Water Quality Office Report

U.S. Army Corps of Engineers
Omaha District

Creation of Emergent Sandbar Habitat (ESH) in the Headwaters of Lewis and Clark Lake and the Impacts on Water Quality

Aerial Photo of Emergent Sandbar Habitat Constructed at Lewis and Clark Lake

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(Report Number: CENWO-ED-HA/WQSS/GavinsPoint/2009)

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EXECUTIVE SUMMARY

The U.S. Fish and Wildlife Service (USFWS) issued a Biological Opinion (BiOp) with recommendations for the U.S. Army Corps of Engineers' (Corps) operations of the Missouri River Mainstem System for protection and enhancement of threatened and endangered species. The BiOp found that the Corps' operations on the Missouri River were not likely to jeopardize the endangered interior least tern *(Sterna antillarum)* and threatened piping plover *(Charadrius melodus)* populations if the Reasonable and Prudent Alternative (RPA) set forth in the BiOp was implemented. The RPA includes recommendations for the mechanical creation and maintenance of Emergent Sandbar Habitat (ESH) as nesting habitat for these two species in terms of habitat acres per river mile. In accordance with the BiOp, the Corps is conducting ongoing efforts to create and/or reclaim a sufficient amount of ESH to stabilize, and eventually recover, interior least tern and piping plover populations along the Missouri River. The Missouri River reach from Gavins Point Dam upstream to the confluence of the Niobrara River, which includes Lewis and Clark Lake, has been identified as a priority reach for both the interior least tern and piping plover. A project to create ESH in the upper reaches of Lewis and Clark Lake was implemented by the Corps during the period September 2006 to November 2008. Hydraulic dredging was used to construct two ESH complexes. The dredged material for building the sandbars was obtained from the delta of deposited material at the inflow of the Missouri River to Lewis and Clark Lake.

Lewis and Clark Lake is utilized for source water by two rural water districts that provide public drinking water; Cedar Knox Rural Water District (CKRWD) and the Bon Homme-Yankton Rural Water District (BYRWD). The City of Yankton draws source water for drinking water use from the Missouri River approximately 5 miles downstream of Gavins Point Dam. Pursuant to the Federal Safe Drinking Water Act, both rural water districts and the City of Yankton monitor their source and treated drinking water for compliance with federal drinking water standards. This monitoring includes testing for trihalomethanes (THMs) and quarterly reporting of the results to the appropriate State authorities. The current MCL (maximum contaminant level) for total THMs is 80 μg/l (micro grams per liter). When testing indicates the MCL for total THMs is exceeded, the water suppliers must notify their users, as well as increase the frequency of testing, numbers of tests, and data reporting. The water suppliers expressed concerns to the Corps that the creation of the ESH in Lewis and Clark Lake degraded water quality to the degree that it impacted the quality of their treated drinking water. Specifically, there was concern that the dredging and sandbar construction increased the level of organic matter (THM precursors) in the reservoir, and this lead to the water suppliers exceeding water quality standards in their treated drinking water for THMs.

THMs include the compounds trichloromethane (chloroform), bromodichloromethane, dibromochloromethane, and tribromomethane (bromoform). THMs are formed when free chlorine reacts with THM precursors, most of which occur naturally. THM formation in treated drinking water occurs when source water containing THM precursors is chlorinated during treatment. THMs do not occur naturally, only when the source water is treated with disenfectants such as chlorine. The organic matter that supplies the carbon compounds that serve as THM precursors in surface waters is derived from allochthonous and autochthonous material. Allochthonous organic matter in watersheds is leached from soils or decaying vegetation and transported to surface waters. Autochthonous organic matter is produced through algal, macrophyte, and bacterial production in surface waters.

THMs commonly occur in the treated drinking water provided by the CKRWD, BYRWD, and the City of Yankton. Quarterly THM levels historically reported by the three treatment facilities indicate a strong seasonal trend with lower levels occurring in the winter and higher levels in the spring and summer. Treatment processes and retention time in the distribution system seemingly have a significant impact on the THM levels occurring at the treatment facilities.

The historical data from BYRWD indicates THM levels are consistently less than half of the 80 μg/l THM MCL standard. The small range of values indicates the treated water is not prone to extreme THM values, and reflects an ability of the BYRWD to effectively manage their water treatment process given the quality of the source water. THM concentrations in the BYRWD treated water were very low before and after ESH construction, so any increase in THM precursor levels in Lewis and Clark Lake that may have occurred from ESH construction or other seasonal sources were manageable with no non-compliance occurrences observed in the quarterly data. The quarterly data indicate the ESH construction in the upper reaches of Lewis and Clark Lake did not have an appreciable impact on the THM levels measured in BYRWD's treated water.

The reported THM levels at Yankton are notably higher than the levels reported for BYRWD. The THM levels at Yankton indicate the treatment facility has a greater vulnerability to high THM values and a greater risk for THM non-compliance events. The treatment process may have a major impact on the occurrence of THMs and non-compliance events at Yankton. The occurrence of high THM levels in Yankton's treated water do not appear to be correlated with the dredging that occurred to construct the ESH in the upper reaches of Lewis and Clark Lake. The level of THM precursors present in the Missouri River at the Yankton water intake appear to rise with the increase in organic matter attributable to spring and summer runoff and algal production in Lewis and Clark Lake.

The reported THM levels at CKRWD were also notably higher than the levels reported for BYRWD. The THM levels at CKRWD also indicate the treatment facility has a greater vulnerability to high THM values and a greater risk for THM non-compliance events. The treatment process may also have a major impact on the occurrence of THMs and non-compliance events at CKRWD. It is not clear as to whether the ESH dredging in the upper reaches of Lewis and Clark Lake had a significant impact on the quarterly THM levels reported for CKRWD. THM levels reported in 2006 and 2007, when dredging occurred, do not indicate a noticeable impact as all quarterly results were within the historical range of normal seasonal variability. Quarterly reporting for 2008 indicated THM level greater than the historic maximum in the 4^{th} quarter. This was during the period that dredging was completed on ESH complex 2.

Additional targeted water quality monitoring of treated water in the CKRWD distribution system during 2008 showed a strong seasonal trend in THM levels (i.e., low in early spring and early fall and high in the summer). THM levels in the CKRWD distribution system were directly related to the distance from the treatment plant (i.e., locations the farthest away had the highest THM levels). Monitored THM levels associated with before and during ESH dredging periods did not indicate any impact; monitored THM levels were lower during ESH dredging.

Ambient water quality conditions monitored in Lewis and Clark Lake during 2008 were similar to conditions monitored in the past. Lewis and Clark Lake is in a eutrophic condition and experiences higher levels of algal growth during the summer. Targeted water quality monitoring was conducted in 2008 to evaluate the impact of the dredging to complete construction of ESH complex 2. Water quality monitoring of Lewis and Clark Lake was conducted immediately before and during dredging. The water quality monitoring included the parameter THM Formation Potential (THM-FP) which is a measure of the potential for THMs to form in water when under the influence of direct chlorination. Monitored levels of THM-FP (i.e., THM precursors) in Lewis and Clark Lake exhibited seasonality (i.e., low levels in spring and fall and higher levels in the summer). This indicates that seasonal runoff and algal production (lacustrine and riverine) may be a primary source of THM precursors in Lewis and Clark Lake. THM-FP levels measured in Lewis and Clark Lake were appreciably lower than levels measured in eutrophic reservoirs in New York and Kentucky (see Section 3.2.2.5.4.3). Monitoring conducted immediately before and during the dredging to complete ESH complex 2 did not detect any significant impact of the dredging on the water quality of Lewis and Clark Lake. Monitored levels of THM-FP in the lake were lower during ESH dredging when compared to levels monitored immediately before dredging.

Five recommendations were formulated to address potential drinking water quality concerns at future ESH construction sites. These five recommendations address: 1) future borrow areas in Lewis and Clark Lake used for fill material, 2) expansion of water quality monitoring at Lewis and Clark Lake, 3) review of quarterly monitoring results at the future potentially impacted water treatment plants, 4) sediment and elutriate sampling at future ESH project sites immediately upstream of drinking water intakes, and 5) proactive discussions will be held with drinking water treatment facilities with water intakes downstream of future ESH construction sites.

1 INTRODUCTION

1.1 CREATION AND MAINTENANCE OF EMERGENT SANDBAR HABITAT (ESH) PURSUANT TO THE MISSOURI RIVER BIOLOGICAL OPINION

In 2000, the U.S. Fish and Wildlife Service (USFWS) issued a Biological Opinion with recommendations for the U.S. Army Corps of Engineers' (Corps) operations of the Missouri River Mainstem System for protection and enhancement of threatened and endangered species (USFWS, 2000). In 2003, the USFWS issued an amendment that supplemented the recommendations of the 2000 Biological Opinion (USFWS, 2003). The amended Biological Opinion (BiOp) was the result of continuing consultation between the Corps and USFWS under the Endangered Species Act (ESA). The BiOp found that the Corps' operations on the Missouri River were not likely to jeopardize the endangered interior least tern *(Sterna antillarum)* and threatened piping plover *(Charadrius melodus)* populations if the Reasonable and Prudent Alternative (RPA) set forth in the BiOp was implemented. Element IVB of the RPA includes recommendations for the mechanical creation and maintenance of Emergent Sandbar Habitat (ESH) as nesting habitat for these two species in terms of habitat acres per river mile.

1.2 CREATION OF EMERGENT SANDBAR HABITAT ON THE MISSOURI RIVER

In accordance with the BiOp, the Corps is conducting ongoing efforts to create and/or reclaim a sufficient amount of ESH to stabilize, and eventually recover, interior least tern and piping plover populations along the Missouri River. The creation of ESH was necessitated by the unforeseen loss of the habitat due to channelization and flood control efforts along the Missouri River, and the resulting decline of tern and plover numbers. The specific purpose for the Corps' actions is to implement the portion of RPA Element IVB of the BiOp that relates to artificially or mechanically created ESH.

The Missouri River from the confluence of the Niobrara River to Gavins Point Dam is identified as Segment 9 in the BiOp (Figure 1). Segment 9 is identified as a "High Priority" reach for both interior least terns and piping plovers. ESH goals of 40 acres per river mile by the year 2005 and 80 acres per river mile by the year 2015 have been established for Segment 9. Existing ESH acreage within Segment 9 is currently well below both the 2005 and 2015 goals.

1.3 CURRENT EFFORTS TO CREATE ESH IN SEGMENT 9

As mentioned, Segment 9 encompasses the Missouri River from its confluence with the Niobrara River, River Mile (RM) 844 to Gavins Point Dam (RM811) a distance of 33 miles (Figure 1). At 40 and 80 acres per mile, the total ESH acreage goals for Segment 9 are 1,320 and 2,640 acres respectively for the years 2005 and 2015. The open water area of Lewis and Clark Lake currently covers the old Missouri River channel from Gavins Point Dam to RM828 a distance of 17 miles or approximately 52 percent of Segment 9.

1.3.1 Lewis and Clark Lake

The closing of Gavins Point Dam in 1955 resulted in the formation of 31,000-acre Lewis and Clark Lake (i.e., Gavins Point Reservoir). Lewis and Clark Lake is normally regulated near 1206 feet at mean sea level (ft/msl) in the spring and early-summer with variations day-to-day due to rainfall runoff. The reservoir level is then increased to elevation 1207.5 ft-msl following the least tern and piping plover nesting season for reservoir recreation enhancement. Lewis and Clark Lake pool levels typically fluctuate only about 2 feet on an annual basis, even in drought periods. The lake is used as a source water supply for drinking water by the Cedar-Knox Rural Water District (CKRWD) in Nebraska and the Bon Homme-Yankton Rural Water District (BYRWD) in South Dakota.

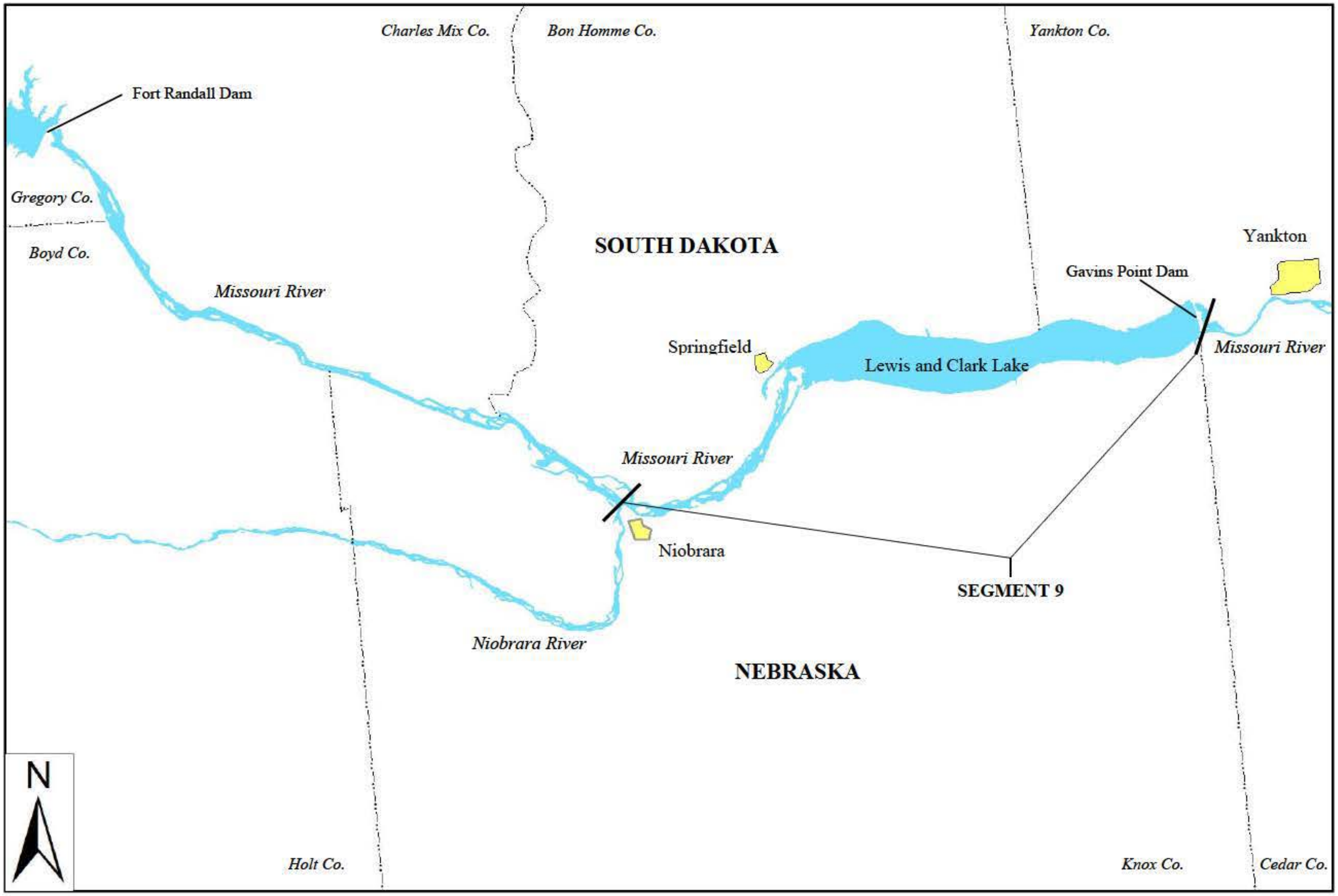

Figure 1. Location of Segment 9 on the Missouri River.

Major inflows to Lewis and Clark Lake are the Missouri and Niobrara Rivers (Figure 1). The rivers annually contribute sediment to Lewis and Clark Lake creating a delta that currently extends downstream to RM827 below 1210 ft-msl. Sediment deposition into Lewis and Clark Lake averages 3.8 million tons, or 2,400 acre-feet, each year. When constructed, the reservoir had a storage volume of 510,000 ac-ft at pool elevation 1208 ft-msl. A sedimentation survey of Lewis and Clark Lake was conducted in 2007 which indicated a storage volume of 393,000 acre feet at pool elevation 1208 ft-msl; a 22 percent loss in storage volume since 1955. The Niobrara River is responsible for approximately 55-60 percent of the sediment input. Upstream of Springfield, South Dakota (RM833), which includes deltas associated with the Niobrara River and Bazille Creek, wetlands establish on sediments that are exposed by fluctuations controlled primarily by river stage. Downstream of Springfield, wetlands establish on sediments where water levels fluctuate due to changes in pool elevation.

1.3.2 Creation of ESH in the Upper Reaches of Lewis and Clark Lake

1.3.2.1 Construction Methods

Two separate ESH complexes were created in the upper reaches of Lewis and Clark Lake. These complexes are between RM826 and RM827. Complex 1 is near the center of the lake, and Complex 2 is closer to the Nebraska bank (Figure 2). Under the normal pool elevation of 1206 ft-msl, the total emergent area of Complex 1 is approximately 90 acres and is surrounded by approximately 49.5 acres of shallow water habitat (SWH). The SWH is important for fish spawning, serves as foraging ground for terns, and increases the amount of wetted area around nesting habitat that is used as foraging habitat by plovers. Photos 1 and 2 show ESH complex 1 after construction was completed. Complex 2 consists of approximately 135 acres of ESH and 51 acres of SWH in this sandbar complex. Photo 3 shows an aerial photo of ESH complex 2 during construction.

Hydraulic dredges, sand scrapers, bulldozers and other construction equipment were used to construct the sandbars in the ESH complexes. Hydraulic dredges were used to pump and place material to build up the existing shallowly submerged sandbars. The hydraulic dredge used a cutter-head to break up sediment and a pump and pipeline was used to transport the dredged material to the deposition site. Sand Scrapers, bulldozers and other construction equipment were used to form the dredged sand to the specified elevations in order to create sandbars that closely resemble naturally formed ESH. Photos 4 and 5 show the dredge mining sediment from the initial borrow area in Lewis and Clark Lake.

Fill material for the constructed sandbars was mined from Lewis and Clark Lake and the delta area in the vicinity of the project area. Figure 2 shows the borrow areas in Lewis and Clark Lake where the dredged material was obtained. It was initially believed that using deposited material from the delta area would emulate a natural process of redistribution of sediments within the river and lake, and would result in no net addition or removal of sediment from the system. As the sandbars were constructed, the mined sediments were monitored for suitability for ESH development. This monitoring revealed that the material mined from Borrow Area A to construct the initial sandbar of Complex 1 was too fine. Because of this, Borrow Area A was abandoned and Borrow Area B was used to obtain needed fill material. Photo 6 shows the construction of the initial sandbar at ESH Complex 1 using the material that was found to be too fine. Borrow Area A was originally chosen as a multiple benefit borrow site that had the potential to increase access to the lake by boaters. Even though Borrow Area A was abandoned, some temporary increase in accessibility was gained.

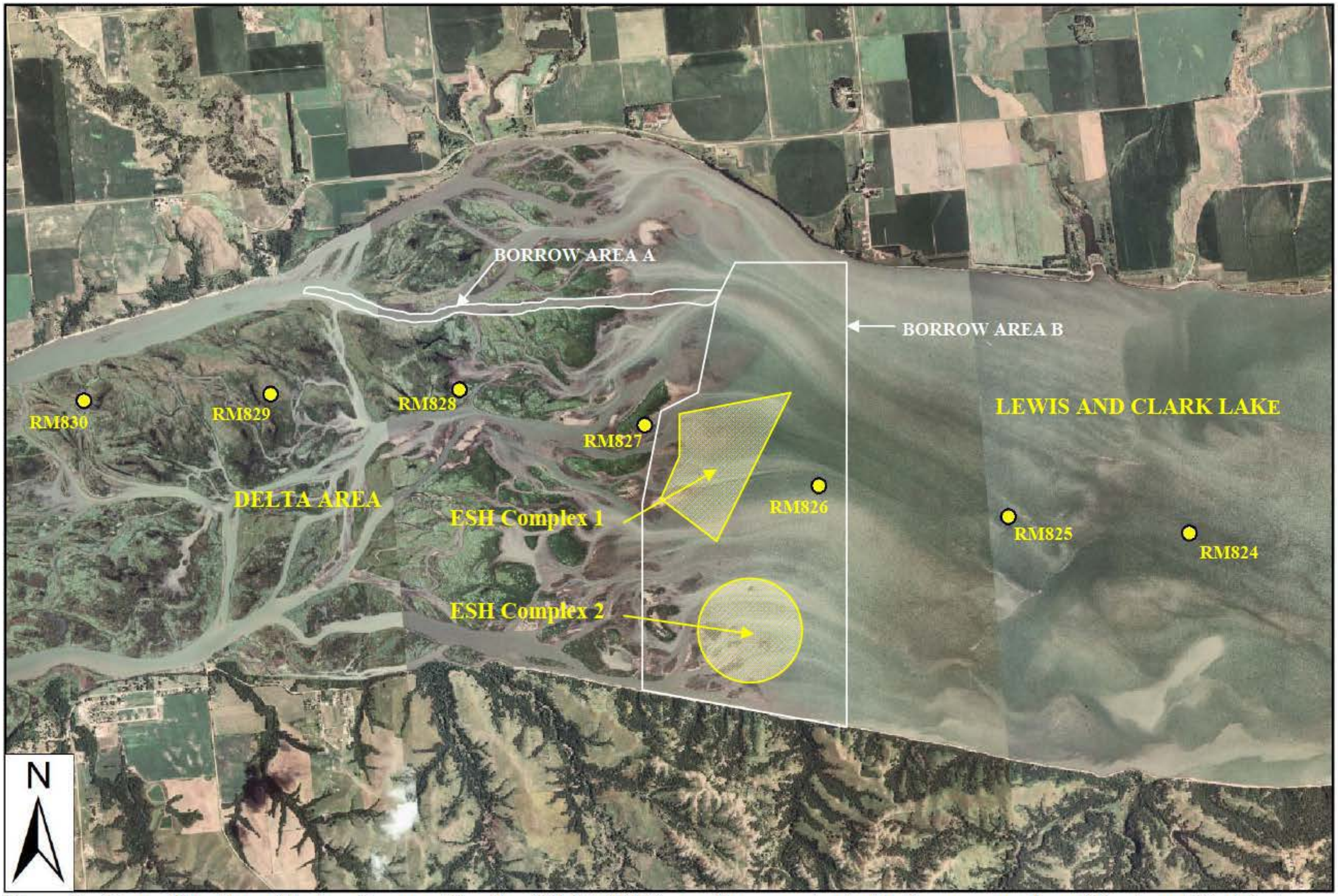

Figure 2. General location of the two Emergent Sandbar Habitat (ESH) complexes constructed in the upper reaches of Lewis and Clark Lake. *(Note: Background aerial photo taken in 2006.)*

Photo 1. Looking north over completed ESH Complex 1.

Photo 2. Looking west over completed ESH Complex 1 toward the delta area.

Photo 3. Looking west over ESH Complex 2 toward ESH Complex 1 and delta area.

Photo 4. Aerial view of hydraulic dredge mining fill material from the initial borrow area (i.e. Borrow Area A).

Photo 5. Wider aerial view of hydraulic dredge mining fill material from Borrow Area A in the delta area of Lewis and Clark Lake.

Photo 6. Aerial photo of the initial sandbar at ESH Complex 1 during construction.

The useful life of the created sandbars will depend on the amount of time it takes for vegetation encroachment to take place. This is expected to be anywhere from 2-5 years. Terns and plovers will tolerate varying amounts of vegetation on sandbars, but the BiOp suggests a vegetation cover percentage of less than 10%. When sandbars have too much vegetative cover, both species of birds will abandon them as the vegetation obscures their vision and their ability to detect approaching predators. The Corps is currently conducting an experiment to determine if an effective vegetation removal method exists. If an effective methodology is found, vegetation management activities will take place on the sandbars. The study is scheduled for completion the fall of 2011.

The rapid re-vegetation of the initial sandbar constructed at ESH Complex 1 (Photos 1, 2, and 3) may be attributed to the material that was used to build this initial sandbar. The fill material for the initial sandbar was obtained from Borrow Area A which was abandoned because the material was too fine. Borrow Area A was in a highly vegetated region in the delta area just upstream from the project area (Figure 2 and Photo 5). This initial fill material was probably rich in decayed vegetative matter (i.e., humus) and seed stock. The richness of the material is indicated by its darker color as shown in Photo 6. The richness of the material would provide the nutrients necessary for rapid re-vegetation versus the later coarser, sandy material utilized for the remaining sandbar construction. This appears evident in Photos 1, 2, and 3 which show the later sandbars constructed in ESH Complex 1 have not re-vegetated to the extent of the initially constructed sandbar.

1.3.2.2 Construction Timeline

The creation of the ESH complexes at Lewis and Clark Lake had to be scheduled around winter conditions and the utilization of sandbar habitat along the Missouri River in the area of the lake for nesting by interior least terns and piping plovers. As a result, there were two time windows for construction activities: 1) in the spring after ice-out on the lake and before the arrival of terns and plovers, and 2) in late-summer/fall after the tern and plover chicks had fledged and before ice-up of the lake. The actual construction of ESH occurred in the fall of 2006, spring and late-summer/fall of 2007, and late-summer/fall of 2008. Figure 3 displays a timeline of the starting and stopping dates of the construction periods to create the ESH complexes in the upper reaches of Lewis and Clark Lake.

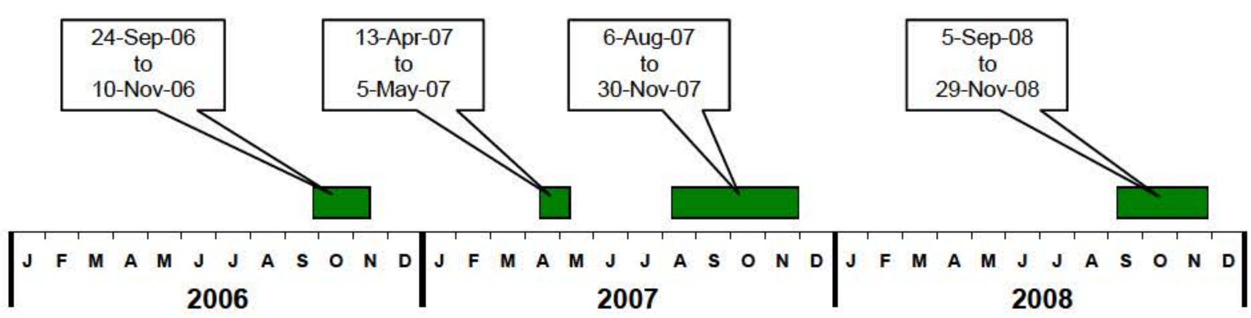

Figure 3. Timeline for constructing ESH in the upper reaches of Lewis and Clark Lake. Green bar denotes periods of active construction.

The initial construction period (24-Sep-06 through 10-Nov-06) encompassed dredging work in Borrow Area A, and the construction of the northeastern-most portions of ESH Complex 1. Due to difficulties encountered while working with the fine sediments mined from Borrow Area A, only nominal progress of approximately 10 acres of ESH was achieved during this period. When construction resumed in the spring of 2007 (13-Apr-07 through 5-May-07), dredging was moved to Borrow Area B to obtain improved materials, and construction continued on ESH Complex 1. Construction resumed on ESH Complex 1 in the fall of 2007 (6-Aug-07) and was completed in October. Construction of ESH Complex 2 was then initiated and continued to the end of November 2007. Completion of ESH Complex 2 was scheduled for the spring of 2008; however, a required renewal of the Section 10/404 regulatory permit delayed construction until late-summer/fall of 2008. The completion of ESH Complex 2 was accomplished during the final construction period (5-Sep-08 through 29-Nov-08).

General weather conditions that occurred during the ESH construction period included mild, wet conditions at the end of 2006 and throughout 2007. Below normal temperatures characterized the first three quarters in 2008, but there was above normal precipitation. Specifically, there was above normal precipitation in the winter of 2006 and early 2007 (20 inches of snowfall occurred in February 2007) which resulted in significant snow melt in spring 2007. This was compounded by record precipitation in March 2007 (4^{th} wettest on record), and above normal precipitation in April, May, August (9 inches of total rainfall – the wettest on record), September, and October. December 2007 also had above normal precipitation, but with below normal temperatures. This carried on into 2008, where colder weather was prevalent from January through August. Precipitation was slightly above normal throughout 2008, including the months of January, February, May, July, September, October and December.

1.4 WATER QUALITY CONCERNS REGARDING THE GAVINS POINT ESH PROJECT

1.4.1 Locally Expressed Concerns and Public Notices

On November 19, 2007, the Corps Gavins Point Project Office received a letter from the Lewis and Clark Natural Resources District (LCNRD) in Nebraska alerting the Corps to "potential adverse affects resulting from the emergent sandbar habitat construction." The LCNRD administers the CKRWD which uses Lewis and Clark Lake as a source supply for drinking water. The letter states that the manager of the CKRWD "noticed a significant change in the makeup of the organic matter in the raw water samples" analyzed from Lewis and Clark Lake since the fall of 2006. The presence of organic matter diminished over the winter months and was worse again in the spring of 2007. The letter also states that BYRWD and the City of Yankton may also be having similar problems. The letter further states that "the dredging process might be releasing decomposing vegetative material that is drifting downstream and not settling." The letter goes on to say "having high organic matter raises the cost of chemical treatment and increases the potential for high trihalomethanes (THMs) that are federally regulated contaminants." The LCNRD asked that the Corps consider this potential problem and investigate it to verify any impacts.

In their Fall 2007 newsletter, the CKRWP reported that the chemist from the company where they buy most of their water treatment supplies attributed the "poorer quality raw water" since the fall of 2006 to the Corps dredging operations in creating ESH in the upper reaches of Lewis and Clark Lake. The newsletter also stated that the BYRWD, the City of Yankton, and the Omaha Metropolitan Utilities District were all having similar problems treating their water as well.

The CKRWD issued a public notice to consumers of their public water system on September 27, 2007 that they were in violation of the established drinking water standard for Total THMs. The established drinking water standard for THMs is 80 μg/l (micro grams per liter) and it is based on a four-quarter running average. The notice states that sampling that occurred during the past four quarters yielded an average result of 85 μg/l. The samples were collected in the distribution system on November 20, 2006; February 26, 2007; May 29, 2007; and August 20, 2007. The average of three samples taken on each of these dates was 66 μg/l, 65 μg/l, 105 μg/l, and 104 μg/l, respectively.

In a January 2009 letter to the Corps' Omaha District Regulatory Office, the LCNRD stated:

"The Lewis & Clark NRD in Hartington, NE continues to have concerns regarding affects resulting from the construction of emergent sandbar habitat upstream from drinking water intakes in Lewis & Clark Lake. We had previously written to the Gavins Point Project Office on this on November 19, 2007 and the Corps has initiated testing to determine if there is a relationship between the dredging activities and elevated levels or organic matter that result in producing high trihalomethanes (THMs) during the water treatment process.

As of January 2009, we haven't seen any results from the water testing; but we do believe that the dredging done in the Lewis and Clark Lake during 2008 has resulted in us again being in violation of the Federal Standards for THMs and currently under Administrative Order to correct the problem."

1.4.2 Water Quality Concerns Identified in the Environmental Assessment Prepared for the ESH Project at Lewis and Clark Lake

The Environmental Assessment (USACE, 2005) identified the following water quality concerns for the ESH project at Lewis and Clark Lake:

"Water quality within the immediate vicinity of the project area may be affected in the following ways:

- *Increased sediment load due to release of dredged material onto submerged sandbars.*
- *Release of fuels, oils, grease from construction equipment.*

Increased sediment load would be a localized impact that may occur due to flowing water carrying off some dredged material during the initial placement and the slow erosion of the sandbars. Erosion and deposition of sediments within the Missouri River is a natural function of this dynamic river system. It should be noted that no new sediment is being added to or removed from the river system. Since a net loss or gain of sediment would not occur, this impact is considered insignificant.

BMPs would be used to minimize any release of fuels or lubricants from the construction equipment. Staging areas would be established as well as off-site fueling locations. Also, an emergency response plan would be developed by the contractor prior to initiating work.

It is anticipated that this project will be authorized under a Nationwide 27 regulatory permit. This permit is for activities of stream and wetland restoration."

Some resuspension of bottom sediments would be expected as "side casting" at the dredge cutter-head. However, this should have been minimal given the suction of the pump. The biggest impact expected was the resuspension of bottom material where the sandbars were constructed. Localized degradation of water quality would be expected at the sandbar sites – especially increases in suspended solids and turbidity.

1.4.3 Evaluation of Additional Water Quality Concerns

As stated in the Environmental Assessment, it was initially believed that using deposited material from the delta area would emulate a natural process of redistribution of sediments within the river and lake, and would result in no net addition or removal of sediment from the system. What the assessment possibly overlooked was the potential mobilization and release of sequestered organic matter that has accumulated in the delta bottom material. The accumulated organic matter could be allochthonous material that has settled, or autochthonous material produced by the lush vegetation in the delta area. Using bottom materials high in accumulated organic matter from the delta could potentially act as source of nutrients and organic matter to Lewis and Clark Lake above the background (i.e., natural) levels expected if the organic matter remained sequestered.

The release of dredged material to construct the ESH could potentially impact other water quality parameters (e.g., nutrients, organic matter, etc.) if the dredged material contained high levels of accumulated organic matter. Bottom sediments enriched with decaying organic matter can be expected to have elevated levels of phosphorus (total and dissolved), nitrogen (total and ammonia), and organic carbon (total and dissolved). The organic carbon compounds can serve as THM precursors. These water quality parameters should be a lesser concern if the dredged bottom sediments are coarser inorganic material (i.e., sand). The downstream area of impact should be dependent on the bottom material dredged. Heavier, coarser material will settle out quickly, while lighter, fine material could be transported a significant distance in Lewis and Clark Lake as the water flows through the reservoir. An unknown is the amount of organic matter that has accumulated in the delta region. The area currently supports a rich wetland community with abundant vegetation and seemingly a large amount of organic matter has accumulated in the delta area and is sequestered in the bottom material. Disturbing and mobilizing this material could represent an appreciable source of organic matter and nutrient loading to Lewis and Clark Lake.

The remainder of this report investigates whether the creation of ESH in the upper reaches of Lewis and Clark Lake influenced the occurrence of organic matter and THM precursors in the lake, and the occurrence of THMs in the CKRWD and BYRWD treated water systems.

1.5 THM OCCURRENCE

THMs include the compounds trichloromethane (chloroform), bromodichloromethane, dibromochloromethane, and tribromomethane (bromoform). THMs are formed when free chlorine reacts with organic substances, most of which occur naturally. When natural waters are chlorinated, chloroform is usually the most abundant THM formed, but brominated compounds tend to increase in regions which have high ambient concentrations of bromide (Owens et. al., 1995). THM formation potential is largely determined by the dissolved organic matter present in the water (Bukaveckas et. al., 2007). These organic substances (THM precursors), are a complex and variable mixture of carbon compounds. THM precursors must be present for THMs to form.

1.5.1 Formation of THM in Treated Drinking Water

THM formation in chlorinated drinking water occurs when free chlorine reacts with THM precursors. The reaction is dependent on chlorine dose, pH, temperature, and contact time (Salvato et. al., 2003). Major precursors affecting THM formation in chlorinated drinking water are believed to be humic and fulvic substances and simple low-molecular-weight organic compounds (Salvato et. al., 2003). Concentration of THMs in treated drinking water using reservoirs for source water have been found to be higher during the summer and right after reservoir turnover, and lowest in the winter (Salvato et. al., 2003). THM occurrence is also related to the presence of phytoplankton and correlates well with chlorine demand of untreated water, but not with organic carbon and chloroform extract (Salvato et. al., 2003).

1.5.2 Formation of THM Precursors in Surface Waters

The organic matter that supplies the carbon compounds that serve as THM precursors in surface waters is derived from external (allochthonous) and internal (autochthonous) material. Allochthonous organic matter in watersheds is leached from soils or decaying vegetation and transported to surface waters (Wetzel, 2001). Autochthonous organic matter is produced through algal, macrophyte, and bacterial production in surface waters (Wetzel, 2001).

Allochthonous organic matter is transported to reservoirs from their watersheds by tributary streams. Most of the tributary contributions (80-90%) to the organic carbon pool of reservoirs are in the dissolved form (Wetzel, 2001). Significant loadings of THM precursors can be delivered to reservoirs during runoff events. It has generally been found that dissolved organic carbon concentrations are relatively low during "base-flow" periods, and increase during the rising stage of a runoff event. Increases of more than a factor or two are not usual during such events (Thurman, 1985).

Autochthonous organic matter is produced within the reservoir through primary production. Primary production is the production of organic compounds from atmospheric or aquatic carbon dioxide, principally through the process of photosynthesis; with chemosynthesis being much less important. Photosynthesis by phytoplankton, periphyton, and macrophytes is the primary source of autochthonous organic matter in reservoirs. Algal cells (alive and dead) and algal excretions can directly act as THM precursors. Phytoplankton that die and settle to the bottom can greatly enhance the accumulation of organic matter in reservoir sediments. During periods of anaerobiosis, when reservoirs are thermally stratified, microorganisms are decomposing organic matter at the reservoir bottom into THM precursors (such as acetic, fulvic, humic, and citric acids and methanol) (USACE, 1987). This can lead to the occurrence of elevated levels of THM precursors in hypolimnetic waters, especially in eutrophic reservoirs (Bukaveckas et. al., 2007). Similar anaerobic decomposition and production of THM precursors can occur in anoxic sediments in the upper reaches of reservoirs, especially in wetland areas with organically-rich sediments.

In general, warm wet weather conditions increase the amount of plant growth and decomposition of vegetative material in a reservoir and its watershed. This increases the amount of organic matter naturally present in surface waters used as source water by drinking water suppliers. These organic compounds can later react to form THMs as a result of the chlorination treatment process. Primary variables that impact the amount, and availability, or mobility of these THM precursors in surface water include temperature, precipitation, and actions that disturb, redistribute, or re-suspend organic matter and sediments. Spring thaw, stormwater runoff, and wet conditions are weather circumstances that increase the loading of organic matter entering a reservoir. Strong winds and associated wave action are factors that increase bank erosion and re-suspension of sediments, silts and other colloidal particles on the bottom of a reservoir. All these factors have a direct influence on the occurrence of THM precursors in surface waters (i.e., Lewis and Clark Lake).

1.6 MONITORING CONDUCTED IN 2008 TO EVALUATE THE IMPACTS OF ESH CREATION IN THE UPPER REACHES OF LEWIS AND CLARK LAKE ON WATER QUALITY

Targeted monitoring was conducted in 2008 to investigate the water quality impacts of the dredging operations carried out to complete ESH Complex 2. Monitoring was conducted in Lewis and Clark Lake and at the CKRWD supply system. The targeted monitoring was designed to evaluate water quality conditions before and during the dredging operation. Initial before-dredging monitoring was conducted in April in anticipation of the dredging to complete ESH Complex 2 being done in the spring. However, a delay in renewing the Section 10/404 regulatory permit pushed the dredging back to the fall. A second round of before-dredging monitoring was conducted in August. Dredging to complete ESH Complex 2 was initiated in September and continued through November. During-dredging monitoring was conducted in October.

2 DRINKING WATER QUALITY CONDITIONS

2.1 POTENTIALLY IMPACTED DRINKING WATER TREATMENT FACILITIES

Three drinking water treatment facilities were identified for evaluation regarding potential impacts from the ESH construction activities in the upper reaches of Lewis and Clark Lake. CKRWD and the BYRWD draw source water from Lewis and Clark Lake. The CKRWD intake is located approximately 3.5 miles downstream from the ESH project area on the Nebraska side, and the BYRWD intake is located about 7 miles downstream on the South Dakota side of the lake (Figure 17). The City of Yankton, South Dakota draws source water from the Missouri River approximately 5 miles downstream of Gavins Point Dam; 20 miles downstream from the ESH project site.

Potential direct and indirect impacts from the ESH construction activities to the water treatment facilities were evaluated. Direct impacts were considered those that would result from a plume of suspended material reaching the treatment facility's water intake. Indirect impacts were considered residual influences that occurred after suspended material has settled and there is no observable plume. The CKRWD and BYRWD water intakes were identified as having the potential to be directly impacted. Since the City of Yankton's water intake is located downstream of Gavins Point Dam, it was identified as having the potential to be indirectly impacted.

The potential for THM problems to occur at drinking water treatment facilities depends on several factors. Facilities that use surface water for source water and utilize chlorine for disinfection are especially vulnerable to THM problems. Other important factors include the type of treatment process employed and the time free chlorine has to react with organic compounds found in the water before reaching their distribution point. There is high potential for naturally occurring THM precursors to be present in surface water used for source water, and the management of these organic compounds is important to avoid THM problems. Background information on the treatment processes and distribution system were provided by the CKRWD, BYRWD, and Yankton treatment facilities.

2.2 QUARTERLY DRINKING WATER QUALITY DATA

2.2.1 Data Compilation and Assessment

Pursuant to the Federal Safe Drinking Water Act, both rural water districts and the City of Yankton monitor their source and treated drinking water for compliance with federal drinking water standards. This monitoring includes testing for THMs and quarterly reporting of the results to the appropriate State authorities. Past quarterly monitoring results provided by the facilities were compiled and used to describe historical water quality conditions at the CKRWD, BYRWD, and Yankton treatment facilities. Water quality conditions (i.e., THMs) monitored during the period of ESH construction in Lewis and Clark Lake were compared to historically monitored water quality conditions. If observable water quality degradation from historical conditions was apparent, further assessment was done to evaluate the potential impact of the ESH construction. Other factors, such as weather conditions, were also reviewed to determine the potential influence on monitored water quality conditions.

The time periods of quarterly THM data compiled for the three treatment facilities were: 2001 through 2009 for CKRWD, 2003 through 2009 for BYRWD, and 1991 through 2008 for the City of Yankton. It should be noted that quarterly monitoring conducted pursuant to the Safe Drinking Water Act and associated regulations, allow water suppliers to choose various ways to report testing results. In this regard, the CKRWD reports total THMs as an average of three distribution points: Crofton, St. Helena, and Obert stations. This combined average is referred to as Cedar-Knox. The BYRWD reports results for only one location (i.e., Mitchell meter station) which is at the end of their distribution system. Results for this monitoring location are referred to as BYRWD. The City of Yankton quarterly data vary between a maximum distance location and an average of four distribution points. For consistency, only the data for the maximum distance location was used in this report.

2.2.2 THM Levels Reported for BYRWD

The total THM levels reported for BYRWD were in compliance with the 80 μg/l MCL standard (calculated as a running average) for all the quarterly data reported during the period 2003 to 2009 (Figures 4 and 5). Figure 4 represents the historical THM levels reported prior to the construction of the ESH in the upper reaches of Lewis and Clark Lake (2003 through spring 2006). Figure 5 gives the reported THM levels for BYRWD during the period of ESH construction (3^{rd} quarter 2006 to 2009). The historically monitored THM levels vary between 18 and 35 μg/l, while levels monitored during ESH construction varied between 17 through 44 μg/l THM (Figures 4 and 5). The quarterly data generally show a seasonal trend: increasing levels of total THMs during the warmer months and lower THM concentrations during colder months (Figures 4 and 5). Figure 6 presents the historical quarterly average, maximum, and minimum THM levels monitored at BYRWD during the period 2003 through spring 2006 (i.e., conditions prior to ESH project as shown in Figure 4). The quarterly average indicates a seasonal trend baseline, and the "whiskers" give the range (maximum and minimum) of reported values and potentially delimits impacts from natural events (e.g., weather conditions, etc.). The historical data from BYWRD clearly shows THM levels are consistently less than half of the 80 μg/l THM MCL standard. The small range of values indicate the treated water is not prone to extreme THM values, and reflects an ability of the BYRWD to effectively manage their water treatment process given the quality of the source water.

The more recent reported quarterly THM data was then combined with the historical THM average and range plot (Figure 7). The trend for late 2006 follows the historical trend within the established range. Data from 2007 and 2008 show an observable increase in THMs slightly above historical levels, but still well below the 80 μg/l MCL standard (Figure 7). The treatment process employed by BYRWD adequately managed the quality of their source water and THM levels. THM concentrations in the BYWRD treated water were very low before and after ESH construction, so any increase in THM precursor levels in Lewis and Clark Lake that may have occurred from ESH construction or other seasonal sources were managed with no non-compliance occurrences observed in the quarterly data. The quarterly data indicate the ESH construction in the upper reaches of Lewis and Clark Lake did not have an appreciable impact on the THM levels measured in BYRWD's treated water.

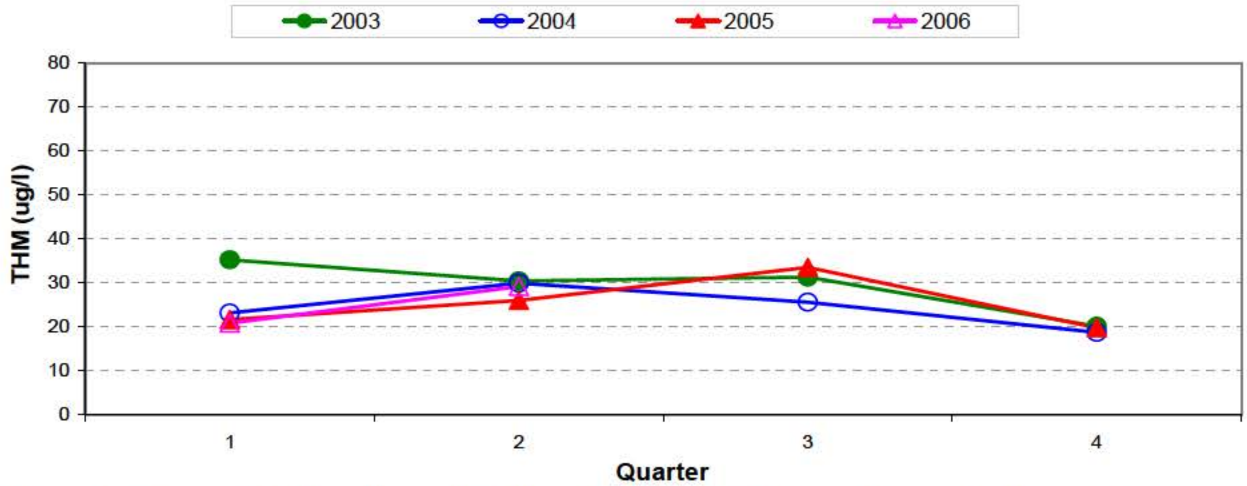

Figure 4. Quarterly trihalomethane (THM) levels monitored at the Bon Homme-Yankton water treatment plant during the period 2003 through spring 2006.

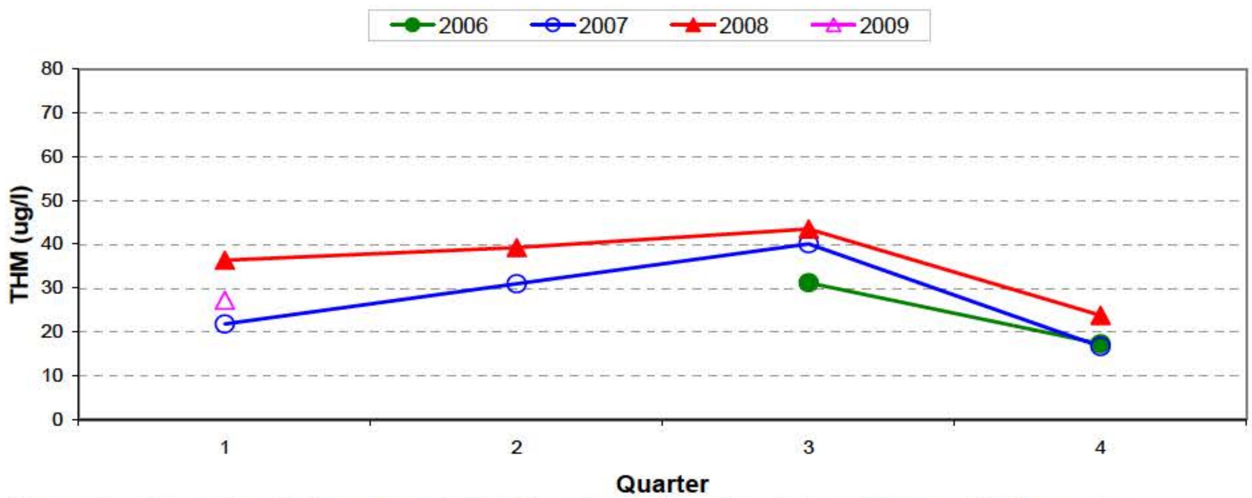

Figure 5. Quarterly trihalomethane (THM) levels monitored at the Bon Homme-Yankton water treatment plant during the period summer 2006 through winter 2009.

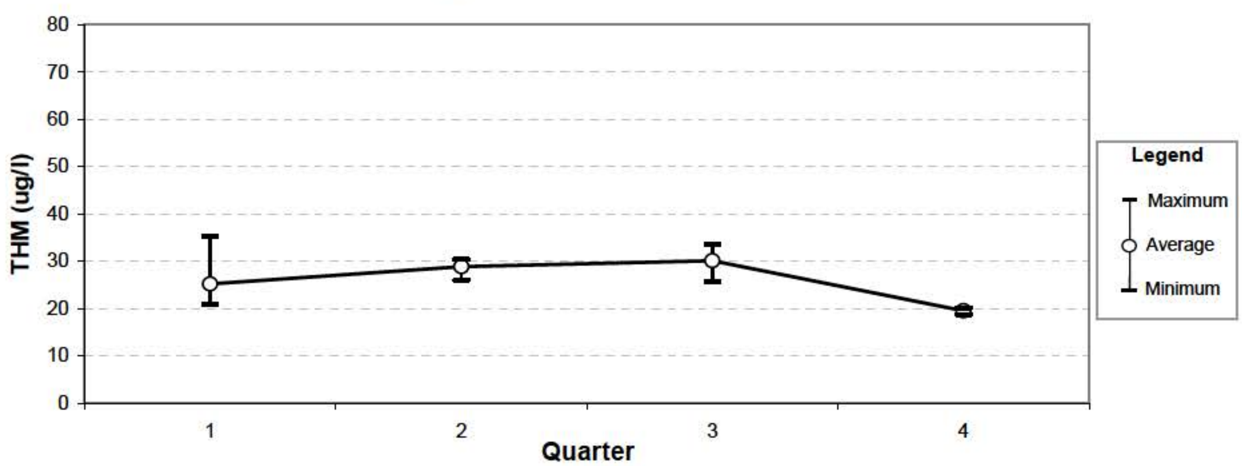

Figure 6. Quarterly average, maximum, and minimum THM levels monitored at the Bon Homme-Yankton water treatment plant during the period 2003 through spring 2006.

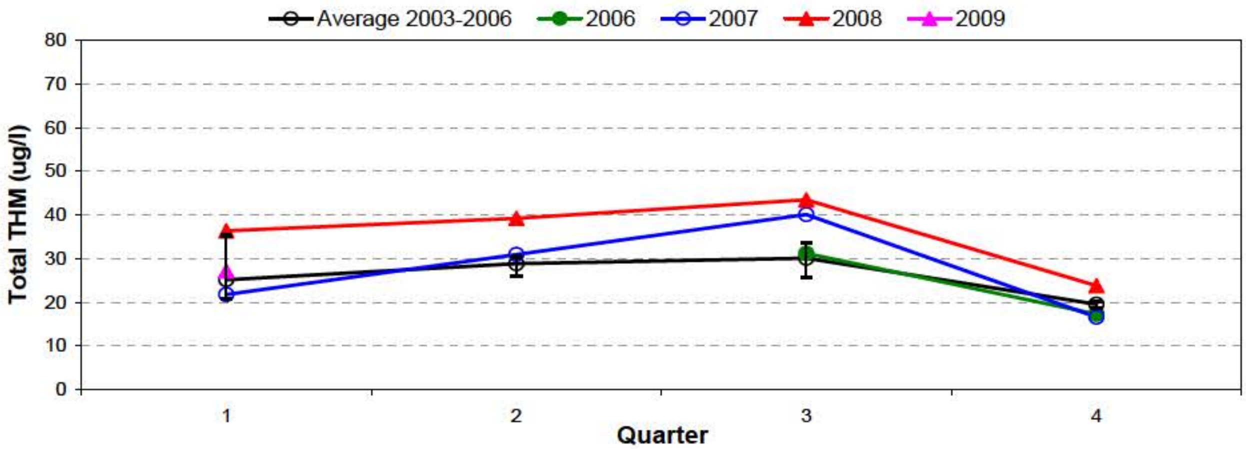

Figure 7. Quarterly historical and 2006, 2007, 2008 and 2009 THM levels monitored at the Bon Homme-Yankton water treatment plant.

2.2.3 THM Levels Reported for the City of Yankton

The water intake for the City of Yankton was considered to be indirectly impacted by the ESH construction in the upper reaches of Lewis and Clark Lake. However, a similar assessment of their reported quarterly THM testing results was done for comparison. The compiled Yankton quarterly THM data encompassed 18 years (1991 through 2008). It included several non-compliance events based on a calculated "running average" that were reported to the State of South Dakota. THM levels above the 80 μg/l MCL standard were reported both before and during ESH construction. Figure 8 shows the calculated average, and maximum and minimum values (range) by quarter for all of the historical THM testing reported prior to the ESH construction (i.e., 1991 through spring 2006). The historical THM data represented by the quarterly average is shown to be near, but lower than the 80 μg/l MCL standard (Figure 8). The upper extent of the range indicates the potential for significant non-compliance. The reported THM levels at Yankton are notably higher than the levels reported for BYRWD. This is likely due to differences in the treatment process employed by the two water treatment plants. The THM levels at Yankton indicate the treatment facility has a greater vulnerability to high THM values and a greater risk for THM non-compliance events. The presence of THM precursors in the Missouri River which serves as the source water for Yankton seemingly exhibits seasonal variation due to storm events, runoff, and algal production in the eutrophic Lewis and Clark Lake. The treatment process may have a major impact on the occurrence of THMs and non-compliance events at Yankton.

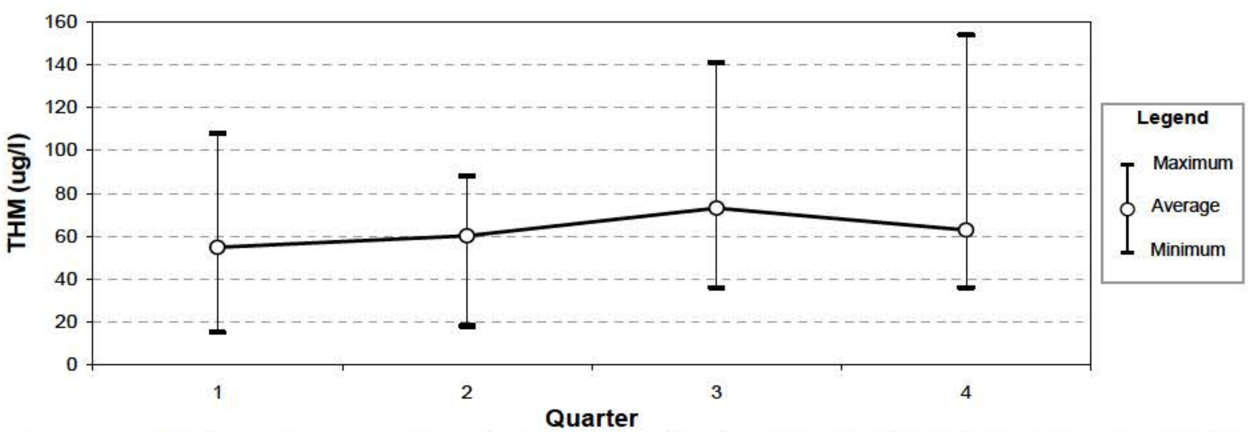

Figure 8. Quarterly average, maximum, and minimum THM levels monitored at the Yankton water treatment plant during the period 1991 through spring 2006.

Figures 9 and 10 overlay the quarterly historic and recent THM levels reported by Yankton. Figure 9 also denotes the periods during 2006, 2007, and 2008 when dredging occurred in the upper reaches of Lewis and Clark Lake as part of the ESH construction. THM levels reported in the 3rd and 4th quarters of 2006 were very similar to the historical average and within the historical range (Figures 9 and 10). The THM levels reported in both 2007 and 2008 indicate the 2nd quarter was above the historical range, and the 3rd and 4th quarters were above the historical average but within the historical range (Figures 9 and 10). In 2007, dredging occurred in the spring and is suspect in attributing to the high THM level reported by Yankton in the 2nd quarter (Figure 9). However, a similar THM level was reported in the 2nd quarter of 2008 when no spring dredging occurred. Also, in the fall of all three years when ESH dredging occurred, a reduction in reported THM levels occurred between the 3rd and 4th quarters (Figure 9). A seasonal trend in quarterly THM levels reported by Yankton is seemingly apparent in the historical average and 2006, 2007, and 2008 data (Figure 10). This indicates that the level of THM precursors in Yankton's source water may be largely driven by the increase in organic matter attributable to spring and summer runoff and algal production in Lewis and Clark Lake.

2.2.4 THM Levels Reported for CKRWD

The CKRWD water intake is located 3.5 miles downstream from the ESH project site and has the greatest potential of the three water intakes to be directly impacted by the ESH construction. The compiled CKRWD quarterly THM data encompassed 9 years (2001 to 2009). It included several non-compliance events that were reported to the State of Nebraska. The reported quarterly results are based on a calculated running average using THM levels measured at three distribution points: Crofton, St. Helena, and Obert. THM levels above the 80 μg/l MCL standard were reported both before and during ESH construction. Figure 11 represents the historical THM levels reported prior to the construction of the ESH in the upper reaches of Lewis and Clark Lake (i.e., 2003 through spring 2006). As with the quarterly results from BYRWD and Yankton, the quarterly plots for all the years follow a seasonal trend of lower in the winter and higher in the summer (Figure 11). Extremes are observed that appeared to be influenced by stormwater runoff events, warmer temperatures, and increased precipitation. Significant storm events occurred on April 21-22, 2001 (9-inch rain), September 8, 2003 (8-inch rain), April 5, 2004 (15 inch-rain), and June 7, 2004 (12-inch rain) (Table 1). These storm events appear to directly relate to the extreme THM results shown in Figure 11 during the 2nd quarter 2001, 3rd quarter 2003, and 2nd and 3rd quarter 2004 (Table 1 and Figure 11). Figure 12 shows the calculated average, and maximum and minimum values (range) by quarter for the historical THM testing reported prior to the ESH construction (i.e., 2001 through spring 2006). The quarterly average indicates a strong seasonal trend, and the "whiskers" give the range (maximum and minimum) of reported values and potentially delimits impacts from natural events (e.g., weather conditions, etc.). The wider range in the second quarter is reflective of the potential for high THM levels to occur in the spring. This is likely related to an influx of organic matter (largely dissolved) from spring runoff and stormwater events. The historical THM data, as represented by the quarterly average, are generally lower than the 80 μg/l THM MCL standard in the 1st and 4th quarters, but higher than the standard in the 2nd and 3rd quarters.

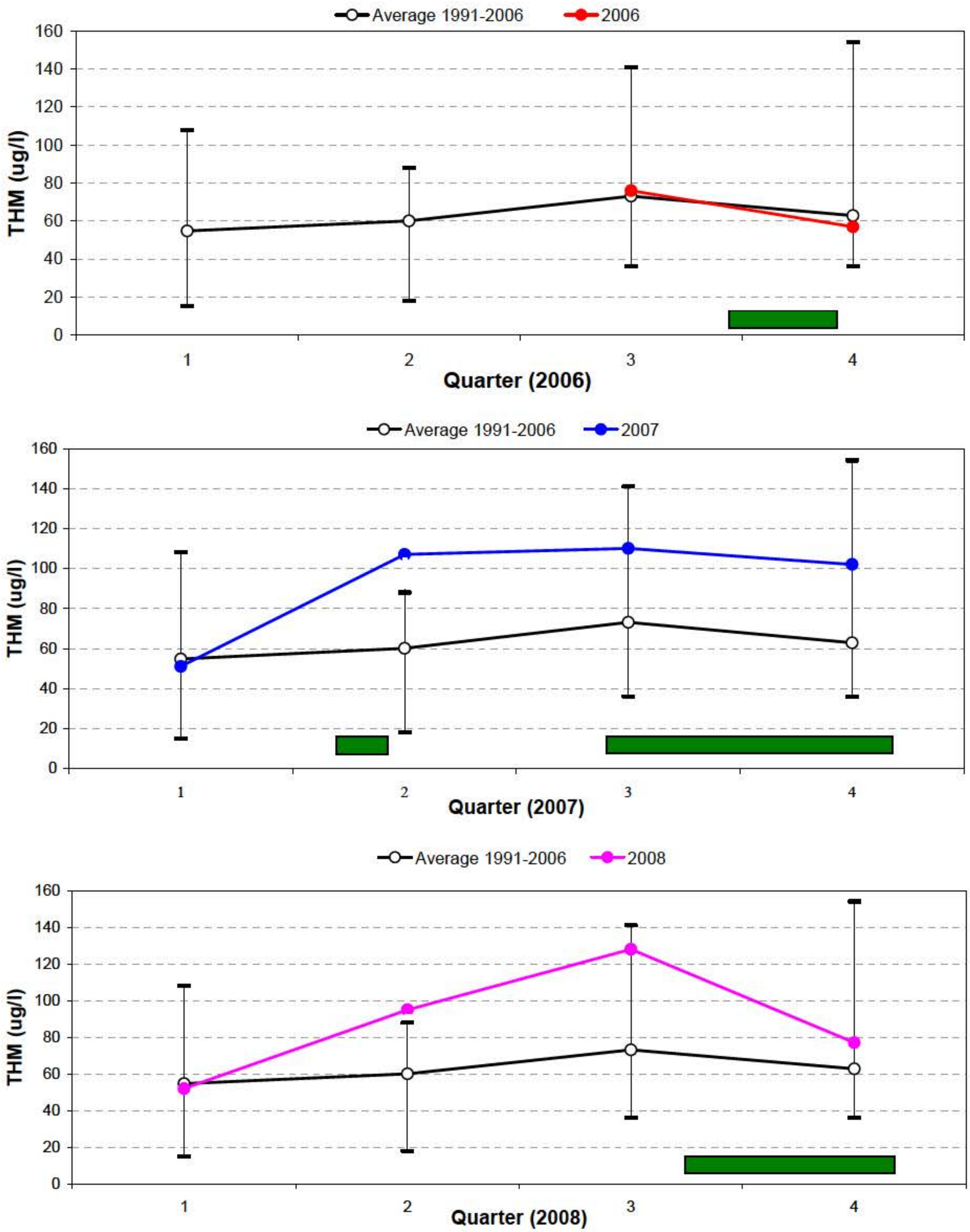

Figure 9. Quarterly historical and 2006, 2007, and 2008 THM levels monitored at the Yankton water treatment plant. Green bar denotes period when dredging occurred to construct ESH.

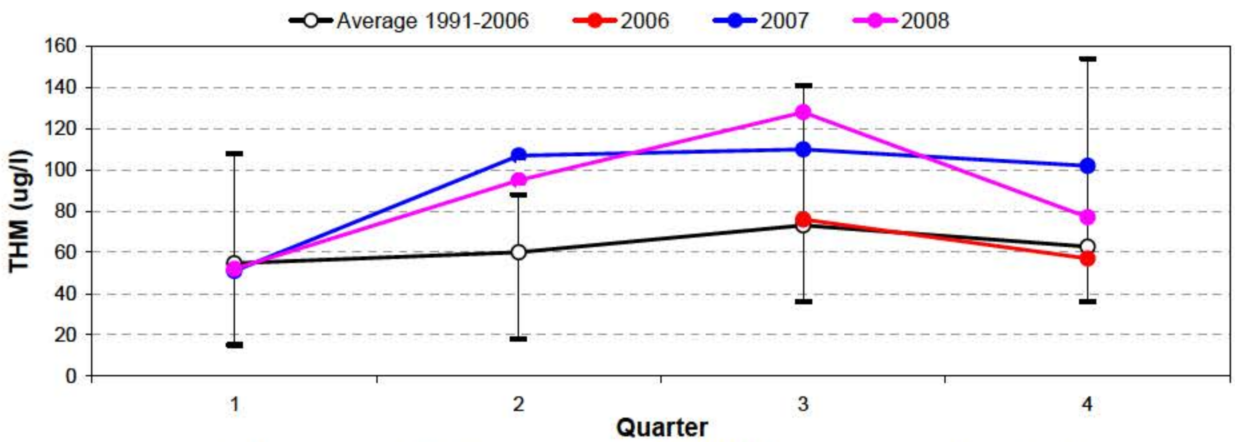

Figure 10. Quarterly historical and 2006, 2007, and 2008 THM levels monitored at the Yankton water treatment plant.

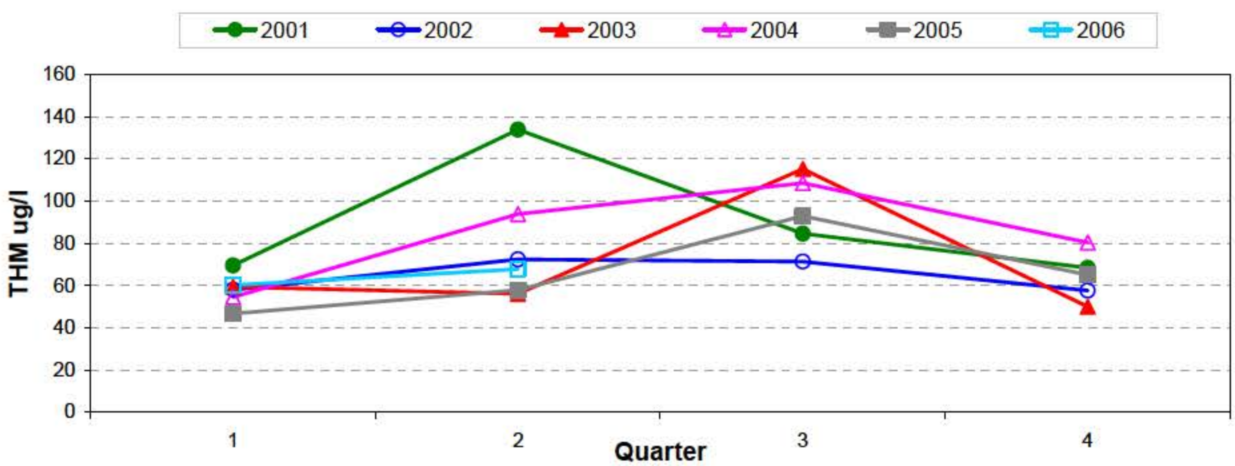

Figure 11. Quarterly average THM levels monitored at three locations (Crofton, St. Helena, and Obert) in the Cedar-Knox water distribution system during the period 2001 through spring 2006.

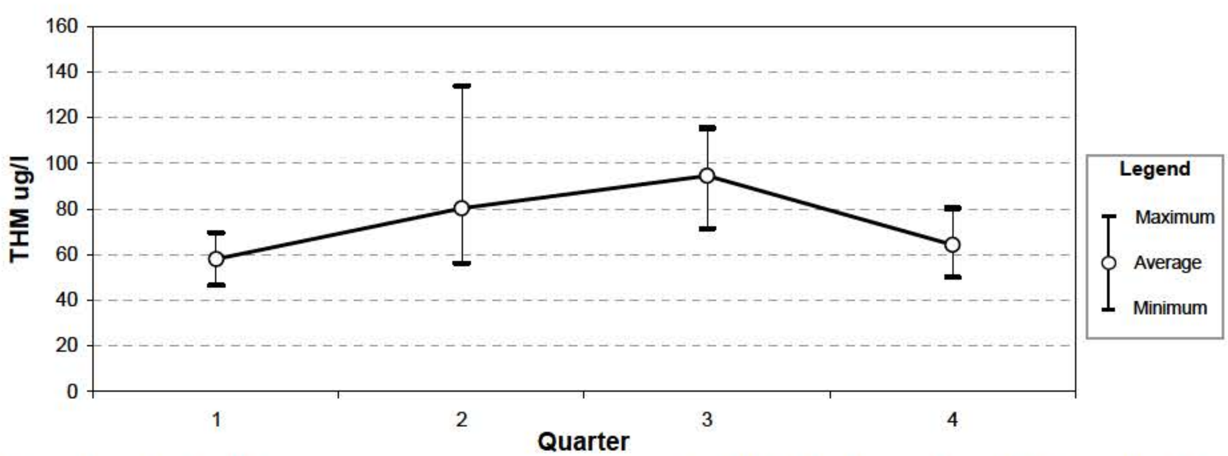

Figure 12. Quarterly average, maximum, and minimum THM levels monitored at three locations (Crofton, St. Helena, and Obert) in the Cedar-Knox water distribution system during the period 2001 through spring 2006.

Table 1. Significant rainfall events that occurred in the Lewis and Clark Lake area during the period 2001 through 2008.

Quarter	Observed Change in Reported THM Level from Previous Quarter	Significant Storm Events	
		Date	Event
2nd Quarter 2001	≈ Doubling of THM level	April 21-22, 2001	9-inch rainfall
3rd Quarter 2003	≈ Doubling of THM level	September 8, 2003	8-inch rainfall
2nd Quarter 2004	≈ Doubling of THM level	April 5, 2004	15-inch rainfall
		June 7, 2004	12-inch rainfall
2nd Quarter 2007	≈ Doubling of THM level	March 31, 2007	2.3-inch rainfall
		April 24-25, 2007	3-inch rainfall
		May 29, 2007	1.7-inch rainfall
3rd Quarter 2007	Elevated THM levels	August 2007	9 inches of rain in August

Figures 13 and 14 overlay the quarterly reported historical levels and the THM levels reported by CKRWD in 2006, 2007, and 2008. Figure 13 also denotes the periods during 2006, 2007, and 2008 when dredging occurred in the upper reaches of Lewis and Clark Lake as part of the ESH construction. The THM levels reported in 2007 were slightly above the historical average the first three quarters, and were slightly below the historical average the 4th quarter (Figure 13). All reported quarterly results during 2007 were within the historical range, and a typical seasonal trend in THM levels is apparent (Figure 13). In 2007, dredging occurred in the spring and is suspect in attributing to the high THM level reported by CKRWD in the 2nd quarter (Figure 13). However, dredging also occurred in the fall of 2007 and the reported THM levels exhibited a significant decline (Figure 13). The significant storm events that occurred in 2007 may have attributed to the elevated THM levels reported in the 2nd and 3rd quarters (Table 1). Quarterly THM levels reported by CKRWD in 2008 exhibit an atypical trend with the lowest level occurring in the 2nd quarter (Figure 13). The THM value reported in the 1st quarter of 2008 seems to be unusually high, and is outside of the historical range (Figure 13). Dredging did occur in the fall of 2007, the previous quarter, but ended on November 30. Since the typical hydraulic residence time of Lewis and Clark Lake is about 10 days (USACE, 2007), any direct effects from the fall 2007 dredging should have passed through the reservoir by the 1st quarter of 2008. The THM value reported in the 4th quarter of 2008 is also unusually high being outside of the historical range (Figure 13). The dredging that occurred in the fall of 2008 is suspect in attributing to the high THM level reported by CKRWD in the 4th quarter (Figure 13). Except for 2008, the quarterly THM levels reported by the CKRWD exhibit a seasonal trend (Figure 14). Given the timeline of the ESH construction it is suspect in contributing to the elevated THM levels reported by the CKRWD in 2008 and possibly 2007.

As mentioned, the reported quarterly results for CKRWD are based on a calculated average using THM levels measured at the three distribution points: Crofton, St. Helena, and Obert. To better interpret the quarterly data, the THM levels monitored at the three individual distribution points were evaluated. Obert is at the end of the CKRWD distribution system approximately 43 miles from the treatment plant. It is estimated that it takes 6 to 7 weeks for the treated water to reach Obert. Once at Obert, the treated water may reside in the Obert distribution system up to an additional 4 weeks prior to being used by a customer. The total contact time of 10 to 11 weeks is significantly higher than the other water distribution systems that typically take a week or less to reach the end of their distribution system. Also, regulations require that a certain amount of residual chlorine be present in the treated water for disinfection purposes, and the longer organic matter is in contact with chlorine the greater the level of THMs that will be potentially formed. This challenge may require CKRWD to selectively target the removal of THM precursors prior to chlorination, or use disinfectants that are more selective chlorinating agents than free chlorine.

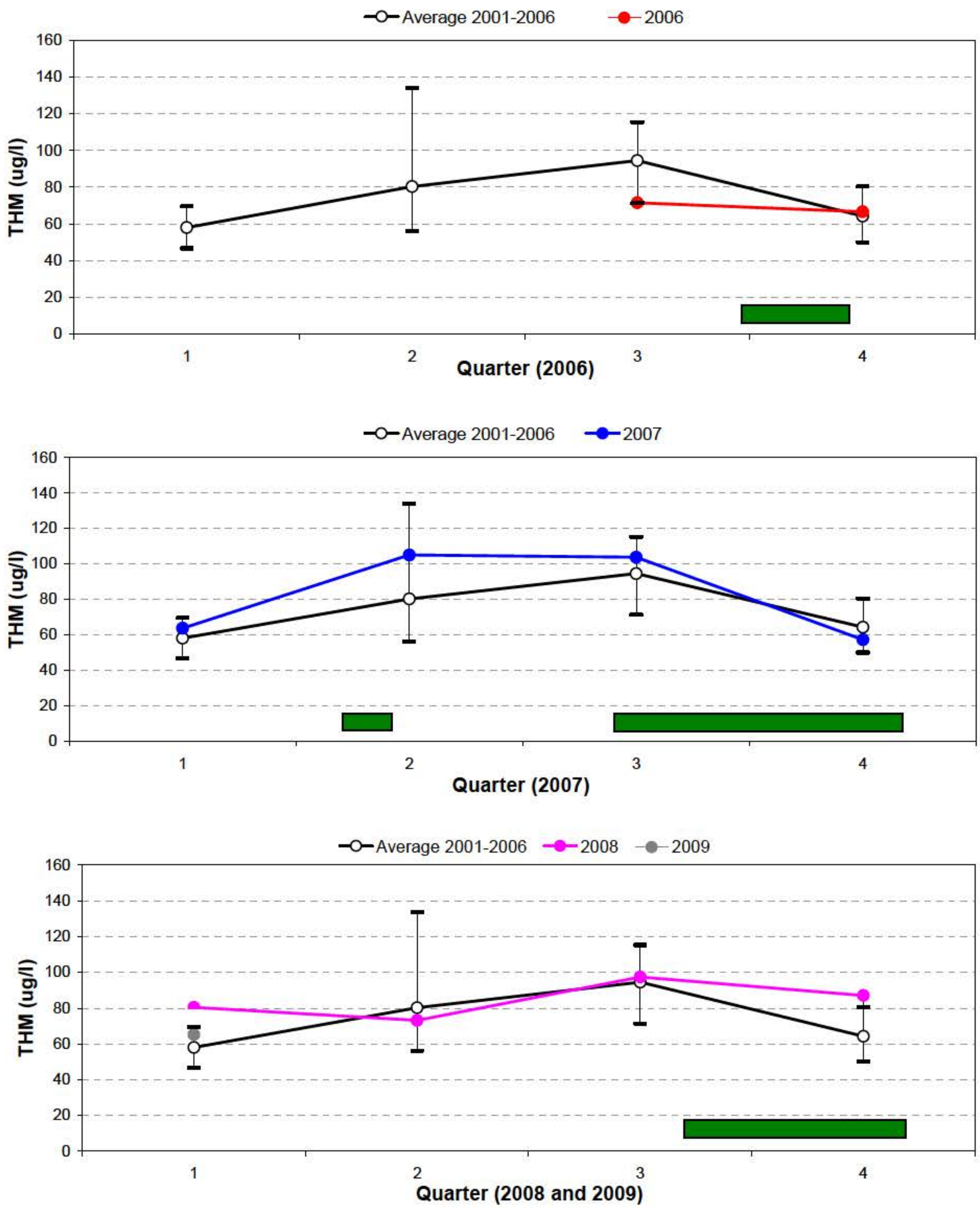

Figure 13. Quarterly historical (2001-2006) and 2006, 2007, 2008, and 2009 average THM levels monitored at three locations (Crofton, St. Helena, and Obert) in the Cedar-Knox water distribution system. Green bar denotes period when dredging occurred to construct ESH.

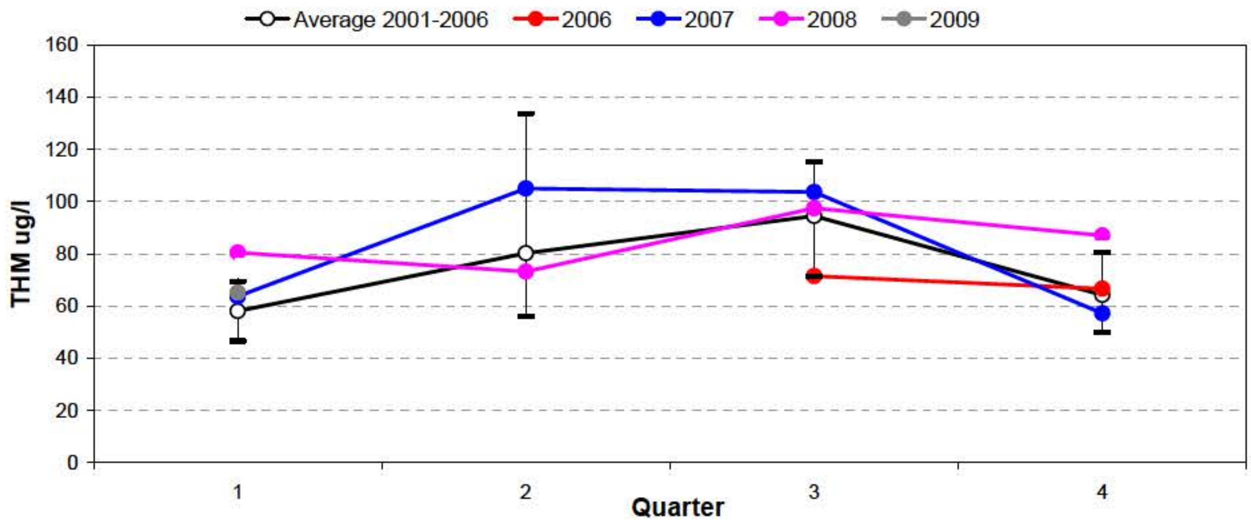

Figure 14. Quarterly historical (2001-2006) and 2006, 2007, 2008, and 2009 average THM levels monitored at three locations (Crofton, St. Helena, and Obert) in the Cedar-Knox water distribution system.

Historic quarterly THM levels (i.e., average and range) monitored in the CKWRD distribution system during the period 2001 through spring 2006 at the water treatment plant, Crofton, St. Helena, and Obert are displayed in Figure 15. The historical THM levels monitored at the four locations show the same general seasonal trend observed at the other water treatment facilities (Figure 15). There is a noted increase in THM levels as the water moves through the CKRWD distribution system (i.e., water treatment plant < Crofton < St. Helena < Obert). Except for an extreme value measured in the 2nd quarter of 2001, at St. Helena, the range of THM levels monitored at each location is consistent. The ranges show a seasonal trend with the maximum and minimum values increasing with distance from the treatment plant (Figure 15). The quarterly THM levels monitored at the four locations for 2001, 2002, 2003, 2004, 2005, and spring 2006 are plotted in Plates 1 and 2. Plate 3 overlays the quarterly historical levels and the THM levels monitored at Crofton, St. Helena, and Obert in late-summer/fall 2006, 2007, and 2008.

2.3 2008 Targeted Monitoring of the CKRWD Water System

Additional water quality monitoring of treated water in the CKRWD distribution system was targeted. The CKRWD water intake was believed to have the greatest potential to be directly impacted by the ESH construction, and their quarterly reporting indicated problematic THM levels. Also, variables such as the 6 to 7 week travel time for treated water to move between the CKRWD treatment plant and the Obert location made it difficult to clearly associate the quarterly reporting data with the construction of the ESH project. Water quality monitoring was conducted in 2008 to measure THM levels in the CKRWD distribution system prior to and during the periods of dredging to construct ESH in the upper reaches of Lewis and Clark Lake.

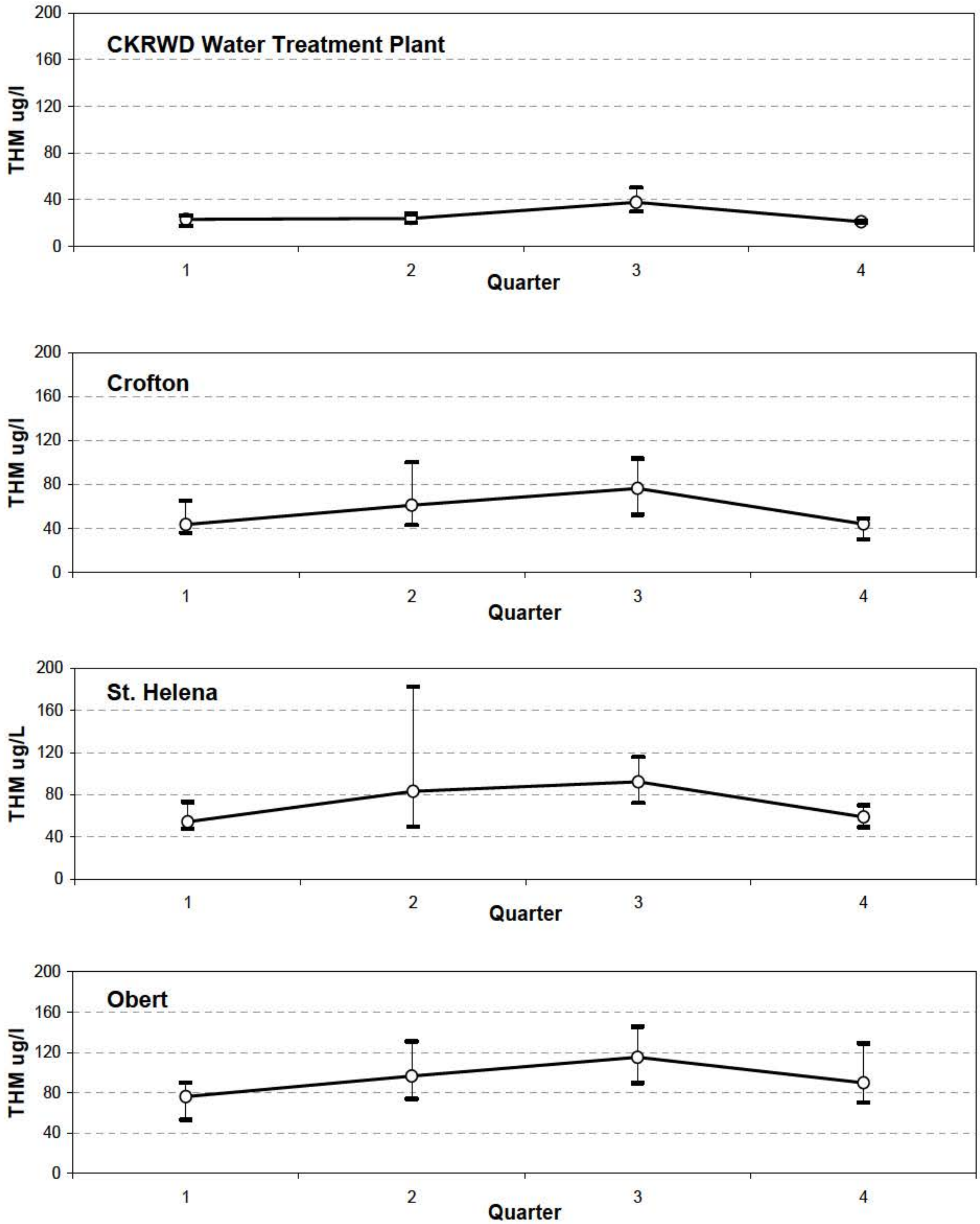

Figure 15. Quarterly average, maximum, and minimum THM levels monitored at four identified locations in the CKRWD water distribution system during the period 2001 through spring 2006.

2.3.1 Data Collection Design

The basic data collection design was to sample THM levels in the CKRWD distribution system before and during possible impacts from the dredging to construct ESH in 2008. Travel times of a possible plume of suspended organic matter were estimated from the ESH project site to the CKRWD water intake. Travel times were then estimated for the treated water to move through the distribution system. The methodology for estimating the travel time in Lewis and Clark Lake is provided in Section 3.2.2.1. Transit times in the distribution system to the water treatment plant (1 day), Crofton (1 week), St. Helena (1 week), and Obert (6 weeks) locations were provided by the CKRWD. The estimated travel times were coordinated with the start of the ESH dredging conducted in 2008 to account for a possible "slug flow" of organic matter from the ESH project site to the water intake and through the distribution system. Sample collection was then targeted to represent before and during ESH dredging conditions. It is believed the coordination of sample collection with estimated travel times better characterized water quality conditions at the four locations in the CKRWD distribution system immediately before and during any potential ESH dredging impacts. Because there was some uncertainty associated with the estimated travel time through the distribution system, a "buffer" of approximately 4 weeks was added to the estimated travel time. This was meant to ensure that any potential impact from the start of ESH construction would have reached each of sampled locations.

2.3.2 Collection of Water Samples

Treated drinking water samples were collected at the four locations (water treatment plant, Crofton, St. Helena, and Obert) by CKRWD personnel. Samples were collected at the same outlets and in the same manner used to collect the CKRWD's quarterly reporting samples. Appropriate quality assurance and quality control samples were collected to validate sampling and analysis procedures. The collected samples were appropriately preserved and sent to the analytical laboratory (i.e., Midwest Laboratories, Inc., Omaha, NE). Analytical methods, detection limits, and reporting limits for the samples analyzed in the laboratory are given in Table 2.

Table 2. Methods, detection limits, and reporting limits for analyses of drinking water samples.

Analyte	Method	Detection Limit	Reporting Limit
Total Trihalomethanes	EPA - 524.2		
Chloroform		0.15 µg/l	1.0 µg/l
Bromodichloromethane		0.36 µg/l	1.0 µg/l
Dibromochloromethane		0.34 µg/l	1.0 µg/l
Bromoform		0.30 µg/l	1.0 µg/l
Trihalomethane Formation Potential	SM - 5710	2.5 µg/l	5 µg/l

2.3.3 Results of Targeted Monitoring to Evaluate Impacts of ESH Construction

2.3.3.1 Summary of Analytical Results

THM and ΔTHM-FP (as defined in SM-5710) measured in the collected treated drinking water samples from the CKRWD distribution system, and the THM-FP estimated for the raw source water are provided in Table 3. The THM-FP estimated for the raw source water provides a conservative estimate of the THM levels that might be expected under "extreme" conditions. As seen in Table 3, ΔTHM-FP generally decreases from the treatment plant to Obert. This is directly related to the formation of THMs as a result of the longer contact times between free chlorine and THM precursors as the treated water moves through the CKRWD distribution system. Given the consistent relationship between THM-FP in the raw source water and levels of THMs in the treated drinking water, THM-FP can be used as a diagnostic tool to evaluate THM concerns at the CKRWD.

Table 3. Total trihalomethanes (THMs) and THM formation potential levels in treated drinking water collected from the Cedar-Know Rural Water District's distribution system.

		Treated Drinking Water		Estimated THM-FP of Raw
Location	**Sampled Period**	**THMs (µg/l)**	**ΔTHM-FP (µg/l)***	**Source Water (µg/l)****
Treatment Plant	Pre-dredging (Apr)	38	64	102
	Pre-dredging (Sep)	48	96	144
Crofton	Pre-dredging (Apr)	31	81	112
	Pre-dredging (Sep)	97	71	168
	During Dredging	78	80	158
St. Helena	Pre-dredging (Apr)	48	52	100
	Pre-dredging (Sep)	113	52	165
	During Dredging	86	60	146
Obert	Pre-dredging (Apr)	75	60	135
	Pre-dredging (Sep)	158	Not Analyzed	Not Analyzed
	During Dredging	125	17	142

* Additional THMs formed above levels all ready present in the treated drinking water.

** Assumes levels of THMs in un-chlorinated raw source water are non-detectable. THM levels measured in Lewis and Clark Lake near the CKRWD water intake were non-detectable.

2.3.3.2 Time Series THM Plots

A time series plot of THM levels monitored in the CKRWD water distribution system in 2008 at the water treatment plant, Crofton, St. Helena, and Obert locations is displayed in Figure 16. Samples reflecting THM levels that were not under the influence of the 2008 ESH dredging are left of the dotted vertical line, and samples that were under the influence of the 2008 ESH dredging conditions are right of the dotted line. Overall, all four locations exhibit a seasonal trend of lower THM levels in the spring and fall and higher THM levels in the summer (Figure 16). The time series plot of the THM levels measured at the water treatment plant shows the lowest overall THM levels (Figure 16). This is expected given the shorter contact time of the treated water with the added chlorine at this location. As contact time increased with the distance from the treatment plant, THM levels also increased (Figure 16). In general, very little difference in the THM levels measured immediately before and during dredging is apparent at the water treatment plant and St. Helena (Figure 16). A noticeable decrease in THM levels from immediately before dredging to during dredging is apparent at Crofton and Obert. These data seemingly indicate that the ESH dredging in 2008 had no adverse impact on THM levels measured at the four sites along the CKRWD distribution system.

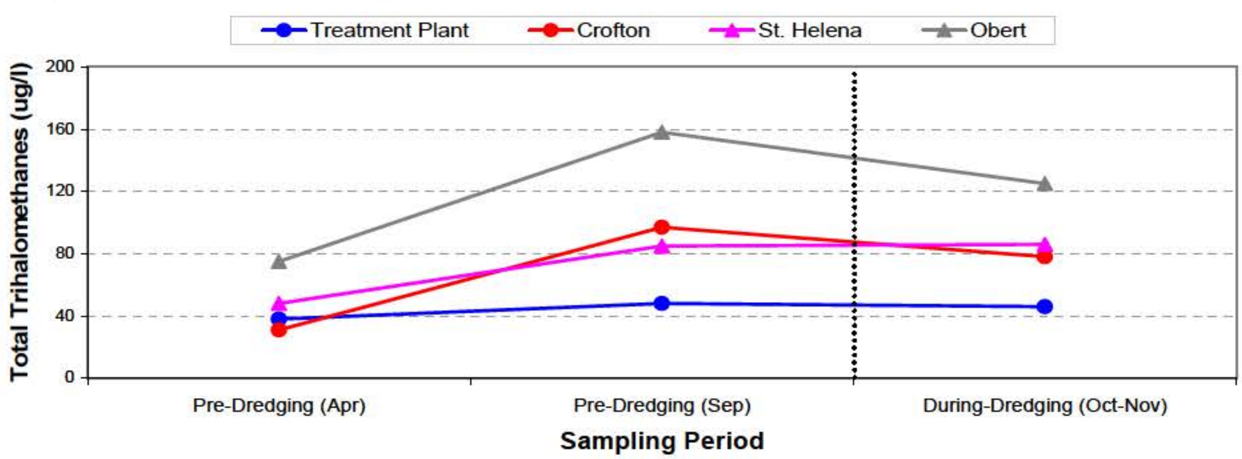

Figure 16. Time series plots of total trihalomethanes (THMs) measured in the Cedar-Knox Rural Water District's water distribution system at the water treatment plant, Crofton, St. Helena, and Obert before and during ESH dredging in 2008.

3 LEWIS AND CLARK LAKE WATER QUALITY CONDITIONS

3.1 HISTORIC LAKE WATER QUALITY CONDITIONS

The Omaha District Corps of Engineers has monitored water quality at the six Missouri River mainstem reservoirs, including Lewis and Clark Lake, since the late 1970's. Lewis and Clark Lake is the smallest and most downstream reservoir of the six Missouri River mainstem reservoirs. Past water quality monitoring indicates that Lewis and Clark Lake is the most nutrient enriched of the six mainstem reservoirs. This monitoring also indicates that Lewis and Clark Lake has been in a eutrophic condition almost since its creation. Eutrophic lakes are nutrient rich with high levels of primary productivity and as such are subject to excessive algal production (i.e., algal blooms). Plate 4 displays scatter-plots of water quality data collected from Lewis and Clark Lake over the 29-year period of 1980 through 2008. The data were collected at the regularly-monitored, near-dam ambient site at the lake. The scatter-plots are for the four parameters: Secchi depth transparency, total phosphorus, chlorophyll *a*, and Trophic State Index, and also display linear regression trend lines. The trend lines indicate that Lewis and Clark Lake is experiencing a slight increase in eutrophication (i.e., continued nutrient enrichment).

3.2 2008 WATER QUALITY MONITORING

3.2.1 Ambient and Intensive Survey Monitoring at the Gavins Point Project

During 2008 three ambient monitoring projects and one intensive water quality survey were conducted that included water quality monitoring at the Gavins Point Project. This included water quality monitoring of Lewis and Clark Lake and on the inflow and outflow from the lake. The following summarizes water quality conditions that were monitored in 2008.

3.2.1.1 Summary of Monitored Ambient Water Quality Conditions

A summary of ambient water quality conditions monitored at five sites (RM811, RM815, RM819, RM822, and RM825) along Lewis and Clark Lake in 2008 is provided in Plates 5 through 9. The eutrophic condition of Lewis and Clark Lake is evident in the monitored ambient water quality conditions. High levels of total phosphorus, total nitrogen, and chlorophyll *a* were monitored during the growing season (May through September) at all five sites. The monitored levels of these parameters seemingly meet the criteria defined by the State of Nebraska to identify Lewis and Clark Lake as impaired, pursuant to Section 303(d) of the Federal Clean Water Act, due to nutrients.

Plates 10 and 11, respectively, summarized water quality conditions monitored in the Missouri and Niobrara River inflows to Lewis and Clark Lake. Nutrient concentrations in the Niobrara River are about double those monitored in the Missouri River. However, nutrient loadings from the Missouri River are likely higher due to the greater flows.

3.2.1.2 Longitudinal Contour Plots of Temperature, Dissolved Oxygen, Turbidity, and Chlorophyll monitored in Lewis and Clark Lake

Longitudinal contour plots were constructed along the length of Lewis and Clark Lake based on depth-profile measurements taken on June 17, August 11, and September 15, 2008. The depth-profiles were measured at the five locations (RM811, RM815, RM819, RM822, and RM825) along the submerged Missouri River channel. Longitudinal contour plots were constructed for water temperature, dissolved oxygen, turbidity, and chlorophyll *a*. The longitudinal contour plots were constructed using the "Hydrologic Information Plotting Program" developed by HydroGeologic Inc. (Hydrogeologic Inc., 2005).

Minor thermal stratification was monitored on the three dates (Plate 12). As has been indicated by past monitoring, Lewis and Clark Lake appears to be polymictic. During periods of "calm" weather in the summer, Lewis and Clark Lake can develop vertical thermal stratification in the deeper area near the dam. The thermal stratification breaks down under "windier" conditions, given the shallow depth of the reservoir, and mixing occurs. There seemingly was enough stratification in August to allow dissolved oxygen degradation to develop at the reservoir bottom in the area near the dam (Plate 13). Turbidity in Lewis and Clark Lake was highest in June and decreased in August and September (Plate 14). Monitored chlorophyll *a* levels were also higher in June (Plate 15).

The ambient monitoring conducted on August 11 and September 15, 2008 "bracket" the onset of dredging to complete ESH complex 2. The longitudinal contour plots constructed for these two dates do not indicate any observable impact to the measured water quality conditions due to the onset of the dredging.

3.2.2 Targeted Monitoring to Evaluate Impacts of ESH Creation

3.2.2.1 Data Collection Design

Five transect locations were monitored in Lewis and Clark Lake: 1) upstream of the dredging activities, 2) immediately downstream of the dredging activities, 3) CKRWD water intake, 4) downstream of CKRWD water intake, and 5) BYRWD water intake (Figure 17). Location 1 originally consisted of three sampling sites, but only two of the sites (2 and 3) were sampled; Location 2 consisted of a transect of six sampling sites (4, 5, 6, 7, 8, and 9); Location 3 consisted of three sampling sites (10, 11, and 12); Location 4 consisted of a transect of six sampling sites (13, 14, 15, 16, 17, and 18); and Location 5 consisted of a transect of six sampling sites (19, 20, 21, 22, 23, and 24).

Water quality monitoring at the five locations included depth-profile field measurements at all 23 sites. Water samples for laboratory analyses were collected at sites 2, 7, 11, 12, 19, and 20. The water samples collected at sites 2 and 7 were near-surface grab samples. The water samples collected at sites 11, 12, 19, and 20 were composite samples obtained from three equal volume samples collected at near-surface, mid-, and near-bottom depths. Before-dredging monitoring was conducted on 2-April-2008 and 25-August-2008, and during-dredging monitoring was conducted on 8-October-2008.

Scheduling of during-dredging water quality monitoring allowed for time-of-travel for any dredging plume to reach Location 5. A travel time through Lewis and Clark Lake was estimated for a pool elevation of 1206.2 ft-msl (347,100 ac-ft estimated reservoir volume) and a Gavins Point Dam outflow of 14,000 cfs (27,770 ac-ft per day). Under these conditions, the hydraulic residence time (HRT) of the reservoir is approximately 12.5 days. The ESH project is near RM827, Location 5 is near RM819, and Gavins Point Dam is near RM811. Assuming a constant velocity through the reservoir, travel time to Location 5 would be [(RM 827 - RM819 = 8 miles) ÷ (RM 827 – RM 811 = 16 miles) = 0.5] x [12.5 days] = 6.25 days. Because reservoir depths are shallower in the upper reaches of the reservoir, velocity in the upper reaches would be faster than in the lower reaches of the reservoir, and the 6.25 day travel time to Location 5 is considered at maximum estimate. Allowing for travel time, during-dredging water quality monitoring was targeted for at least 6 days after the onset of dredging. Dredging to complete ESH Complex 2 was initiated on 5-September-2008 and completed on 29-November-2008. The during-dredging lake monitoring was conducted on 8-October-2008, 32 days after the onset of the dredging and 52 days prior to the completion of dredging.

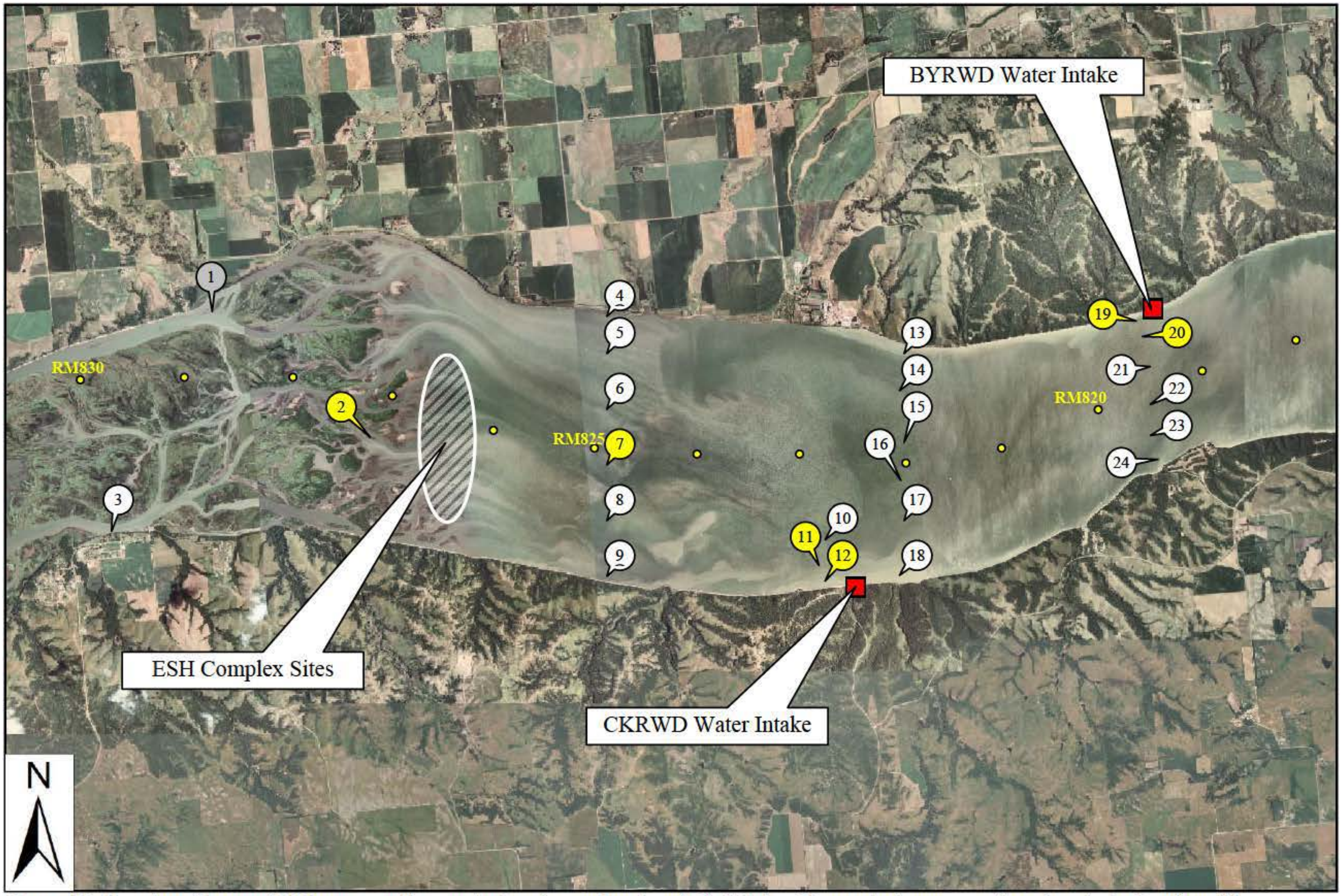

Figure 17. Location of targeted 2008 water quality monitoring sites on Lewis and Clark Lake. No monitoring was conducted at site 1. Depth-profile measurements were taken at sites 2 - 24. Water quality samples were collected at sites 2, 7, 11, 12, 19, and 20.

3.2.2.2 Field Measurements

Water temperature (°C), pH (S.U.), specific conductance (μmhos/cm), dissolved oxygen (mg/l and % saturation), turbidity (NTUs), oxidation-reduction potential (mV), and chlorophyll *a* (μg/l) were measured in the field with a "Hydrolab" equipped with a DataSonde 5 probe and Surveyor 4 data logger. The field measurements were collected in accordance with the Corps Omaha District's standard operating procedures for taking "Hydrolab" measurements (USACE, 2008). A depth-profile was measured in ½-meter increments at sites 4 through 24. At sites 2 and 3 a plastic bucket was used to collect a sample from just below the surface. The Hydrolab was then immediately placed in the plastic bucket and the measurements taken.

3.2.2.3 Collection of Water Quality Samples

Near-surface grab samples were collected at sites 2 and 7 by dipping a plastic churn bucket just below the water surface. At sites 11, 12, 19, and 20 composite samples were collected. The composite samples were obtained by placing equal volumes of water collected at three depths (i.e., near-surface, mid-depth, and near-bottom) into a plastic churn bucket and mixing. The appropriate sample containers were then filled from the spigot of the churn bucket as the water was slowing churned. The collected samples were appropriately preserved and transported to the analytical laboratory (i.e., Midwest Laboratories, Inc., Omaha, NE). Analytical methods, detection limits, and reporting limits for the samples analyzed in the laboratory are given in Table 4.

Table 4. Methods, detection limits, and reporting limits for analyses of river and lake samples.

Analyte	Method	Detection Limit	Reporting Limit
Total Suspended Solids	EPA - 160.2	4 mg/L	10 mg/L
Total Dissolved Solids	EPA - 160.1	5 mg/L	10 mg/L
Total Organic Carbon	EPA - 415.0	0.20 mg/L	1.0 mg/L
Bromide	EPA 300.0	0.1 mg/L	0.3 mg/L
Alkalinity	SM - 2320	4 mg/L	10 mg/L
True Color	ASTM D-1209-05	1 S.U.	3 S.U.
Total Trihalomethanes	EPA - 524.2		
Chloroform		0.15 μg/l	1.0 μg/l
Bromodichloromethane		0.36 μg/l	1.0 μg/l
Dibromochloromethane		0.34 μg/l	1.0 μg/l
Bromoform		0.30 μg/l	1.0 μg/l
Trihalomethane Formation Potential	SM - 5710	2.5 μg/l	5 μg/l

3.2.2.4 Water Quality Parameters of Special Interest

3.2.2.4.1 <u>Temperature and Dissolved Oxygen</u>

Thermal variation in reservoirs can result in temperature-induced density stratification which inhibits mixing of the water column. If this stratification persists, it can result in a quiescent zone at the bottom of the reservoir during the summer. As previously mentioned, this can result in the production of THM precursors during periods of anaerobiosis as organic matter is decomposed at the reservoir bottom. Temperature and depth-profiles were used to evaluate the occurrence of thermal stratification and anoxic conditions in Lewis and Clark Lake.

3.2.2.4.2 Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level. Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. The creation of the ESH would be expected to affect, at least locally, the turbidity levels in Lewis and Clark Lake due to the mobilization of matter in the bottom sediments during dredging and sandbar construction. Highly turbid source water is more difficult to treat for drinking water purpose and may require higher chlorine dosage for effective treatment. Depending on the matter attributing to turbidity, it may be indicative of the potential occurrence of THM precursors.

3.2.2.4.3 Chlorophyll *a*

Chlorophyll *a* is photosynthetic pigment of green plants. Chlorophyll *a* constitutes approximately 1 to 2 percent of the dry weight of planktonic algae and is used as an indicator of algal biomass (APHA, 1998). Assuming that chlorophyll *a* constitutes, on average, 1.5 percent of the dry weight of organic matter (ash-fee weight) of algae, algal biomass can be estimated by multiplying the chlorophyll *a* content by a factor of 67. Other studies have established that algal biomass and their extra-cellular products can act as THM precursors (Stepczuk et. al., 1998b). The seasonality of the occurrence of THM precursors that has been well documented in eutrophic reservoirs has been attributed to primary production associated with algae (Stepczuk 1998c). Chlorophyll *a* levels may provide insights into the variability of the occurrence of THM precursors in Lewis and Clark Lake.

3.2.2.4.4 Solids (Suspended and Dissolved)

Solids refer to matter (organic and inorganic) suspended or dissolved in water. "Total solids" is the term applied to the material residue left in a vessel after evaporation of a water sample and its subsequent drying in an oven. Total solids include "total suspended solids," the portion retained by a filter, and "total dissolved solids" the portion that passes through the filter. Total suspended and dissolved solids measure the total organic and inorganic matter suspended or dissolved in water. The creation of the ESH would be expected to affect, at least locally, the solids levels in Lewis and Clark Lake due to the mobilization of dredged material during sandbar construction.

3.2.2.4.5 Total Organic Carbon (TOC)

The organic carbon in water is composed of a variety of organic compounds in various oxidation states. Total organic carbon (TOC) is a direct measure of the organic matter content of water. TOC does not measure other organically bound elements such as nitrogen and hydrogen. Some of the organic carbon compounds measured by TOC can serve as THM precursors. TOC levels in Lewis and Clark Lake may be affected by the mobilization and dispersal of organic matter in the bottom sediments during dredging to construction ESH.

3.2.2.4.6 True Color

Color in water may result from the presence of natural metallic ions (iron and manganese), humus and peat materials, plankton, weeds, and industrial wastes (APHA, 1998). "True color" is the color of water from which turbidity has been removed. True color can be indicative of the amount of dissolved humic substances present in water, and dissolved humic substances can be THM precursors. Measures of true color can potentially provide insights into the occurrence of dissolved THM precursors not associated with suspended material and turbidity.

3.2.2.4.7 Bromide

As previously mentioned, chloroform is usually the most abundant THM formed when natural surface waters are chlorinated, but brominated compounds tend to increase in regions which have high ambient concentrations of bromide. The brominated THMs pose a higher carcinogen risk than chloroform, especially bromodichloromethane and dibromochloromethane (NDEQ, 2006). Water quality samples were collected in Lewis and Clark Lake and analyzed to determine ambient bromide concentrations in the reservoir.

3.2.2.4.8 Trihalomethanes (THMs)

THMs are not expected to occur in natural surface waters. An exception could be in surface waters receiving discharges from point sources that are using chlorination to disinfect their effluent prior to discharge. Samples were collected from Lewis and Clark Lake and analyzed for the four THM compounds (trichloromethane, bromodichloromethane, dibromochloromethane, and tribromomethane) to verify the suspected absence of THMs in the reservoir.

3.2.2.4.9 Trihalomethane Formation Potential (THM-FP)

Trihalomethane Formation Potential (THM-FP) is a measure of the potential for THMs, and other disinfection by-products, to form in water when under the influence of direct chlorination. THM-FP is a direct measure of the THMs present in a water sample after "rigorous" chlorination. THM-FP is an indirect measure of the organic carbon compounds in a sample that are THM precursors. Procedures for measuring THM-FP are given in Section 5710 of *"Standard Methods for the Examination of Water and Wastewater"* (APHA, 1998). THM-FP is the difference between the initial total concentration of THMs of a water sample and the total concentration of THMs after the water sample is chlorinated. If the sample does not contain chlorine at the time of collection (i.e., lake samples), the initial total THM concentration will be close to zero and the term THM-FP is appropriate. THM formation is enhanced by elevated temperatures, alkaline pH, increasing concentrations of free chlorine residuals (although THM formation tends to level off at free chlorine residuals of 3 mg/l and above), and longer reaction times (APHA, 1998). The THM-FP of raw source water for a treatment facility that chlorinates will indicate the maximum THMs that are likely to be produced if no pre-treatment of the raw water is used. The THM-FP gives a worst-case scenario. The test is performed in a closed system and thus does not mimic conditions in a flowing water distribution system. The chlorine dosages and temperatures used to determine THM-FP are rather extreme and may not be typical of operating conditions at the water treatment facility. Therefore, THM-FP usually provides worst-case concentrations of THMs. A THM-FP test done on the raw water and compared to the actual THMs occurring in the treated water can be used to gage the maximum potential THM concentrations possible regarding the measured THM-FP.

Concerns have been expressed that the dredging of bottom sediments in the delta area of Lewis and Clark Lake during the creation of ESH increased the levels of THM precursors in Lewis and Clark Lake. Purportedly, the dredging mobilized and dispersed THM precursors sequestered in the bottom sediments dredged. Measures of THM-FP should allow for a direct assessment of THM precursors in Lewis and Clark Lake and potential threats for the formation of THMs at water treatment systems using the reservoir for source water.

3.2.2.5 Results of Targeted Monitoring to Evaluate Impacts of ESH Construction

3.2.2.5.1 Summary of Analytical Results

The water quality conditions monitored in Lewis and Clark Lake at sites 2, 7, 11, 12, 19, and 20 on April 2, 2008, August 25, 2008, and October 8, 2008 are given in Plates 16 through 21.

3.2.2.5.2 Transect Contour Plots

Transect contour plots were constructed for Location 1 (site 2), Location 2 (sites 4, 5, 6, 7, 8, and 9), Location 4 (sites 13, 14, 15, 16, 17, and 18), and Location 5 (sites 19, 20, 21, 22, 23, and 24). Transect contours were plotted for water temperature, dissolved oxygen, turbidity, and chlorophyll *a* based on levels measured immediately before and during dredging (i.e., 25-August-2008 and 8-October -2008). The temperature contour plots show significant cooling from August to October (Plates 22 and 23). The dissolved oxygen contour plots show higher dissolved oxygen levels in October (Plates 24 and 25). The higher dissolved oxygen levels in Lewis and Clark Lake in October are attributed to the cooler water temperatures. The turbidity contour plots show vertical and horizontal variability across all the transects for both the August and October periods (Plates 26 and 27). Measured turbidity levels in Lewis and Clark Lake during the two periods were similar to slightly lower during dredging. The chlorophyll *a* contour plots are shown in Plates 28 and 29. Chlorophyll *a* levels measured in August were more variable and significantly higher than those measured in October. This is attributed to the seasonal growth of phytoplankton.

3.2.2.5.3 Time-Series Plots of Selected Parameters

Time series plots of true color, chlorophyll *a*, turbidity, TOC, total suspended solids, and total dissolved solids are shown in Figures 18 and 19. The plot of true color shows a significant increase in color between April and August which remains through October (Figure 18). This is believed to indicate that a significant increase in humic substances occurred between April and August and these higher levels remained through October. The plot of chlorophyll *a* is believed to show a typical seasonal occurrence of phytoplankton with lower levels in April and October and higher levels in August (Figure 18). The plots of turbidity, TOC, total suspended solids, and total dissolved solids show no discernable tendency over the period (Figures 18 and 19). The sample dates that directly bracket the onset of the dredging to complete ESH complex 2 (i.e., August and October) were compared. This comparison seemingly indicated no degradation of water quality conditions due to the dredging operations. The measured pre-dredging chlorophyll *a* levels in Lewis and Clark Lake were noticeably higher than the levels measured during the dredging operation. This is attributed to the seasonal occurrence of phytoplankton that was seemingly not influenced by the dredging.

3.2.2.5.4 THMs and THM Formation Potential

3.2.2.5.4.1 Monitored Levels of THMs

None of the 18 samples collected in Lewis and Clark Lake during 2008 were found to contain detectable levels of any of the four THM compounds (Plates 16-21).

3.2.2.5.4.2 Results of THM-FP Analyses

The concentrations of THMs formed in the THM-FP analyses are given in Plates 16 through 21. Chloroform, by far, was the most abundant THM formed. No bromoform was formed (Plates 16-21). The highest THM-FP level measured was 190 μg/l at site 19 in August (Plate 21). Figure 20 gives a time-series plot of the THM-FP levels measured at sites 2, 7, 11, 12, 19, and 20 during April, August and October. THM-FP levels measured at all six sites were appreciable higher before dredging to complete ESH Complex 2 than during dredging (Figure 20). This indicates that the dredging to complete ESH complex 2 did not show a measured increase the levels of THM precursors in Lewis and Clark Lake.

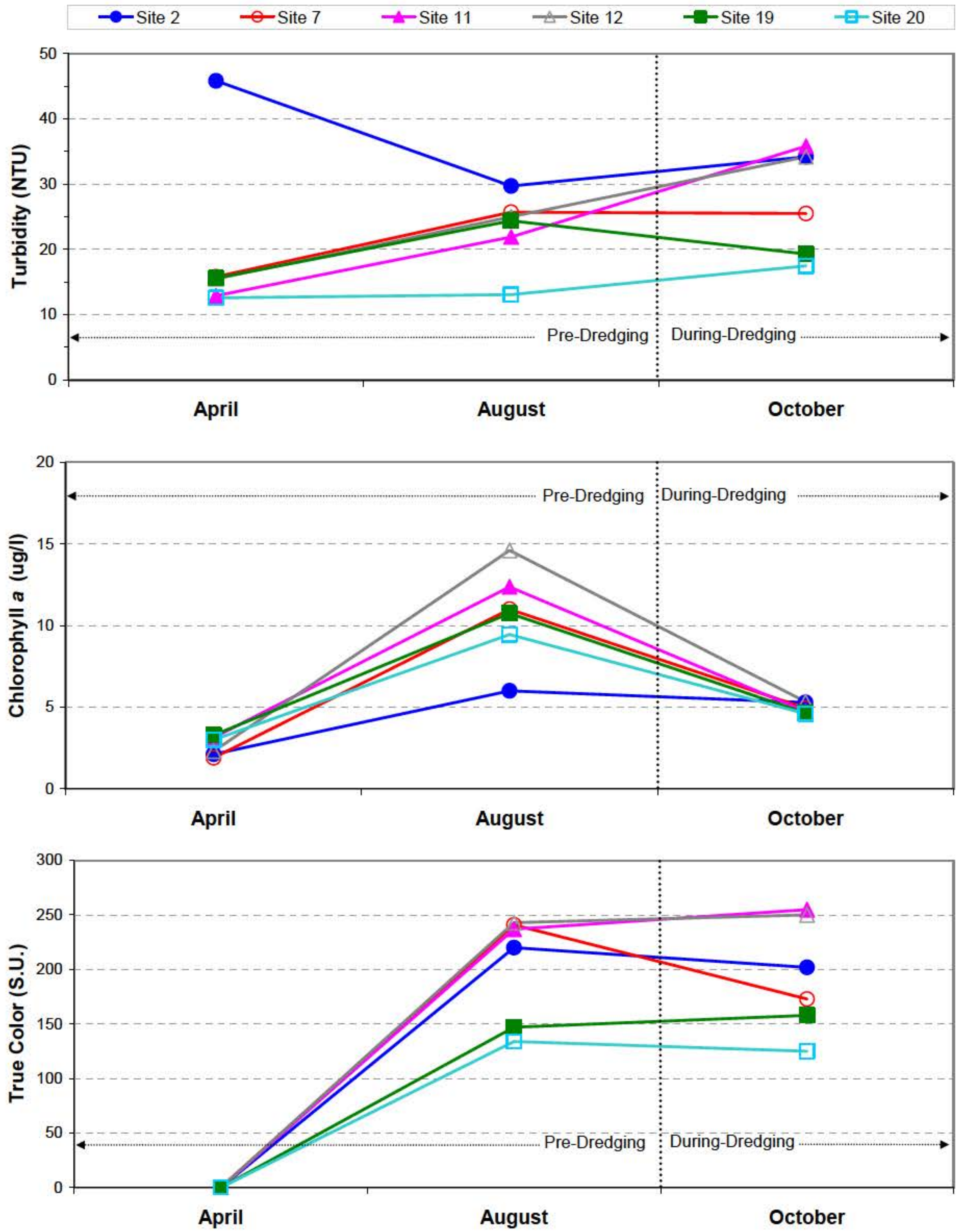

Figure 18. Time series plots of turbidity, chlorophyll *a*, and true color measured in Lewis and Clark Lake at sites 2, 7, 11, 12, 19, and 20 (See Figure 17) in April, August, October 2008.

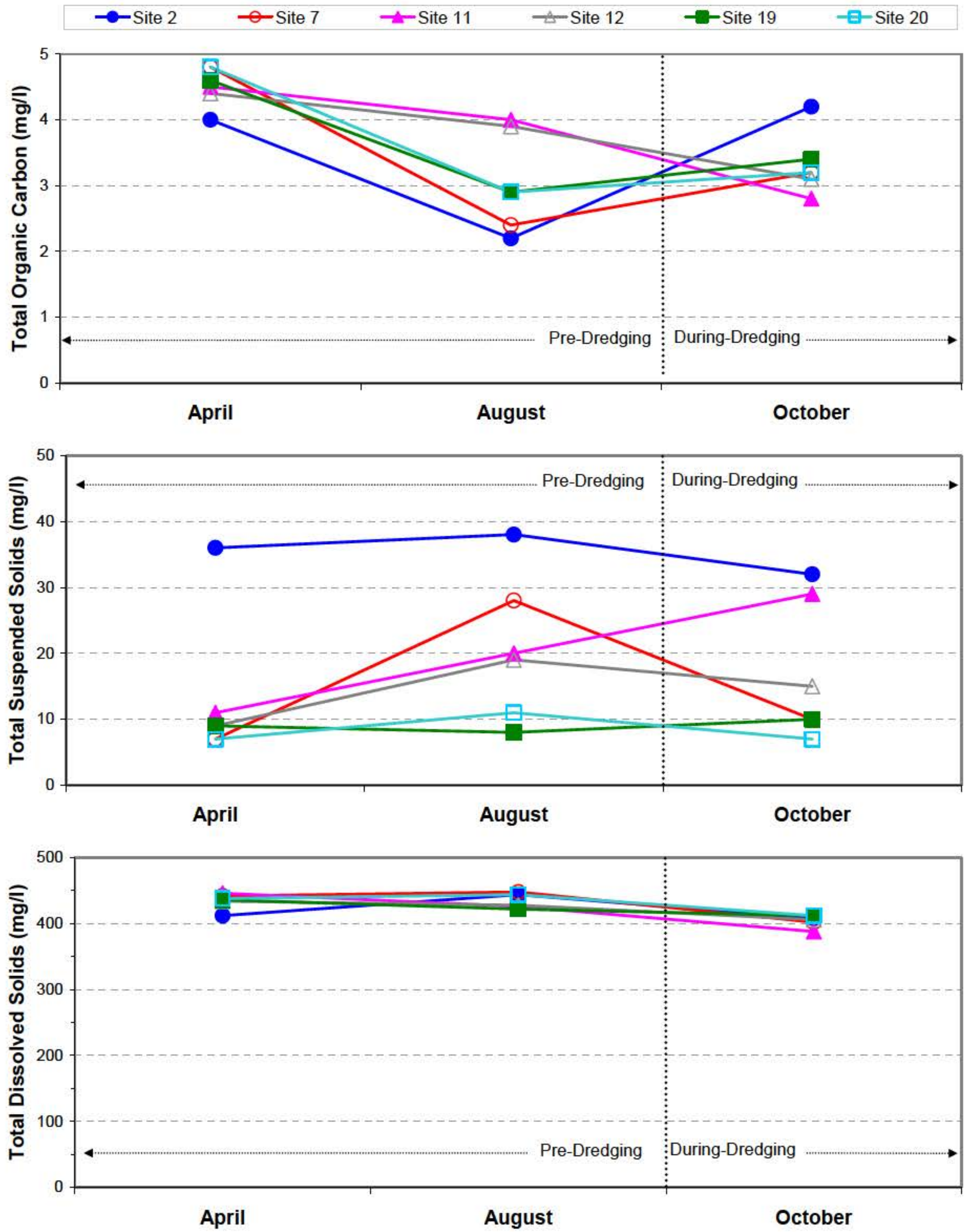

Figure 19. Time series plots of total organic carbon, total suspended solids, and total dissolved solids measured in Lewis and Clark Lake at sites 2, 7, 11, 12, 19, and 20 in April, August, October 2008.

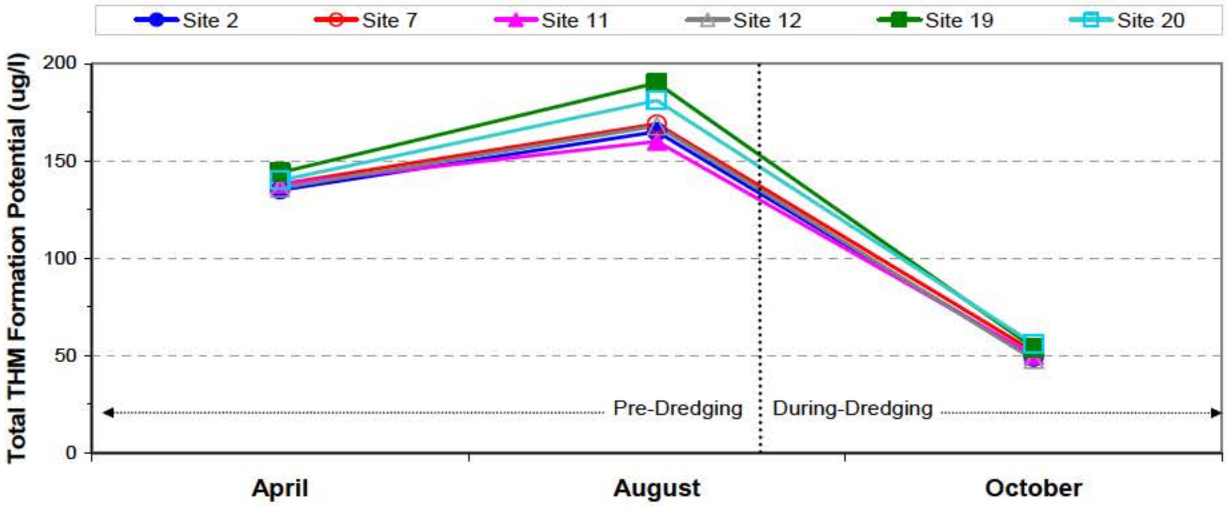

Figure 20. Time series plots of total trihalomethane formation potential measured in Lewis and Clark Lake at sites 2, 7, 11, 12, 19, and 20 in April, August, October 2008.

3.2.2.5.4.3 *<u>Comparison of THM-FP Levels Measured in Lewis and Clark Lake and other Eutrophic Reservoirs</u>*

The literature was reviewed to find other occurrences where THM precursors (i.e., THM-FP) have been monitored in eutrophic reservoirs. Figure 21 displays a plot of the THN-FP levels measured in Lewis and Clark Lake and two other eutrophic reservoirs; Cannonsville Reservoir, NY and Taylorsville Lake, KY (Stepczuk et. al., 1998b and Bukaveckas et. al., 2007). Cannonville Reservoir is a 4,800-acre impoundment on the Delaware River that was completed in 1967 and is a drinking water supply for New York City, NY. Taylorsville Lake is a 3,050-acre flood control reservoir near Louisville, KY that was created in 1983 (Bukaveckas et. al., 2007). The THM-FP levels measured in Lewis and Clark Lake during 2008 were appreciably lower than those measured at the other two reservoirs (Figure 21). The THM-FP levels measured in Lewis and Clark Lake when ESH dredging was ongoing (i.e., 8-Oct-2008) were the lowest levels measured at any of the three reservoirs.

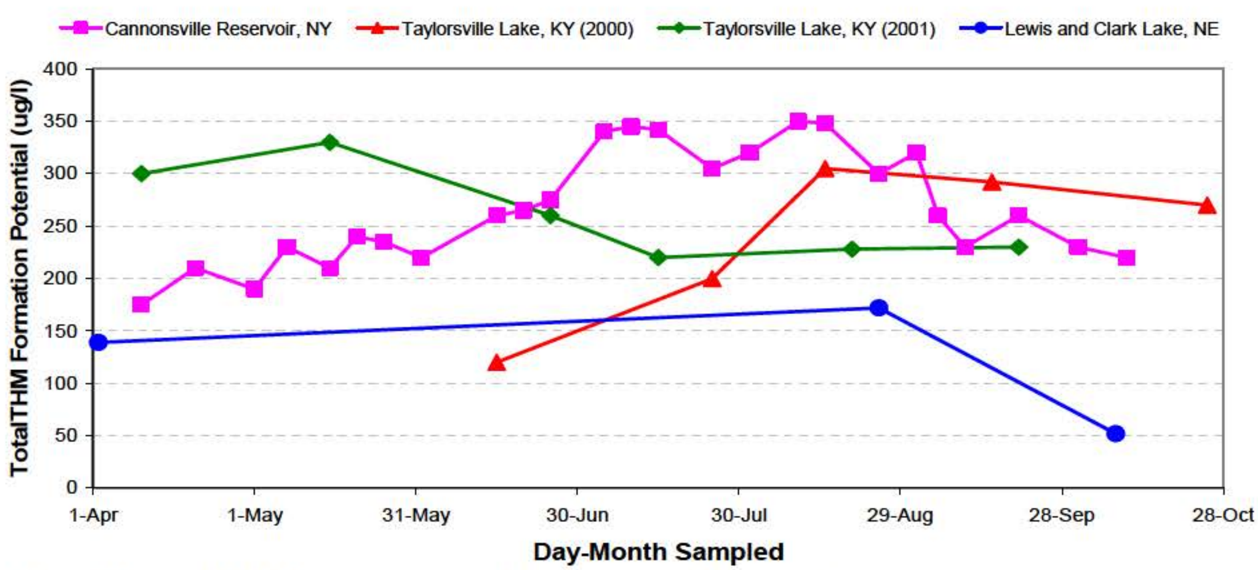

Figure 21. Total THM formation potential levels measured in eutrophic reservoirs.

4 CONCLUSIONS

4.1 WATER QUALITY CONDITIONS OF TREATED DRINKING WATER

THMs occurred in the treated drinking water provided by the CKRWD, BYRWD, and the City of Yankton. Quarterly THM levels historically reported by the three treatment facilities indicate a strong seasonal trend with lower levels occurring in the winter and higher levels in the spring and summer. Treatment processes and retention time in the distribution system seem to have a significant impact on the THM levels occurring at the treatment facilities.

The historical data from BYRWD clearly shows THM levels are consistently less than half of the 80 μg/l THM MCL standard. The small range of values indicates the treated water is not prone to extreme THM values, and reflects an ability of the BYRWD to effectively manage their water treatment process given the quality of the source water. THM concentrations in the BYRWD treated water were very low before and after ESH construction, so any increase in THM precursor levels in Lewis and Clark Lake that may have occurred from ESH construction or other seasonal sources were manageable with no non-compliance occurrences observed in the quarterly data. The quarterly data indicate the ESH construction in the upper reaches of Lewis and Clark Lake did not have an appreciable impact on the THM levels measured in BYRWD's treated water.

The reported THM levels at Yankton are notably higher than the levels reported for BYRWD. The THM levels at Yankton indicate the treatment facility has a greater vulnerability to high THM values and a greater risk for THM non-compliance events. The treatment process may have a major impact on the occurrence of THMs and non-compliance events at Yankton. The occurrence of high THM levels in Yankton's treated water do not appear to be correlated with the dredging that occurred to construct the ESH in the upper reaches of Lewis and Clark Lake. The level of THM precursors present in the Missouri River at the Yankton water intake appear to rise with the increase in organic matter attributable to spring and summer runoff and algal production in Lewis and Clark Lake.

The reported THM levels at CKRWD were also notably higher than the levels reported for BYRWD. The THM levels at CKRWD also indicate the treatment facility has a greater vulnerability to high THM values and a greater risk for THM non-compliance events. The treatment process may also have a major impact on the occurrence of THMs and non-compliance events at CKRWD. It is not clear as to whether the ESH dredging in the upper reaches of Lewis and Clark Lake had a significant impact on the quarterly THM levels reported for CKRWD. THM levels reported in 2006 and 2007, when dredging occurred, do not indicate a noticeable impact as all quarterly results were within the historical range of normal seasonal variability. Quarterly reporting for 2008 indicated THM level greater than the historic maximum in the 4th quarter. This was during the period that dredging was completed on ESH complex 2 and may indicate a potential impact.

Additional targeted water quality monitoring of treated water in the CKRWD distribution system during 2008 showed a strong seasonal trend in THM levels (i.e., low in early spring and early fall and high in the summer). THM levels in the CKRWD distribution system were directly related to the distance from the treatment plant (i.e., locations the farthest away had the highest THM levels). Monitored THM levels associated with before and during ESH dredging periods did not indicate any impact; monitored THM levels were lower during ESH dredging.

4.2 WATER QUALITY CONDITIONS IN LEWIS AND CLARK LAKE

Ambient water quality conditions monitored in Lewis and Clark Lake during 2008 were similar to conditions monitored in the past. Lewis and Clark Lake is in a eutrophic condition and experiences higher levels of algal growth during the summer. Monitored levels of THM precursors (i.e., THM-FP) in Lewis and Clark Lake exhibited seasonality ("i.e., low levels in spring and fall and higher levels in the summer). This seemingly indicates that seasonal runoff and algal production (lacustrine and riverine) may be a primary source of THM precursors in Lewis and Clark Lake. THM-FP levels measured in Lewis and Clark Lake were appreciably lower than levels measured in eutrophic reservoirs in New York and Kentucky. Monitoring conducted immediately before and during the dredging to complete ESH complex 2 did not detect any significant impact of the dredging on the water quality of Lewis and Clark Lake. Monitored levels of THM-FP in the lake were lower during dredging when compared to levels monitored immediately before dredging.

5 RECOMMENDATIONS

5.1 FUTURE BORROW AREAS IN LEWIS AND CLARK LAKE USED FOR FILL MATERIAL

Borrow areas used in the future to obtain fill material for construction of ESH in the upper reaches of Lewis and Clark Lake should avoid delta areas that have accumulated high levels of organic matter. Bottom sediments high in organic matter (i.e., decayed vegetation) are likely to contain significant levels of nutrients and THM precursors formed during microbial decomposition. Dredging these bottom sediments and using them for ESH fill would release these sequestered nutrients and THM precursors to the lake where they could be transported downstream of the ESH project area. Such a release of THM precursors would have the greatest potential to directly impact the CKRWD water supply. The release of the nutrients in the bottom sediments could also enhance eutrophication of Lewis and Clark Lake, and a resulting increase in primary production could also increase the occurrence of THM precursors.

Avoiding bottom sediments high in organic matter and utilizing coarser, "sandy" material for fill material will improve the habitat quality of the ESH created while minimizing potential water quality impacts to Lewis & Clark Lake. Coarser fill material is easier to contour and is better suited for the construction of ESH. The coarser material should contain significantly less nutrients and seed stocks which should slow down the encroachment of vegetation on the created sandbars. This will maximize the time period the created sandbars provide quality habitat for the terns and plovers, and extend the time before control measures are needed to manage encroaching vegetation.

5.2 EXPANSION OF WATER QUALITY MONITORING AT LEWIS AND CLARK LAKE

Water quality monitoring at Lewis and Clark Lake during 2009 will be implemented under four ongoing monitoring projects: 1) ambient monitoring of the Missouri River mainstem reservoirs, 2) ambient monitoring of the Missouri River mainstem powerplants, 3) ambient monitoring of the lower Missouri River, and 4) intensive water quality survey of Lewis and Clark Lake (2nd year of a planned 3-year survey). Additional monitoring will be added to these ongoing products to provide information regarding how the creation of ESH in the upper reaches of Lewis and Clark Lake may be affecting water quality conditions in the reservoir. The following additions will be made (see Figure 21):

1) Station MORRR0841 has been added to the lower Missouri River monitoring project. Under this project 10 sites now will be monitored along the Missouri River from the Fort Randall Dam tailwaters to Rulo, NE. Sites MORRR0851 (Verdel, NE) and GPTRRTW1 (Gavins Point Dam tailwaters) are two of these 10 sites. These sites are monitored monthly year-round. The parameters THM Formation Potential, Dissolved Organic Carbon, and Chlorophyll *a* will be added to the list of parameters to be analyzed.

2) The second year of a planned 3-year intensive water quality survey is being implemented at Lewis and Clark Lake in 2009. Sites L2, L3, L4, L5, and NF2 are being monitored as part of this survey. The planned monitoring of these sites was scheduled for monthly sampling from June through September. The monitoring will be expanded to include the collection of May samples. The parameters THM Formation Potential and Dissolved Organic Carbon will be added to the parameter list.

3) 2008 sampling at Lewis and Clark Lake and results reported in the literature from other reservoirs indicated that the occurrence of THM precursors are highly dependent upon seasonal algal production. Seasonal occurrence of THM precursors related to algal production will be evaluated in Lewis and Clark Lake.

4) The potential for dredged sediment to be a source of THM precursors will be further evaluated by collecting sediment samples in the delta region of Lewis and Clark Lake. Sediment samples will be collected at the following sites: 1) initially dredged area that was abandoned because the material was too fine, 2) previously dredged area that was used to obtain coarser material, and 3) areas identified for future dredging. Representative sediment samples will be collected and elutriate samples prepared and analyzed. Elutriate samples will be analyzed for traditional parameters and THM Formation Potential. Analysis of elutriate samples will include both total and dissolved fractions.

5) Results from the above monitoring will be used to: 1) provide additional insights into current water quality conditions at Lewis and Clark Lake, 2) provide background information applicable to other Corps reservoirs used for drinking water, and 3) possible inclusion in ongoing CE-QUAL-W2 water quality model development at the Missouri River mainstem reservoirs.

5.3 REVIEW OF QUARTERLY MONITORING RESULTS AT FUTURE POTENTIALLY IMPACTED WATER TREATMENT PLANTS

The Omaha District will communicate proactively with and attempt to obtain quarterly water quality monitoring conducted by water treatment plants within the immediate area of future ESH construction projects. These results will be reviewed for early detection of possible source water quality concerns.

5.4 SEDIMENT AND ELUTRIATE SAMPLING AT FUTURE ESH PROJECT SITES IMMEDIATELY UPSTREAM OF DRINKING WATER INTAKES

Sediment and elutriate sampling will be conducted at future ESH project sites that are located immediately upstream of drinking water supply intakes. Regarding ESH projects on the Missouri River, “immediate” is defined as 25 river miles. All projects that would introduce dredged material to reservoirs used as raw water for drinking water supply will also be sampled. Sediment and elutriate sampling will be done in accordance with the “Inland Testing Manual” (USEPA and USACE, 1998). Sediment samples will be collected from identified borrow areas, and receiving water will be collected from the project site. THM-FP will be analyzed from the prepared elutriate samples. The potential of the proposed borrow area material to increase THM precursors above background levels in the receiving water will be determined. Potential increases of THM precursors above background levels will be evaluated regarding the travel time to downstream intakes, dilution afforded by the receiving water, the occurrence of other THM precursor sources (e.g. tributaries, point sources, nonpoint sources, wetlands, etc.), and the treatment methods employed by downstream drinking water facilities. Proposed ESH projects that are identified as having a potential impact to a downstream drinking water facility will be further evaluated. If feasible, measures to control the release of THM precursors will be identified and implemented.

5.5 NOTIFICATION OF DRINKING WATER TREATMENT FACILITIES WITH WATER INTAKES DOWNSTREAM OF FUTURE ESH CONSTRUCTION SITES

Water supply facilities with water intakes immediately downstream of future ESH construction sites will be notified before the initiation of dredging activities. All water supply facilities that use a reservoir for source water will be notified before dredged material from an ESH project is discharged to the reservoir.

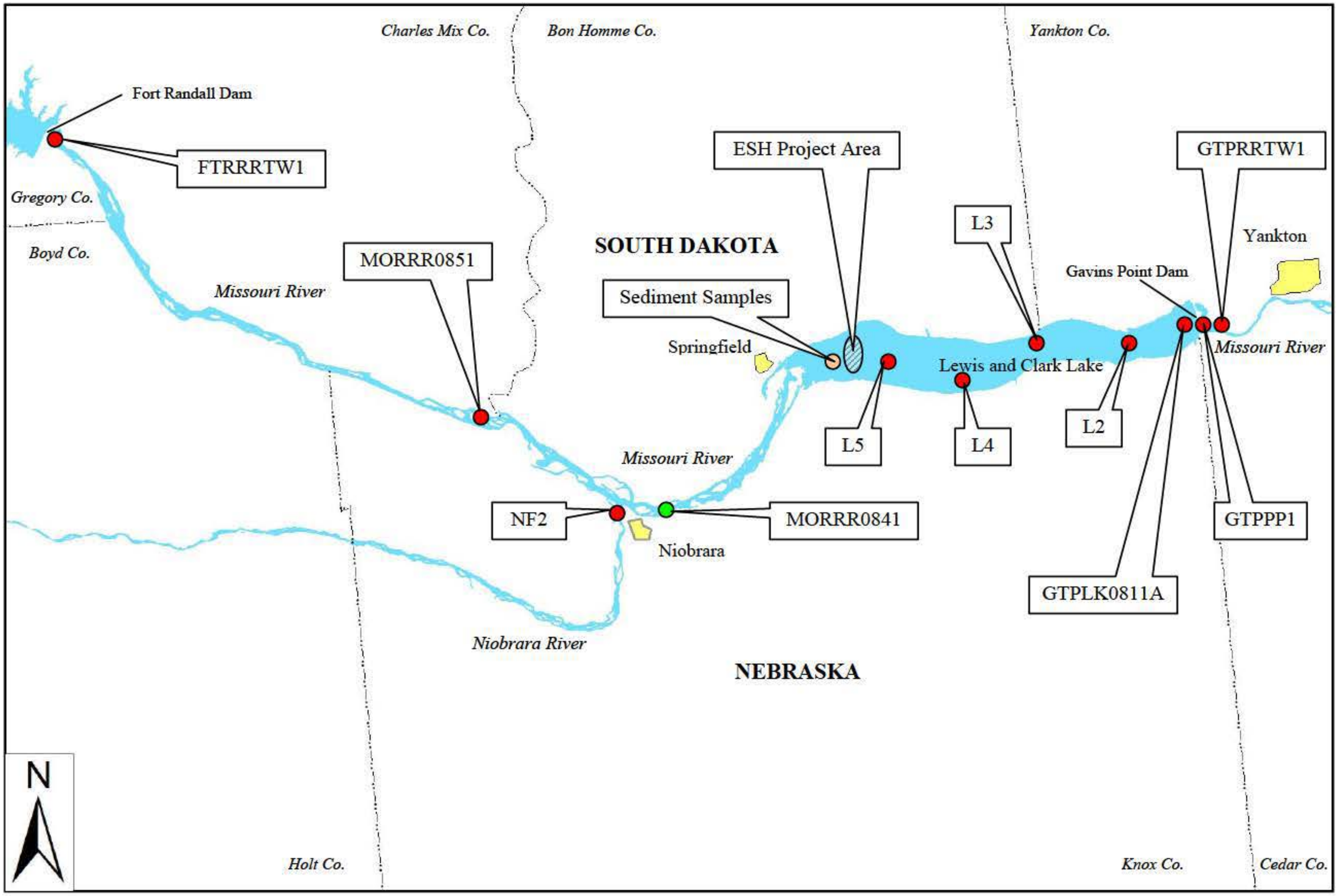

Figure 22. Location of sites where water quality monitoring is planned at the Gavins Point Project in 2009.

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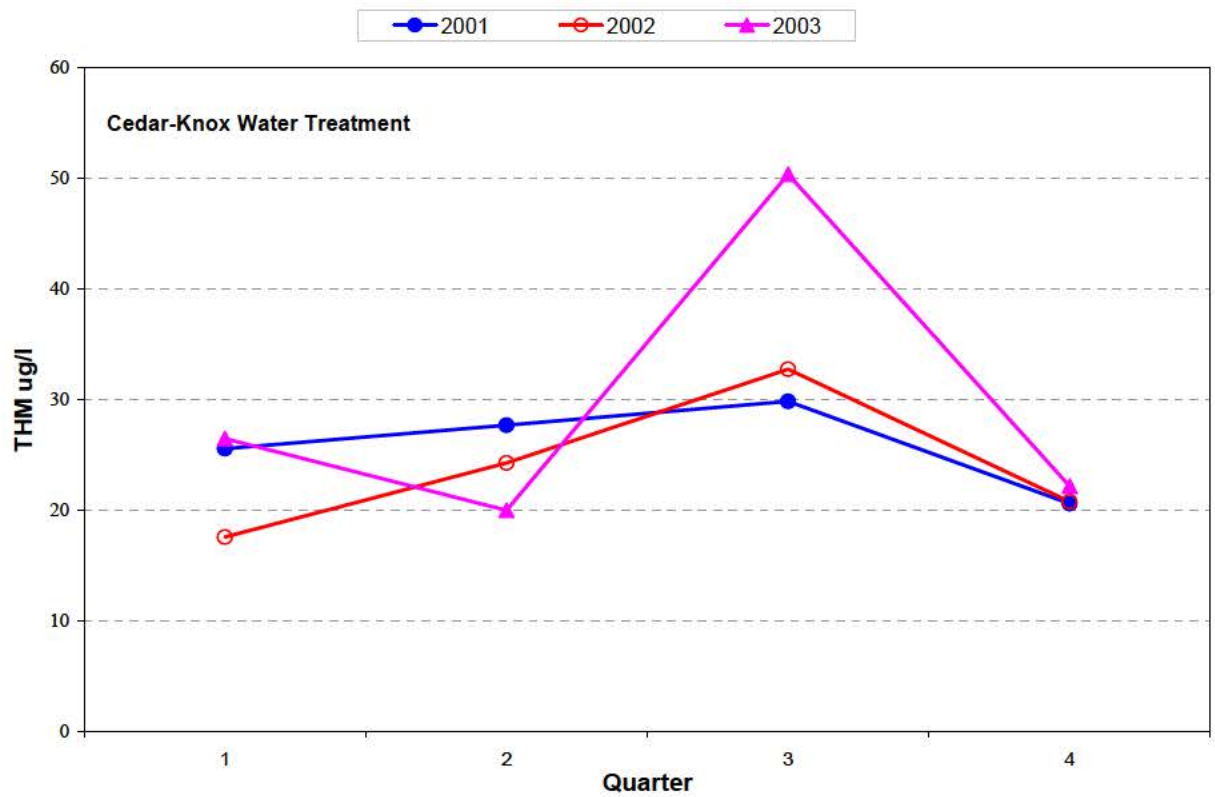


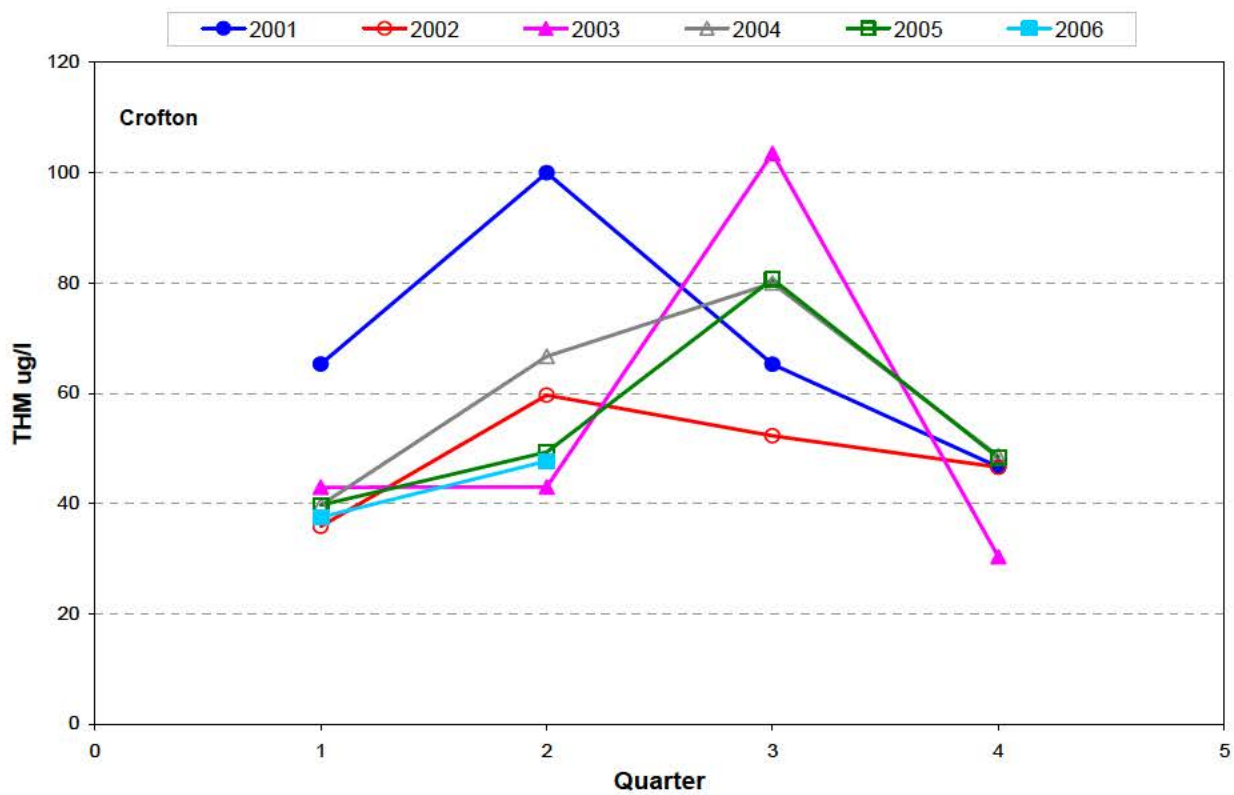
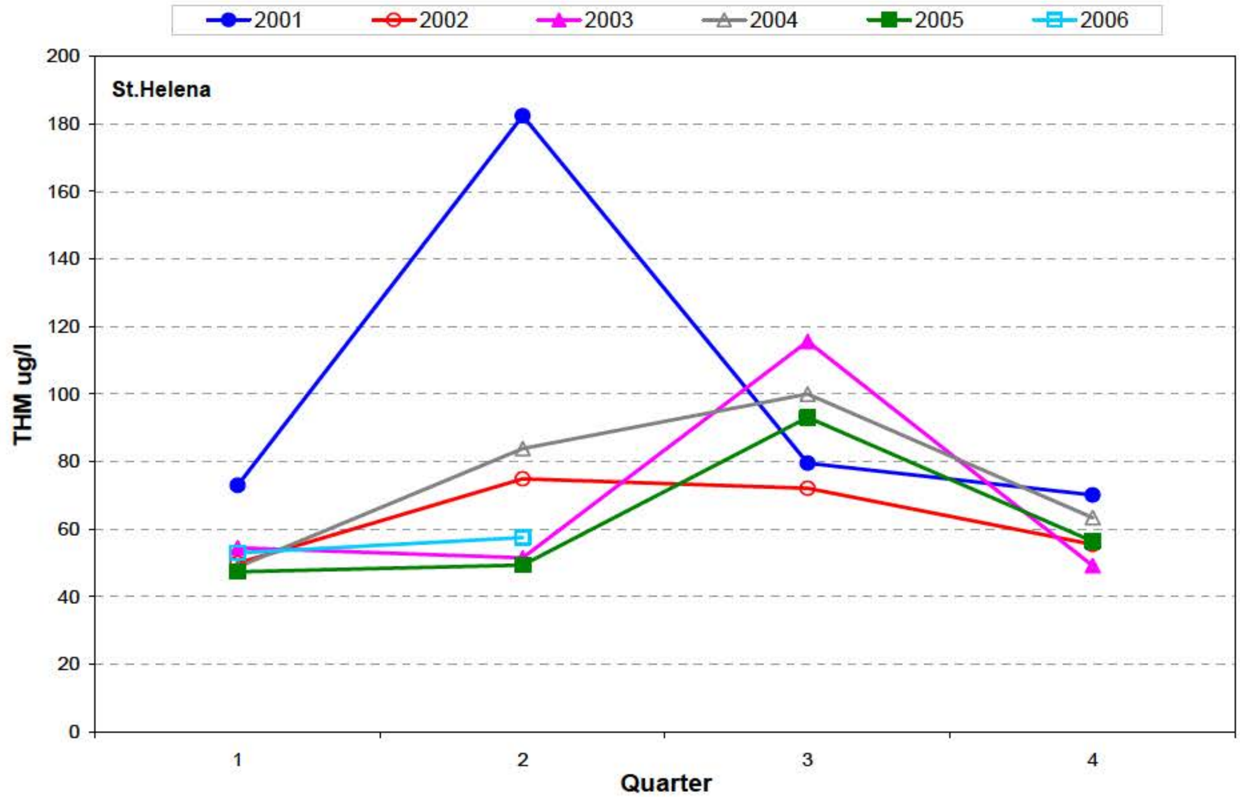


Plate 1. Historically monitored THM levels in the Cedar-Knox water distribution system at the water treatment plant and Crofton.



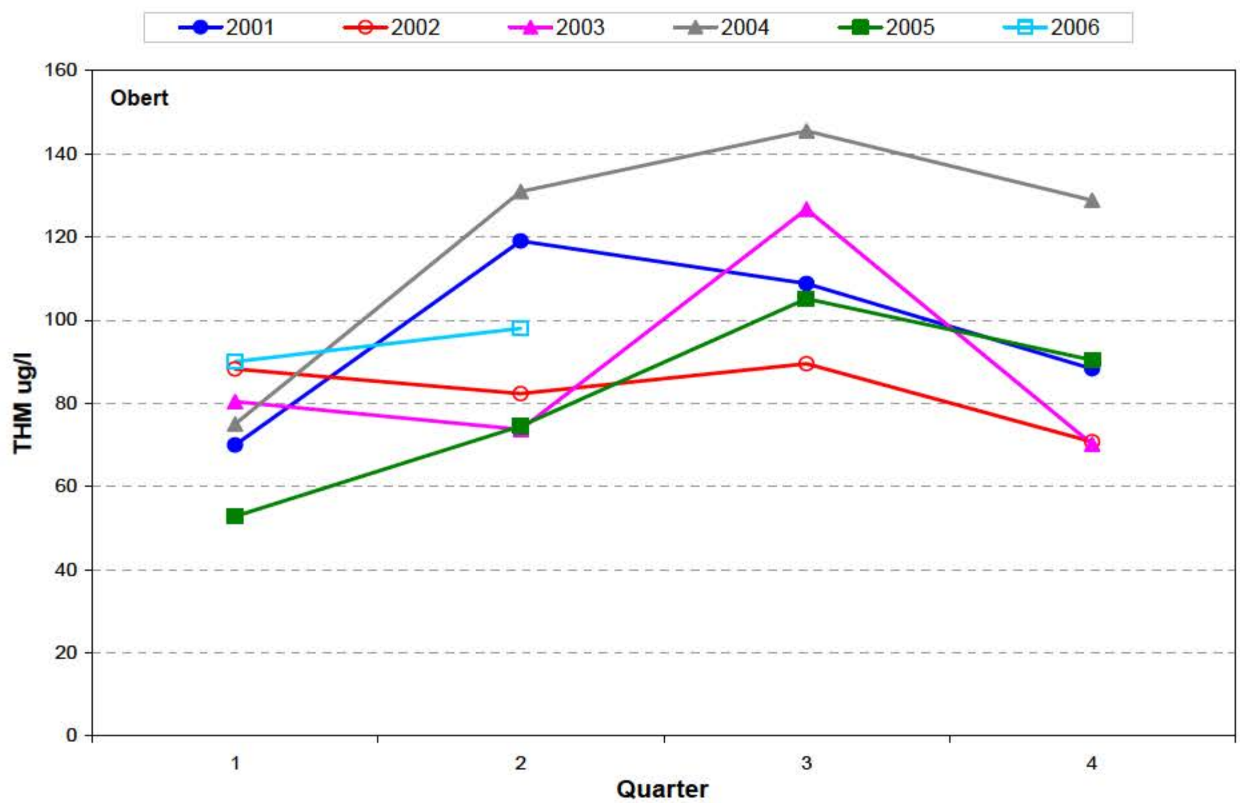


Plate 2. Historically monitored THM levels in the Cedar-Knox water distribution system at St. Helena and Obert.

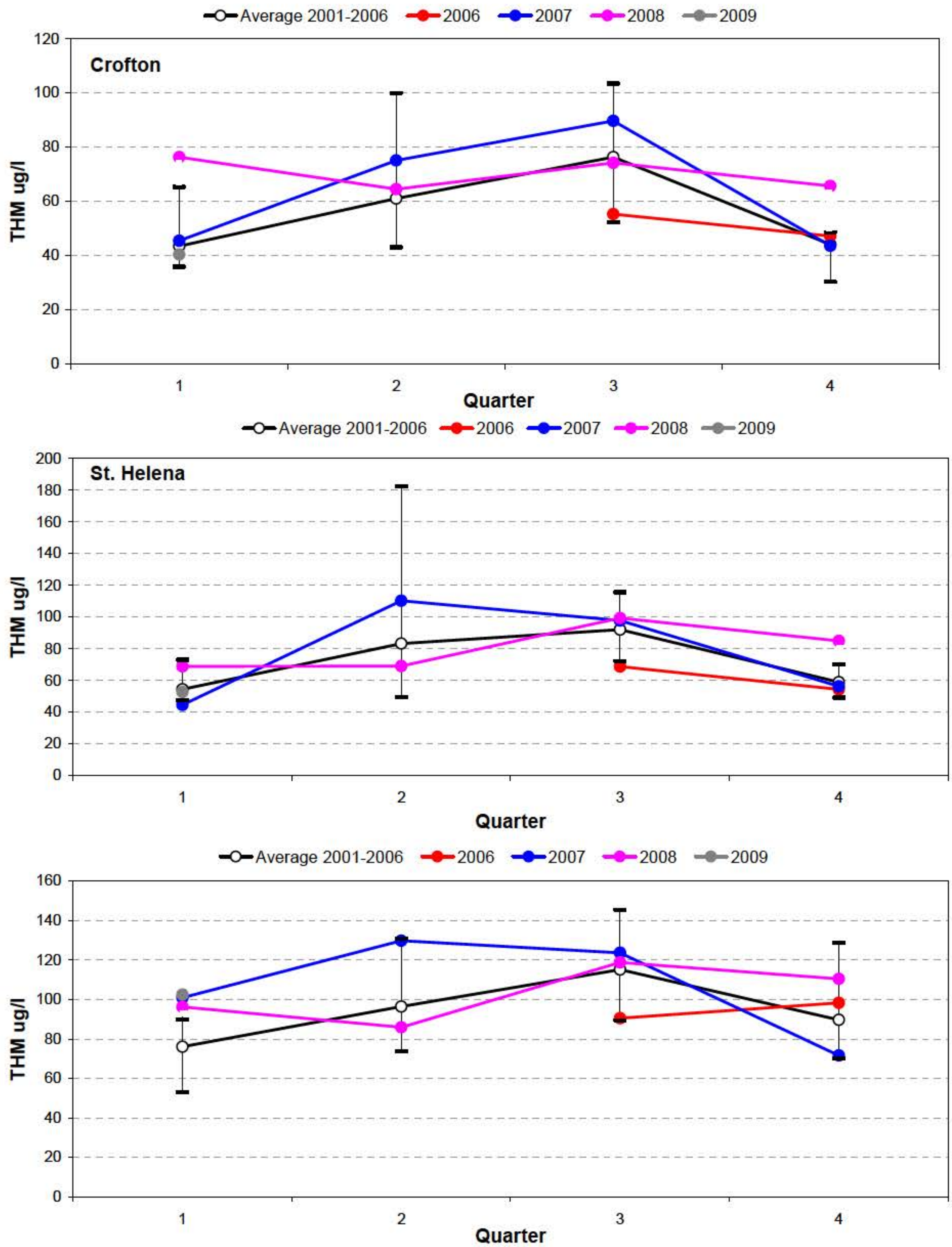


Plate 3. Historical average (2001-2006) and 2006, 2007, 2008, and 2009 THM levels monitored at Crofton, St. Helena, and Obert in the Cedar-Knox water distribution system. [Note: Bars on average are the range of data (i.e., maximum and minimum).]

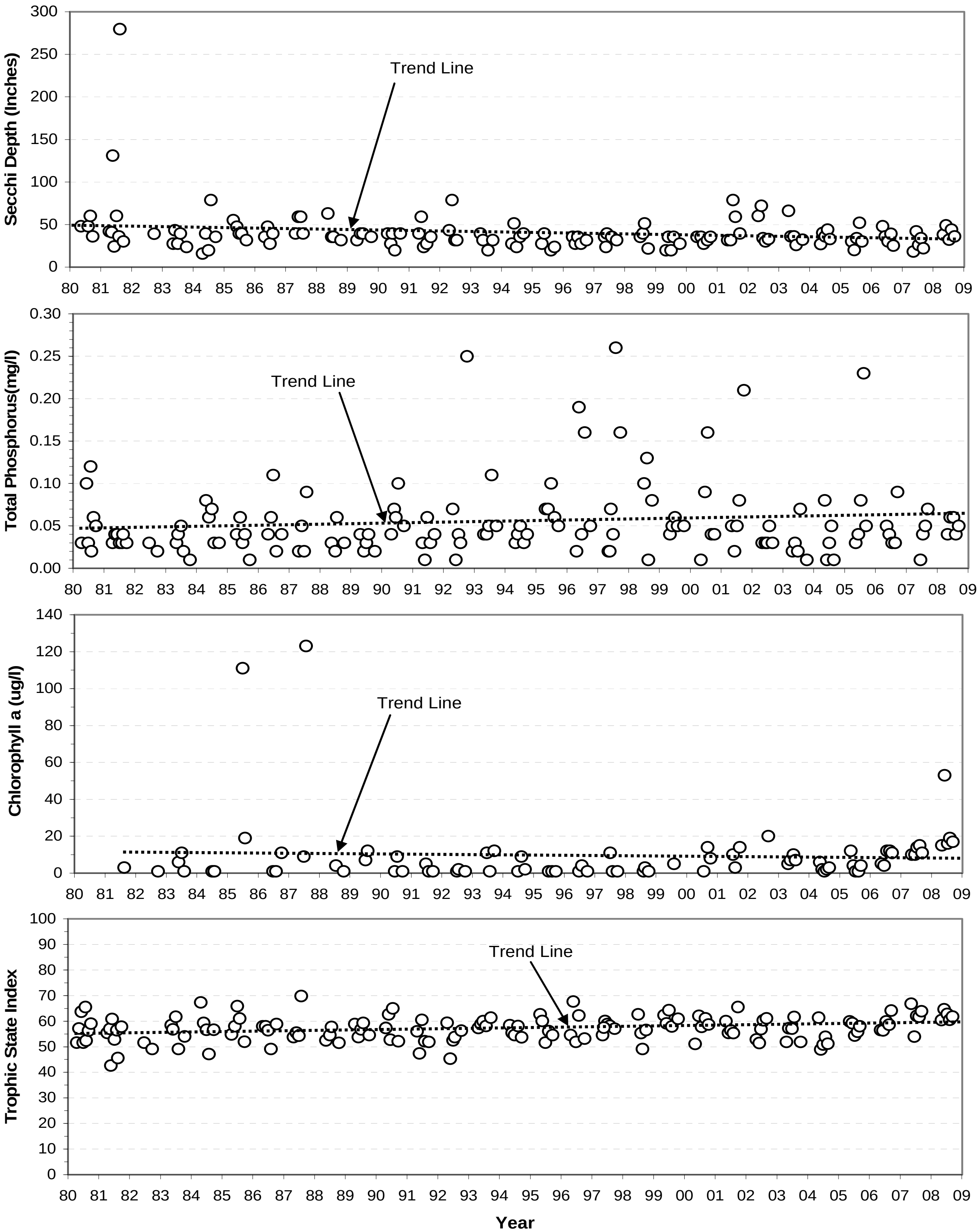


Plate 4. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Gavins Point Reservoir at the near-dam, ambient site (i.e., site GTPLK0811A) over the 29-year period of 1980 to 2008. (Note: Trophic conditions based on TSI are Oligotrophic 0-35, Mesotrophic 36-50, Moderately Eutrophic 51-55, Eutrophic 56-65, and Hypereutrophic 66-100).

Plate 5. Summary of monthly (May through September) water quality conditions monitored in Lewis and Clark Lake near Gavins Point Dam (RM811) during 2008. [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 Secchi depth and chlorophyll a (lab determined) are for "samples" collected at a near-surface depth. Results for other parameters are for samples collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	5	1206.5	1206.4	1205.9	1207.5	-----	-----	-----
Water Temperature (C)	0.1	60	20.7	21.9	10.0	26.4	27.0 29.0	0 0	0% 0%
Dissolved Oxygen (mg/l)	0.1	60	9.1	9.0	2.5	13.1	≥ 5.0	5	8%
Dissolved Oxygen (% Sat.)	0.1	60	103.8	106.1	31.0	151.5	-----	-----	-----
Specific Conductance (umho/cm)	1	59	694	697	663	712	2,000[5]	0	0%
pH (S.U.)	0.1	60	8.4	8.5	7.9	8.7	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	60	14	12	3	38	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	60	321	312	281	386	-----	-----	-----
Secchi Depth (in.)	1	5	40	38	32	49	-----	-----	-----
Alkalinity, Total (mg/l)	7	10	157	157	150	162	≥ 20	0	0%
Ammonia, Total (mg/l)	0.01	10	-----	0.05	n.d.	0.22	3.9 [1,2], 0.8 [1,3]	0	0%
Carbon, Total Organic (mg/l)	0.05	10	3.9	3.4	2.8	6.1	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	10	13	13	5	19	-----	-----	-----
Chloride (mg/l)	1	10	11	11	10	11	860[2], 230[3], 250[4]	0	0%
Chlorophyll *a* (ug/l) – Field Probe	1	60	11	10	3	37	8[6]	34	57%
Chlorophyll *a* (ug/l) – Lab Determined	1	5	24	17	15	53	8[6]	5	100%
Dissolved Solids, Total (mg/l)	5	10	455	449	418	576	1,750[4], 500[7]	0, 1	0%, 10%
Nitrogen, Total Kjeldahl (mg/l)	0.1	10	0.6	0.5	n.d.	1.1	-----	-----	-----
Nitrogen, Total (mg/l)	0.1	10	0.7	0.5	0.3	1.4	0 57[6]	4	40%
Nitrate-Nitrite N, Total (mg/l)	0.02	10	-----	n.d.	n.d.	0.30	10[4]	0	0%
Phosphorus, Dissolved (mg/l)	0.02	10	-----	0.02	n.d.	0.05	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	10	0.06	0.06	0.03	0.12	0.06[6]	2	20%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	10	-----	n.d.	n.d.	0.04	-----	-----	-----
Sulfate (mg/l)	1	10	183	180	177	195	875[4], 250[7]	0	0%
Suspended Solids, Total (mg/l)	4	10	-----	6	n.d.	9	158[2], 90[3]	0	0%

n.d. = Not detected.
[A] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).
[B] [1] Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.
[2] Acute criterion for aquatic life.
[3] Chronic criterion for aquatic life.
[4] Daily maximum criterion for domestic water supply.
[5] Agricultural criterion for surface waters.
[6] Nutrient criteria. (Lewis and Clark Lake is classified R9 by Nebraska for application of nutrient criteria.)
[7] The criteria for total dissolved solids and sulfate are listed by the State of Nebraska to protect the beneficial use of public drinking water. Where the natural background level is greater than these criteria, the State of Nebraska states that the background level is to be used in place of the criteria. The levels monitored in Lewis and Clark Lake are believed indicative of natural background conditions.

Plate 6. Summary of monthly (June through September) water quality conditions monitored in Lewis and Clark Lake near Weigand Area (RM815) during 2008. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) 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 Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	4	1206.4	1206.2	1205.9	1207.4	-----	-----	-----
Water Temperature (C)	0.1	37	22.1	22.3	18.4	25.3	27.0 29.0	0 0	0% 0%
Dissolved Oxygen (mg/l)	0.1	37	8.1	7.9	6.3	10.2	≥ 5.0	0	0%
Dissolved Oxygen (% Sat.)	0.1	37	95.9	95.5	74.7	121.0	-----	-----	-----
Specific Conductance (umho/cm)	1	37	694	697	662	715	2,000[1]	0	0%
pH (S.U.)	0.1	37	8.2	8.3	7.8	8.5	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	37	31	30	14	71	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	37	323	328	269	392	-----	-----	-----
Secchi Depth (in.)	1	4	21	20	19	26	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	37	9	9	4	21	8[2]	23	62%

n.d. = Not detected.
[A] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).
[B] [1] Agricultural criterion for surface waters.
[2] Nutrient criteria. (Lewis and Clark Lake is classified R9 by Nebraska for application of nutrient criteria.)

Plate 7. Summary of monthly (May through September) water quality conditions monitored in Lewis and Clark Lake near Bloomfield Area (RM819) during 2008. [Note 1: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for Secchi depth and chlorophyll a (lab determined) are for "samples" collected at a near-surface depth. Results for other parameters are for samples collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	4	1206.4	1206.2	1205.9	1207.4	-----	-----	-----
Water Temperature (C)	0.1	35	20.1	21.3	10.2	24.6	27.0 29.0	0 0	0% 0%
Dissolved Oxygen (mg/l)	0.1	35	9.3	9.0	5.1	13.3	≥ 5.0	0	0%
Dissolved Oxygen (% Sat.)	0.1	35	106.1	104.3	58.9	156.2	-----	-----	-----
Specific Conductance (umho/cm)	1	35	697	707	636	727	2,000(5)	0	0%
pH (S.U.)	0.1	35	8.3	8.4	7.8	8.6	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	28	36	29	12	123	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	35	331	326	274	399	-----	-----	-----
Secchi Depth (in.)	1	4	20	19	16	24	-----	-----	-----
Alkalinity, Total (mg/l)	7	8	156	157	148	162	≥ 20	0	0%
Ammonia, Total (mg/l)	0.01	8	-----	0.06	n.d.	0.18	3.9 (1,2), 0.8 (1,3)	0	0%
Carbon, Total Organic (mg/l)	0.05	8	4.6	3.2	2.8	9.2	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	8	15	14	6	29	-----	-----	-----
Chloride (mg/l)	1	8	11	12	8	12	860(2), 230(3), 250(4)	0	0%
Chlorophyll *a* (ug/l) – Field Probe	1	26	10	9	4	35	8(6)	20	77%
Chlorophyll *a* (ug/l) – Lab Determined	1	4	33	24	8	76	8(6)	3	75%
Dissolved Solids, Total (mg/l)	5	8	470	463	430	560	1,750(4), 500(7)	0, 1	0%, 13%
Nitrogen, Total Kjeldahl (mg/l)	0.1	8	0.8	0.8	0.3	1.5	-----	-----	-----
Nitrogen, Total (mg/l)	0.1	8	0.9	0.8	0.3	1.8	0 57(6)	5	63%
Nitrate-Nitrite N, Total (mg/l)	0.02	8	-----	n.d.	n.d.	0.5	10(4)	0	0%
Phosphorus, Dissolved (mg/l)	0.02	7	0.04	0.05	n.d.	0.08	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	8	0.09	0.08	0.05	0 15	0.06(6)	5	63%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	8	-----	0.02	n.d.	0.07	-----	-----	-----
Sulfate (mg/l)	1	8	188	187	172	208	875(4), 250(7)	0	0%
Suspended Solids, Total (mg/l)	4	8	10	9	5	18	158(2), 90(3)	0	0%

n.d. = Not detected.

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

(B) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

(2) Acute criterion for aquatic life.

(3) Chronic criterion for aquatic life.

(4) Daily maximum criterion for domestic water supply.

(5) Agricultural criterion for surface waters.

(6) Nutrient criteria. (Lewis and Clark Lake is classified R9 by Nebraska for application of nutrient criteria.)

(7) The criteria for total dissolved solids and sulfate are listed by the State of Nebraska to protect the beneficial use of public drinking water. Where the natural background level is greater than these criteria, the State of Nebraska states that the background level is to be used in place of the criteria. The levels monitored in Lewis and Clark Lake are believed indicative of natural background conditions.

Plate 8. Summary of monthly (May through September) water quality conditions monitored in Lewis and Clark Lake near Devils Nest Area (RM822) during 2008. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) 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 Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	5	1206.5	1206.4	1205.9	1207.4	-----	-----	-----
Water Temperature (C)	0.1	27	20	22	10	23.8	27.0 29.0	0 0	0% 0%
Dissolved Oxygen (mg/l)	0.1	27	905	8.8	6.2	13.6	≥ 5.0	0	0%
Dissolved Oxygen (% Sat.)	0.1	27	107.0	103.9	73.6	138.2	-----	-----	-----
Specific Conductance (umho/cm)	1	27	701	708	647	729	2,000(1)	0	0%
pH (S.U.)	0.1	27	8.3	8.3	7.9	8.6	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	21	37	33	11	115	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	27	334	328	276	398	-----	-----	-----
Secchi Depth (in.)	1	5	20	17	12	33	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	21	10	10	5	45	8(2)	18	86%

n.d. = Not detected.

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

(B) (1) Agricultural criterion for surface waters.

(2) Nutrient criteria. (Lewis and Clark Lake is classified R9 by Nebraska for application of nutrient criteria.)

Plate 9. Summary of monthly (May through September) water quality conditions monitored in Lewis and Clark Lake near Charley Creek Area (RM825) during 2008. [Note 1: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for Secchi depth and chlorophyll a (lab determined) are for "samples" collected at a near-surface depth. Results for other parameters are for samples collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	5	1206.5	1206.4	1205.9	1207.4	-----	-----	-----
Water Temperature (C)	0.1	18	20.0	21.8	14.0	24.2	27.0 29.0	0 0	0% 0%
Dissolved Oxygen (mg/l)	0.1	18	9.8	9.4	8.1	12.2	≥ 5.0	5	8%
Dissolved Oxygen (% Sat.)	0.1	18	112.1	110.5	94.8	128.1	-----	-----	-----
Specific Conductance (umho/cm)	1	18	691	690	674	712	2,000(5)	0	0%
pH (S.U.)	0.1	18	8.3	8.4	8.0	8.5	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	14	55	57	31	91	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	18	337	335	277	399	-----	-----	-----
Secchi Depth (in.)	1	5	13	11	9	22	-----	-----	-----
Alkalinity, Total (mg/l)	7	4	162	159	157	172	≥ 20	0	0%
Ammonia, Total (mg/l)	0.01	4	-----	0.05	n.d.	0.09	3.9 (1,2), 0.8 (1,3)	0	0%
Carbon, Total Organic (mg/l)	0.05	4	5.2	4.7	3.2	8.3	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	4	14	13	8	23	-----	-----	-----
Chloride (mg/l)	1	4	12	11	11	14	860(2), 230(3), 250(4)	0	0%
Chlorophyll *a* (ug/l) – Field Probe	1	14	14	13	10	21	8(6)	14	100%
Chlorophyll *a* (ug/l) – Lab Determined	1	4	27	27	9	46	8(6)	4	100%
Dissolved Solids, Total (mg/l)	5	4	449	448	432	468	1,750(4), 500(7)	0	0%
Nitrogen, Total Kjeldahl (mg/l)	0.1	4	1.0	1.0	0.6	1.4	-----	-----	-----
Nitrogen, Total (mg/l)	0.1	4	1.1	1.0	0.6	1.5	0 57(6)	4	100%
Nitrate-Nitrite N, Total (mg/l)	0.02	4	-----	0.08	n.d.	0.15	10(4)	0	0%
Phosphorus, Dissolved (mg/l)	0.02	3	0.04	0.04	0.02	0.06	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	4	0 11	0.09	0.08	0 16	0.06(6)	2	20%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	4	-----	n.d.	n.d.	0.05	-----	-----	-----
Sulfate (mg/l)	1	4	185	185	175	194	875(4), 250(7)	0	0%
Suspended Solids, Total (mg/l)	4	4	25	26	19	28	158(2), 90(3)	0	0%

n.d. = Not detected.

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

(B) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

(2) Acute criterion for aquatic life.

(3) Chronic criterion for aquatic life.

(4) Daily maximum criterion for domestic water supply.

(5) Agricultural criterion for surface waters.

(6) Nutrient criteria. (Lewis and Clark Lake is classified R9 by Nebraska for application of nutrient criteria.)

(7) The criteria for total dissolved solids and sulfate are listed by the State of Nebraska to protect the beneficial use of public drinking water. Where the natural background level is greater than these criteria, the State of Nebraska states that the background level is to be used in place of the criteria. The levels monitored in Lewis and Clark Lake are believed indicative of natural background conditions.

Plate 10. Summary of monthly (March through December) water quality conditions monitored in the Missouri River near Verdel, Nebraska during 2008.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Streamflow (cfs)	1	10	14,613	16,985	3,011	24,285	-----	-----	-----
Water Temperature (C)	0.1	10	12.4	13.6	0.5	21.7	27.0 29.0	0 0	0% 0%
Dissolved Oxygen (mg/l)	0.1	9	10.8	11.1	7.7	13.3	≥ 5.0	5	8%
Dissolved Oxygen (% Sat.)	0.1	9	99.8	99.4	89.2	110.8	-----	-----	-----
Specific Conductance (umho/cm)	1	10	735	728	710	814	2,000(5)	0	0%
pH (S.U.)	0.1	9	8.3	8.3	8.1	8.6	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	9	12	11	n.d.	33	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	9	378	353	322	486	-----	-----	-----
Alkalinity, Total (mg/l)	7	10	161	160	152	168	≥ 20	0	0%
Ammonia, Total (mg/l)	0.02	10	-----	0.04	n.d.	0.21	4.7 (1,2), 1.5 (1,3)	0	0%
Carbon, Total Organic (mg/l)	0.05	10	3.5	3.2	2.1	7.2	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	10	11	11	4	14	-----	-----	-----
Chloride (mg/l)	1	10	13	13	11	15	860(2), 230(3), 250(4)	0	0%
Dissolved Solids, Total (mg/l)	5	10	483	477	452	538	1,750(4), 500(7)	0, 2	0%, 20%
Nitrogen, Total Kjeldahl (mg/l)	0.1	10	0.5	0.5	0.2	0.8	-----	-----	-----
Nitrogen, Total (mg/l)	0.1	10	0.5	0.5	0.2	0.8	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	10	-----	n.d.	n.d.	0.08	10(4)	0	0%
Phosphorus, Dissolved (mg/l)	0.02	5	0.03	0.02	n.d.	0.08	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	10	0.04	0.04	n.d.	0 10	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	5	-----	0.02	n.d.	0.02	-----	-----	-----
Sulfate (mg/l)	1	5	209	205	196	236	875(4), 250(7)	0	0%
Suspended Solids, Total (mg/l)	4	10	10	8	n.d.	33	158(2), 90(3)	0	0%

n.d. = Not detected.

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

(B) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

(2) Acute criterion for aquatic life.

(3) Chronic criterion for aquatic life.

(4) Daily maximum criterion for domestic water supply.

(5) Agricultural criterion for surface waters.

(6) Nutrient criteria. (Lewis and Clark Lake is classified R9 by Nebraska for application of nutrient criteria.)

(7) The criteria for total dissolved solids and sulfate are listed by the State of Nebraska to protect the beneficial use of public drinking water. Where the natural background level is greater than these criteria, the State of Nebraska states that the background level is to be used in place of the criteria. The levels monitored in Lewis and Clark Lake are believed indicative of natural background conditions.

Plate 11. Summary of monthly (May through September) water quality conditions monitored in the Niobrara River near Niobrara, Nebraska during 2008.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Streamflow (cfs)	1	5	1,414	1,439	753	2,450	-----	-----	-----
Water Temperature (C)	0.1	5	22.4	22.6	17.1	27.2	29.0	0	0%
Dissolved Oxygen (mg/l)	0.1	4	8.5	8.4	7.5	9.6	≥ 5.0	5	8%
Dissolved Oxygen (% Sat.)	0.1	4	105.2	102.0	91.2	125.4	-----	-----	-----
Specific Conductance (umho/cm)	1	5	304	309	255	364	2,000[5]	0	0%
pH (S.U.)	0.1	4	8.5	8.5	8.0	8.8	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	0.1	4	94	70	50	188	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	5	377	326	322	491	-----	-----	-----
Alkalinity, Total (mg/l)	7	5	133	128	121	161	≥ 20	0	0%
Ammonia, Total (mg/l)	0.02	5	-----	n.d.	n.d.	0.26	4.7 [1,2], 1.5 [1,3]	0	0%
Carbon, Total Organic (mg/l)	0.05	5	6.0	6.0	2.5	11.6	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	5	24	24	6	38	-----	-----	-----
Chloride (mg/l)	1	5	3	3	2	6	860[2], 230[3], 250[4]	0	0%
Dissolved Solids, Total (mg/l)	5	5	212	224	168	262	1,750[4], 500[7]	0, 2	0%, 20%
Nitrogen, Total Kjeldahl (mg/l)	0.1	5	1.1	1.2	0.7	1.5	-----	-----	-----
Nitrogen, Total (mg/l)	0.1	5	1.6	1.6	1.1	2.0	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	5	0.50	0.40	0.04	0.90	10[4]	0	0%
Phosphorus, Dissolved (mg/l)	0.02	5	0.05	0.04	0.02	0.09	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	5	0 22	0.20	0.14	0 28	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	5	0.04	0.02	n.d.	0.09	-----	-----	-----
Sulfate (mg/l)	1	5	24	26	15	30	875[4], 250[7]	0	0%
Suspended Solids, Total (mg/l)	4	5	177	150	66	342	-----	-----	-----

n.d. = Not detected.

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

[B] [1] Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

[2] Acute criterion for aquatic life.

[3] Chronic criterion for aquatic life.

[4] Daily maximum criterion for domestic water supply.

[5] Agricultural criterion for surface waters.

[6] Nutrient criteria. (Lewis and Clark Lake is classified R9 by Nebraska for application of nutrient criteria.)

[7] The criteria for total dissolved solids and sulfate are listed by the State of Nebraska to protect the beneficial use of public drinking water. Where the natural background level is greater than these criteria, the State of Nebraska states that the background level is to be used in place of the criteria. The levels monitored in Lewis and Clark Lake are believed indicative of natural background conditions.

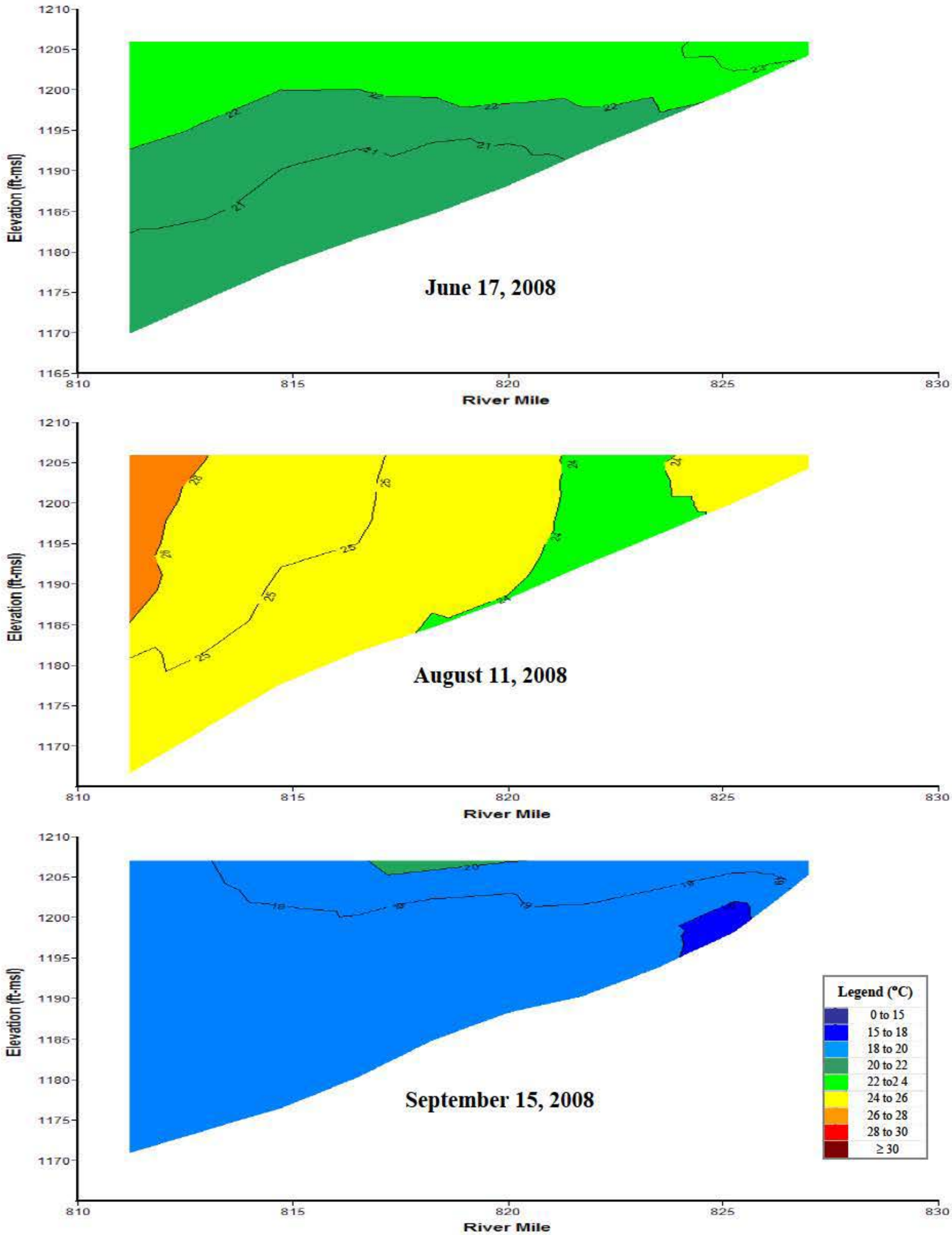


Plate 12. Longitudinal temperature contour plots of Lewis and Clark Lake based on depth-profile temperature measurements taken in 2008.

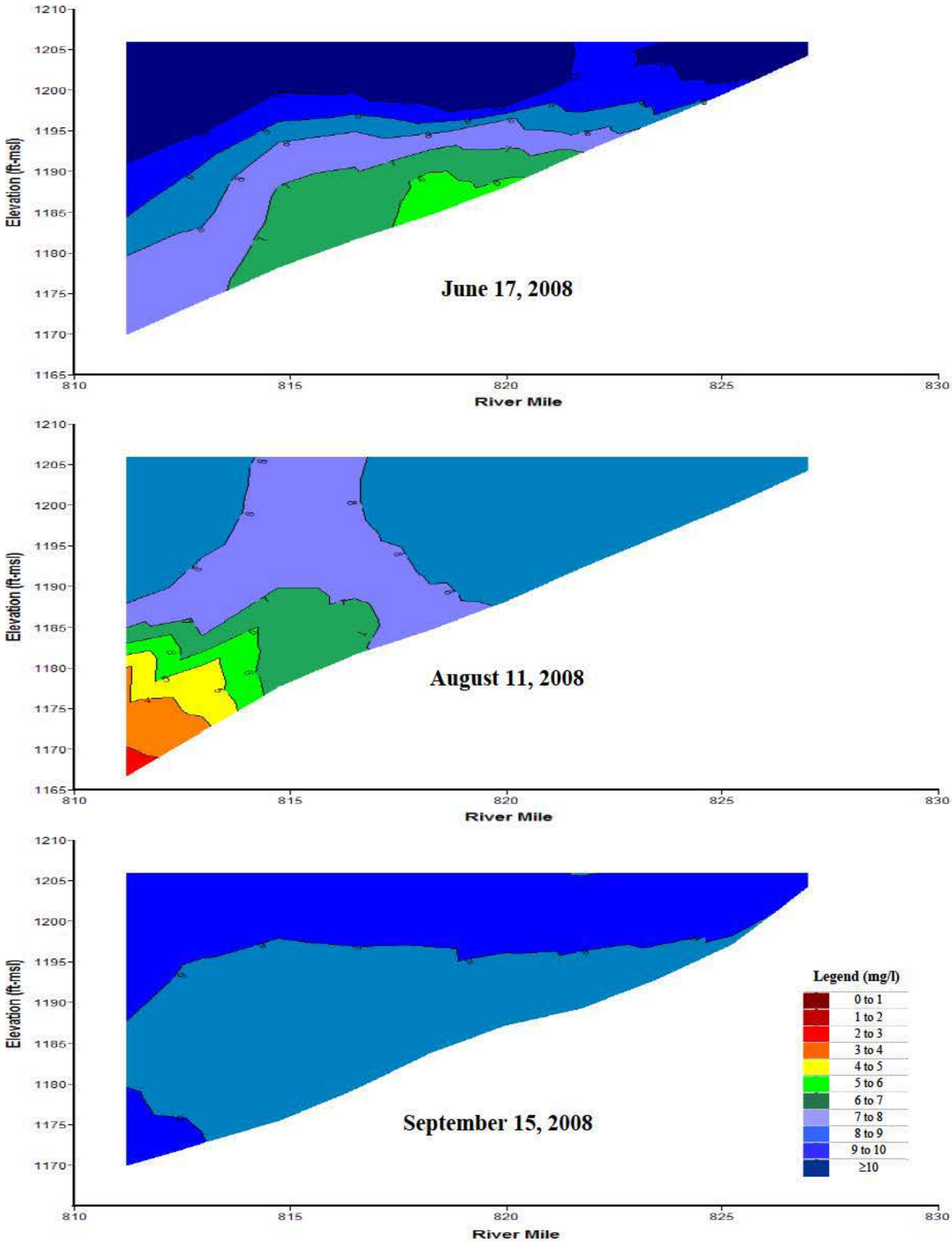


Plate 13. Longitudinal dissolved oxygen contour plots of Lewis and Clark Lake based on depth-profile dissolved oxygen measurements taken in 2008.

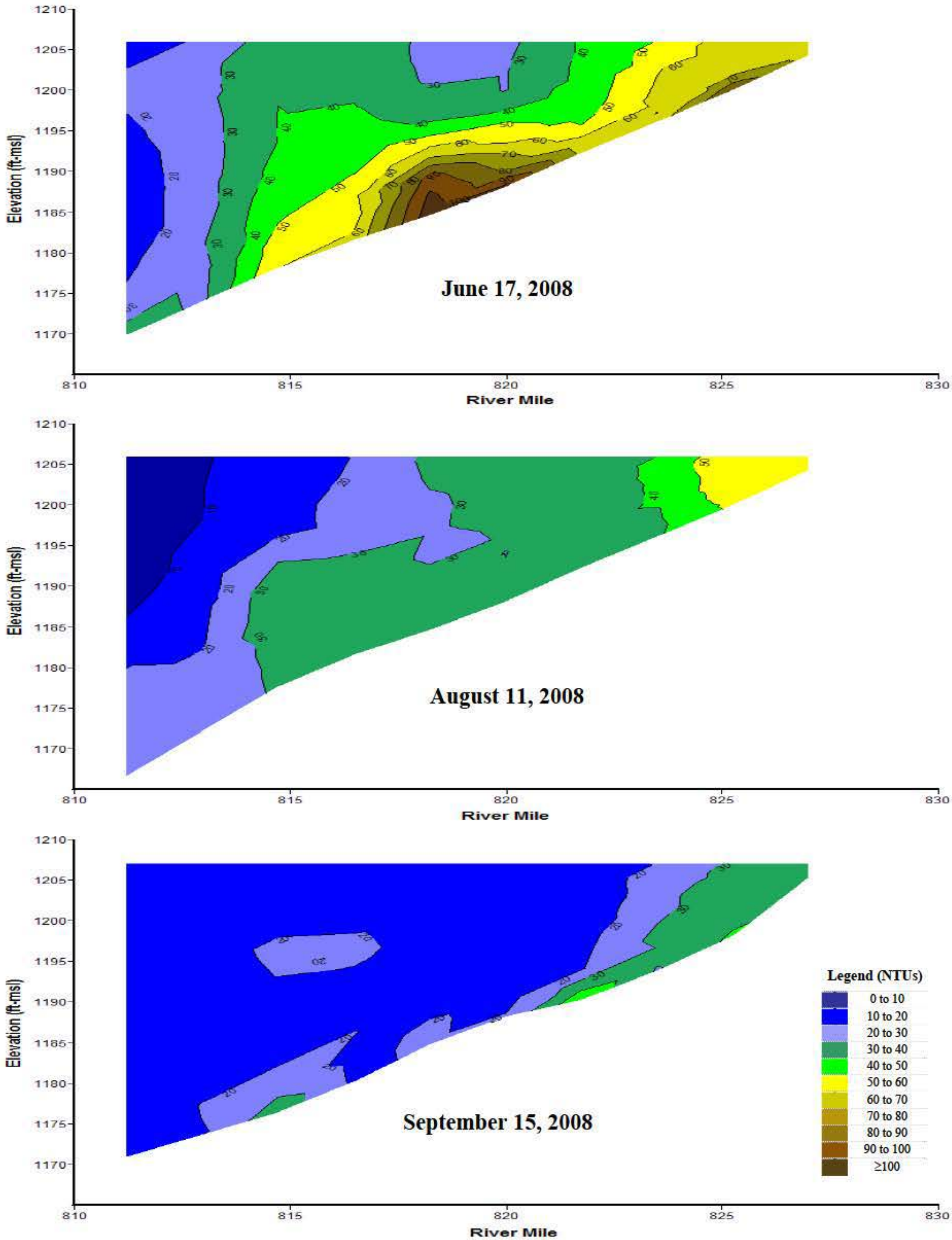


Plate 14. Longitudinal turbidity contour plots of Lewis and Clark Lake based on depth-profile turbidity measurements taken in 2008

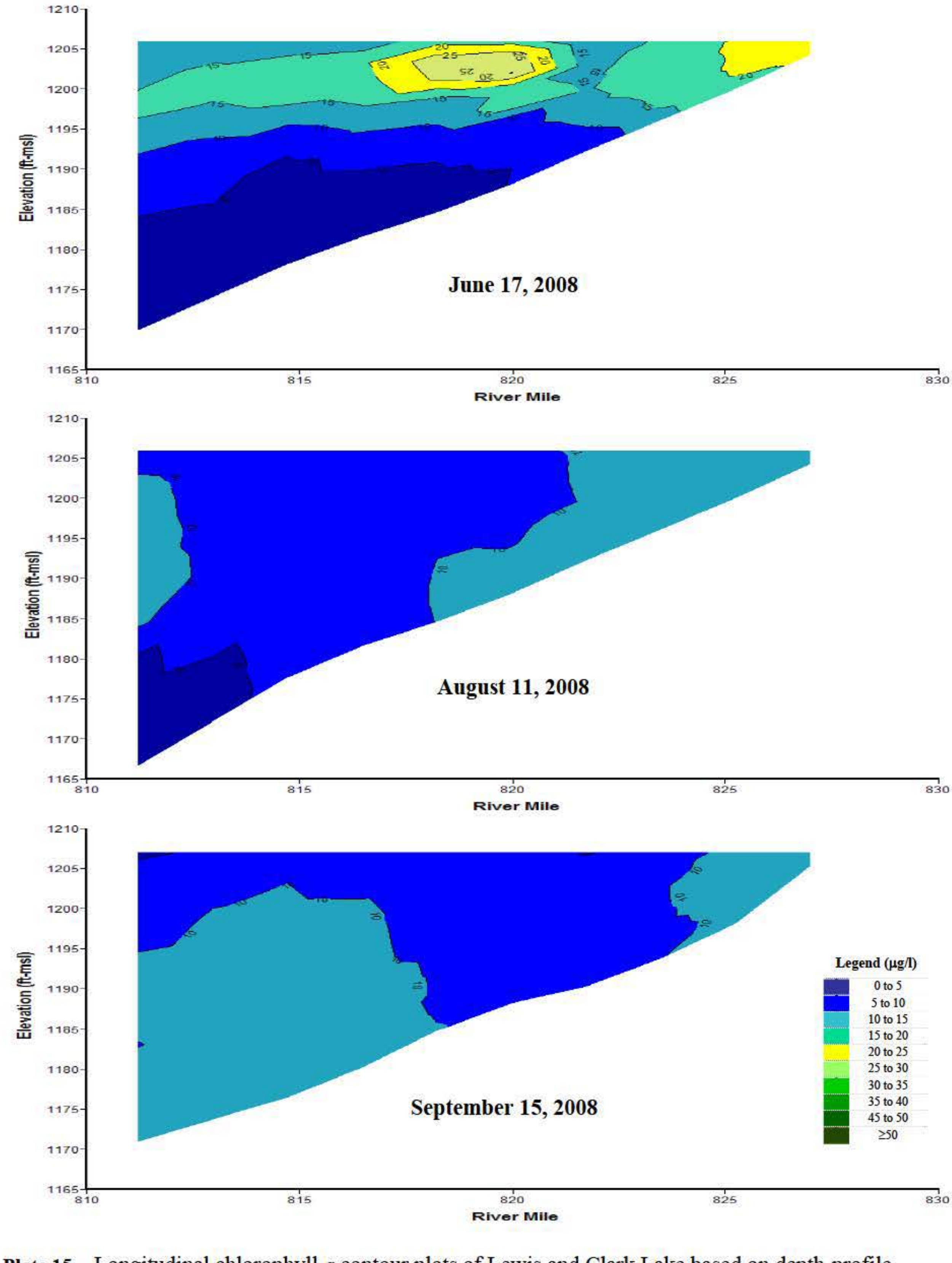


Plate 15. Longitudinal chlorophyll *a* contour plots of Lewis and Clark Lake based on depth-profile chlorophyll *a* measurements taken in 2008.

Plate 16. Water quality conditions monitored at site 2.

Parameter	Date Sampled		
	April 2, 2008	August 25, 2008	October 8, 2008
Pool Elevation (ft-msl)	1206.6	1205.8	1207.6
Secchi Depth (in.)	-----	11	10
Water Temperature (°C)	4.5	23.4	16.4
Dissolved Oxygen (mg/l)	12.7	8.1	9.0
Specific Conductance (μmhos/cm)	619	701	673
pH (S.U.)	8.3	8.3	8.3
Oxidation-Reduction Potential (mV)	361	339	272
Turbidity (NTU)	46	30	34
Chlorophyll *a* (μg/l)	2	6	5
Alkalinity (mg/l)	158	156	154
Total Dissolved Solids (mg/l)	412	444	408
Total Suspended Solids (mg/l)	36	38	32
Total Organic Carbon (mg/l)	4.0	2.2	4.2
True Color (S.U.)	n.d.	220	202
Bromide (mg/l)	n.d.	n.d.	n.d.
Bromodichloromethane (μg/l)	n.d.	n.d.	n.d.
Bromoform (μg/l)	n.d.	n.d.	n.d.
Chlorodibromomethane (μg/l)	n.d.	n.d.	n.d.
Chloroform (μg/l)	n.d.	n.d.	n.d.
Trihalomethane Formation Potential (μg/l)	135	165	49
Chlorodibromomethane (μg/l)	4.4	5.3	3.5
Bromodichloromethane (μg/l)	22	28	13
Bromoform (μg/l)	n.d.	n.d.	n.d.
Chloroform (μg/l)	108	135	33

Plate 17. Water quality conditions monitored at site 7.

Parameter	April 2, 2008	August 25, 2008	October 8, 2008
Pool Elevation (ft-msl)	1206.6	1205.8	1207.6
Secchi Depth (in.)	-----	16	22
Water Temperature (°C)	3.8	22.8	16.3
Dissolved Oxygen (mg/l)	12.5	8.3	8.9
Specific Conductance (μmhos/cm)	657	711	664
pH (S.U.)	8.3	8.3	8.2
Oxidation-Reduction Potential (mV)	371	337	272
Turbidity (NTU)	16	26	26
Chlorophyll *a* (μg/l)	2	11	5
Alkalinity (mg/l)	159	153	150
Total Dissolved Solids (mg/l)	442	448	402
Total Suspended Solids (mg/l)	7	28	10
Total Organic Carbon (mg/l)	4.8	2.4	3.2
True Color (S.U.)	n.d.	241	173
Bromide (mg/l)	n.d.	n.d.	n.d.
Bromodichloromethane (μg/l)	n.d.	n.d.	n.d.
Bromoform (μg/l)	n.d.	n.d.	n.d.
Chlorodibromomethane (μg/l)	n.d.	n.d.	n.d.
Chloroform (μg/l)	n.d.	n.d.	n.d.
Trihalomethane Formation Potential (μg/l)	138	169	52
Chlorodibromomethane (μg/l)	5.9	5.9	3.8
Bromodichloromethane (μg/l)	25	29	14
Bromoform (μg/l)	n.d.	n.d.	n.d.
Chloroform (μg/l)	107	134	34

Plate 18. Water quality conditions monitored at site 11.

Parameter	Date Sampled		
	April 2, 2008	August 25, 2008	October 8, 2008
Pool Elevation (ft-msl)	1206.6	1205.8	1207.6
Secchi Depth (in.)	-----	15	12
Water Temperature (°C)	3.5	24.1	16.3
Dissolved Oxygen (mg/l)	12.7	9.1	9.1
Specific Conductance (μmhos/cm)	670	698	670
pH (S.U.)	8.3	8.4	8.2
Oxidation-Reduction Potential (mV)	361	333	268
Turbidity (NTU)	13	22	36
Chlorophyll *a* (μg/l)	3	12	5
Alkalinity (mg/l)	162	156	150
Total Dissolved Solids (mg/l)	446	426	388
Total Suspended Solids (mg/l)	11	20	29
Total Organic Carbon (mg/l)	4.5	4.0	2.8
True Color (S.U.)	n.d.	237	255
Bromide (mg/l)	n.d.	n.d.	n.d.
Bromodichloromethane (μg/l)	n.d.	n.d.	n.d.
Bromoform (μg/l)	n.d.	n.d.	n.d.
Chlorodibromomethane (μg/l)	n.d.	n.d.	n.d.
Chloroform (μg/l)	n.d.	n.d.	n.d.
Trihalomethane Formation Potential (μg/l)	138	160	50
Chlorodibromomethane (μg/l)	6.1	5.7	4.0
Bromodichloromethane (μg/l)	25	28	13
Bromoform (μg/l)	n.d.	n.d.	n.d.
Chloroform (μg/l)	107	126	33

Plate 19. Water quality conditions monitored at site 12.

Parameter			
	April 2, 2008	August 25, 2008	October 8, 2008
Pool Elevation (ft-msl)	1206.6	1205.8	1207.6
Secchi Depth (in.)	-----	13	12
Water Temperature (°C)	3.5	24.3	16.4
Dissolved Oxygen (mg/l)	12.7	8.9	9.1
Specific Conductance (μmhos/cm)	648	698	670
pH (S.U.)	8.3	8.4	8.2
Oxidation-Reduction Potential (mV)	378	326	272
Turbidity (NTU)	16	25	34
Chlorophyll *a* (μg/l)	2	15	5
Alkalinity (mg/l)	157	155	150
Total Dissolved Solids (mg/l)	434	428	406
Total Suspended Solids (mg/l)	9	19	15
Total Organic Carbon (mg/l)	4.4	3.9	3.1
True Color (S.U.)	n.d.	243	250
Bromide (mg/l)	n.d.	n.d.	n.d.
Bromodichloromethane (μg/l)	n.d.	n.d.	n.d.
Bromoform (μg/l)	n.d.	n.d.	n.d.
Chlorodibromomethane (μg/l)	n.d.	n.d.	n.d.
Chloroform (μg/l)	n.d.	n.d.	n.d.
Trihalomethane Formation Potential (μg/l)	136	168	48
Chlorodibromomethane (μg/l)	5.6	5.5	3.7
Bromodichloromethane (μg/l)	24	28	12
Bromoform (μg/l)	n.d.	n.d.	n.d.
Chloroform (μg/l)	107	135	32

Plate 20. Water quality conditions monitored at site 19.

Parameter	Date Sampled		
	April 2, 2008	August 25, 2008	October 8, 2008
Pool Elevation (ft-msl)	1206.6	1205.8	1207.6
Secchi Depth (in.)	-----	26	18
Water Temperature (°C)	3.8	24.1	17.3
Dissolved Oxygen (mg/l)	12.5	9.3	9.3
Specific Conductance (µmhos/cm)	660	703	711
pH (S.U.)	8.3	8.6	8.3
Oxidation-Reduction Potential (mV)	351	324	264
Turbidity (NTU)	16	24	19
Chlorophyll *a* (µg/l)	3	11	5
Alkalinity (mg/l)	159	156	159
Total Dissolved Solids (mg/l)	436	422	412
Total Suspended Solids (mg/l)	9	8	10
Total Organic Carbon (mg/l)	4.6	2.9	3.4
True Color (S.U.)	n.d.	147	158
Bromide (mg/l)	n.d.	n.d.	n.d.
Bromodichloromethane (µg/l)	n.d.	n.d.	n.d.
Bromoform (µg/l)	n.d.	n.d.	n.d.
Chlorodibromomethane (µg/l)	n.d.	n.d.	n.d.
Chloroform (µg/l)	n.d.	n.d.	n.d.
Trihalomethane Formation Potential (µg/l)	144	190	54
Chlorodibromomethane (µg/l)	6.2	6.5	5.0
Bromodichloromethane (µg/l)	26	31	14
Bromoform (µg/l)	n.d.	n.d.	n.d.
Chloroform (µg/l)	112	152	35

Plate 21. Water quality conditions monitored at site 20.

Parameter			
	April 2, 2008	August 25, 2008	October 8, 2008
Pool Elevation (ft-msl)	1206.6	1205.8	1207.6
Secchi Depth (in.)	-----	25	17
Water Temperature (°C)	3.9	23.4	17.1
Dissolved Oxygen (mg/l)	12.5	9.1	9.3
Specific Conductance (µmhos/cm)	661	708	709
pH (S.U.)	8.3	8.5	8.3
Oxidation-Reduction Potential (mV)	395	324	261
Turbidity (NTU)	13	13	18
Chlorophyll *a* (µg/l)	3	9	5
Alkalinity (mg/l)	160	155	154
Total Dissolved Solids (mg/l)	438	444	412
Total Suspended Solids (mg/l)	7	11	7
Total Organic Carbon (mg/l)	4.8	2.9	3.2
True Color (S.U.)	n.d.	134	125
Bromide (mg/l)	n.d.	n.d.	n.d.
Bromodichloromethane (µg/l)	n.d.	n.d.	n.d.
Bromoform (µg/l)	n.d.	n.d.	n.d.
Chlorodibromomethane (µg/l)	n.d.	n.d.	n.d.
Chloroform (µg/l)	n.d.	n.d.	n.d.
Trihalomethane Formation Potential (µg/l)	140	181	56
Chlorodibromomethane (µg/l)	6.0	6.2	5.0
Bromodichloromethane (µg/l)	25	29	15
Bromoform (µg/l)	n.d.	n.d.	n.d.
Chloroform (µg/l)	109	146	36

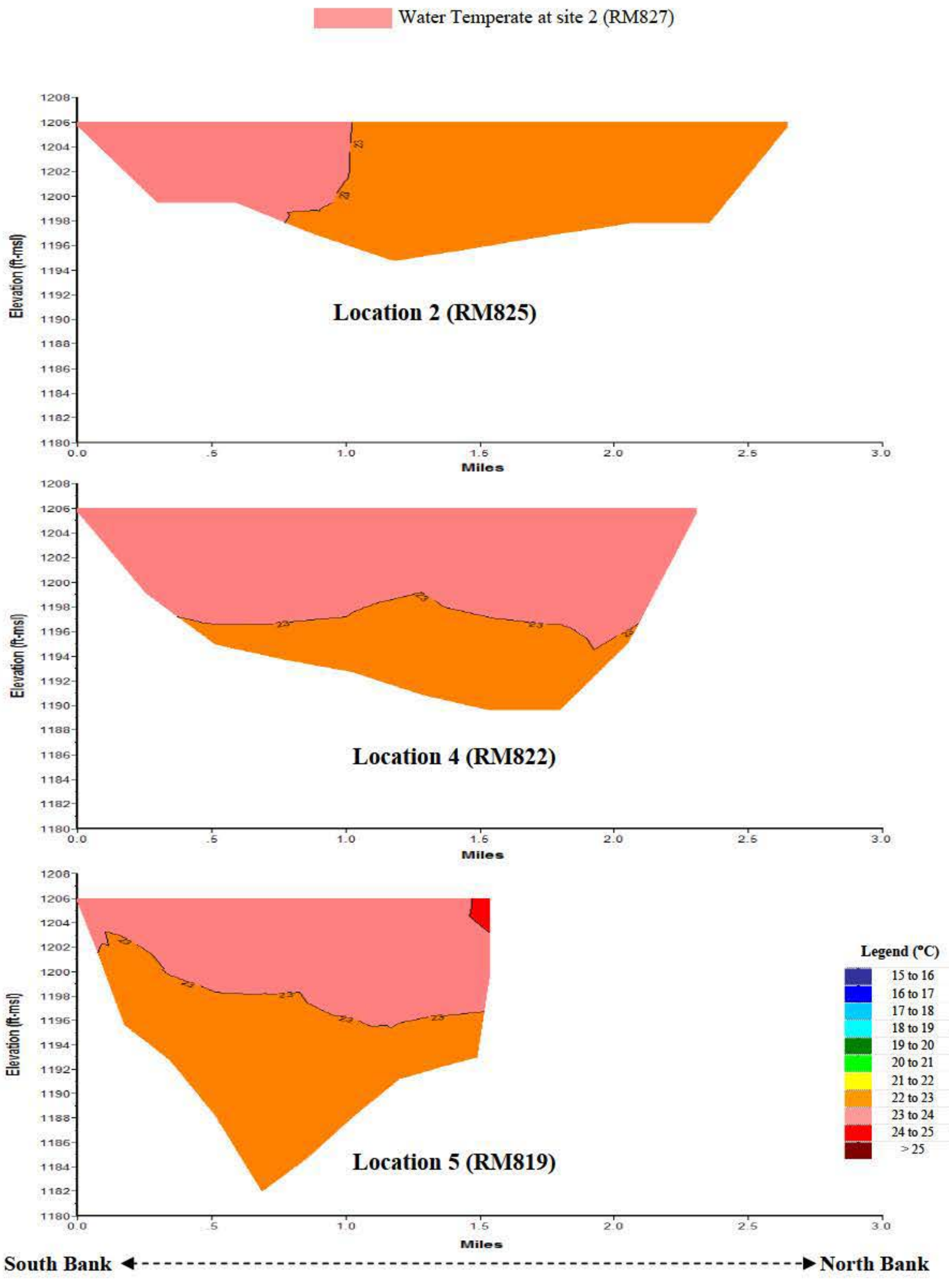


Plate 22. Transect contour plots for water temperatures measured in Lewis and Clark Lake on August 25, 2008. (Note transect miles are measured from south bank.)

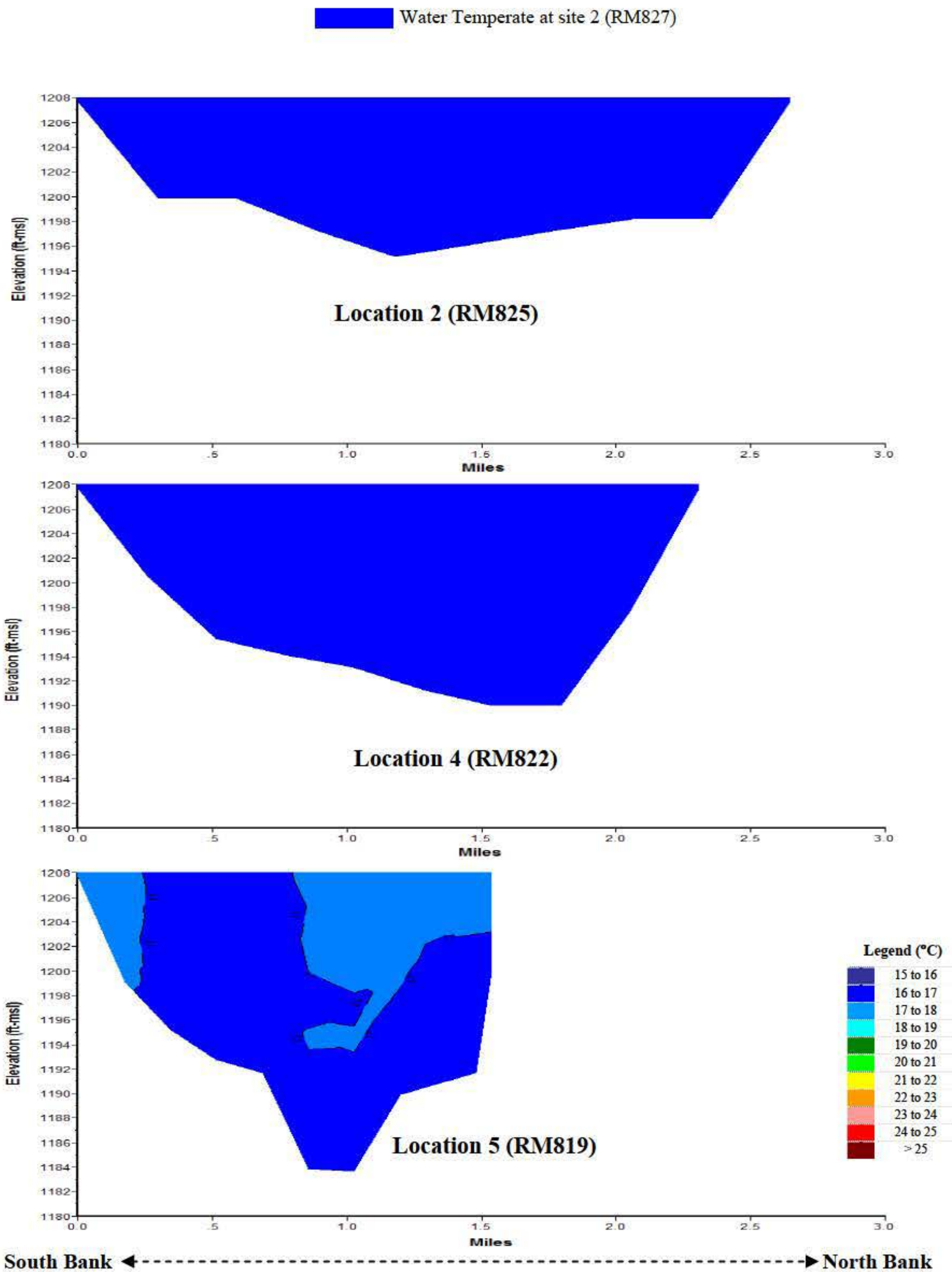


Plate 23. Transect contour plots for water temperatures measured in Lewis and Clark Lake on October 8, 2008. (Note transect miles are measured from south bank.)

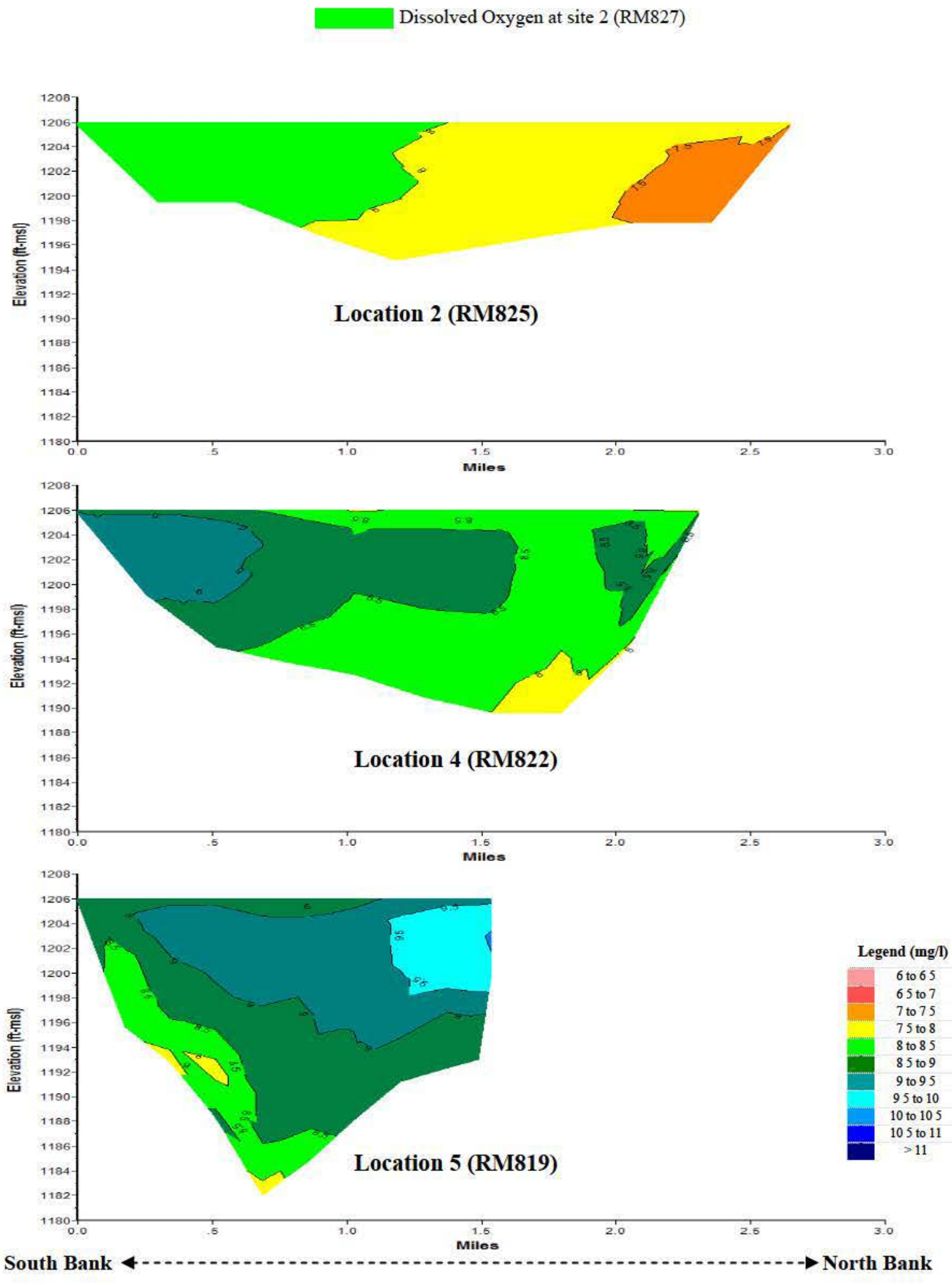


Plate 24. Transect contour plots for dissolved oxygen measured in Lewis and Clark Lake on August 25, 2008. (Note transect miles are measured from south bank.)

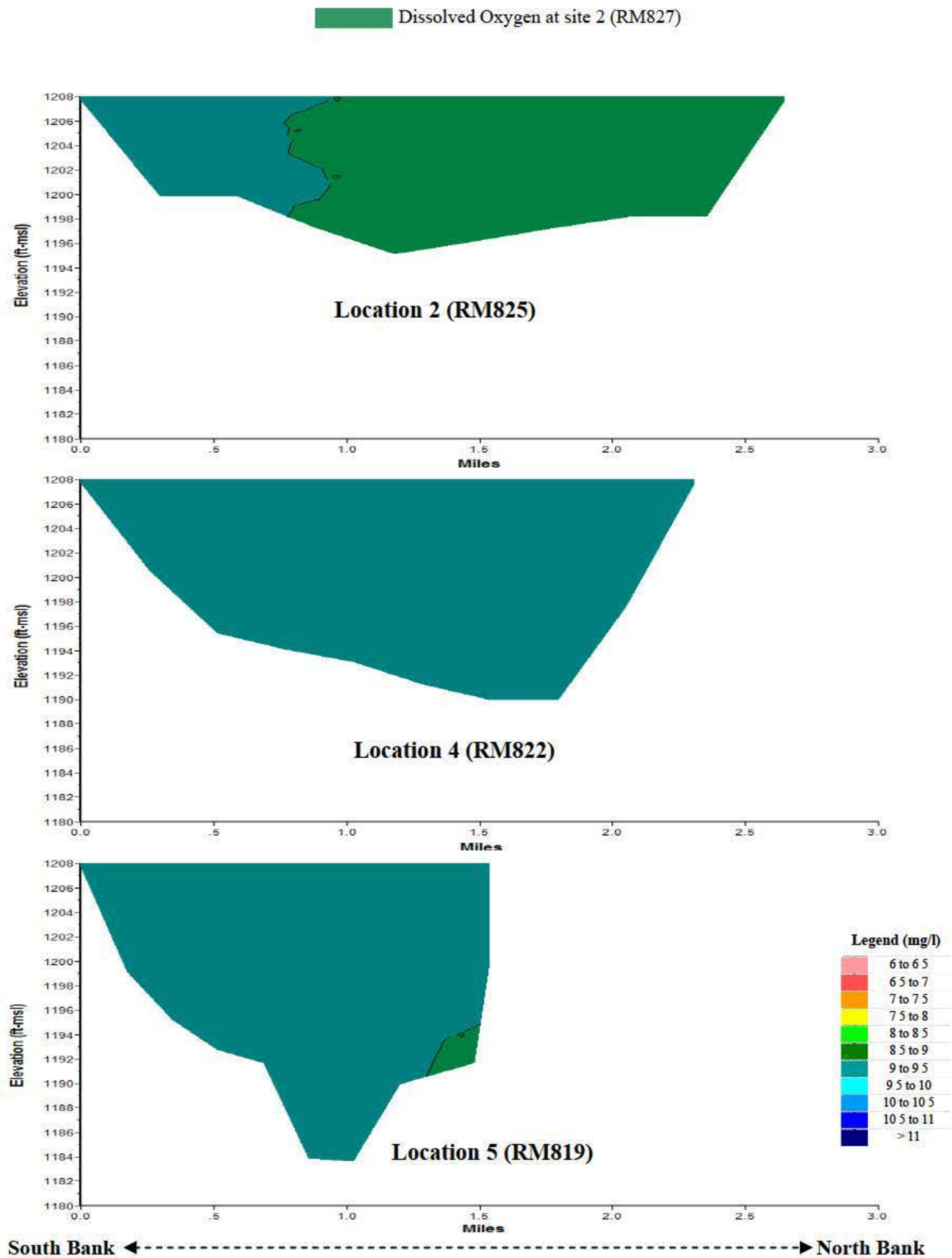


Plate 25. Transect contour plots for dissolved oxygen measured in Lewis and Clark Lake on October 8, 2008. (Note transect miles are measured from south bank.)

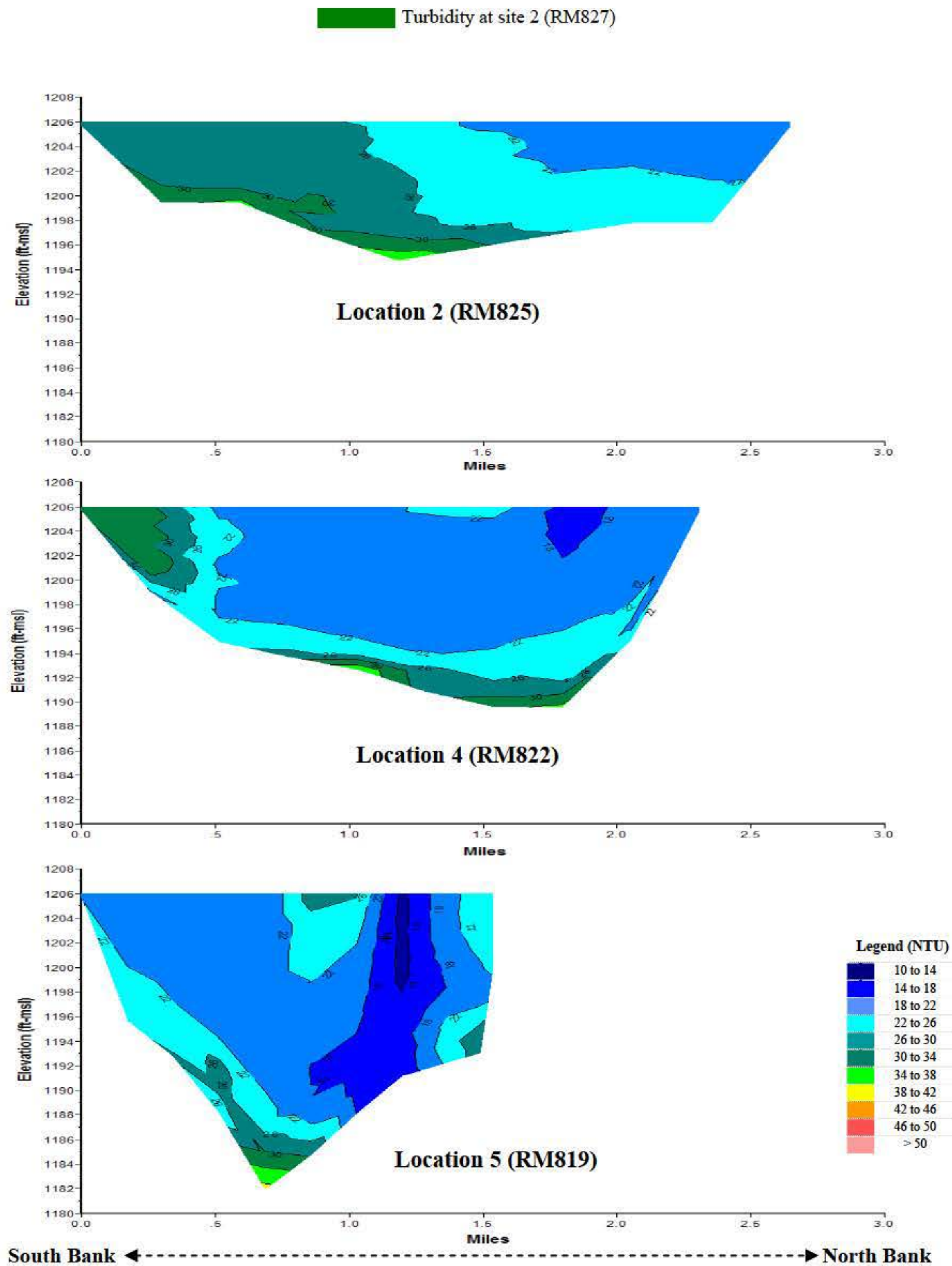


Plate 26. Transect contour plots for turbidity measured in Lewis and Clark Lake on August 25, 2008. (Note transect miles are measured from south bank.)

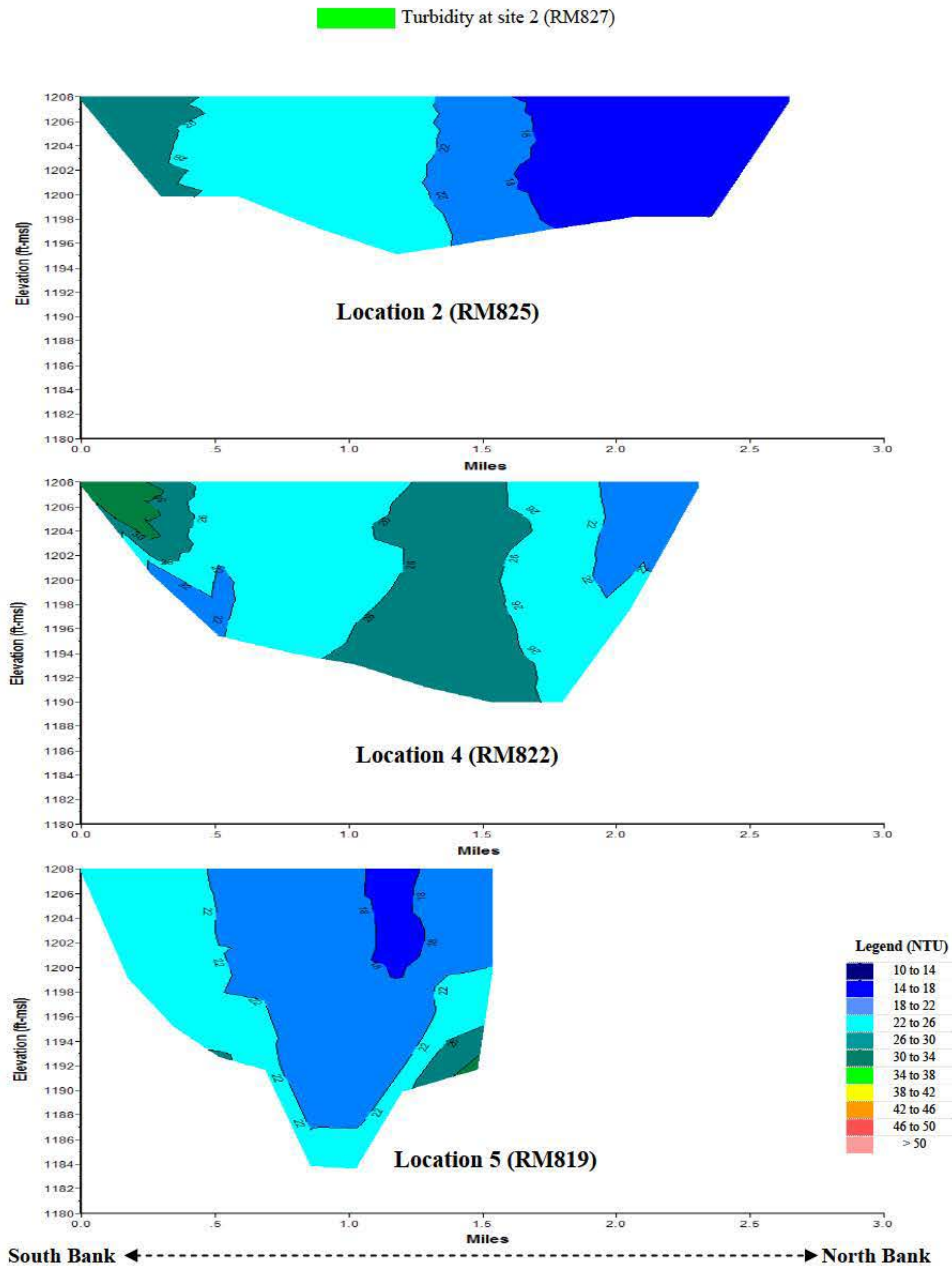


Plate 27. Transect contour plots for turbidity measured in Lewis and Clark Lake on October 8, 2008. (Note transect miles are measured from south bank.)

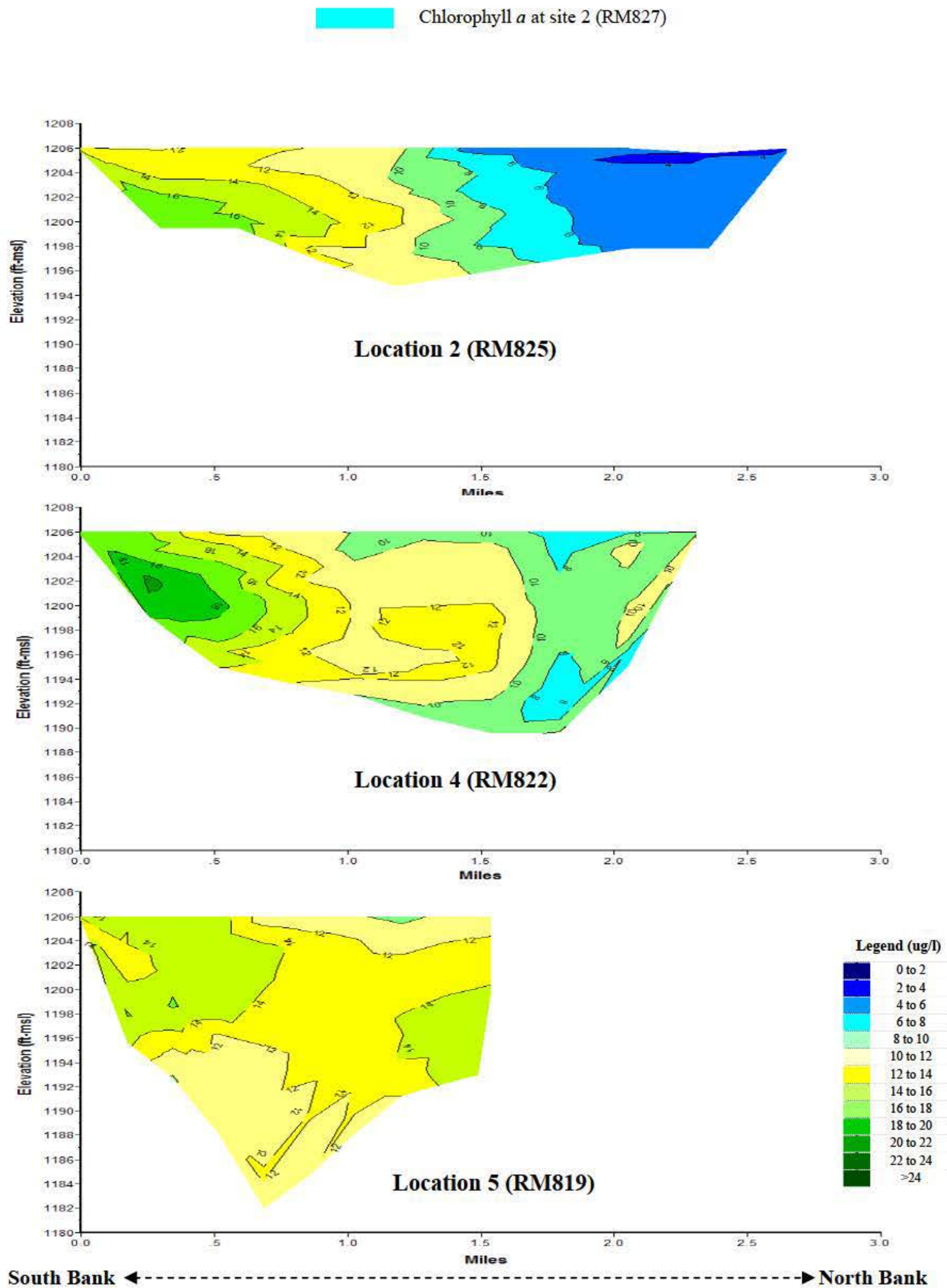


Plate 28. Transect contour plots for chlorophyll *a* measured in Lewis and Clark Lake on August 25, 2008. (Note transect miles are measured from south bank.)

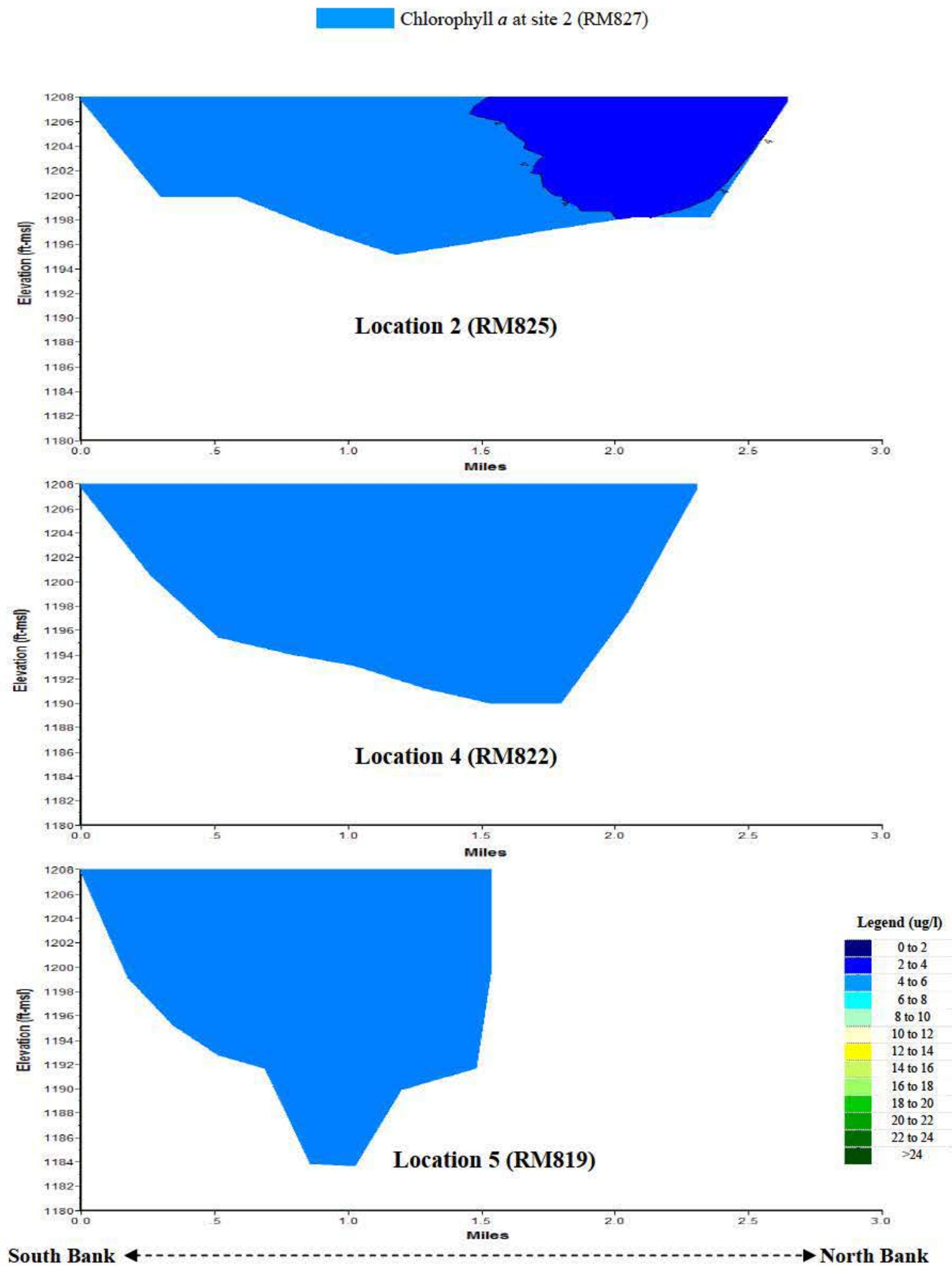


Plate 29. Transect contour plots for chlorophyll *a* measured in Lewis and Clark Lake on October 8, 2008. (Note transect miles are measured from south bank.)