15.56	15.00	5.00	30.00	-----	-----	-----
Turbidity (NTUs)	1	154	49.97	33.55	5.60	243.60	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	161	343.14	361.00	67.00	454.00	-----	-----	-----
Specific Conductance (umho/cm)	1	161	259.79	253.00	188.30	352.00	2,000[3]	0	0%
pH (S.U.)	0.1	161	8.65	8.73	6.80	10.02	≥6.5 & ≤9.0 [1]	0,65	0%,40%
Alkalinity, Total (mg/l)	1	50	119.12	119.50	76.00	151.00	>20[1]	0	0%
Suspended Solids, Total (mg/l)	4	50	22.58	22.50	n.d.	54.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	50	-----	0.10	n.d.	0.76	0.74[4,5], 0.18[4,6]	2,14	4%,28%
Ammonia, Total, Near-Surface (mg/l) [C]	0.02	25	-----	0.07	0.01	0.72	0.57[4,5], 0.14[4,6]	1,7	4%,28%
Kjeldahl N, Total (mg/l)	0.08	50	2.17	1.99	0.99	4.17	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	50	-----	n.d.	n.d.	1.29	100[3]	0	0%
Nitrogen, Total (mg/l)	0.08	50	2.38	2.26	1.12	4.19	1[7]	50	100%
Nitrogen, Total, Near-Surface (mg/l) [C]	0.08	25	2.34	2.26	1.23	3.87	1[7]	25	100%
Phosphorus, Total (mg/l)	0.005	50	0.44	0.38	0.08	0.98	0.05[7]	50	100%
Phosphorus, Total, Near-Surface (mg/l) [C]	0.005	25	0.42	0.36	0.08	0.95	0.05[7]	25	100%
Phosphorus-Ortho, Dissolved (mg/l)	0.005	50	0.27	0.20	n.d.	0.74	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	99.14	99.00	89.25	109.90	-----	-----	-----
Arsenic, Dissolved (ug/l) [C]	0.008	5	29.40	33.00	16.00	41.00	340[5], 16.7[8]	0,4	0%,80%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	n.d.	5.84[5], 0.24[6]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	587.21[5], 76.45[6]	0	0%
Copper, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	13.31[5], 8.88[6]	0	0%
Iron, Dissolved (ug/l)	10	5	119.00	30.00	25.00	450.00	1000[6]	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	63.88[5], 7.49[6]	0	0%
Manganese, Dissolved (ug/l)	3	5	47.00	20.00	15.00	90.00	1000[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	464.27[5], 51.57[6]	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	3.39[5]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	116.19[5], 117.14[6]	0	0%
Antimony, Dissolved (ug/l)	0.5	5	-----	0.60	n.d.	0.70	88[5], 30[6]	0	0%
Aluminum, Dissolved (ug/l)	40	5	-----	n.d.	n.d.	600.00	750[5], 87[6]	0,1	0%,20%
Mercury, Dissolved (ug/l)	0.008	5	-----	n.d.	n.d.	0.05	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Chlorophyll a (ug/l) – Lab Determined[C]	6	25	64	42	n.d.	204	10[7]	23	92%
Chlorophyll a (ug/l) – Field Probe	6	153	72	42	n.d.	349	10[7]	131	86%
Atrazine, Total (ug/l) [D]	0.1	25	3.08	2.70	0.30	13.70	330[5], 12[6]	0,1	0%,4%
Metolachlor, Total (ug/l)[D]	0.1	25	1.19	1.00	0.20	3.10	390[5], 100[6]	0	0%
Acetochlor, Total (ug/l)[D]	0.1	25	1.34	0.90	n.d.	5.90	-----	-----	-----
Microcystin, Extracellular (ug/l)	0.1	24	-----	n.d.	n.d.	1.10	20[9]	0	0%
Pesticide Scan (ug/l)[E]									
Atrazine, Tot	0.13	5	1.49	1.40	0.38	2.82	330[5], 12[6]	0	0%
Acetochlor, Tot	0.08	5	-----	n.d.	n.d.	0.16	-----	-----	-----
Metolachlor, Tot	0.13	5	-----	n.d.	n.d.	2.37	390[5], 100[6]	0	0%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-60. Summary of water quality conditions monitored in Olive Creek Reservoir at site OCRLKML1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1333.55	1333.60	1330.80	1336.10	-----	-----	-----
Water Temperature (°C)	0.1	140	23.22	23.79	16.17	29.99	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	140	7.93	7.97	0.30	14.55	≥5(2)	23	16%
Dissolved Oxygen (% Sat.)	0.1	139	97.50	91.90	9.70	177.70	-----	-----	-----
Secchi Depth (in.)	1	25	14.68	14.00	5.00	30.00	-----	-----	-----
Turbidity (NTUs)	1	133	49.46	33.20	7.40	236.10	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	139	342.98	357.00	125.00	479.00	-----	-----	-----
Specific Conductance (umho/cm)	1	139	259.24	248.80	193.20	351.90	2,000(3)	0	0%
pH (S.U.)	0.1	139	8.69	8.82	6.98	9.89	≥6.5 & ≤9.0 (1)	0,58	0%,42%
Chlorophyll a (ug/l) – Field Probe	6	133	83	42	3	1225	10(4)	114	86%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-61. Summary of water quality conditions monitored in Olive Creek Reservoir at site OCRLKUP1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1333.55	1333.60	1330.80	1336.10	-----	-----	-----
Water Temperature (°C)	0.1	57	22.93	23.87	16.26	30.56	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	57	7.39	7.66	2.25	15.83	≥5(2)	14	25%
Dissolved Oxygen (% Sat.)	0.1	57	89.96	90.80	24.30	199.00	-----	-----	-----
Secchi Depth (in.)	1	25	13.00	14.00	4.00	24.00	-----	-----	-----
Turbidity (NTUs)	1	56	66.56	39.45	8.30	266.70	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	57	353.53	378.00	154.00	466.00	-----	-----	-----
Specific Conductance (umho/cm)	1	57	240.20	231.60	192.40	351.60	2,000(3)	0	0%
pH (S.U.)	0.1	57	8.59	8.93	7.16	9.93	≥6.5 & ≤9.0 (1)	0,25	0%,44%
Chlorophyll a (ug/l) – Field Probe	6	55	71	38	3	816	10(4)	43	78%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

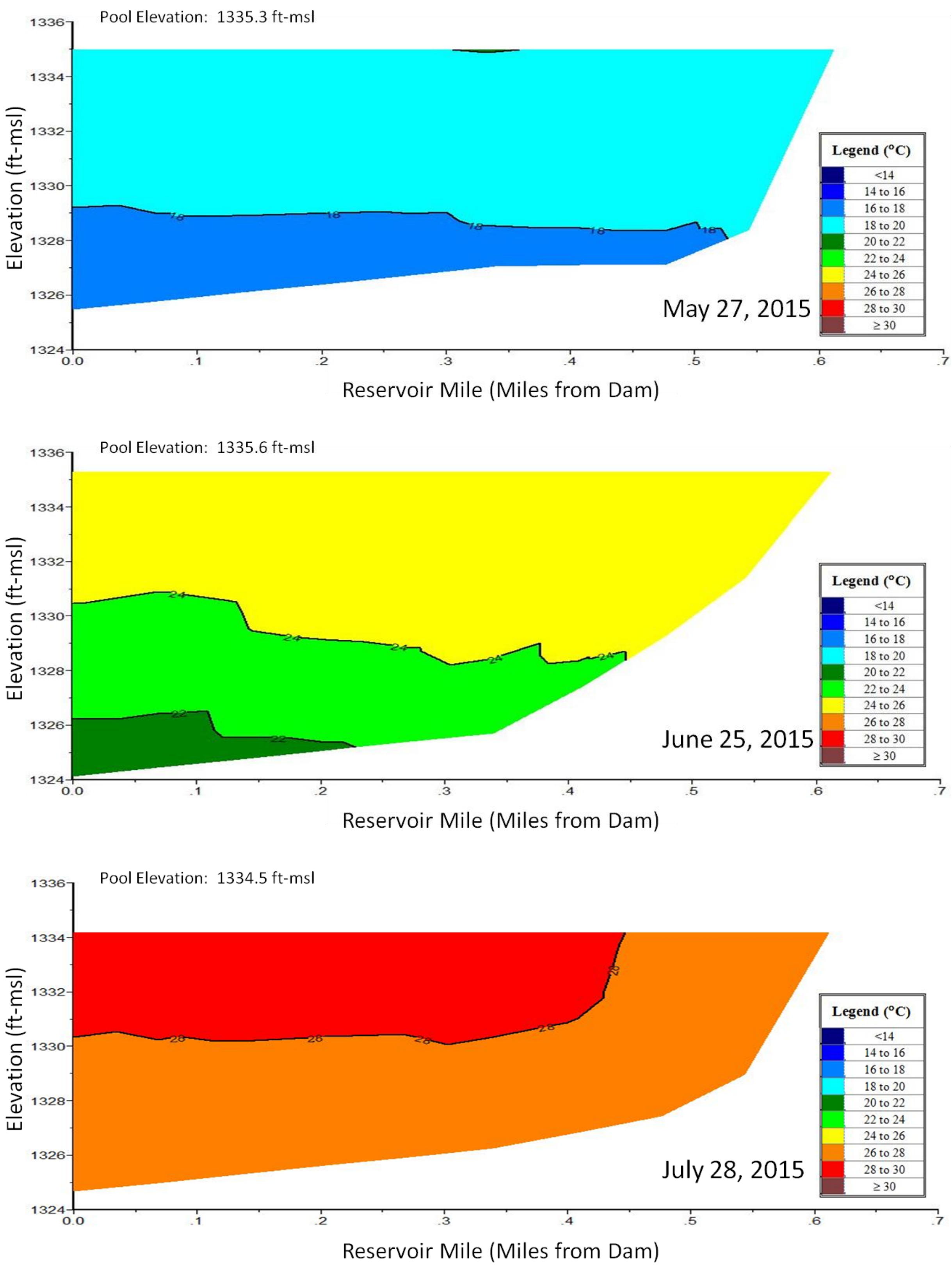
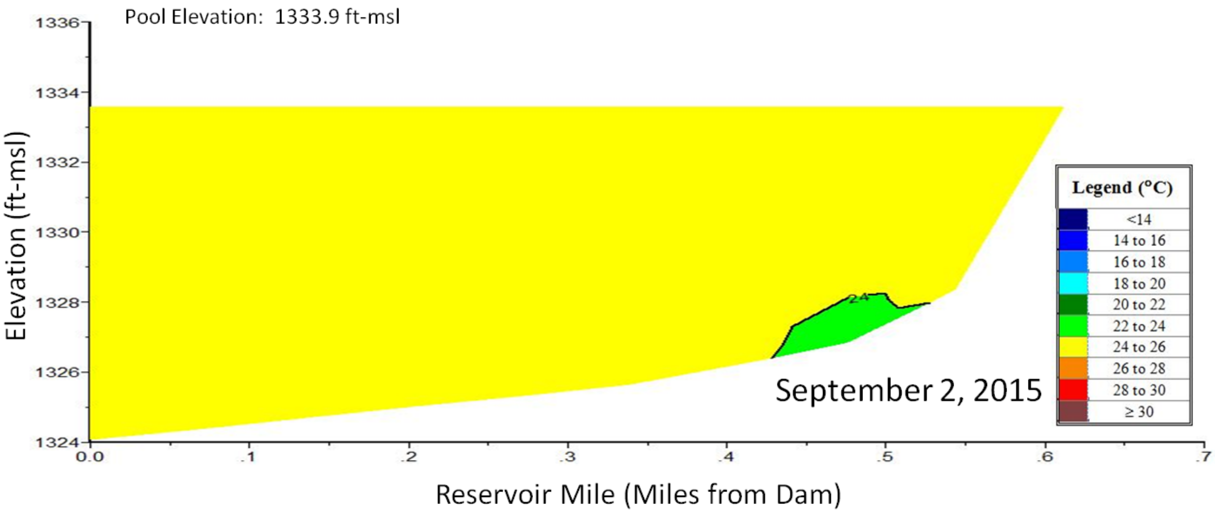


Plate 6-62. Longitudinal water temperature contour plots of Olive Creek Reservoir based on depth-profile water temperatures (°C) measured at sites OCRLKND1, OCRLKML1, and OCRLKUP1 in 2015.



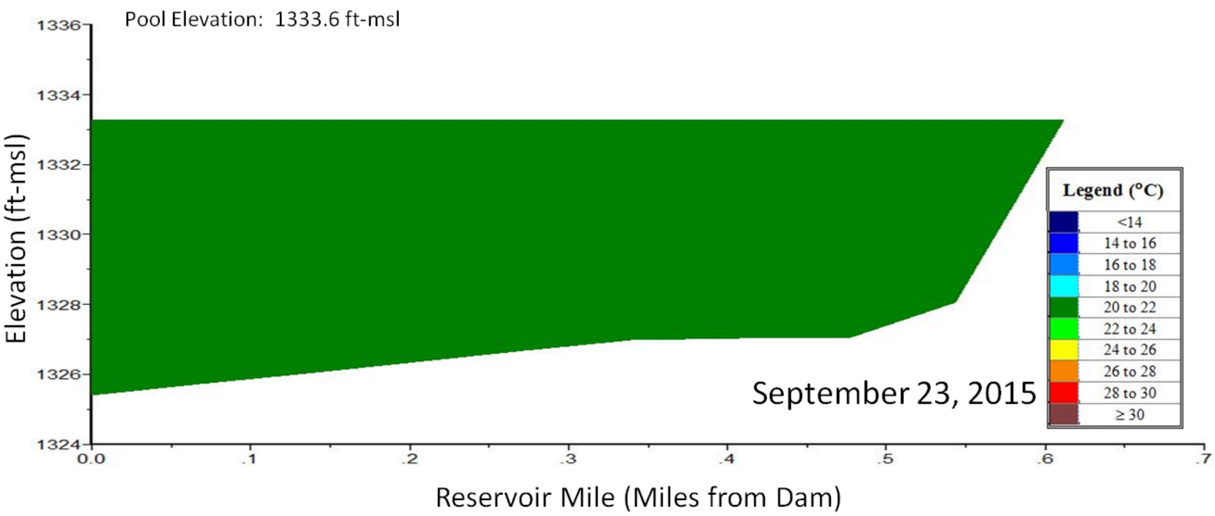


Plate 6-62. (Continued).

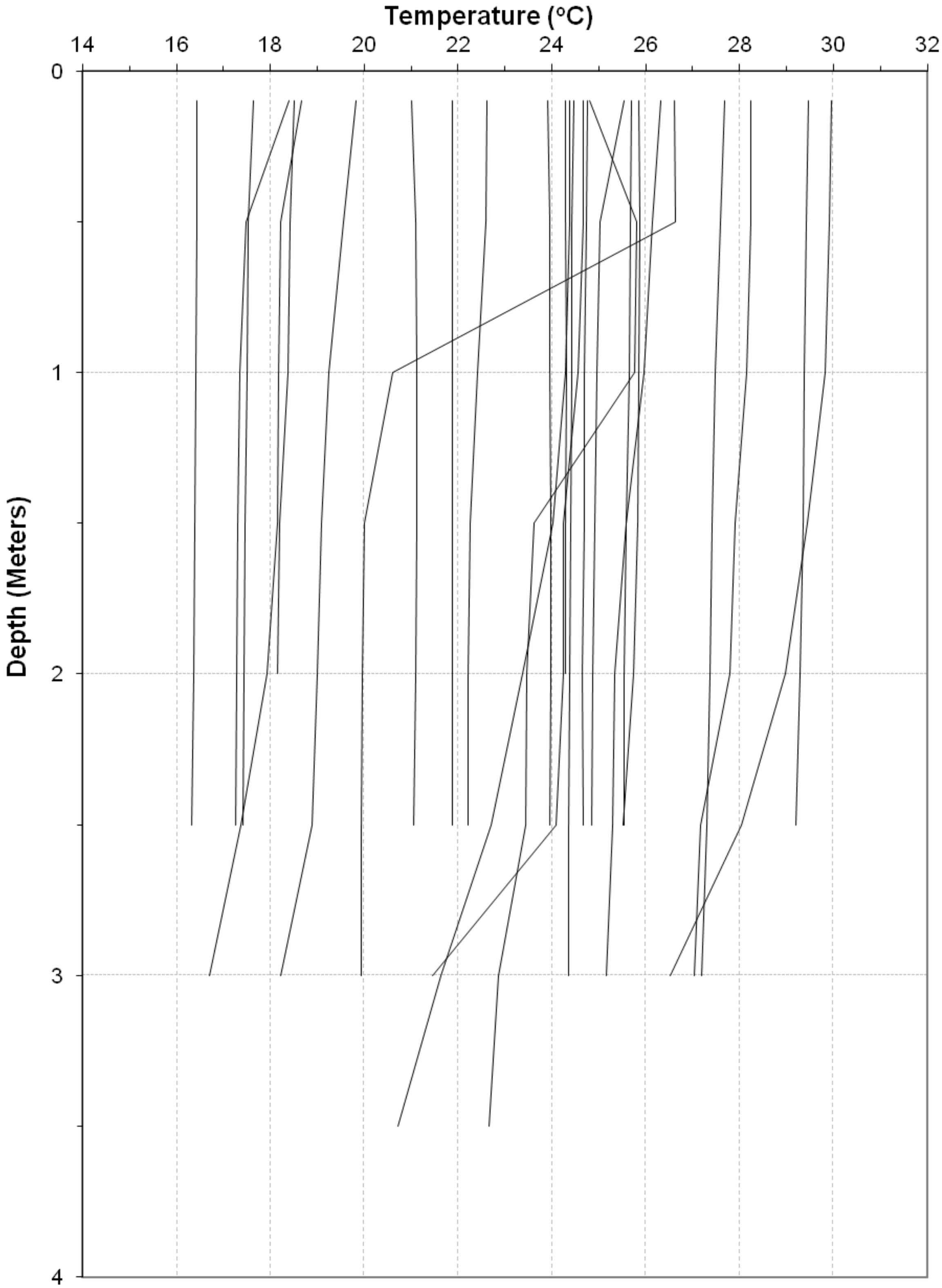


Plate 6-63. Temperature depth profiles for Olive Creek Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1) during the summer over the 5-year period of 2011 through 2015.

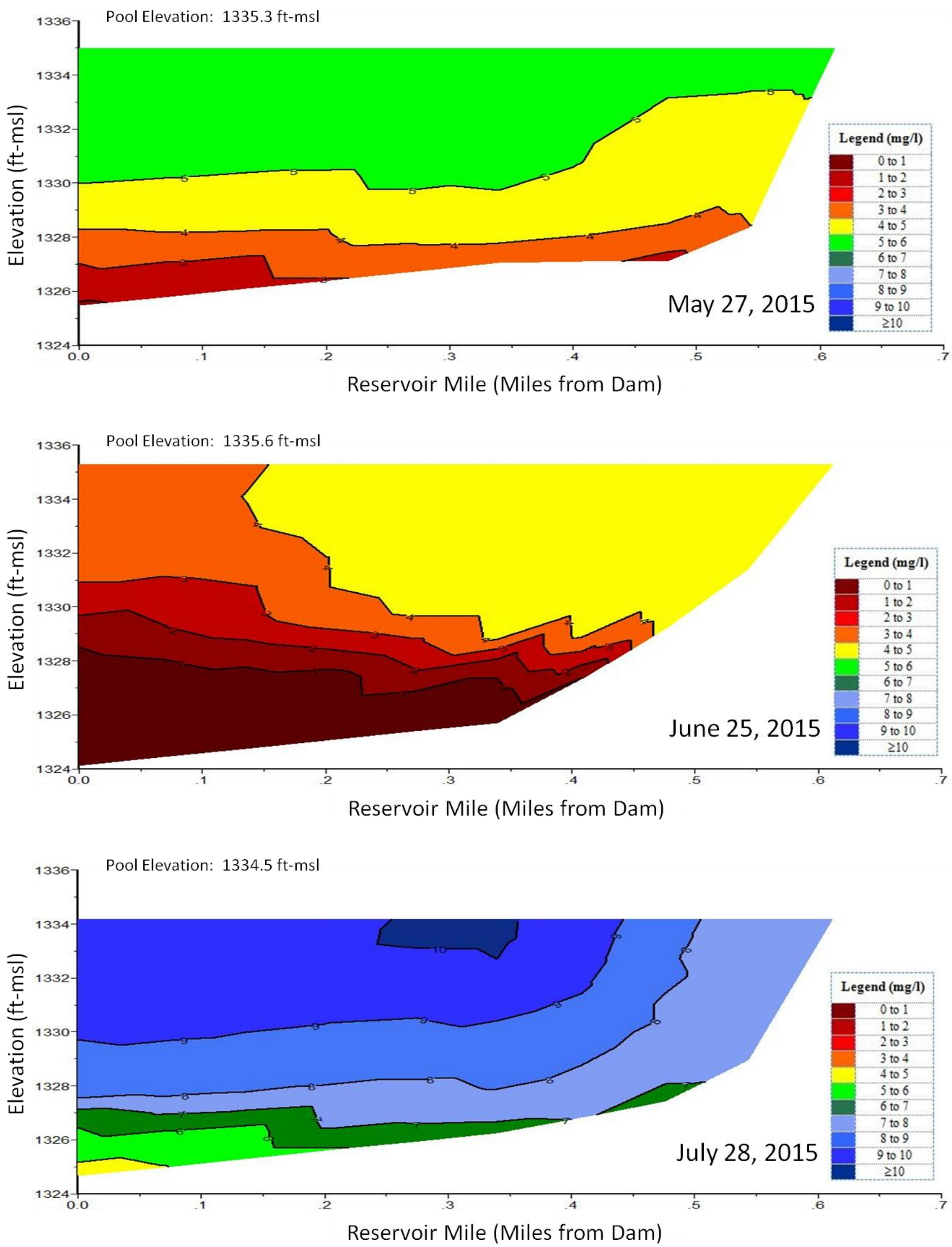
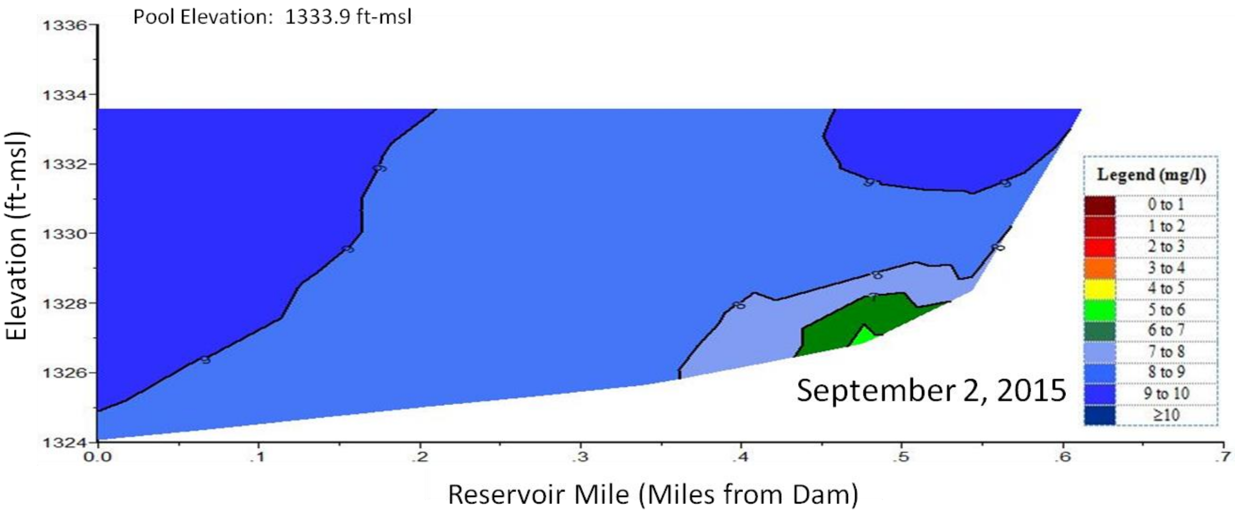


Plate 6-64. Longitudinal dissolved oxygen contour plots of Olive Creek Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites OCRLKND1, OCRLKML1, and OCRLKUP1 in 2015.



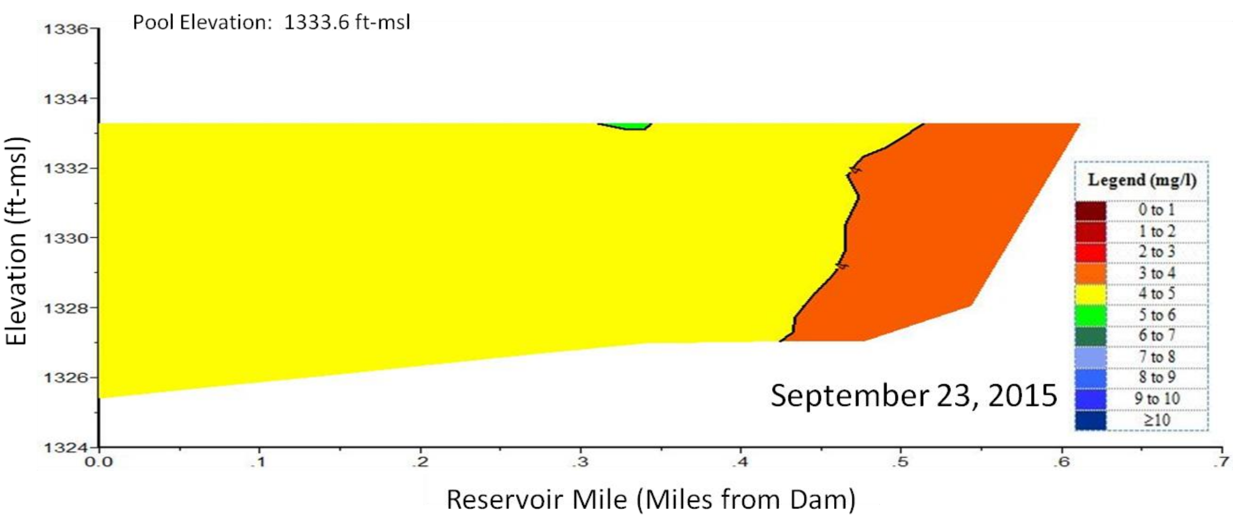


Plate 6-64. (Continued).

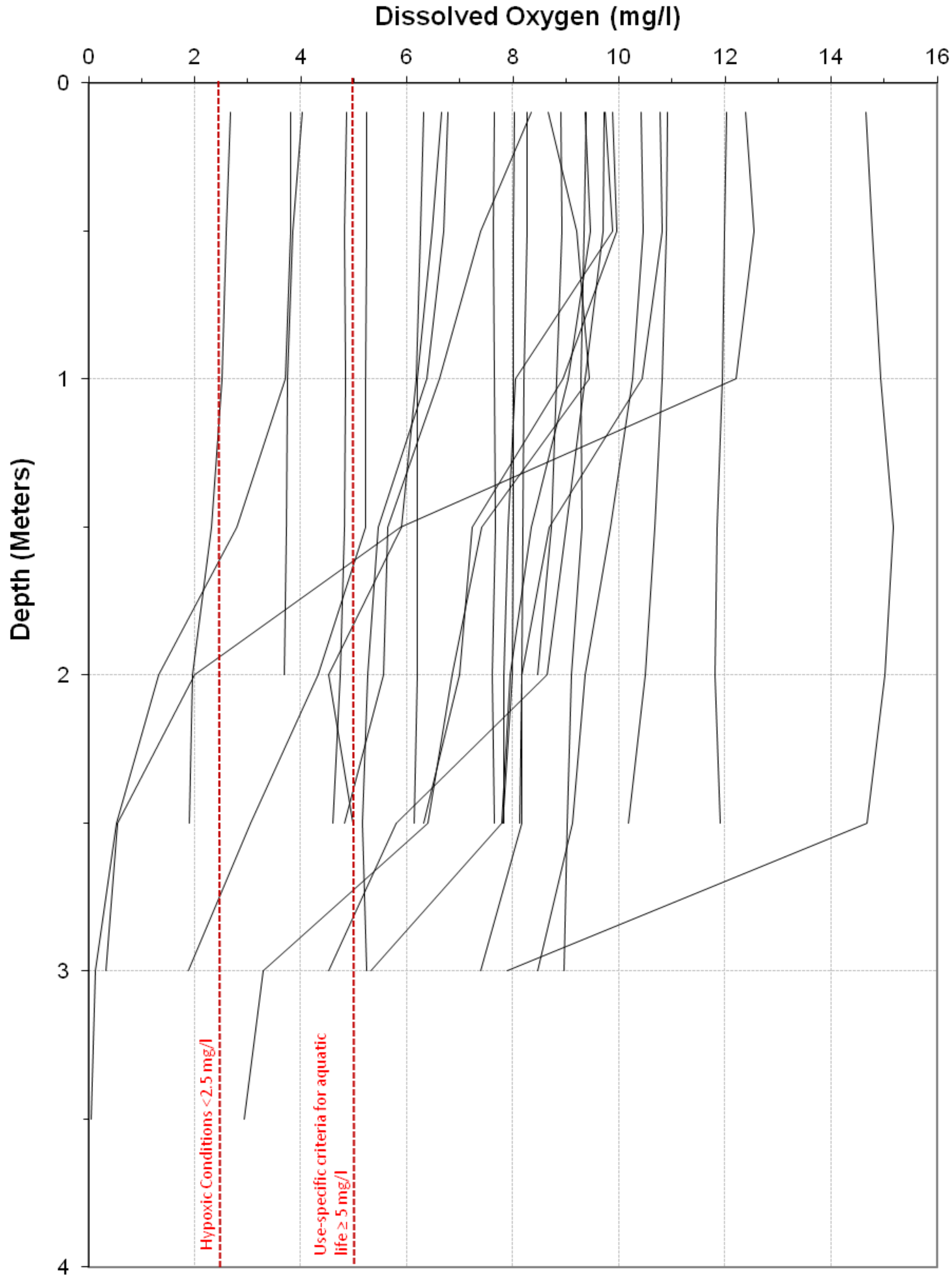
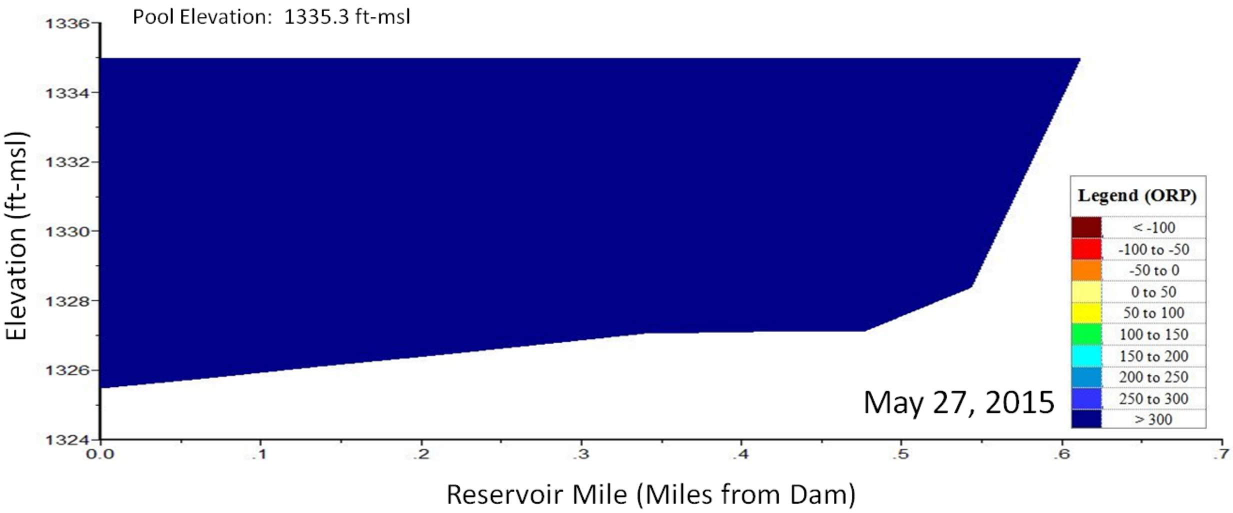


Plate 6-65. Dissolved oxygen depth profiles for Olive Creek Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1) during the summer over the 5-year period 2011 through 2015.



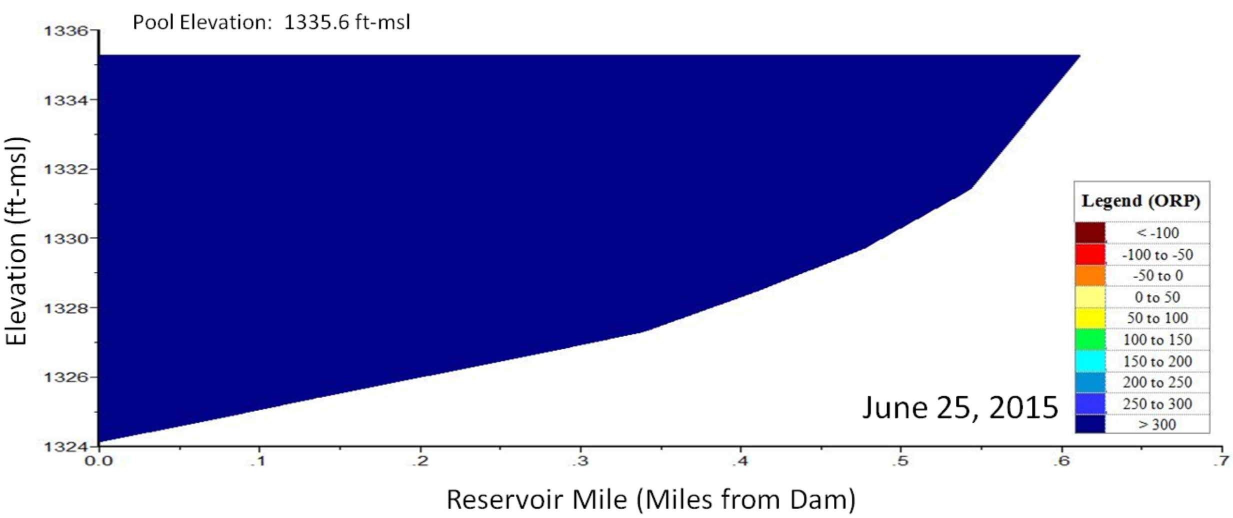
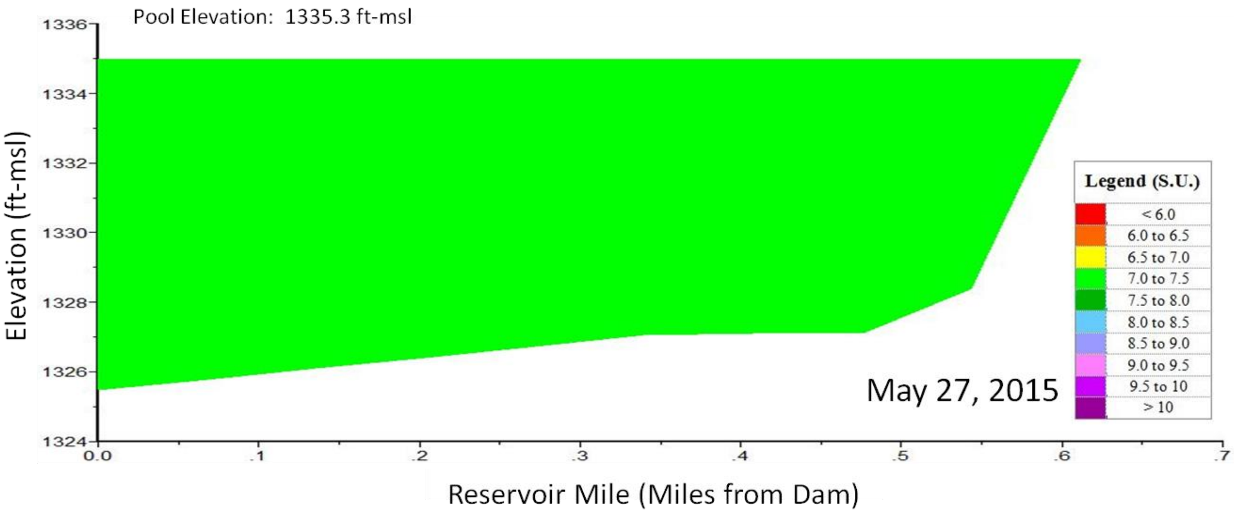


Plate 6-66. Longitudinal oxidation-reduction potential contour plots of Olive Creek Reservoir based on depth-profile ORP levels (mV) measured at sites OCRLKND1, OCRLKML1, and OCRLKUP1 in 2015.



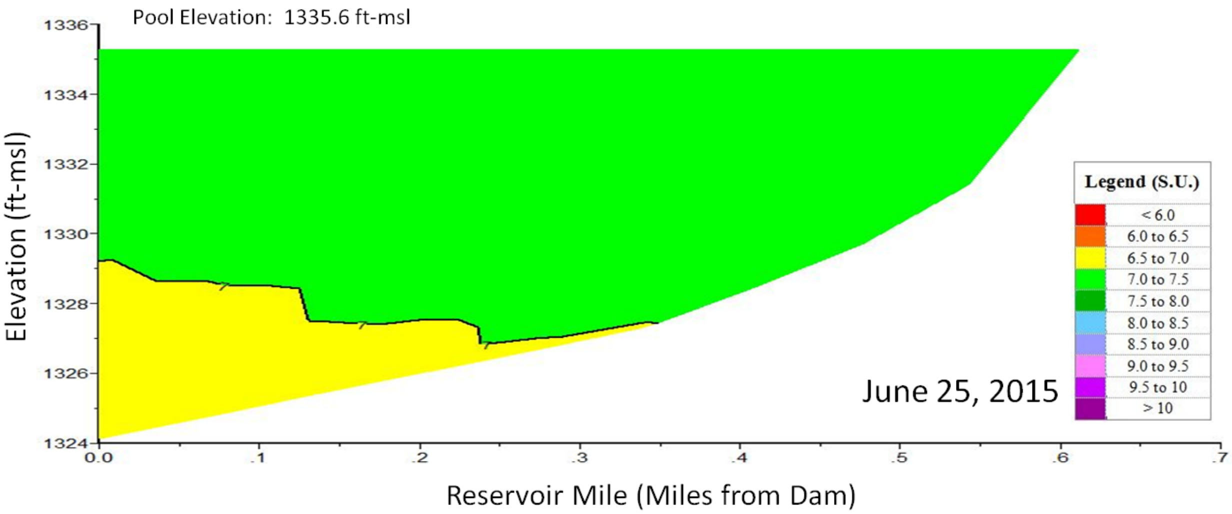


Plate 6-67. Longitudinal pH contour plots of Olive Creek Reservoir based on depth-profile pH levels (S.U.) measured at sites OCRLKND1, OCRLKML1, and OCRLKUP1 in 2015.

Plate 6-68. Total biovolume and density by taxonomic group for phytoplankton grab samples from Olive Creek Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)
23-May-11	4,742	143	45,507	648	-----	-----	127,871	2,512	363,453	13,248	23,696	53	1,026,613	5,317	-----	-----
28-Jul-11	6,126	6	14,605	374	-----	-----	-----	-----	5,132,084	68,339	1,148	6	2,198,974	1,878	5,518	3
22-Sep-11	127	0	50,494	324	1,696	6	25,177	329	2,558,931	116,370	3,656	6	2,148	11	23,326	53
01-May-12	22,271	8	679,195	9,648	27,039	8	27,763	344	41,335	4,003	-----	-----	275,369	153	22,782	0
06-Jul-12	1,064	1	415,914	8,948	178	0	316,499	1,355	6,882,674	116,573	145,249	95	4,998,866	7,620	814,795	27
07-Sep-12	-----	-----	1,344,406	36,699	-----	-----	4,745,496	4,753	9,246,909	388,340	-----	-----	1,933,286	1,921	-----	-----
14-May-13	-----	-----	3,077,785	5,090	84,616	50	600,981	4,555	5,112	58	-----	-----	1,295,286	2,272	-----	-----
09-Jul-13	21,299	15	211,793	2,543	-----	-----	-----	-----	10,353,218	86,072	-----	-----	6,443,165	9,840	-----	-----
12-Sep-13	616	7	23,503	77	-----	-----	-----	-----	1,310,575	5,720	-----	-----	306,654	684	10,338	0
13-May-14	-----	-----	620,853	2,396	-----	-----	37,582	443	302,005	1,660	-----	-----	229,535	5,180	-----	-----
15-Jul-14	260,557	11	4,190	19	-----	-----	-----	-----	2,597,332	29,378	37,364	6	3,240,469	688	-----	-----
11-Sep-14	-----	-----	-----	-----	-----	-----	186,941	176	4,132,750	84,386	-----	-----	-----	-----	-----	-----
27-May-15	-----	-----	-----	-----	-----	-----	58,198	81	-----	-----	-----	-----	20,129	69	-----	-----
28-Jul-15	-----	-----	10,326	278	-----	-----	76,764	409	2,927,333	54,768	403,016	462	1,169,268	958	590,997	11
23-Sep-15	-----	-----	349	17	-----	-----	17,520	24	1,794,603	24,974	226	0	65,721	87	-----	-----

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

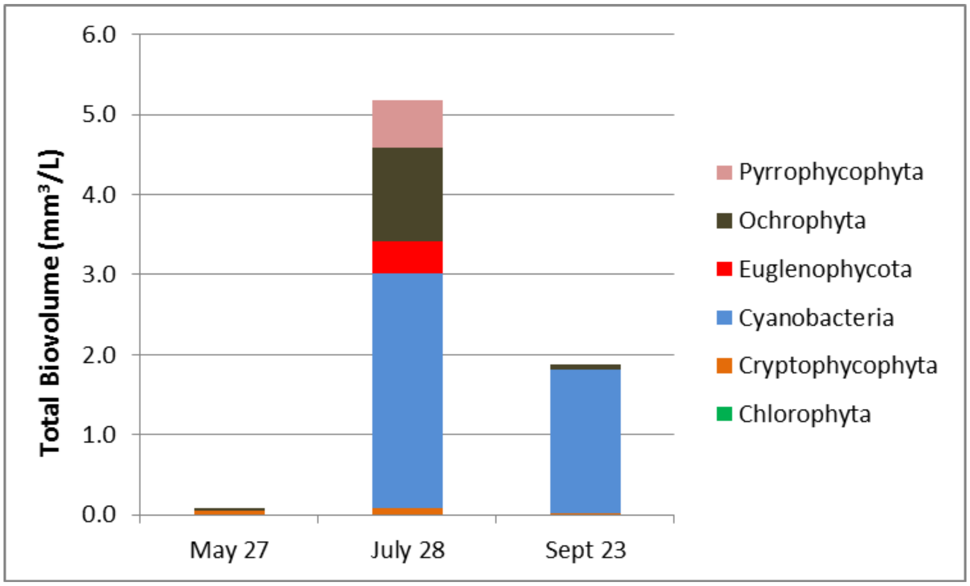


Plate 6-69. Relative abundance of phytoplankton in samples collected from Olive Creek Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1).

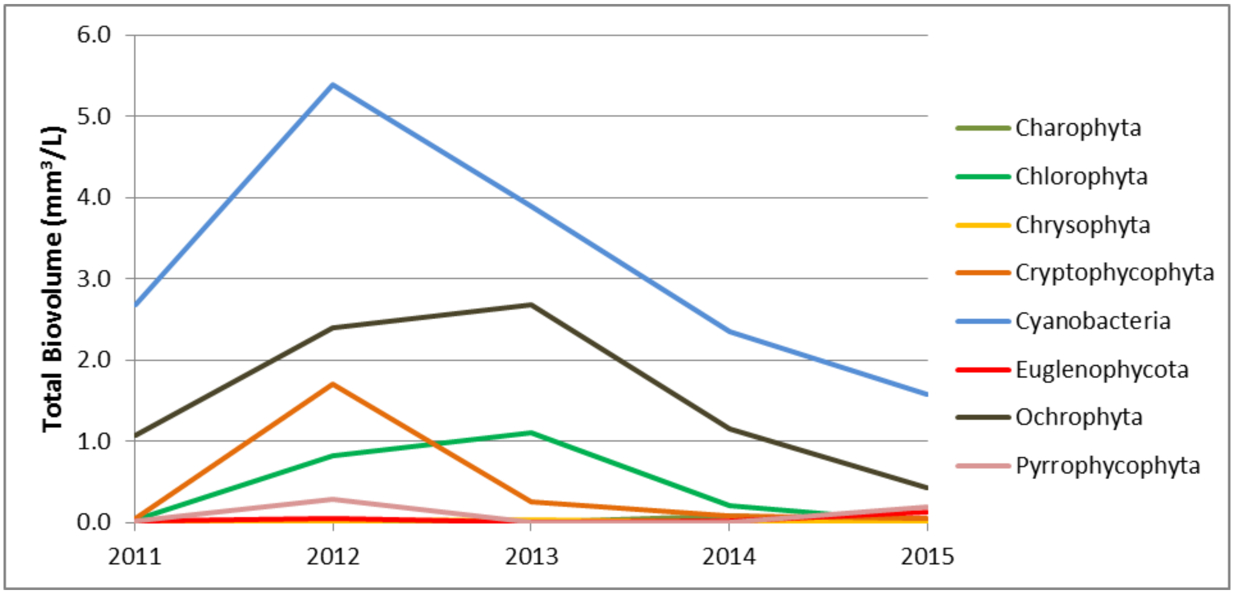


Plate 6-70. Relative abundance of phytoplankton in samples collected from Olive Creek Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are a yearly average of three summer samples (i.e. May, July, and September).

Plate 6-71. Total biomass and density by taxonomic grouping for zooplankton vertical-tow samples from Olive Creek Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)
23-May-11	2	2.64	16	10.30	19	30.46	3	2.71
28-Jul-11	182	340.21	80	62.58	4	3.23	234	6.44
22-Sep-11	111	437.65	21	6.50	1	0.11	91	1.18
01-May-12	134	1,179.84	53	174.97	5	0.29	59	0.83
06-Jul-12	19	10.52	239	32.25	5	0.23	965	14.27
07-Sep-12	15	24.84	196	158.00	-----	-----	38	0.51
14-May-13	517	800.29	690	192.99	7	41.10	173	1.91
09-Jul-13	34	171.53	37	18.18	1	0.18	101	1.29
12-Sep-13	90	195.64	10	56.35	1	0.05	46	0.80
13-May-14	11	24.19	21	41.63	-----	-----	18	1.36
15-Jul-14	128	375.09	33	52.51	-----	-----	42	0.73
11-Sep-14	359	1,853.63	210	122.51	-----	-----	728	15.63
27-May-15	9	29.09	36	29.83	11	14.75	3	0.02
28-Jul-15	9	15.40	15	15.27	0	0.11	6	0
23-Sep-15	116	494.65	27	26.78	2	0.08	70	2.03

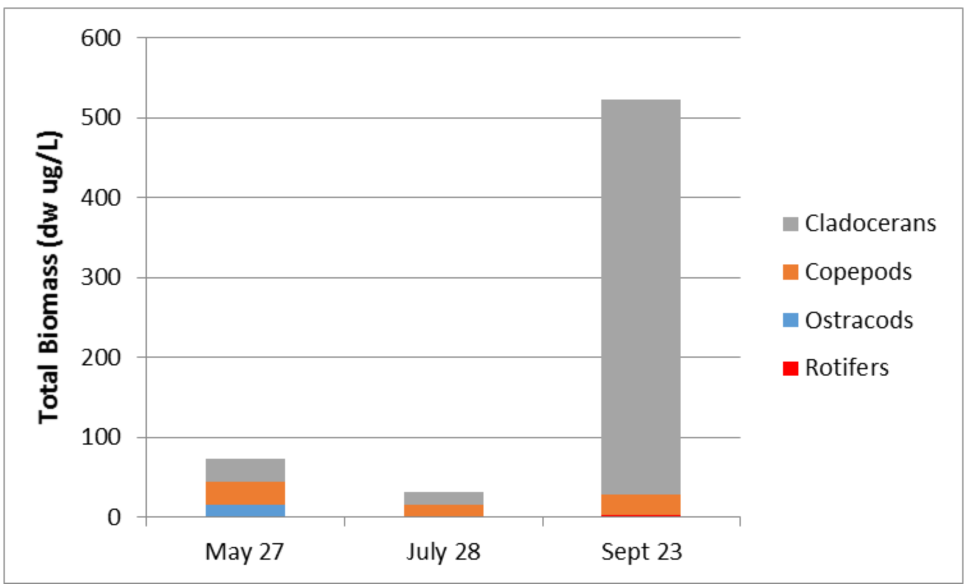


Plate 6-72. Relative abundance of zooplankton in samples collected from Olive Creek Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1).

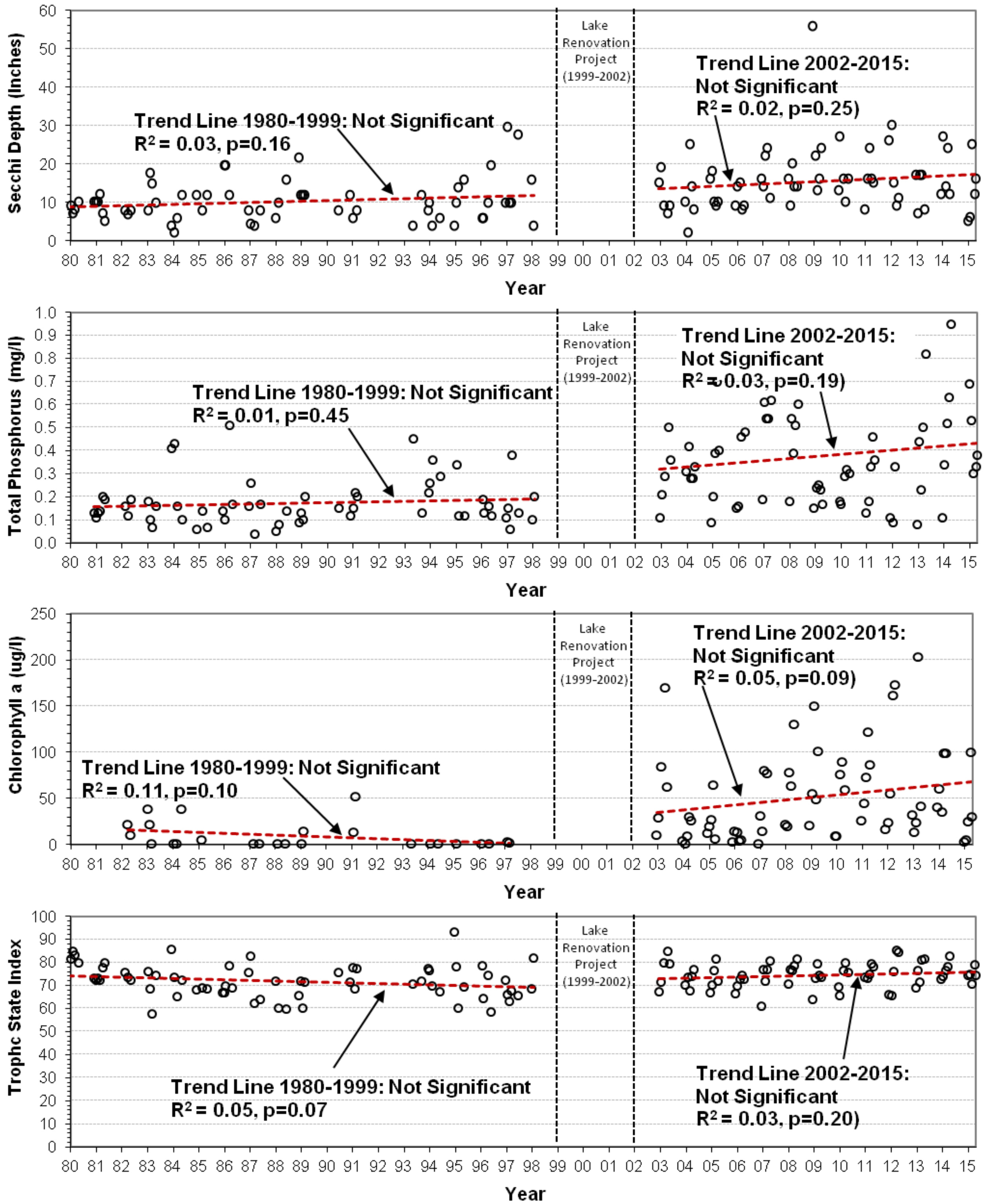


Plate 6-73. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Olive Creek Reservoir at the near-dam, ambient site (i.e., site OCRLKND1) over the 36-year period of 1980 through 2015. Regression analysis showed no signficicant change in trend lines for secchi (p=0.60), total phosphorus (p=0.27), or chlorophyll a (p=0.09)). The TSI trend increased post renovation (p=0.04).

6.7 PAWNEE RESERVOIR

6.7.1 BACKGROUND INFORMATION

6.7.1.1 Project Overview

The dam forming Pawnee Reservoir is located on North Middle Creek. The dam was completed on July 16, 1964 and the reservoir reached its initial fill on June 21, 1967. The Pawnee Reservoir watershed is 35.9 square miles. The watershed was largely agricultural when the dam was built in 1964 and has remained so to the present time.

6.7.1.2 Pawnee Dam Intake Structure

The Pawnee Dam intake structure is a single reinforced concrete box shaft commonly called a drop inlet structure. Its inside dimensions are 5 feet by 10 feet. The intake structure has two ungated openings, each 34" x 120" with crest elevations at 1244.3 ft-msl. A 42" x 60" gated opening was constructed into the upstream wall of the inlet structure at a crest elevation of 1236.0 ft-msl. The purpose of the gated opening is to lower the level of the conservation pool in order to inspect the conduit, make shoreline repairs, and manage fish populations.

6.7.1.3 Reservoir Storage Zones

Figure 6.11 depicts the current storage zones of Pawnee Reservoir based on the 1991 survey data and estimated sedimentation. It is estimated that 27 to 28 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2015. The annual volume loss is estimated to be 0.55-0.57 percent. Based on the State of Nebraska's impairment assessment criteria, these values indicate that Pawnee Reservoir's water quality dependent uses are impaired due to sedimentation at this time.

6.7.1.4 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Pawnee 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. Figure 6.12 shows the location of the sites that have been monitored for water quality during the 5-year period 2008 through 2012. The bacteria sites (PAWLKBACT1 and PAWLKBACT2) were sampled by the NDEQ. The other in-reservoir sites (PAWLKND1, PAWLKML1, and PAWLKUP1) were sampled by the District. The near-dam location (PAWLKND1) has been continuously monitored by the District since 1980.

6.7.2 WATER QUALITY IN PAWNEE RESERVOIR

6.7.2.1 Existing Water Quality Conditions

6.7.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Pawnee Reservoir at sites PAWLKND1, PAWLKML1, and PAWLKUP1 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 6-74 through Plate 6-76. A review of these results indicated possible water quality concerns regarding dissolved oxygen and nutrients.

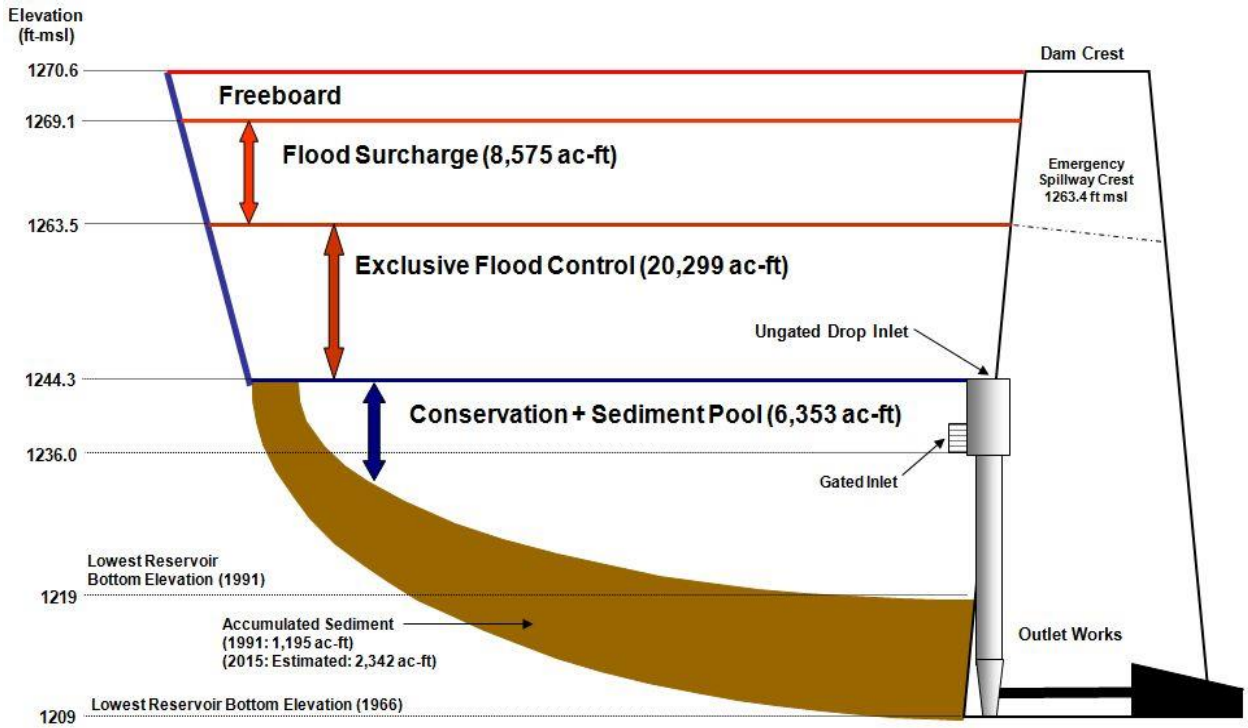


Figure 6.11. Current storage zones of Pawnee Reservoir based on the 1991 survey data and estimated sedimentation.

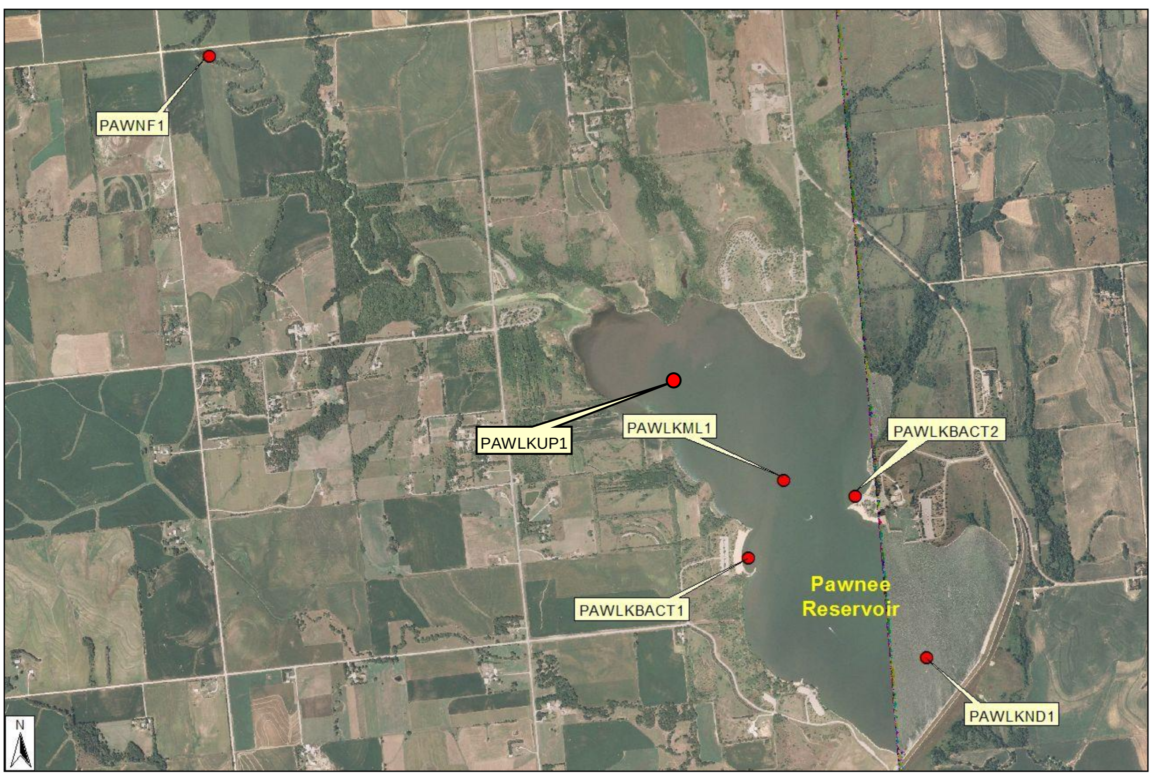


Figure 6.12. Location of sites where water quality monitoring was conducted at Pawnee Reservoir during the period 2011 through 2015.

A significant number of dissolved oxygen measurements throughout Pawnee Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 6-74-Plate 6-76). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and appeared to be associated with a slight thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Pawnee Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation. However, thermal stratification in Pawnee Reservoir was relatively limited during the 5-year sampling period of 2011 through 2015 (Plate 6-78). This limited stratification could lead to the above provision not applying to the reservoir and possible impairment for dissolved oxygen for the protection of aquatic life in Pawnee Reservoir. In addition, dissolved oxygen measurements on June 9, 2014 were below the 5 mg/l criterion for the protection of warmwater aquatic life from the reservoirs surface to bottom.

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September) to be considered for impairment assessment. All three of these criteria were exceeded Pawnee Reservoir (Plate 6-74). The near-surface chlorophyll *a* criterion was exceeded in 100 percent of the "lab analyzed" samples taken in the reservoir at site PAWLKND1. The total phosphorus and total nitrogen criteria were exceeded by 96 percent for both parameters. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values (Plate 6-74) represent the growing season average for the 5-year period 2011 through 2015. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.14 mg/l), total nitrogen (1.52 mg/l), and chlorophyll *a* (51 ug/l) values at PAWLKND1 indicate impairment of the aquatic life use due to nutrients.

6.7.2.1.2 Thermal Stratification

6.7.2.1.2.1 ***Longitudinal Temperature Contour Plots***

Late-spring and summer thermal conditions of Pawnee Reservoir measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 6-77 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites PAWLKND1, PAWLKML1, and PAWLKUP1 in 2015. These temperature plots indicate that Pawnee Reservoir rarely exhibited thermal stratification. The maximum difference monitored between the surface and bottom water temperatures during 2015 was about 4°C in July.

6.7.2.1.2.2 ***Near-Dam Temperature Depth-Profile Plots***

Existing summer thermal stratification of Pawnee Reservoir, at the deep water area near the dam, measured over the 5-year period 2011 through 2015 is depicted by depth-profile temperature plots (Plate 6-78). The depth-profile temperature plots indicate that the reservoir rarely exhibited significant summer thermal stratification over the 5-year sampling period. Since Pawnee Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.7.2.1.3 Dissolved Oxygen Conditions

6.7.2.1.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of Pawnee Reservoir based on depth-profile measurements taken in 2015 at sites PAWLKND1, PAWLKML1, and PAWLKUP1. Plate 6-79 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 May through July near the reservoir bottom near the dam. Super-saturation of dissolved oxygen was also monitored in shallow water areas. Dissolved oxygen supersaturation was attributed to high rates of photosynthesis by aquatic vegetation in the reservoir during the day.

6.7.2.1.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

Existing summer dissolved oxygen conditions in Pawnee Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2011 through 2015 (Plate 6-80). On several occasions there was a significant vertical gradient in summer dissolved oxygen levels. Forty-four percent of the profiles showed hypoxic conditions near the reservoir bottom and one of the 25 profiles showed dissolved oxygen levels below the Nebraska's dissolved oxygen criterion for the protection of warmwater aquatic life (≥ 5 mg/l) through the entire depth of the profile. Although Pawnee Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition to mixing to allow hypoxic conditions to occasionally develop near the reservoir bottom.

6.7.2.1.3.3 ***Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of Pawnee 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 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 July 27, 2015 contour plot indicates a pool elevation of 1244.4 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1236.5 ft-msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1234.5 ft-msl (Plate 6-79). The current District Area-Capacity Tables (1993 Survey) give storage capacities of 7573 ac-ft for elevation 1244.4 ft-msl, 3022 ac-ft for elevation 1236.5 ft-msl, and 2255 ac-ft for elevation 1234.5 ft-msl. On July 27, 2015 it is estimated that 40 percent of the volume of Pawnee Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 30 percent of the reservoir volume was hypoxic.

6.7.2.1.4 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in Pawnee Reservoir indicated hypoxic conditions May through July 2015. As a result, longitudinal contour plots for ORP and pH were constructed during these months. Depth profiles and near-surface/near-bottom sample comparisons were also constructed for periods of hypoxic conditions during the sampling periods from 2011 through 2015.

6.7.2.1.4.1 ***Oxidation-Reduction Potential***

Plate 6-81 provides longitudinal ORP contour plots based on depth-profile measurements taken in 2015 when hypoxic conditions were present in Pawnee Reservoir. The ORP values indicated slightly reduced conditions occurred near the reservoir bottom near the dam in July 2015, with measurements below 100 mV. However, much of the reservoir ORP measurements were greater than 300 mV. Plate 6-82 plots depth profiles for ORP measured during the summer over the 5-year sampling period in the deep water area of Pawnee Reservoir near the dam when hypoxic conditions were present. The ORP depth profiles indicate that slightly reduced conditions occasionally occurred in Pawnee Reservoir during the summer, however, these conditions were rarely below 100 mV (Plate 6-82).

6.7.2.1.4.2 ***pH***

Longitudinal contour plots for pH conditions measured in 2015 when hypoxic conditions were present are provided in Plate 6-83. Plate 6-84 plots depth profiles for pH measured during the summer over the 5-year sampling period in the deep water area of Pawnee Reservoir near the dam when hypoxic conditions were present. A slight vertical gradient in pH occasionally occurred in the reservoir during the summer. Lower pH levels near the bottom of the reservoir could be attributable to reservoir stratification and ongoing decomposition/respiration near the reservoir bottom. This would lead to an increase in CO_2 and decrease in pH. The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 6.5 for the protection of warmwater aquatic life. One of the depth profiles measured pH values greater than the upper pH criterion (9.0 SU) for the protection of warmwater aquatic life.

6.7.2.1.4.3 ***Comparison of Near-Surface and Near-Bottom Water Quality Conditions***

Paired near-surface and near-bottom water quality samples collected from Pawnee Reservoir during the summer when hypoxia was present 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 PAWLKND1 during the 5-year period 2011 through 2015. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 11 (44%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 6-85). 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 total ammonia nitrogen (p=0.16), nitrate-nitrite nitrogen (p=0.46), total phosphorus (p=0.08), and Orthophosphorus (p=0.12). Total alkalinity was significantly higher in the near-bottom samples when hypoxia was present ($p<0.05$). Parameters that were significantly lower in the near-bottom water of Pawnee Reservoir when hypoxia was present included water temperature, dissolved oxygen, oxidation-reduction potential and pH ($p<0.05$).

6.7.2.1.4.4 ***Reservoir Trophic Status***

Trophic State Index (TSI) values for Pawnee Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., PAWLKND1). Table 6.23 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Pawnee Reservoir is in a hypereutrophic condition.

Table 6.23. Summary of Trophic State Index (TSI) values calculated for Pawnee Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	70	70	60	78
TSI(TP)	25	66	66	55	75
TSI(Chl)	25	77	77	65	84
TSI(Avg)	25	71	72	61	76

* 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 for the individual parameters.

Note: See Section 4.1.3 for discussion of TSI calculation.

*6.7.2.1.4.5 **Monitoring at Swimming Beaches***

Two designated swimming beaches are located on Pawnee Reservoir. Bacteria (i.e., *E. coli*) and the cyanobacteria toxin microcystin were monitored at the two swimming beaches (i.e., sites PAWLKBACT1 and PAWLKBACT2) by the NDEQ during the 5-year sampling period. Bacteria and total microcystin were monitored from May through September over the 5-year period 2011 through 2015.

6.7.2.1.4.5.1 Bacteria Monitoring

Table 6.24 summarizes the results of the bacteria sampling. The "running 5-week" geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The "pooled" geomean was determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for *E. coli* bacteria:

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

The pooled geomeans were compared to the State of Nebraska's impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using *E. coli* bacteria data. Based on those criteria a Primary Contact Recreation use in Pawnee Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

Table 6.24. Summary of weekly (May through September) bacteria samples collected at Pawnee Reservoir (i.e., sites PAWLKBACT1 and PAWLKBACT2) during the 5-year period 2011 through 2015.

West Swimming Beach Site: PAWLKBACT1			
***E. coli* Bacteria – Individual Samples**		***E. coli* Bacteria – Geomeans**	
Number of Samples	100	Number of Geomeans	80
Mean (cfu/100ml)	92	Average	18
Median (cfu/100ml)	6	Median	7
Minimum (cfu/100ml)	1	Minimum	1
Maximum (cfu/100ml)	1,733	Maximum	195
Percent of samples exceeding 235/100ml	7%	Number of Geomeans exceeding 126/100ml	3%
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	9
East Swimming Beach Site: PAWLKBACT2			
***E. coli* Bacteria – Individual Samples**		***E. coli* Bacteria – Geomeans**	
Number of Samples	102	Number of Geomeans	82
Mean (cfu/100ml)	82	Average	14
Median (cfu/100ml)	6	Median	8
Minimum (cfu/100ml)	1	Minimum	1
Maximum (cfu/100ml)	2,420	Maximum	185
Percent of samples exceeding 235/100ml	5%	Number of Geomeans exceeding 126/100ml	1%
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	9

6.7.2.1.4.5.2 Microcystin Monitoring

Table 6.25 summarizes the total microcystin monitoring conducted at the Pawnee Reservoir swimming beaches during the 5-year period 2011 through 2015. These results were compared to the 20 ug/l
criterion for issuing health advisories and the posting of swimming beaches. Two percent of the samples collected in Pawnee Reservoir exceeded the criterion for total microcystin. The monitored levels of microcystin do not indicate a cyanobacteria toxin concern at Pawnee Reservoir. Based on the State of Nebraska's impairment assessment criteria, the monitored levels of microcystin do not indicate any impairment of the Primary Contact Recreation beneficial use of Pawnee Reservoir due to algal toxins.

Table 6.25. Summary of weekly (May through September) total microcystin samples collected at Pawnee Reservoir (i.e., sites PAWLKBACT1 and PAWLKBACT2) during the 5-year period 2011 through 2015.

Summary Statistic	West Swimming Beach (Site PAWLKBACT1)	East Swimming Beach (Site PAWLKBACT2)
Number of Samples	100	104
Minimum (ug/l)	n.d.	n.d.
25th percentile (ug/l)	0.15	0.15
Median (ug/l)	0.26	0.33
75th Percentile (ug/l)	0.97	1.07
Maximum (ug/l)	35	35
Percent of samples exceeding 20 ug/l	2%	2%

6.7.2.1.5 Reservoir Plankton Community

6.7.2.1.5.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at the Pawnee Reservoir near-surface, near-dam sampling site during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-86). The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 6-87. The highest phytoplankton total biovolume was observed in September. Ochrophyta and Cyanobacteria dominated most of the 2015 growing season. The phytoplankton population followed successional patterns commonly observed in eutrophic reservoirs. Cool water taxa such as Ochrophyta dominate spring and late fall while warm water taxa such as Cyanobacteria dominate the summer and early fall. Major and dominant phytoplankton genera sampled in 2015 at Pawnee Reservoir are provided in Table 6.26.

Table 6.26. Listing of Major and Dominant Phytoplankton Genera Sampled in Pawnee Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1)

Division	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cryptophycophyta	*Cryptomonas*	-----
Cyanobacteria	-----	*Aphanizomenon, Microcystis*
Ochrophyta	-----	*Stephanodiscus, Aulacoseira*

Annual variation in phytoplankton community composition is displayed in Plate 6-88. During the 5-year period 2011 through 2015, Pawnee reservoir was mostly dominated by Cyanobacteria and Ochrophyta. Cyanobacteria density levels reached levels greater than the World Health Organizations high level of health risk (>100,000 Cells/ml) in 2012 through 2015 (Plate 6-86). 2012 was a particularily warm and dry year. The resulting longer residence time, decreased mixing, and warmer waters could have resulted in a longer Cyanobacterial growing season, causing the observed high densities. Maximum measured extracellular microcystin toxin levels at the near-dam site during the 5-year period was 2.0 µg/l (Plate 6-74).

6.7.2.1.5.2 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at Pawnee Reservoir near-dam sampling sites during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-89). The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in Plate 6-90. Pawnee Reservoir was dominated by Cladocerans and Copepods in 2015 with total zooplankton biomass remaining relatively constant through the growing season. Dominant and major zooplankton genera sampled in Pawnee Reservoir during 2015 are provided in Table 6.27.

Table 6.27. Listing of major and dominant zooplankton genera sampled in Pawnee Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1)

Taxonomic Group	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cladocerans	*Bosmina, Chydorus*	*Daphnia*
Copepods	Cyclopoida, Leptodiaptomus	*Mesocyclops*

6.7.2.1.6 Zebra Mussel Monitoring

Zebra mussel veliger sampling has been conducted once yearly since 2012 at Pawnee Reservoir. During the sampling period (2012-2015) no veligers have been identified.

6.7.2.1 Water Quality Trends (1980 through 2015)

Water quality trends from 1980 to 2015 were determined for Pawnee 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., PAWLKND1). Plate 6-91 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, Pawnee Reservoir exhibited increasing trends in total phosphorus ($p<0.05$, $R^2=0.03$), chlorophyll *a* levels ($p<0.05$, $R^2=0.15$) and TSI ($p<0.05$, $R^2=0.03$). No significant trend was observed for Secchi depth. Over the 36-year period since 1980, Pawnee Reservoir has remained in a slightly hypereutrophic condition.

6.7.3 Plates

Plate 6-74. Summary of water quality conditions monitored in Pawnee Reservoir at site PAWLKND1 from May to September during the 5-year 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	25	1251.54	1244.30	1242.10	1339.50	-----	-----	-----
Water Temperature (°C)	0.1	314	22.97	23.11	15.56	30.30	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	314	6.84	7.04	n.d.	15.25	≥5(2)	69	22%
Dissolved Oxygen, Near-Surface (mg/l)(C)	0.1	25	8.52	8.15	4.60	15.19	≥5(2)	1	4%
Dissolved Oxygen (% Sat.)	0.1	314	82.13	80.65	n.d.	201.00	-----	-----	-----
Secchi Depth (in.)	1	25	20.92	20.00	11.00	39.00	-----	-----	-----
Turbidity (NTUs)	1	301	18.07	15.30	2.30	83.40	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	314	353.09	361.00	57.00	532.00	-----	-----	-----
Specific Conductance (umho/cm)	1	314	386.94	389.00	342.40	435.30	2,000(3)	0	0%
pH (S.U.)	0.1	314	8.39	8.42	7.42	9.43	≥6.5 & ≤9.0 (1)	0,13	0%,4%
Alkalinity, Total (mg/l)	1	50	159.34	159.00	137.00	182.00	>20(1)	0	0%
Suspended Solids, Total (mg/l)	4	50	21.88	18.50	7.00	101.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	50	-----	0.07	n.d.	2.43	1.55(4,5), 0.35(4,6)	1,4	2%,8%
Ammonia, Total, Near-Surface (mg/l)(C)	0.02	25	-----	0.03	n.d.	1.33	1.02(4,5), 0.26(4,6)	1,2	4%,8%
Kjeldahl N, Total (mg/l)	0.08	50	1.63	1.57	0.86	3.71	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	50	-----	n.d.	n.d.	0.30	100(3)	0	0%
Nitrogen, Total (mg/l)	0.08	49	1.67	1.57	0.99	3.73	1(7)	48	98%
Nitrogen, Total, Near-Surface (mg/l)(C)	0.08	25	1.52	1.55	0.99	2.12	1(7)	24	96%
Phosphorus, Total (mg/l)	0.005	50	0.17	0.14	0.04	0.84	0.05(7)	49	98%
Phosphorus, Total, Near-Surface (mg/l) (C)	0.005	25	0.14	0.13	0.04	0.32	0.05(7)	24	96%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	n.d.	n.d.	0.66	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	133.58	133.50	128.00	142.80	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	5	7.40	5.00	4.00	15.00	340(5), 16.7(8)	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	0.30	7.81(5), 0.30(6)	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	750.14(5), 97.66(6)	0	0%
Copper, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	17.64(5), 11.46(6)	0	0%
Iron, Dissolved (ug/l)	10	5	-----	20.00	n.d.	60.00	1000(6)	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	88.33(5), 3.44(6)	0	0%
Manganese, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	250.00	1000(6)	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	597.89(5), 66.41(6)	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5.67(5)	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	149.68(5), 150.91(6)	0	0%
Antimony, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	0.70	88(5), 30(6)	0	0%
Aluminum, Dissolved (ug/l)	40	5	-----	n.d.	n.d.	n.d.	750(5), 87(6)	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77(6)	0	0%
Chlorophyll a (ug/l) – Lab Determined(C)	6	25	51	46	14	94	10(7)	25	100%
Chlorophyll a (ug/l) – Field Probe	6	314	113	53	13	7903	10(7)	314	100%
Atrazine, Total (ug/l)(D)	0.1	25	2.37	2.40	0.30	4.50	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l) (D)	0.1	24	-----	0.45	n.d.	1.30	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l) (D)	0.1	25	0.67	0.50	n.d.	2.40	-----	-----	-----
Microcystin, Extracellular (ug/l)	0.1	23	-----	n.d.	n.d.	2.00	20(9)	0	0%
Pesticide Scan (ug/l)(E)									
Atrazine, Tot	0.13	4	1.25	1.25	0.55	1.96	330(5), 12(6)	0	0%
Acetochlor, Tot	0.08	4	-----	n.d.	n.d.	0.10	-----	-----	-----
Metolachlor, Tot	0.05	4	-----	0.33	n.d.	1.18	390(5), 100(6)	0	0%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. . Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-75. Summary of water quality conditions monitored in Pawnee Reservoir at site PAWLKML1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1253.31	1244.00	1242.10	1339.50	-----	-----	-----
Water Temperature (°C)	0.1	199	23.19	23.28	15.72	30.64	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	199	8.17	7.81	0.52	14.55	≥5(2)	10	5%
Dissolved Oxygen (% Sat.)	0.1	199	98.98	91.20	7.00	190.20	-----	-----	-----
Secchi Depth (in.)	1	25	15.60	15.00	3.00	28.00	-----	-----	-----
Turbidity (NTUs)	1	191	28.00	21.80	5.40	96.40	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	199	359.88	349.00	165.00	527.00	-----	-----	-----
Specific Conductance (umho/cm)	1	199	381.72	385.30	313.10	432.10	2,000(3)	0	0%
pH (S.U.)	0.1	199	8.56	8.56	7.97	9.45	≥6.5 & ≤9.0 (1)	0,18	0%,9%
Chlorophyll a (ug/l) – Field Probe	6	199	129	67	12	7299	10(4)	199	100%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-76. Summary of water quality conditions monitored in Pawnee Reservoir at site PAWLKUP1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1253.31	1244.00	1242.10	1339.50	-----	-----	-----
Water Temperature (°C)	0.1	44	23.40	23.25	16.03	30.90	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	44	9.02	8.72	5.36	13.38	≥5(2)	0	0%
Dissolved Oxygen (% Sat.)	0.1	44	110.01	105.25	73.10	173.80	-----	-----	-----
Secchi Depth (in.)	1	25	11.08	10.00	3.00	25.00	-----	-----	-----
Turbidity (NTUs)	1	43	52.88	48.60	5.70	139.30	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	44	355.93	339.00	204.00	515.00	-----	-----	-----
Specific Conductance (umho/cm)	1	44	378.10	374.10	296.50	431.40	2,000(3)	0	0%
pH (S.U.)	0.1	44	8.69	8.63	8.17	9.36	≥6.5 & ≤9.0 (1)	0,7	0%,16%
Chlorophyll a (ug/l) – Field Probe	6	44	85	71	12	403	10(4)	44	100%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

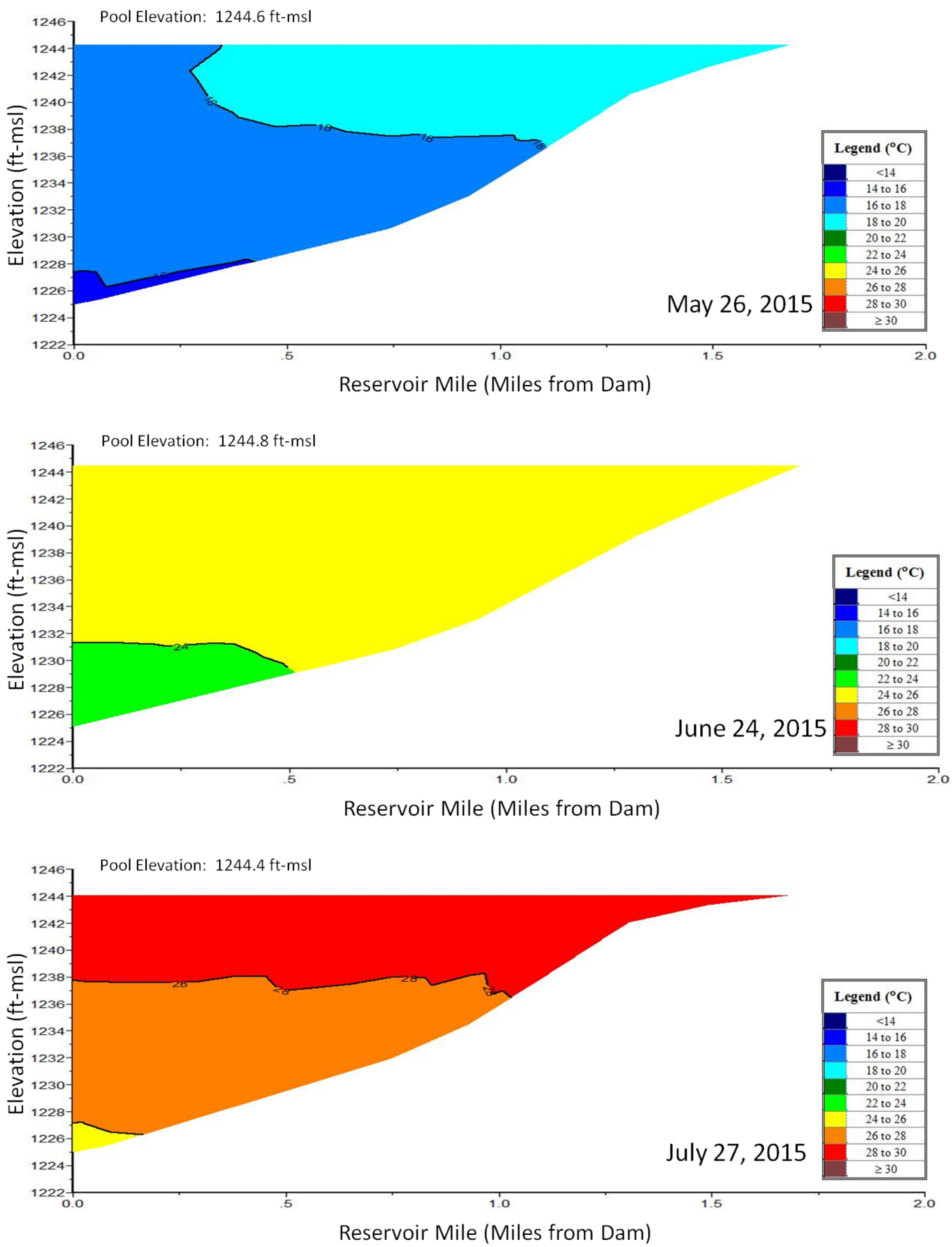
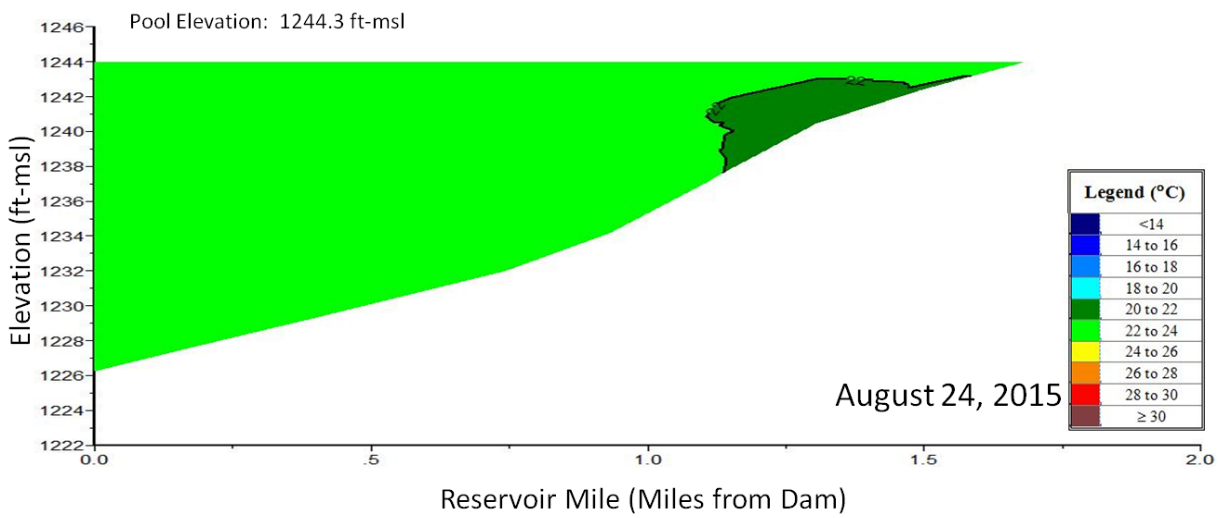


Plate 6-77. Longitudinal water temperature contour plots of Pawnee Reservoir based on depth-profile water temperatures (°C) measured at sites PAWLKND1, PAWLKML1, and PAWLKUP1 in 2015.



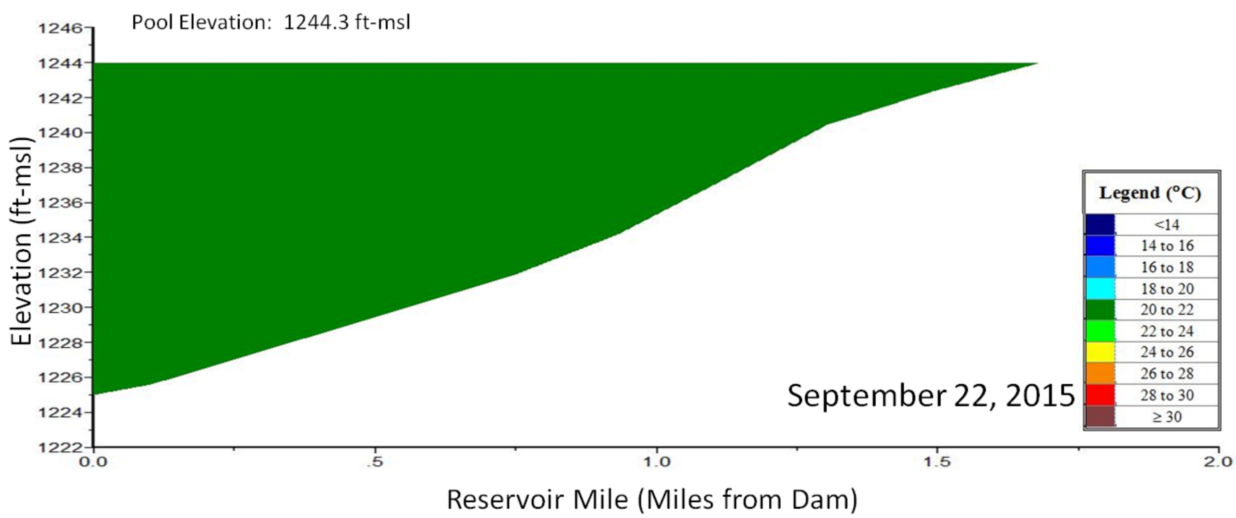


Plate 6-77. (Continued).

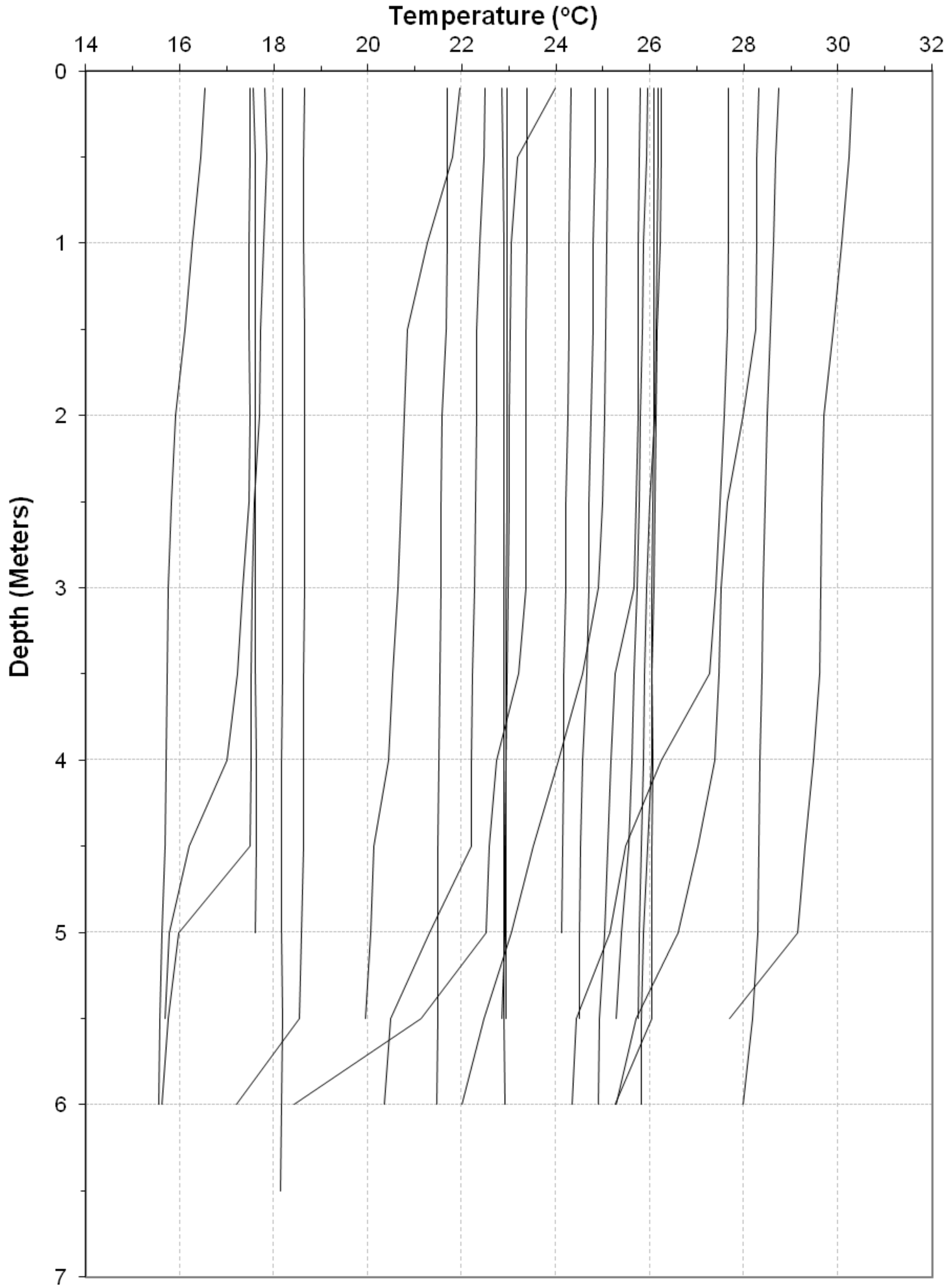


Plate 6-78. Temperature depth profiles for Pawnee Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1) during the summer over the 5-year period of 2011 through 2015.

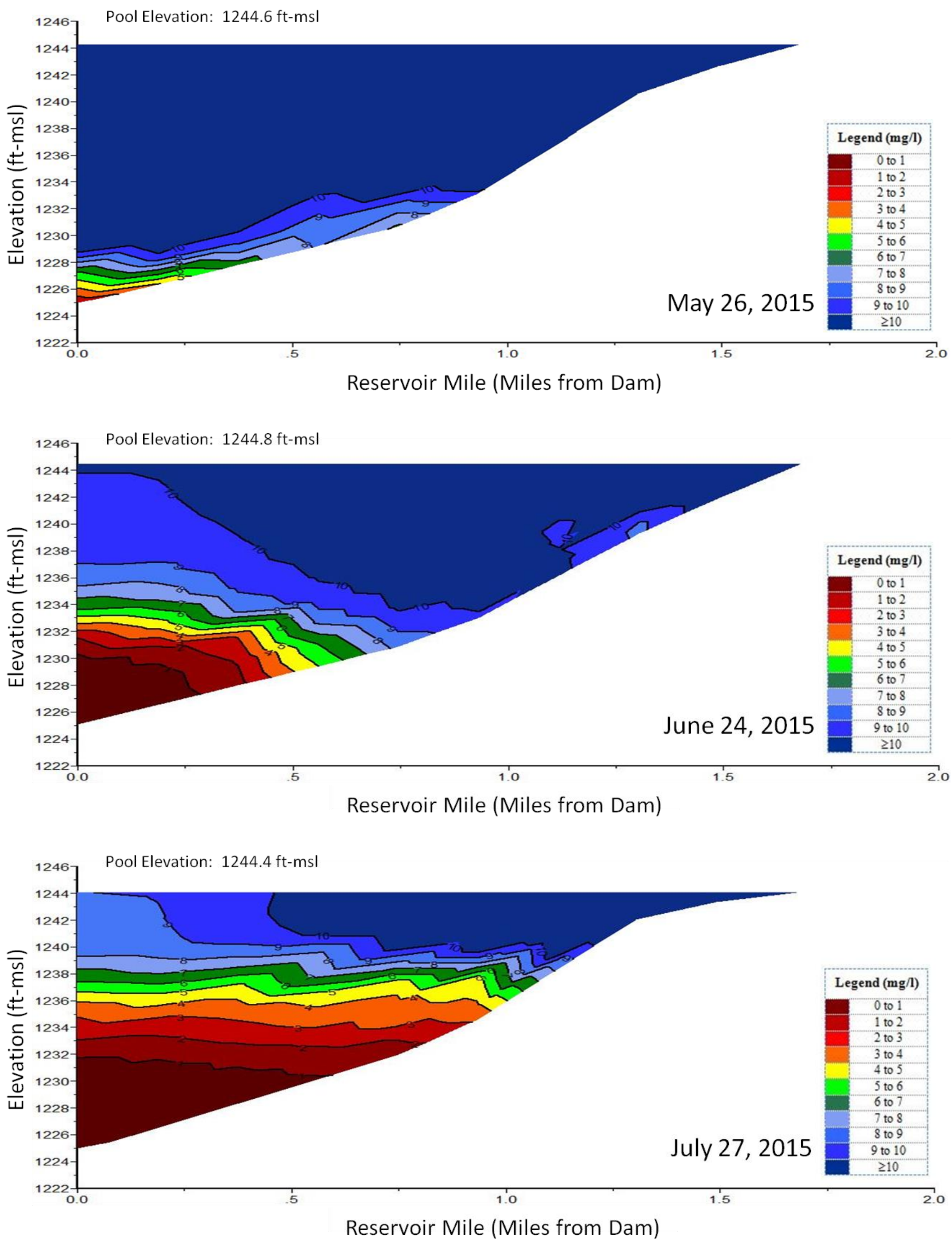
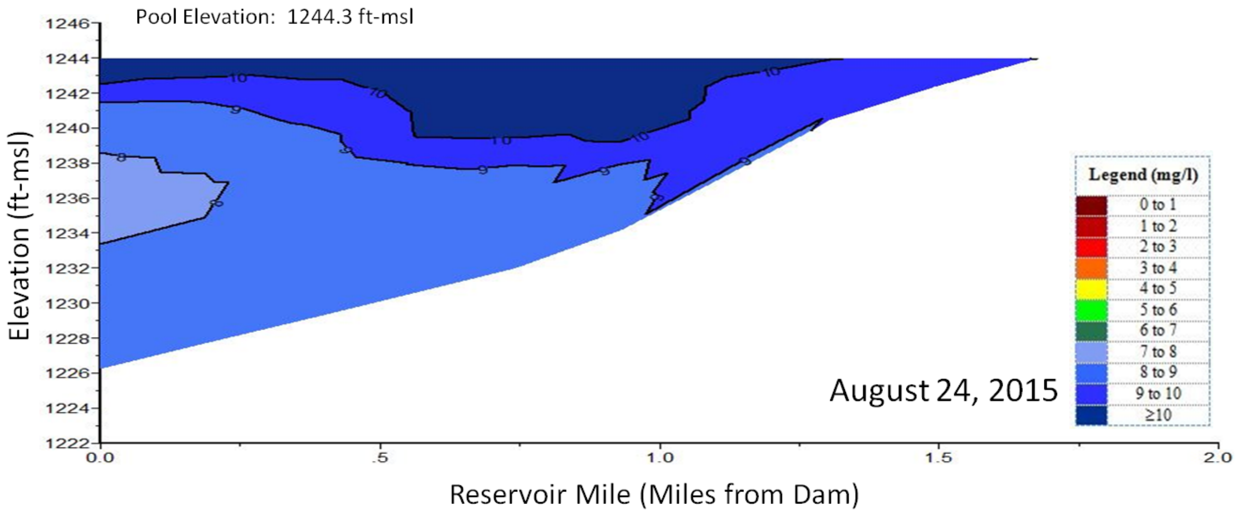


Plate 6-79. Longitudinal dissolved oxygen contour plots of Pawnee Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites PAWLKND1, PAWLKML1, and PAWLKUP1 in 2015.



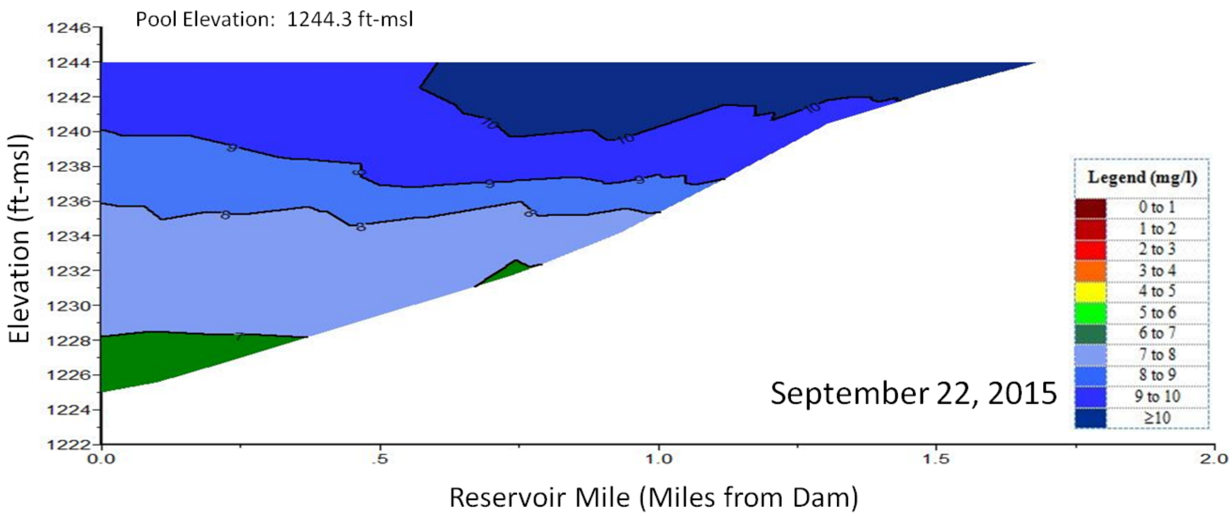


Plate 6-79. (Continued).

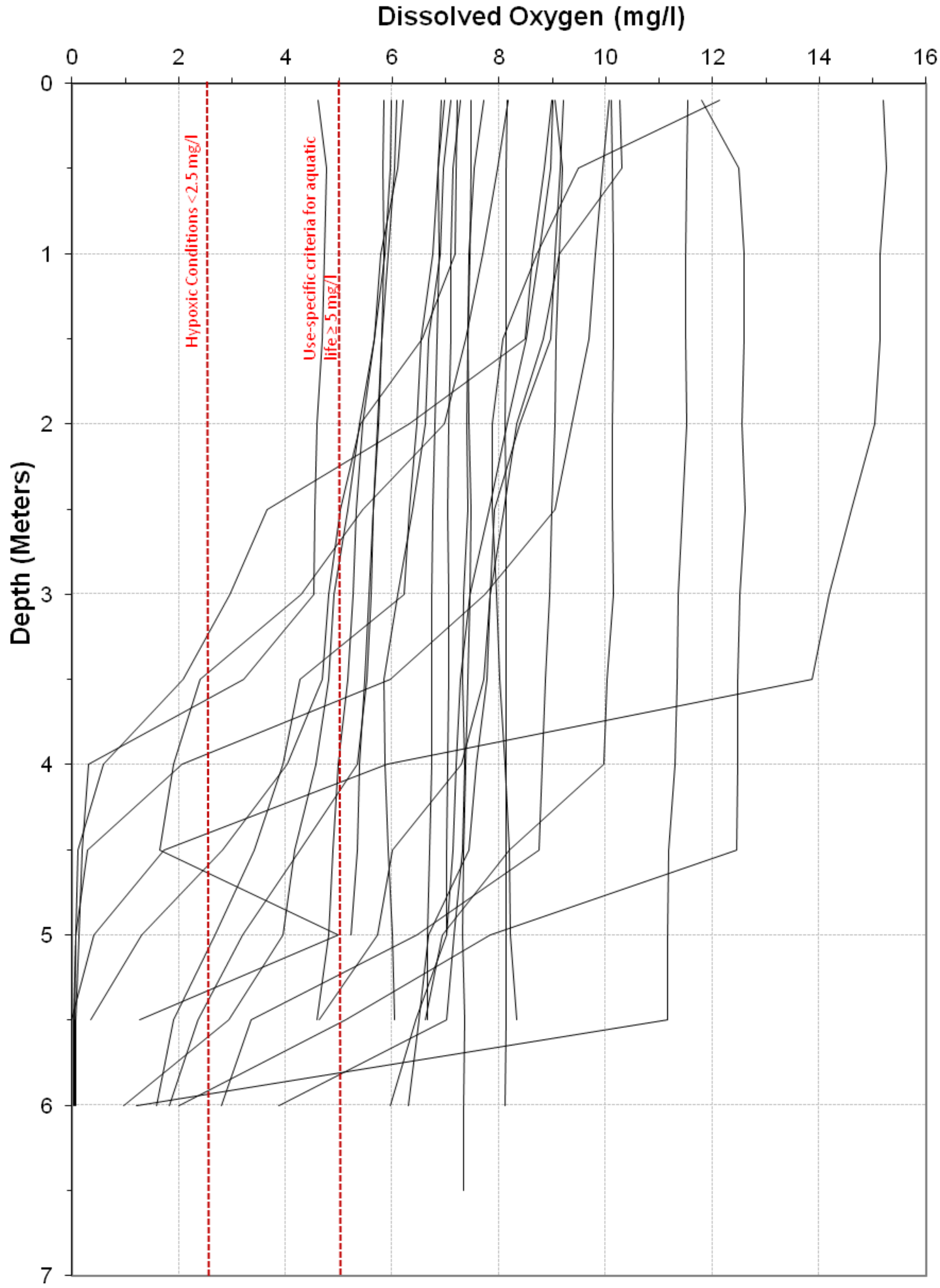


Plate 6-80. Dissolved oxygen depth profiles for Pawnee Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1) during the summer over the 5-year period 2011 through 2015.

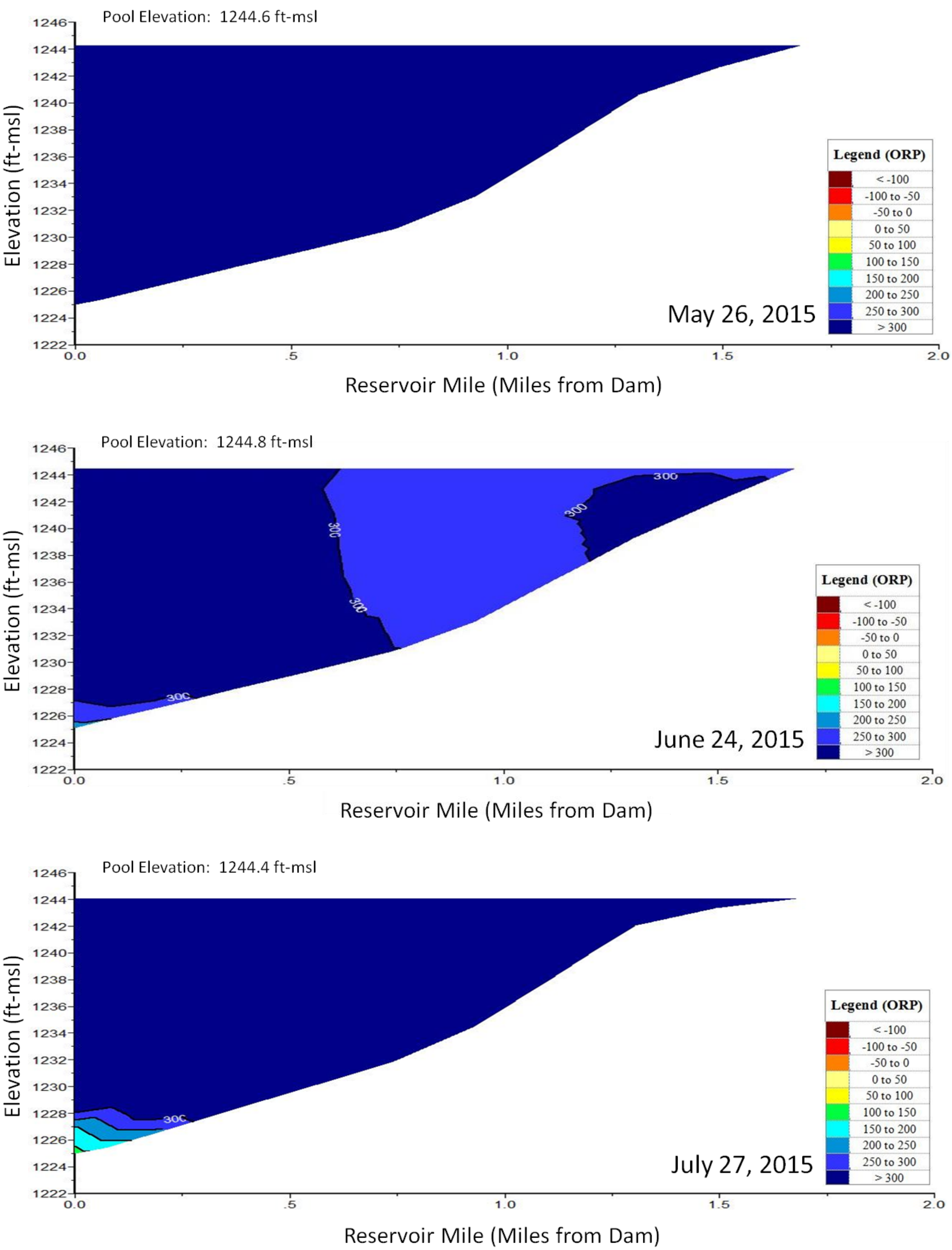


Plate 6-81. Longitudinal oxidation-reduction potential contour plots of Pawnee Reservoir based on depth-profile ORP levels (mV) measured at sites PAWLKND1, PAWLKML1, and PAWLKUP1 in 2015.

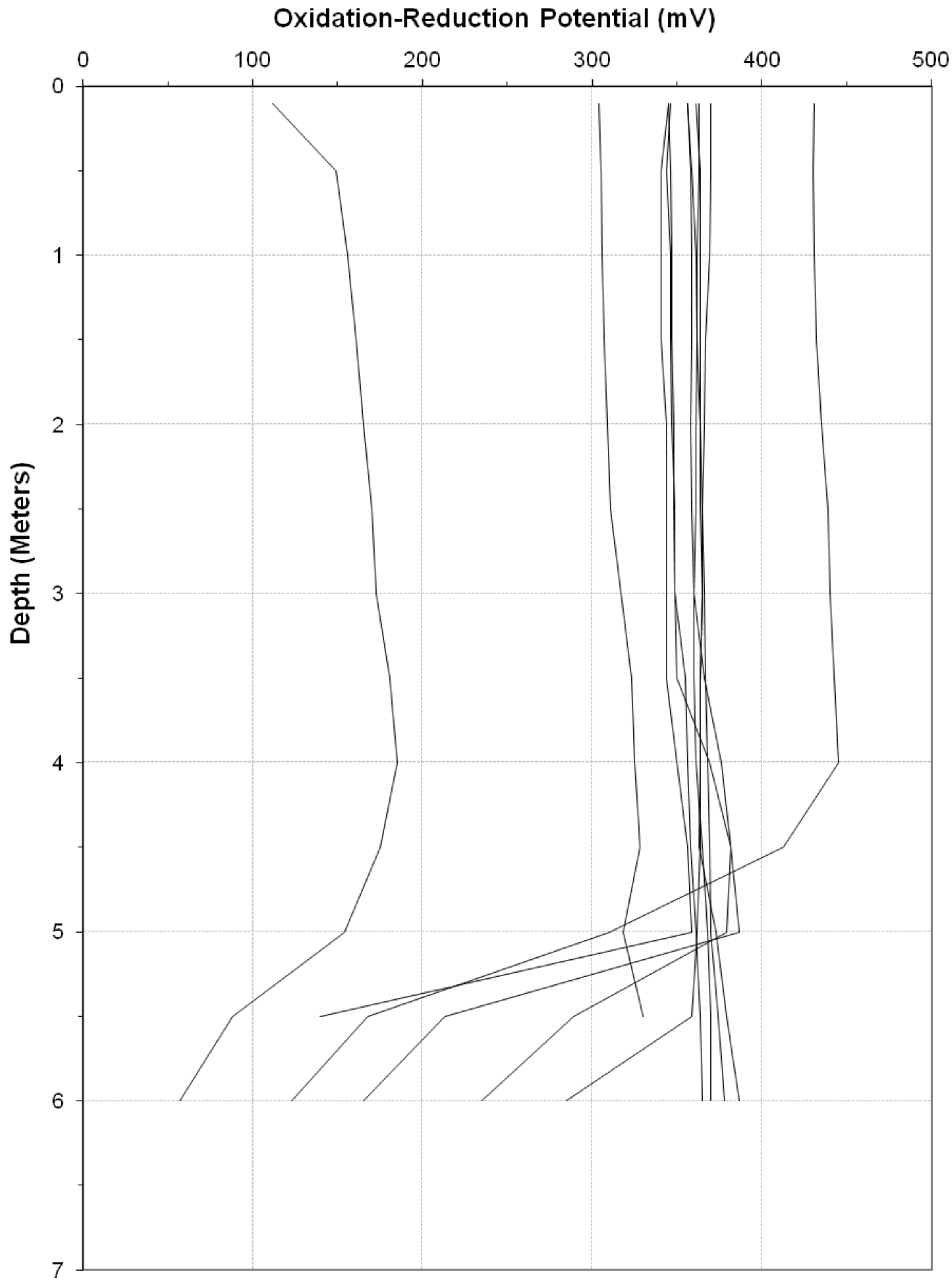


Plate 6-82. Oxidation-reduction potential depth profiles for Pawnee Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1) when hypoxic conditions were present, during the summer, over the 5-year period of 2011 through 2015.

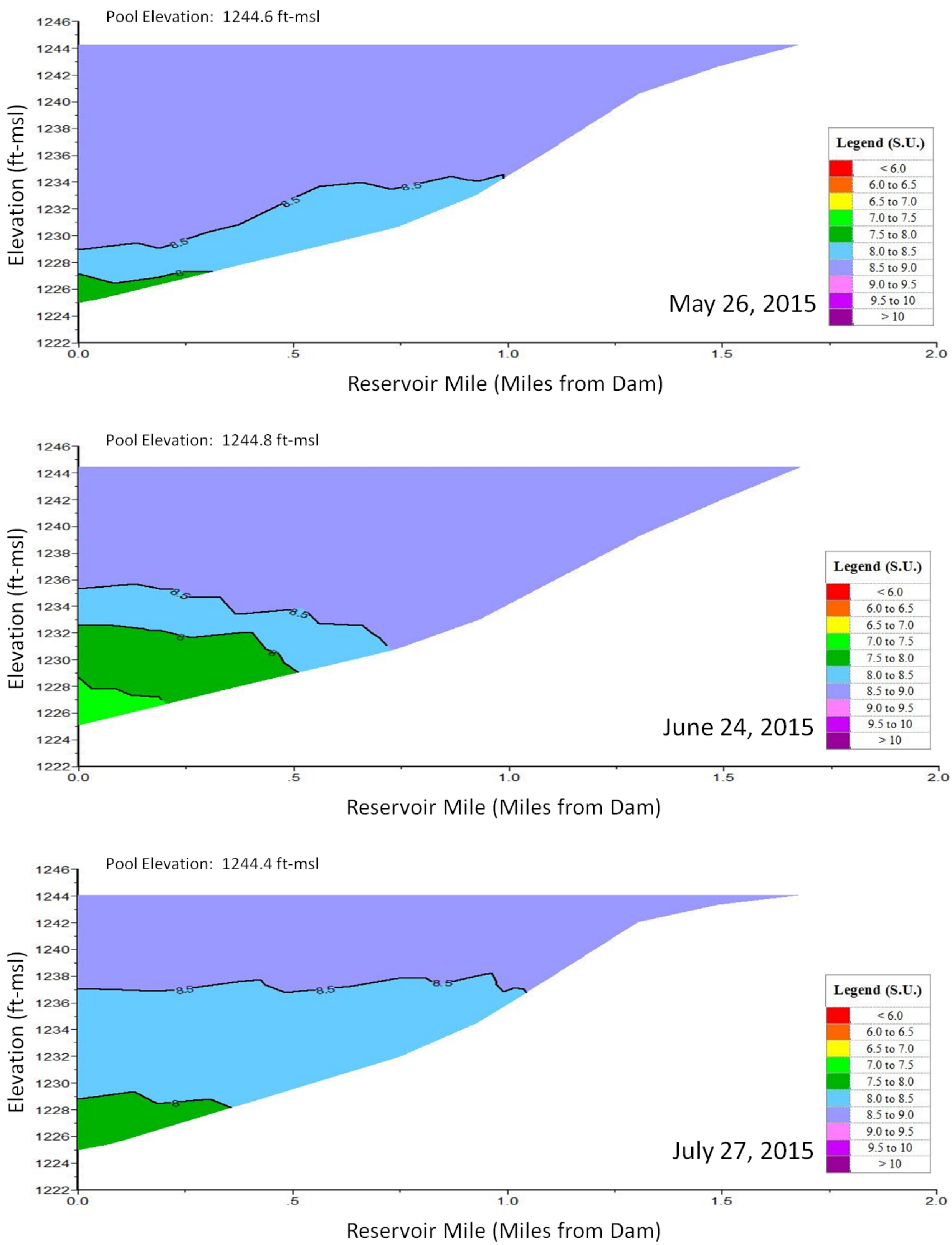


Plate 6-83. Longitudinal pH contour plots of Pawnee Reservoir based on depth-profile pH levels (S.U.) measured at sites PAWLKND1, PAWLKML1, and OCRLKUP1 in 2015.

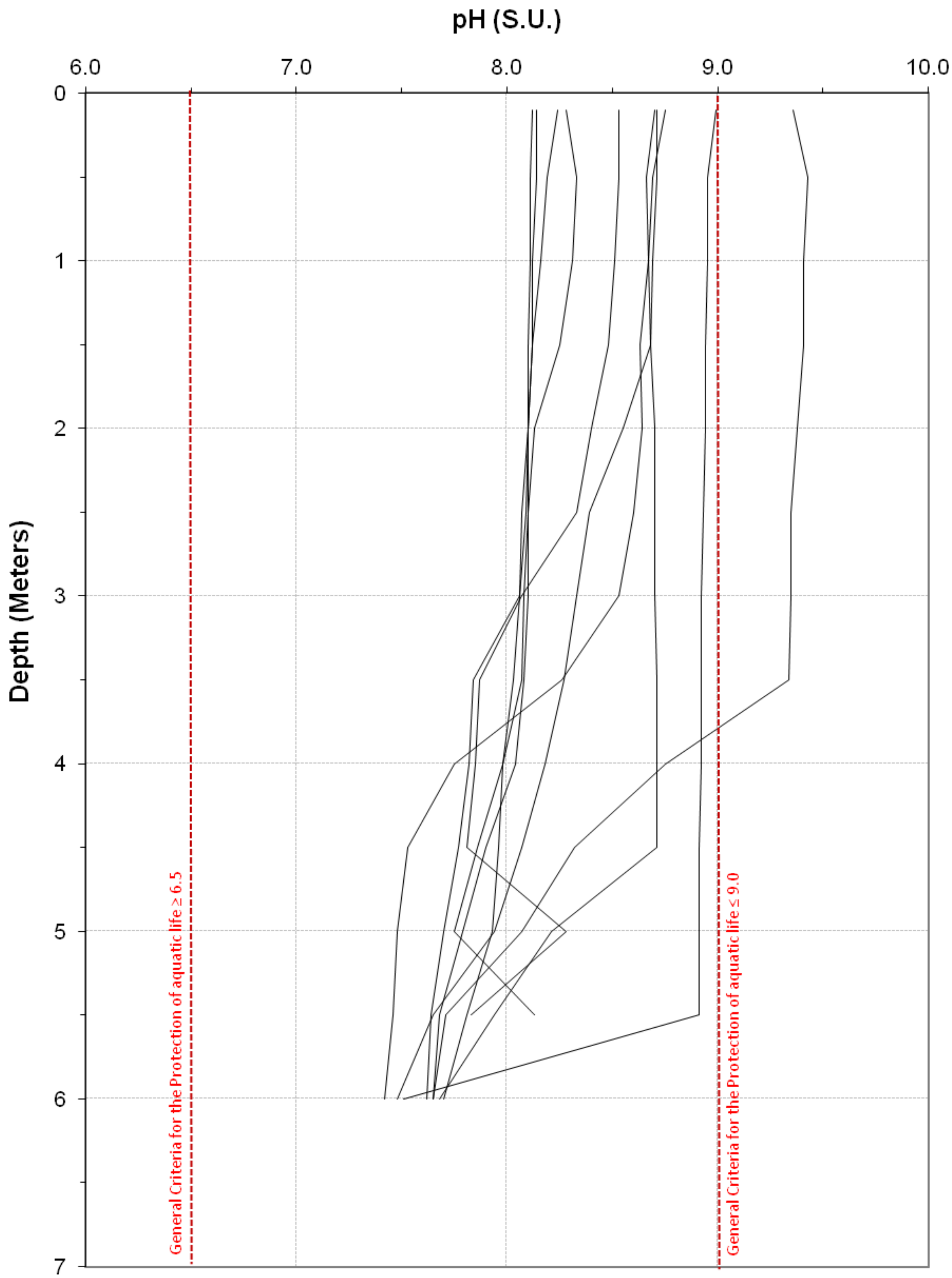


Plate 6-84. pH depth profiles for Pawnee Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1) during the summer over the 5-year period of 2011 through 2015, when hypoxic conditions were present.

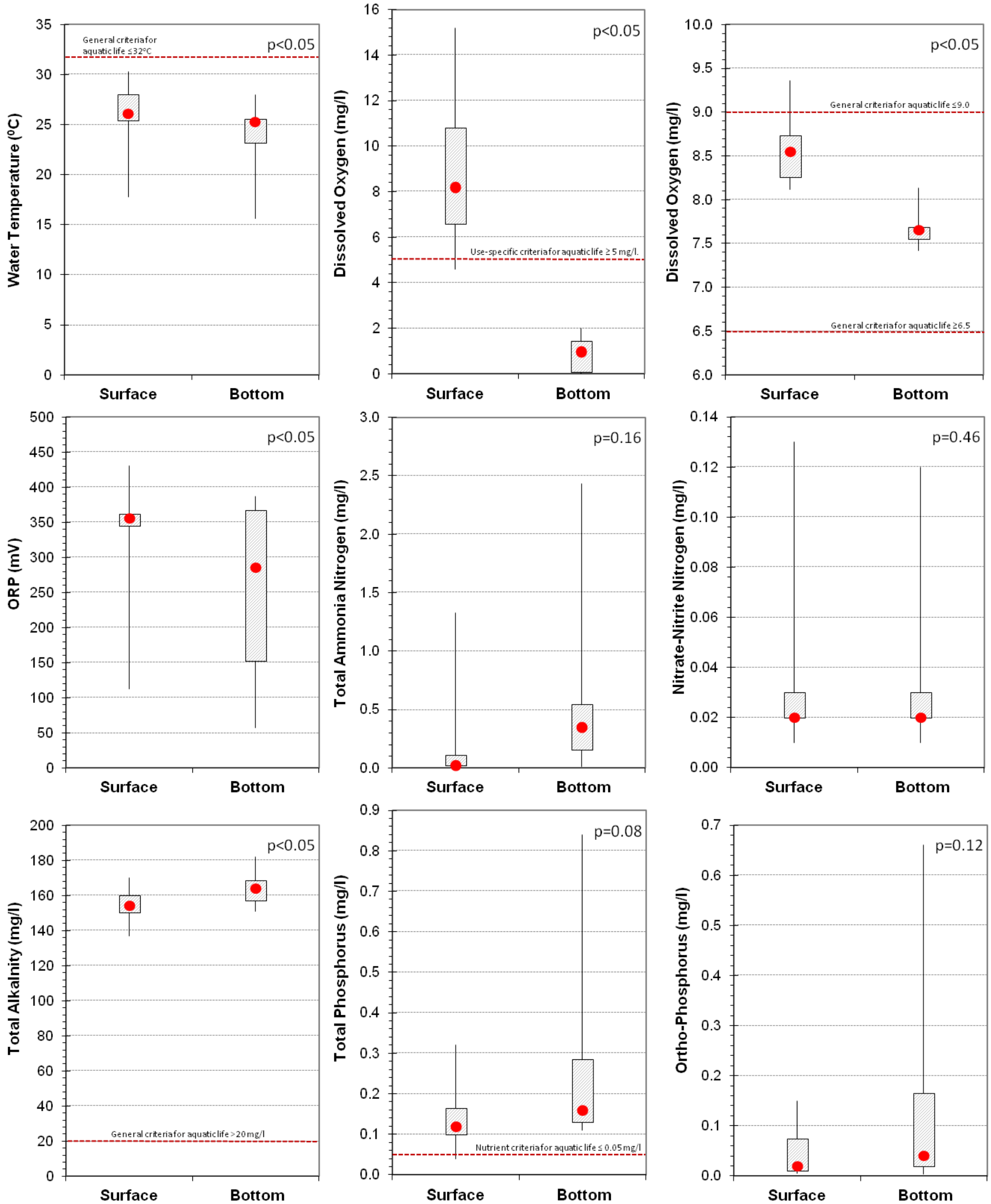


Plate 6-85. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, total ammonia nitrogen, nitrate-nitrite nitrogen, alkalinity, total phosphorus, and ortho-phosphorus measured in Pawnee Reservoir when summer hypoxic conditions were present during the 5-year period of 2011 through 2015 (n=11). P-values indicate significant differences between the near-surface and near-bottom samples via a paired two-tailed t-test (α = 0.05). (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot. Water quality criteria marked with red line when applicable)

Plate 6-86. Total biovolume and density by taxonomic group for phytoplankton grab samples from Pawnee Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)	Biovolume (μm^3/ml)	Density (Cells/ml)
24-May-11	5,891	63	239,360	6,314	19	0	-----	-----	3,771	193	7,086	11	199,378	279	2,006	1
27-Jul-11	786	20	43,519	884	-----	-----	5	251	34,433	2,937	1,689	4	230,058	379	2,769	1
21-Sep-11	317	3	90,167	966	-----	-----	165,478	3,200	5,706	211	5,496	13	1,026,407	2,800	48,530	26
30-Apr-12	-----	-----	700,986	43,133	180,760	214	2,106,970	15,187	55,481	41,333	66,573	51	429,537	1,653	7,963	11
05-Jul-12	1,629	1	614,566	9,587	29,791	61	2,419,358	4,339	957,139	230,335	154,482	68	2,730,404	8,881	3,762,280	183
06-Sep-12	-----	-----	2,596,386	54,485	47,878	535	1,700,651	27,539	8,638,337	285,969	730,770	1,069	7,410,424	47,895	-----	-----
15-May-13	407,612	115	1,732,188	17,494	-----	-----	1,080,756	20,641	3,063,860	200,527	-----	-----	5,560,254	16,809	-----	-----
08-Jul-13	191,067	57	715,246	6,078	-----	-----	566,070	6,674	1,550,527	74,051	44,606	29	5,120,874	7,090	35,170	1
10-Sep-13	3,515,463	713	3,148,189	6,731	-----	-----	1,923,186	22,673	5,838,953	284,155	760	0	8,475,756	34,702	46,142	2
12-May-14	536	0	1,761,331	14,052	22,394	7	4,281,810	50,479	6,843,452	188,656	833	0	18,808,030	41,525	-----	-----
14-Jul-14	125,269	471	10,664,015	22,347	-----	-----	3,634	11	1,357	7	-----	-----	483,086	692	-----	-----
10-Sep-14	37,624	19	711,444	1,313	-----	-----	-----	-----	52,755,099	122,363	-----	-----	7,412,023	3,360	-----	-----
26-May-15	-----	-----	56,636	304	-----	-----	717,100	1,069	125,007	696	-----	-----	2,045,059	241	-----	-----
27-Jul-15	-----	-----	832,111	1,794	-----	-----	1,527,663	1,754	4,544,060	141,721	-----	-----	8,260,359	6,289	-----	-----
22-Sep-15	-----	-----	121,702	647	-----	-----	381,314	1,219	31,991,296	174,158	-----	-----	4,210,897	3,192	1,736,580	112

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

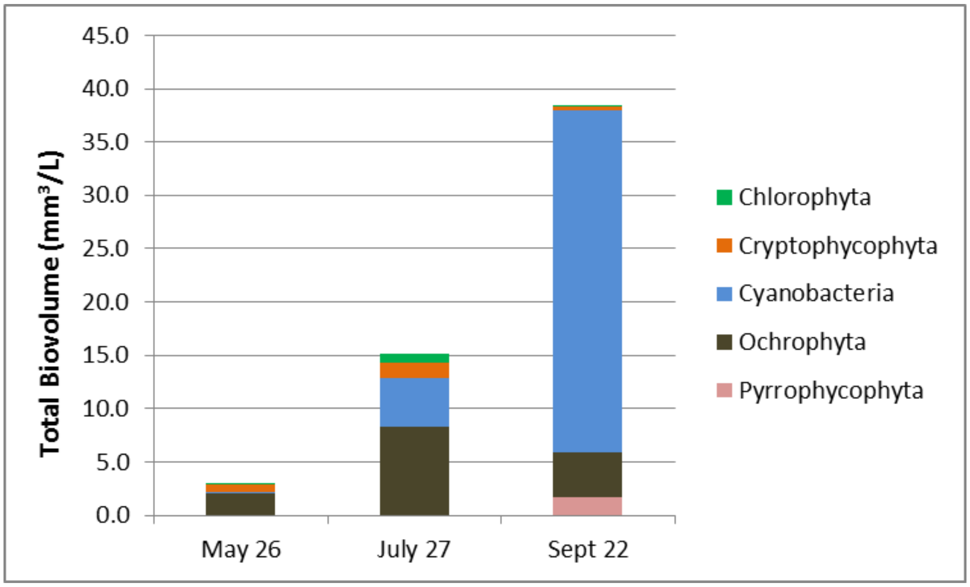


Plate 6-87. Relative abundance of phytoplankton in samples collected from Pawnee Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1).

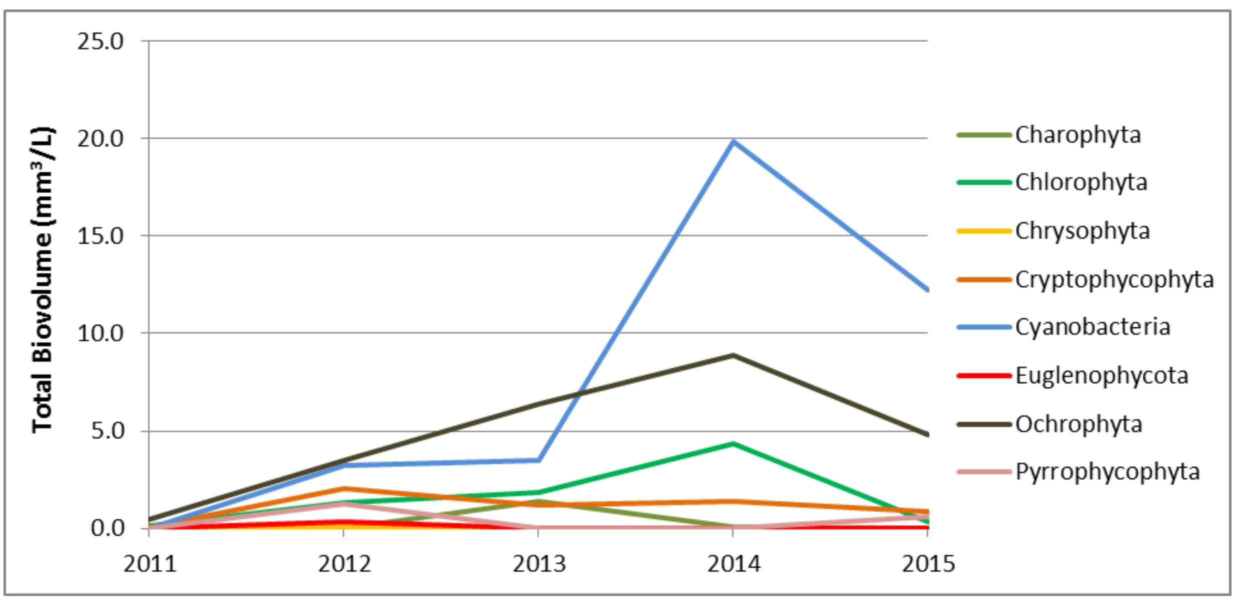


Plate 6-88. Relative abundance of phytoplankton in samples collected from Pawnee Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are a yearly average of three summer samples (i.e. May, July, and September).

Plate 6-89. Total biomass and density by taxonomic grouping for zooplankton vertical-tow samples from Pawnee Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)
25-May-11	105	124.34	117	73.69	-----	-----	126	1.27
27-Jul-11	30	20.74	205	70.02	-----	-----	208	1.39
21-Sep-11	0	2.70	42	30.29	-----	-----	7	0.07
30-Apr-12	1	0.38	27	21.72	-----	-----	125	6.04
05-Jul-12	14	21.22	104	74.71	-----	-----	58	31.91
06-Sep-12	3	4.97	64	32.74	-----	-----	62	1.24
15-May-13	3	9.02	58	37.92	-----	-----	151	3.91
08-Jul-13	30	307.03	103	186.76	-----	-----	46	0.31
10-Sep-13	2	5.95	43	52.98	-----	-----	7	0.09
12-May-14	11	20.56	491	1,176.04	-----	-----	12	7.54
14-Jul-14	201	459.52	1,146	477.48	-----	-----	274	7.72
10-Sep-14	72	225.80	202	121.89	1	0.15	62	1.15
26-May-15	20	79.71	66	85.65	1	0.03	14	1.17
27-Jul-15	71	73.25	74	160.56	-----	-----	107	3
22-Sep-15	53	227.35	31	18.61	-----	-----	23	0.59

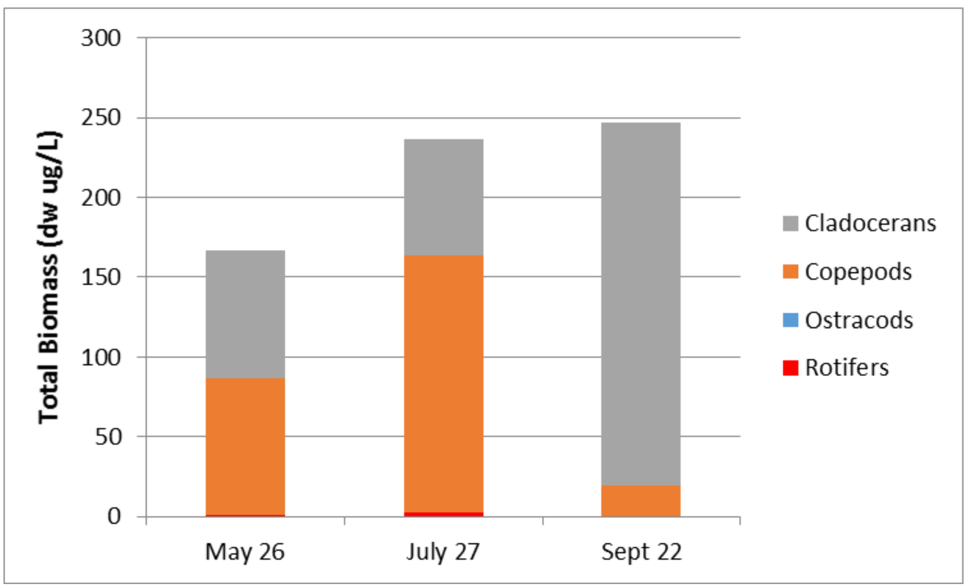


Plate 6-90. Relative abundance of zooplankton in samples collected from Pawnee Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1).

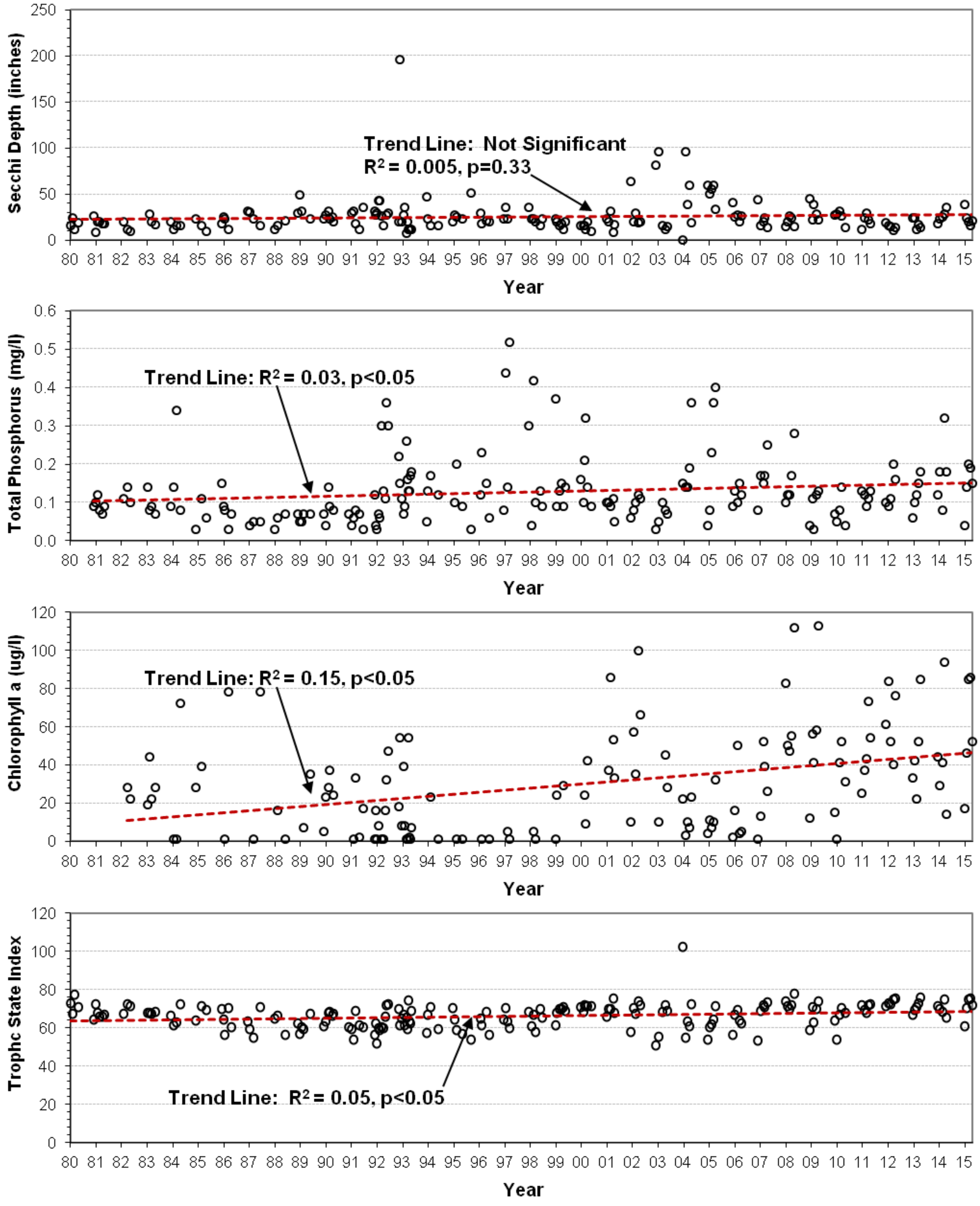


Plate 6-91. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Pawnee Reservoir at the near-dam, ambient site (i.e., site PAWLKND1) over the 36-year period of 1980 through 2015.

6.8 STAGECOACH RESERVOIR

6.8.1 BACKGROUND INFORMATION

6.8.1.1 Project Overview

The dam forming Stagecoach Reservoir is located on a tributary of the Hickman Branch. The dam was completed on August 27, 1963 and the reservoir reached its initial fill in May 1965. The Stagecoach Reservoir watershed is 9.7 square miles. The watershed was largely agricultural when the dam was built in 1963 and has remained so to the present time.

6.8.1.2 Stagecoach Dam Intake Structure

The dam intake at Stagecoach Dam is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 4 feet by 6 feet. The intake structure has four ungated openings – two 24" x 72" openings with a crest elevation at 1277.1 ft-msl and two 12" x 30" openings with a crest elevation at 1271.1. A 36" x 36" gated opening with a crest elevation of 1261.0 ft-msl was constructed into the upstream wall. The purpose of the gated opening is to lower the level of the conservation pool in order to inspect the conduit, make shoreline repairs, and manage fish populations. It may also be used to release water for downstream needs.

6.8.1.3 Reservoir Storage Zones

Figure 6.13 depicts the current storage zones of Stagecoach Reservoir based on the 1990 survey data and estimated sedimentation. It is estimated that 26 to 35 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2015. The annual volume loss is estimated to be 0.52 to 0.69 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Stagecoach Reservoir's water quality dependent uses may be impaired due to sedimentation.

6.8.1.1 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Stagecoach 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. Figure 6.14 shows the location of the sites that have been monitored for water quality during the 5-year sampling period (i.e., 2011 through 2015). The inflow runoff site (STGNF1) was sampled by the NDEQ. The other in-reservoir sites (STGLKND1, STGLKML1, and STGLKUP1) were sampled by the District. The near-dam location (STGLKND1) has been continuously monitored by the District since 1980

6.8.2 WATER QUALITY IN STAGECOACH RESERVOIR

6.8.2.1 Existing Water Quality Conditions

6.8.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Stagecoach Reservoir at sites STGLKND1, STGLKML1, and STGLKUP1 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 6-92 through Plate 6-94. A review of these results indicated possible water quality concerns regarding dissolved oxygen and nutrients.

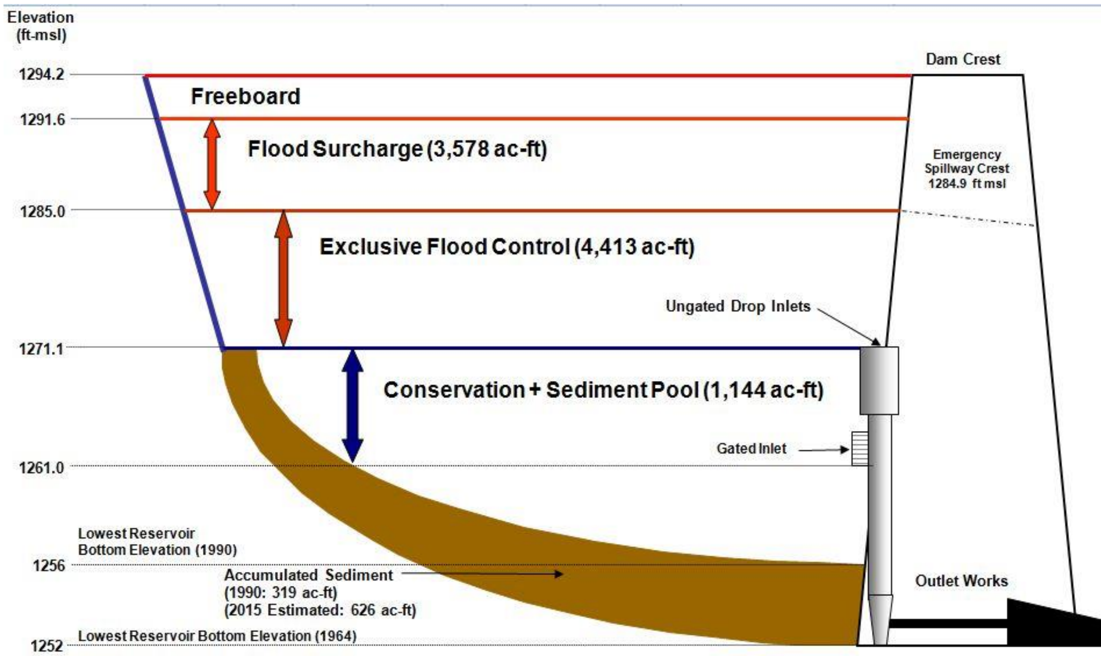


Figure 6.13. Current storage zones of Stagecoach Reservoir based on the 1990 survey data and estimated sedimentation**.**

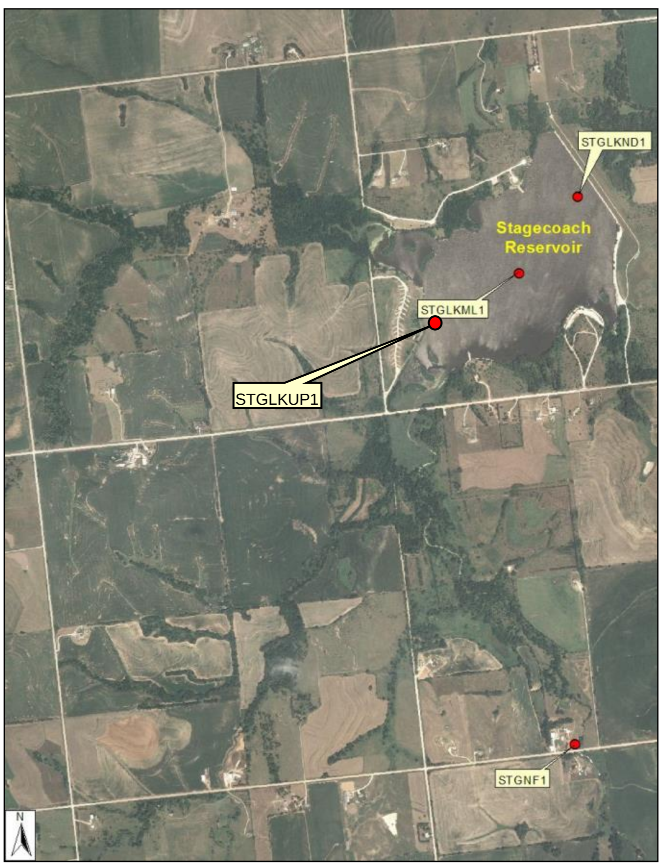


Figure 6.14. Location of sites where water quality monitoring was conducted at Stagecoach Reservoir during the period 2011 through 2015.

A significant number of dissolved oxygen measurements throughout Stagecoach Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 6-92 - Plate 6-94). Most of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and appeared to be associated with a slight thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Stagecoach Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation. However, thermal stratification in Stagecoach Reservoir was relatively limited during the 5-year sampling period of 2011 through 2015 (Plate 6-96). This limited stratification could lead to the above provision not applying to the reservoir and possible impairment for dissolved oxygen for the protection of aquatic life in Stagecoach Reservoir. In addition, dissolved oxygen measurements were below the 5 mg/l criterion for the protection of warmwater aquatic life from the reservoirs surface to bottom several times during the 5-year sampling period (Plate 6-98).

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September) to be considered for impairment assessment. All three of these criteria were exceeded Stagecoach Reservoir (Plate 6-92). The near-surface chlorophyll *a* criterion was exceeded in 92 percent of the "lab analyzed" samples taken in the reservoir at site STGLKND1. The total phosphorus and total nitrogen criteria were exceeded in all samples collected for both parameters. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values (Plate 6-92) represent the growing season average for the 5-year period 2011 through 2015. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.17 mg/l), total nitrogen (1.96 mg/l), and chlorophyll *a* (47 ug/l) values at STGLKND1 indicate impairment of the aquatic life use due to nutrients.

6.8.2.1.2 Thermal Stratification

6.8.2.1.2.1 ***Longitudinal Temperature Contour Plots***

Late-spring and summer thermal conditions of Stagecoach Reservoir measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 6-95 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites STGLKND1, STGLKML1, and STGLKUP1 in 2015. These temperature plots indicate that Stagecoach Reservoir rarely exhibited thermal stratification. The maximum difference monitored between the surface and bottom water temperatures during 2015 was about 6°C in May.

6.8.2.1.2.2 ***Near-Dam Temperature Depth-Profile Plots***

Existing summer thermal stratification of Stagecoach Reservoir, at the deep water area near the dam, measured over the 5-year period 2011 through 2015 is depicted by depth-profile temperature plots (Plate 6-96). The depth-profile temperature plots indicate that the reservoir rarely exhibited significant summer thermal stratification over the 5-year sampling period. Since Stagecoach Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.8.2.1.3 Dissolved Oxygen Conditions

6.8.2.1.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of Stagecoach Reservoir based on depth-profile measurements taken in 2015 at sites STGLKND1, STGLKML1, and STGLKUP1. Plate 6-97 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 May through June near the reservoir bottom near the dam. In late June, much of the dissolved oxygen measurements throughout the reservoir were below Nebraska's minimum dissolved oxygen criterion (5 mg/L) for the protection of warmwater aquatic life.

6.8.2.1.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

Existing summer dissolved oxygen conditions in Stagecoach Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2011 through 2015 (Plate 6-98). On several occasions there was a significant vertical gradient in summer dissolved oxygen levels. Sixteen percent of the profiles showed hypoxic conditions near the reservoir bottom and two of the 25 profiles showed dissolved oxygen levels below the Nebraska's dissolved oxygen criterionfor the protection of warmwater aquatic life (≥ 5 mg/l) through the entire depth of the profile. Although Stagecoach Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition to mixing to allow hypoxic conditions to occasionally develop near the reservoir bottom.

6.8.2.1.3.3 ***Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of Stagecoach 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 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 June 25, 2015 contour plot indicates a pool elevation of 1,271.8 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1,270.0 ft-msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1,265.0 ft-msl (Plate 6-97). The current District Area-Capacity Tables (1993 Survey) give storage capacities of 1,590 ac-ft for elevation 1271.8 ft-msl, 1,242.0 ac-ft for elevation 1,270.0 ft-msl, and 503 ac-ft for elevation 1,265.0 ft-msl. On June 25, 2015 it is estimated that 98 percent of the volume of Stagecoach Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 40 percent of the reservoir volume was hypoxic.

6.8.2.1.4 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in Stagecoach Reservoir indicated hypoxic conditions during May and June 2015. As a result, longitudinal contour plots for ORP and pH were constructed during these months. During the last 5-years (2011 through 2015) only sixteen percent of the depth profiles at the near dam site have showed hypoxic conditions near the reservoir bottom (Plate 6-98). Due to this, further analysis was not performed.

6.8.2.1.4.1 ***Oxidation-Reduction Potential***

Plate 6-99 provides longitudinal ORP contour plots based on depth-profile measurements taken in 2015 when hypoxic conditions were present in Stagecoach Reservoir. The longitudinal contour plots showed that no appreciable reduced conditions occurred in 2015 at Stagecoach Reservoir, with all measurements being greater than 300 mV. Given the polymictic nature of the reservoir, reduced conditions seemingly are not long-term.

6.8.2.1.4.2 ***pH***

Longitudinal contour plots for pH conditions measured in 2015 when hypoxic conditions were present are provided in Plate 6-100. Only slight pH differences were observed during hypoxic conditions at Stagecoach Reservoir in 2015.

6.8.2.1.4.3 ***Reservoir Trophic Status***

Trophic State Index (TSI) values for Stagecoach Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., STGLKND1). Table 6.28 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Stagecoach Reservoir is in a hypereutrophic condition.

Table 6.28. Summary of Trophic State Index (TSI) values calculated for Stagecoach Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	80	81	69	93
TSI(TP)	25	68	68	60	78
TSI(Chl)	25	75	79	50	85
TSI(Avg)	25	74	75	68	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 for the individual parameters.

Note: See Section 4.1.3 for discussion of TSI calculation.

6.8.2.1.5 Reservoir Plankton Community

6.8.2.1.5.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at the Stagecoach Reservoir near-surface, near-dam sampling site during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-101). The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 6-102. The highest phytoplankton total biovolume was observed in September. Ochrophyta dominated most of the 2015 growing season. While Ochrophyta dominated most of the year, some successional patterns commonly observed in eutrophic reservoirs could be observed. Typically, cool water taxa such as Ochrophyta dominate spring and late fall while warm water taxa such as Cyanobacteria dominate summer and early fall. Cyanobacteria biovolumes were greatest during the warm water seasons in 2015 at Stagecoach reservoir. Major and dominant phytoplankton genera sampled in 2015 at Stagecoach Reservoir are provided in Table 6.29.

Annual variation in phytoplankton community composition is displayed in Plate 6-103. During the 5-year period 2011 through 2015, Stagecoach reservoir was mostly dominated by Cyanobacteria, Ochrophyta, and Cryptophycophyta. Cyanobacteria density levels reached levels significantly higher than the World Health Organizations high level of health risk (>100,000 Cells/ml) in 2012 and early 2013 (Plate 6-101). 2012 was a particularily warm and dry year. The longer reservoir residence times, decreased mixing, and warmer water could have resulted in a longer Cyanobacterial growing season, which resulted in the large densities and biovolumes observed. The high Cyanobacteria densities observed in May 2013 could have been a carry over from 2012's high densities. Maximum measured extracellular microcystin toxin levels at the near-dam site during the 5-year period was 0.2 µg/l (Plate 6-92).

Table 6.29. Listing of major and dominant phytoplankton genera Sampled in Stagecoach Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1)

Division	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Chlorophyta	*Coelastrum*	-----
Cryptophycophyta	-----	*Cryptomonas*
Cyanobacteria	*Microcystis*	-----
Ochrophyta	-----	*Aulacoseira, Stephanodiscus*

6.8.2.1.5.2 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at Stagecoach Reservoir near-dam sampling sites during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-104). The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in Plate 6-105. Stagecoach Reservoir was dominated largely by Cladocerans and Copepods, however, Rotifers showed an increase in dominance in September. Dominant and major zooplankton genera sampled in Stagecoach Reservoir during 2015 are provided in Table 6.30.

Table 6.30. Listing of major and dominant zooplankton genera sampled in Stagecoach Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1)

Taxonomic Group	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cladocerans	*Kurzia*	*Daphnia*
Copepods	*Acanthocyclops, Calanoida, Cyclopoida, Leptodiaptomus*	*Skistodiaptomus*
Rotifers	*Asplanchna*	-----

6.8.2.1.6 Zebra Mussel Monitoring

Zebra mussel veliger sampling has been conducted once yearly since 2012 at Stagecoach Reservoir. During the sampling period (2012-2015) no veligers have been identified.

6.8.2.2 <u>Water Quality Trends (1980 through 2015)</u>

Water quality trends from 1980 to 2015 were determined for Stagecoach 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., STGLKND1). Plate 6-106 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, Stagecoach Reservoir exhibited increasing trends in TSI ($p<0.05$, $R^2=0.03$) and decreasing trends in Secchi depth ($p<0.05$, $R^2=0.05$). No significant trend was observed for total phosphorus ($p=0.34$, $R^2=0.006$) and chlorophyll a ($p=0.76$, $R^2=0.0008$). Over the 36-year period since 1980, Stagecoach Reservoir has remained in a hypereutrophic condition.

6.8.3 PLATES

Plate 6-92. Summary of water quality conditions monitored in Stagecoach Reservoir at site STGLKND1 from May to September during the 5-year 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	25	1265.09	1271.10	1103.67	1286.50	-----	-----	-----
Water Temperature (°C)	0.1	191	23.08	23.92	16.55	30.15	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	191	7.02	6.69	0.17	13.04	≥5(2)	32	17%
Dissolved Oxygen, Near-Surface (mg/l) (C)	0.1	25	7.83	6.91	4.22	13.02	≥5(2)	2	8%
Dissolved Oxygen (% Sat.)	0.1	191	84.28	81.40	2.00	152.10	-----	-----	-----
Secchi Depth (in.)	1	25	10.76	9.00	4.00	21.00	-----	-----	-----
Turbidity (NTUs)	1	191	70.69	38.40	10.50	579.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	191	363.19	365.00	169.00	467.00	-----	-----	-----
Specific Conductance (umho/cm)	1	191	387.86	380.00	277.60	498.70	2,000(3)	0	0%
pH (S.U.)	0.1	191	8.13	8.17	6.82	9.07	≥6.5 & ≤9.0 (1)	0,7	0%,4%
Alkalinity, Total (mg/l)	1	50	123.30	121.50	91.00	171.00	>20(1)	0	0%
Suspended Solids, Total (mg/l)	4	50	34.20	31.00	12.00	72.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	50	-----	0.08	n.d.	0.89	2.00(4,5), 0.46(4,6)	0,2	0%,4%
Ammonia, Total, Near-Surface (mg/l)(C)	0.02	25	-----	0.05	n.d.	0.83	1.49(4,5), 0.36(4,6)	0,2	0%,8%
Kjeldahl N, Total (mg/l)	0.08	50	1.66	1.70	n.d.	2.98	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	50	-----	0.04	n.d.	1.27	100(3)	0	0%
Nitrogen, Total (mg/l)	0.08	50	1.98	1.84	1.02	3.68	1(7)	50	100%
Nitrogen, Total, Near-Surface (mg/l)(C)	0.08	25	1.96	1.80	1.02	3.22	1(7)	25	100%
Phosphorus, Total (mg/l)	0.005	50	0.18	0.16	0.07	0.47	0.05(7)	50	100%
Phosphorus, Total, Near-Surface (mg/l) (C)	0.005	25	0.17	0.16	0.07	0.42	0.05(7)	25	100%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	n.d.	n.d.	0.21	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	120.54	125.10	102.50	135.00	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	5	3.00	3.00	2.00	4.00	340(5), 16.7(8)	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	n.d.	7.34(5), 0.29(6)	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	711.25(5), 92.59(6)	0	0%
Copper, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	16.60(5), 10.84(6)	0	0%
Iron, Dissolved (ug/l)	7	5	-----	20.00	n.d.	30.00	1000(6)	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	82.34(5), 3.21(6)	0	0%
Manganese, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	10.00	1000(6)	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	565.91(5), 62.85(6)	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5.07(5)	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	141.66(5), 142.82(6)	0	0%
Antimony, Dissolved (ug/l)	0.03	5	-----	0.90	n.d.	0.90	88(5), 30(6)	0	0%
Aluminum, Dissolved (ug/l)	40	5	-----	n.d.	n.d.	50.00	750(5), 87(6)	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77(6)	0	0%
Chlorophyll a (ug/l) – Lab Determined(C)	6	25	47	54	n.d.	100	10(7)	23	92%
Chlorophyll a (ug/l) – Field Probe	6	183	67	55	n.d.	724	10(7)	155	85%
Atrazine, Total (ug/l)(D)	0.1	25	2.38	1.80	0.30	6.80	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l) (D)	0.1	25	1.94	1.90	0.40	3.30	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l) (D)	0.1	25	1.76	1.50	n.d.	4.80	-----	-----	-----
Microcystin, Extracellular (ug/l)	0.1	24	-----	n.d.	n.d.	0.20	20(9)	0	0%
Pesticide Scan (ug/l)(E)									
Atrazine, Tot	0.13	5	4.30	2.50	0.46	14.50	330(5), 12(6)	0,1	0%,20%
Acetochlor, Tot	0.08	5	-----	n.d.	n.d.	0.69	-----	-----	-----
Metolachlor, Tot	0.05	5	-----	1.06	n.d.	2.55	390(5), 100(6)	0	0%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. . Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-93. Summary of water quality conditions monitored in Stagecoach Reservoir at site STGLKML1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances**	**Percent WQS Exceedance**
Pool Elevation (ft-msl)	0.1	20	1263.54	1271.15	1103.67	1286.50	-----	-----	-----
Water Temperature (°C)	0.1	152	23.23	23.74	16.51	30.21	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	152	6.96	6.70	0.40	13.18	≥5(2)	26	17%
Dissolved Oxygen (% Sat.)	0.1	152	83.82	82.20	4.80	150.50	-----	-----	-----
Secchi Depth (in.)	1	25	10.04	9.00	4.00	21.00	-----	-----	-----
Turbidity (NTUs)	1	152	78.00	38.05	11.90	3000.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	152	363.53	368.00	160.00	484.00	-----	-----	-----
Specific Conductance (umho/cm)	1	152	385.99	380.05	277.30	498.20	2,000(3)	0	0%
pH (S.U.)	0.1	152	8.10	8.15	6.95	9.04	≥6.5 & ≤9.0 (1)	0,2	0%,1%
Chlorophyll a (ug/l) – Field Probe	6	145	77	48	1	497	10(4)	119	82%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-94. Summary of water quality conditions monitored in Stagecoach Reservoir at site STGLKUP1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances**	**Percent WQS Exceedance**
Pool Elevation (ft-msl)	0.1	20	1263.54	1271.15	1103.67	1286.50	-----	-----	-----
Water Temperature (°C)	0.1	43	23.70	24.51	16.40	30.34	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	43	7.46	7.17	4.76	13.09	≥5(2)	3	7%
Dissolved Oxygen (% Sat.)	0.1	43	90.70	86.60	59.80	162.10	-----	-----	-----
Secchi Depth (in.)	1	25	9.76	8.00	4.00	22.00	-----	-----	-----
Turbidity (NTUs)	1	42	136.07	41.25	12.60	3000.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	43	361.02	369.00	164.00	466.00	-----	-----	-----
Specific Conductance (umho/cm)	1	43	378.78	376.20	279.60	499.70	2,000(3)	0	0%
pH (S.U.)	0.1	43	8.11	8.21	7.24	9.09	≥6.5 & ≤9.0 (1)	0,1	0%,2%
Chlorophyll a (ug/l) – Field Probe	6	41	54	39	3	288	10(4)	34	83%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

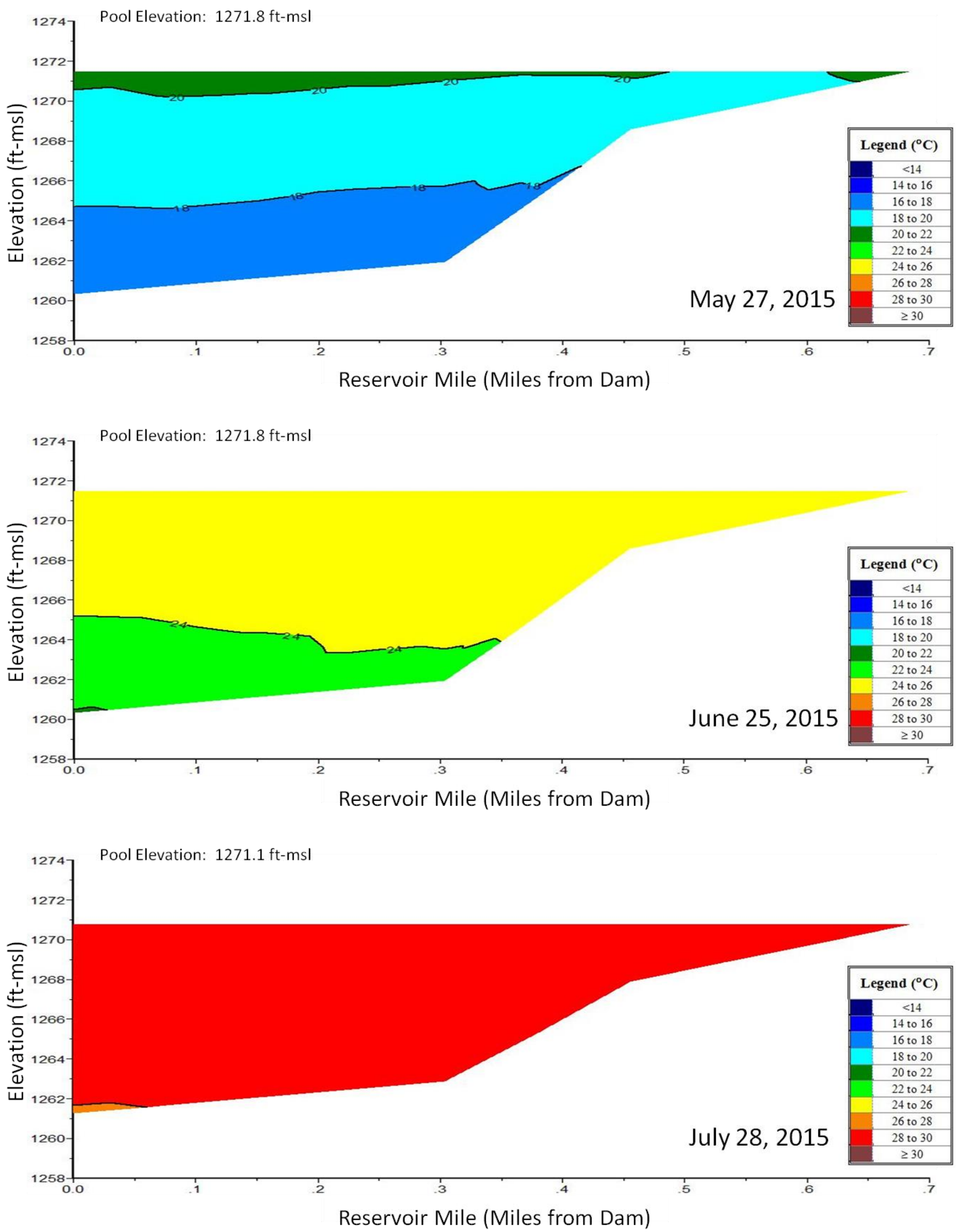
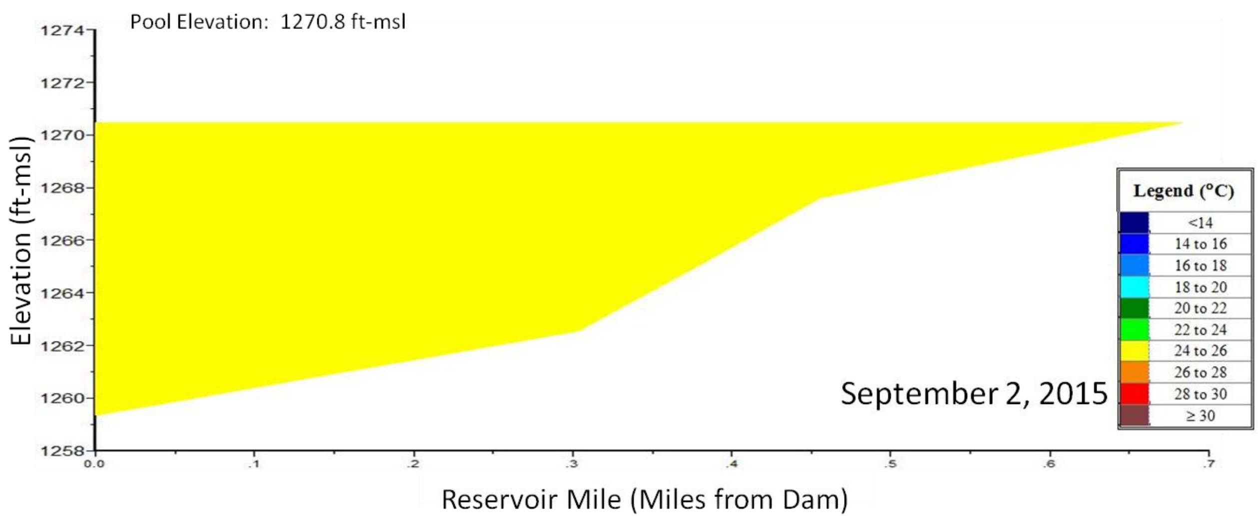


Plate 6-95. Longitudinal water temperature contour plots of Stagecoach Reservoir based on depth-profile water temperatures (°C) measured at sites STGLKND1, STGLKML1, and STGLKUP1 in 2015.



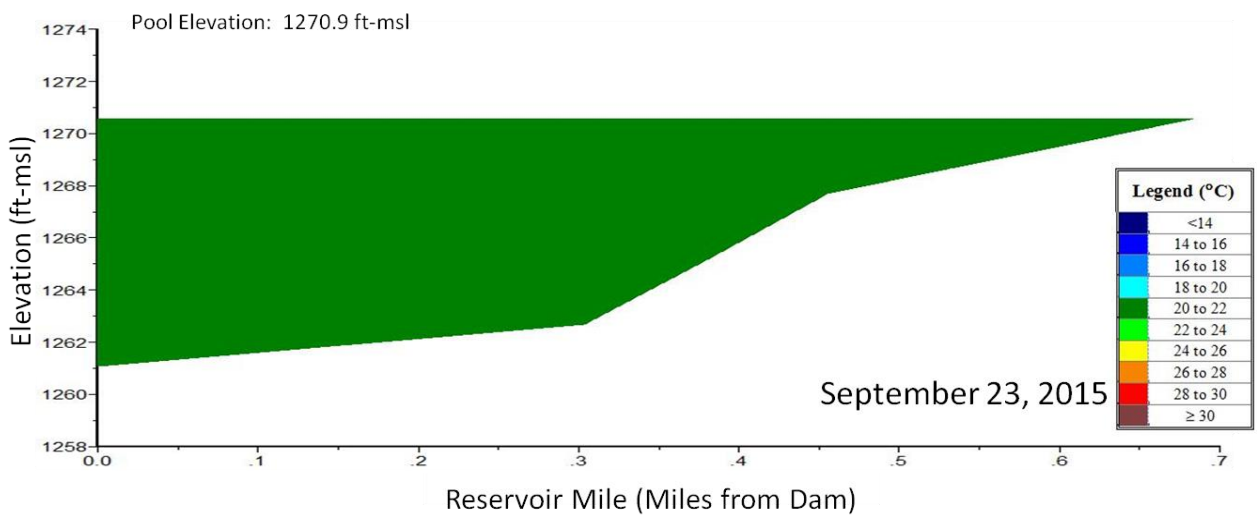


Plate 6-95. (Continued).

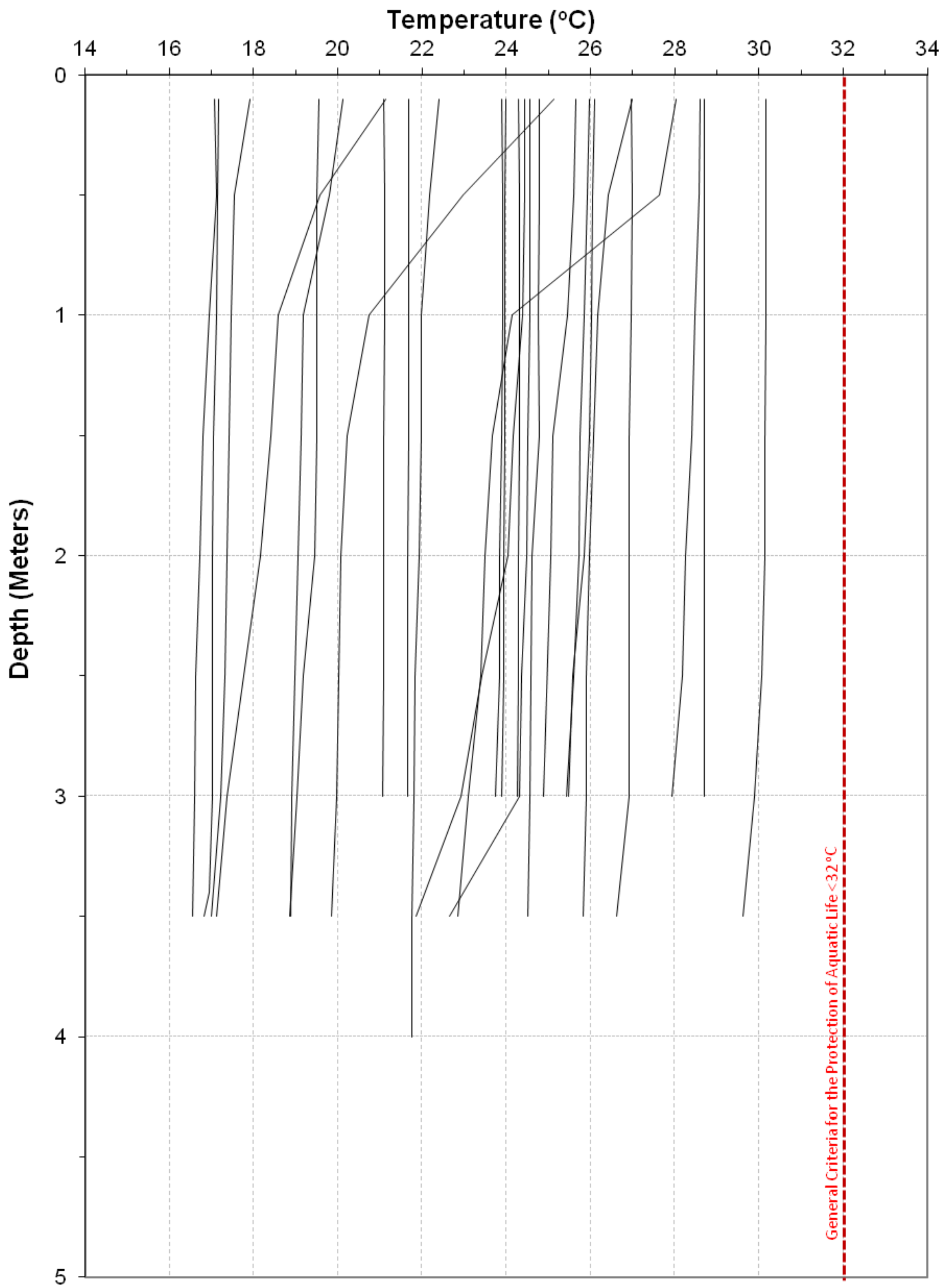


Plate 6-96. Temperature depth profiles for Stagecoach Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1) during the summer over the 5-year period of 2011 through 2015.

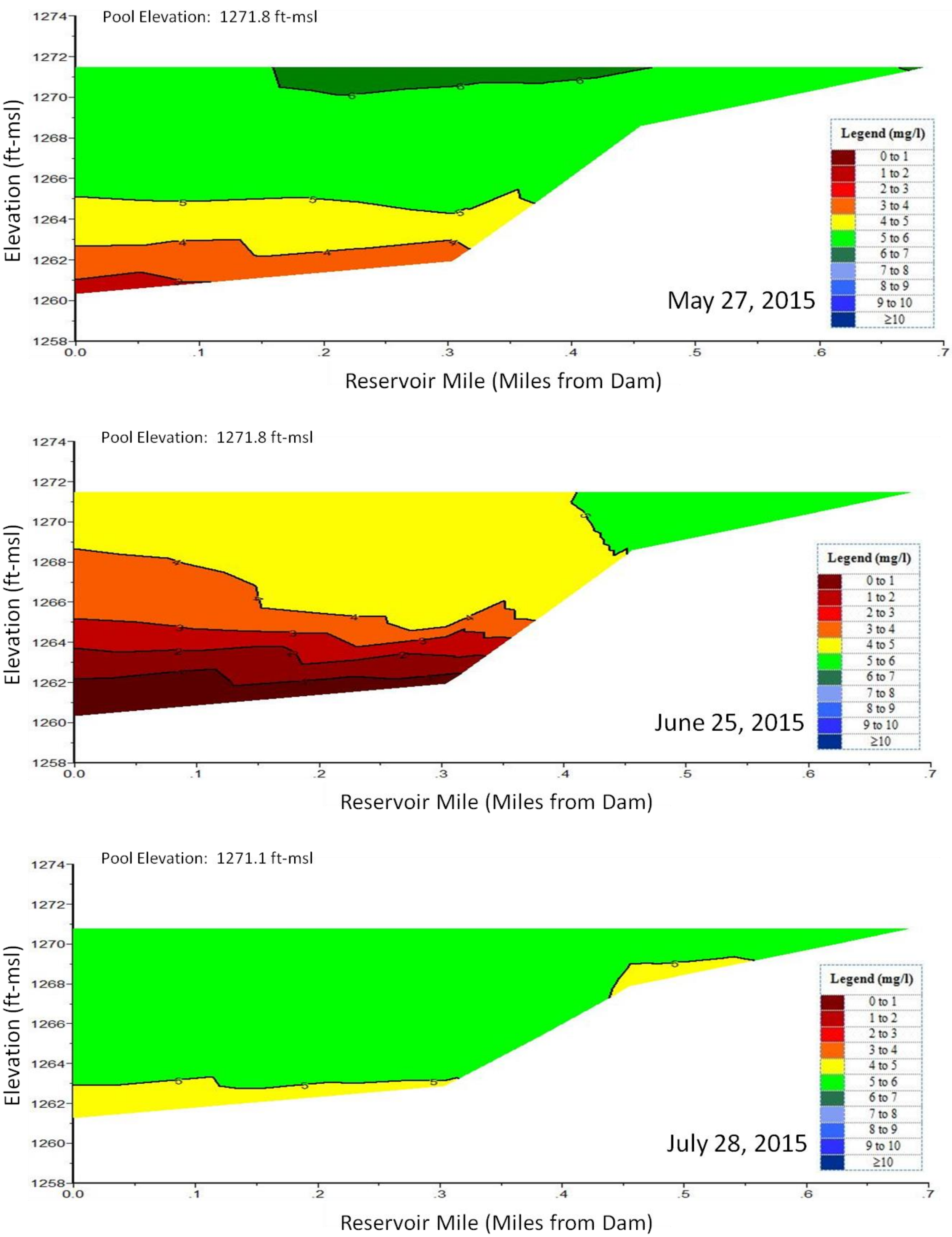
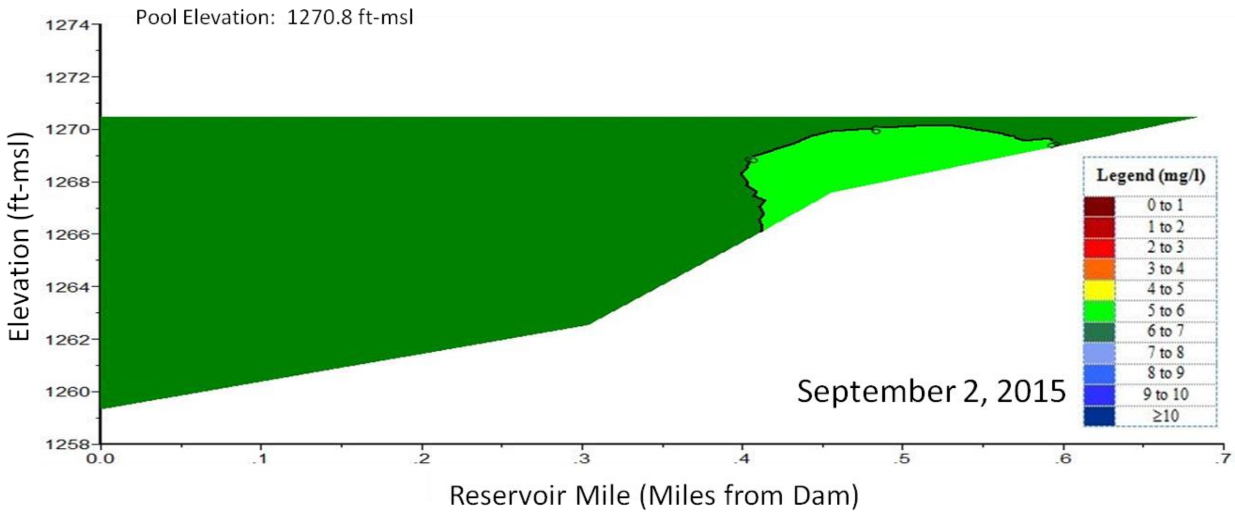


Plate 6-97. Longitudinal dissolved oxygen contour plots of Stagecoach Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites STGLKND1, STGLKML1, and STGLKUP1 in 2015.



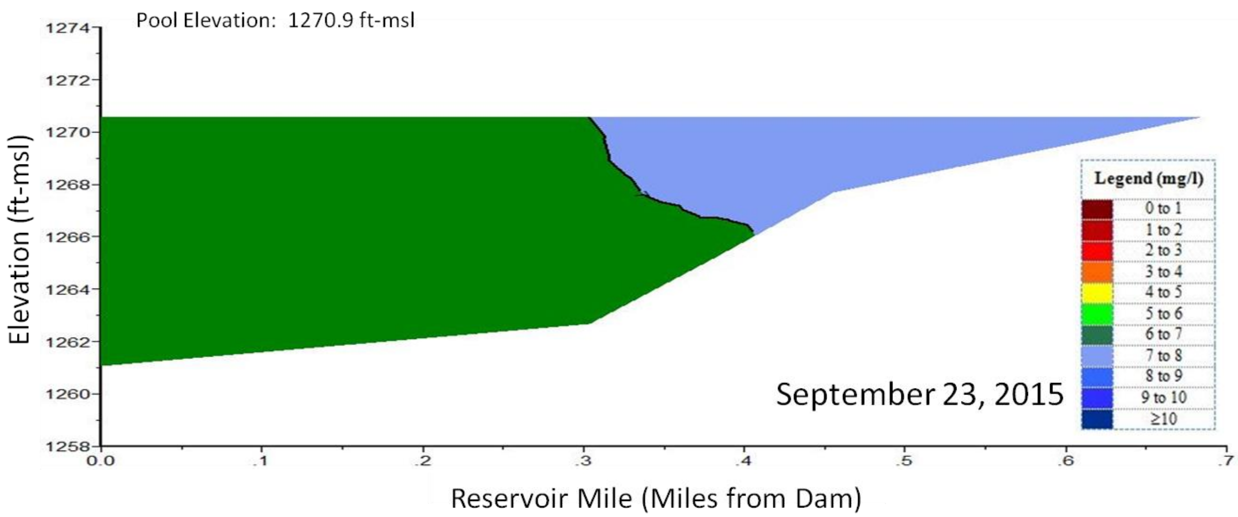


Plate 6-97. (Continued).

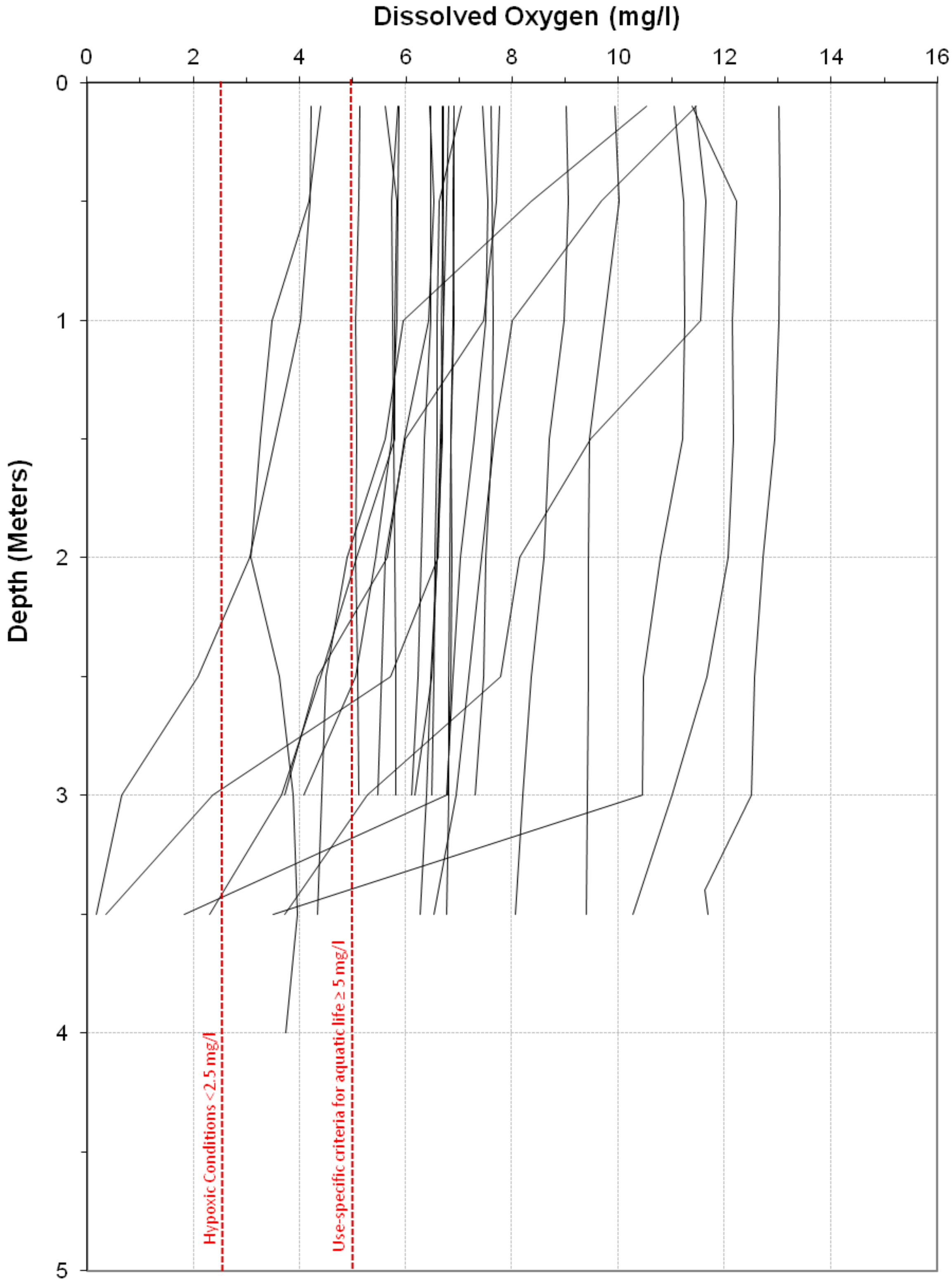
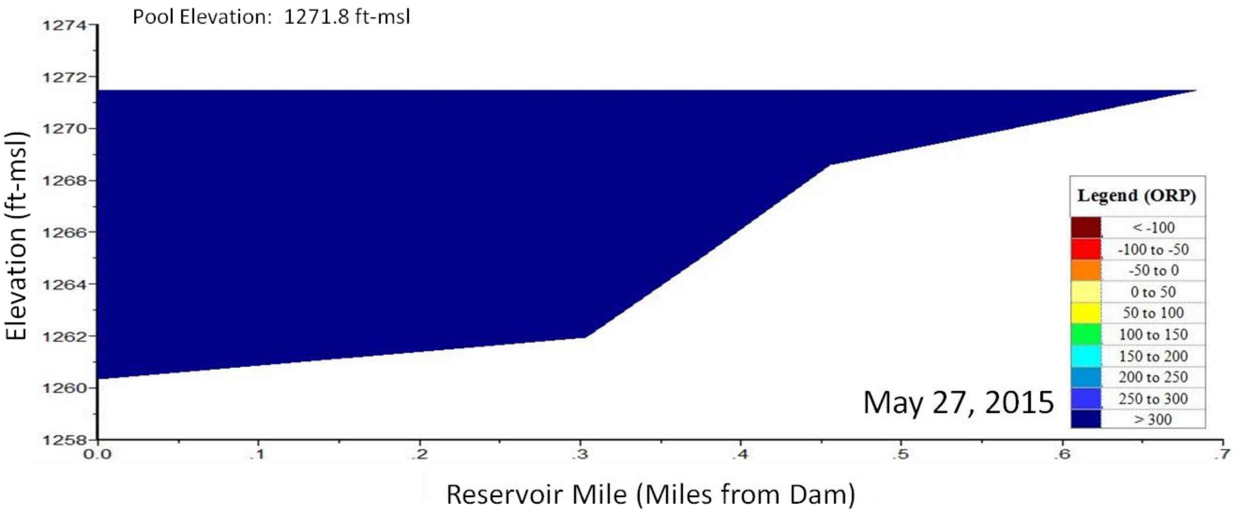


Plate 6-98. Dissolved oxygen depth profiles for Stagecoach Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1) during the summer over the 5-year period 2011 through 2015.



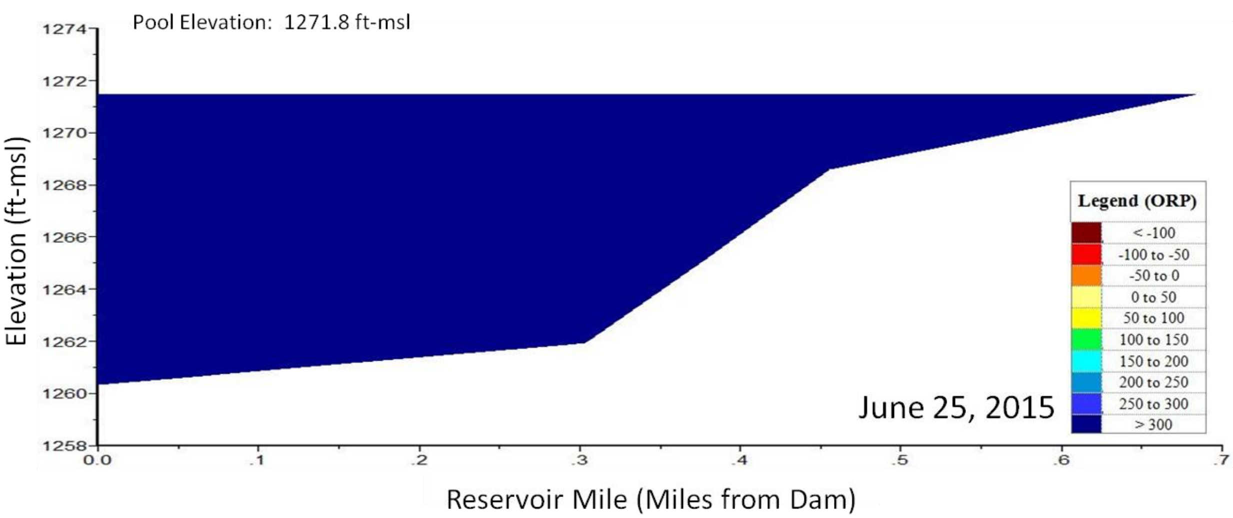
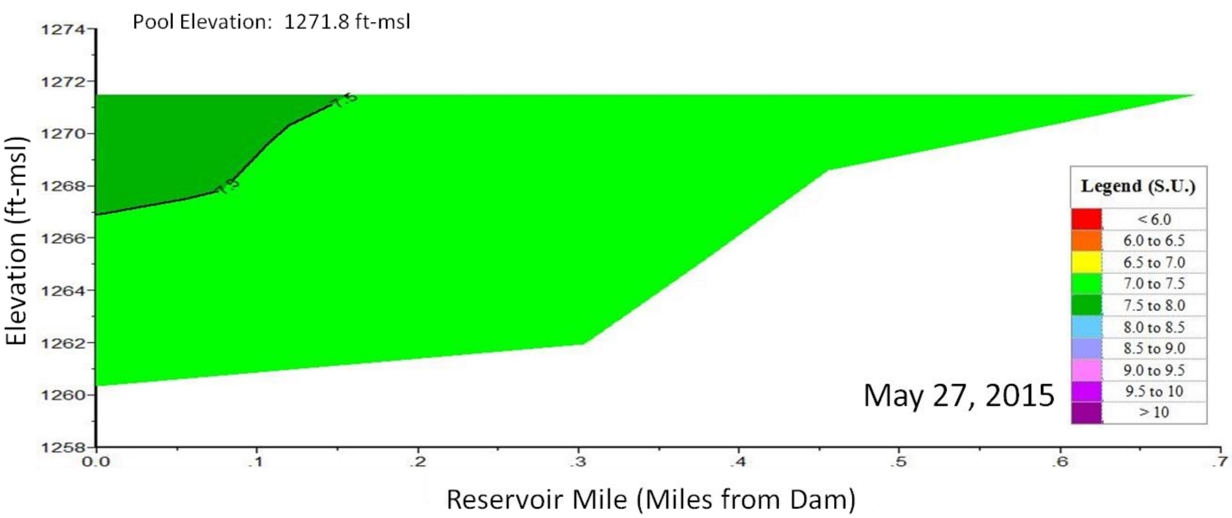


Plate 6-99. Longitudinal oxidation-reduction potential contour plots of Stagecoach Reservoir based on depth-profile ORP levels (mV) measured at sites STGLKND1, STGLKML1, and STGLKUP1 in 2015.



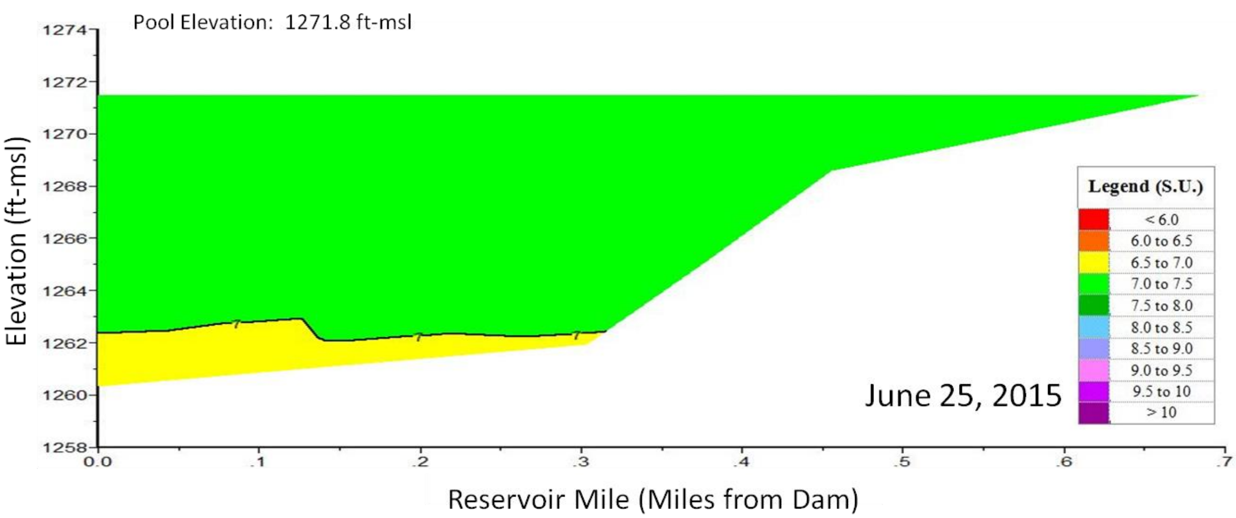


Plate 6-100. Longitudinal pH contour plots of Stagecoach Reservoir based on depth-profile pH levels (S.U.) measured at sites STGLKND1, STGLKML1, and STGLKUP1 in 2015.

Plate 6-101. Total biovolume and density by taxonomic group for phytoplankton grab samples from Stagecoach Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**
23-May-11	3,306	26	239,429	3,289	7,299	26	60,695	1,349	7,037	3,142	14,416	20	71,681	264	5,355	3
28-Jul-11	6,674	79	85,444	2,041	-----	-----	161,907	2,565	421,651	64,856	212,923	423	1,243,707	2,778	54,636	41
22-Sep-11	557	3	156,960	2,855	-----	-----	58,183	899	54,691	17,640	24,822	85	1,836,658	2,578	985	3
03-May-12	-----	-----	984,570	4,299	-----	-----	3,604,063	4,729	84	8	16,563	24	279,370	2,400	810,117	167
09-Jul-12	38,619	359	396,670	8,007	-----	-----	1,735,929	3,957	10,663,000	1,046,826	314,483	321	1,782,093	18,407	-----	-----
07-Sep-12	-----	-----	294,309	14,524	-----	-----	52,532	2,977	8,489,267	1,001,032	625,871	1,341	6,899,982	32,727	21,715	2
14-May-13	-----	-----	983,512	4,716	-----	-----	1,469,604	17,326	110,111,088	1,782,821	-----	-----	611,787	2,669	-----	-----
12-Sep-13	104,760	150	769,753	7,410	-----	-----	1,487,748	17,539	1,406,887	24,099	3,447	1	5,557,515	33,934	-----	-----
13-May-14	114,018	15	123,564	1,787	-----	-----	264,211	3,115	47,248	267	779	0	625,989	1,780	-----	-----
15-Jul-14	32,301	69	1,394,867	2,809	-----	-----	92,714	29	117,535	6,810	265,492	46	1,057,570	6,379	1,375,889	53
11-Sep-14	12,920	76	1,291,037	10,248	-----	-----	15,110,039	6,612	1,372,981	54,657	1,500,753	126	5,233,987	2,633	-----	-----
27-May-15	27,578	13	4,157	34	-----	-----	472,742	321	-----	-----	240	0	53,877	183	-----	-----
28-Jul-15	-----	-----	701,079	1,368	-----	-----	167,518	1,364	98,696	1,257	81,309	214	2,037,667	5,933	85,315	4
23-Sep-15	-----	-----	275,201	1,908	-----	-----	337,918	3,984	428,853	2,402	141,361	42	2,409,334	6,069	92,251	8

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

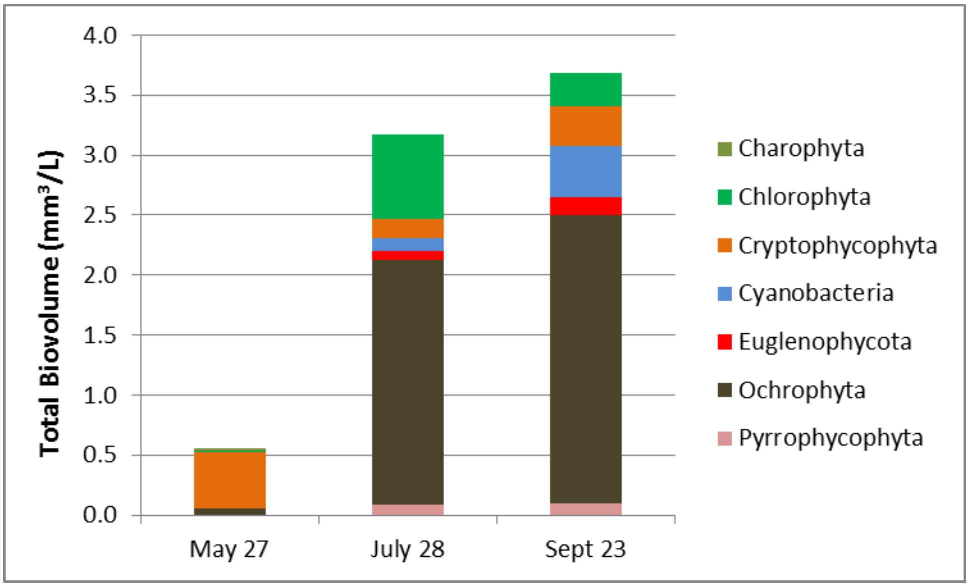


Plate 6-102. Relative abundance of phytoplankton in samples collected from Stagecoach Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1).

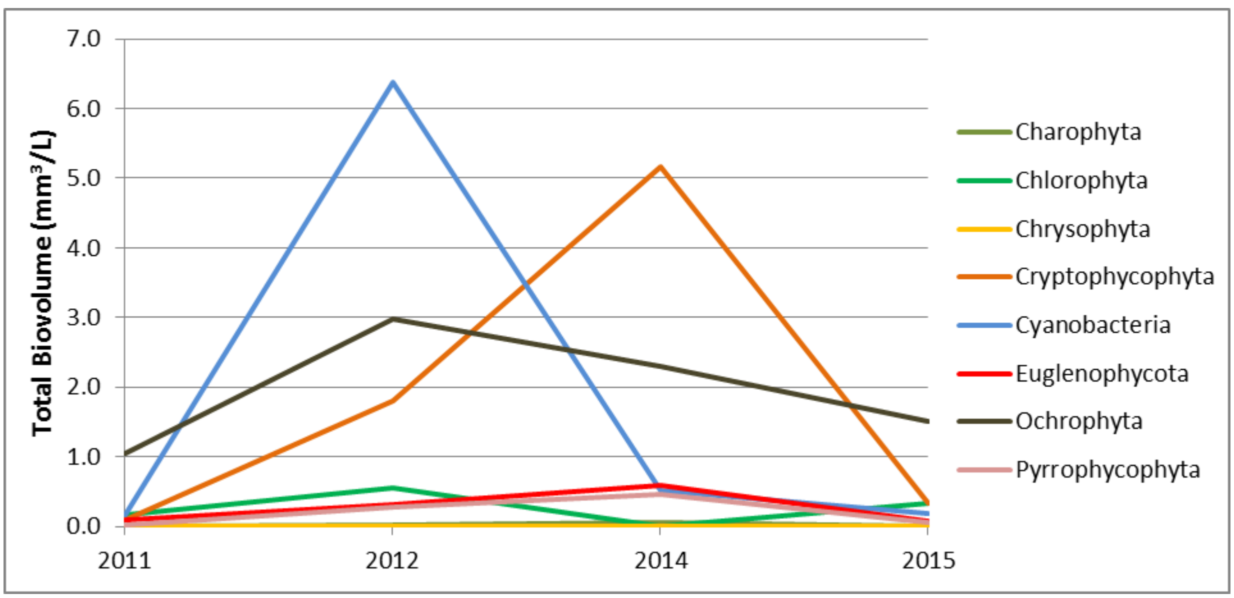


Plate 6-103. Relative abundance of phytoplankton in samples collected from Stagecoach Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are a yearly average of three summer samples (i.e. May, July, and September). Note: Analysis did not include 2013 due to an incomplete data set.

Plate 6-104. Total biomass and density by taxonomic grouping for zooplankton vertical-tow samples from Stagecoach Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	**Density (Count/L)**	**Biomass (dw µg/L)**	**Density (Count/L)**	**Biomass (dw µg/L)**	**Density (Count/L)**	**Biomass (dw µg/L)**	**Density (Count/L)**	**Biomass (dw µg/L)**
23-May-11	6	14.00	21	8.67	-----	-----	1	0.00
28-Jul-11	10	4.31	129	48.75	-----	-----	266	23.26
22-Sep-11	0	0.35	51	15.16	-----	-----	43	0.91
03-May-12	55	37.00	89	65.52	-----	-----	182	1.87
09-Jul-12	49	14.61	281	76.14	-----	-----	2,810	27.09
07-Sep-12	3	0.74	121	35.48	-----	-----	361	7.51
14-May-13	2	2.21	64	68.96	1	1.74	8	0.34
09-Jul-13	28	262.44	241	239.74	-----	-----	2,202	73.84
12-Sep-13	9	1.29	58	17.33	-----	-----	182	7.84
13-May-14	66	97.28	140	141.01	-----	-----	73	6.83
15-Jul-14	6	3.69	125	72.26	-----	-----	509	13.62
11-Sep-14	4	1.78	72	44.27	-----	-----	267	24.86
27-May-15	20	50.44	75	23.24	1	0.19	124	1.71
28-Jul-15	28	53.39	186	103.22	-----	-----	46	1
23-Sep-15	34	35.30	83	97.02	-----	-----	478	38.34

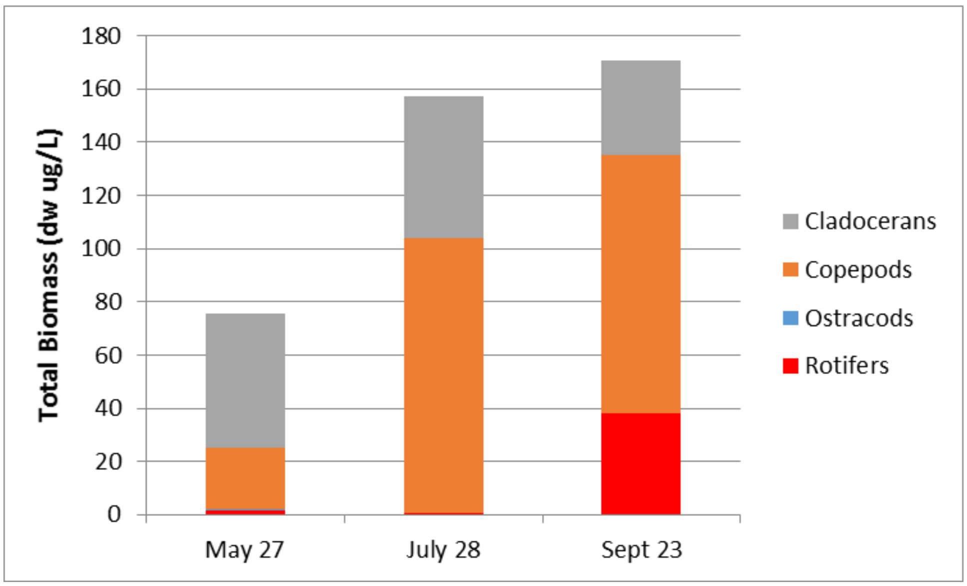


Plate 6-105. Relative abundance of zooplankton in samples collected from Stagecoach Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1).

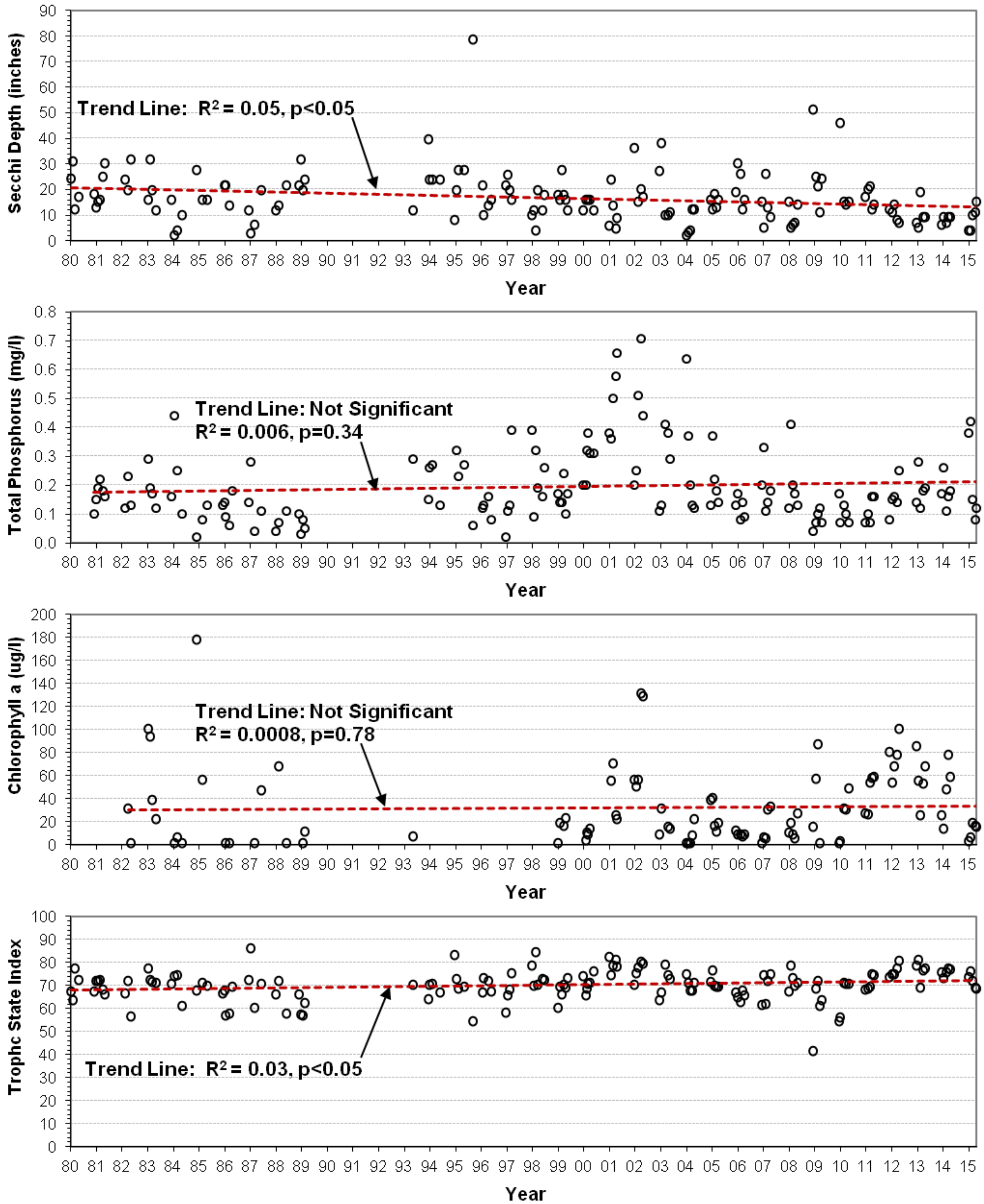


Plate 6-106. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Stagecoach Reservoir at the near-dam, ambient site (i.e., site STGLKND1) over the 36-year period of 1980 through 2015.

6.9 TWIN LAKES RESERVOIR (EAST AND WEST TWIN RESERVOIRS)

6.9.1 BACKGROUND INFORMATION

6.9.1.1 Project Overview

The dam forming Twin Lakes Reservoir is located on Middle Creek. The dam was completed on September 26, 1965 and the reservoir reached its initial fill on March 18, 1969. Twin Lakes Reservoir is composed of an east and west arm. The two arms of the reservoir basins are connected by a channel. The purpose of the connecting channel is to interconnect the reservoirs of the two embankments so they operate as a single reservoir with one outlet works and one spillway at the east embankment. Under lower pool levels, the two arms are referred to separately as the East and West Twin Reservoirs (see Figure 6.16). The Twin Lakes Reservoir watershed is 11.0 square miles. The watershed was largely agricultural when the dam was built in 1965 and has remained so to the present time.

6.9.1.2 Twin Lakes Dam Intake Structure

The dam intake at East Twin Reservoir is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 42 inches by 63 inches. The intake structure has two 24” x 63” ungated openings with a crest elevation at 1341.0 ft-msl. A 42” x 54” gated opening with a crest elevation of 1333.0 ft-msl was constructed into the upstream wall. The purpose of the gated opening is to lower the level of the conservation pool in order to inspect the conduit, make shoreline repairs, and manage fish populations. It may also be used to release water for downstream needs.

6.9.1.3 Reservoir Storage Zones

Figure 6.15 depicts the current storage zones of Twin Lakes Reservoir based on the 1994 survey data and estimated sedimentation. It is estimated that 27 to 40 percent of the “as-built” volume to the top of the Conservation Pool has been lost to sedimentation as of 2015. The annual volume loss is estimated to be 0.56 to 0.82 percent. Based on the State of Nebraska’s impairment assessment methodology, these values indicate that Twin Lakes Reservoir’s water quality dependent uses are possibly impaired due to sedimentation.

6.9.1.1 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Twin Lakes Reservoir since the late 1970’s. Water quality monitoring locations have included sites on both reservoirs and on the inflow and outflow of the reservoir. Figure 6.16 shows the location of the sites that have been monitored for water quality during the 5-year sampling period (i.e., 2011 through 2015). The inflow runoff sites (ETNNF1 and WTNNF1) were sampled by the NDEQ. The other in-reservoir sites (ETNLKND1, ETNNF1, ETNLKUP1, and WTNLKND1) were sampled by the District. The near-dam locations (ETNLKD1 and WTNLKND1) have been monitored since 1980; however, site WTNLKND1 was not monitored during the period 2008 through 2012 due to low water conditions.

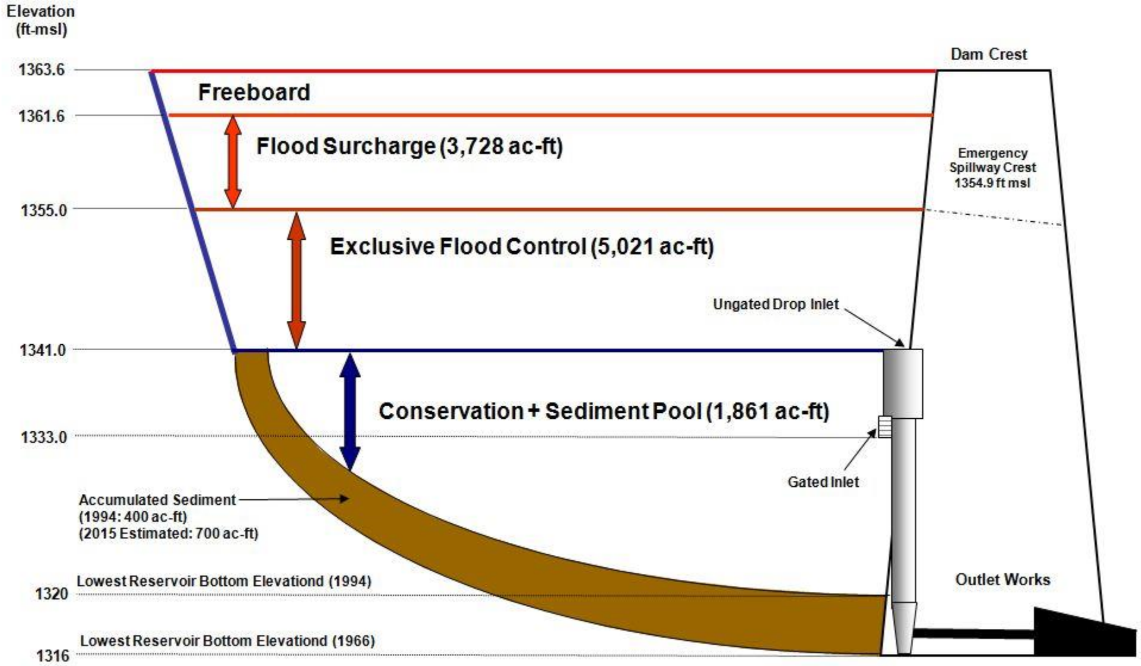


Figure 6.15. Current storage zones of Twin Lakes Reservoir based on the 1994 survey data and estimated sedimentation**.**

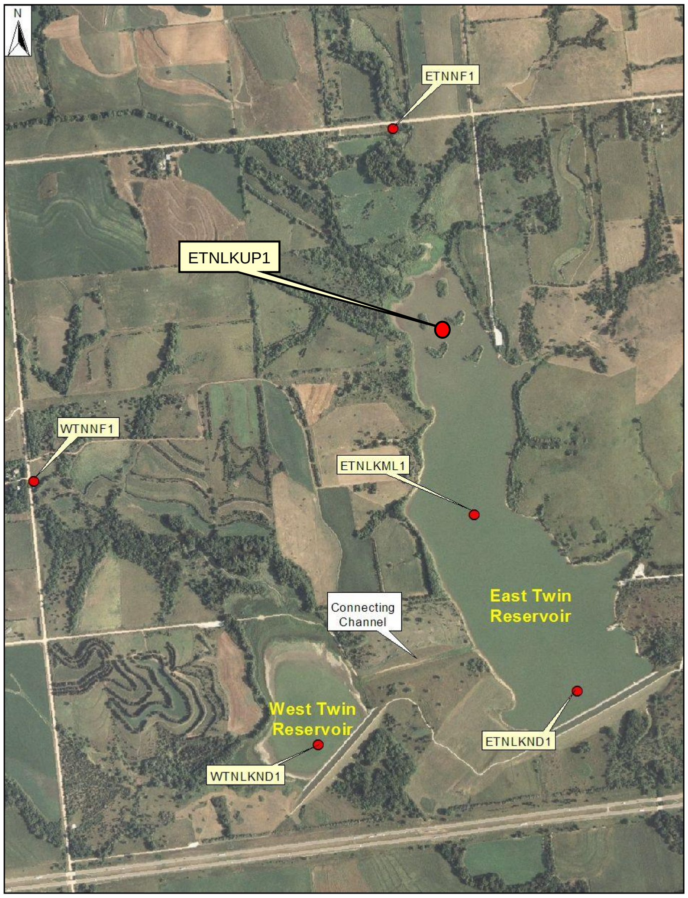


Figure 6.16. Location of sites where water quality monitoring was conducted at Twin Lakes Reservoir during the period 2011 through 2015.

6.9.2 WATER QUALITY IN TWIN LAKES RESERVOIR

6.9.2.1 Existing Water Quality Conditions

6.9.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in East Twin Reservoir at sites ETNLKND1, ETNLKML1, and ETNLKUP1 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 6-107-Plate 6-109. A review of these results indicated possible water quality concerns regarding dissolved oxygen and nutrients.

A significant number of dissolved oxygen measurements throughout East Twin Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 6-107-Plate 6-109). Most of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and appeared to be associated with a slight thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in East Twin Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation. However, thermal stratification in East Twin Reservoir was relatively limited during the 5-year sampling period of 2011 through 2015 (Plate 6-111). This limited stratification could lead to the above provision not applying to the reservoir and possible impairment for dissolved oxygen for the protection of aquatic life in East Twin Reservoir. In addition, dissolved oxygen measurements were below the 5 mg/l criterion for the protection of warmwater aquatic life from the reservoirs surface to bottom on June 24, 2015 (Plate 6-112).

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September) to be considered for impairment assessment. All three of these criteria were exceeded in East Twin Reservoir (Plate 6-107). The near-surface chlorophyll *a* criterion was exceeded in 92 percent of the "lab analyzed" samples taken in the reservoir at site ETNLKND1. The total phosphorus criteria was exceeded in all samples collected and the total nitrogen criteria was exceeded in 96 percent of the samples taken. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values (Plate 6-107) represent the growing season average for the 5-year period 2011 through 2015. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.10 mg/l), total nitrogen (1.56 mg/l), and chlorophyll *a* (37 ug/l) values at ETNLKND1 indicate impairment of the aquatic life use due to nutrients.

6.9.2.1.2 Thermal Stratification

6.9.2.1.2.1 ***Longitudinal Temperature Contour Plots***

Late-spring and summer thermal conditions of East Twin Reservoir measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 6-110 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites ETNLKND1, ETNLKML1, and ETNLKUP1 in 2015. These temperature plots indicate that East Twin Reservoir exhibited only slight thermal stratification in 2015.

6.9.2.1.2.2 ***Near-Dam Temperature Depth-Profile Plots***

Existing summer thermal stratification of East Twin Reservoir, at the deep water area near the dam, measured over the 5-year period 2011 through 2015 is depicted by depth-profile temperature plots (Plate 6-111). The depth-profile temperature plots indicate that the reservoir rarely exhibited significant summer thermal stratification over the 5-year sampling period. Since East Twin Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.9.2.1.3 Dissolved Oxygen Conditions

6.9.2.1.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of East Twin Reservoir based on depth-profile measurements taken in 2015 at sites ETNLKND1, ETNLKML1, and ETNLKUP1. Plate 6-112 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 May through July near the reservoir bottom. In late June, all of the dissolved oxygen measurements throughout the reservoir were below Nebraska's dissolved oxygen criterion for the protection of warmwater aquatic life (≥ 5 mg/l).

6.9.2.1.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

Existing summer dissolved oxygen conditions in East Twin Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2011 through 2015 (Plate 6-113). On several occasions there was a significant vertical gradient in summer dissolved oxygen levels. Thirty-six percent of the profiles showed hypoxic conditions near the reservoir bottom and one of the 25 profiles showed dissolved oxygen levels below the Nebraska's dissolved oxygen criterion for the protection of warmwater aquatic life (≥ 5 mg/l) through the entire depth of the profile. Although East Twin Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition of mixing to allow hypoxic conditions to occasionally develop near the reservoir bottom.

6.9.2.1.3.3 ***Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of East Twin 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 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 June 24, 2015 contour plot indicates a pool elevation of 1,341.3 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation at the reservoir surface, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1,331.5 ft-msl (Plate 6-112). The current District Area-Capacity Tables (1993 Survey) give storage capacities of 2,234 ac-ft for elevation 1,341.3 ft-msl and 608 ac-ft for elevation 1,331.5 ft-msl. On June 24, 2015 it is estimated that 100 percent of the volume of East Twin Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 46 percent of the reservoir volume was hypoxic.

6.9.2.1.4 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in East Twin Reservoir indicated hypoxic conditions May through July 2015. As a result, longitudinal contour plots for ORP and pH were constructed during these months. Depth profiles and near-surface/near-bottom sample comparisons were also constructed for periods of hypoxic conditions during the summer from 2011 through 2015.

6.9.2.1.4.1 ***Oxidation-Reduction Potential***

Plate 6-114 provides longitudinal ORP contour plots based on depth-profile measurements taken in 2015 when hypoxic conditions were present in East Twin Reservoir. The ORP values indicated slightly reduced conditions occurred near the reservoir bottom near the dam in July 2015, with measurements below 150 mV. However, much of the reservoir ORP measurements were greater than 300 mV. Plate 6-115 plots depth profiles for ORP measured during the summer over the 5-year sampling period in the deep water area of East Twin Reservoir near the dam when hypoxic conditions were present. The ORP depth profiles indicate that slightly reduced conditions occasionally occurred in East Twin Reservoir during the summer, however, these conditions were rarely below 150 mV.

6.9.2.1.4.2 ***pH***

Longitudinal contour plots for pH conditions measured in 2015 when hypoxic conditions were present are provided in Plate 6-116. Plate 6-117 plots depth profiles for pH measured during the summer over the 5-year sampling period in the deep water area of East Twin Reservoir near the dam when hypoxic conditions were present. A slight vertical gradient in pH occasionally occurred in the reservoir during summer hypoxic conditions. Lower pH levels near the bottom of the reservoir could be attributable to reservoir stratification and ongoing decomposition/respiration near the reservoir bottom. This would lead to an increase in CO_2 and decrease in pH. All of the measurement were within Nebraska's pH criterion for the protection of warmwater aquatic life.

6.9.2.1.4.3 ***Comparison of Near-Surface and Near-Bottom Water Quality Conditions***

Paired near-surface and near-bottom water quality samples collected from East Twin Reservoir during the summer when hypoxia was present 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 ETNLKND1 during the 5-year period 2011 through 2015. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 9 (36%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 6-118). A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were not significantly different for nitrate-nitrite nitrogen (p=0.32) and Orthophosphorus (p=0.06). Total alkalinity, total ammonia nitrogen, and total phosphorus were significantly higher in the near-bottom samples when hypoxia was present ($p<0.05$). Parameters that were significantly lower in the near-bottom water of East Twin Reservoir when hypoxia was present included water temperature, dissolved oxygen, oxidation-reduction potential and pH ($p<0.05$).

6.9.2.1.4.4 ***Reservoir Trophic Status***

Trophic State Index (TSI) values for East Twin Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., ETNLKND1). Table 6.31 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of East Twin Reservoir is in a slightly hypereutrophic condition.

6.9.2.1.5 Reservoir Plankton Community

6.9.2.1.5.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at the East Twin Reservoir near-surface, near-dam sampling site during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-119). The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 6-120. The highest phytoplankton total biovolume was observed in September. Ochrophyta and Pyrrophycophyta dominated the 2015 growing season. Major and dominant phytoplankton genera sampled in 2015 at East Twin Reservoir are provided in Table 6.32.

Annual variation in phytoplankton community composition is displayed in Plate 6-121. During the 5-year period 2011 through 2015, East Twin Reservoir was mostly dominated by Cyanobacteria, with the exception of 2015 which was dominated by Ochrophyta and Pyrrophycophyta. Cyanobacteria density levels reached levels higher than the World Health Organizations high level of health risk (>100,000 Cells/ml) in 2012 and early 2013 (Plate 6-119). 2012 was a particularily warm and dry year. The longer residence time, decreased mixing, and warmer waters could have lead to a longer Cyanobacterial growing season, causing the observed high biovolumes and densities in 2012. The high Cyanobacterial density observed in May 2013 could be a carry over from the high densities in 2012. Maximum measured extracellular microcystin toxin level at the near-dam site during the 5-year period was 0.8 µg/l (Plate 6-107).

Table 6.31. Summary of Trophic State Index (TSI) values calculated for East Twin Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	24	73	72	64	87
TSI(TP)	25	63	63	59	75
TSI(Chl)	25	73	75	53	83
TSI(Avg)	25	69	69	66	75

* 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 for the individual parameters.

Note: See Section 4.1.3 for discussion of TSI calculation.

Table 6.32. Listing of major and dominant phytoplankton genera Sampled in East Twin Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1)

Division	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cryptophycophyta	*Rhodomonas*	*Cryptomonas*
Ochrophyta	-----	*Aulacoseira, Stephanodiscus*
Pyrrophycophyta	-----	*Ceratium*

6.9.2.1.5.1 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at East Twin Reservoir near-dam sampling sites during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-122). The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in Plate 6-123. East Twin Reservoir was dominated largely by Cladocerans and Copepods with the highest zooplankton total biomass in July. Dominant and major zooplankton genera sampled in East Twin Reservoir during 2015 are provided in Table 6.33.

Table 6.33. Listing of major and dominant zooplankton genera sampled in East Twin Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1)

Taxonomic Group	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cladocerans	*Diaphanosoma*	*Daphnia*
Copepods	*Cyclopoida, Leptodiaptomus, Mesocyclops*	*Calanoida*

6.9.2.1.6 Zebra Mussel Monitoring

Zebra mussel veliger sampling has been conducted once yearly since 2012 at East Twin Reservoir. During the sampling period (2012-2015) no veligers have been identified.

6.9.2.2 Water Quality Trends (1980 through 2015)

Water quality trends from 1980 to 2015 were determined for East Twin 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., ETNLKND1). Plate 6-124 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, no significant trend was observed for Secchi depth (p=0.66, R^2=0.002), total phosphorus (p=0.06, R^2=0.03), and chlorophyll a (p=0.07, R^2=0.04), and TSI (p=0.15, R^2=0.008). Over the 36-year period since 1980, East Twin Reservoir has remained in a slightly hypereutrophic condition.

6.9.3 PLATES

Plate 6-107. Summary of water quality conditions monitored in East Twin Reservoir at site ETNLKND1 from May to September during the 5-year 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	24	1332.33	1340.70	1241.00	1341.80	-----	-----	-----
Water Temperature (°C)	0.1	258	23.17	23.61	16.09	30.66	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	258	6.62	7.11	n.d.	13.56	≥5(2)	63	24%
Dissolved Oxygen, Near-Surface (mg/l)(C)	0.1	25	8.10	7.98	4.43	12.50	≥5(2)	1	4%
Dissolved Oxygen (% Sat.)	0.1	258	80.07	85.55	n.d.	164.70	-----	-----	-----
Secchi Depth (in.)	1	24	17.33	17.00	6.00	29.00	-----	-----	-----
Turbidity (NTUs)	1	248	31.35	25.85	6.70	185.60	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	258	356.12	363.00	110.00	490.00	-----	-----	-----
Specific Conductance (umho/cm)	1	258	381.14	379.95	264.40	460.30	2,000(3)	0	0%
pH (S.U.)	0.1	258	8.13	8.19	6.82	8.84	≥6.5 & ≤9.0 (1)	0	0%
Alkalinity, Total (mg/l)	1	50	127.92	127.00	104.00	160.00	>20(1)	0	0%
Suspended Solids, Total (mg/l)	4	50	22.60	19.00	n.d.	102.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	50	-----	0.13	n.d.	1.47	1.92(4,5), 0.44(4,6)	0,3	0%,6%
Ammonia, Total, Near-Surface (mg/l)(C)	0.02	25	-----	0.07	n.d.	0.61	1.57(4,5), 0.38(4,6)	0,1	0%,4%
Kjeldahl N, Total (mg/l)	0.08	50	1.56	1.48	0.95	3.58	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	50	-----	0.03	n.d.	0.70	100(3)	0	0%
Nitrogen, Total (mg/l)	0.08	50	1.68	1.54	0.99	3.60	1(7)	49	98%
Nitrogen, Total, Near-Surface (mg/l)(C)	0.08	25	1.56	1.49	0.99	2.35	1(7)	24	96%
Phosphorus, Total (mg/l)	0.005	50	0.12	0.10	0.06	0.40	0.05(7)	50	100%
Phosphorus, Total, Near-Surface (mg/l) (C)	0.005	25	0.10	0.09	0.06	0.30	0.05(7)	25	100%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	n.d.	n.d.	0.18	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	126.56	126.40	119.00	137.10	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	5	3.20	3.00	2.00	4.00	340(5), 16.7(8)	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	0.30	7.41(5), 0.29(6)	0,1	0%,20%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	717.30(5), 93.38(6)	0	0%
Copper, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	16.76(5), 10.94(6)	0	0%
Iron, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	20.00	1000(6)	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	83.27(5), 3.24(6)	0	0%
Manganese, Dissolved (ug/l)	2	5	-----	4.00	n.d.	10.00	1000(6)	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	570.88(5), 63.41(6)	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5.16(5)	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	142.91(5), 144.08(6)	0	0%
Antimony, Dissolved (ug/l)	0.03	5	-----	0.60	n.d.	0.70	88(5), 30(6)	0	0%
Aluminum, Dissolved (ug/l)	40	5	-----	n.d.	n.d.	n.d.	750(5), 87(6)	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77(6)	0	0%
Chlorophyll a (ug/l) – Lab Determined(C)	6	25	37	38	n.d.	83	10(7)	23	92%
Chlorophyll a (ug/l) – Field Probe	6	258	47	38	n.d.	144	10(7)	234	91%
Atrazine, Total (ug/l)(D)	0.1	25	2.32	2.20	0.20	4.60	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l) (D)	0.1	24	1.00	0.80	n.d.	3.20	390(5), 100(6)	0	0%
Acetochlor, Total (ug/l) (D)	0.05	25	196.45	0.70	n.d.	4890.00	-----	-----	-----
Microcystin, Extracellular (ug/l)	0.1	23	-----	n.d.	n.d.	0.80	20(9)	0	0%
Pesticide Scan (ug/l)(E)									
Atrazine, Tot	0.13	4	1.41	1.11	0.61	2.80	330(5), 12(6)	0	0%
Acetochlor, Tot	0.08	4	-----	n.d.	n.d.	n.d.	-----	-----	-----
Metolachlor, Tot	0.05	4	-----	0.62	n.d.	1.60	390(5), 100(6)	0	0%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-108. Summary of water quality conditions monitored in East Twin Reservoir at site ETNLKML1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	19	1330.04	1340.60	1241.00	1341.80	-----	-----	-----
Water Temperature (°C)	0.1	208	23.19	23.52	15.55	30.98	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	208	6.94	6.97	0.00	12.00	≥5(2)	36	17%
Dissolved Oxygen (% Sat.)	0.1	208	84.34	84.95	0.00	162.60	-----	-----	-----
Secchi Depth (in.)	1	25	15.32	14.00	6.00	32.00	-----	-----	-----
Turbidity (NTUs)	1	200	33.62	27.30	9.40	208.50	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	208	363.70	369.00	129.00	518.00	-----	-----	-----
Specific Conductance (umho/cm)	1	208	378.29	378.40	269.50	448.20	2,000(3)	0	0%
pH (S.U.)	0.1	208	8.18	8.18	6.86	8.89	≥6.5 & ≤9.0 (1)	0	0%
Chlorophyll a (ug/l) – Field Probe	6	208	49	41	3	381	10(4)	185	89%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-109. Summary of water quality conditions monitored in East Twin Reservoir at site ETNLKUP1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	19	1330.04	1340.60	1241.00	1341.80	-----	-----	-----
Water Temperature (°C)	0.1	48	23.49	23.73	16.84	31.75	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	48	7.73	7.11	4.00	12.81	≥5(2)	6	13%
Dissolved Oxygen (% Sat.)	0.1	48	95.31	87.70	53.50	177.50	-----	-----	-----
Secchi Depth (in.)	1	24	10.33	9.50	3.00	22.00	-----	-----	-----
Turbidity (NTUs)	1	47	58.78	38.70	15.80	219.80	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	48	364.88	371.50	188.00	496.00	-----	-----	-----
Specific Conductance (umho/cm)	1	48	369.08	369.55	306.00	447.50	2,000(3)	0	0%
pH (S.U.)	0.1	48	8.25	8.40	7.30	9.11	≥6.5 & ≤9.0 (1)	0,1	0%,2%
Chlorophyll a (ug/l) – Field Probe	6	48	52	42	3	174	10(4)	41	85%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

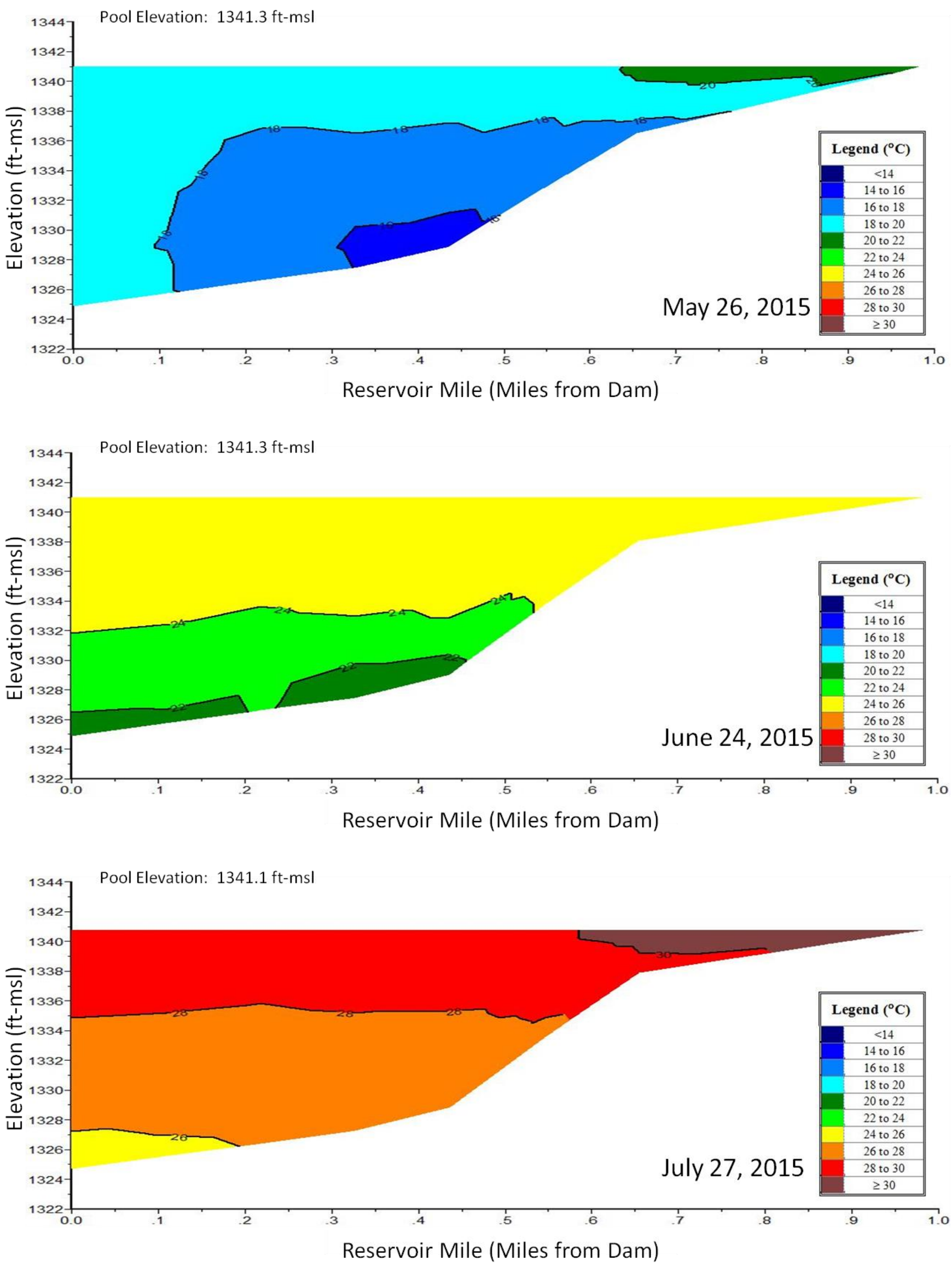
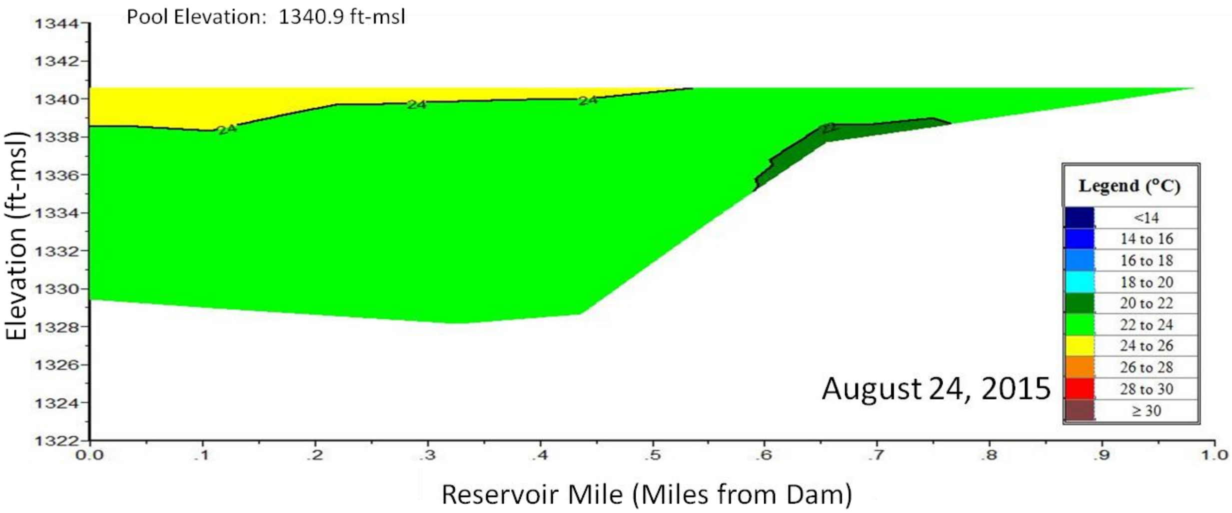


Plate 6-110. Longitudinal water temperature contour plots of East Twin Reservoir based on depth-profile water temperatures (°C) measured at sites ETNLKND1, ETNLKML1, and ETNLKUP1 in 2015.



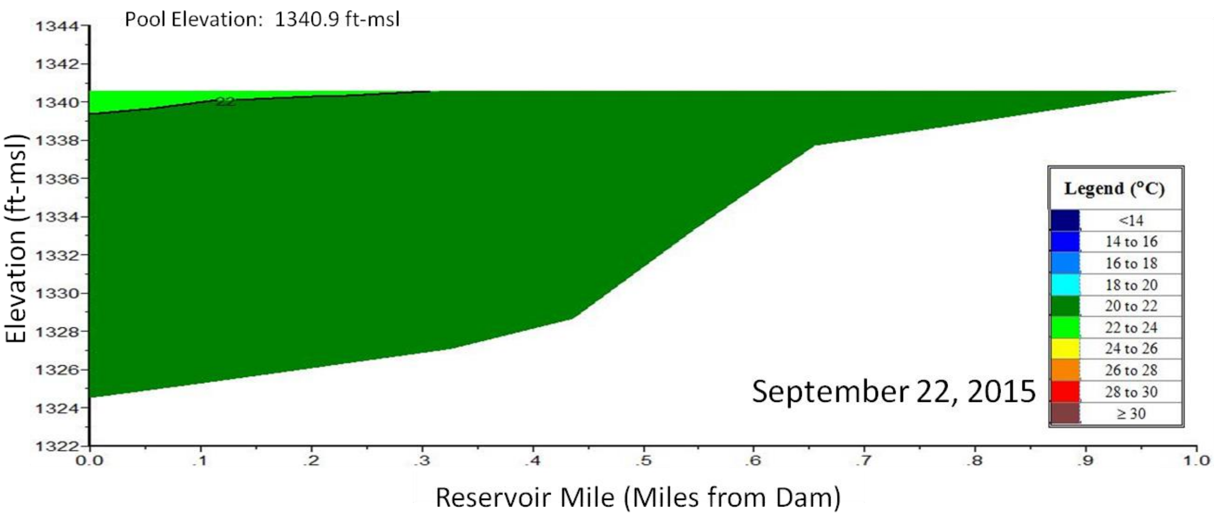


Plate 6-110. (Continued).

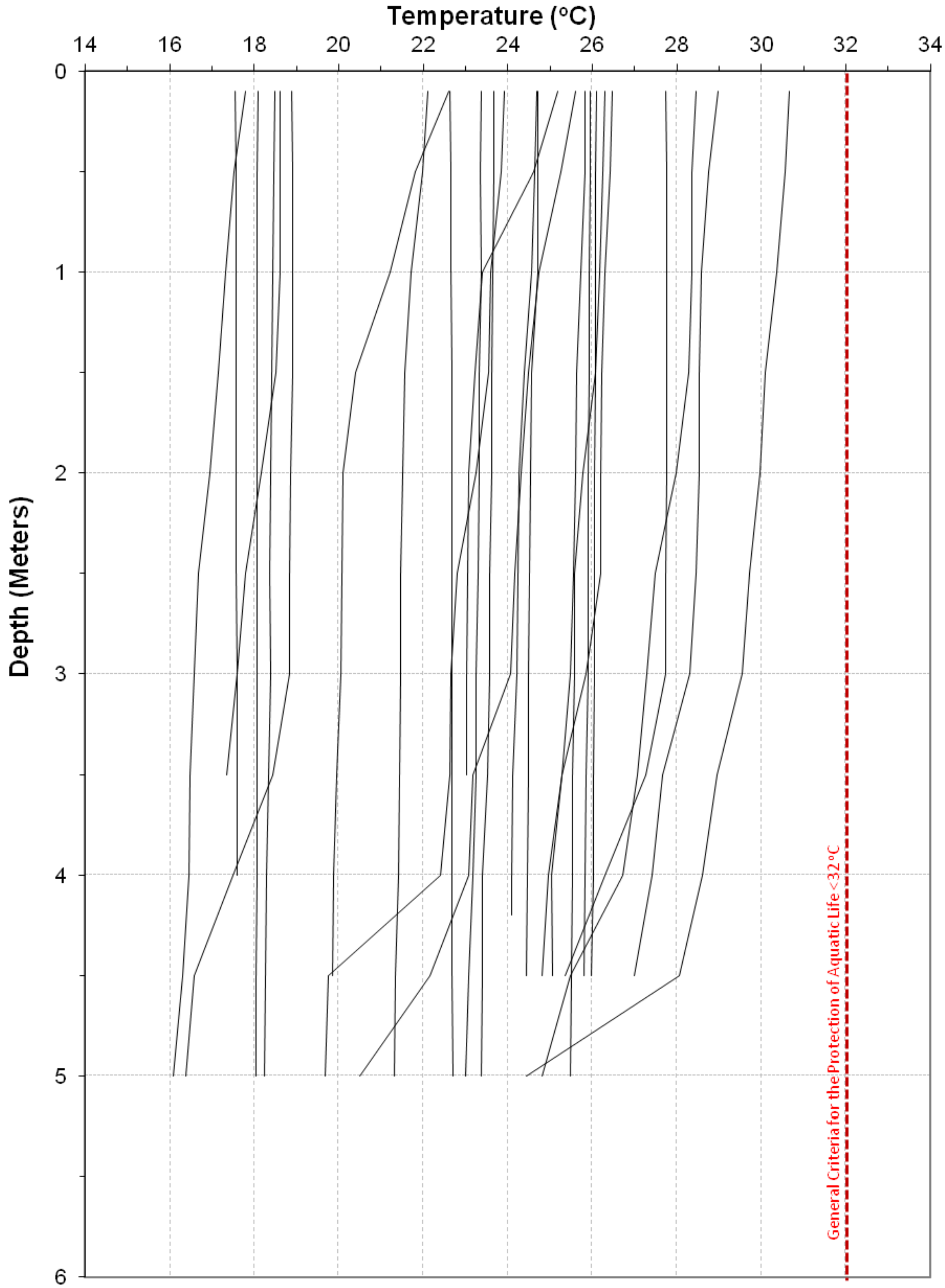
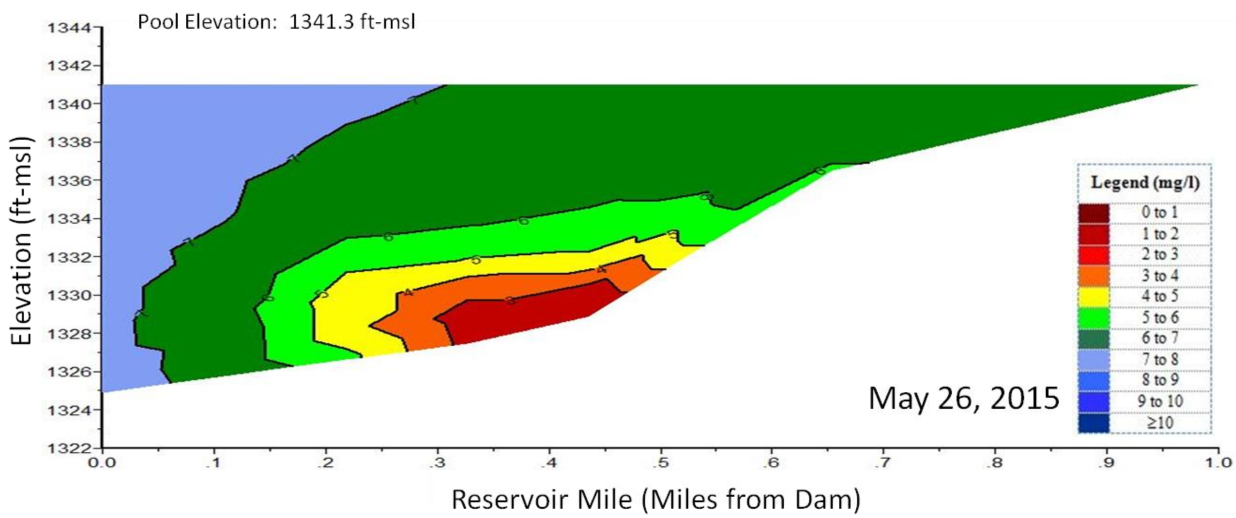
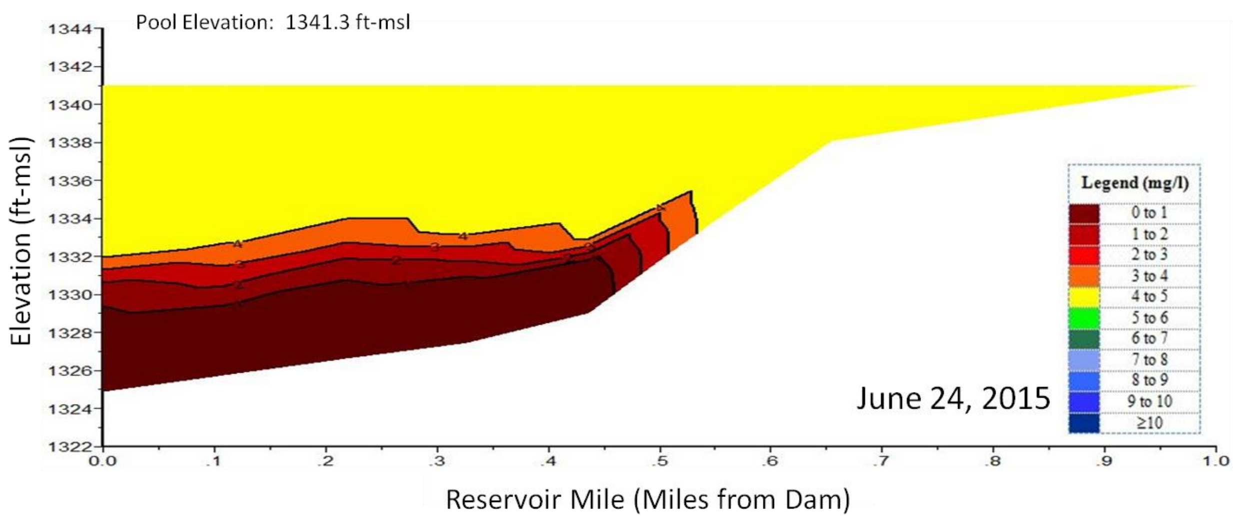


Plate 6-111. Temperature depth profiles for East Twin Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1) during the summer over the 5-year period of 2011 through 2015.





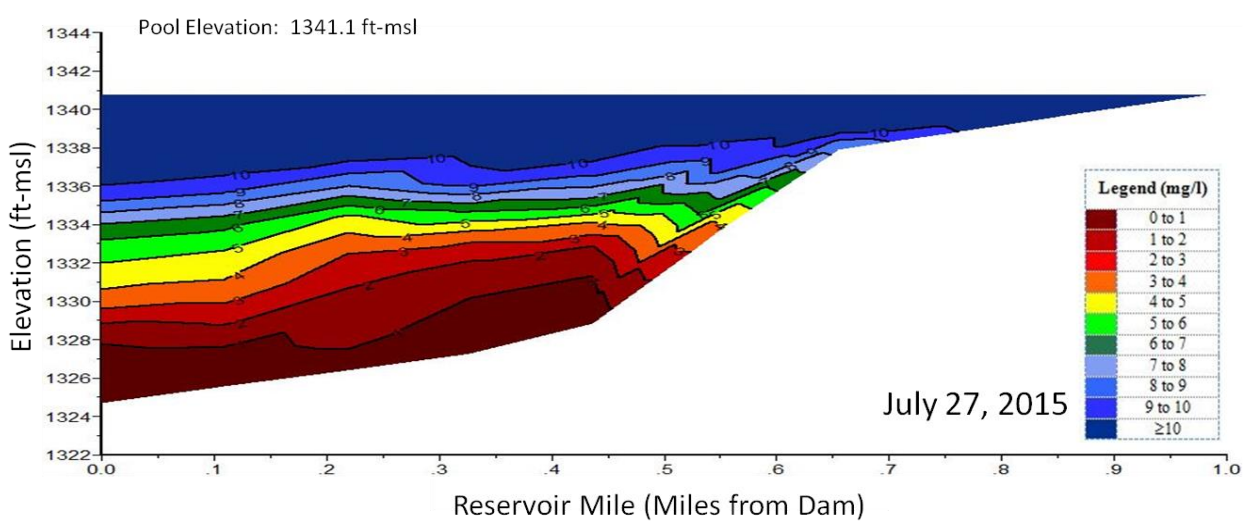
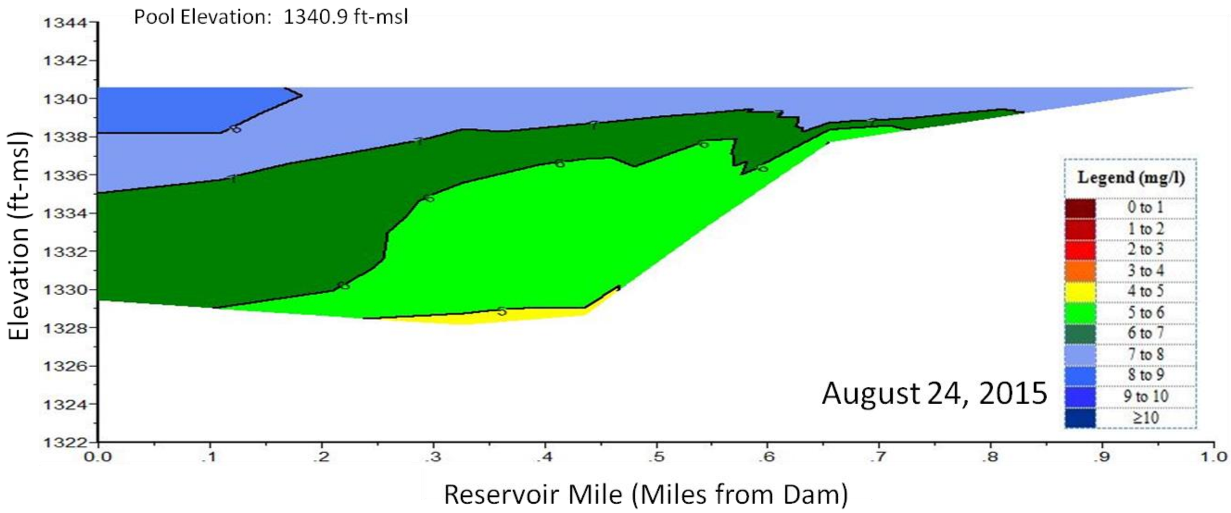


Plate 6-112. Longitudinal dissolved oxygen contour plots of East Twin Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites ETNLKND1, ETNLKML1, and ETNLKUP1 in 2015.



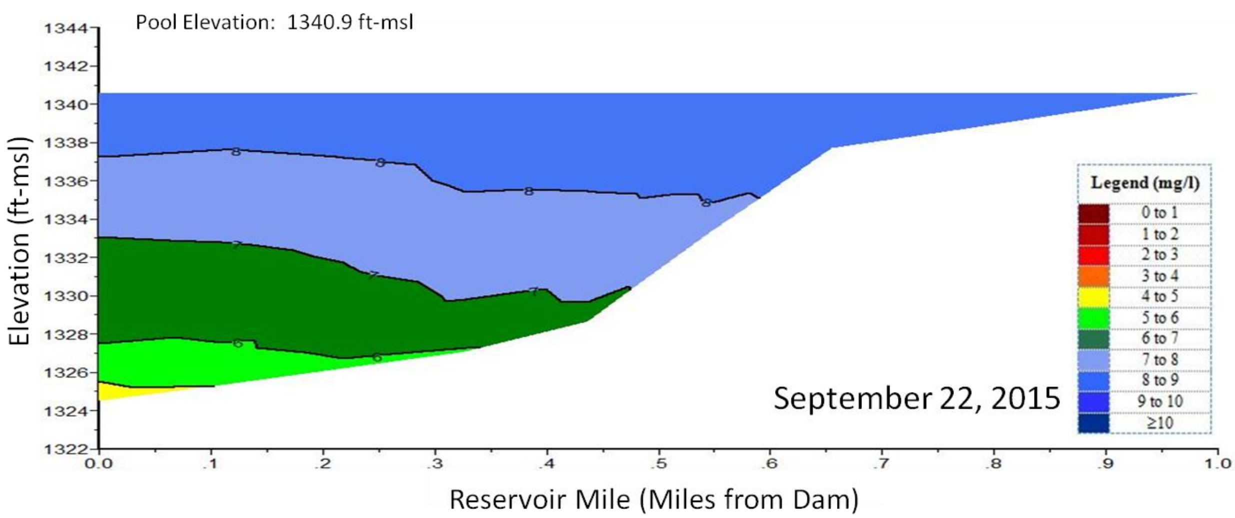


Plate 6-112. (Continued).

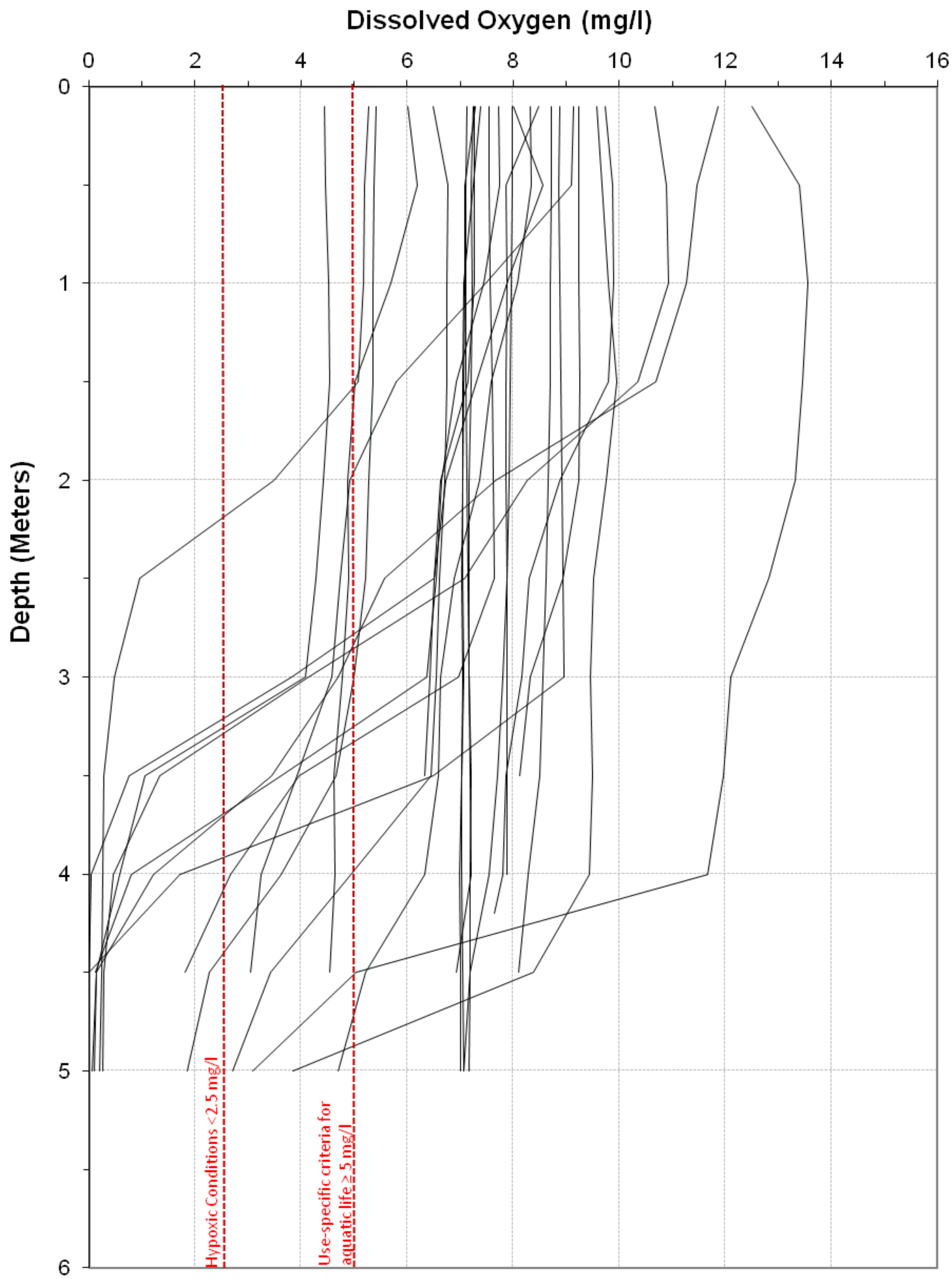


Plate 6-113. Dissolved oxygen depth profiles for East Twin Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1) during the summer over the 5-year period 2011 through 2015.

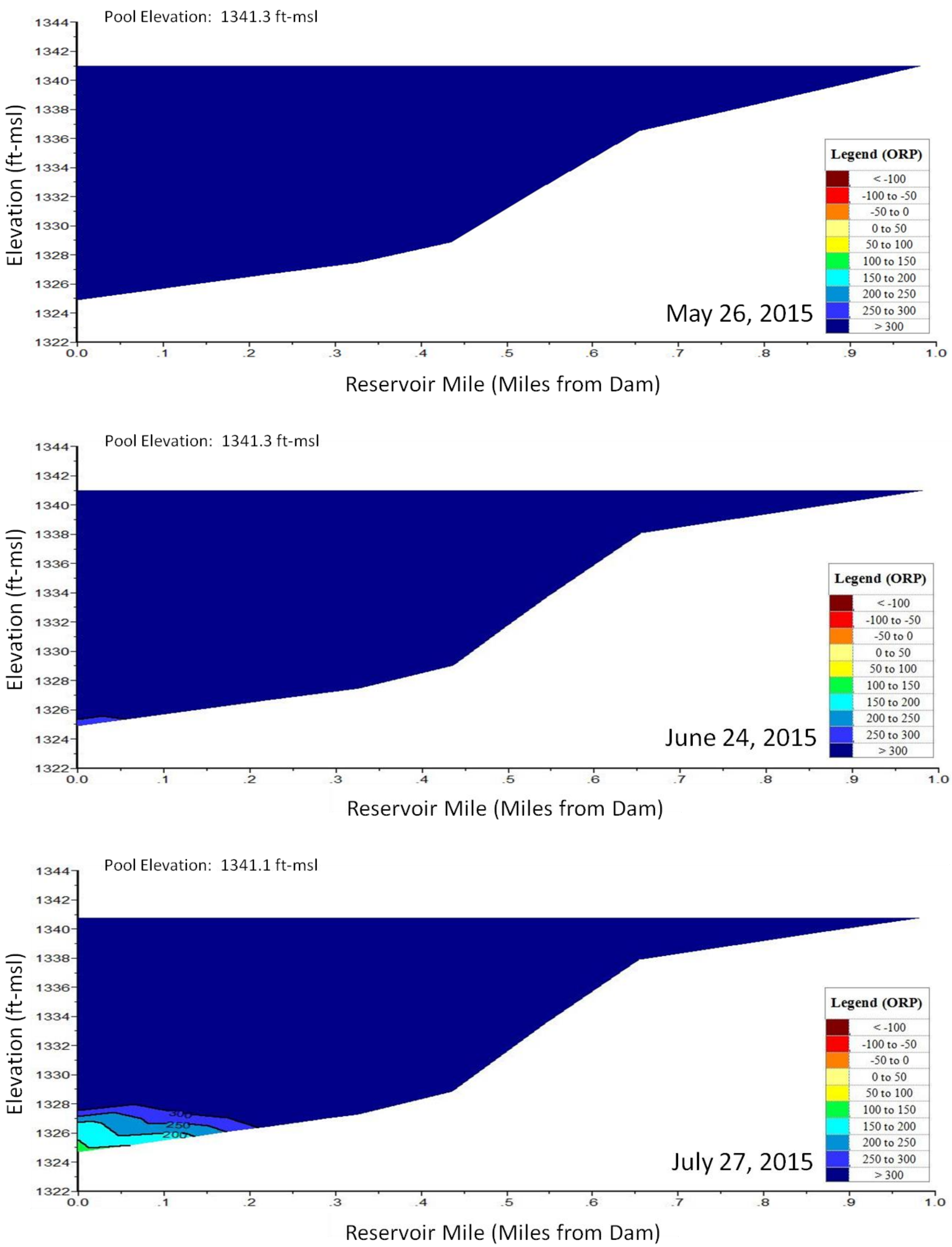


Plate 6-114. Longitudinal oxidation-reduction potential contour plots of East Twin Reservoir based on depth-profile ORP levels (mV) measured at sites ETNLKND1, ETNLKML1, and ETNLKUP1 in 2015.

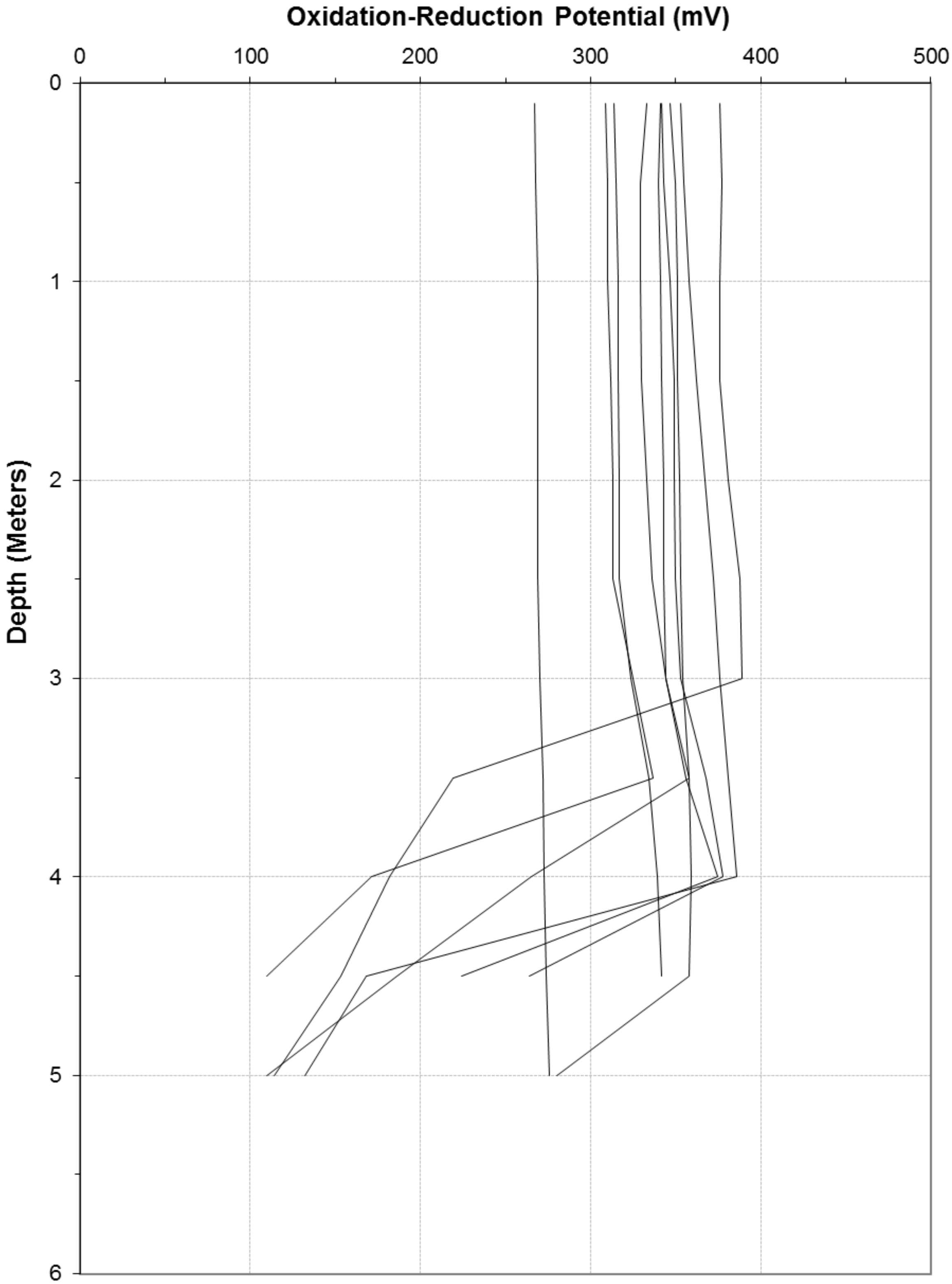
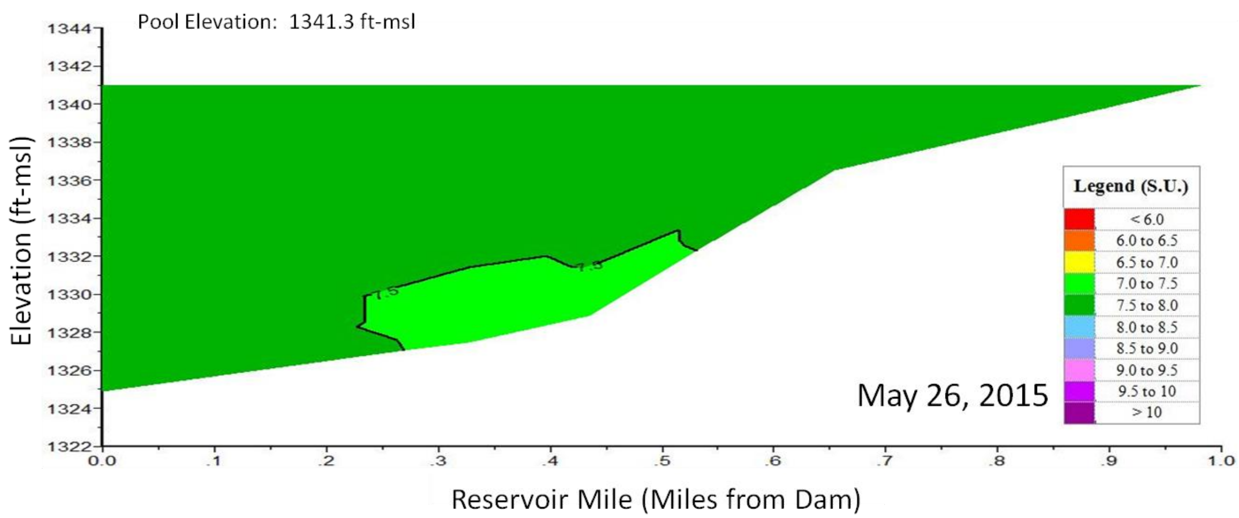
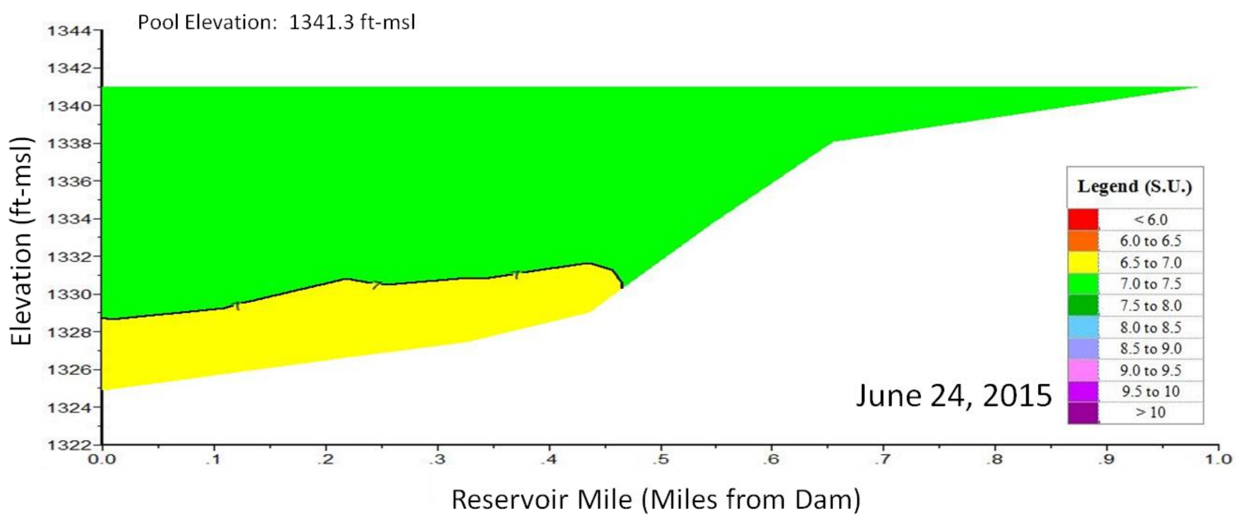


Plate 6-115. Oxidation-reduction potential depth profiles for East Twin Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1) when hypoxic conditions were present, during the summer, over the 5-year period of 2011 through 2015.





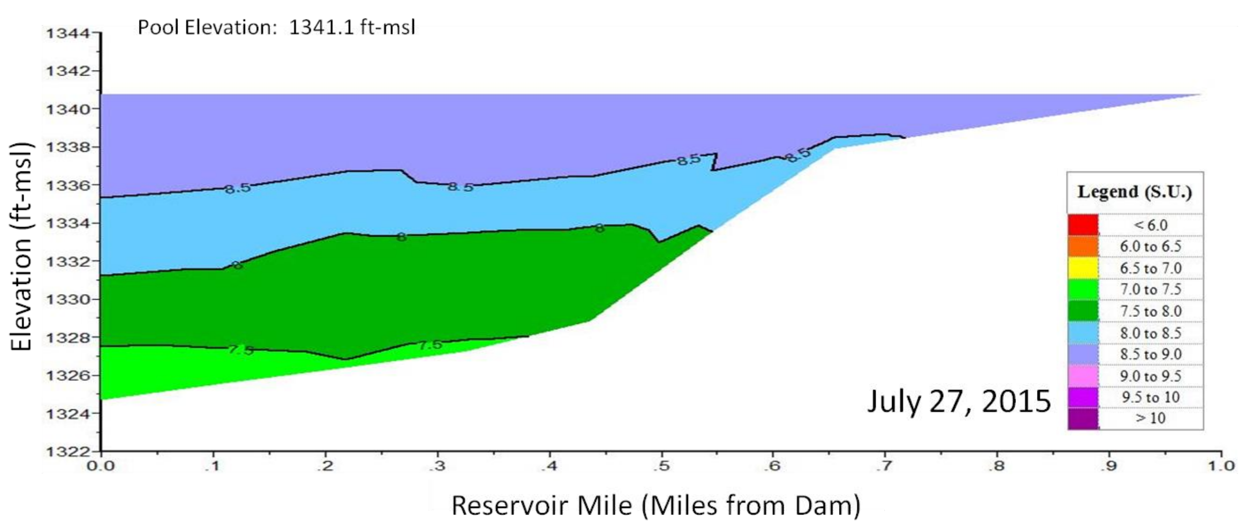


Plate 6-116. Longitudinal pH contour plots of Stagecoach Reservoir based on depth-profile pH levels (S.U.) measured at sites STGLKND1, STGLKML1, and STGLKUP1 in 2015.

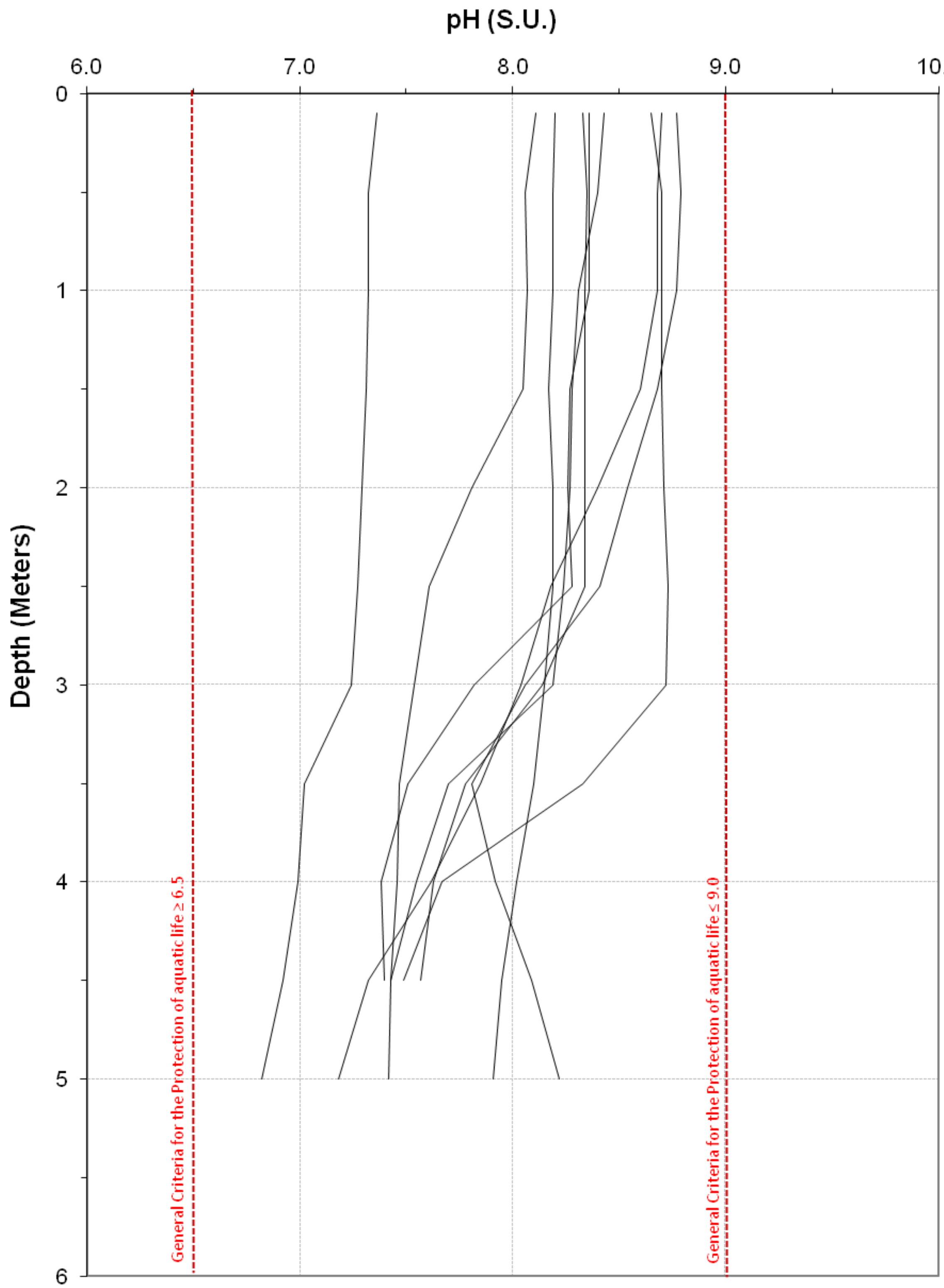


Plate 6-117. pH depth profiles for East Twin Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1) during the summer over the 5-year period of 2011 through 2015, when hypoxic conditions were present.

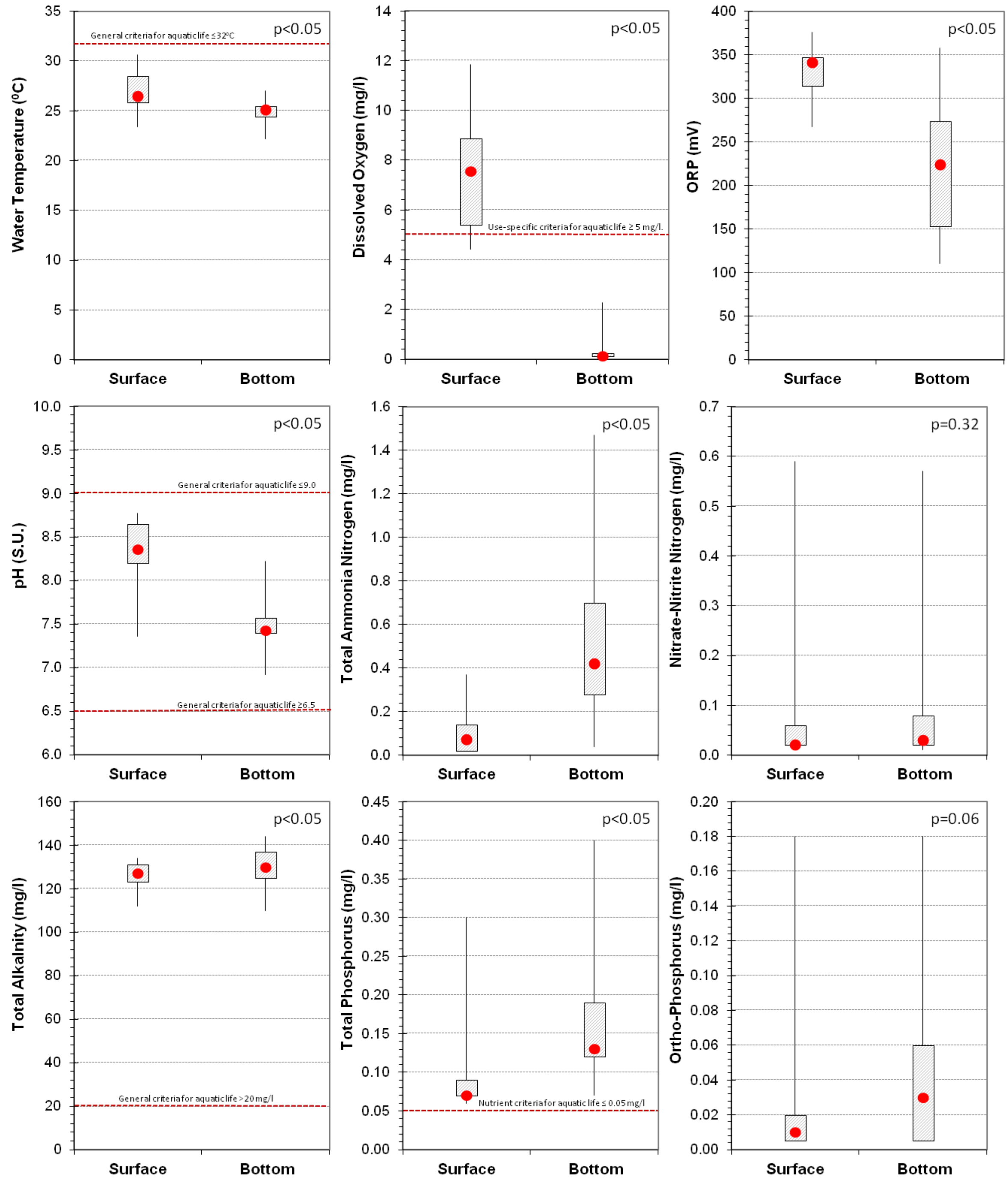


Plate 6-118. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, total ammonia nitrogen, nitrate-nitrite nitrogen, alkalinity, total phosphorus, and ortho-phosphorus measured in East Twin Reservoir when summer hypoxic conditions were present during the 5-year period of 2011 through 2015 (n=9). P-values indicate significant differences between the near-surface and near-bottom samples via a paired two-tailed t-test (α = 0.05). (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot. Water quality criteria marked with red line when applicable)

Plate 6-119. Total biovolume and density by taxonomic group for phytoplankton grab samples from East Twin Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**
24-May-11	5,971	20	162,606	1,470	-----	-----	7,009	149	74,161	5,980	900	3	78,743	91	6,243	3
27-Jul-11	3,256	11	88,377	1,980	-----	-----	6,347	79	536,068	42,442	41,998	53	172,622	594	11,399	17
21-Sep-11	18,301	53	28,574	185	12,804	191	15,603	238	645,194	70,053	1,600	3	186,984	200	1,524	3
30-Apr-12	-----	-----	91,329	1,473	-----	-----	47,194	204	9,942,720	283,609	73,049	31	151,853	281	-----	-----
05-Jul-12	-----	-----	313,942	2,863	8,362	12	81,878	630	386,202	119,293	60,343	48	2,136,654	1,781	-----	-----
06-Sep-12	-----	-----	548,517	7,520	-----	-----	3,309,345	1,604	9,091,343	347,327	167,369	131	3,559,729	13,766	-----	-----
15-May-13	605,671	61	612,071	5,169	-----	-----	1,005,655	11,856	11,028,851	131,393	-----	-----	2,900,896	6,493	-----	-----
08-Jul-13	-----	-----	658,086	570	-----	-----	1,149,073	13,547	6,756,348	49,520	69,824	57	2,211,575	1,236	6,266,955	285
10-Sep-13	7,307	0	1,282,543	3,487	-----	-----	892,044	10,517	199,378	18,431	34,792	36	908,041	2,296	813,087	36
12-May-14	457,430	58	82,180	959	40,893	15	255,899	2,742	220,960	3,059	-----	-----	2,120,882	4,437	-----	-----
14-Jul-14	-----	-----	2,061,393	5,867	-----	-----	2,590,939	1,939	4,111,343	46,483	1,395,007	111	942,842	2,763	3,819,058	232
26-May-15	49,588	9	26,612	280	27,479	7	479,738	1,289	13,144	29	5,237	4	254,213	704	-----	-----
27-Jul-15	148,901	46	339,596	2,907	33,848	59	1,270,589	3,506	178,266	7,247	-----	-----	4,395,983	13,547	31,610	6
22-Sep-15	-----	-----	316,005	1,516	-----	-----	1,294,199	7,078	419,886	10,743	21,419	8	2,608,646	7,584	7,745,524	272

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

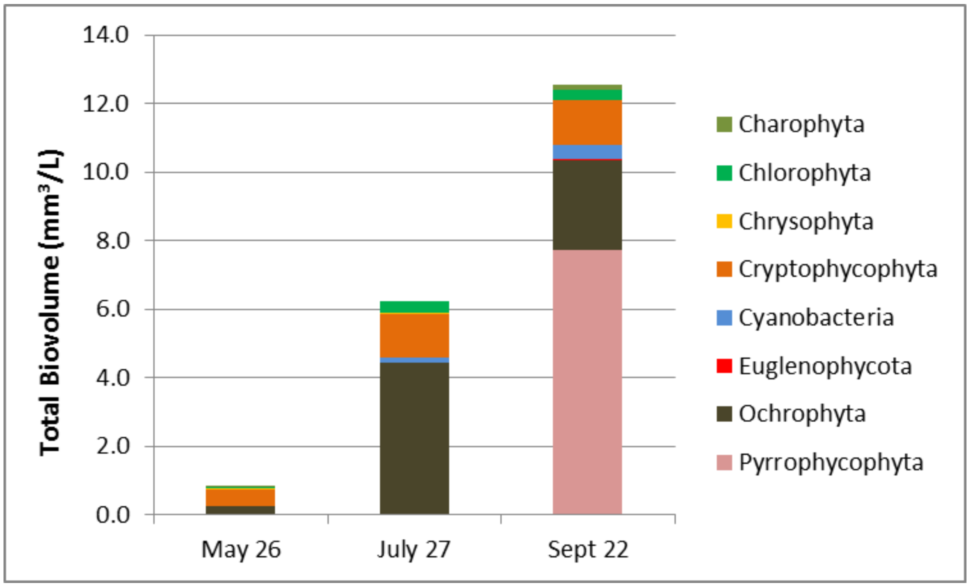


Plate 6-120. Relative abundance of phytoplankton in samples collected from East Twin Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1).

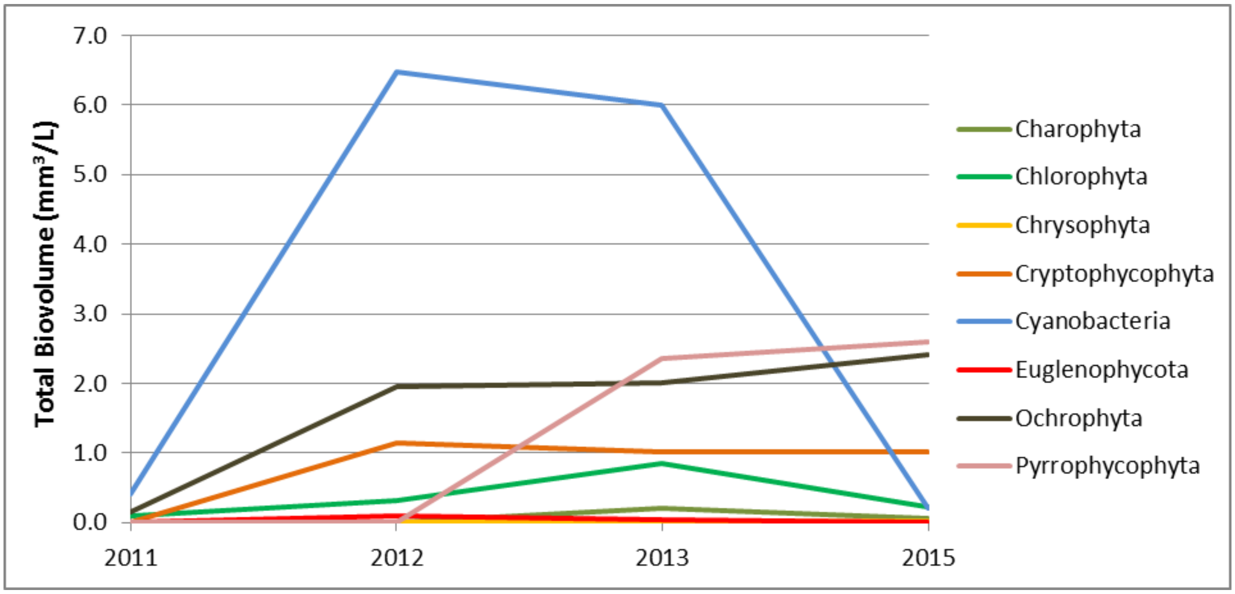


Plate 6-121. Relative abundance of phytoplankton in samples collected from East Twin Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are a yearly average of three summer samples (i.e. May, July, and September). Note: Analysis did not include 2014 due to an incomplete data set.

Plate 6-122. Total biomass and density by taxonomic grouping for zooplankton vertical-tow samples from East Twin Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	**Density (Count/L)**	**Biomass (dw µg/L)**	**Density (Count/L)**	**Biomass (dw µg/L)**	**Density (Count/L)**	**Biomass (dw µg/L)**	**Density (Count/L)**	**Biomass (dw µg/L)**
25-May-11	30	244.50	200	91.58	-----	-----	34	3.88
27-Jul-11	29	45.41	116	170.53	0	0.03	14	0.19
21-Sep-11	59	111.68	35	24.19	-----	-----	3	0.00
30-Apr-12	32	387.00	60	137.65	-----	-----	18	0.27
05-Jul-12	56	516.38	484	823.97	4	15.12	1,368	18.02
06-Sep-12	4	4.09	99	73.79	-----	-----	7	0.14
15-May-13	3	38.06	87	103.89	-----	-----	32	4.49
08-Jul-13	6	16.99	19	17.27	-----	-----	63	1.21
10-Sep-13	11	23.49	185	147.44	-----	-----	477	15.20
12-May-14	4	13.08	47	34.85	-----	-----	33	3.65
14-Jul-14	13	27.51	149	211.08	-----	-----	279	14.37
10-Sep-14	8	46.67	101	71.68	-----	-----	60	1.80
26-May-15	29	80.75	71	77.08	-----	-----	29	0.22
27-Jul-15	42	122.07	112	144.48	-----	-----	62	5
22-Sep-15	9	42.54	80	57.96	-----	-----	105	1.79

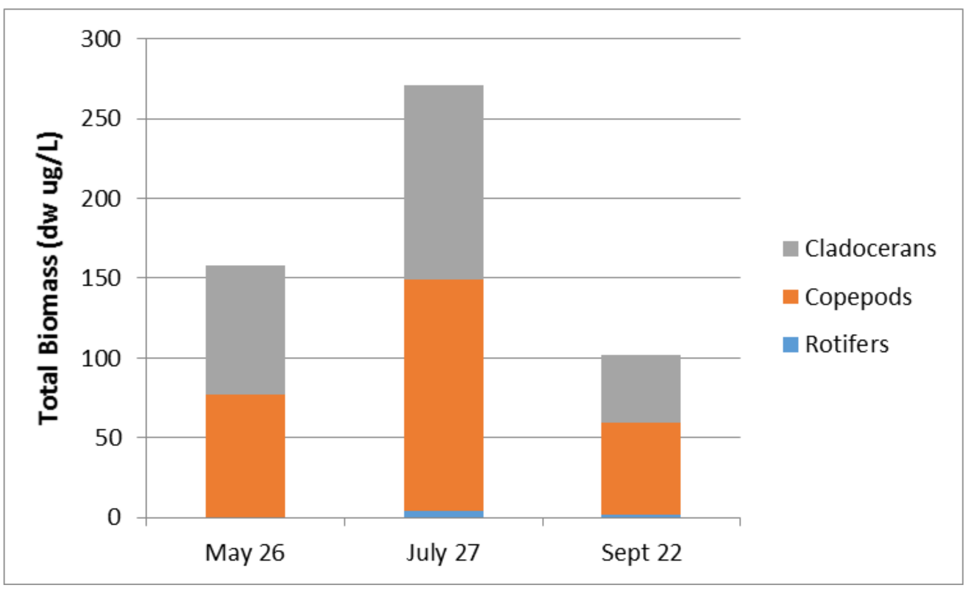


Plate 6-123. Relative abundance of zooplankton in samples collected from East Twin Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1).

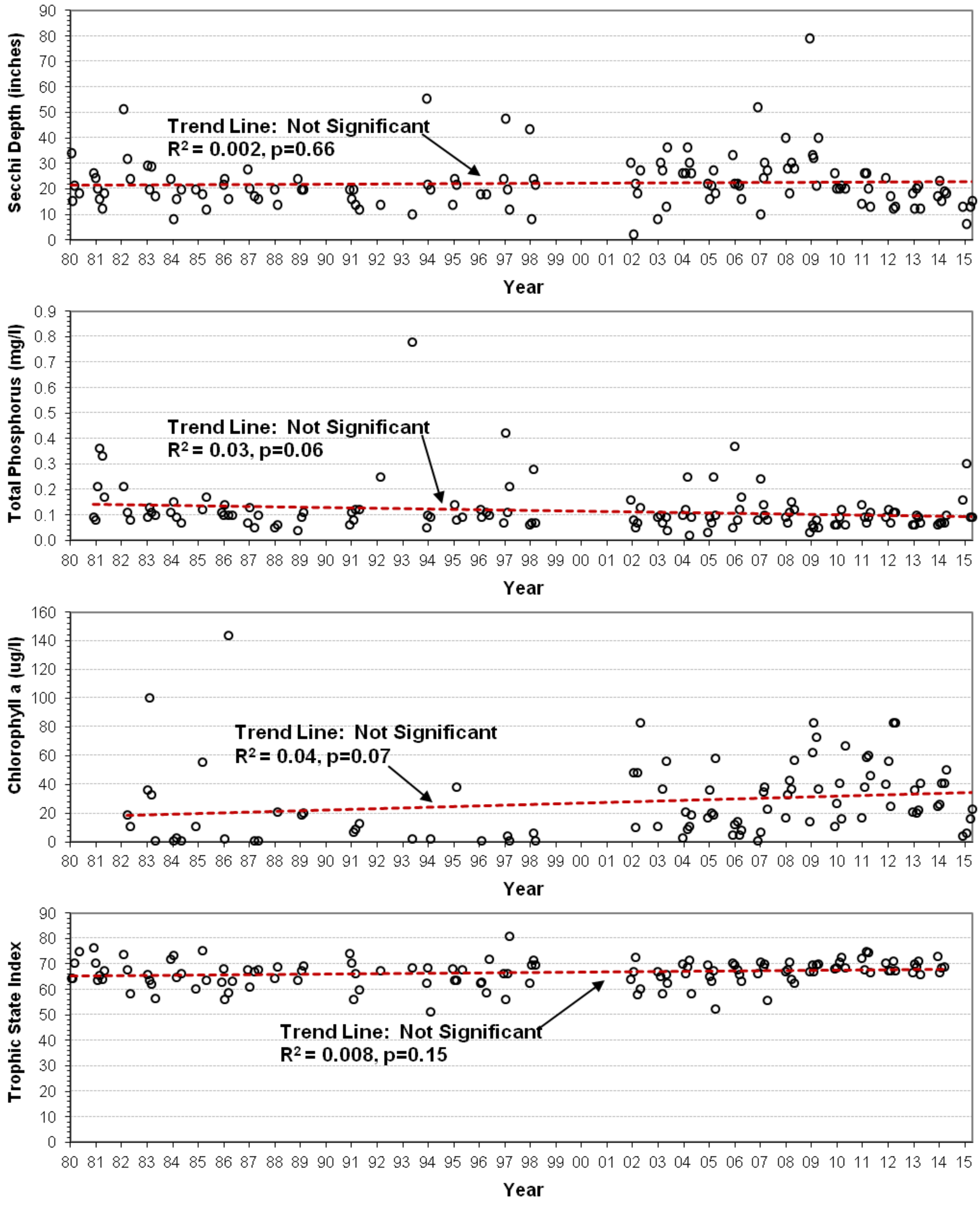


Plate 6-124. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in East Twin Reservoir at the near-dam, ambient site (i.e., site ETNLKND1) over the 36-year period of 1980 through 2015.

6.10 WAGON TRAIN RESERVOIR

6.10.1 BACKGROUND INFORMATION

6.10.1.1 Project Overview

The dam forming Wagon Train Reservoir is located on a tributary to the Hickman Branch. The dam was completed on September 24, 1962 and the reservoir reached its initial fill on June 24, 1963. The Wagon Train Reservoir watershed is 15.6 square miles. The watershed was largely agricultural when the dam was built in 1962 and has remained so to the present time.

6.10.1.2 Aquatic Habitat Improvement and Water Quality Management Project

A lake renovation project was completed at Wagon Train Reservoir in 2003. The goal of the project was to stabilize eroding shorelines and create fringe wetlands, reduce sediment and nutrient loading to the reservoir, manipulate water levels to promote colonization of aquatic vegetation, eliminate the rough fish dominated community using rotenone, and restock the reservoir with sport fish. Approximately $2.7 million in Federal, State, and Local funding was spent on the lake renovation project.

Included in the project were the construction of a two-stage sediment/nutrient dike in the upper end of the reservoir and a single-stage sediment/nutrient dike at the upper end of the east bay (Figure 6.17). Each dike has an estimated trapping efficiency of about 60 percent. Further, five breakwater jetties totaling 1,175 feet were constructed at strategic locations and now protect 2,350 additional feet of adjacent shoreline from erosive waves. Finally, three islands were constructed just downstream of the large sediment/nutrient dike and have each added about 1,000 feet of shoreline. Collectively, the structures created in this project have added 8,750 feet of additional shoreline, increasing the reservoir's total by 36 percent. The dikes, jetties, and islands have all promoted growth of cattails, bulrushes, arrowhead, and a variety of submersed aquatic plants. This aquatic vegetation is resulting in development of an exceptional fishery. To protect this fishery from unwanted reintroduction of rough fish, the Nebraska Game and Parks Commission has implemented a ban on the possession and use of all baitfish, dead or alive, at the reservoir.

Two-Stage Sediment/Nutrient Dike and Basin

One-Stage Sediment/Nutrient Dike and Basin.

Figure 6.17. Aerial views of sediment/nutrient dikes and basins constructed on Wagon Train Reservoir as part of the lake renovation project (see Figure 6.19 for constructed sediment/nutrient dikes locations on the reservoir).

6.10.1.3 Wagon Train Dam Intake Structure

The dam intake at Wagon Train Dam is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 5 feet by 8 feet. The intake structure has four ungated openings – two 30" x 96" openings with a crest elevation at 1292.4 ft-msl and two 12" x 54" openings with a crest elevation at 1287.8. A 36" x 36" gated opening with a crest elevation of 1283.5 ft-msl was constructed into the upstream wall. As part of the recent lake renovation project a "stop-log" structure was attached to the concrete box shaft over the 36" x 36" gated opening. The 36" x 36" gate is permanently left open and pool levels are managed with the external stop-log structure. The purpose of the gate modification is to allow for better management of pool elevations for water quality and fishery management. The gated outlet may also be used to release water for downstream needs.

6.10.1.4 <u>Reservoir Storage Zones</u>

Figure 6.18 depicts the current storage zones of Wagon Train Reservoir based on the 1993 survey data, results of the recent lake renovation project, and estimated sedimentation. After accounting for the sediment removed from the reservoir basin as part of the recent lake renovation project, it is estimated that 15 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2015. The annual volume loss, prior to the implementation of the lake renovation project, is estimated to be 0.32 percent. However, measures implemented as part of the lake renovation project (i.e., sediment/nutrient dikes) are believed to have reduced the annual volume loss. Based on the State of Nebraska's impairment assessment criteria, these values indicate that Wagon Train Reservoir's water quality dependent uses are not impaired due to sedimentation.

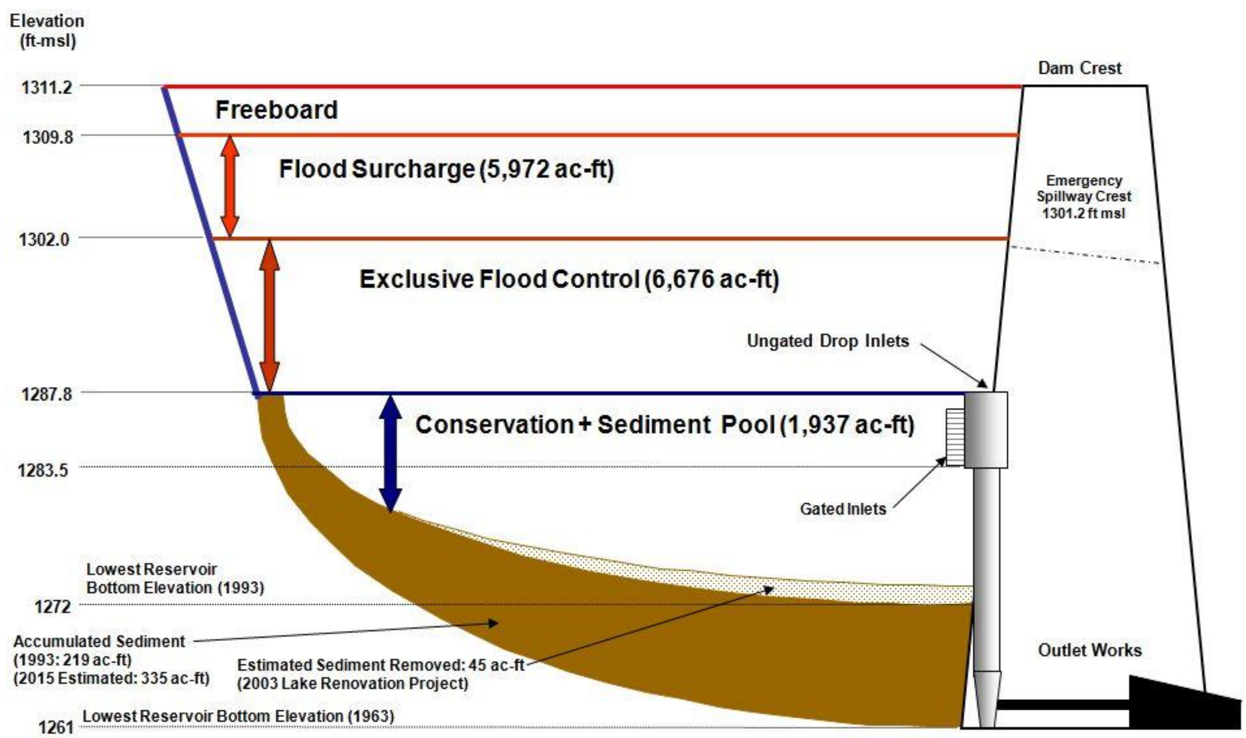


Figure 6.18. Current storage zones of Wagon Train Reservoir based on the 1993 survey data and estimated sedimentation**.**

6.10.1.5 <u>Ambient Water Quality Monitoring</u>

The District has monitored water quality conditions at Wagon Train 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. Figure 6.19 shows the location of the sites that have been monitored for water quality during the 5-year sampling period (i.e., 2008 through 2012). The inflow runoff site (WAGNF1) was sampled by the NDEQ. The other in-reservoir sites (WAGLKND1, WAGLKML1, and WAGLKUP1) were sampled by the District. The near-dam location (WAGLKND1) has been monitored by the District since 1980.

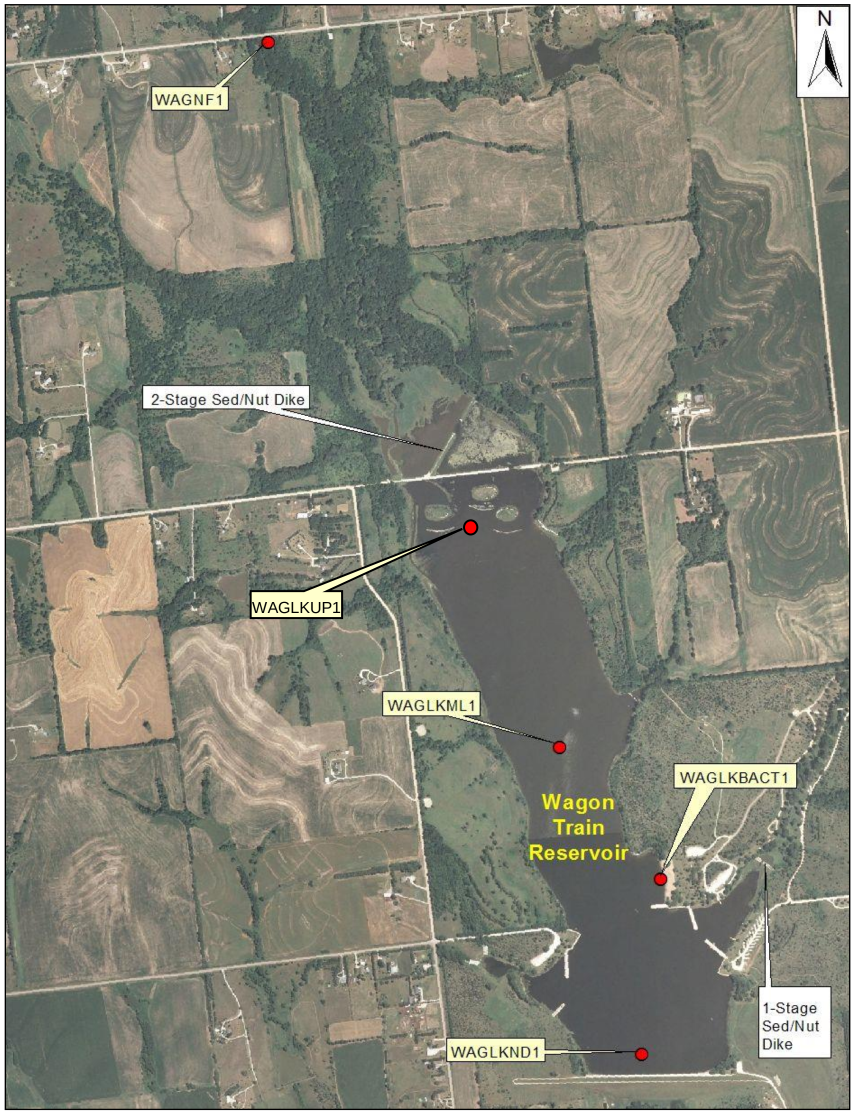


Figure 6.19. Location of sites where water quality monitoring was conducted at Wagon Reservoir during the period 2011 through 2015

6.10.2 WATER QUALITY IN WAGON TRAIN RESERVOIR

6.10.2.1 <u>Existing Water Quality Conditions</u>

6.10.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Wagon Train Reservoir at sites WAGLKND1, WAGLKML1, and WAGLKUP1 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 6-125-Plate 6-127. A review of these results indicated possible water quality concerns regarding dissolved oxygen and nutrients.

A significant number of dissolved oxygen measurements throughout Wagon Train Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 6-125-Plate 6-127). Most of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and appeared to be associated with a slight thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."

This provision seemingly applies to the low dissolved oxygen situation in Wagon Train Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation. However, thermal stratification in Wagon Reservoir was relatively limited during the 5-year sampling period of 2011 through 2015 (Plate 6-129). This limited stratification could lead to the above provision not applying to the reservoir and possible impairment for dissolved oxygen for the protection of aquatic life in Wagon Train Reservoir. In addition, near-dam dissolved oxygen measurements were below the 5 mg/l criterion for the protection of warmwater aquatic life from the reservoirs surface to bottom several times from 2011 through 2015 (Plate 6-131).

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September) to be considered for impairment assessment. All three of these criteria were exceeded in Wagon Train Reservoir (Plate 6-125). The near-surface chlorophyll *a* criterion was exceeded in 92 percent of the "lab analyzed" samples taken in the reservoir at site WAGLKND1. The total phosphorus criteria was exceeded in all samples collected and the total nitrogen criteria was exceeded in 96 percent of the samples taken. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values (Plate 6-125) represent the growing season average for the 5-year period 2011 through 2015. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.35 mg/l), total nitrogen (1.83 mg/l), and chlorophyll *a* (47 ug/l) values at WAGLKND1 indicate impairment of the aquatic life use due to nutrients.

6.10.2.1.2 Thermal Stratification

6.10.2.1.2.1 ***Longitudinal Temperature Contour Plots***

Late-spring and summer thermal conditions of Wagon Train Reservoir measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 6-128 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites WAGLKND1, WAGLKML1, and WAGLKUP1 in 2015. These temperature plots indicate that Wagon Train Reservoir exhibited only slight thermal stratification in 2015.

6.10.2.1.2.2 ***Near-Dam Temperature Depth-Profile Plots***

Existing summer thermal stratification of Wagon Train Reservoir, at the deep water area near the dam, measured over the 5-year period 2011 through 2015 is depicted by depth-profile temperature plots (Plate 6-129). The depth-profile temperature plots indicate that the reservoir rarely exhibited significant summer thermal stratification over the 5-year sampling period. Since Wagon Train Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.10.2.1.3 Dissolved Oxygen Conditions

6.10.2.1.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of Wagon Train Reservoir based on depth-profile measurements taken in 2015 at sites WAGLKND1, WAGLKML1, and WAGLKUP1. Plate 6-130 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 May through early September near the reservoir bottom near the dam. In late June, all of the dissolved oxygen measurements throughout the reservoir were below Nebraska's dissolved oxygen criterion for the protection of warmwater aquatic life (≥ 5 mg/l).

6.10.2.1.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

Existing summer dissolved oxygen conditions in Wagon Train Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2011 through 2015 (Plate 6-131). On several occasions there was a significant vertical gradient in summer dissolved oxygen levels. Twenty percent of the profiles showed hypoxic conditions near the reservoir bottom and three of the 25 profiles showed dissolved oxygen levels below the Nebraska's dissolved oxygen criterion for the protection of warmwater aquatic life (≥ 5 mg/l) through the entire depth of the profile. Although Wagon Train Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition of mixing to allow hypoxic conditions to occasionally develop near the reservoir bottom.

6.10.2.1.3.3 ***Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of Wagon Train 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 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. On June 25th, 100 percent of the volume of Wagon Train Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, however, only a small fraction of the reservoir was hypoxic (Plate 6-130). The July 28, 2015 contour plot indicates a pool elevation of 1,288.6 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1,280.5 ft-msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1,279.0 ft-msl. The current District Area-Capacity Tables (1993 Survey) give storage capacities of 2,003 ac-ft for elevation 1,288.6 ft-msl, 451 ac-ft for elevation 1280.5 ft-msl, and 278 ac-ft for elevation 1,279 ft-msl. On July 25, 2015 it is estimated that 23 percent of the volume of Wagon Train Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 14 percent of the reservoir volume was hypoxic.

6.10.2.1.4 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in Wagon Train Reservoir indicated hypoxic conditions May through early September 2015. As a result, longitudinal contour plots for ORP and pH were constructed during these months. During the last 5-years (2011 through 2015) only twenty percent of the depth profiles at the near dam site have showed hypoxic conditions near the reservoir bottom (Plate 6-131). Due to this, further analysis of hypoxic conditions was not performed.

6.10.2.1.4.1 ***Oxidation-Reduction Potential***

Plate 6-132 provides longitudinal ORP contour plots based on depth-profile measurements taken in 2015 when hypoxic conditions were present in Wagon Train Reservoir. The longitudinal contour plots showed that no appreciable reduced conditions occurred in 2015 at the Reservoir, with all measurements being greater than 300 mV. Given the polymictic nature of the reservoir, reduced conditions seemingly are not long-term.

6.10.2.1.4.2 ***pH***

Longitudinal contour plots for pH conditions measured in 2015 when hypoxic conditions were present are provided in Plate 6-133. Only slight pH differences were observed during hypoxic conditions at Wagon Train Reservoir in 2015.

6.10.2.1.4.3 ***Reservoir Trophic Status***

Trophic State Index (TSI) values for Wagon Train Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., WAGLKND1). Table 6.34 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Wagon Train Reservoir is in a hypereutrophic condition.

Table 6.34. Summary of Trophic State Index (TSI) values calculated for Wagon Train Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	75	75	62	90
TSI(TP)	25	76	76	68	81
TSI(Chl)	25	75	77	57	86
TSI(Avg)	25	75	76	67	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 for the individual parameters.

Note: See Section 4.1.3 for discussion of TSI calculation.

6.10.2.1.5 Reservoir Plankton Community

6.10.2.1.5.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at the Wagon Train Reservoir near-surface, near-dam sampling site during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-134). The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 6-135. The highest phytoplankton total biovolume was observed in September. While Ochrophyta dominated most of the 2015 growing season, some successional patterns commonly observed in eutrophic reservoirs can be observed. Typically, cool water taxa such as Ochrophyta dominate spring and late fall while warm water taxa such as Cyanobacteria species dominate summer and early fall. Cyanobacteria densities were greatest in July and September in 2015. Major and dominant phytoplankton genera sampled in 2015 at Wagon Train Reservoir are provide in Table 6.35.

Table 6.35. Listing of major and dominant phytoplankton genera Sampled in Wagon Train Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1)

Division	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cryptophycophyta	-----	*Cryptomonas*
Ochrophyta	-----	*Aulacoseira, Stephanodiscus*
Pyrrophycophyta	*Ceratium*	-----

Annual variation in phytoplankton community composition is displayed in Plate 6-136. During the 5-year period 2011 through 2015, Wagon Train Reservoir was mostly dominated by Ochrophyta. Cyanobacteria density levels reached levels higher than the World Health Organizations high level of health risk (>100,000 Cells/ml) in 2012 and 2013 (Plate 6-134). 2012 was a particularily warm and dry year. The longer residence time, decreased mixing, and warmer waters could have resulted in a longer Cyanobacterial growing season, causing the high densities observed in 2012. The high densities observed early in 2013 could be a result of a large number of the 2012 Cyanobacteria surviving the winter, leading to a relatively large starting population in 2013. Maximum measured extracellular microcystin toxin level at the near-dam site during the 5-year period was 0.5 µg/l (Plate 6-125).

6.10.2.1.5.2 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at Wagon Train Reservoir near-dam sampling sites during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-137). The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in Plate 6-138. Wagon Train Reservoir was dominated largely by Cladocerans and Copepods with the highest zooplankton total biomass in July. Dominant and major zooplankton genera sampled in Wagon Train Reservoir during 2015 are provided in Table 6.36.

Table 6.36. Listing of major and dominant zooplankton genera sampled in Wagon Train Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1)

Taxonomic Group	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cladocerans	-----	*Daphnia*
Copepods	*Cyclopoida, Leptodiaptomus*	*Calanoida, Mesocyclops*

6.10.2.1.6 Zebra Mussel Monitoring

Zebra mussel veliger sampling has been conducted once yearly since 2012 at Wagon Train Reservoir. During the sampling period (2012-2015) no veligers have been identified.

6.10.2.1.7 Monitoring at Swimming Beaches

A designated swimming beach is located on Wagon Train Reservoir. Bacteria (i.e., *E. coli*) and the cyanobacteria toxin microcystin were monitored at the swimming beach on the reservoir at site WAGLKBACT1 by the NDEQ (Figure 6.19). Bacteria and total microcystins were monitored from May through September over the 5-year period 2011 through 2015.

6.10.2.1.7.1 ***Bacteria Monitoring***

Table 6.37 summarizes the results of the *E. coli* bacteria monitoring. The "running 5-week" geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The "pooled" geomean was determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for *E. coli* bacteria:

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

Table 6.37. Summary of weekly (May through September) *E. coli* bacteria samples collected at Wagon Train Reservoir (i.e., site WAGLKBACT1) during the 5-year period 2011 through 2015.

***E. coli* – Individual Samples**		***E. coli* – Geomeans (Running 5-Week)**	
Number of Samples	108	Number of Geomeans	88
Mean (cfu/100ml)	64	Average	22
Median (cfu/100ml)	6	Median	9
Minimum (cfu/100ml)	1	Minimum	1
Maximum (cfu/100ml)	1,203	Maximum	92
Percent of samples exceeding 235/100ml	6%	Percent of Geomeans exceeding 126/100ml	0%
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	9

The pooled geomean was compared to the State of Nebraska's impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using *E. coli* bacteria data. Based on the criteria a Primary Contact Recreation use in Wagon Train Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

6.10.2.1.7.2 ***Microcystin Monitoring***

Table 6.38 summarizes the total microcystin monitoring conducted at the Wagon Train Reservoir swimming beach during the 5-year period 2011 through 2015. These results were compared to the 20 ug/l criterion for issuing health advisories and the posting of swimming beaches. No samples exceeded the criterion. The monitored levels of total microcystin do not indicate a significant cyanobacteria toxin concern at Wagon Train Reservoir.

Table 6.38. Summary of weekly (May through September) total microcystin samples collected at the Wagon Train Reservoir swimming beach (i.e., site WAGLKBACT1) during the 5-year period 2011 through 2015.

Summary Statistic	Swimming Beach (Site WAGLKBACT1)
Number of Samples	108
Minimum (ug/l)	n.d.
25^{th} percentile (ug/l)	n.d.
Median (ug/l)	n.d.
75^{th} Percentile (ug/l)	0.18
Maximum (ug/l)	17.50
Percent of samples exceeding 20 ug/l	0%

6.10.2.2 **<u>Water Quality Trends (1980 through 2015)</u>**

Water quality trends from 1980 to 2015 were determined for Wagon Train 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., WAGLKND1). Plate 6-139 displays a scatter-plot of the collected data for the four parameters and linear regression lines for the period 1980 through 1998 and 2003 through 2015. The data gap of 1998 through 2003 is the period when the lake renovation project was implemented at Wagon Train Reservoir. Prior to the renovation project there were no significant trends in transparency ($p=0.08$, $R^2=0.05$), total phosphorus ($p=0.83$, $R^2=0.0007$), chlorophyll a ($p=0.20$, $R^2=0.06$) and TSI ($p=0.69$, $R^2=0.002$). Due to the renovation project, Nebraska's water quality standards placed Wagon Train Reservoir in category 4R from 2003 to 2010. Nutrient assessment of category 4R designated waters may be misleading due to a trophic upsurge upon refill which is typically followed by a period of decline. Due to this trophic instability, analysis was not performed on the data between 2003 and 2010. Post renovation analysis of years 2010 through 2015 showed no significant trends in total phosphorus ($p=0.05$, $R^2=0.02$), chlorophyll a ($p=0.29$, $R^2=0.04$), and TSI ($p=0.20$, $R^2=0.06$) while transparency significantly decreased ($p<0.05$, $R^2=0.11$). Further regression analysis was performed to test if the renovation project had any affect on trends. No significant changes in trends were observed in total phosphours ($p=0.09$), chlorophyll a ($p=0.76$), and TSI ($p=0.36$). Transparency trends significantly decreased post renovation ($p=0.04$). The lack of improving conditions due to the renovation project may be due to trophic instability caused by the project. More time may be needed in order for changes to be observed. Wagon Train was in a hypereutrophic condition prior to the renovation project and has remained so post renovation.

6.10.3 PLATES

Plate 6-125. Summary of water quality conditions monitored in Wagon Train Reservoir at site WAGLKND1 from May to September during the 5-year 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	25	1287.82	1287.80	1286.40	1289.10	-----	-----	-----
Water Temperature (°C)	0.1	233	22.75	23.56	14.00	30.71	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	233	6.28	6.49	n.d.	14.04	≥5[2]	64	27%
Dissolved Oxygen, Near-Surface (mg/l)[C]	0.1	25	7.54	7.52	3.25	13.03	≥5[2]	3	12%
Dissolved Oxygen (% Sat.)	0.1	233	75.01	76.70	0.90	170.80	-----	-----	-----
Secchi Depth (in.)	1	25	15.20	14.00	5.00	34.00	-----	-----	-----
Turbidity (NTUs)	1	232	47.64	23.95	7.80	571.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	233	357.79	365.00	175.00	468.00	-----	-----	-----
Specific Conductance (umho/cm)	1	233	394.82	398.70	274.40	477.90	2,000[3]	0	0%
pH (S.U.)	0.1	233	8.32	8.46	7.34	9.06	≥6.5 & ≤9.0 [1]	0,6	0%,3%
Alkalinity, Total (mg/l)	1	50	176.98	184.00	106.00	217.00	>20[1]	0	0%
Suspended Solids, Total (mg/l)	4	50	22.92	22.00	6.00	69.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	50	-----	0.06	n.d.	0.85	1.45[4,5], 0.34[4,6]	0,2	0%,4%
Ammonia, Total, Near-Surface (mg/l) [C]	0.02	25	-----	0.04	n.d.	0.68	1.19[4,5], 0.30[4,6]	0,1	0%,4%
Kjeldahl N, Total (mg/l)	0.08	50	1.65	1.68	0.75	2.94	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	50	-----	n.d.	n.d.	1.35	100[3]	0	0%
Nitrogen, Total (mg/l)	0.08	50	1.85	1.72	0.90	3.12	1[7]	49	98%
Nitrogen, Total, Near-Surface (mg/l) [C]	0.08	25	1.83	1.72	0.90	3.12	1[7]	24	96%
Phosphorus, Total (mg/l)	0.005	50	0.37	0.37	0.15	0.66	0.05[7]	50	100%
Phosphorus, Total, Near-Surface (mg/l) [C]	0.005	25	0.35	0.33	0.15	0.56	0.05[7]	25	100%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	0.20	0.20	n.d.	0.45	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	131.34	132.00	122.80	145.80	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	5	15.20	16.00	12.00	17.00	340[5], 16.7[8]	0,2	0%,40%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	n.d.	7.73[5], 0.30[6]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	743[5], 96.76[6]	0	0%
Copper, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	17.46[5], 11.35[6]	0	0%
Iron, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	1000[6]	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	87.26[5], 3.40[6]	0	0%
Manganese, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	5.00	1000[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	592.20[5], 65.78[6]	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5.56[5]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	148.26[5], 149.47[6]	0	0%
Antimony, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	88[5], 30[6]	0	0%
Aluminum, Dissolved (ug/l)	40	5	-----	n.d.	n.d.	n.d.	750[5], 87[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Chlorophyll a (ug/l) – Lab Determined[C]	6	25	47	45	n.d.	115	10[7]	23	92%
Chlorophyll a (ug/l) – Field Probe	6	233	57	53	n.d.	140	10[7]	214	92%
Atrazine, Total (ug/l)[D]	0.02	25	2.63	2.60	n.d.	5.90	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l) [D]	0.05	25	1.46	1.10	n.d.	4.70	390[5], 100[6]	0	0%
Acetochlor, Total (ug/l) [D]	0.1	25	1.53	1.30	n.d.	3.90	-----	-----	-----
Microcystin, Extracellular (ug/l)	0.1	24	-----	n.d.	n.d.	0.50	20[9]	0	0%
Pesticide Scan (ug/l)[E]									
Atrazine, Tot	0.13	5	-----	0.64	n.d.	14.00	330[5], 12[6]	0,1	0%,20%
Acetochlor, Tot	0.08	5	-----	n.d.	n.d.	2.30	-----	-----	-----
Metolachlor, Tot	0.13	5	-----	0.73	n.d.	3.83	390[5], 100[6]	0	0%

n.d. = Not detected.

(A) Nondetected values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-126. Summary of water quality conditions monitored in Wagon Train Reservoir at site WAGLKML1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1287.69	1287.75	1286.40	1289.10	-----	-----	-----
Water Temperature (°C)	0.1	170	23.22	23.86	15.36	30.02	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	170	7.16	7.12	0.37	16.51	$\geq$5(2)	30	18%
Dissolved Oxygen (% Sat.)	0.1	170	86.35	83.75	4.40	203.30	-----	-----	-----
Secchi Depth (in.)	1	25	12.76	12.00	6.00	23.00	-----	-----	-----
Turbidity (NTUs)	1	170	41.98	24.90	9.90	386.80	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	170	349.34	351.00	191.00	457.00	-----	-----	-----
Specific Conductance (umho/cm)	1	170	390.44	395.25	265.70	474.60	2,000(3)	0	0%
pH (S.U.)	0.1	170	8.42	8.54	7.08	9.09	$\geq$6.5 & $\leq$9.0 (1)	0,2	0%,1%
Chlorophyll a (ug/l) – Field Probe	6	170	64	55	4	761	10(4)	154	91%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-127. Summary of water quality conditions monitored in Wagon Train Reservoir at site WAGLKUP1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1287.69	1287.75	1286.40	1289.10	-----	-----	-----
Water Temperature (°C)	0.1	48	23.84	24.69	15.70	29.68	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	48	7.68	8.12	2.39	15.10	$\geq$5(2)	9	19%
Dissolved Oxygen (% Sat.)	0.1	48	93.88	95.70	29.60	187.90	-----	-----	-----
Secchi Depth (in.)	1	25	10.88	10.00	6.00	18.00	-----	-----	-----
Turbidity (NTUs)	1	48	45.83	25.55	0.00	481.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	48	341.94	350.50	157.00	462.00	-----	-----	-----
Specific Conductance (umho/cm)	1	48	380.82	392.45	272.40	472.80	2,000(3)	0	0%
pH (S.U.)	0.1	48	8.49	8.66	7.24	9.14	$\geq$6.5 & $\leq$9.0 (1)	0,1	0%,2%
Chlorophyll a (ug/l) – Field Probe	6	48	53	47	4	115	10(4)	42	88%

n.d. = Not detected.
(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

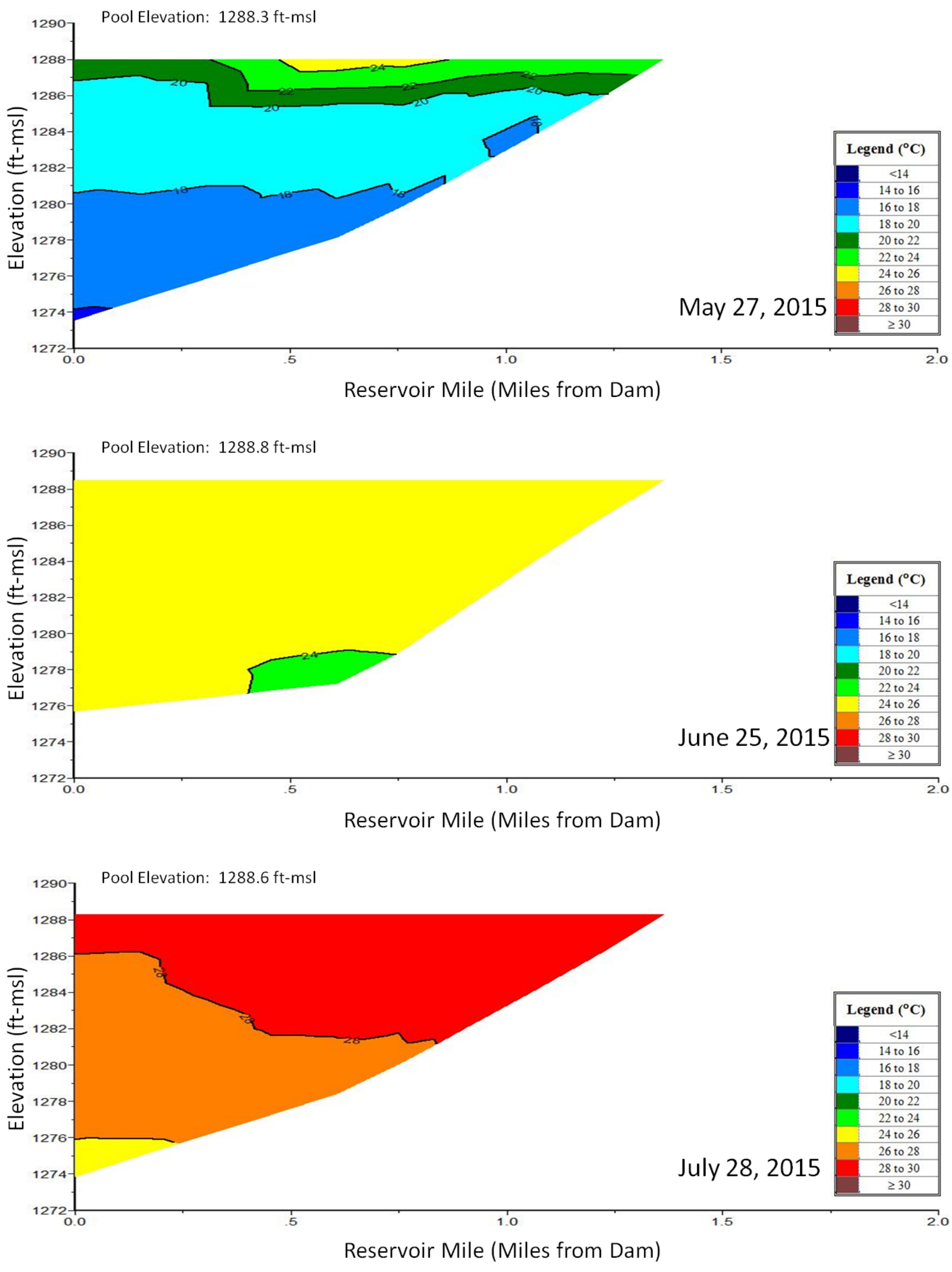
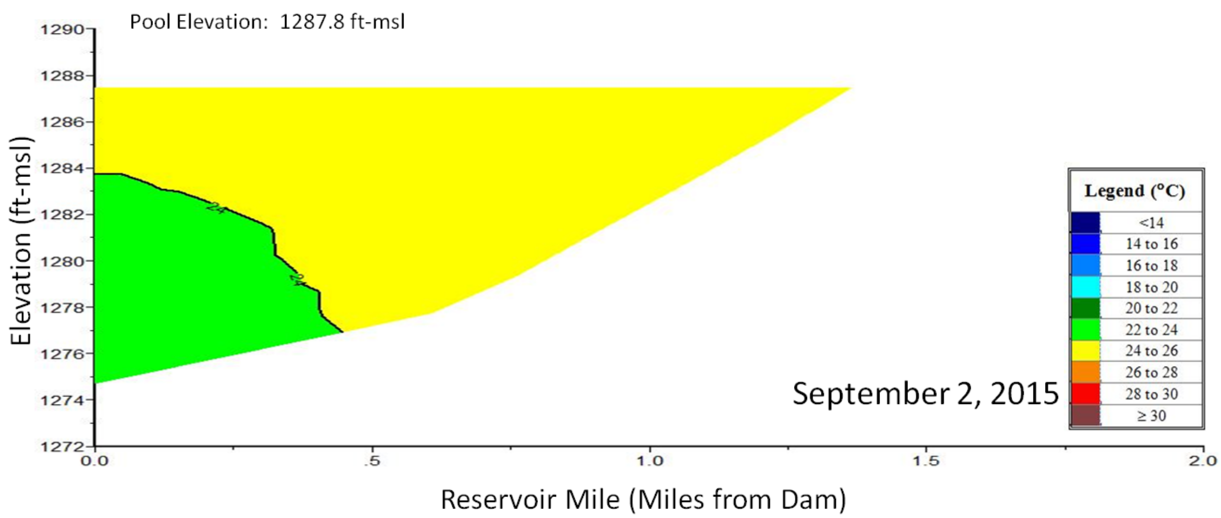


Plate 6-128. Longitudinal water temperature contour plots of Wagon Train Reservoir based on depth-profile water temperatures (°C) measured at sites WAGLKND1, WAGLKML1, and WAGLKUP1 in 2015.



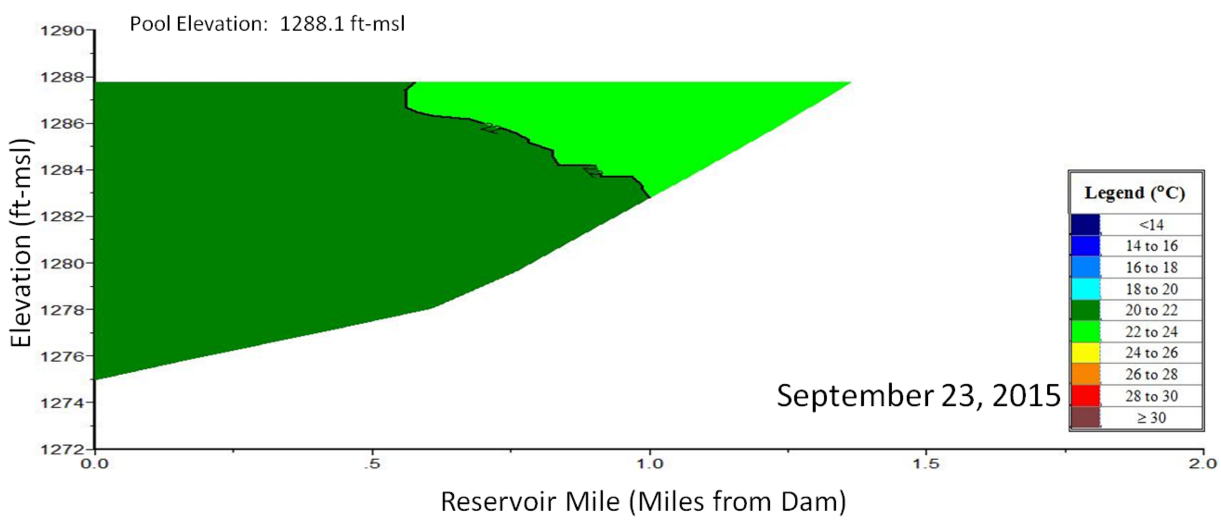


Plate 6-128. (Continued).

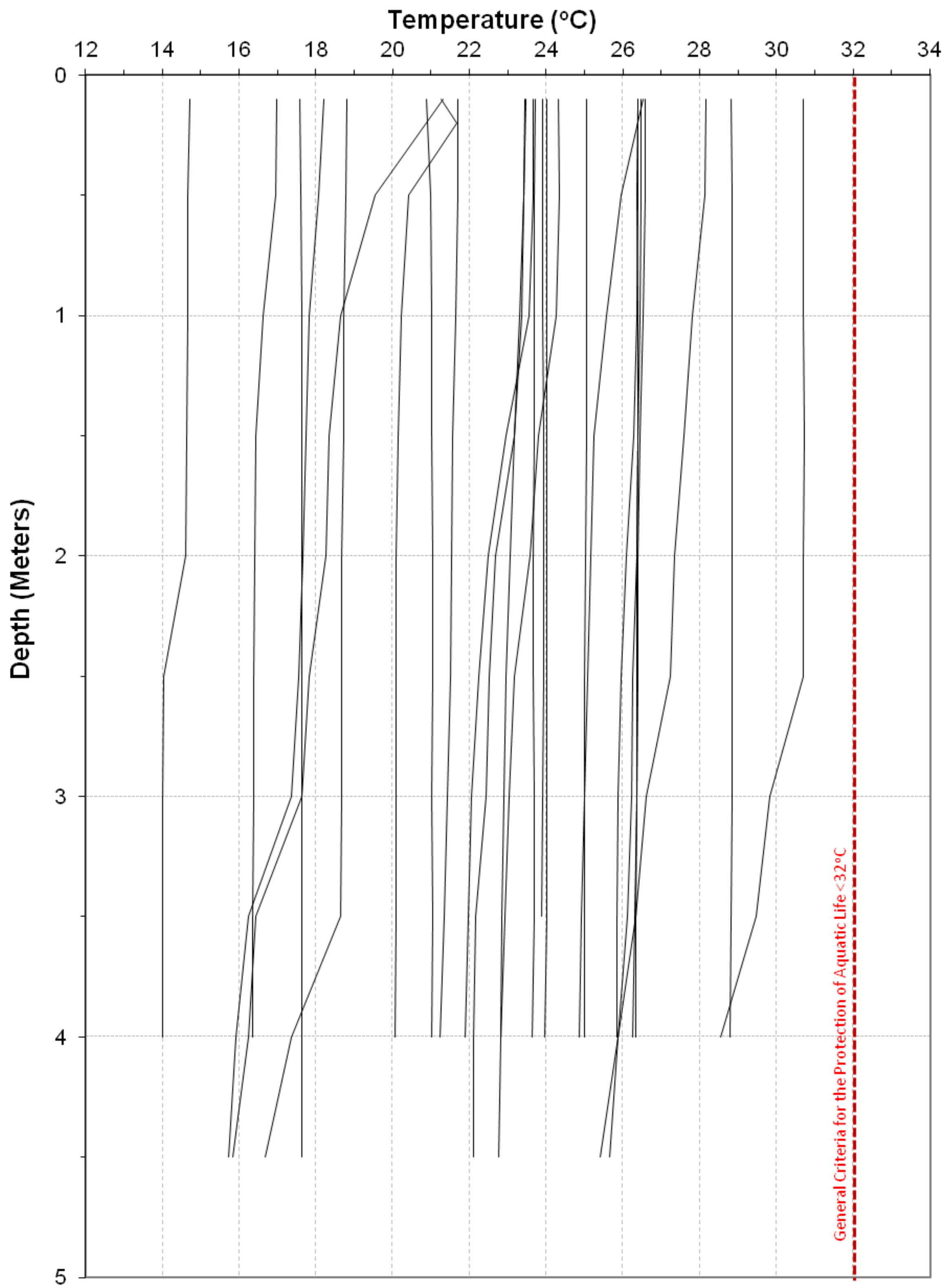


Plate 6-129. Temperature depth profiles for Wagon Train Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1) during the summer over the 5-year period of 2011 through 2015.

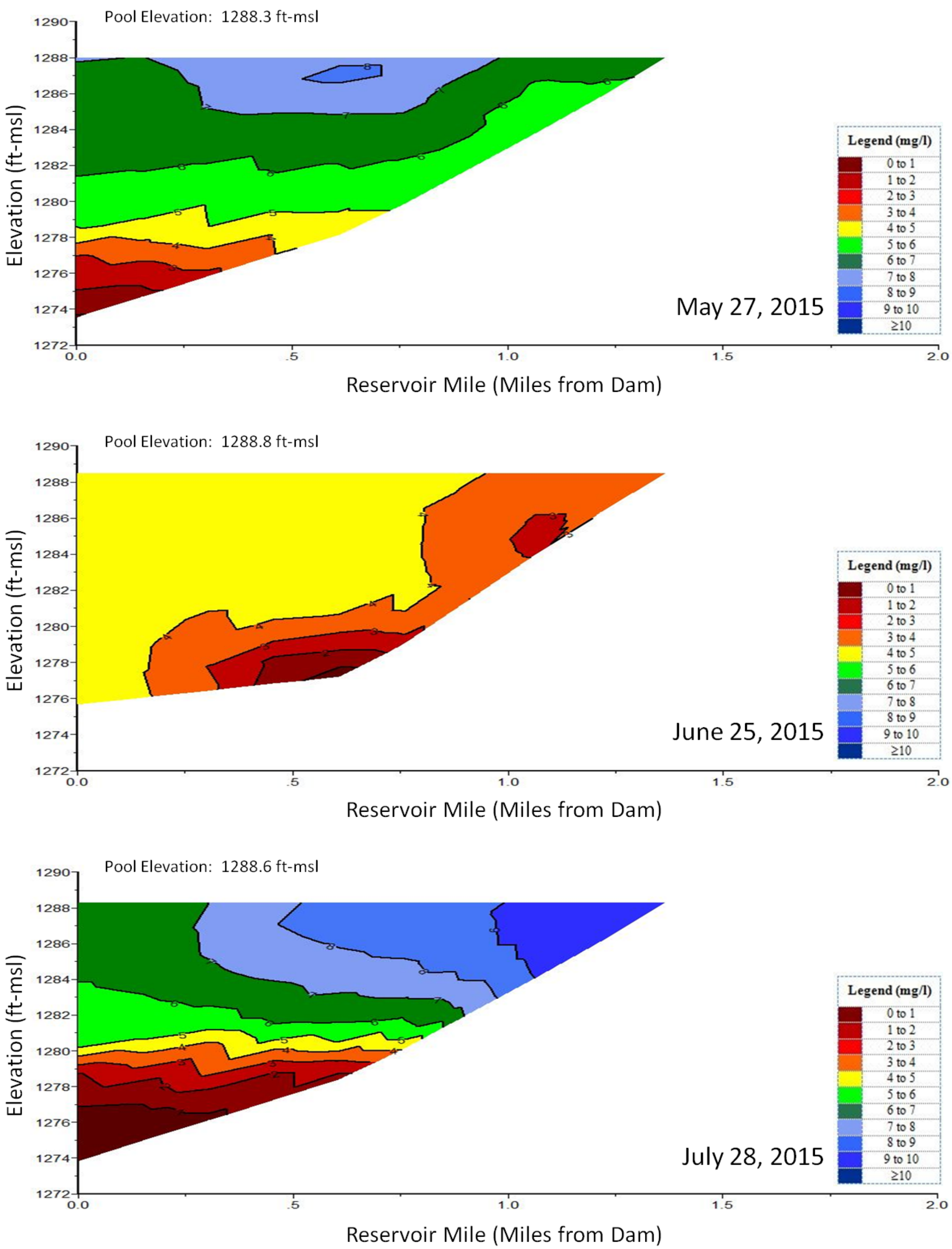
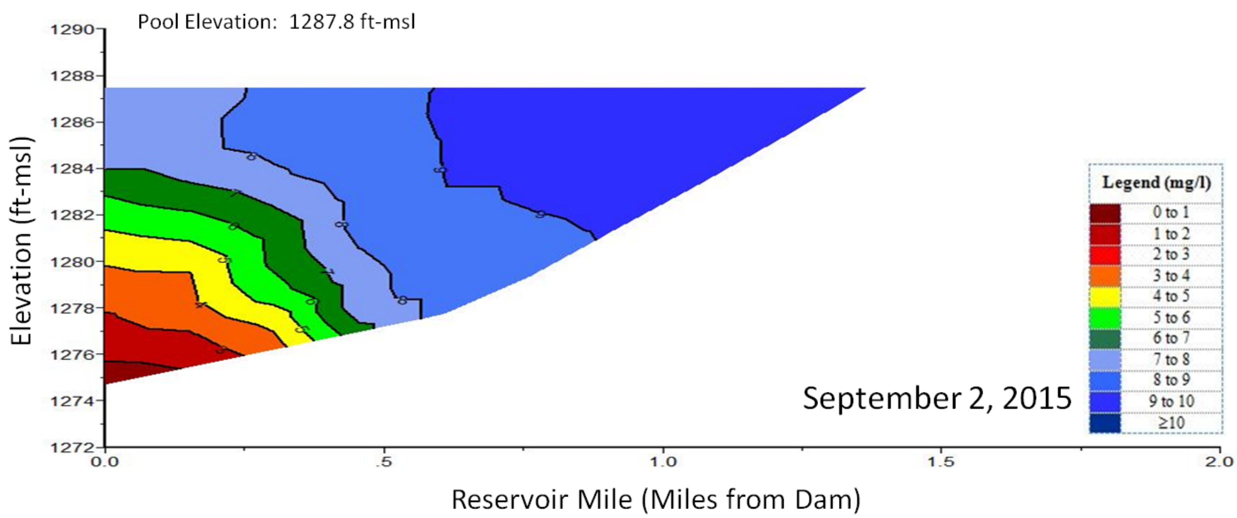


Plate 6-130. Longitudinal dissolved oxygen contour plots of Wagon Train Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites WAGLKND1, WAGLKML1, and WAGLKUP1 in 2015.



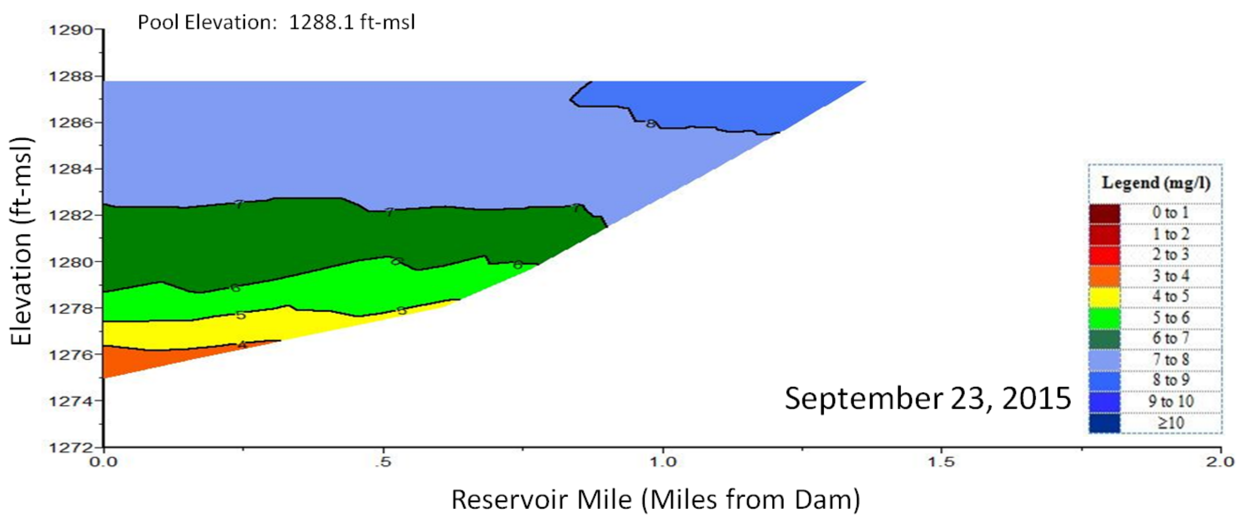


Plate 6-130. (Continued).

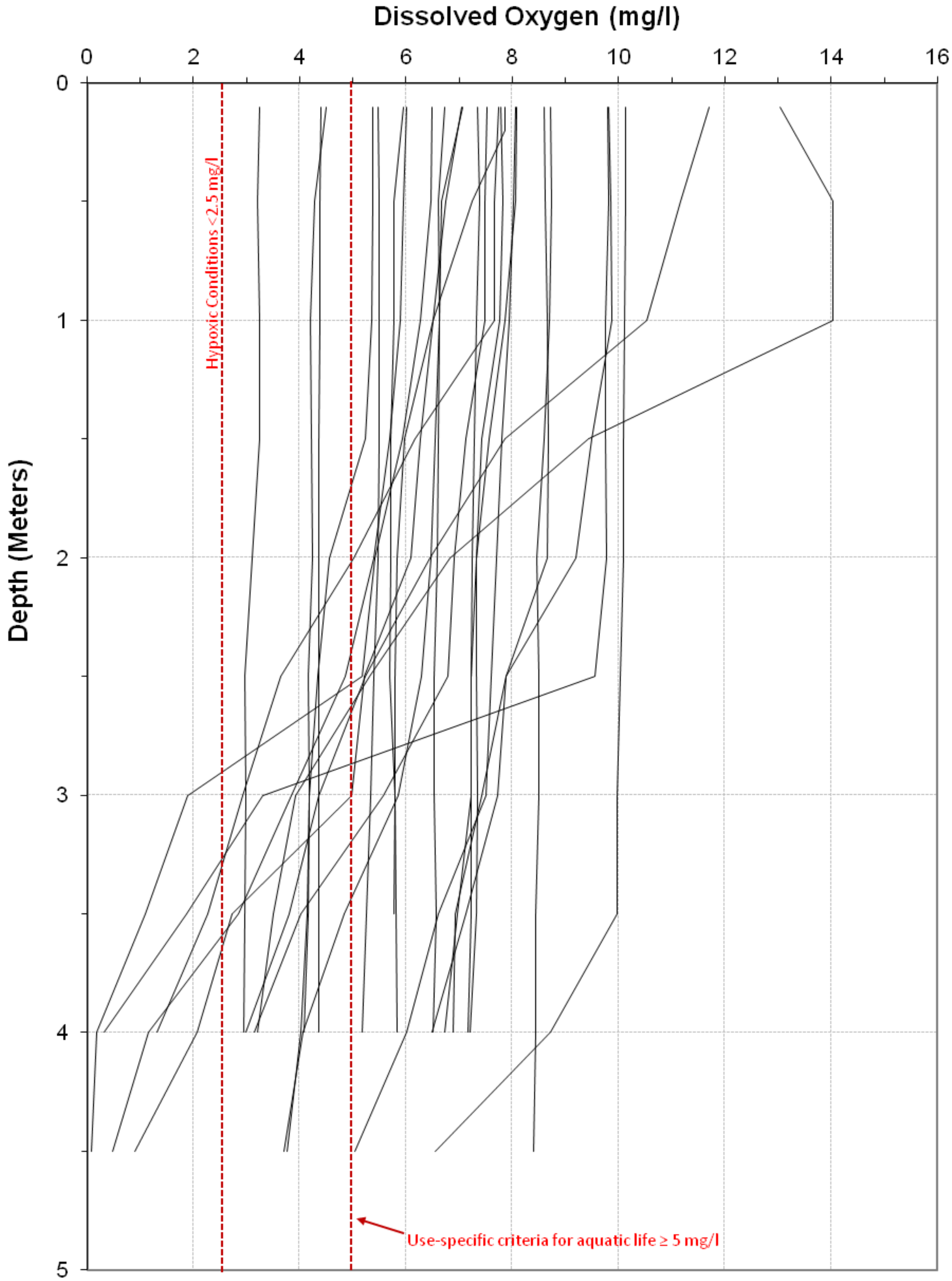
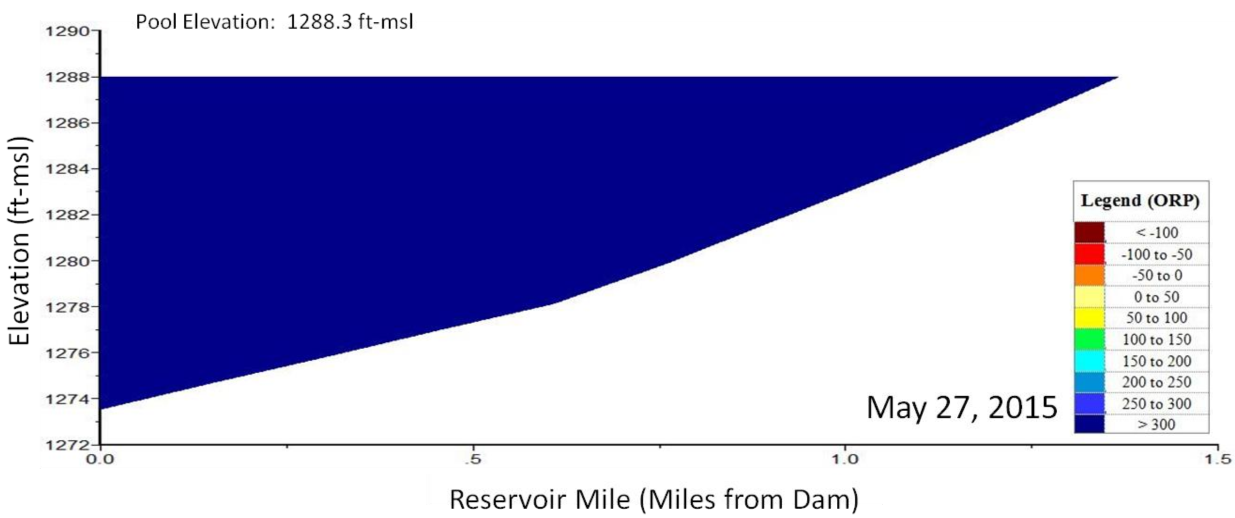
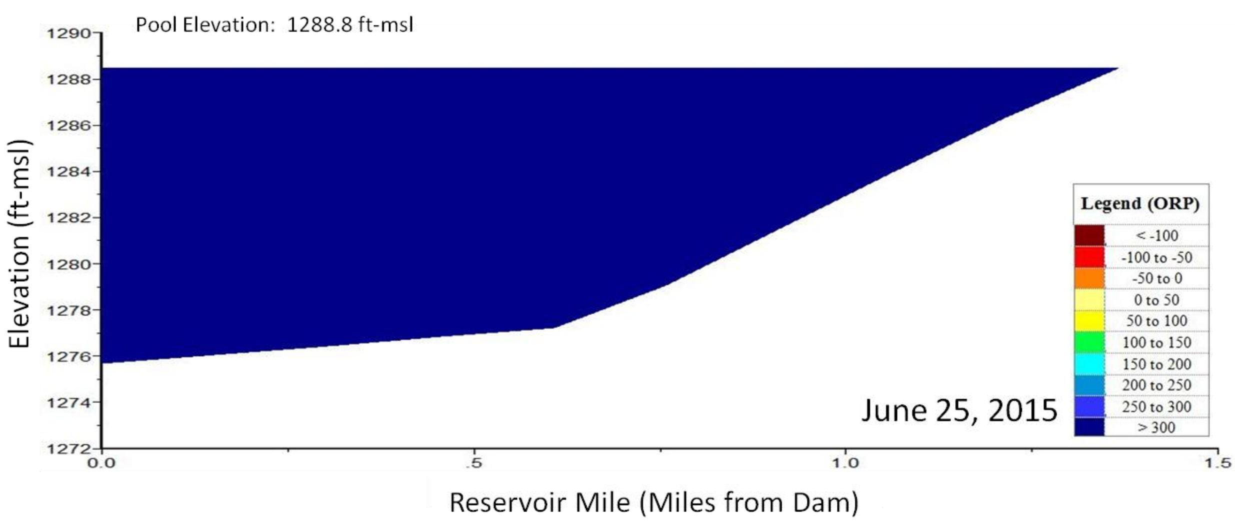


Plate 6-131. Dissolved oxygen depth profiles for Wagon Train Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1) during the summer over the 5-year period 2011 through 2015.





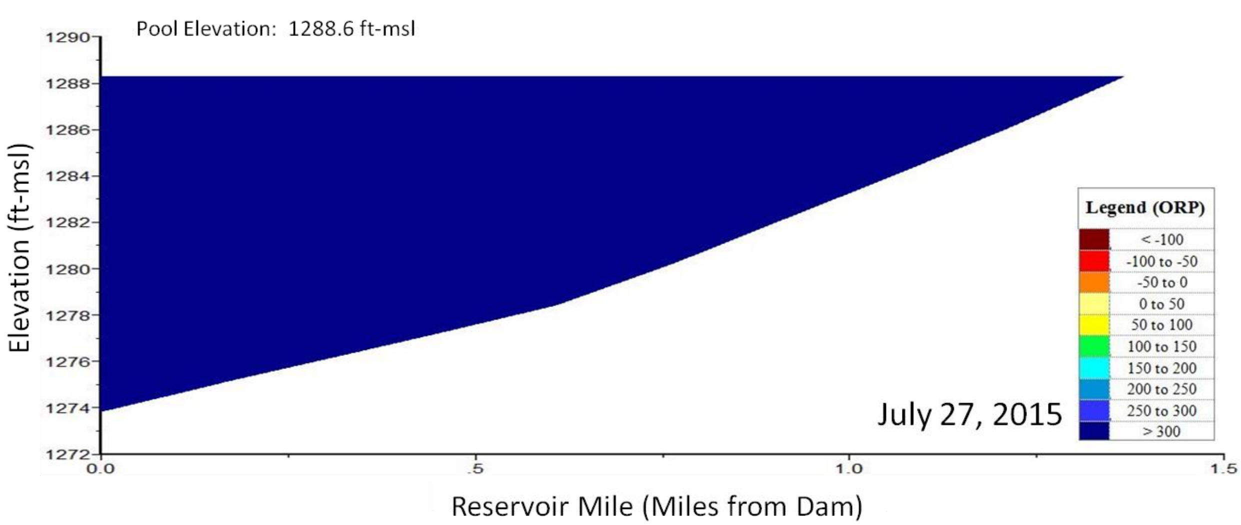


Plate 6-132. Longitudinal oxidation-reduction potential contour plots of Wagon Train Reservoir based on depth-profile ORP levels (mV) measured at sites WAGLKND1, WAGLKML1, and WAGLKUP1 in 2015.

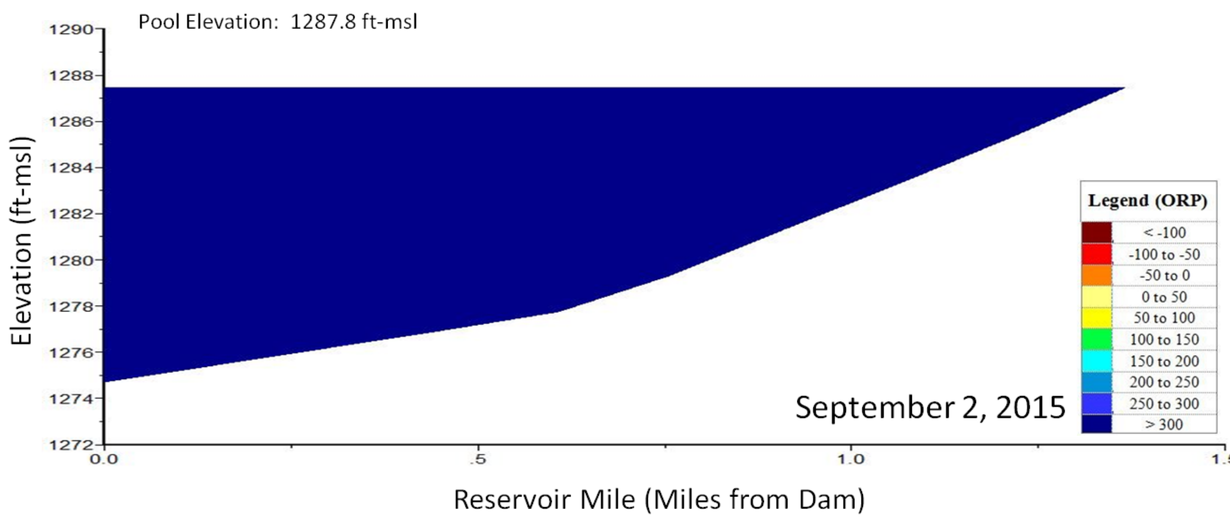


Plate 6-132. (Continued).

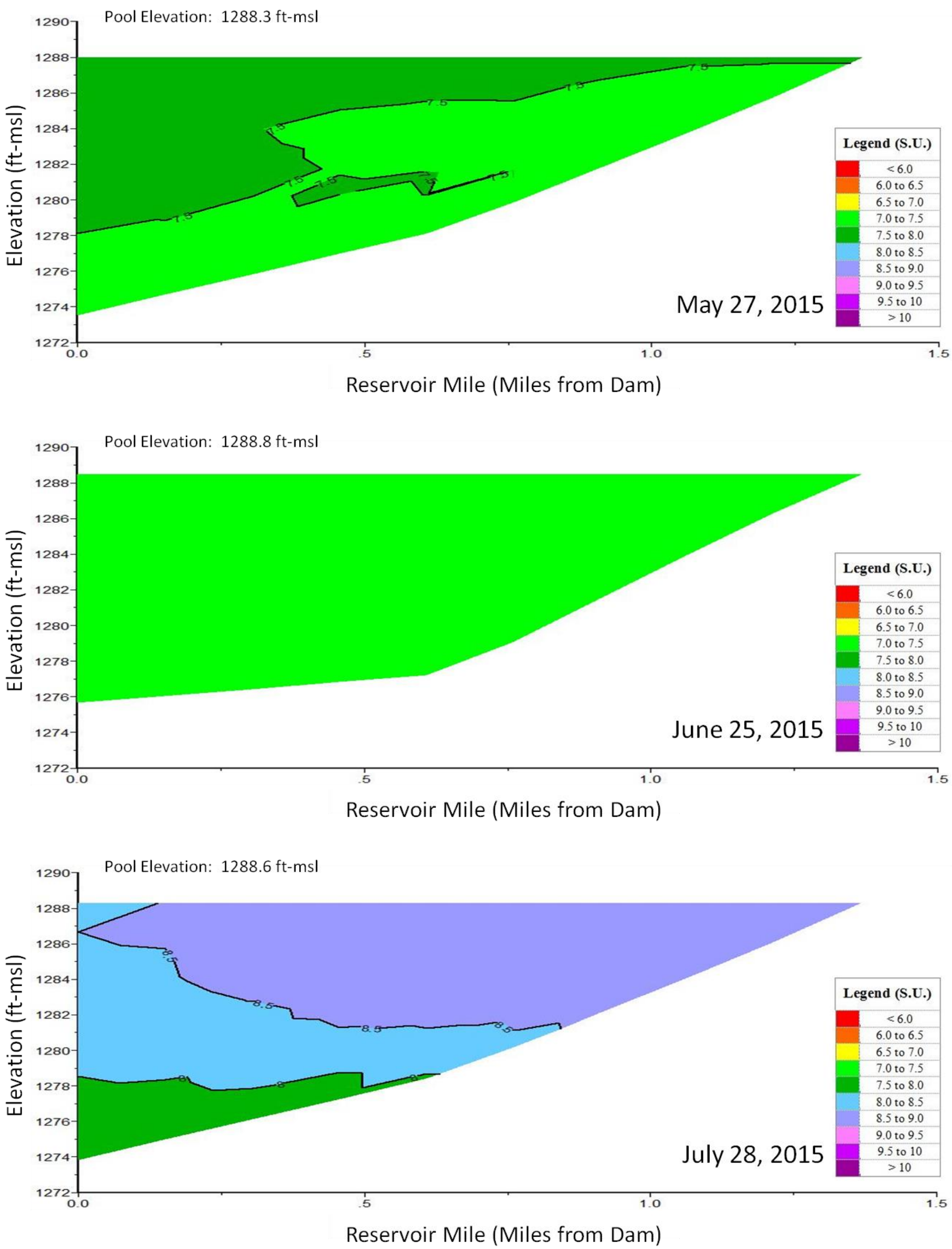


Plate 6-133. Longitudinal pH contour plots of Wagon Train Reservoir based on depth-profile pH levels (S.U.) measured at sites WAGLKND1, WAGLKML1, and WAGLKUP1 in 2015.

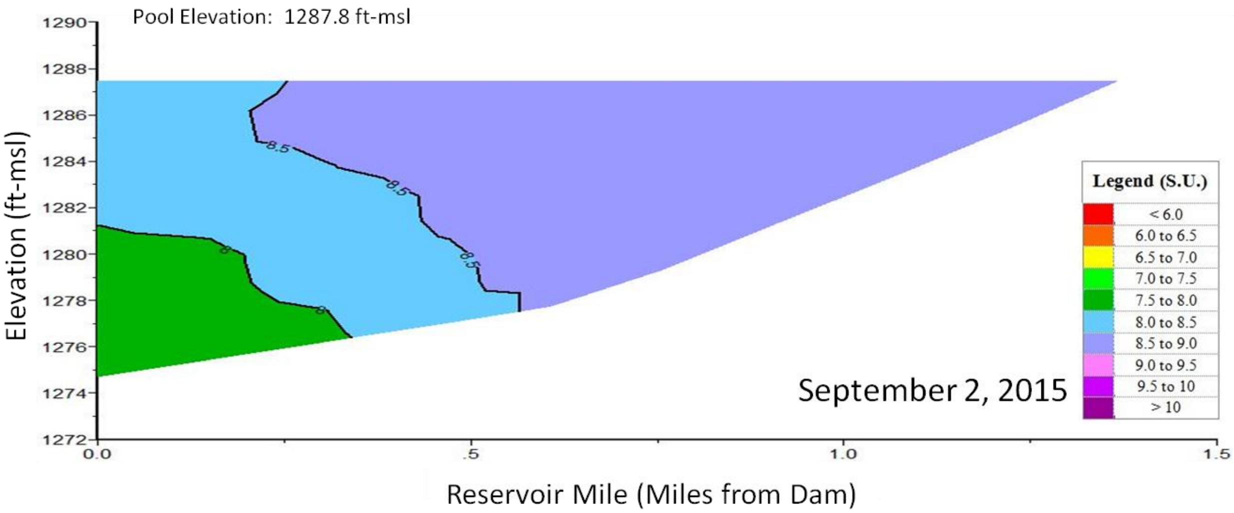


Plate 6-133. (Continued).

Plate 6-134. Total biovolume and density by taxonomic group for phytoplankton grab samples from Wagon Train Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**
23-May-11	6,907	48	25,494	476	6,586	121	2,036	26	8,390	83	1,417	2	388,004	1,469	137	0
28-Jul-11	-----	-----	49,278	617	-----	-----	101,126	1,851	3,437,500	38,519	2,771	6	1,435,117	6,161	73,588	33
22-Sep-11	1,979	56	129,182	2,924	-----	-----	285,864	5,131	113,691	6,669	121	0	557,621	1,801	17,331	14
03-May-12	858	0	1,102,126	477	8,367	7	70,888	1,219	25,552	1,807	39,199	21	480,244	810	-----	-----
06-Jul-12	-----	-----	1,167,641	2,104	2,191	7	833,583	4,896	1,609,908	44,510	36,137	95	12,550,311	13,697	2,003,723	238
07-Sep-12	-----	-----	434,425	11,973	-----	-----	1,209,551	8,021	3,596,758	527,815	158,294	109	5,458,910	76,714	-----	-----
13-May-13	755,153	4,954	-----	-----	-----	-----	717,667	8,461	119,462	7,605	-----	-----	4,001,446	13,529	365,852	48
09-Jul-13	1,170,992	6,485	-----	-----	-----	-----	384,032	4,527	7,561,207	171,919	-----	-----	4,696,192	5,704	212,453	7
12-Sep-13	250,870	428	3,203,252	8,184	-----	-----	2,286,051	26,951	1,847,485	13,664	11,793	8	26,034,367	54,986	75,923	3
14-May-14	16,639	61	790,970	4,999	21,420	7	782,752	9,228	34,658	196	177,562	123	3,542,145	14,521	-----	-----
15-Jul-14	-----	-----	1,310,821	3,857	-----	-----	8,694,007	2,810	158,510	6,384	26,244	6	2,733,264	10,894	859,931	33
11-Sep-14	293,930	348	2,547,181	16,258	-----	-----	6,165,606	2,909	1,060,908	42,177	320,313	29	434,905	1,357	-----	-----
27-May-15	-----	-----	3,864	36	-----	-----	1,880,454	1,854	-----	-----	633	1	331,748	1,091	-----	-----
28-Jul-15	1,438	4	216,395	5,255	-----	-----	251,468	1,141	27,211	488	43,995	72	4,984,120	7,480	-----	-----
23-Sep-15	-----	-----	519,340	4,401	-----	-----	3,109,889	7,914	1,220,681	42,850	243,598	143	18,086,742	20,677	3,835,844	143

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

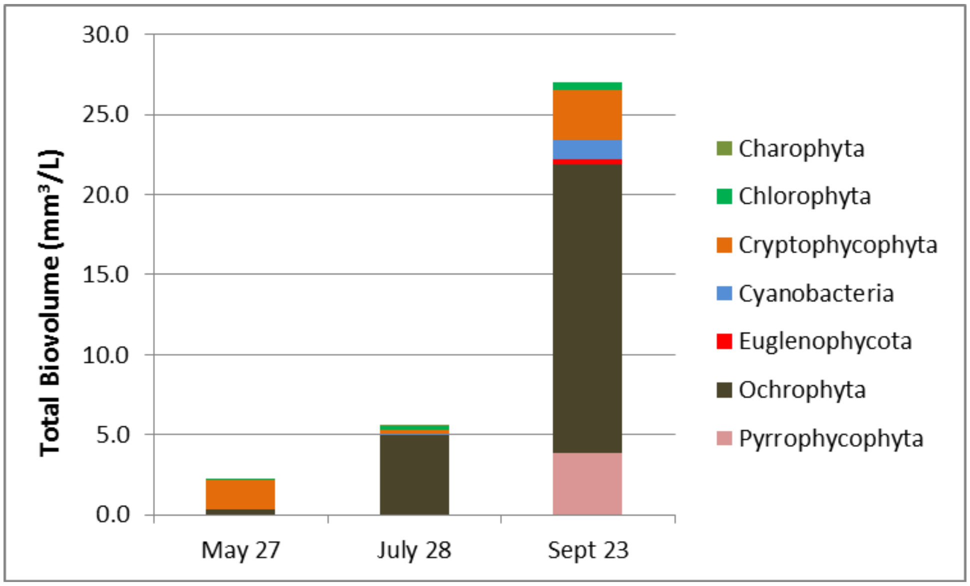


Plate 6-135. Relative abundance of phytoplankton in samples collected from Wagon Train Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1).

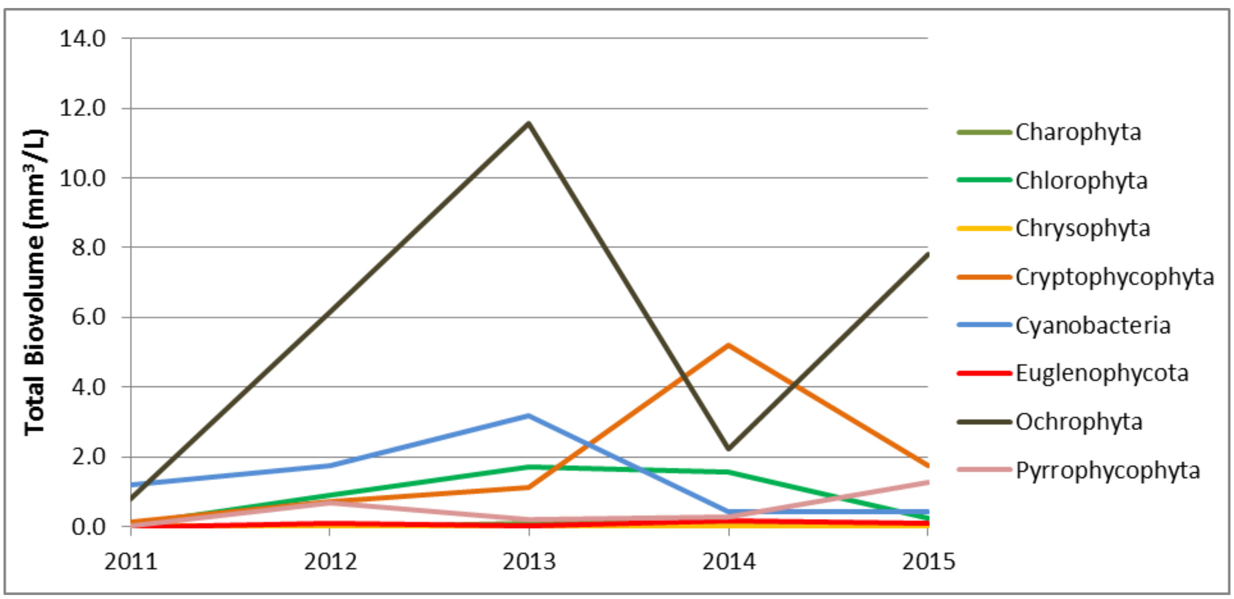


Plate 6-136. Relative abundance of phytoplankton in samples collected from Wagon Train Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are a yearly average of three summer samples (i.e. May, July, and September).

Plate 6-137. Total biomass and density by taxonomic grouping for zooplankton vertical-tow samples from Wagon Train Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)
23-May-11	9	15.80	8	3.61	------	------	131	0.74
28-Jul-11	16	11.04	241	79.15	------	------	26	0.56
22-Sep-11	1	4.45	61	58.54	------	------	25	0.52
03-May-12	3	25.07	55	57.21	------	------	83	0.71
09-Jul-12	9	12.38	199	276.70	------	------	497	10.52
07-Sep-12	4	6.44	72	58.11	------	------	176	7.98
13-May-13	------	------	4	1.31	------	------	167	17.19
09-Jul-13	37	398.04	61	41.47	------	------	283	10.95
12-Sep-13	24	8.19	99	78.19	------	------	77	55.76
14-May-14	39	140.57	234	181.81	------	------	61	68.06
15-Jul-14	6	7.71	37	15.19	------	------	319	7.52
11-Sep-14	4	5.28	59	20.87	------	------	192	8.12
27-May-15	14	74.40	82	116.64	------	------	133	0.90
28-Jul-15	94	298.71	66	41.33	------	------	326	6
23-Sep-15	3	8.32	83	64.02	------	------	30	1.03

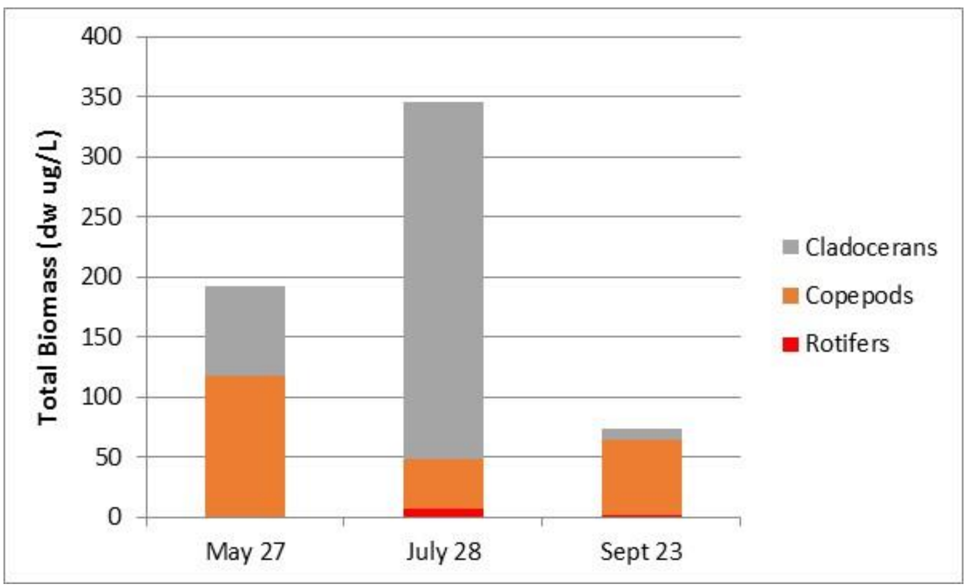


Plate 6-138. Relative abundance of zooplankton in samples collected from Wagon Train Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1).

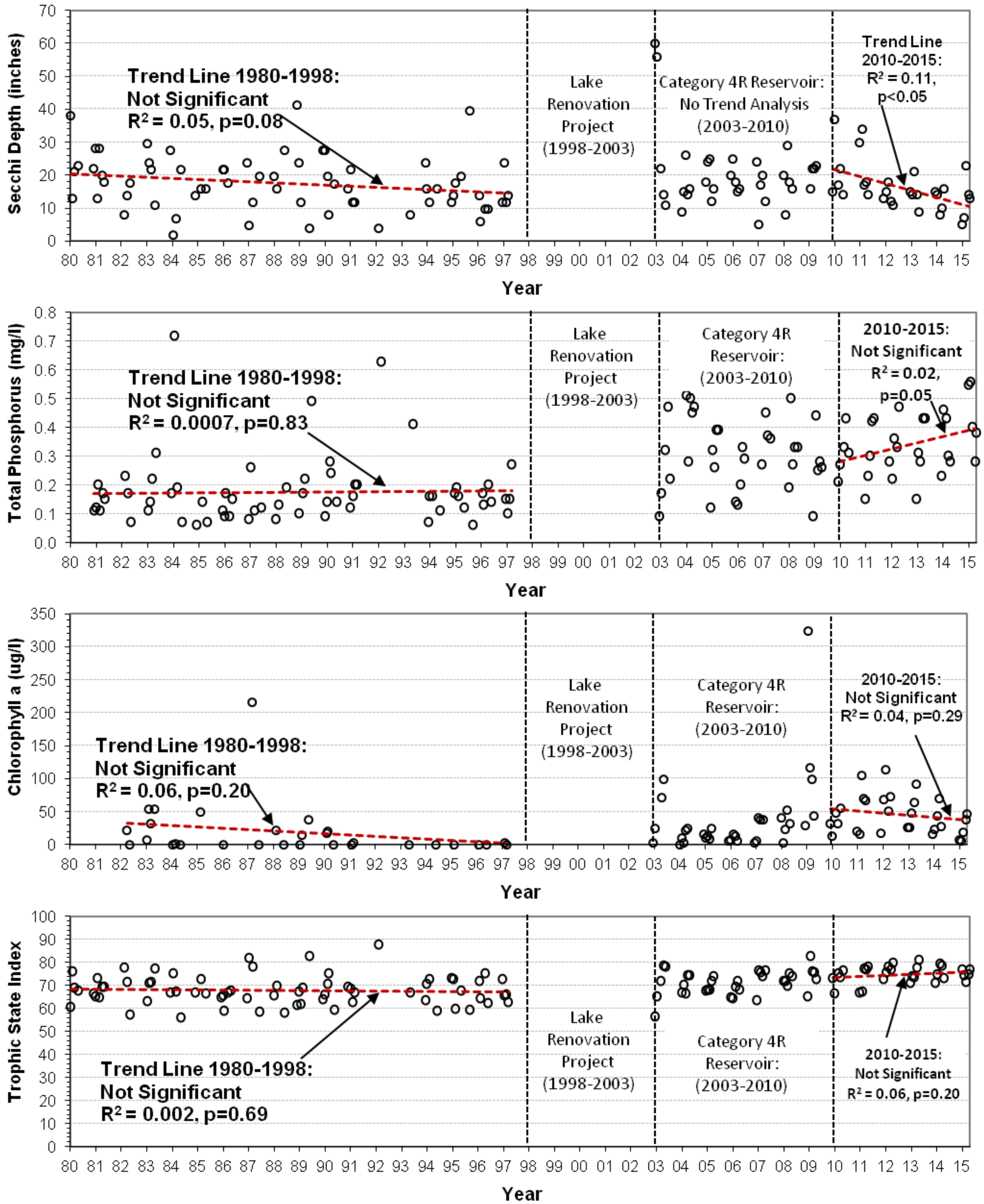


Plate 6-139. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Wagon Train Reservoir at the near-dam, ambient site (i.e., site WAGLKND1) over the 36-year period of 1980 through 2015. Regression analysis showed no signficicant change in trend lines for total phosphours (p=0.09), chlorophyll a (p=0.76), and TSI (p=0.36). The secchi depth trend decreased post renovation (p=0.04)

6.11 YANKEE HILL RESERVOIR

6.11.1 BACKGROUND INFORMATION

6.11.1.1 Project Overview

The dam forming Yankee Hill Reservoir is located on the Cardwell Branch. The dam was completed on August 27, 1963 and the reservoir reached its initial fill in May 1965. The Yankee Hill Reservoir watershed is 9.7 square miles. The watershed was largely agricultural when the dam was built in 1963 and has remained so to the present time.

6.11.1.2 Aquatic Habitat Improvement and Water Quality Management Project

A lake renovation project was started at Yankee Hill Reservoir in 1999 and completed in 2005. To facilitate the project, the reservoir was drawn down in 1998 and refilled in 2006. The goal of the project was to reduce the threat of winter fish kills, create more open water habitat for fish, stabilize shorelines and create fringe wetlands, reduce sediment and nutrient loading into the reservoir, manipulate water levels to promote fish production, and set back succession by restructuring the rough fish dominated fishery. Approximately $1.9 million in Federal, State, and Local funding was spent on the lake renovation project.

Included in the project were three sediment/nutrient dikes, three offshore breakwaters, three islands, five jetties, six hardpoints, seven underwater islands, modification of the outlet structure, a new boat ramp and parking lot, reservoir basin excavation, and fish renovation and restocking. Reservoir basin excavation included the excavation and disposal of 349,800 cubic yards of material beyond the reservoir's flood pool and the relocation of 95,000 cubic yards as compact fill for jetties, offshore breakwaters, and sediment dikes within the reservoir basin. Material disposed outside the flood pool has enlarged the reservoir's volume by 216.7 ac-ft, a 19 percent increase, and increased the mean depth of the reservoir from 6.4 to 7.1 feet. The three sediment dikes are expected to reduce sediment loads by 50 percent annually. Collectively, the jetties, breakwaters, and islands have added 16,135 feet of productive shoreline to the reservoir, a 79 percent increase. Fish attractors in the form of cedar trees have also been added to the reservoir. Aerial views of Yankee Hill Reservoir during construction of the lake renovation project are provided in Figure 6.20.

Figure 6.20. Aerial views of Yankee Hill Reservoir during construction of the lake renovation project.

6.11.1.3 Yankee Hill Dam Intake Structure

The dam intake at Yankee Hill is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 3.5 feet by 5.25 feet. The intake structure has four ungated openings – two 18” x 63” openings with a crest elevation at 1250.0 ft-msl and two 12” x 30” openings with a crest elevation at 1244.9 ft-msl. A 36” x 36” gated opening with a crest elevation of 1237.0 ft-msl was constructed into the upstream wall. As part of the recent lake renovation project a "stop-log" structure was attached to the concrete box shaft over the 36" x 36" gated opening. The 36" x 36" gate is permanently left open and pool levels are managed with the external stop-log structure. The purpose of the gate modification is to allow for better management of pool elevations for water quality and fishery management. The gated outlet may also be used to release water for downstream needs.

6.11.1.4 Reservoir Storage Zones

Figure 6.21 depicts the current storage zones of Yankee Hill Reservoir based on the 1994 survey data, results of the recent lake renovation project, and estimated sedimentation. After accounting for the sediment removed from the reservoir basin as part of the recent lake renovation project, it is estimated that 14-17 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2015. The annual volume loss, prior to the implementation of the lake renovation project, is estimated to be 0.52 percent. However, measures implemented as part of the lake renovation project (i.e., sediment/nutrient dikes) are believed to have reduced the annual volume loss. Based on the State of Nebraska's impairment assessment criteria, these values indicate that Yankee Hill Reservoir's water quality dependent uses are not impaired due to sedimentation.

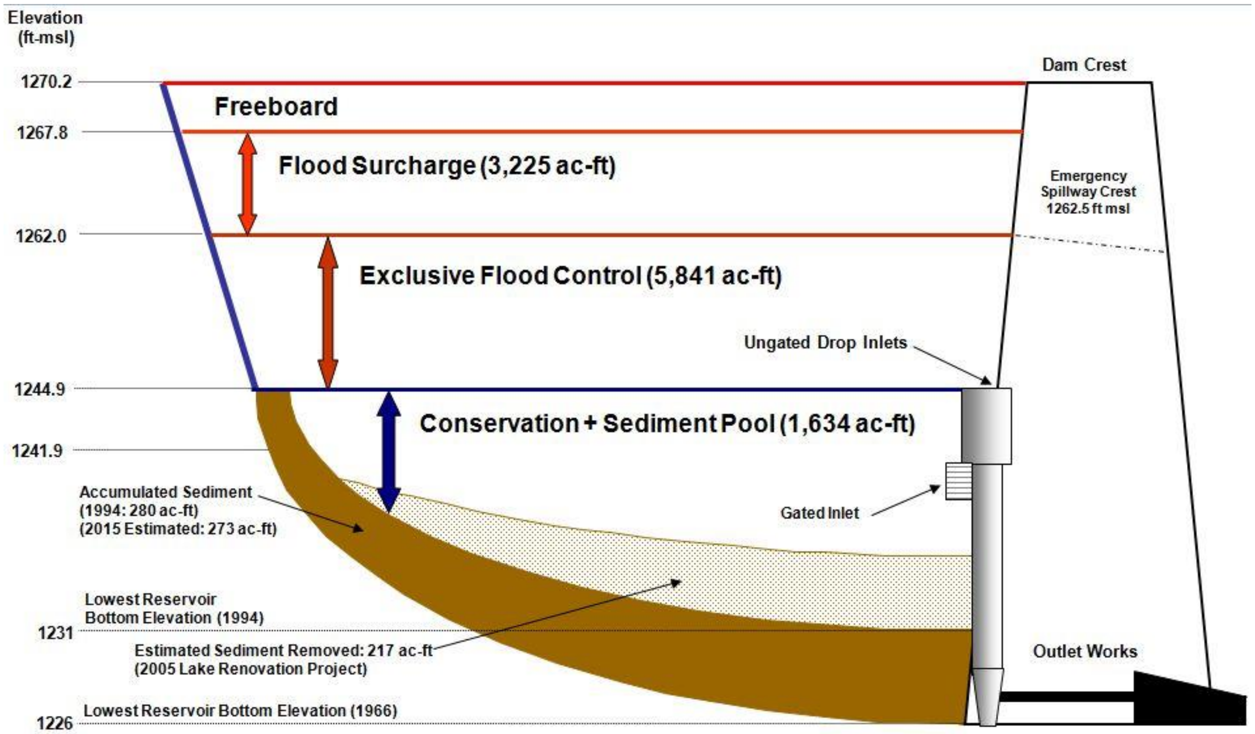


Figure 6.21. Current storage zones of Yankee Hill Reservoir based on the 1994 survey data and estimated sedimentation**.**

6.11.1.5 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Yankee Hill 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. As mentioned, a lake renovation project was implemented at Yankee Hill reservoir from 1999 through 2005. During this period the reservoir was drawn down to facilitate construction activities, and in-reservoir water quality monitoring by the District was discontinued. In-reservoir monitoring was restarted in 2007. Runoff monitoring by the NDEQ on the two main tributary inflows to the reservoir continued during the lake renovation project. Figure 6.22 shows the location of the sites that have been monitored for water quality during the 5-year sampling period (i.e., 2011 through 2015). The near-dam location (YANLKND1) has been monitored by the District since 1980.

6.11.2 WATER QUALITY IN YANKEE HILL RESERVOIR

6.11.2.1 Existing Water Quality Conditions

6.11.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Yankee Hill Reservoir at sites YANLKND1, YANLKMLW1, YANLLKMLS1, YANLKUPW1 and WAGLKUPS1 from May through September during the 5-year period 2011 through 2015 are summarized, respectively, in Plate 6-140 through Plate 6-144. A review of these results indicated possible water quality concerns regarding dissolved oxygen, pH, and nutrients.

A significant number of dissolved oxygen measurements throughout Yankee Hill Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 6-140 through 6-144). Most of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and appeared to be associated with a slight thermal stratification. The following provision is included in Nebraska's Water Quality Standards (117 NAC 2.004.01) regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Yankee Hill Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation. However, thermal stratification in Yankee Hill Reservoir was relatively limited during the 5-year sampling period of 2011 through 2015 (Plate 6-146). This limited stratification could lead to the above provision not applying to the reservoir and possible impairment for dissolved oxygen for the protection of aquatic life in Yankee Hill Reservoir. In addition, on June 9, 2014, near-dam dissolved oxygen measurements were below the 5 mg/l criterion for the protection of warmwater aquatic life from the reservoirs surface (Plate 6-148).

A large number (>48%) of pH readings measured throughout Yankee Hill Reservoir were above the numeric pH criteria of 9.0 for the protection of warmwater aquatic life (Plate 6-140 through 6-144). The lowest and highest pH levels measured were, respectively, 6.9 and 10.0. The magnitude and number of pH criterion exceedances indicate a noteworthy water quality concern. Based on the State of Nebraska's impairment assessment criteria, the percent exceedance of the upper pH criterion indicates impairment of the Aquatic Life beneficial use of Yankee Hill Reservoir. It is believed the high pH values may be associated with periods of high algal production and CO_2 uptake during photosynthesis.

Nutrient criteria defined in Nebraska's water quality standards for eastern Nebraska impounded waters include: total phosphorus (0.05 mg/l), total nitrogen (1.0 mg/l), and chlorophyll *a* (10 ug/l). Samples collected for these parameters must represent epilimnetic conditions of the lake during the "growing season" (i.e., May through September) to be considered for impairment assessment. All three of these criteria were exceeded in Yankee Hill Reservoir (Plate 6-140). The near-surface chlorophyll *a* criterion was exceeded in 96 percent of the "lab analyzed" samples taken in the reservoir at site YANLKND1. The total phosphorus and total nitrogen criteria was exceeded in all samples collected. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" and the reported mean values (Plate 6-140) represent the growing season average for the 5-year period 2011 through 2015. Based on the State of Nebraska's impairment assessment methodology, the near-surface mean total phosphorus (0.30 mg/l), total nitrogen (2.12 mg/l), and chlorophyll *a* (55 ug/l) values at YANLKND1 indicate impairment of the aquatic life use due to nutrients.

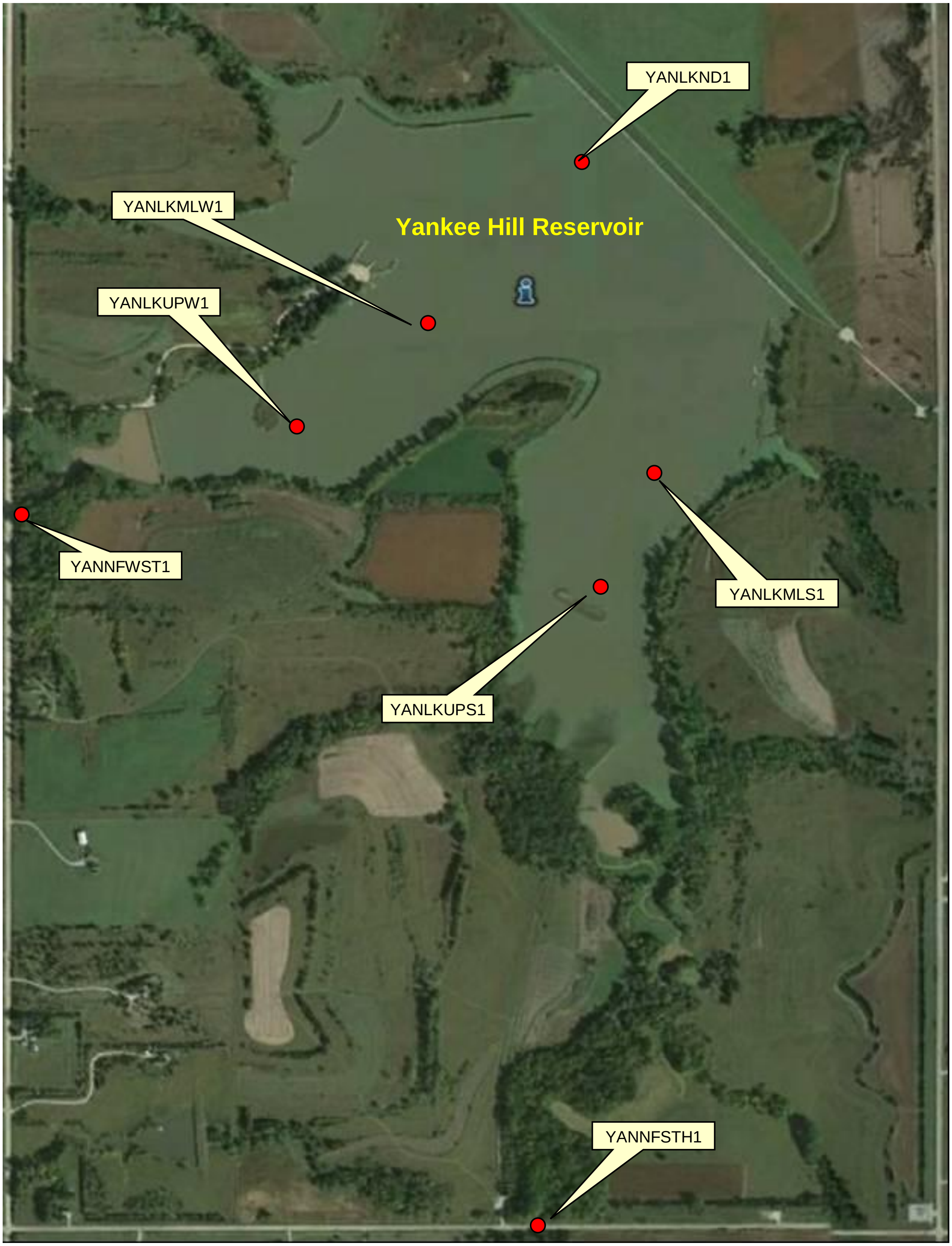


Figure 6.22. Location of sites where water quality monitoring was conducted at Yankee Hill during the period 2011 through 2015**.**

6.11.2.1.2 Thermal Stratification

6.11.2.1.2.1 ***Longitudinal Temperature Contour Plots***

Late-spring and summer thermal conditions of Yankee Hill Reservoir measured during 2015 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 6-145 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites YANLKND1, YANLKMLW1, and YANLKUPW1 in 2015. These temperature plots indicate that Yankee Hill Reservoir exhibited only slight thermal stratification in 2015.

6.11.2.1.2.2 ***Near-Dam Temperature Depth-Profile Plots***

Existing summer thermal stratification of Yankee Hill Reservoir, at the deep water area near the dam, measured over the 5-year period 2011 through 2015 is depicted by depth-profile temperature plots (Plate 6-146). The depth-profile temperature plots indicate that the reservoir occasionally exhibited significant summer thermal stratification over the 5-year sampling period. Since Yankee Hill Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.11.2.1.3 Dissolved Oxygen Conditions

6.11.2.1.3.1 ***Longitudinal Dissolved Oxygen Contour Plots***

Dissolved oxygen contour plots were constructed along the length of Yankee Hill Reservoir based on depth-profile measurements taken in 2015 at sites YANLKND1, YANLKMLW1, and YANLKUPW1. Plate 6-147 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 May and July (June 2015 measurements not collected) near the reservoir bottom near the dam.

6.11.2.1.3.2 ***Near-Dam Dissolved Oxygen Depth-Profile Plots***

Existing summer dissolved oxygen conditions in Yankee Hill Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2011 through 2015 (Plate 6-148). Several of the depth-profiles show a significant vertical gradient in summer dissolved oxygen levels. Forty-two percent of the profiles showed hypoxic conditions near the reservoir bottom and one of the 24 profiles showed dissolved oxygen levels below the Nebraska's dissolved oxygen criterion for the protection of warmwater aquatic life (≥ 5 mg/l) through the entire depth of the profile. Super-saturation near the surface of the reservoir was also observed. Although Yankee Hill Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition of mixing to allow hypoxic conditions to occasionally develop near the reservoir bottom.

6.11.2.1.3.3 ***Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions***

The volume of Yankee Hill 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 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 July 27, 2015 contour plot indicates a pool elevation of 1,244.5 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1,238.5 ft-msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1,237.5 ft-msl (Plate 6-148). The current District Area-Capacity Tables (1993 Survey) give storage capacities of 1,547 ac-ft for elevation 1,244.5 ft-msl, 563 ac-ft for elevation 1238.5 ft-msl, and 447 ac-ft for elevation 1,237.5 ft-msl. On July 27, 2015 it is estimated that 36 percent of the volume of Yankee Hill Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 29 percent of the reservoir volume was hypoxic.

6.11.2.1.4 Water Quality Conditions Based on Hypoxia

Dissolved oxygen levels monitored in Yankee Hill Reservoir indicated hypoxic conditions May and July 2015 (No measurements collected in June). As a result, longitudinal contour plots for ORP and pH were constructed during these months. Depth profiles and near-surface/near-bottom sample comparisons were also constructed for periods of hypoxic conditions during the summer from 2011 through 2015.

6.11.2.1.4.1 ***Oxidation-Reduction Potential***

Plate 6-149 provides longitudinal ORP contour plots based on depth-profile measurements taken in 2015 when hypoxic conditions were present in Yankee Hill Reservoir. The ORP values indicated reduced conditions occurred near the reservoir bottom near the dam in July 2015, with measurements below 100 mV. However, much of the reservoir ORP measurements were greater than 300 mV. Plate 6-150 plots depth profiles for ORP measured during the summer over the 5-year sampling period in the deep water area of Yankee Hill Reservoir near the dam when hypoxic conditions were present. The ORP depth profiles indicate that reduced conditions occasionally occurred in Yankee Hill Reservoir during the summer, however, these conditions were rarely below 150 mV.

6.11.2.1.4.2 ***pH***

Longitudinal contour plots for pH conditions measured in 2015 when hypoxic conditions were present are provided in Plate 6-151. Plate 6-152 plots depth profiles for pH measured during the summer over the 5-year sampling period in the deep water area of Yankee Hill Reservoir near the dam when hypoxic conditions were present. An appreciable vertical gradient in pH regularly occurred in the reservoir during the summer. Lower pH levels near the bottom of the reservoir could be attributable to reservoir stratification and ongoing decomposition/respiration near the reservoir bottom. This would lead to an increase in CO_2 and decrease in pH. Higher pH levels near the reservoir surface were likely due to “hyper” photosynthesis resulted in higher pH levels near the reservoir surface. The highest measured pH levels exceeded the upper pH criterion of 9.0 for the protection of warmwater aquatic life.

6.11.2.1.4.3 ***Comparison of Near-Surface and Near-Bottom Water Quality Conditions***

Paired near-surface and near-bottom water quality samples collected from Yankee Reservoir during the summer when hypoxia was present 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 YANLKND1 during the 5-year period 2011 through 2015. During the 5-year period a total of 24 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 10 (42%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 6-153). 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 oxidation-reduction potential (p=0.43), total ammonia nitrogen (p=0.11), for nitrate-nitrite nitrogen (p=0.31), total alkalinity (p=0.93), total phosphorus (p=0.19), and orthophosphorus (p=0.09). Parameters that were significantly lower in the near-bottom water of Yankee Hill Reservoir when hypoxia was present included water temperature, dissolved oxygen, and pH ($p<0.05$).

6.11.2.1.4.4 ***Reservoir Trophic Status***

Trophic State Index (TSI) values for Yankee Hill Reservoir were calculated from monitoring data collected during the 5-year period 2011 through 2015 at the near-dam ambient monitoring site (i.e., YANLKND1). Table 6.39 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Yankee Hill Reservoir is in a hypereutrophic condition.

Table 6.39. Summary of Trophic State Index (TSI) values calculated for Yankee Hill Reservoir for the 5-year period 2011 through 2015.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	24	74	73	60	85
TSI(TP)	24	74	75	59	80
TSI(Chl)	24	78	79	53	91
TSI(Avg)	24	75	75	66	82

* 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 for the individual parameters.

Note: See Section 4.1.3 for discussion of TSI calculation.

6.11.2.1.5 Reservoir Plankton Community

6.11.2.1.5.1 ***Phytoplankton Community***

Phytoplankton grab samples were collected at the Yankee Hill Reservoir near-surface, near-dam sampling site during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-154). The relative abundance of phytoplankton, based on biovolume, in May, July, and September 2015 is provided in Plate 6-155. The highest phytoplankton total biovolume was observed in July. Cyanobacteria dominated most of the 2015 growing season. The phytoplankton populations for 2015 match successional patterns commonly observed in eutrophic reservoirs. Cool water taxa such as Ochrophyta tend to dominate spring and late fall while warm water taxa such as Cyanobacteria tend to dominate summer and ealy fall. Major and dominant phytoplankton genera sampled in 2015 at Yankee Hill Reservoir are provided in Table 6.40.

Annual variation in phytoplankton community composition is displayed in Plate 6-156. During the 5-year period 2011 through 2015, Yankee Hill was mostly dominated by Cyanobacteria. Cyanobacteria density levels reached levels higher than the World Health Organizations high level of health risk (>100,000 Cells/ml) in 2011, 2012 and 2015 (Plate 6-154). Spring water temperatures in these years were relatively high. These high spring temperatures could have resulted in a longer Cyanobacterial growing season which caused the observed high densities. Maximum measured extracellular microcystin toxin level during the 5-year period at the near-dam site was 1.0 µg/l (Plate 6-140).

Table 6.40. Listing of major and dominant phytoplankton genera Sampled in Yankee Hill Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1)

Division	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cryptophycophyta	*Rhodomonas*	*Cryptomonas*
Ochrophyta	-----	*Stephanodiscus*
Cyanobacteria	*Anabaena*	*Microcystis*

6.11.2.1.5.2 ***Zooplankton Community***

Zooplankton vertical-tow samples were collected at Yankee Hill Reservoir near-dam sampling sites during the spring and summer of the 5-year period 2011 through 2015 (Plate 6-157). The sampled zooplankton included four taxonomic groupings: Cladocerans, Copepods, Rotifers, and Ostracods. The relative abundance of zooplankton, based on biomass, in May, July, and September 2015 is provided in Plate 6-158. The highest zooplankton total biomass was in May 2015. Cladocerans and Copepods dominated May while only Cladocerans dominated July and September. Dominant and major zooplankton genera sampled in Yankee Hill Reservoir during 2015 are provided in Table 6.41.

Table 6.41. Listing of major and dominant zooplankton genera sampled in Yankee Hill Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1)

Taxonomic Group	Major Genera (>10% Total Biovolume in a single sample)	Dominant Genera (>25% Total Biovolume in a single sample)
Cladocerans	-----	*Ceriodaphnia*, *Daphnia*
Copepods	-----	*Mesocyclops*

6.11.2.1.6 Zebra Mussel Monitoring

Zebra mussel veliger sampling has been conducted once yearly since 2012 at Yankee Hill Reservoir. During the sampling period (2012-2015) no veligers have been identified.

6.11.2.2 Water Quality Trends (1980 through 2015)

Water quality trends from 1980 to 2015 were determined for Yankee Hill 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., YANLKND1). Plate 6-159 displays a scatter-plot of the collected data for the four parameters for the period 1980 through 1998 and 2007 through 2015. The data gap of 1999 through 2006 is the period when the lake renovation project was implemented at Yankee Hill Reservoir. Regression analysis was performed on the data collected from 1980 through 1998. Prior to the renovation project there were no significant trends in transparency ($p=0.22$, $R^2=0.02$), total phosphorus ($p=0.19$, $R^2=0.03$), chlorophyll a ($p=0.17$, $R^2=0.06$) and TSI ($p=0.59$, $R^2=0.004$). Due to the recent renovation project, Nebraska's water quality standards place Yankee Hill Reservoir in category 4R. Nutrient assessment of category 4R designated waters may be misleading due to a trophic upsurge upon refill which is typically followed by a period of decline. Once the reservoir category has changed and the more "post-project" water quality data is collected, further analyses will be pursued to test for water quality changes from "pre-project" conditions. Yankee Hill was in a hypereutrophic condition prior to the renovation project and has remained so post renovation.

6.11.3 Plates

Plate 6-140. Summary of water quality conditions monitored in Yankee Hill Reservoir at site YANLKND1 from May to September during the 5-year 2011 through 2015. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths, unless otherwise indicated.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	24	1244.78	1244.65	1242.70	1246.60	-----	-----	-----
Water Temperature (°C)	0.1	207	23.18	23.37	16.04	33.75	32[1]	3	1%
Dissolved Oxygen (mg/l)	0.1	207	8.19	8.41	n.d.	17.22	≥5[2]	37	18%
Dissolved Oxygen, Near-Surface (mg/l)[C]	0.1	23	10.48	9.88	3.65	17.22	≥5[2]	1	4%
Dissolved Oxygen (% Sat.)	0.1	207	99.87	103.70	n.d.	234.50	-----	-----	-----
Secchi Depth (in.)	1	24	16.29	15.50	7.00	40.00	-----	-----	-----
Turbidity (NTUs)	1	198	46.10	32.95	6.70	406.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	207	311.09	323.00	49.00	437.00	-----	-----	-----
Specific Conductance (umho/cm)	1	207	355.60	358.40	256.30	478.10	2,000[3]	0	0%
pH (S.U.)	0.1	207	8.92	9.06	7.20	10.35	≥6.5 & ≤9.0 [1]	0,104	0%,50%
Alkalinity, Total (mg/l)	1	48	137.33	137.00	101.00	179.00	>20[1]	0	0%
Suspended Solids, Total (mg/l)	4	48	30.15	25.00	5.00	79.00	-----	-----	-----
Ammonia, Total (mg/l)	0.02	48	-----	n.d.	n.d.	1.19	0.44[4,5], 0.12[4,6]	2,3	4%,6%
Ammonia, Total, Near-Surface (mg/l) [C]	0.02	24	0.06	0.02	0.01	0.53	0.30[4,5], 0.08[4,6]	0	0%
Kjeldahl N, Total (mg/l)	0.08	48	1.98	1.89	1.12	3.43	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.03	48	-----	n.d.	n.d.	0.87	100[3]	0	0%
Nitrogen, Total (mg/l)	0.08	48	2.14	1.97	1.49	3.52	1[7]	48	100%
Nitrogen, Total, Near-Surface (mg/l) [C]	0.08	24	2.12	1.95	1.49	3.52	1[7]	24	100%
Phosphorus, Total (mg/l)	0.005	48	0.35	0.34	0.06	1.35	0.05[7]	48	100%
Phosphorus, Total, Near-Surface (mg/l) [C]	0.005	24	0.30	0.31	0.06	0.51	0.05[7]	24	100%
Phosphorus-Ortho, Dissolved (mg/l)	0.01	48	0.18	0.17	n.d.	0.59	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	123.54	125.00	110.00	141.40	-----	-----	-----
Arsenic, Dissolved (ug/l)	0.008	5	12.80	12.00	10.00	18.00	340[5], 16.7[8]	0,1	0%,20%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	0.40	7.33[5], 0.29[6]	0,1	0%,20%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	710.79[5], 92.53[6]	0	0%
Copper, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	16.58[5], 10.84[6]	0	0%
Iron, Dissolved (ug/l)	10	5	-----	20.00	n.d.	33.00	1000[6]	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	82.27[5], 3.21[6]	0	0%
Manganese, Dissolved (ug/l)	3	5	-----	40.00	n.d.	260.00	1000[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	565.52[5], 62.81[6]	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5.06[5]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	141.57[5], 142.73[6]	0	0%
Antimony, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	0.70	88[5], 30[6]	0	0%
Aluminum, Dissolved (ug/l)	40	5	-----	n.d.	n.d.	n.d.	750[5], 87[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Chlorophyll a (ug/l) – Lab Determined[C]	6	24	58	55	n.d.	180	10[7]	23	96%
Chlorophyll a (ug/l) – Field Probe	6	207	66	49	n.d.	373	10[7]	197	95%
Atrazine, Total (ug/l)[D]	0.05	24	3.65	3.00	n.d.	13.00	330[5], 12[6]	0,1	0%,4%
Metolachlor, Total (ug/l)[D]	0.05	23	0.81	0.70	0.10	1.70	390[5], 100[6]	0	0%
Acetochlor, Total (ug/l)[D]	0.05	24	0.82	0.70	n.d.	2.00	-----	-----	-----
Microcystin, Extracellular (ug/l)	0.1	22	-----	0.15	n.d.	1.00	20[9]	0	0%
Pesticide Scan (ug/l)[E]									
Atrazine, Tot	0.13	3	3.16	3.10	2.36	4.03	330[5], 12[6]	0	0%
Acetochlor, Tot	0.08	3	-----	n.d.	n.d.	0.22	-----	-----	-----
Metolachlor, Tot	0.13	3	-----	n.d.	n.d.	0.53	390[5], 100[6]	0	0%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are median criteria values calculated from individual sampling events.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l total microcystins in recreation water for impairment assessment. Note that Corps microcystin is extracellular only.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Nebraska's Impairment assessment of thermally stratified reservoirs establishes that samples must represent epilimnetic conditions (i.e. near-surface).

(D) Immunoassay analysis.

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

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-141. Summary of water quality conditions monitored in Yankee Hill Reservoir at site YANLKMLW1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1244.77	1244.85	1242.70	1246.60	-----	-----	-----
Water Temperature (°C)	0.1	162	23.15	23.29	15.37	32.73	32(1)	2	1%
Dissolved Oxygen (mg/l)	0.1	162	9.13	9.08	0.24	18.48	≥5(2)	17	10%
Dissolved Oxygen (% Sat.)	0.1	162	111.38	111.65	3.00	241.30	-----	-----	-----
Secchi Depth (in.)	1	24	16.83	14.00	8.00	46.00	-----	-----	-----
Turbidity (NTUs)	1	156	43.82	32.00	6.40	850.00	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	162	326.50	324.50	103.00	412.00	-----	-----	-----
Specific Conductance (umho/cm)	1	162	355.85	358.80	255.40	473.80	2,000(3)	0	0%
pH (S.U.)	0.1	162	8.98	9.12	7.14	10.34	≥6.5 & ≤9.0 (1)	0,87	0%,54%
Chlorophyll a (ug/l) – Field Probe	6	162	67	52	3	367	10(4)	154	95%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.

(2) Use-specific criteria for aquatic life.

(3) Agricultural criteria for surface waters.

(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-142. Summary of water quality conditions monitored in Yankee Hill Reservoir at site YANLKMLS1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1244.77	1244.85	1242.70	1246.60	-----	-----	-----
Water Temperature (°C)	0.1	159	23.24	23.37	15.99	32.84	32(1)	3	2%
Dissolved Oxygen (mg/l)	0.1	159	9.00	8.93	0.33	20.51	≥5(2)	16	10%
Dissolved Oxygen (% Sat.)	0.1	159	109.69	110.80	2.80	263.30	-----	-----	-----
Secchi Depth (in.)	1	24	15.63	14.50	7.00	27.00	-----	-----	-----
Turbidity (NTUs)	1	152	39.50	31.70	8.90	98.40	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	159	326.53	330.00	118.00	447.00	-----	-----	-----
Specific Conductance (umho/cm)	1	159	356.39	358.90	255.30	474.20	2,000(3)	0	0%
pH (S.U.)	0.1	159	8.98	9.13	7.23	10.44	≥6.5 & ≤9.0 (1)	0,82	0%,52%
Chlorophyll a (ug/l) – Field Probe	6	159	75	50	4	1563	10(4)	151	95%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.

(2) Use-specific criteria for aquatic life.

(3) Agricultural criteria for surface waters.

(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-143. Summary of water quality conditions monitored in Yankee Hill Reservoir at site YANLKUPW1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1244.77	1244.85	1242.70	1246.60	-----	-----	-----
Water Temperature (°C)	0.1	62	23.17	22.73	16.12	32.36	32(1)	1	2%
Dissolved Oxygen (mg/l)	0.1	62	10.10	10.07	4.06	17.14	≥5(2)	2	3%
Dissolved Oxygen (% Sat.)	0.1	62	123.44	118.05	43.70	224.50	-----	-----	-----
Secchi Depth (in.)	1	24	16.33	16.50	7.00	27.00	-----	-----	-----
Turbidity (NTUs)	1	61	43.88	31.70	6.50	175.20	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	62	319.66	312.00	224.00	430.00	-----	-----	-----
Specific Conductance (umho/cm)	1	62	343.22	329.40	254.30	471.10	2,000(3)	0	0%
pH (S.U.)	0.1	62	9.05	9.22	7.33	10.22	≥6.5 & ≤9.0 (1)	0,35	0%,56%
Chlorophyll a (ug/l) – Field Probe	6	62	82	56	4	338	10(4)	57	92%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

Plate 6-144. Summary of water quality conditions monitored in Yankee Hill Reservoir at site YANLKUPS1 from May to September during the 5-year period 2011 through 2015. [Note: Except for pool elevation and Secchi depth, results are for water column depth-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 Exceedances	Percent WQS Exceedance
Pool Elevation (ft-msl)	0.1	20	1244.77	1244.85	1242.70	1246.60	-----	-----	-----
Water Temperature (°C)	0.1	64	23.13	23.01	16.20	32.31	32(1)	1	2%
Dissolved Oxygen (mg/l)	0.1	64	9.23	8.36	4.01	20.03	≥5(2)	6	9%
Dissolved Oxygen (% Sat.)	0.1	64	112.11	103.85	47.40	258.90	-----	-----	-----
Secchi Depth (in.)	1	24	14.25	13.50	7.00	24.00	-----	-----	-----
Turbidity (NTUs)	1	63	39.90	30.60	11.30	114.30	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	64	334.19	334.00	216.00	437.00	-----	-----	-----
Specific Conductance (umho/cm)	1	64	346.91	330.00	256.10	478.80	2,000(3)	0	0%
pH (S.U.)	0.1	64	8.94	8.94	7.28	10.57	≥6.5 & ≤9.0 (1)	0,31	0%,48%
Chlorophyll a (ug/l) – Field Probe	6	64	86	56	3	342	10(4)	57	89%

n.d. = Not detected.

(A) Nondetect values set to detection limit 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) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean, number of exceedances, or percent exceedance indicates use impairment based on State of Nebraska 2012 Section 303(d) impairment assessment criteria.

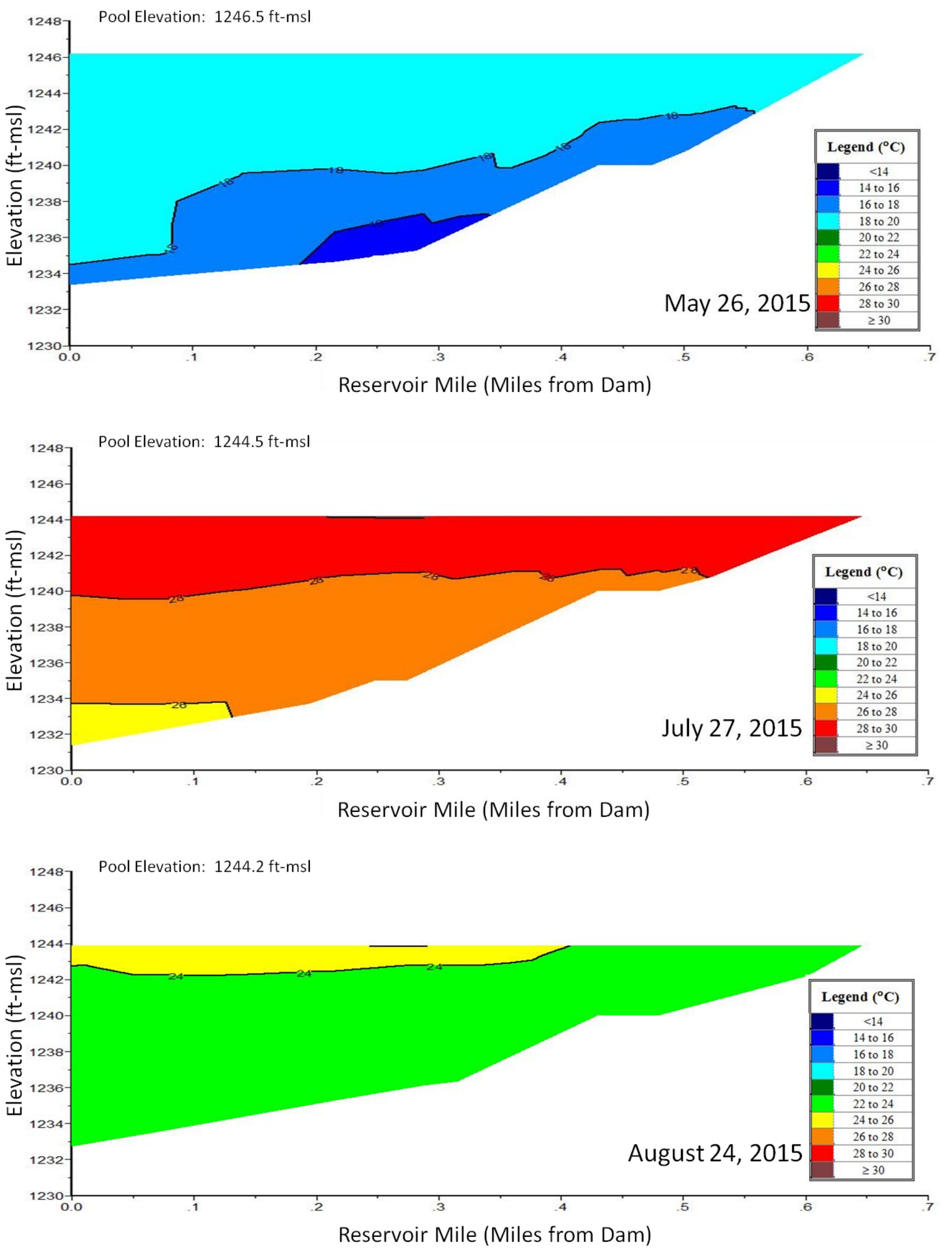


Plate 6-145. Longitudinal water temperature contour plots of Yankee Hill Reservoir based on depth-profile water temperatures (°C) measured at sites YANLKND1, YANLKMLW1, and YANLKUPW1 in 2015.

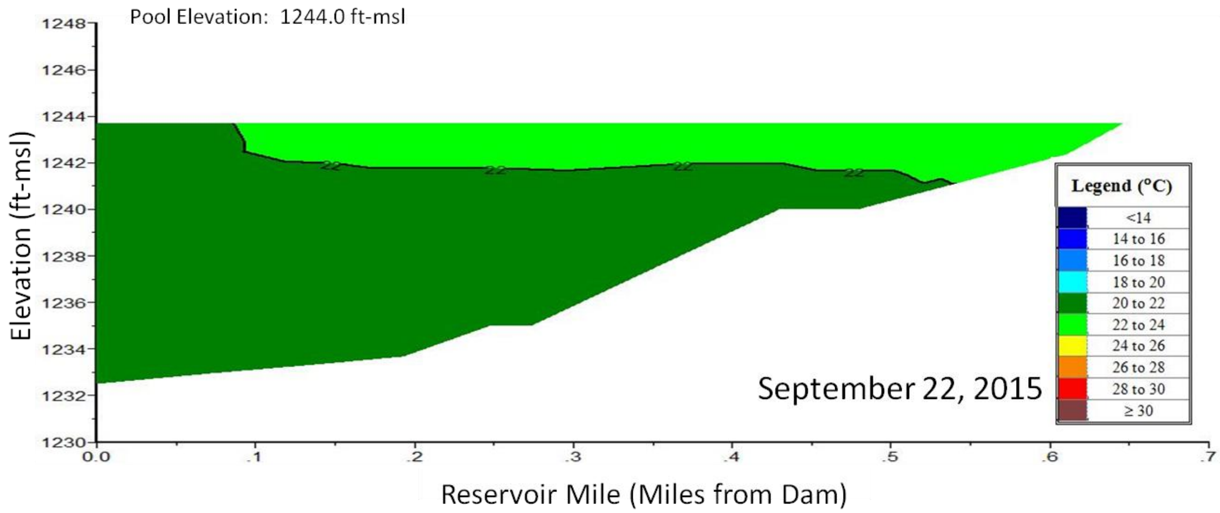


Plate 6-145. (Continued).

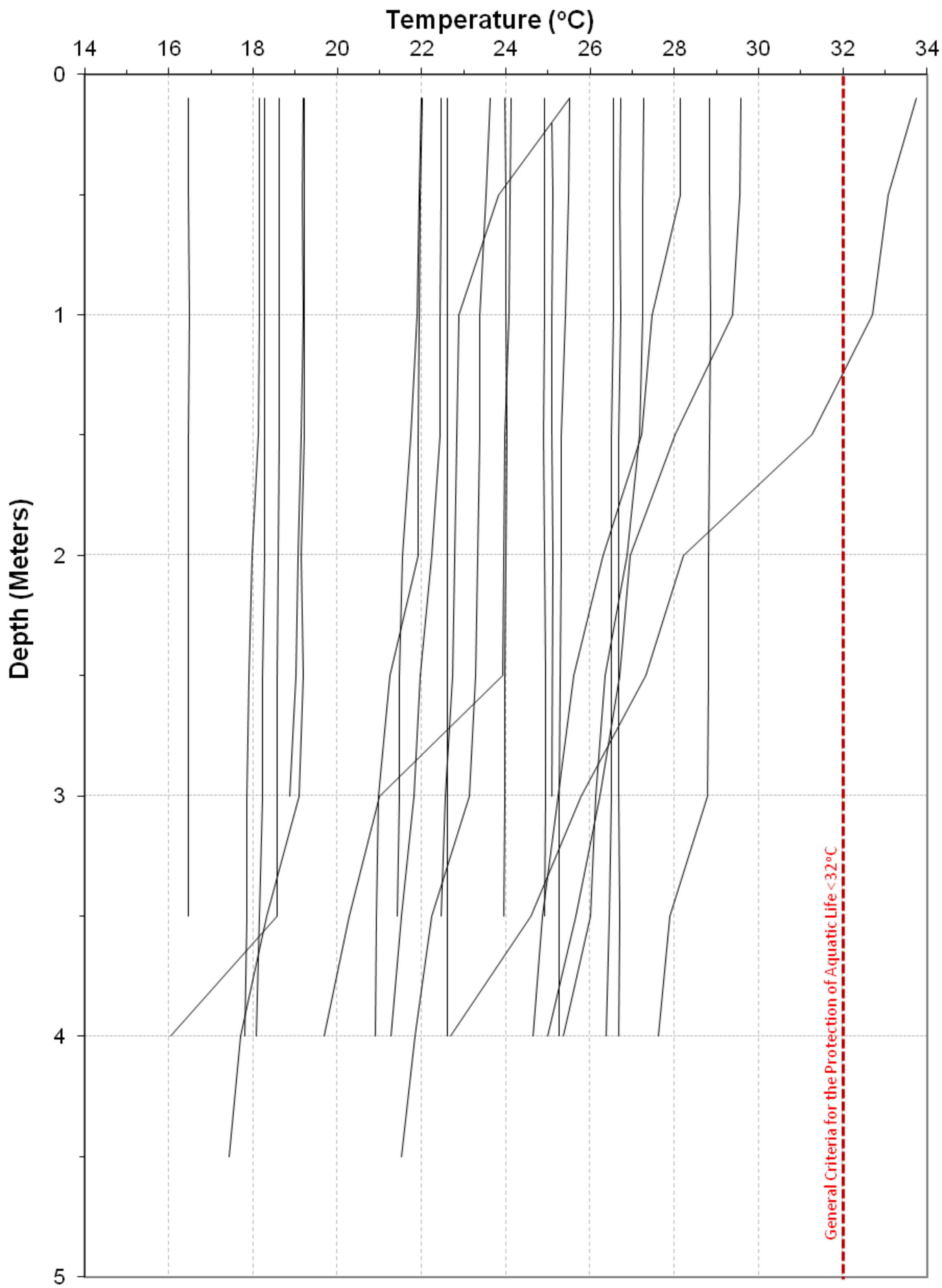


Plate 6-146. Temperature depth profiles for Yankee Hill Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1) during the summer over the 5-year period of 2011 through 2015.

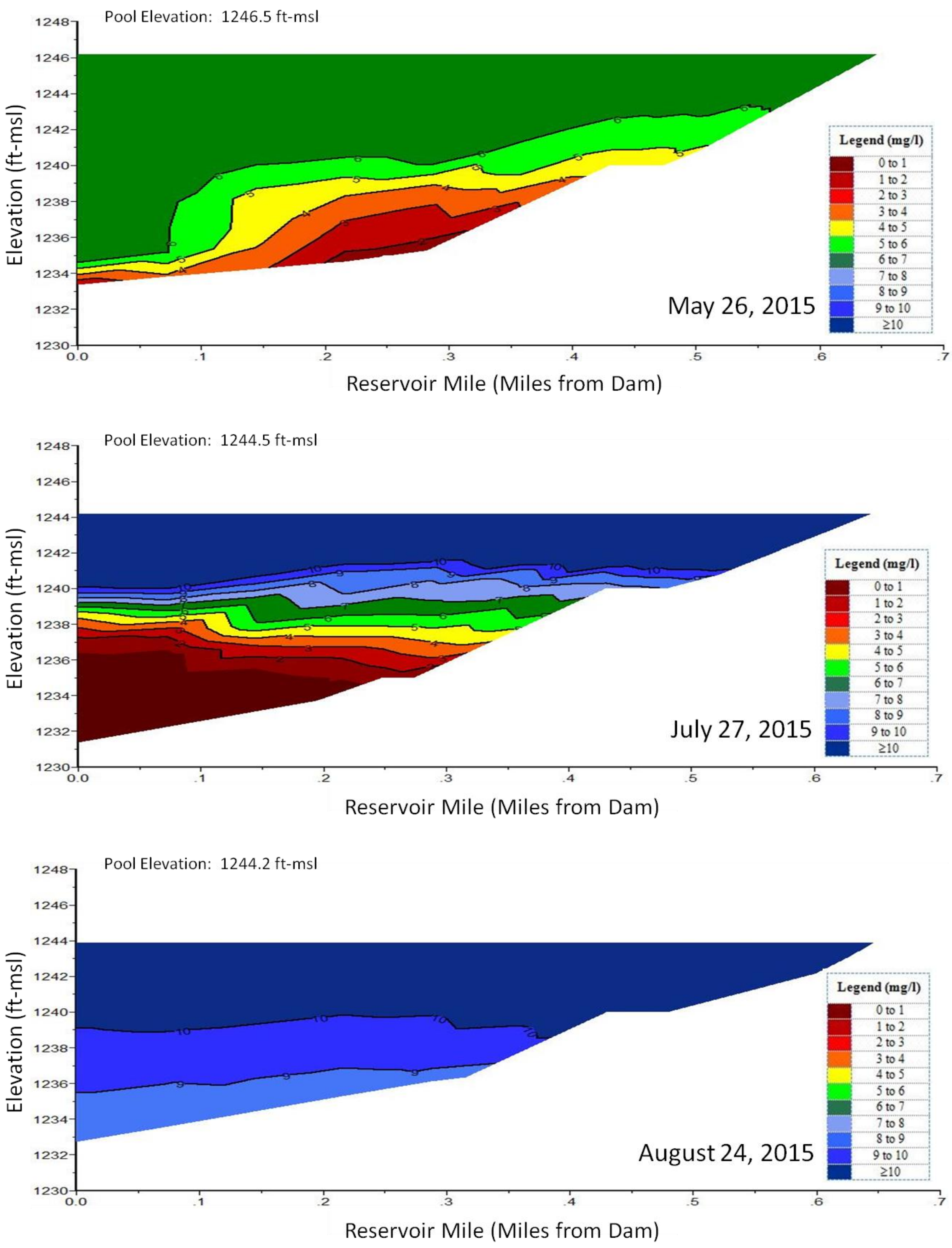


Plate 6-147. Longitudinal dissolved oxygen contour plots of Yankee Hill Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites YANLKND1, YANLKMLW1, and YANLKUPW1 in 2015.

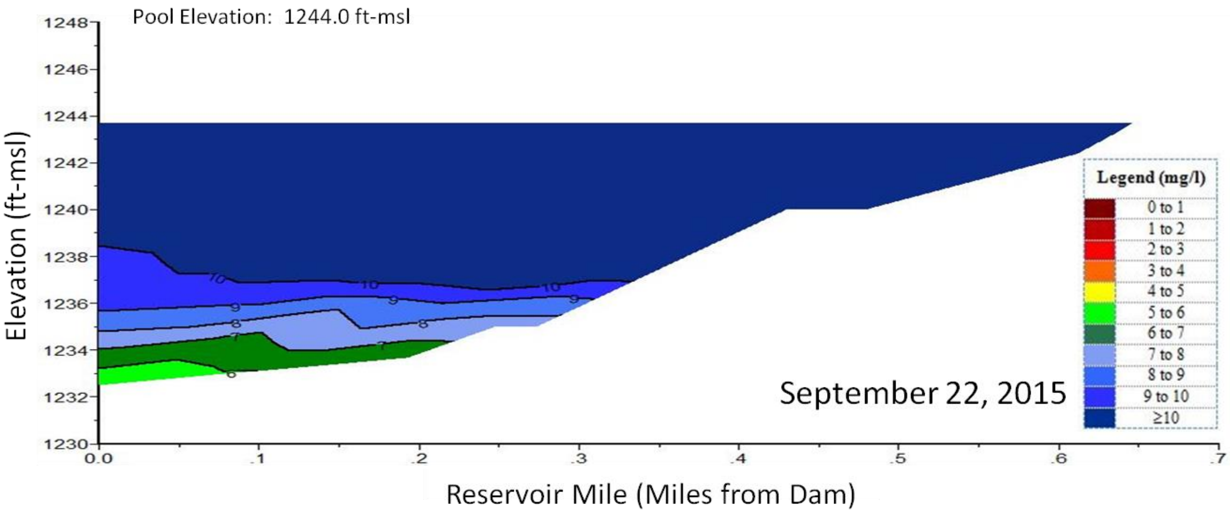


Plate 6-147. (Continued).

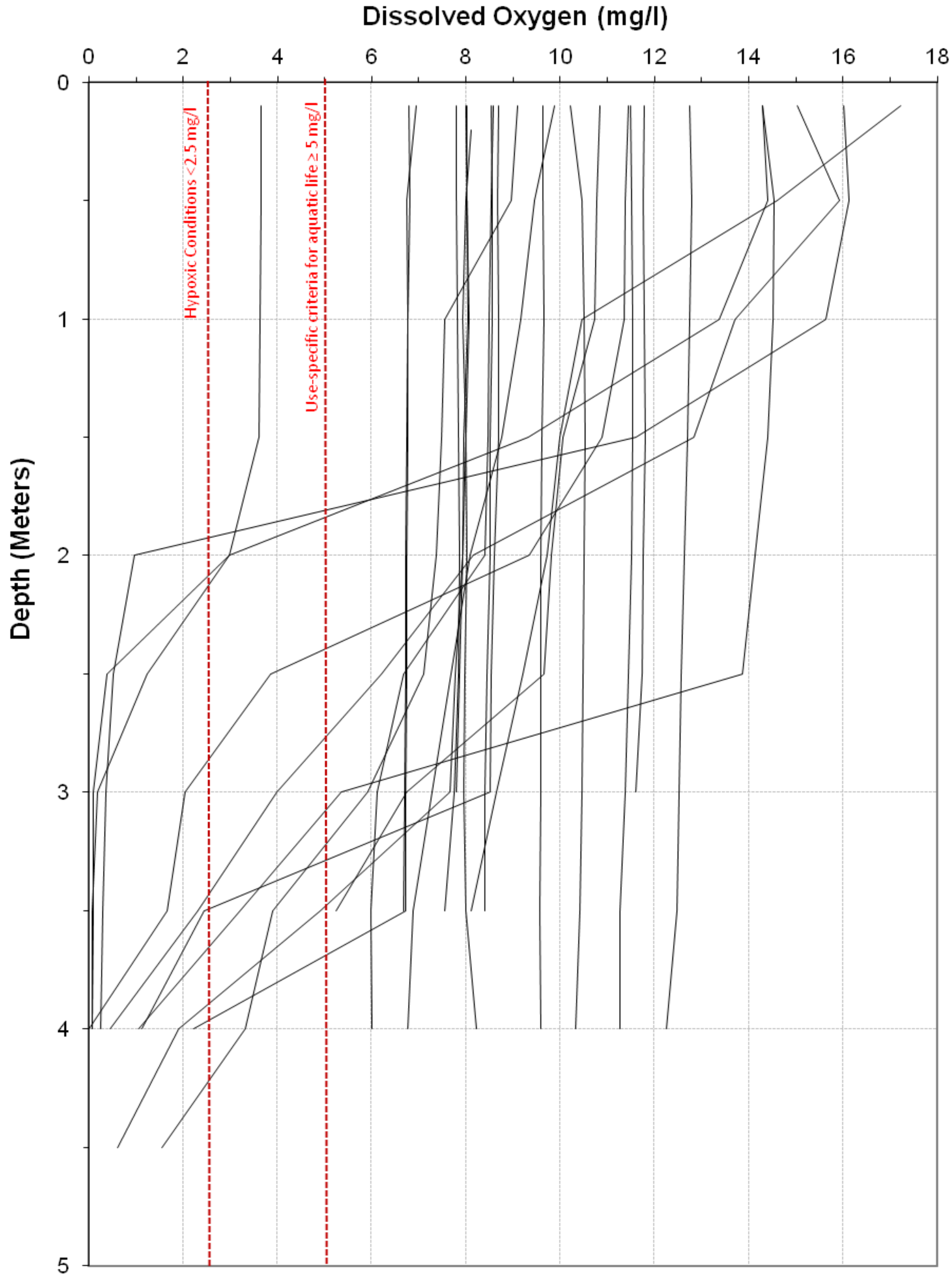
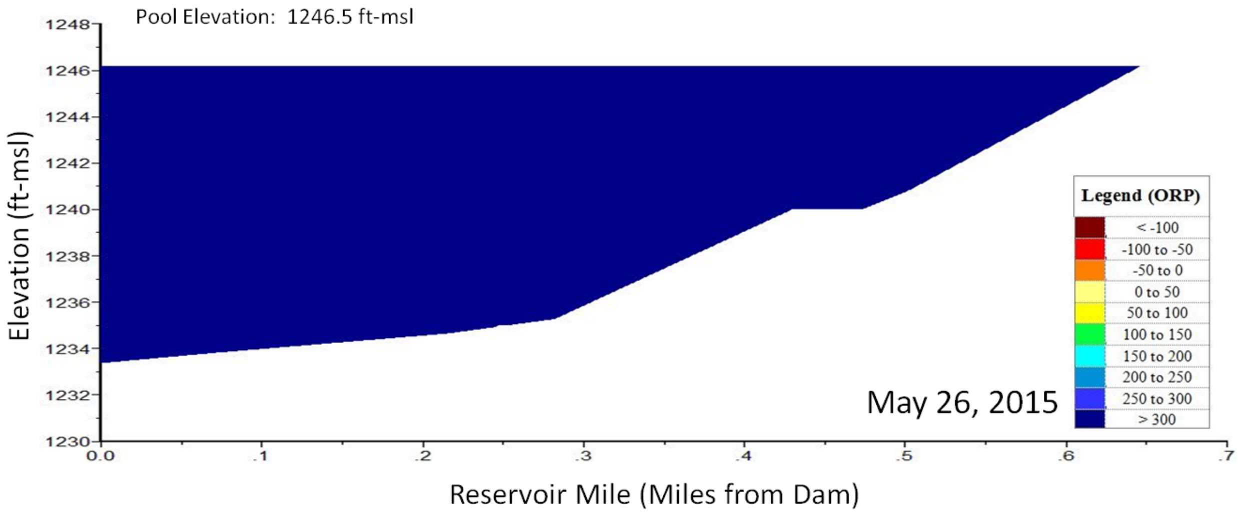


Plate 6-148. Dissolved oxygen depth profiles for Yankee Hill Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1) during the summer over the 5-year period 2011 through 2015.



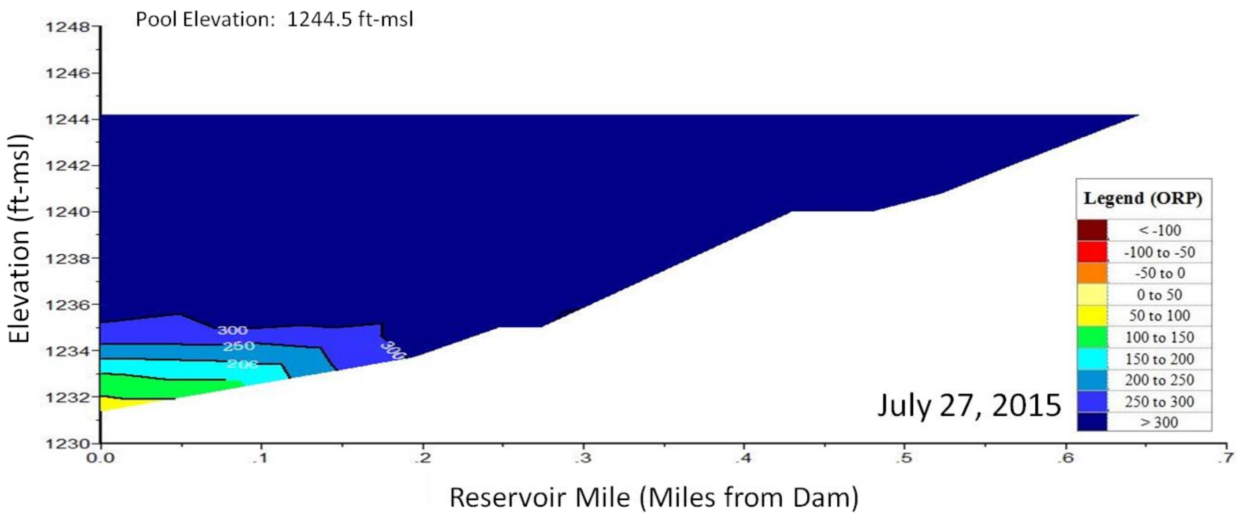


Plate 6-149. Longitudinal oxidation-reduction potential contour plots of Yankee Hill Reservoir based on depth-profile ORP levels (mV) measured at sites YANLKND1, YANLKMLW1, and YANLKUPW1 in 2015.

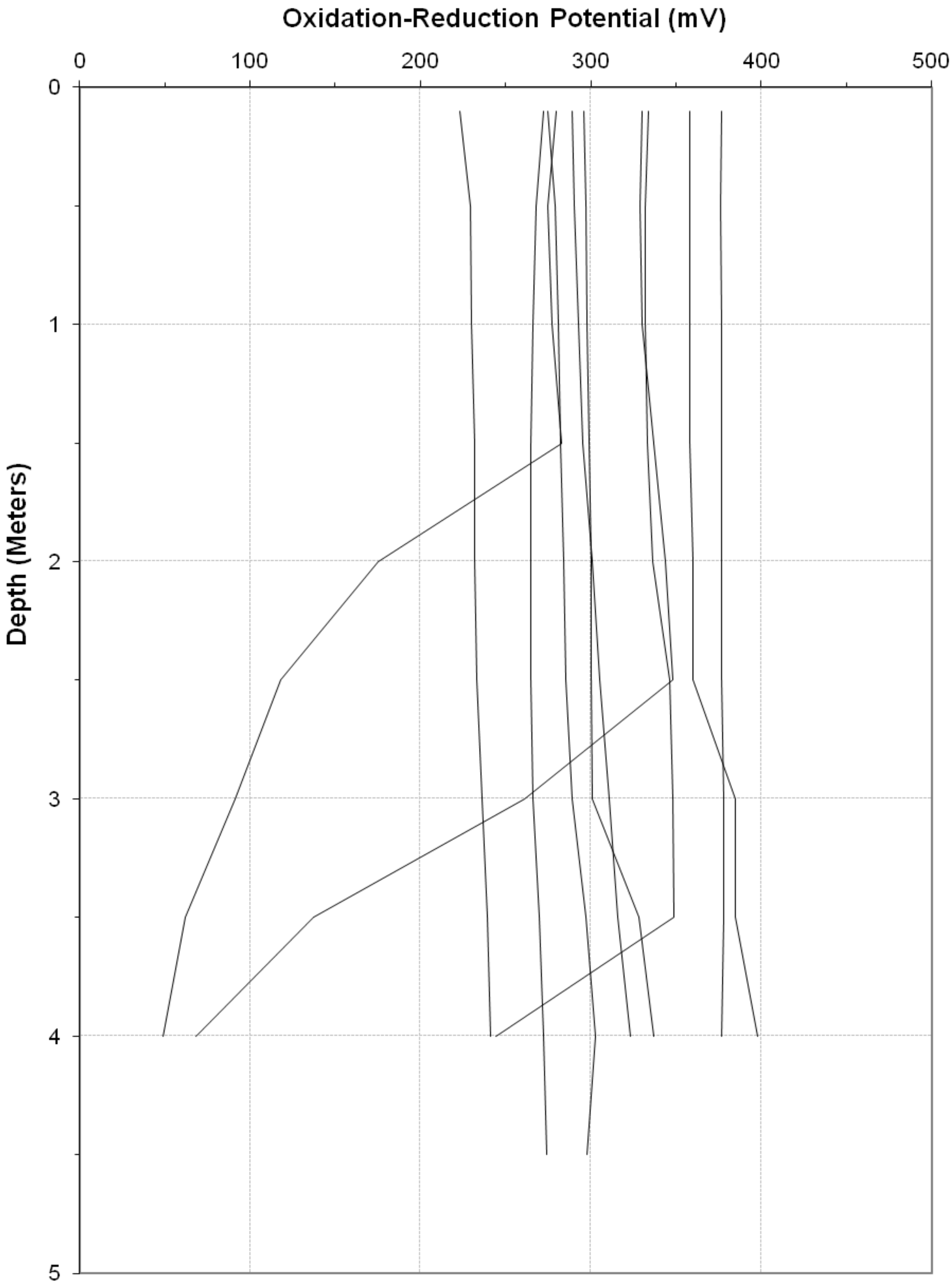
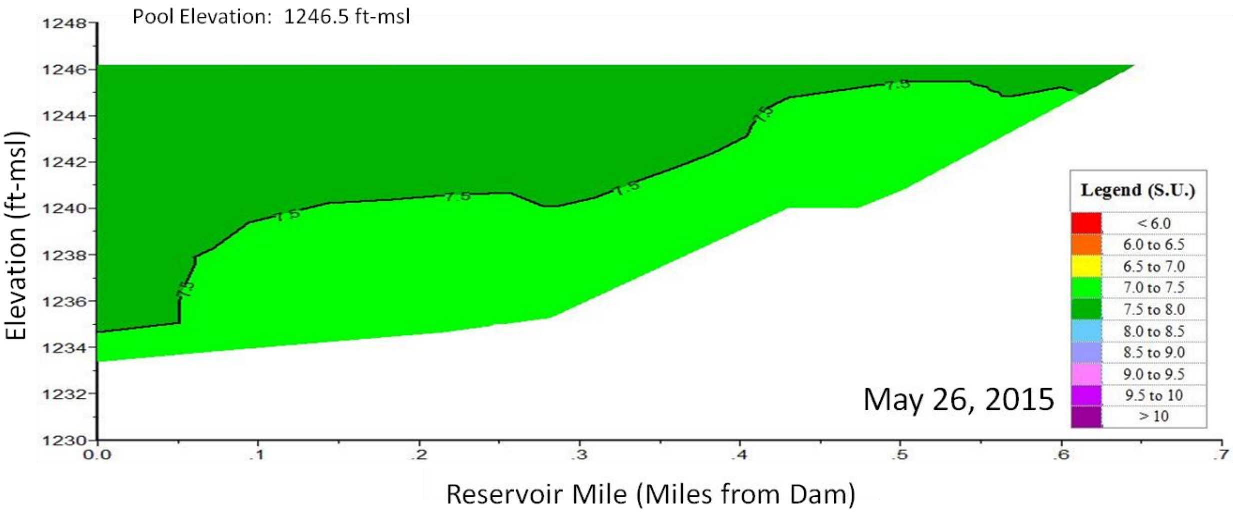


Plate 6-150. Oxidation-reduction potential depth profiles for Yankee Hill Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1) when hypoxic conditions were present, during the summer, over the 5-year period of 2011 through 2015.



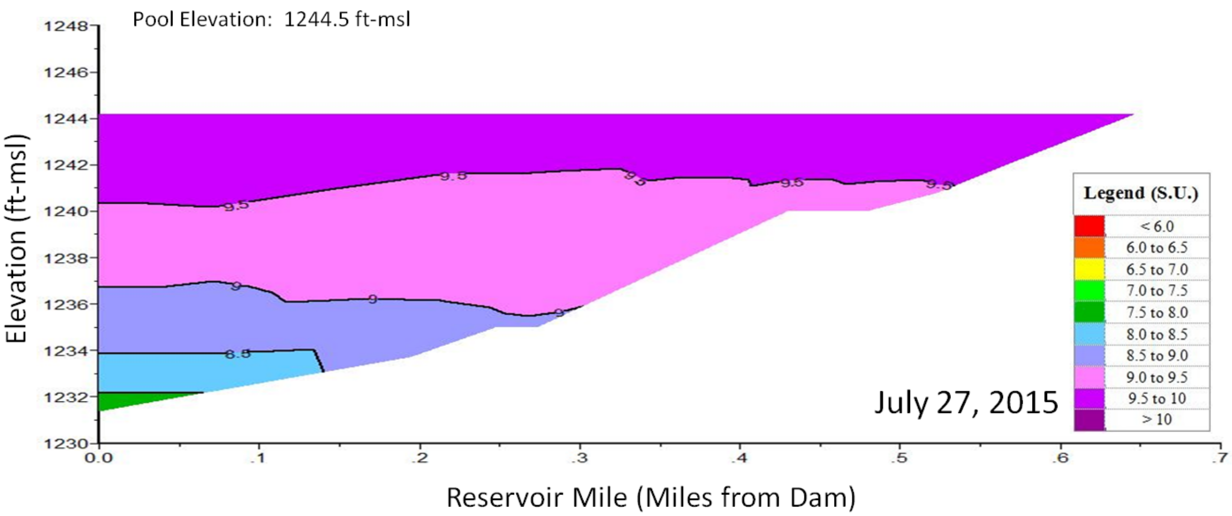


Plate 6-151. Longitudinal pH contour plots of Yankee Hill Reservoir based on depth-profile pH levels (S.U.) measured at sites YANLKND1, YANLKMLW1, and YANLKUPW1 in 2015.

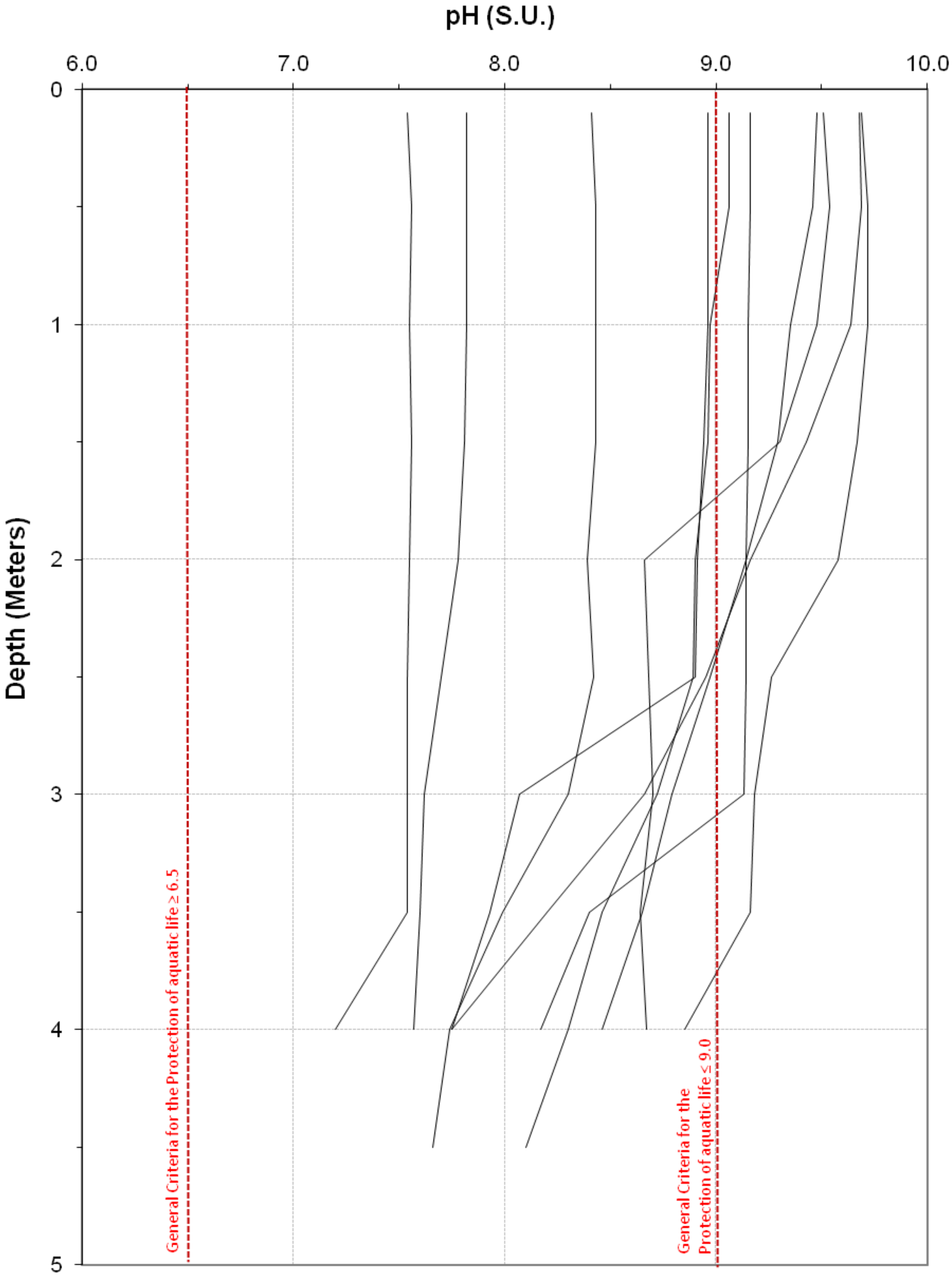


Plate 6-152. pH depth profiles for Yankee Hill Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1) during the summer over the 5-year period of 2011 through 2015, when hypoxic conditions were present.

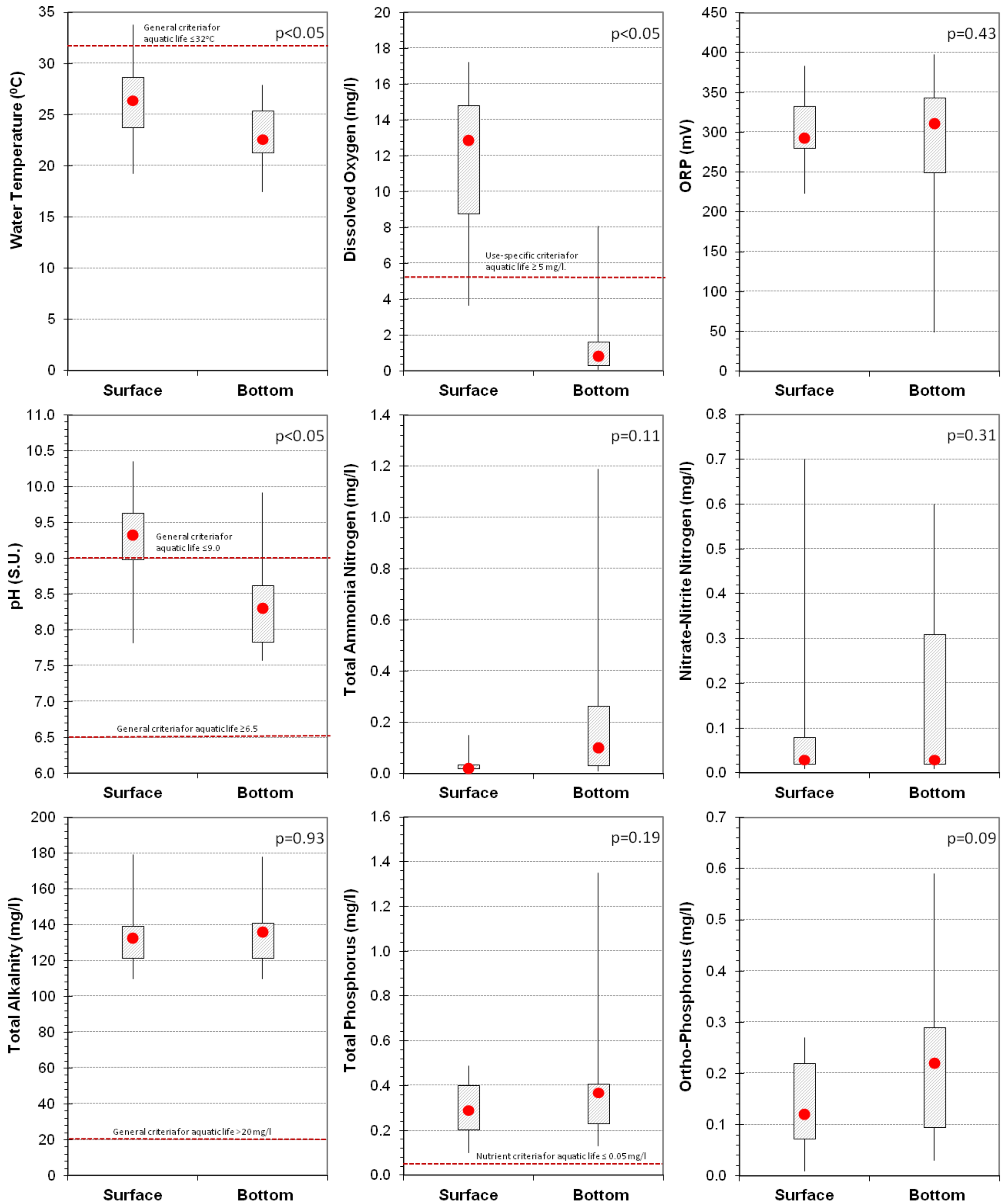


Plate 6-153. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, total ammonia nitrogen, nitrate-nitrite nitrogen, alkalinity, total phosphorus, and ortho-phosphorus measured in Yankee Hill Reservoir when summer hypoxic conditions were present during the 5-year period of 2011 through 2015 (n=10). P-values indicate significant differences between the near-surface and near-bottom samples via a paired two-tailed t-test (α = 0.05). (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot. Water quality criteria marked with red line when applicable.)

Plate 6-154. Total biovolume and density by taxonomic group for phytoplankton grab samples from Yankee Hill Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1) during the summer over the 5-year period of 2011 through 2015.

	Charophyta		Chlorophyta		Chrysophyta		Cryptophycophyta		Cyanobacteria		Euglenophyta		Ochrophyta		Pyrrophycophyta	
Sample Date	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**	**Biovolume (μm^3/ml)**	**Density (Cells/ml)**
25-May-11	18,602	173	232,651	4,287	2,319	9	81,932	1,604	65,528	812	20,654	35	575,728	929	-----	-----
27-Jul-11	957	6	2,112	20	-----	-----	14,625	185	1,777,349	84,322	-----	-----	526,612	479	29,515	79
21-Sep-11	2,596	29	17,268	195	-----	-----	41,654	555	1,627,363	27,144	27,680	59	1,209,594	1,282	57,204	26
01-May-12	28,910	14	826,789	8,942	-----	-----	585,478	1,946	623,725	29,603	5,854	7	7,418,243	221	-----	-----
06-Jul-12	-----	-----	65,652	552	40,958	25	14,279	426	27,122,051	410,788	41,255	19	412,188	1,034	-----	-----
06-Sep-12	26,034	4	16,900	495	-----	-----	420,704	197	12,307,610	195,134	7,768	13	564,703	248	-----	-----
14-May-13	10,436	3	1,185,494	13,390	-----	-----	6,202,560	43,956	94,238	861	5,538	7	495,098	23	-----	-----
08-Jul-13	73,480	22	111,034	243	52,918	21	36,287	428	45,069,782	377,975	23,276	15	383,636	729	819,873	29
10-Sep-13	-----	-----	54,206	86	-----	-----	87,088	1,027	15,809,547	237,168	3,812	4	3,555,678	90	-----	-----
13-May-14	321,735	15	1,439,822	4,411	-----	-----	130,027	1,533	203,205	1,797	-----	-----	649,507	113	-----	-----
14-Jul-14	11,909	0	22,259	47	-----	-----	486,827	99	3,980,868	20,557	151,215	33	21,400	35	145,294	6
10-Sep-14	-----	-----	4,154	53	-----	-----	-----	-----	1,297,360	29,140	58,165	11	122,024	23	-----	-----
16-May-15	-----	-----	137,833	549	1,180	0	1,098,494	2,560	4,312	24	719	1	1,467,986	50	-----	-----
27-Jul-15	-----	-----	95,475	2,683	7,607	15	293,044	3,178	11,731,456	195,495	-----	-----	3,145	9	-----	-----
22-Sep-15	-----	-----	33,983	213	-----	-----	72,031	372	9,027,702	50,358	26,289	7	68,970	99	11,648	0

Green highlighted total density indicates a value greater than the World Health Organization's moderate risk of adverse health effects of >20,000 Cells /ml

Yellow highlighted total density indicates a value greater than the World Health Organization's high risk of adverse health effects of >100,000 Cells /ml

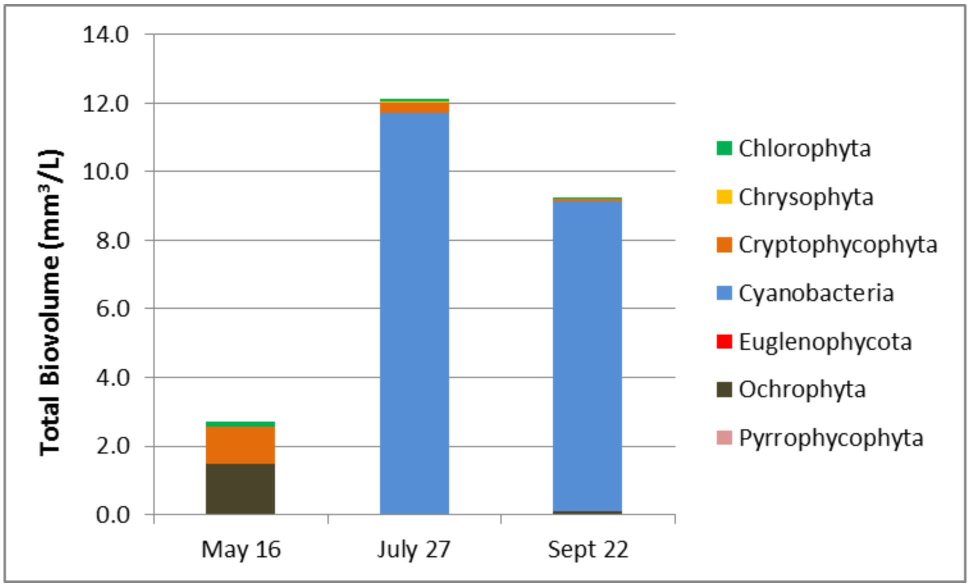


Plate 6-155. Relative abundance of phytoplankton in samples collected from Yankee Hill Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1).

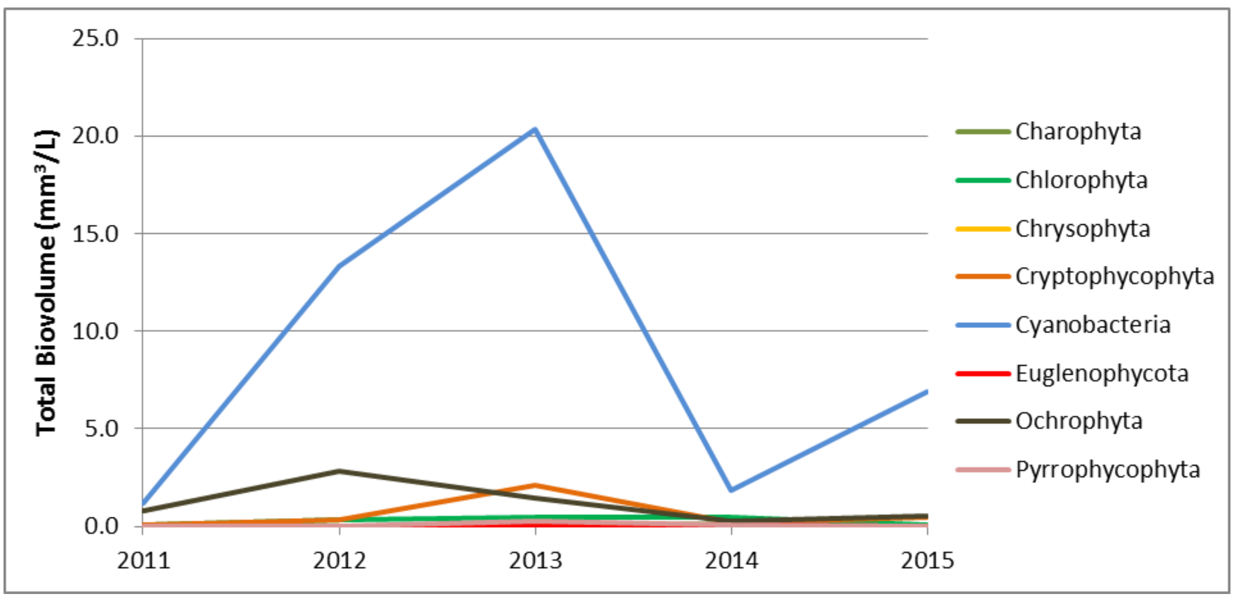


Plate 6-156. Relative abundance of phytoplankton in samples collected from Yankee Hill Reservoir at the at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1) during the summer over the 5-year period of 2011 through 2015. Yearly biovolumes are a yearly average of three summer samples (i.e. May, July, and September).

Plate 6-157. Total biomass and density by taxonomic grouping for zooplankton vertical-tow samples from Yankee Hill Reservoir collected at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1) during the summer over the 5-year period of 2011 through 2015.

	Cladocerans		Copepods		Ostracods		Rotifers	
Sample Date	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)	Density (Count/L)	Biomass (dw µg/L)
25-May-11	69	145.03	273	86.73	5	0.45	65	54.51
27-Jul-11	75	65.75	29	2.28	4	5.58	56	0.56
21-Sep-11	79	64.45	45	12.27	-----	-----	126	1.67
01-May-12	29	226.03	24	28.70	-----	-----	19	49.80
06-Jul-12	223	370.68	64	48.59	8	1.35	151	3.45
06-Sep-12	618	659.25	48	121.52	-----	-----	215	2.03
14-May-13	110	933	119	172.82	3	46.48	150	1.00
08-Jul-13	35	136.91	25	97.95	2	9.02	28	3.36
10-Sep-13	149	491.02	14	13.17	2	0.19	2	0.02
13-May-14	228	1,486.52	263	55.69	2	9.32	145	14.92
14-Jul-14	38	72.72	66	33.61	7	0.56	32	0.90
10-Sep-14	86	386.75	32	11.49	-----	-----	76	1.90
26-May-15	27	104.98	35	99.20	8	12.77	4	0.03
27-Jul-15	93	118.71	10	2.68	3	1.41	26	1
22-Sep-15	7	14.11	1	0.12	-----	-----	44	0.34

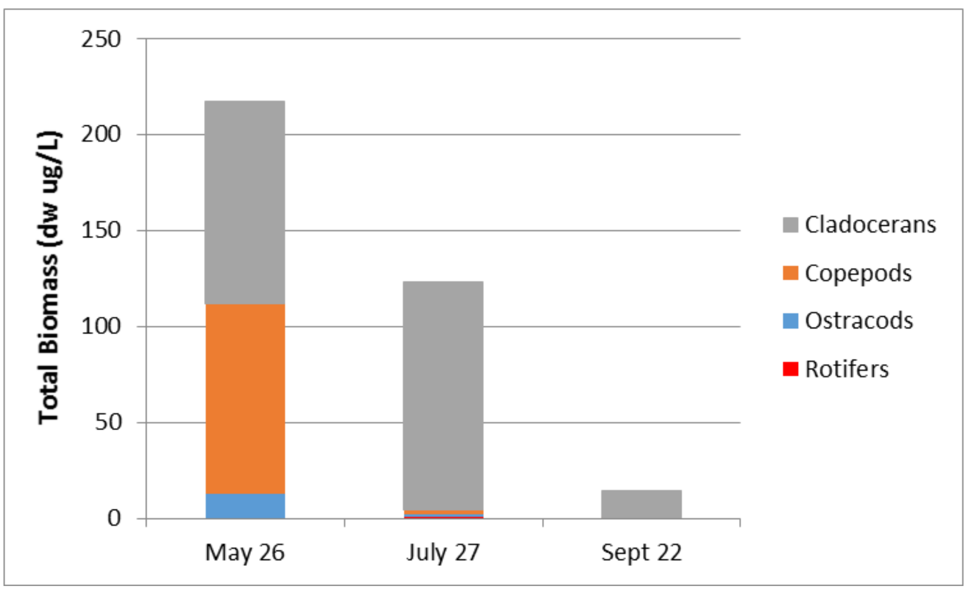


Plate 6-158. Relative abundance of zooplankton in samples collected from Yankee Hill Reservoir in 2015 at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1).

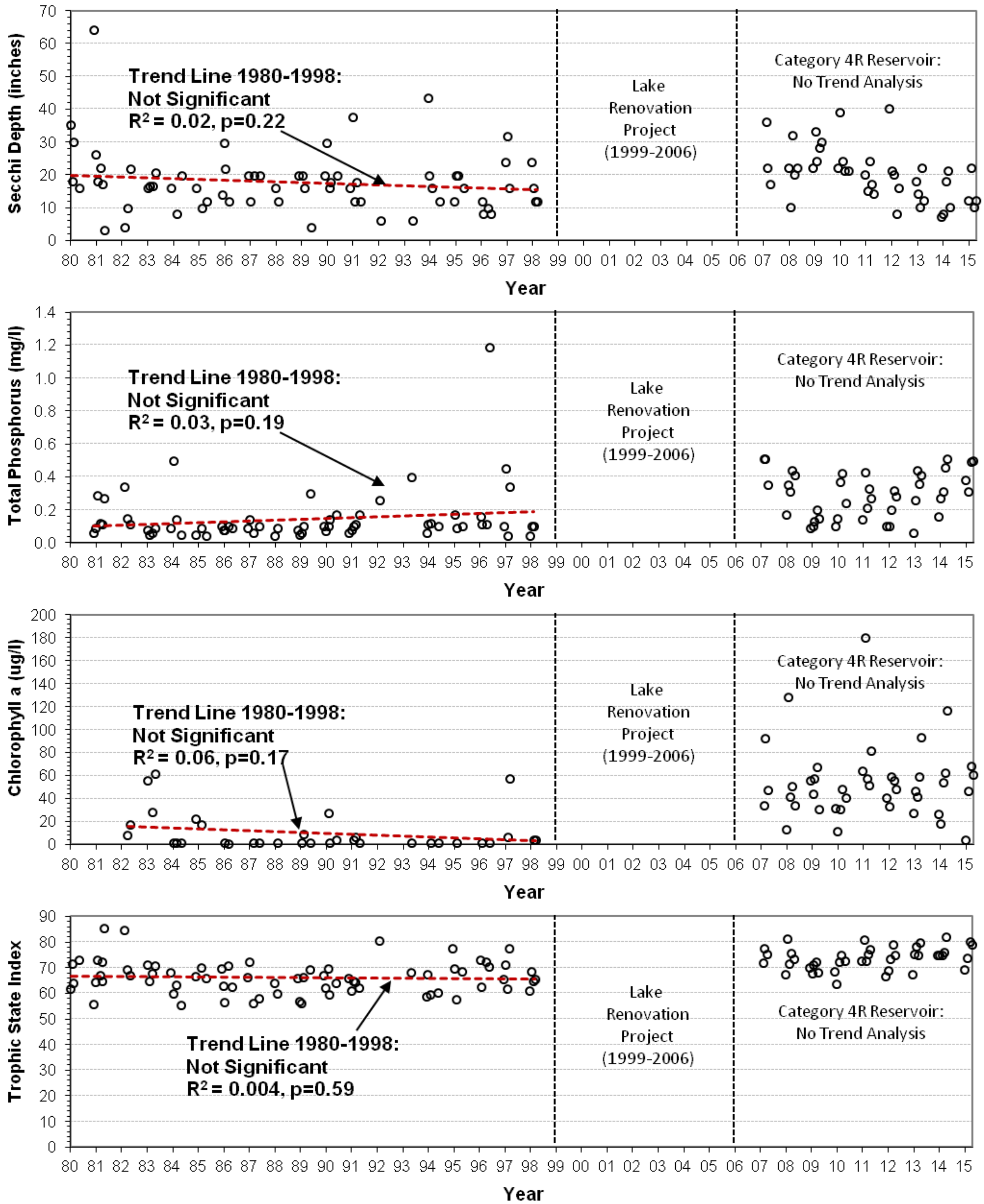


Plate 6-159. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Yankee Hill Reservoir at the near-dam, ambient site (i.e., site YANLKND1) over the 36-year period of 1980 through 2015.

7 SUMMARY OF WATER QUALITY CONDITIONS MONITORED AT THE NEBRASKA TRIBUTARY PROJECTS

7.1 EXCEEDENCES OF NUMERIC WATER QUALITY STANDARDS CRITERIA

Table 7.1 presents a summary of the State water quality standards exceedances that occurred at the Papillion and Salt Creek Tributary Project reservoirs based on water quality monitoring conducted over the 5-year period of 2011 through 2015. Blank values indicate no criteria exceedance occurred. Except for *E. coli* and microcystin, all measurements were collected from the near-dam, deepwater sampling sites. *E. coli* and microcystin samples were collected at designated swimming beaches or areas of high recreational use. Results for dissolved oxygen and pH are for water column profile measurements while all other measurements are "grab samples" collected near the reservoir surface.

7.2 IMPAIRED WATERBODIES

The Papillion and Salt Creek Tributary Project reservoirs that are potentially impaired based on water quality conditions monitored by the District over the 5-year period of 2011 through 2015 are presented in Table 7.2. The table lists the reservoir, potential impaired beneficial use, parameters for which water quality criteria are exceeded, and potential discrepancies of impaired criteria with the State of Nebraska. Impairments were identified by applying the criteria used by the State of Nebraska to develop their 2016 Integrated Water Quality Report. It is noted that the "official" determination of whether the Papillion and Salt Creek Tributary Project reservoirs are impaired, pursuant to the Federal CWA, is by the State of Nebraska pursuant to their Section 305(b) and Section 303(d) assessments compiled in their Integrated Water Quality Report (Table 2.2).

7.3 PHYTOPLANKTON COMMUNITY

Figure 7.1 shows the average relative abundances of phytoplankton communities in the Papillion and Salt Creek tributary reservoirs during the 5-year period 2011 through 2015. Averages were calculated to include three sampling events per year (May, July, September) and any years missing a complete data set were excluded from analysis. Pawnee Reservoir showed the greatest total average phytoplankton biovolume, while Olive Creek Reservoir showed the least. Cyanobacteria made up a large percentage of the phytoplankton total biovolume for several of the reservoirs. Figure 7.2 shows the average cyanobacteria cell densities during the 5-year period and compares those averages to the World Health Organization's guidelines for acute human health risk (Table 4.1). During the 5-year period, all reservoirs were above the moderate risk guidline while Ed Zorinsky, Standing Bear, Holmes, Pawnee, Stagecoach, and Yankee Hill Reservoirs were above the high risk guidline.

7.4 TROPHIC CONDITION

Figure 7.3 presents a box plot of Trophic State Index (TSI) values calculated for the Papillion and Salt Creek tributary reservoirs. The TSI values are based on Secchi depth, total phosphorus, and chlorophyll *a* levels monitored at the reservoirs over the 5-year period of 2011 through 2015. TSI values were calculated as described by Carlson (1977). Median TSI values determined for Ed Zorinsky, Glenn Cunningham, and Standing Bear Reservoirs indicate a eutrophic condition. Median TSI values for the other reservoirs (i.e., Wehrspann, Bluestem, Branched Oak, Conestoga, East Twin, Holmes, Olive Creek, Pawnee, Stagecoach, Wagon Train, and Yankee Hill) indicate that they are in a hypereutrophic condition.

7.5 WATER QUALITY TRENDS

Significant water quality trends (i.e., linear regression) observed for transparency (i.e., Secchi Depth), total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) for the period of 1980 through 2015 at the Papillion and Salt Creek Tributary Project reservoirs are presented in Table 7.3.

Table 7.1. Percent exceedance and mean values that exceed Nebraska's water quality standards criteria for the Papillion and Salt Creek Reservoirs during the 5-year period of 2011 through 2015. (Note: All values represent near-surface samples collected at near-dam, deepwater monitoring sites with the exception of *E. coli* and Microcystin data, which were collected at designated swimming beaches or areas of high recreational use.)

	Total Nitrogen, Mean (>1.0 mg/l)(1)	Total Phosphorus, Mean (>0.05 mg/l)(1)	Chlorophyll a, Mean (>10 ug/l)(1)	Dissolved Oxygen, All-Depths, Percent Exceedance (<5mg/l)(2)	pH (>9 SU)	Total Ammonia, Percent Exceedance (Variable)(3)	Dissolved Arsenic, Percent Exceedance (>16.7 ug/l)	*E. Coli* (4), Percent Exceedance (>126/100ml)(5) (>235/100ml)(6)	Microcystin, Percent Exceedance (>20 ug/l)(6)	Annual Percent Volume Loss due to Sedimentation (>0.75%)	Estimated Percent of "As Built" Lost to Sedimentation (>25%)
Papillion Creek Reservoirs											
Ed Zorinsky	-----	0.05	20	50%	-----	-----	-----	-----	-----	-----	-----
Glenn Cunningham	1.17	0.05	29	25%	-----	-----	-----	-----	-----	0.56%-0.89%	15%-27%
Standing Bear	1.06	0.06	37	43%	-----	-----	-----	-----	-----	-----	20%-29%
Wehrspann	1.11	0.06	34	34%	10%	-----	-----	-----	-----	0.55%-0.77%	-----
Salt Creek Reservoirs											
Bluestem	1.95	0.25	29	14%	-----	-----	-----	-----	-----	0.59%-0.82%	30%-42%
Branched Oak	1.24	0.11	40	18%	-----	-----	-----	-----	-----	-----	-----
Conestoga	1.84	0.12	68	15%	-----	-----	-----	-----	-----	0.67%-0.84%	34%-43%
East Twin	1.56	0.10	37	24%	-----	-----	-----	-----	-----	0.82%	27%-40%
Holmes	1.42	0.17	44	16%	45%	-----	-----	-----	-----	0.87%	20%-26%
Olive Creek	2.34	0.42	64	23%	40%	28%	80%	-----	-----	-----	-----
Pawnee	1.52	0.14	51	22%	-----	-----	-----	-----	-----	-----	27%-28%
Stagecoach	1.96	0.17	47	17%	-----	-----	-----	-----	-----	-----	26%-35%
Wagon Train	1.83	0.35	47	27%	-----	-----	-----	-----	-----	-----	-----
Yankee Hill	2.12	0.30	58	18%	50%	-----	-----	-----	-----	-----	-----

(1) Impairment assessment for nutrients in Eastern Nebraska lakes and impounded waters based on growing season mean values of epilimnion being greater than nutrient criteria.
(2) Dissolved oxygen values are represented by depth-profile data. Nebraska's Impairment assessment of thermally stratified reservoirs establishes that dissolved oxygen criterion must represent epilimnetic conditions.
(3) Total ammonia criteria are pH and temperature dependent. Percent exceedance based on median surface pH and temperature conditions and may not represent conditions when total ammonia was measured.
(4) Samples collected at designated swimming beaches or areas of heavy recreational use.
(5) Criterion is for geometric mean of 5 samples collected within a 30-day period.
(6) Criterion is for an individual observation. Samples collected at designated beaches if applicable.
* Blank values indicate value did not exceed state water quality criteria

Table 7.2. Papillion and Salt Creek Tributary Project reservoirs which are potentially impaired based on current water quality monitoring data collected by the District during the 5-year period of 2011 through 2015. (Note: Impairment discrepancies with the Nebraska Department of Environmental Quality identified using information provided in the 2016 Water Quality Integrated Report.)

Reservoir	Potential Impaired Beneficial Use	Criteria Exceeded	Impairment Discrepancies with the Nebraska Department of Environmental Quality
Ed Zorinsky	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	-----
Glen Cunningham*	-----	-----	-----
Standing Bear	Aesthetics Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Sedimentation	-----
Wehrspann	Aesthetics, Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), High pH	High pH exceedance not identified by the State of Nebraska
Bluestem	Aquatic Life, Aesthetics	Sedimentation, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	-----
Branched Oak	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	-----
Conestoga**	-----	-----	-----
Holmes	Aquatic Life, Aesthetics	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), pH, Sedimentation	Sedimentation exceedance (Aesthetics Impairment) not identified by the State of Nebraska
Olive Creek	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Ammonia, Arsenic, High pH	Arsenic exceedance not identified by the State of Nebraska
Pawnee	Aquatic Life, Aesthetics, Recreation	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Sedimentation	Algal Toxin exceedance identified by the State of Nebraska
Stagecoach	Aquatic Life, Aesthetics	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Sedimentation	-----
Twin Lakes	Aquatic Life, Aesthetics	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Sedimentation	Sedimentation exceedance (Aesthetics Impairment) not identified by the State of Nebraska
Wagon Train	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	Dissolved oxygen exceedance identified by the State of Nebraska
Yankee Hill*	-----	-----	-----
Bluestem	Aquatic Life, Aesthetics	Sediment, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	-----

*Category 4R – Waterbody data exceeds the impairment threshold however a TMDL may not be needed. The category will only be used for nutrient assessments in new or renovated lakes and reservoirs. Newly filled reservoirs usually go through a period of trophic instability – a trophic upsurge followed by the trophic decline. Erroneous water quality assessments are likely to occur during this period. To account for this, all new or renovated reservoirs will be placed in this category for a period not to exceed eight years following the fill or re-fill process. After the eighth year monitoring data will be assessed and the waterbody will be appropriately placed into category 1, 2, or 5.
** Conestoga Reservoir currently undergoing a renovation project. No current data available for assessment.

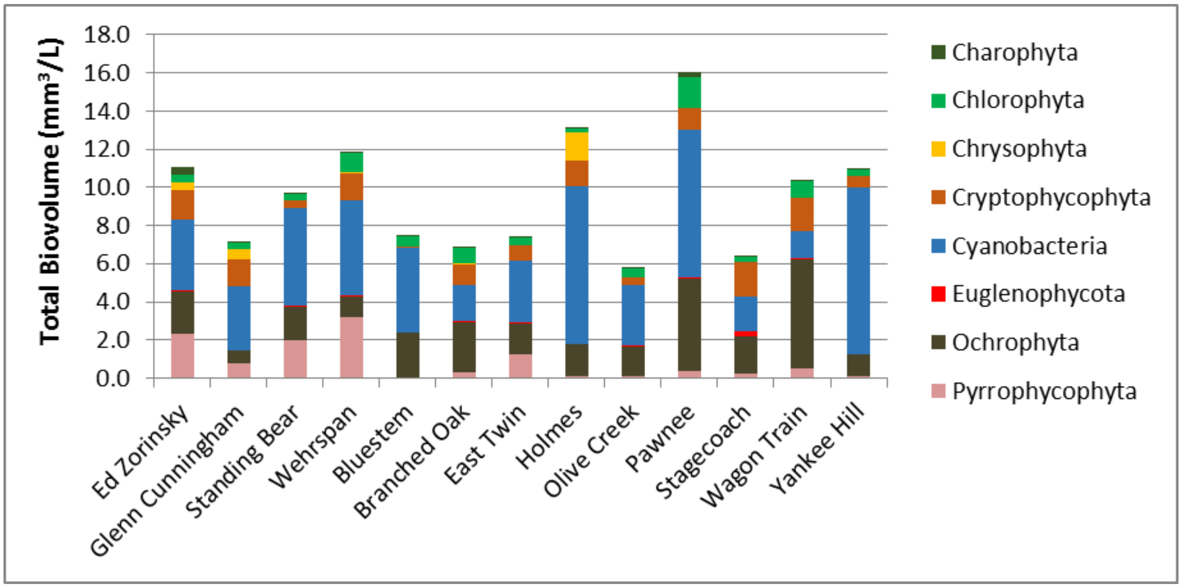


Figure 7.1. Average relative abundances of phytoplankton based on biovolume during the 5-year period 2011 through 2015 for the Papillion and Salt Creek Tributary Reservoirs. Values represent average of three sampling events per growing season (May, July, September). Years missing a complete data set were excluded from analysis.

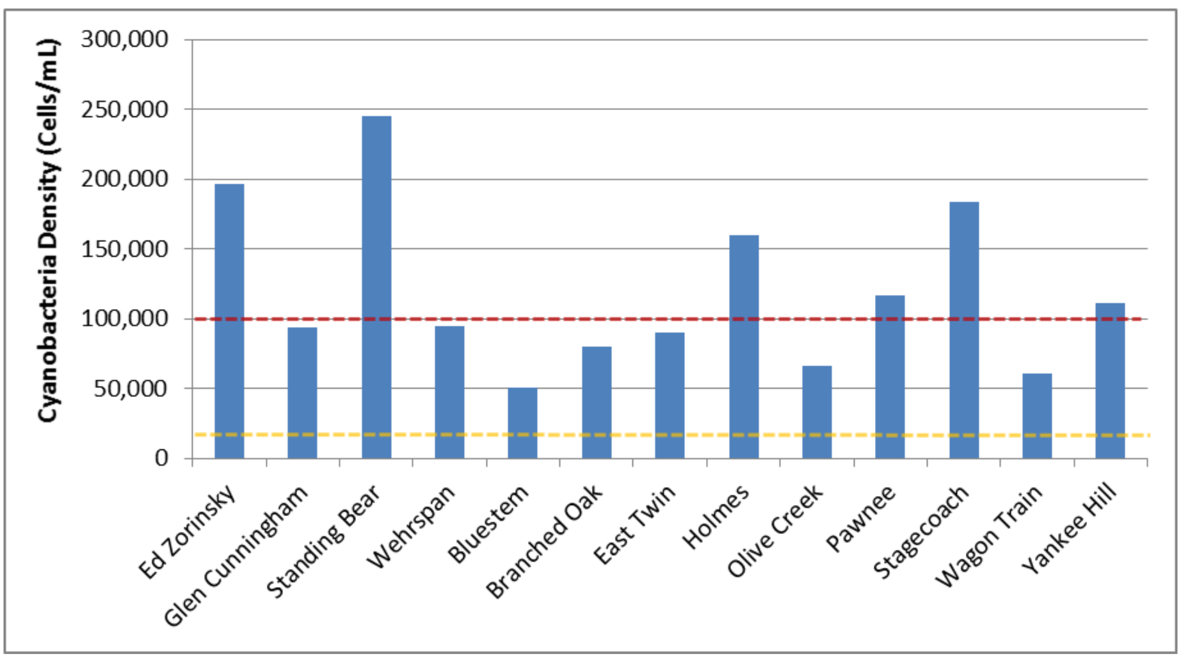


Figure 7.2. Average Cyanobacteria cell densities during the 5-year period 2011 through 2015 for the Papillion and Salt Creek Tributary Reservoirs. Values represent average of three sampling events per growing season (May, July, September). Years missing a complete data set were excluded from analysis. Dashed lines represent the World Health Organization's risk assessment criteria for cyanobacteria cell densities. Values below the yellow line represent low risk. Values between the yellow and red represent moderate risk. Values above the red line represent high risk.

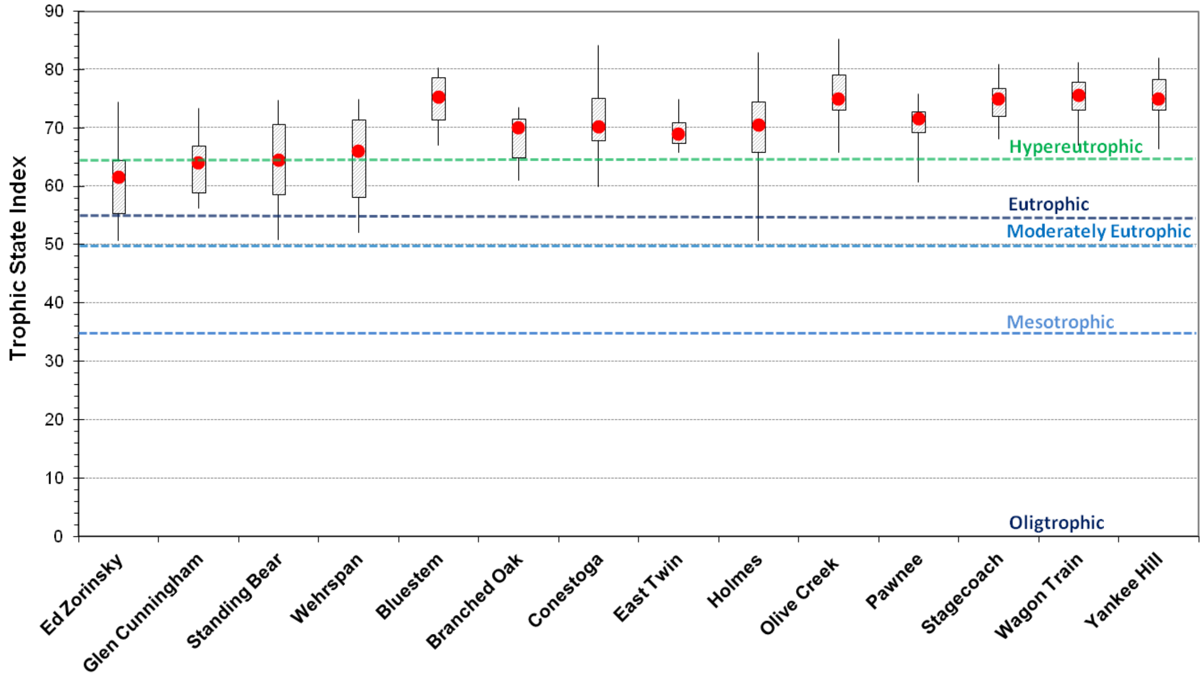


Figure 7.3. Box plot of Trophic State Index values calculated for the Papillion and Salt Creek Tributary Project reservoirs based on Secchi depth, total phosphorus, and chlorophyll *a* levels measured in the area near the dam over the 5-year period of 2011 through 2015.

Table 7.3. Observable trends in transparency, total phosphorus, chlorophyll *a*, and trophic state index (TSI) based on monitoring conducted over the 36-year period of 1980 through 2015.

Reservoir	Transparency	Total Phosphorus	Chlorophyll *a*	TSI
Papillion Creek Reservoirs:				
Ed Zorinsky	None	Decreasing	None	Increasing
Standing Bear	None	None	Increasing	None
Wehrspann	Decreasing	Decreasing	Increasing	Increasing
Salt Creek Reservoirs:				
Bluestem	Decreasing	Increasing	None	Increasing
Branched Oak	Decreasing	Increasing	Increasing	Increasing
Olive Creek	None	None	None	None
East Twin	None	None	None	None
Pawnee	None	Increasing	Increasing	Increasing
Stagecoach	Decreasing	None	None	Increasing
Wagon Train	Decreasing	None	None	None

Note: Trends are not given for Glenn Cunningham, Conestoga, Holmes, and Yankee Hill Reservoirs. Lake renovations projects have recently been completed at these reservoirs.

8 REFERENCES

Nebraska Department of Environmental Quality, Water Quality Division. 2016. 2016 Water Quality Integrated Report. Lincoln, NE.

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.

Nebraska Administrative Code. Revised 2012. Nebraska Department of Environmental Quality, Title 117 – Nebraska Surface Water Quality Standards, Lincoln, Nebraska. Retrieved from http://deq.ne.gov/RuleAndR.nsf/Title_117.xsp.

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.