

OOLOGAH LAKE, OKLAHOMA, WATERSHED STUDY

INTERIM REPORT OF FINDINGS
APRIL – SEPTEMBER 2000



US Army Corps of Engineers
Southwestern Division
Tulsa District
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DRAFT

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Prepared by:
U.S. Army Corps of Engineers
Tulsa District

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EXECUTIVE SUMMARY

This report provides a summary of data and findings obtained during fiscal year (FY) 2000 for the Oologah Lake, Oklahoma, Watershed Study. The project is a multi-year investigation aimed at evaluating potential water quality threats and solutions to an important ecological and water supply resource for northeast Oklahoma. Field sampling and data collection for the project were initiated by the U.S. Army Corps of Engineers, Tulsa District (TD) during April 2000 and will continue for an estimated 3-year period (funding permitting). The initial, first year focus of the study was in-lake and major tributary data gathering for water quality problem identification and assessment. Accordingly, study activities were confined to Oologah Lake itself and major tributary sampling sites immediately adjacent to the reservoir. The purpose of this interim report is to present study findings for the period April through September 2000 in an effort to inform study partners and the public of study progress, initial findings, and rationale for future study direction. Additional reports will be provided as the study progresses.

Study activities from April through September 2000 included water quality sampling on 11 dates at five in-lake stations along the longitudinal axis of Oologah Lake. Sampling included recording of field data and collection of water samples for a wide variety of physicochemical and biological parameters. Sediment samples were also collected along the main axis of the lake as well as at shallow, mid-lake areas along the eastern shore of the reservoir. Finally, data collection at two major Oologah Lake tributaries (the Verdigris River and Big Creek) included installation of continuous monitoring equipment and logging of hourly data for selected parameters as well as water quality sample collection during both base and storm flows.

As a quick reference to summary statistics for data collected during this study, the following tables can be consulted: tributary data (Tables 5.2-2 through 5.2-6, pp. 31-34), reservoir data (Table 5.3-1, pp. 67-68, Table 5.3.5-1, p. 106) and sediment data (Tables 5.6-1 and 5.6-2, pp. 156-158).

Major findings and conclusions of the study are provided below. Findings are provided separately for tributary data, Oologah Lake general limnology, water quality contaminants, and sediment sampling and analysis.

OOLOGAH LAKE TRIBUTARIES (VERDIGRIS RIVER AND BIG CREEK)

1. While concentrations of many water quality constituents were similar in samples collected from both major tributaries, substantial differences were noted for several key parameters. Mean and median turbidity, total suspended solids, settleable solids, total iron, and total manganese concentrations in samples from the Verdigris River were approximately twice those measured in samples from Big Creek. Concentrations of total phosphorus and nitrogen were also substantially higher in the Verdigris River relative to those in Big Creek.

2. Total phosphorus (P) concentrations in both tributaries were high, particularly during periods of high flow. Mean and median total P were 0.32 and 0.20 mg/l, respectively, in samples

from the Verdigris River and 0.25 and 0.14 mg/l, respectively, in samples from Big Creek. Based on median values, approximately half of total P concentrations in samples from both systems were associated with suspended matter.

3. Temporal changes in nephelometric turbidity closely mirrored the hydrograph in both tributaries. Based on continuous monitoring data for the study period, mean and median turbidity values were 96.6 and 44.9 nephelometric turbidity units (NTU), respectively, for the Verdigris River (n = 3,984) and 42.4 and 13.1 NTU, respectively, for Big Creek (n = 3,402). Continuously recorded turbidity exceeded the State of Oklahoma water quality standard for turbidity in warm water streams (50 NTU) in 44% of observations in the Verdigris River and 16% in Big Creek.

4. Tributary-specific multiple regression equations for estimating important physical and chemical parameters based on continuously monitored field data were developed and appeared reasonable for use in preliminary estimation of delivered loads. For the Verdigris River, selected equations were capable of explaining approximately 93, 91, 87, and 73% of observed variability in total suspended solids, total organic carbon, total Kjeldahl nitrogen, and total P, respectively. Nephelometric turbidity was among selected surrogate parameters in regression equations for all these constituents.

5. For the study period (April through September 2000), multiple regression analyses were used to estimate average combined daily loads (kg/day) from both tributaries as follows: total P (3,160), total nitrogen (11,600), and total suspended solids (1,830,600 kg/day or approximately 2,000 tons/day). Of these loads, relative contributions from the Verdigris River were as follows: total P (97%), total nitrogen (96%), and total suspended solids (93%). Evaluating estimated loadings from the Verdigris River and Big Creek watersheds in terms of loading per unit area reveals that Big Creek contributions are approximately one-half of Verdigris River watershed loads.

OOLOGAH LAKE (GENERAL LIMNOLOGY)

1. Turbidity values in Oologah Lake frequently exceeded the State of Oklahoma lake water quality standard of 25 NTU. For field turbidity values measured throughout the water column (n = 634), readings ranged from 8.3 to 209 NTU with mean and median values of 51.7 and 41.2 NTU, respectively. Total suspended solids ranged from <4 to 170 mg/l with a mean of 32.5 mg/l and a median of 17.4 mg/l. Turbidity and suspended solids were highest and extremely variable in shallow water areas above Winganon Bridge. Variability in both parameters was much lower near Oologah Dam, indicating a “buffering effect” at near-dam water supply intake locations.

2. Total P concentrations were high in samples from Oologah Lake. Concentrations of total P ranged from 0.035 to 0.495 mg/l with mean and median values of 0.118 and 0.083 mg/l, respectively. Both concentration and variability increased from Oologah Dam to uptake stations, particularly in shallow water areas above Winganon Bridge. A strong correlation existed

between total P and total suspended solids. On average, 55% of total P existed in the particulate phase.

3. A measurable concentration of dissolved ortho-phosphorus was reported for every water sample collected from Oologah Lake. Concentrations of dissolved ortho-phosphorus ranged from 0.008 to 0.076 mg/l with an identical mean and median of 0.040 mg/l. No distinct horizontal gradient of ortho-phosphorus was observed in the reservoir.

4. Mean lake-wide nitrogen to phosphorus ratio (N:P) was 8.0 with a median value of 6.8. By site, average N:P was lowest (6.0) in the upper end of the reservoir and increased with down-lake distance to a high of 10.4 near Oologah Dam. Under conditions when nutrient concentrations limit algal growth, all N:P derived during this study support a hypothesis of nitrogen limitation both spatially and temporally in Oologah Lake – a condition somewhat unusual for reservoirs of the region.

5. Lake-wide concentrations of chlorophyll *a*, a commonly used indicator of algal production, ranged from <2 to 46 µg/l with mean and median concentrations of 9.3 and 5.7 µg/l, respectively. Seasonally, concentrations peaked in August and September 2000. Based on chlorophyll data collected during this study and several commonly used indices, Oologah Lake can be classified as borderline mesotrophic/eutrophic with moderate to moderately high levels of productivity. Classification toward eutrophic is supported by nutrient and phytoplankton assemblage data. Eutrophic conditions increase with up-lake distance from Oologah Dam.

6. Phytoplankton (suspended algae) during the study period were represented by 49 genera within 13 orders and 5 divisions. Major divisions included green algae (43% of species), blue-greens (24% of species) and diatoms (14% of species). Across all sampling sites and dates, algal densities were dominated by diatoms. Near the location of water supply intakes at Oologah Dam, algal densities were generally dominated by green algae and diatoms, with seasonal increases of blue-greens observed. Dominant blue-greens included the genera *Anacystis* (a colonial form) and *Merismopedia*, both of which can be associated with taste and odor problems.

7. Secchi depths (SD) ranged from 0.10 to 0.90 m with an overall lake average of 0.36 m. Mean SD was highest near Oologah dam (0.61 m) and lowest at the upper end of the lake (0.21 m).

8. Estimates of euphotic zone depths (Z_{eu}) revealed the presence of a very limited layer of light intensity suitable for algal production in surface waters of Oologah Lake. Calculated values for Z_{eu} ranged from 0.46 to 3.56 m with an overall average of 1.69 m (5.5 feet) for the lake through the sampling period. Site-specific averages were highest near Oologah Dam (2.52 m) and lowest near the upper end of the lake (0.90 m). Light attenuation was closely correlated with turbidity and suspended solids but not with chlorophyll *a*.

9. During the study period, Oologah Lake exhibited neither a strong nor prolonged period of thermal stratification and/or hypolimnetic anoxia. When sporadic occurrences of these conditions did exist, they were confined to lower reaches of the lake during periods of intense

heating and calm weather. Extreme wind mixing and a short hydraulic residence time most likely limit these conditions in Oologah Lake.

10. For the study period (April – September 2000), average hydraulic residence time was approximately 100 days. This was similar to the long-term average of 110 days, indicating fairly typical hydrologic conditions during the study.

11. Oologah Lake waters can be described as slightly alkaline (median pH = 8.0), well buffered (median alkalinity = 114 mg/l as CaCO₃), and moderately hard to hard (median total hardness = 157 mg/l as CaCO₃).

12. During the study period, reservoir water quality modeling exercises were initiated. Activities included development of the CE-QUAL-W2 computational grid and initial water balance simulations. Initial stages of thermal calibration were likewise initiated. This effort is expected to continue in project out-years.

13. Field data for preparation of a new bottom contour map of Oologah Lake have been collected. At the time of preparation of this report, data processing was nearly complete. Upon completion of this task, evaluation of sedimentation patterns and other morphometric analyses will be conducted and presented in a separate report.

OOLOGAH LAKE (WATER QUALITY CONTAMINANTS)

1. On all sampling dates, surface water samples from Oologah Lake were collected and analyzed for diesel range total petroleum hydrocarbons (TPH). While detectable concentrations of TPH were reported in 31% of primary field samples, concentrations were all low and at or near low-level analytical quantitation limits. The range of detected concentrations was 101 to 196 µg/l (parts per billion). There did appear to be somewhat of an inverse relationship between lake-wide average TPH concentration and lake surface elevation. Owing to limited TPH data for other Oklahoma reservoirs, it was difficult to determine whether low TPH concentrations measured in Oologah lake waters were atypical for lakes of the region. Regardless, based on results of this study, it appears that contamination of Oologah Lake waters with petroleum constituents is not currently a major concern despite location of the lake in an area of intense historical petroleum production. These data should prove useful in future petroleum-related monitoring efforts at Oologah Lake.

2. In general, concentrations of a wide range of metals measured in monthly samples across Oologah Lake during the study period were below State of Oklahoma raw water numerical criteria for water supply reservoirs. The one exception was an anomalous condition measured 19 July 2000 when concentrations of cadmium and chromium exceeded raw water criteria in samples across the lake. Similar conditions were not observed in subsequent sampling events and reasons for these findings were unexplained. With the exception of this date, toxic metals concentrations did not appear to be at concentrations of concern in Oologah Lake waters.

3. Lake-wide average concentrations of total iron (1.60 mg/l) and manganese (0.09 mg/l) exceeded U.S. EPA criteria of 0.3 and 0.05 mg/l, respectively, for domestic water supplies. Concentrations were strongly correlated with suspended solids.

4. Concentrations of organochlorine pesticides, organochlorine herbicides, organo-phosphorus pesticides, and semi-volatile organic compounds were below analytical quantitation limits in all water samples collected from Oologah Lake following a period of high inflows. Atrazine, a triazine herbicide, was detected at concentrations ranging from 0.05 to 0.15 µg/l, but concentrations were well below the Federal drinking water standard of 3.0 µg/l.

OOLOGAH LAKE (SEDIMENTS)

1. Oologah Lake sediment samples were dominated by clay- and silt-sized grains. Atypical longitudinal patterns of grain size distribution were noted. Main pool solids content in sediments ranged from approximately 44% at the upper end of the impoundment to 22% near the dam.

2. Total organic carbon concentrations measured in Oologah Lake sediments were considerably lower and exhibited atypical distributional patterns relative to several other Oklahoma reservoirs. Potential explanations for these findings were presented.

3. Extractable (diesel range) TPH concentrations were measured in Oologah Lake main pool sediments and the sediments along the eastern shoreline near the Winganon Bridge at approximately mid-lake. Detectable concentrations were present in many samples but were low and near analytical quantitation limits. Concentrations in sediments from the main pool ranged from <13.3 to 19.8 mg/Kg (parts per million) dry weight with an identical mean and median of 15.7 mg/Kg. Concentrations in samples from shallow areas near the Winganon Bridge were significantly lower with mean and median concentrations of 9.10 and 5.37 mg/Kg dry weight, respectively. Differences in concentrations between the two areas could not be explained readily by correlation with other sediment parameters. Similar to results for TPH water analyses, results are difficult to interpret. However, it does appear that sediment TPH levels are detectable but low, at least in areas sampled during this study. It is important to note that detection of TPH in sediments was generally not associated with detectable concentrations of compound-specific organics (i.e., semi-volatile organics) or elevated metals concentrations that often accompany petroleum contamination (see below).

4. Concentrations of many total metals in Oologah sediments exceeded typical “background” concentrations for freshwater sediments and northeastern Oklahoma surface soils. This is most likely the result of a strong correlation between metals concentrations and clay-sized grains that dominate particle size distribution in Oologah sediments. When evaluated using conservative screening-level criteria, no metals were excessively high or at levels posing significant potential risk to ecological receptors.

5. Concentrations of organochlorine pesticides, chlorinated herbicides, and organo-phosphorus pesticides were below analytical quantitation limits in all sediment samples from

main pool sampling sites. With the exception of a single low detection of benzo(g,h,i)perylene (783 µg/Kg dry wt), concentrations of all semi-volatile organic compounds were likewise below quantitation limits in all samples from Oologah Lake.

Recommendations for further study include continued limnological data collection at Oologah Lake. Based on a review of data collected as a result of this study, it is likely that sampling can be focused on a more narrow list of parameters (and possibly sampling sites). Further sampling will provide valuable information on seasonal trends and year-to-year variability and will add to the data set available for model testing. In addition, it is recommended that collection of continuously monitored data be continued at the two tributary sampling sites established for the study. This, combined with continued manual sampling under both base and storm flow conditions, will increase predictive capability of regression equations developed during this study and will help further define loading dynamics for Oologah Lake. Details for these activities will be provided in an addendum to the existing work plan and Quality Assurance Project Plan (QAPP) for the study (USACE 2000b).

It is also recommended that modeling efforts for the reservoir continue, and that watershed modeling be initiated for the project. Lake modeling will include further calibration of the CE-QUAL-W2 water quality model to increase predictive capabilities of this valuable tool. Initiation of watershed modeling would include quantification of land use and model development for evaluation of key constituent loading to Oologah Lake.

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APPENDICES

A	Data Validation Report – Lake Water TPH Samples
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C	Vertical Profiles of Temperature, Specific Conductance, pH, and Dissolved Oxygen

**OOLOGAH LAKE, OKLAHOMA, WATERSHED STUDY
INTERIM REPORT OF FINDINGS:
APRIL – SEPTEMBER 2000**

1.0 INTRODUCTION

This document provides a summary of data and findings obtained during fiscal year (FY) 2000 for the Oologah Lake, Oklahoma, Watershed Study. Overall, the project is a multi-year investigation aimed at evaluating potential water quality threats to an important water supply source for the City of Tulsa, Oklahoma, and a number of communities surrounding Oologah Lake. Field sampling and data collection for the project were initiated by the U.S. Army Corps of Engineers, Tulsa District (TD) during April 2000 and will continue for an estimated 3-year period (funding permitting). The initial, first year focus of the study was in-lake and major tributary data gathering for water quality problem identification and assessment. Accordingly, study activities for FY 2000 were confined to Oologah Lake itself and major tributary sampling sites immediately adjacent to the reservoir. The purpose of this interim report is to present study findings for the period April through September 2000 in an effort to inform study partners and the public of study progress, initial findings, and rationale for future study direction and activities. Additional reports will be provided as the study progresses.

Receipt of analytical results and/or data processing for several study activities conducted during FY 2000 were incomplete as of preparation date of this interim report. It was the decision of the study team not to delay release of initial findings pending receipt of these data, but rather to include this information in future addenda to this document. Where applicable, ongoing data analyses are identified in this report with results to be provided in subsequent documents.

2.0 STUDY OBJECTIVES

This study was designed to evaluate potential water quality-related threats for three main areas of concern identified during project scoping: (1) excessive sedimentation and high inorganic turbidity, (2) petroleum-related contaminants, and (3) excessive nutrient (nitrogen and phosphorus) loading and resulting impacts on lake algal assemblages. The intent was to evaluate these three main areas of concern relative to potential impacts on Oologah Lake as a current and future water supply. As such, the study was focused on major sources of contaminant loading and impacts on main pool water and sediment quality. The study was not specifically designed to evaluate minor localized areas of impact or to quantify impacts of localized activities on near-shore water quality in isolated areas of the reservoir.

A major objective of FY 2000 sampling activities was in-lake data collection for problem identification and definition. Related objectives included collection of information necessary to establish preliminary loading estimates to the reservoir and to support a predictive water quality modeling effort for ultimate evaluation of potential water quality management alternatives. Accordingly, this interim report presents results of these specific activities for the period April through September 2000.

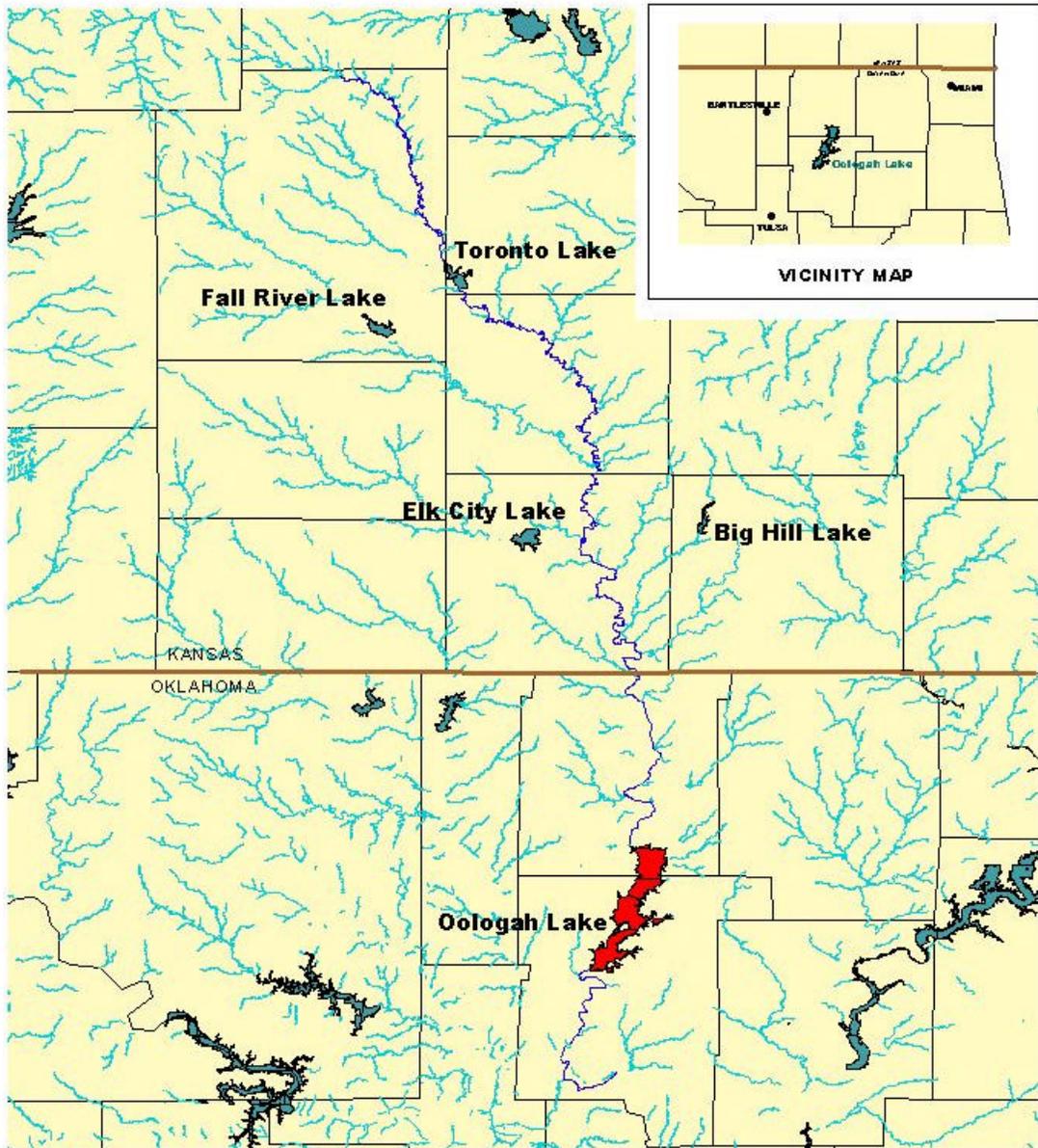
An ultimate goal of the complete Oologah Lake Watershed Study will be to develop site-specific tools for evaluating potential watershed and in-pool remedial techniques for water quality improvement. For year 2 of the project (FY 2001), the City of Tulsa and the TD have entered into a Planning Assistance to States (PAS) cooperative agreement which will expand the scope of study into the extensive 4,339-square-mile (11,238-square-km) watershed above Oologah Dam. Included in this effort will be watershed modeling activities, continued refinement of the reservoir model, and continued in-lake and tributary data collection. Results of these activities will be included in a subsequent interim report provided around February 2002.

3.0 STUDY AREA

3.1 Location and Project Purposes. Oologah Dam is located at mile 90.2 on the Verdigris River, approximately 2 miles southeast of Oologah and 22 miles northeast of Tulsa. The reservoir covers portions of both Rogers and Nowata counties, Oklahoma (Figure 3.1-1). The lake is a multipurpose project for flood control, water supply, recreation, navigation, and fish and wildlife. When operated in conjunction with the Arkansas River Basin System, the project is designed to provide maximum flood protection on the Lower Verdigris and Arkansas Rivers. The U.S. Army Corps of Engineers, Tulsa District is the operating agency for Oologah Lake.

3.2 Project History. Oologah Lake was authorized for construction by the Flood Control Act approved June 28, 1938 (Committee Document No. 1, 75th Congress, 1st Session). Construction began in July 1950 but was temporarily suspended in October 1951 after the right abutment access road was completed. Construction resumed in December 1955 and was completed for initial development in May 1963. Construction of the project for ultimate development was initiated in July 1967, the final conservation pool was filled in 1972, and all structures were completed in 1974.

3.3 Project Description. At the top of conservation pool (elevation 638.0 feet (194.46 m) National Geodetic Vertical Datum (NGVD)), Oologah Lake possesses a surface area of 31,040 acres (12,562 ha), a volume of 552,210 acre-feet (68,121 ha m), and a shoreline length of 209 miles (336 km). At conservation pool, mean and maximum depths are 17.8 and 88.0 feet (5.4 and 26.8 m), respectively. Average annual inflow-volume ratio is 3.3, resulting in an average retention time of approximately 110 days. It should be noted that these morphometric data are based on a 1977 sedimentation survey and may be updated once new (1999) sedimentation survey data are analyzed.



LEGEND

 Verdigris River

 Oologah Lake



Figure 3.1-1

Location of Oologah Lake, Oklahoma

SCALE: 1" EQUALS APPROXIMATELY 16 MILES

Oologah Dam is a rolled, earth-filled structure consisting of random fill with an impervious core. The embankment has a crest length of 4,000 feet (1,219 m) and a crest width of 36 feet (11 m). The upstream slope of the embankment is protected by 24-inch riprap on backing material, and the downstream slope is grass-covered. Outlet works consist of two 19-foot- (5.8 m) diameter conduits placed on firm rock on the right side of the old river channel. Invert elevation for these conduits is 565.0 feet (172.21 m) NGVD. The intake structure is provided with four 9- by 19-foot broom-type gates, two for each conduit. Low-flow releases are provided by a 48-inch- (1.22 m) diameter bypass sluice located in the dividing pier between conduits and discharging into the left conduit. Water supply facilities at the intake structure consist of an 84-inch- (2.13 m) diameter conduit that transitions to a 66-inch (1.68 m) conduit and is located in a wet well on the right side of the intake structure. The invert elevation of the water supply conduit is 565.0 feet (172.21 m). The wet well has two intake gates with invert elevations at 586.8 feet (178.86 m) and 612.0 feet (186.54 m).

The spillway structure is located in a saddle approximately 2 miles east of the main embankment at Oologah Lake. The spillway is a gated, concrete, gravity, ogee weir type structure with a gross total length of 328 feet (100 m), a net overflow length of 280 feet (85 m), and a crest elevation of 640 feet (195.07 m) NGVD. Spillway flows are controlled by seven 40- by 21-foot tainter gates operated by individual electric power hoists.

An important morphological feature of Oologah Lake is a rather significant change in water depth at approximately mid-lake. A county road connecting State Highways 169 and 28 crosses the reservoir at approximately mid-lake just west of the town of Winganon, Oklahoma (Figure 3.3-1). Features associated with this crossing, generally referred to as the “Winganon Bridge”, restrict down-lake movement of water to a relatively narrow bridge opening. Sedimentation above this bridge has contributed to an expansive area of relatively shallow water from just below the bridge to the upper end of the lake. This is significant to limnology of the lake and results in logistical difficulties for sampling this shallow, yet extensive area of the reservoir.

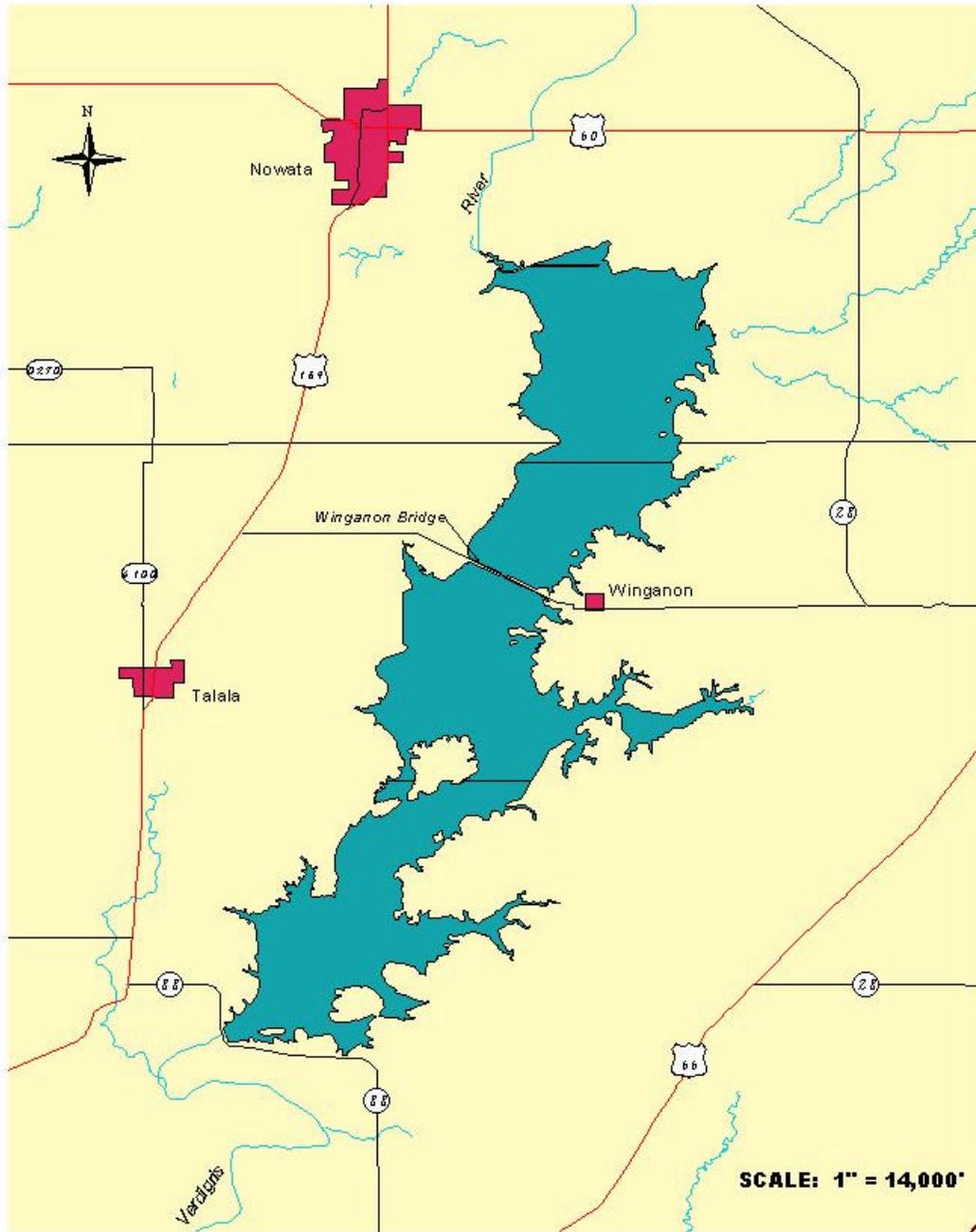


Figure 3.3-1
Oologah Lake Map

Oologah Lake includes 342,600 acre-feet of storage allocated for water supply, with a dependable yield of 154 million gallons per day (mgd). Total storage currently under contract is 332,375 acre-feet distributed among nine entities. Of this total, the Tulsa Metropolitan Water Authority contracts for 285,450 acre-feet of storage (128.3 mgd yield) and obtains between 40 and over 50% of its current water supply from the lake. Other entities and their presently-contacted storage (acre-feet) include Public Service Company of Oklahoma (20,990), the City of Collinsville (6,670), Rogers County Rural Water Districts 3 (5,960) and 4 (1,590), Washington County Rural Water District 3 (4,170), the City of Chelsea (670), the City of Claremore (6,675), and Nowata County Rural Water District No. 1 (200).

The Corps of Engineers maintains ten parks and one access point on Oologah Lake. A public overlook and picnic area is located on the upstream side of the left abutment. The lake is a popular location for swimming, fishing, camping, sailing, and a number of other forms of water-based recreation.

3.4 General Watershed Characteristics. The Verdigris River originates in the Flint Hills of Chase County, Kansas, and flows generally southeast from the vicinity of Madison to Neodosha, Kansas, and then in a southerly direction to its confluence with the Arkansas River, about 5 miles northeast of Muskogee, Oklahoma. The drainage area above Oologah Dam is elliptical in shape, covers 4,339 square miles (11,238 square km), and is approximately 100 miles (160.9 km) long and 45 miles (72.4 km) wide. Of the total drainage area above Oologah Dam, approximately 77% (3,354 square miles) occurs in Kansas while the remaining 23% (985 square miles) resides in Oklahoma.

Major lakes upstream of Oologah Dam in the Verdigris River Basin are all located in Kansas and include Elk City Lake on the Elk River, Big Hill Lake on Big Hill Creek, Fall River Lake on the Fall River, and Toronto Lake on the Verdigris River (Figure 3.3-1). Collectively, these lakes control 1,986 square miles (5,144 square km) of drainage, leaving 2,353 square miles (6,094 square km) of drainage area between upstream reservoirs and Oologah Dam. This area represents 54% of the total drainage in the Verdigris River Basin above Oologah Dam.

The greater portion of the Verdigris River watershed is in undulating plain. However, the western boundary, formed by the Flint Hills in Kansas and the Osage Hills in Oklahoma, is rough and broken with elevations rising to 1600 feet (487.7 m). The Verdigris River channel is well defined but winds considerably and contains many sharp bends in its course through the valley.

In terms of soils and geology, Oologah Lake is in the Cherokee Plains subdivision of the Prairie Plains physiographic province. The bedrock strata are shale and limestone of Pennsylvanian age. Sediments consist of silts and clays with scattered outcroppings of sandstone and limestone rock.

3.5 General Land-Use Characteristics. The primary industry in the Verdigris River Basin below the Kansas-Oklahoma State line is agriculture and its related industries. Production of mineral commodities in the basin is also significant, with petroleum, stone, natural gas, coal, cement, and clay among the most important. Other industries found in the watershed include the manufacture of zinc products, clothing, brick, tile, paint, and oil field equipment. Principal agricultural crops in the basin below the Kansas-Oklahoma State line are wheat, soybeans, sorghum, pecans, and alfalfa. Raising of beef cattle is also an important industry in the basin (USACE 1997). Confined animal feeding operations (CAFO's) and major industrial point source discharges are not nearly as prevalent in the watershed as they are in some other portions of Oklahoma and Kansas.

A large, 42-section area along the upper two-thirds of the eastern shore of Oologah Lake is the approximate location of an extensive, shallow oil field discovered in the early 1900's. The producing reservoir is the Bartlesville sand, and the area has been extensively drilled with thousands of wells over the field's history. While some production is still occurring in the area, many of the wells have been abandoned with few records available as to their number and locations. Several thousand of these wells were plugged in and around Oologah Lake over an approximate 17-year time span (1955 to 1972) prior to impoundment of the reservoir. A number

of improperly or unplugged abandoned wells still exist in this area, some of which have been noted to purge oil to surface soils and waters. The U.S. Environmental Protection Agency (EPA) and the Oklahoma Corporation Commission (OCC) have recently initiated a well-plugging effort on private lands around the reservoir with most of the plugging activity to take place along the eastern shore at the approximate center of the lake. Matters pertaining to the TD's involvement with this activity can be found in the Draft Oologah Lake Well Plugging Response and Action Plan (USACE 2000a).

3.6 Climate. Climate in the Verdigris River Basin is characterized by moderate winters and long summers with relatively high temperatures. Mean annual temperature is around 59.3 °F (15.2 °C). Average annual precipitation for the drainage basin above Oologah Dam, based on a 1930 through 1995 period of record, is 39.22 inches (99.62 cm), with highest percentages of this total occurring during May and June (approximately 13% each). On average, 66.5% of annual precipitation occurs during the growing season (April through September). Approximately 56% of average annual runoff in the basin above Oologah Lake occurs during the 4-month period from March through June. Average annual pan evaporation for Oologah Lake is 73.25 inches (186.1 cm), with approximately 30% of this total occurring from June through August. Prevailing winds are from the south with greatest velocities occurring during spring months (USACE 1997).

3.7 General Historical Water Quality. Historical water quality data are fairly limited for Oologah Lake. Limited summertime data were collected by contract for the TD in 1978 at nine lake sites and one tailwater site below Oologah Dam (Clark, Mooney, Norton & Associates 1978). In addition, the TD conducted baseline sampling at the lake in the summer of 1990 (USACE 1994). As a part of their Lake Water Quality Assessment (LWQA) Program, the Oklahoma Water Resources Board (OWRB) collected data on Oologah Lake in 1992/1993 (OWRB 1998) and again during the summer of 1996 (OWRB 1999). Based on the latest data collected by the OWRB, the lake was found to have an average lake-wide turbidity of 28 nephelometric turbidity units (NTU's), an average lake-wide chlorophyll *a* value of 8.75 µg/l, and an average Secchi depth of 55 cm. Based on these findings, the OWRB classified the lake as

eutrophic with high primary productivity (OWRB 1999). All studies to date have reported turbidity levels commonly exceeding the Oklahoma water quality standard of 25 NTU. Oologah Lake has been listed by the OWRB as non-supportive of recreational beneficial uses based on suspended solids concerns (OWRB 1998), and the lake is listed in Appendix D of OAC 785:46 (Oklahoma Water Quality Standards Implementation) as a threatened water body.

Oologah Lake is currently listed on the State of Oklahoma's 303(d) list of waters not meeting water quality standards. Cited causes include siltation, suspended solids, and pesticides. Sources identified on this list include contributions from non-irrigated crop production, pasturelands, and rangeland.

Vertical profile data collected by all agencies to date have identified a general trend of a lack of (or very weak and transitory) development of stable thermal stratification and/or oxygen depletion with depth in Oologah Lake during summer months. While this is fairly unusual for large Oklahoma lakes, this situation is most likely a result of shallow water depths, extreme wind exposure and mixing, and short hydraulic residence times for Oologah Lake. This situation is of significance to Oologah Lake limnology as well as to design of a sampling plan for the reservoir.

4.0 METHODS

4.1 General. Detailed methodology for FY 2000 study tasks was provided in the Project Work Plan and Quality Assurance Project Plan (QAPP) for the Oologah Lake Watershed Study (USACE 2000b). Data quality management issues for the study were likewise addressed in this document. With few exceptions, methodology outlined in the project work plan was followed in execution of FY 2000 activities and should be consulted for the majority of methods used in the study. This section provides additional details regarding final selection of specific sampling sites, actual sampling dates, environmental conditions during the sampling period, and other specifics generally not provided in the project work plan.

4.2 Baseline In-Lake Sampling. A major focus of the initial year of this study was in-lake data collection for water quality problem identification and definition. In-lake data collection included sampling of both lake waters and sediments in accordance with established TD standard operating procedures (SOP's) (copies of which are provided in Appendix A of USACE (2000b)). Sampling details for each media are presented separately below.

4.2.1 Lake Water Quality Sampling. Water quality sampling at Oologah Lake was conducted by TD personnel at five sampling sites along the thalweg from the upper end of the impoundment to Oologah Dam. These sites were spaced in an attempt to account for horizontal gradients common to large reservoirs and facilitated data collection in areas commonly designated as riverine, transitional, and lacustrine zones (Thornton et al. 1981, 1990). Sampling site coordinates were initially established using an on-board global positioning system (GPS), and GPS equipment was used for navigation to these sites for subsequent sampling events. Sampling locations and coordinates are shown in Figure 4.2.1-1.

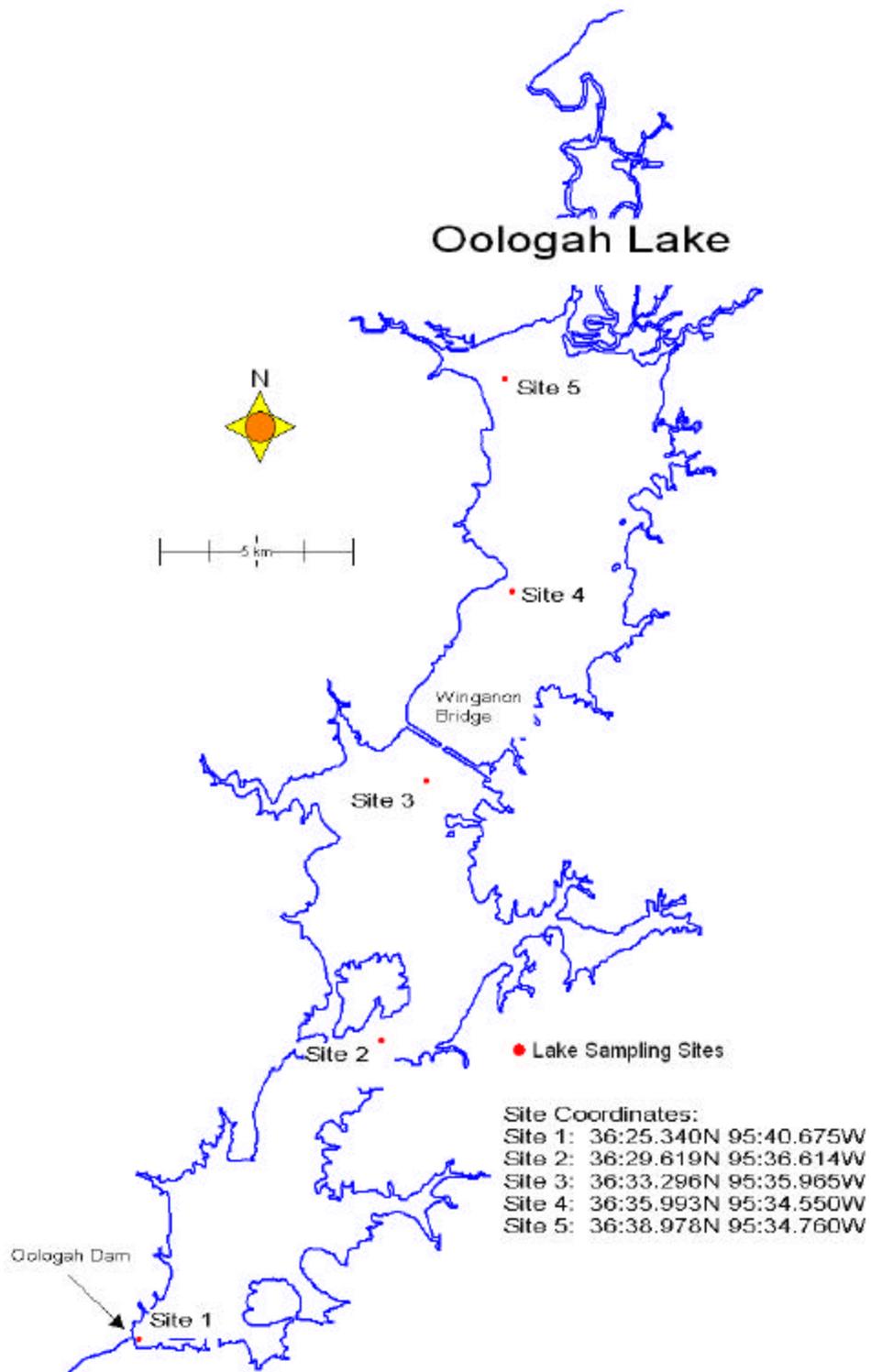


Figure 4.2.1-1
Oologah Lake water quality sampling sites.

In general, lake water quality sampling was conducted once during April and biweekly May through September 2000. No sampling dates were missed during the study. Specific sampling dates in 2000 were as follows:

- 18 April
- 02 May
- 16 May
- 06 June
- 20 June
- 05 July
- 19 July
- 01 August
- 15 August
- 06 September
- 19 September

Sampling was generally conducted between 0900 and 1500 hours. Sampling order at sites among sampling dates was varied to minimize time-dependent bias in sampling results. Rainfall measured at Oologah Dam as well as the range of pool elevations recorded during the sampling period are shown in Figures 4.2.1-2 and 4.2.1-3, respectively.

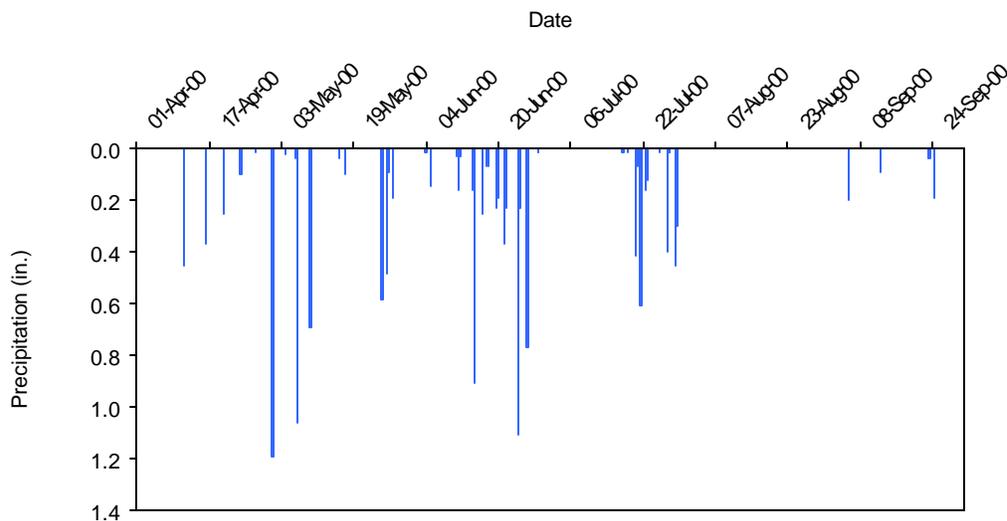


Figure 4.2.1-2
Precipitation at gage OOLO2 from April through September 2000.

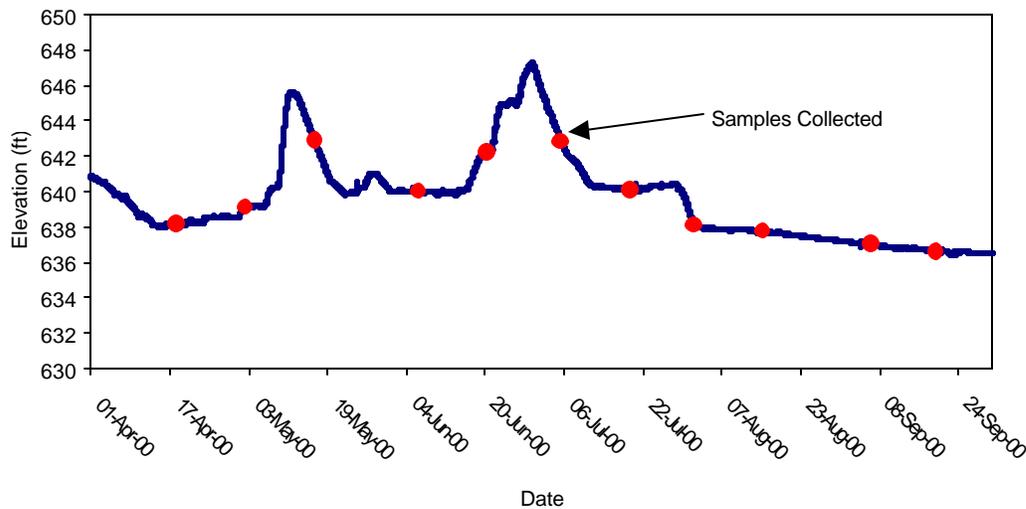


Figure 4.2.1-3
Oologah Lake elevation (feet) from April through September 2000.
Elevation at sampling times is indicated.

Field data recorded at each site included both Secchi disk transparency and vertical profiles of photosynthetically active radiation (PAR). In addition, vertical profiles of water temperature, dissolved oxygen (DO), pH, conductivity, and nephelometric turbidity were recorded at the surface (0.1- and 0.5- m depth) and at 1- m depth intervals throughout the entire water column. Profile data were electronically logged and downloaded to a PC to minimize data transcription errors.

Water samples for physical, chemical, and biological laboratory analyses were collected at an approximate depth of 0.5 m at each site. The exception was the near dam site (Site OOL-1, Figure 4.2.1-1) where samples were collected at depths of 0.5 m and 1 m above the sediments. Vertical profile data collected during this study generally substantiated historical findings that Oologah Lake rarely exhibits vertical thermal stratification and/or significant oxygen depletion with depth, though some minor exceptions were noted at down-lake sites during a brief period of intense heating and drought (see results section). Accordingly, samples at depth were collected only at Site 1. This sampling strategy and the need for additional

samples at depth will be re-evaluated based on analysis of current lake bathymetry and data from the initial year of sampling.

Analytical parameters for all Oologah Lake water samples as well as laboratory methods employed for each constituent are included in Table 4.2.1-1. The list included a broad range of common limnological parameters including those important for water supply evaluation and those necessary to support the water quality modeling effort. As suspended solids were one area of focus for the study, the parameter list included a number of solids-related parameters as well as analysis for both total and dissolved fractions for important analytes. Triplicate samples for chlorophyll were collected at each site. Owing to petroleum-related concerns, all samples were analyzed for extractable fraction total petroleum hydrocarbons (TPH). These samples were collected at an approximate depth of 0.1 m to include surface waters.

Water samples at each lake sampling site were collected at a depth of 0.5 m on all sampling dates for phytoplankton speciation and enumeration. Dr. Robert A. Lynch of the University of Oklahoma Health Sciences Center conducted algal analyses. Samples for zooplankton analyses were collected on all sampling dates and preserved to facilitate long-term storage. To date, zooplankton samples have been archived for future analysis, funding permitting.

While parameters listed in Table 4.2.1-1 were included in analyses of all water samples collected at Oologah Lake, several other contaminant-related analyses were conducted on a subset of water samples from the reservoir. These analyses and associated methods are listed in Table 4.2.1-2. Included in this list were pesticides and herbicides, semi-volatile organic compounds (to include many commonly associated with petroleum production), and a greatly expanded list of metals. While most of these constituents exhibit low solubilities in water, their affinity for lake sediments and a high concentration of suspended solids in Oologah Lake waters could result in their presence in the water column at detectable levels. These analyses were included as part of a “screening-level” investigation for presence of these constituents. Samples for organics analyses were initially collected at the five regular sampling sites (Figure 4.2.1-1) on 20 June 2000 following a period of high inflow when lake solids concentrations were elevated

(representing “worst-case” conditions). At the request of the analytical lab, replacement samples for semi-volatile organics analyses were collected on 5 July 2000. Samples for the full suite of metals were collected on 16 May, 20 June, 19 July, 15 August, and 19 September 2000.

Table 4.2.1-1. Analytical parameters and methods for all lake water samples, Oologah Lake, Oklahoma.

Parameter	Analytical Method
Nutrients	
Total phosphorus	EPA 365.2
Total dissolved phosphorus	EPA 365.2
Dissolved ortho-phosphorus	EPA 365.2
Nitrate + Nitrite-N	EPA 353.2
Ammonia-N	EPA 350.1
Total Kjeldahl-N	EPA 351.2
Inorganics	
Total alkalinity	SM 2320-B
Total hardness	EPA 130.2
Chloride	EPA 325.3
Sulfate	EPA 375.2
Total dissolved solids	SM 2540-C
Solids	
Settleable solids	SM 2540-F
Total suspended solids	EPA 160.2
Volatile suspended solids	EPA 160.4
Turbidity	EPA 180.1
Metals	
Total iron	EPA 200.7
Dissolved iron	EPA 200.7
Total manganese	EPA 200.7
Dissolved manganese	EPA 200.7
Biological	
Phytoplankton speciation & enumeration	SM 10200-F
Zooplankton speciation & enumeration	SM 10200-G
Other	
Chlorophyll <i>a</i>	SM 10200-H(3)
Total organic carbon	SM 5310-C
Dissolved organic carbon	SM 5310-C
BOD (5-day)	EPA 405.1
Total petroleum hydrocarbons (DRO)	SW-846 8015M

Table 4.2.1-2. Analytical parameters and methods for select (see text) water samples, Oologah Lake, Oklahoma.

Parameter	Analytical Method
Organics	
Chlorinated pesticides	SW-846 8081A
Chlorinated herbicides	SW-846 8151A
Organo-phosphorus pesticides	SW-846 8141
Semi-volatile organics	SW-846 8270C
Metals	
Total metals*	EPA 200.7 / 200.9
Dissolved metals*	EPA 200.7 / 200.9

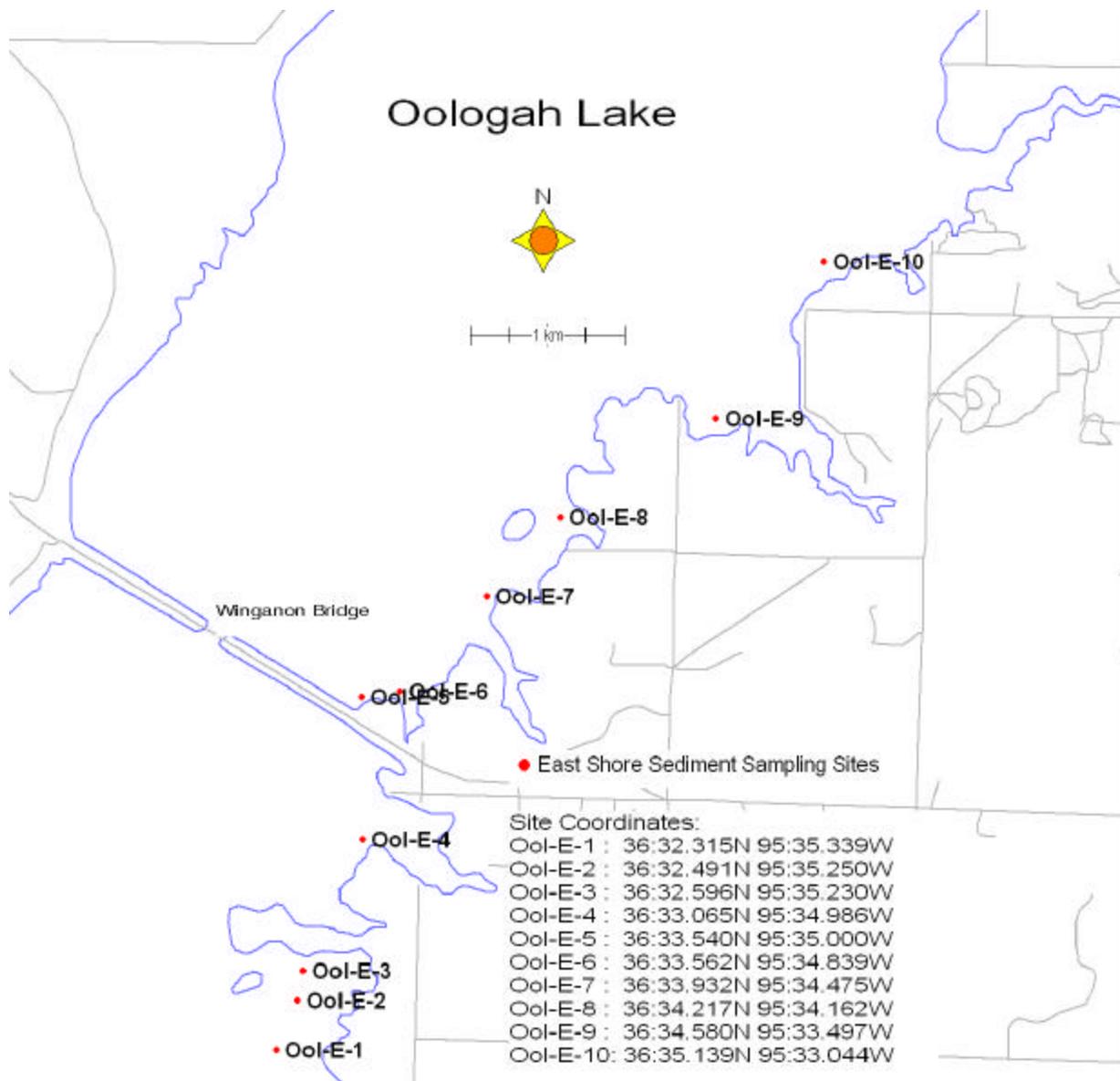
* Includes aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silica, silver, sodium, thallium, zinc.

In addition to collection of primary field samples, additional water samples were analyzed for quality assurance/quality control (QA/QC) purposes. This included one QC duplicate sample per trip that was analyzed for all chemical constituents for that sampling date. In addition, one field blank sample for all chemical parameters accompanied samples through the entire sampling, transportation, and analytical process on each lake sampling date. All samples were documented by signed chain-of-custody.

With the exception of chlorophyll *a*, TPH, and biological parameters (phytoplankton and zooplankton), analyses of water samples for all other parameters were conducted by the City of Tulsa Quality Assurance Laboratory, Tulsa, Oklahoma. The City of Tulsa QA lab performed data validation for all their analyses. Primary field samples and QC duplicates for TPH in water samples were analyzed by Environmental Testing and Consulting, Inc., Memphis, Tennessee. Quality assurance samples for TPH were analyzed by Test America, Inc., Nashville, Tennessee. Data validation for TPH analyses were provided by Tulsa District chemists (Appendix A). Filtration and fluorometric analyses for chlorophyll *a* was conducted by the Tulsa District.

4.2.2 Lake Sediment Sampling. Sediment samples from Oologah Lake were collected 21-22 August 2000 and analyzed for a number of physical and chemical parameters. Samples were collected at a composited sediment depth of approximately 0-8 cm employing core

sampling procedures described in Section 4 of the TD SOP manual (Appendix A of USACE (2000b)). Fifteen (15) primary field samples were collected as follows: five (5) at the regular water quality sampling sites (Figure 4.2.1-1) and ten (10) at selected locations along the east shore of the lake, both north and south of the Winganon Bridge (Figure 4.2.2-1). The latter area is in proximity to a large number of abandoned oil wells, many of which are part of a USEPA/OCC abandoned well plugging initiative on private lands (see discussion in USACE (2000a)). Samples in this area were collected at shallow water (<1 m) locations adjacent to the shoreline and documented by GPS coordinates (listed on Figure 4.2.2-1). Objectives of this effort were to establish “baseline” conditions for sediment quality in this general area prior to completion of most on-shore well plugging activities. In addition to primary field samples, triplicate samples were collected at two locations for QA/QC analyses, and a rinsate blank was collected as a measure of sampling equipment cleaning efficiency.



**Figure 4.2.2-1
East shore sediment sampling sites near Winganon bridge.**

Sediment samples collected at regular Oologah Lake water quality sampling sites (Figure 4.2.1-1) were analyzed for all parameters listed in Table 4.2.2-1. Samples collected along the east shore of the lake (Figure 4.2.2-1) were analyzed for petroleum related constituents (TPH, semi-volatiles, metals, total organic carbon) and physical characteristics (particle size, % solids) only. Primary field sample analyses were conducted by Environmental Testing and

Consulting, Inc., Memphis, Tennessee. Test America, Inc., Nashville, Tennessee, conducted analyses for QA samples. Particle size tests were conducted by Law Engineering and Environmental Services, Tulsa, Oklahoma. Data validation for sediment analyses was provided by TD chemists (Appendix B).

Table 4.2.2-1. Analytical parameters and methods for sediment samples, Oologah Lake, Oklahoma

Parameter	Analytical Method
Total phosphorus	365.3
Total nitrogen	352.1
Total organic carbon	415.1
Sulfate	300
Sulfide	376.2
Chloride	300
Total metals*	6010 / 7041 / 7060A / 7091 / 7131/ 7421 / 7470 & 7471 / 7740 / 7841
Chlorinated pesticides	SW-846 8081A
Chlorinated herbicides	SW-846 8151A
Organo-phosphorus pesticides	SW-846 8141A
Total petroleum hydrocarbons (extractable)	SW-846 8015M
Semi-volatile organics	SW-846 8270C
Particle size distribution (% sand, silt, clay)	ASTM D422
% solids	2540B

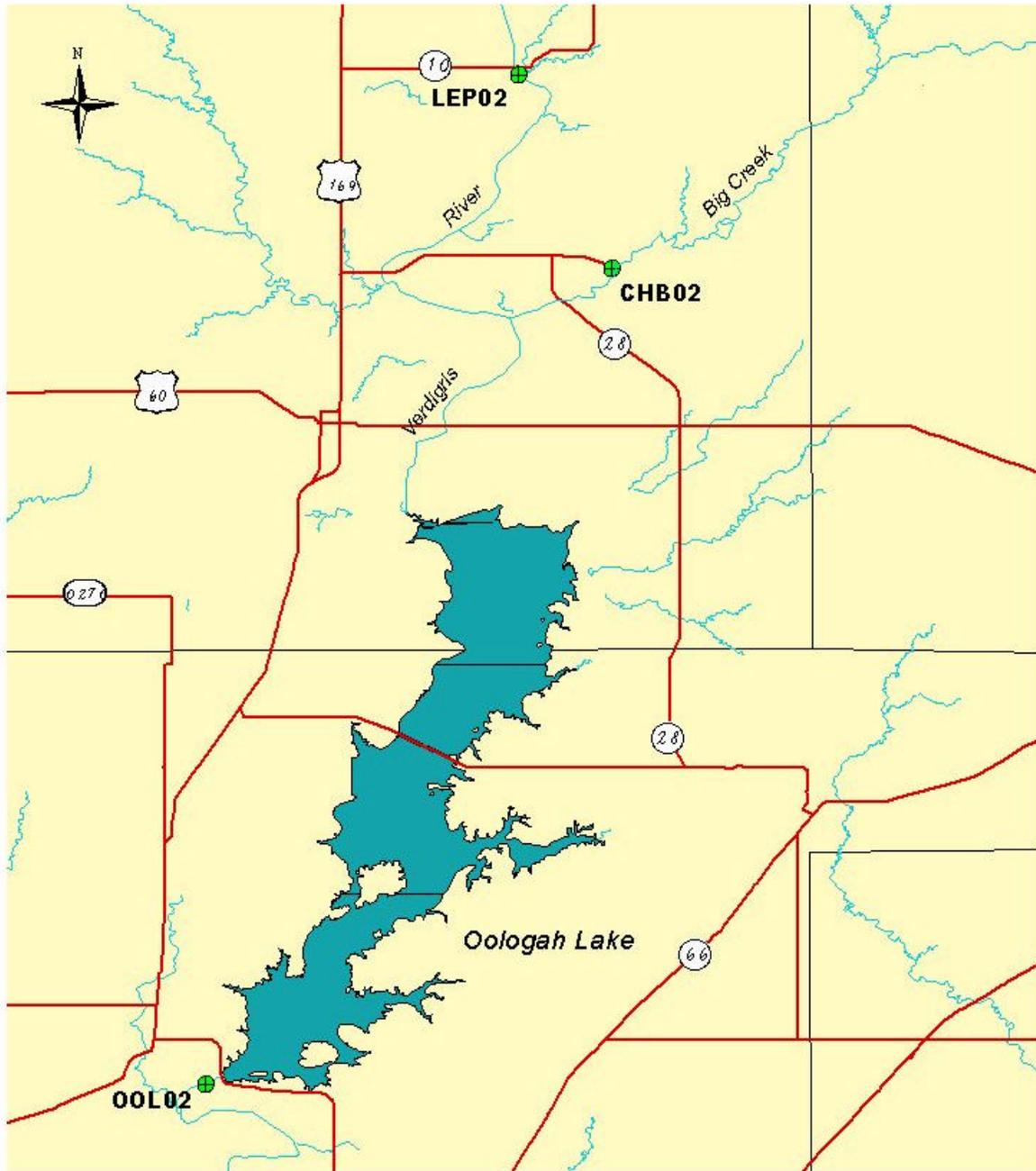
* Includes aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silica, silver, sodium, thallium, zinc.

4.3 Major Tributary Gaging, Continuous Monitoring, and Water Quality Sampling. In an attempt to estimate constituent loading and establish boundary conditions for the water quality modeling effort, continuous monitoring gaging stations were established on two major tributaries to Oologah Lake and in the Oologah Lake tailwaters. Upstream gages included existing U.S. Geological Survey (USGS) gage 07171000 located on the Verdigris River at State Highway 10, 2.8 miles east of Lenapah, Oklahoma, (hereafter referred to as LEP02) which was upgraded with continuous recording water quality equipment for this study. In addition, a new gaging site was established on Big Creek near Twin Bridges, approximately 4 miles east and 1 mile north of

Childers, Oklahoma (hereafter referred to as CHB02). Finally, stage recording and water quality instrumentation were installed at the discontinued USGS surface water station 07171400 in the Oologah Lake tailwaters (hereafter referred to as OOL02). Locations of all gages are shown in Figure 4.3-1 and background information for these sites is provided in USACE (2000b).

Instrumentation included at all gaging stations for the study included a continuous stage recorder and multi-probe water quality instrument capable of providing readings for water temperature, pH, dissolved oxygen, conductivity, and nephelometric turbidity. Data for these parameters were logged at 1-hour frequency, transferred via SDI-12 protocol to a data control platform (DCP), and uploaded via satellite to the TD Water Control Data System (WCDS). Data were archived by the TD and were available to the public real-time via the District's webpage (<http://www.swt-wc.usace.army.mil>). Periodic in-stream discharge measurements, gage maintenance, and regular instrument calibration were accomplished by TD Hydrology and Hydraulics personnel. Continuous data collection was initiated on 1, 6, and 10 April 2000 at OOL02, LEP02, and CHB02, respectively. At a minimum, data collection at these sites will continue through the second year of the study.

Water quality sample collection and analysis for load estimation were conducted at the two tributary sites listed above. Similar sampling was conducted at OOL02 as a measure of mass discharge from the impoundment. Periodic sampling at these locations generally, but not always, corresponded to lake sampling events and provided sampling data over a range of flow regimes and seasons. Samples were not collected during periods of zero discharge (particularly common at the tailwater site).



● Gaging Sites

Figure 4.3-1
Location of Gaging Sites, Oologah Lake, Oklahoma

Water sample collection and analysis in Oologah Lake tributaries during high inflow periods was an important part of this study as a high proportion of loading to reservoirs typically occurs during such events. Several mid-channel grab samples were collected at both tributary sites during major inflow events in late spring and early summer of 2000. Analytical parameters for all gaging site samples (“base” as well as storm flow) included those listed in Table 4.2.1-1 with the exception of TPH at LEP02 and CHB02 and phytoplankton and zooplankton analyses at all sites. With the exception of chlorophyll, the City of Tulsa Quality Assurance Laboratory conducted analyses for all tributary and tailwater samples. Sampling dates, corresponding flows, recorded rainfall, and results of these sampling efforts are thoroughly described in Section 5.2 of this report.

4.4 Bathymetric Mapping. Prior to this study, the most recent sediment survey for Oologah Lake was completed in 1977. In anticipation of the study, sedimentation survey data linking fathometer readings and GPS coordinates were collected by the TD at Oologah Lake during 1999. During the summer of 2000, a small segment of the upper end of the lake not covered in 1999 was surveyed. Data are being processed by the TD to produce an updated bathymetric map of the reservoir. Mapping data were used in estimating water volumes and depths necessary for establishing the computational grid for water quality modeling purposes and will be used in evaluating sedimentation patterns in the reservoir.

4.5 Reservoir Water Quality Modeling. A significant task for the overall Oologah Lake Watershed Study will be ultimate development of a means of evaluating watershed or in-lake management strategies on water quality in the reservoir. The overall goal of this task will be to provide a tool for simulating lake water quality response to a variety of possible management actions as a means of conducting “what if” type analyses. When properly applied, reservoir water quality modeling is particularly well suited for this purpose.

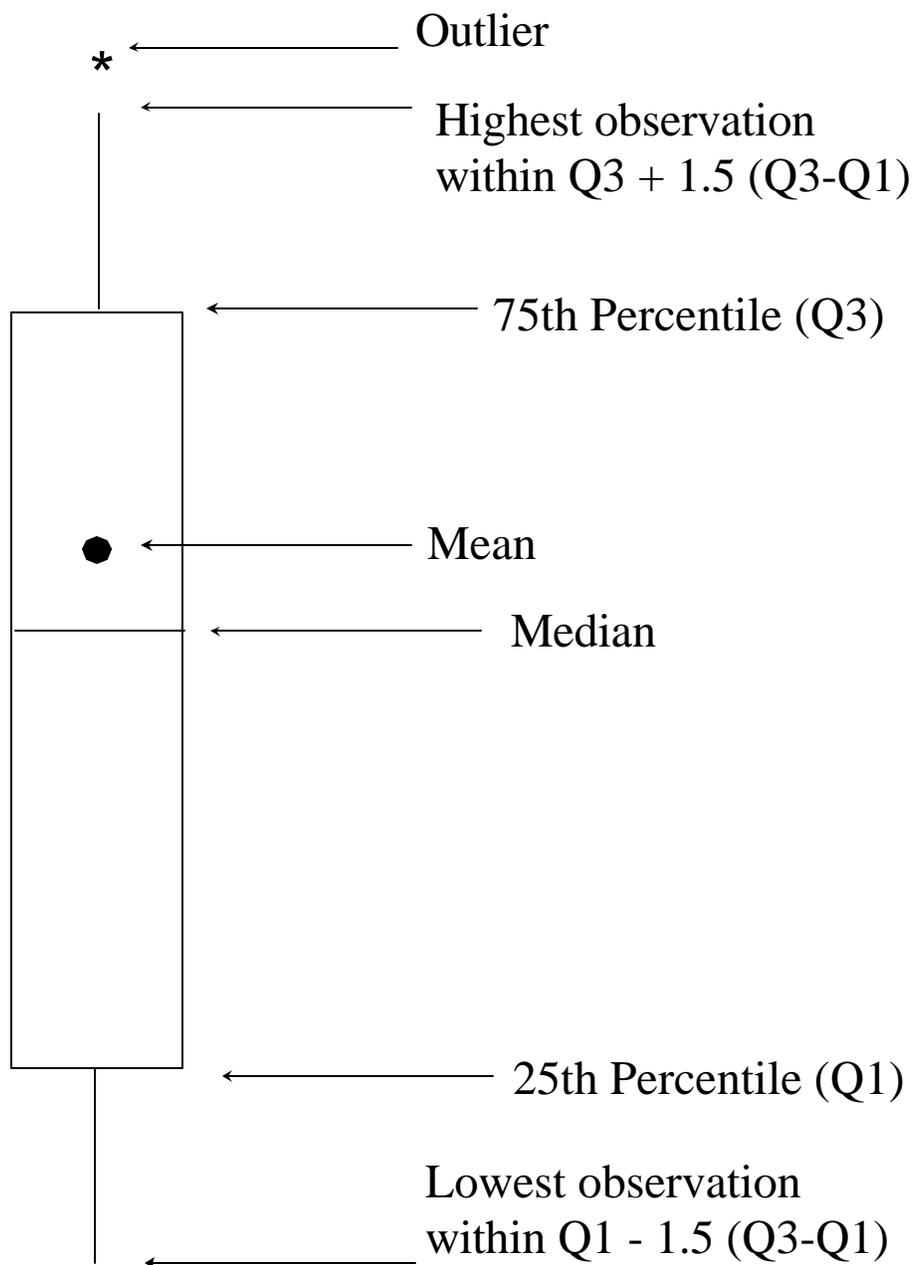
The reservoir model to be applied in this study is CE-QUAL-W2, a two-dimensional, longitudinal/vertical hydrodynamic and water quality model. Goals of the overall modeling exercise and its applicability to alternatives analysis are discussed in USACE (2000b). For

FY 2000, modeling efforts included initial model set-up and preliminary application by the U.S. Army Engineer Research and Development Center (ERDC), formerly the Waterways Experiment Station (WES), Vicksburg, Mississippi. These initial efforts are described in Section 5.7.

4.6 Statistical Analyses. Statistical analyses were conducted using MINITAB 13 (Minitab, Inc. 2000). For hypothesis testing, differences were considered statistically significant at $\alpha \leq 0.05$. Analyses were first performed to determine if the data deviated significantly from that of a normal distribution using the Anderson-Darling normality test. Once a normal or lognormal distribution was determined, analyses were performed to determine differences between sampling sites both spatially and temporally using tests appropriate for the distribution. Generally, differences among sampling sites and events were determined using analysis of variance (ANOVA) on ranked data. When differences among the medians were detected, Tukey's multiple comparison test was utilized to determine which medians were different. At Site 1, the statistical model used to determine differences between surface and bottom data was the t-test on ranked data. Spearman's rank correlation was generally used in correlation analyses.

A 'best subsets' linear regression analysis, within the statistical software package MINITAB (Minitab Inc. 2000), was used to determine least-squares relationships between selected constituents of the field collected tributary water samples and correlated continuously monitored constituents. Calculated Pearson product moment correlation coefficients between selected field sample constituents and continuously monitored constituents were evaluated to identify potential surrogates.

"Box and whisker" plots were used for presentation of much of the data collected for this study. A generalized presentation of how these plots can be interpreted is provided below.



5.0 RESULTS

5.1 Bathymetric mapping. All field data required to produce a detailed, updated bathymetric map of Oologah Lake were collected during the summers of 1999 and 2000. Processing of these data is ongoing and was not complete at the time of preparation of this interim report. When complete, the map and evaluations of changes in lake bathymetry, sedimentation patterns, and other morphometric analyses will be prepared as an addendum to this report.

5.2 Tributary Water Chemistry. Tributaries to Oologah Lake (Verdigris River at Lenapah (LEPO2), and Big Creek near Childers, Oklahoma, (CHBO2) were continuously monitored (hourly) from April through September 2000. Continuously monitored parameters include precipitation, stage, discharge, water temperature, DO, pH, conductivity, and turbidity. In addition, a continuous monitoring station was established in the tailwaters immediately below Oologah Dam (OOLO2). Figure 5.2-1 shows the approximate locations of the gaging stations. Field samples were collected at the tributaries during storm events and base flow in an attempt to sample a broad range of stream flow conditions. The distributions of water samples collected across the range of flows (or stages) during the sampling period are shown for LEPO2 and CHBO2, in Figure 5.2-2 and Figure 5.2-3, respectively. Indicated in the figures are the flows (or stages) at which samples were collected and the relative frequency of occurrence. Field samples were collected according to methods described in the Project Work Plan and Quality Assurance Project Plan for the Oologah Lake Watershed Study (USACE 2000b) and analyzed for a wide range of chemical, nutrient, and metals parameters described in Table 5.2-1.

Graphic representations of continuous stream discharge and turbidity recorded at LEPO2 and CHBO2 from April through September 2000 are presented in Figure 5.2-4 and Figure 5.2-5, respectively. A close correlation between rising limbs of discharge during storm runoff events and increased turbidity measurements are evident for each site. Inspection of individual storm runoff events at each site (Figure 5.2-6 (LEPO2) and Figure 5.2-7 (CHBO2)) makes this correlation more evident. Initial runoff carried slugs of inorganic and organic matter in suspension to the streams.

The analysis of tributary data was limited by the number of field samples collected at each tributary site. For the period April through September 2000, 15 samples were collected from LEPO2 and 12 from CHBO2. Periodic absence of flow in Big Creek limited the opportunities for sampling at that site. Analysis of the field data from CHBO2 was further constrained by a significant number of gaps in the continuously monitored data from that site (i.e., discharge). Statistical summaries of constituents analyzed in field-collected samples are presented in Table 5.2-2 for the two tributary sites. Field data collected from OOLO2 were also limited in number due to a lack of water releases from the reservoir through significant portions of the period. OOLO2 data are summarized in Table 5.2-3, and results of metals analyses at OOLO2 are presented in Table 5.2-4. Laboratory analyses resulting in constituent concentrations below the analysis method detection limit were included in subsequent calculations as one-half the detection limit.

Mean values of most constituents are similar for the two tributary sites. Mean concentrations of total Kjeldahl (TKN) and nitrate plus nitrite (NO_x) nitrogen were higher at LEPO2 (1.93 and 0.60 mg/l as N, versus 0.84 and 0.13 mg/l as N, respectively). Mean total suspended solids (TSS) and turbidity were also higher at LEPO2 (416 mg/l and 332 NTU, respectively) than mean values at CHBO2 (255 mg/l and 116 NTU, respectively). Release water quality (OOLO2) essentially mirrored inputs from the tributaries for most constituents with the exception of suspended solids that were lower due to settling processes.

Statistical summaries of continuously monitored constituents at LEPO2 and CHBO2 are presented in Table 5.2-5. Other than the obvious difference in discharge at the two tributary sites, mean constituent values are very similar with the exception of turbidity. Mean and median turbidity values from LEPO2 were higher for the monitored period than those at CHBO2, consistent with the field sample results. A summary of continuously monitored data from OOLO2 in Table 5.2-6 shows similar constituent levels in lake release waters.

Concentrations of constituents in surface water are often strongly related to other constituent concentrations and additional environmental factors (Christensen et al. 2000). Regression equations that are based on surrogate physical properties measured in real time can

be useful in estimating those constituents not measured in real time. A ‘best subsets’ linear regression analysis, within the statistical software package MINITAB (Minitab Inc. 2000), was used to determine least-squares relationships between selected constituents of the field collected tributary water samples and correlated continuously monitored constituents. Calculated Pearson product moment correlation coefficients between selected field sample constituents and continuously monitored constituents were evaluated to identify potential surrogates. For some developed relationships, the independent variable(s), dependent variable(s), or both, were log transformed to develop linear equations. Relationships were evaluated using mean square error (MSE) and the coefficient of determination (R^2). Relative percentage differences (RPDs) between measured and estimated constituent concentrations were also calculated to evaluate each developed relationship. The developed relationships were also used to compare selected measured and estimated constituent loading at the tributary sites.

Resulting regression equations for each tributary site are presented in Table 5.2-7. Regression relationships were developed for alkalinity, hardness, total dissolved solids (TDS), TSS, chloride, sulfate, total organic carbon (TOC), NO_x , TKN, and total P at both LEPO2 and CHBO2. At LEPO2, the equation with the highest R^2 was that developed for alkalinity (0.98). Equations developed for hardness, TSS, chloride, and TOC had R^2 values above 0.90. NO_x and total P equations had the lowest R^2 values at this site (0.72 and 0.73, respectively). At CHBO2, the relationship with the highest R^2 value was that developed for hardness (0.97), and equations for TSS and TOC had R^2 values of 0.93. Lowest coefficients of determination for relationships at this site were for chloride (0.69), TDS (0.70), and TKN (0.73).

Regression equations for estimates of each constituent at each site were then used to estimate concentrations that were plotted against measured constituent concentrations (Figure 5.2-8 thru Figure 5.2-17 for LEPO2, and Figure 5.2-18 thru Figure 5.2-27 for CHBO2), and RPD’s between measured and estimated concentrations were calculated. The RPD was calculated as:

$$RPD = |(B - A) / A \times 100|$$

where

RPD = relative percentage difference;
A = measured constituent load; and
B = the estimated concentration.

The median RPD was calculated and reported for each relationship (Table 5.2-8). At LEPO2, five constituents, alkalinity, hardness, TDS, chloride, and TOC, had calculated median RPDs of less than 10% with the lowest being 3% for alkalinity. The highest median RPD at LEPO2 was for the NO_x relationship (36%). At CHBO2, only one constituent relationship (hardness) had a median RPD less than 10%, and TOC, TDS, and alkalinity had median RPD's less than 20%. The highest calculated median RPD at CHBO2 was 74% for the NO_x relationship.

Regression equations were used to estimate selected constituent concentrations throughout the sampling period. A smaller portion of the sampling period wherein several measured observations were made was used to graphically compare the relative accuracy of the estimated versus measured concentrations at the two tributary sites. Six stream samples were collected from LEPO2 and five from CHBO2 for the period 6 – 13 May 2000. Included in the figures is one surrogate measure to which the constituent of concern was most highly correlated. At LEPO2, measured concentrations of alkalinity and TDS (Figure 5.2-28 and Figure 5.2-29, respectively) were highly correlated with conductivity. Measured concentrations of TSS, TOC, TKN, and total P at LEPO2 were most highly correlated with turbidity (Figure 5.2-30 through Figure 5.2-33). Regression estimates appear reasonably accurate for alkalinity, TDS, TSS, and TOC, and somewhat less accurate for the nutrient constituents TKN and total P. Similar figures were prepared for CHBO2 (Figure 5.2-34 through Figure 5.2-39) that show less overall accuracy, partially due to fewer available observations.

Nutrient and solids loading estimates were also compared to 'measured' loads. Accurate estimates of constituent loading necessarily require observations throughout individual storm events since constituents are delivered to the stream at varying rates in the rising and falling limbs of each individual storm hydrograph. Measured instantaneous loads of total nitrogen (total N), total P, TDS, and TSS were calculated from measured concentrations and corresponding

continuous discharge measurements and reported in units of kg/d. Total N was not analyzed directly, but rather estimated as the sum of TKN and NO_x . Estimated concentrations were calculated using the regression equations reported in Table 5.2-7 and multiplied by corresponding instantaneous discharge and a conversion factor to get units of kg/d. Tabular results are presented in Table 5.2-9 and Table 5.2-10 for LEPO2 and CHBO2, respectively. The relatively few measured observations of nutrient and solids concentrations at each tributary site do not provide enough information for an accurate estimate of individual storm event or long-term loading. Regression estimates based on continuously monitored surrogates may provide a better picture of delivered loads. At LEPO2, estimated minimum and maximum loads of all four constituents included minimum and maximum measured loads, and estimated median and mean loads of all constituents were lower than measured median and mean loads. With fewer measured loads at CHBO2, results were not as consistent but a similar pattern was evident.

Figures 5.2-40 through 5.2-47 compare measured and estimated loads of total N, total P, TDS, and TSS for LEPO2 and CHBO2. Median RPDs for estimates of loading are presented in Table 5.2-11. The median RPD for TDS load was less than 10% at both LEPO2 and CHBO2. The highest median RPD was 39.1% for total N load at CHBO2.

Comparisons of measured and estimated total N, total P, TDS, and TDS loads across the entire sampling period are presented in Figure 5.2-48 through Figure 5.2-55 for both LEPO2 and CHBO2. Estimated loadings of each of the constituents compare well to measured loads at LEPO2. Estimated loadings at CHBO2 agree similarly well, although total N loading at CHBO2 appears less accurate, but follows the measured trend reasonably well.

Table 5.2-1. Analytical parameters and analysis methods for Oologah Lake tributary water samples.

Parameter	Analytical Method
Nutrients	
Total phosphorus	EPA 365.2
Total dissolved phosphorus	EPA 365.2
Dissolved ortho-phosphorus	EPA 365.2
Nitrate + Nitrite-N	EPA 353.2
Ammonia-N	EPA 350.1
Total Kjeldahl-N	EPA 351.2
Dissolved total Kjeldahl-N	EPA 351.2
Inorganics	
Total alkalinity	SM 2320-B
Total hardness	EPA 130.2
Chloride	EPA 325.3
Sulfate	EPA 375.2
Total dissolved solids	SM 2540-C
Solids	
Settleable solids	SM 2540-F
Total suspended solids	EPA 160.2
Volatile suspended solids	EPA 160.4
Turbidity	EPA 180.1
Metals	
Total iron	EPA 200.7
Dissolved iron	EPA 200.7
Total manganese	EPA 200.7
Dissolved manganese	EPA 200.7
Other	
Chlorophyll <i>a</i>	SM 10200-H(3)
Total organic carbon	SM 5310-C
Dissolved organic carbon	SM 5310-C
BOD (5-day)	EPA 405.1

Table 5.2-2. Chemical parameter summary statistics for field collected samples at two tributary sites above Oologah Lake from May to September 2000.

Constituent	Units	Big Creek near Childers, Oklahoma (CHBO2)						Verdigris River at Lenapah, Oklahoma (LEPO2)					
		Mean	Median	St. Dev.	Min.	Max.	N	Mean	Median	St. Dev.	Min.	Max.	N
Alkalinity, Total (as CaCO ₃)	mg/l	97.58	72.50	54.70	38.00	194.00	12	104.87	103.00	37.17	51.00	168.00	15
BOD(5) Day	mg/l	3.10	2.65	1.81	<2.0	6.20	12	2.99	2.30	2.18	<2.0	6.80	15
Carbon, Organic, Dissolved	mg/l	5.31	6.00	2.34	2.00	8.60	12	5.01	4.60	1.21	3.30	8.00	15
Carbon, Organic, Total	mg/l	6.05	6.55	2.87	2.30	9.90	12	5.34	5.10	1.30	3.30	7.70	15
Chloride	mg/l	4.35	4.50	2.82	<1.00	9.80	12	13.45	14.00	6.21	5.00	26.00	15
Chlorophyll <i>a</i>	µg/l	7.9	4.7	6.3	0.7	17.9	21	8.2	6.1	9.3	2.0	50.5	27
Hardness, Total (as CaCO ₃)	mg/l	124.17	109.00	63.26	46.00	228.00	12	123.40	120.00	38.49	66.40	188.00	15
Iron, Dissolved	mg/l	0.66	0.50	0.64	0.02	1.70	12	1.46	1.50	1.12	0.08	3.60	15
Iron, Total	mg/l	1.61	1.35	1.45	0.14	5.30	12	4.52	3.20	4.66	0.35	18.00	15
Manganese, Dissolved	mg/l	0.01	0.00	0.01	<0.008	0.02	12	0.01	0.01	0.02	<0.008	0.08	15
Manganese, Total	mg/l	0.22	0.15	0.23	0.04	0.86	12	0.36	0.28	0.29	0.04	0.83	15
Nitrogen, Ammonia (as N)	mg/l	0.05	0.03	0.04	<0.06	0.12	12	1.33	0.03	3.36	<0.06	10.00	15
Nitrogen, Kjeldahl, Dissolved (as N)	mg/l	0.54	0.58	0.34	<0.30	1.11	12	0.64	0.50	0.52	<0.30	2.11	15
Nitrogen, Kjeldahl, Total (as N)	mg/l	0.84	0.77	0.57	<0.30	1.96	12	1.93	1.71	1.25	<0.30	4.18	15
Nitrogen, Nitrate-Nitrite (as N)	mg/l	0.13	0.09	0.14	<0.03	0.45	12	0.60	0.59	0.37	<0.03	1.43	15
Ortho-Phosphorus, Dissolved (as P)	mg/l	0.04	0.04	0.03	<0.005	0.08	12	0.07	0.08	0.03	0.03	0.13	15
Phosphorus, Dissolved, Total (as P)	mg/l	0.07	0.06	0.07	0.01	0.26	12	0.25	0.09	0.43	0.05	1.71	15
Phosphorus, Total (as P)	mg/l	0.25	0.14	0.31	0.03	1.06	12	0.32	0.20	0.29	0.09	1.03	15
Solids Settleable	ml/l	0.26	0.10	0.42	<0.10	1.50	12	0.52	0.20	0.61	<0.10	2.00	15
Solids, Total Dissolved	mg/l	176.60	180.50	51.34	96.20	268.00	12	208.87	211.00	37.94	125.00	259.00	15
Solids, Total Suspended	mg/l	254.58	104.00	382.31	<4.0	1270.00	12	415.81	232.00	419.41	24.36	1160.00	15
Solids, Volatile Suspended	mg/l	60.03	13.00	123.61	<4.0	432.00	12	40.44	28.00	36.00	4.30	110.00	15
Sulfate	mg/l	17.92	12.50	14.12	2.90	50.00	12	44.65	24.00	44.88	3.70	130.00	15
Turbidity	NTU	115.64	114.35	95.59	5.52	259.00	12	332.18	288.00	269.24	18.30	706.00	15

Table 5.2-3. Chemical parameter summary statistics for field collected samples at OOLO2 from May to September 2000.

Constituent	Units	Mean	Median	St. Dev.	Min	Max	N	#BDL
Alkalinity, Total (as CaCO ₃)	mg/l	81.20	97.00	44.84	<4.0	113.00	5	1
BOD(5 Day)	mg/l	<2.0	-	0.00	<2.0	<2.0	5	5
Carbon, Organic, Dissolved	mg/l	3.90	3.80	0.17	3.80	4.20	5	0
Carbon, Organic, Total	mg/l	4.06	4.00	0.19	3.80	4.30	5	0
Chloride	mg/l	12.10	12.00	3.51	7.50	16.00	5	0
Chlorophyll <i>a</i>	µg/l	3.0	1.7	2.5	0.8	6.4	17	0
Hardness, Total (as CaCO ₃)	mg/l	153.60	158.00	13.20	132.00	167.00	5	0
Nitrogen, Ammonia (as N)	mg/l	<0.06	-	-	<0.06	<0.06	5	5
Nitrogen, Kjeldahl, Dissolved (as N)	mg/l	0.30	-	0.26	<0.06	0.61	5	2
Nitrogen, Kjeldahl, Total (as N)	mg/l	0.68	0.42	0.67	<0.30	1.84	5	1
Nitrogen, Nitrate-Nitrite (as N)	mg/l	0.31	0.40	0.19	<0.03	0.48	5	1
Ortho-Phosphorus, Dissolved (as P)	mg/l	0.04	0.04	0.01	0.03	0.06	5	0
Phosphorus, Dissolved, Total (as P)	mg/l	0.05	0.05	0.01	0.03	0.07	5	0
Phosphorus, Total (as P)	mg/l	0.07	0.07	0.04	<0.005	0.11	5	1
Solids Settleable	ml/l	<0.10	-	-	<0.10	<0.10	5	5
Solids, Total Dissolved	mg/l	205.60	248.00	112.58	<10.0	270.00	5	1
Solids, Total Suspended	mg/l	52.92	9.67	97.36	5.92	227.00	5	0
Solids, Volatile Suspended	mg/l	9.12	-	-	<4.0	33.30	5	3
Sulfate	mg/l	63.50	-	68.19	<1.0	180.00	5	1
Turbidity	NTU	27.75	-	21.25	<0.10	53.40	5	1

Table 5.2-4. Results of metals analyses at OOLO2 from 16 May, 20 June, and 19 July sampling.

Constituent	Units	Mean	Median	St. Dev.	Min	Max	N	#BDL
Aluminum, Dissolved	mg/l	0.553	-	0.588	<0.10	1.200	3	1
Aluminum, Total	mg/l	2.033	1.400	1.365	1.100	3.600	3	0
Antimony, Dissolved	mg/l	<0.006	-	-	<0.006	<0.006	3	3
Antimony, Total	mg/l	<0.006	-	-	<0.006	<0.006	3	3
Arsenic, Dissolved	mg/l	<0.002	-	-	<0.002	0.002	2	1
Arsenic, Total	mg/l	<0.002	-	-	<0.002	0.002	3	2
Barium, Dissolved	mg/l	0.059	0.058	0.003	0.056	0.062	3	0
Barium, Total	mg/l	0.081	0.076	0.027	0.056	0.110	3	0
Beryllium, Dissolved	mg/l	<0.004	-	-	<0.004	<0.004	3	3
Beryllium, Total	mg/l	<0.004	-	-	<0.004	<0.004	3	3
Cadmium, Dissolved	mg/l	0.244	-	-	<0.003	0.730	3	2
Cadmium, Total	mg/l	0.734	-	-	<0.003	2.200	3	2
Calcium, Dissolved	mg/l	43.633	45.000	3.179	40.000	45.900	3	0
Calcium, Total	mg/l	43.167	40.000	6.371	39.000	50.500	3	0
Chromium, Dissolved	mg/l	<0.03	-	-	<0.03	<0.03	3	3
Chromium, Total	mg/l	<0.03	-	-	<0.03	<0.03	3	3
Copper, Dissolved	mg/l	<0.02	-	-	<0.02	<0.02	3	3
Copper, Total	mg/l	<0.02	-	-	<0.02	<0.02	3	3
Iron, Dissolved	mg/l	0.463	0.465	0.323	0.150	0.770	4	0
Iron, Total	mg/l	1.310	1.395	0.942	0.250	2.200	4	0
Lead, Dissolved	mg/l	<0.001	-	-	<0.001	<0.001	3	3
Lead, Total	mg/l	0.002	-	0.001	<0.001	0.003	3	1
Magnesium, Dissolved	mg/l	8.400	8.500	0.557	7.800	8.900	3	0
Magnesium, Total	mg/l	8.000	7.800	1.015	7.100	9.100	3	0
Manganese, Dissolved	mg/l	0.045	-	0.061	<0.008	0.135	4	1
Manganese, Total	mg/l	0.097	0.060	0.086	0.045	0.225	4	0
Mercury, Dissolved	mg/l	0.067	-	-	<0.00001	0.200	3	2
Mercury, Total	mg/l	0.067	-	-	<0.00001	0.200	3	2
Nickel, Dissolved	mg/l	<0.02	-	-	<0.02	<0.02	3	3
Nickel, Total	mg/l	<0.02	-	-	<0.02	<0.02	3	3
Potassium, Dissolved	mg/l	2.600	2.600	0.400	2.200	3.000	3	0
Potassium, Total	mg/l	2.733	2.800	0.404	2.300	3.100	3	0
Selenium, Dissolved	mg/l	<0.003	-	-	<0.003	<0.003	2	2
Selenium, Total	mg/l	<0.003	-	-	<0.003	<0.003	3	3
Silicon, Dissolved	mg/l	5.067	5.200	2.003	3.000	7.000	3	0
Silicon, Total	mg/l	7.667	8.600	2.914	4.400	10.000	3	0
Silver, Dissolved	mg/l	<0.02	-	-	<0.02	<0.02	3	3
Silver, Total	mg/l	<0.02	-	-	<0.02	<0.02	3	3
Sodium, Dissolved	mg/l	13.0	14.0	2.646	10.0	15.0	3	0
Sodium, Total	mg/l	13.0	12.0	1.732	12.0	15.0	3	0
Thallium, Dissolved	mg/l	0.005	-	-	<0.002	0.010	2	1
Thallium, Total	mg/l	<0.002	-	-	<0.002	<0.002	3	3
Zinc, Dissolved	mg/l	<0.02	-	-	<0.02	<0.02	3	3
Zinc, Total	mg/l	<0.02	-	-	<0.02	<0.02	3	3

Table 5.2-5. Statistical summaries of continuously (hourly) measured parameters at Oologah Lake tributary sites for the period April through September 2000.

	Conductivity (mS/cm)	DO (mg/l)	pH Units	Water Temp. °C	Turbidity NTU	Stage (feet)	Discharge (cfs)
Verdigris River at Lenapah, Oklahoma (LEPO2)							
Mean	376	7.49	-	24.83	96.6	5.73	2002
Median	376	7.26	7.92	25.55	44.9	4.80	580
St. Dev.	97	1.58	0.27	4.55	149.1	4.00	4371
Min.	139	2.97	7.07	13.63	5.2	2.68	13
Max.	604	13.37	8.76	34.05	1140.9	29.36	31729
N	4189	4200	4188	4210	3984	4306	4306
Big Creek near Childers, Oklahoma (CHBO2)							
Mean	324	6.39	-	24.54	42.4	9.28	250
Median	335	7.10	7.88	25.05	13.1	9.08	17
St. Dev.	84	3.07	0.24	4.83	104.5	1.37	1390
Min.	80	0.02	7.21	11.88	0.1	8.20	1
Max.	454	16.09	9.07	34.13	1147.7	23.59	16951
N	3590	3524	3579	3591	3402	4031	2004

Table 5.2-6. Statistical summary of continuously (hourly) measured parameters below the Oologah Lake Dam (OOL02) for the period April through September 2000.

	Conductivity (mS/cm)	DO (mg/l)	pH Units	Water Temp. °C	Turbidity NTU	Flow in (cfs)	Flow out (cfs)	Elev. (feet)	Storage (ac-ft)
Mean	324	7.34	-	24.12	58.6	2708	2790	639.59	606478
Median	310	7.38	7.72	25.24	38.5	110	10	639.62	604216
St. Dev.	51	1.72	0.30	3.53	59.1	6974	5389	2.46	84356
Min.	251	3.62	7.33	14.82	4.5	0	0	636.42	20564
Max.	485	14.30	8.85	31.41	1131.1	75240	24570	647.28	886690
N	3503	3686	3685	3686	3679	4356	4369	4359	4359

Table 5.2-7. Regression equations for estimates of alkalinity, hardness, TDS, TSS, chloride, sulfate, TOC, NO_x, TKN, and total P in the Verdigris River at Lenapah, Oklahoma, and Big Creek near Childers, Oklahoma.

Constituent	Equation	MSE	R ²
Verdigris River at Lenapah, Oklahoma (LEPO2)			
Alkalinity (<i>Alk</i>)	$Alk = 154.3\log_{10}SC + 116.7\log_{10}DO - 34.7\log_{10}TURB - 285.9$	30.0	0.983
Hardness (<i>HARD</i>)	$HARD = 176.0\log_{10}SC - 3.4TEMP - 39.8\log_{10}TURB - 133.3$	75.9	0.960
Total Dissolved Solids (<i>TDS</i>)	$\log_{10}TDS = 0.698\log_{10}SC - 0.324\log_{10}DO + 0.000005FLOW + 0.836$	0.0016	0.828
Total Suspended Solids (<i>TSS</i>)	$\log_{10}TSS = 0.732pH + 1.265\log_{10}TURB - 6.25$	0.0288	0.928
Chloride (<i>Cl</i>)	$\log_{10}Cl = 1.333\log_{10}SC - 0.213pH - 0.000186TURB - 0.464$	0.0045	0.931
Sulfate (<i>SO₄</i>)	$SO_4 = 334.5\log_{10}SC - 22.04DO + 111.2\log_{10}TURB - 881.7$	341.7	0.867
Total Organic Carbon (<i>TOC</i>)	$\log_{10}TOC = 0.0353DO - 0.1064pH + 0.0943\log_{10}TURB + 1.076$	0.0013	0.910
Nitrate + Nitrite (<i>NO_x</i>)	$\log_{10}NO_x = 0.0346TEMP - 0.00189TURB + 1.675\log_{10}TURB - 4.37$	0.07726	0.715
Total Kjeldahl Nitrogen (<i>TKN</i>)	$\log_{10}TKN = 1.47\log_{10}SC + 0.963\log_{10}TURB - 5.67$	0.026	0.867
Total Phosphorus (<i>TP</i>)	$TP = 0.00225SC - 0.189DO + 0.710\log_{10}TURB - 0.711$	0.0296	0.728
Big Creek Near Childers, Oklahoma (CHBO2)			
Alkalinity (<i>Alk</i>)	$Alk = 0.0361\log_{10}TURB - 1.753\log_{10}STAGE + 3.79$	0.01675	0.786
Hardness (<i>HARD</i>)	$HARD = 0.282SC + 0.0152TURB - 259.32\log_{10}STAGE + 340.62$	196	0.971
Total Dissolved Solids (<i>TDS</i>)	$TDS = -0.048SC - 5TEMP - 55.8\log_{10}TURB + 401.3$	1076	0.703
Total Suspended Solids (<i>TSS</i>)	$TSS = -261.1\log_{10}TEMP + 0.583TURB - 260.4\log_{10}STAGE + 626$	4813	0.930
Chloride (<i>Cl</i>)	$Cl = .0204SC - 24.66\log_{10}TEMP - 12.91\log_{10}STAGE + 46.96$	4.269	0.692
Sulfate (<i>SO₄</i>)	$SO_4 = -142.2\log_{10}TEMP - 23.85\log_{10}TURB + 3.211STAGE + 209.5$	79.48	0.775
Total Organic Carbon (<i>TOC</i>)	$\log_{10}TOC = -1.089\log_{10}TEMP + .114\log_{10}TURB + 1.987$	0.0048	0.932
Total Kjeldahl Nitrogen (<i>TKN</i>)	$TKN = -0.00096SC + 0.00094TURB + 0.719$	0.1064	0.731
Nitrate + Nitrite (<i>NO_x</i>)	$NO_x = -0.304STAGE + 9.326\log_{10}STAGE - 6.137$	0.001958	0.840
Total Phosphorus (<i>TP</i>)	$\log_{10}TP = -3.242\log_{10}TEMP + 0.45\log_{10}STAGE + 0.0564\log_{10}TURB + 2.77$	0.05315	0.831
MSE = mean square error, R ² = coefficient of determination, SC = specific conductance, DO = dissolved oxygen, pH = pH, TURB = turbidity, TEMP = water temperature, FLOW = discharge, STAGE = stream stage height. Units are mg/l for chemical constituents, NTU for TURB, μS/cm for SC, °C for TEMP, cfs for FLOW, and feet for STAGE.			

Table 5.2-8. Median relative percentage differences (RPDs) between measured and estimated constituent concentrations at LEPO2 and CHBO2, May through September 2000.

Constituent	LEPO2	CHBO2
Alkalinity	2.98	17.79
Hardness	4.33	7.81
Total Dissolved Solids	6.19	11.11
Total Suspended Solids	27.62	32.60
Chloride	8.58	30.40
Sulfate	35.05	21.29
Total Organic Carbon	4.52	10.91
Nitrate + Nitrite	35.96	74.00
Total Kjeldahl Nitrogen	22.53	28.99
Total Phosphorus	23.84	23.27

Table 5.2-9. Measured and estimated loads of selected nutrients and sediment at LEPO2 from May through September 2000. Measured loads are based on analyzed field samples and corresponding discharge.

Statistic	Total Nitrogen Load (as N) Measured (kg/d)	Total Nitrogen Load (as N) Estimated (kg/d)	Total Phosphorus Load (as P) Measured (kg/d)	Total Phosphorus Load (as P) Estimated (kg/d)	Total Dissolved Solids Load Measured (kg/d)	Total Dissolved Solids Load Estimated (kg/d)	Total Suspended Solids Load Measured (kg/d)	Total Suspended Solids Load Estimated (kg/d)
Median	42,790	740	3,130	470	1,906,000	283,920	2,217,550	64,970
Mean	62,060	11,190	6,890	3,070	3,541,240	935,970	13,649,110	1,703,000
St. Dev.	81,090	30,180	11,720	6,680	4,246,800	1,947,350	21,114,820	6,666,410
Min.	30	10	10	<10	38,990	7,450	3,820	170
Max.	258,130	264,470	46,110	48,130	12,767,590	14,281,600	62,876,010	80,961,750
N	15	3,954	15	1,904	15	4,152	15	3,961

Table 5.2-10. Measured and estimated loads of selected nutrients and sediment at CHBO2 from May through September 2000. Measured loads are based on analyzed field samples and corresponding discharge.

Statistic	Total Nitrogen Load (as N) Measured (kg/d)	Total Nitrogen Load (as N) Estimated (kg/d)	Total Phosphorus Load (as P) Measured (kg/d)	Total Phosphorus Load (as P) Estimated (kg/d)	Total Dissolved Solids Load Measured (kg/d)	Total Dissolved Solids Load Estimated (kg/d)	Total Suspended Solids Load Measured (kg/d)	Total Suspended Solids Load Estimated (kg/d)
Median	20	20	<10	<10	8,970	7,970	590	1,510
Mean	6,670	410	1,570	90	1,253,960	100,100	837,830	127,600
St. Dev.	12,030	2,150	2,950	600	2,165,490	529,300	1,599,190	706,960
Min.	<10	<10	<10	<10	2,620	410	50	<10
Max.	29,790	29,990	7,340	6,890	5,293,650	6,170,440	3,991,020	9,440,590
N	6	1,858	6	1,895	6	1,890	6	1,356

Table 5.2-11. Median relative percentage differences (RPDs) between measured and estimated constituent loads at LEPO2 and CHBO2, May through September 2000.

Constituent	LEPO2	CHBO2
Total Nitrogen	21.45	39.10
Total Phosphorus	23.84	23.02
Total Dissolved Solids	6.19	9.26
Total Suspended Solids	27.62	21.97

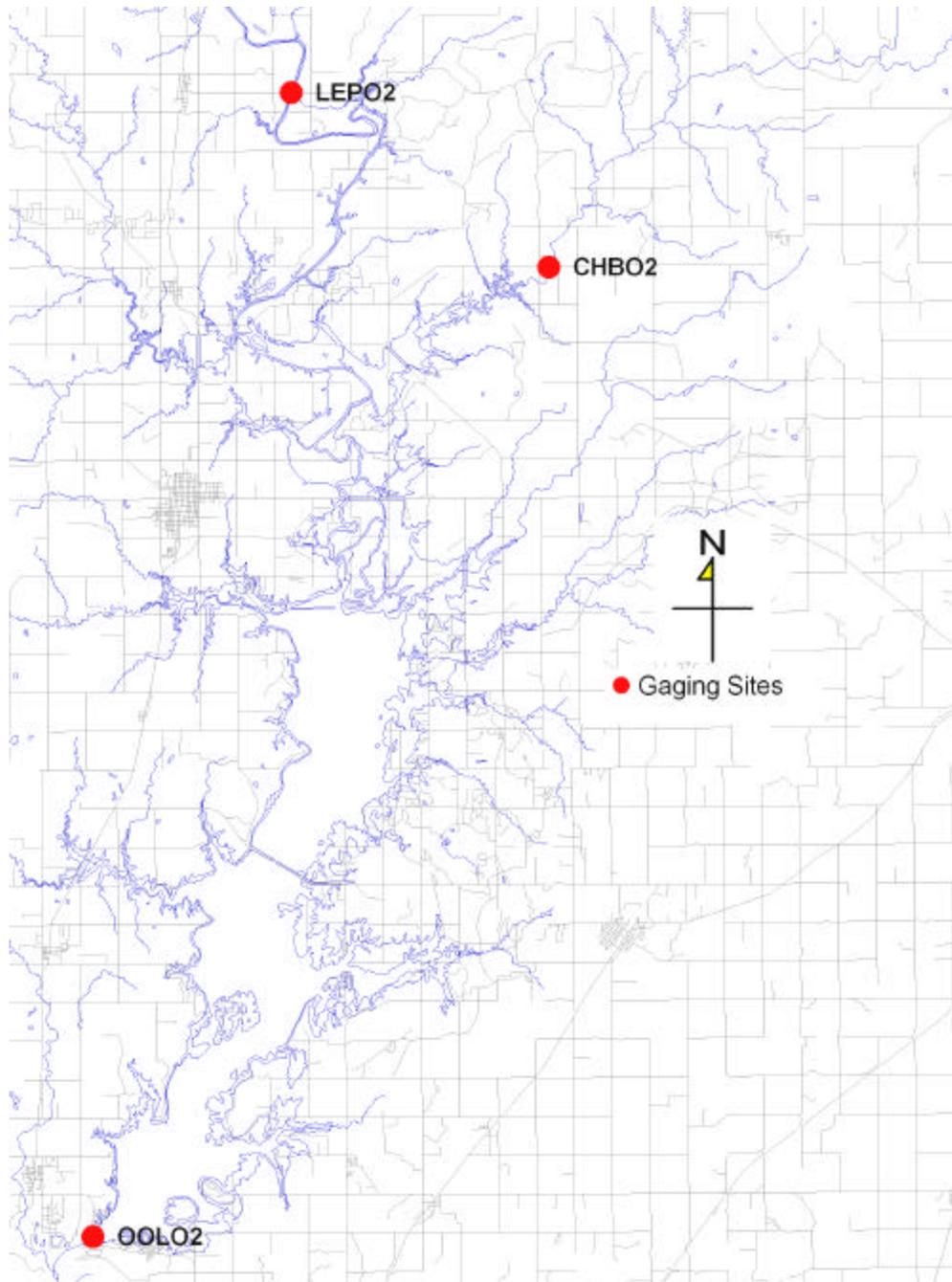


Figure 5.2-1
Locations of gaging sites LEPO2, CHBO2, and OOLO2.

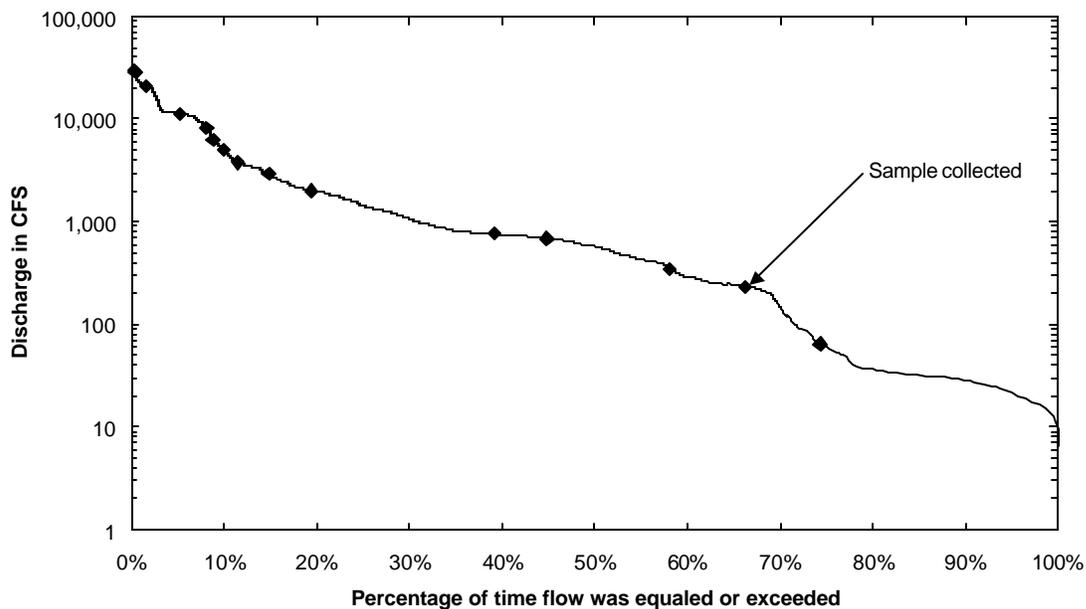


Figure 5.2-2
Flow-duration curve for the Verdigris River at Lenapah (April through September 2000)
with indications of stream flow at which field samples were collected.

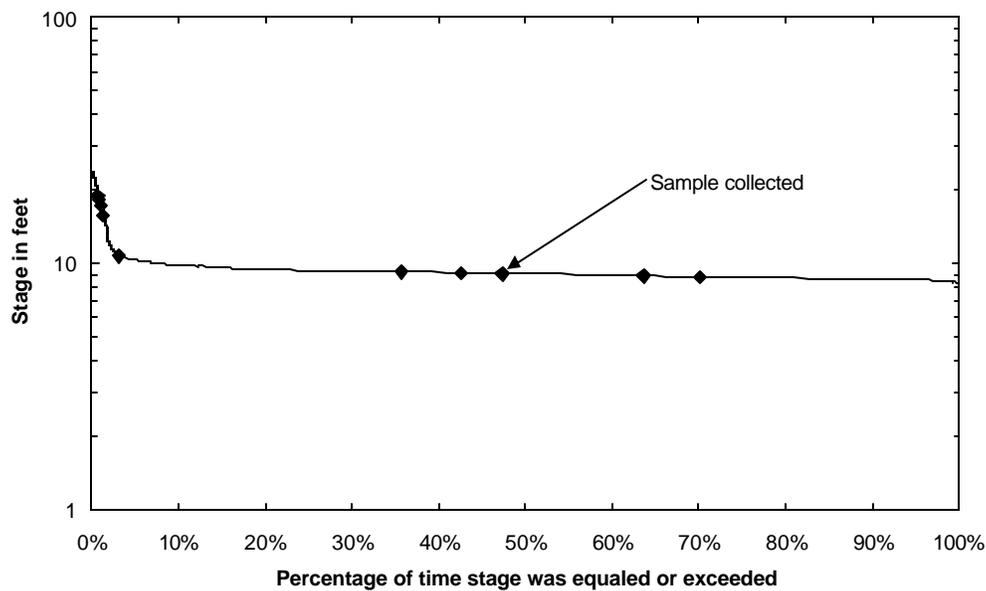


Figure 5.2-3
Stage-duration curve for Big Creek near Childers (April through September 2000),
with indications of stage at which field samples were collected.

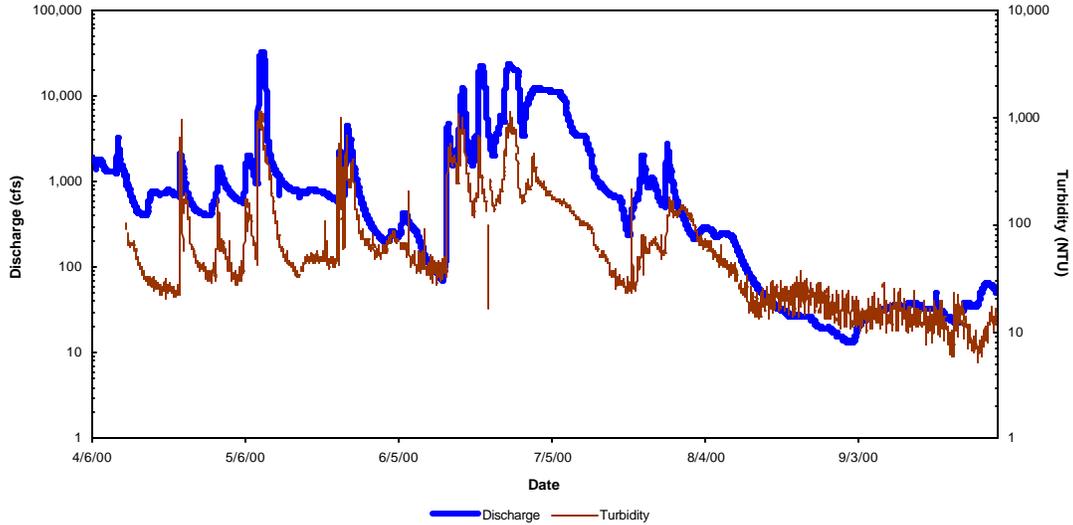


Figure 5.2-4
Comparison of hourly discharge and turbidity measured at the Verdigris River at Lenapah, Oklahoma, from April 2000 through September 2000.

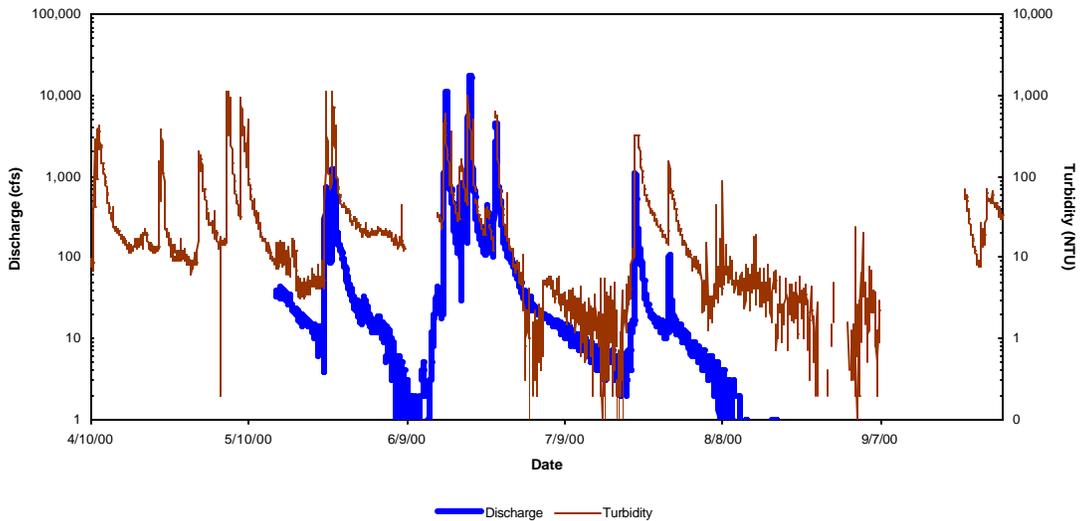


Figure 5.2-5
Comparison of hourly discharge and turbidity measured at Big Creek near Childers, Oklahoma, from April 2000 through September 2000.
 (Note: Stage records exist for April through early May. Discharge will be computed from stage when data base is updated. Discharge from early August to end of study period was essentially zero.)

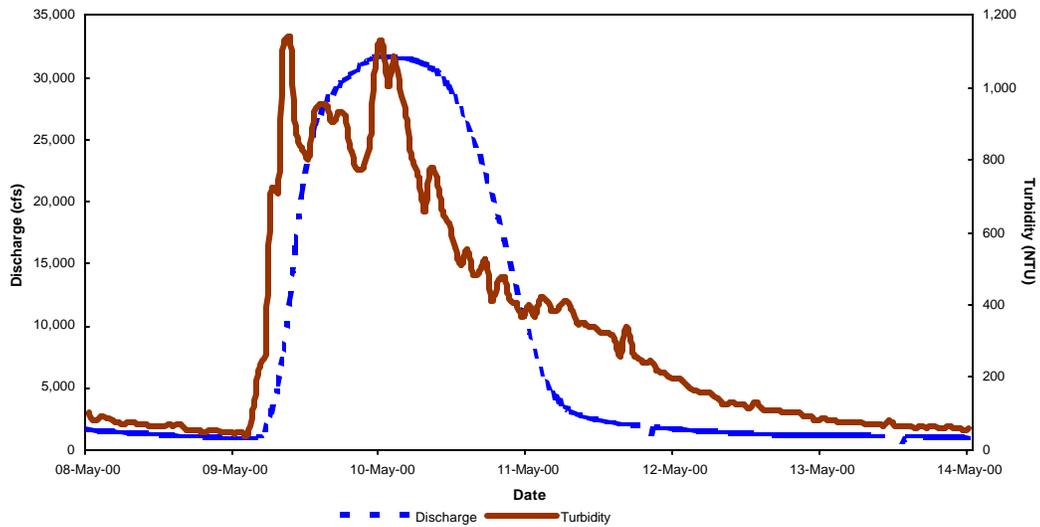


Figure 5.2-6
Hourly discharge and turbidity at the Verdigris River at Lenapah, Oklahoma,
from 8 May 2000 through 13 May 2000.

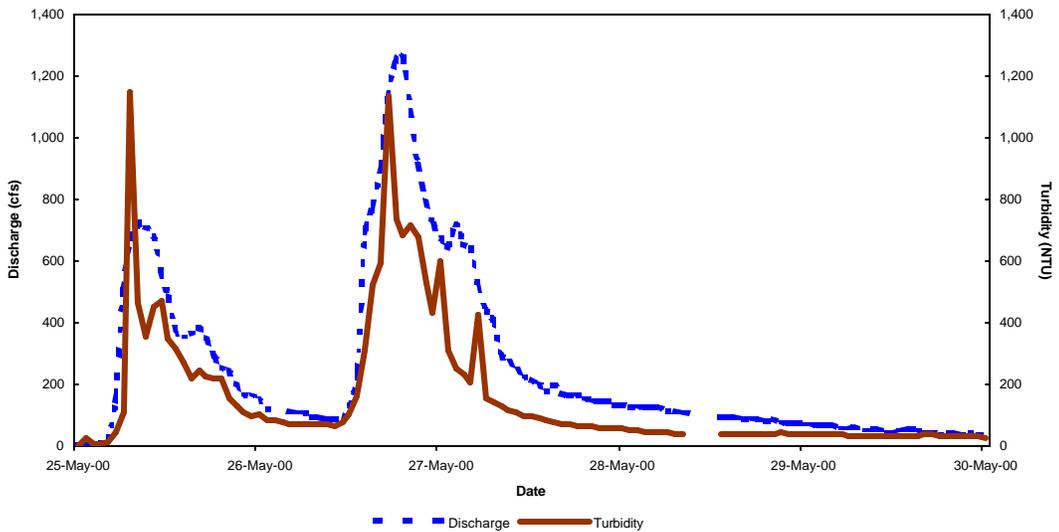


Figure 5.2-7
Hourly discharge and turbidity at Big Creek near Childers, Oklahoma,
from 25 May 2000 through 29 May 2000.

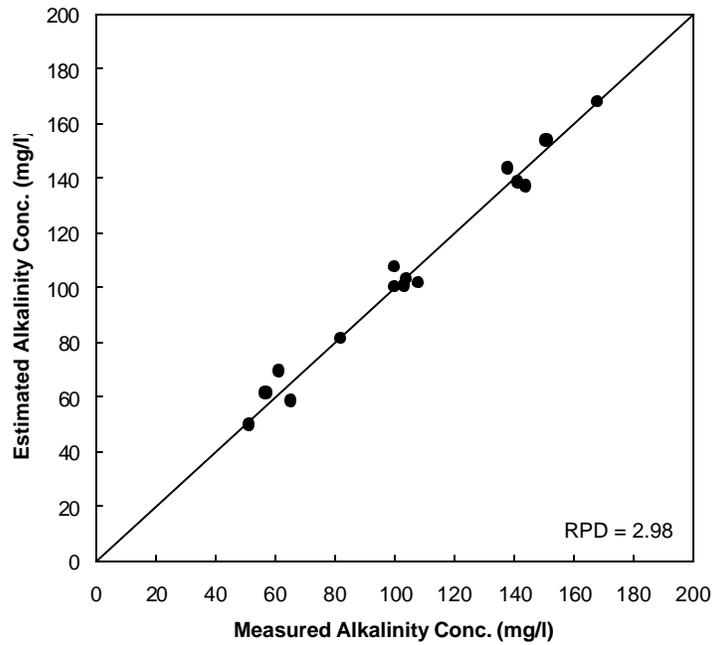


Figure 5.2-8
Comparison of measured and estimated alkalinity at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

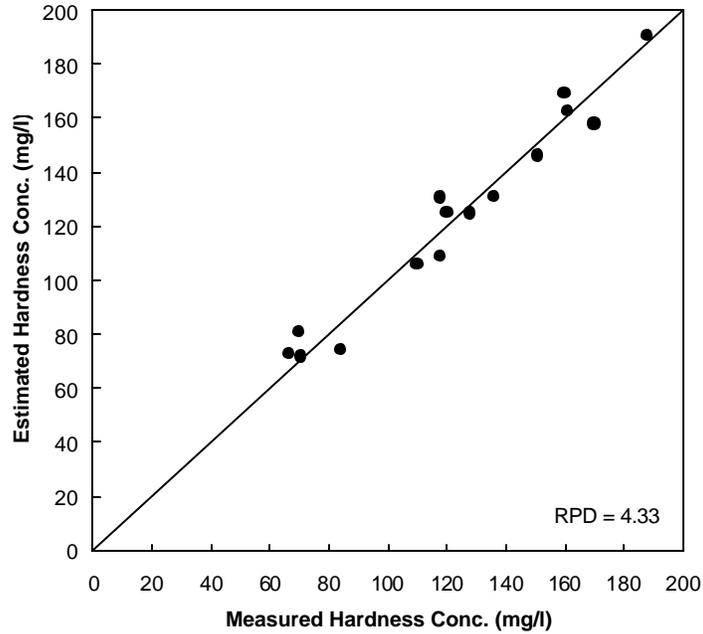


Figure 5.2-9
Comparison of measured and estimated hardness at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

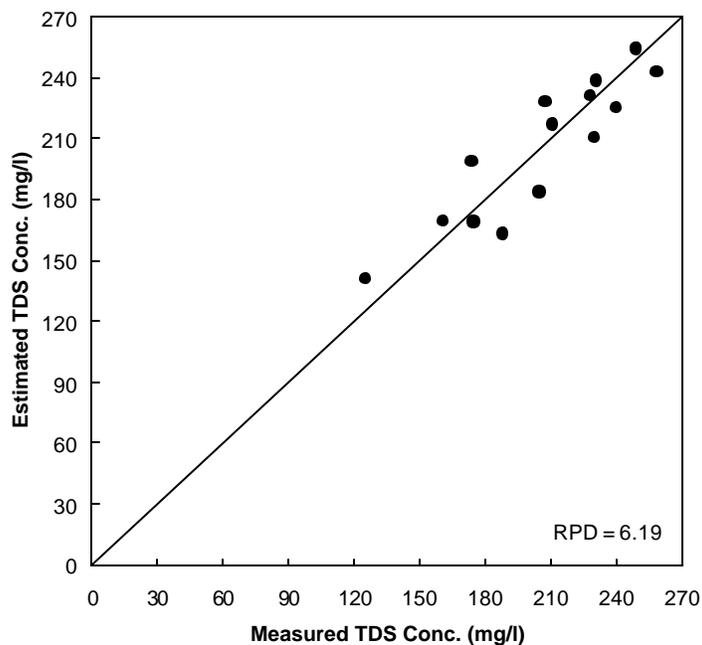


Figure 5.2-10
Comparison of measured and estimated total dissolved solids concentration at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

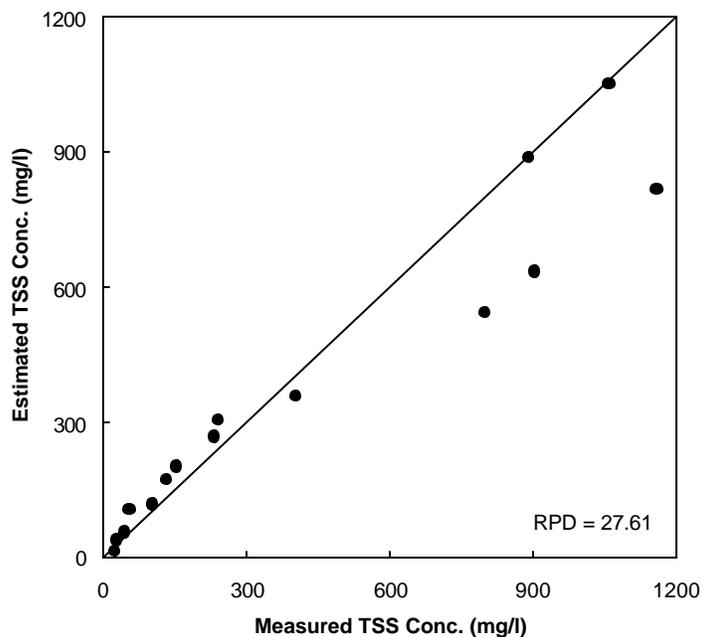


Figure 5.2-11
Comparison of measured and estimated total suspended solids concentration at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

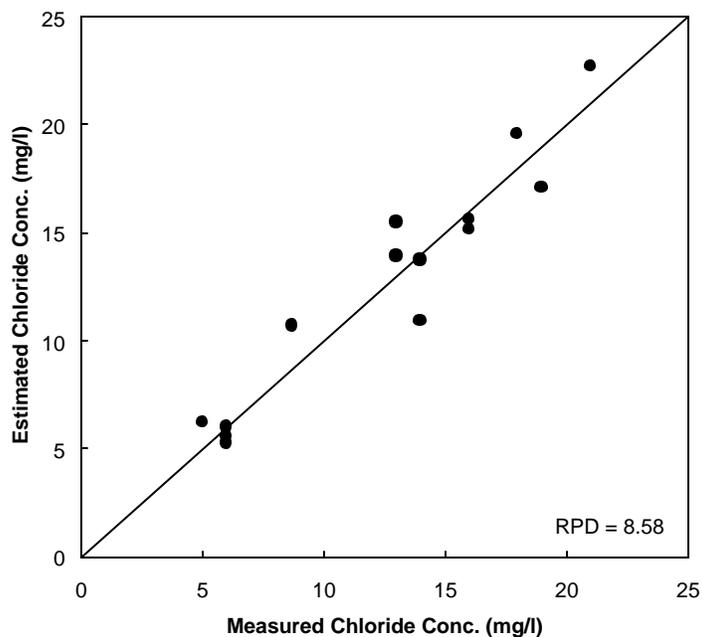


Figure 5.2-12
Comparison of measured and estimated chloride concentration at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

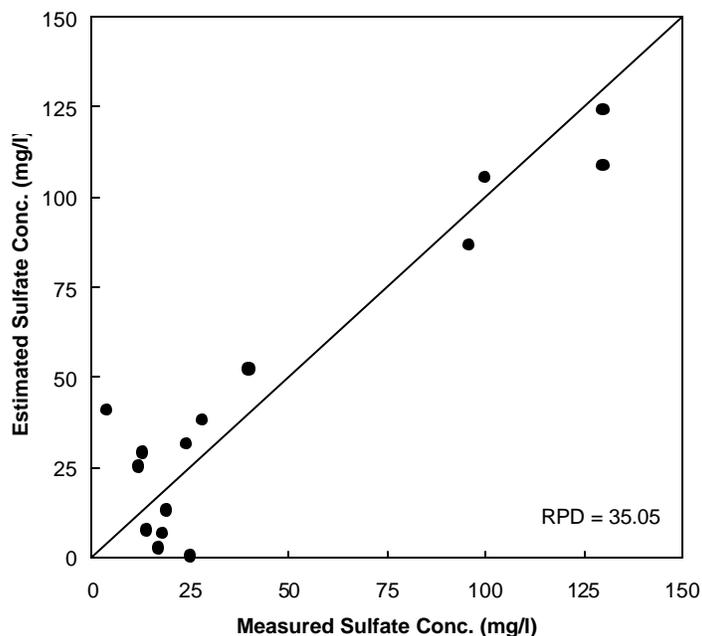


Figure 5.2-13
Comparison of measured and estimated sulfate concentration at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

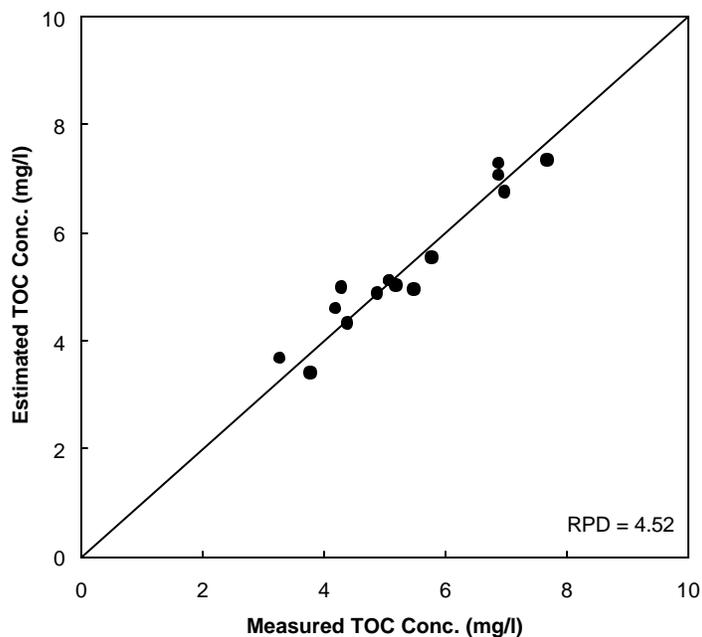


Figure 5.2-14
Comparison of measured and estimated total organic carbon concentration at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

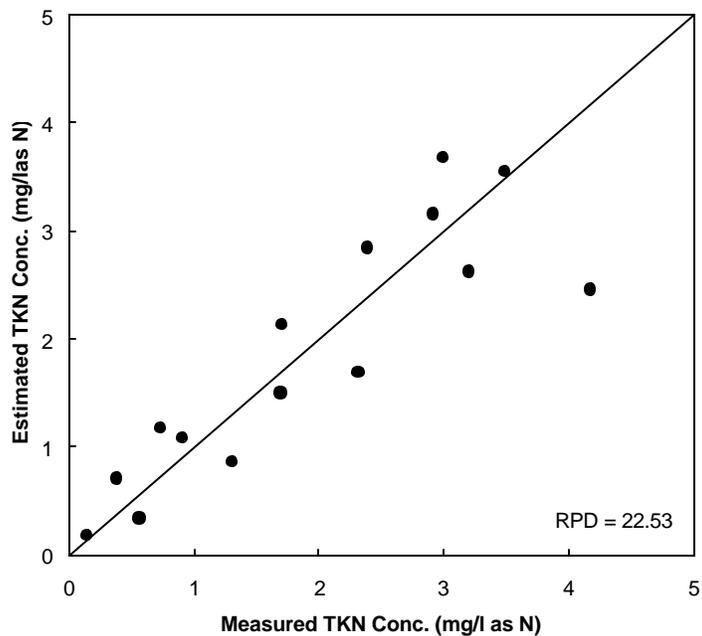


Figure 5.2-15
Comparison of measured and estimated total Kjeldahl nitrogen concentration at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

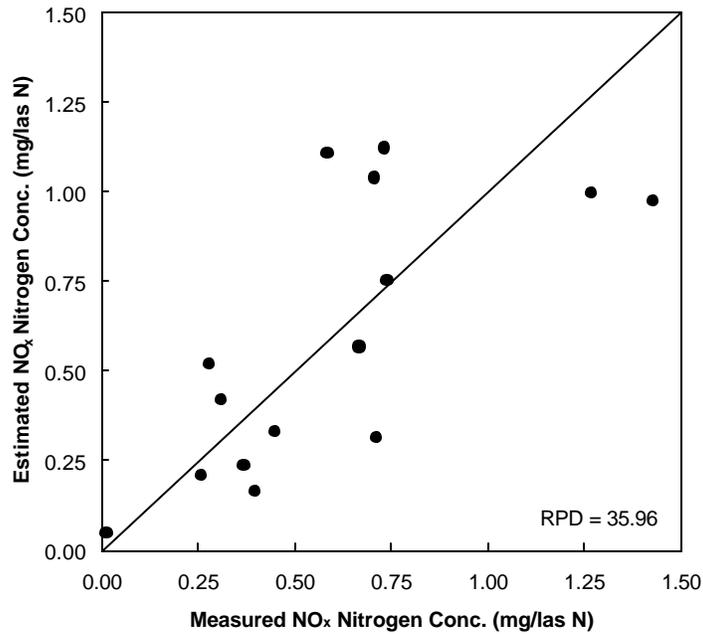


Figure 5.2-16
Comparison of measured and estimated NO_x concentration at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

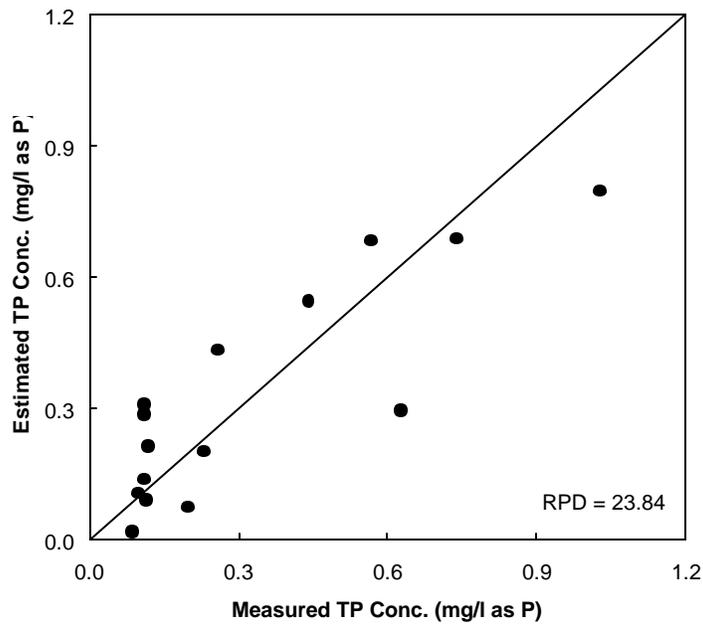


Figure 5.2-17
Comparison of measured and estimated total phosphorus concentration at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

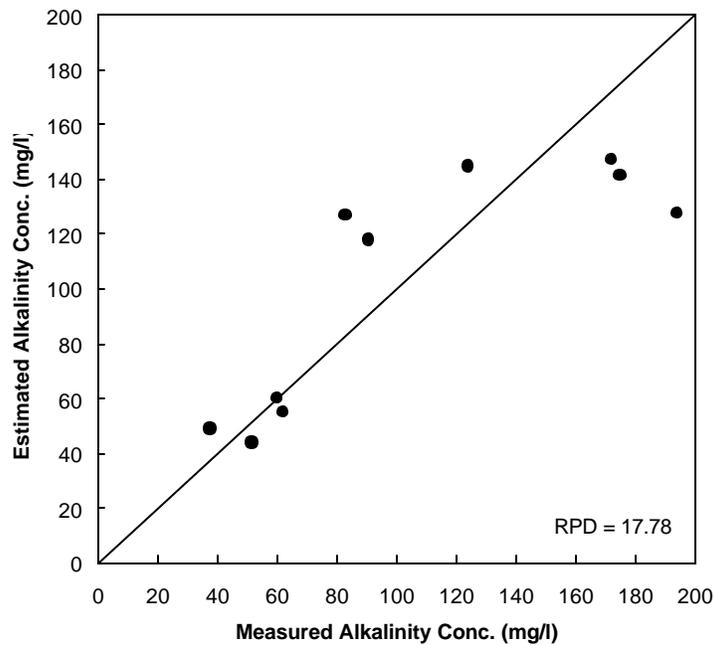


Figure 5.2-18
Comparison of measured and estimated alkalinity at CHBO2,
May through September 2000 (RPD = median relative percentage difference).

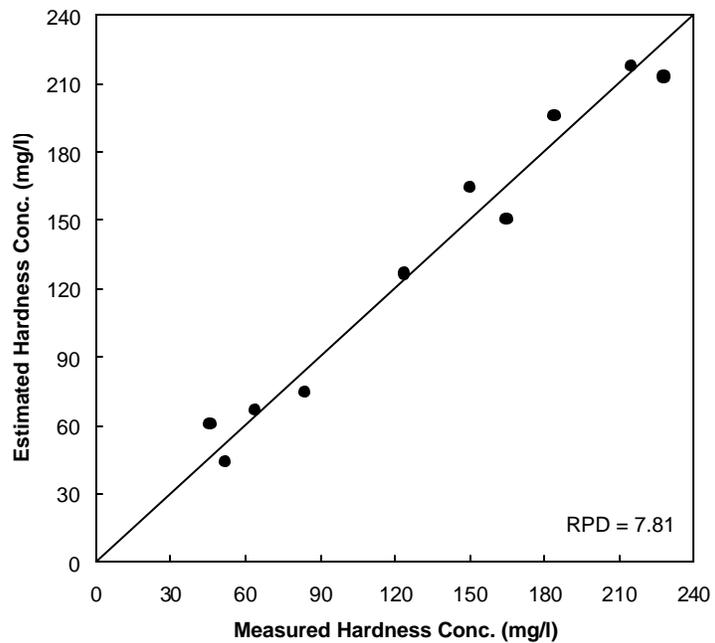


Figure 5.2-19
Comparison of measured and estimated hardness at CHBO2,
May through September 2000 (RPD = median relative percentage difference).

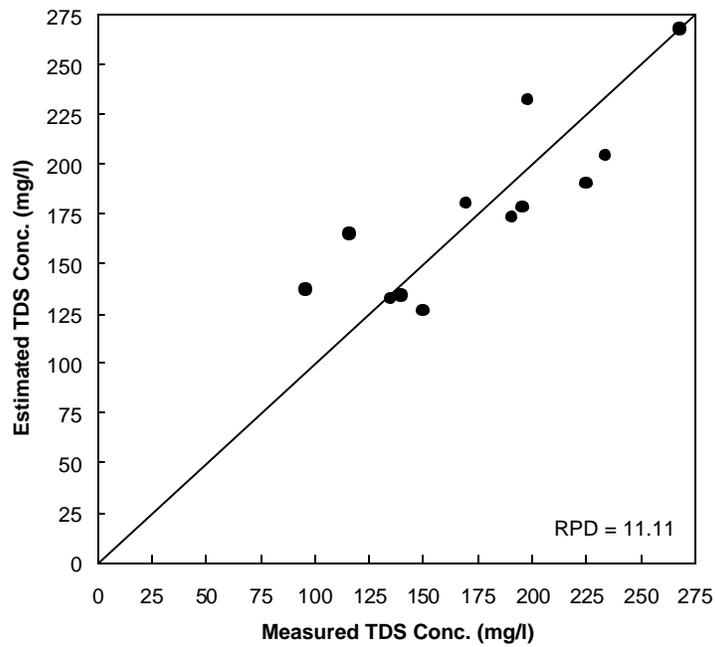


Figure 5.2-20
Comparison of measured and estimated total dissolved solids concentration at CHBO2,
May through September 2000 (RPD = median relative percentage difference).

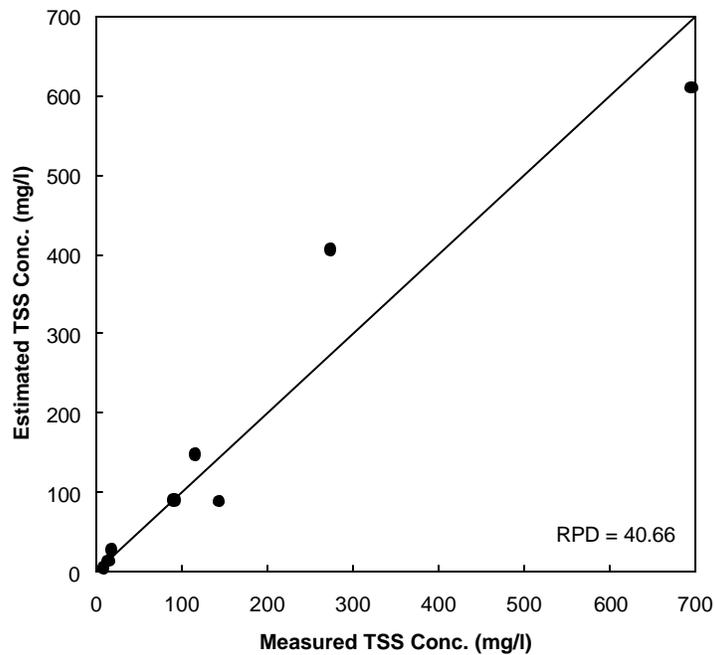


Figure 5.2-21
Comparison of measured and estimated total suspended solids concentration at CHBO2,
May through September 2000 (RPD = median relative percentage difference).

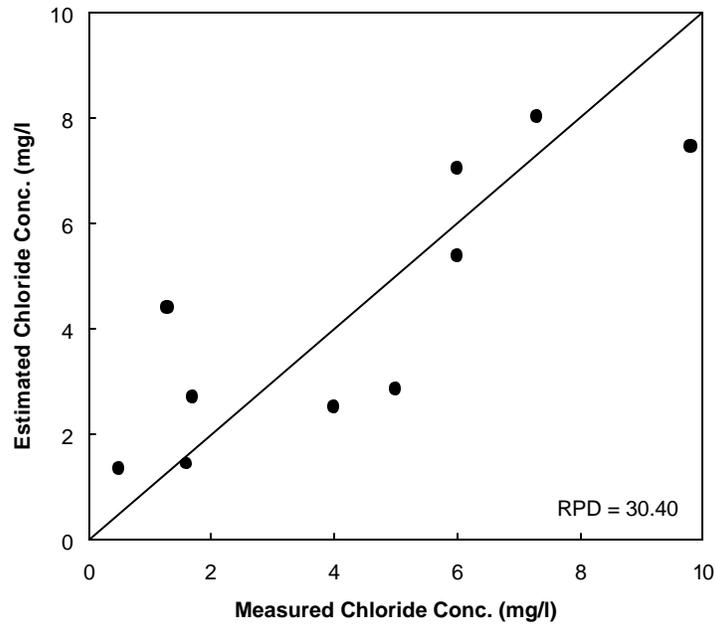


Figure 5.2-22
Comparison of measured and estimated chloride concentration at CHBO2,
May through September 2000 (RPD = median relative percentage difference).

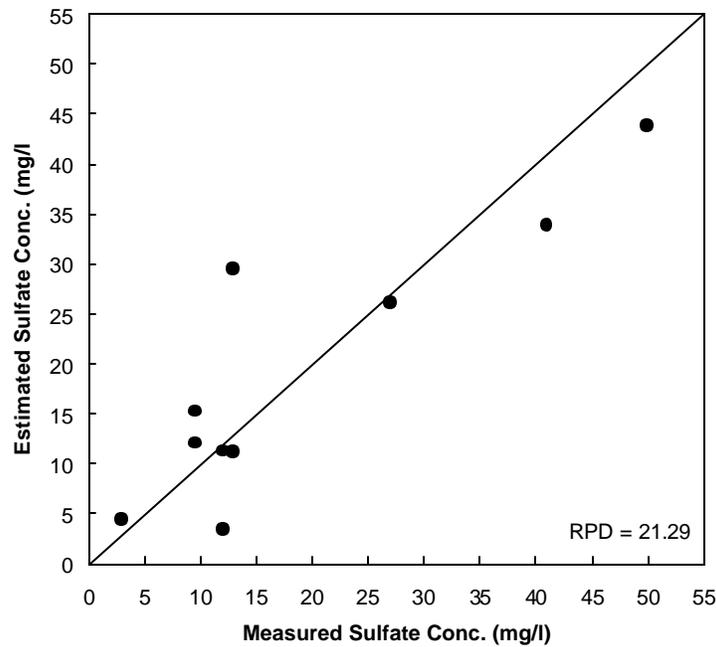


Figure 5.2-23
Comparison of measured and estimated sulfate concentration at CHBO2,
May through September 2000 (RPD = median relative percentage difference).

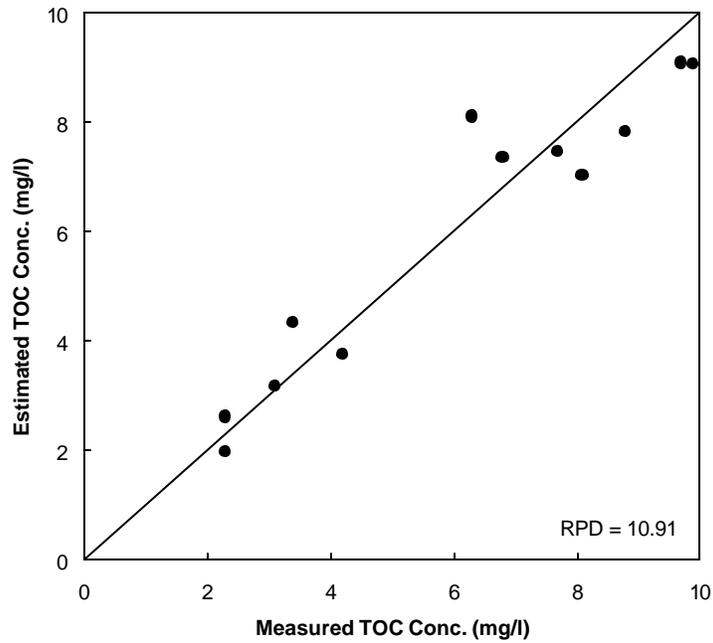


Figure 5.2-24
Comparison of measured and estimated total organic carbon concentration at CHBO2,
May through September 2000 (RPD = median relative percentage difference).

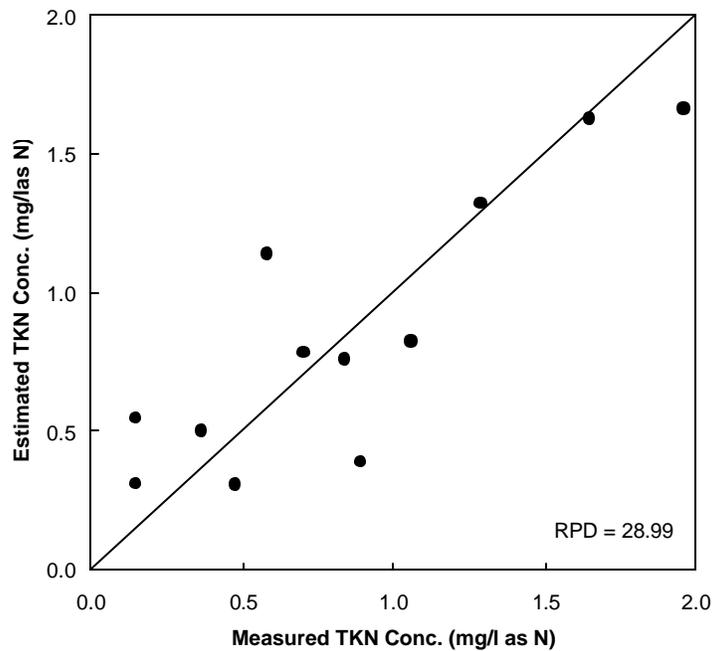


Figure 5.2-25
Comparison of measured and estimated total Kjeldahl nitrogen concentration at CHBO2,
May through September 2000 (RPD = median relative percentage difference).

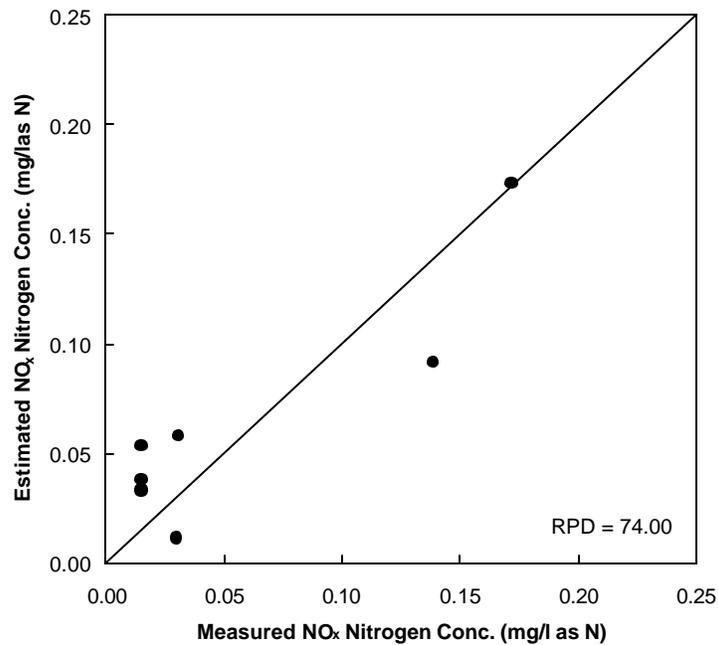


Figure 5.2-26
Comparison of measured and estimated nitrate + nitrite concentration at CHBO2,
May through September 2000 (RPD = median relative percentage difference).

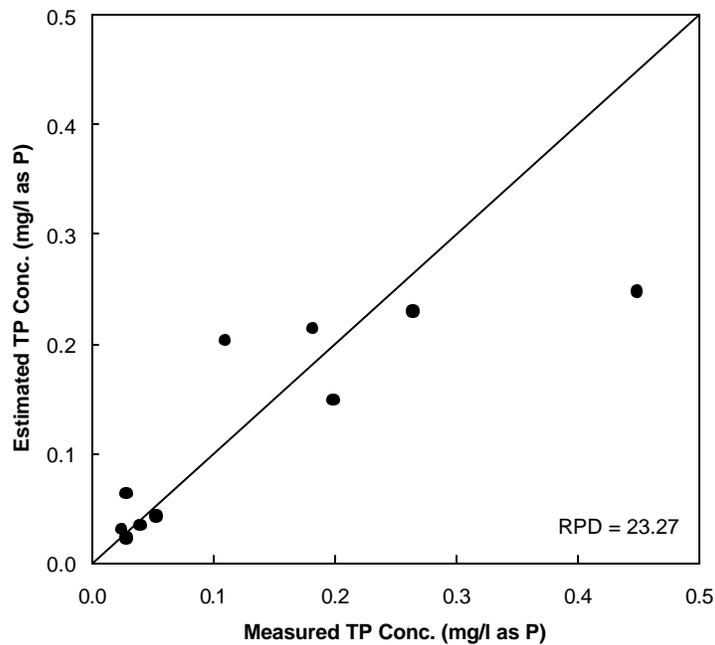


Figure 5.2-27
Comparison of measured and estimated total phosphorus concentration at CHBO2,
May through September 2000 (RPD = median relative percentage difference).

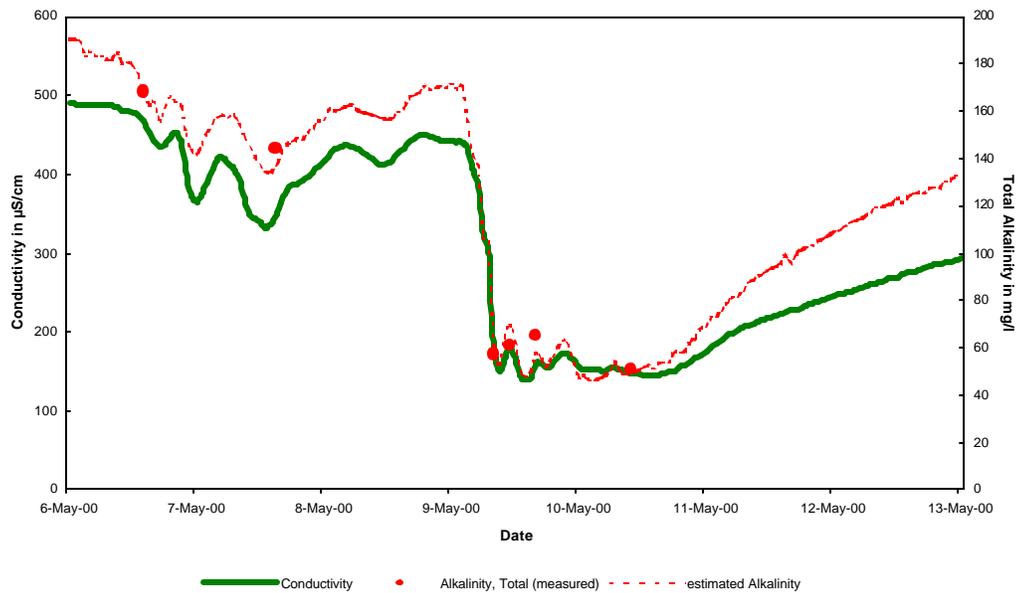


Figure 5.2-28
Comparison of measured and estimated total alkalinity and measured conductivity
at LEPO2, 6 – 13 May 2000.

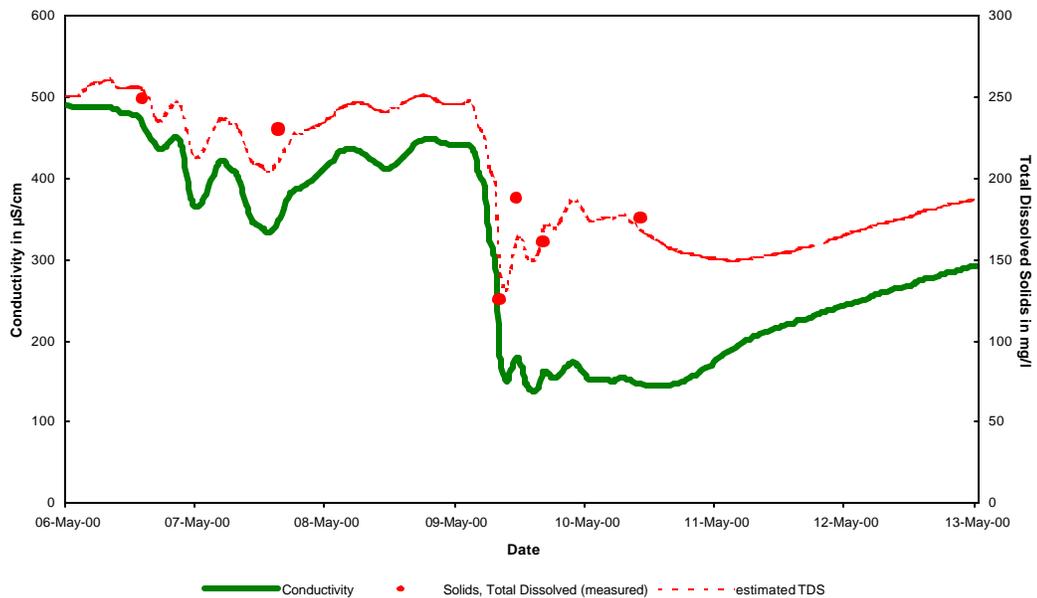


Figure 5.2-29
Comparison of measured and estimated total dissolved solids and measured conductivity
at LEPO2, 6 – 13 May 2000.

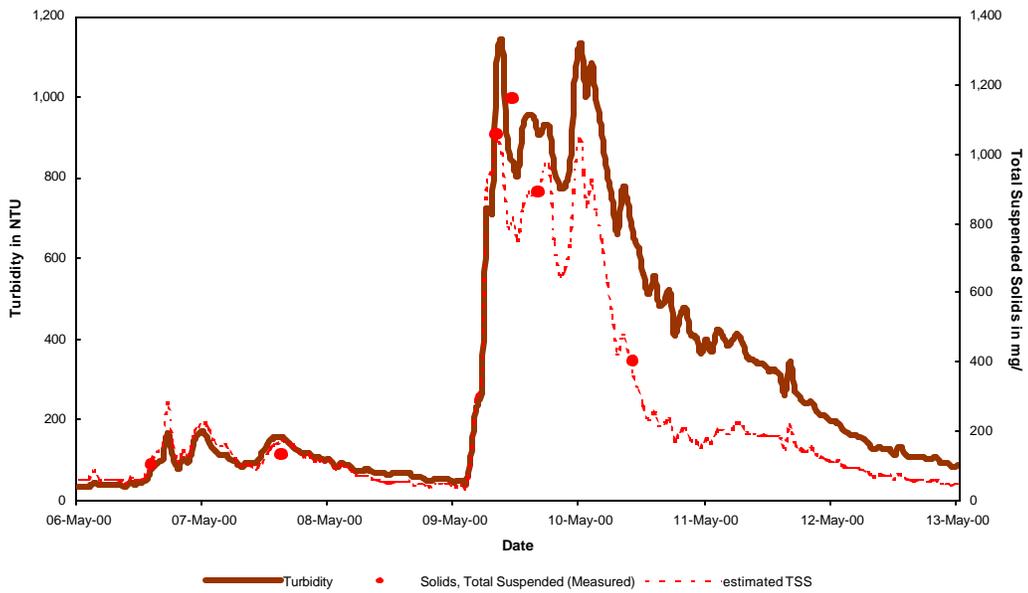


Figure 5.2-30
Comparison of measured and estimated total suspended solids and measured turbidity
at LEPO2, 6 – 13 May 2000.

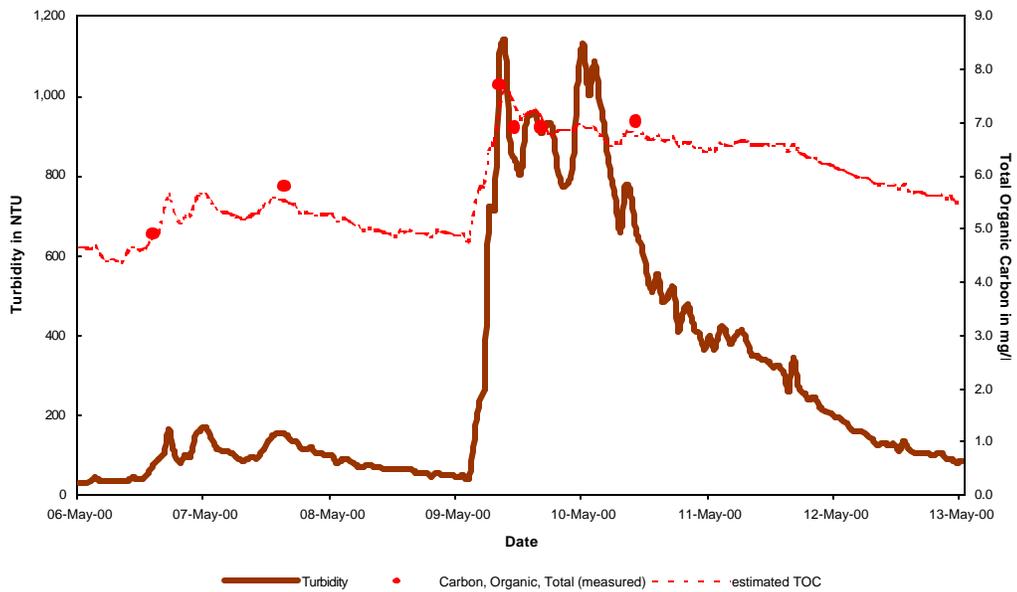


Figure 5.2-31
Comparison of measured and estimated total organic carbon and measured turbidity
at LEPO2, 6 – 13 May 2000.

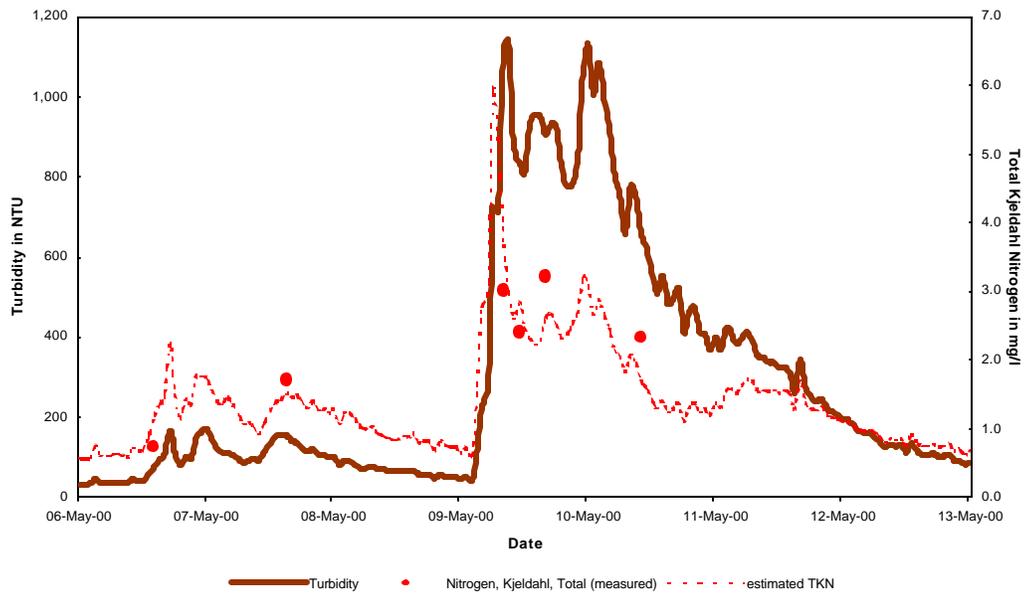


Figure 5.2-32
Comparison of measured and estimated total Kjeldahl nitrogen and measured turbidity
at LEPO2, 6 – 13 May 2000.

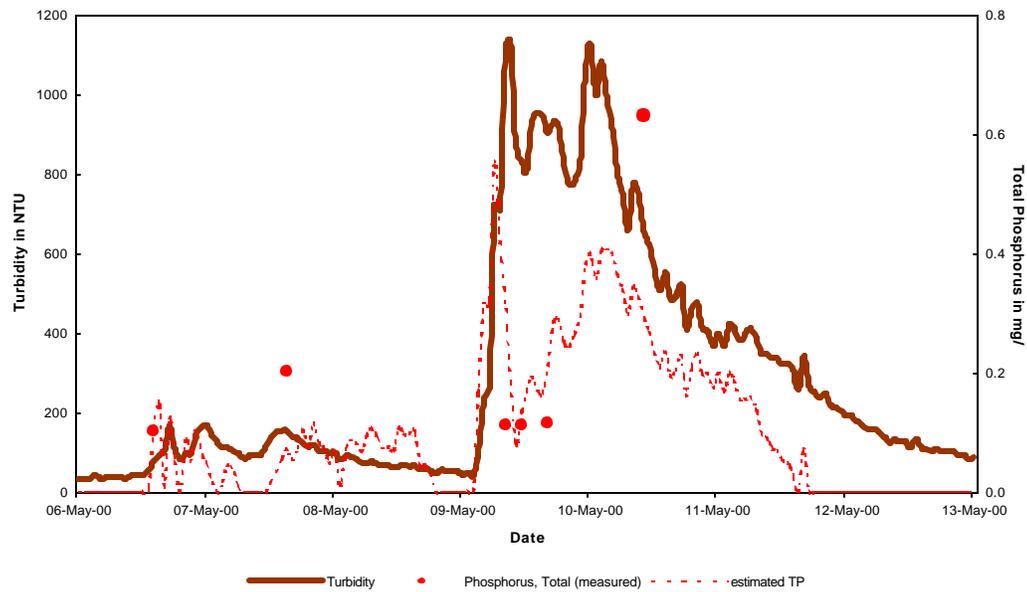


Figure 5.2-33
Comparison of measured and estimated total phosphorus and measured turbidity
at LEPO2, 6 – 13 May 2000.

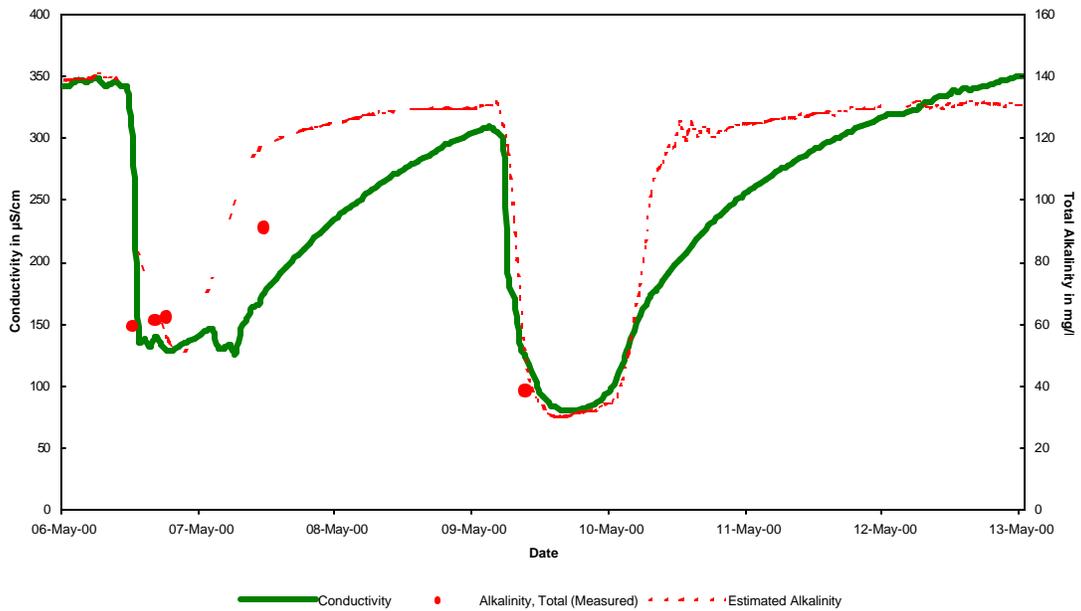


Figure 5.2-34
Comparison of measured and estimated total alkalinity and measured conductivity
at CHBO2, 6 – 13 May 2000.

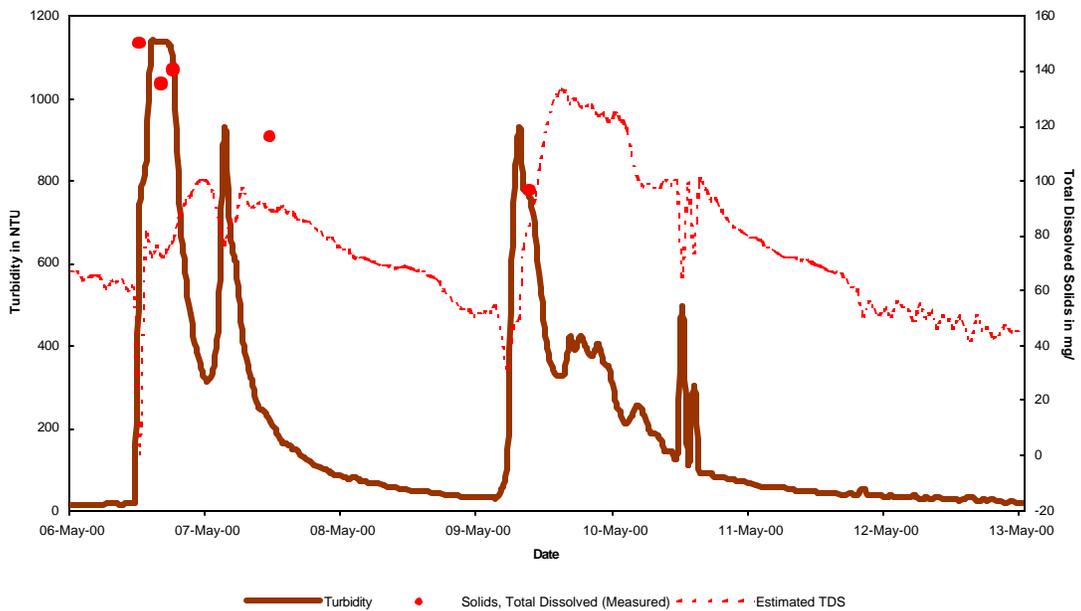


Figure 5.2-35
Comparison of measured and estimated total dissolved solids and measured turbidity
at CHBO2, 6 – 13 May 2000.

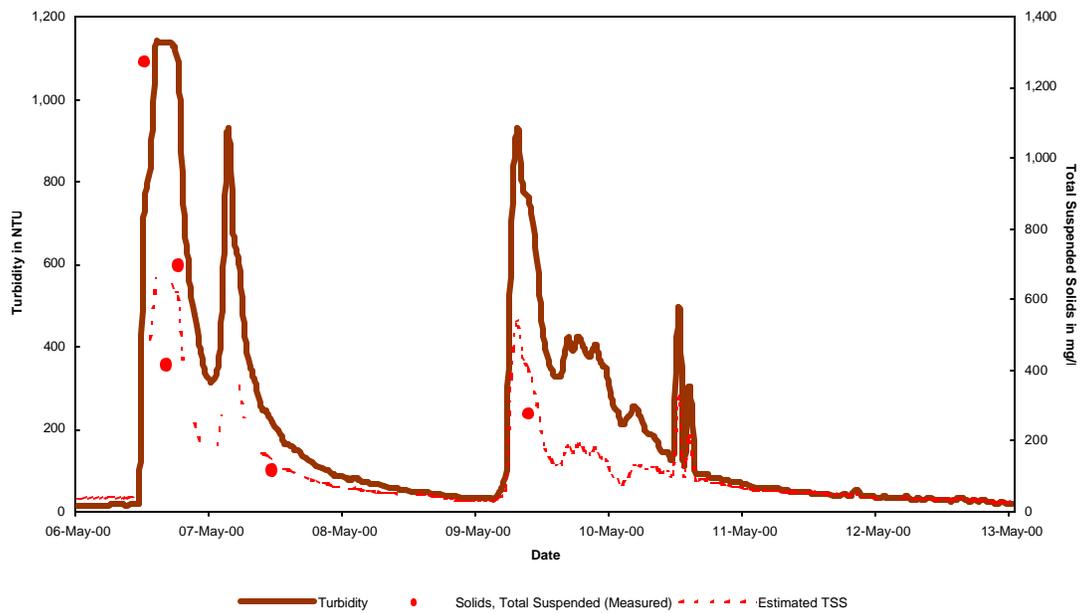


Figure 5.2-36
Comparison of measured and estimated total suspended solids and measured turbidity
at CHBO2, 6 – 13 May 2000.

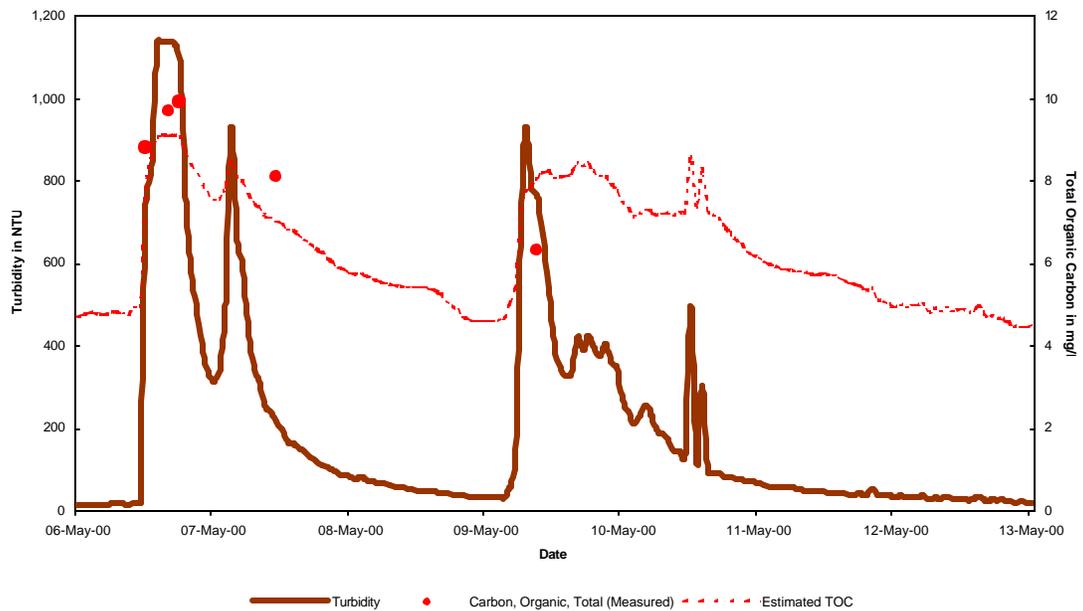


Figure 5.2-37
Comparison of measured and estimated total organic carbon and measured turbidity
at CHBO2, 6 – 13 May 2000.

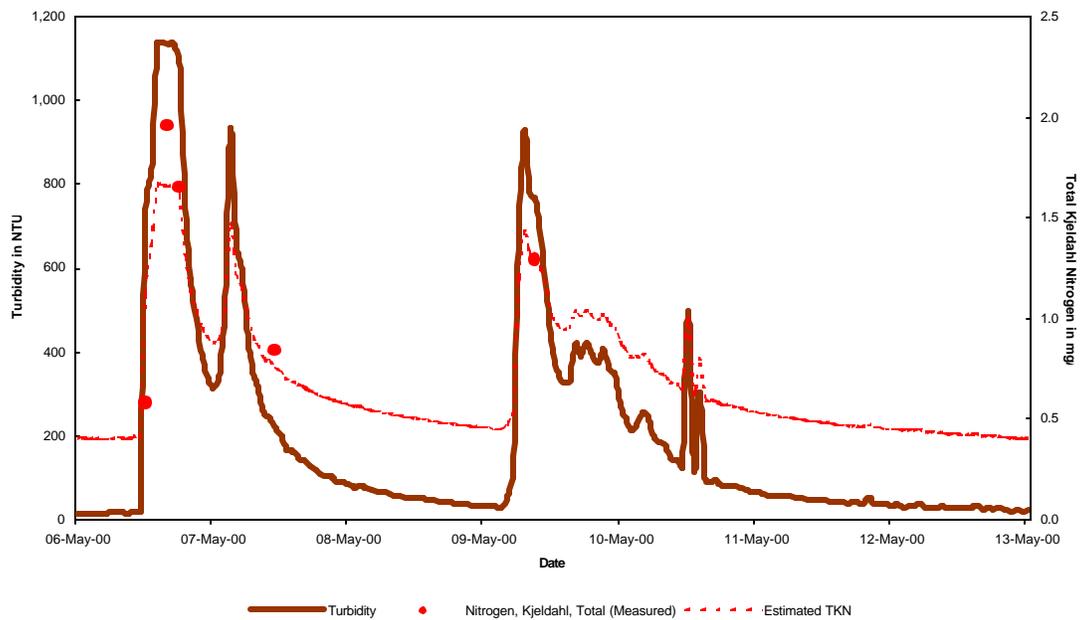


Figure 5.2-38
Comparison of measured and estimated total Kjeldahl nitrogen and measured turbidity
at CHBO2, 6 – 13 May 2000.

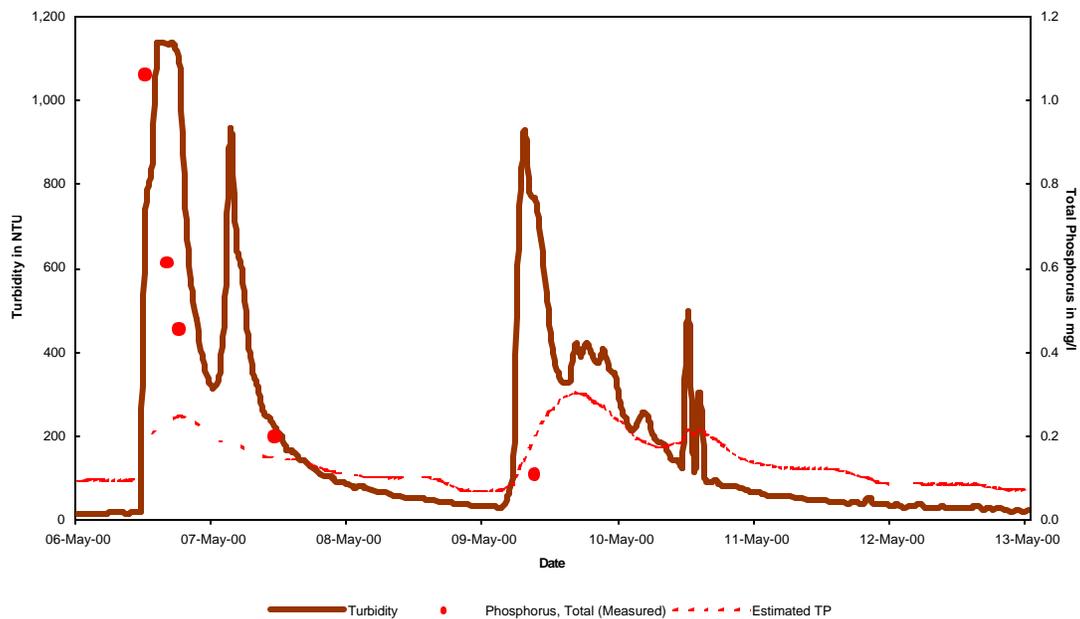


Figure 5.2-39
Comparison of measured and estimated total phosphorus and measured turbidity
at CHBO2, 6 – 13 May 2000.

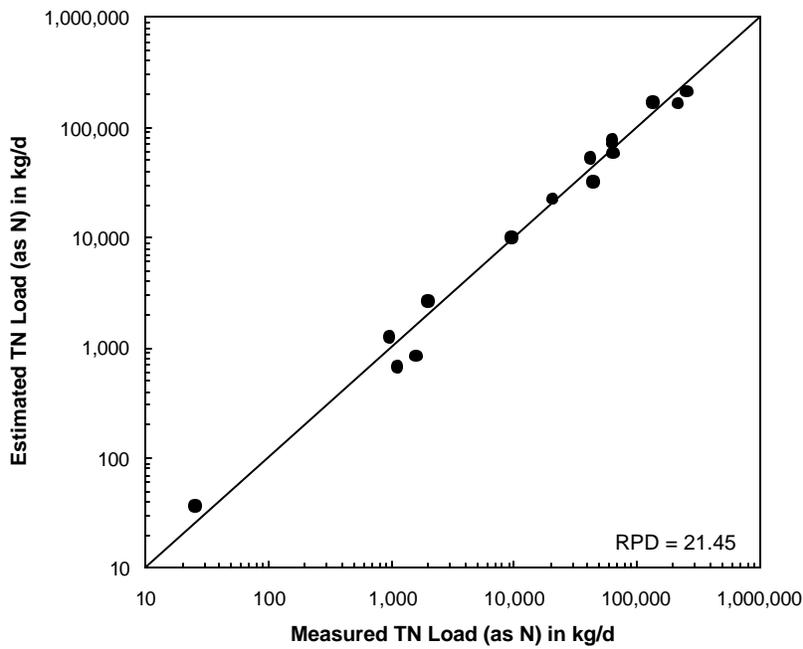


Figure 5.2-40
Comparison of measured and estimated total nitrogen load at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

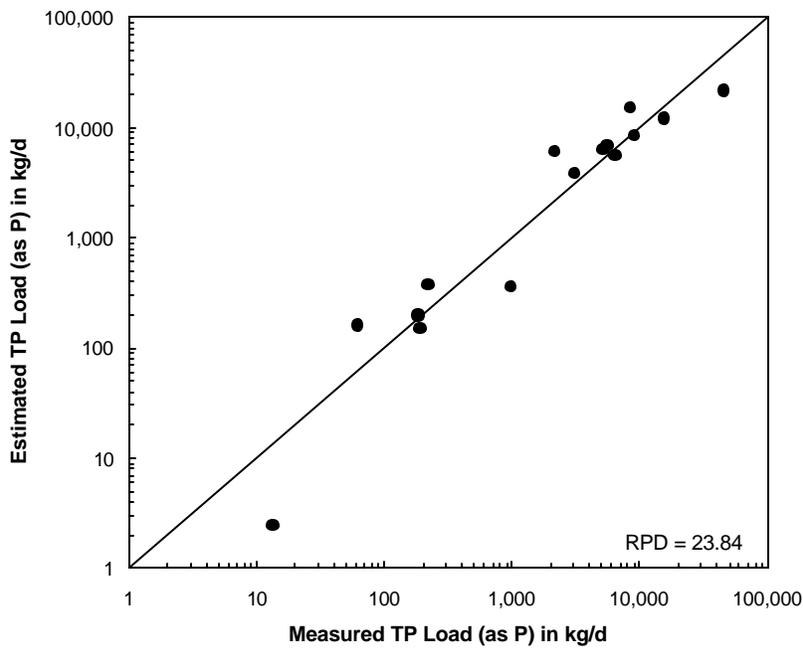


Figure 5.2-41
Comparison of measured and estimated total phosphorus load at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

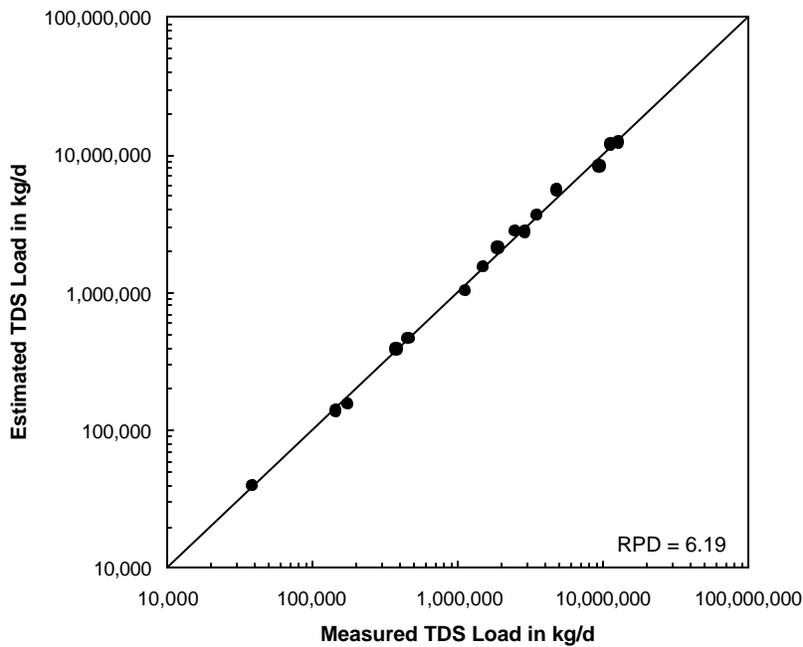


Figure 5.2-42
Comparison of measured and estimated total dissolved solids load at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

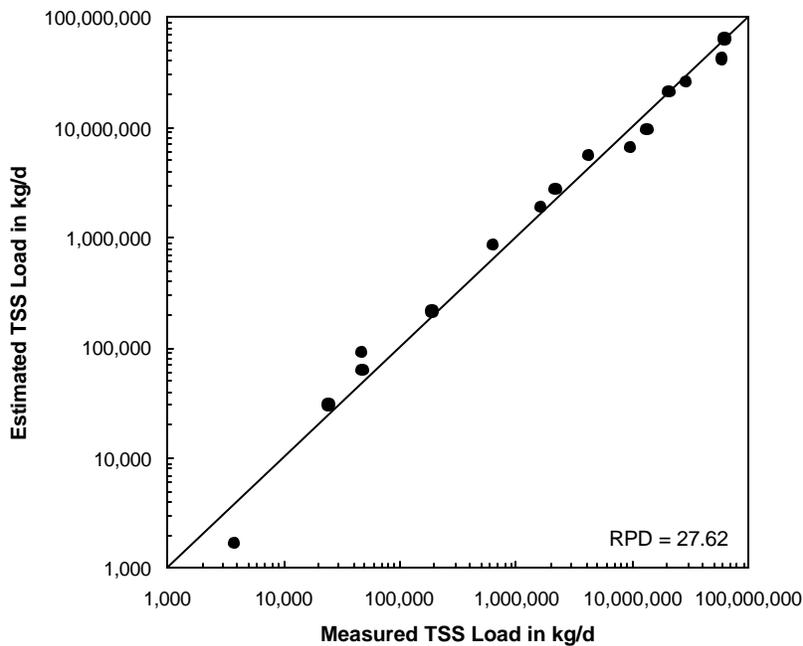


Figure 5.2-43
Comparison of measured and estimated total suspended solids load at LEPO2,
May through September 2000 (RPD = median relative percentage difference).

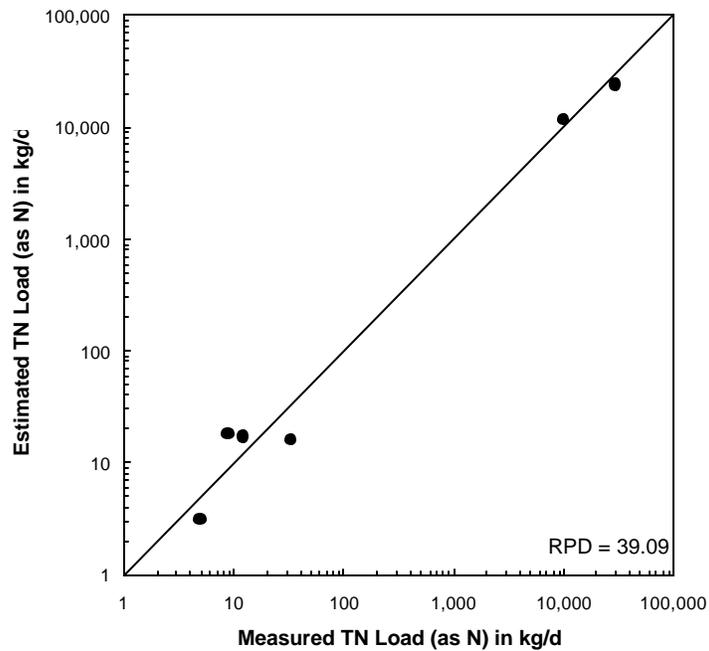


Figure 5.2-44
Comparison of measured and estimated total nitrogen load at CHBO2,
May through September 2000 (RPD = median relative percentage difference).

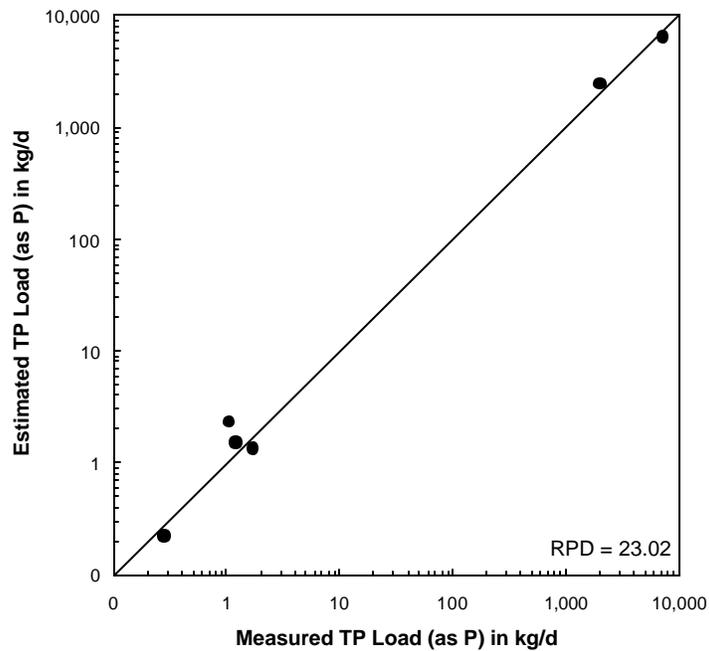


Figure 5.2-45
Comparison of measured and estimated total phosphorus load at CHBO2,
May through September 2000 (RPD = median relative percentage difference).

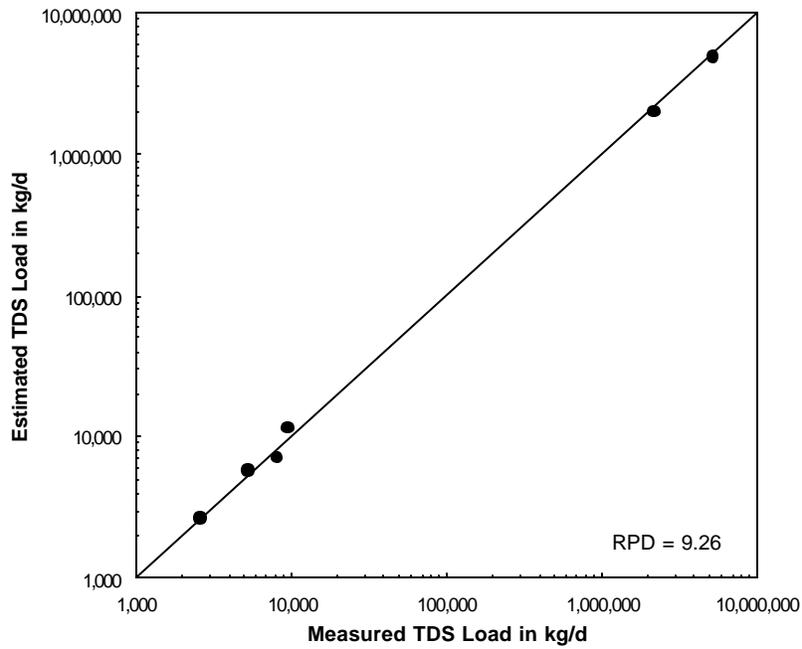


Figure 5.2-46
Comparison of measured and estimated total dissolved solids load at CHBO2, May through September 2000 (RPD = median relative percentage difference).

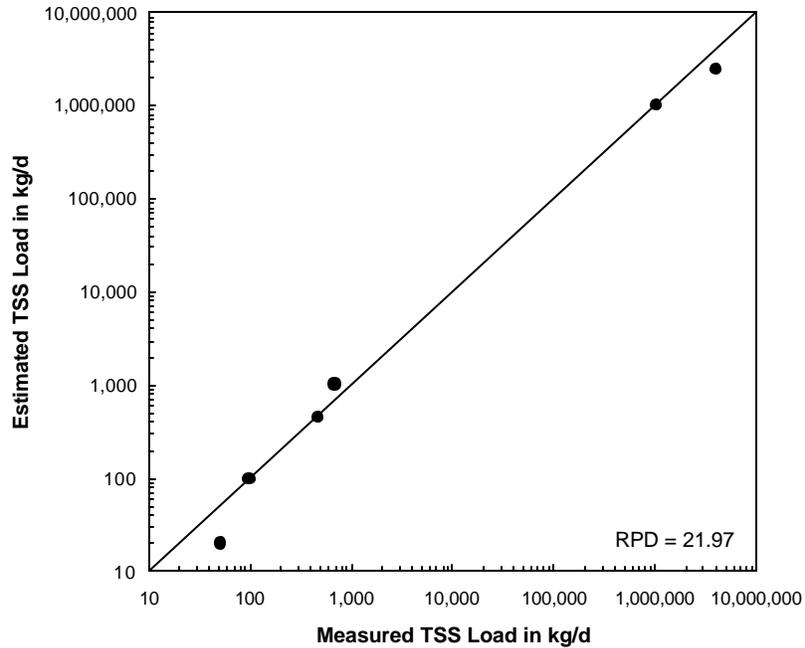


Figure 5.2-47
Comparison of measured and estimated total suspended solids load at CHBO2, May through September 2000 (RPD = median relative percentage difference).

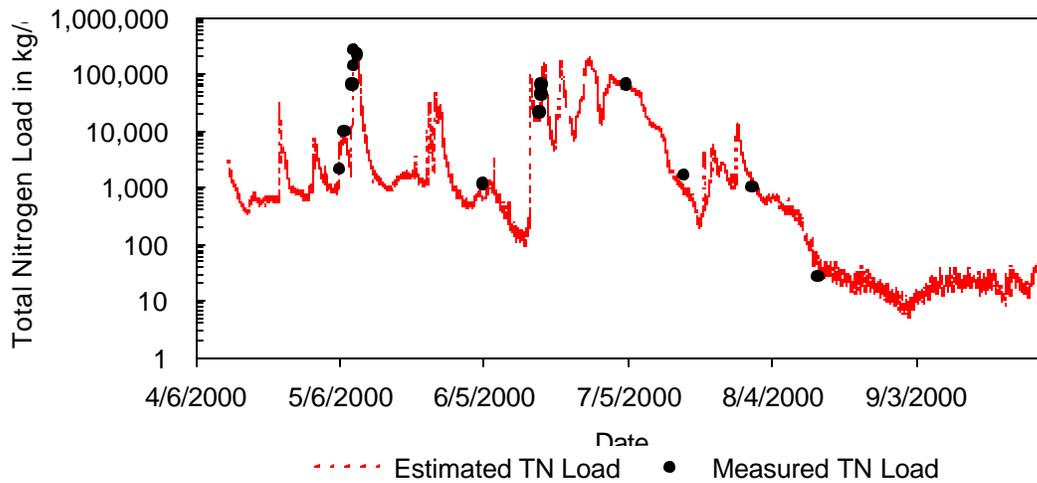


Figure 5.2-48
Comparison of measured and estimated total nitrogen load at LEPO2,
April through September 2000.

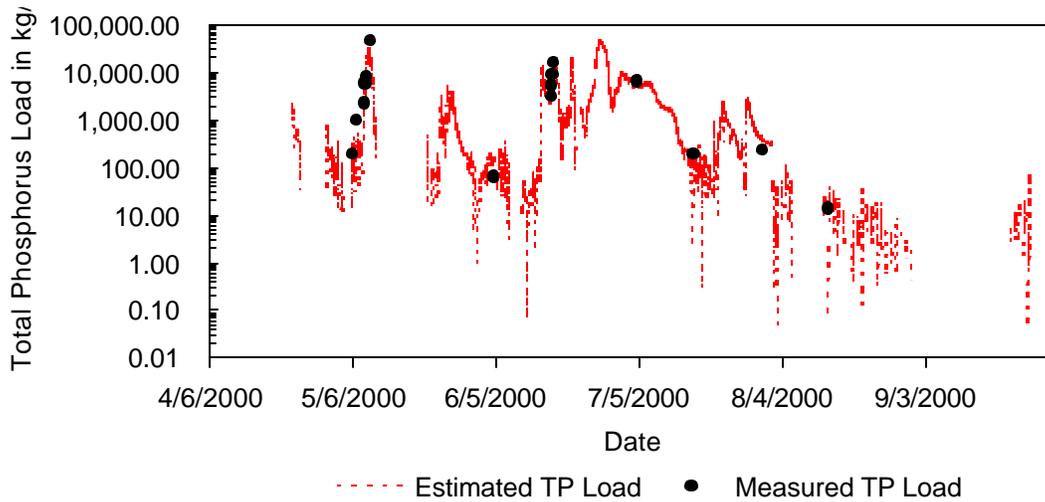


Figure 5.2-49
Comparison of measured and estimated total phosphorus load at LEPO2,
April through September 2000.

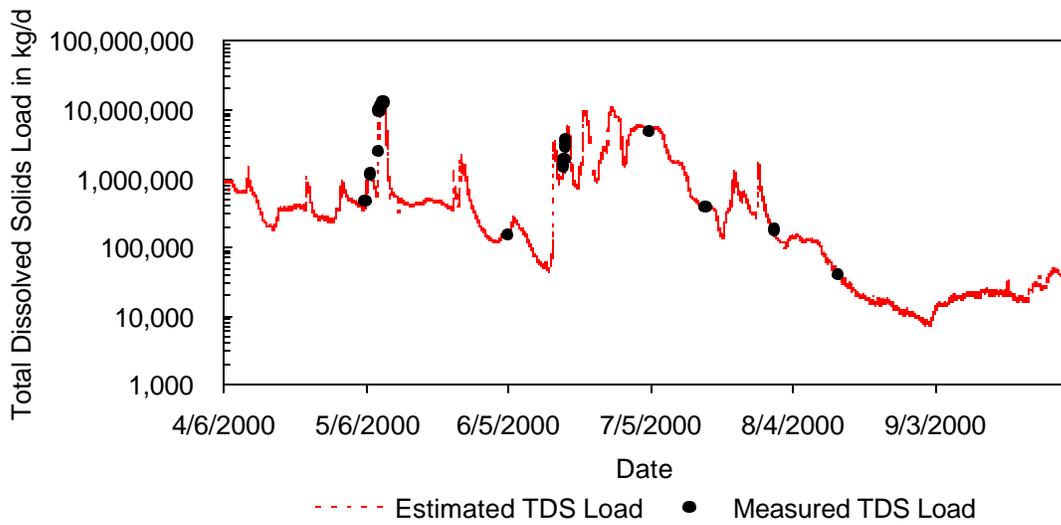


Figure 5.2-50
Comparison of measured and estimated total dissolved solids load at LEPO2, April through September 2000.

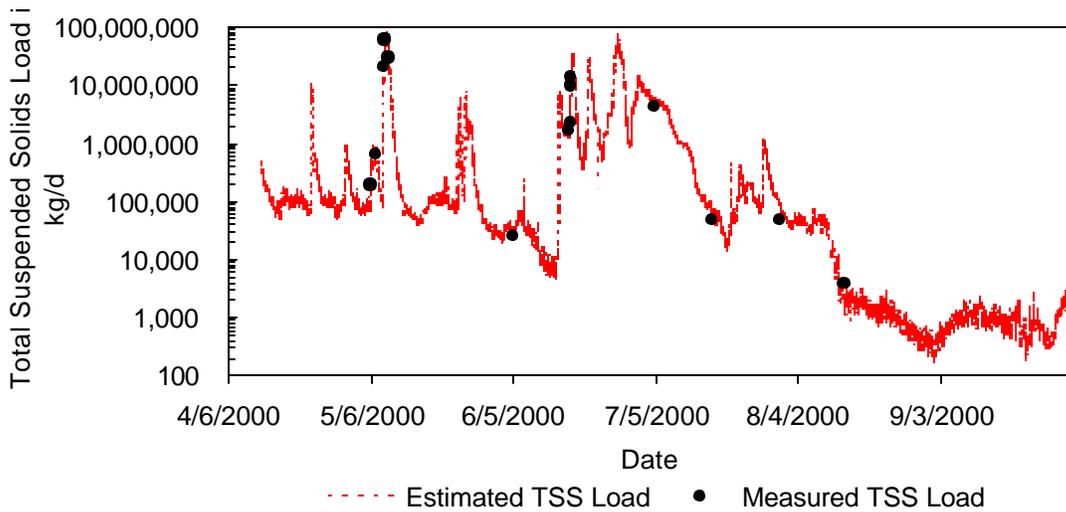


Figure 5.2-51
Comparison of measured and estimated total suspended solids load at LEPO2, April through September 2000.

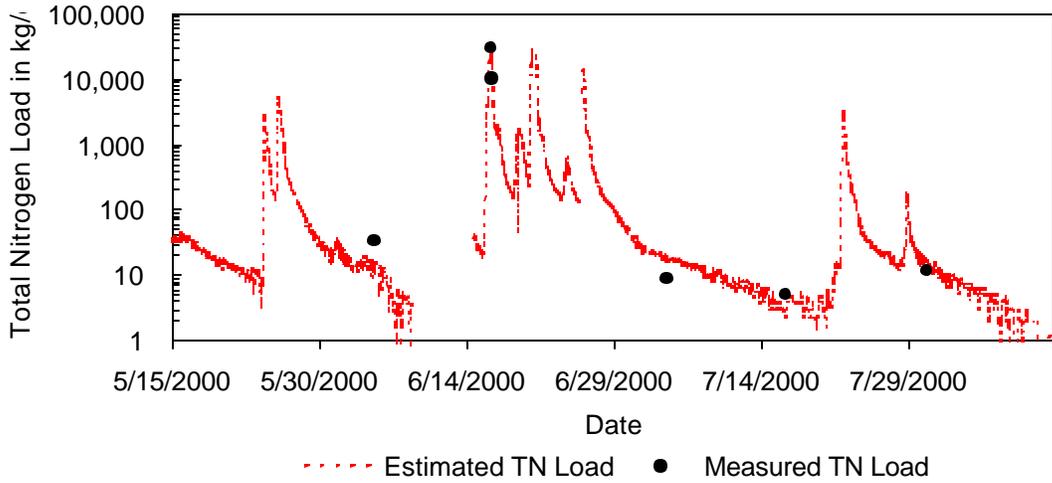


Figure 5.2-52
Comparison of measured and estimated total nitrogen load at CHBO2,
May through September 2000.

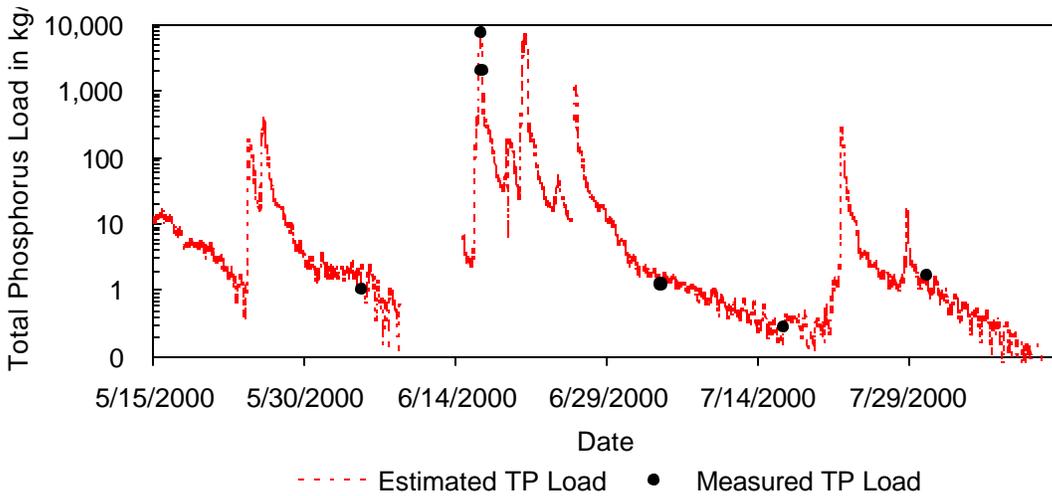


Figure 5.2-53
Comparison of measured and estimated total phosphorus load at CHBO2,
May through September 2000.

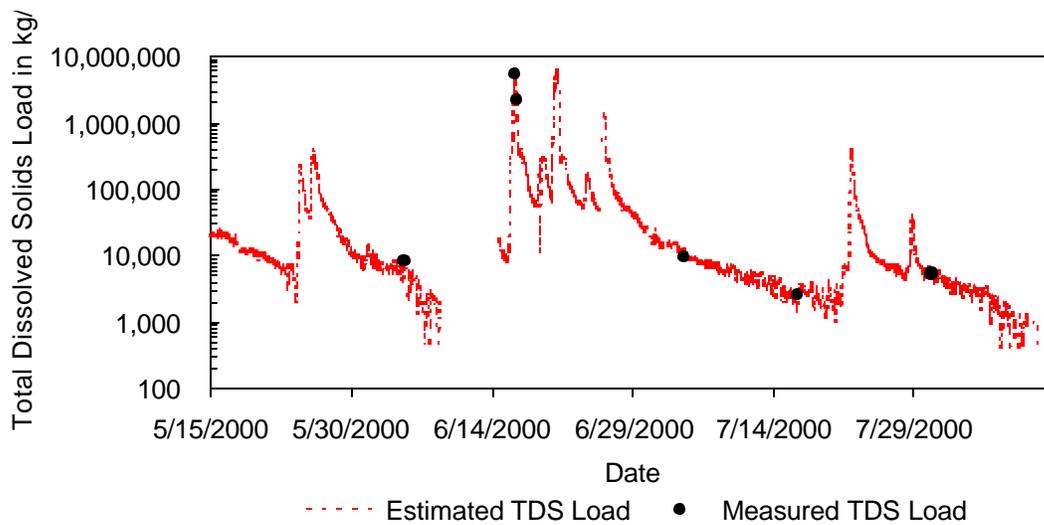


Figure 5.2-54
Comparison of measured and estimated total dissolved solids load at CHBO2, May through September 2000.

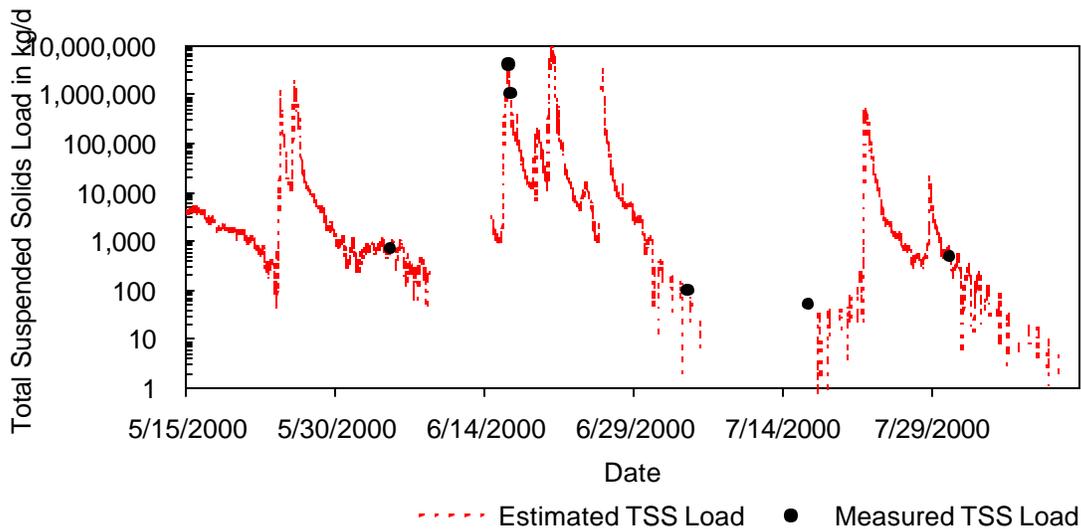


Figure 5.2-55
Comparison of measured and estimated total suspended solids load at CHBO2, May through September 2000.

5.3 Reservoir Water Chemistry. Descriptive statistics for most reservoir water quality parameters measured during this study are presented in Table 5.3-1. Results for individual parameters are described in detail in the following sections.

Table 5.3-1. Descriptive statistics for water quality parameters, all sites and dates, Oologah Lake, Oklahoma, 2000.

Parameter	Median	Mean	Min.	Max.	N	# BDL
Alkalinity, Total (mg/l as CaCO ₃)	113.5	114.85	72.0	162.0	66	0
Aluminum, Dissolved (mg/l)	0.515	0.912	0.3	3.0	24	0
Aluminum, Total (mg/l)	1.35	1.885	0.4	7.9	24	0
Antimony, Dissolved (mg/l)		< 0.006			24	24
Antimony, Total (mg/l)		< 0.006			23	23
Arsenic, Dissolved (mg/l)			< 0.002	0.002	24	19
Arsenic, Total (mg/l)			< 0.002	0.003	24	17
Barium, Dissolved (mg/l)	0.061	0.06	0.05	0.078	24	0
Barium, Total (mg/l)	0.087	0.08	0.051	0.150	24	0
Beryllium, Dissolved (mg/l)		< 0.004			24	24
Beryllium, Total (mg/l)		< 0.004			24	24
BOD ₅ (mg/l)			< 2.0	3.8	66	57
Cadmium, Dissolved (mg/l)	0.003	0.098	0.003	0.450	24	18
Cadmium, Total (mg/l)	0.003	0.319	0.003	2.20	24	16
Calcium, Dissolved (mg/l)	39.0	39.06	22.5	49.0	24	0
Calcium, Total (mg/l)	41.9	41.48	25.2	52.0	24	0
Chlorophyll <i>a</i> (µg/l)	5.7	9.25	0.9	46.2	195	0
Carbon, Organic, Dissolved (mg/l)	4.05	4.14	3.5	5.0	66	0
Carbon, Organic, Total (mg/l)	4.3	4.69	2.9	10.0	66	0
Chloride (mg/l)	12.0	12.39	6.5	19.0	66	0
Chromium, Dissolved (mg/l)		< 0.030			24	24
Chromium, Total (mg/l)	0.03	0.830	0.03	9.80	24	20
Copper, Dissolved (mg/l)		< 0.020			24	24
Copper, Total (mg/l)			< 0.020	0.023	24	23
Hardness, Total (mg/l as CaCO ₃)	157.0	152.3	88.4	191.0	66	0
Iron, Dissolved (mg/l)	0.260	0.381	< 0.020	2.00	60	5
Iron, Total (mg/l)	0.825	1.603	0.2	8.8	60	0
Lead, Dissolved (mg/l)			< 0.001	0.001	24	20
Lead, Total (mg/l)			< 0.001	0.004	24	12
Magnesium, Dissolved (mg/l)	7.75	7.47	4.4	9.9	24	0
Magnesium, Total (mg/l)	7.75	7.76	4.5	11.0	24	0
Manganese, Dissolved (mg/l)			< 0.008	0.325	60	36
Manganese, Total (mg/l)	0.062	0.092	0.01	0.31	60	1
Mercury, Dissolved (mg/l)			< 0.0001	0.0001	24	23
Mercury, Total (mg/l)			< 0.0001	0.0005	24	15

Table 5.3-1 (continued)

Parameter	Median	Mean	Min.	Max.	N	# BDL
Nickel, Dissolved (mg/l)		< 0.020			24	24
Nickel, Total (mg/l)		< 0.020			24	24
Nitrogen, Ammonia (mg/l)			< 0.06	0.22	66	37
Nitrogen, Dissolved Kjeldahl (mg/l)	0.616	0.524	< 0.3	2.11	66	24
Nitrogen, Total Kjeldahl (mg/l)	0.669	0.763	< 0.3	1.89	66	7
Nitrogen, Nitrate-Nitrite (mg/l)	0.328	0.282	< 0.03	0.512	66	8
Dissolved Oxygen (mg/l)*	7.04	6.89	0.03	12.98	634	0
pH (standard units)*	7.99		6.73	8.72	634	0
Phosphorus, Ortho, Dissolved (mg/l)	0.04	0.04	0.008	0.076	66	0
Phosphorus, Dissolved, Total (mg/l)	0.048	0.052	0.014	0.156	66	0
Phosphorus, Total (mg/l)	0.083	0.118	0.035	0.495	66	0
Potassium, Dissolved (mg/l)	3.05	3.07	2.6	3.6	24	0
Potassium, Total (mg/l)	3.3	3.83	2.4	10.0	24	0
Selenium, Dissolved (mg/l)		< 0.003			24	24
Selenium, Total (mg/l)		< 0.003			24	24
Silicon, Dissolved (mg/l)	4.35	4.78	2.0	18.0	24	0
Silicon, Total (mg/l)	6.0	8.03	2.9	36.0	24	0
Silver, Dissolved (mg/l)		< 0.020			24	24
Silver, Total (mg/l)		< 0.020			24	24
Sodium, Dissolved (mg/l)	10.0	10.26	6.7	13.0	24	0
Sodium, Total (mg/l)	12.0	12.43	8.3	16.0	24	0
Secchi Depth (m)*	0.31	0.37	0.10	0.90	55	0
Specific Conductance ($\mu\text{S}/\text{cm}$)*	332.5	337.1	204.0	432.0	634	0
Solids, Settable (mg/l)			< 0.1	0.1	66	62
Solids, Dissolved, Total (mg/l)	238.0	238.74	170.0	348.0	66	0
Solids, Suspended, Total (mg/l)	17.40	32.52	< 4.0	170	66	5
Solids, Suspended, Volatile (mg/l)			< 4.0	41	66	50
Sulfate (mg/l)	44.0	43.95	9.6	100.0	66	0
Thallium, Dissolved (mg/l)			< 0.002	0.002	22	21
Thallium, Total (mg/l)		< 0.002			24	24
Turbidity, Field (NTU)*	41.2	51.7	8.3	209.0	634	0
Turbidity, Laboratory (NTU)	32.0	46.8	4.10	180.0	66	0
Light attenuation coefficient* (m^{-1})	2.55	3.47	1.29	11.01	40	0
Water Temperature ($^{\circ}\text{C}$)*	24.9	24.0	13.7	30.1	634	0
Zinc, Dissolved (mg/l)		< 0.020			24	24
Zinc, Total (mg/l)			< 0.020	0.079	24	21

* Denotes field measured parameters.

5.3.1 Nutrients. Surface concentrations of ammonia (mg/l as N) ranged from < 0.06 to 0.22 mg/l across all sampling sites and dates. Concentrations of ammonia did not exhibit a normal distribution across all sampling sites and dates (Anderson-Darling normality

test, $p = 0.003$). However, at Sites 1, 2, and 3, concentrations were not significantly different from that of a normal distribution across all sampling dates. Bottom concentrations at Site 1 across all sampling sites and dates ranged from <0.06 to 0.18 mg/l and were normally distributed. Spatially, there was no significant longitudinal (one-way ANOVA on ranked data, $F = 0.98$, $p = 0.435$) or vertical (independent t-test, $p = 0.711$) gradient of ammonia in the reservoir (Figures 5.3.1-1 and 5.3.1-2). Concentrations of ammonia within the reservoir were significantly correlated with sampling date discharge in the Verdigris River (Spearman correlation, $r = 0.643$, $p < 0.001$), and the only nutrient parameter significantly correlated with ammonia was nitrate + nitrite (Spearman correlation, $r = 0.405$, $p = 0.029$). The correlation between discharge and ammonia concentrations within the reservoir was supported by the temporal variability observed during this study period, with higher surface concentrations occurring in conjunction with periods of increased discharge (Figure 5.3.1-3). Temporal differences in ammonia concentrations were significant (one-way ANOVA on ranked data, $F = 8.89$, $p < 0.001$), with two distinct seasonal groups identified: April = May = June = July \neq September (Tukey's multiple comparison test, $\alpha = 0.05$).

Concentrations of nitrate + nitrite ranged from < 0.03 to 0.512 mg/l at the surface, across all sampling sites and dates, and from 0.14 to 1.56 mg/l at 1 meter above the bottom at Site 1. Normality testing (Anderson-Darling) revealed that surface concentrations of nitrate + nitrite, across all sampling stations and dates, did not exhibit a normal distribution ($p < 0.05$). At individual sampling sites across all sampling dates, only Site 2 (surface) and Site 1 (bottom) exhibited a non-normal distribution ($p = 0.028$ and $p < 0.001$, respectively). Spatially, there was no significant longitudinal gradient in nitrate + nitrite concentrations (Figure 5.3.1-4) (one-way ANOVA on ranked data, $F = 0.58$, $p = 0.676$) across all sampling dates. However, as Figure 5.3.1-5 illustrates, on any given sampling date slight longitudinal gradients can occur within the reservoir. Additionally, there was no significant difference in nitrate + nitrite concentrations between surface and bottom samples (one-way ANOVA on ranked data, $F = 0.97$, $p = 0.336$) at Site 1. Concentrations of nitrate + nitrite were found to be significantly correlated with sampling date discharge (Spearman correlation, $r = 0.678$, $p < 0.001$) from the Verdigris River, with

significant seasonal differences (one-way ANOVA on ranked data, $F = 20.75$, $p < 0.001$) related to periods of peak discharge (Figure 5.3.1-5).

Kjeldahl nitrogen analyses during the course of this study included both dissolved and total Kjeldahl nitrogen. Total Kjeldahl nitrogen (TKN) ranged from < 0.30 to 1.89 mg/l at the surface, across all sampling sites and dates, and from < 0.3 mg/l to 1.05 mg/l at Site 1, 1 meter above the bottom. TKN concentrations at individual sampling sites across all dates were normally distributed, with the exception of Site 4 for which values were not normally distributed (Anderson-Darling normality test, $p = 0.034$). When all stations and dates were analyzed together, the distribution of TKN concentrations was not normally distributed ($p < 0.001$). A significant correlation (Spearman correlation) was found between TKN and 5-day biochemical oxygen demand ($r = 0.34$, $p = 0.006$), dissolved organic carbon ($r = 0.37$, $p = 0.002$), total suspended solids ($r = 0.656$, $p < 0.001$), volatile suspended solids ($r = 0.481$, $p < 0.001$), and laboratory turbidity ($r = 0.549$, $p < 0.001$). The spatial distribution of TKN concentrations within the reservoir closely mirrored that of total suspended solids and laboratory turbidity, with concentrations being greater and more variable in uplake portions above Winganon Bridge relative to areas below Winganon Bridge (Figure 5.3.1-6). One-way ANOVA on ranked data found significant differences in TKN concentrations among sampling sites ($F = 6.87$, $p < 0.001$). Tukey's multiple comparison test ($\alpha = 0.05$) determined the following relationship: $1 = 2 = 3 \leq 4 = 5$. At Site 1, average TKN concentrations were significantly higher (one-way ANOVA, $F = 6.68$, $p = 0.019$) and more variable at depth (1 meter above the bottom) relative to surface concentrations (Figures 5.3.1-7 and 5.3.1-8) and were, on average, 0.21 mg/l (39.7%) greater in the hypolimnion. Although discharge and TKN concentrations were not significantly correlated across all sampling dates, the correlation between discharge and surface TKN concentrations was significant in late May, early June, and throughout July 2000 (Table 5.3.1-1). Temporally, TKN concentrations were higher and exhibited greater variability during periods of increased discharge and dissolved oxygen concentrations in bottom waters were less than 2 mg/l.

Dissolved Kjeldahl nitrogen (DKN) ranged from < 0.30 to 2.11 mg/l at the surface, across all sampling sites and dates, and from < 0.30 to 1.41 mg/l at Site 1, 1 meter above the bottom. The dissolved fraction of Kjeldahl nitrogen comprised 80.7% of TKN across all

sampling sites and dates at the surface, and 94.6 % of TKN at 1 meter above the bottom (Site 1) across all sampling dates. Among individual dates, the fraction of DKN ranged from 58.7% to 93.6% at the surface and from 49.6% to 91.9% at 1 meter above the bottom (Table 5.3.1-2). The distribution of DKN at Sites 2 and 4 followed a normal distribution, and concentrations at Sites 1 (surface and bottom), 3, and 5 were not normally distributed across all sampling dates (Anderson-Darling normality test, $p < 0.05$). Spatially, DKN concentrations did not exhibit a significant pattern of horizontal or vertical variability (one-way ANOVA on ranked data, $F = 0.31$, $p = 0.872$, and $F = 0.53$, $p = 0.479$, respectively) (Figures 5.3.1-9 and 5.3.1-10). Temporally, no distinct pattern in DKN was evident from month to month (Figure 5.3.1-11). However, when individual sampling events were compared, significant differences were observed (one-way ANOVA on ranked data $F = 3.53$, $p = 0.004$). Tukey's multiple comparison test identified DKN concentrations on 16 May 2000 and 1 August 2000 as significantly different ($\alpha = 0.05$) from the concentrations present on all other sampling dates (Figure 5.3.1-12).

Total phosphorus (P) at the surface averaged 0.118 mg/l with a standard deviation (SD) of 0.106 mg/l. At Site 1, 1 meter above the bottom, concentrations averaged 0.086 mg/l (SD = 0.030 mg/l). The concentrations of total P did not follow a normal distribution across all sampling sites and dates. Among individual sampling sites, only surface concentrations at Site 1 exhibited a normal distribution (Anderson-Darling normality test, $p = 0.008$). A significant correlation (Spearman non-parametric correlation) was identified between total P and 5-day biochemical oxygen demand ($r = 0.403$, $p = 0.001$), dissolved organic carbon ($r = 0.515$, $p < 0.001$), total organic carbon (TOC) ($r = 0.508$, $p < 0.001$), total suspended solids (TSS) ($r = 0.811$, $p < 0.001$), and volatile suspended solids (VSS) ($r = 0.573$, $p < 0.001$). Spatially, one-way ANOVA on ranked data detected differences in total P concentrations both vertically ($F = 15.01$, $p = 0.001$) and horizontally ($F = 20.97$, $p < 0.001$). Horizontally, concentrations tended to be greater and more variable in areas of the reservoir above Winganon Bridge (56% greater on average) relative to areas below the bridge (Figure 5.3.1-13), and Tukey's multiple comparison test determined three distinct groups based upon surface concentrations: $1 \neq 2 = 3 \neq 4 \leq 5$. Temporally, surface concentrations of total P showed very little variability from month to month with the exception of May and September (Figure 5.3.1-14). Median surface total P

concentration across all stations was statistically greater (one-way ANOVA on ranked data $F = 3.98$, $p = 0.003$) in these months and exhibited a greater overall variability.

Total dissolved phosphorus averaged 0.052 mg/l (SD = 0.027 mg/l) at the surface and 0.055 mg/l (SD = 0.013 mg/l) at 1 meter above the bottom (Site 1). The average dissolved fraction of total P at the surface was 44.3%. At Site 1, the average dissolved fraction of total P 1 meter above the bottom was 68.2%. Among individual dates, the dissolved fraction of total P ranged from 29.4% to 81.3% across all sites at the surface and from 51.8% to 87.4% at 1 meter above the bottom. Across all sampling sites and dates, total dissolved phosphorus was significantly different from a normal distribution (Anderson-Darling normality test, $p < 0.001$). At three sampling sites (Sites 1, 2, and 3), distributions of total dissolved phosphorus, across all sampling dates, was not significantly different from that of a normal distribution ($p > 0.05$). At Sites 4 and 5, the distribution of total dissolved phosphorus did differ significantly from a normal distribution (Anderson-Darling normality test, $p = 0.018$ and $p = 0.034$, respectively). Spatially, total dissolved phosphorus showed no distinct horizontal pattern (Figure 5.3.1-15). Vertically, however, concentrations at Site 1 were greater at 1 meter above the bottom than surface concentrations on 9 of the 11 sampling events (Figures 5.3.1-16 and 5.3.1-17). One-way ANOVA on ranked data indicated that there was a statistically significant difference between months ($F = 4.52$, $p < 0.001$). Tukey's multiple comparison test ($\alpha = 0.05$) determined no significant difference between April, May, June, July, and September, and did determine total dissolved phosphorus concentrations in August to be significantly different from concentrations in June, July, and September. However, no general seasonal trend was evident (Figure 5.3.1-18).

Dissolved ortho-phosphorus averaged 0.04 mg/l (SD = 0.016 mg/l) at the surface and 0.040 mg/l (SD = 0.010 mg/l) at 1 meter above the bottom (Site 1). The distribution of ortho-phosphorus across all sampling sites and dates did not differ significantly from a normal distribution at the surface. Ortho-phosphorus was also found to be normally distributed both at the surface and at the bottom at Site 1; however, at Sites 2, 3, 4, and 5, surface concentrations of dissolved ortho-phosphorus were found to differ significantly from a normal distribution (Anderson-Darling normality test, $\alpha = 0.05$). Dissolved ortho-phosphorus was significantly correlated with dissolved organic carbon ($r = 0.329$, $p = 0.007$), TSS ($r = 0.525$, $p < 0.001$), VSS

($r = 0.257$, $p = 0.037$), and laboratory turbidity ($r = 0.706$, $p < 0.001$). Spatially, no distinct horizontal gradient in dissolved ortho-phosphorus concentrations was evident (Figure 5.3.1-19). At Site 1, surface concentrations were lower, but exhibited a greater variability than did concentrations at 1 meter above the bottom (Figure 5.3.1-20), and, on average, surface dissolved ortho-phosphorus concentrations were 62.9% less than bottom concentrations. Temporally, no significant difference among months (one-way ANOVA on ranked data, $F = 1.19$, $p = 0.391$) was found with no discernible seasonal trend evident (Figure 5.3.1-21). However, differences in median dissolved ortho-phosphorus concentrations between individual sampling dates were found to be significant (one-way ANOVA on ranked data, $F = 76.12$, $p = 0.002$). Tukey's multiple comparison test ($\alpha = 0.05$) identified two distinct groups of sampling dates:

$$8/1 \leq 4/18 \leq 9/6 \leq 5/2 \leq 8/15 \leq 7/19 \leq 6/6 \neq 9/19 \leq 7/5 \leq 5/16 \leq 6/20$$

with significant differences between sampling dates of the same month in May, July, and September (Figure 5.3.1-22) due in part to markedly different inflows from the Verdigris River as well as releases from the reservoir on the two dates.

Table 5.3.1-1. Spearman non-parametric correlation between discharge and TKN.

Sampling Date	r	Probability
18 April 2000	-0.686	*
2 May 2000	-0.443	*
16 May 2000	-0.898	0.015
6 June 2000	-0.771	0.073
20 June 2000	0.711	*
5 July 2000	0.931	0.007
19 July 2000	0.922	0.026
1 August 2000	-0.392	*
15 August 2000	-0.606	*
6 September 2000	-0.567	*
19 September 2000	--	--

* no significance at $\alpha = 0.05$.

Table 5.3.1-2. Dissolved Kjeldahl nitrogen fraction (percent) of total Kjeldahl nitrogen at the surface (0.5 meter depth, all stations) and bottom (1 meter above bottom, Site 1 only).

Sampling Date	Surface	Bottom
18 April 2000	71.3	69.7
2 May 2000	72.0	+
16 May 2000	72.0	49.6
6 June 2000	58.7	61.9
20 June 2000	+	62.2
5 July 2000	86.3	+
19 July 2000	93.6	--
1 August 2000	70.4	91.9
15 August 2000	60.4	56.0
6 September 2000	59.5	--
19 September 2000	--	--

-- one or both parameters were below the detection limit (0.30 mg/l).

+ dissolved fraction was greater than total fraction.

Table 5.3.1-3. Total dissolved phosphorus fraction (percent) of total phosphorus at the surface (0.5 meter depth, all stations) and bottom (1 meter above bottom, Site 1 only).

Sampling Date	Surface	Bottom
18 April 2000	44.8	67.9
2 May 2000	29.4	51.8
16 May 2000	33.5	55.3
6 June 2000	81.3	83.1
20 June 2000	63.3	74.1
5 July 2000	57.6	87.4
19 July 2000	65.2	64.2
1 August 2000	40.5	59.1
15 August 2000	45.9	65.2
6 September 2000	48.1	69.2
19 September 2000	32.5	78.3

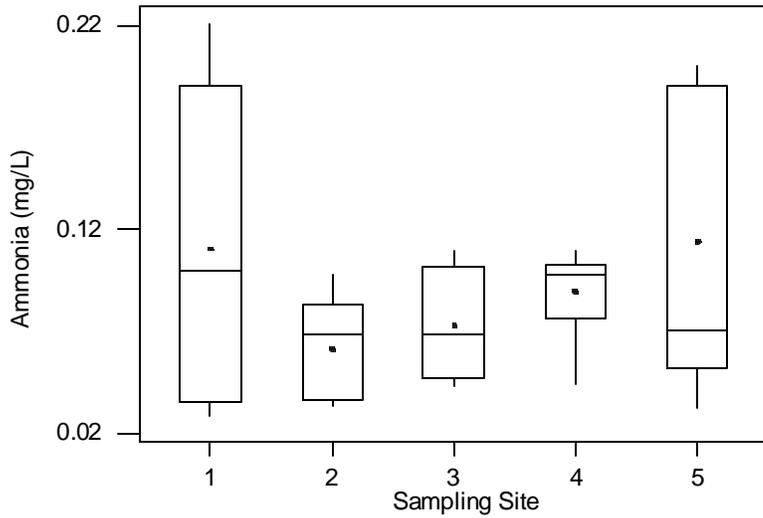


Figure 5.3.1-1
Ammonia (mg/l) variability by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

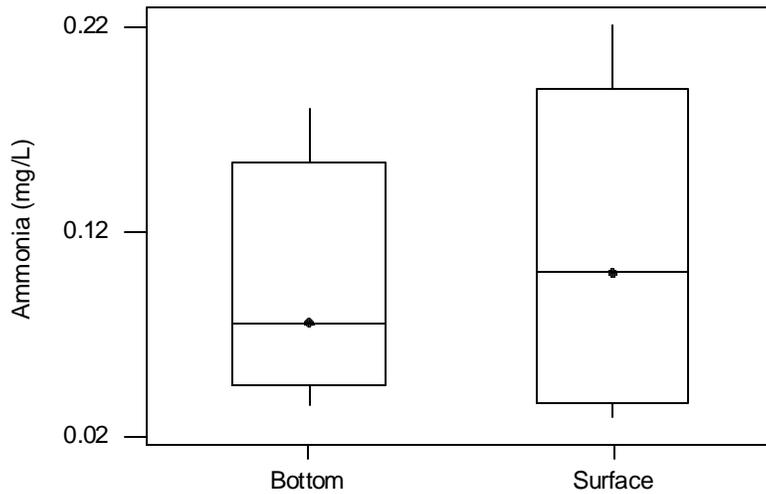


Figure 5.3.1-2
Ammonia (mg/l) variability between surface and bottom samples at Site 1,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

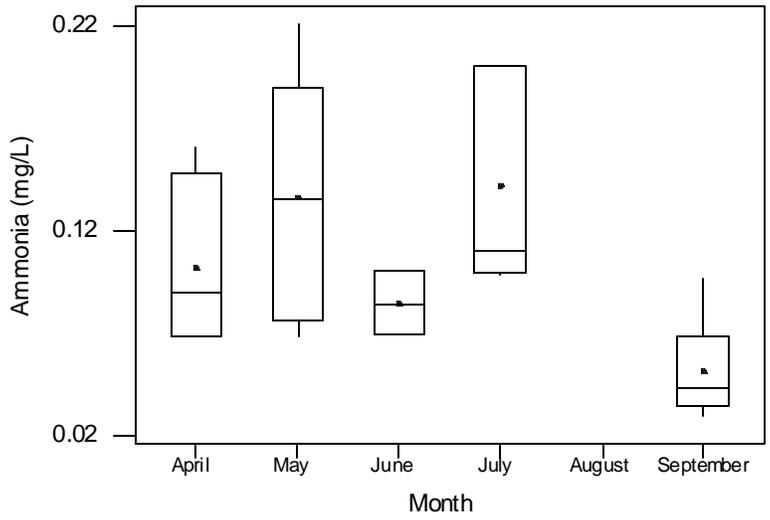


Figure 5.3.1-3
Seasonal ammonia (mg/l) variability,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

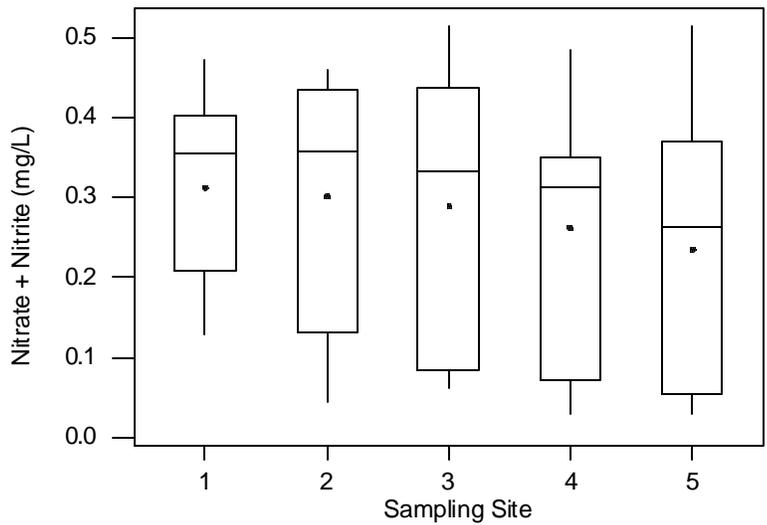


Figure 5.3.1-4
Nitrate + Nitrite (mg/l) variability by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

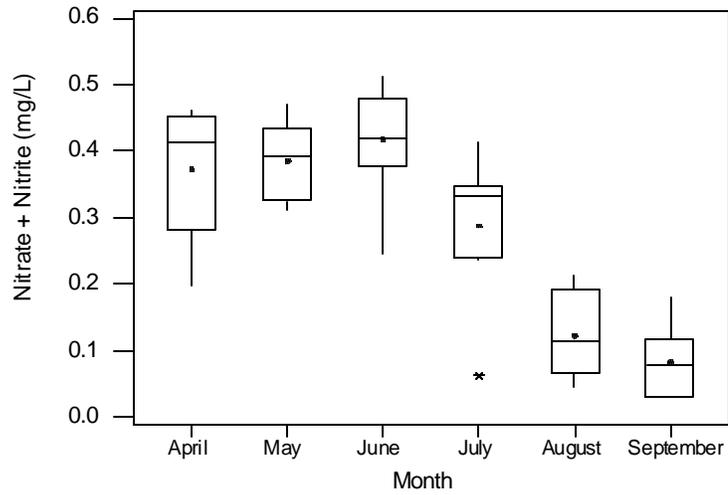


Figure 5.3.1-5
Seasonal nitrate + nitrite (mg/l) variability,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

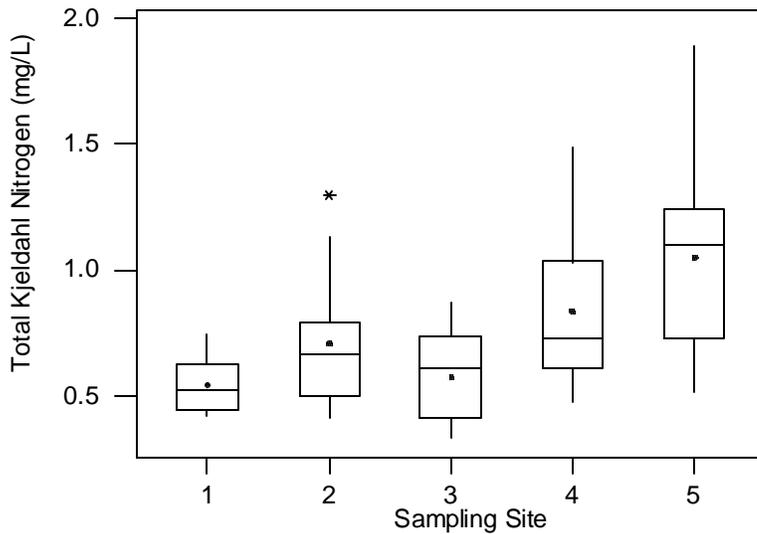


Figure 5.3.1-6
Total Kjeldahl nitrogen (mg/l) variability by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

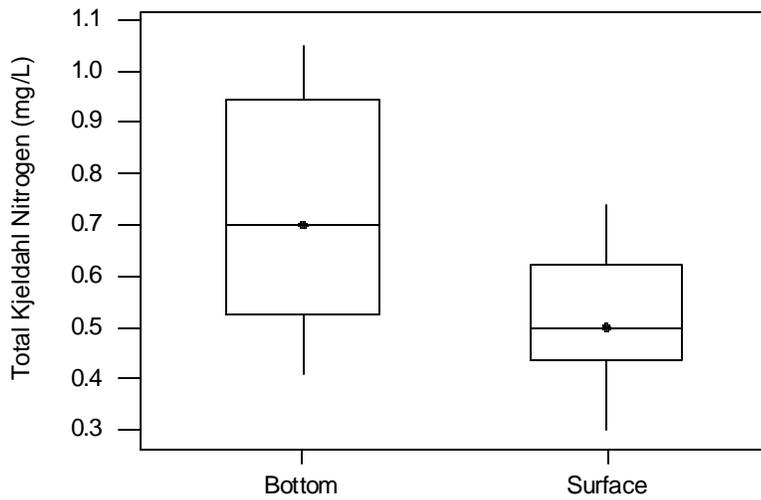


Figure 5.3.1-7
Total Kjeldahl nitrogen (mg/l) variability between surface and bottom samples at Site 1, 18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

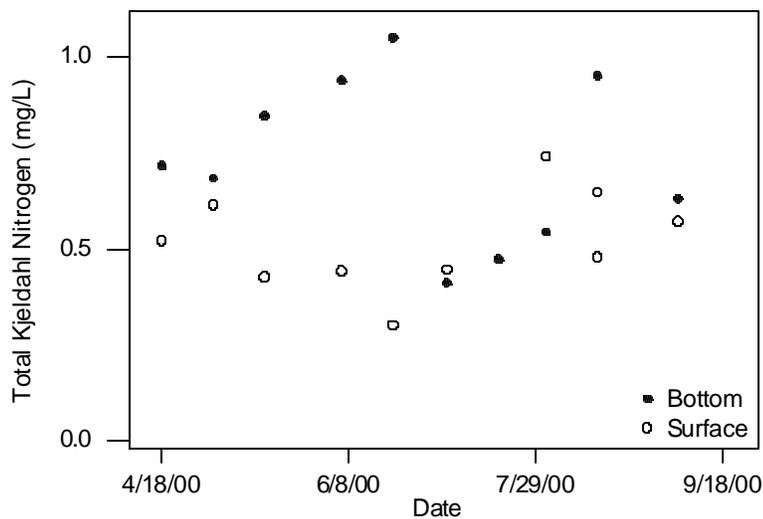


Figure 5.3.1-8
Bottom (■) and surface (○) concentrations of total Kjeldahl nitrogen (mg/l) at Site 1, Oologah Lake, Oklahoma.

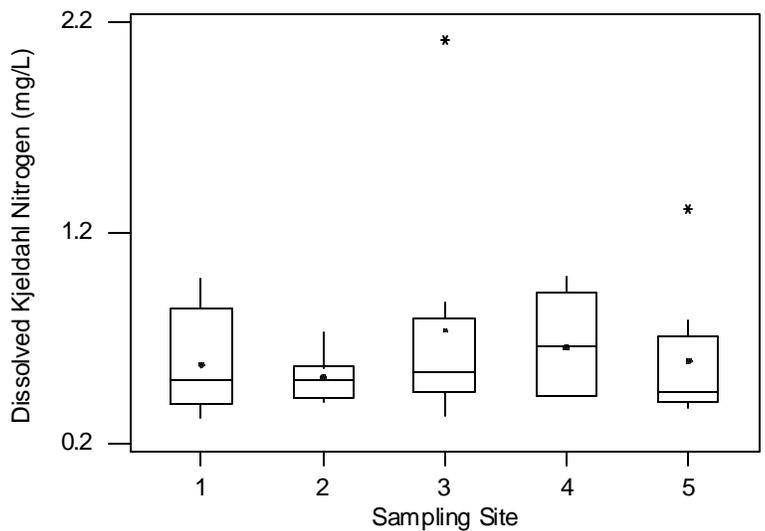


Figure 5.3.1-9
Dissolved Kjeldahl nitrogen (mg/l) variability by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.



Figure 5.3.1-10
Dissolved Kjeldahl nitrogen (mg/l) variability in surface and bottom samples at Site 1,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

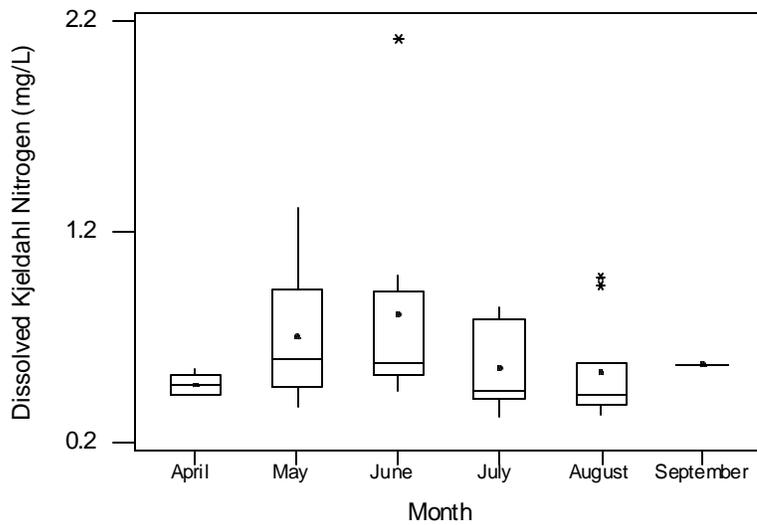


Figure 5.3.1-11
Seasonal dissolved Kjeldahl nitrogen (mg/l) variability,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

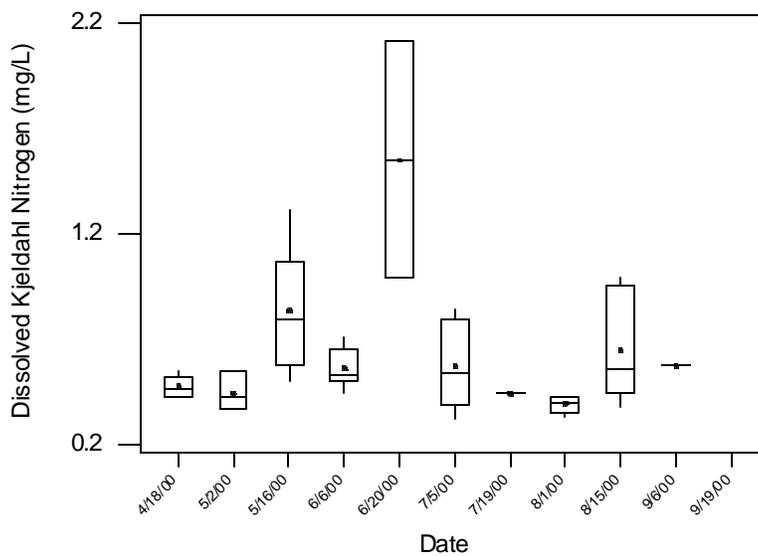


Figure 5.3.1-12
Dissolved Kjeldahl nitrogen (mg/l) variability by sampling date, Oologah Lake, Oklahoma.

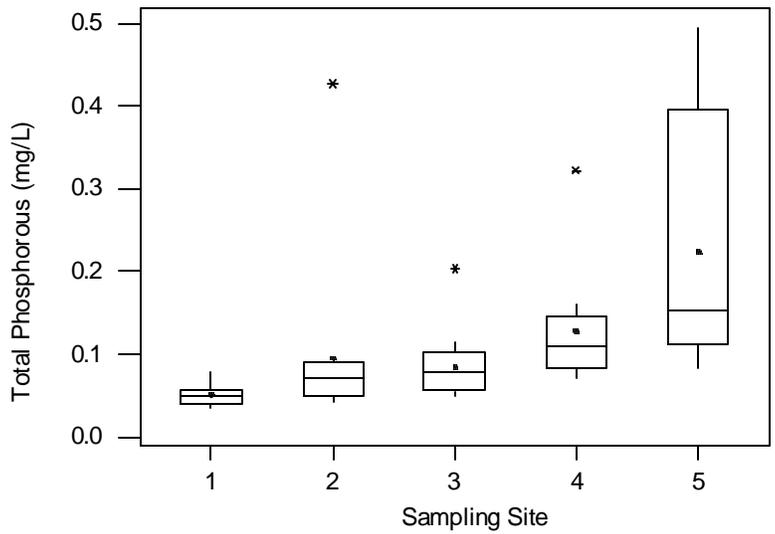


Figure 5.3.1-13
Total phosphorus (mg/l) variability by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

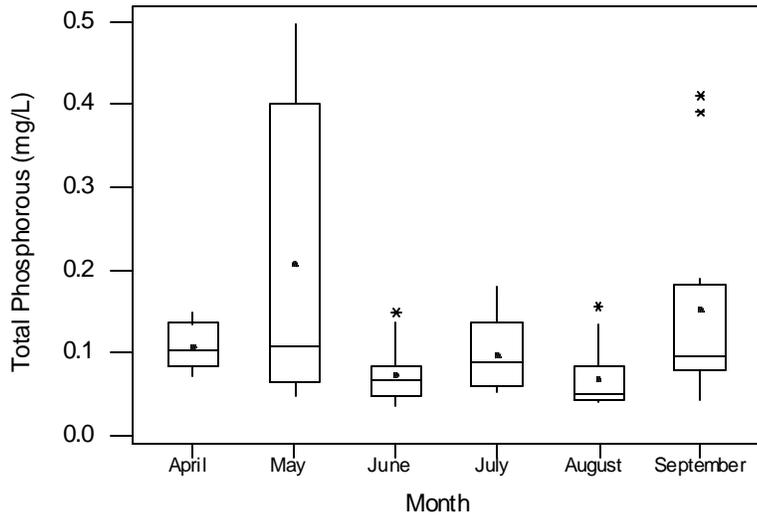


Figure 5.3.1-14
Seasonal total phosphorus (mg/l) variability,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

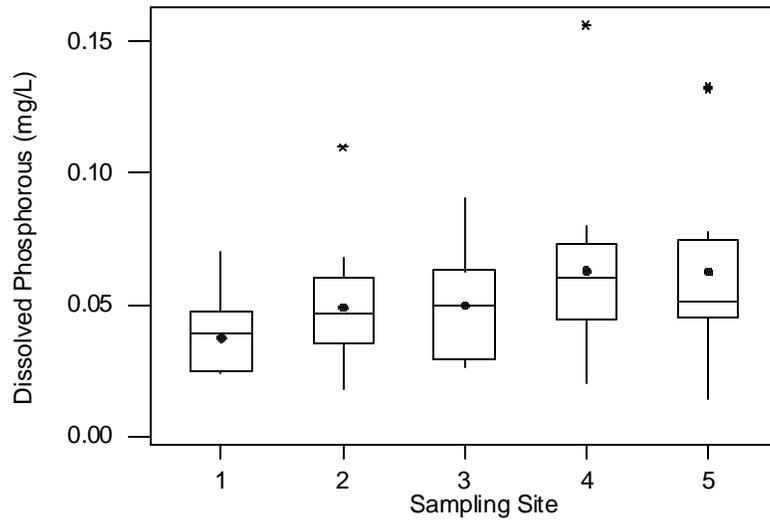


Figure 5.3.1-15
Total dissolved phosphorus (mg/l) variability by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

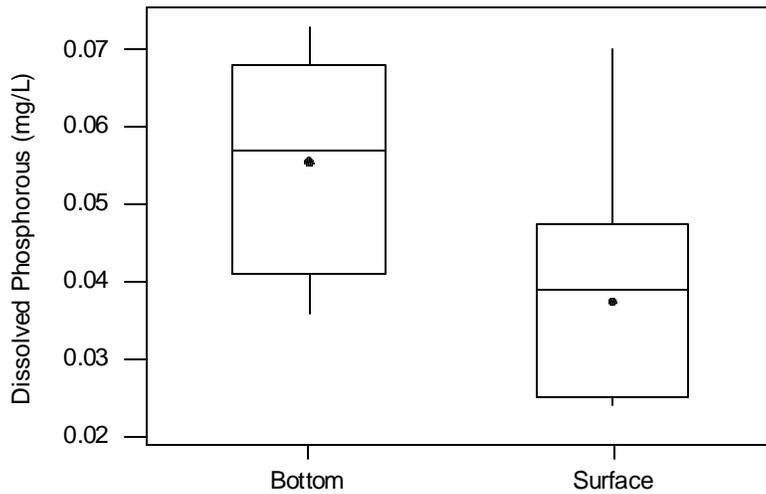


Figure 5.3.1-16
Total dissolved phosphorus (mg/l) variability between surface and bottom samples
at Site 1, 18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

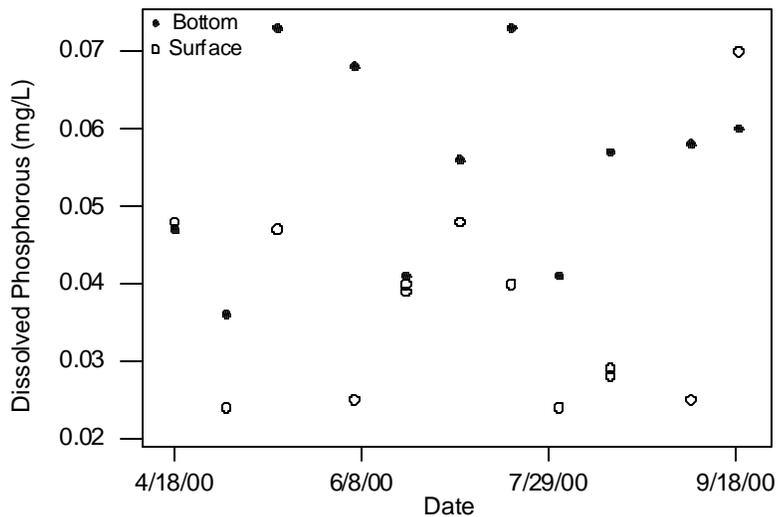


Figure 5.3.1-17
Bottom (●) and surface (□) concentrations of total dissolved phosphorus (mg/l)
at Site 1, Oologah Lake, Oklahoma.

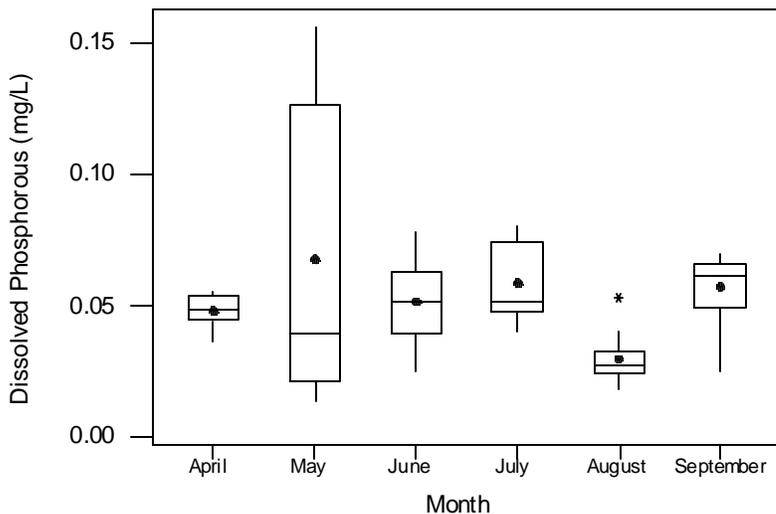


Figure 5.3.1-18
Seasonal total dissolved phosphorus (mg/l) variability,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

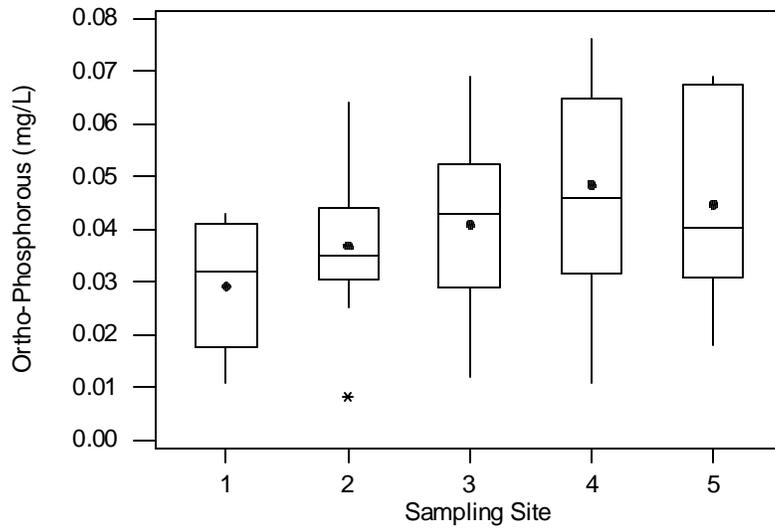


Figure 5.3.1-19
Dissolved ortho-phosphorus (mg/l) variability by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

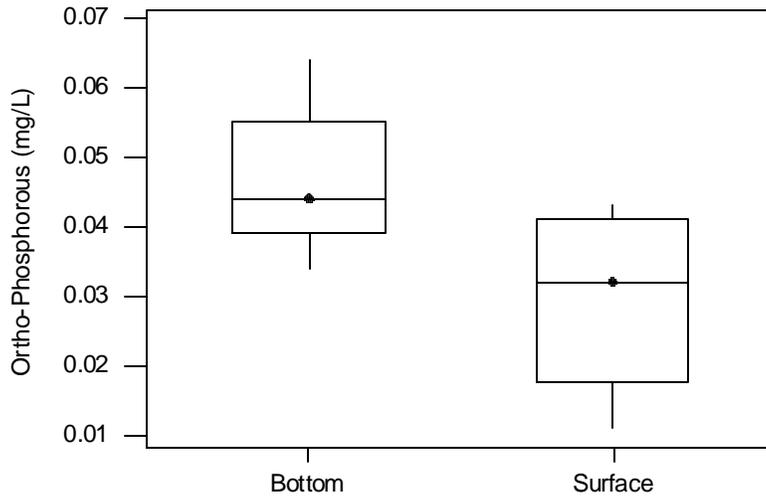


Figure 5.3.1-20
Dissolved ortho-phosphorus (mg/l) variability between surface and bottom samples
at Site 1, 18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

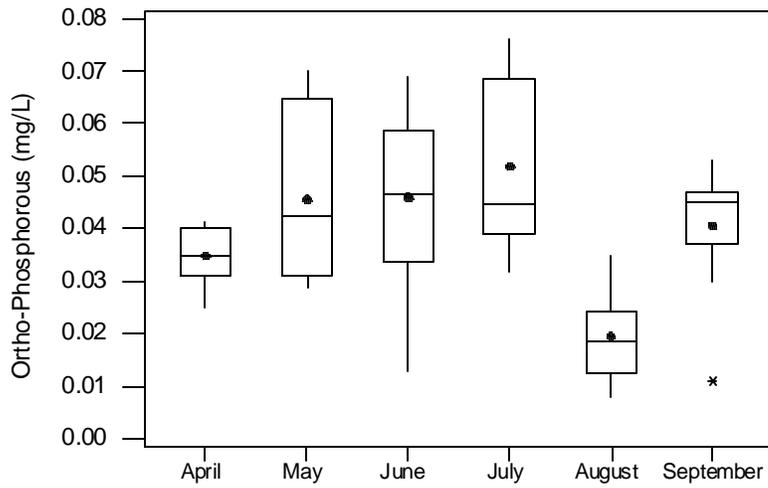


Figure 5.3.1-21
Seasonal dissolved ortho-phosphorus (mg/l) variability,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

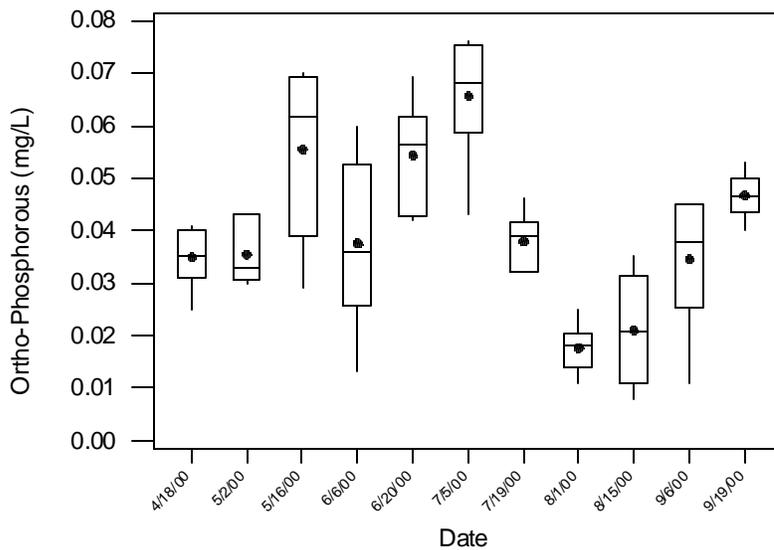
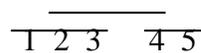


Figure 5.3.1-22
Dissolved ortho-phosphorus (mg/l) variability by sampling date,
Oologah Lake, Oklahoma.

5.3.2 Turbidity and Suspended Solids. Average laboratory turbidity across all sampling stations and dates was 46.8 NTU (SD = 41.48 NTU). Laboratory turbidity was significantly correlated with several water quality parameters. Table 5.3.2-1 lists the Spearman correlation coefficient (r) and probabilities for laboratory turbidity and select water quality parameters. Turbidity values were greatest in the uplake portions of the reservoir (Sites 4 and 5) and exhibited substantial decrease towards the dam (Figure 5.3.2-1), with the greatest variability being observed at sites above Winganon Bridge (Sites 4 and 5). Surface turbidity at sites above Winganon Bridge ranged from 9.7 to 180.0 NTU with a mean value of 77 NTU (SD = 48.4 NTU). Surface turbidity values below Winganon Bridge ranged from 4.1 to 65.9 NTU with a mean value of 25.9 NTU (SD = 15.61 NTU). One-way ANOVA on ranked data across all sampling dates detected a significant difference in laboratory turbidity among the sampling sites ($F = 13.81$, $p < 0.001$), and Tukey's multiple comparison test identified the relationship among the sampling sites as:



Temporally, surface turbidity values exhibited the greatest variability during periods of increased discharge in the Verdigris River upstream of Oologah Lake (Figure 5.3.2-2), with sampling date discharge and turbidity significantly correlated across all sampling stations and dates (Spearman rank correlation, $r = 0.419$, $p < 0.001$). The strongest correlation between turbidity and discharge ($r = 0.671$, $p < 0.001$) was observed at sampling sites below Winganon Bridge (Sites 1, 2, and 3). Laboratory turbidity values were significantly different between months (one-way ANOVA on ranked data, $F = 4.22$, $p = 0.002$) and turbidity in August was found to be significantly less than turbidity in April, May, June, and July (Tukey's multiple comparison test, $\alpha = 0.05$).

The surface concentration of total suspended solids (TSS) across all sampling stations and dates ranged from <4.0 to 170 mg/l. The bottom concentration of TSS at Site 1 ranged from 5.0 to 42.5 mg/l. Spatially, the distribution of TSS within the reservoir closely resembles that of turbidity with higher concentrations found in riverine portions of the reservoir above Winganon Bridge (mean = 56.9 mg/l, SD = 39.92 mg/l). The average TSS concentration

in portions below Winganon Bridge was 11.9 mg/l (SD = 7.61 mg/l). This spatial gradient is significant both longitudinally (Figure 5.3.2-3) (one-way ANOVA on ranked data, $F = 55.6$, $p < 0.001$) with sampling sites separated into four distinct groups: $1 < 2 = 3 < 4 < 5$ (Tukey's multiple comparisons test, $\alpha = 0.05$) and vertically (Figure 5.3.2-4) with TSS concentrations exhibiting a significant increase with depth (Independent t-test on ranked data, $p < 0.001$). Temporally, TSS concentrations were higher and exhibited greater whole lake variability during periods of increased inflow from the Verdigris River but concentrations were not significantly different among months (one-way ANOVA on ranked data, $F = 1.42$, $p = 0.228$). Water quality parameters significantly correlated with TSS are listed in Table 5.3.2-2.

Volatile suspended solids (VSS) concentrations were detectable in 16 of 66 (24.2%) samples collected at the surface and in 2 of 11 (18.2%) samples collected at depth (Site 1). VSS concentrations within the reservoir ranged from < 4.0 to 41.0 mg/l at the surface across all sampling sites and dates, and from < 4.0 to 6.0 mg/l at depth at Site 1 across all dates. Spatially, VSS concentrations and variability were greatest above Winganon Bridge (Figure 5.3.2-6) and decreased with depth at Site 1. One-way ANOVA on ranked data detected a significant difference in VSS among the sampling sites ($F = 12.65$, $p < 0.001$). Tukey's multiple comparisons test ($\alpha = 0.05$) separated the five sampling sites into two statistically distinct groups: $1 = 2 = 3 = 4 < 5$. Temporally, VSS concentration showed little variability (Figure 5.3.2-7), with no detectable difference in concentration over the course of this study (One-way ANOVA on ranked data, $F = 0.87$, $p = 0.541$). Water quality parameters significantly correlated with VSS are listed in Table 5.3.2-3.

Table 5.3.2-1. Spearman correlation coefficient (r) between laboratory turbidity and select water quality parameters.

Parameter	r	p
total Kjeldahl nitrogen	0.549	< 0.001
nitrate + nitrite	0.289	0.019
dissolved orthophosphate	0.706	<0.001
dissolved total phosphorus	0.680	< 0.001
total phosphorus	0.775	< 0.001
total suspended solids	0.810	< 0.001
volatile suspended solids	0.488	< 0.001
Biochemical oxygen demand	0.293	0.017
dissolved organic carbon	0.510	< 0.001
total organic carbon	0.462	< 0.001

Table 5.3.2-2. Spearman correlation coefficient (r) between total suspended solids and select water quality parameters.

Parameter	r	p
dissolved total Kjeldahl nitrogen	0.287	0.019
total Kjeldahl nitrogen	0.656	< 0.001
dissolved orthophosphate	0.525	< 0.001
dissolved total phosphorus	0.562	< 0.001
total phosphorus	0.811	< 0.001
volatile suspended solids	0.676	< 0.001
laboratory turbidity	0.810	< 0.001
chlorophyll <i>a</i>	0.332	0.007
Biochemical oxygen demand	0.476	< 0.001
dissolved organic carbon	0.364	0.003
total organic carbon	0.358	0.003

Table 5.3.2-3. Spearman correlation coefficient (r) between volatile suspended solids and select water quality parameters.

Parameter	r	p
total Kjeldahl nitrogen	0.481	< 0.001
nitrate + nitrite	-0.291	0.018
Dissolved orthophosphorus	0.257	0.037
dissolved total phosphorus	0.333	0.006
total phosphorus	0.573	< 0.001
total suspended solids	0.676	< 0.001
laboratory turbidity	0.488	< 0.001
chlorophyll <i>a</i>	0.437	< 0.001
biochemical oxygen demand	0.516	< 0.001
total organic carbon	0.366	0.003

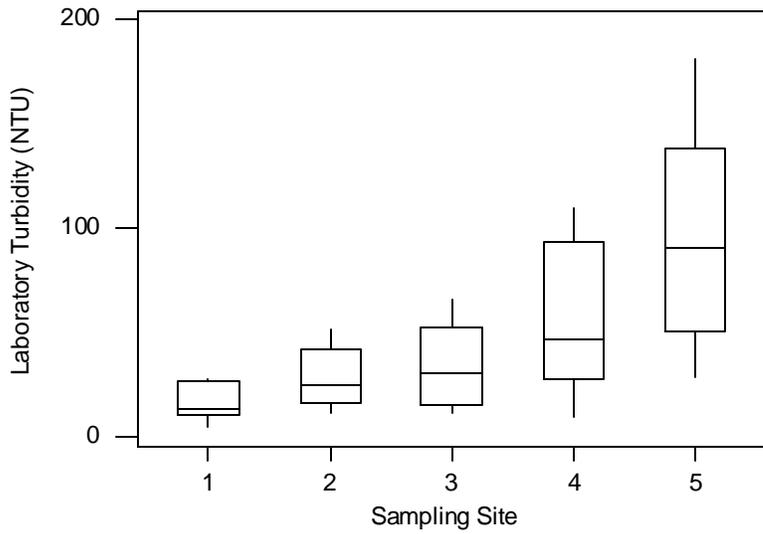


Figure 5.3.2-1
Laboratory turbidity (NTU) variability by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

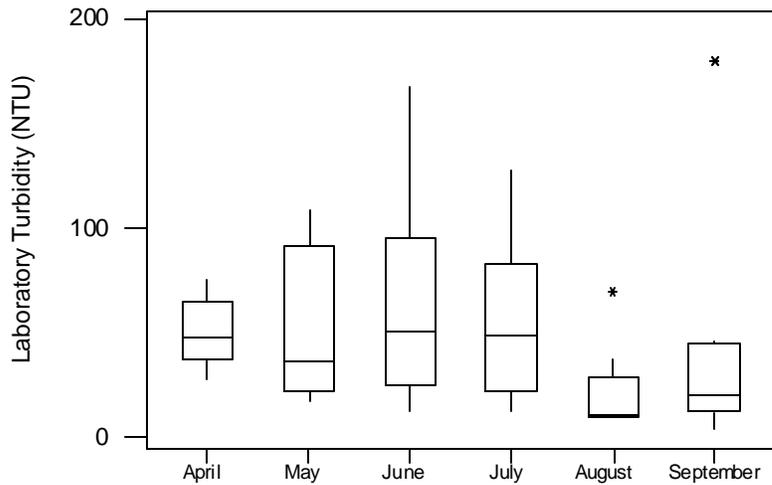


Figure 5.3.2-2
Seasonal laboratory turbidity (NTU) variability,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

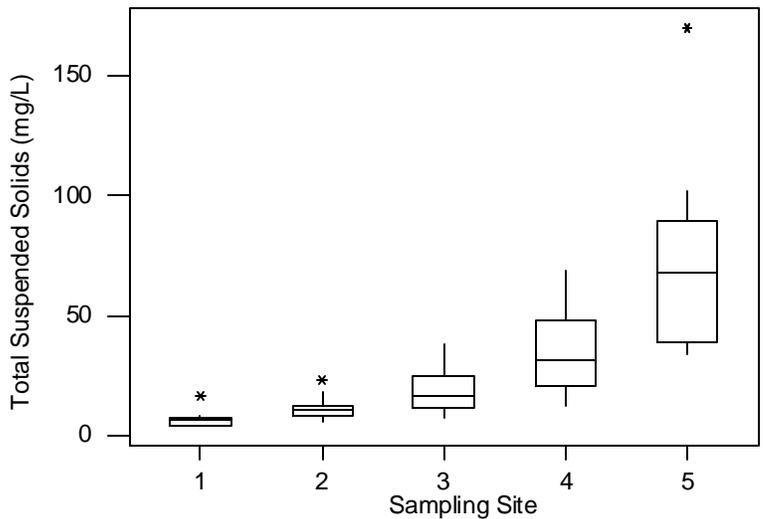


Figure 5.3.2-3
Total suspended solids (mg/l) variability, by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

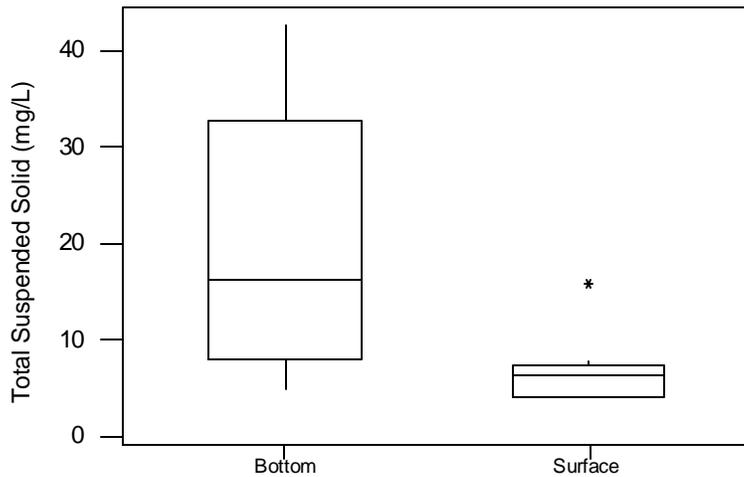


Figure 5.3.2-4
Total suspended solids (mg/l) variability between surface and bottom samples at Site 1,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

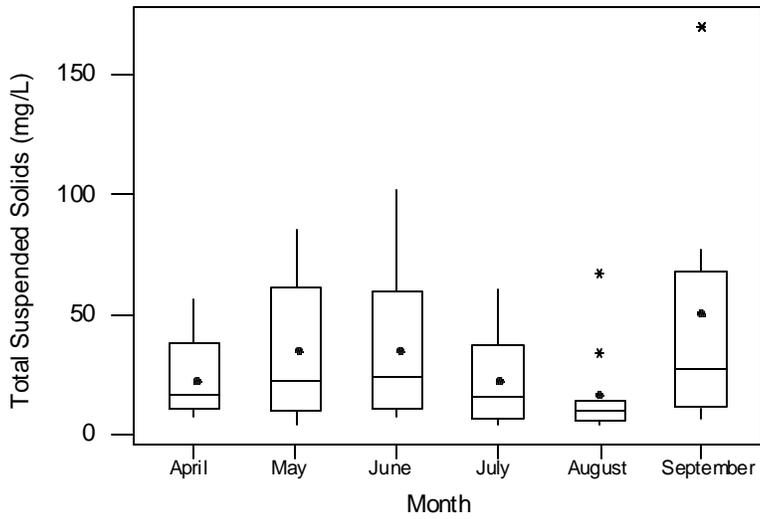


Figure 5.3.2-5
Seasonal total suspended solids (mg/l) variability,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

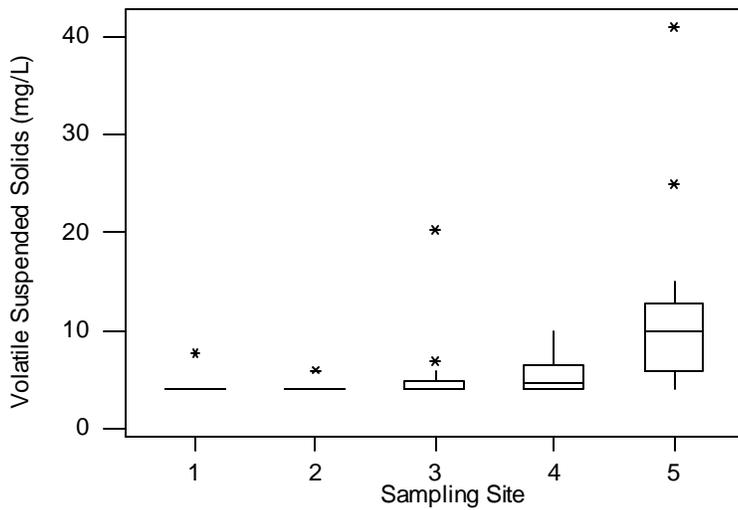


Figure 5.3.2-6
Volatile suspended solids (mg/l) variability by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

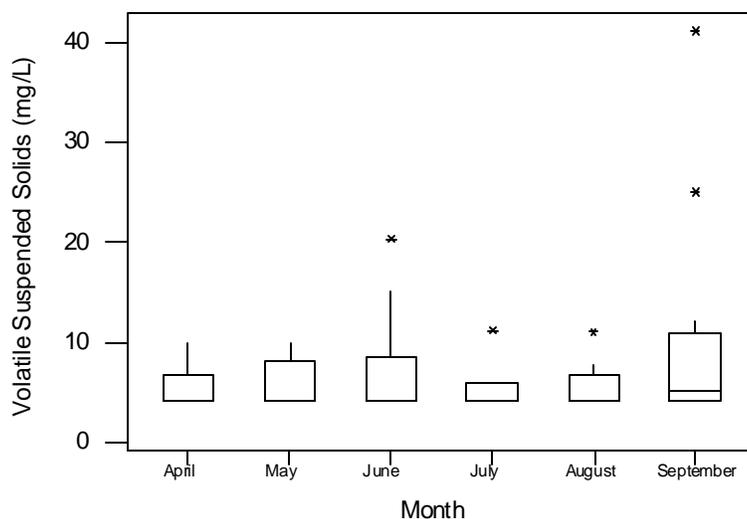


Figure 5.3.2-7
Seasonal volatile suspended solids (mg/l) variability,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

5.3.3 Metals. Surface samples at each station and samples at depth (Site 1) for total and dissolved iron and manganese analyses were collected on each sampling event, with the exception of 16 May 2000. Detection frequencies and descriptive statistics of these and other metals are listed in Table 5.3.3-1. Total iron was detected in 100% of the samples collected with an average concentration of 1.6 mg/l and ranged from 0.2 to 8.8 mg/l. In 1990, the Tulsa District reported the average total iron concentration in the reservoir to be 1.5 mg/l (USACE 1994).

Spatially, total iron concentrations were greater and more variable at Site 5 than at other sampling sites in the lake (Figure 5.3.3-1). One-way ANOVA on ranked data detected a significant difference among stations across all sampling sites and dates ($F = 6.25, p < 0.001$). Tukey's multiple comparison test ($\alpha = 0.05$) identified Site 5 as significantly different from Sites 1 and 2 only with no other significant differences identified among the sampling stations. At Site 1, the average concentration of total iron was 0.56 mg/l at the surface and 1.56 mg/l at the bottom. A significant difference was found between top and bottom concentrations of total iron

across all dates (independent t-test on ranked data, $p = 0.007$) and on average the bottom concentrations were greater than surface concentrations (Figure 5.3.3-2).

Temporally, concentrations of total iron were greater and more variable during the summer and early fall from June to September (Figure 5.3.3-3). One-way ANOVA on ranked data detected a significant difference in the median concentration of total iron between months ($F = 4.60$, $p = 0.001$) with June and September having a significantly greater total iron concentration than April and May (Tukey's multiple comparison test).

Concentrations of dissolved iron ranged from < 0.02 to 2.0 mg/l at the surface with dissolved iron detected in 55 of 60 samples (92%). At depth (1 m above the bottom at Site 1 only), dissolved iron was detected in 9 of 10 samples (90 %), and concentrations ranged from < 0.02 to 1.0 mg/l. Both at the surface and at depth dissolved iron constituted 26.7% of total iron. Spearman correlation analysis identified a significant positive correlation between dissolved iron and Verdigris River flow ($r = 0.410$, $p < 0.001$). A significant negative correlation between dissolved iron and dissolved oxygen ($r = -0.308$, $p = 0.029$) and chlorophyll *a* ($r = -0.277$, $p = 0.029$) across all sampling sites and dates was also identified. Unlike total iron, no longitudinal gradient was evident for dissolved iron, and mean concentrations were consistent across all stations (Figure 5.3.3-4) with no significant difference found (one-way ANOVA on ranked data, $F = 0.38$, $p = 0.823$). Likewise, no significant difference was found between surface and bottom dissolved iron concentrations at Site 1 (one-way ANOVA on ranked data, $F = 0.87$, $p = 0.363$), and average concentrations between surface and bottom differed by 35.8%. Temporally, average concentration across all sampling sites and months was relatively consistent (Figure 5.3.3-5), and no significant differences were detected among months (one-way ANOVA on ranked data, $F = 2.10$, $p = 0.08$). However, when individual sampling dates are compared within month, between month variability was more pronounced (Figure 5.3.3-6). With the p-value (0.08) so close to the level of significance ($\alpha = 0.05$), a second one-way ANOVA was performed across all sampling sites and individual sampling dates. When analyzed for differences among individual sampling dates, the ANOVA detected a significant difference in mean dissolved iron concentration ($F = 16.52$, $p < 0.001$). Tukey's multiple comparison test identified significant differences between

sampling dates within the months of June, August, and September as well as significant differences between sampling dates of different months.

Total manganese was detected in 59 of 60 (98.3 %) surface samples across the lake and in 10 of 10 (100%) bottom samples at Site 1. Concentrations of total manganese ranged from < 0.02 to 0.31 mg/l at the surface and from 0.045 to 1.6 mg/l (mean = 0.307) at depth. A significant positive correlation (Spearman correlation) was found between total manganese and TSS ($r = 0.882$, $p < 0.001$), VSS ($r = 0.546$, $p < 0.001$), chlorophyll *a* ($r = 0.403$, $p < 0.001$), and biochemical oxygen demand ($r = 0.398$, $p = 0.002$). Total manganese exhibits a strong longitudinal gradient both horizontally (Figure 5.3.3-7) and vertically (5.3.3-8). One-way ANOVA on ranked data determined a significant difference between sampling sites across all sampling dates ($F = 35.43$, $p < 0.001$) and between surface and bottom concentrations at Site 1 across all sampling dates (Independent t-test on ranked data, $p < 0.001$). Across all sampling sites and dates, Tukey's multiple comparison test identified the following relationship: $1 \neq 2 \leq 3 \leq 4 \neq 5$. Temporally, there was not a well defined trend in total manganese concentrations (Figure 5.3.3-9), and no significant differences were found between individual sampling dates across all stations (one-way ANOVA on ranked data, $F = 1.32$, $p = 0.25$).

Dissolved manganese was detected in 24 of 60 (40%) surface samples and in 7 of 10 (70%) samples collected from depth at Site 1. At the surface, dissolved manganese concentrations ranged from < 0.008 to 0.039 mg/l and from < 0.008 to 1.4 mg/l. At the surface, significant positive correlations (Spearman correlation) were found between dissolved manganese and TSS ($r = 0.474$, $p < 0.001$) and VSS ($r = 0.459$, $p < 0.001$), and a significant negative correlation was identified between dissolved manganese and dissolved oxygen ($r = -0.468$, $p = 0.001$). Spatially, no horizontal gradient in dissolved manganese concentrations (Figure 5.3.3-10) existed among sampling sites ($F = 1.91$, $p = 0.122$) across all sampling sites and dates. At Site 1, there was a vertical gradient between surface and bottom concentrations with dissolved manganese concentrations being more variable and at depth (Figure 5.3.3-11). Temporally, no clear trend was evident over the period of this study (Figure 5.3.3-12). Dissolved manganese concentrations at the surface were below the quantitation limit throughout May, and on 6 June, 5 July, 1 August, and 6 September dissolved manganese was below the

quantitation limit at four of the five surface sampling sites. At depth, dissolved manganese was below the quantitation limit in April, May, and on 5 July, and when present, no clear trend was evident (Figure 5.3.3-13).

On one date, 19 July 2000, concentrations of dissolved cadmium, total cadmium, and total chromium were found to exceed the raw water numerical criteria (Table 5.3.3-2) established by the Oklahoma Water Resources Board and outlined in the Oklahoma Administrative Code 785:45-5-10. The descriptive statistics of other metals analyzed as part of this study are listed in Table 5.3.3-1.

Table 5.3.3-1. Descriptive statistics for surface metals concentrations, Oologah Lake, Oklahoma, 2000

Parameter	Median	Mean	Min.	Max.	N	# BDL
Aluminum, Dissolved (mg/l)	0.515	0.912	0.3	3.0	24	0
Aluminum, Total (mg/l)	1.35	1.885	0.4	7.9	24	0
Antimony, Dissolved (mg/l)		< 0.006			24	24
Antimony, Total (mg/l)		< 0.006			23	23
Arsenic, Dissolved (mg/l)			< 0.002	0.002	24	19
Arsenic, Total (mg/l)			< 0.002	0.003	24	17
Barium, Dissolved (mg/l)	0.061	0.06	0.05	0.078	24	0
Barium, Total (mg/l)	0.087	0.08	0.051	0.150	24	0
Beryllium, Dissolved (mg/l)		< 0.004			24	24
Beryllium, Total (mg/l)		< 0.004			24	24
Cadmium, Dissolved (mg/l)	0.003	0.098	0.003	0.450	24	18
Cadmium, Total (mg/l)	0.003	0.319	0.003	2.20	24	16
Calcium, Dissolved (mg/l)	39.0	39.06	22.5	49.0	24	0
Calcium, Total (mg/l)	41.9	41.48	25.2	52.0	24	0
Chromium, Dissolved (mg/l)		< 0.030			24	24
Chromium, Total (mg/l)	0.03	0.830	0.03	9.80	24	20
Copper, Dissolved (mg/l)		< 0.020			24	24
Copper, Total (mg/l)			< 0.020	0.023	24	23
Iron, Dissolved (mg/l)	0.260	0.381	< 0.020	2.00	60	5
Iron, Total (mg/l)	0.825	1.603	0.2	8.8	60	0
Lead, Dissolved (mg/l)			< 0.001	0.001	24	20
Lead, Total (mg/l)			< 0.001	0.004	24	12
Magnesium, Dissolved (mg/l)	7.75	7.47	4.4	9.9	24	0
Magnesium, Total (mg/l)	7.75	7.76	4.5	11.0	24	0
Manganese, Dissolved (mg/l)			< 0.008	0.325	60	36
Manganese, Total (mg/l)	0.062	0.092	0.01	0.31	60	1
Mercury, Dissolved (mg/l)			< 0.0001	0.0001	24	23
Mercury, Total (mg/l)			< 0.0001	0.0005	24	15
Nickel, Dissolved (mg/l)		< 0.020			24	24
Nickel, Total (mg/l)		< 0.020			24	24
Potassium, Dissolved (mg/l)	3.05	3.07	2.6	3.6	24	0
Potassium, Total (mg/l)	3.3	3.83	2.4	10.0	24	0
Selenium, Dissolved (mg/l)		< 0.003			24	24
Selenium, Total (mg/l)		< 0.003			24	24
Silver, Dissolved (mg/l)		< 0.020			24	24
Silver, Total (mg/l)		< 0.020			24	24
Sodium, Dissolved (mg/l)	10.0	10.26	6.7	13.0	24	0
Sodium, Total (mg/l)	12.0	12.43	8.3	16.0	24	0
Thallium, Dissolved (mg/l)			< 0.002	0.002	22	21
Thallium, Total (mg/l)		< 0.002			24	24
Zinc, Dissolved (mg/l)		< 0.020			24	24
Zinc, Total (mg/l)			< 0.020	0.079	24	21

Table 5.3.3-2. Dissolved cadmium, total cadmium, and total chromium (mg/l) concentrations on 19 July 2000, Oologah Lake, Oklahoma (numeric criteria for raw water in parentheses).

Site	Dissolved Cadmium (0.02 mg/l)	Total Cadmium (0.02 mg/l)	Total Chromium (0.05 mg/l)
1	0.33	0.65	< 0.03
2	0.37	0.82	0.15
3	0.43	1.04	9.80
4	0.45	1.30	9.20
5	0.41	2.20	0.17
5 – Duplicate	0.31	1.90	< 0.03

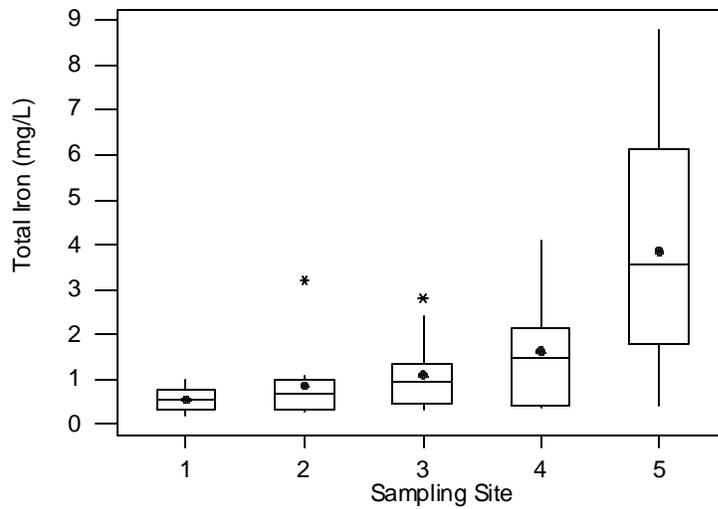


Figure 5.3.3-1
Total iron (mg/l) variability by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

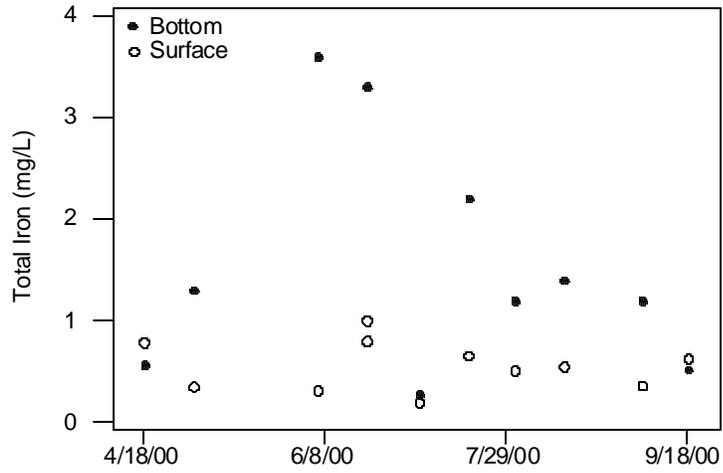


Figure 5.3.3-2
Bottom (●) and surface (○) concentrations of total iron (mg/l) at Site 1, Oologah Lake, Oklahoma.

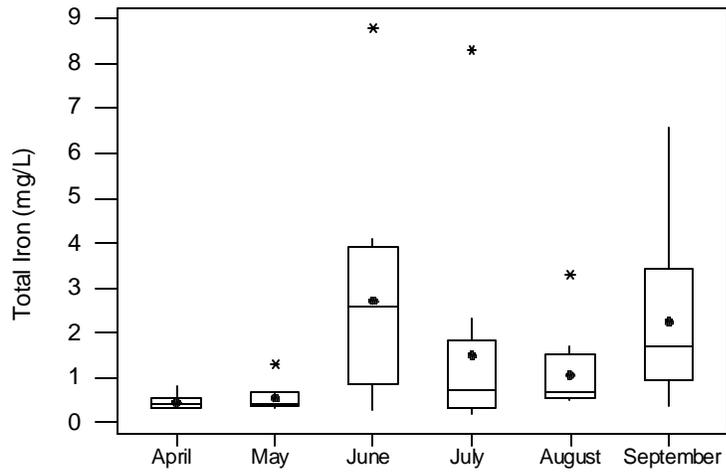


Figure 5.3.3-3
Seasonal total iron (mg/l) variability, 18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

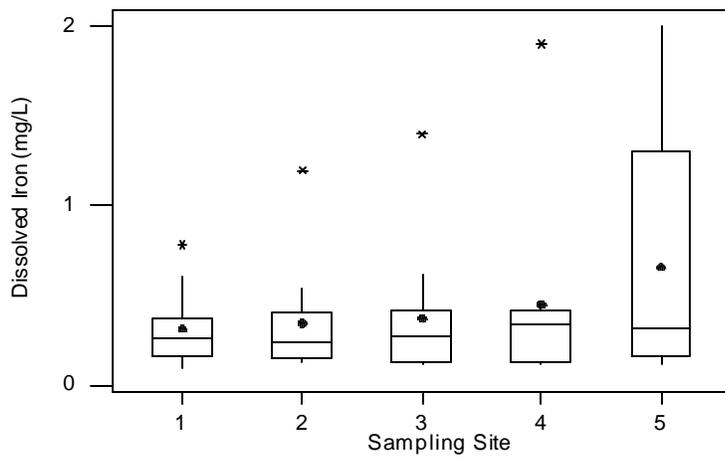


Figure 5.3.3-4
Dissolved iron (mg/l) variability by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

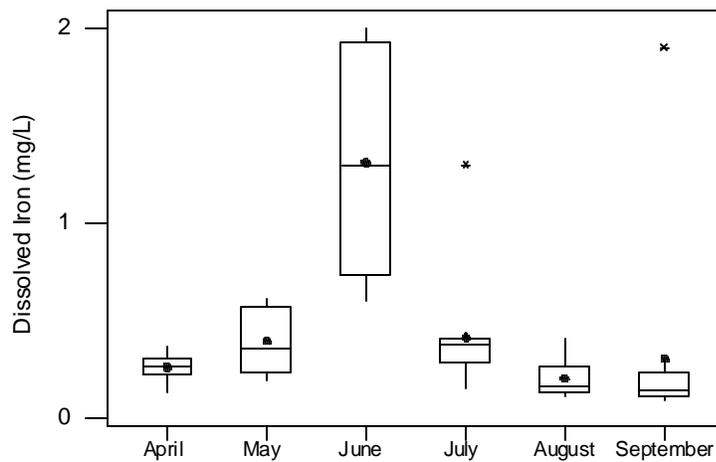


Figure 5.3.3-5
Seasonal dissolved iron (mg/l) variability,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

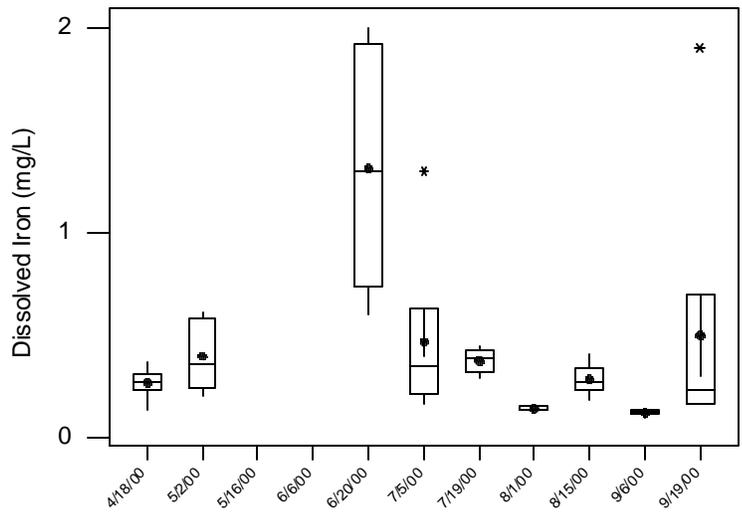


Figure 5.3.3-6
Dissolved iron (mg/l) variability by sampling date, Oologah Lake, Oklahoma.

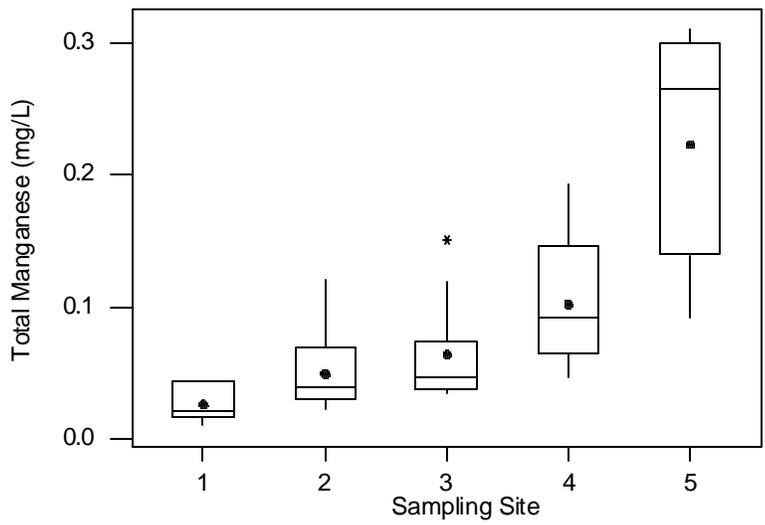


Figure 5.3.3-7
Total manganese (mg/l) variability by station, 18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

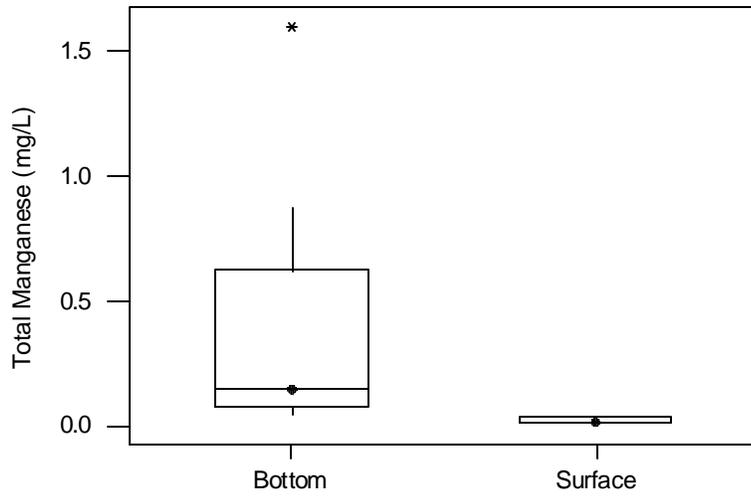


Figure 5.3.3-8
Total manganese (mg/l) variability between surface and bottom samples at Site 1, 18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

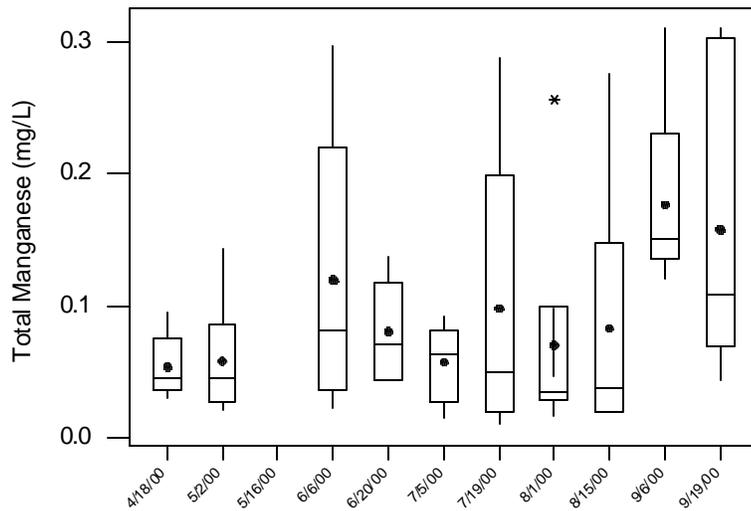


Figure 5.3.3-9
Total manganese (mg/l) variability by sampling date, Oologah Lake, Oklahoma, 2000.

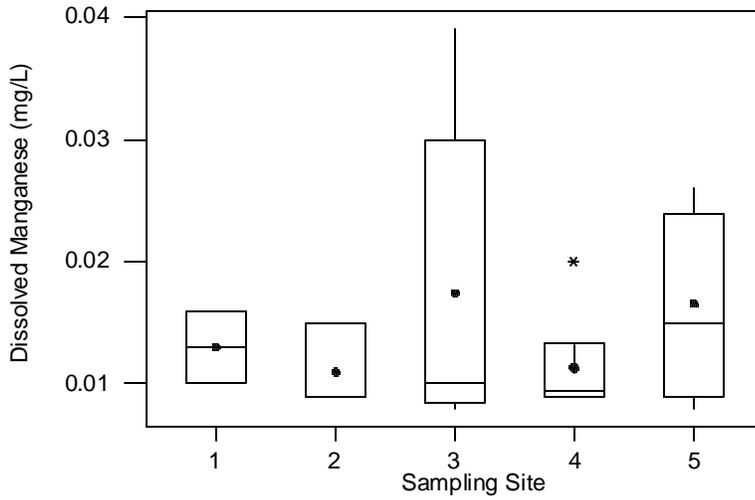


Figure 5.3.3-10
Dissolved manganese (mg/l) variability by station,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

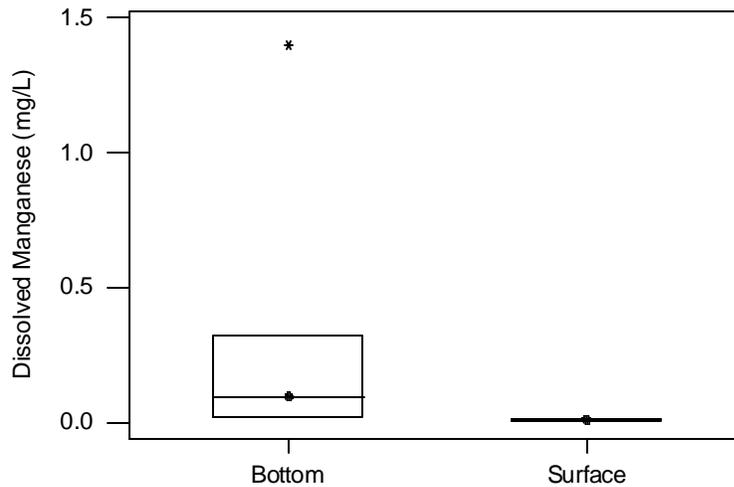


Figure 5.3.3-11
Dissolved manganese (mg/l) variability between surface and bottom samples at Site 1,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

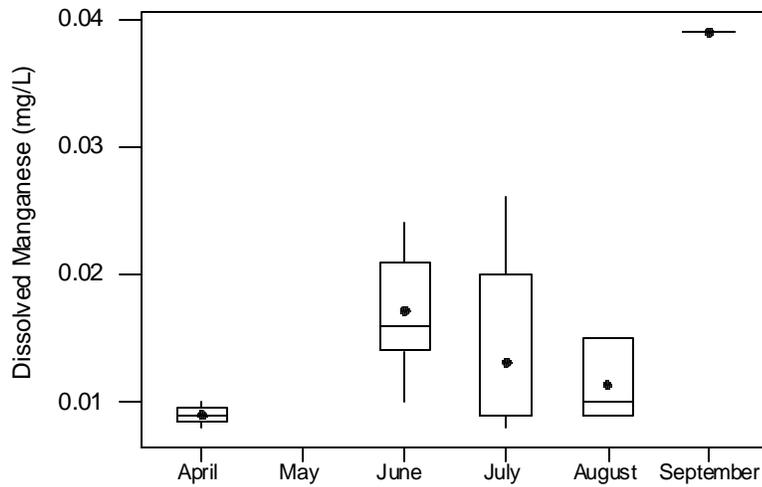


Figure 5.3.3-12
Seasonal dissolved manganese (mg/l) variability,
18 April 2000 through 19 September 2000, Oologah Lake, Oklahoma.

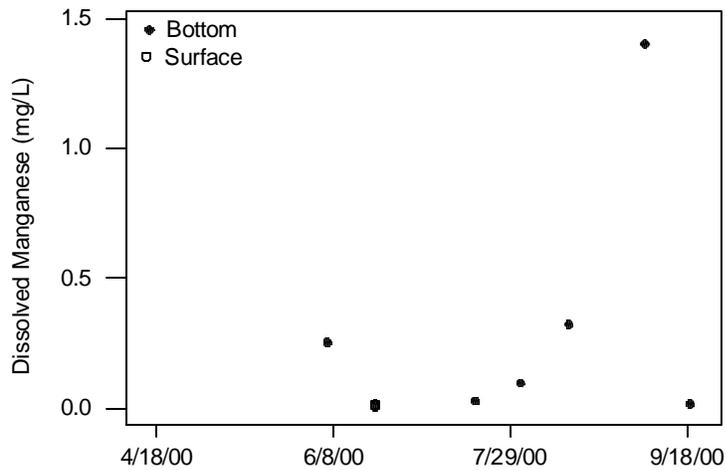


Figure 5.3.3-13
Bottom (0) and surface (1) concentrations of dissolved manganese (mg/l)
at Site 1, Oologah Lake, Oklahoma.

5.3.4 Organics. On 20 June 2000 and 5 July 2000 (semi-volatiles only), water samples were collected for organics analyses. Samples included primary field samples from the reservoir and its tailwaters, field blank samples, and quality assurance/quality control (QA/QC) replicates. Surface samples were collected at a depth of approximately 0.5 m. Samples collected at depth were collected at a depth of 18 to 19 m at Site 1 only. Analyses for organic compounds included chlorinated pesticides, chlorinated herbicides, organo-phosphorus pesticides, and semi-volatile organics.

Atrazine, the only compound to be detected in the reservoir, was detected in concentrations at or near sample quantitation limits, and ranged from 0.05 µg/l at Site 1 to 0.15 µg/l at Site 4 (Table 5.3.4-1). Atrazine was detected in 57 % (4/7) of reservoir samples collected on 20 June 2000, and concentrations were well below the Federal drinking water standard of 3.0 µg/L (USEPA 2000). In the tailwaters, Atrazine was again the only compound to be detected (0.05 µg/L). Concentrations of all other analytes (i.e., herbicides, pesticides, semi-volatiles) were below quantitation limits in all samples.

Table 5.3.4-1. Atrazine concentrations (µg/L) on 20 June 2000, Oologah Lake, Oklahoma.

Sampling Site	Atrazine Concentration (µg/L)
Tailwater	0.05
Site 1 (0.1 m)	0.05
Site 1 (19 m)	
Site 2	
Site 3	0.10
Site 4	0.13
Site 5	0.15

5.3.5 Total Petroleum Hydrocarbons. On all sampling dates, water samples were collected, preserved, and analyzed for diesel range organics (DRO) total petroleum hydrocarbons (TPH) using Method SW-846/8015B/3510C. Low level analyses were requested to minimize sample quantitation limits. Samples included primary field samples from the lake and its tailwaters (three dates only), QA/QC replicates, and field blank samples. With the exception of samples collected at depth (generally 18 to 19 m) at Site 1, all field samples were collected at a

depth of approximately 0.1 m from the surface. Resulting data were validated by Tulsa District chemists and found to be of acceptable quality (Appendix A).

Detected concentrations of DRO-TPH in Oologah Lake water samples are presented in Table 5.3.5-1. Detected concentrations were all very low, at or near sample quantitation limits, and ranged from 101 $\mu\text{g/l}$ at Site 4 on several dates to 196 $\mu\text{g/l}$ at Site 5 on 6 June 2000 (Table 5.3.5-1). Over the entire sampling period, petroleum hydrocarbons were detected in 20 of 65 primary field samples for an overall detection frequency of 31%. On a site-specific basis, detection frequency was highest at Site 5 (45%) and lowest at Site 2 (9%). Detection frequencies were 27% for Sites 1 (bottom) and 3 and 36% for Sites 1 (surface) and 4, respectively. Detected TPH concentrations were similar at all sites (Table 5.3.5-1). When TPH was detected, no significant correlation (Spearman's rank) was observed between lakewater TPH and total suspended solids ($r = 0.076$, $p = 0.752$) or lab turbidity ($r = 0.18$, $p = 0.940$).

Though sample numbers were limited and reported concentrations below analytical quantitation limits in a number of samples, there did appear to be a relationship between lakewater TPH concentration and lake surface elevation. On sampling dates when lake elevation was less than 639 feet, overall detection frequency was 40%. Overall detection frequency was approximately half this amount (22%) for all dates when lake elevation exceeded 639 feet. When one-half the quantitation limit of 100 $\mu\text{g/l}$ was substituted for non-detect values, a significant ($\alpha = 0.05$), negative correlation was observed between lake-wide mean surface water TPH concentration and lake surface elevation (Spearman's $r = -0.615$, $p = 0.044$, $n = 11$).

Concentrations of TPH were below the sample quantitation limit (100 $\mu\text{g/l}$ for all analyses) in all field blank samples, QA/QC replicates, and samples from Oologah Lake tailwaters (collected 5 and 19 July and 1 August 2000 only).

Table 5.3.5-1. Detected concentrations ($\mu\text{g/l}$) of diesel range total petroleum hydrocarbons, Oologah Lake, Oklahoma. Concentrations for all other samples were $<100 \mu\text{g/l}$.

	Site 1 (0.1m)	Site 1 (19m)	Site 2	Site 3	Site 4	Site 5
04/18/2000	114	111				
05/02/2000						106
05/16/2000						
06/06/2000	115			142	101	196
06/20/2000					101	
07/05/2000						
07/19/2000		100		104		
08/01/2000						
08/15/2000	146		102	102	106	111
09/06/2000					101	112
09/19/2000	102	150				155

5.3.6 Vertical Profiles. Vertical profiles of pH (standard units), specific conductance ($\mu\text{S/cm}$), dissolved oxygen (mg/l), temperature ($^{\circ}\text{C}$), and field turbidity (NTU) were recorded at each sampling site on each sampling date from 18 April 2000 through 19 September 2000. Descriptive statistics across all sampling sites, depths, and dates are listed in Table 5.3.6-1, and vertical profiles at each sampling site on individual dates are provided in Appendix C. During the study, Oologah Lake exhibited neither a strong nor prolonged period of thermal stratification in the traditional sense (i.e., metalimnetic temperature change of $> 1^{\circ}\text{C}$ per meter). However, thermal stratification was evident at Site 1 on 6 June 2000 and 15 August 2000, with the thermocline located at a depth of 12 and 10 meters, respectively (Figure 5.3.6-1). Thermal stratification was also observed at Site 2 on 19 July 2000, with the thermocline located at a depth of 8 meters (Figure 5.3.6-2). No other sampling sites exhibited thermal stratification during the course of this study.

Chemical-physical profiles of temperature ($^{\circ}\text{C}$), dissolved oxygen (mg/l), specific conductance ($\mu\text{S/cm}$), and pH (standard units) at Sites 1 and 2 indicate chemical stratification can occur in the absence of thermal stratification; however, in the presence of thermal stratification, the chemical stratification is much more pronounced. Chemical stratification, in the presence or absence of thermal stratification, is characterized primarily by a decrease in

dissolved oxygen (to below 2 mg/l) (Figure 5.3.6-3) and pH (Figure 5.3.6-4) and an increase in specific conductance (Appendix C), a trend that mirrors chemical stratification detected in other turbid reservoir systems (Hubbs *et al.* 1976; Matthews and Hill 1988; Clyde 1996).

The occurrence of dissolved oxygen concentrations below 2.0 mg/l within the hypolimnion was sporadic, and such conditions were present on 6 June (Sites 1 and 2), 19 July (Sites 1, 2, and 3), and 15 August through 6 September (Site 1). The greatest extent of hypolimnetic oxygen depletion was observed on 6 September. On that date, reduced DO concentrations in the hypolimnion were generally confined to the main pool area of the reservoir extending from the dam to the Goose Island area (Site 2) (Figure 5.3.6-5). Clark, Mooney, Norton & Associates (1978) reported the sporadic development of hypolimnetic anoxia at all stations below Winganon bridge between 8 July 1978 and 14 October 1978. The USACE (1994) found no evidence of hypolimnetic anoxia in a 1990 water quality survey of the reservoir. Specific conductance, pH, and temperature were all within the ranges previously reported in limited historical surveys.

Table 5.3.6-1. Descriptive statistics of temperature (°C), specific conductance (µS/cm), pH (standard units), dissolved oxygen (mg/l), and field turbidity (NTU), across all sampling sites, sampling depths, and sampling dates, Oologah Lake, Oklahoma, 2000.

Variable	Median	Mean	Min.	Max.	N
Temperature	24.9	24.0	13.7	30.1	634
Specific Conductance	332.5	337.1	204.0	432.0	634
pH	7.99		6.73	8.72	634
Dissolved Oxygen	7.04	6.89	0.03	12.98	634
Field Turbidity	41.2	51.7	8.3	209.0	634

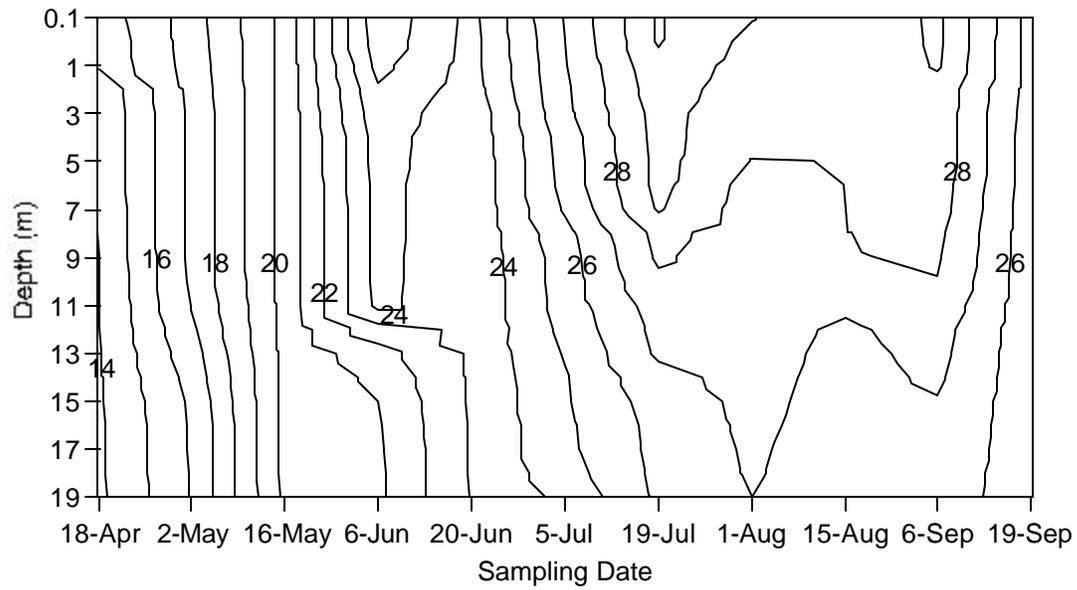


Figure 5.3.6-1
Depth-time diagram of temperature (°C) isotherms at Site 1,
18 April 2000 through 19 September 2000.

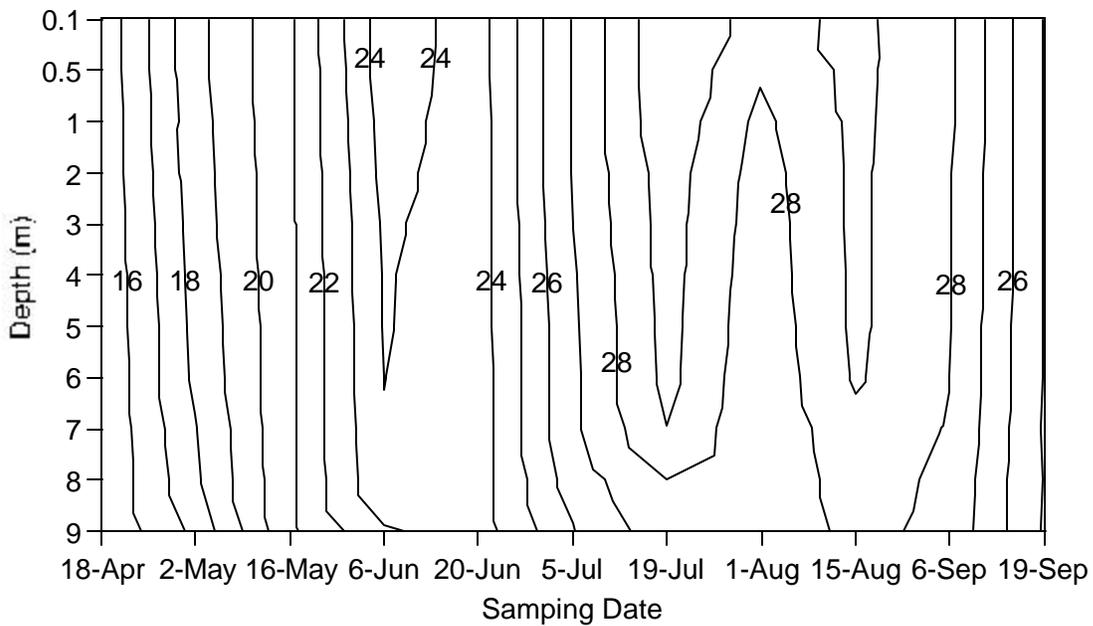


Figure 5.3.6-2
Depth-time diagrams of temperature (°C) isotherms at Site 2,
18 April 2000 through 19 September 2000.

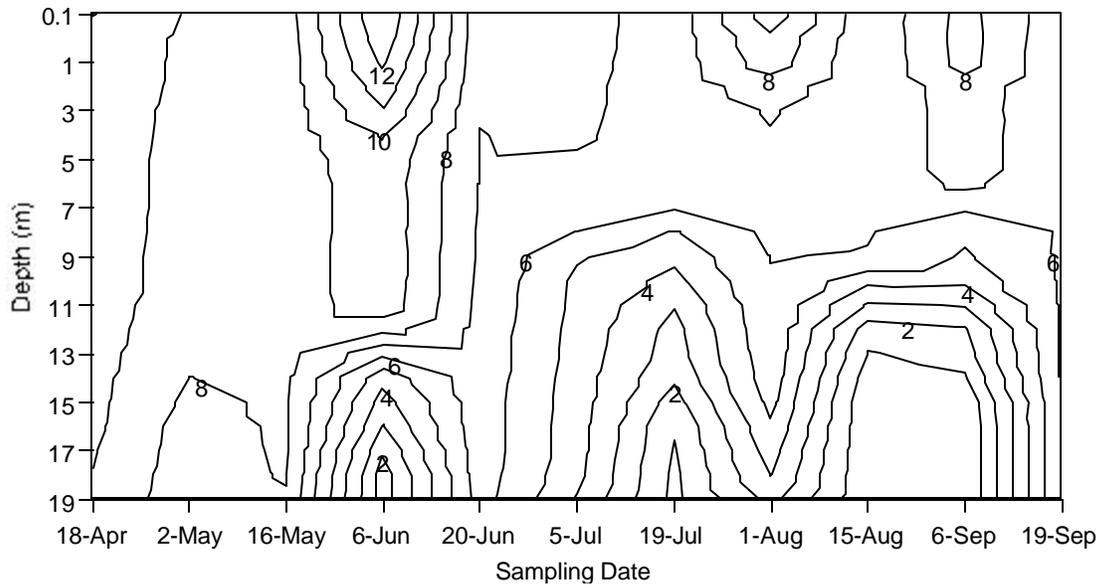


Figure 5.3.6-3
Depth-time diagram of isopleths of dissolved oxygen (mg/l) at Site 1,
18 April 2000 through 19 September 2000.

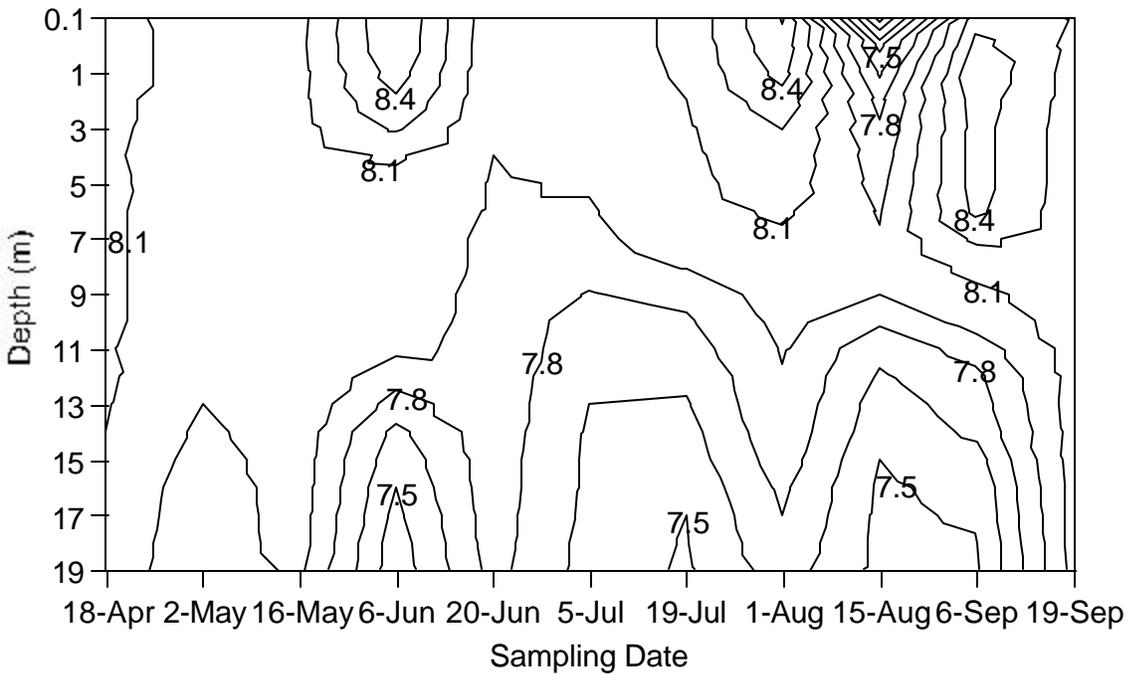


Figure 5.3.6-4
Depth-time diagram of isopleths of pH (SU) at Site 1,
18 April 2000 through 19 September 2000.

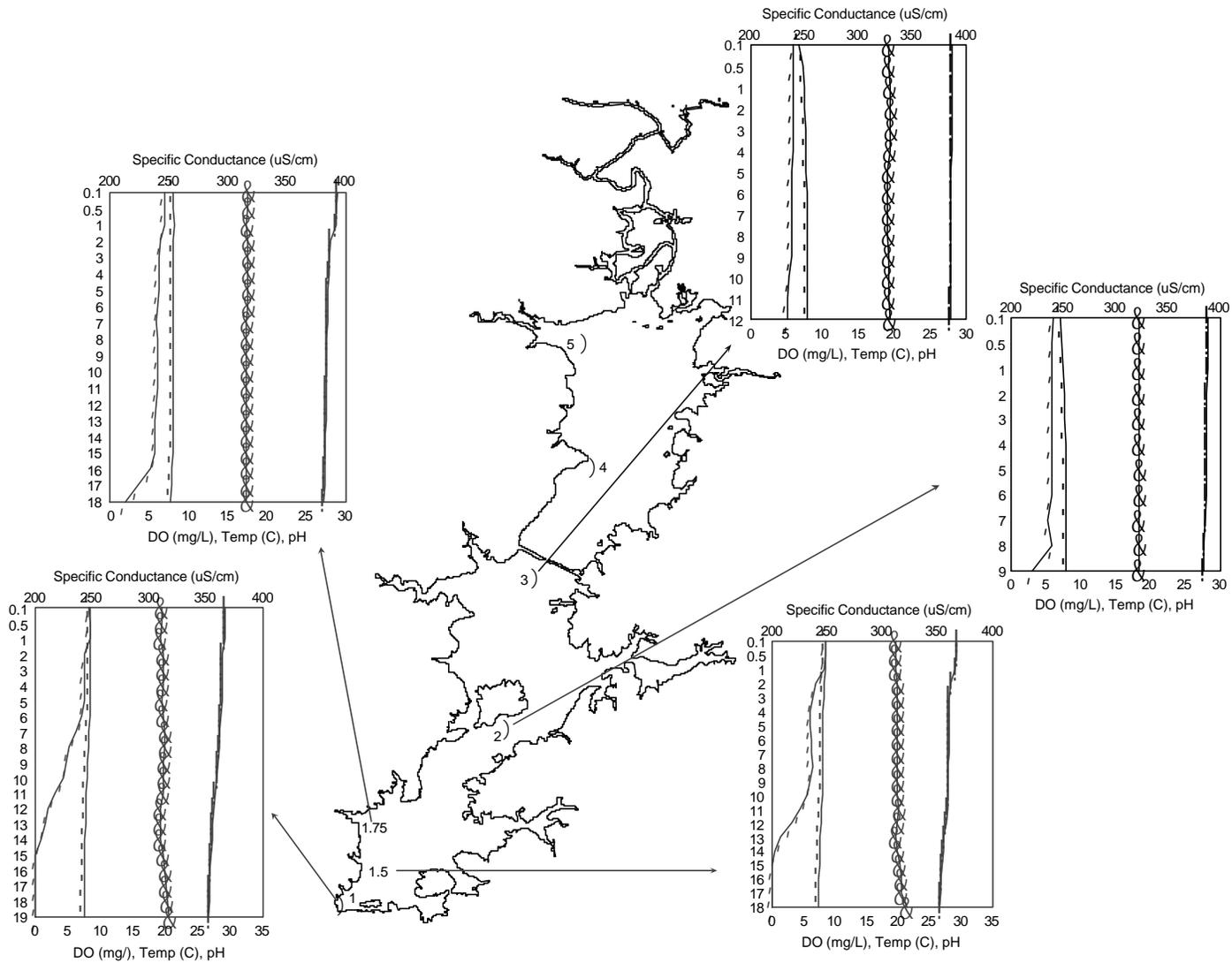


Figure 5.3.6-5

Vertical profiles of temperature (dot), specific conductance (diamond), pH (triangle), dissolved oxygen (square) in the main pool area between the dam and Goose Island, Oologah Lake, Oklahoma, 6 September 2000.

5.4 Biological Parameters

5.4.1 Chlorophyll *a*. Table 5.4.1-1 lists average chlorophyll *a* concentrations by date and site. Chlorophyll *a* values ranged from < 2.0 to 46.2 µg/l across all sampling sites and dates with an average concentration of 9.2 µg/l. The distribution of chlorophyll *a* values across all sampling sites and individual sampling sites across all dates was significantly different from a normal distribution (Anderson-Darling normality test, $p < 0.001$). The highest concentrations and greatest variability in chlorophyll *a* values occurred in the riverine portion of the reservoir (Site 5). Sampling sites down reservoir of Site 5 showed both lower chlorophyll *a* concentrations and less variability (Figure 5.4.1-1). One-way ANOVA on ranked data detected a significant difference in chlorophyll *a* concentration among the sampling sites ($F = 13.25$, $p < 0.001$). Tukey's multiple comparison test ($\alpha = 0.05$) identified a significant difference between Site 5 and all other sampling sites with following relationship: $1 \leq 2 \leq 3 \leq 4 \neq 5$. Factors significantly correlated with chlorophyll *a* in the reservoir included: alkalinity ($r = 0.397$, $p = 0.001$), biological oxygen demand ($r = 0.366$, $p = 0.003$), hardness ($r = 0.560$, $p < 0.001$), nitrate + nitrite ($r = -0.579$, $p < 0.001$), ortho-phosphorus ($r = -0.425$, $p < 0.001$), dissolved phosphorus ($r = -0.363$, $p = 0.003$), total suspended solids ($r = 0.332$, $p = 0.007$), and volatile suspended solids ($r = 0.437$, $p < 0.001$). Seasonally, chlorophyll *a* concentrations peaked during August and September (Figure 5.4.1-2). One-way ANOVA on ranked data indicated a significant difference in median concentration between the months ($F = 9.17$, $p < 0.001$). Tukey's multiple comparison test ($\alpha = 0.05$) identified the following relationship in seasonal chlorophyll *a* concentration: $\text{May} \leq \text{June} \leq \text{July} \neq \text{April} \leq \text{August} \leq \text{September}$.

Carlson's Trophic State Index (TSI) (Carlson 1977) was calculated from chlorophyll *a* values for each station and sampling date (Figure 5.4.1-3). Across all sampling sites and sampling dates, the mean TSI (chlorophyll *a*) value was 48.6 which classifies the lake as mesotrophic. Trophic state indices at individual stations across all dates ranged from mesotrophic (sites 1, 2, 3, and 4) to eutrophic (site 5) (Figure 5.4.1-3). An alternate methodology to the Carlson TSI is the trophic classification system proposed by Reckhow and Chapra (1983). This trophic classification system defines the trophic status using mean chlorophyll *a* concentrations as follows:

Oligotrophic	< 4 µg/l
Mesotrophic	4 – 10 µg/l
Eutrophic	10 – 25 µg/l
Hypereutrophic	> 25 µg/l

Using this classification scheme, Oologah Lake would be considered mesotrophic, based on an overall mean of 9.2 µg/l. Both classification schemes identified Oologah Lake to be a mesotrophic reservoir. In 1990, a water quality survey of Oologah Lake (Tulsa District, 1994) reported an overall mean chlorophyll *a* concentration of 17.6 µg/l (52.3 % greater than 2000 overall mean concentration). A second water quality survey conducted by the Oklahoma Water Resources Board (OWRB) in 1996 (OWRB, 1999) reported an overall mean chlorophyll *a* concentration of 8.75 µg/l (5.1 % less than 2000 overall mean concentration) and a Carlson TSI value of 55. Both reports classified the reservoir as being at the lower end of eutrophy with high primary productivity, whereas, the current water quality survey has identified the reservoir as being mesotrophic with moderate primary productivity. Although there is no significant correlation between turbidity and chlorophyll *a* (Spearman correlation, $r = -0.001$, $p = 0.992$), there is a significant correlation between chlorophyll *a* and suspended solids (see above), both of which significantly influence turbidity within the reservoir (see section 5.3.2). The general trend observed between chlorophyll *a*, suspended solids, and turbidity is for chlorophyll *a* concentrations to decrease as suspended solids and turbidity concentrations increase (Figure 5.4.1-4). This trend is further supported by the Tulsa District (1994) and the OWRB (1999). In 1990, the Tulsa District (1994) reported a mean overall turbidity value of 34.8 NTU and in 1996, the OWRB (1999) reported an overall mean turbidity of 28 NTU. In 2000, the overall mean turbidity was 46.8 NTU, which represents a 67.1% increase in turbidity over the 1990 survey (Tulsa District, 1994) and a 34.4% increase in turbidity over the 1996 survey (OWRB 1999).

Table 5.4.1-1. Mean chlorophyll *a* (µg/l) concentrations, Oologah Lake, Oklahoma, 2000.
 Values are mean concentration of three replicate samples at each site.

Date	Site 1	Site 2	Site 3	Site 4	Site 5	Date Mean
18 April	4.1	5.0	7.0	13.1	19.5	8.9
2 May	2.4	6.0	7.9	13.1	23.0	10.1
15 May	2.2	2.0	2.4	2.0	2.8	2.3
6 June	14.3	4.7	4.1	5.1	11.7	7.4
20 June	2.0	< 2.0	9.7	4.5	3.2	3.9
5 July	4.5	4.1	4.1	2.8	4.3	3.8
19 July	2.3	5.6	4.1	3.6	13.2	6.9
1 August	20.7	11.8	11.4	33.4	42.4	21.8
15 August	2.4	9.7	10.5	8.5	35.6	11.5
6 September	12.2	7.6	3.7	9.8	22.6	10.9
19 September	< 2.0	3.1	8.5	11.9	26.7	13.0
Site Mean	5.6	5.5	7.1	9.4	18.1	

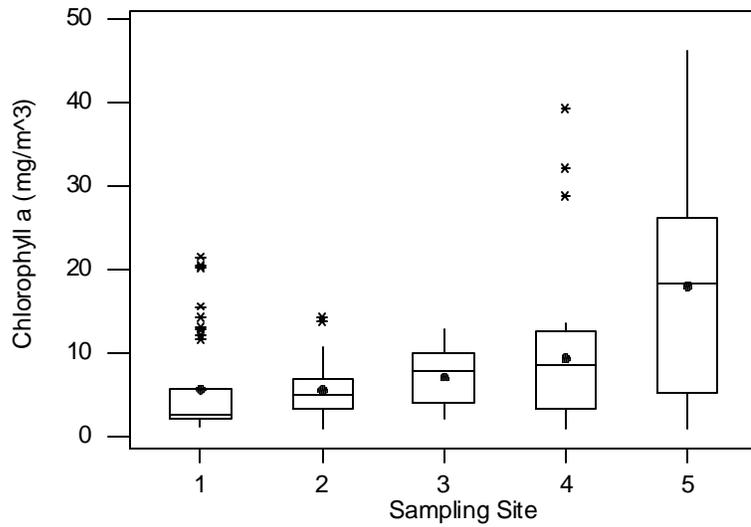


Figure 5.4.1-1
Chlorophyll *a* (µg/l) variability, by sampling site, Oologah Lake, Oklahoma, 2000.

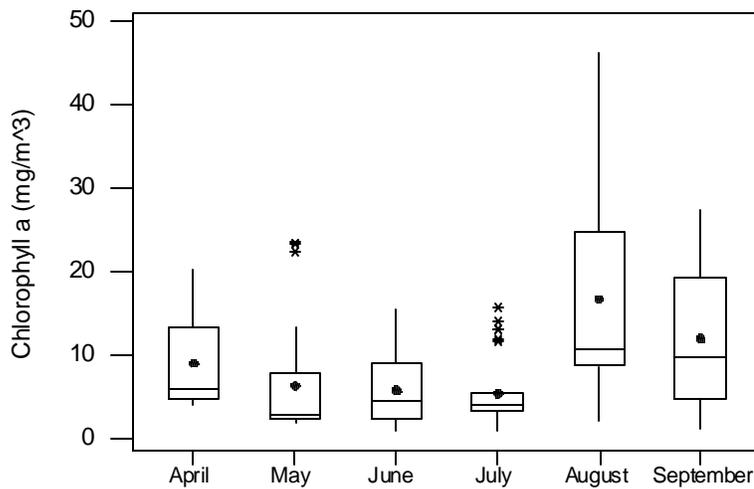


Figure 5.4.1-2
Chlorophyll *a* (µg/l) variability, by month, Oologah Lake, Oklahoma, 2000.

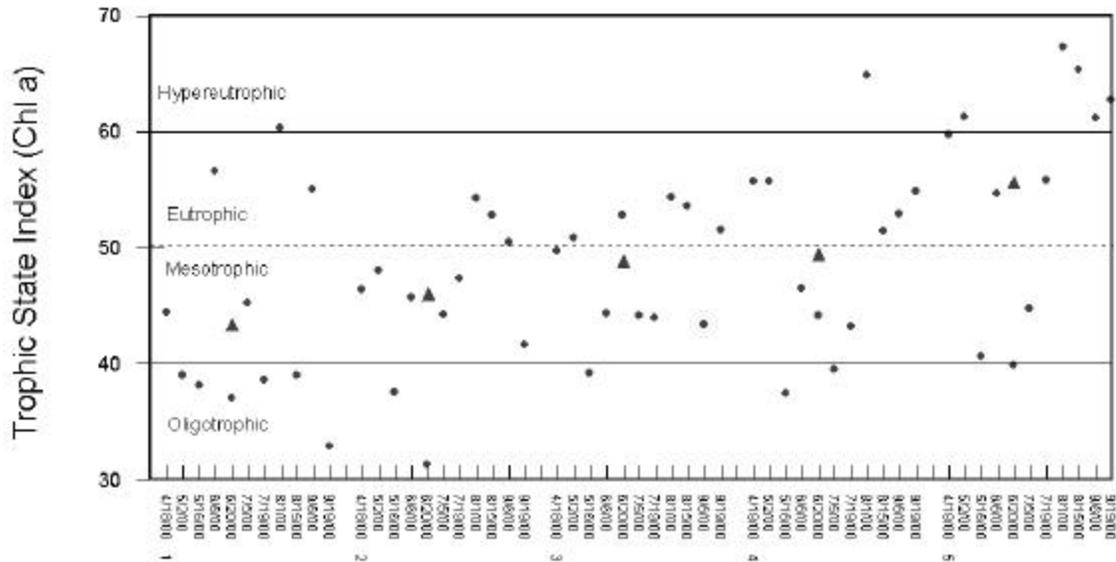


Figure 5.4.1-3

Carlson Trophic State Index (chlorophyll *a*) at each station on individual sampling dates () and station mean across all sampling dates (), Oologah Lake, Oklahoma, 2000.

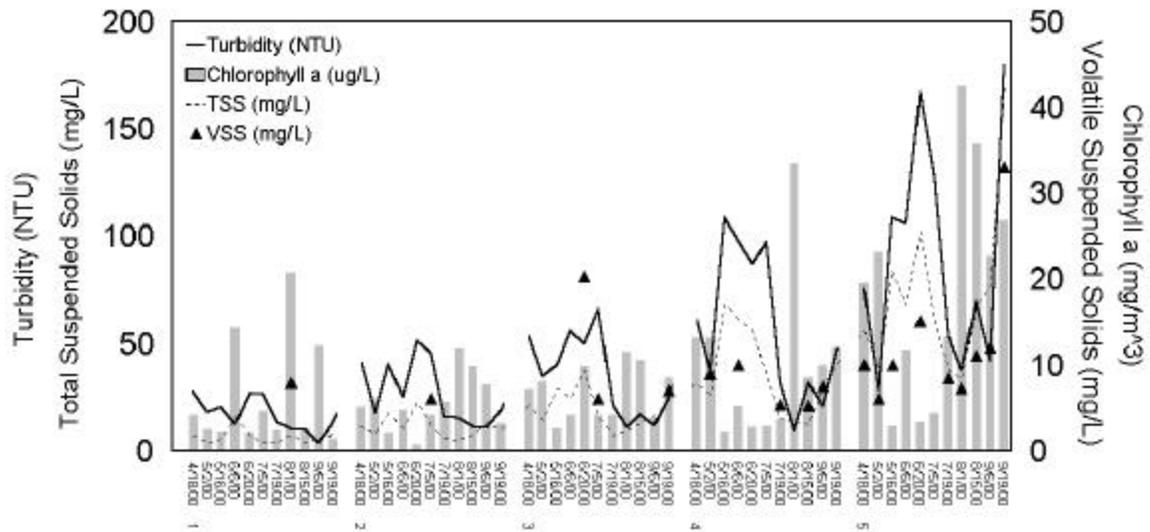


Figure 5.4.1-4

Turbidity (NTU), chlorophyll *a* (µg/l), total suspended solids (mg/l), and volatile suspended solids (mg/l) trends across all sampling sites and sampling dates, Oologah Lake, Oklahoma, 2000.

5.4.2 Phytoplankton The phytoplankton assemblage in Oologah Lake during this study was represented by 49 genera within 13 orders and 5 divisions. Table 5.4.2-1 list the phytoplankton taxa present at each sampling site during the study period. Of the 49 genera present in Oologah Lake, 24.4 % (12/49) were found to be of the division Cyanophyta (Cyanobacteria), 14.3 % (7/49) were found to be of the division Bacillariophyta (Diatoms), 42.8 % (21/49) were found to be of the division Chlorophyta (Green Algae), 10.2 % (5/49) were found to be of the division Euglenophyta (Euglenoids), and 8.2 % (4/49) were found to be of the division Phyrrophyta (Dinoflagellates).

The green algae exhibited the greatest overall species richness. Species abundance was equitably split between the green algae and diatoms (43.1 % and 36.5 %, respectively) with the Cyanobacteria, Dinoflagellates, and Euglenoids contributing 20.5 % of overall species abundance (Figure 5.4.2-1). Within the Volvocales (Chlorophyta), the genus *Chlamydomonas* was the most abundant across the study period. Within the Centrales (Bacillariophyta), the most abundant species were the filamentous diatoms *Aulacoseira distans* and *A. granulata*, and within the Chroococcales (Cyanophyta) the most abundant species included *Merismopedia tenuissima* and *Anacystis* sp. (Figure 5.4.2-2). Spatially, across all sampling dates, Site 1 was the only sampling site to be dominated by green algae. At Site 2, green algae and diatoms were equally dominant, and at Sites 3, 4, and 5 diatoms tended to dominate the algal assemblage (Figure 5.4.2-3). Degree of similarity in species composition between sites was assessed with the Bray-Curtis index of similarity. This analysis supports the observation that the community assemblage at Site 1 is different from Sites 2, 3, 4, and 5. The Bray-Curtis analysis (Figure 5.4.2-4) detected a 55 % degree of similarity between Site 2 and Site 3 (node 1), a 45 % degree of similarity between Site 4 and Site 5 (node 2), and a 43 % degree of similarity between the nodes of these groupings. The degree of similarity between Site 1 and the groupings of Sites 2-3 and Sites 4-5 was 28 %.

Temporal trends in algal assemblage structure are shown in Figures 5.4.2-5 through 5.4.2-7 for Sites 1, 3, and 5. In general, diatoms tended to dominate the phytoplankton assemblage temporally (as well as spatially) over much of the survey period, with seasonal peaks in the occurrence of a green algae and Cyanobacteria during warmer periods (July-August).

Much of the increase in green algae was attributable to the genera *Oocystis* and *Chlamydomonas*. Seasonal increases in the abundance of the Cyanobacteria were attributed to representatives of the genera *Anacystis* and *Merismopedia*, both of which can contribute to taste and odor problems in surface water supplies.

Table 5.4.2-1. Phytoplankton taxa present at each site, Oologah Lake, Oklahoma, 18 April 2000 through 19 September 2000.

Division	Order	Genus species	Site 1	Site 2	Site 3	Site 4	Site 5		
Cyanophyta	Chroococcales	<i>Anacystis</i> sp.1		x	x	x	x		
		<i>Anacystis</i> sp.2		x	x	x	x		
		<i>Anacystis</i> sp.3	x						
		<i>Aphanothece</i> sp.	x	x					
		<i>Chroococcus</i> sp.	x	x	x	x			
		<i>Dactylococcopsis</i> sp.				x			
		<i>Gomphosphaeria</i> sp.		x	x	x	x		
		<i>Merismopedia glauca</i>	x	x	x	x	x		
		<i>Merismopedia tenuissima</i>	x	x	x	x	x		
		<i>Merismopedia</i> sp.				x			
		<i>Microcystis</i> (?) sp.	x						
		<i>Pelogloea bacillifera</i>			x				
		<i>Raphidiopsis</i> (?) sp.	x						
		unspecified			x				
			Hormogonales	<i>Anabaena circinalis</i>	x	x	x	x	x
				<i>Anabaena</i> sp.	x	x	x	x	x
				<i>Aphanizomenon</i> sp.	x	x	x	x	
	<i>Oscillatoria</i> sp.	x		x			x		
	unspecified						x		
Bacillariophyta	Centrales	<i>Aulacoseira distans</i>	x	x	x	x	x		
		<i>Aulacoseira granulata</i>	x	x	x	x	x		
		<i>Chaetoceros</i> sp.	x	x					
		<i>Melosira varians</i>	x						
		<i>Stephanodiscus</i> spp.	x	x	x	x	x		
			Pennales	<i>Asterionella formosa</i>	x	x	x	x	x
				<i>Gyrosigma</i> sp.			x	x	x
Bacillariophyta	Pennales	<i>Synedra ulna</i>	x	x		x			
		<i>Synedra</i> sp.	x			x			
		unspecified	x	x	x	x	x		
Chlorophyta	Chlorococcales	<i>Actinastrum hantzschii</i>	x	x	x	x	x		
		<i>Actinastrum</i> sp.				x			
		<i>Ankistrodesmus falcatus</i>	x	x	x	x	x		
		<i>Coelastrum</i> sp.	x	x	x	x	x		
		<i>Crucigenia</i> sp.	x			x	x		
		<i>Gloeocystis</i> (?) sp.	x	x	x	x	x		
		<i>Golenkinia</i> sp.	x		x	x			
		<i>Micratinium pusillum</i>		x					

Table 5.4.2-1 (Continued)

Division	Order	Genus species	Site 1	Site 2	Site 3	Site 4	Site 5
		<i>Oocystis</i> sp.	x	x	x	x	x
		<i>Oocystis</i> (?) sp.				x	x
		<i>Oocystis</i> spp.			x		x
		<i>Pediastrum duplex</i>	x	x	x	x	x
		<i>Quadrigula lacustris</i>	x	x	x		
		<i>Scenedesmus bijuga</i>			x		
		<i>Scenedesmus quadricauda</i>	x	x	x	x	x
		<i>Scenedesmus</i> sp.	x	x		x	x
		<i>Schroederia setigera</i>	x	x	x	x	x
		<i>Selenastrum</i> sp.		x			x
		<i>Tetraedron</i> sp.			x	x	
		<i>Tetrastrum</i> sp.	x		x	x	
		<i>Treubaria</i> sp.				x	
		Unspecified	x				
Chlorophyta	Desmidiiales	<i>Closterium</i> sp.	x		x		x
		<i>Cosmarium</i> sp. (<i>dentatum</i> ?)	x		x		
		<i>Cosmarium</i> sp.		x			
		<i>Staurastrum</i> sp.		x		x	x
	Volvocales	<i>Carteria</i> sp.		x	x		x
		<i>Chlamydomonas</i> sp.	x	x	x	x	x
		<i>Chlamydomonas</i> spp.	x	x	x	x	x
		unspecified flagellate	x	x	x	x	
Euglenophyta	Euglenales	<i>Euglena</i> sp.	x	x	x	x	x
		<i>Euglena</i> spp.					x
		<i>Phacus</i> sp.	x	x	x	x	x
		<i>Phacus</i> (?) sp.		x			x
		<i>Lepocinclis</i> sp.	x	x			
		<i>Trachelomonas</i> sp.	x	x	x	x	x
		<i>Trachelomonas</i> spp.			x	x	
Pyrrophyta	Cryptomonadales	<i>Cryptomonas ovata</i>	x	x	x	x	x
		<i>Cryptomonas</i> sp. (<i>aspera</i> ?)		x	x	x	x
		<i>Cryptomonas</i> sp.	x				
	Ceratiales	<i>Ceratium cornutum</i>			x		
		<i>Ceratium hirundinella</i>	x	x	x	x	x
	Gymnodinales	<i>Gymnodinium</i> (?) sp.		x	x		x
	Peridinales	<i>Peridinium</i> sp.	x	x	x	x	x
unspecified flagellate				x	x	x	

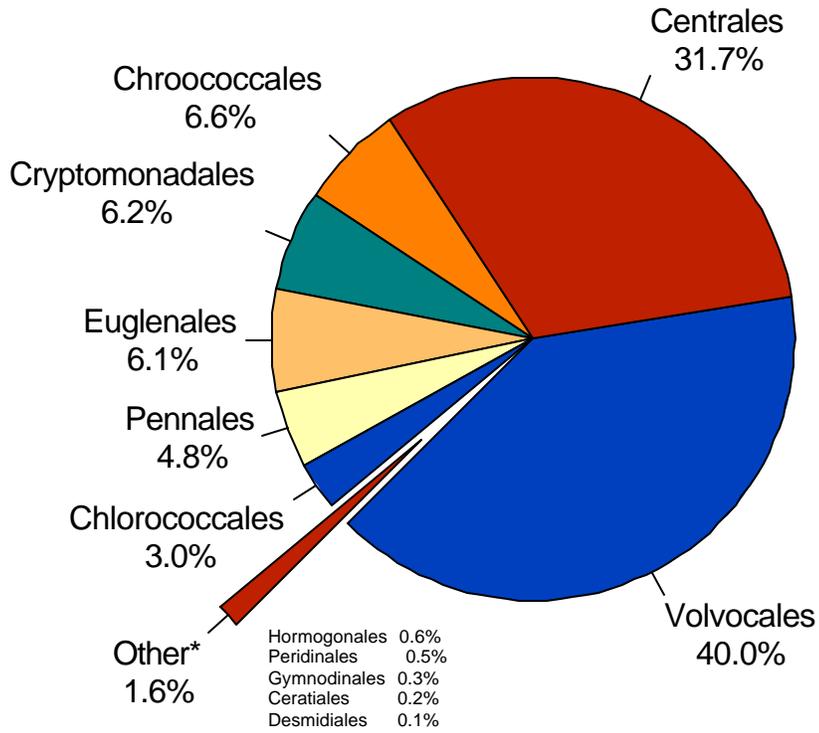


Figure 5.4.2-1
Percent contribution of various orders to phytoplankton densities
Oologah Lake, Oklahoma, April – September 2000

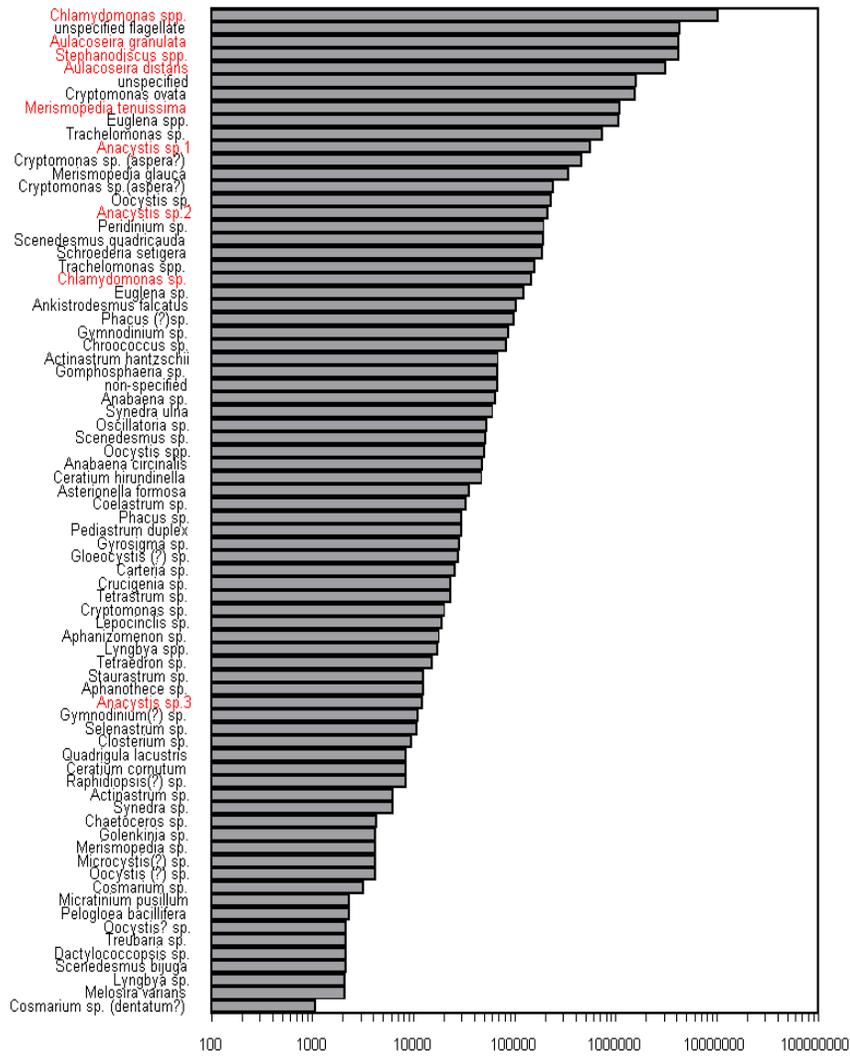


Figure 5.4.2-2
Mean algal densities across all sampling sites and sampling dates,
Oologah Lake, Oklahoma, April – September 2000.

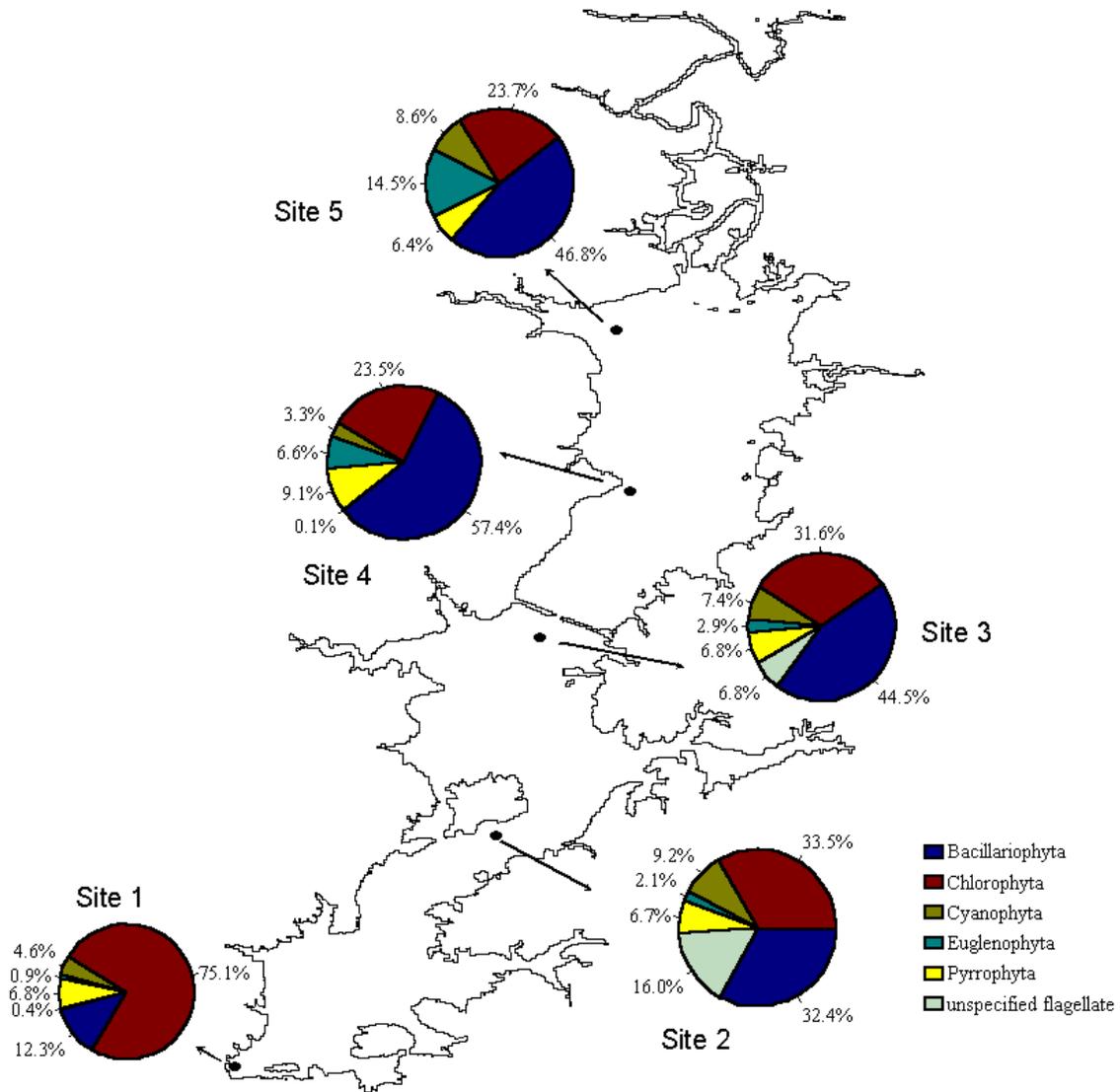


Figure 5.4.2-3
Average algal assemblage composition at the division level at each site across all sampling dates, Oologah Lake, Oklahoma, April – September 2000.

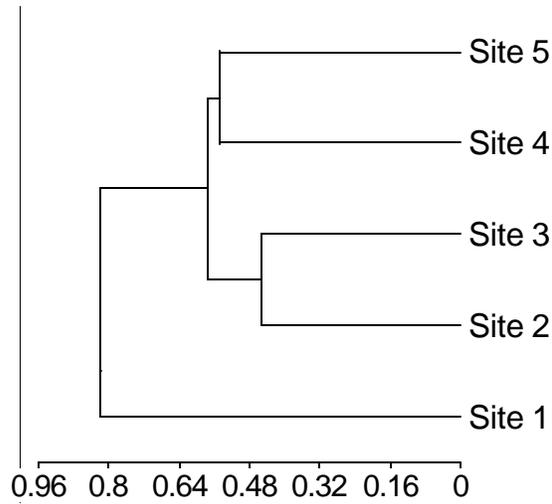


Figure 5.4.2-4
Bray-Curtis dissimilarity of sampling sites, Oologah Lake, Oklahoma,
April – September 2000.

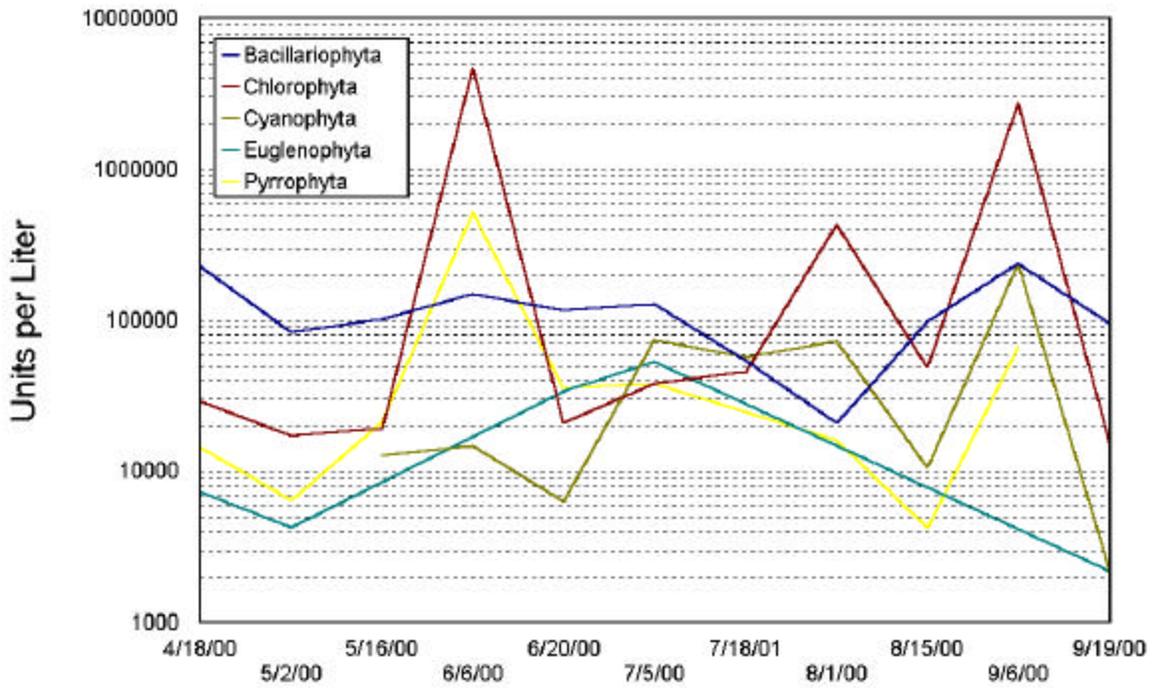


Figure 5.4.2-5
Comparison of mean algal densities, by division, on each sampling date
at Site 1, Oologah Lake, Oklahoma, 2000.

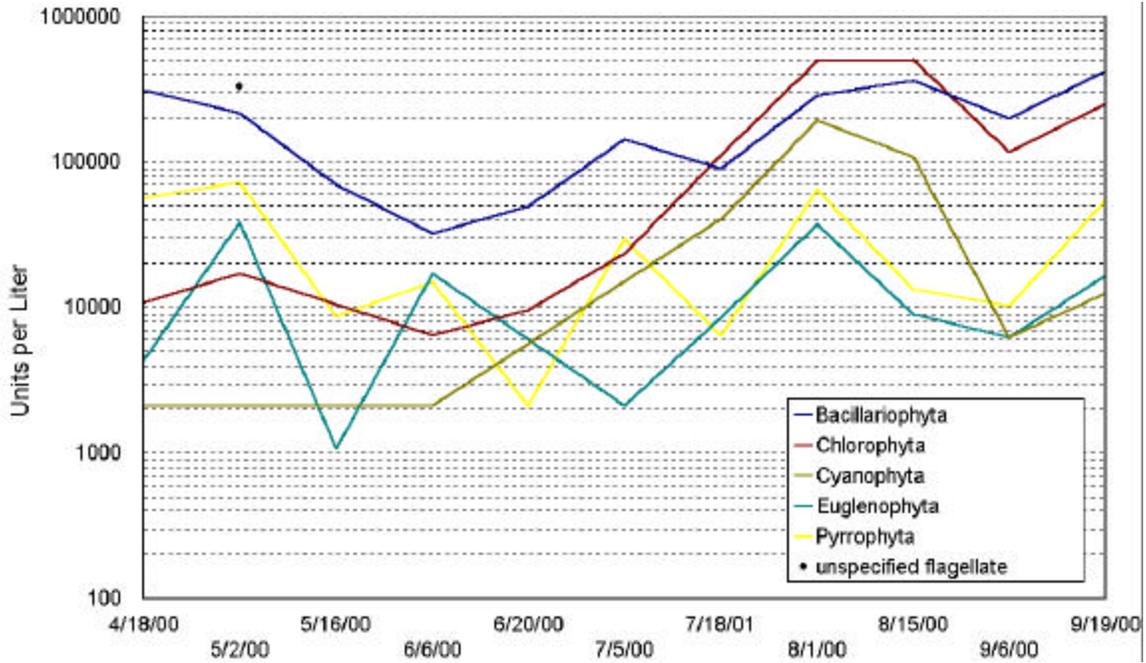


Figure 5.4.2-6
Comparison of mean algal densities, by division, on each sampling date
at Site 3, Oologah Lake, Oklahoma, 2000.

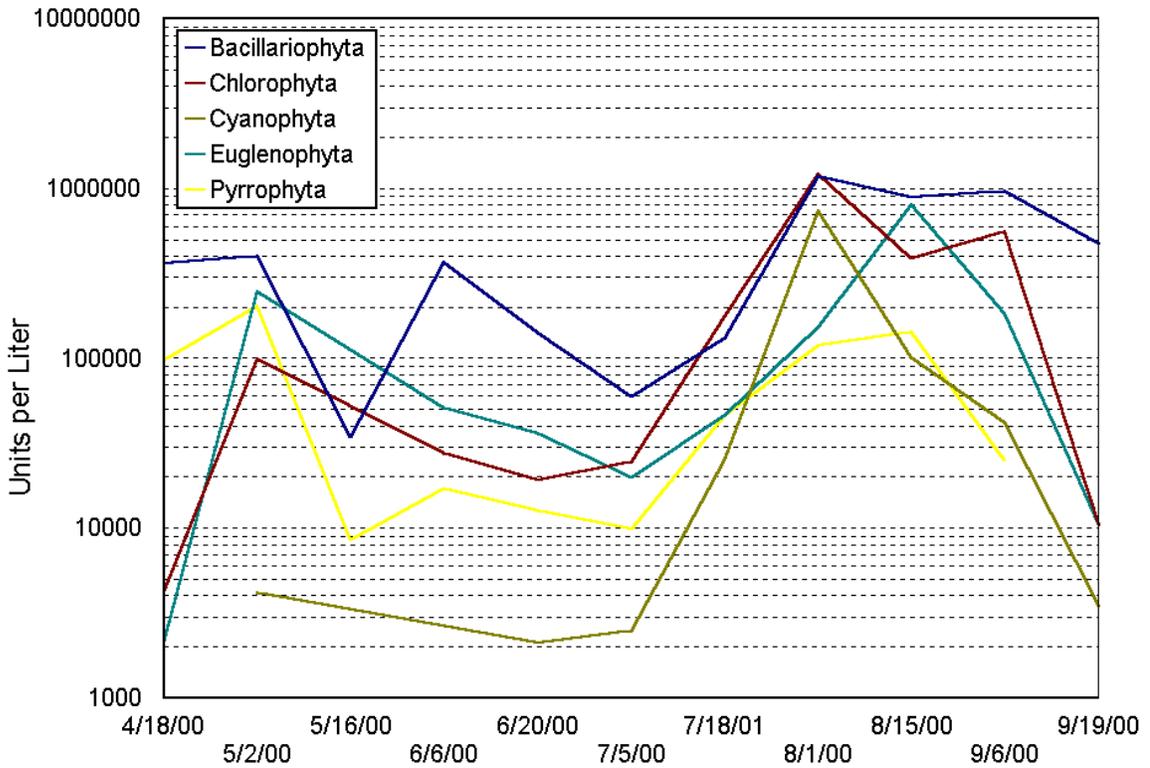


Figure 5.4.2-7
Comparison of mean algal densities, by division, on each sampling date
at Site 5, Oologah Lake, Oklahoma, 2000.

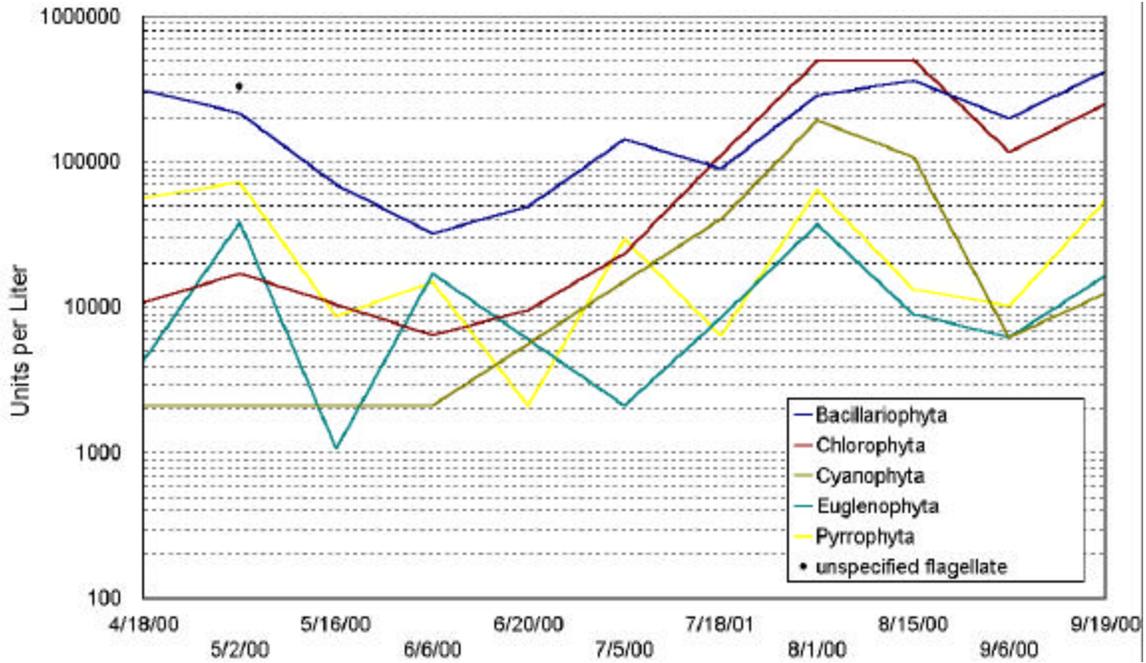


Figure 5.4.2-6
Comparison of mean algal densities, by division, on each sampling date
at Site 3, Oologah Lake, Oklahoma, 2000.

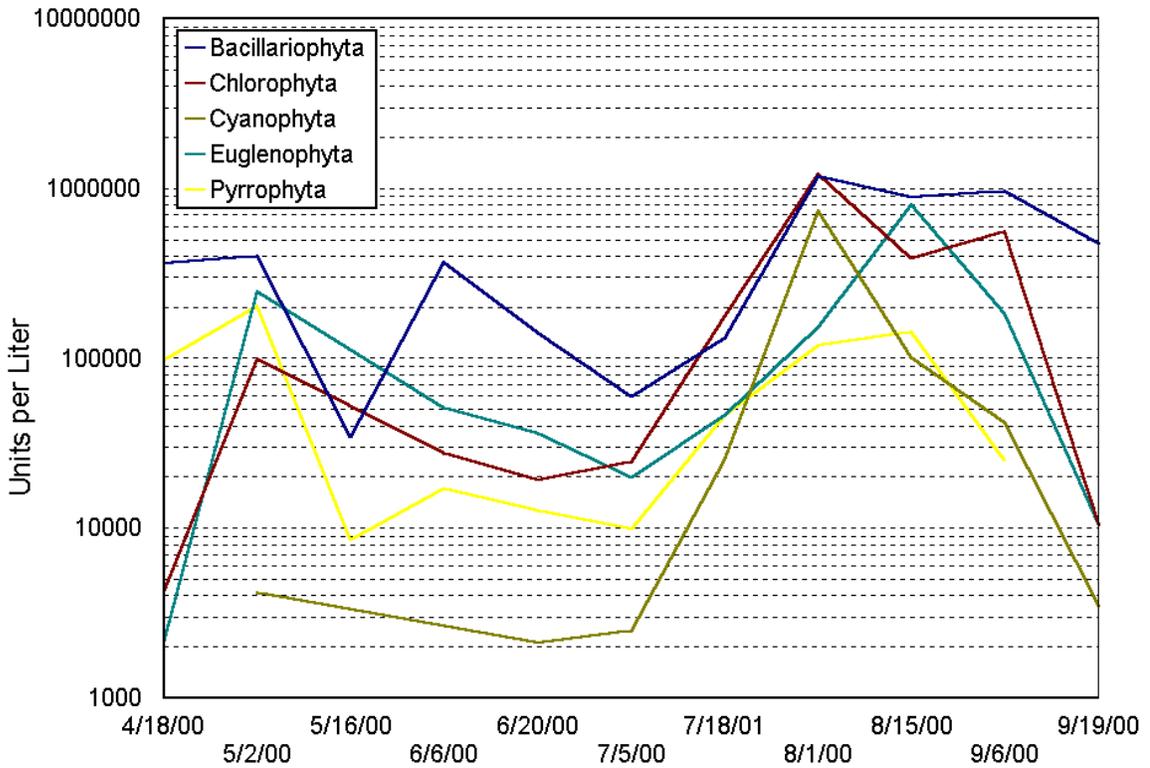


Figure 5.4.2-7
Comparison of mean algal densities, by division, on each sampling date
at Site 5, Oologah Lake, Oklahoma, 2000.

5.4.3 Zooplankton. Samples for zooplankton analyses were collected on most sampling dates at principal water quality sampling sites at Oologah Lake (Figure 4.2.1-1). Samples were preserved for long-term storage and are currently archived at the Tulsa District headquarters. Consideration will be given to future analysis of these samples for zooplankton speciation and abundance, funding permitting.

5.5 Light Characterization. Light meter and Secchi data collected (April through September 2000) at five in-lake sampling sites in Oologah Lake were analyzed using the techniques described by Lind (1985) and Horne and Goldman (1994). A LI-COR model LI-192SA was used to record photosynthetically active radiation (PAR) at the surface (0.1m) and at 0.5-meter increments until = 1% of incident surface radiation was detected. Channel 1 of the unit recorded a reference surface reading and channel 2 simultaneously recorded penetrating radiation at incremental depths. Channel 1 (surface reference) measurements varied due to natural variation, wave action, and cloud cover. Analysis of the data included using the variable surface readings to recalculate interval depth measurements relative to initial surface recordings.

Plots of light adsorbance as a percent of surface illumination (0.1 m) versus depth at Oologah sampling sites for all dates when data were collected were prepared (Figure 5.5-1 through Figure 5.5-5). For all sites, >80% of surface illumination was adsorbed in the first meter of depth on all sampling dates. Data collected 19 July 2000 for Sites 3, 4, and 5 appear to be anomalous. The rate of adsorption by depth increases moving up the lake from the dam site (Site 1) to Site 5.

Light attenuation coefficients (h'') were calculated for each site by sampling date using the least squares method described by Lind (1985). The light attenuation coefficient was calculated by use of the relation

$$I_z = I_0 e^{-h''z}$$

Where

I_z	=	light intensity at depth z
I_o	=	light intensity at surface
h''	=	Vertical extinction coefficient.

The least square estimate of h'' is given by Lind (1985):

$$h'' = \frac{\ln I_o (\sum z) - \sum [z(\ln I_z)]}{\sum z^2}$$

An h'' of 0.69 indicates 50% attenuation per meter, and an h'' of 2.30 indicates 90% attenuation per meter. Generally, the results describe expected conditions in the lake with highest h'' s at the upper end of the lake (Site 5) decreasing toward Site 1, the dam site (Table 5.5-1). The lowest h'' was 1.29 m^{-1} measured at Site 1 on 6 September 2000, and the highest was 11.01 m^{-1} measured at Site 5 on 19 September 2000. Light attenuation coefficients were increasingly variable moving from Site 1 to Site 5. Again, data collected 19 July 2000 for Sites 3, 4, and 5 appear to be anomalous but were used in calculating station mean coefficients across sampling dates. Site mean h'' s were greater than 2.30 m^{-1} (>90% light attenuation per meter) for Sites 2, 3, 4, and 5. Mean h'' at Site 1 was 1.90 m^{-1} .

Figure 5.5-6 through Figure 5.5-10 graphically compare h'' s versus depth for each lake site by sampling date. Figure 5.5-11 through Figure 5.5-19 compare h'' s versus depth for each sampling date by site. Decreasing water clarity moving up the lake from the dam site results in a regular pattern with lowest h'' s evident at the dam site (Site1) increasing toward Site 5. Extreme conditions on 6 June 2000 and 5 July 2000 (wind and waves) limited the ability to collect data at all sites on those dates.

Additionally, h'' s were calculated for sampled depth intervals by Lind (1985):

$$h'' = \frac{\ln I_{z1} - I_{z2}}{z^2}$$

This calculation allows for the detection of abnormally high or low light altering strata within the water column (Lind 1985). Almost all sites on all dates had highest h'' s in the upper water column stratum (0.1 to 0.5 m). The pattern of light attenuation coefficients calculated at Site 1, typical of all sites, was highest in the upper stratum (mean of 1.84 m^{-1}), decreasing about 40% to the second stratum (0.5 to 1.0 m), an additional 45% decrease to the third stratum (1.0 to 1.5 m), and an approximate 15 – 25% decrease per 0.5 m increasing depth. These results are shown graphically for each site in Figure 5.5-20 through Figure 24.

Estimation of true euphotic zone depth (Z_{eu}) was determined by inverse prediction of the regression of depth against the natural log of percent light transmission (Atkinson et al. 1999). Average depth of Z_{eu} was highest at Site 1 (2.52 m) and lowest at Site 5 (0.90m). The highest calculated Z_{eu} was 3.56 m at Site 1 on 6 September 2000, and the lowest was 0.46 m at Site 5 on 19 September 2000. The overall average depth of Z_{eu} for the lake through the sampling period was 1.69 m. These results are presented in Table 5.5-2, and graphically in Figure 5.5-25 and Figure 5.5-26.

Graphics were prepared showing Secchi depth (SD) measured at each site on each date and across sites by date. Table 5.5-3 presents descriptive statistics for SD measured at each site. Highest average SD was measured at Site 1 (0.61 m) and lowest at Site 5 (0.21 m). A consistent pattern of decreasing SD from the dam site (Site 1) to the upper part of the lake (Site 5) was evident across all sampling dates. The maximum observed SD was 0.90 m at Site 1, and the minimum was 0.10 m recorded at Site 5. Overall average SD for the lake over the sampling period was 0.36 m. Figure 5.5-27 through Figure 5.5-31 show SD's by site for each date, and Figure 5.5-32 through Figure 5.5-42 show SD's at all five sites on each sampling date.

Figure 5.5-43 is a box and whisker representation of all Secchi data recorded for each site, and Figure 5.5-44 is a graphic representation of an Analysis of Means test showing that mean SD's at Sites 1 and 5 are significantly different from the overall mean SD at $\alpha = 0.05$. A Mood's Median Test performed on median SD's at each site resulted in rejecting the null hypothesis that all medians are equal at $\alpha = 0.05$. The 95% confidence intervals for median SD at Sites 2, 3, and 4 included the overall median of 0.31 m. The SD 95% confidence intervals for Sites 1 and 5 did

not include the overall median. Figure 5.5-45 identifies sampling site locations on Oologah Lake and provides a visual approximation of the gradient of mean SD in the lake.

The product of h'' x SD was determined for each site on each sampling date, yielding the constant, k , which allows estimation of h'' using only a Secchi disk by the following relationship (Buiteveld, 1995):

$$h'' = \frac{k}{SD}$$

Resultant k values are presented in Table 5.5-4. Average k values were similar among stations, ranging from 0.97 at Site 2 to 1.22 at Site 1. The k values did not show the expected pattern of increasing from zones of high turbidity to zones of low turbidity probably due to the relatively high turbidity throughout the lake.

A constant, derived from the ratio $Z_{eu} : SD$, allows estimation of Z_{eu} in the absence of submarine photometer data (Lind 1985). Data from each lake site were grouped across sampling dates for this analysis. Resulting $Z_{eu} : SD$ values (Table 5.5-5) were similar for the five lake sampling sites ranging from 4.13 (Site 1) to 5.01 (Site 2).

Table 5.5-1. Light Attenuation Coefficients (m^{-1}) at Oologah Lake Sampling Sites.

Date	Site				
	1	2	3	4	5
05/02/00	2.07	2.30	3.43	3.71	3.82
06/06/00	1.87	2.37	5.28	6.99	6.64
06/20/00	2.55	NA	NA	NA	NA
07/05/00	2.39	3.64	NA	6.00	7.27
07/19/00	1.70	1.86	1.66	1.96	2.30
08/01/00	1.73	2.02	2.17	2.44	4.85
08/15/00	1.59	1.78	2.20	3.59	5.87
09/06/00	1.29	2.54	2.67	4.10	6.82
09/19/00	1.94	2.60	3.23	4.44	11.01
Mean	1.90	2.39	2.95	4.15	6.07
Median	1.87	2.34	2.67	3.90	6.26
St. Dev.	0.39	0.59	1.20	1.68	2.60

Table 5.5-2. Calculated True Euphotic Depth (Z_{eu}) in Meters at Oologah Lake Sampling Sites.

Date	Site				
	1	2	3	4	5
05/02/00	2.23	2.01	1.35	1.25	1.20
06/06/00	2.48	1.95	0.94	0.70	0.70
06/20/00	1.81	NA	NA	NA	NA
07/05/00	1.93	1.28	NA	0.78	0.65
07/19/00	2.73	2.47	2.53	2.32	1.74
08/01/00	2.64	2.26	2.12	1.89	0.97
08/15/00	2.91	2.59	2.09	1.29	0.82
09/06/00	3.56	1.79	1.71	1.14	0.69
09/19/00	2.37	1.76	1.43	1.01	0.46
Mean	2.52	2.01	1.74	1.30	0.90
Median	2.48	1.98	1.71	1.19	0.76
St. Dev.	0.53	0.43	0.55	0.55	0.40

Table 5.5-3. Descriptive Statistics for Secchi Depths (m) at Oologah Lake Sampling Sites.

Site	Mean	Median	Standard Deviation	Range	Minimum	Maximum	Count
1	0.61	0.58	0.19	0.59	0.31	0.90	11
2	0.39	0.37	0.14	0.52	0.20	0.72	11
3	0.35	0.30	0.17	0.42	0.20	0.62	11
4	0.26	0.22	0.13	0.43	0.12	0.55	11
5	0.21	0.19	0.09	0.25	0.10	0.35	11

Table 5.5-4. Product (k) of Light Attenuation Coefficient and Secchi Depth.

Date	Site				
	1	2	3	4	5
05/02/00	1.08	0.94	1.03	0.82	1.15
06/06/00	1.09	0.88	1.06	0.84	1.00
06/20/00	1.07	NA	NA	NA	NA
07/05/00	1.46	1.13	NA	0.90	0.87
07/19/00	1.53	0.37	1.00	0.68	0.64
08/01/00	1.00	1.11	1.35	1.34	1.70
08/15/00	1.27	1.28	1.32	1.62	1.76
09/06/00	1.14	1.02	1.02	0.98	1.43
09/19/00	1.32	1.06	1.03	1.02	1.10
Mean	1.22	0.97	1.11	1.02	1.21
Median	1.14	1.04	1.03	0.94	1.12
St. Dev.	0.19	0.27	0.15	0.31	0.39

Table 5.5-5. Mean Euphotic Depth, Mean Secchi Depth, and the Ratio of Z_{eu} : Mean SD.

Site	Z_{eu} (m)	Mean SD	Z_{eu} :Mean SD
1	2.52	0.61	4.13
2	2.01	0.39	5.01
3	1.74	0.35	4.97
4	1.30	0.26	5.00
5	0.90	0.21	4.29

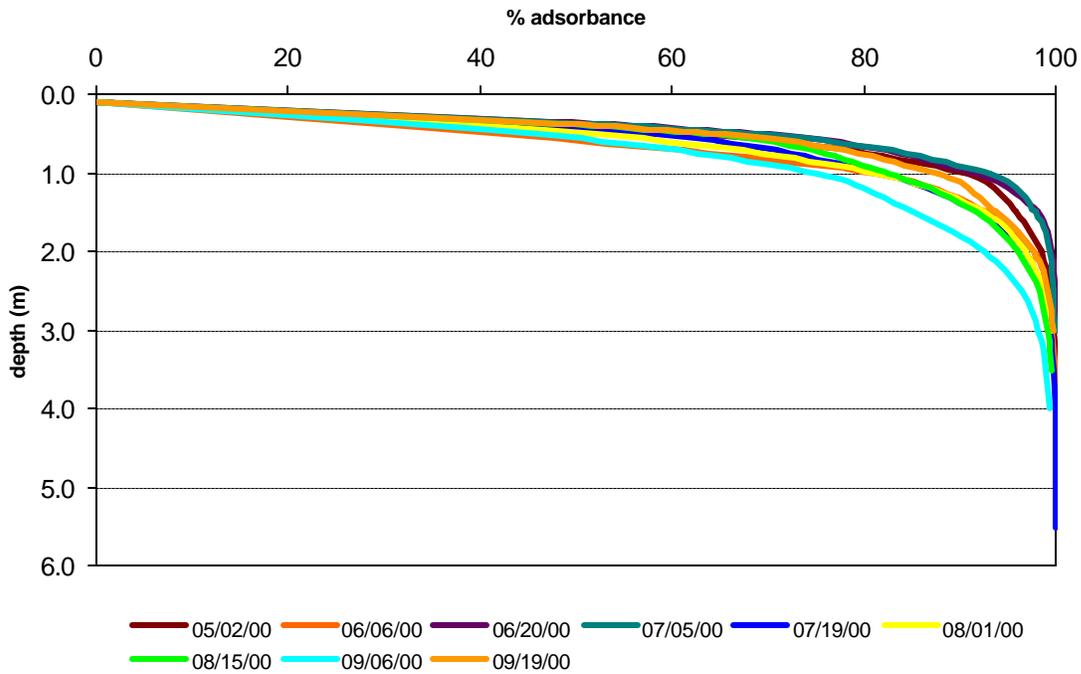


Figure 5.5-1
Oologah Lake Site 1 percent surface light adsorbance versus depth by sampling date.

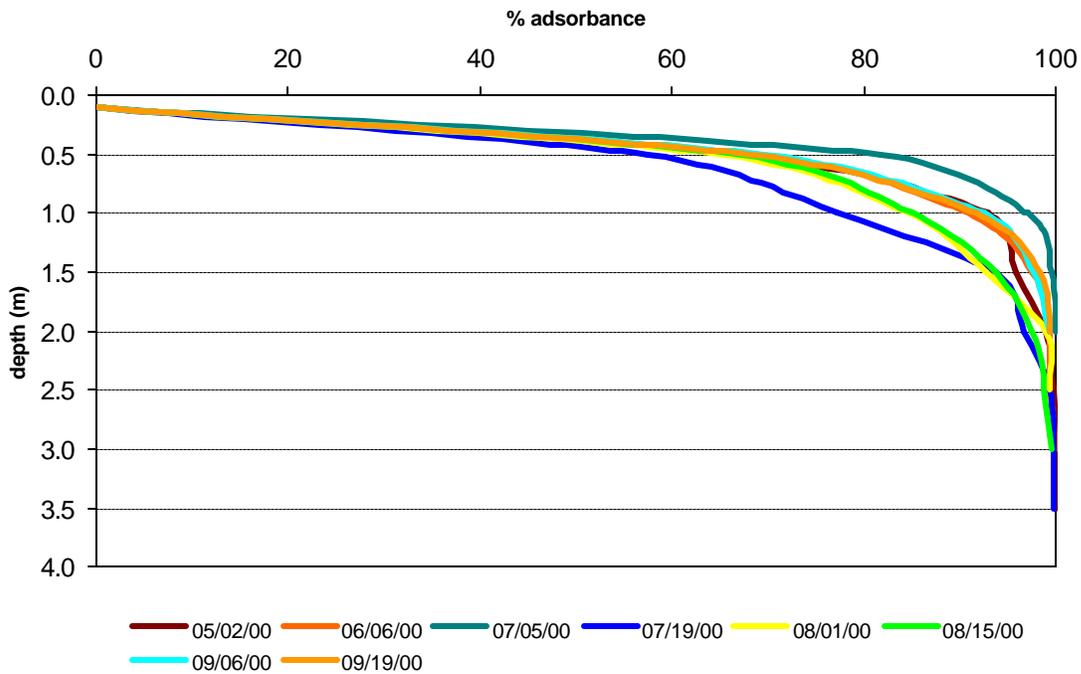


Figure 5.5-2
Oologah Lake Site 2 percent surface light adsorbance versus depth by sampling date.

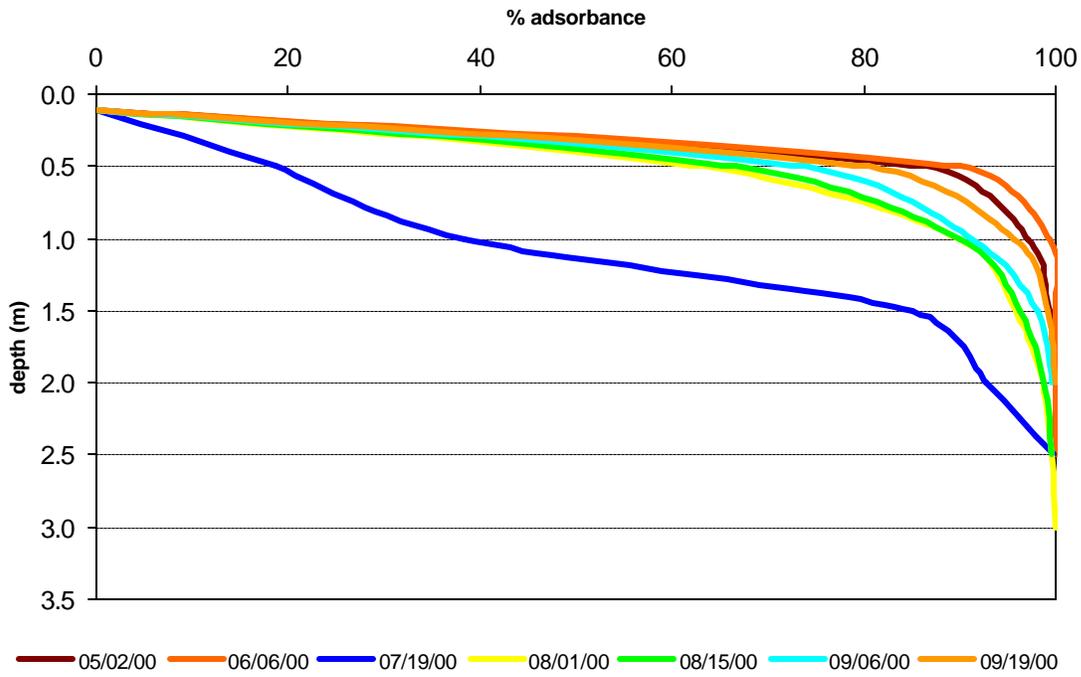


Figure 5.5-3
Oologah Lake Site 3 percent surface light adsorbance versus depth by sampling date.

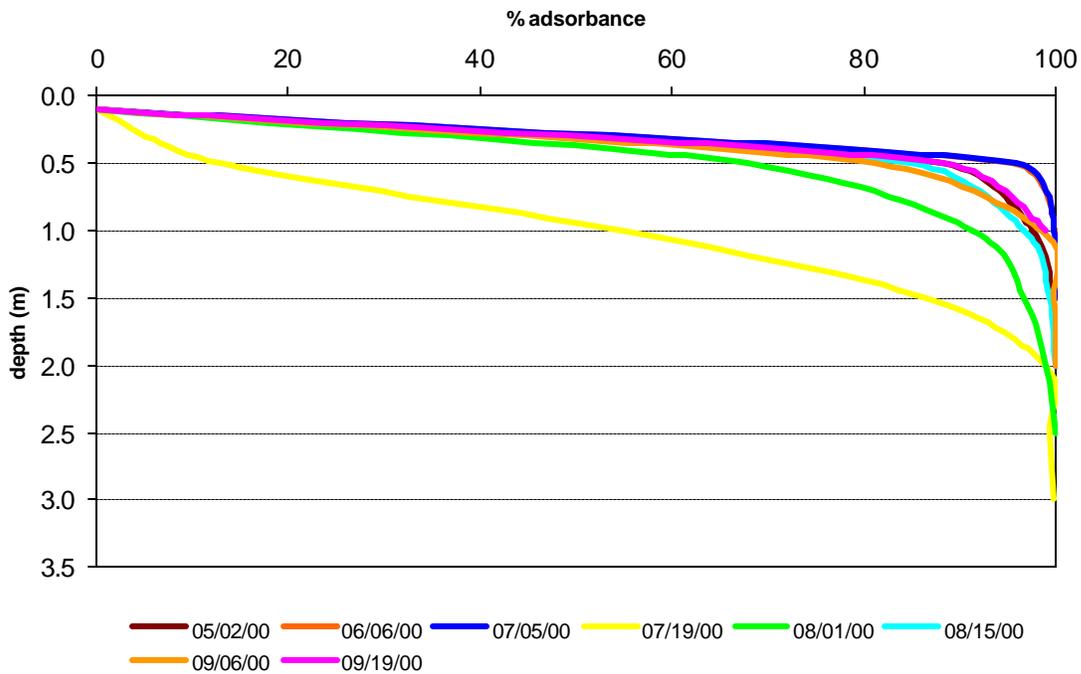


Figure 5.5-4
Oologah Lake Site 4 percent surface light adsorbance versus depth by sampling date.

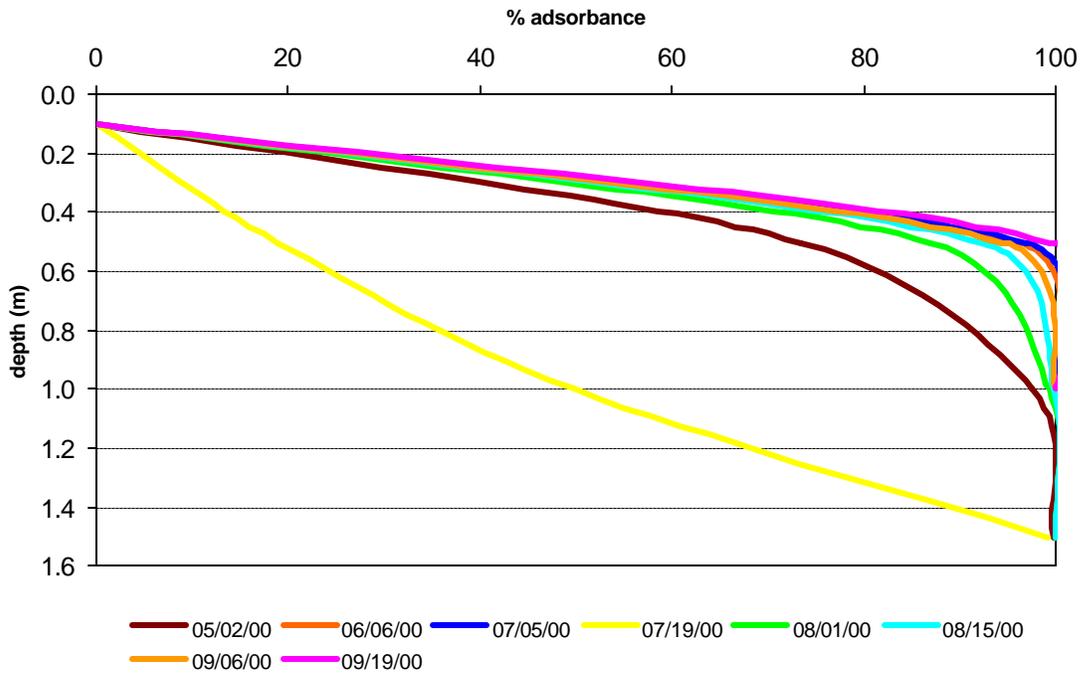


Figure 5.5-5
Oologah Lake Site 5 percent surface light adsorbance versus depth by sampling date.

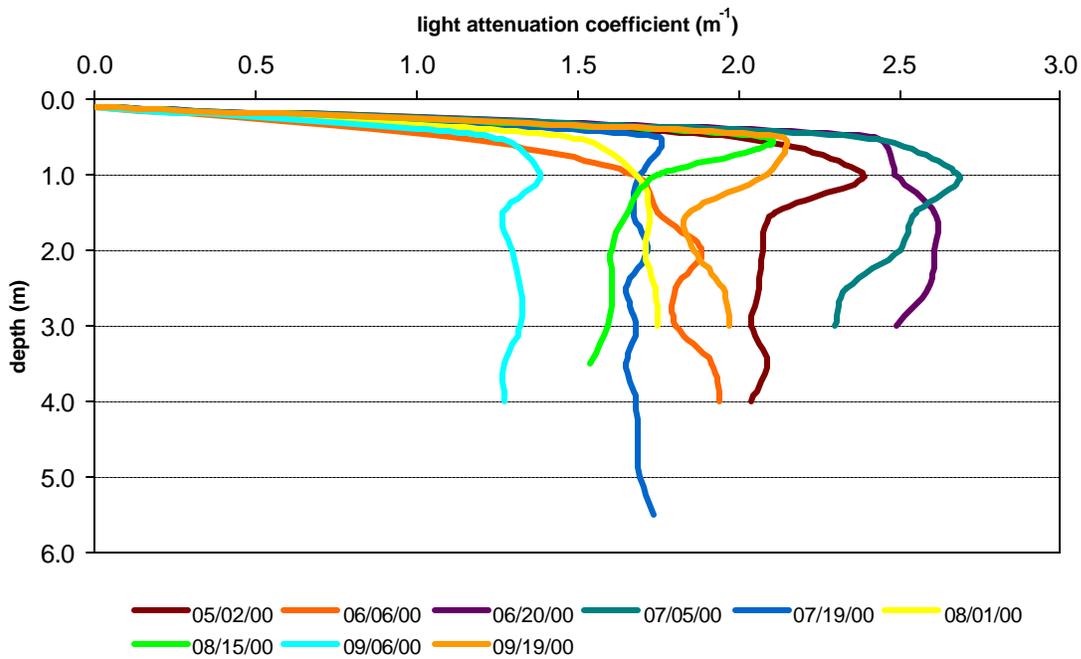


Figure 5.5-6
Oologah Lake Site 1 light attenuation coefficient versus depth for each sampling date.

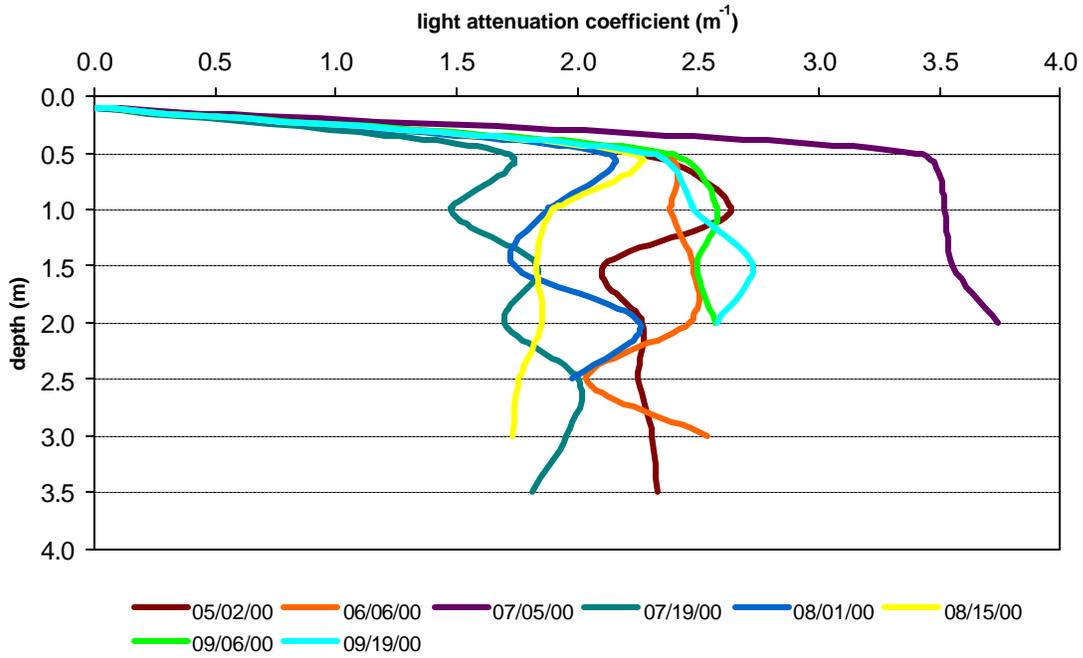


Figure 5.5-7
Oologah Lake Site 2 light attenuation coefficient versus depth for each sampling date.

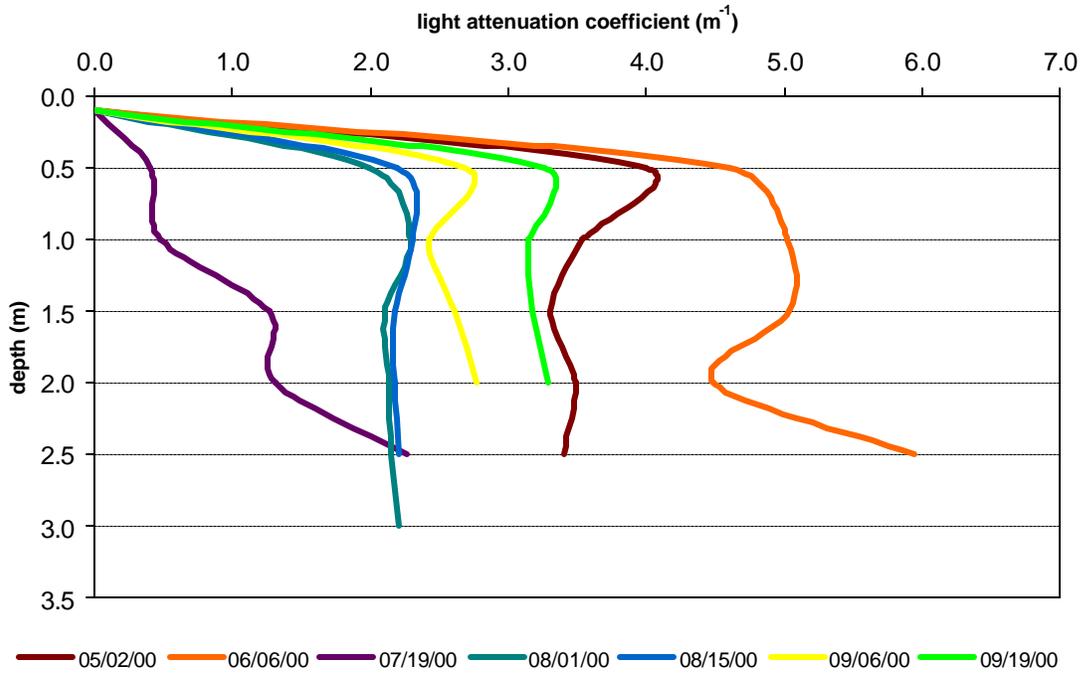


Figure 5.5-8
Oologah Lake Site 3 light attenuation coefficient versus depth for each sampling date.

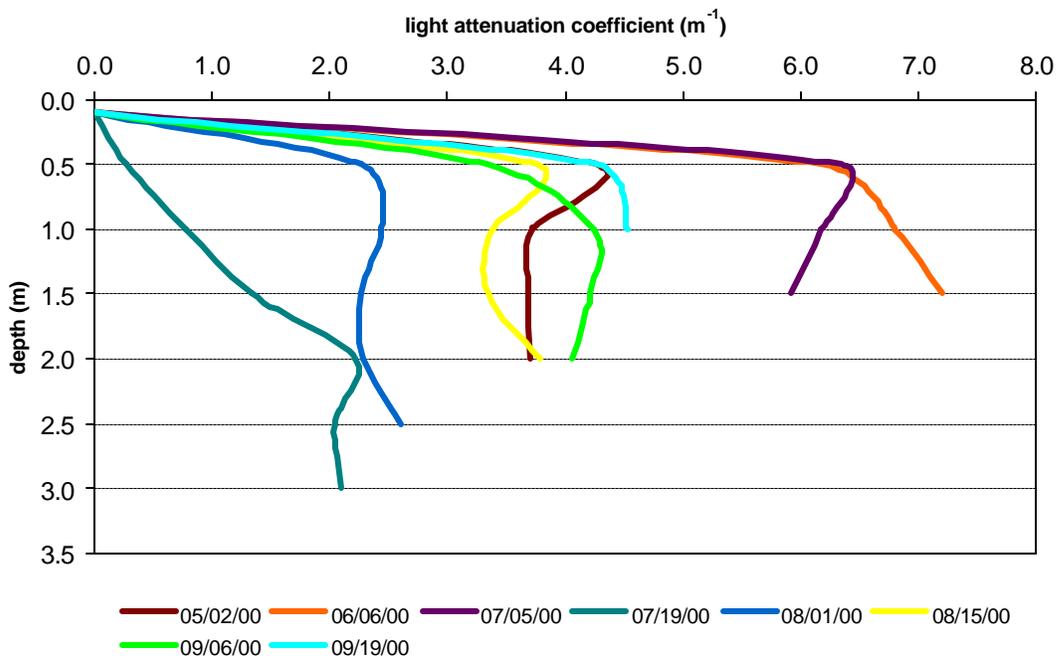


Figure 5.5-9
Oologah Lake Site 4 light attenuation coefficient versus depth for each sampling date.

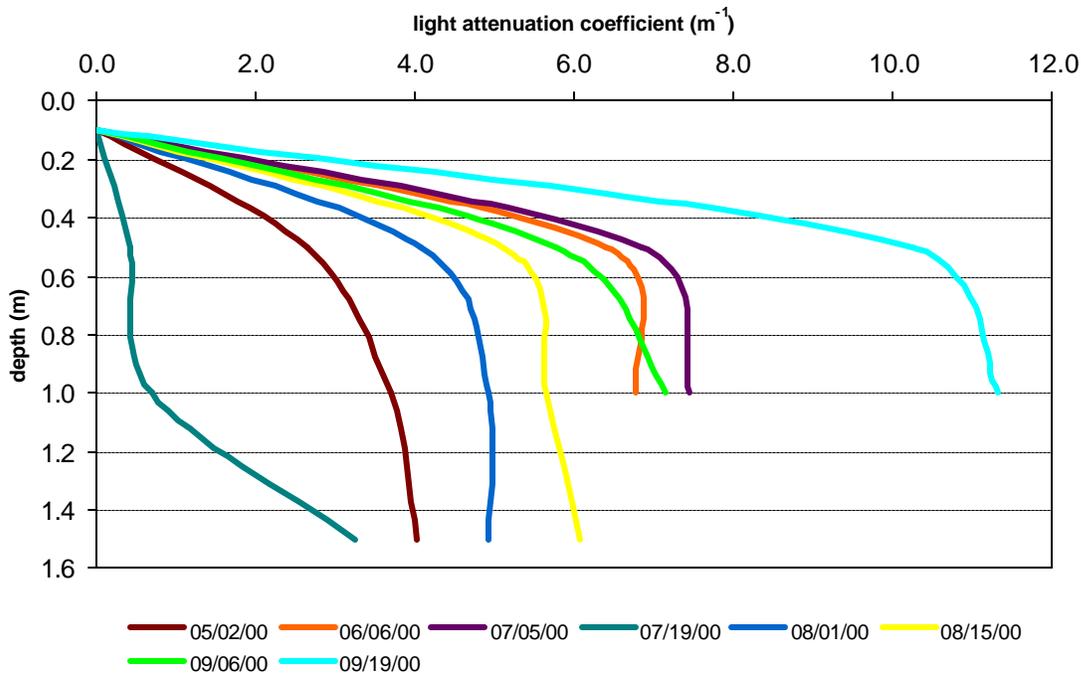


Figure 5.5-10
Oologah Lake Site 5 light attenuation coefficient versus depth for each sampling date.

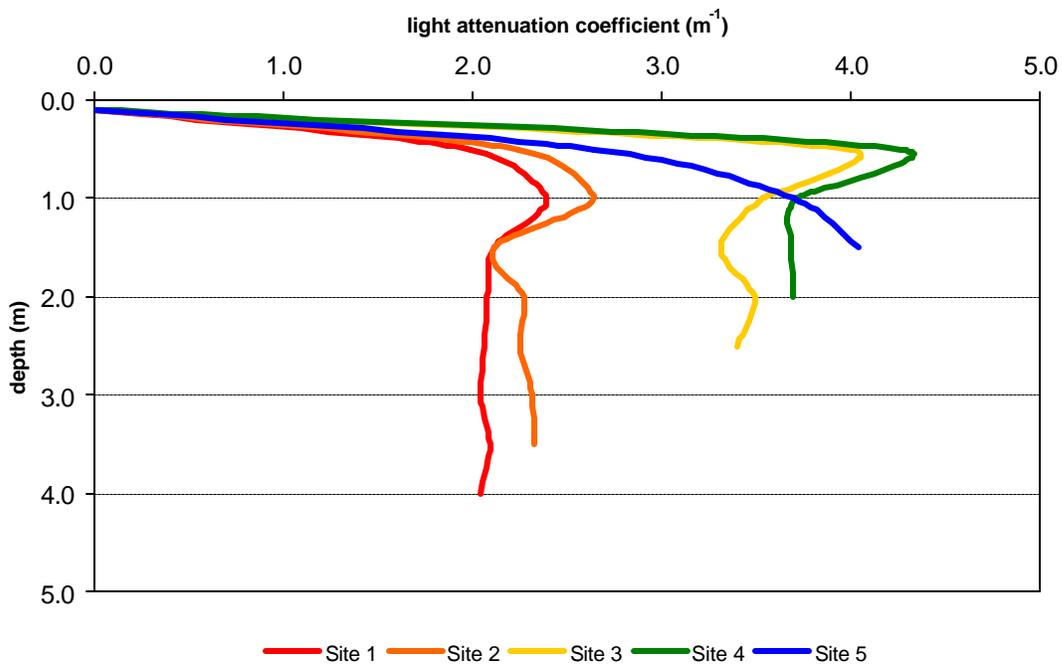


Figure 5.5-11
Light attenuation coefficient versus depth at each Oologah Lake
sampling site on 2 May 2000.

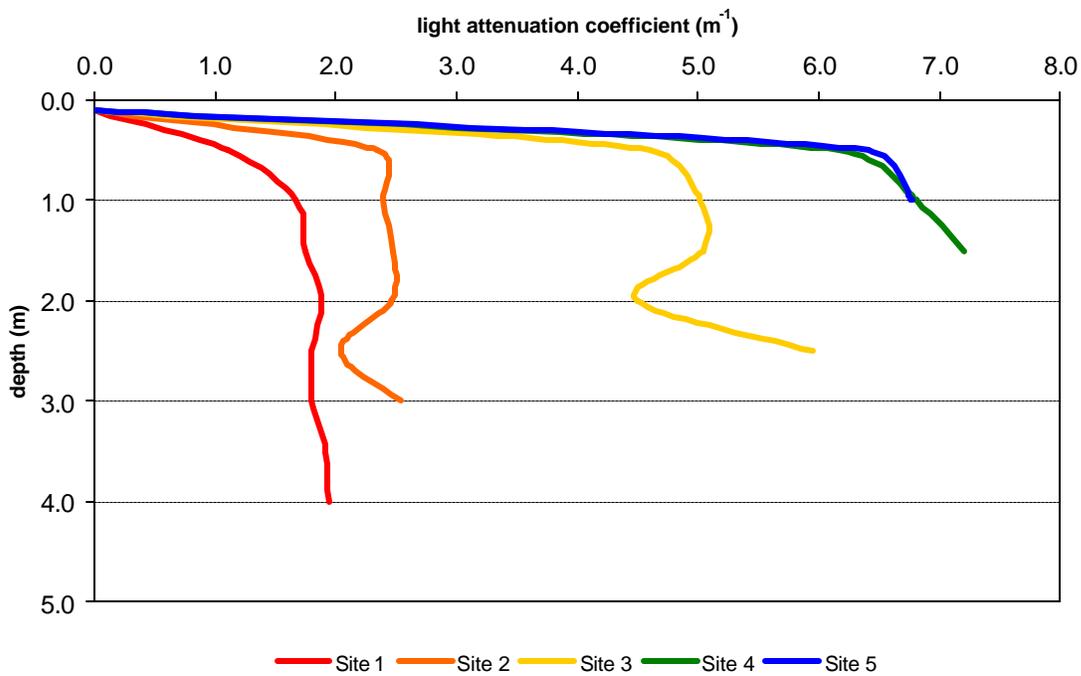


Figure 5.5-12
Light attenuation coefficient versus depth at each Oologah Lake
sampling site on 6 June 2000.

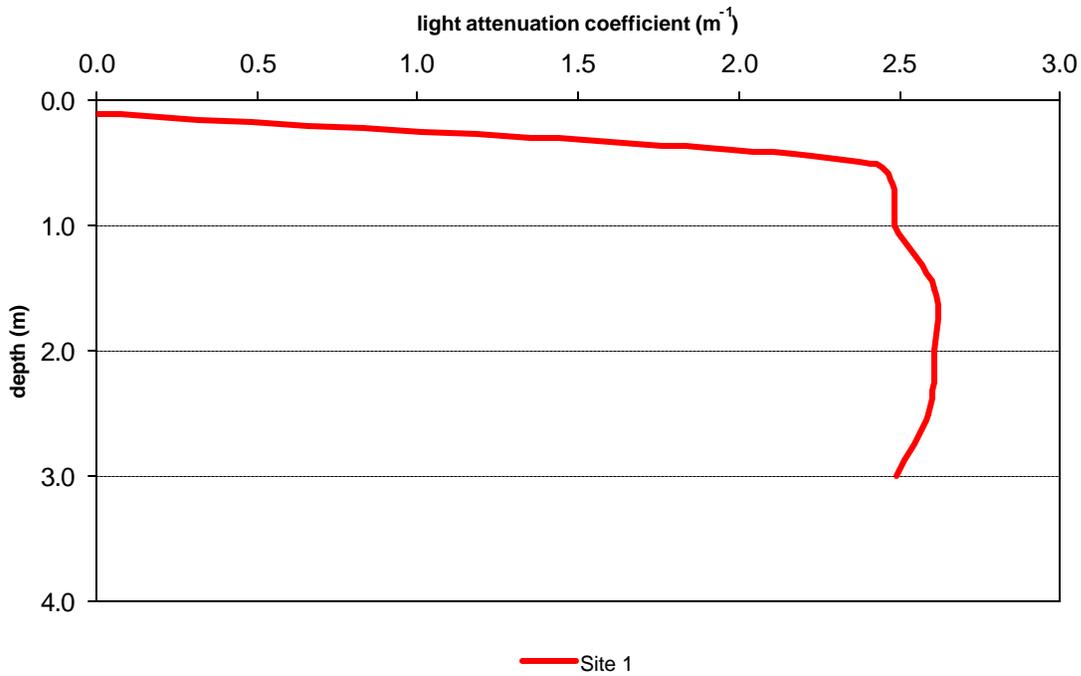


Figure 5.5-13
Light attenuation coefficient versus depth at each Oologah Lake
sampling site on 20 June 2000.

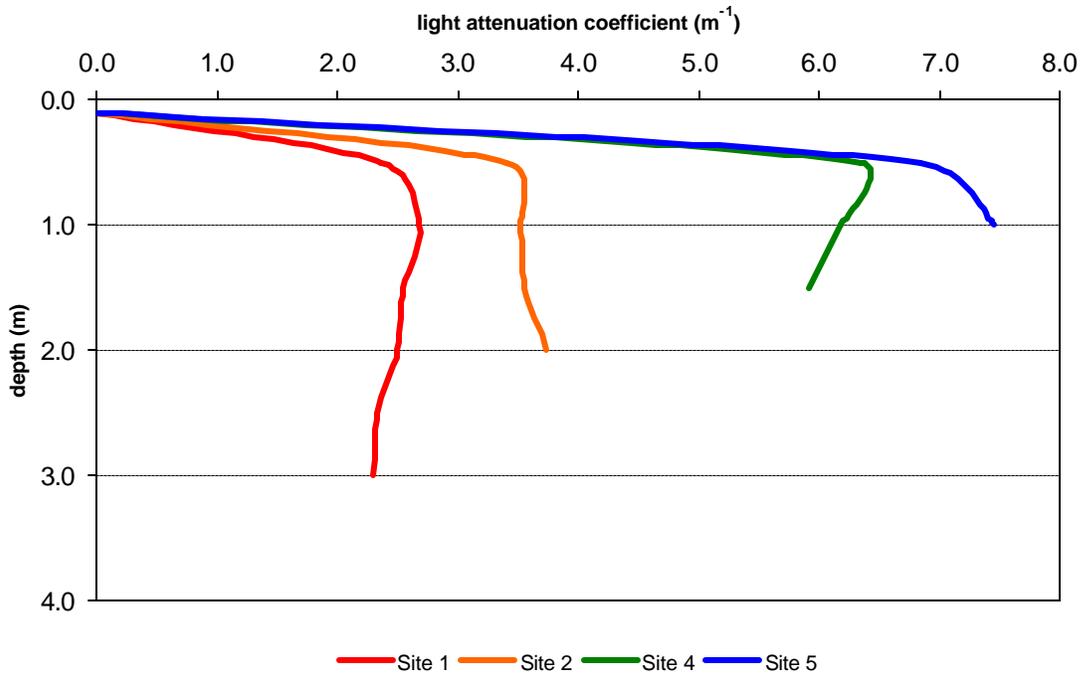


Figure 5.5-14
Light attenuation coefficient versus depth at each Oologah Lake
sampling site on 5 July 2000.

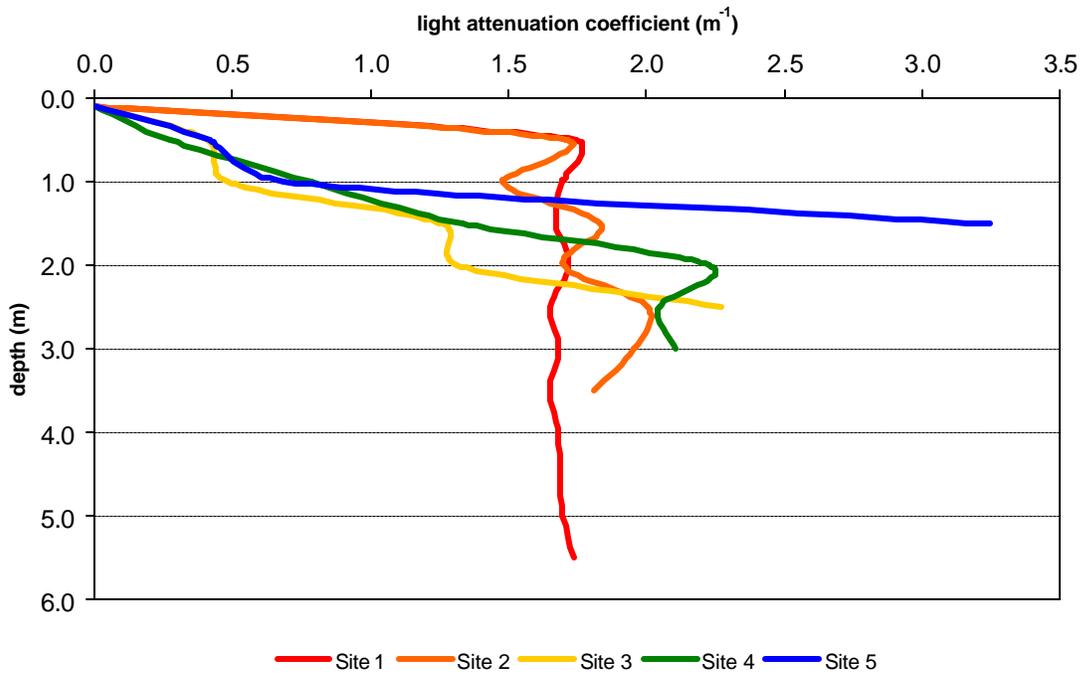


Figure 5.5-15
Light attenuation coefficient versus depth at each Oologah Lake
sampling site on 19 July 2000.

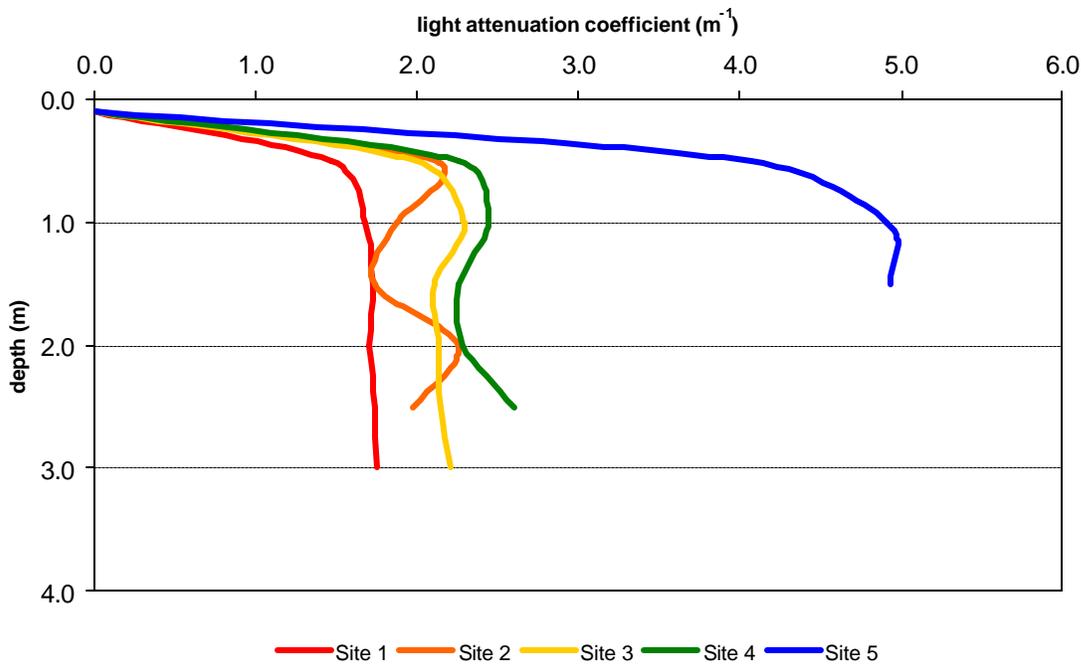


Figure 5.5-16
Light attenuation coefficient versus depth at each Oologah Lake
sampling site on 1 August 2000.

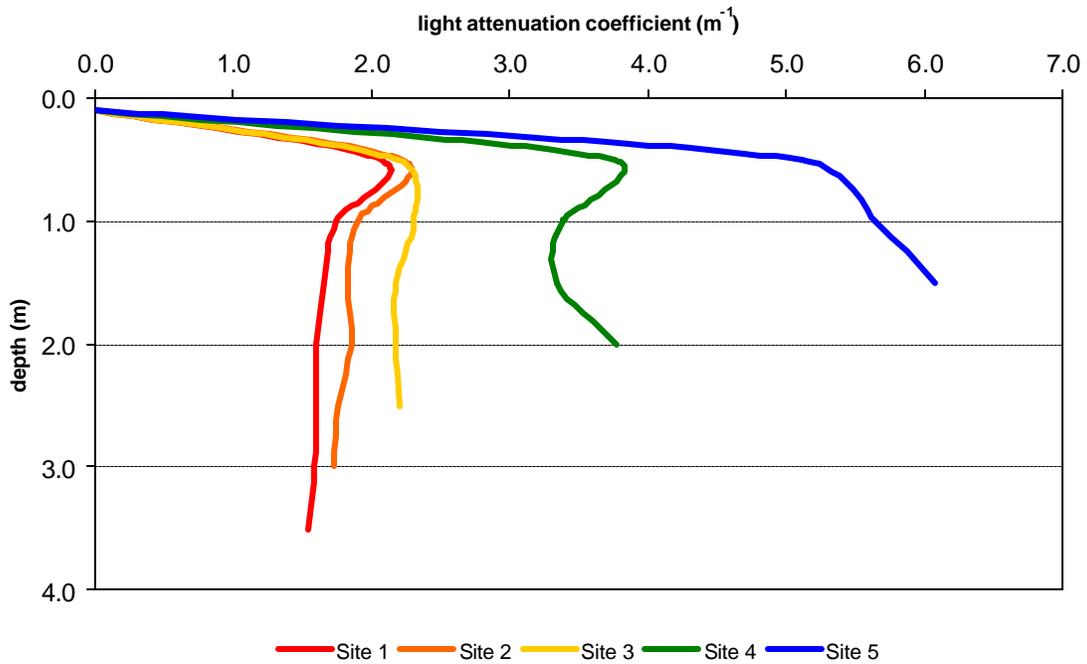


Figure 5.5-17
Light attenuation coefficient versus depth at each Oologah Lake
sampling site on 15 August 2000.

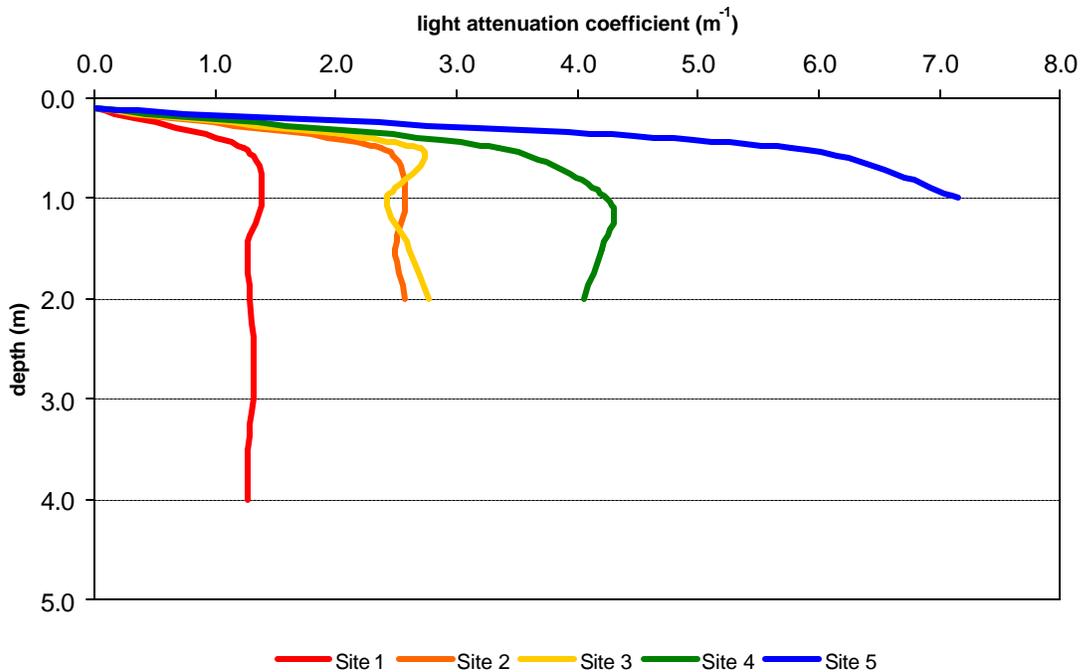


Figure 5.5-18
Light attenuation coefficient versus depth at each Oologah Lake
sampling site on 6 September 2000.

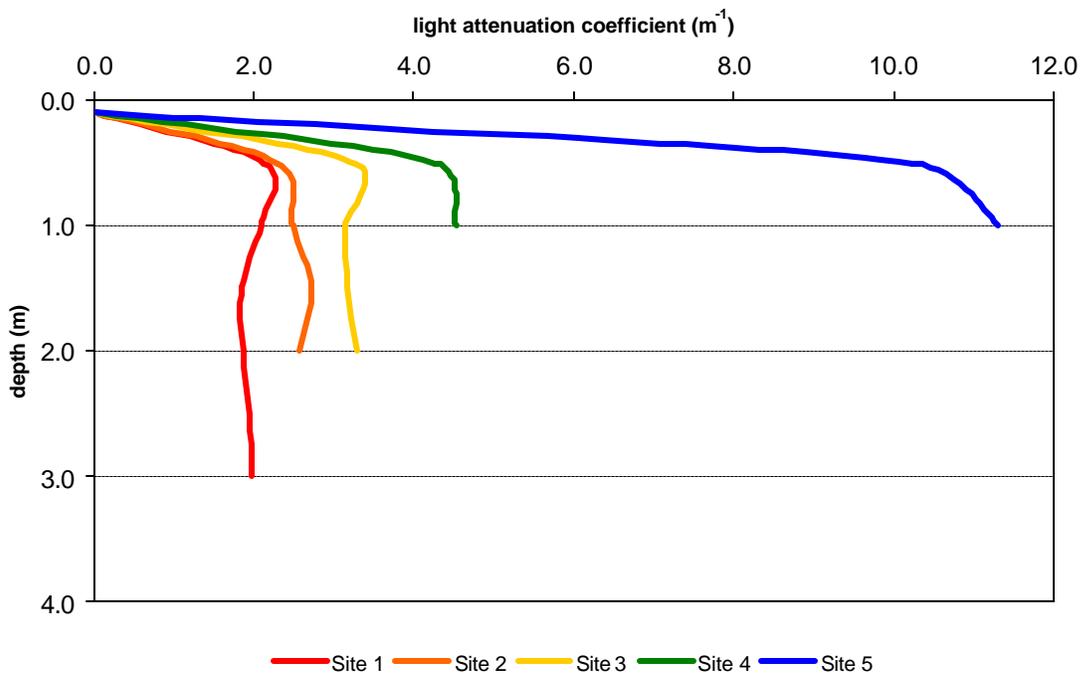


Figure 5.5-19
Light attenuation coefficient versus depth at each Oologah Lake
sampling site on 19 September 2000.

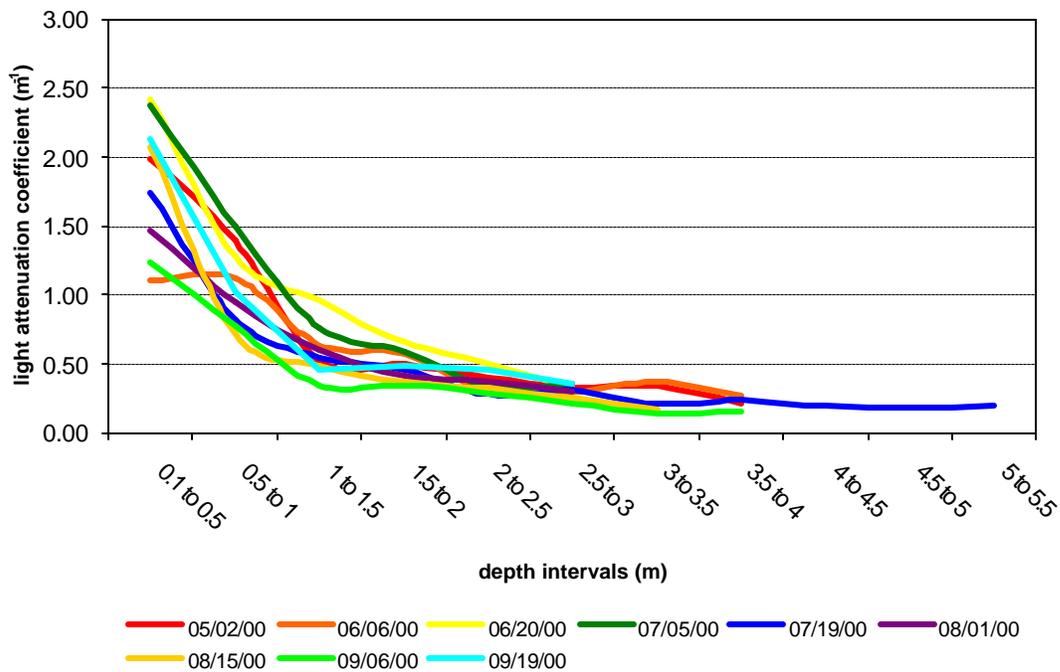


Figure 5.5-20
Oologah Lake light attenuation coefficient versus depth interval comparisons
for Site 1 on all sampling dates.

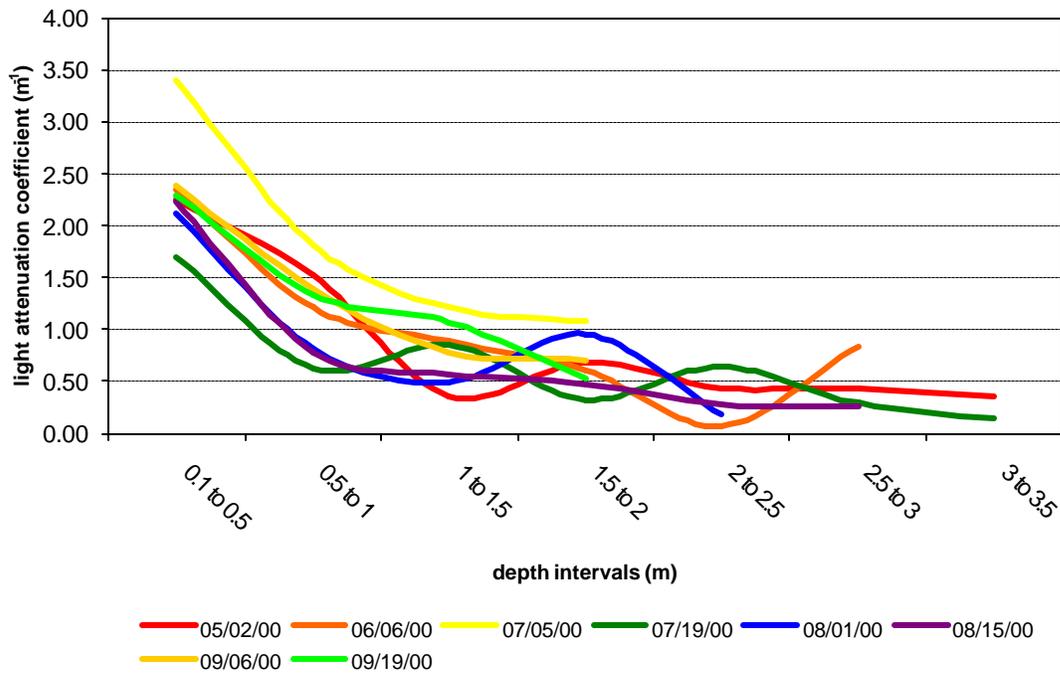


Figure 5.5-21
Oologah Lake light attenuation coefficient versus depth interval comparisons for Site 2 on all sampling dates.

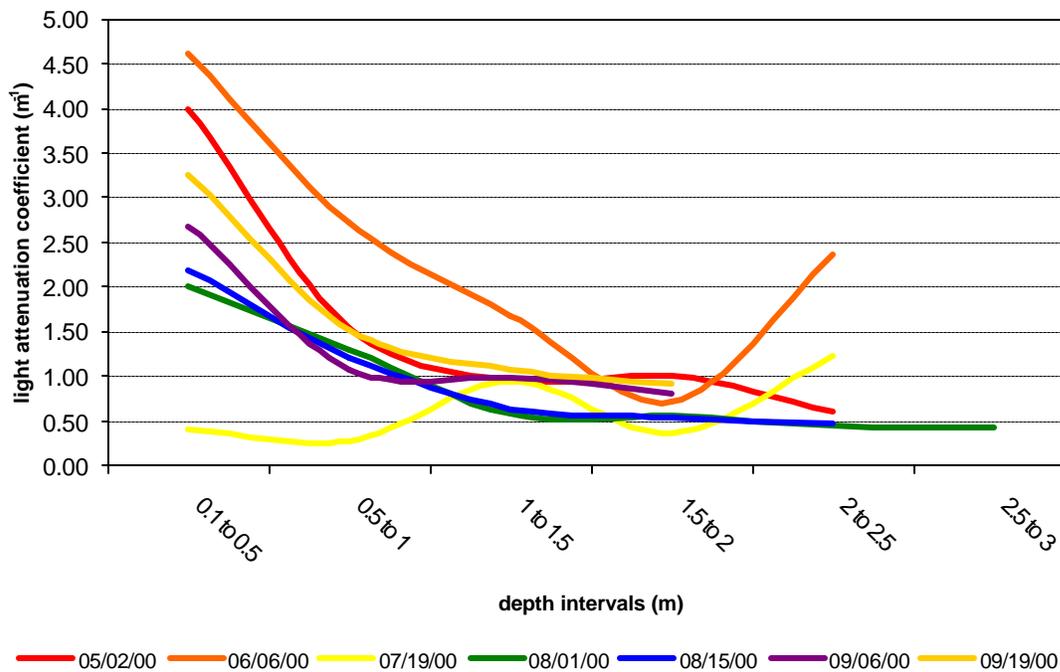


Figure 5.5-22
Oologah Lake light attenuation coefficient versus depth interval comparisons for Site 3 on all sampling dates.

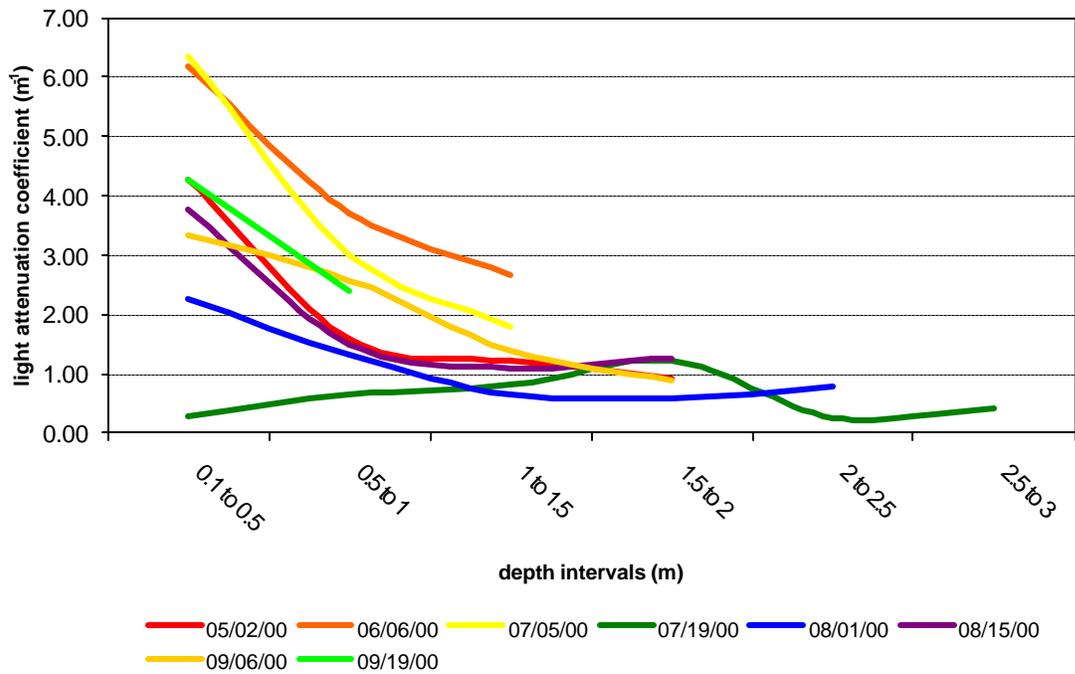


Figure 5.5-23
Oologah Lake light attenuation coefficient versus depth interval comparisons for Site 4 on all sampling dates.

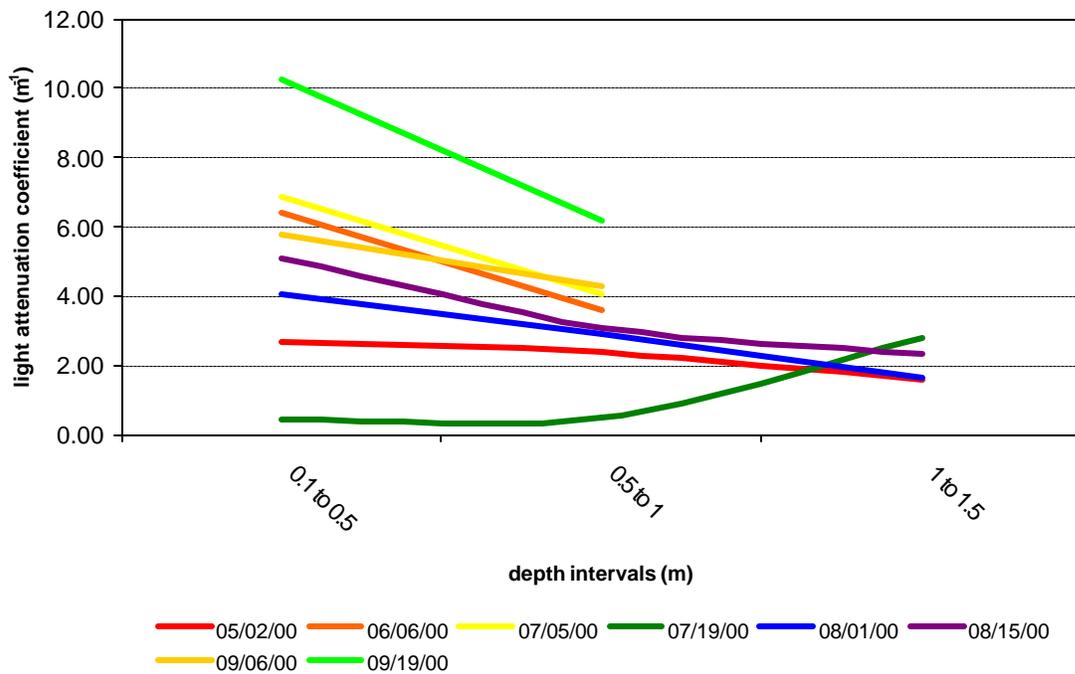


Figure 5.5-24
Oologah Lake light attenuation coefficient versus depth interval comparisons for Site 5 on all sampling dates.

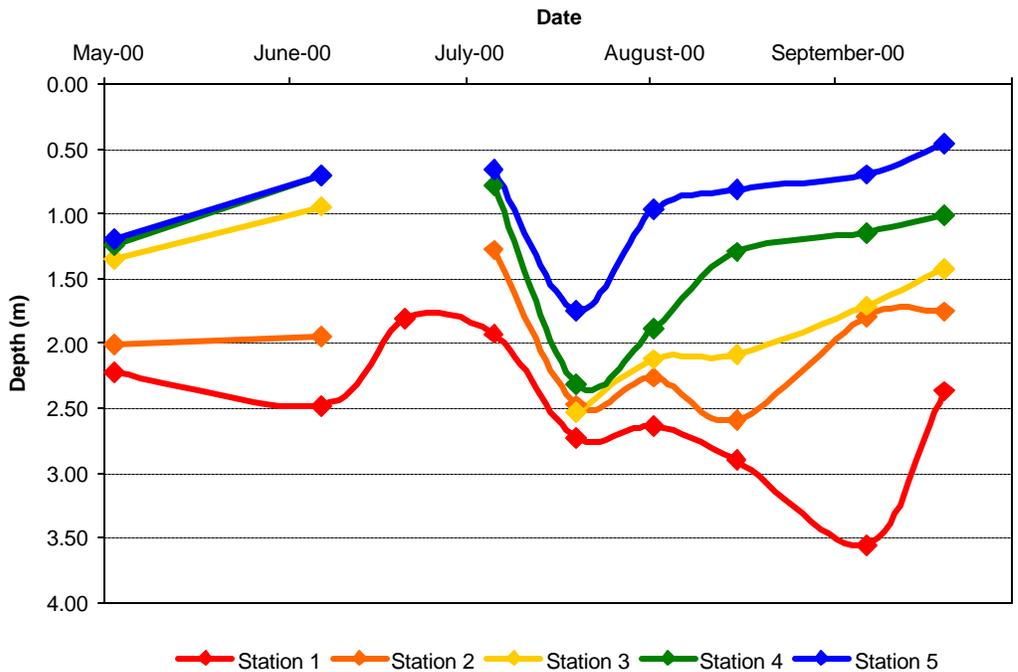


Figure 5.5-25
Oologah Lake calculated true euphotic depth for each sampling site across sampling dates.

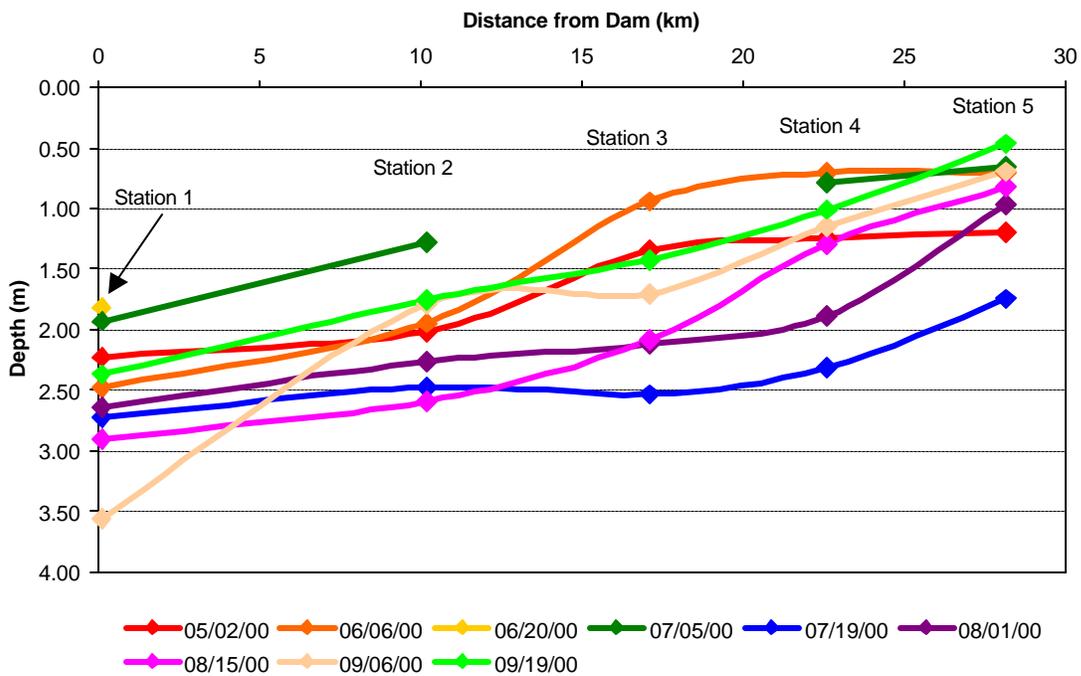


Figure 5.5-26
Oologah Lake calculated true euphotic depth for each sampling date across sampling sites.

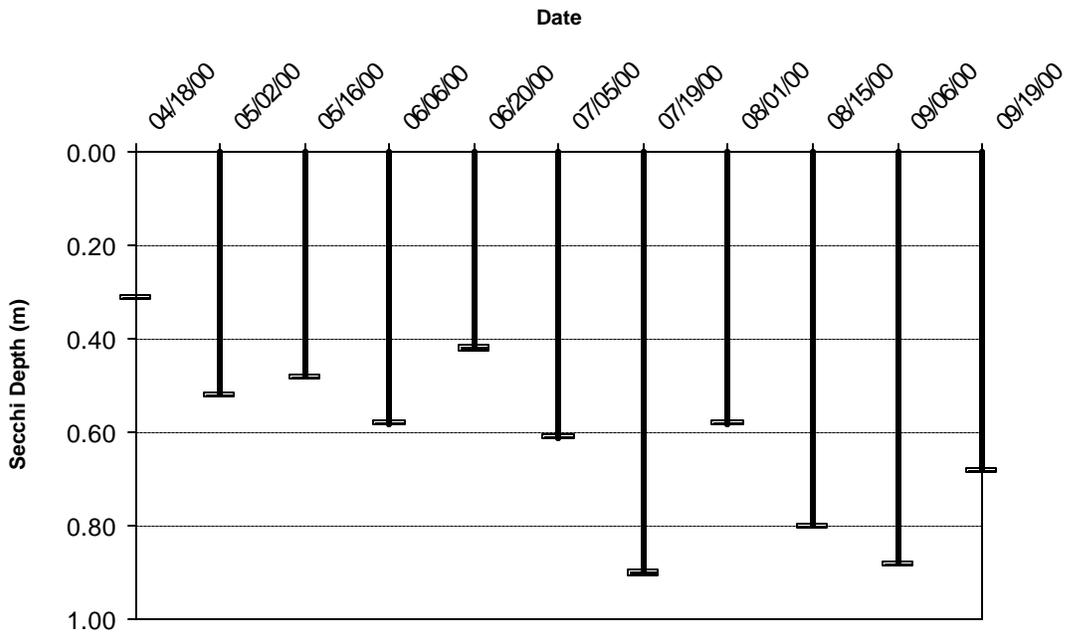


Figure 5.5-27
Oologah Lake Site 1 measured Secchi depths.

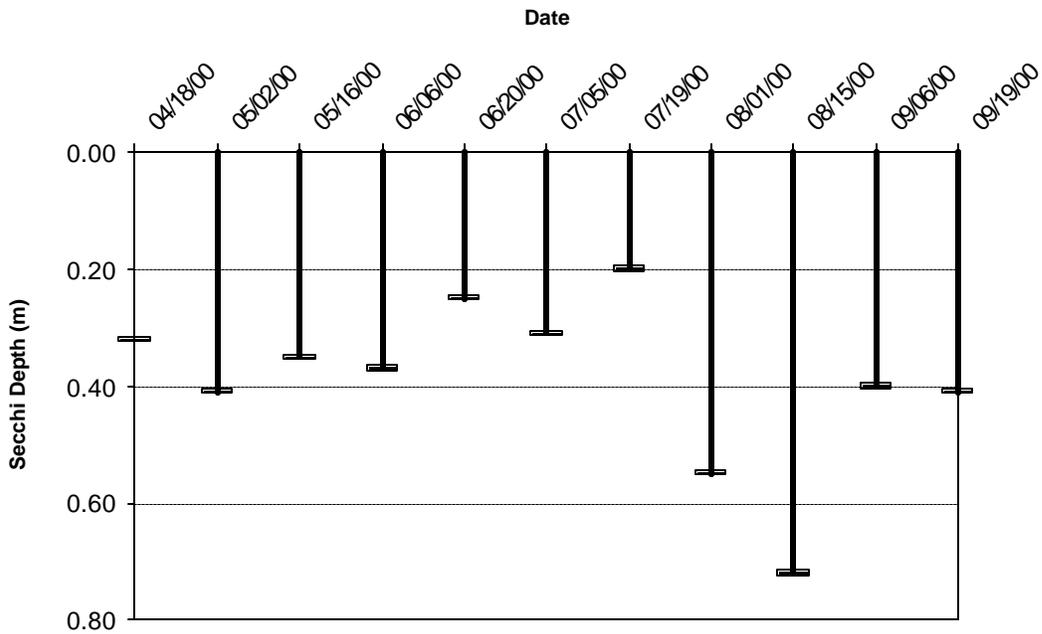


Figure 5.5-28
Oologah Lake Site 2 measured Secchi depths.

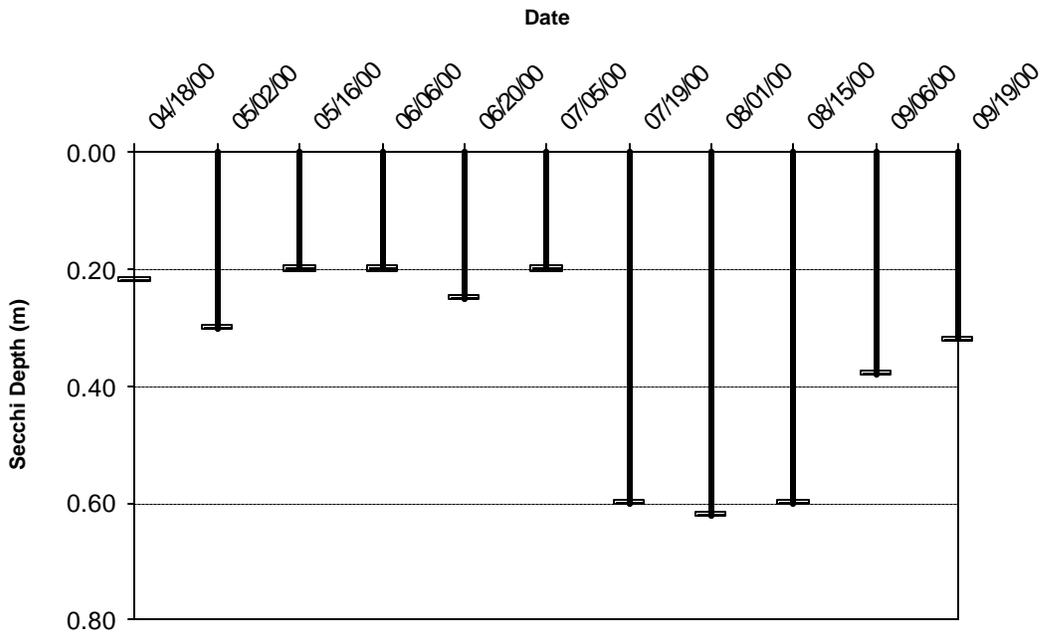


Figure 5.5-29
Oologah Lake Site 3 measured Secchi depths.

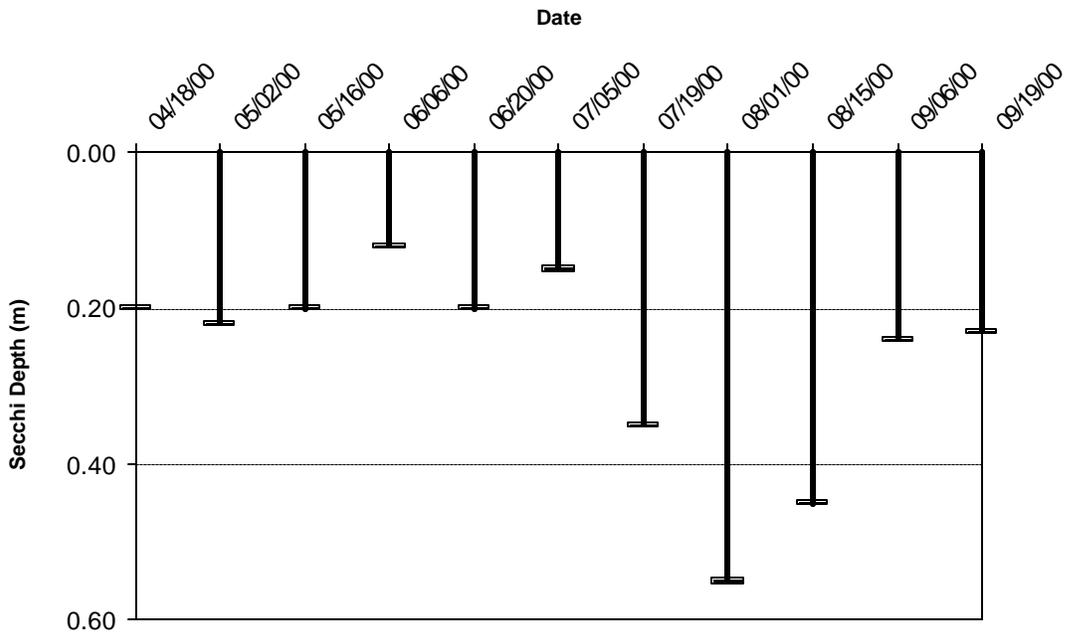


Figure 5.5-30
Oologah Lake Site 4 measured Secchi depths.

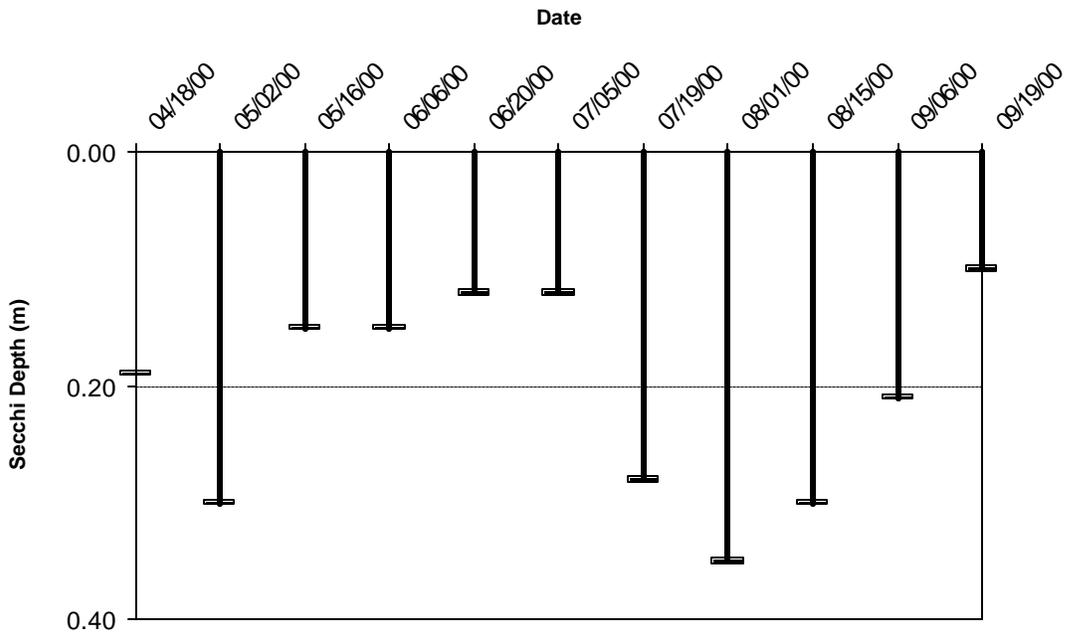


Figure 5.5-31
Oologah Lake Site 5 measured Secchi depths.

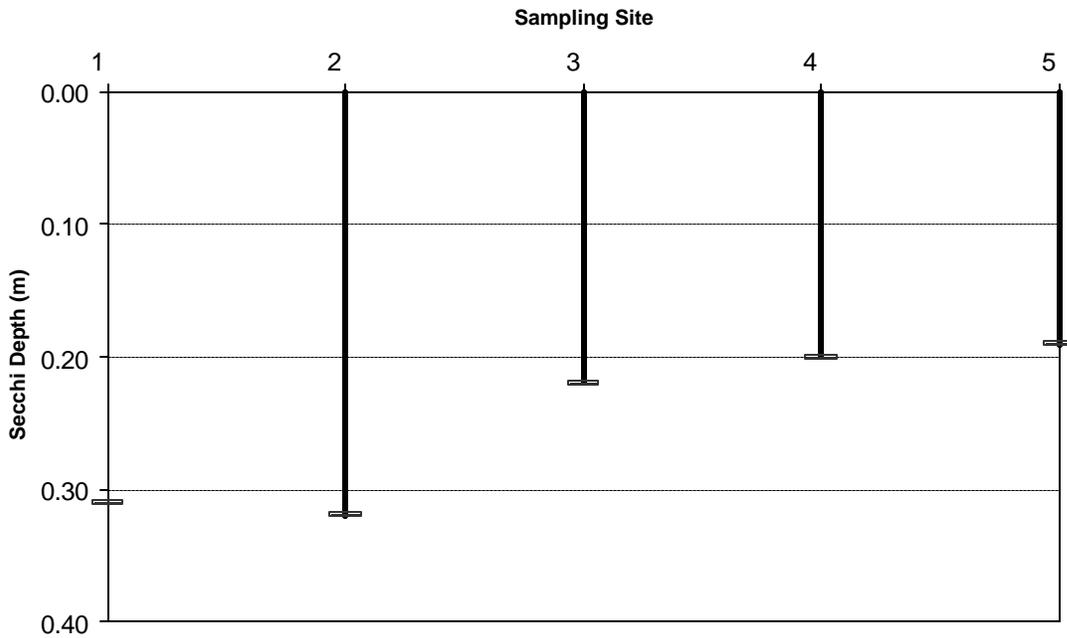


Figure 5.5-32
Oologah Lake measured Secchi depths on 18 April 2000.

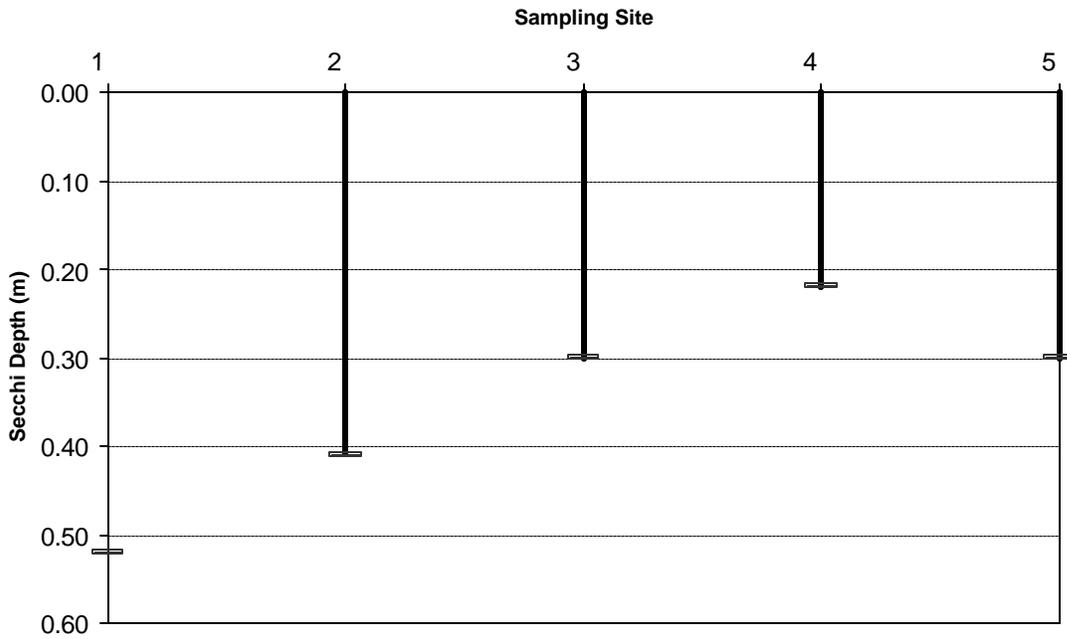


Figure 5.5-33
Oologah Lake measured Secchi depths on 2 May 2000.

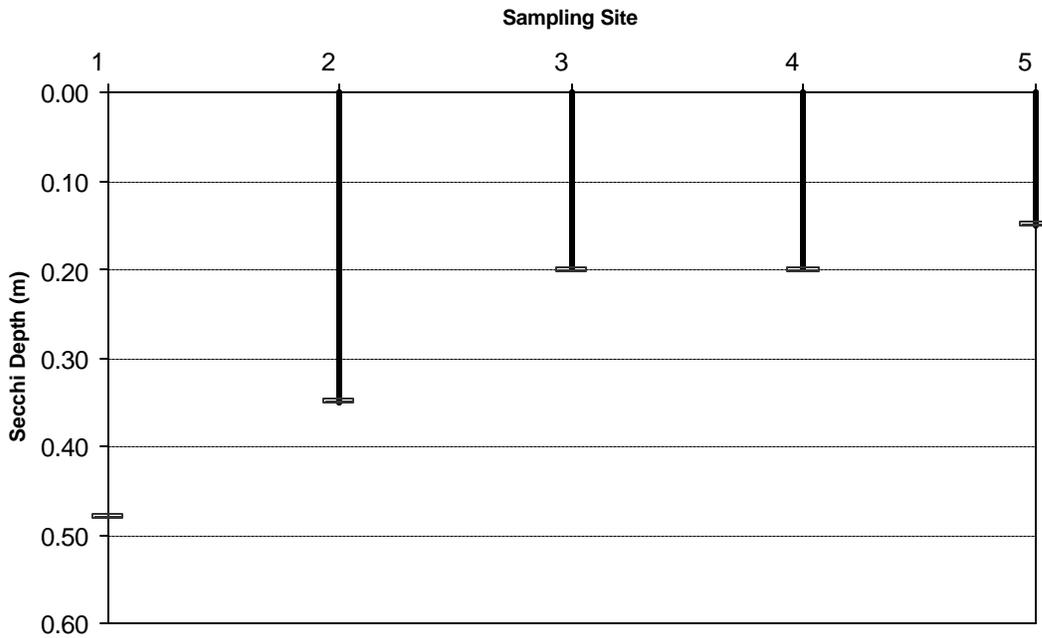


Figure 5.5-34
Oologah Lake measured Secchi depths on 16 May 2000.

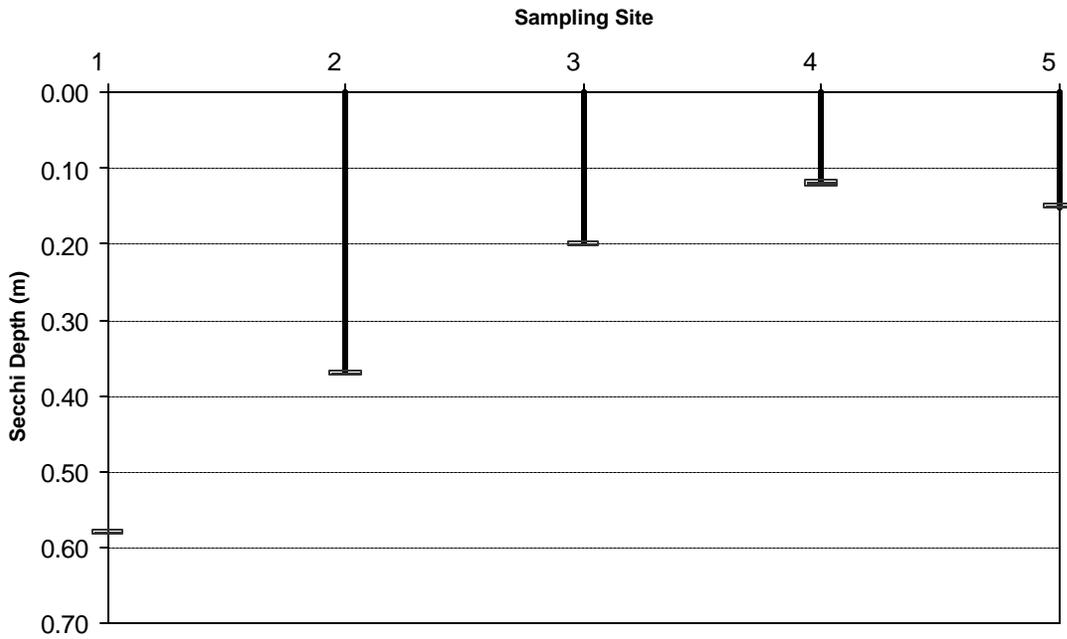


Figure 5.5-35
Oologah Lake measured Secchi depths on 6 June 2000.

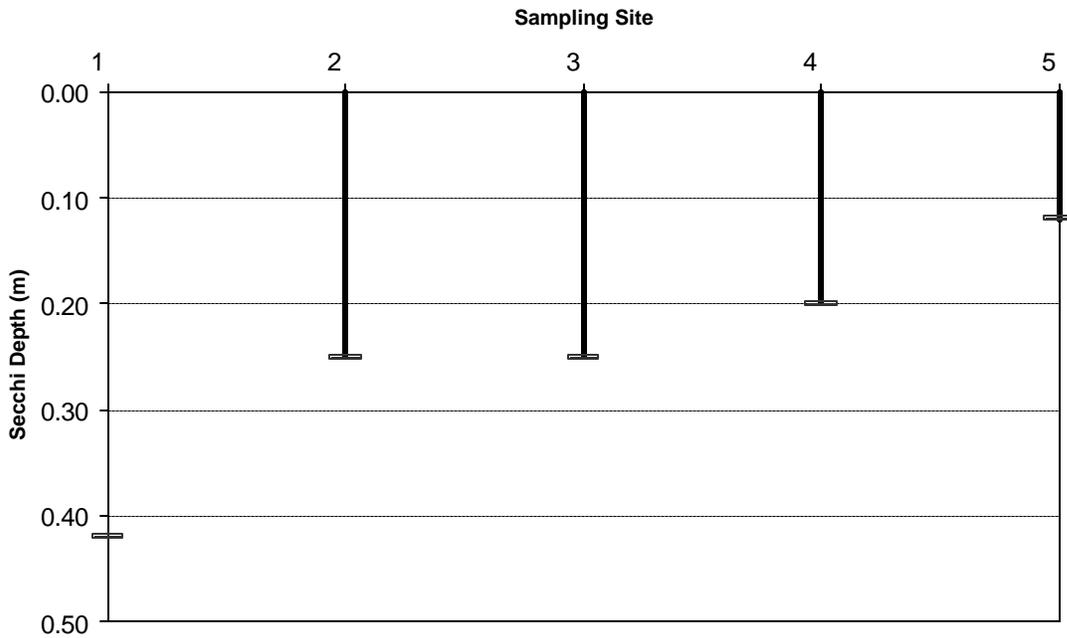


Figure 5.5-36
Oologah Lake measured Secchi depths on 20 June 2000.

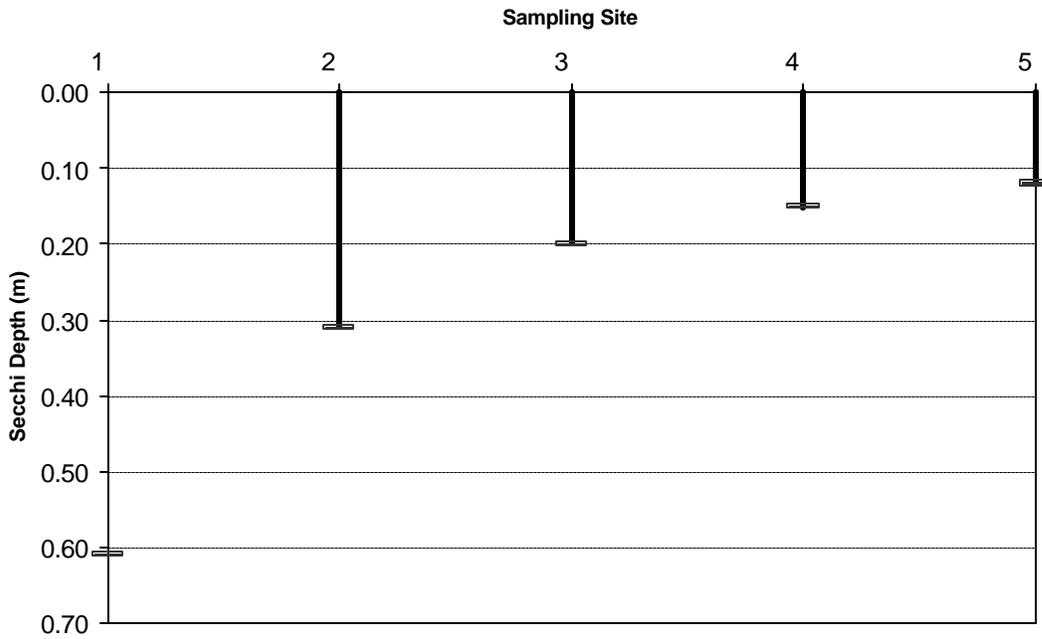


Figure 5.5-37
Oologah Lake measured Secchi depths on 5 July 2000.

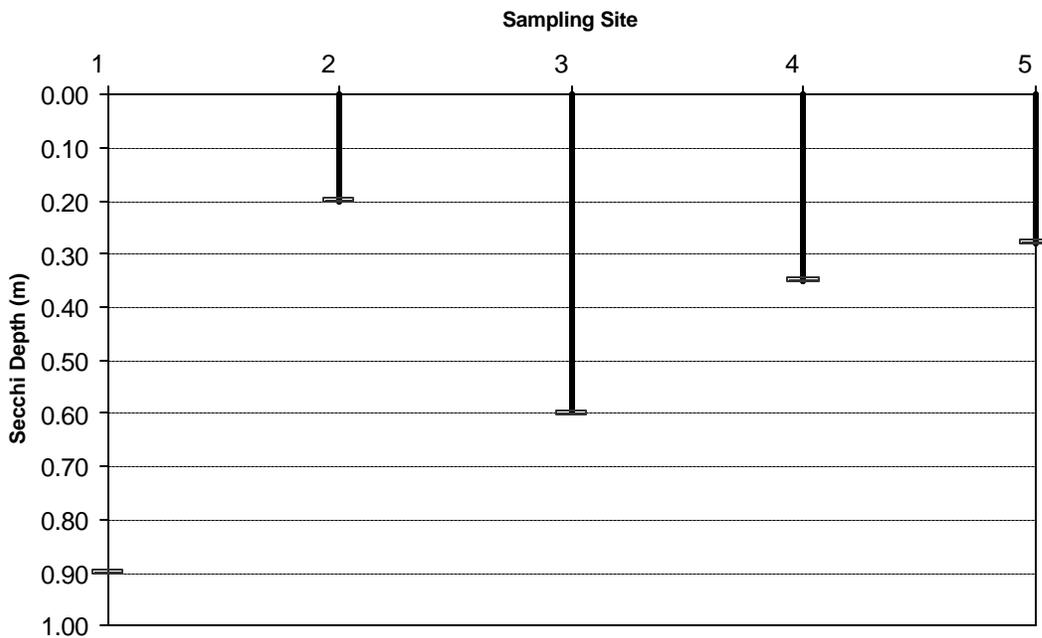


Figure 5.5-38
Oologah Lake measured Secchi depths on 19 July 2000.

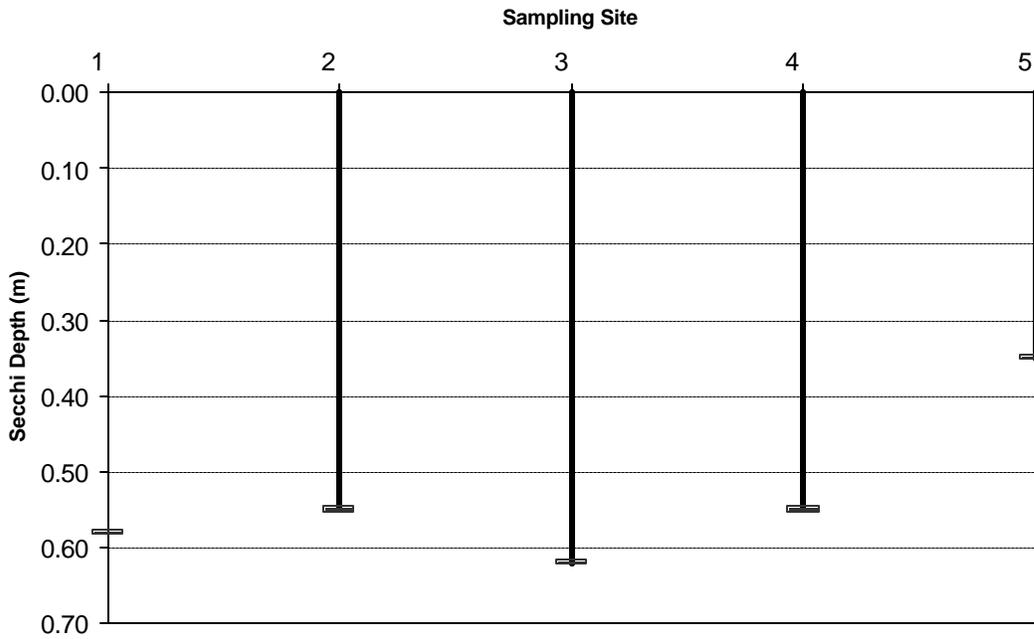


Figure 5.5-39
Oologah Lake measured Secchi depths on 1 August 2000.

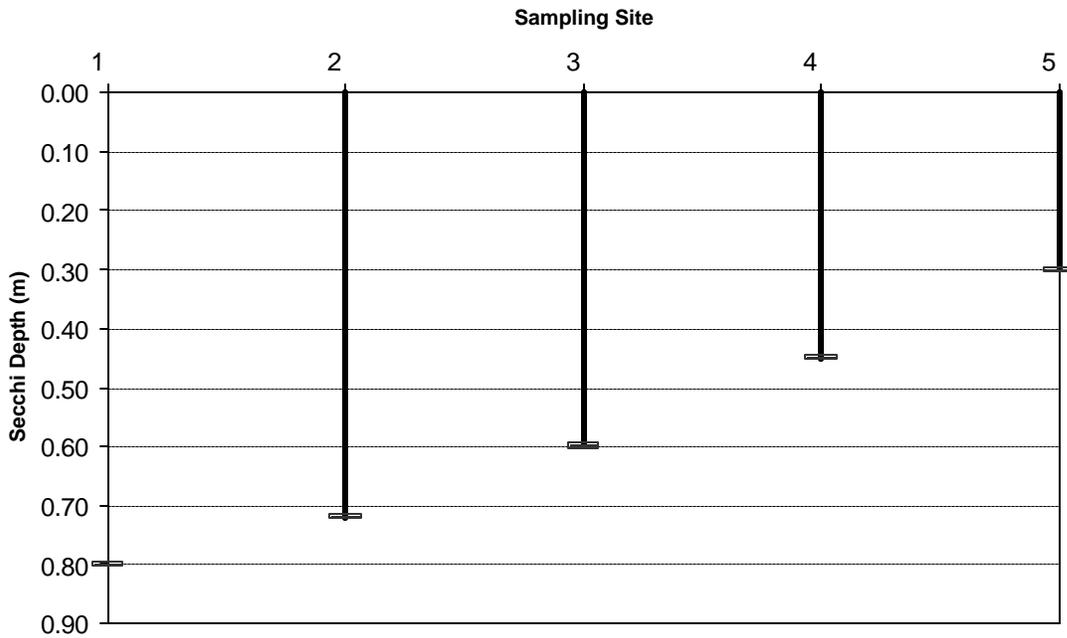


Figure 5.5-40
Oologah Lake measured Secchi depths on 15 August 2000.

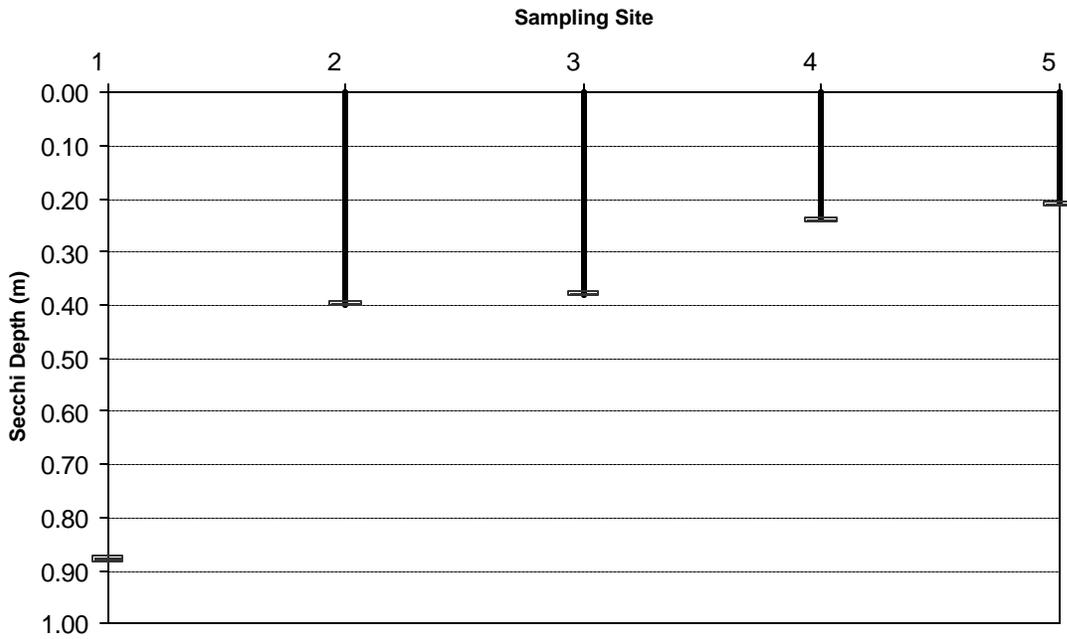


Figure 5.5-41
Oologah Lake measured Secchi depths on 6 September 2000.

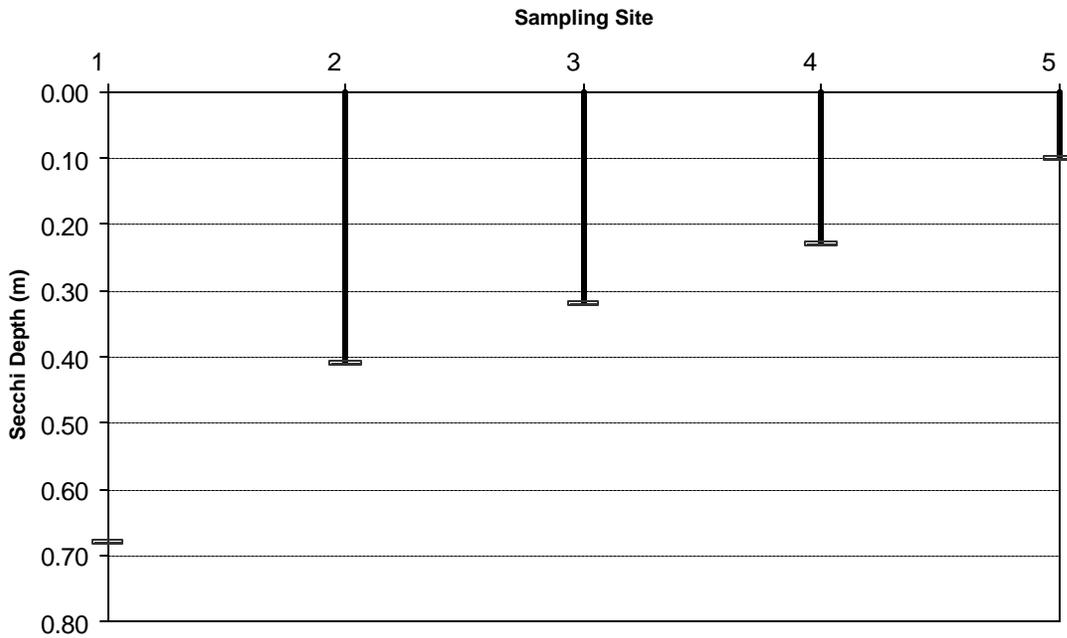


Figure 5.5-42
Oologah Lake measured Secchi depths on 19 September 2000.

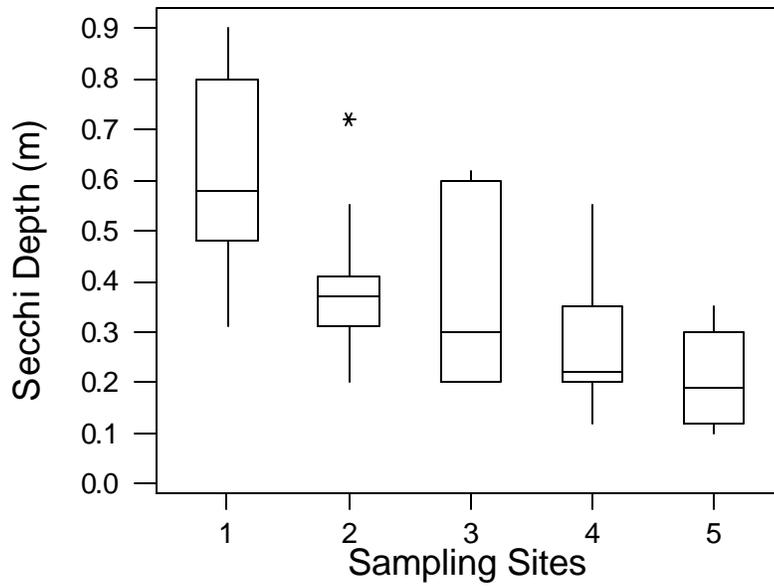


Figure 5.5-43
Box and whisker plot of measured Secchi depth (m) at each lake station
for all sampling dates showing minimum, maximum, median,
interquartile range, and outlier data.

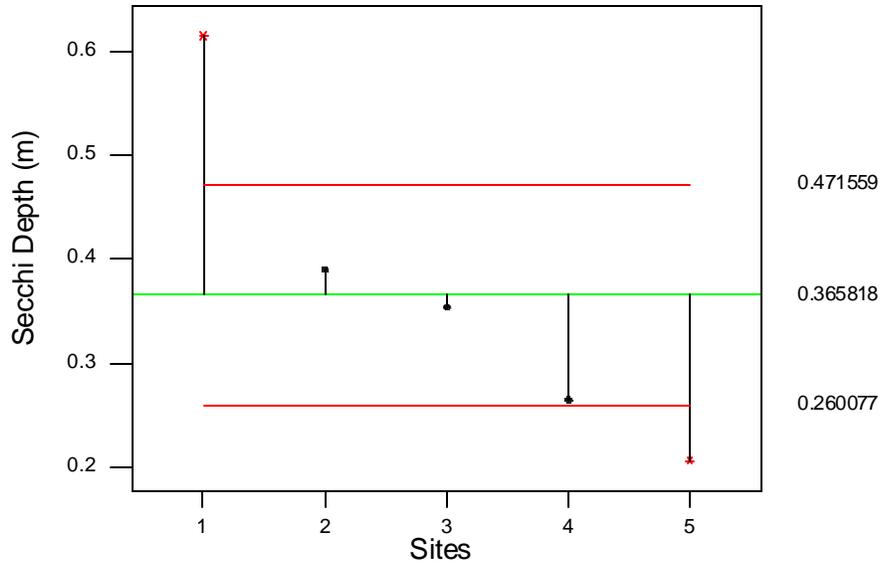


Figure 5.5-44
Analysis of Secchi depth means at the lake stations indicating that Sites 1 and 5
mean Secchi depths are different from the overall mean at $\alpha = 0.05$.

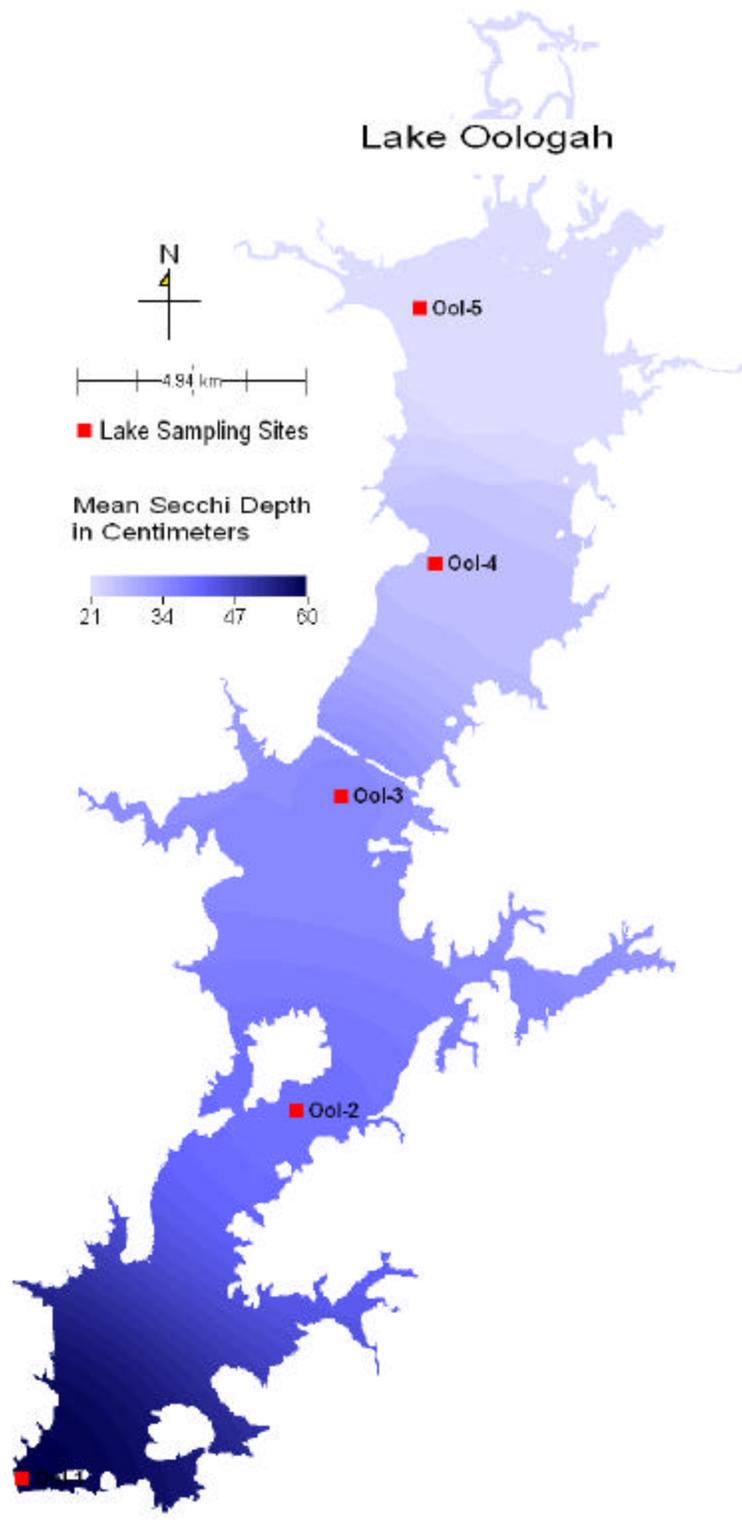


Figure 5.5-45
Locations of Oologah Lake sampling sites and mean Secchi depth (cm)
through the sampling period.

5.6 Sediment Sampling and Analysis. Results of sediment analyses for parameters measured exclusively at routine Oologah Lake water quality sampling sites (Figure 4.2.1-1) are presented in Table 5.6-1. Results of analyses for parameters common to samples from both routine sites and those located in shallow water along the eastern shore of the lake near the Winganon Bridge (Figure 4.2.2-1) are presented in Table 5.6-2. Included are data for physical parameters, general inorganics, organic carbon, petroleum hydrocarbons, and a number of naturally-occurring metals. Results for each of these general classes of constituents are described separately below.

Table 5.6-1. Results of selected inorganic analyses (mg/Kg dry weight) of sediments collected 21-22 August 2000, Oologah Lake, Oklahoma.

Parameter	Sampling Site (Figure 4.2.1-1)						
	OOL-1	OOL-2	OOL-3	OOL-4	OOL-5	OOL-5QC	OOL-5QA
Chloride	<10	<10	<10	<10	<10	<10	<13.5
Sulfate	<10	<10	16.5	<10	<10	<10	<67.6
Sulfide	33	42.2	<10	<10	<10	<10	53
Total phosphorus	252	60.2	194	185	367	372	332
Total nitrogen	435	686	554	58.5	613	692	859

5.6.1 Physical Parameters. Dry weight solids content in Oologah Lake sediment samples ranged from 22.2 to 80.0% and were generally highest at near-shore locations (Table 5.6-2). For samples collected from the main pool of the reservoir, solids content ranged from 22.2 to 43.7% and exhibited a gradual increase from Oologah Dam to the upper end of the impoundment (Figure 5.6.1-1).

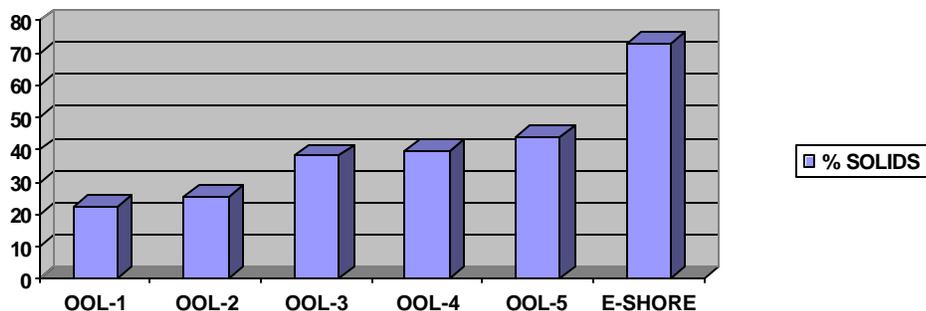


Figure 5.6.1-1
Percent solids, Oologah Lake sediments.

Table 5.6-2. Results of sediment analysis, 21-22 August 2000, Oologah Lake, Oklahoma.
Unless otherwise noted, all values are mg/Kg dry weight.

Site (Figure 4.2.1 -1)	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper
OOL-1	27,500	<1.00	9.86	293.0	1.59	0.584	8,460	29.5	12.4	25.7
OOL-2	25,900	<1.00	9.44	238.0	1.38	0.613	7,190	28.3	10.5	21.3
OOL-3	23,000	<1.00	7.11	205.0	1.17	0.713	5,180	25.6	9.62	18.5
OOL-4	24,400	<1.00	6.82	232.0	1.34	0.869	5,650	27.9	13.3	21.8
OOL-5	21,300	<1.00	7.89	180.0	1.11	0.593	6,260	24.8	10.8	17.7
OOL-5-QC	19,700	<1.00	7.08	187.0	1.20	0.641	6,460	23.4	11.5	20.0
OOL-5-QA	34,576	<1.3	8.71	212.7	<1.3	2.111	4,645	41.4	<13.2	14.3
Mean	24,420	<1.00	8.22	229.6	1.32	0.674	6,548	27.2	11.3	21.0
Median	24,400	<1.00	7.89	232.0	1.34	0.613	6,260	27.9	10.8	21.3
Minimum	21,300	<1.00	6.82	180.0	1.11	0.584	5,180	24.8	9.6	17.7
Maximum	27,500	<1.00	9.86	293.0	1.59	0.869	8,460	29.5	13.3	25.7
Site (Figure 4.2.2 -1)	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper
OOL-E-1	10,900	<1.00	2.97	117.0	0.637	0.093	2,300	12.6	4.87	6.80
OOL-E-2	10,300	<1.00	2.63	133.0	0.545	0.052	1,730	13.0	7.65	5.23
OOL-E-3	7,210	<1.00	1.92	92.1	0.516	0.039	1,770	9.3	6.88	4.92
OOL-E-4	20,700	<1.00	5.79	183.0	1.040	0.118	3,520	24.4	11.60	10.50
OOL-E-5	11,400	<1.00	2.56	96.7	0.706	0.069	3,600	10.3	5.59	8.00
OOL-E-6	6,720	<1.00	2.61	81.6	0.480	0.153	2,020	10.4	3.66	6.31
OOL-E-7	12,400	<1.00	5.54	79.1	0.689	0.105	1,480	21.9	16.20	7.04
OOL-E-8	4,730	<1.00	2.21	39.0	0.250	0.104	824	8.2	2.36	3.55
OOL-E-8-QC	5,190	<1.00	2.55	40.9	0.272	0.082	846	9.1	2.49	3.71
OOL-E-8-QA	8,982	<12.5	2.50	57.1	<1.248	<1.248	839	14.0	<12.48	3.74
OOL-E-9	8,520	<1.00	4.38	90.6	0.574	0.100	1,240	16.7	5.85	6.96
OOL-E-10	20,600	<1.00	7.45	199.0	1.120	0.224	3,020	29.4	25.80	15.70
Mean	11,348	<1.00	3.81	111.1	0.656	0.106	2,150	15.62	9.05	7.50
Median	24,400	<1.00	7.89	232.0	1.34	0.613	6,260	27.9	10.8	21.3
Minimum	4,730	<1.00	1.92	39.0	0.250	0.039	824	8.23	2.36	3.55
Maximum	20,700	<1.00	7.45	199.0	1.120	0.224	3,600	29.40	25.80	15.70
Note: QC and QA samples not included in summary statistics. One-half detection limit used for censored data										

Table 5-6-2 (Continued)

Site (Figure 4.2.1 -1)	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Strontium	Thallium
OOL-1	38,100	26.1	4,010	1,390	0.049	35.6	4,040	1.21	<0.500	70.7	<1.00
OOL-2	32,200	23.2	3,410	1,120	0.060	29.1	3,820	1.50	<0.500	62.7	<1.00
OOL-3	28,300	21.6	3,080	817	0.045	25.4	3,560	1.06	<0.500	51.1	<1.00
OOL-4	32,700	24.6	3,810	709	0.048	31.0	3,670	0.612	<0.500	57.8	<1.00
OOL-5	27,300	19.4	3,200	834	0.041	25.4	3,320	<0.500	<0.500	54.1	<1.00
OOL-5-QC	28,700	20.4	3,160	898	0.164	26.2	3,170	0.538	<0.500	54.4	<1.00
OOL-5-QA	23,015	15.0	3,854	699	<0.135	22.7	7,073	<1.3	<1.320		<1.3
Mean	31,720	23.0	3,502	974	0.049	29.3	3,682	1.096	<0.500	59.3	<1.00
Median	32,200	23.2	3,410	834	0.048	29.1	3,670	1.135	<0.500	57.8	<1.00
Minimum	27,300	19.4	3,080	709	0.041	25.4	3,320	0.612	<0.500	51.1	<1.00
Maximum	38,100	26.1	4,010	1,390	0.060	35.6	4,040	1.500	<0.500	70.7	<1.00
Site (Figure 4.2.2 -1)	Iron	Lead	Magnesium	Manganese	Mercury	Nickel	Potassium	Selenium	Silver	Strontium	Thallium
OOL-E-1	10,500	10.70	934	256	0.013	8.34	1,170	0.393	<0.500	20.5	<1.00
OOL-E-2	10,300	7.38	770	536	0.009	8.45	982	<0.500	<0.500	13.9	<1.00
OOL-E-3	8,250	9.52	548	206	0.013	5.89	579	0.395	<0.500	14.4	<1.00
OOL-E-4	22,000	13.90	1,900	305	0.011	17.90	2,240	<0.500	<0.500	36.6	<1.00
OOL-E-5	12,000	9.15	1,340	166	0.004	12.20	1,160	<0.500	<0.500	28.5	<1.00
OOL-E-6	8,180	9.25	615	229	0.022	6.61	762	<0.500	<0.500	15.2	<1.00
OOL-E-7	13,600	11.90	810	485	0.006	11.70	997	0.749	<0.500	15.4	<1.00
OOL-E-8	6,180	5.45	447	132	0.010	5.03	612	0.292	<0.500	9.34	<1.00
OOL-E-8-QC	6,700	5.59	473	142	0.011	5.42	672	<0.500	<0.500	9.15	<1.00
OOL-E-8-QA	7,011	6.49	756	146.5	<0.124	6.24	1,215	<1.248	<1.248		<1.248
OOL-E-9	14,100	11.20	626	422	0.041	8.80	739	0.283	<0.500	19	<1.00
OOL-E-10	28,900	26.10	1,920	822	0.018	23.90	2,110	<0.500	<0.500	38.1	<1.00
Mean	13,401	11.46	991	356	0.015	10.88	1,135	0.336	<0.5	21.09	<1
Median	11,250	10.11	790	281	0.012	8.63	990	0.267	<0.5	17.20	<1
Minimum	6,180	5.45	447	132	0.004	5.03	579	0.250	<0.5	9.34	<1
Maximum	28,900	26.10	1,920	822	0.041	23.90	2,240	0.749	<0.5	38.10	<1

Table 5.6-2 (Continued)

Site (Figure 4.2.1 -1)	Vanadium	Zinc	TOC	% Solids	%Sand	%Silt	%Clay	TPH (DRO)
OOL-1	39.7	113	481	22.2	31.5	21.9	46.7	16.4
OOL-2	38.1	102	350	25.4	0.6	25.1	74.0	<13.3
OOL-3	31.8	94.9	422	38.0	20.6	32.4	47.0	15.0
OOL-4	34.1	112	508	39.7	0.4	42.1	57.3	11.5
OOL-5	29.0	91.4	429	43.7	13.7	33.2	53.1	19.8
OOL-5-QC	27.7	96.9	392	45.3	0.4	47.8	51.7	18.7
OOL-5-QA	51.5	82.6	17,600	74.0				<13.5
Mean	34.5	102.7	438	33.8	13.4	30.9	55.6	15.7
Median	34.1	102.0	429	38.0	13.7	32.4	53.1	15.7
Minimum	29.0	91.4	350	22.2	0.4	21.9	46.7	11.5
Maximum	39.7	113.0	508	43.7	31.5	42.1	74.0	19.8
Site (Figure 4.2.2 -1)	Vanadium	Zinc	TOC	% Solids	%Sand	%Silt	%Clay	TPH (DRO)
OOL-E-1	18.4	23.6	583	72.7	40.0	37.0	22.9	<3.33
OOL-E-2	16.9	23.1	322	68.9	27.0	49.9	22.7	5.71
OOL-E-3	14.4	14.3	379	73.4	26.5	51.0	22.3	6.77
OOL-E-4	30.4	37.3	405	71.6	28.0	34.1	37.8	7.39
OOL-E-5	8.23	22.6	425	73.9	24.3	35.2	39.4	<3.33
OOL-E-6	14.6	20.0	290	68.2	28.1	54.4	17.2	<4.90
OOL-E-7	31.1	22.1	437	72.4	26.8	50.5	22.4	<3.33
OOL-E-8	9.98	16.0	333	73.1	66.7	25.9	7.4	5.60
OOL-E-8-QC	11.0	16.8	273	76.4	27.0	65.1	7.8	5.29
OOL-E-8-QA	17.215	17.7	3,700	80.0				<12.6
OOL-E-9	24.0	20.2	487	75.1	34.7	53.5	11.7	52.9
OOL-E-10	39.1	44.5	337	72.8	32.1	32.0	34.5	5.14
Mean	20.7	24.4	400	72.2	33.4	42.4	23.8	9.10
Median	17.7	22.4	392	72.8	28.1	43.5	22.6	5.37
Minimum	8.2	14.3	290	68.2	24.3	25.9	7.4	1.67
Maximum	39.1	44.5	583	75.1	66.7	54.4	39.4	52.90
TOC = total organic carbon								
TPH (DRO) = Total petroleum hydrocarbons (diesel range)								

Solids content was substantially higher in samples collected near the shore in the Winganon bridge area (median = 72.8%, n=10). Significant differences in solids content were noted between samples from the main pool and those collected along the east shore (Mann-Whitney, $p = 0.0027$, $n_1=5$, $n_2=10$). During sample collection in this near-shore area, it was observed that samples were more consolidated than those collected from the main pool of the reservoir. This shallow and wind-exposed area is most likely a low depositional environment owing to high sediment resuspension rates.

Particle size distributions in sediment samples collected at Oologah Lake on 21-22 August 2000 are listed in Table 5.6-2 and depicted in Figure 5.6.1-2. Typically, reservoirs exhibit longitudinal gradients in particle size distribution owing to differential settling of varying sizes of particulate matter in inflowing waters. This particle size sorting generally results in predominance of larger particles (i.e., heavier sands and coarse silts) in sediments of the upper end of impoundments with a higher proportion of fine-grained materials toward the dam (Nolen et al. 1985, Thornton et al. 1990). This pattern was not clearly evident in limited samples collected at Oologah Lake (Figure 5.6.1-2). Percentage of sand-sized particles actually increased toward Oologah Dam from Site 5 (13.7%) to Site 3 (20.6%) to Site 1 (31.5%) but were less than 1% at Sites 2 and 4. With the exception of Site 5, silt-sized particle percentages followed a more typical longitudinal distribution with percentages decreasing toward Oologah Dam. Percentage of clays was actually lowest near Oologah Dam (46.7%), substantially higher at Site 2 (74.0%), and similar at Sites 3 through 5 (47.0 to 57.3%) (Figure 5.6.1-2). Overall, this atypical pattern may reflect dynamics of sedimentation patterns in Oologah Lake resulting from high rates of wind-induced sediment resuspension and/or influences of water control practices (Thornton et al. 1990).

Median particle size percentages from samples (n=10) collected at near-shore areas around the Winganon Bridge (Figure 4.2.2-1) are likewise shown in Figure 5.6.1-2. In general, these samples possessed higher percentages of sands and lower percentages of clays relative to samples collected from the main pool of the reservoir.

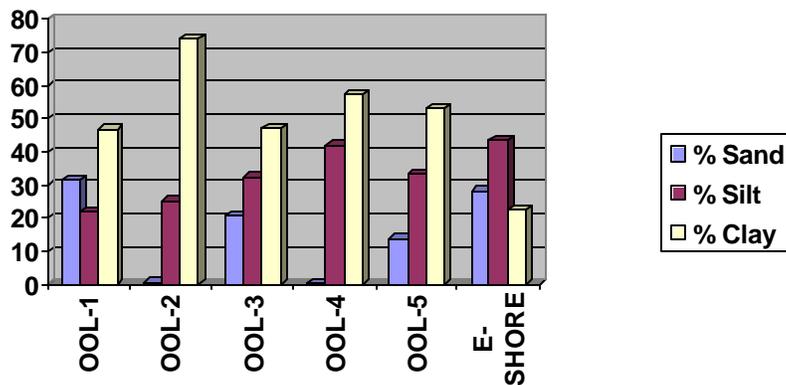


Figure 5.6.1-2
Sediment particle size distribution, Oologah Lake, Oklahoma.

5.6.2 General Inorganics. Results of selected inorganic analyses of sediment samples collected from the main pool of Oologah Lake are presented in Table 5.6-1. Concentrations of both chlorides and sulfates were generally below analytical quantitation limits at all sites, with the exception of a reported sulfate concentration of 16.5 mg/Kg in the sediment sample collected at Site 3. Sulfide concentrations were likewise below quantitation limits in samples from the upper end of the impoundment but were reported at 33 and 42.2 mg/Kg in samples from Sites 1 and 2, respectively. These results are not surprising given reducing conditions in lower water strata at these sites during the period of sediment sample collection (see Section 5.3.6).

Concentrations of total nitrogen (N) and phosphorus (P) measured in Oologah Lake sediment samples are presented in Table 5.6-1 and depicted in Figure 5.6.2-1. Total N concentrations ranged from 58.5 (Site 4) to 686 mg/Kg (Site 5) and exhibited no general longitudinal gradient in the reservoir. Total P concentration was highest at Site 5 (367 mg/Kg), lowest at Site 2 (60.2 mg/Kg) and likewise exhibited no discernable longitudinal gradient in Oologah Lake. Correlation analysis using Spearman’s rank correlation ($\alpha = 0.05$) failed to identify significant correlations between nutrients (N and P) and sediment TOC or any grain size fraction.

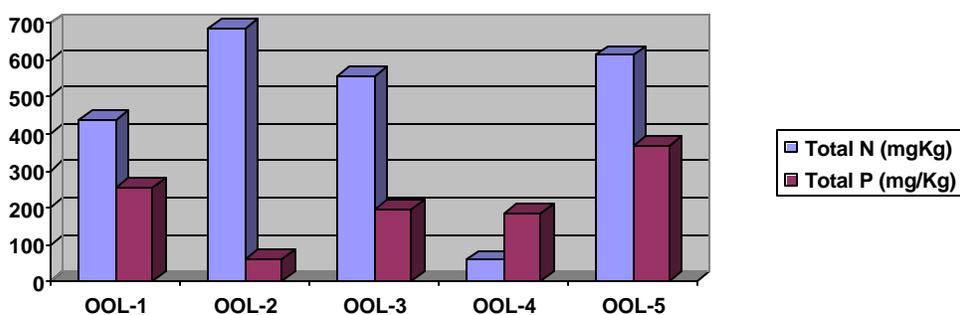


Figure 5.6.2-1
Total nitrogen (N) and phosphorus (P), Oologah Lake sediments.

5.6.3 Organic Carbon. Total organic carbon (TOC) concentrations reported for Oologah Lake sediments were extremely low in samples from both the main pool and the east lake shore near the Winganon Bridge. Values from both areas were similar and ranged from 290 to 583 mg/Kg dry weight (Table 5.6-2) with an overall mean value of 413 mg/Kg (ca 0.04 percent TOC). It should be noted that reported TOC concentrations in QA sediment samples were considerably higher (3,700 and 17,600 mg/Kg) than those in corresponding field samples (see comparison in Table 5.6-2). However, field sample TOC concentrations measured during this study were very similar to those reported in Oologah Lake backwater, shoreline, and floodplain areas (48 to 508 mg/Kg) from field investigations by Roberts/Shornick and Associates, Inc. (1999).

Organic carbon concentrations measured in Oologah Lake sediments during this study were considerably lower and exhibited atypical distributional patterns relative to other reservoirs. In a study of two Oklahoma reservoirs, Hyne (1978) reported average sediment TOC concentrations of 1- and 1.2% for Lakes Texoma and Fort Gibson, respectively. He also reported consistency with findings from other systems in which sediment TOC is strongly correlated with both increasing water depth and proportion of clay-sized grains. Such findings were not observed in limited samples from Oologah Lake. No significant correlation was observed between sediment TOC and water depth (Spearman's $r = 0.103$, $p = 0.870$) and concentrations from deep, main pool sampling sites were not significantly different from those measured in sediments from shallow, near-shore sites (Mann-Whitney, $p = 0.2979$). Finally, no

significant correlation was observed between sediment TOC and percent clays ($r = 0.293$, $p = 0.289$).

Hyne (1978) also cited a high sedimentation rate as a factor reducing organic matter content of sediments owing to “dilution” of organics with inorganic sediments. This effect was noted in Lakes Texoma and Fort Gibson and could help explain extremely low TOC values measured in Oologah Lake sediments as well. Finally, Hyne (1978) cited sediment carbon:nitrogen (C:N) ratio as an indicator of the nature of organic contribution to bed sediments with higher C:N resulting from input of allochthonous material (e.g., terrestrial detritus). He reported C:N of 11.5 and 9.6 in Lakes Texoma and Fort Gibson, respectively. In comparison, a C:N of approximately 0.9 in Oologah Lake sediments was obtained during this study. Further evidence for low inputs of allochthonous organics to Oologah Lake may likewise be observed in low C:N in inflowing tributary waters (see data in Section 5.2).

5.6.4 Petroleum Hydrocarbons. Extractable (diesel range) total petroleum hydrocarbon (TPH) concentrations measured in Oologah Lake sediments from both the main pool (Figure 4.2.1-1) and mid-lake east shoreline (Figure 4.2.2-1) are presented in Table 5.6-2 and graphically depicted in Figure 5.6.4-1. Similar to water analyses, detectable concentrations were present, but low and at or near the quantitation limit. Concentrations in sediment samples from the main pool ranged from below quantitation limits (<13.3 mg/Kg) to 19.8 mg/Kg dry weight with an identical mean and median of 15.7 mg/Kg. Concentrations in samples from shallow areas near the Winganon Bridge were lower, ranging from <3.3 to 52.9 mg/Kg (location E-9, Figure 4.2.2-1) with a mean and median concentration of 9.10 and 5.37 mg/Kg, respectively. Median TPH concentration was significantly higher ($\alpha = 0.05$) in samples from the main pool than that for near-shore samples (Mann-Whitney, $p = 0.0321$, $n_1 = 5$, $n_2 = 10$).

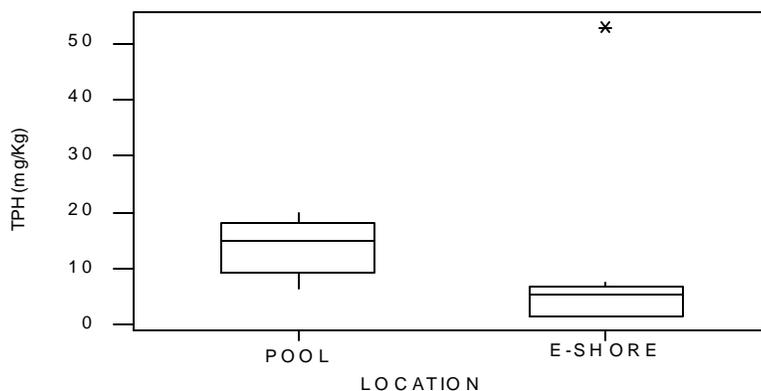


Figure 5.6.4-1
Sediment total petroleum hydrocarbons (TPH) concentrations.

Correlation analyses using Spearman's rank were used to test for significant ($\alpha = 0.05$) correlation between TPH and other sediment parameters. Significant correlations were not observed between TPH and percentages of sands ($r = -0.226$, $p = 0.418$), silts (-0.168 , $p = 0.548$), clays ($r = 0.297$, $p = 0.282$), or total solids ($r = -0.333$, $p = 0.225$). Similarly, a significant correlation did not exist between TPH and sediment TOC ($r = 0.254$, $p = 0.360$) or any of the 23 metals except nickel ($r = 0.654$, $p = 0.008$). Accordingly, significant differences in sediment TPH concentrations between the main pool and shoreline area could not be explained readily by correlation with other measured sediment parameters.

Sediment petroleum hydrocarbon data are limited (or nonexistent) for other Oklahoma reservoirs. It was therefore difficult to determine whether low TPH concentrations measured in Oologah Lake sediments during this study were the result of naturally-occurring petroleum products in the local environment, a reflection of oilfield activities around the lake, residual from boating and similar activities, or a combination of these factors. Regardless, it is apparent that TPH concentrations are low, at least in areas sampled during this study. Further, these data should prove useful in future petroleum-related monitoring efforts at Oologah Lake.

5.6.5 Metals. Concentrations of 23 metals measured in Oologah Lake sediment samples are presented in Table 5.6-2. These metals are all naturally occurring, but were evaluated as a screen for potential contamination associated with petroleum production or other anthropogenic activities.

Concentrations of most metals were higher in sediment samples from main-pool reservoir sites (Figure 4.2.1-1) than those in samples from mid-lake shallow water areas (Figure 4.2.2-1). This can most likely be explained by a significantly higher percentage of clays in main pool sediments (Mann-Whitney, $p = 0.0027$) and a strong positive correlation between most metals and proportion of clays. These correlations are presented in Table 5.6.5-1.

Table 5.6.5-1. Spearman's rank correlation coefficients (r) for % clays and metals, Oologah Lake sediments (n = 15).

Metal	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Calcium
r	0.911	0.739	0.861	0.893	0.693	0.929
p	<0.001	0.002	<0.001	<0.001	0.004	<0.001
Metal	Chromium	Cobalt	Copper	Iron	Lead	Magnesium
r	0.711	0.529	0.875	0.800	0.685	0.929
p	0.003	0.043	<0.001	<0.001	0.005	<0.001
Metal	Manganese	Mercury	Nickel	Potassium	Selenium	Strontium
r	0.693	0.544	0.885	0.914	0.315	0.889
p	0.004	0.036	<0.001	<0.001	0.252	<0.001
Metal	Vanadium	Zinc				
r	0.604	0.893				
p	0.017	<0.001				

Significant correlations with clay percentage were observed for all metals except selenium. As might be expected, highest coefficients were obtained for metals such as aluminum, calcium, magnesium, and potassium. No significant correlations were noted between TOC and any metal measured in Oologah Lake sediments.

As a general evaluation of metals concentrations in Oologah Lake sediments, both maximum and median values for sediment metals obtained during this study were analyzed using

several criteria. First, metals concentrations were compared to “background” values typical for freshwater sediments as compiled by NOAA (1999). Similarly, concentrations were next compared to soils and other surficial materials metals concentrations in northeastern Oklahoma near the Oologah Lake area as measured by the USGS (1984). Both comparisons are presented in Table 5.6.5-2. While these approaches provide a reasonable general evaluation, caution should be exercised in placing too much emphasis on these comparisons as “background” is difficult to define for an extreme diversity of freshwater environments and soils and sediment data are not directly comparable.

A number of metals in Oologah Lake sediments exceeded “background” values typical for freshwater sediments. In addition, a smaller subset exceeded northeast Oklahoma surface soil concentrations (Table 5.6.5-2). Collectively, it appeared that arsenic, iron, manganese, nickel, selenium, and zinc concentrations in Oologah sediments substantially exceeded both. With the exception of selenium, concentrations of all these metals were closely correlated with proportion of clay-sized grains (Table 5.6.5-1) which dominate Oologah Lake sediments, particularly in deeper, main-pool locations (Figure 5.6.1-2).

A second means of evaluating Oologah Lake sediment metals data involved comparing maximum reported values with several ecological “screening” values available for selected metals. These values are conservative criteria commonly used to screen chemical constituents in ecological risk assessment. It should be noted that these criteria represent very conservative sediment quality guidelines developed for the most sensitive ecological receptors. Field concentrations exceeding these values do not necessarily indicate definitive impact on ecological receptors, only that further evaluation may be warranted. Values used for these comparisons were “consensus-based” guidelines recently developed by MacDonald et al. (2000), guidelines from Screening Quick Reference Tables developed by NOAA (1999), and those developed by Long et al. (1995). Comparisons are presented in Table 5.6.5-2.

Table 5.6.5-2. Comparison of Oologah Lake sediments metals concentrations with ecological screening criteria. All values are mg/Kg dry weight. Shaded values exceed one or more screening criteria.

Metal	Oologah Maximum (all data)	Oologah Median (main pool)	Freshwater Sediment "Background"¹	Northeast Oklahoma Surface Soil Concentrations²	Threshold Effect Concentration³	Probable Effect Concentration³	Threshold Effect Level¹	Effects Range-Low⁴
Aluminum	27,500 (2.8%)	24,400 (2.4%)	0.26%	0.07-2%				
Antimony	<1.00	<1.00	0.160	<1				
Arsenic	9.86	7.89	1.100	4.1-6.5	9.79	33.0	5.9	8.2
Barium	293.0	232.0		10-200				
Beryllium	1.59	1.34		<1				
Cadmium	0.869	0.613	0.100-0.300		0.99	4.98	0.596	1.2
Chromium	29.5	27.9	7-13	50	43.4	111	37.3	
Cobalt	25.80	10.8	10.000	3-10				
Copper	25.7	21.3	10-25	<1-15	31.6	149	35.7	34
Iron	38,100 (3.8%)	32,200 (3.2%)	0.99-1.8%	1.5%				
Lead	26.1	23.2	4-17	<10-10	35.8	128	35.00	47
Manganese	1,390	834	400	200-300				
Mercury	0.060	0.048	0.004-0.051	<0.001-0.032	0.18	1.06	0.174	0.15
Nickel	35.6	29.1	9.9	7-15	22.7	48.6	18.00	21
Selenium	1.500	1.135	0.290	<0.1-0.2				
Silver	<0.500	<0.500	<0.500					
Strontium	70.7	57.8	49	<5-100				
Vanadium	39.7	34.1	50	<7-50				
Zinc	113.0	102.0	7-38	<5-17	121	459	123.100	150

¹ NOAA (1999)

² USGS (1984)

³ Threshold Effect Concentration (TEC): concentration "below which adverse effects are not expected to occur" (MacDonald et al. 2000)
 Probable Effect Concentration (PEC): concentration "above which adverse effects are expected to occur more often than not" (MacDonald et al. 2000)

⁴ Long et al. (1995)

The only metals whose maximum concentrations in Oologah sediment samples exceeded any of the screening criteria were arsenic, cadmium, and nickel (Table 5.6.5-2). For arsenic, the maximum concentration of 9.86 mg/Kg barely exceeded the consensus-based threshold effect concentration (TEC) proposed by MacDonald et al. (2000) but was well below the probable effect concentration (PEC) recommended by these authors. For cadmium, the maximum level (0.869 mg/Kg) was below the TEC and other criteria with the exception of the NOAA (1997) threshold effect level. For nickel, both maximum and median values exceeded the TEC and criteria proposed by NOAA (1997) and Long et al. (1995) but were well below the consensus-based PEC (MacDonald et al. 2000). Accordingly, none of these metals were excessively high or at levels posing significant potential risk to ecological receptors.

5.6.6 Herbicides and Pesticides. Sediment samples from main pool sampling sites (Figure 4.2.1-1) were analyzed for organochlorine pesticides and chlorinated herbicides. While the manufacture of these compounds has been discontinued, it is possible that they could exist as legacy pollutants in Oologah Lake sediments. However, no chlorinated pesticides or herbicides were detected in any field, QC, or QA sediment sample collected at Oologah Lake during this study. Similarly, samples were analyzed for organophosphorus pesticides with no detection of these compounds reported for any sample.

5.6.7 Semi-volatile Organics. Sediment samples from all sampling sites (Figures 4.2.1-1 and 4.2.2-1) were analyzed for semi-volatile organic constituents. With the exception of a single low detection of benzo(g,h,i)perylene at 783 ug/Kg (dry wt) at OOL-1, concentrations of all semi-volatile organic compounds were below analytical quantitation limits in all samples from Oologah Lake.

5.7 Reservoir Modeling. During FY 00, the CE-QUAL-W2 computation grid was developed based on sediment range information collected at Oologah Lake. An initial water balance was conducted using flow and water surface elevation information for the period 1 April through 30 September 2000. Computed surface water elevations (TSR 2) compared favorably with observed surface elevations (Figure 5.7-1). Meteorological data for the site were processed and are currently being used in initial stages of thermal calibration of the model. Work involving

incorporation of observed temperature and constituent concentrations into the model is continuing.

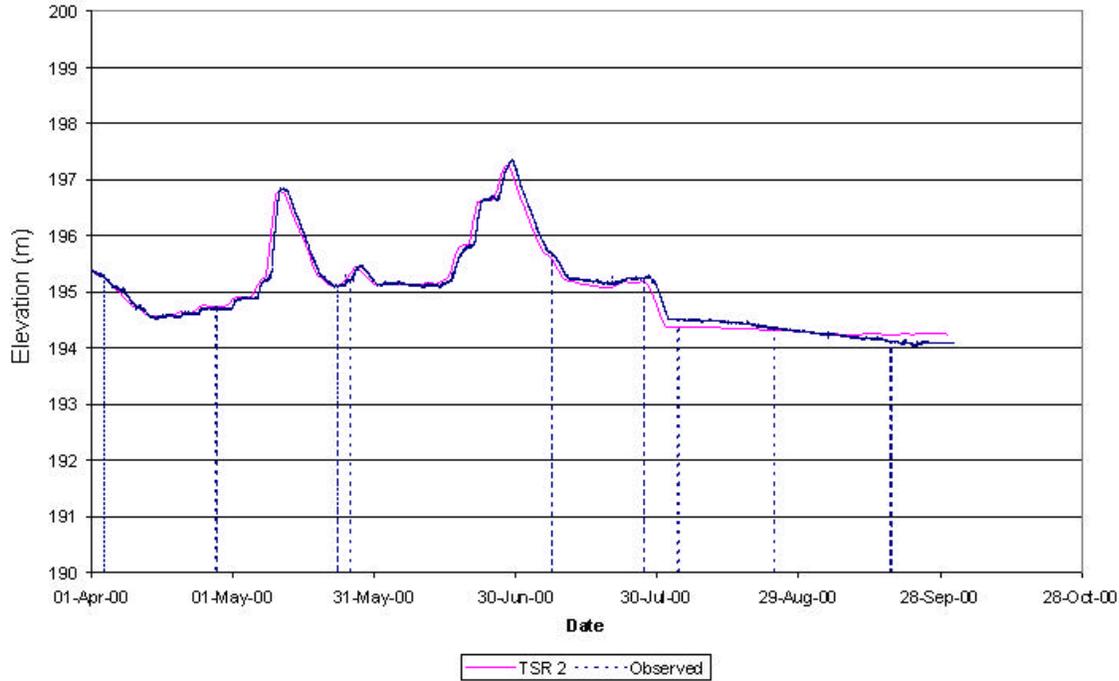


Figure 5.7-1
Elevation time series for period 1 April through 30 September 2000.
Vertical lines result from short period of missing observations.

Future work will include thermal calibration of the model followed by calibration for other constituents. Additionally, work has begun to include the ability to model any number of inorganic suspended solids group during a simulation.

6.0 DISCUSSION

Data collected during the initial phase of this study have shed considerable light on the limnology of Oologah lake and water quality of its major tributaries. Given the scarcity of historical data for the reservoir system, this study has greatly expanded our knowledge of factors affecting loading rates, solids dynamics, nutrient/algae relationships, light and temperature

regimes, contaminant issues, and a variety of other water quality-related factors that influence ecological integrity, recreational aesthetics, and water supply suitability of Oologah Lake. Understanding of system dynamics will continue to increase as additional data are collected and investigations expand into the extensive Oologah Lake watershed.

Major tributary sites sampled as a part of this study included the Verdigris River and Big Creek, a tributary to the Verdigris River above Oologah Lake. While limited historical water quality data exist for these systems, increased sampling frequency and installation of continuous monitoring equipment have more clearly defined conditions in these tributaries, at least for the short period of record encompassed by this study.

Concentrations of chemical constituents were similar in samples collected from the two major tributary sites, although a significant number of higher mean and median levels were noted at LEPO2 (Verdigris River). Mean and median chloride and sulfate concentrations were at least two times greater at LEPO2. Mean total iron and manganese concentrations were also nearly two times greater at LEPO2. Mean nutrient (nitrogen and phosphorus) parameters were consistently higher at LEPO2. Mean levels of all solids were higher at LEPO2 with the exception of volatile suspended solids. Mean and median turbidity was also approximately two times higher at LEPO2. Further analysis and subsequent comparison of land uses in the watersheds above each gaging site will likely provide some explanations for observed differences.

Precipitation measured at gaging sites LEPO2 and CHBO2 (Big Creek) was abundant through mid-July and near absent after that. For the period from April through September 2000, median discharges at LEPO2 and CHBO2 were 580 and 17 cfs, respectively. Discharges ranged from 13 to 31,729 cfs at LEPO2, and 0 to 16,951 cfs at CHBO2. Discharge was not computed for the full period, and there were occurrences of no flow at CHBO2.

Continuously recorded turbidity ranges were similar for the two tributary sites, 5.2 to 1,140.9 NTU at LEPO2 and 0.1 to 1,147.7 NTU at CHBO2, although median turbidity was higher at LEPO2 (44.9 NTU) than that at CHBO2 (13.1 NTU). As expected, the highest

recorded turbidities at each station, during each runoff event, corresponded with the rising limbs of discharge hydrographs. Continuously recorded turbidity exceeded the State of Oklahoma water quality standard for turbidity for warm water streams (50 NTU) in 44% of the observations at LEPO2 and 16% at CHBO2.

Regression equations were developed using continuously monitored physical properties as surrogates to predict chemical water quality parameters. Alkalinity, hardness, TDS, TOC, and TP concentrations, estimated based on the regression equations developed in this report, had median relative percentage differences (RPDs) of less than 25% at both stations. Other parameters having RPDs of less than 25% included chloride and TKN at LEPO2 and sulfate at CHBO2. Estimated concentrations of TSS and NO_x had RPDs greater than 25% at both stations, and other parameters with RPDs greater than 25% included sulfate at LEPO2 and chloride and TKN at CHBO2. Of the ten regression equations developed for each station, eight at LEPO2 and five at CHBO2 explained greater than 80% of the constituent variability. The two most common continuously monitored surrogate parameters were turbidity (17 of 20 equations) and specific conductance (11 of 20 equations). It is assumed that a greater number of manual samples collected at each site, as the study progresses, could improve the predictive regression equations.

Prediction of nutrient and sediment loads, based on the same regression equations, resulted in RPDs of less than 25% for TP and TDS at both tributary sites. Additionally, TN at LEPO2 and TSS at CHBO2 had RPDs less than 25%. Estimated TSS load at LEPO2 and TN load at CHBO2 had RPDs greater than 25%. Estimates of median combined (LEPO2 plus CHBO2) daily loads of TN, TP, TDS, and TSS through the sampling period were 760, 470, 291,890, and 66,480 kg/d, respectively. Contributions of LEPO2 estimated loads to each of these combined loads were greater than 97%. The limited contribution of estimated loading from the Big Creek watershed should be evaluated in light of the fact that it accounts for less than 5% of the total watershed area above Oologah Lake. Calculating and comparing estimated loading per unit area reveals that Big Creek watershed contributions for constituents listed above are about 50% of those from the Verdigris River watershed.

Even for those constituents with large relative percentage differences between estimated concentrations and loads, the estimation of concentrations and loads with regression analysis and continuous water quality monitoring has advantages over periodic manual sampling alone. Seasonal trends can be identified more readily, and likely increased accuracy of nutrient and sediment load estimation can be made. Accordingly, refinement of this method will continue as the study progresses.

Data collection activities at Oologah Lake during 2000 generally confirmed, but helped to further quantify, several areas of assumed limnological conditions in Oologah Lake. While it is apparent that Oologah Lake is a system highly impacted by suspended solids, these conditions and their influence on nutrients, light regimes, and algal productivity are now somewhat more clearly defined, at least for conditions experienced during the period of study. In addition, the limited and transitory nature of thermal stratification and hypolimnetic oxygen depletion were confirmed by this study, although brief periods of both were observed at near-dam stations during periods of intense heating, calm winds, and restricted outflow.

The degree of internal loading and associated significance to nutrient dynamics in Oologah Lake appears less important than it may be in other reservoirs. The relatively short hydraulic retention time of the reservoir (average of approximately 110 days) and the absence of a prolonged period of hypolimnetic anoxia minimize the importance of internal nutrient cycling. In addition, the relatively strong correlation ($r > 0.5$, $p \leq 0.05$) of total Kjeldahl nitrogen, dissolved ortho-phosphorus, dissolved total phosphorus, and total phosphorus with turbidity and total suspended solids (Tables 5.3.2-1 and 5.3.2-2) would indicate that allochthonous nutrient inputs can greatly impact nutrient loading and availability in Oologah Lake. The spatial distribution of total Kjeldahl nitrogen (TKN), total phosphorus (TP), total suspended solids (TSS), and turbidity were similar with the greatest concentrations occurring at Site 5 and decreasing sequentially at each site down-reservoir (Figures 5.3.1-6, 5.3.1-13, 5.3.2-1, and 5.3.2-3). At Site 1, concentrations of TP and TKN at depth were generally greater than surface concentrations (independent of hypolimnetic anoxia (Figures 5.3.1-8, 5.3.1-17)). The most pronounced increases in turbidity with depth were observed at Sites 1 and 2 (Figures 6-1 and

6-2) and concentrations of TSS at depth at Site 1 approximately equaled or exceeded surface concentrations on all sampling dates (Figure 5.3.2-4).

The light regime may be of particular importance to phytoplankton productivity in a highly turbid reservoir such as Oologah Lake. Light penetration in Oologah shows a distinct spatial trend with water clarity being highest near the dam and diminishing moving up lake. Of the total light energy reaching the water, a portion is scattered and the remainder absorbed by the water, dissolved compounds, and suspended matter. The sum total of this reduction of radiant energy is light attenuation. The attenuation coefficient is an expression of the exponential attenuation of irradiance at depth compared to that at the surface (Wetzel, 1983). Calculated light attenuation coefficients (h'') ranged from 1.29 m^{-1} (Site 1, 6 September 2000) to 11.01 m^{-1} (Site 5, 19 September 2000), with an overall lake mean of 3.47 m^{-1} . The mean h'' for the lake implies > 95% light attenuation per meter for the lake as a whole. Mean h'' s at each sampling site ranged from 1.90 m^{-1} at Site 1 to 6.07 m^{-1} at Site 5. A trend indicating increasing light attenuation moving from the dam site (Site1) to the upper portion of the lake (Site 5) was apparent.

The euphotic zone extends from the lake surface to the depth where light dims to about 1% of that at the surface. This zone is the region of net oxygen production during the day by plants (Horne and Goldman 1994). Available light levels below the euphotic zone are too low for photosynthesis to occur. Euphotic depth ranged from 0.46 m (Site 5, 09/19/2000) to 3.56 m (Site 1, 6 September 2000) with an overall lake mean of 1.71 m. Mean euphotic depths at each station ranged from 0.90 m at Site 5 to 2.52 m at Site 1. A trend of decreasing euphotic depth was evident moving from the dam site to the upper portion of the lake.

Secchi disk transparency is a function of the reflection of light from its surface, and thus influenced by the absorption characteristics of the water and its dissolved and suspended particulate matter. Secchi depth (SD) roughly corresponds to the depth of about 10% of surface light (Wetzel 1983). SDs ranged from 0.10 (Site 5, 19 September 2000) to 0.90 m (Site 1, 19 July 2000) with an overall lake mean of 0.37 m. Mean SD at each station ranged from 0.20 m at Site 5 to 0.61 m at Site 1. Again, an evident trend indicated decreasing SDs moving from the

dam site to the upper portion of the lake. Empirical data suggests a relationship between the light attenuation coefficient and SD of $h'' = 1.7/SD$ (Wetzel 1983). This relationship is approximately correct for Oologah Lake.

Oologah Lake exhibits significant non-algal turbidity. A linear regression (Figure 6-3) reveals that attenuation coefficient can explain 93% of the variation in turbidity, whereas the relationship between attenuation coefficient and chlorophyll *a* is much weaker ($r^2 = 0.12$). Similarly, a nonlinear relationship between SD and turbidity suggests 82% of the variation in turbidity can be explained by SD, while a linear relationship between chlorophyll *a* and SD explains only 2% of the variation in chlorophyll *a* (Figure 6-4). The level of nonalgal turbidity in the lake suggests that SD would not be an effective indicator of chlorophyll *a* or trophic state.

Based on findings described above, it is apparent that phytoplankton of Oologah Lake are exposed to a very limited surface layer of light intensity suitable for photosynthesis. In addition, a short average hydraulic residence time (approximately 100 days for the period of this study) results in advective transport of phytoplankton and nutrients through the system. Though currently undefined, these combined factors probably play a role in limiting total algal biomass production in the reservoir. However, the role that nutrient concentrations play in phytoplankton dynamics is also an important consideration. If macronutrients at times limit algal production, an important consideration is which nutrient can generally be considered most limiting.

Nitrogen to phosphorus (N:P) ratios are commonly used in evaluation of nutrient limitation in lakes. An approximate N:P of >10 is generally considered indicative of phosphorus limitation while a ratio of <10 indicates nitrogen limitation (Horne and Goldman 1994). Cooke et al. (1986) propose N:P of >20 as indicative of phosphorus limitation and ratios <13 evidence that nitrogen may be limiting. When considered together, recommended evaluation methods of both sources would conclude that N:P of <10 support the hypothesis of nitrogen limitation.

The overall Oologah Lake-wide average N:P based on total concentrations of each element for this study period was 8.0 (median = 6.8). By site, average N:P was lowest (6.0) in

the upper end of the reservoir (Site 5) and increased with down-lake distance to a high of 10.4 at Oologah Dam (Site 1). When phosphate concentrations are generally detectable in most samples (as is the case for this study), N:P ratios may be more precisely derived using soluble inorganic fractions (i.e., dissolved ortho-phosphorus : nitrate/nitrite + ammonia) (Horne and Goldman 1994). When applied to Oologah data from this study, this analysis results in slightly lower N:P with an overall lake-wide average of 6.7 (median = 5.9). By site, average N:P using dissolved inorganic concentrations ranged from 6.0 at Site 5 to 10.4 at Site 1. When analyzed by month, all lake-wide average N:P ratios were <10 with a range of 2.1 (September 2000) to 9.3 (April 2000). All ratios derived during this study would support a hypothesis of nitrogen limitation both spatially and temporally in Oologah Lake – a condition somewhat unusual for reservoirs of the region.

Algal dynamics during mid to late summer 2000 may provide further evidence of at least seasonal nitrogen limitation of phytoplankton in Oologah Lake. For example, at Site 1 diatoms dominated the phytoplankton assemblage during winter months, with green algae, dinoflagellates, and euglenoids equally dominating the assemblage in early summer. As summer progressed, ammonia concentrations declined considerably to concentrations below the practical level of quantitation and dissolved nitrogen species decreased as well (see Section 5.3.1). Concurrently, blue-green algae (Cyanobacteria) abundance (consisting primarily of *Anacystis* sp. and *Merismopedia* sp.) increased to approximately 25% of the assemblage at this site (Figure 6.0-3). The proliferation of Cyanobacteria is not uncommon during periods of nitrogen limitation because as a whole, this group of phytoplankton are capable of nitrogen fixation (Wetzel 1983).

Definition of trophic status of Oologah Lake was an important objective of this study. Based on chlorophyll data during the study period and several commonly-used indices, Oologah Lake can be classified as borderline mesotrophic/eutrophic with moderate to moderately high levels of productivity. Based on Wetzel's (1983) general characteristics of lake fertility as related to phytoplankton assemblage, Oologah Lake can be classified as eutrophic based upon dominant algae (i.e., diatoms and greens) and water quality characteristics (i.e., alkaline with nutrient enrichment). Oologah Lake might be considered slightly eutrophic when all components

(chemical, physical, biological) are examined in concert. Eutrophic conditions increase with up-lake distance from Oologah Dam.

While detectable levels of diesel range total petroleum hydrocarbons in water and sediment samples from Oologah Lake were measured in some samples collected during this study, concentrations in both media were low and at or near analytical quantitation limits. In general, no clear pattern of lakewater total petroleum hydrocarbon contamination was revealed in sampling at Oologah Lake though TPH in sediments of the main pool were somewhat higher than those collected in near-shore, shallow water locations. There did appear to be a relationship between lakewater TPH and lake surface elevation with detection frequency higher at lower lake levels. Plausible though completely unsubstantiated explanations for this relationship include dilution of TPH constituents at higher lake volumes and/or oil release owing to reduced hydraulic head on in-lake abandoned wells. Resuspension of sediment-bound TPH at lower lake level is a less likely explanation as significant positive relationships between lakewater TPH and solids-related parameters (i.e., suspended solids or turbidity) were not identified in this study. It is important to note that detection of TPH in both water and sediments was not associated with detectable concentration of compound-specific organics (i.e., semi-volatile organics) or elevated metals concentrations that often accompany petroleum contamination.

Total petroleum hydrocarbon data are limited for other Oklahoma or mid-western reservoirs. It was therefore difficult to determine whether low TPH concentrations measured in Oologah Lake during this study were the result of naturally-occurring petroleum compounds in the local environment, a reflection of oilfield activities around the lake, evidence of historical spills, residual from boating and similar activities, or a combination of these factors. Regardless, based on results of this study, it appears that contamination of lakewaters and sediments of Oologah Lake with petroleum-related constituents is not currently a major concern despite location of the lake in an area of intense historical petroleum production. Finally, these data should prove useful in future petroleum-related monitoring efforts for the reservoir.

Sediment sampling conducted during this study provided valuable insight into current limnological status of Oologah Lake. Most notable was a general absence of detectable

concentrations of pesticides and herbicides in lake sediment samples. This was somewhat surprising given the expansive, agriculturally-dominated watershed. While concentrations of some of the 23 metals measured in lake sediments appeared somewhat elevated relative to general “background” concentrations typical for freshwater sediments or local soils, metals concentrations were not at levels posing significant potential threat to ecological receptors. With respect to physical parameters, sediments of the main pool of Oologah Lake are dominated by clay-sized grains and, to a lesser degree, silts. A rather atypical longitudinal distribution of sediment particle sizes most likely reflects the high degree of sediment resuspension and short hydraulic residence time of the reservoir.

An interesting finding of this study was the extremely low concentration and atypical distributional pattern of total organic carbon in sediment samples from Oologah Lake. Sediment TOC concentrations were significantly lower than those reported for other Oklahoma reservoirs. Possible explanations include some combination of the following: low inputs of allochthonous organic matter (e.g., detritus) from the watershed, high inorganic particle sedimentation rates resulting in “dilution” of settled organic carbon, flushing effects owing to a short hydraulic residence time, and low autochthonous production in the lake owing to an extremely shallow photic zone. As a follow up to these findings, further evaluation of organic carbon dynamics in Oologah Lake is warranted.

An ultimate goal of this project is development of site-specific tools for predictive evaluation of watershed and/or in-lake management strategies on water quality in Oologah Lake. Data collection during this initial year of investigations at Oologah Lake and initiation of the reservoir modeling effort have contributed significantly to this effort. Future work in the basin to help achieve this goal will include continued, more focused monitoring of limnological conditions of Oologah Lake and its tributaries, expansion of data collection and modeling efforts to the lake’s expansive watershed, and ultimate evaluation of water quality management strategies. Results of these evaluations will be provided as they become available.

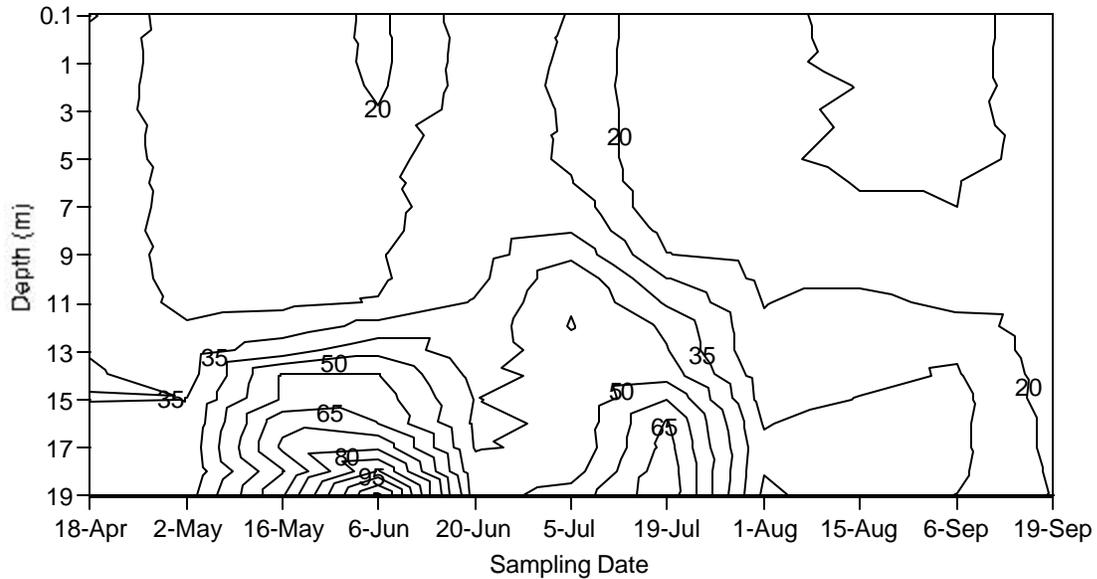


Figure 6-1
Depth-time diagram of turbidity (NTU) isopleths at Site 1, Oologah Lake, Oklahoma,
April – September 2000.

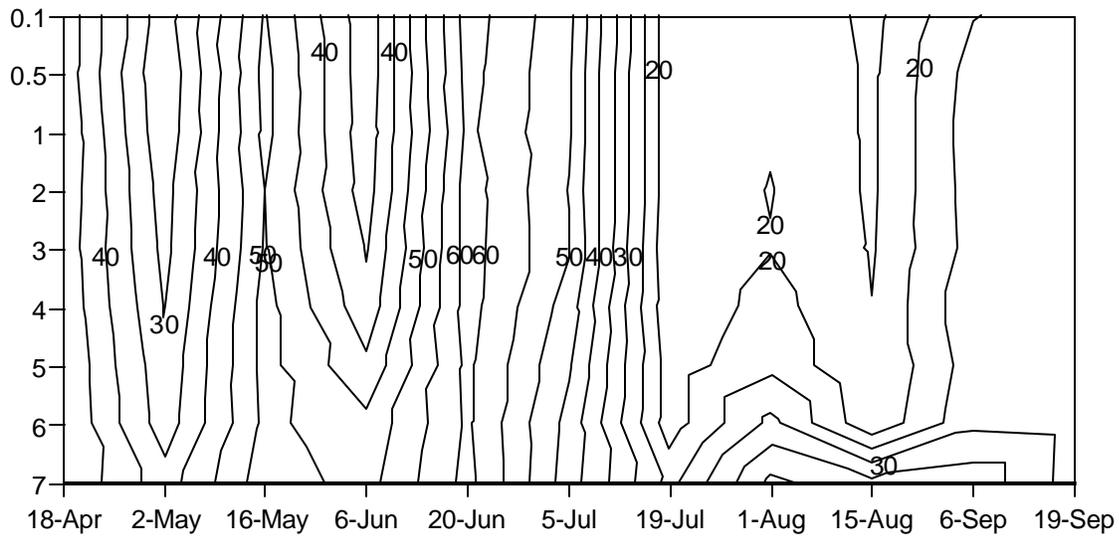


Figure 6-2
Depth-time diagram of turbidity (NTU) isopleths at Site 2, Oologah Lake, Oklahoma,
April – September 2000.

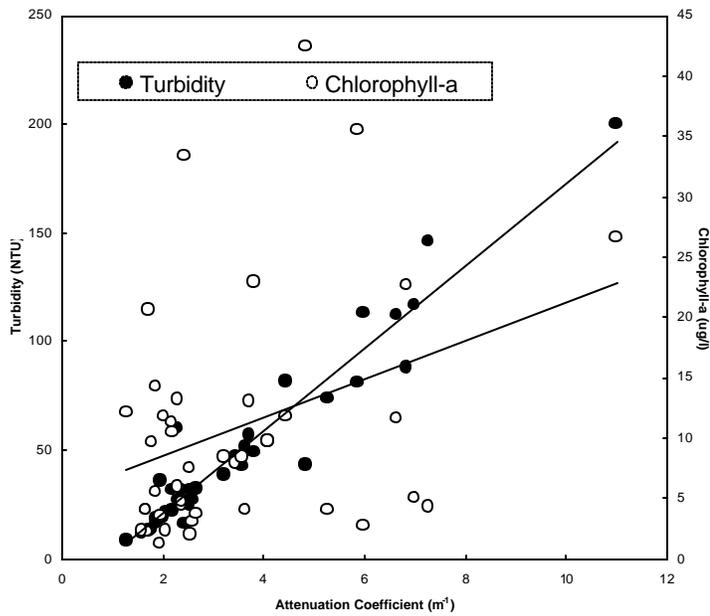


Figure 6-3
Relationships between turbidity and chlorophyll *a* versus attenuation coefficient
($r^2 = 0.93$ and 0.12 , respectively)

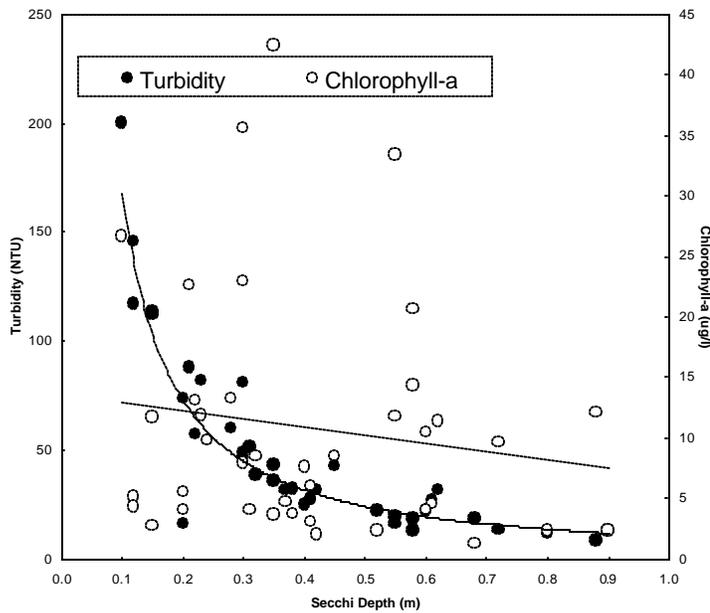


Figure 6-4
Relationships between turbidity and chlorophyll *a* versus Secchi depth
($r^2 = 0.82$ and 0.02 , respectively).

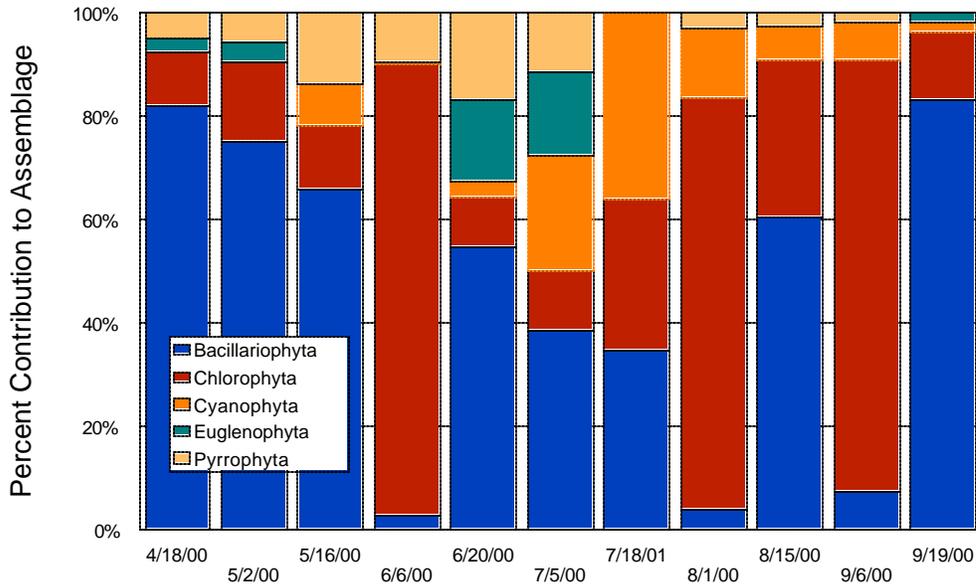


Figure 6.5
Percent composition of the phytoplankton assemblage on each sampling date, Site 1, Oologah Lake, Oklahoma, April – September 2000.

7.0 INTERIM CONCLUSIONS AND RECOMMENDATIONS

Major findings and conclusions of this study (as previously presented in the executive summary of this report) are provided below. Findings are provided separately for tributary data, Oologah Lake general limnology, water quality contaminants, and sediment sampling and analysis.

7.1 Oologah Lake Tributaries (Verdigris River and Big Creek)

1. While concentrations of many water quality constituents were similar in samples collected from both major tributaries, substantial differences were noted for several key parameters. Mean and median turbidity, total suspended solids, settleable solids, total iron, and total manganese concentrations in samples from the Verdigris River were approximately twice those measured in samples from Big Creek. Concentrations of total phosphorus and nitrogen were also substantially higher in the Verdigris River relative to those in Big Creek.

2. Total phosphorus (P) concentrations in both tributaries were high, particularly during periods of high flow. Mean and median total P were 0.32 and 0.20 mg/l, respectively, in samples from the Verdigris River and 0.25 and 0.14 mg/l, respectively, in samples from Big Creek. Based on median values, approximately half of total P concentrations in samples from both systems were associated with suspended matter.

3. Temporal changes in nephelometric turbidity closely mirrored the hydrograph in both tributaries. Based on continuous monitoring data for the study period, mean and median turbidity values were 96.6 and 44.9 NTU, respectively, for the Verdigris River (n = 3,984) and 42.4 and 13.1 NTU, respectively, for Big Creek (n = 3,402). Continuously recorded turbidity exceeded the State of Oklahoma water quality standard for turbidity in warm water streams (50 NTU) in 44% of observations in the Verdigris River and 16% in Big Creek.

4. Tributary-specific multiple regression equations for estimating important physical and chemical parameters based on continuously monitored field data were developed and appeared reasonable for use in preliminary estimation of delivered loads. For the Verdigris River, selected equations were capable of explaining approximately 93, 91, 87, and 73% of observed variability in total suspended solids, total organic carbon, total Kjeldahl nitrogen, and total phosphorus, respectively. Nephelometric turbidity was among selected surrogate parameters in regression equations for all these constituents.

5. For the study period (April through September 2000), multiple regression analyses were used to estimate average combined daily loads (kg/day) from both tributaries as follows: total phosphorus (3,160), total nitrogen (11,600), total suspended solids (1,830,600 kg/day or approximately 2,000 tons/day). Of these loads, relative contributions from the Verdigris River were as follows: total phosphorus (97%), total nitrogen (96%), and total suspended solids (93%).

7.2 Oologah Lake (General Limnology)

1. Turbidity values in Oologah lake frequently exceeded the State of Oklahoma lake water quality standard of 25 nephelometric turbidity units (NTU). For field turbidity values

measured throughout the water column (n = 634), readings ranged from 8.3 to 209 NTU with mean and median values of 51.7 and 41.2 NTU, respectively. Total suspended solids ranged from <4 to 170 mg/l with a mean of 32.5 and median of 17.4 mg/l. Turbidity and suspended solids were highest and extremely variable in shallow water areas above Winganon Bridge. Variability in both parameters was much lower near Oologah Dam, indicating a “buffering effect” at near-dam water supply intake locations.

2. Total phosphorus concentrations were high in samples from Oologah Lake. Concentrations of total P ranged from 0.035 to 0.495 mg/l with mean and median values of 0.118 and 0.083 mg/l, respectively. Both concentration and variability increased from Oologah Dam to uplake stations, particularly in shallow water areas above Winganon Bridge. A strong correlation existed between total P and total suspended solids. On average, 55% of total phosphorus existed in the particulate phase.

3. A measurable concentration of dissolved ortho-phosphorus was reported for every water sample collected from Oologah Lake. Concentrations of dissolved ortho-phosphorus ranged from 0.008 to 0.076 mg/l with an identical mean and median of 0.040 mg/l. No distinct horizontal gradient of ortho-phosphorus was observed in the reservoir.

4. Mean lake-wide nitrogen to phosphorus ratio (N:P) was 8.0 with a median value of 6.8. By site, average N:P was lowest (6.0) in the upper end of the reservoir and increased with down-lake distance to a high of 10.4 near Oologah Dam. Under conditions when nutrient concentrations limit algal growth, all N:P derived during this study support a hypothesis of nitrogen limitation both spatially and temporally in Oologah Lake – a condition somewhat unusual for reservoirs of the region.

5. Lake-wide concentrations of chlorophyll *a*, a commonly used indicator of algal production, ranged from <2 to 46 µg/l with mean and median concentrations of 9.3 and 5.7 µg/l, respectively. Seasonally, concentrations peaked in August and September 2000. Based on chlorophyll data collected during this study and several commonly-used indices, Oologah Lake can be classified as borderline mesotrophic/eutrophic with moderate to moderately high levels of

productivity. Classification toward eutrophic is supported by nutrient and phytoplankton assemblage data. Eutrophic conditions increase with up-lake distance from Oologah Dam.

6. Phytoplankton (suspended algae) during the study period were represented by 49 genera within 13 orders and 5 divisions. Major divisions included green algae (43% of species), blue-greens (24% of species) and diatoms (14% of species). Across all sampling sites and dates, algal densities were dominated by diatoms. Near the location of water supply intakes at Oologah Dam, algal densities were generally dominated by green algae and diatoms, with seasonal increases of blue-greens observed. Dominant blue-greens included the genera *Anacystis* (a colonial form) and *Merismopedia*, both of which can be associated with taste and odor problems.

7. Secchi depths (SD) ranged from 0.10 to 0.90 m with an overall lake average of 0.36 m. Mean SD was highest near Oologah dam (0.61 m) and lowest at the upper end of the lake (0.21 m).

8. Estimates of euphotic zone depths (Z_{eu}) revealed the presence of a very limited layer of light intensity suitable for algal production in surface waters of Oologah Lake. Calculated values for Z_{eu} ranged from 0.46 to 3.56 m with an overall average of 1.69 m (5.5 feet) for the lake through the sampling period. Site-specific averages were highest near Oologah Dam (2.52 m) and lowest near the upper end of the lake (0.90 m). Light attenuation was closely correlated with turbidity and suspended solids but not with chlorophyll *a*.

9. During the study period, Oologah Lake exhibited neither a strong or prolonged period of thermal stratification and/or hypolimnetic anoxia. When sporadic occurrences of these conditions did exist, they were confined to lower reaches of the lake during periods of intense heating and calm weather. Extreme wind mixing and a short hydraulic residence time most likely limit these conditions in Oologah Lake.

10. For the study period (April – September 2000), average hydraulic residence time was approximately 100 days. This was similar to the long-term average of 110 days, indicating fairly typical hydrologic conditions during the study.

11. Oologah Lake waters can be described as slightly alkaline (median pH = 8.0), well-buffered (median alkalinity = 114 mg/l as CaCO₃), and moderately hard to hard (median total hardness = 157 mg/l as CaCO₃).

12. During the study period, reservoir water quality modeling exercises were initiated. Activities included development of the CE-QUAL-W2 computational grid and initial water balance simulations. Initial stages of thermal calibration were likewise initiated. This effort is expected to continue in project out-years.

13. Field data for preparation of a new bottom contour map of Oologah Lake have been collected. At the time of preparation of this report, data processing were nearly complete. Upon completion of this task, evaluation of sedimentation patterns and other morphometric analyses will be conducted and presented in a separate report.

7.3 Oologah Lake (Water Quality Contaminants)

1. On all sampling dates, surface water samples from Oologah Lake were collected and analyzed for diesel range total petroleum hydrocarbons (TPH). While detectable concentrations of TPH were reported in 31% of primary field samples, concentrations were all low and at or near low-level analytical quantitation limits. The range of detected concentrations was 101 to 196 µg/l (parts per billion). There did appear to be somewhat of an inverse relationship between lake-wide average TPH concentration and lake surface elevation. Owing to limited TPH data for other Oklahoma reservoirs, it was difficult to determine whether low TPH concentrations measured in Oologah lake waters were atypical for lakes of the region. Regardless, based on results of this study, it appears that contamination of Oologah Lake waters with petroleum constituents is not currently a major concern despite location of the lake in an area of intense historical petroleum production. These data should prove useful in future petroleum-related monitoring efforts at Oologah Lake.

2. In general, concentrations of a wide range of metals measured in monthly samples across Oologah Lake during the study period were below State of Oklahoma raw water numerical criteria for water supply reservoirs. The one exception was an anomalous condition measured 19 July 2000 when concentrations of cadmium and chromium exceeded raw water criteria in samples across the lake. Similar conditions were not observed in subsequent sampling events and reasons for these findings were unexplained. With the exception of this date, toxic metals concentrations did not appear to be at concentrations of concern in Oologah Lake waters.

3. Lake-wide average concentrations of total iron (1.60 mg/l) and manganese (0.09 mg/l) exceeded USEPA criteria of 0.3 and 0.05 mg/l, respectively for domestic water supplies. Concentrations were strongly correlated with suspended solids.

4. Concentrations of organochlorine pesticides, organochlorine herbicides, organo-phosphorus pesticides, and semi-volatile organic compounds were below analytical quantitation limits in all water samples collected from Oologah Lake following a period of high inflows. Atrazine, a triazine herbicide, was detected at concentrations ranging from 0.05 to 0.15 µg/l, but concentrations were well below the Federal drinking water standard of 3.0 µg/l.

7.4 Oologah Lake (Sediments)

1. Oologah Lake sediment samples were dominated by clay- and silt-sized grains. Atypical longitudinal patterns of grain size distribution were noted. Main pool solids content in sediments ranged from approximately 44% at the upper end of the impoundment to 22% near the dam.

2. Total organic carbon concentrations measured in Oologah Lake sediments were considerably lower and exhibited atypical distributional patterns relative to several other Oklahoma reservoirs. Potential explanations for these findings were presented.

3. Extractable (diesel range) total petroleum hydrocarbon concentrations were measured in Oologah Lake main pool sediments and those from along the eastern shoreline near the

Winganon Bridge at approximately mid-lake. Detectable concentrations were present in many samples but were low and near analytical quantitation limits. Concentrations in sediments from the main pool ranged from <13.3 to 19.8 mg/Kg (parts per million) dry weight with an identical mean and median of 15.7 mg/Kg. Concentrations in samples from shallow areas near the Winganon Bridge were significantly lower with mean and median concentrations of 9.10 and 5.37 mg/Kg dry weight, respectively. Differences in concentrations between the two areas could not be explained readily by correlation with other sediment parameters. Similar to results for TPH water analyses, results are difficult to interpret. However, it does appear that sediment TPH levels are detectable but low, at least in areas sampled during this study. It is important to note that detection of TPH in sediments was generally not associated with detectable concentration of compound-specific organics (i.e., semi-volatile organics) or elevated metals concentrations that often accompany petroleum contamination (see below).

4. Concentrations of many total metals in Oologah sediments exceeded typical “background” concentrations for freshwater sediments and northeastern Oklahoma surface soils. This is most likely the result of a strong correlation between metals concentrations and clay-sized grains which dominate particle size distribution in Oologah sediments. When evaluated using conservative screening-level criteria, no metals were excessively high or at levels posing significant potential risk to ecological receptors.

5. Concentrations of organochlorine pesticides, chlorinated herbicides, and organo-phosphorus pesticides were below analytical quantitation limits in all sediment samples from main pool sampling sites. With the exception of a single low detection of benzo(g,h,i)perylene (783 ug/Kg dry weight), concentrations of all semi-volatile organic compounds were likewise below quantitation limits in all samples from Oologah Lake.

Recommendations for further study include continued limnological data collection at Oologah Lake. Based on a review of data collected as a result of this study, it is likely that sampling can be focused on a more narrow list of parameters (and possibly sampling sites). Further sampling will provide valuable information on seasonal trends, year-to-year variability, and will add to the data set available for model testing. In addition, it is recommended that

collection of continuously-monitored data be continued at the two tributary sampling sites established for the study. This, combined with continued manual sampling under both base and stormflow conditions, will increase predictive capability of regression equations developed during this study and will help further define loading dynamics for Oologah Lake. Details for these activities will be provided in an addendum to the existing workplan and QAPP for the study (USACE 2000b).

It is also recommended that modeling efforts for the reservoir continue and that watershed modeling be initiated for the project. Lake modeling will include further calibration of the CE-QUAL-W2 water quality model to increase predictive capabilities of this valuable tool. Initiation of watershed modeling would include quantification of land use and model development for evaluation of key constituent loading to the Oologah Lake.

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APPENDIX A

**DATA VALIDATION REPORT –
LAKEWATER TPH SAMPLES**

Chemical Data Quality Assurance Report

Oologah Lake Water TPH Investigation



TPH Analysis of Surface Waters

April – September 2000 Sampling Events



**US Army Corps
of Engineers.**

Prepared by US Army Corps of Engineers
November 2000

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- 1.0 Introduction**
- 2.0 Chain of Custody Synopsis**
- 3.0 Organic Data Evaluation**
- 4.0 Technical Summary**
- 5.0 Conclusion**

1.0 Introduction

Representatives from the U.S. Army Corps of Engineers (USACE), Tulsa District conducted a series of environmental investigations at Oologah Lake between the months of April and September 2000. The purpose of these investigations was to collect sufficient chemical and physical data necessary to evaluate the site for the presence of petroleum products.

This phase of the investigation required the collection and analysis of several surface water samples between April and September of 2000. Surface water samples were analyzed for extractable petroleum hydrocarbons only. In general, five surface water locations were selected and sampled. One rinsate blank, one quality control duplicate, and one quality assurance duplicate sample were typically collected on each sampling date.

2.0 Chain of Custody Synopsis

See Appendix A regarding the multiple sampling events.

3.0 Organic Data Evaluation

USACE District staff selected both the primary and quality assurance analytical laboratories. The primary analytical laboratory was Environmental Testing and Consulting Inc. (ETC) located in Memphis, TN. The quality assurance laboratory was Test America (TA) located in Nashville, TN.

3.1.1 Analytical Method

SW846 method 8015 (modified) was used to characterize surface water samples for extractable petroleum hydrocarbons, i.e., diesel range organics (DRO). All samples were reported by the laboratory to have been properly containerized and received at or below the recommended shipping temperature. All samples were prepared and analyzed within the proper holding time.

3.1.2 18 April Event

No deviations in the analytical method or sample handling protocol were noted.

3.1.3 02 May Event

No deviations in the analytical method or sample handling protocol were noted.

3.1.4 16 May Event

No deviations in the analytical method or sample handling protocol were noted.

3.1.5 06 June Event

No deviations in the analytical method or sample handling protocol were noted.

3.1.6 20 June Event

No deviations in the analytical method or sample handling protocol were noted.

3.1.7 05 July Event

No deviations in the analytical method or sample handling protocol were noted.

3.1.8 19 July Event

No deviations in the analytical method or sample handling protocol were noted.

3.1.9 01 August Event

No deviations in the analytical method or sample handling protocol were noted.

3.1.10 15 August Event

No deviations in the analytical method or sample handling protocol were noted.

3.1.11 06 September Event

No deviations in the analytical method or sample handling protocol were noted.

3.1.12 19 September Event

No deviations in the analytical method or sample handling protocol were noted.

3.2 Accuracy

In general, matrix spike (MS) and laboratory control spike (LCS) recoveries were reported to have fallen within acceptable quality control limits. Surrogate standard (SS) recoveries were also reported to have fallen within acceptable limits.

ETC typically reported that due to the limited amount of sample available, no MS was extracted. ETC analyzed a LCS instead.

TA typically reported MS recoveries associated with unrelated samples due to the limited amount of sample associated with the single QA duplicate sample.

3.2.1 18 April Event

No discrepancies noted.

3.2.2 02 May Event

No discrepancies noted.

3.2.3 16 May Event

No discrepancies noted.

3.2.4 06 June Event

No discrepancies noted.

3.2.5 20 June Event

No discrepancies noted.

3.2.6 05 July Event

No discrepancies noted.

3.2.7 19 July Event

No discrepancies noted.

3.2.8 01 August Event

Due to a preparation error at the QA laboratory (TA), no MS or additional QC data was generated for the sample batch containing OOL-3-QA. Surrogate recoveries for the sample fell within the acceptable QC limits. No additional discrepancies were noted with either lab.

3.2.9 15 August Event

No discrepancies noted.

3.2.10 06 September Event

No discrepancies noted.

3.2.11 19 September Event

No discrepancies noted.

3.3 Precision

In general, duplicate matrix spike (MSD) and laboratory control spike (LCSD) recoveries were reported to have fallen within acceptable quality control limits. Relative percent differences (RPDs) were reported to have fallen within acceptable limits.

Rinsate blank and method blank data was collected and evaluated. No contamination was noted.

ETC typically reported that due to the limited amount of sample available, no MSD was extracted. ETC analyzed a LCSD instead.

TA typically reported MSD recoveries associated with unrelated samples due to the limited amount of sample associated with the single QA duplicate sample shipped. No LCSD was analyzed.

3.3.1 18 April Event

No discrepancies noted.

3.3.2 02 May Event

No discrepancies noted.

3.3.3 16 May Event

No discrepancies noted.

3.3.4 06 June Event

No discrepancies noted.

3.3.5 20 June Event

No discrepancies noted.

3.3.6 05 July Event

No discrepancies noted.

3.3.7 19 July Event

No discrepancies noted.

3.3.8 01 August Event

Due to a preparation error at the QA laboratory (TA), no MSD or additional QC data was generated for the sample batch containing OOL-3-QA. No additional discrepancies were noted with either lab.

3.3.9 15 August Event

No discrepancies noted.

3.3.10 06 September Event

No discrepancies noted.

3.3.11 19 September Event

No discrepancies noted.

3.4 Representativeness

Field and quality control duplicate (QC) results have been tabulated in Appendix B of this report. In general all the results are comparable. Instrument operation and technique appear consistent.

3.4.1 18 April Event

Sample OOL-2 was collected in duplicate.

3.4.2 02 May Event

Sample OOL-3 was collected in duplicate.

3.4.3 16 May Event

Sample OOL-5 was collected in duplicate.

3.4.4 06 June Event

Sample OOL-2 was collected in duplicate.

3.4.5 20 June Event

Sample OOL-1S was collected in duplicate.

3.4.6 05 July Event

Sample OOL-4 was collected in duplicate.

3.4.7 19 July Event

Sample OOL-5 was collected in duplicate.

3.4.8 01 August Event

Sample OOL-3 was collected in duplicate.

3.4.9 15 August Event

Sample OOL-1S was collected in duplicate. The field sample noted a relatively low TPH response in relation to the QC duplicate.

3.4.10 06 September Event

Sample OOL-4 was collected in duplicate. The field sample noted a relatively low TPH response in relation to the QC duplicate.

3.4.11 19 September Event

No quality control duplicate samples have been collected.

3.5 Comparability

Field and quality assurance duplicate (QA) results have been tabulated in Appendix B of this report. In general the results are comparable. Instrument operation and technique appear consistent.

3.5.1 18 April Event

Sample OOL-2 was collected in duplicate.

3.5.2 02 May Event

Sample OOL-3 was collected in duplicate.

3.5.3 16 May Event

Sample OOL-5 was collected in duplicate.

3.5.4 06 June Event

Sample OOL-2 was collected in duplicate.

3.5.5 20 June Event

Sample OOL-1S was collected in duplicate.

3.5.6 05 July Event

Sample OOL-4 was collected in duplicate.

3.5.7 19 July Event

Sample OOL-5 was collected in duplicate.

3.5.8 01 August Event

Sample OOL-3 was collected in duplicate. The results are comparable. However, limited QC data is available to substantiate the QA data results. QA data should be properly qualified if used.

3.5.9 15 August Event

Sample OOL-1S was collected in duplicate. The field sample noted a relatively low TPH response in relation to the QA duplicate.

3.5.10 06 September Event

Sample OOL-4 was collected in duplicate. The field sample noted a relatively low TPH response in relation to the QA duplicate.

3.5.11 19 September Event

No quality assurance duplicate samples appear to have been collected.

3.6 Completeness

Upon reviewing the project work plan with regards to sample collection and analysis, a completeness of approximately 99% was demonstrated. During the last surface water sampling event (19 September) no quality control and quality assurance duplicate sample or rinsate blank were collected.

3.7 Sensitivity

The analytical method selected to analyze the surface water locations was determined to meet the project data quality objectives.

4.0 Technical Summary

In general, no outstanding or additional problems were noted with sample collection, shipment, and analysis, except for the following exceptions:

4.1 01 August 00 (QA Laboratory)

Due to a preparation error, a limited amount of laboratory quality control data was collected to substantiate the results relating to OOL-3-QA. The results should be properly qualified if used.

4.2 19 September 00 (Sample Collection)

During the last surface water sampling event (19 September), it was noted that no quality control and quality assurance duplicate sample or rinsate blank were collected. No additional details were provided regarding this discrepancy.

5.0 Conclusion

A chemical data quality assurance review and report (CDQAR) have been completed with regards to a series of environmental investigations conducted at Oologah Lake between the months of April and September 2000 by the USACE, Tulsa District. The purpose of these investigations was to collect sufficient chemical and physical data necessary to evaluate the site for the presence of petroleum products.

An evaluation of the analytical data indicates that the sample handling, shipment, and analytical procedures have been adequately completed and that the analytical results should be considered accurate except in those cases where they have been qualified as estimated within this report.

**Christopher Kennedy,
Senior Chemist**

**Michelle Wilson,
Chemist**

Appendix A-1 – Chain of Custody Synopsis

Oologah Lake TPH Investigation
18 April 2000 Event

Chemical and Physical Parameters				
Sample ID	Sampling Date	Matrix	Sample Type	Total Petroleum Hydrocarbon
OOL-1S	4/18/00	Water	Field	1
OOL-1B	4/18/00	Water	Field	1
OOL-2	4/18/00	Water	Field	1
OOL-2-QC	4/18/00	Water	QC	1
OOL-2-QA	4/18/00	Water	QA	2
OOL-3	4/18/00	Water	Field	1
OOL-4	4/18/00	Water	Field	1
OOL-5	4/18/00	Water	Field	1
BLNK-1	4/18/00	Water	Field	1

Key -

- 1 Environmental Testing and Consulting Inc.
- 2 **Test America, Inc. (Formerly Specialized Assays Inc.) (QA Lab)**

Oologah Lake TPH Investigation
02 May 2000 Event

Chemical and Physical Parameters				
Sample ID	Sampling Date	Matrix	Sample Type	Total Petroleum Hydrocarbon
BLNK-1	5/2/00	Water	Rinsate	1
OOL-1S	5/2/00	Water	Field	1
OOL-1B	5/2/00	Water	Field	1
OOL-2	5/2/00	Water	Field	1
OOL-3	5/2/00	Water	Field	1
OOL-3-QC	5/2/00	Water	QC	1
OOL-3-QA	5/2/00	Water	QA	2
OOL-4	5/2/00	Water	Field	1
OOL-5	5/2/00	Water	Field	1

Key -

- 1 Environmental Testing and Consulting Inc.
- 2 **Test America, Inc. (Formerly Specialized Assays Inc.) (QA Lab)**

Oologah Lake TPH Investigation
16 May 2000 Event

Chemical and Physical Parameters				
Sample ID	Sampling Date	Matrix	Sample Type	Total Petroleum Hydrocarbon
OOL-1S	5/16/00	Water	Field	1
OOL-1B	5/16/00	Water	Field	1
OOL-2	5/16/00	Water	Field	1
OOL-3	5/16/00	Water	Field	1
OOL-4	5/16/00	Water	Field	1
OOL-5	5/16/00	Water	Field	1
OOL-5-QC	5/16/00	Water	QC	1
OOL-5-QA	5/16/00	Water	QA	2
VR-1	5/16/00	Water	Field	1
BLNK-1	5/16/00	Water	Rinsate	1

Key -

1 Environmental Testing and Consulting Inc.

2 Test America, Inc. (Formerly Specialized Assays Inc.) (QA Lab)

Oologah Lake TPH Investigation
06 June 2000 Event

Chemical and Physical Parameters				
Sample ID	Sampling Date	Matrix	Sample Type	Total Petroleum Hydrocarbon
OOL-1S	6/20/00	Water	Field	1
OOL-1B	6/20/00	Water	Field	1
OOL-2	6/20/00	Water	Field	1
OOL-2-QC	6/20/00	Water	QC	1
OOL-2-QA	6/20/00	Water	QA	2
OOL-3	6/20/00	Water	Field	1
OOL-4	6/20/00	Water	Field	1
OOL-5	6/20/00	Water	Field	1
BLNK-1	6/20/00	Water	Rinsate	1

Key -

1 Environmental Testing and Consulting Inc.

2 Test America, Inc. (Formerly Specialized Assays Inc.) (QA Lab)

Oologah Lake TPH Investigation
20 June 2000 Event

Chemical and Physical Parameters				
Sample ID	Sampling Date	Matrix	Sample Type	Total Petroleum Hydrocarbon
BLNK-1	6/20/00	Water	Rinsate	1
OOL-1S	6/20/00	Water	Field	1
OOL-1S-QC	6/20/00	Water	QC	1
OOL-1S-QA	6/20/00	Water	QA	2
OOL-1B	6/20/00	Water	Field	1
OOL-2	6/20/00	Water	Field	1
OOL-3	6/20/00	Water	Field	1
OOL-4	6/20/00	Water	Field	1
OOL-5	6/20/00	Water	Field	1

Key -

- 1 Environmental Testing and Consulting Inc.
- 2 Test America, Inc. (Formerly Specialized Assays Inc.) (QA Lab)**

Oologah Lake TPH Investigation
05 July 2000 Event

Chemical and Physical Parameters				
Sample ID	Sampling Date	Matrix	Sample Type	Total Petroleum Hydrocarbon
OOL-1S	7/5/00	Water	Field	1
OOL-1B	7/5/00	Water	Field	1
OOL-2	7/5/00	Water	Field	1
OOL-3	7/5/00	Water	Field	1
OOL-4	7/5/00	Water	Field	1
OOL-4-QC	7/5/00	Water	QC	1
OOL-4-QA	7/5/00	Water	QA	2
OOL-5	7/5/00	Water	Field	1
VR-1	7/5/00	Water	Field	1
BLNK-1	7/5/00	Water	Rinsate	1

Key -

- 1 Environmental Testing and Consulting Inc.
- 2 Test America, Inc. (Formerly Specialized Assays Inc.) (QA Lab)**

Oologah Lake TPH Investigation
19 July 2000 Event

Chemical and Physical Parameters				
Sample ID	Sampling Date	Matrix	Sample Type	Total Petroleum Hydrocarbon
OOL-1S	7/19/00	Water	Field	1
OOL-1B	7/19/00	Water	Field	1
OOL-2	7/19/00	Water	Field	1
OOL-3	7/19/00	Water	Field	1
OOL-4	7/19/00	Water	Field	1
OOL-5	7/19/00	Water	Field	1
OOL-5-QC	7/19/00	Water	QC	1
OOL-5-QA	7/19/00	Water	QA	2
VR-1	7/19/00	Water	Field	1
BLNK-1	7/19/00	Water	Rinsate	1

Key -

1 Environmental Testing and Consulting Inc.

2 Test America, Inc. (Formerly Specialized Assays Inc.) (QA Lab)

Oologah Lake TPH Investigation
01 August 2000 Event

Chemical and Physical Parameters				
Sample ID	Sampling Date	Matrix	Sample Type	Total Petroleum Hydrocarbon
OOL-1S	8/1/00	Water	Field	1
OOL-1B	8/1/00	Water	Field	1
OOL-2	8/1/00	Water	Field	1
OOL-3	8/1/00	Water	Field	1
OOL-3-QC	8/1/00	Water	QC	1
OOL-3-QA	8/1/00	Water	QA	2
OOL-4	8/1/00	Water	Field	1
OOL-5	8/1/00	Water	Field	1
VR-1	8/1/00	Water	Field	1
BLNK-1	8/1/00	Water	Rinsate	1

Key -

1 Environmental Testing and Consulting Inc.

2 Test America, Inc. (Formerly Specialized Assays Inc.) (QA Lab)

Oologah Lake TPH Investigation
15 August 2000 Event

Chemical and Physical Parameters				
Sample ID	Sampling Date	Matrix	Sample Type	Total Petroleum Hydrocarbon
OOL-1S	8/15/00	Water	Field	1
OOL-1S-QC	8/15/00	Water	QC	1
OOL-1S-QA	8/15/00	Water	QA	2
OOL-2	8/15/00	Water	Field	1
OOL-3	8/15/00	Water	Field	1
OOL-4	8/15/00	Water	Field	1
OOL-5	8/15/00	Water	Field	1
BLNK-1	8/15/00	Water	Rinsate	1

Key -

- 1 Environmental Testing and Consulting Inc.
- 2 **Test America, Inc. (Formerly Specialized Assays Inc.) (QA Lab)**

Oologah Lake TPH Investigation
06 September 2000 Event

Chemical and Physical Parameters				
Sample ID	Sampling Date	Matrix	Sample Type	Total Petroleum Hydrocarbon
OOL-1S	9/6/00	Water	Field	1
OOL-1B	9/6/00	Water	Field	1
OOL-2	9/6/00	Water	Field	1
OOL-3	9/6/00	Water	Field	1
OOL-4	9/6/00	Water	Field	1
OOL-4-QC	9/6/00	Water	QC	1
OOL-4-QA	9/6/00	Water	QA	2
OOL-5	9/6/00	Water	Field	1
BLNK-1	9/6/00	Water	Rinsate	1

Key -

- 1 Environmental Testing and Consulting Inc.
- 2 **Test America, Inc. (Formerly Specialized Assays Inc.) (QA Lab)**

Oologah Lake TPH Investigation
19 September 2000 Event

Chemical and Physical Parameters				
Sample ID	Sampling Date	Matrix	Sample Type	Total Petroleum Hydrocarbon
OOL-1S	9/19/00	Water	Field	1
OOL-1B	9/19/00	Water	Field	1
OOL-2	9/19/00	Water	Field	1
OOL-3	9/19/00	Water	Field	1
OOL-4	9/19/00	Water	Field	1
OOL-5	9/19/00	Water	Field	1

Key -

1 Environmental Testing and Consulting Inc.

2 Test America, Inc. (Formerly Specialized Assays Inc.) (QA Lab)

Appendix A-2 – Analytical Comparability Tables

Appendix A-2 - Quality Control and Quality Assurance Duplicate Results

Oologah Lake Sediment Investigation			Field	QC Duplicate	QA Duplicate	
18-Apr-00			Sample ID	OOL-2	OOL-2-QC	OOL-2 -QA
			Lab ID			
			Sampling Date	4/18/00	4/18/00	4/18/00
Analytical Parameter	Analytical Method	Analyte	Units			
Total Petroleum Hydrocarbon	8015Mod	Extractable	ug/L	<100	<100	<90

Appendix A-2 - Quality Control and Quality Assurance Duplicate Results

Oologah Lake Sediment Investigation			Field	QC Duplicate	QA Duplicate	
02-May-00			Sample ID	OOL-3	OOL-3-QC	OOL-3 -QA
			Lab ID			
			Sampling Date	5/2/00	5/2/00	5/2/00
Analytical Parameter	Analytical Method	Analyte	Units			
Total Petroleum Hydrocarbon	8015Mod	Extractable	ug/L	<100	<100	<90

Appendix A-2 - Quality Control and Quality Assurance Duplicate Results

Oologah Lake Sediment Investigation			Field	QC Duplicate	QA Duplicate	
16-May-00			Sample ID	OOL-5	OOL-5-QC	OOL-5 -QA
			Lab ID			
			Sampling Date	5/16/00	5/16/00	5/16/00
Analytical Parameter	Analytical Method	Analyte	Units			
Total Petroleum Hydrocarbon	8015Mod	Extractable	ug/L	<100	<100	<90

Appendix A-2 - Quality Control and Quality Assurance Duplicate Results

Oologah Lake Sediment Investigation			Field	QC Duplicate	QA Duplicate	
06-Jun-00			Sample ID	OOL-2	OOL-2-QC	OOL-2 -QA
			Lab ID			
			Sampling Date	6/20/00	6/20/00	6/20/00
Analytical Parameter	Analytical Method	Analyte	Units			
Total Petroleum Hydrocarbon	8015Mod	Extractable	ug/L	<100	<100	<100

Appendix A-2 - Quality Control and Quality Assurance Duplicate Results

Oologah Lake Sediment Investigation			Field	QC Duplicate	QA Duplicate	
20-Jun-00			Sample ID	OOL-1S	OOL-1S-QC	OOL-1S -QA
			Lab ID			
			Sampling Date	6/20/00	6/20/00	6/20/00
Analytical Parameter	Analytical Method	Analyte	Units			
Total Petroleum Hydrocarbon	8015Mod	Extractable	ug/L	<100	<100	<100

Appendix A-2 - Quality Control and Quality Assurance Duplicate Results

Oologah Lake Sediment Investigation 05-Jul-00				Field	QC Duplicate	QA Duplicate
			Sample ID	OOL-4	OOL-4-QC	OOL-4 -QA
			Lab ID			
			Sampling Date	7/5/00	7/5/00	7/5/00
Analytical Parameter	Analytical Method	Analyte	Units			
Total Petroleum Hydrocarbon	8015Mod	Extractable	ug/L	<100	<100	<90

Appendix A-2 - Quality Control and Quality Assurance Duplicate Results

Oologah Lake Sediment Investigation 19-Jul-00				Field	QC Duplicate	QA Duplicate
			Sample ID	OOL-5	OOL-5-QC	OOL-5 -QA
			Lab ID			
			Sampling Date	7/19/00	7/19/00	7/19/00
Analytical Parameter	Analytical Method	Analyte	Units			
Total Petroleum Hydrocarbon	8015Mod	Extractable	ug/L	<100	<100	<100

Appendix A-2 - Quality Control and Quality Assurance Duplicate Results

Oologah Lake Sediment Investigation 01-Aug-00				Field	QC Duplicate	QA Duplicate
			Sample ID	OOL-3	OOL-3-QC	OOL-3 -QA
			Lab ID			
			Sampling Date	8/1/00	8/1/00	8/1/00
Analytical Parameter	Analytical Method	Analyte	Units			
Total Petroleum Hydrocarbon	8015Mod	Extractable	ug/L	<100	<100	<90

Appendix A-2 - Quality Control and Quality Assurance Duplicate Results

Oologah Lake Sediment Investigation 15-Aug-00				Field	QC Duplicate	QA Duplicate
			Sample ID	OOL-1S	OOL-1S-QC	OOL-1S -QA
			Lab ID			
			Sampling Date	8/15/00	8/15/00	8/15/00
Analytical Parameter	Analytical Method	Analyte	Units			
Total Petroleum Hydrocarbon	8015Mod	Extractable	ug/L	146	<100	<90

Appendix A-2 - Quality Control and Quality Assurance Duplicate Results

Oologah Lake Sediment Investigation 06-Sep-00				Field	QC Duplicate	QA Duplicate
			Sample ID	OOL-4	OOL-4-QC	OOL-4 -QA
			Lab ID			
			Sampling Date	9/6/00	9/6/00	9/6/00
Analytical Parameter	Analytical Method	Analyte	Units			
Total Petroleum Hydrocarbon	8015Mod	Extractable	ug/L	101	<100	<90

Appendix A-2 - Quality Control and Quality Assurance Duplicate Results

Oologah Lake Sediment Investigation 19-Sep-00				Field	QC Duplicate	QA Duplicate			
						Sample ID			
						Lab ID			
						Sampling Date			
Analytical Parameter	Analytical Method	Analyte	Units						
Total Petroleum Hydrocarbon	8015Mod	Extractable	ug/L						

APPENDIX B

**CHEMICAL DATA QUALITY ASSURANCE REPORT –
SEDIMENT STUDY**

Chemical Data Quality Assurance Report

The Investigation of



Oologah Lake Sediment Study August 2000 Sampling Event



**US Army Corps
of Engineers.**

Prepared by US Army Corps of Engineers
January 2001

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Appendix A- Chain of Custody Synopsis Table

Appendix B- Chemical Data Quality Assurance Report

Appendix C- Quality Assurance Program

1.0 Introduction

Representatives from the US Army Corps of Engineers (USACE), Tulsa District conducted a Sediment Investigation at Oologah Lake during the month of August 2000. The purpose of the investigation was to collect sufficient chemical and physical data necessary to evaluate the sediments for the presence of petroleum products.

Sediment samples were collected 21-22 August of 2000. Samples were collected and analyzed for total phosphorous, total nitrogen, total organic carbon, sulfate, sulfide, chloride, total metals, chlorinated pesticides, chlorinated herbicides, organo-phosphorus pesticides, total petroleum hydrocarbon, and semivolatile organics. In addition, samples were analyzed for two physical parameters, i.e., particle size distribution and sediment bulk density. Specific metal analytes characterized for total metals included antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, mercury, molybdenum, nickel, potassium, selenium, silver, sodium, thallium, vanadium, and zinc.

2.0 Chain of Custody Synopsis

The primary analytical laboratory was Environmental Testing and Consulting Inc. (ETC) located in Memphis, TN. The quality assurance laboratory was Test America (TA) located in Nashville, TN.

See Appendix A for Chain of Custody Synopsis Table.

3.0 Total Petroleum Hydrocarbons (TPH) Data Evaluation

SW846 method 8015 (modified) was used to characterize samples for extractable total petroleum hydrocarbons, i.e., diesel range organics (DRO). All samples were reported by the laboratory to have been properly containerized and received at or below the recommended shipping temperature. All samples were prepared and analyzed within the proper holding time.

3.1 Accuracy

Matrix (MS), laboratory control spike (LCS), and surrogate standard recoveries were reported to fall within acceptable quality control limits.

3.2 Precision

Duplicate matrix spike (MSD) recoveries were reported to have fallen within acceptable quality control limits for target analytes. Relative percent differences (RPDs) were reported to have fallen within acceptable limits.

Method blank and rinsate blank data was collected and evaluated. No contamination was noted.

3.3 Representativeness

Field and quality control duplicate (QC) results have been tabulated in Appendix B of this report. All the results are comparable. Instrument operation and technique appear consistent.

3.4 Comparability

Field and quality assurance duplicate (QA) results have been tabulated in Appendix B of this report. The value differences for TPH-DRO were outside the acceptable quality control limit of five times the field value. There was no apparent reason for this anomaly. Instrument operation and technique appear consistent.

3.5 Sensitivity

The analytical method selected to analyze the samples was determined to meet the project data quality objectives.

4.0 Semivolatile Organic Compounds Data Evaluation

Method 8270 was used to characterize soil samples for semivolatile organic compounds. All samples were reported by the laboratory to have been properly containerized and received at or below the recommended shipping temperature. All samples were prepared and analyzed within the proper holding time.

4.1 Accuracy

Matrix spike (MS), laboratory control spike (LCS), and surrogate standard recoveries had some analytes recovered outside of acceptable quality control limits. Several surrogate recoveries were outside of QC limits but were not detected in the samples. The analyte 4-nitrophenol had high MS and LCS recoveries but was not detected in the samples. There is no affect on the data.

4.2 Precision

Matrix spike duplicate (MSD) recoveries were reported to have fallen within acceptable quality control limits with the exception of 4-nitrophenol. The compound was not detected in the samples. There is no affect on the data. Relative percent differences (RPDs) were reported to have fallen outside acceptable limits for 4-nitrophenol. All other RPD values were within acceptable quality control limits.

Method blank and rinsate blank data was collected and evaluated. There was a detection of 2- bis ethylhexyl phthalate (21.7 µg/L) in the method blank. Since there was no detection of the analyte in the sample, there is no affect on the data.

4.3 Representativeness

Field and quality control duplicate (QC) results have been tabulated in Appendix B of this report. The results are comparable. Instrument operation and technique appear consistent.

4.4 Comparability

Field and quality assurance duplicate (QA) results have been tabulated in Appendix B of this report. The results are comparable. Instrument operation and technique appear consistent.

4.5 Sensitivity

The analytical method selected to analyze the soil samples was determined to meet the project data quality objectives.

5.0 Inorganic Data Evaluation

Inorganics analysis includes chloride, nitrite, nitrate, phosphorous, sulfide, sulfate, total Kjeldahl nitrogen, total solids, and TOC analytical tests. Methods 300.0, 365.2, 376.2, 351.4, 415.1, and SM2540B respectively were used to characterize samples for the inorganic parameters. All samples were reported by the laboratory to have been properly containerized and received at or below the recommended shipping temperature. All samples were prepared and analyzed within the proper holding time.

No formal evaluation of sediment bulk density analysis was conducted.

5.1 Accuracy

Matrix (MS) and laboratory control spike (LCS) were reported to fall within acceptable quality control limits.

5.2 Precision

Matrix spike duplicate (MSD) recoveries were reported to have fallen within acceptable quality control limits. Relative percent differences (RPDs) were reported to have fallen within acceptable limits.

Method blank and rinsate blank data was collected and evaluated. No contamination was noted.

5.3 Representativeness

Field and quality control duplicate (QC) results have been tabulated in Appendix B of this report. The results are comparable. Instrument operation and technique appear consistent.

5.4 Comparability

Field and quality assurance duplicate (QA) results have been tabulated in Appendix B of this report. In general the results are comparable. The exceptions are for sulfide and total organic carbon. There is no apparent reason for this anomaly. No reason was given or apparent for the differences. Instrument operation and technique appear consistent.

5.5 Sensitivity

The analytical method selected to analyze the surface water locations and the soil samples was determined to meet the project data quality objectives.

6.0 Total Metals Data Evaluation

Methods 6010B and 7471A\7470 were used to characterize samples for total metals. All samples were reported by the laboratory to have been properly containerized and received at or below the recommended shipping temperature. All samples were prepared and analyzed within the proper holding time.

6.1 Accuracy

In general, matrix (MS) and laboratory control spike (LCS) recoveries were reported to fall within acceptable quality control limits. ETC noted that MS recoveries of aluminum, barium, iron, potassium, magnesium, manganese, lead, and antimony were recovered high outside of QC limits. The data has been properly reported and qualified.

6.2 Precision

In general, matrix spike duplicate (MSD) recoveries were reported to have fallen within acceptable quality control limits. ETC noted that MSD recoveries of aluminum, barium, iron, potassium, magnesium, manganese, lead, and antimony were recovered high outside of QC limits. There is no affect on the data.

Relative percent differences (RPDs) were reported to have generally fallen within acceptable limits. TA laboratories failed to mention in the case narrative that one RPD value was outside of QC limits. With this exception, these observations have been properly reported and qualified.

Method blank and rinsate blank data was collected and evaluated. Zinc contamination was noted and properly qualified.

6.3 Representativeness

Field and quality control duplicate (QC) results have been tabulated in Appendix B of this report. The results are comparable. Instrument operation and technique appear consistent.

6.4 Comparability

Field and quality assurance duplicate (QA) results have been tabulated in Appendix B of this report. In general the results are comparable. The exceptions are for beryllium, cobalt, and mercury. There was no apparent reason for the anomaly. Instrument operation and technique appear consistent.

TA and ETC had different metal analytes on their respective list of total metals. The differences are with strontium (analyzed by ETC but not TA) and sodium (analyzed by TA but not ETC).

6.5 Sensitivity

The analytical method selected to analyze samples was determined to meet the project data quality objectives.

7.0 Organochlorine Pesticides Data Evaluation

SW846 method 8081A was used to characterize the samples for pesticides. All samples were reported by the laboratory to have been properly containerized and received at or below the recommended shipping temperature. All samples were prepared and analyzed within the proper holding time.

7.1 Accuracy

In general, matrix (MS) and laboratory control spike (LCS) recoveries were reported to fall within acceptable quality control limits. Surrogate standard recoveries in the field samples consistently recovered decachlorobiphenyl (DBC) outside of QC limits. The data is qualified as estimated, biased low because of low surrogate recoveries in aqueous and soil matrices. ETC qualified these results as matrix interference. These observations have been properly reported and qualified.

7.2 Precision

In general, matrix spike duplicate (MSD) recoveries were reported to have fallen within acceptable quality control limits. Relative percent differences (RPDs) were reported to have fallen within acceptable limits. The data has been properly reported and qualified.

Method blank and rinsate blank data was collected and evaluated. No contamination was noted.

7.3 Representativeness

Field and quality control duplicate (QC) results have been tabulated in Appendix B of this report. The results are comparable. Instrument operation and technique appear consistent.

7.4 Comparability

Field and quality assurance duplicate (QA) results have been tabulated in Appendix B of this report. The results are comparable. Instrument operation and technique appear consistent.

7.5 Sensitivity

The analytical method selected to analyze the samples was determined to meet the project data quality objectives.

8.0 Chlorinated Herbicides Data Evaluation

SW846 method 8151 was used to characterize samples for herbicides. All samples were reported by the laboratory to have been properly containerized and received at or below the recommended shipping temperature. All samples were prepared and analyzed within the proper holding time.

8.1 Accuracy

In general, matrix (MS), laboratory control spike (LCS), and surrogate standard recoveries were reported to fall within acceptable quality control limits. One exception is surrogate standard recoveries of field samples of DCAA. The case narrative addressed the low recoveries of some of its surrogates. This affects samples OOL-2 and OOL-3. The data should be considered estimated, biased low.

8.2 Precision

In general, duplicate matrix spike (MSD) recoveries were reported to have fallen within acceptable quality control limits. There were low recoveries of 2,4-D outside of quality control limits. The data has been properly reported and qualified. Relative percent

differences (RPDs) were reported to have fallen within acceptable limits except of 2,4-D. There is no affect on the data.

Method blank and rinsate blank data was collected and evaluated. No contamination was noted.

8.3 Representativeness

Field and quality control duplicate (QC) results have been tabulated in Appendix B of this report. The results are comparable. Instrument operation and technique appear consistent.

8.4 Comparability

Field and quality assurance duplicate (QA) results have been tabulated in Appendix B of this report. The results are comparable. Instrument operation and technique appear consistent.

8.5 Sensitivity

The analytical method selected to analyze samples was determined to meet the project data quality objectives.

9.0 Organophosphorous Pesticides Data Evaluation

SW846 method 8270C (ETC) and method 8141A (TA) (methods are comparable) was used to characterize samples for organophosphorous pesticides. All samples were reported by the laboratory to have been properly containerized and received at or below the recommended shipping temperature. All samples were prepared and analyzed within the proper holding time.

9.1 Accuracy

In general, matrix (MS), laboratory control spike (LCS), and surrogate standard recoveries were reported to fall within acceptable quality control limits. The LCS recoveries for beta-BHC, delta-BHC, and gamma-BHC were recovered high outside of limits. There is no affect on the data. The data has been properly reported and qualified.

9.2 Precision

In general, laboratory control spike duplicate (LCSD) recoveries were reported to have fallen within acceptable quality control limits. Recoveries for endosulfan I were outside of quality control limits (high). There was no detection of endosulfan I in the samples and there is no affect on the data. Relative percent differences (RPDs) were reported to have fallen within acceptable limits with the exception of endosulfan I. The data has been properly reported and qualified.

Method blank and rinsate blank data was collected and evaluated. No contamination was noted.

9.3 Representativeness

Field and quality control duplicate (QC) results have been tabulated in Appendix A of this report. The results are comparable. Instrument operation and technique appear consistent.

9.4 Comparability

Field and quality assurance duplicate (QA) results have been tabulated in Appendix B of this report. The results are comparable. Instrument operation and technique appear consistent.

9.5 Sensitivity

The analytical method selected to analyze samples was determined to meet the project data quality objectives.

10.0 Completeness

Upon reviewing the project work plan with regards to sample collection and analysis, a completeness of greater than 90% was demonstrated.

11.0 Technical Summary

The following section documents various events relating to sample handling, transportation, laboratory details, and other aspects of the investigation that were not addressed in Sections 3.0-10.0 of this report. In general, no outstanding or additional problems were noted with sample collection, shipment, and analysis, except for the following:

11.1 Organochlorine Pesticide Surrogate Standard Recovery Review

The organochlorine pesticide data is qualified as estimated, biased low because of low surrogate recoveries of decachlorobiphenyl in aqueous and soil matrices affecting samples OOL-1, OOL-2, OOL-3, OOL-4, OOL-5, and OOL-5QC.

11.2 Chlorinated Herbicides Surrogate Standard Recovery Review

Surrogate standard recoveries of field samples of DCAA were low for some of its surrogates. This affects samples OOL-2 and OOL-3. The data should be considered estimated, biased low.

12.0 Conclusion

A chemical data quality assurance report (CDQAR) has been completed with regards to the environmental investigation conducted at Oologah Lake August 2000 by the USACE, Tulsa District. The purpose of this investigation was to collect sufficient chemical and physical data necessary to evaluate the site for the presence of contamination.

An evaluation of the analytical data indicates that the sample handling, shipment, and analytical procedures have been adequately completed and that the analytical results should be considered accurate except in those cases where they have been qualified as estimated within this report.

**Michelle Wilson,
Chemist**

**Christopher Kennedy,
Senior Chemist**

Appendix B-1
Chemical Data Quality Assurance Report

			Field	QC Duplicate	QA Triplicate	Field	QC Duplicate	QA Triplicate	
Oologah Lake Sediment Investigation			Sample ID	OOL-5	OOL-5-QC	OOL-5-QA	OOL-8-QC	OOL-8-QC	OOL-8-QA
			Lab ID	0008644-05	0008644-06	00-A119899	0008644-15	0008644-14	00-A119898
			Sampling Date	8/21/2000	8/21/2000	8/21/2000	8/22/2000	8/22/2000	8/22/00
Analytical Parameter	Analytical Method	Analyte	Units						
Total Metals	6010B	Aluminum	mg/Kg	21,300	19,700	34,575	4730	5190	8982
	6010B	Arsenic		7.89	7.08	3.71	2.21	2.55	2.50
	6010B	Barium		180	187	213	39	40.9	57.1
	6010B	Beryllium		1.11	1.2	< 0.07	0.25	0.272	< 0.07
	6010B	Calcium		6260	6460	4646	824	846	838.3
	6010B	Cadmium		0.593	0.641	2.11	0.104	0.082	< 0.24
	6010B	Cobalt		10.8	11.5	< 0.37	2.36	2.49	< 0.37
	6010B	Chromium		24.8	23.4	41.43	8.23	9.08	14.0
	6010B	Copper		17.7	20	14.25	3.55	3.71	3.74
	6010B	Iron		27,300	28,700	23,015	6180	6700	7011
	7471A	Mercury		0.041	0.164	< 0.019	.010J	.011J	< 0.019
	6010B	Potassium		3320	3170	7073	612	672	1215
	6010B	Magnesium		3200	3160	3853	447	473	756
	6010B	Manganese		834	898	699	132	142	146
	6010B	Nickel		25.4	26.2	22.70	5.03	5.42	6.23
	6010B	Lead		19.4	20.4	15.05	5.45	5.59	6.49
	6010B	Selenium		< 0.5	0.538	< 0.66	0.292J	< 0.50	< 0.660
		Sodium		NT	NT	301	NT	NT	47.66
	6010B	Strontium		54.1	54.4	NT	9.34	9.15	NT
6010B	Vanadium	29	27.7	51.47	9.98	11	17.22		
6010B	Zinc	91.4	96.9	82.61	16	16.8	17.72		
TPH	8015B	DRO	mg/Kg	19.8	18.7	< 3.60	5.6	5.29	< 3.3
Inorganics	300	Nitrate Nitrogen	mg/Kg	< 1.0	1.06	NT	---	---	---
	365.2	Phosphorous		367	372	332	---	---	---
	351.4	Nitrogen-Total Kjeldah		613	691	NT	---	---	---
	9056	Sulfide		< 10.0	< 10.0	53.0	---	---	---
	415.1	Total Organic Carbon		429	392	17,600	333	273	3700
	Calc.	Total Nitrogen		613	692	859	---	---	---
SM2540B	Total Solids	%	43.7	45.3	74	73.1	76.4	80	

Appendix B-2
Quality Assurance Program

1.0 USACE Quality Assurance Program

The USACE assures that chemical data results generated from in-house programs and architect-engineering (AE) contracts are reliable and defensible. This is accomplished by following guidelines set forth in ER 1110-1-263; Chemical Data Quality Management for Hazardous Waste Remedial Activities. Other guidance documents associated with sampling, analysis, and validation, include but are not limited to:

- RCRA Groundwater Monitoring Draft Technical Guidance; EPA/530-R-93-001 (November 1992)
- Monitor Well Design, Installation, and Documentation at HTRW Sites; EM 1110-1-4000 (August 1994)
- Groundwater Handbook; EPA/625/6-90/016a (September 1990)
- Compendium of ERT Groundwater Sampling Procedures, EPA/540/P-91/007 (January 1991)
- Compendium of ERT Soil Sampling and Geophysics Procedures; EPA/540/P-91/006 (January 1991)
- USACE CX Sampling and Analysis Requirements for Measurement of Chemicals in the Environment (June 1993)
- National Functional Guidelines for Organic Data Review; EPA CLP (June 1991)
- National Functional Guidelines for Evaluating Inorganic Analyses; EPA CLP (July 1988)
- Good Laboratory Practice Standards; EPA (October 1989)

The USACE assures that laboratories under contract meet current Federal and State regulatory requirements and are capable of producing reliable and defensible data. The USACE requires that all AE contract laboratories submit to the EPA's Proficiency Evaluation (PE) program to monitor the ability of the lab to perform specified analytical methods. All AE contract laboratories are required to submit to other Federal and State certification programs and maintain this certification whenever applicable. The USACE also requests that all AE contract laboratories submit to a laboratory evaluation conducted by personnel from the USACE Center of Expertise (HTRW-CX) or otherwise seek the approval from the contracting USACE District office several months prior to start of work.

2.0 Data Evaluation

The USACE data evaluation process begins with the receipt of all participating laboratory data submittals and associated chemical data quality review reports or case narratives. A primary laboratory will have been selected to analyze the majority of field and quality control (QC) samples, with another laboratory having been selected to analyze the related quality assurance (QA) samples. These laboratories will have been required to meet a list of laboratory deliverables designed specifically for each project prior to start of work. USACE project chemists then evaluate the data generated by all the laboratories and determine whether the data is reliable, defensible, and complete.

USACE representatives evaluate the data with regards to project specific QA objectives, i.e., Precision, Accuracy, Representativeness, Comparability, Completeness, and Sensitivity; otherwise known as PARCC. They are defined as follows:

- **Accuracy** - Accuracy measures the bias in a measurement system and is difficult to measure for the entire data collection activity. Analytical accuracy is commonly assessed by evaluating known and unknown QC sample and spiked sample recoveries. This includes the evaluation of internal and surrogate standard recoveries. Evaluating travel blank, method blank, and equipment blank results to determine potential concentration contribution from various outside sources, i.e., field or lab activities, is also used to assess accuracy.
- **Precision** – Precision examines the distribution of the reported values about their mean. The distribution of reported values refers to how different the individual reported values are from the average reported value. Evaluating spiked sample recoveries and associated duplicate recoveries is commonly used to assess analytical precision.
- **Representativeness** – Representativeness expresses the degree to which sample data accurately and precisely depicts the characteristics of a population of samples. Representativeness is commonly assessed by evaluating duplicate field and laboratory samples, i.e., field and QC samples.
- **Comparability** – Comparability is a qualitative parameter expressing the confidence with which one data set can be compared with another. Comparability is assessed by evaluating both field and QA samples.
- **Completeness** – Completeness is defined as the percentage of measurements made which are judged to be valid measurements compared to the total number of measurements planned.
- **Sensitivity** – Sensitivity addresses how well selected analytical methods and instruments respond to change in analyte concentration. USACE representatives must select the appropriate analytical methods to meet or exceed specific project data requirements. Some methods may not be applicable for the analysis of certain environmental matrices. Sensitivity is assessed by evaluating the reported method detection limits and evaluating calibration information provided by the laboratory.

Comparability and representativeness are qualitative objectives of the data; while completeness goals, if defined for individual sampling and analytical protocols, are normally combined to assess, and are dictated by the expectations of the project as a whole. Precision and accuracy parameters represent quantitative limits outside of which the data is unacceptable unless qualified.

The project chemists closely scrutinize field, quality control, and quality assurance sample results. Inconsistencies found between these results are investigated. Guidelines previously mentioned are employed to judge the validity of the results. The USACE applies a simplified approach to screening the data for inconsistencies. Differences in field and QC (or QA) results, which are greater than five times the practical quantitation limit (PQL), are noted and reviewed.

Duplicate sample result differences that are greater than a factor of two (for aqueous samples) and a factor of five (for soil/sediment samples) are considered to fall outside typical quality control ranges and are reviewed. Differences, which cannot be adequately interpreted by the project chemist, are noted and evaluated by the technical team. The data will be accepted, rejected, or, if practical; the sample in question may be reanalyzed.

3.0 Laboratory Deliverables

To ensure that the quality of data is adequate for the decision making process, the USACE requires that the following minimum laboratory deliverables be provided for this project:

- Tabulated results of field samples, laboratory blanks, surrogate spikes, surrogate recoveries, matrix spikes, laboratory control samples, laboratory duplicates, matrix spike duplicates, relative percent differences, field duplicates, and field blanks.
- The selected analytical methods must be able to adequately detect the analytes of concern. Action levels must be taken into account by the technical staff.
- Sample identification numbers cross-referenced with laboratory identification numbers and quality control sample numbers. Table(s) which cross-reference field samples with associated method blanks, matrix spikes, and matrix spike duplicate samples.
- Legible copies of the fully executed chain of custody forms and cooler receipt forms on which the laboratory has documented the condition of the samples on arrival.
- Each analyte will be reported as an actual value or less than a specified method quantitation limit. Actual sample results will be reported in a tabular format. Data qualifiers will be used to address sample/analytical anomalies associated with an analyte.
- Dilution factors, sampling dates, extraction dates, and analysis dates will be reported. Soil samples will be reported on a dry weight basis with moisture content

The analytical details, such as, calibration data, mass spectra, chromatograms, method detection limit studies, performance standards, and other lab quality control information, are available upon request.

4.0 Quality Assurance and Quality Control General Guidance

The following paragraphs identify specific analytical sample types, which are collected to monitor the various factors addressed by the USACE in-house quality assurance/quality control program. This information assists the evaluator when addressing the overall project QA objectives, i.e., (PARCC). Some of these sample types are discussed in detail below:

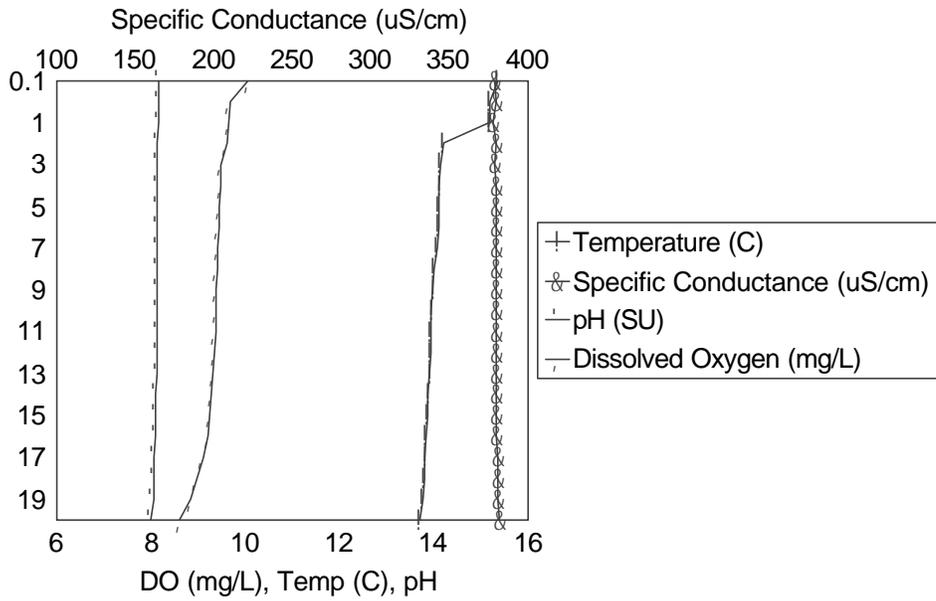
- The USACE recommends that one quality assurance and one quality control sample will be collected for every 10% of the sample population. The QA sample is shipped to a separate

laboratory other than the laboratory performing the field and QC samples. Results from these samples assist in evaluating overall sampling and analysis techniques.

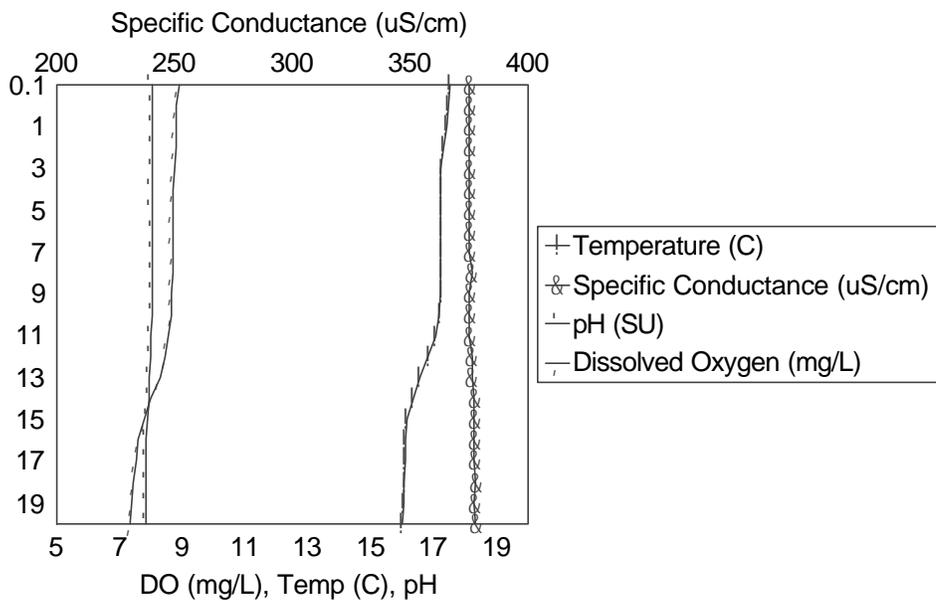
- The USACE recommends that one equipment or rinsate blank be collected and analyzed for every 5% of the sample population; whenever the same sampling equipment is used repeatedly. Results from these samples assist in evaluating decontamination procedures and equipment cross-contamination.
- The USACE recommends that travel blanks and temperature blanks accompany all aqueous sample shipments; specifically with those samples being collected and analyzed for volatile organics. Travel blanks are collected and analyzed to assist with evaluating cross-contamination among each volatile organic sample shipment. Temperature blanks are collected and submitted to evaluate the temperature of the sample cooler upon arrival at the laboratory.

APPENDIX C

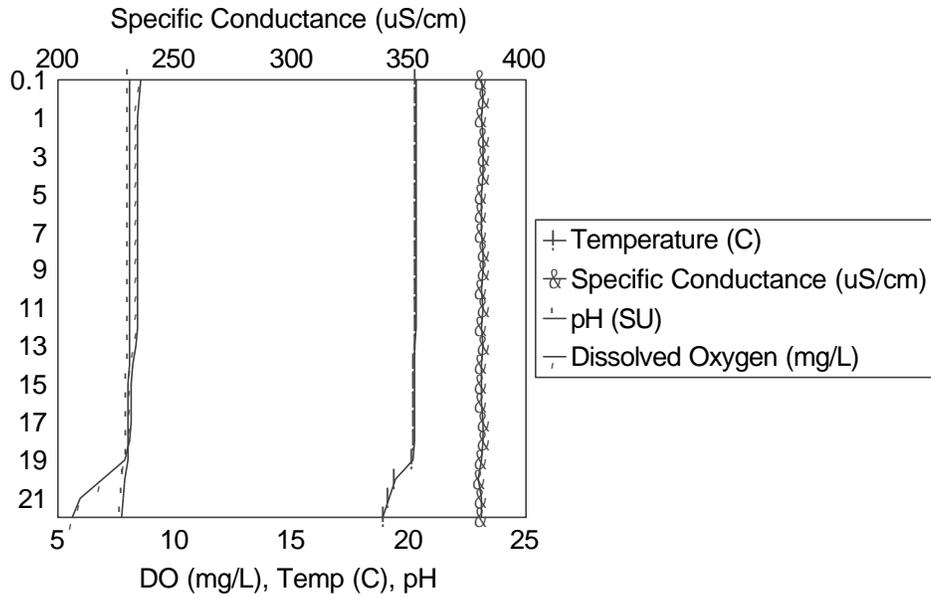
VERTICAL PROFILES OF TEMPERATURE, SPECIFIC CONDUCTANCE, pH, AND DISSOLVED OXYGEN



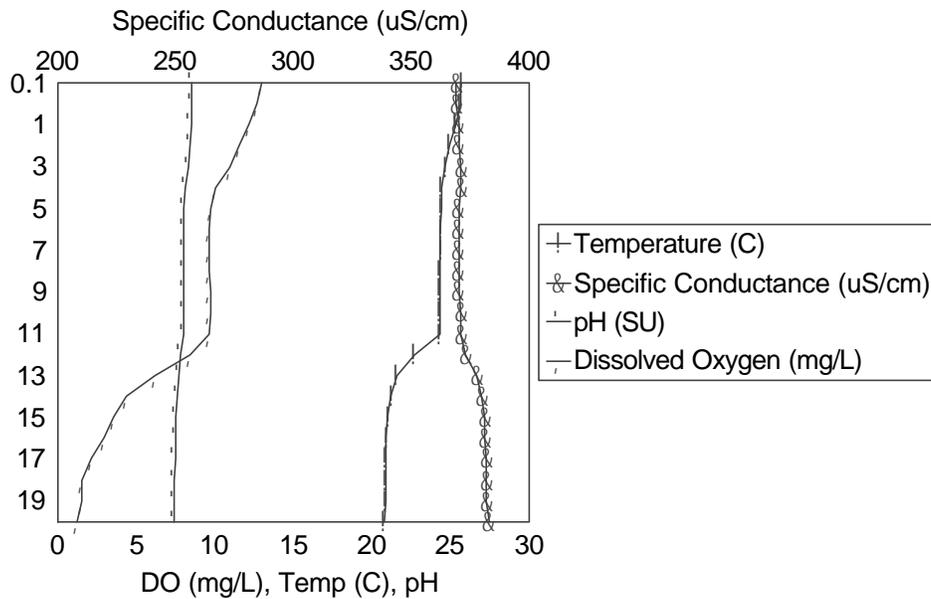
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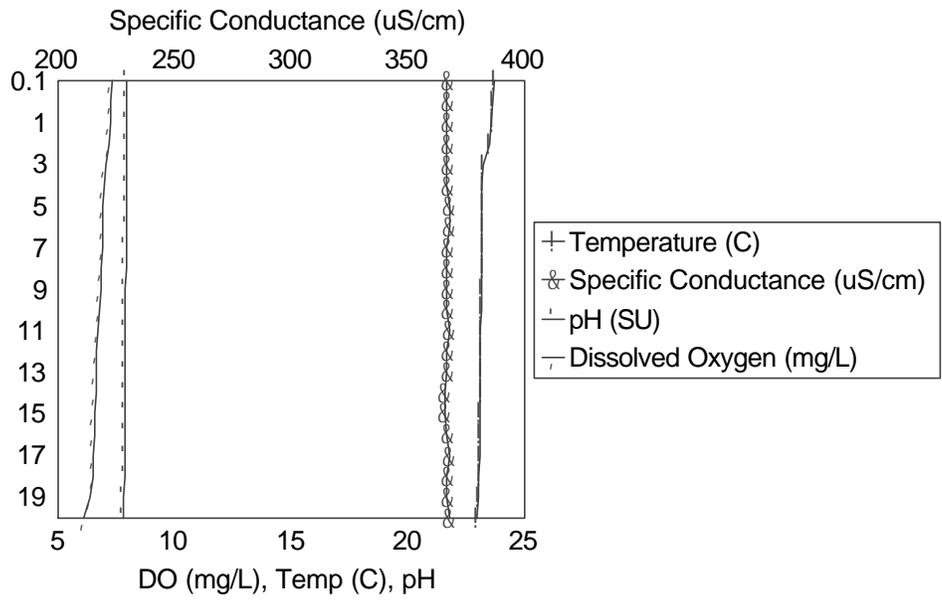
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 1, 2 May 2000.



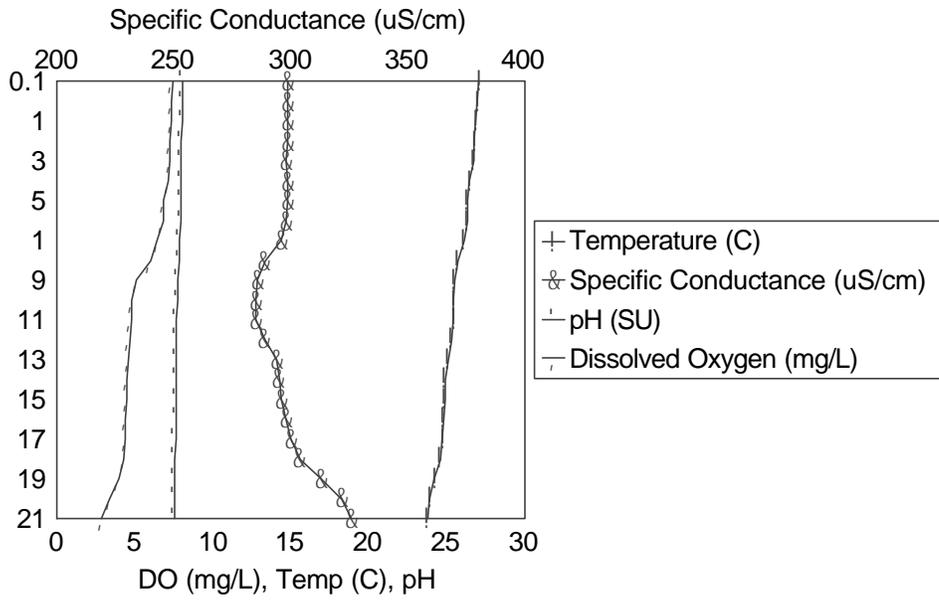
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 1, 16 May 2000.



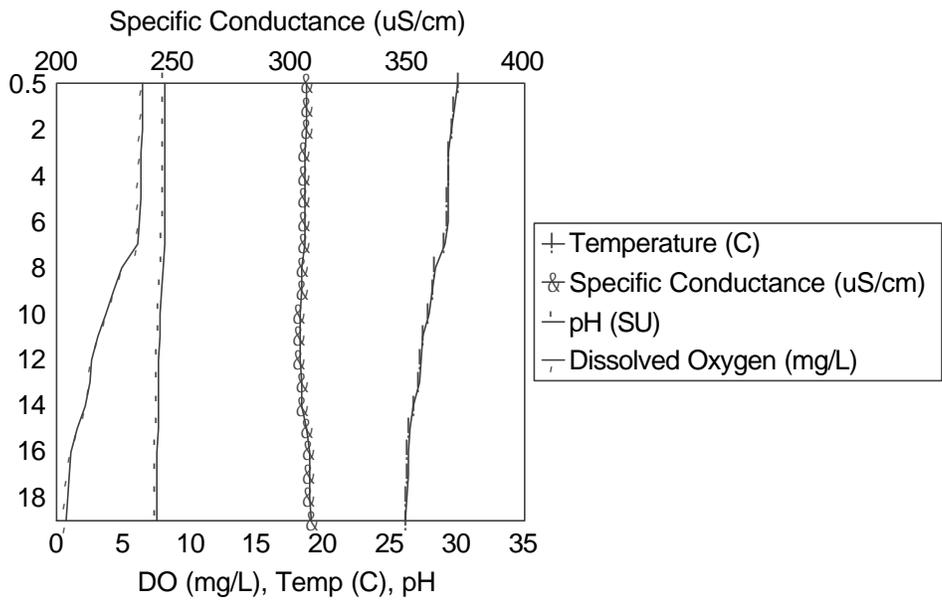
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 1, 6 June 2000.



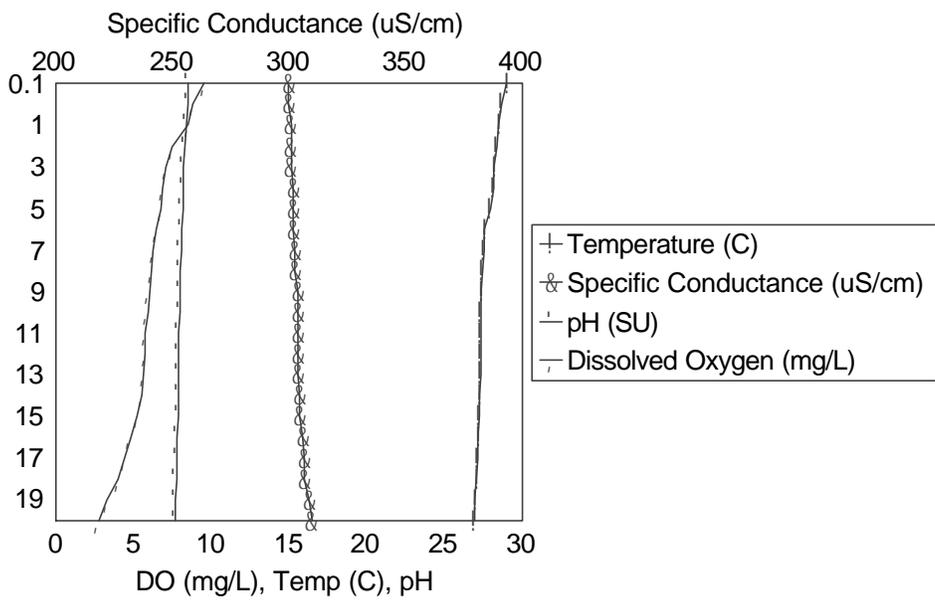
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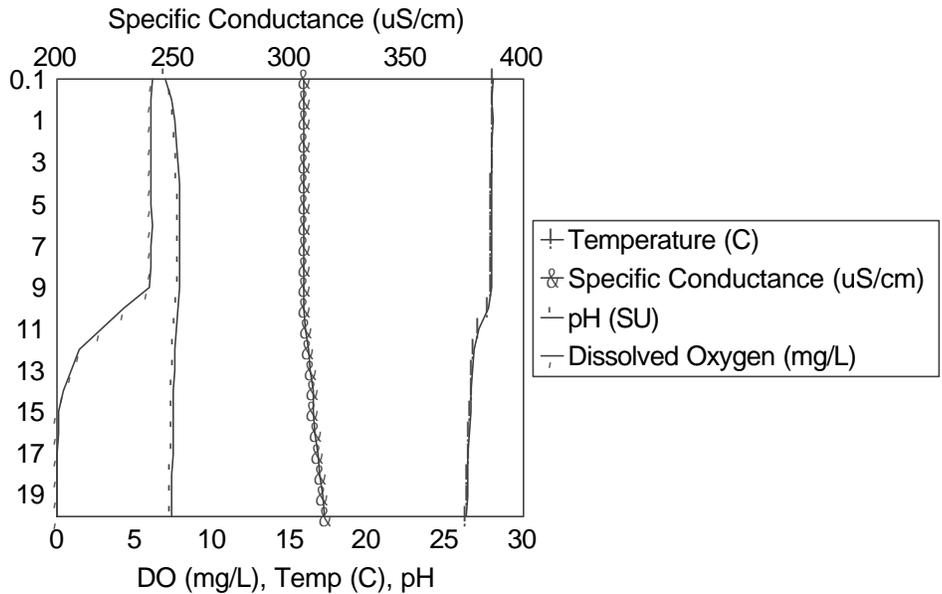
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 1, 5 July 2000.



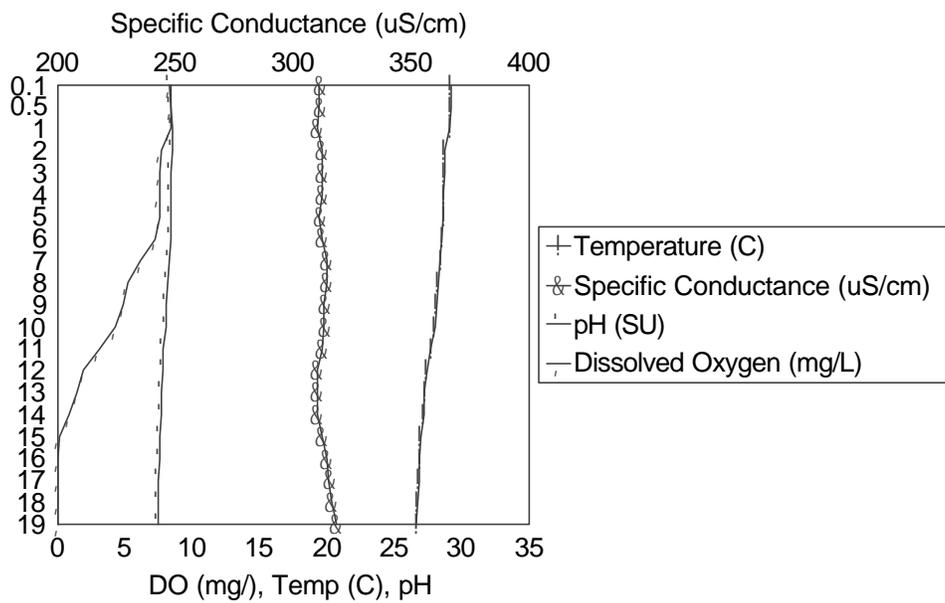
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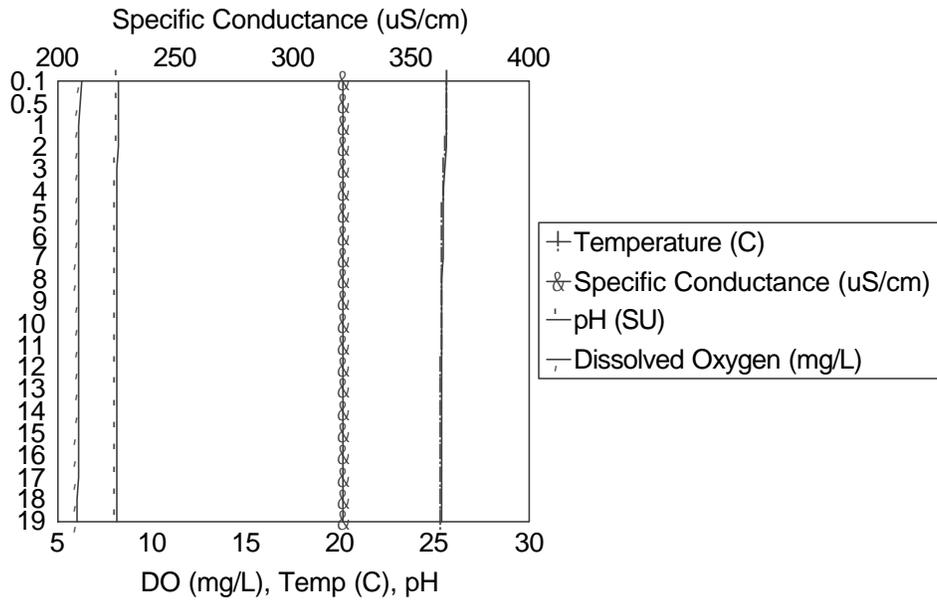
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 1, 1 August 2000.



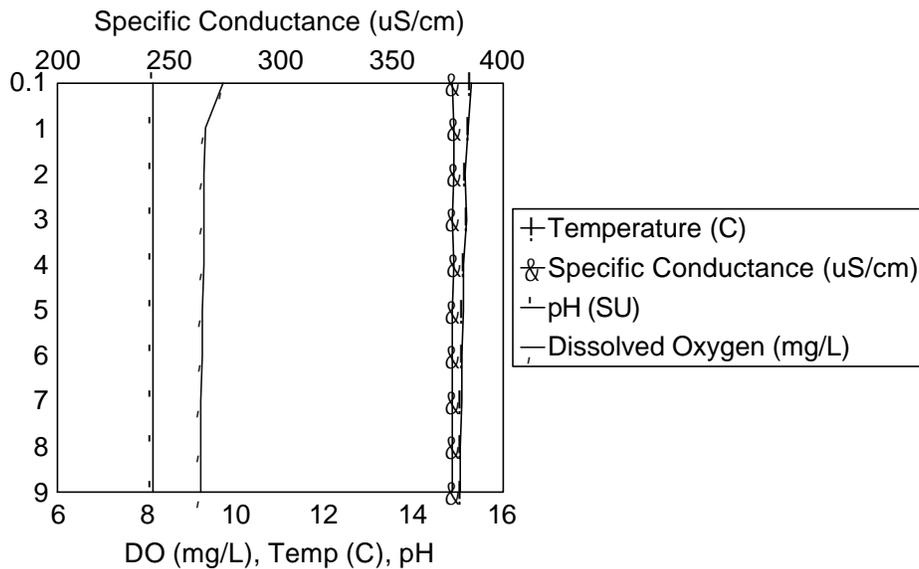
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 1, 15 August 2000.



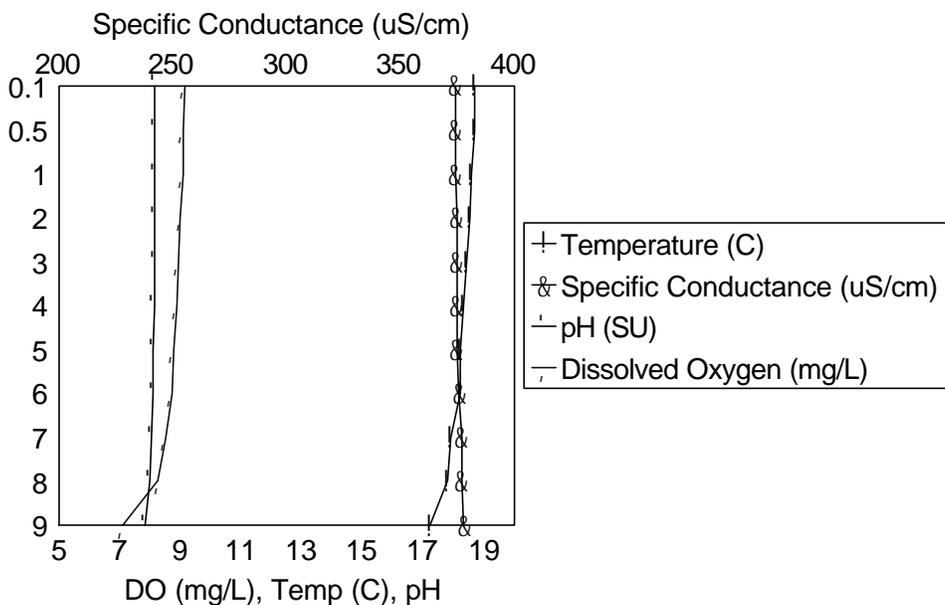
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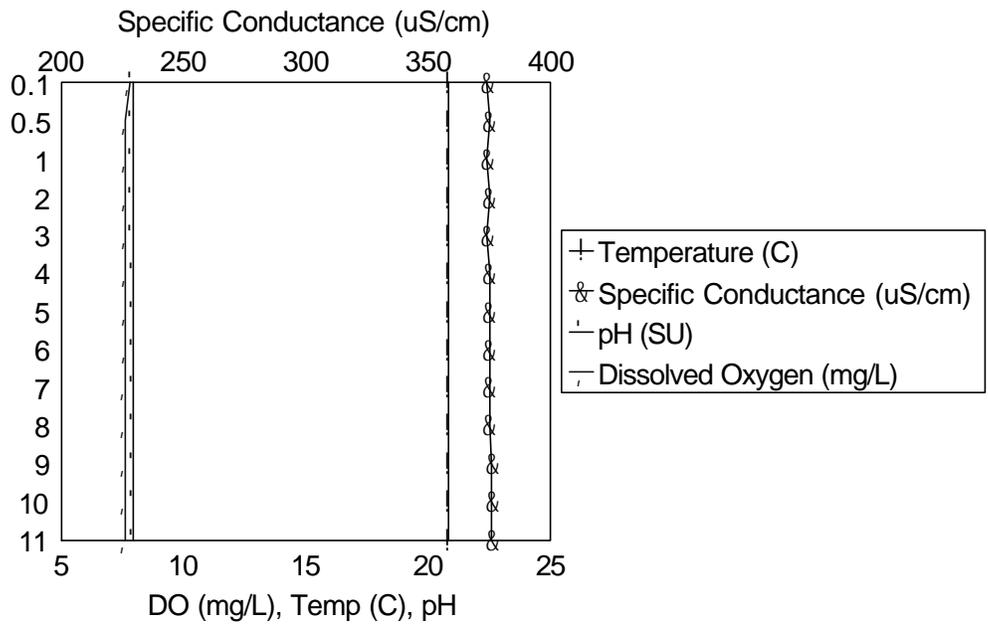
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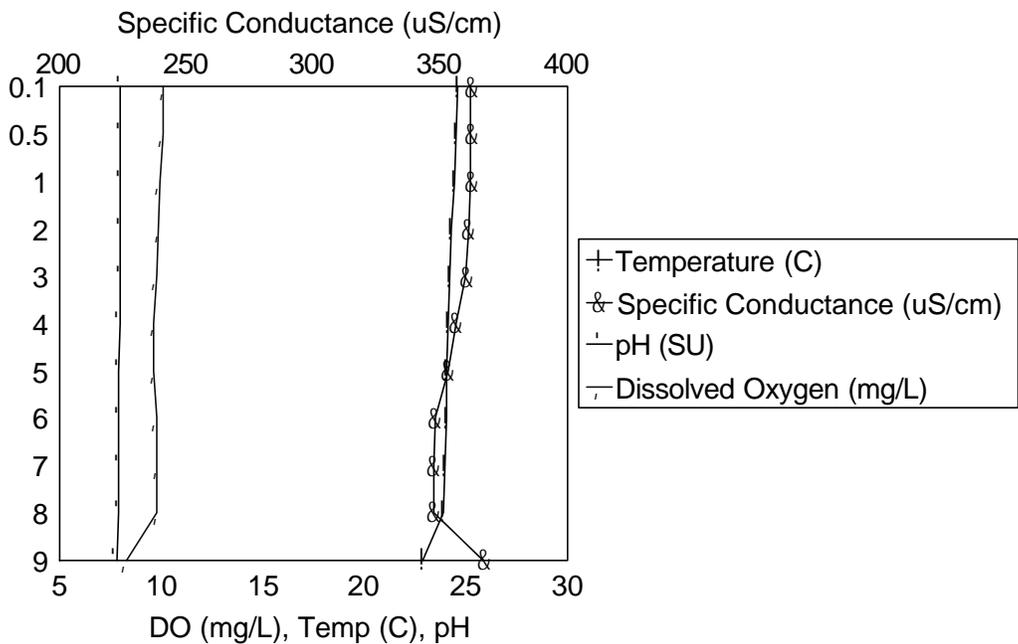
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 2, 18 April 2000.



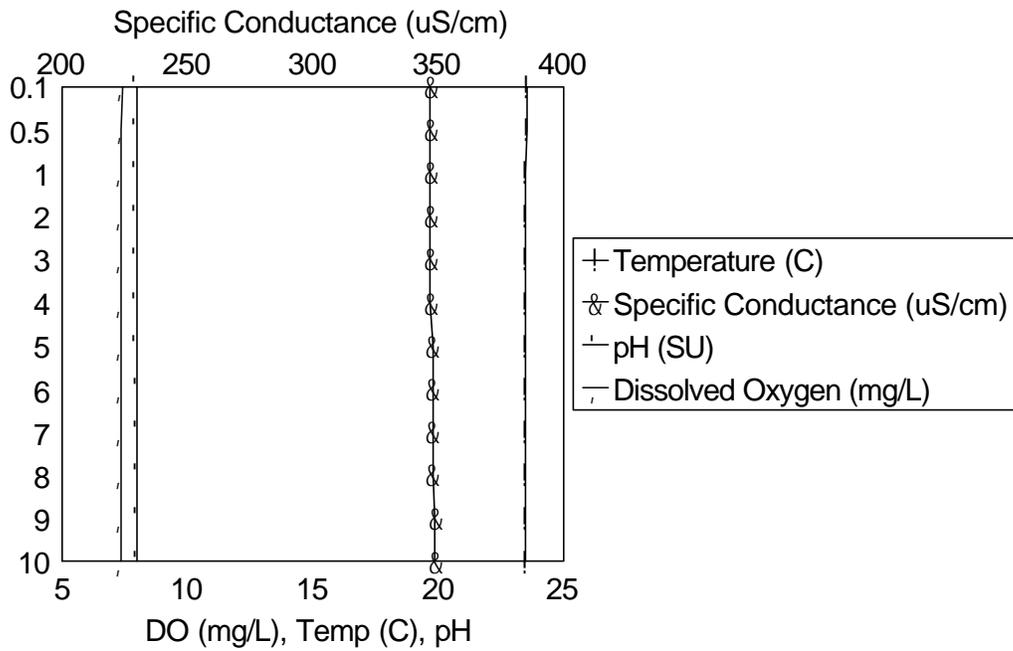
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 2, 5 May 2000.



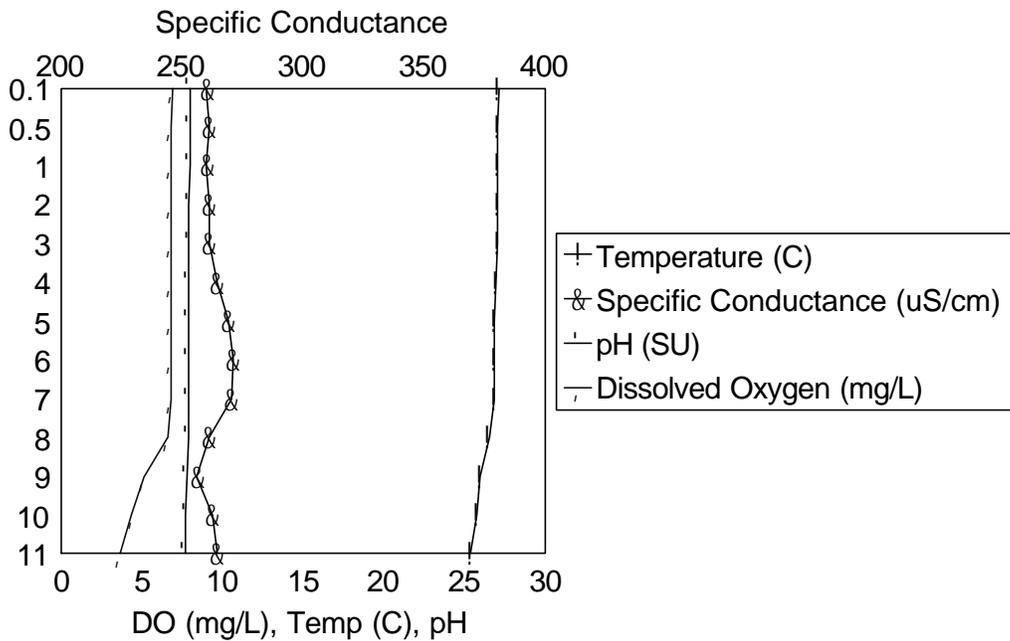
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 2, 16 May 2000.



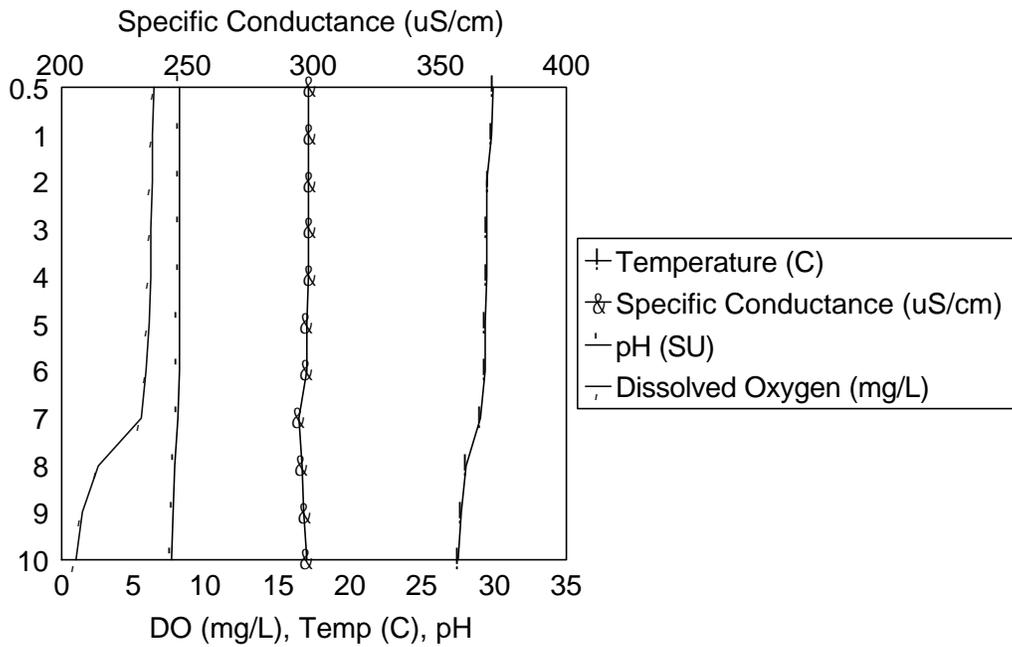
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 2, 6 June 2000.



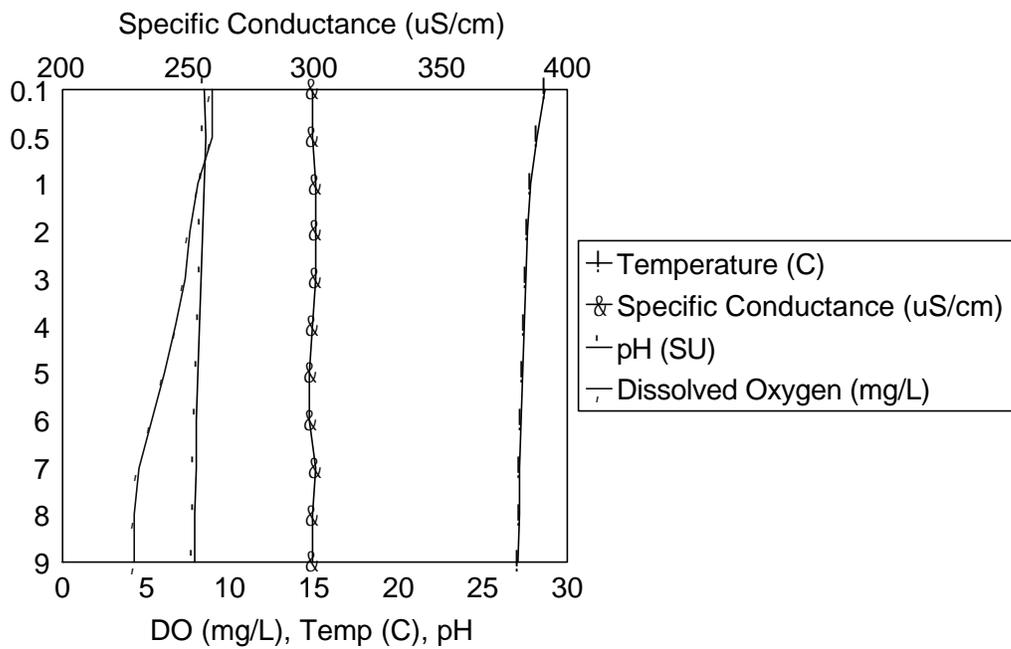
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 2, 20 June 2000.



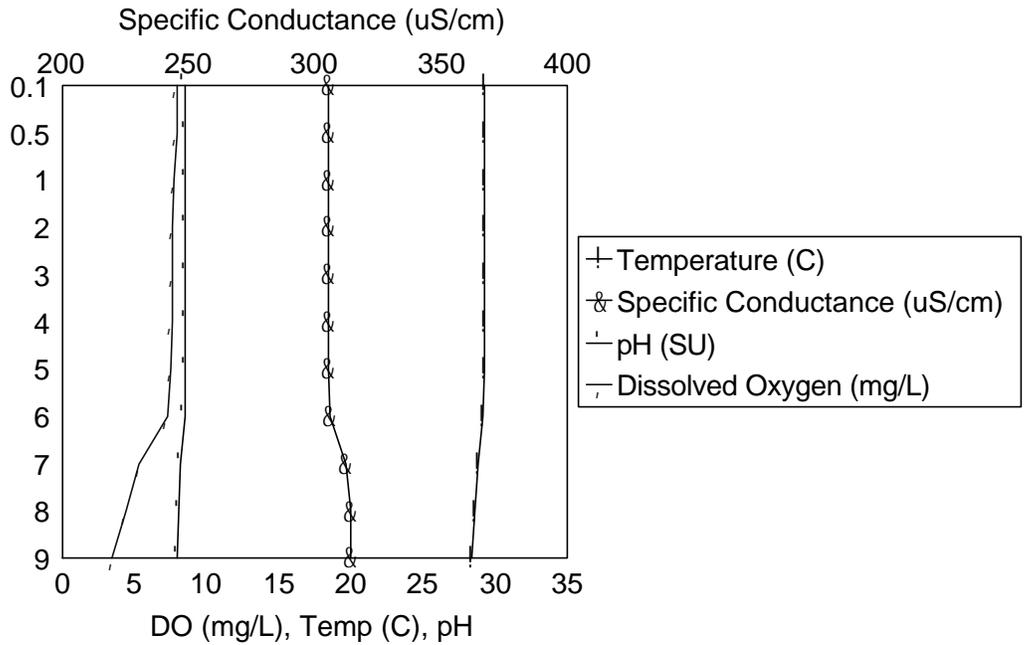
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 2, 5 July 2000.



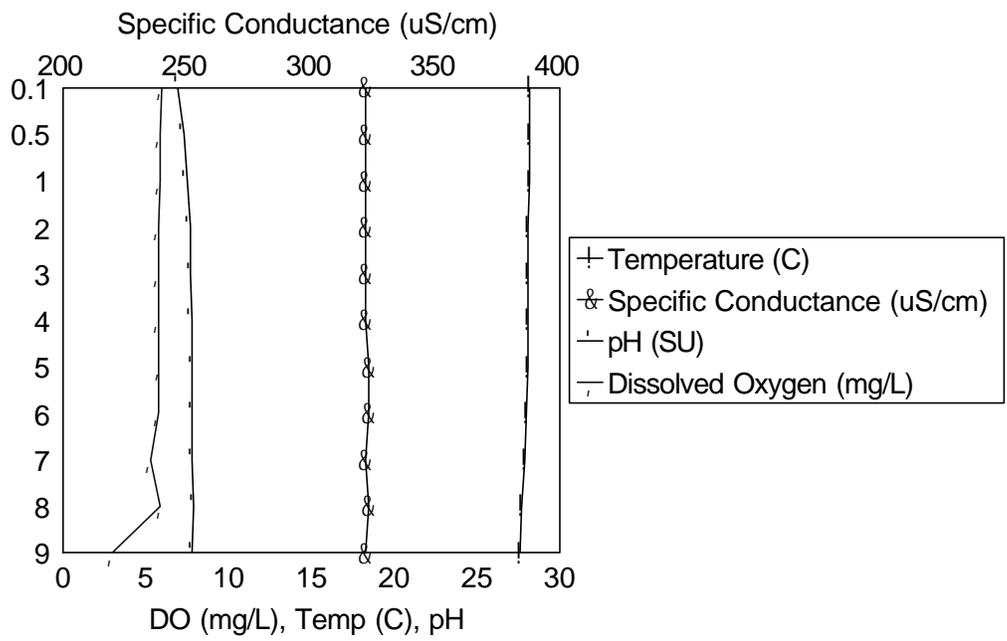
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 2, 19 July 2000.



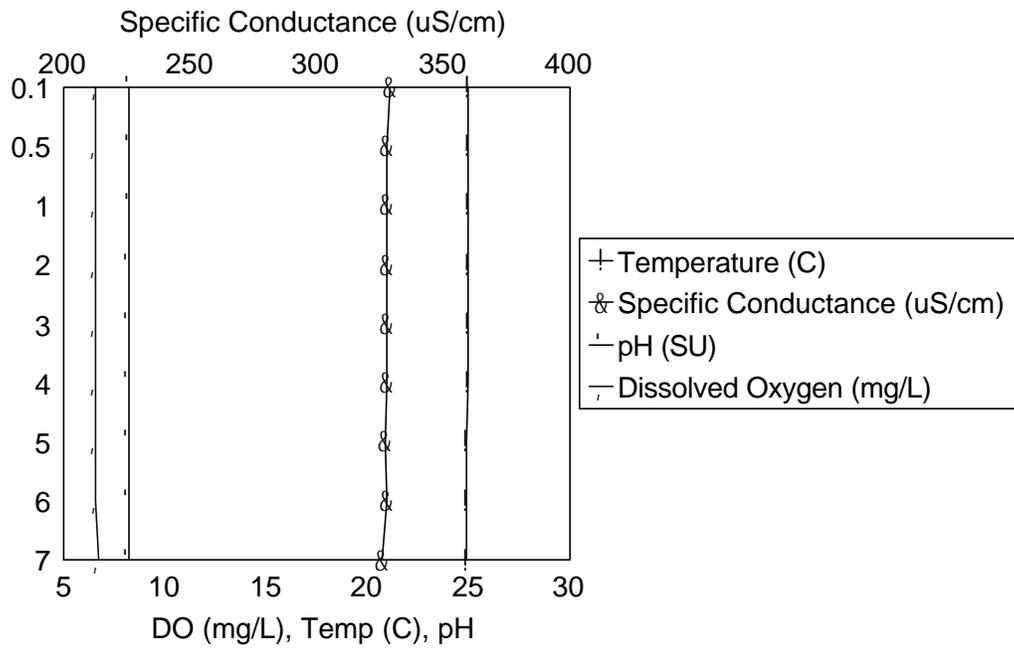
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 2, 1 August 2000.



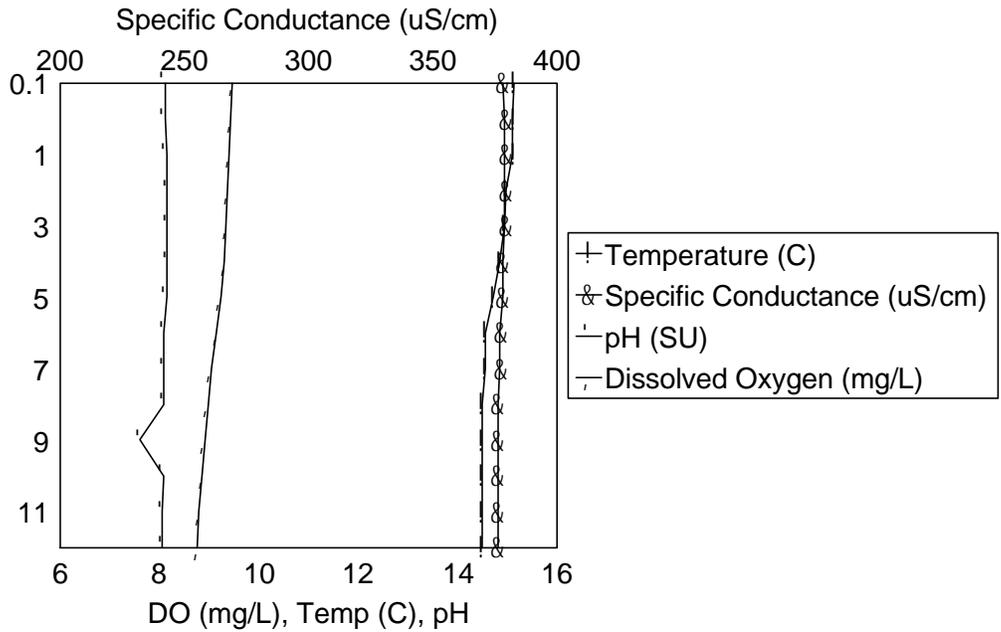
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 2, 15 August 2000.



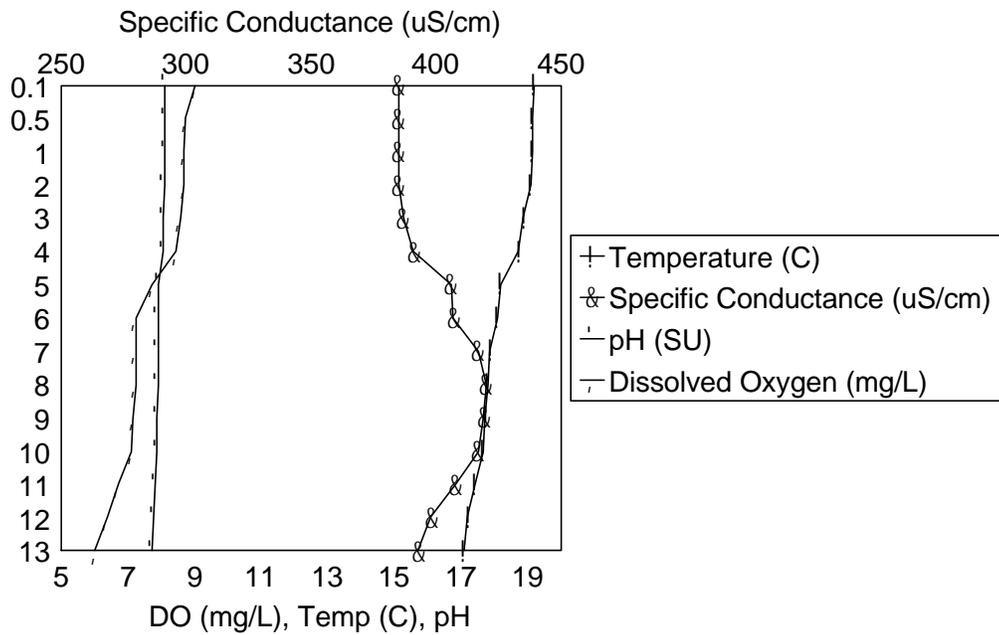
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 2, 6 September 2000.



Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 2, 19 September 2000.

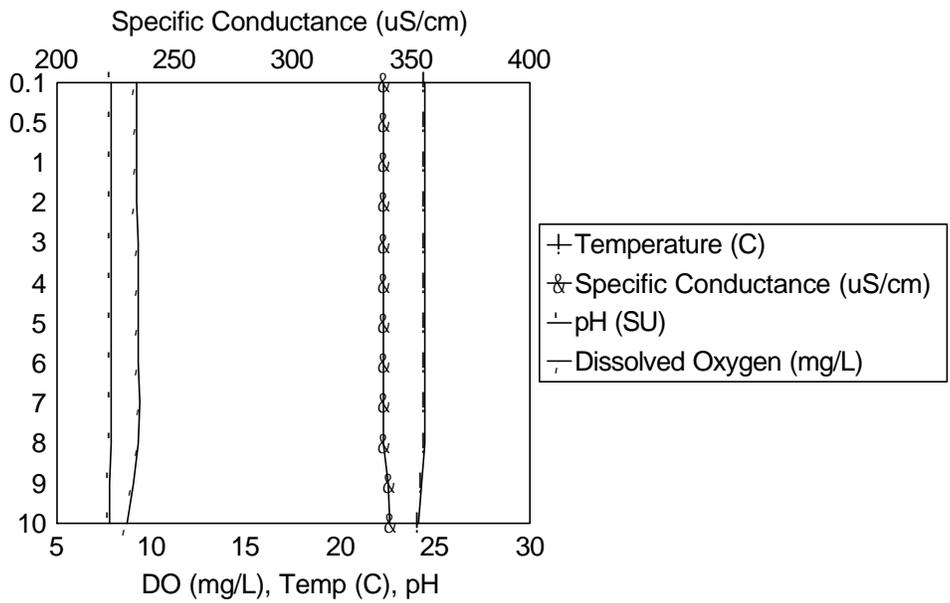


Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 3, 18 April 2000.

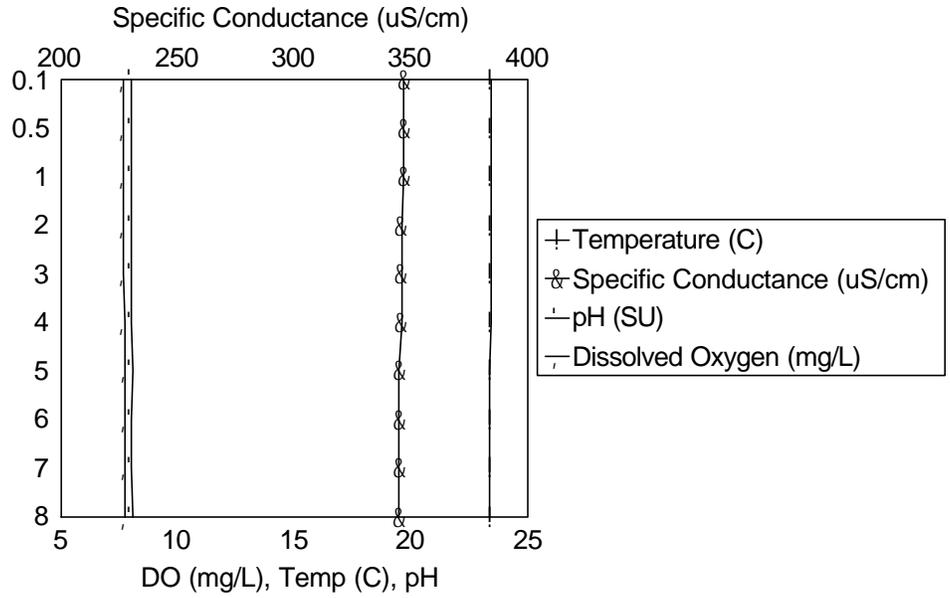


Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 3, 2 May 2000.

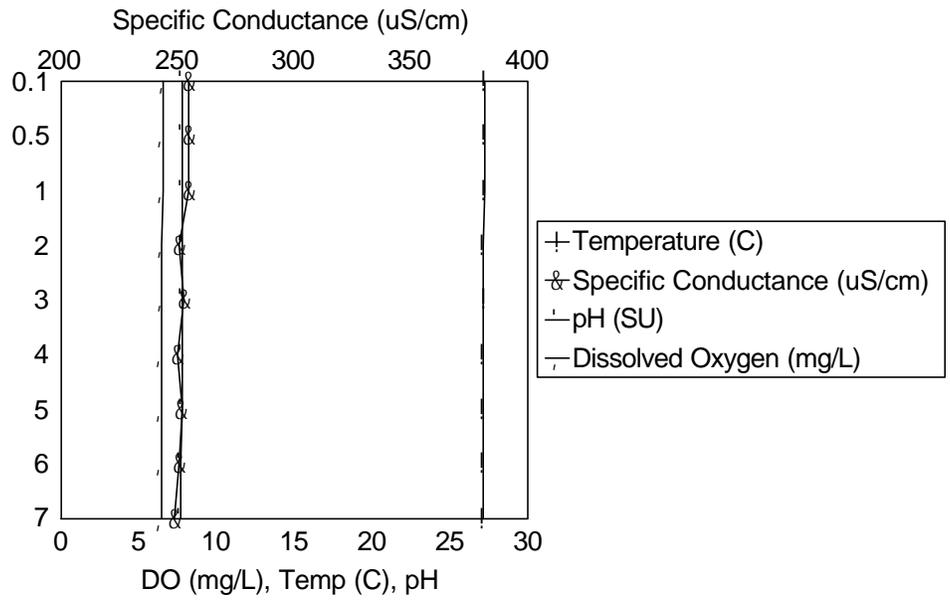
NOTE: Due to high wind conditions on 16 May 2000, no vertical profile was obtained at Site 3.



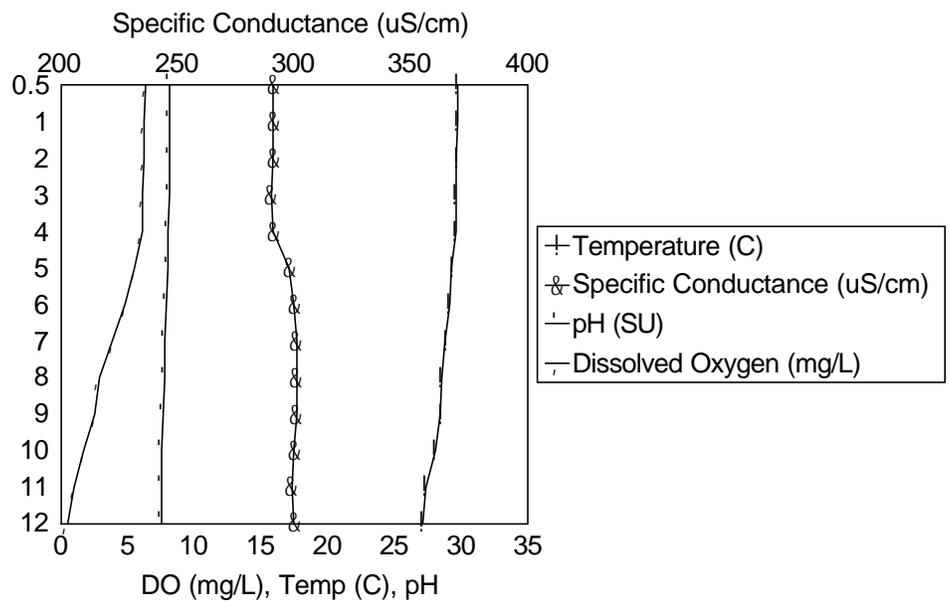
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 3, 6 June 2000.



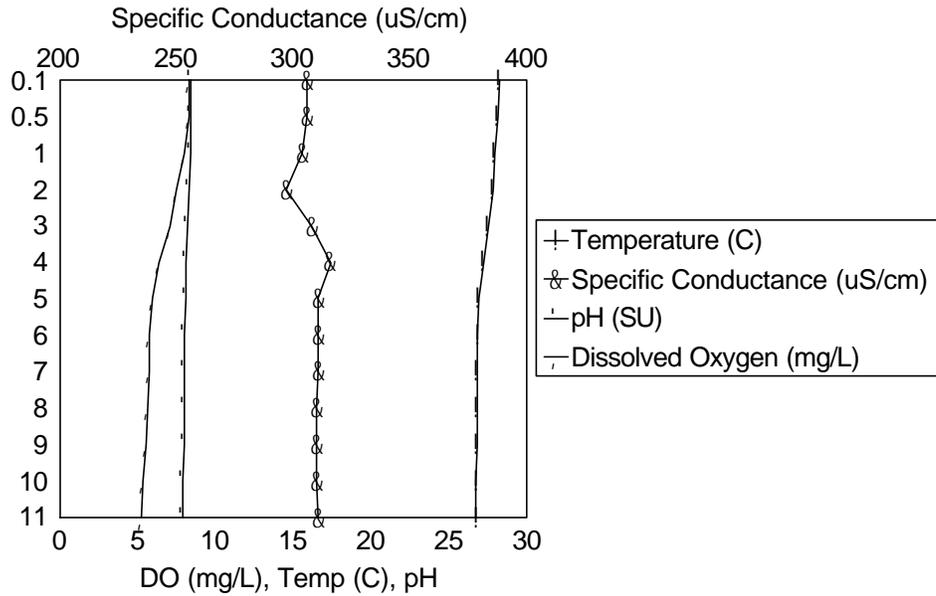
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 3, 20 June 2000.



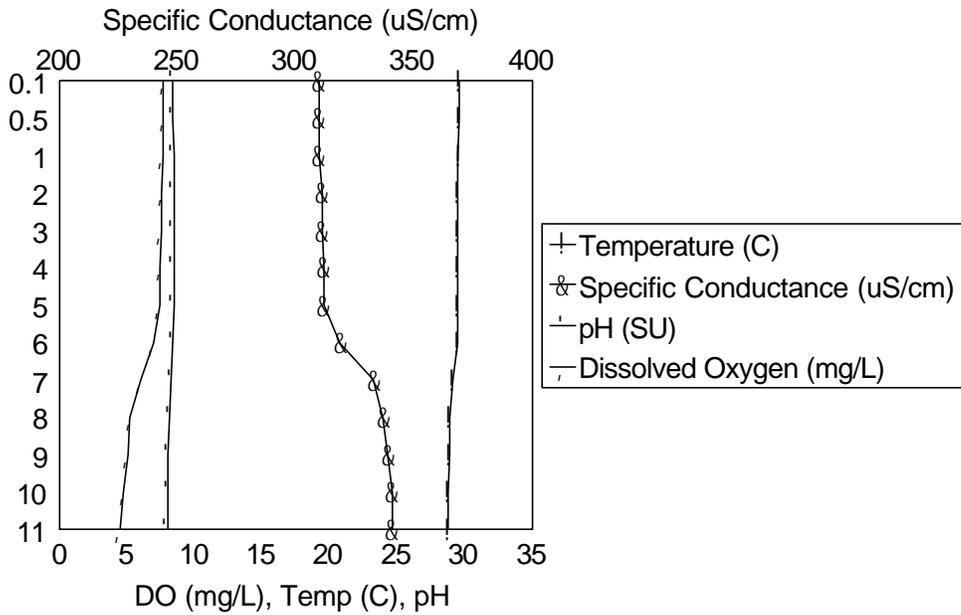
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 3, 5 July 2000.



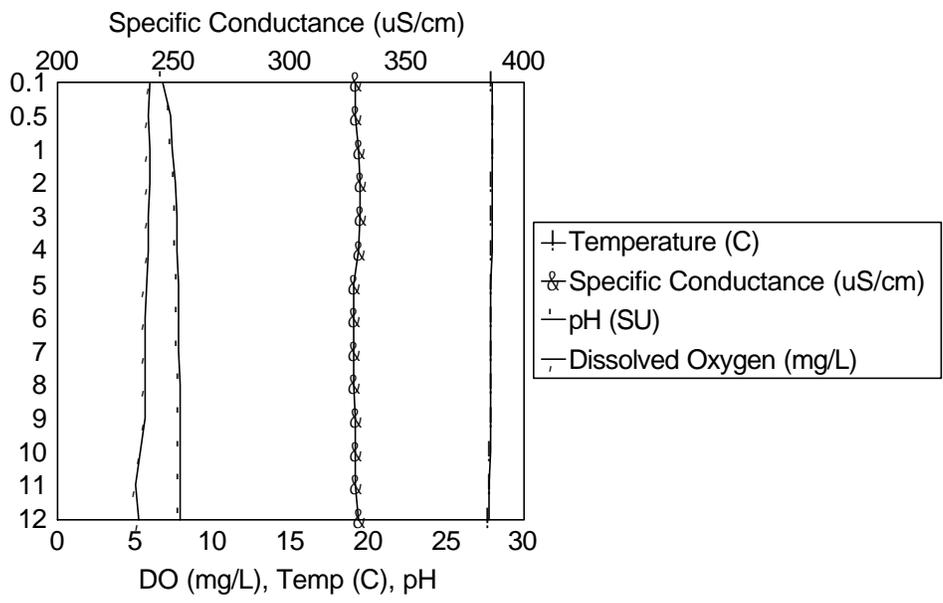
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 3, 19 July 2000.



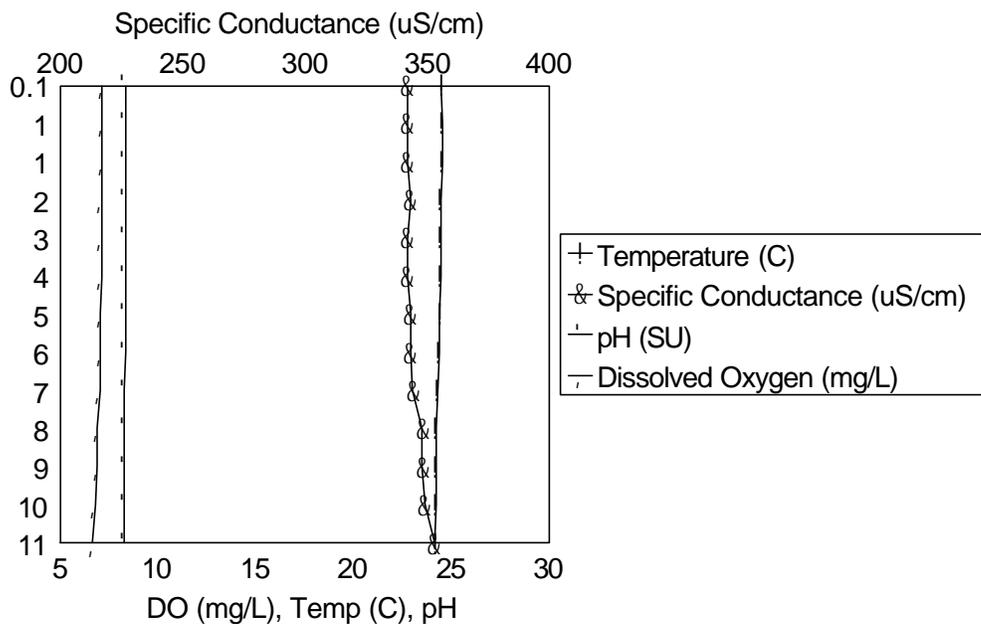
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 3, 1 August 2000.



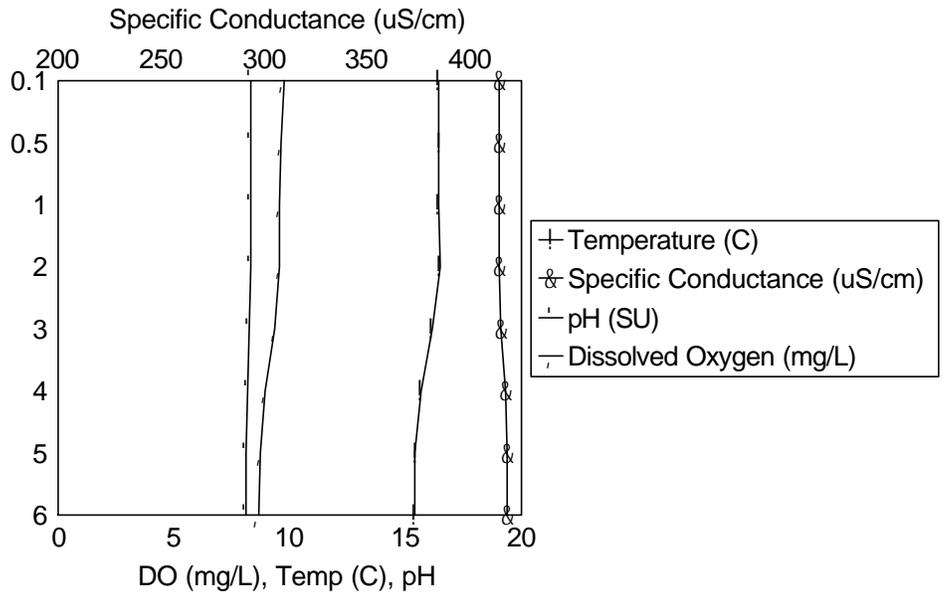
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 3, 15 August 2000.



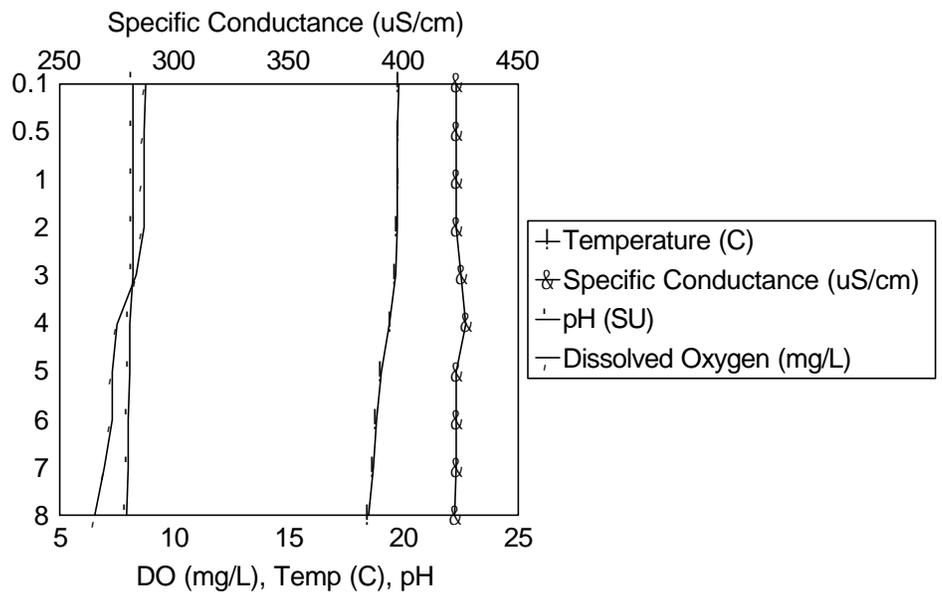
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 3, 6 September 2000.



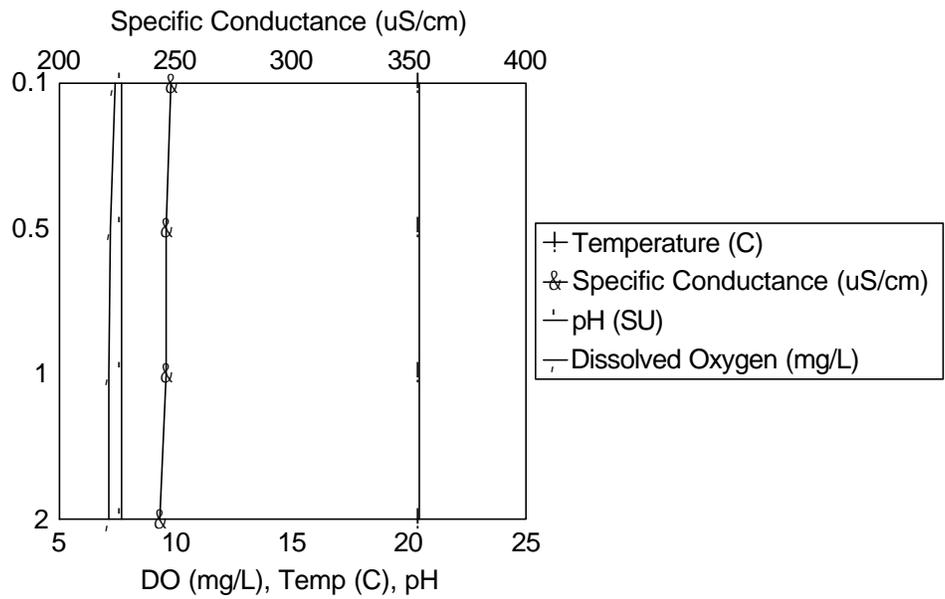
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 3, 19 September 2000.



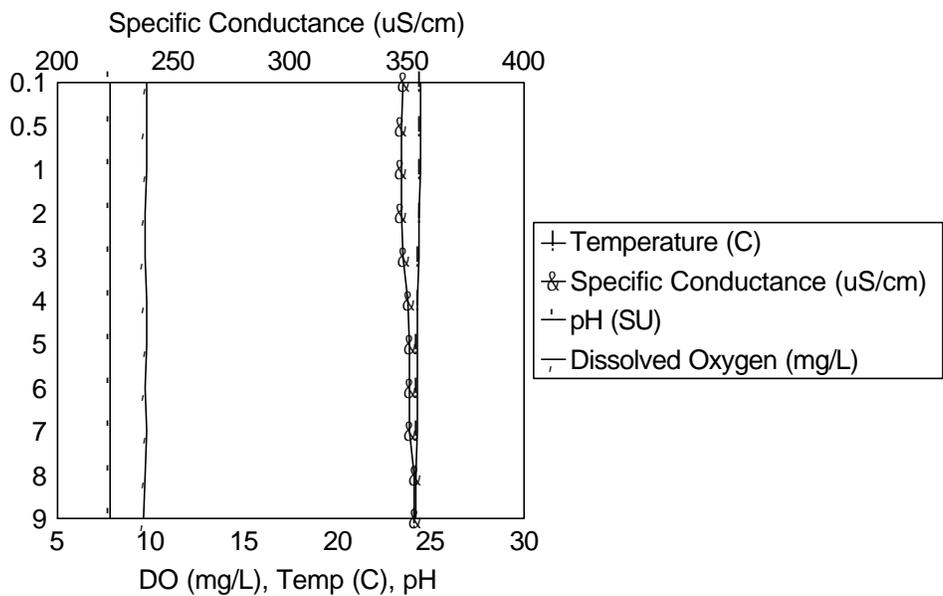
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 4, 18 April 2000.



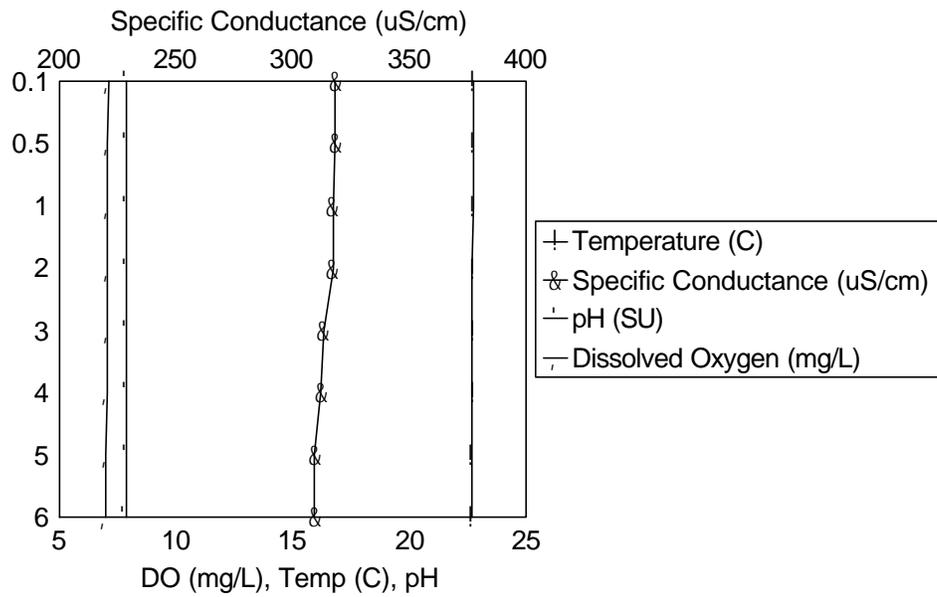
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 4, 2 May 2000.



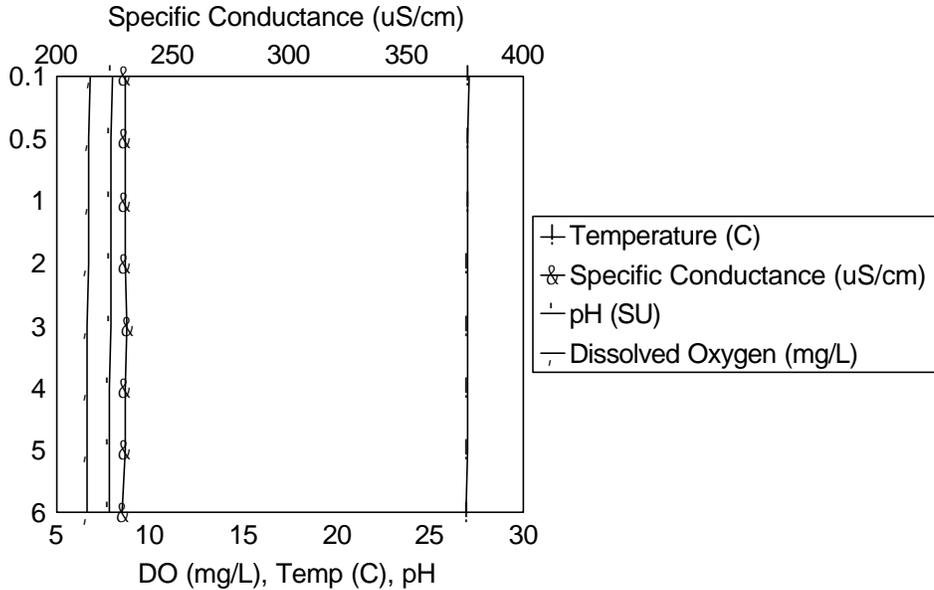
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 4, 16 May 2000.



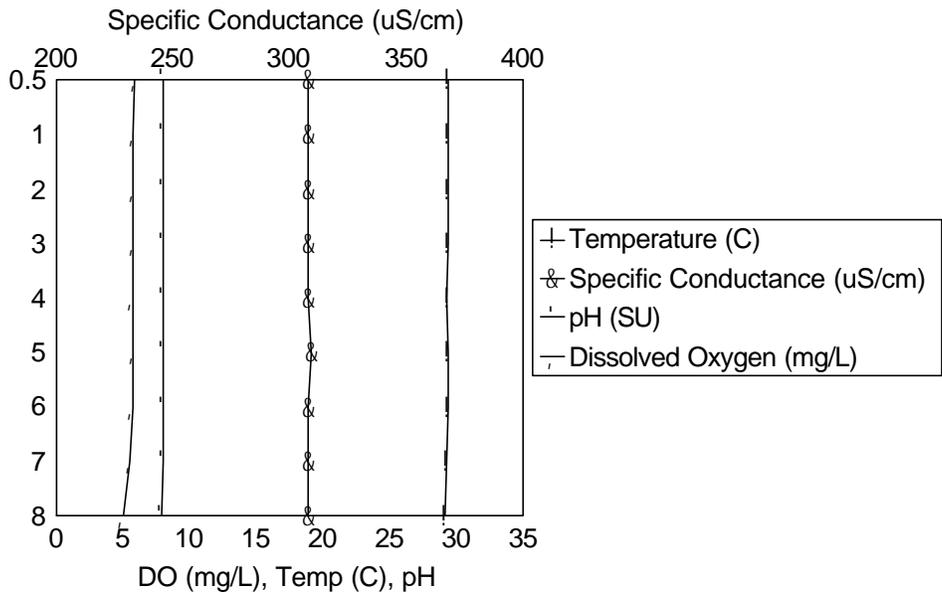
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 4, 6 June 2000.



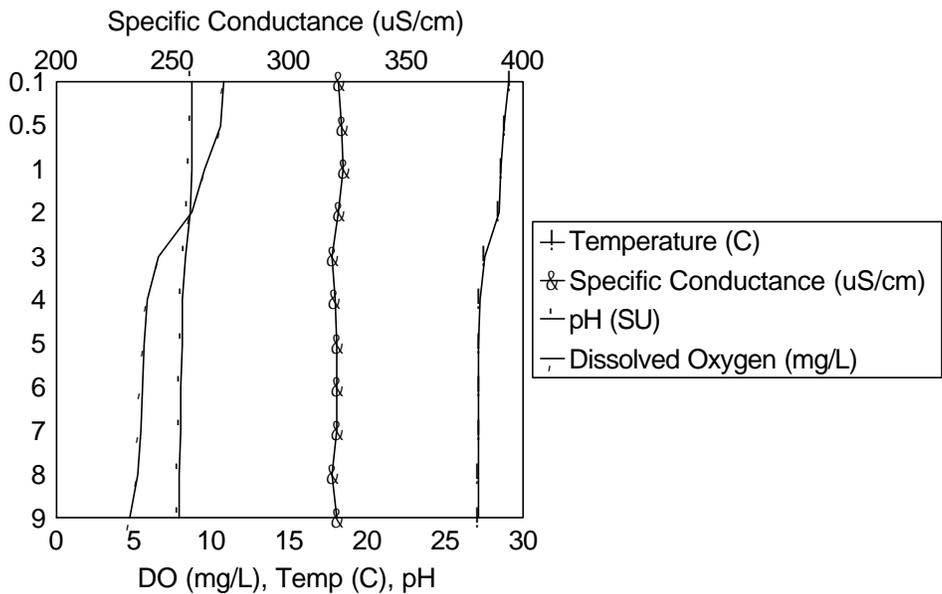
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 4, 20 June 2000.



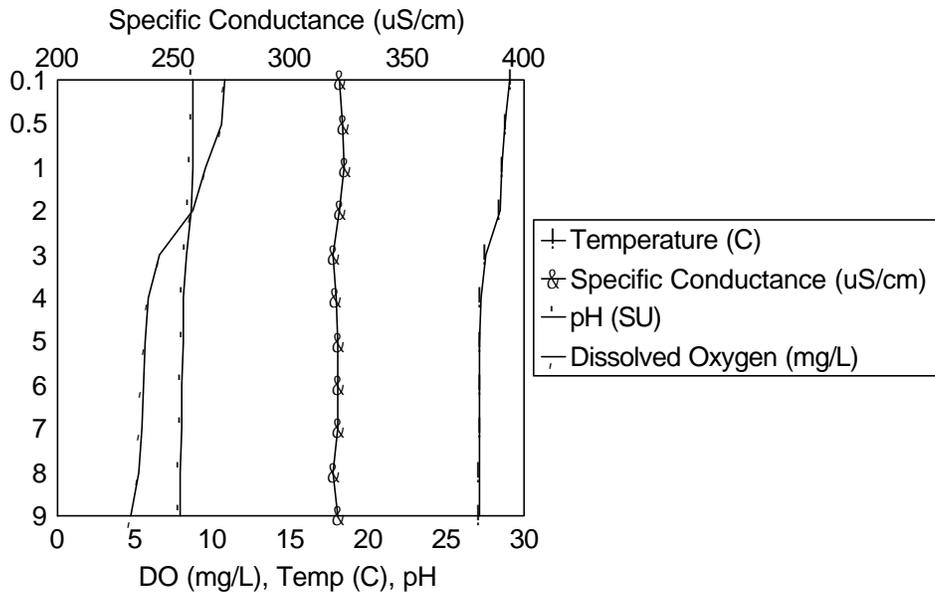
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 4, 5 July 2000.



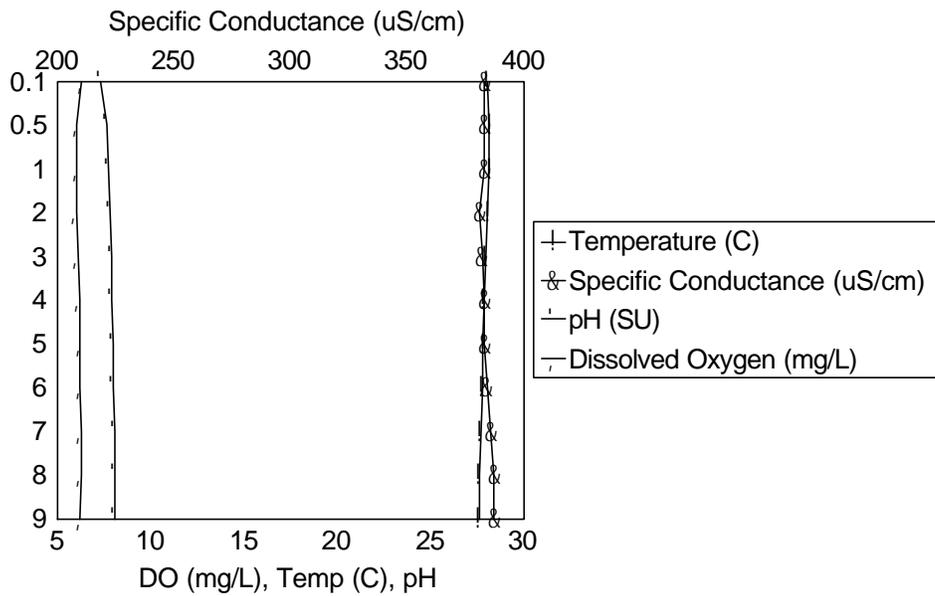
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 4, 19 July 2000.



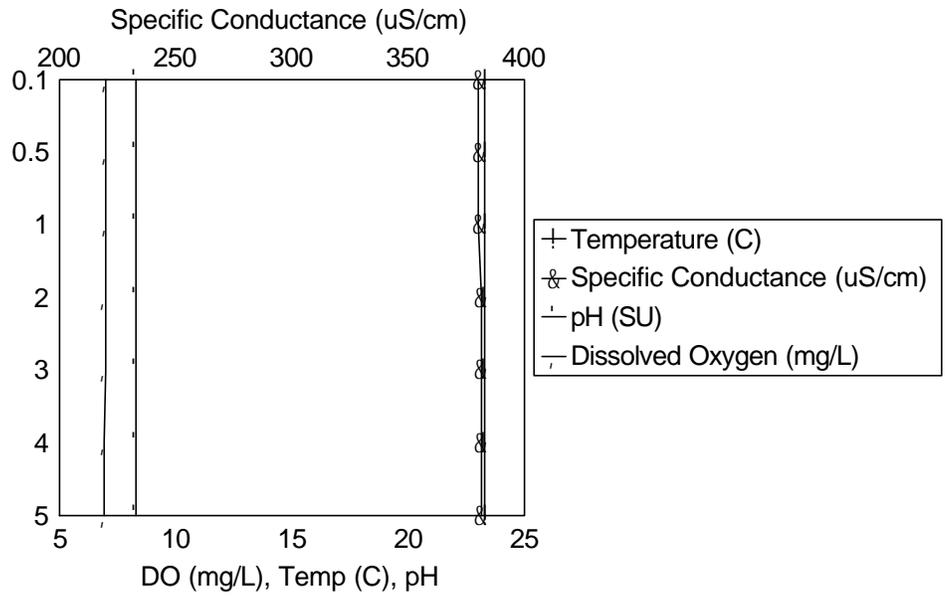
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 4, 1 August 2000.



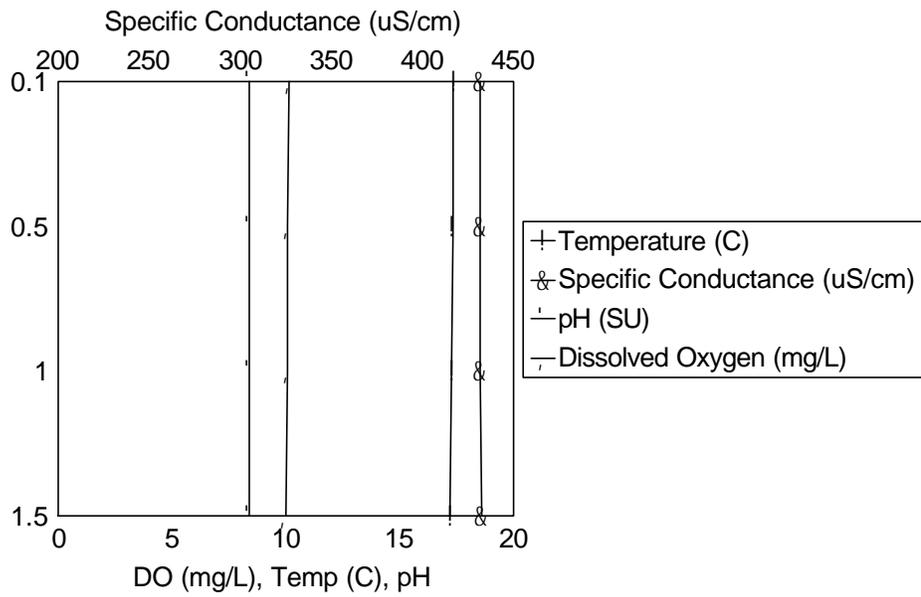
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 4, 15 August 2000.



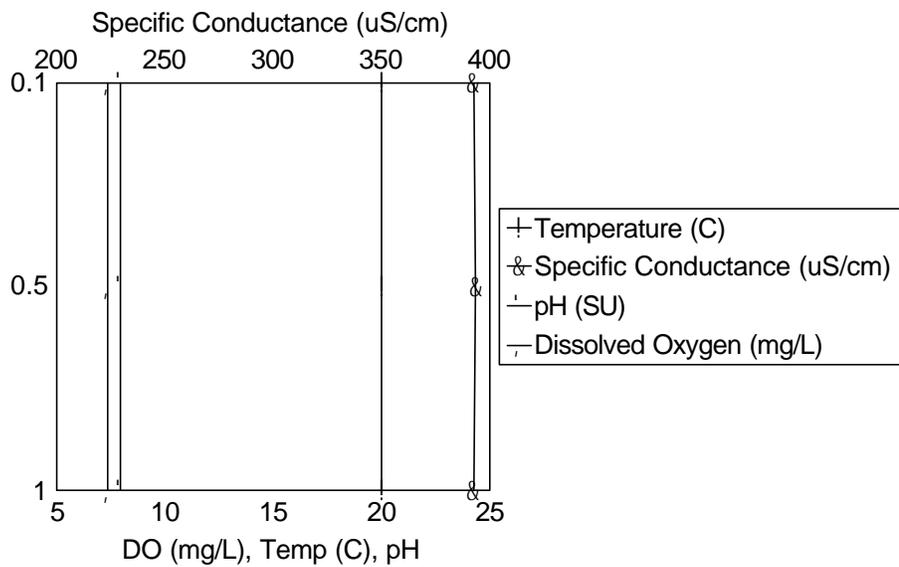
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 4, 6 September 2000.



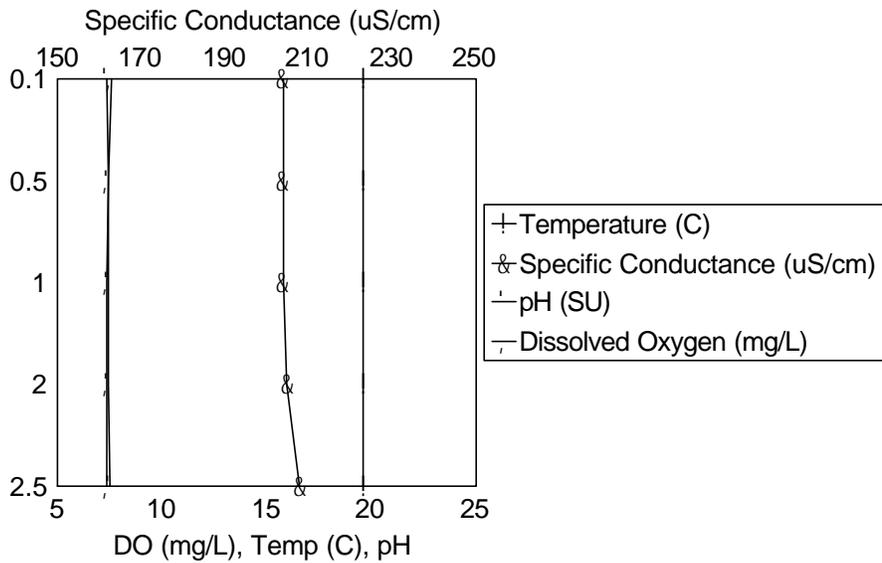
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 4, 19 September 2000.



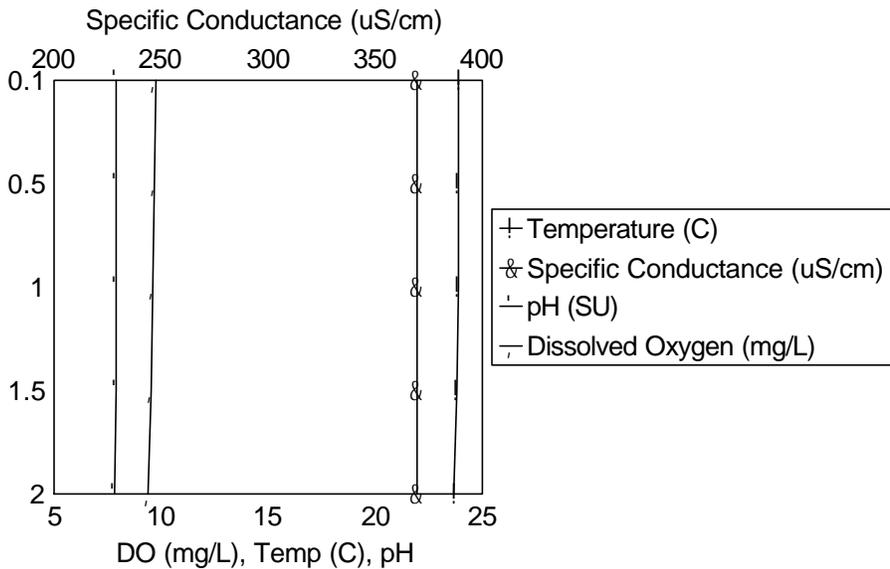
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 5, 18 April 2000.



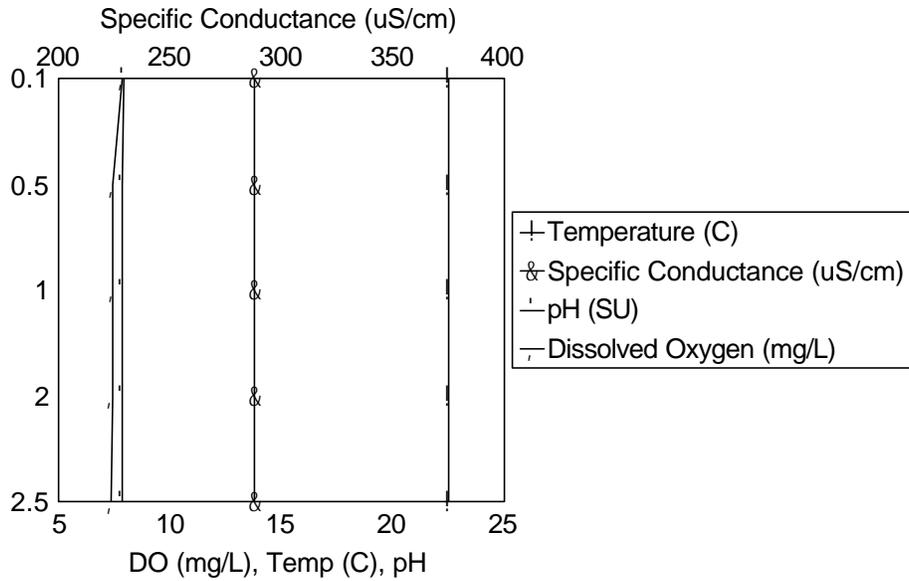
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 5, 2 May 2000.



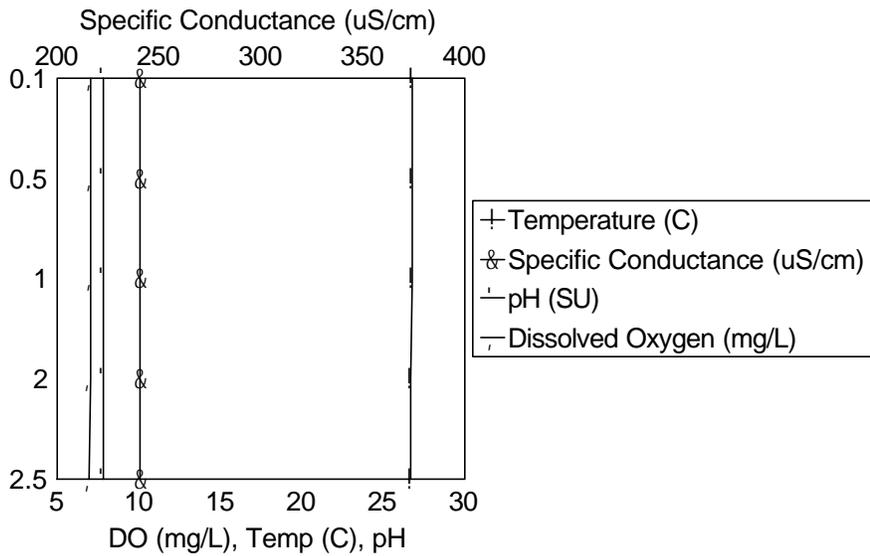
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 5, 16 May 2000.



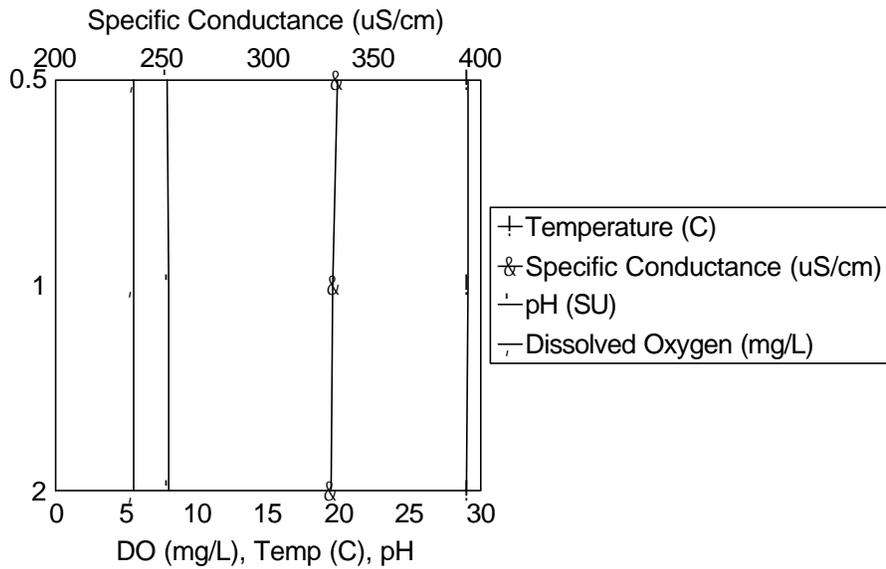
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 5, 6 June 2000.



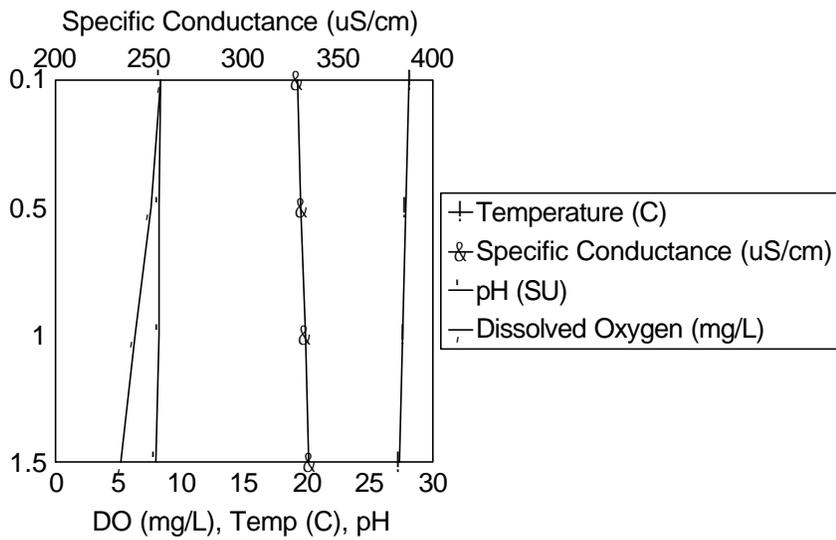
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 5, 20 June 2000.



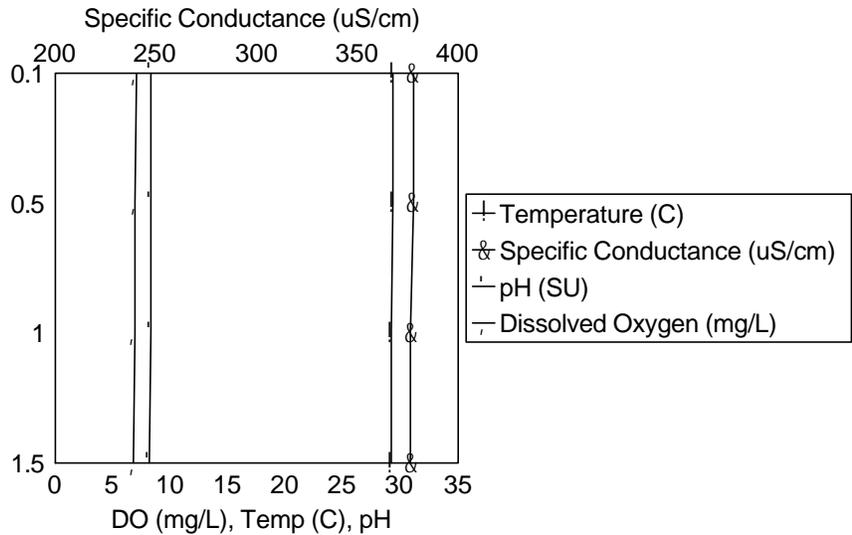
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 5, 5 July 2000.



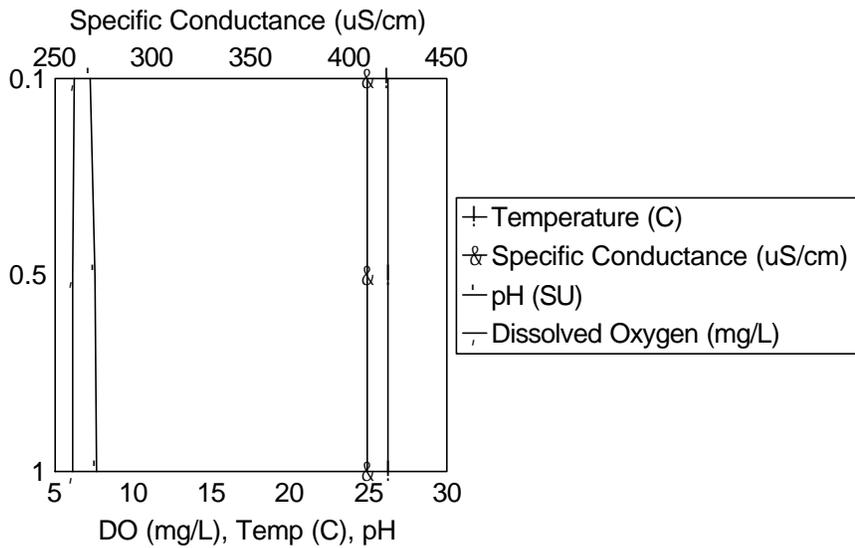
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 5, 19 July 2000.



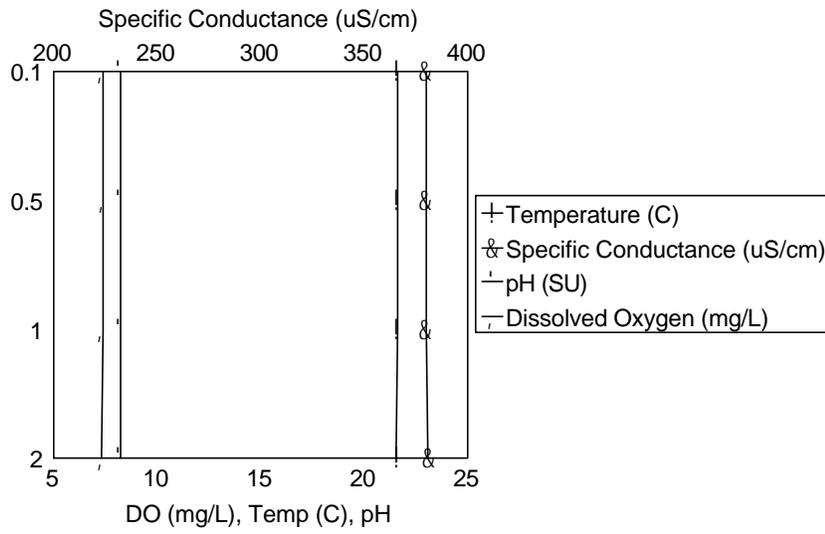
Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 5, 1 August 2000.



Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 5, 15 August 2000.



Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 5, 6 September 2000.



Vertical Profile of Temperature, Specific Conductance, pH, and Dissolved Oxygen for Site 5, 19 September 2000.