IMPACT OF CONCENTRATED ANIMAL FEEDING OPERATIONS ON OKLAHOMA CITY'S WATER SUPPLIES

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March 6, 2002

ACKNOWLEDGEMENTS

There are numerous individuals who have contributed greatly to the completion of this report. First, special thanks to all the individuals who assisted in the fieldwork necessary to sample the six reservoirs quarterly for three years and the stream sampling crew. For the drafting of the report, Ken Del Regno's time and effort in the initial draft and providing the background knowledge on Oklahoma City water supply systems. Several temporary employees who researched, compiled, and entered historical data from the USGS, DEQ, and City of Oklahoma City. Acknowledgement also goes to those individuals at the abovementioned agencies and the City who provided us with the historical data. Lynda Loucks, Bill Cauthron, and Paul Koenig for their editing, proofreading, and contributions to the draft versions of the document and providing guidance and insight in analyses. Lynda Loucks who also calculated nutrient loadings for the North Canadian River, which provided critical information in the summation of the amount of nutrients reaching Oklahoma City water supplies. Also, Julie Chambers and Crystal McLaren, who created various graphics for the report. And last, however by no means least, Monty Porter who coordinated the North Canadian River sampling, analyzed the data, and drafted the river section of this report. Special thanks and deepest gratitude to all of these individuals for their selflessness to provide the assistance needed to complete this report.

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Executive Summary

This report summarizes the water quality condition of Oklahoma City's water supplies. Oklahoma City's western reservoirs are formed from the North Canadian River. The river was sampled at three locations from the Beaver River at Beaver, Oklahoma in the panhandle to Seiling, then data was acquired from the City of Oklahoma City from a site three miles upstream of Lake Overholser. Sampling stations were also established in the six reservoirs that serve Oklahoma City water supplies. Water quality data collected for this study was compared to historical data, where available, to assess possible changes in water quality over time and determine current trophic status of the reservoirs.

<u>Reservoirs</u>
All six of Oklahoma City's water supply lakes were sampled extensively for this study and current lake conditions were assessed. Of the six lakes investigated Overholser was the most productive, or highest trophic state based on all Carlson's indices (Chlorophyll-a, total phosphorus, and secchi disk depth) and nutrient (TN and TP) concentrations. The CHL TSI, used by the OWRB and State of Oklahoma for beneficial use threats, would list the lake as a "nutrient limited watershed". For the other five reservoirs, CHL TSI's classed the lakes as eutrophic (Canton and Hefner), mesotrophic (Atoka and McGee) and oligotrophic (Draper). Overholser's TN:TP ratio determined the lake was nitrogen limited, whereas Atoka Lake's TN:TP ratio indicated that the lake was neither phosphorus or nitrogen limited. The remaining four reservoirs were all phosphorus limited, which is normal for Oklahoma reservoirs.

Lakes Overholser, Stanley Draper, and Atoka all exceeded OWQS for turbidity of 25 NTUs with an overall turbidity average of 36, 40 and 74 NTUs, respectively. Lakes Stanley Draper and Atoka have relatively low productivity (low CHL TSI) due to light limitation, however nutrient concentrations are high enough that the potential for high productivity exists if turbidity improved. McGee Creek reservoir is also low in productivity (low CHL TSI) with high water clarity. However, McGee Creek is experiencing anoxic conditions resulting in the water quality not supporting its' Fish and Wildlife Propagation beneficial use. Greater than 70% of the water column during the summer sampling months has less than 2 mg/l of dissolved oxygen, and pH values are below 6.5 standard units. Nevertheless, McGee Creek has the lowest turbidity, TN and TP concentrations and TSI's (TP and SD) of all the reservoirs.

<u>NorthCanadian River</u>
The Beaver/ North Canadian River was monitored monthly, February through November from 1999 and 2000 at three sites; Beaver, Seiling and El Reno. Sporadic historic data was available at these sites. Trend analyses were performed as well as statistical tests for differences between the medians of the historic versus current data sets when data were obtainable.

At the Beaver site, recent total nitrogen data showed a decreasing trend. Nitrite/nitrate medians were 150% greater in the recent data compared to the historic. Phosphorus showed no significant trend in recent data. A two-tailed comparison of the medians for turbidity determined that recent data was significantly lower than historical, however no significant trend was detected. Nutrient loadings calculated at this site were for TN 8,579 kg/yr and for TP 1,081 kg/yr. These loads were considerably lower than the other sites, as expected since the Beaver River is a much smaller stream than the North Canadian River.

An overview of this Beneficial Use Monitoring Program (BUMP) Report (OWRB, 2000) states that the Warm Water Aquatic Community (WWAC), Agriculture (AG) and the Primary Body

Contact and Recreation (PBCR) beneficial uses are not being supported. WWAC failed with high selenium concentrations, whereas the AG beneficial use criteria was exceeded by total dissolved solids, sulfates and chlorides. PBCR failed with high fecal coliform, *E. Coli* and enterococci concentrations. However, this segment of the Beaver River is not nutrient-threatened. For detailed information on beneficial use assessment refer to the 2000 BUMP annual report (OWRB, 2000).

Trend analyses performed on data from the Seiling site for both recent and historical total nitrogen data; no trend was detected. In addition, a two-tailed comparison of the medians revealed no significant difference between historical and recent TN data. Likewise, there was an 18% increase in TN medians in the recent data compared to the historic. Trend analyses were also performed on both historical and recent TP data. Phosphorus showed no significant trend in recent data, and a decreasing trend from the historical data (collected from 1980 to 1986). A two-tailed comparison of the medians for turbidity determined that recent data was significantly higher than historical, however no significant trend was detected. Nutrient loadings calculated at this site were for TN 272,036 kg/yr and for TP 33,557 kg/yr.

An overview of the BUMP Report states that the WWAC beneficial use is partially supported at this site with 21% of turbidity samples exceeding numerical criteria of 50 NTU's. The AG beneficial use is supported by all three parameters; total dissolved solids, sulfates and chlorides. The PBCR beneficial use is not supported with high enterococci concentrations. However, this segment of the North Canadian River is not nutrient-threatened. For detailed information on beneficial use assessment refer to the 2000 BUMP annual report (OWRB, 2000).

At the El Reno Site, trend analyses showed no detection on both recent and historical TN data. In addition, a two-tailed comparison of the medians revealed no significant difference between historical and recent TN data. Likewise, there was less than a 5% increase in TN medians in the recent data compared to the historic. Trend analyses were also performed on both historical and recent TP data. Phosphorus showed no significant trend in recent data, and a positive trend from the historical data (collected from 1980 to 1986). A two-tailed comparison of the medians for turbidity determined that recent data was significantly higher than historical, however no significant trend was detected. Nutrient loadings calculated at this site were for TN 307,685 kg/yr and for TP 66,6613 kg/yr.

An overview of the 2000 BUMP Report states that the WWAC beneficial use is not supported at this site with 31% of turbidity samples exceeding numerical criteria of 50 NTU's. The AG beneficial use is supported by all three parameters; total dissolved solids, sulfates and chlorides. The PBCR beneficial use is not supported with high enterococci concentrations. However, this segment of the North Canadian River is not nutrient-threatened. Only 18% of the TP concentrations and none of the nitrate/ nitrite concentrations were above the prescribed thresholds of 0.36 mg/l and 5.00 mg/l, respectively. For detailed information on beneficial use assessment refer to the 2000 BUMP annual report (OWRB, 2000).

<u>Microbial Strain Tracing</u>
To investigate whether a link exists between land-applied CAFO wastes and downstream areas, the BioEnvironmental Engineering and Science Laboratory at the University of Oklahoma was retained to conduct microbial strain tracing of environmental samples. The aim of strain tracing was to identify microbial species that are found in CAFO lagoons and whether they occur in surface waters. Microbial strain tracing identified one organism, *Lactococcus lactis,* which was

found in both CAFO lagoons and in the river downstream of the areas where land application of CAFO wastes occurred. This organism did not occur upstream of the CAFOs.

Bathymetry

Extensive surveys were also conducted to produce bathymetric maps for Lakes Hefner, Overholser, Stanley Draper, Atoka and McGee Creek Reservoir. These surveys document current storage capacity, and when compared to historic capacity, loss of capacity can be determined. Some loss of yield are expected in man-made reservoirs, however this data will also be useful for future survey's to identify areas of extreme sedimentation, if present, and signify landuse changes that may preserve the life of the reservoir.

Conclusions

In conclusion, there is no direct connection between CAFO runoff and the North Canadian River, and supply reservoirs. There is generally an increase in TN at the river sites and bacteria seem to be a problem for meeting beneficial uses. Lake Overholser is experiencing extreme eutrophication, which is not unlikely for a reservoir of its age. This reservoir will likely be listed as an "NLW" in the Oklahoma Water Quality Standards which may require more intensive investigation and resolution to its aging process. Turbidity is a problem for Overholser, but also Stanley Draper and Atoka. Inevitably, for Draper and Atoka, responsible watershed management and shoreline stabilization, or other in-lake restorative tools will mediate the impact of excessive turbidity. McGee Creek should be further investigated to determine the cause of anoxia and develop restoration alternatives to prevent future degradation. All of the reservoirs are undergoing some storage loss, again expected for man-made reservoirs. It would be useful to resurvey these reservoirs in five years, now that a database exists, to determine sedimentation rates and identify areas of concern.

Introduction

The Oklahoma Water Resources Board (OWRB) was directed by the 1997 Oklahoma Legislature to conduct a study on the impact of Concentrated Animal Feeding Operations (CAFOs)[1] on those watersheds which supply potable water to municipalities with a population over 250,000. According to the last federal decennial census (Okla. Session Laws, 1997), two municipalities, Oklahoma City and Tulsa, meet the stated criteria. The OWRB subsequently entered into an agreement with the City of Oklahoma City to conduct a project entitled *Study On Potable Water Impacts From Concentrated Animal Feeding Operations As Enacted By House Bill 1522.*

In April 1991, the Oklahoma legislature passed Senate Bill 518, which created a broad exception to the anti-corporate farming statute found in Title 18 § 951 of the Oklahoma Statutes. The exceptions allowed, for the first time, foreign and corporate ownership of agricultural land. In 1993, SB 147, the "right to farm" bill, granted legal protections to licensed CAFOs against nuisance suits from nearby residents. These regulatory changes helped to facilitate the growth of industrial-sized hog operations. In 1991, Oklahoma had 190,000 hogs in production, by January 1, 2000, this number had increased to approximately 2.26 million (OASS, 2000).

The first significant change in the way CAFOs were regulated came about following a 1996 Oklahoma Attorney General's Opinion (# 96-76). The opinion stated that the Board of Agriculture must conduct a hearing when landowners within the vicinity of a proposed feed yard operation present specific factual allegations showing that the feed yard may have a " direct, substantial and immediate effect upon their property or legal interest". Following this opinion, the Legislature began to address the impacts of animal wastes from large CAFOs. The result was H.B. 1522, which required licensing hearings and all large swine feeding operations that use liquid waste systems to obtain licenses. Other requirements included setback provisions, prohibitions against liquid waste applications within 500 feet of occupied dwellings and 300 feet from drinking water wells and submission of pollution prevention and design plans. This bill was codified as the Oklahoma Concentrated Animal Feeding Operations Act in Title 2 § 9-201 of the Oklahoma Statutes.

Historical livestock inventories from January 1, 1994 showed 5.15 million cattle, 4.86 million chickens, and 300,000 hogs in Oklahoma. Since 1994, cattle and chicken populations have not changed dramatically, however hog populations have increased more than seven-fold. The panhandle of Oklahoma supports the majority of the hog population within the state with an increase from 40,000 in 1994 to over 1.3 million in 2000 (OASS, 2000). In 1992, Texas County in the Oklahoma panhandle was ranked # 797 in counties in the United States in number of hogs. By 1997, its rank was # 3 in the U.S. with 907,046 hogs (National Pork Producers Council, 2000). While hog CAFO's are concentrated in the west, poultry CAFOs are largely concentrated in eastern Oklahoma (Figure 1).

[1] Title 2 § 9-202 of the Oklahoma Statutes defines a CAFO as a licensed managed feeding operation (1,000 animal units or greater) and when pollutants are discharged into the waters of the state.

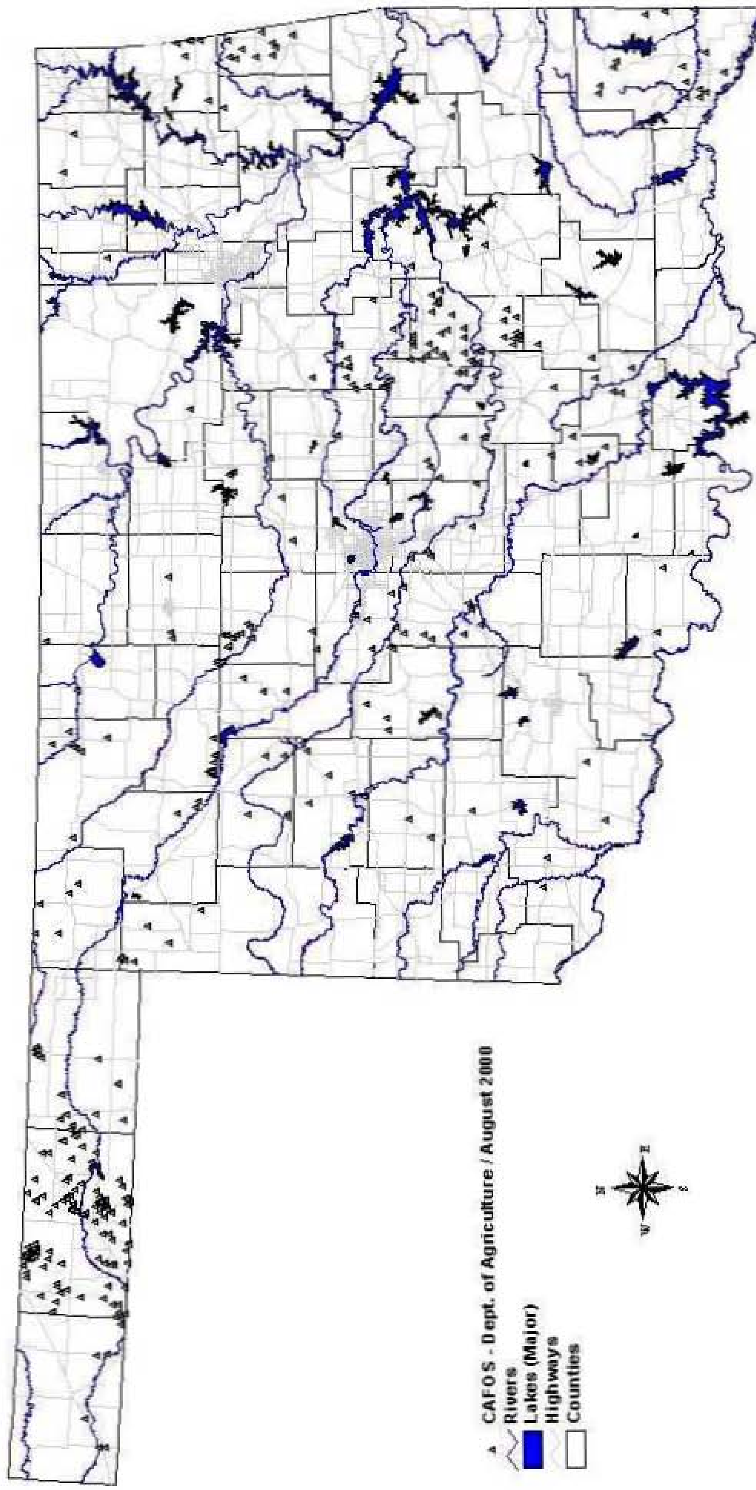


Figure 1. Locations of Oklahoma Department of Agriculture permitted CAFOs in August 2000. Marked CAFO's are not differentiated between cattle, poultry or hog.

Confined Animal Feeding Operations can pose a potential threat to water quality because the animal waste generated contains large quantities of nutrients and microorganisms are concentrated in relatively small areas. Lagoons, which hold solid and liquid wastes prior to their application on cropland, can leak into groundwater or overflow into surface waters (Andrews, 1999). In addition, the usual method for disposal of liquid wastes is by land application.

Considerable research has been directed toward the development of proper methods for land application of CAFO wastes (USDA, 2000). After solid and liquid wastes from hogs are collected in troughs beneath feeder buildings, the wastes are periodically flushed into anaerobic lagoons. Many livestock producers handle their wastes as a liquid because of labor saving advantages. The lagoons act as small-scale waste treatment plants containing manure that is diluted with building wash water, water wasted from animal waterers and rainfall. Anaerobic lagoons decompose more organic matter per volume than aerobic lagoons and require less space, therefore almost all livestock lagoons in current use are anaerobic.

Anaerobic processes liquefy or degrade organic wastes that contain high biochemical oxygen demand (BOD). Advantages of anaerobic lagoons include efficient manure handling with liquid hydraulic methods, high stabilization of wastes, high nitrogen reduction that minimizes the amount of land required for application and low-cost long-term storage of wastes. Disadvantages include public perceptions, undesirable odors during storage and land application, low nutrient availability to crops due to denitrification processes and disposal costs of lagoon solids. In addition to risks of lagoon failure such as leaking into groundwater or overflow into surface waters.

Land application of animal manure can be an efficient disposal method due to lower costs than other methods and nutrient benefits derived by crops. Two principal objectives in applying animal manure to land are to ensure maximum utilization of the nutrients by crops and to minimize water pollution hazards. Surface spreading and subsurface injection are the two most common land application methods. To prevent adverse environmental impacts, several guidelines must be followed. They include tests of soil fertility and moisture, manure and wastewater fertility tests and selection of application rates that do not exceed crop nutrient requirements. Soil slope, saturation and proximity to streams are also major concerns.

Runoff from farms is a source of phosphorus and nitrogen entering streams, rivers and lakes. These nutrient sources are described as nonpoint because they involve widely dispersed activities. Measurement of nonpoint sources is difficult because of their diffuse origins and because their extent varies with season and weather. Nonpoint nutrient sources, however, are the major source of water pollution in the United States today and have widespread impacts (Carpenter *et al*., 1998). The major sources of nonpoint pollution are agricultural and urban activities. According to Oklahoma's 1998 305(b) Report, agriculture is the major source of pollution in Oklahoma's rivers and streams, followed by petroleum extraction and construction (EPA, 1998). This report also identifies agriculture is the most common source of pollution to lakes, followed by sedimentation from varying land use practices. Title 33 of the U.S. Code section 1362(14) defines CAFOs as point sources of pollution when the facility is discharging pollutants without a National Pollutant Discharge Elimination System (NPDES) permit.

Excessive concentrations of nutrients in streams and rivers eventually end up in lakes and reservoirs located downstream. These nutrients can exacerbate a process known as eutrophication, which is a detrimental response to nutrient enrichment. Over-enrichment causes a wide range of problems, including algae blooms, loss of oxygen, drinking water problems and fish kills.

The most common impairment of surface water uses in the United States is eutrophication caused by excessive inputs of phosphorus and nitrogen. Impaired waters are defined as those that are not suitable for designated uses such as drinking water, irrigation, recreation, fishing or aesthetics. In 1998, eutrophication accounted for about half of the impaired lake area and 60 percent of impaired river reaches in the U. S. and was the most widespread pollution problem in estuaries (Carpenter *et al*., 1998). Soil erosion from logging, agricultural and a construction activity not only causes siltation but also transports nutrients to downstream areas.

In recent decades, point sources of water pollution have been reduced due to their ease of identification and control. Though point sources are substantial, the largest remaining source of nutrients to water supplies is nonpoint in nature. For example, 72 to 82 percent of eutrophic lakes would require control of nonpoint nutrient inputs to meet water quality standards, even if point source inputs were reduced to zero (Novotny and Olem, 1994).

The significant increase in hog populations in the Oklahoma panhandle have the potential to impact downstream water quality. The panhandle is included in the watershed of the North Canadian/ Beaver River, which supplies Oklahoma City with a large portion of its drinking water and is therefore a major focus of this project.

Reservoir Limnology

Over long periods of time, eutrophication through nutrient and sediment inflow is a natural aging process by which relatively shallow warm water lakes evolve into dry land (Wetzel, 1983). Today, human activities can greatly accelerate this process. Nutrient enrichment, which is a concern from CAFO operations, can cause a variety of problems in treatment of drinking water, including greater use of water treatment chemicals, increased backwashing of filters, additional settling times to attain acceptable drinking water quality and increased production of carcinogenic disinfecting by-products (Nordin, 1985). Also, nutrient enrichment can cause pronounced diurnal fluctuations in pH and dissolved oxygen (DO) in rivers and lakes. Low DO can cause releases of toxic metals and other pollutants from sediments, and/ or result in fish and benthic macroinvertebrate kills.

The most important nutrients that cause a lake to shift from lower to higher productivity are phosphorus and nitrogen (Wetzel, 1983). Numerous studies have shown that phosphorus is most commonly the limiting nutrient in lakes and reservoirs (OWRB, 2000). Total phosphorus can be separated into inorganic and organic fractions. Of the total organic phosphorus in lakes, about 70 percent are within the particulate organic material, principally algae. The remainder is present as dissolved and colloidal organic phosphorus. Within the epilimnion (the upper portion of a lake), approximately 95 percent of the total phosphorus is present in particulate form. The remainder is present as reactive inorganic soluble orthophosphate (PO_4^{-3}), low molecular weight organic phosphorus compounds and soluble high molecular weight colloidal phosphorus. Orthophosphate has a very short turnover time and is the form that is chemically available for algal growth.

Phosphorus dynamics are further complicated by thermal stratification. Lake sediments contain much higher concentrations of phosphorus than the water (Olsen, 1958, 1964; Holden, 1961; Hepher, 1966). Under aerobic conditions when a lake is not stratified, phosphorus exchange equilibria are largely unidirectional toward the sediments. Therefore, during most of the year, phosphorus is continuously deposited on the lake bottom. Under the anaerobic conditions that form in the hypolimnion (the lower portion of a lake) during stratification, sediment exchange is strongly influenced by redox conditions and considerable amounts of phosphorus are released to the lake water. The presence of a thermocline restricts the amount of phosphorus that is able to move to the trophogenic areas (stratum of the lake where photosynthetic production predominates) in the epilimnion of a lake. This is one reason that continuous external phosphorus sources are important in sustaining large algae populations during summer stratification. An additional source of available phosphorus during summer is provided by conversion of colloidal and particulate forms in the epilimnion and by some resuspension of shallow bottom sediments. Algae blooms can follow fall turnover when relatively large amounts of inorganic orthophosphate are suddenly made available to the algae populations (Zicker, *et al*., 1965). Blooms can also follow periods of high water clarity.

The nitrogen cycle in lakes is more complex than that for phosphorus. Nitrogen occurs in fresh waters in many forms: dissolved molecular N_2, large numbers of organic compounds, ammonia (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-). Although ammonia is a good source of nitrogen for algae, most algae and macrophytes grow better with nitrate as their nitrogen source. As nitrate is assimilated by algae, it is reduced to ammonia. Sources of nitrogen include precipitation on the lake surface, nitrogen fixation in the water and sediments, and inputs from surface and groundwater drainage. Losses occur by lake outflow, reduction of nitrate to nitrite by bacteria with subsequent return to the atmosphere, permanent loss of both inorganic and organic forms to the sediments and by fish harvest. The cycling of nitrogen in lakes can be greatly altered by increased loading of inorganic and organic nitrogenous compounds from their watersheds.

When high levels of phosphorus and nitrogen are found in lakes, excess fertilization from external sources is usually the cause. This is important to algal nutrient dynamics. The importance of phosphorus in algal physiology is of special interest because phosphorus is typically the least abundant element (phosphorus limited) of the major nutrients required for algal growth in the large majority of fresh waters. A continuous supply of phosphorus is therefore necessary to sustain high algal populations. Total nitrogen: total phosphorus (TN:TP) ratios are important to determine which nutrient is limiting algal growth. A ratio greater than 10:1 is phosphorus limited, while less than 7:1 is nitrogen limited. USEPA (2000) indicates that in shallow, hypereutrophic lakes low ratios (nitrogen limited) are due to excessive amounts of phosphorus. Therefore nitrogen limitation would indicate very high amounts of nutrients, both phosphorus and nitrogen.

Under these conditions algae populations can be dominated by blue-green algae. Blue-green algae can cause taste and odors in drinking water, while some can produce a variety of toxins. Blooms of *Microcystis, Anabaena* and *Oscillatoria* have been recognized as producers of potent toxins that can kill fish and other aquatic organisms, land animals and birds. Certain species of *Cylindrospermopsis*, have recently been shown to cause toxicity in fish and other animals (Carmichael, 1998; Chiswell et al., 1997). These toxins are not normally present in quantities that are toxic to humans and are largely inactivated by ozonation or chlorination treatment processes.

<u>Trophic State Classification System</u>
Excessive nutrient levels in lakes can be quantified using Carlson's Trophic State Index (Carlson, 1977). Lake trophic status is important from a water quality perspective because it is an indicator of current and potential nutrient impacts to a lake. In general, the higher the trophic state index (TSI) of a lake, the more nutrient loading into the system is occurring. The Oklahoma Water Resources Board uses trophic assessment for the prioritization of lakes most in need of remediation and to make relative comparisons among lakes. It is also useful when comparing current conditions to historical conditions when historical data is available. TSI classification of Oklahoma water bodies was set forth by Oklahoma's 1990 Lake Water Quality Assessment (LWQA). Some lakes, due to the nature of their watershed and basin

morphometry, may never be able to attain the water quality of other more pristine waters. A variety of factors can affect trophic state index classifications. Soil types can play an important role in eutrophication measurements. For example, clays have a very small particle size and are constantly re-suspended in a lake's water column, and never settle out. This creates a very turbid water body and blocks sunlight penetration. A reservoir with these characteristics may be classified as eutrophic by total phosphorus content but oligotrophic by algal productivity, measured by chlorophyll-a concentrations. This scenario shows that the lack of light penetration is preventing available phosphorus from being utilized for plant growth. Therefore in using trophic state indexes to classify reservoirs, many data combinations must be considered to accurately reflect a lake's true condition.

Microbial Strain Tracing

The determination of direct impacts from CAFOs is difficult to achieve due to all the possible sources of nutrients in the environment. Nutrients can come from fertilizers, breakdown of organic debris, wildlife, livestock or human waste. Various studies have been conducted to identify sources of nutrients, specifically nitrates and bacteria. One method to identify sources of various chemicals is called Isotope Ratio Mass Spectrometry. Certain chemicals have characteristic ratios of stable nitrogen isotopes (N_{15}:N_{14}) that are dependent upon their source. For example, atmospheric nitrogen's stable isotope ratio is N = -3 to +2. Nitrate leached from soils ranges from +2 to +8, while nitrate from animal waste can range from +10 to +20 (Krietler, 1975). However, water quality data can typically range from +2 to +8, which means that results are often indeterminate (Andrews, 1999). This could indicate that nitrates are from soils, soils mixed with fertilizers and/or animal waste. Also, denitrifying bacteria use lighter molecules as a source of oxygen for their metabolism, leaving isotopically heavier nitrate. This can further confuse the results of nitrogen-isotope ratios in determining sources rendering this method inconclusive.

Source tracking, also known as microbial strain tracing, is a more specific method to determine the source of microorganisms in water supplies. Various methods have been developed for microbial strain tracing, including Fatty Acid Methyl Ester (FAME) analysis, ribotyping or rapid strain tracing (API or Biolog Assays). Each method has advantages and disadvantages over each other (Evenson *et al*., 2000). In an effort to trace in-stream microorganisms to possible CAFO origins, this project utilized the rapid strain tracing method (Biolog Assay). This method uses growth media that allow for the simultaneous testing of a bacteria's ability to utilize 95 separate carbon compounds through a patented redox technology. The resulting pattern of positive and negative results produces a metabolic fingerprint that is unique to each species or strain of bacteria. This allows for a rapid and cost effective isolation of bacterial types. Results are compared to a large database of previously tested organisms.

Radioactive tracers have been employed in many environmental applications to monitor movements of water-borne materials. Their use is especially prevalent in oilfield applications for leak detection and migration of injection brines to adjacent aquifers. Such an approach could be useful to investigate CAFO lagoon leachates and the fate of land-applied liquid wastes.
To address whether CAFO wastes from land application, leakage or other sources is impacting Oklahoma City's water supplies, an assessment study was conducted by the Oklahoma Water Resources Board.

Oklahoma City Water Supply Reservoirs

Oklahoma City's North Canadian River water supply lakes include Canton Reservoir, an in-stream impoundment of the North Canadian River in Blaine and Dewey Counties and Lakes Overholser and Hefner, both off-channel impoundment's located farther downstream in Canadian and Oklahoma Counties, respectively. Recent trophic state indices for these lakes were developed and compared to historical data, when available. Oklahoma City's eastern water supply sources were also assessed as part of this study, although they are not in regions where CAFOs are concentrated. These include Lakes Atoka, McGee Creek and Stanley Draper.

Canton Lake

Canton Lake (Figure 2) is a 7,910-acre impoundment of the North Canadian River at river mile 394.3 in Blaine County. It was started in 1940 and completed in 1948. Its primary purpose is flood control with water supply, irrigation and recreation as secondary uses. It has relatively high total dissolved solids (TDS) and hardness; consequently water from Canton Lake is blended with other supplies prior to use as a potable water supply. Prior to its use by Oklahoma City, water supply releases from Canton Lake are diverted into Lakes Overholser and Hefner.

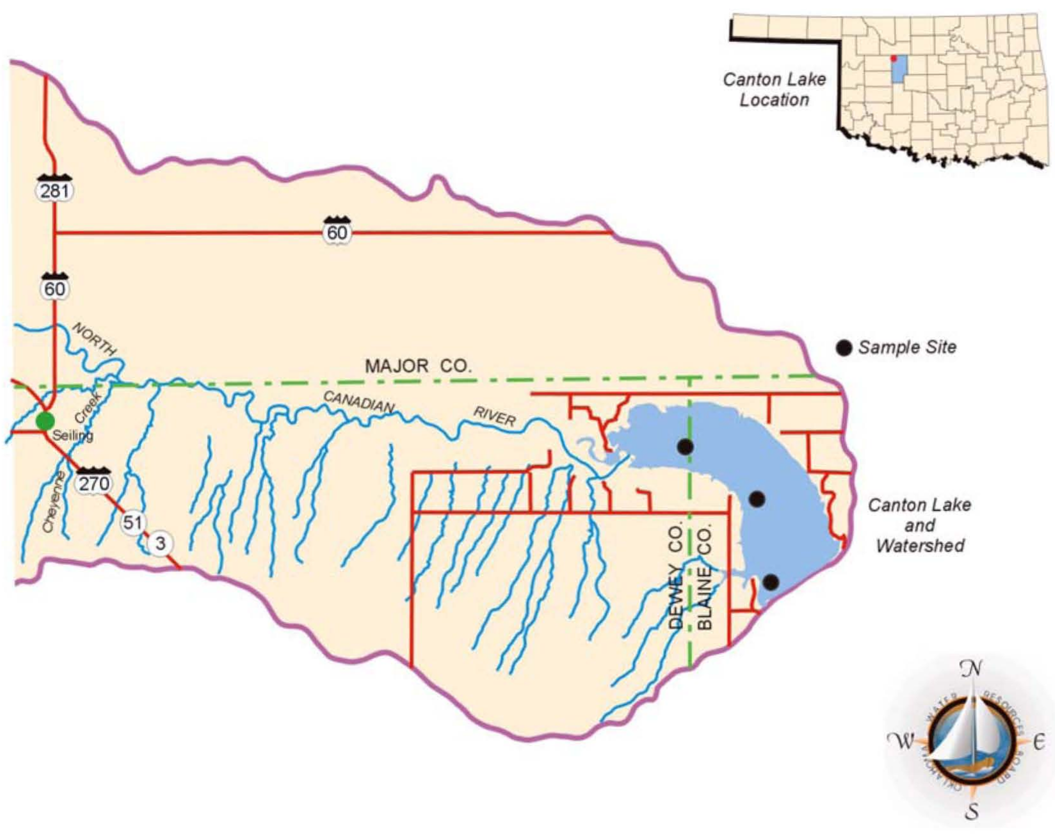


Figure 2. Location of Canton Lake and its watershed**.**

Lake Overholser

Lake Overholser (Figure 3) is a 1500-acre off-channel impoundment of the North Canadian River located in Canadian and Oklahoma Counties. It was constructed in 1919 by the City of Oklahoma City for water supply and recreational purposes. It has essentially no uncontrolled watershed and was constructed off-channel to allow for diversion of water from the North Canadian River when water quality was highest. This typically took advantage of rainfall runoff from the watershed below Canton Lake. That area produces runoff with much lower TDS and hardness than water from areas farther upstream and is therefore less expensive to treat.

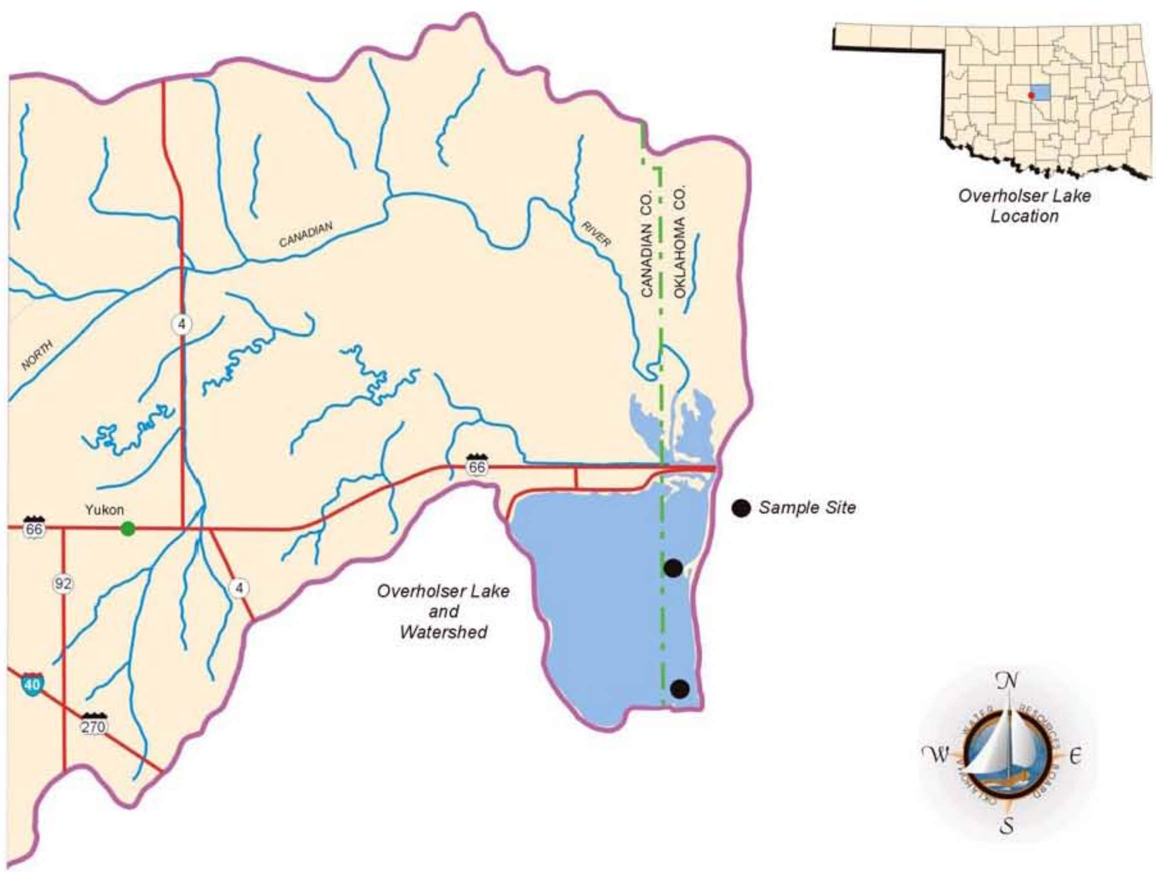


Figure 3. Location of Lake Overholser and its watershed.

Hefner Lake

Hefner Lake (Figure 4) is a 2,500-acre off-channel impoundment of the North Canadian River located in Oklahoma County. The lake was constructed in 1947 by the City of Oklahoma City for water supply and recreation. Like Overholser Lake, it has very little uncontrolled watershed and is filled by diverting the North Canadian River when water quality conditions are optimal.

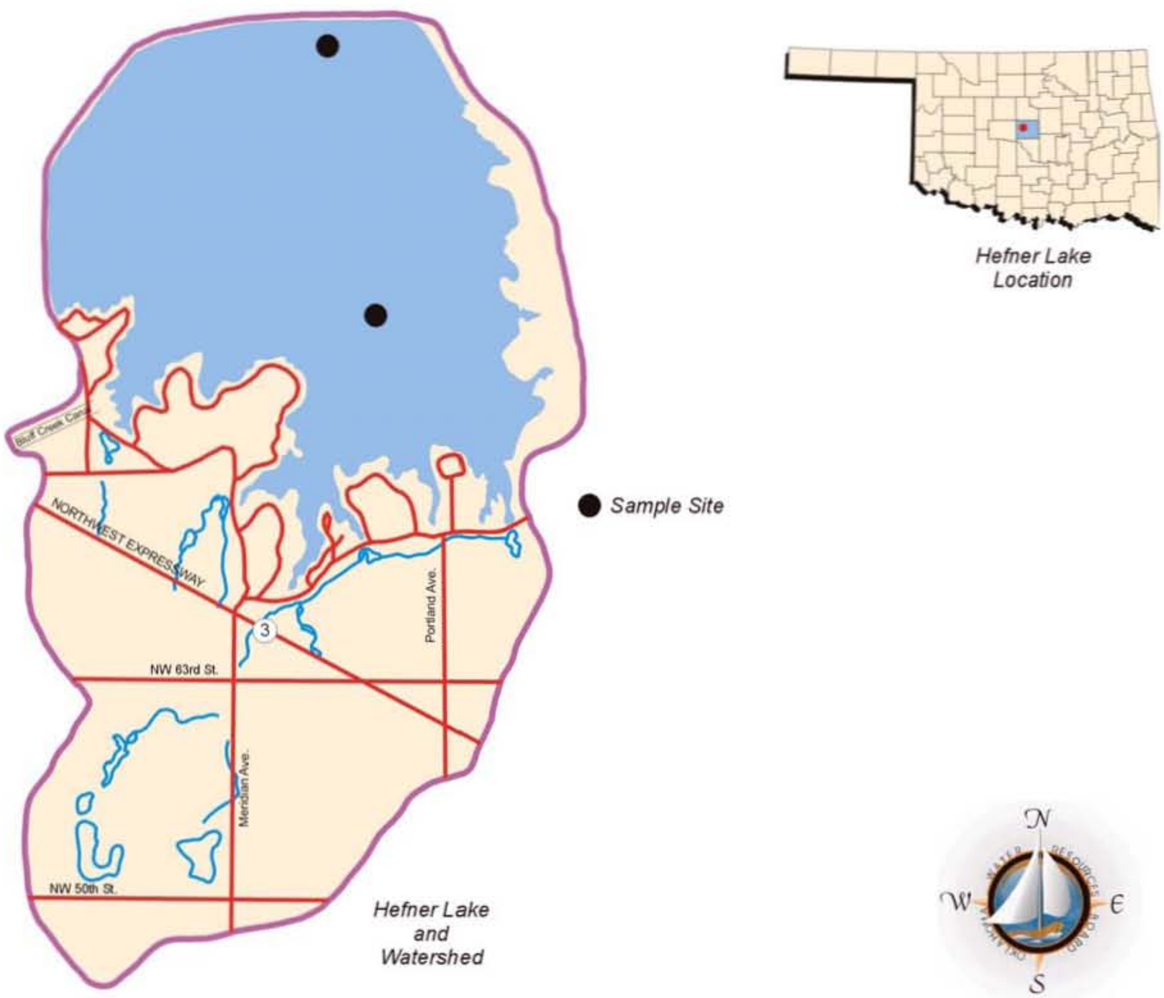


Figure 4. Location of Hefner Lake and its watershed**.**

Lake Stanley Draper

Lake Stanley Draper (Figure 5) is a 5,700-acre impoundment of East Elm Creek located in Cleveland and Oklahoma Counties. Its uncontrolled watershed is not a significant contributor to its yield. Water for its public water supply and recreation uses is pumped from Lake Atoka.

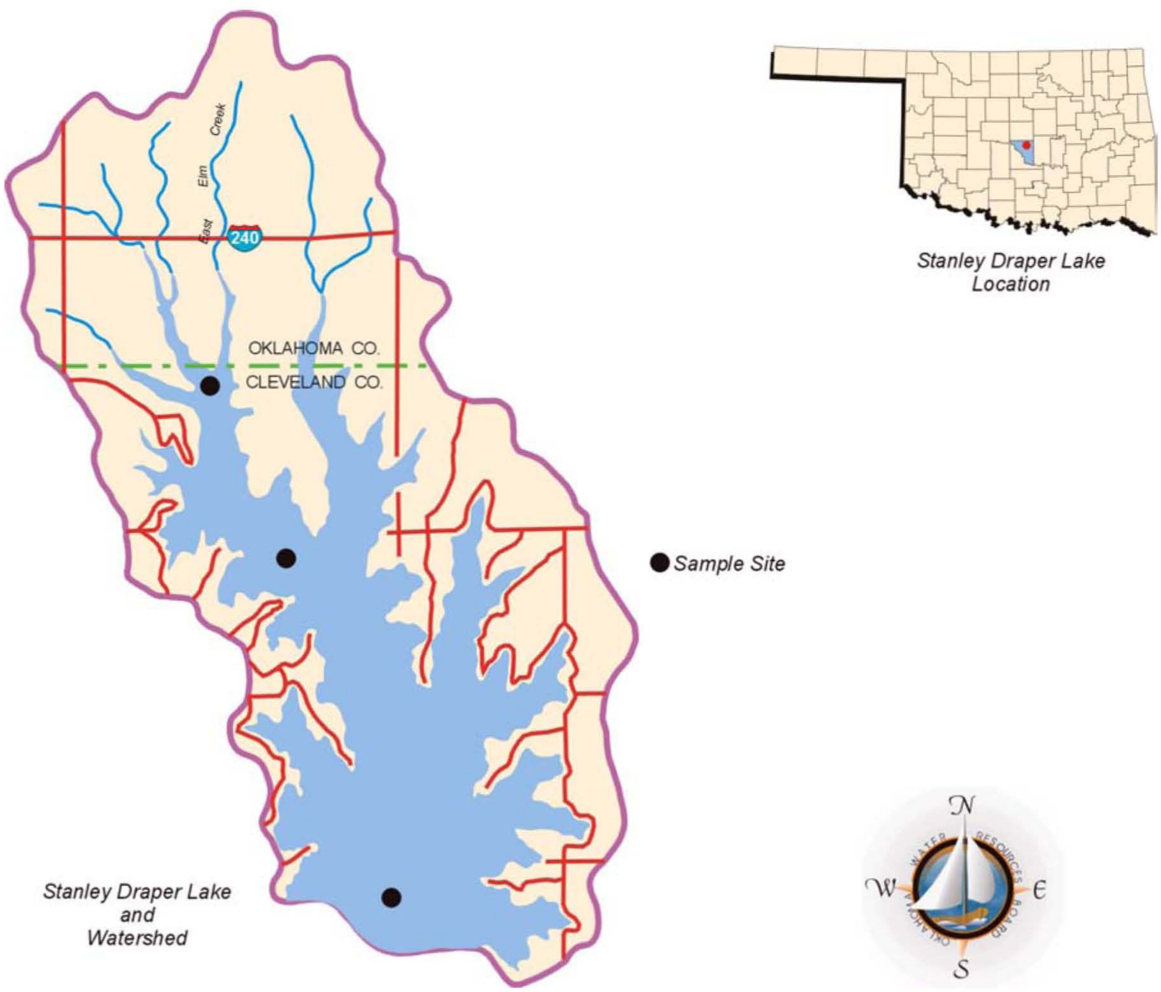


Figure 5. Location of Lake Stanley Draper and its watershed.

Atoka Lake

Atoka Lake (Figure 6) is a 5,700-acre impoundment of North Boggy Creek located in Atoka County. The lake was constructed in 1964 by the City of Oklahoma City for water supply and recreation. Oklahoma City conveys water from Lake Atoka via a 60-inch pipeline approximately 100 miles to Lake Stanley Draper prior to use for domestic water supply.

Figure 6. Location of Atoka Lake and its watershed.

McGee Creek Reservoir

McGee Creek Reservoir (Figure 7) is a 3,810-acre impoundment of McGee Creek located in Atoka County. This Bureau of Reclamation project was completed in 1988. Its uses are designated as flood control, water supply, water quality control, recreation and fish and wildlife. Water from McGee Creek Reservoir is pumped to Lake Atoka through a 72-inch pipeline and then to Lake Draper for use by Oklahoma City.

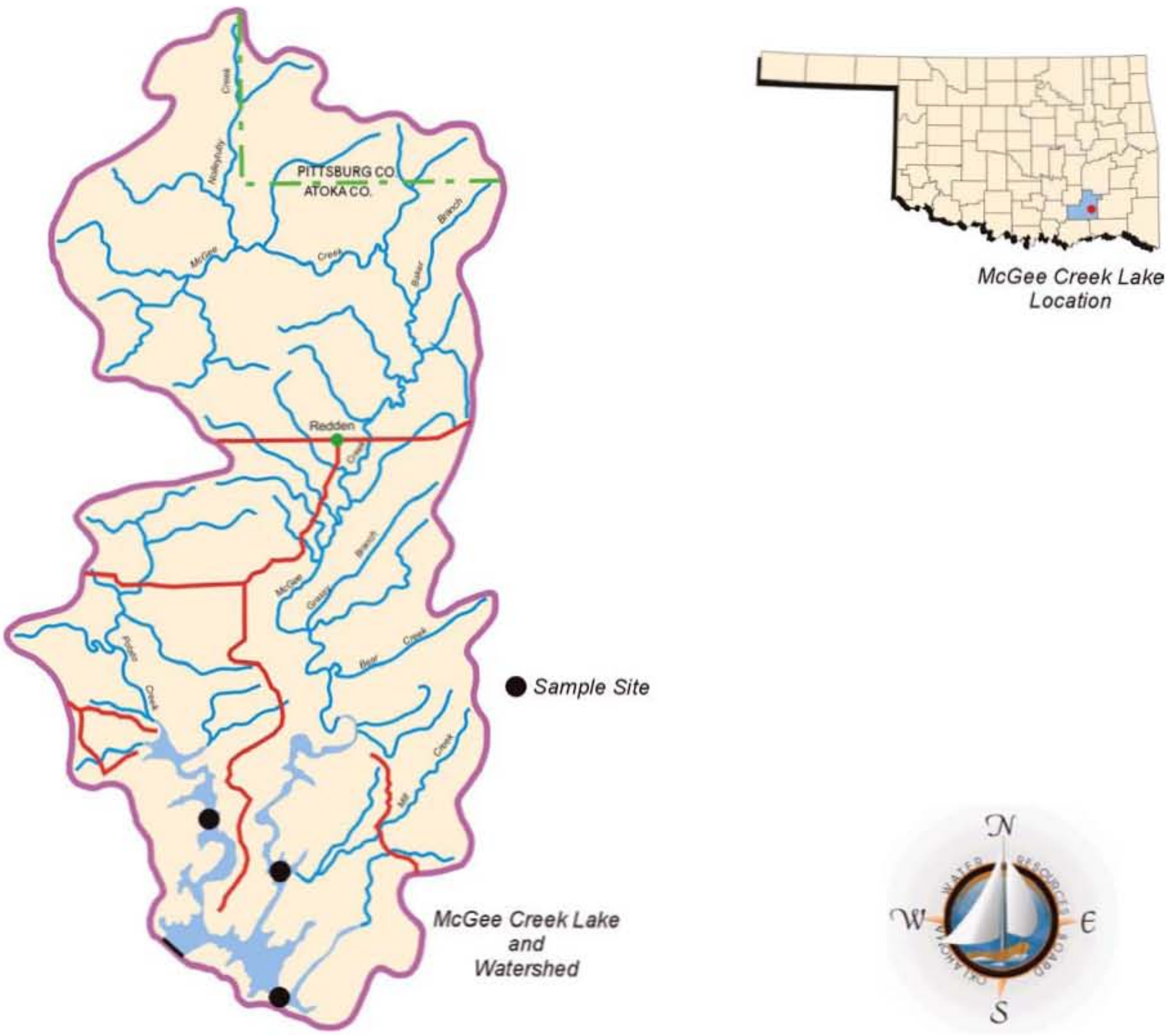


Figure 7. Location of McGee Creek Reservoir and its watershed**.**

Materials and Methods

The principal goal of this project was to determine whether the growth of the CAFO industry in the North Canadian River watershed has had an adverse impact on Oklahoma City's water supplies. It is difficult to ascertain if CAFO's are influencing water quality with out very specific sampling in controlled environments (for example, bacteria strain tracing and/or radio active isotope tracking). Therefore, this project collected current water quality data to determine the current productivity and or nutrient levels in the six reservoirs and at three sites along the North Canadian River; Beaver, Seiling and El Reno. Comparisons were made to historical data, when data were available.

The overall project tasks to achieve this goal were:

Task 1: Compile existing water quality data for Oklahoma City water supply reservoirs and their watersheds using sources from OWRB and City of Oklahoma City data records. Compile existing historical data on the North Canadian River using Ambient Trend Monitoring Stations (ODEQ), USGS gaging stations and City of Oklahoma City data records.

Task 2: Establish a baseline monitoring program in each of these water supply reservoirs and at three sites along the North Canadian River to determine current productivity and or nutrient levels at these sites.

Subtask 2.1. Contract with the University of Oklahoma to perform microbial strain tracking to identify bacteria present in lagoon waters and present in nearby surface waters.

Task 3: Perform bathymetric surveys of the water supply lakes that serve Oklahoma City and develop current bathymetric maps. Maps can be used for future sedimentation studies and provide current volume information.

River Sampling

Data Used. A baseline-monitoring program was established along the Beaver/North Canadian River. Three stations—the Beaver River near Beaver and the North Canadian River near Seiling and El Reno—were selected for long term monitoring and are part of the OWRB's Beneficial Use Monitoring Program. These stations represent strategic areas within the watershed. A fifth station, the North Canadian River near Yukon (State Highway 4 bridge), is a long-term monitoring location for the City of Oklahoma City. General information for each station is provided in Table 1. Along with strategic location, the stations were selected based on the availability of historical data and real-time discharge as well as location within the watershed. All discharge data as well as historical water quality data were provided by the USGS. Data at the Yukon station was provided by the City of OKC. All recent data were provided by the OWRB. The parameters collected are listed in Table 2. A breakdown of the available historical and recent data used in this report is given in Table 3.

Table 1. Baseline monitoring stations for the OKC project.

Operated by	WBID #	STATION NAME	COUNTY	AREA WITHIN WATERSHED	STATUS
OWRB	720500020290	Beaver River near Beaver, OK	Beaver	Middle Panhandle	Active 02/98-present
OWRB	720500010010	North Canadian River near Seiling	Dewey	Above Canton Lake	Active 11/98-present
OWRB	520530000010	North Canadian River near El Reno	Canadian	Below Canton Lake	Active 10/00-present
City of OKC	520530000010	North Canadian River near Yukon- Hwy 4	Canadian	Below Canton Lake	Active 01/80-12/99

Table 2. Parameters Monitored.

SAMPLE PARAMETERS		
General Water Quality Parameters – Sampled Monthly		
Temperature	Dissolved Oxygen	% D.O. Saturation
pH	Chloride	Sulfate
Specific Conductance	Total Dissolved Solids (TDS)	Nephelometric Turbidity
Nutrients – Sampled Monthly		
Kjeldahl Nitrogen (TKN)	Ammonia Nitrogen (NH3)	Ortho-Phosphorus (O-P)
Nitrate Nitrogen/ Nitrite Nitrogen (NO3/NO2)	Total Nitrogen (calculation) (TN)	Total Phosphorus (TP)

Table 3. An overview of available data (N/A = not available).

WQ Group	Beaver River near Beaver	North Canadian River near Seiling	North Canadian River near El Reno	North Canadian River near Yukon
Historical General WQ	Turbidity only	Turbidity only	Turbidity only	**N/A**
Recent General WQ	All	All	All	**N/A**
Historical Nitrogen	NH3 & NO3/NO2	TKN & TN	TKN & TN	NO3
Recent Nitrogen	All	All	All	NO3
Historical Phosphorus	**N/A**	**TP**	**TP**	TP
Recent Phosphorus	All	All	All	TP
Discharge	Continuous	Continuous	Continuous	**N/A**

Data Collection.
Data for water quality parameters were collected in one of two ways. Some parameters were monitored in-situ utilizing a Hydrolab® multiparameter sonde unit or YSI multi-probe instrument. The measurements were taken at the deepest point of the channel at a depth of at least 0.1 meters and no greater than one-half of the total depth. The data were uploaded from the instrument to a data recorder and transferred manually to a field log sheet. These parameters include dissolved oxygen, %D.O. saturation, water temperature, pH, total dissolved solids, and specific conductance.

Data for all other parameters were gathered from water quality samples collected at the station. Samples were collected either by suspending a modified DH-81 handline depth-integrating sampler (polyethylene collection bottle) from a bridge or by wading the stream with a DH-81 wadable depth-integrating sampler (polyethylene collection bottle). If sampling occurred from a bridge, the sampling was done on the down-stream side of the bridge spanning the stream of interest. Samples were collected using a combination of the depth-integration method and the equal-width increment method. The depth-integration method involves collection of samples from the surface of the water to just above the riverbed/streambed. The equal-width-increments-method allows for collection of a composite sample by sampling with depth-integration at 5 to 10 equal widths across the stream. As each increment was sampled, the water was added to a polyethylene churn splitter. From this composite water sample, water quality parameters were monitored in several ways. For laboratory analysis of minerals and nutrients, water was aliquotted from the churn splitter to two (2) ½-gallon bottles (one for sulfuric acid/ice preservation and one for ice preservation). Nephelometric turbidity was determined through use of a HACH Portable turbidimeter. All instruments and test kits were calibrated and used according to manufacturer's instructions. For a more detailed discussion of sampling procedures, refer to the OWRB's BUMP Standard Operating Procedures (SOP). The SOP document can be obtained by contacting the Oklahoma Water Resources Board/Water Quality Programs Division at (405) 530-8800. (NOTE: Samples collected during 1998 were composite grab samples.)

Quality Assurance/Quality Control (QA/QC). QA/QC will not be discussed in detail in this report. However, for a comprehensive description of field QA/QC methods, please contact the Oklahoma Water Resources Board/Water Quality Programs Division at (405) 530-8800. For laboratory QA/QC methods please contact the Oklahoma Department of Environmental Quality/Customer Services Division at (405) 702-6100. Comprehensive QA/QC has been performed on all data collected and utilized for this report.

Statistical Methods. An analysis of central tendency was made for recent data and available historical data using Minitab v. 13 for Windows. The analysis includes the median, minimum, maximum, 25th percentile (Q1), and 75th percentile (Q3). Because data were not normally distributed, the arithmetic means of the data were not included. For available historical and recent total nitrogen, total phosphorus, turbidity and total dissolved solids data, an analysis of trend and a comparison of historical and recent medians were performed using WQStat Plus v. 1.5 for Windows. Using Minitab v. 13 for Windows, The Locally Weighted Scatterplot Smoothing (LOWESS) method removed flow as a confounding factor in the trend analyses. Using the weighted residuals from LOWESS, trend was then analyzed using the Seasonal Kendall based upon three seasons beginning on the first of February, July, and October. Only trends significant at $p < 0.90$ are reported. Because an $n > 40$ is recommended for trend analysis, all analysis of recent trend is questionable and should be viewed as such. The slope of the trend was calculated using the Seasonal Kendall Slope Estimator. The slope represents the magnitude of trend and should not be considered a reflection of constituent concentration.

The Wilcoxen Rank Sum Test ($p < 0.90$) was used to compare medians. Only results significant at $p < 0.90$ are reported.

Other Available Analysis. Analyses of the stations listed in Table 1 are available in several other reports. Wright (1994) analyzed historical water quality data from the Seiling and El Reno stations. Data were collected as part of the Oklahoma State Department of Health's Ambient Water Quality Monitoring Program and were analyzed for central tendency and trend. Textual comparisons of the trend results are reported in the results and discussion section of this document. The OWRB has performed beneficial use assessments on the Beaver, Seiling, and El Reno stations. These assessments are available in the 2000 Beneficial Use Monitoring Program report which is available by contacting the Oklahoma Water Resources Board/Water Quality Programs Division at (405) 530-8800 or on OWRB website at http://www.state.ok.us/~owrb/reports/bump/Bump1.html.

Loading Calculations. Loads were calculated using two methods: 1) the annual average concentration times the annual average flow and 2) flow weighted mean concentrations, (for sample years where data was available). Flow data was obtained from the corresponding USGS gaging station for the three sample sites. The following equation was used to convert the concentration times flow calculation into an annual load value:

$$\text{Load (kg/yr)} = \text{conc (g/m}^3\text{)} \times \text{flow (cfs)} \times 0.02832\ (\text{m}^3/\text{bft}^3) \times 86400\ \text{(sec/day)} \times 365\ \text{(day/yr)} \times (1\text{kg}/1000\text{g})$$

Flow-weighted concentrations were calculated for each collected sample within a stratum using the mean discharge for that stratum. The first stratum was considered low flow and included all discharge values less than one-half the long term mean discharge (Qμ/2). The second stratum was considered medium flow and included all values with the discharge equal to or greater than Qμ/2 to less than two times the mean discharge (Qμ*2). The third stratum was considered high flow and included all observations with discharge equal to or greater than Qμ*2. Once divided into the appropriate strata, a flow-weighted mean concentration was calculated to determine average annual loading. The equation for flow-weighted concentration is as follows (OWRB et al, 1996):

$$\mathbf{c_{fw} = c_i{*}(Q\mu/qi)}$$

where c_{fw} = flow-weighted concentration, c_i = i^{th} observed concentration, $Q\mu$ = mean discharge, and qi = = i^{th} observed discharge.

All flow-weighted concentrations within each stratum were summed and divided by the number of observations per stratum to obtain the mean flow-weighted concentration. The mean flow-weighted concentration for each stratum was then multiplied by the mean flow and percent frequency of observed flows within the corresponding stratum and this value was used to calculate the average annual load for each stratum (mean c_{fw} * mean flow * frequency). The loading calculation is listed as follows:

$$\text{Loading per stratum} = ((\text{mean } c_{fw} * \text{mean flow} * \text{frequency}) * 0.02832*86400*365)/1000$$

Finally, the three average annual load values per stratum were summed to obtain one annual load value for each site.

Microbial Strain Tracing

As part of this study, the Bio Environmental Engineering and Science Laboratory (BEESL) at the University of Oklahoma was contracted to develop methodology for the use of microbial strain tracing as an indicator of CAFO pollution. This procedure attempts to identify bacterial species that are peculiar to CAFOs and that can be isolated from downstream environmental samples. Such a finding would be definitive evidence of off-site migration of CAFO wastes. The specific materials and methods employed by BEESL are included in Appendix A of this report.

The study conducted by OU as part of the OKC CAFO project was used to determine if it is possible that lagoon wastewater could be reaching surrounding streams. To attempt this connection, samples were taken from CAFO lagoons and from the identified river sites. Control samples were collected from river locations upstream from the CAFOs. The results from the testing were then compiled and analyzed through tier testing for both strain and species to determine if specific organisms were found in lagoons. Presence of like organisms in lagoon wastewater and downstream of CAFOs may indicate the CAFOs as their probable origin.

Lake Sampling

A general analysis of water quality was performed for each lake and water quality condition maps were then generated. These condition maps are a representation of average water quality over the sampling period 1998-2000. In addition, a narrative summary is presented for each lake discussing water quality issues related to the reservoir. The brief synopses of information presented should be beneficial in providing a relative comparison of lake water quality in the six Oklahoma City reservoirs.

In addition, water quality data collected by the City of Oklahoma City was analyzed for trends using Seasonall Kendalls Trend test. The data was collected from 1980 through 1999 on Lakes Hefner, Draper, Overholser and Atoka and from 1992-1999 at McGee Creek.

Vertical profiles for dissolved oxygen, pH, temperature, specific conductance, oxidation-reduction potential, total dissolved solids (TDS) and salinity were recorded at one meter intervals at all sample sites using a Hydrolab® multiparameter sonde unit (Table 4). Water quality samples were collected at the surface for all sites, and 0.5 m from the bottom at Site 1, near the dam at each lake. Samples were analyzed at City County Health Department Laboratory until its closure in the summer of 2000 then the remaining samples were taken to the Oklahoma Department of Environmental Quality State Environmental Laboratory. Parameters analyzed include chlorides (mg/l), sulfates (mg/l), ammonia (mg/l), nitrite (mg/l), nitrate (mg/l), kjeldahl nitrogen (mg/l), ortho-phosphorus (mg/l) and total phosphorus (mg/l). Total nitrogen was calculated as nitrite + nitrate + kjeldahl nitrogen(mg/l) (USEPA, 2000). TN:TP ratios will be used as a basis for estimating which nutrient limits algal growth. For reporting purposes total phosphorus and total nitrogen will be discussed in reference to lake trophic state and productivity.

Table 4. Summary table of field measured water quality parameters and their associated range of values, precision and accuracy.

Parameter	Range of Values	Precision	Calibrated Accuracy
Temperature	-5°C to 45°C	0.02°C	± 0.2°C
Dissolved Oxygen	0 to 20 ppm	0.01 ppm	± 2% of reading
pH	0 to 14	0.01	± 0.2
Specific Conductance	0 to 150 µSiemens/cm	0.1% of reading	± 1% of reading
Redox Potential	-1 to +1 V	0.001 V	± 0.010 V
Salinity	0 to 70 ppt	0.1 ppt	± 0.7 ppt

Additional surface samples were collected for chlorophyll-a and turbidity. Filtration and preparation (grinding) of the chlorophyll samples were performed in the field, when possible, and stored in a dark, iced container for subsequent analysis. If filtration was not done in the field, samples were stored in a dark container at 32º C and returned to the OWRB laboratory. Filtration and grinding was performed within 24 hours of collection. Analysis of prepared chlorophyll-a samples was done at the contract laboratory. Turbidity samples were maintained on ice until returning to the OWRB laboratory. Turbidity was determined using a HACH Portable Turbidimeter within 24 hours of sample collection. Secchi disk depths were also recorded at each sample site in each lake. All lake sampling was conducted under the EPA approved BUMP Standard Operating Procedures.

Lakewide Trophic State Indices were calculated using chlorophyll-a (CHL), Secchi disk depth (SD), and total phosphorus (TP) for each lake by averaging all values from the growing season (May and August), annually and cumulatively for the growing season and annually. Carlson (1977) stated chlorophyll-a seems to be the most acceptable parameter to use in calculating TSI and estimating algal biomass, especially during the growing season. In accordance with historical OWRB calculations and Carlson's suggestion to use chlorophyll-a concentration, rather than secchi disk depth or total phosphorus, it is the variable used for TSI calculations by the OWRB. Carlson's TSI equation using chlorophyll-a (in µg/L) as the trophic state indicator is as follows:

$$TSI = 9.81 \times \ln(\text{chlorophyll-}\underline{a}) + 30.6.$$

Secchi Disk depth (SD) TSI is not a good parameter to use as it does not account for inorganic turbidity, which is fairly common in Oklahoma lakes. Reservoirs characterized by a high degree of inorganic turbid this parameter may give a false positive for high productivity, when it is likely indexing the high suspended solids. For this report it will be discussed only in terms of water clarity, not differentiating between types of turbidity. The TSI calculation using secchi disk depth (in meters) as the variable is:

$$TSI = 60 - (14.41 \times \ln(\text{secchi depth})).$$

TSI was also calculated with TP for comparison purposes. The TP TSI values represent the potential TSI for the lake if all phosphorus was used to produce chlorophyll through primary production. Inorganic turbidity may also affect the resulting TSI based on TP calculations through light attenuation reducing algal productivity (EPA, 1990). In addition, phosphorus may not be an accurate variable to use in calculating the TSI in lakes that are not phosphorus-limited. The TSI calculation using total phosphorus (in mg/m^3) as the variable is:

$$\mathbf{TSI = 14.42 \times \ln(total\ phosphorus) + 4.15.}$$

The OWRB uses the following ranges for trophic state classification for all three parameters (Table 5); less than 40 indicates oligotrophy or low productivity, 41- 50 indicates mesotrophy or moderate productivity, 51- 60 indicates eutrophy or high productivity, and greater than 61 as hypereutrophy or excessive productivity. The OWRB states lakes with a TSI $\geq$ 62 are considered a "nutrient limited watershed" and are threatened due to nutrient impacts. A nutrient-limited watershed ("NLW") is "a watershed of a waterbody with a designated beneficial use which is adversely affected by excess nutrients as determined by Carlson's Trophic State Index (using chlorophyll-a) of 62 or greater, or is otherwise listed in Appendix A of Chapter 785:45 of OWQS."

Table 5. Lake Trophic State categories.

Carlson TSI No.	Trophic State	Definition
< 40	Oligotrophic	Low primary productivity with low nutrient levels
41 – 50	Mesotrophic	Moderate primary productivity with moderate nutrient levels
51 – 60	Eutrophic	High primary productivity and nutrient rich
> 61	Hypereutrophic	Excessive primary productivity and greatly excessive nutrients

Each measure or index was designed to reflect a doubling of phytoplankton biomass for every 10-unit increase in the TSI value, ranging from 0 -100. The chlorophyll-a TSI (CHL TSI) was developed as the most direct measure of trophic state. The total phosphorus TSI (TP TSI) serves as a measure of trophic state potential for the water body. Secchi depth TSI (SD TSI) was developed to directly reflect the trophic status of the water body. The underlying assumption for the application of Secchi TSI is that water transparency is directly related to algal biomass. This assumption is valid for waters where turbidity is relatively low and a considerable portion is organic in nature.

Lake wide averages were used by combining all sites within each lake. Through this technique, the effect of localized trophic conditions are minimized (i.e. the effects of a single isolated elevated chlorophyll-a or total phosphorus value is minimized in the calculation of the overall TSI). The derived TSI represents an accurate assessment of the water quality of the reservoir as a whole. Individual areas of a sample lake may be impacted by eutrophication but may not be reflected in the overall TSI reported. The lake was then classified according to the resultant value from the combined annual CHL TSI average, according to Oklahoma methodologies. Comparisons were made among TSI types to ascertain whether each lake would be classified differently, depending upon the measure used. This can give a more complete picture of the trophic state of each lake.

An analysis of the limnological data collected on the six lakes was performed by combining all sites on a particular lake, and determining, ranges, annual averages, and cumulative averages for each parameter. Surface turbidity measurements were compared to Oklahoma's turbidity standard of 25 NTU. Lakes that exceed this value were classified as violating the Fish and Wildlife Propagation beneficial use as defined in Oklahoma Statutes Chapter 45 Section 785. In addition, dissolved oxygen (mg/l), pH, and minerals (total dissolved solids, chlorides and sulfates) and fecal coliforms were compared to OWQS where applicable.

Bathymetric Mapping

Bathymetric mapping is the process used to determine the storage capacity of reservoirs and lake bottom contours. As performed by OWRB, a differential global positioning satellite system (DGPS) is used in conjunction with an acoustic depth sounder (Fathometer) and Coastal Oceanographic Hypack software. The use of this technology has allowed the surveying process to become more efficient and accurate. This mapping process was utilized to survey Lakes Hefner, Overholser, Stanley Draper, Atoka and McGee Creek during the span of this study.

The bathymetric surveys consist of three successive procedures. These include setup, field surveying and post-processing of the collected data. In the first procedure, Hypack software from Coastal Oceanographic is used to create virtual track lines that are laid across a digital rendering of the reservoir with GPS coordinates. These virtual track lines are spaced according to the accuracy that is required for each project. Closely spaced virtual lines will result in the collection of considerable amounts of data. Data directories for stored data are also created in the setup procedure. The next step in the surveying process is the field surveying.

Field Surveying consists of the data collection. The fathometer is calibrated on-site to the salinity concentration of the lake. Virtual lines are followed across the lake until the entire navigable surface area of the reservoir has been covered. A differential GPS (XY) point and a depth reading (Z) are collected every 300 ms while navigating each virtual line. The raw data is collected in State Plane 1983 Geodetic Parameters. In this mode the XYZ coordinates are collected in feet. The Coastal Oceanographic Hypack software is used to display the map of the reservoir, the virtual lines and store all data points. After the field surveying has been completed the mapping process continues back in the office where post-processing takes place.

This last procedure involves reviewing the data for accuracy and completeness using the Hypack Single Beam Editing program. This editing program displays each virtual line and the profile of the data collected on that line. Coordinate points on each line that are not accurate are integrated with adjacent accurate points this process reduces the “noise” in data collection. Fluctuations in lake levels are also adjusted in the raw data during this process. This is done by recording the lake levels on the days that the surveying took place and then adjusting the raw Z coordinate values. Once the raw data has been corrected the data is sorted. The sort program can eliminate conflicting data points based on either a Radius or DX-DY distance. With a Radius, the preferred method, the program eliminates any other data point within the radial distance of the accepted point. The smaller the radius, the less edited data is rejected and a larger radius, the accepted value results in more edited data that is rejected. The Sort program then saves the edited data to an ASCII XYZ data file with the .XYZ extension. The XYZ data file is then imported into Arc View 3.0 where data is rendered in a map, such as a contour map, or some other form of graphical representation to satisfy the needs of the project. Volume calculations can then be made for comparison to original volumes and/or projected volumes.

Results and Discussion

Part I. North Canadian River

Beaver River near Beaver, Beaver County

Station AT234000 is a permanent ambient trend monitoring station located on the Beaver River in Oklahoma. Situated in the north central portion of Beaver County, the site was established north of the City of Beaver at State Highway 23. The station is positioned near the midpoint of stream segment 720500020290 and is classified within the Middle Beaver River 8 digit HUC watershed (11100102). Water enters the stream system from several tributaries, including Willow Creek, Sixmile Creek, Home Creek and Clear Creek, among others. For purposes of reporting, this station is representative of the Beaver River from below the confluence of Sharp Creek downstream to below the confluence of Clear Creek with the Beaver River. Appendix A, Table 7 of OAC 785:45 assigns to this water quality management segment the following designated beneficial uses: 1) Warm Water Aquatic Community-Fish and Wildlife Propagation (WWAC), 2) Agriculture-Class III Irrigation (AG), and 3) Primary Body Contact-Recreation (PBCR).

General Water Quality
Dissolved oxygen (D. O.), D. O. percent saturation, pH, and total dissolved solids (TDS) were measured monthly from January of 1999 through September of 2000 and turbidity was measured monthly from February of 1998 through September of 2000. Sporadic historical data exists for turbidity from February of 1980 through July of 1994. Recent data for all but percent saturation is graphically displayed in Figure 8. Dissolved oxygen is plotted versus water temperature (^{o}C).

For each variable, an analysis of central tendency was made (Table 6). Percent saturation of D. O. indicates that the reach is highly productive. Not only is the median 114%, but half of the measurements lie between 97 and 143%. Although data were not collected, the high saturation rates could produce higher than normal instream algal growth as well as anoxic conditions during the nighttime. The moderately basic pH suggests conditions that are typical for this area of the state, although one value (9.1 units) lies above the upper limit for the support of the Fish and Wildlife beneficial use. Recent turbidity data is well within the state water quality standard of 50 NTU's while historical data show several spikes in levels of suspended particulates. For turbidity, a two-tailed comparison of the medians reveals that recent data are significantly lower than historical data (Z_{test} = -1.964; Z_{table} = 1.960 at $p < 0.975$), but 75% of both data sets are below 12 NTU's. Low turbidity levels also enhance the availability of light for photosynthetic organisms. Elevated levels of TDS indicate saline conditions. The TDS median of 4288.0 mg/l is above segment specific long-term average of 2575 mg/l listed in the OWQS. In addition, trend analyses were made on turbidity and TDS (Table 7) with no significant trend detected.

Nitrogen

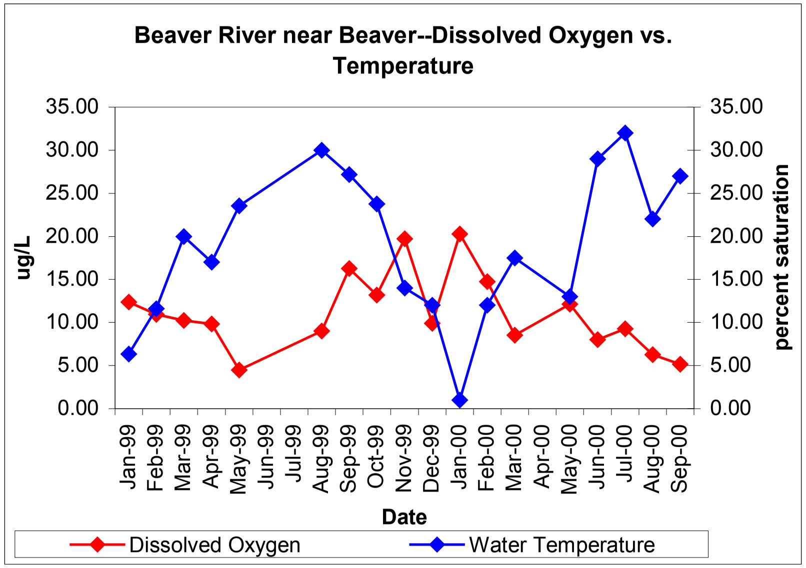
From February of 1998 through September of 2000, nitrogen was measured monthly as several species including ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), and total Kjeldahl nitrogen (TKN). Total nitrogen (TN) was calculated as NO_2+NO_3+TKN (USEPA, 2000). Sporadic historical data exists for ammonia from February of 1980 through July of 1994 and for nitrite and nitrate from November of 1985 through July of 1994. Nitrate and nitrite are analyzed as a combined species. The calculated TN for recent data is graphically displayed in Figure 9.

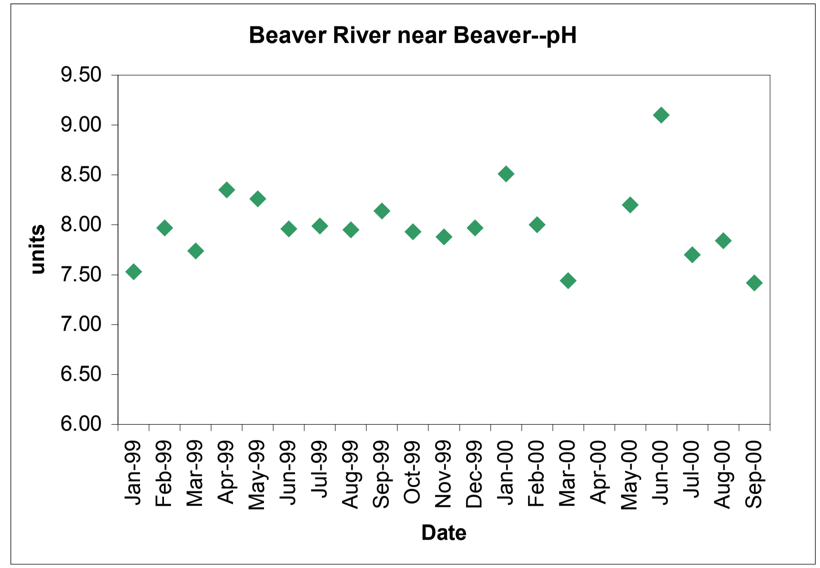
For each variable, an analysis of central tendency was made (Table 8). Recent ammonia is well within recognized freshwater aquatic and human health limits with an upper range of 0.120 mg/l and 75% of samples below 0.050 mg/l. Recent TN and biologically available nitrate/nitrite were also within recognized freshwater aquatic and human health limits with upper ranges of 1.25 and 0.92 mg/l, respectively. In addition, a trend analysis was performed on recent total nitrogen (Table 7). Raw TN data (Figure 10) as well as flow-adjusted TN data (Figure 11) display a significant negative trend since February of 1998.

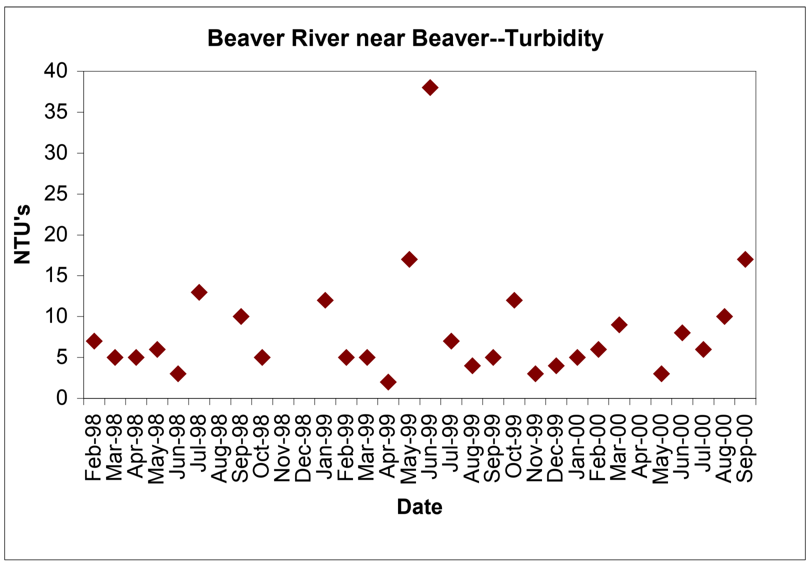
Phosphorus

From February of 1998 through September of 2000, total phosphorus (TP) was measured monthly as well as ortho-phosporus (ortho-P). No historical data exists for either parameter. The current TP data is graphically displayed in Figure 9.

For each variable, an analysis of central tendency was made (Table 6). With a median of 0.050 mg/l, TP is above the generally accepted freshwater background level of 0.03 mg/l , however no water quality standard for phosphorus exists at this time. When comparing the third quartile of ortho-P (0.015 mg/l) to TP (0.077 mg/l), it can be determined that inorganic phosphate contributes approximately 20% of the total phosphorus concentration. In addition, trend analysis was performed on TP (Table 7) with no significant trend detected.







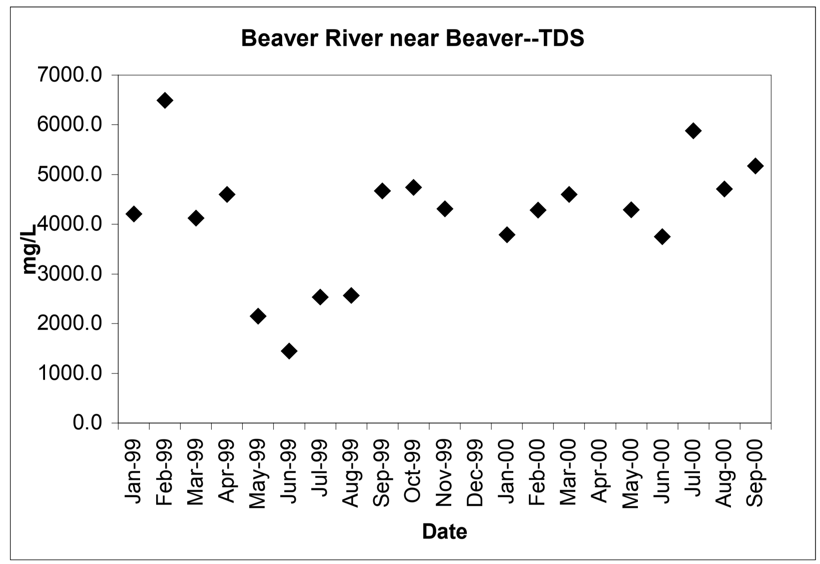


Figure 8. General water quality data collected at Beaver River near Beaver, OK, from February 1998 through September of 2000. (Note: Connected lines in D. O. graph do not indicate a suggested trend.)

Table 6. Measurements of central tendency for general water quality parameters collected at the Beaver River near Beaver, OK, from February 1998 through September of 2000 and historical data collected from February of 1980 through July of 1994.

Parameters	N	Median	Minimum	Maximum	Q1	Q3
Dissolved Oxygen (mg/l)	18	10.06	4.47	20.28	8.40	13.59
Dissolved Oxygen (% saturation)	18	114.2	53.3	199.0	96.6	142.5
pH (units)	20	7.97	7.42	9.10	7.77	8.19
Turbidity (NTU's)	28	6	2	38	4	12
Historical Turbidity (NTU's)	58	4	0	280	2	11
Total Dissolved Solids (mg/l)	19	4288.0	1445.0	6492.0	3758.0	4701.0

Table 7. Trend analysis for data collected at the Beaver River near Beaver, OK, from February 1998 through September of 2000.

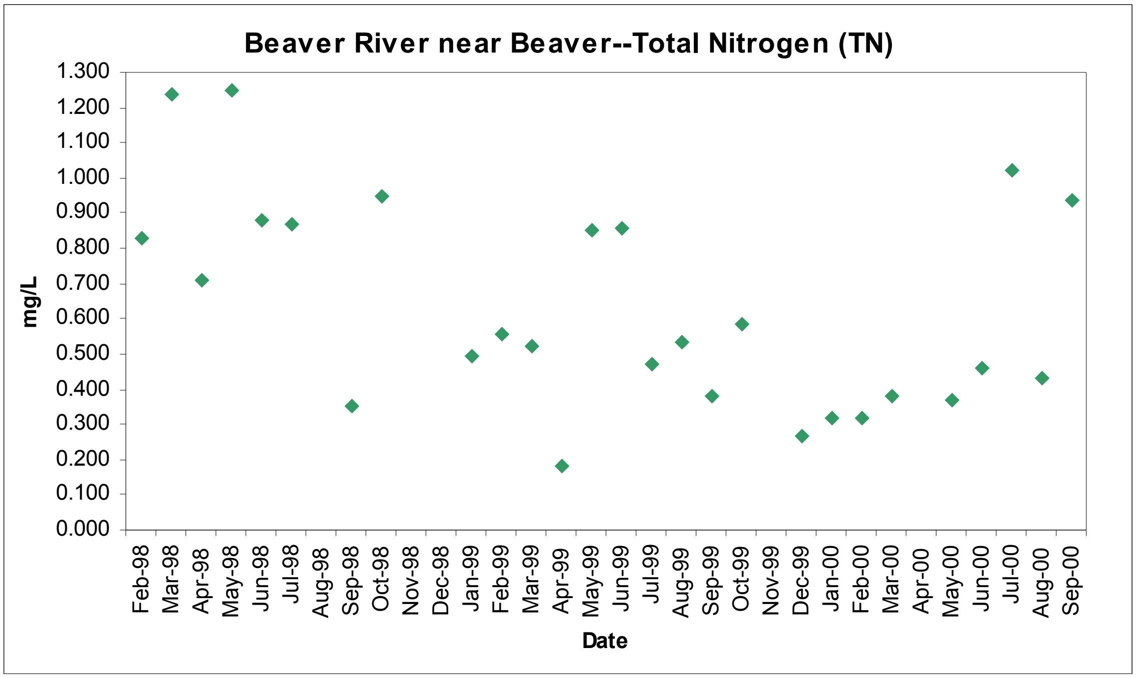
Parameter	N	Z (test stat)	Conf. Level	Slope (units/yr)
Total N	27	-1.866	0.95	-0.210
Flow-adj. Total N	27	-1.743	0.90	-0.204
Total P	27	0.847	NS	
Flow-adj. Total P	27	1.623	NS	
TDS	28	1.122	NS	
Flow-adj. TDS	28	1.533	NS	
Turbidity	28	0.711	NS	
Flow-adj. Turbidity	28	1.415	NS	

NS = non-significance at the 0.90 confidence level.

Table 8. Measurements of central tendency for nitrogen and phosphorus data collected at the Beaver River near Beaver, OK, from February 1998 through September of 2000 and historical data collected from February of 1980 through July of 1994.

Parameters	N	Median	Minimum	Maximum	Q1	Q3
Ammonia (mg/l)	25	0.025	0.025	0.120	0.025	0.050
Historical Ammonia (mg/l)	57	0.050	0.010	1.200	0.020	0.090
Nitrite/Nitrate (mg/l)	27	0.050	0.025	0.920	0.050	0.100
Historical Nitrite/Nitrate (mg/l)	33	0.020	0.020	0.280	0.020	0.020
Total Kjeldahl Nitrogen (mg/l)	27	0.450	0.130	1.150	0.320	0.770
Total Nitrogen (mg/l)	27	0.535	0.180	1.250	0.380	0.870
Ortho-Phosphorus (mg/l)	27	0.007	0.003	0.258	0.003	0.015
Total Phosphorus (mg/l)	27	0.050	0.008	0.430	0.019	0.077

Figure 9. Total nitrogen and total phosphorus data collected at Beaver River near Beaver, OK, from February 1998 through September of 2000.



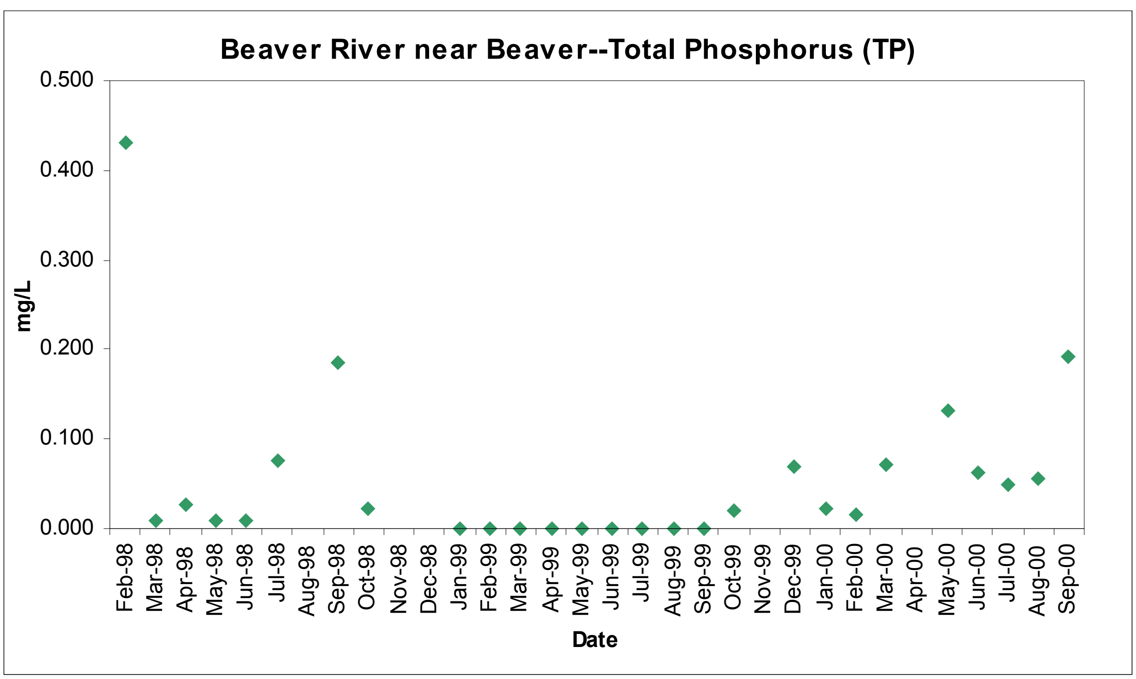


Figure 10. Trend analysis for raw total nitrogen data collected from February of 1998 through September of 2000 at the Beaver River near Beaver, OK. Slope calculated using the Seasonal Kendall slope estimator. Data deseasonalized based on three seasons beginning February 1, July 1, and October 1. Values on Y-axis are LOWESS calculated residuals.

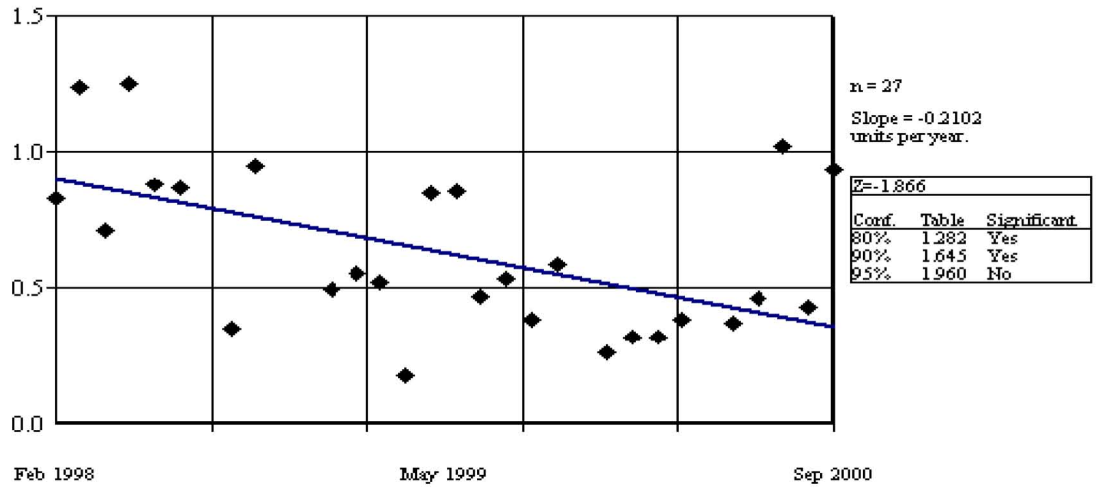
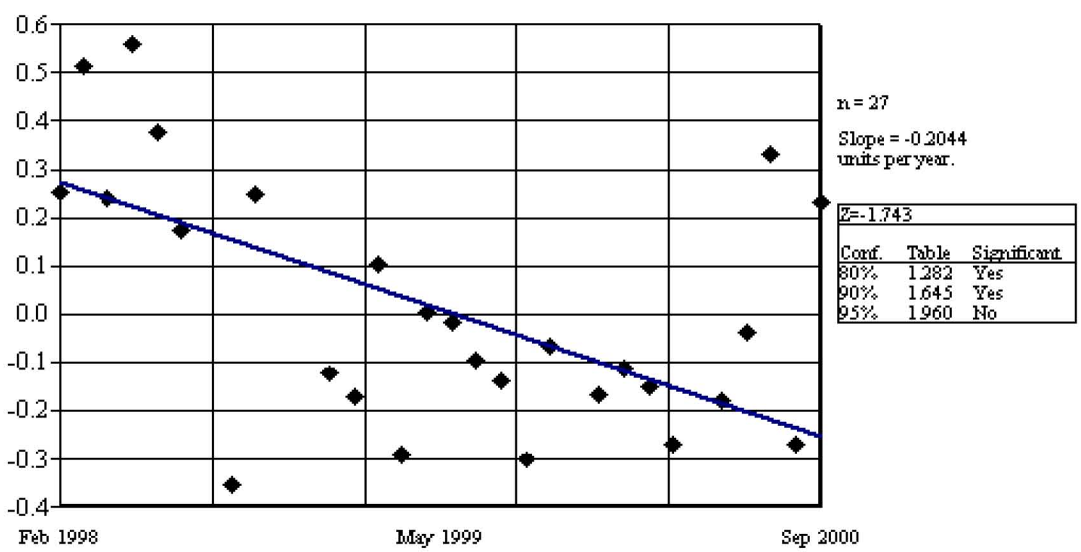


Figure 11. Trend analysis for flow-adjusted total nitrogen data collected from February of 1998 through September of 2000 at the Beaver River near Beaver, OK. Slope calculated using the Seasonal Kendall slope estimator. Data deseasonalized based on three seasons beginning February 1, June 1, and October 1. Values on Y-axis are LOWESS calculated residuals.



Nutrient Loads

Loadings were calculated for this site using current data from February of 1998 through August 2000. Insufficient historical data was available. Overall the loading values are relatively small in comparison to other watersheds and larger order streams. The average annual flow in 1999 was higher than the other report years (1998 and 2000), likewise the average of all flows reported on the sample collection days also reflects a higher value in 1999, making the loading representative of conditions for that sample year.

Loads were calculated from both the average concentration times average of daily flow (Table 9) and flow weighted mean concentrations. Flow weighted mean values resulted in a much higher value (almost 4 times higher) than were loadings calculated using the average flow and average concentration from 1998 to 2000. Flow weighted mean values utilized 27 samples collected over the 1998 through 2000 sampling interval. The period of record flow at this station, 16 cfs (1979-2000), was used to separate the sample events into low ($<Q\mu/2$), medium ($\geq Q\mu/2$ and $<Q\mu*2$), and high ($\geq Q\mu*2$) flow strata. Of these 27 samples, 14 were considered low flow (52%), 11 medium (41%), and 2 high flow (7%). The loadings calculated using this method were 4,065 kg/yr for TP and 23,242 kg/yr for TN. Although only 2 of the 27 days (7%) were high flow periods, over 25% of the load contribution was during high flow events.

Table 9. Summary of TP and TN loads at the Beaver Site, Beaver River.

	No. of samples	Avg flow of samples (cfs)	Annual avg. flow (cfs)	TP load (kg/yr)	TN load (kg/yr)
1998	8	7.48	8.99	639	5,908
1999	11	26.81	18.4	1,066	12,812
2000	8	6.06	5.74	409	2,977
Total from 1998-2000	27	15	16 (period of record)	1,081	8,579

North Canadian River near Seiling

Station AT238000 is a permanent ambient trend monitoring station located on the North Canadian River. Situated in the southwestern portion of Major County, the site was established north of the town of Seiling on US Highway 281. The station is positioned near the midpoint of stream segment 720500010010 and is classified within the Middle North Canadian River 8 digit HUC watershed (11100301). Water enters the stream system from several tributaries including Bent Creek, Deep Creek, and Cheyenne Creek, among others. For purposes of reporting, this station is representative of the North Canadian River from the confluence of an unnamed tributary near Mutual, Oklahoma downstream to confluence of the North Canadian River with Canton Lake. As per Appendix A, Table 7 of OAC 785:45, this water quality management segment is assigned the following designated beneficial uses: 1) Public and Private Water Supply (PPWS), 2) Warm Water Aquatic Community—Fish and Wildlife Propagation (WWAC), 3) Agriculture—Class III Irrigation (AG), and 4) Primary Body Contact—Recreation (PBCR).

General Water Quality
Dissolved oxygen (mg/l), D. O. percent saturation, pH, turbidity, and total dissolved solids (TDS) were measured monthly from January of 1999 through September of 2000. Sporadic historical data exists for turbidity from January of 1980 through July of 1995. Recent data for all but percent saturation is graphically displayed in Figure 12. Dissolved oxygen is plotted versus water temperature (^{o}C).

For each variable, an analysis of central tendency was made (Table 10). In addition, trend analyses were made on turbidity and TDS (Table 11). Percent saturation of D. O. indicates that the reach is moderately productive. Not only is the median 99%, but half of the measurements lie between 87 and 116%. Although data were not collected, the moderate saturation rates could produce higher than normal instream algal growth as well as anoxic conditions during the nighttime. The moderately basic pH suggests conditions that are typical for this area of the state, although one value (9.1 s.u.) lies above the upper limit for the support of biological life. The median turbidity value, calculated from recent data, was 32 NTU's, well within the state water quality streams standard of 50 NTU's. Only 25% of the turbidity data were above the standard (Q3 = 69 NTU's), while 75% of historical turbidity data are well below the standard (Q3 = 24 NTU's). A two-tailed comparison of the medians reveals that recent data are significantly higher than historical data (Z_{test} = 3.744; Z_{table} = 2.32 at p < 0.99). Furthermore, an analysis of the recent data detects a significantly positive trend in flow-adjusted turbidity levels (Figure 14). Although no significant trend was detected for available historical data, Wright (1994) reported a significant upward trend for turbidity between December of 1975 through February of 1993.

Levels of TDS indicate moderately saline conditions, but are within the segment specific criterion listed in the OWQS. No significant trend was detected, but Wright (1994) reported a significant downward trend for specific conductance between December of 1975 through February of 1993.

Nitrogen

From January of 1999 through September of 2000, nitrogen was measured monthly as several species including ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), and total Kjeldahl nitrogen (TKN). Total nitrogen (TN) was calculated as NO_2+NO_3+TKN (USEPA, 2000). Sporadic historical data exists for TKN and TN from January of 1980 through September of 1993. Nitrate and nitrite are analyzed as a combined species. The calculated TN for recent data is graphically displayed in Figure 13.

For each variable, an analysis of central tendency was made (Table 12). Recent ammonia is within recognized human health limits, but the upper limit (0.310 mg/l) is within the range of what may be considered harmful to freshwater aquatic life. Recent TN and biologically available nitrate/nitrite were also within recognized freshwater aquatic and human health limits with upper ranges of 1.61 and 0.885 mg/l, respectively. In addition, trend analyses was performed on historical and recent total nitrogen (Table 11). No significant trends were detected. A two-tailed comparison of the medians reveals no significant difference between historical and recent TN data.

Phosphorus

From January of 1999 through September of 2000, total phosphorus (TP) was measured monthly as well as ortho-phosporus (ortho-P). Sporadic historical data exists for TP from January of 1980 through September of 1993. The current TP data is graphically displayed in Figure 2.

For each variable, an analysis of central tendency was made (Table 12). With a median of 0.108 mg/l, TP is above the generally accepted freshwater background level of 0.03 mg/l, however no water quality standard currently exists for total phosphorus. When comparing the third quartile of ortho-P (0.056 mg/l) to TP (0.169 mg/l), it can be determined that inorganic phosphate contributes approximately 33% of the total phosphorus concentration. In addition, trend analysis was performed on both historical and recent TP (Table 11). No significant trend was detected for recent TP. Historical raw TP data (Figure 15) as well as flow-adjusted TP data (Figure 16) displayed a significant negative trend from January of 1980 through September of 1986. In contrast, Wright (1994) reported a significant upward trend for TP between December of 1975 through February of 1993 (larger data set). A two-tailed comparison of the medians reveals no significant between historical and recent TP data.

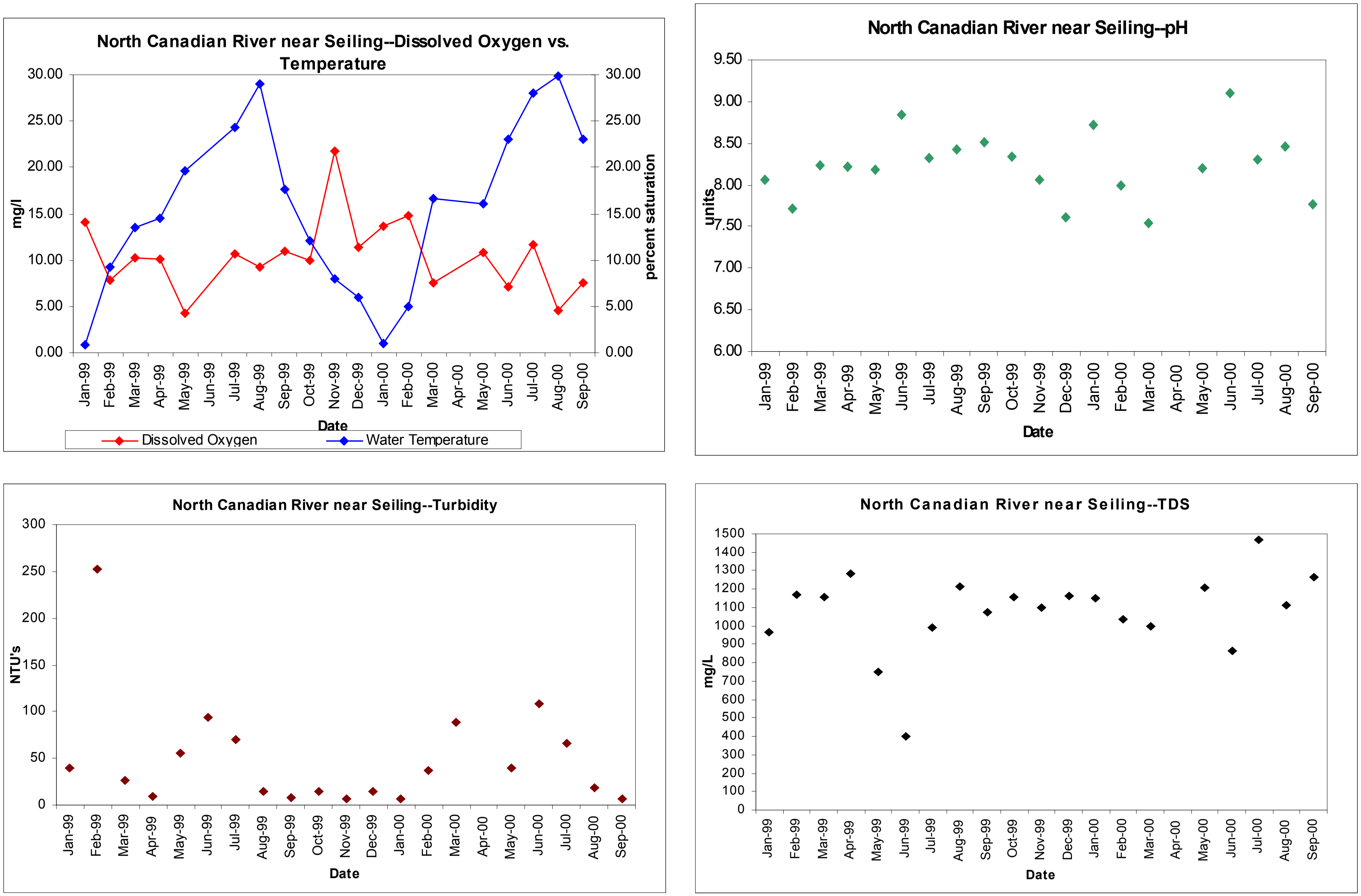


Figure 12. General water quality data collected at North Canadian River near Seiling, OK, from January 1999 through September of 2000. (Note: Connected lines in D. O. graph does not indicate a suggested trend.)

Table 10. Measurements of central tendency for general water quality parameters collected at the North Canadian River near Seiling, OK, from January 1999 through September of 2000 and historical data collected from February of 1980 through July of 1995.

Variable	N	Median	Minimum	Maximum	Q1	Q3
D.O. (mg/l)	19	10.24	4.20	21.73	7.53	11.63
D.O. Percent Saturation	19	98.8	46.1	185.0	87.1	116.1
pH (units)	20	8.22	7.54	9.10	8.02	8.45
Turbidity (NTU's)	20	32	6	253	10	69
Historical Turbidity (NTU's)	112	8	1	460	3	24
TDS	20	1131.5	398.5	1471.0	995.4	1198.5

Table 11. Trend analysis for data collected at the North Canadian River near Seiling, OK, from January 1999 through September of 2000 and historical data collected from January of 1980 through September of 1986.

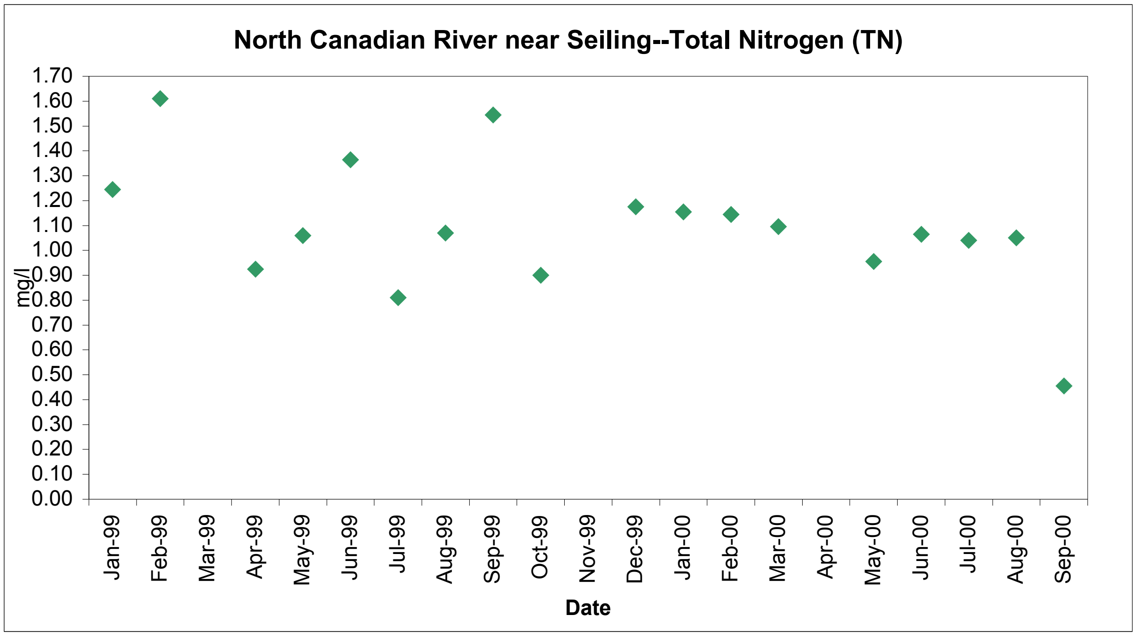
Parameters	N	Z (test stat)	Conf. Level	Slope (units/yr)
Historical Total N	56	-0.507	NS	
Flow-adj. Hist. Total N	56	-1.372	NS	
Total N	18	-0.992	NS	
Flow-adj. Total N	18	-0.992	NS	
Historical Total P	79	-2.056	0.95	-0.023
Flow-adj. Hist. Total P	79	-2.622	0.95	-0.025
Total P	19	0.230	NS	
Flow-adj. Total P	19	0.803	NS	
TDS	20	0.770	NS	
Flow-adj. TDS	20	0.110	NS	
Hist. Turbidity	79	0.812	NS	
Flow-adj. Hist. Turbidity	79	-0.958	NS	
Turbidity	20	0.221	NS	
Flow-adj. Turbidity	20	1.650	0.90	12.0

NS = non-significance at the 0.90 confidence level.

Table 12. Measurements of central tendency for nitrogen and phosphorus data collected at the North Canadian River near Seiling, OK, from January of 1999 through September of 2000 and historical data collected from January of 1980 through February of 1993.

Variable	N	Median	Minimum	Maximum	Q1	Q3
Ammonia (NH_3)	18	0.025	0.025	0.310	0.025	0.130
Nitrite (NO2) + Nitrate (NO3)	18	0.413	0.050	0.885	0.194	0.779
Total Kjeldahl Nitrogen (TKN)	18	0.640	0.270	1.160	0.400	0.818
Historical TKN	94	0.783	0.100	5.140	0.559	1.145
Total Nitrogen (TN)	18	1.068	0.455	1.610	0.948	1.193
Historical TN	75	0.900	0.100	5.140	0.560	1.510
Ortho-Phosphorus (O-P)	20	0.033	0.003	0.131	0.016	0.056
Total Phosphorus (TP)	19	0.108	0.038	0.319	0.090	0.169
Historical TP	94	0.227	0.005	1.550	0.115	0.370

Figure 13. Total nitrogen and total phosphorus data collected at North Canadian River near Seiling, OK, from January 1999 through September of 2000.



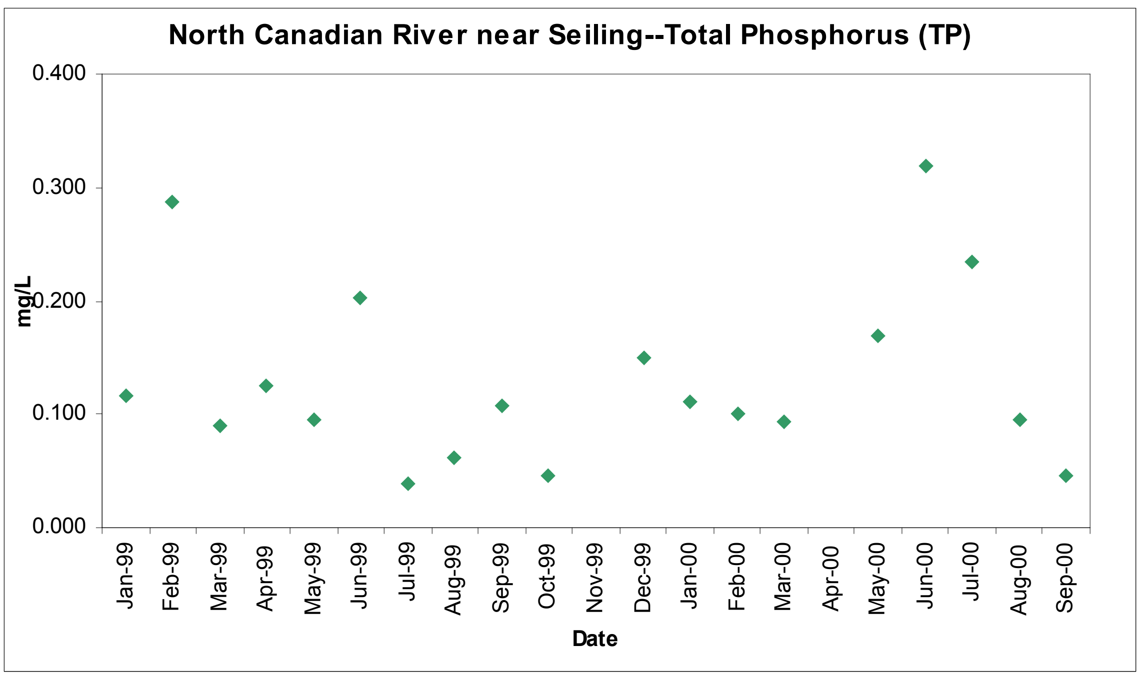


Figure 14. Trend analysis for flow-adjusted turbidity data collected from January of 1999 through September of 2000 at the North Canadian River near Seiling, OK. Slope calculated using the Seasonal Kendall slope estimator. Data deseasonalized based on three seasons beginning February 1, July 1, and October 1. Values on Y-axis are LOWESS calculated residuals.

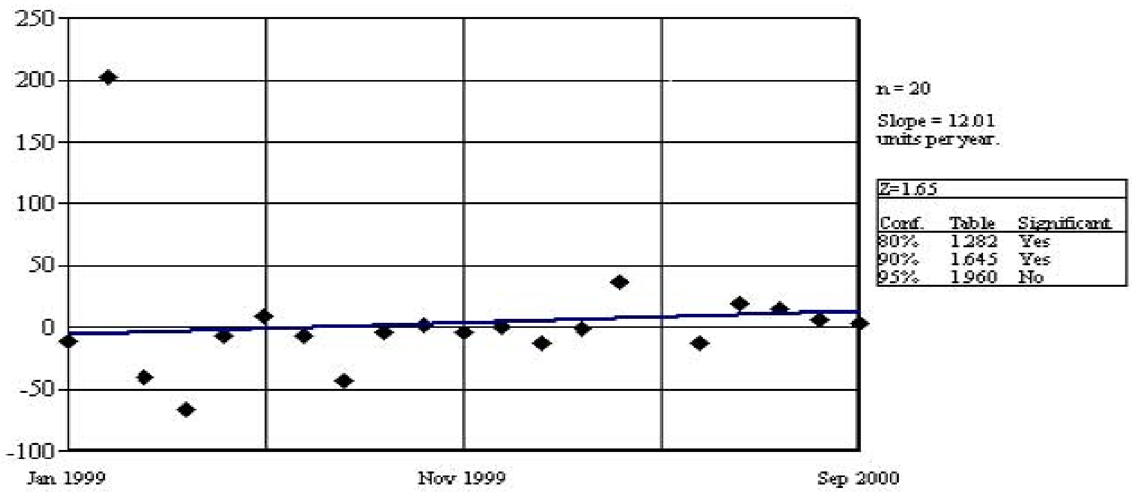


Figure 15. Trend analysis for raw historical total phosphorus data collected from January of 1980 through September of 1986 at the North Canadian River near Seiling, OK. Slope calculated using the Seasonal Kendall slope estimator. Data deseasonalized based on three seasons beginning February 1, July 1, and October 1. Values on Y-axis are LOWESS calculated residuals.

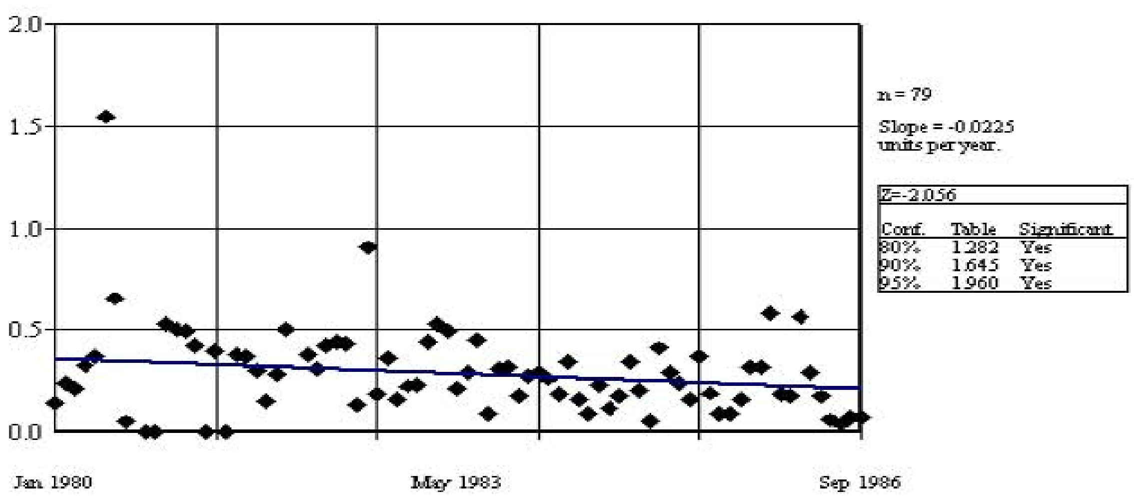
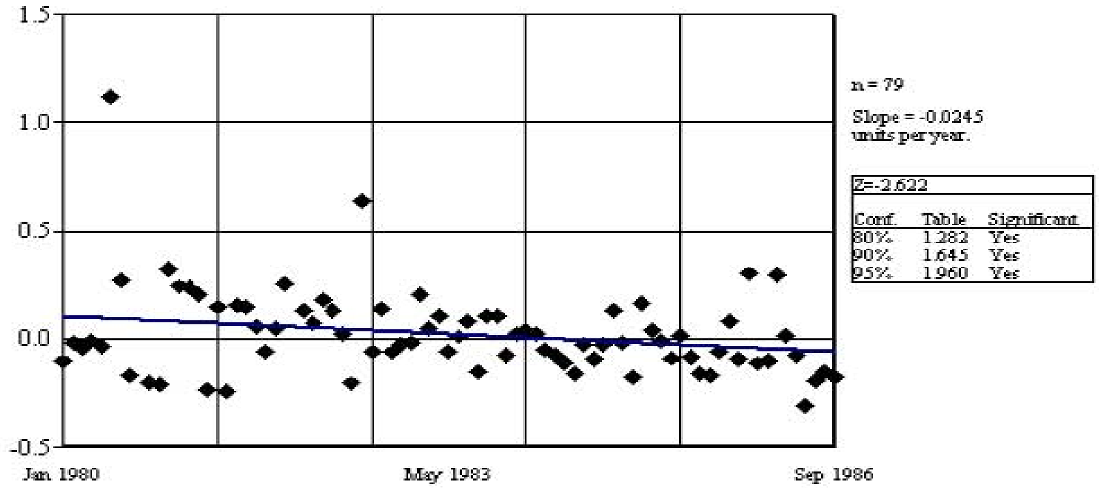


Figure 16. Trend analysis for flow-adjusted historical total phosphorus data collected from January of 1980 through September of 1986 at the North Canadian River near Seiling, OK. Slope calculated using the Seasonal Kendall slope estimator. Data deseasonalized based on three seasons beginning February 1, July 1, and October 1. Values on Y-axis are LOWESS calculated residuals.



Nutrient Loads

Loadings were determined from both historical and current data. Historical data was available from January 1980 through February 1993. Loads, calculated by annual average flow and annual average concentration, were 29,696 kg TP/year and 123,918 kg TN/year. Of the 94 historical values from 1980 – 1993, 19 values used in calculating TN were actually Total Kjeldhal N (TKN) values as TN was not available. Therefore, the TN load calculated for historical value may actually be higher than reported (and mostly likely is as TN is oftentimes higher than the TKN value).

For current data, loads were calculated from both annual average concentration times the annual average daily flow (Table 12) and flow weighted mean concentration. The 1999 flow value, average of all sample days, was much higher than the historical average from 1980 – 1993 as well as the period of record value. Based on this information, the 1999 sample year seems to be a "wet year" with extraordinarily higher loading values. The average flow values for both 1999 and 2000 (the average flow of all sample days) were similar to the annual average flow reported for this station, indicating the loading values calculated were representative of conditions for that sample year.

For current data, flow weighted mean values utilized 18 samples collected from 1999 through 2000. Of these, 4 were considered low flow, 11 medium, and 4 high flow based on the period of record flow value (170 cfs, 1979-2000). These values may not be representative of the split between low, medium, and high flows as the medium flow interval is the most common, as opposed to low flow, and high flow intervals were as common as low flow. When data was separated out according to flow-weighted mean values, the loading values were much higher than the loadings calculated using the average flow and average concentration from 1999 to

2000. The loadings calculated using this method were 48,258 kg/yr for TP and 315,101 kg/yr for TN. Although only 4 of the 18 days (22%) were high flow periods, 57% of the TP load contribution and 46% of the TN load contribution was during high flow events. It has been documented that higher nutrient concentrations are common during higher flow events.

Table 12. Summary of TN and TP loads for the Seiling Site, North Canadian River.

	No. of samples	Avg flow of samples (cfs)	Annual avg. flow (cfs)	TP load (kg/yr)	TN load (kg/yr)
Historical	94	125	170 (period of record)	29,696	123,918
1999	11	361	332	38,631	357,457
2000	8	186	213	24,204	164,953
Total from 1999-2000	19	287		33,551	272,036

The loading values from this site are much higher than the values calculated at the Beaver Site, understandably so since the North Canadian River is a much larger order stream than the Beaver River. The TP and TN loading values for 1999 were much higher than historical values. However, in 2000, the loading values decreased and the 2000 TP load was in fact lower than the historical value.

North Canadian River near El Reno

Station AT239500 is a permanent ambient trend monitoring station located on the North Canadian River. Situated in the central portion of Canadian County, the site was established within the city of El Reno on US Highway 81. The station is positioned between the midpoint and the lower end of stream segment 520530000010 and is classified within the Middle North Canadian River 8 digit HUC watershed (11100301). Water enters the stream system from several tributaries including Sixmile Creek, Purcell Creek, and Shell Creek, among others. For purposes of reporting, this station is representative of the North Canadian River from where it intersects the Canadian/Blaine County Line downstream to confluence of the North Canadian River with Lake Overholser. As per Appendix A, Table 5 of OAC 785:45, this water quality management segment is assigned the following designated beneficial uses: 1) Public and Private Water Supply (PPWS), 2) Warm Water Aquatic Community—Fish and Wildlife Propagation (WWAC), 3) Agriculture—Class I Irrigation (AG), and 4) Primary Body Contact—Recreation (PBCR).

General Water Quality
Dissolved oxygen (D. O.), D. O. percent saturation, pH, turbidity, and total dissolved solids (TDS) were measured monthly from February of 1999 through September of 2000. Sporadic historical data exists for turbidity from January of 1980 through October of 1994. Recent data for all but percent saturation is graphically displayed in Figure 17. Dissolved oxygen (mg/l) is plotted versus water temperature (^{o}C).

For each variable, an analysis of central tendency was made (Table 13). In addition, trend analyses were made on turbidity and TDS (Table 14). Percent saturation of D. O. indicates that the reach is moderately productive. Not only is the median 94%, but half of the measurements lie between 87 and 104%. Although data were not collected, the moderate saturation rates could produce higher than normal instream algal growth as well as anoxic conditions during the nighttime. The moderately basic pH suggests conditions that are typical for this area of the state, although one value (9.3 units) lies above the upper limit for the support of biological life. The turbidity median of 38 NTU's is within the state water quality stream standard of 50 NTU's, although 25% of the data are above the standard (Q3 = 85 NTU's). In contrast, at least 75% of historical turbidity data are well below the standard (Q3 = 28 NTU's). A two-tailed comparison of the medians reveals that recent turbidity data are significantly higher than historical data (Z_{test} = 3.067; Z_{table} = 2.565 at $p < 0.99$), however no significant trends were detected for historical and recent turbidity. Wright (1994) also reported no significant trend for turbidity between December of 1975 through February of 1993.

Levels of TDS indicate moderately saline conditions, but are within the segment specific criterion listed in the OWQS. No significant trend was detected, but Wright (1994) reported a significant downward trend for specific conductance between December of 1975 through February of 1993.

Nitrogen

From February of 1999 through September of 2000, nitrogen was measured monthly as several species including nitrite (NO_2), nitrate (NO_3), and total Kjeldahl nitrogen (TKN). Total nitrogen (TN) was calculated as NO_2+NO_3+TKN (USEPA, 2000). Sporadic historical data exists for TKN and TN from January of 1980 through September of 1993. Nitrate and nitrite are analyzed as a combined species. The calculated TN for recent data is graphically displayed in Figure 18.

For each variable, an analysis of central tendency was made (Table 15). Recent TN and biologically available nitrate/nitrite were within recognized freshwater aquatic and human health limits with upper ranges of 1.73 and 0.39 mg/l, respectively. In addition, trend analyses was performed on historical and recent total nitrogen (Table 14). No significant trends were detected, but Wright (1994) reported a significant downward trend for TN between October of 1977 through October of 1984. Furthermore, a two-tailed comparison of the medians reveals no significant difference between historical and recent TN data.

Phosphorus

From January of 1999 through September of 2000, total phosphorus (TP) was measured monthly as well as ortho-phosporus (ortho-P). Sporadic historical data exists for TP from January of 1980 through September of 1993. The current TP data is graphically displayed in Figure 2.

For each variable, an analysis of central tendency was made (Table 15). With a median of 0.134 mg/l, TP is above the generally accepted freshwater background level of 0.03 mg/l, however, no water quality standard currently exists for TP. When comparing the third quartile of ortho-P (0.097 mg/l) to TP (0.249 mg/l), it can be determined that inorganic phosphate contributes approximately 39% of the total phosphorus concentration. In addition, trend analysis was performed on both historical and recent TP (Table 14). No significant trend was detected for recent TP. Historical raw TP data (Figure 19) as well as flow-adjusted TP data (Figure 20) displayed a significant positive trend from January of 1980 through September of 1986. In contrast, Wright (1994) detected no trend for TP between October of 1976 through September of 1986. Furthermore, a two-tailed comparison of the medians reveals that historical TP data are significantly higher than recent data (Z_{test} = -2.074; Z_{table} = 1.960 at $p < 0.975$).

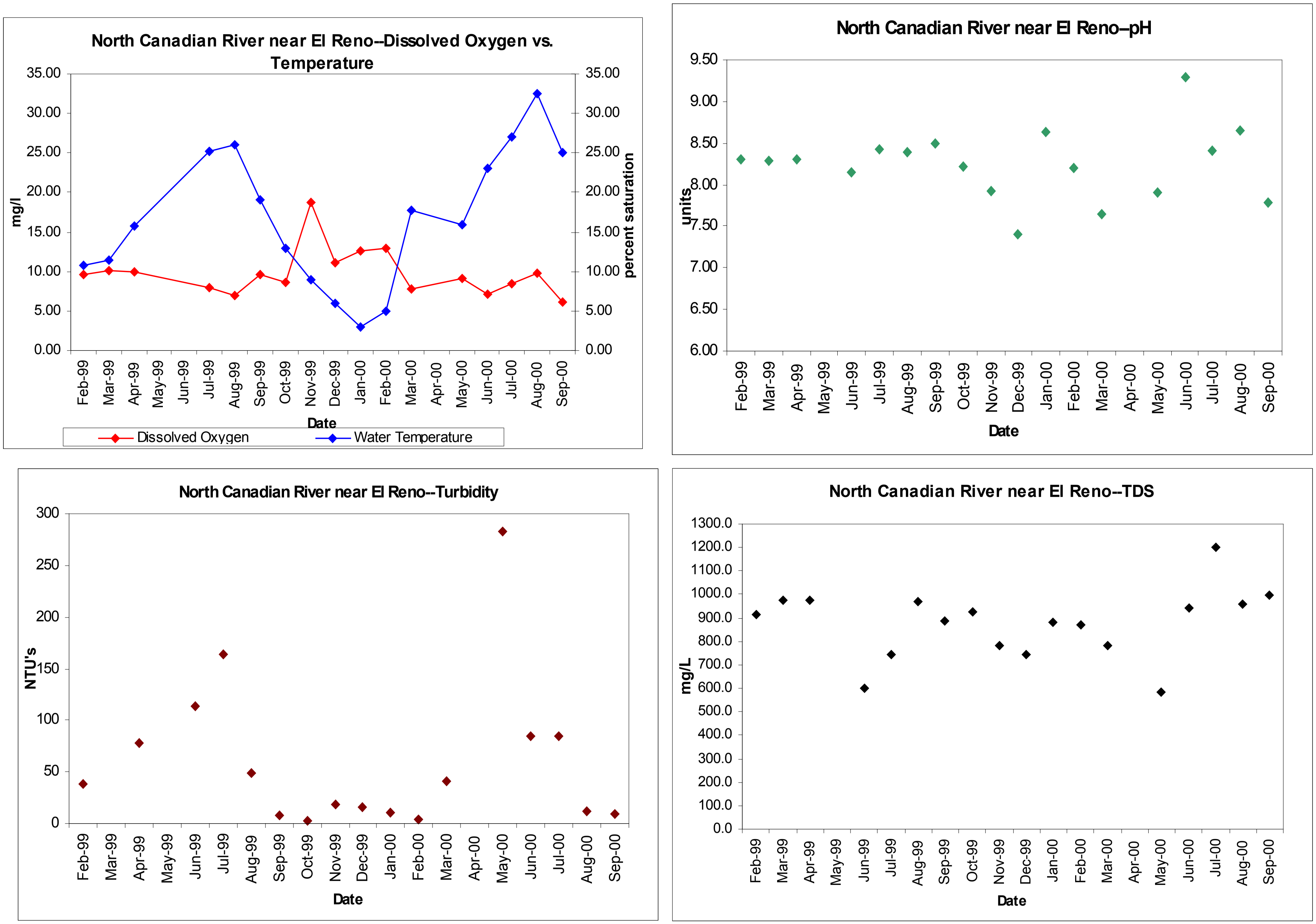


Figure 17. General water quality data collected at North Canadian River near El Reno, OK, from February 1999 through September of 2000. (Note: Connected lines in D. O. graph do not indicate a suggested trend.)

Table 13. Measurements of central tendency for general water quality parameters collected at the North Canadian River near El Reno, OK, from February 1999 through September of 2000 and historical data collected from January of 1980 through October of 1994.

Variable	N	Median	Minimum	Maximum	Q1	Q3
D.O. (mg/l)	17	9.65	6.19	18.69	7.88	10.60
D.O. Percent Saturation	17	94.4	78.1	162.8	87.2	103.5
pH (units)	18	8.30	7.41	9.30	7.92	8.45
Turbidity (NTU's)	17	38	3	283	10	85
Historical Turbidity (NTU's)	85	5	1	300	2	28
TDS	18	901.3	581.5	1202.0	771.0	971.0

Table 14. Trend analysis for data collected at the North Canadian River near El Reno, OK, from February 1999 through September of 2000 and historical data collected from January of 1980 through September of 1986.

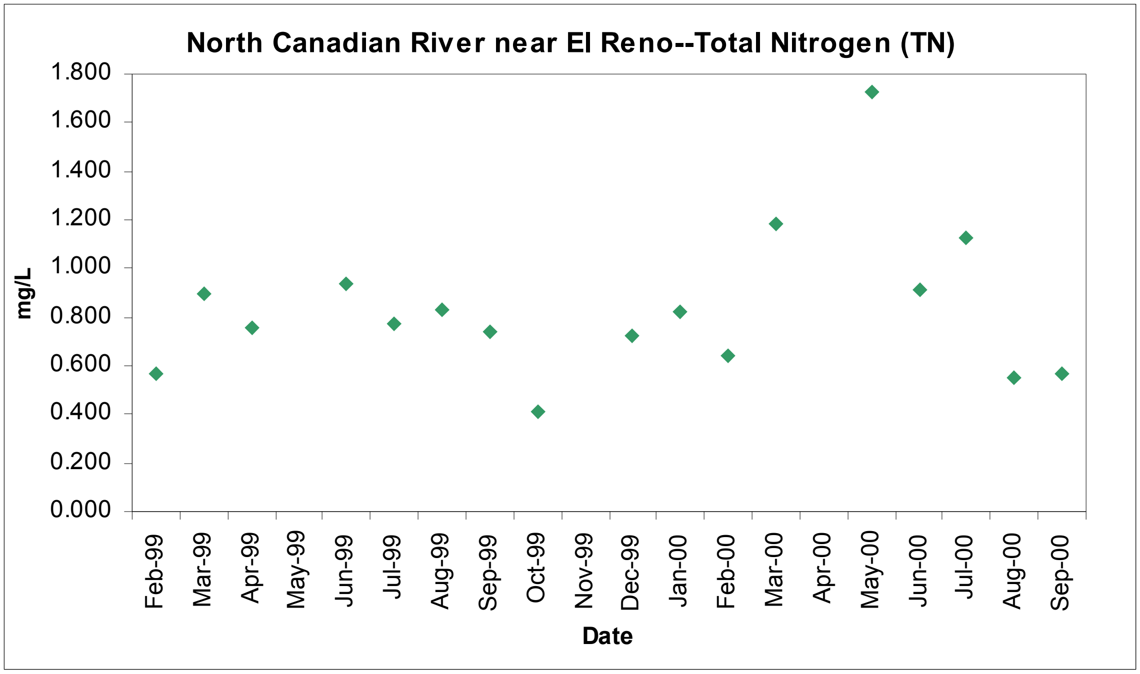
Parameters	N	Z (test stat)	Conf. Level	Slope (units/yr)
Historical Total N	58	0.000	NS	
Flow-adj. Hist. Total N	58	0.583	NS	
Total N	17	0.657	NS	
Flow-adj. Total N	17	0.657	NS	
Historical Total P	81	2.939	0.95	0.028
Flow-adj. Hist. Total P	81	2.780	0.95	0.023
Total P	17	0.131	NS	
Flow-adj. Total P	17	0.394	NS	
TDS	18	0.000	NS	
Flow-adj. TDS	18	0.512	NS	
Hist. Turbidity	85	0.546	NS	
Flow-adj. Hist. Turbidity	85	1.502	NS	
Turbidity	17	-0.976	NS	
Flow-adj. Turbidity	17	-0.693	NS	

NS = non-significance at the 0.90 confidence level.

Table 15. Measurements of central tendency for nitrogen and phosphorus data collected at the North Canadian River near El Reno, OK, from February of 1999 through September of 2000 and historical data collected from January of 1980 through February of 1993.

Variable	N	Median	Minimum	Maximum	Q1	Q3
Nitrite (NO2) + Nitrate (NO3)	17	0.140	0.050	0.390	0.050	0.308
Total Kjeldahl Nitrogen (TKN)	17	0.610	0.240	1.400	0.440	0.800
Historical TKN	80	0.735	0.100	4.903	0.558	1.212
Total Nitrogen (TN)	17	0.775	0.415	1.730	0.608	0.923
Historical TN	58	0.745	0.100	3.400	0.558	1.230
Ortho-Phosphorus (O-P)	17	0.040	0.003	0.278	0.017	0.097
Total Phosphorus (TP)	17	0.134	0.014	0.469	0.060	0.249
Historical TP	81	0.250	0.005	3.900	0.151	0.370

Figure 18. Total nitrogen and total phosphorus data collected at North Canadian River near El Reno, OK, from February 1999 through September of 2000.



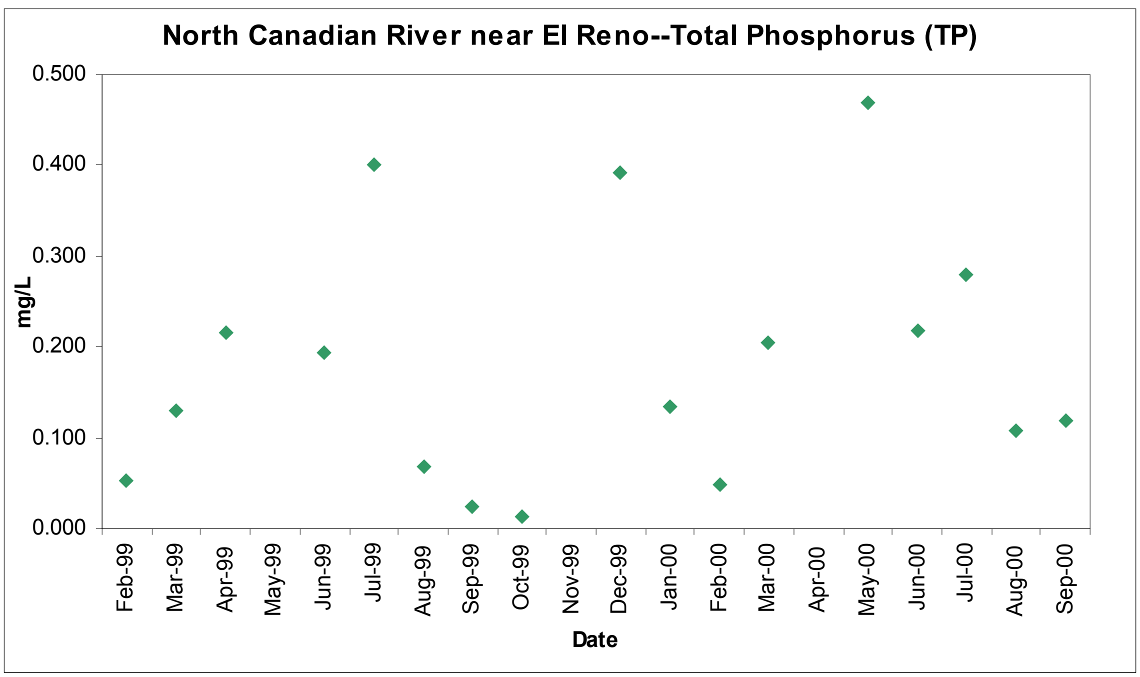


Figure 19. Trend analysis for raw historical total phosphorus data collected from January of 1980 through September of 1986 at the North Canadian River near El Reno, OK. Slope calculated using the Seasonal Kendall slope estimator. Data deseasonalized based on three seasons beginning February 1, July 1, and October 1. Values on Y-axis are LOWESS calculated residuals.

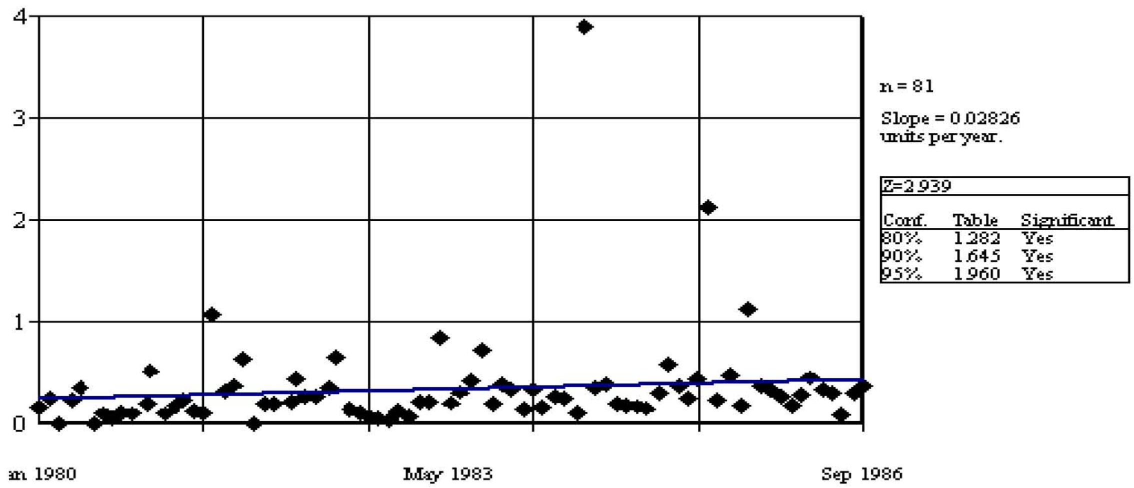
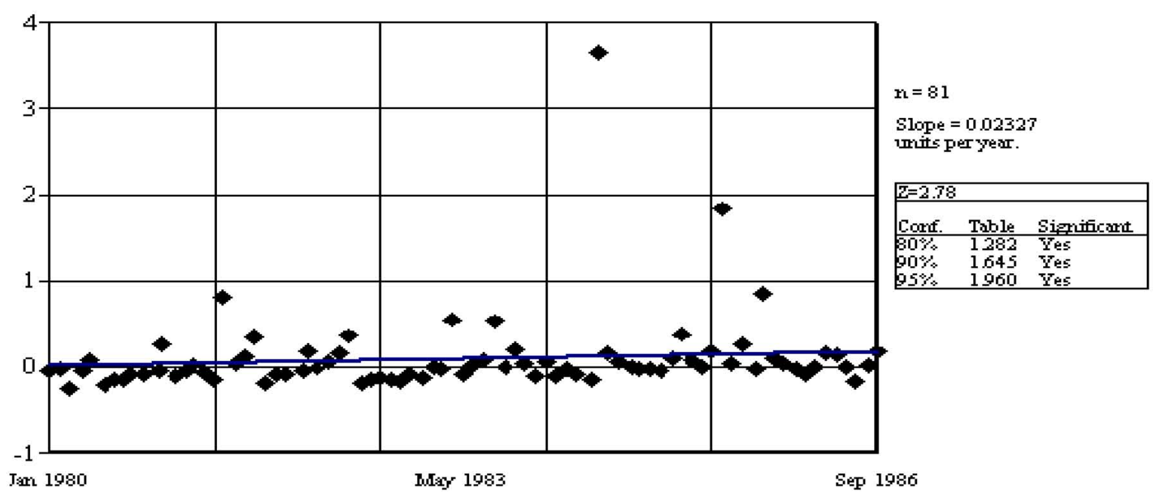


Figure 20. Trend analysis for flow-adjusted historical total phosphorus data collected from January of 1980 through September of 1986 at the North Canadian River near El Reno, OK. Slope calculated using the Seasonal Kendall slope estimator. Data deseasonalized based on three seasons beginning February 1, July 1, and October 1. Values on Y-axis are LOWESS calculated residuals.



Nutrient Loads

Loadings were determined from both historical and current data. Historical data was available from January 1980 through February 1993. Loads, calculated by the annual average flow and annual average concentration, were 42,060 kg TP/year and 123,912 kg TN/year. Of the 94 historical values from 1980 - 1993, 19 values used in calculating TN were actually Total Kjeldhal N (TKN) values as TN was not available, corresponding to the same sampling dates as the Seiling station. Therefore, the TN load calculated for historical value may actually be higher than reported (and mostly likely is as TN is oftentimes higher than the TKN value).

For current data, loads were calculated from both the annual average concentration times the annual average flow (Table 16) and flow weighted mean concentration. The 1999 loading values are slightly higher than the 2000 values, probably due to more rainfall, resulting in a higher average flow. The average flow values for both 1999 and 2000 (the average flow of all sample days) were similar to the annual average flow reported for this station, indicating the loading values calculated were representative of conditions for that sample year.

Table 16. Summary of TN and TP loads at the El Reno Site, North Canadian River.

	No. of samples	Avg flow of samples (cfs)	Annual avg. flow (cfs)	TP load (kg/yr)	TN load (kg/yr)
Historical	94	141	234 (period of record)	42,060	123,912
1999	9	463	469	68,363	305,314
2000	8	357	321	63,028	300,199
Total from 1999-2000	17	413		66,613	307,685

These loadings are similar, although slightly higher, to the values calculated at the North Canadian River at Seiling gaging station. The TP and TN loading values for both 1999 and 2000 were much higher than historical values. The average flow value calculated from the samples collected from 1980-1993 was lower than both the 1999 and 2000 average flow and annual flow values. The flow pattern may have changed over time at this station and historical conditions may not be reflective of current conditions, or the sample dates from 1980 - 1993 did not capture the true flow conditions at this site. Either way, the recent data indicate a higher loading of TP and TN into the system than historical data (1980-1993).

Flow weighted mean concentrations were also calculated from the data over the 1999 through 2000 sampling interval. Of the 17 samples collected, 6 were considered low flow, 4 medium, and 7 high flow based on the period of record flow value (234 cfs, 1949-2000). These values may not be representative of the split between low, medium, and high flows as the high flow interval is the most common, as opposed to low flow, resulting in a higher load result for both TN and TP. When data was separated out into the three strata according to flow-weighted mean values, the loading values were higher than the loadings calculated using the average flow and average concentration from 1999 to 2000. The loadings calculated using this method were 84,512 kg/yr for TP and 384,304 kg/yr for TN. Although only 7 of the 17 days (41%) were high flow periods, 80% of the TP load contribution and 77% of the TN load contribution was during high flow events. It has been documented that higher nutrient concentrations are common during higher flow events. Although the loading values calculated at this station are much higher than the other stations, both the TN and TP annual loads are significantly less than results in the Illinois River Basin (OWRB, 2001) and other basins in Oklahoma.

North Canadian River near Yukon (State Highway 4)

North Canadian River near Yukon at is a station located on the North Canadian River and monitored by the City of Oklahoma City. Situated in the far eastern portion of Canadian County, the site was established northeast of the town of Yukon on State Highway 4. The station is positioned near the terminal end of stream segment 520530000010 and is classified within the Middle North Canadian River 8 digit HUC watershed (11100301). Water enters the stream system from several tributaries including Six Mile Creek, Purcell Creek, and Shell Creek, among others. As per Appendix A, Table 7 of OAC 785:45, this water quality management segment is assigned the following designated beneficial uses: 1) Public and Private Water Supply (PPWS), 2) Warm Water Aquatic Community—Fish and Wildlife Propagation (WWAC), 3) Agriculture—Class III Irrigation (AG), and 4) Primary Body Contact—Recreation (PBCR).

General Water Quality
No general water quality data is available for this station.

Nitrogen
From January of 1980 through July of 1999, nitrate was measured quarterly and is graphically displayed in Figure 21. An analysis of central tendency (Table 17) reveals that nitrate is within human and freshwater aquatic health limits. However, the upper range (2.47 mg/l) as well as the upper 25% of the data (Q3 = 0.485 mg/l) indicate concentrations that may become of some concern in the future. An unadjusted trend analysis showed no significant trend (Table 18).

Phosphorus
From January of 1980 through July of 1999, total phosphorus was measured quarterly and is graphically displayed in Figure 21. An analysis of central tendency (Table 17) reveals a median of 0.285 mg/l which is above the generally accepted freshwater background level of 0.03 mg/l as well as the suggested federal criterion (EPQ Gold Book) of 0.05 mg/l for streams entering lakes. An unadjusted trend analysis (Table 18) showed a significant downward trend (Figure 22).

Table 17. Measurements of central tendency for nitrogen and phosphorus data collected at the North Canadian River near Yukon, from January of 1980 through July of 1999.

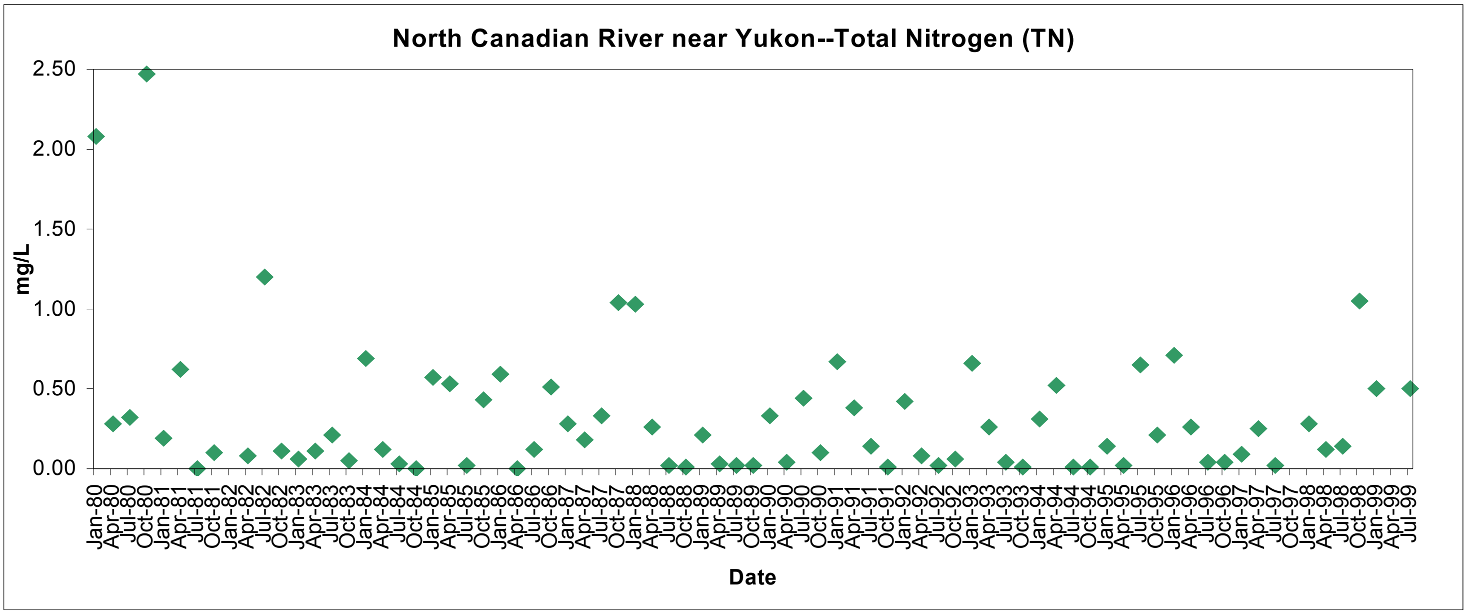
Variable	N	Median	Minimum	Maximum	Q1	Q3
Nitrate	76	0.185	0.000	2.470	0.040	0.485
Total Phosphorus	76	0.285	0.010	3.090	0.113	0.630

Table 18. Trend analysis for data collected at the North Canadian River near Yukon, from January of 1980 through July of 1999.

Parameters	N	Z (test stat)	Conf. Level	Slope (units/yr)
Nitrate	76	-0.790	NS	
Total P	76	-4.753	0.95	-0.025

NS = non-significance at the 0.90 confidence level.

Figure 21. Nitrate and total phosphorus data collected at North Canadian River near Yukon, from January of 1980 through July of 1999.



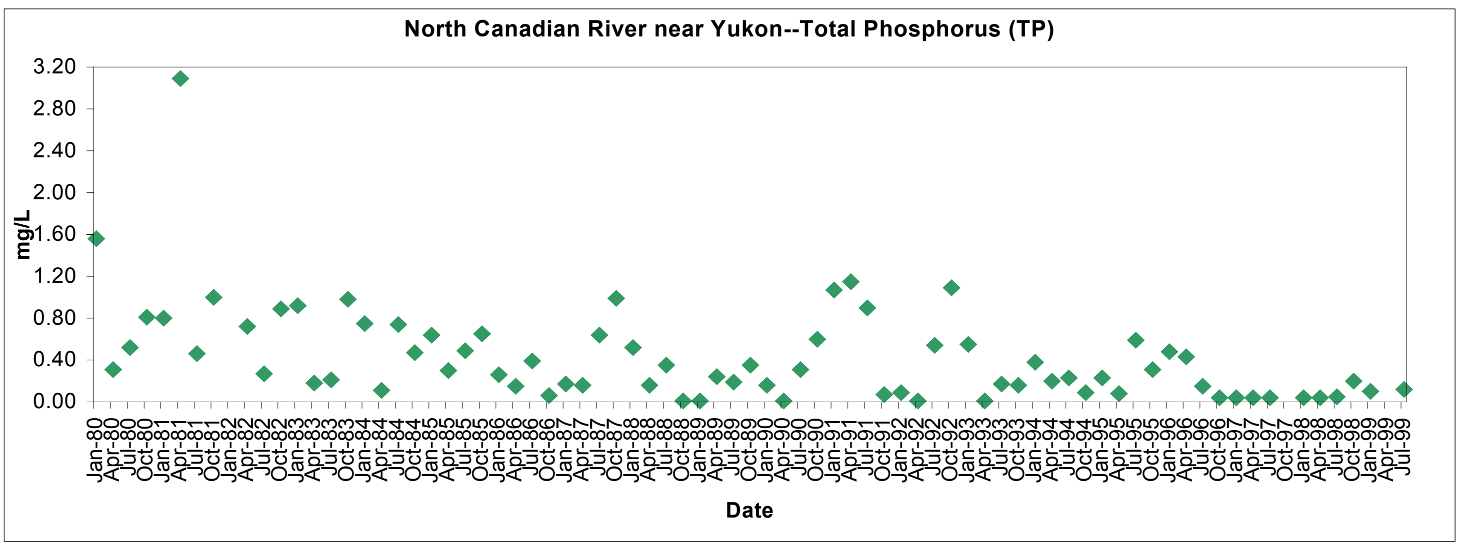
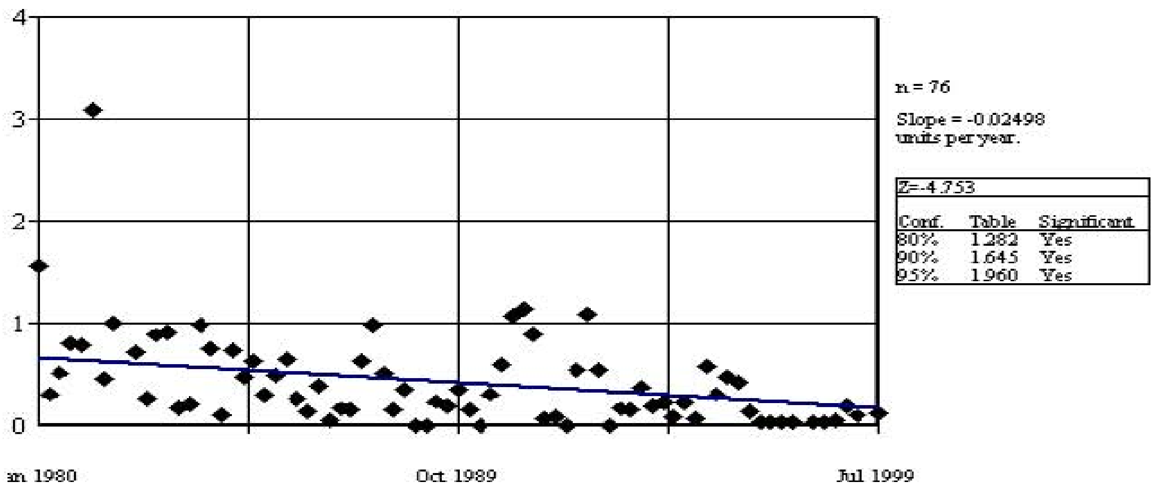


Figure 22. Trend analysis for total phosphorus data collected from January of 1980 through July of 1999 at the North Canadian River near Yukon. Slope calculated using the Seasonal Kendall slope estimator. Data deseasonalized based on four seasons beginning January 1, April 1, July 1, and October 1. Values on Y-axis are LOWESS calculated residuals.



Part II. Microbial Strain Tracing

The complete report produced by the BioEnvironmental Engineering and Science Laboratory, University of Oklahoma, on Microbial Strain Tracing for this project is included in Appendix A of this report. Below summarizes the findings from the report for inculsion in the text of this report.

Lagoon samples were collected at representative sites located in Kingfisher, Johnston, Major, Beaver, Blaine and Texas counties. River samples were collected at the same ambient trend monitoring stations in the previous section. Samples were collected on four occasions from June 7 through September 7, 2000.

Microbial isolates were segregated into either Tier 1 (separated by strain) or Tier 2 (separated by species). The first tier contained 4 strains that were found in both the lagoon and stream samples. One of the four strains (*Aeromonas veronii*, Biotype 10) was also found in upstream background samples and two of the strains (*Pseudomas putida* Biotype A, and *Escherichia coli* (USPS-7085)) were only found in one sample. All three species were therefore rejected for consideration. Therefore, that left *Lactococcus lactis* ss lactis remaining as a potential indicator organism (Table 19).

Tier 2 utilized the identification of species. A total of 9 species were found in both the CAFO lagoons and downstream samples. Again, several species were eliminated due to their presence in upstream background samples or because they were only found in one stream sample. The remaining species that were found to be possible indicator organisms were *Citrobacter braakii*, *Enterococcus casseliflavus* and *Enterococcus gallinarum.* Tier 2 separates organisms based on identifications to the species level in both lagoon and surface water samples.

It is concluded that the strain (*L . lactis*) identified during the Tier 1 testing was found to be indicative of CAFO waste but could not be used to link the waste directly to any specific CAFO. It was also concluded that the species identified during Tier 2 testing (*C. braakii*, *E. casseliflavus* and *E. gallinarum*) were useful indicators of the fecal matter of mammals. However, because there may be several strains (similar to subspecies) of the species present in the environment, identification of species alone was not definitive to indicate CAFO waste as the sole source of pollution. The strain identification is much more useful however because it is more specific. This strain (*Lactococcus lactis* ss lactis) is much less likely to be found in other areas that are not impacted by CAFO waste.

Table 19. Bacterial species indicative of possible CAFO pollution.

	Species Name
Tier 1	*Lactococcus lactis* ss lactis
Tier 2	*Citrobacter braakii*
	Enterococcus casseliflavus
	Enterococcus gallinarum

To achieve more specificity, further analysis of additional fecal coliform and fecal streptococci colonies that were not initially isolated and identified needs to be done. The selection and isolation of additional bacterial colonies has the potential to increase the number of sites where the indicator species are found and thereby increasing the probability that a particular species is an indicator of CAFO pollution.

Further sampling and bacterial strain tracing needs to be performed following a rainfall runoff event. Since microorganisms are carried into surface waters by rainfall runoff, samples taken immediately after a rain event are more likely to contain microorganisms associated with land application of CAFO wastes. This has the potential to give a more accurate representation of the impact of CAFO wastes on surface water quality.

Part III. Oklahoma City Water Supply Reservoirs

The following narrative discusses each lake in detail for all measured parameters, including trophic state indices and TN:TP ratios. All water quality data used in analysis may be found in Appendix B of this report. Hypereutrophic lakes have the potential for beneficial use impairments due to low dissolved oxygen concentrations, taste and odor problems, nutrient inputs, excessive productivity, and general lake aesthetics. Lake Overholser is the only OKC water supply reservoir that ranked in this classification. Eutrophic lakes also have the potential for beneficial use impairments although less than hypereutrophic. Mesotrophic lakes have little to no threat of beneficial use impairment and are representative of good water quality, with low to moderate levels of nutrient inputs and productivity. In Oklahoma, oligotrophic lakes are either very clear with little nutrient inputs and good water quality conditions, or very turbid waters, with poor water clarity, inhibiting productivity. Overall, Oklahoma City's water supply reservoirs, excluding Lake Overholser, are in the mesotrophic to eutrophic range, meaning moderate to high productivity and nutrient rich conditions. Since the inception of the Beneficial Use Monitoring Program, eighty-eight lakes have been sampled, which is the largest data set for comparison purposes for Oklahoma reservoirs. Figure 23 depicts trophic state percentage of these lakes.

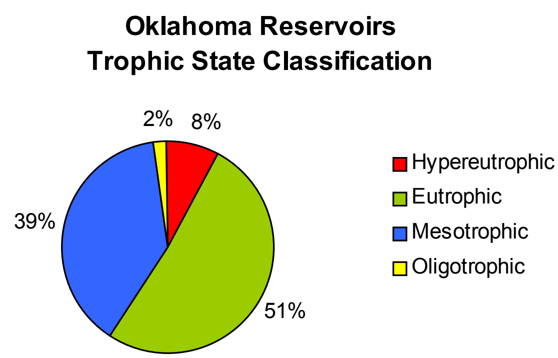


Figure 23. Trophic state of Oklahoma reservoirs based on BUMP data collected 1998 through 2000 using Chlorophyll-a annual averages.

Canton Lake Water Quality

Canton Lake was sampled quarterly from November 1997 through August of 2000 at three sites representing the lacustrine zone (Site 1, near the dam), transition zone (Site 2) and the riverine zone (Site 3, headwaters of the reservoir). The data was analyzed annually for comparisons between sample years as well as cumulatively to represent the entire sampling period. Each sample year was from November of the proceeding year through August of the year indicated for sample years, 1998, 1999 and 2000.

Canton Lake was classified as eutrophic from both annual and growing season CHL TSI averages for the entire sample period. The TN:TP ratio indicated the lake is phosphorus limited, meaning there is an abundance of nitrogen available, and phosphorus is the controlling nutrient in regards to productivity. Total nitrogen and total phosphorus concentrations (mg/l) based on Wetzel (1983), would classify Canton as eutrophic, again moderate productivity. The abundance of both nitrogen and phosphorus, and high Secchi Depth TSI, would indicate that light limitation is the primary controlling factor for productivity. Water quality studies should continue in the future to more accurately identify specific watershed practices that contribute to the water quality degradation of the lake, and implement phosphorus controlling best management practices.

Physical Characteristics

Turbidity and Secchi Disk Depth
The lake-wide average turbidity over the three years was 14.1 in 1998, 17.8 in 1999 and 21.4 NTU in 2000 (Figures 24-26), with an overall average of 17.8 NTU (n= 36). In all three sample years, only 3 samples exceeded the WQS of 25 NTU. These were February 1999 (28 NTU), February 2000 (42 NTU) and June 2000 (32 NTU), all violations occurred at Site 3. Site 3 is in the riverine zone, which is shallow (3-4 m) and more prone to resuspension of bottom sediments. The cumulative average from the entire sample period was below the OWQS.

The average annual Secchi disk depth was 54, 53 and 38 centimeters, while the overall average secchi disk depth was 48 centimeters (n= 34). Secchi disk depth was about average for Oklahoma reservoirs (OWRB, 2000).

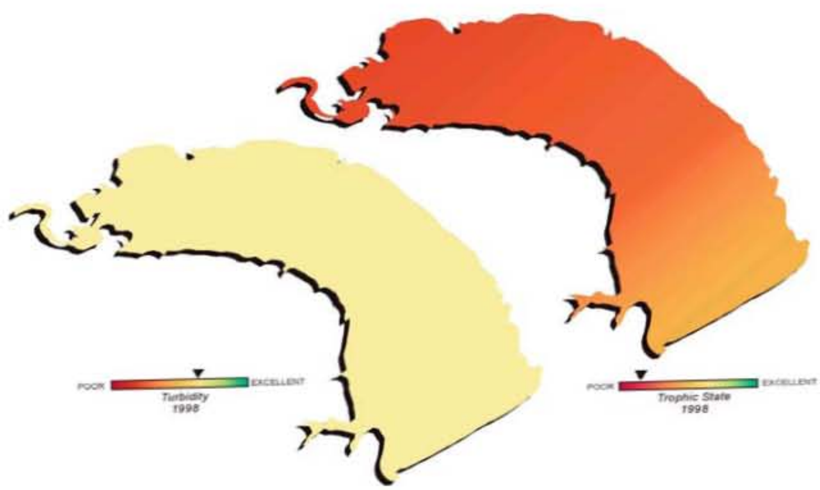


Figure 24. Turbidity and Chlorophyll a trophic state index for Canton Lake in 1998.

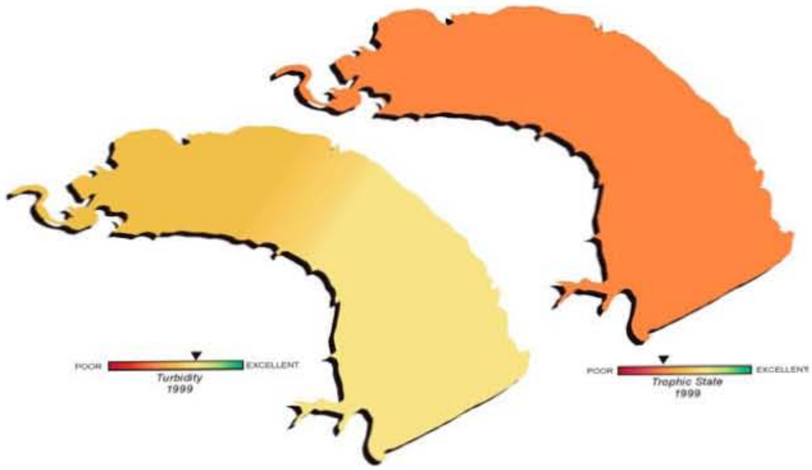


Figure 25. Turbidity and Chlorophyll a trophic state index for Canton Lake in 1999.

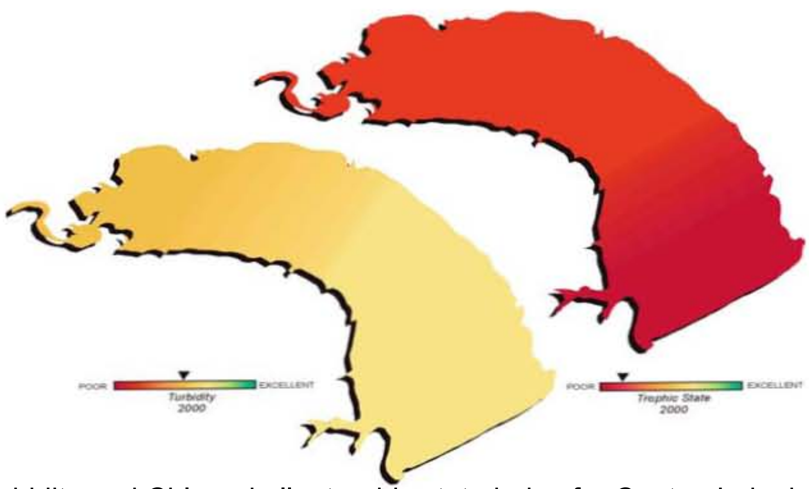


Figure 26. Turbidity and Chlorophyll a trophic state index for Canton Lake in 2000.

Salinity, Specific Conductance and Oxidation-Reduction Potential

Vertical profiles were collected at each site for salinity, specific conductance and oxidation-reduction potential. Canton Lake salinity values ranged from 0.70- 0.81 parts per thousand (ppt) in 1998, 0.58- 0.9 ppt in 1999 and 0.42- 0.88 ppt in 2000, while overall salinity ranged from 0.42- 0.9 ppt (n= 216). These values are higher than most Oklahoma reservoirs, but were similar to Ft. Supply, and less than Great Salt Plains Reservoir (OWRB, 2000). All three of these lakes are found in the North Canadian River drainage basin, which is characterized by higher mineral concentrations.

Specific conductivity ranged from 1350- 1564μS/cm in 1998, 1100- 1722 μS/cm in 1999 and 808- 1658μS/cm in 2000, while overall specific conductance ranged from 808 μS/cm (Site 1 throughout the water column in November 1999) to 1722 μS/cm (site 3, near the bottom in February 1999). These values show that there are high concentrations of electrical conducting compounds such as chlorides, salts, or other analogous materials present compared to other

Oklahoma reservoirs (BUMP, 2000). Again, this is typical for lakes in the North Canadian River drainage basin.

Oxidation-reduction potentials were positive at all sample sites and ranged from 116- 425 mV in 1998, from 71- 467 mV in 1999 and from 110- 361 mV during 2000, while overall conditions ranged from 71- 487 mV. In general, reduction of sulfate to hydrogen sulfide (H_2S) occurs as the redox potential declines below 100 mV as a result of bacterial decomposition (Wetzel, 1983). Wetzel (1983) also suggests that this reduction of sulfate to sulfides, and the oxidation of H_2S plays a significant role in the mobilization of phosphorus and other nutrients from the lake sediments.

Chlorides, Sulfates and Total Dissolved Solids

Chlorides and sulfates were analyzed for in surface water quality samples throughout the three year sample period. Chloride concentrations ranged from 160- 220 mg/l in 1998, from 160- 210 mg/l in 1999 and from 180- 221 mg/l in 2000. Overall, the cumulative ranges were from 160- 221 mg/l, with an average of 190 (n= 33). None of the chloride values recorded exceeded the OWQS of 250mg/l.

Sulfates ranged from 268-475 mg/l in 1998, 248-324 mg/l in 1999 and 182-310 mg/l in 2000. Cumulative ranges from the entire data set were 182-875 mg/l, with an average of 288 mg/l (n= 33). Although the average sulfate concentration was above the sulfate standard of 250 mg/l, the average did not exceed the yearly mean standard, nor the sample standard listed in Appendix F of OWQS for Canton Lake, which is 1118 mg/l and 736 mg/l, respectively. Therefore, Canton Lake was supporting its' Agriculture beneficial use.

Total dissolved solids (TDS) was measured at one-meter intervals at each site with the use of a Hydrolab®. TDS concentrations for the lake were 914-1076 mg/l for 1998, 704-1103 mg/l for 1999 and 517-1061 mg/l for 2000. TDS ranged over the three years sampled from 517 mg/l - 1103 mg/l, with an average concentration of 868 mg/l (n= 179). The TDS standard listed in OWQS is 750 mg/l, however the yearly mean standard and sample standard listed in Appendix F for Canton Lake are 2575 mg/l and 3275 mg/l, respectively. Again Canton Lake TDS did not violate OWQS based on the yearly mean and sample standards.

pH, Temperature and Dissolved Oxygen

The pH was slightly alkaline with values (in standard units) ranging from 7.97- 8.47 in 1998, 7.66- 8.68 during 1999 and from 7.61-8.53 in 2000. Overall pH values ranged from 7.61- 8.68 (n= 216), with an average of 8.32. Canton Lake was well within the OWQS range of 6.5- 9.0 standard units.

Temperature ranged from 6.7 °C to 29.0 °C, with warmer temperatures present in the summer months and cooler temperatures in the winter. The lake was not thermally stratified at any time during the three year sample period and appeared to be well mixed at all sites. High winds and the shallowness of this reservoir (maximum depth approx. 10.7 m) most likely kept the water column mixed.

Dissolved oxygen did drop below 5mg/l at Sites 1 and 2 in the lower depths of the lake during May and August 1999 and 2000. In May 2000 the entire water column at the dam was below 5mg/l. OWQS states that 70% or more of the water column must anoxic (less than 2mg/l) for the Fish and Wildlife Propagation (FWP) beneficial use to not be supported (USAP 785:46-15-5). Canton Lake was only anoxic at the bottom depth (6.5 m) at Site 2 in May 1999. Therefore, Canton Lake is meeting the FWP beneficial use based on USAP OAC 785. Figure 27 depict dissolved oxygen/ temperature relationships from four different seasons within the three-year sample period.

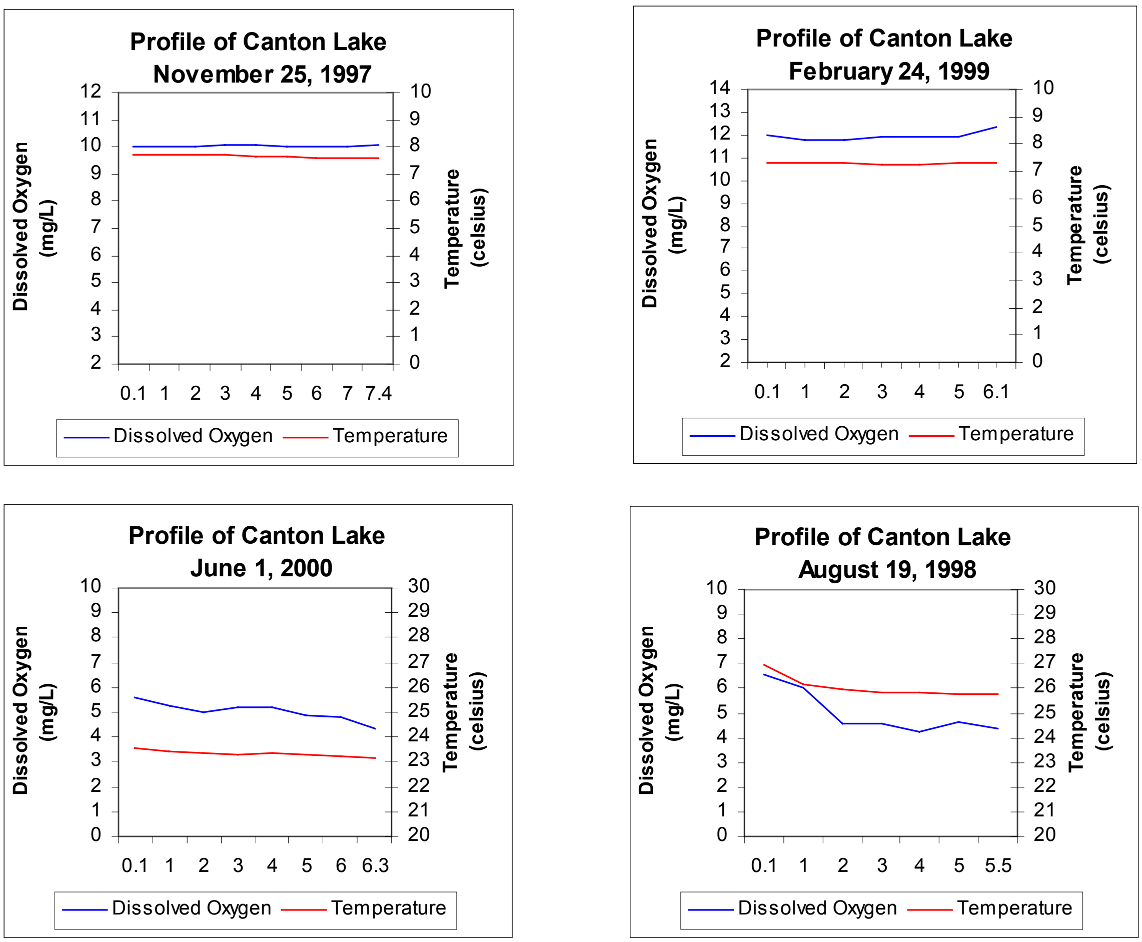


Figure 27. Vertical dissolved oxygen and temperature profiles representing four seasons measured at Site 1 in Canton Lake.

Chemical Characteristics

<u>Nitrogen</u>

Total nitrogen (TN) collected at the surface ranged from 0.705- 1.367 mg/l (n= 12) during 1998, 0.805- 1.357 mg/l (n= 9) during 1999 and 0.718- 1.295 mg/l (n= 6) for 2000, with an overall range was 0.705- 1.367mg/l (n= 27). The high values occurred in August of 1998 at Site 2, November of 1998 at Site 3 and February 2000 at Site 2. The overall average TN at the surface was 0.998 mg/l (n-=27). Bottom samples collected at Site 1 for TN ranged from 0.705- 1.21

mg/l (n= 9), with an overall average from the three sample years of 0.93 mg/l. The high values for each sample year were in August 1998, February 1999, and November 1999. The lake was not stratified during any of these sample dates. No discernable pattern in TN data was evident. Wetzel (1983) uses TN values less than 0.661 mg/l for oligotrophic conditions, 0.753 mg/l for mesotrophic and greater than 1.9 mg/l are indicative of eutrophic to hypereutrophic conditions. According to Wetzel, the overall TN concentration for Canton Lake of 0.998 mg/l would classify Canton Lake between mesotrophic and eutrophic, with moderately high productivity. The most significant sources of nitrogen are from runoff and groundwater, however, other sources may include precipitation and nitrogen fixation from blue green algae (Wetzel, 1983). Nitrogen exists in many forms, and several different forms were analyzed, however total nitrogen was the parameter discussed as the primary parameter of interest in regards to total nitrogen:total phosphorus ratios (TN:TP). Figure 28 depicts nitrogen concentrations throughout the project period.

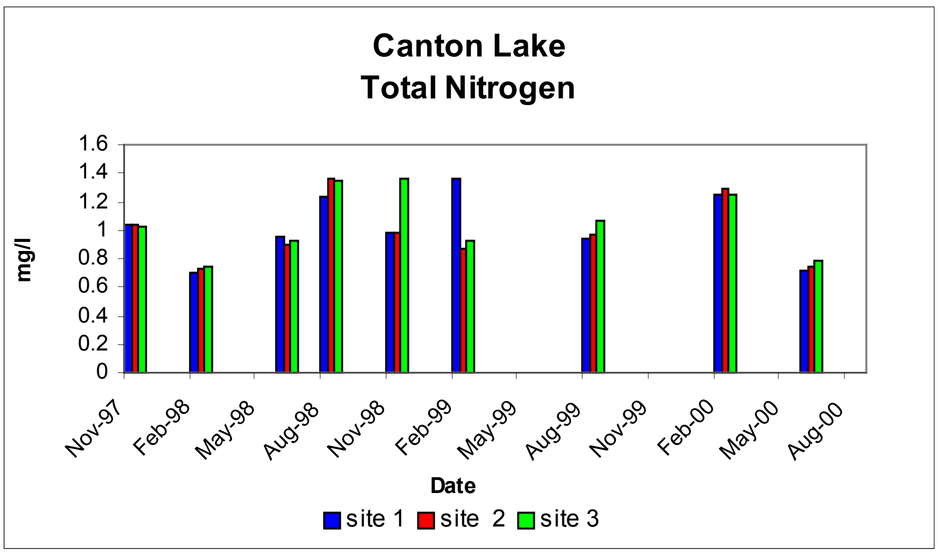


Figure 28. Canton Lake TN concentrations, November 1997 through August 2000.

Phosphorus

Total phosphorus (TP) collected at the surface ranged from 0.031- 0.091 mg/l (n= 12) during 1998, 0.047- 0.13 mg/l (n= 12) during 1999 and 0.049- 0.141 mg/l (n= 12) for 2000, with an overall range of 0.031- 0.141 mg/l (n= 36), and an average of 0.081 mg/l. The high values occurred in November of 1997, November of 1998 and June of 2000, all at Site 3. Site 3 is in the headwaters, or riverine zone of Canton Lake. It is common to see higher concentrations of nutrients in the upper reaches of reservoirs. Phosphorus, and other nutrients, will tend to settle out of the water column as the water moves down the main body of the lake and flow diminishes, resulting in lower concentrations towards the dam. Wetzel (1983) states that TP concentrations of .008 mg/l indicate oligotrophic, 0.027 mg/l indicate mesotrophic and 0.084 mg/l for eutrophic conditions. Likewise, USEPA (2000) states concentrations of TP greater than 0.1 mg/l indicate hypereutrophic conditions. The overall average phosphorus concentration of 0.081 mg/l for Canton Lake would classify this lake as eutrophic, indicating high productivity. Bottom samples collected at Site 1 for TP ranged from 0.076- 0.115 mg/l (n= 3) during 1998, 0.076- 0.121 mg/l (n= 4) during 1999 and 0.072- 0.147 mg/l (n= 3) during 2000, with an overall range of 0.072- 0.147 mg/l (n=10) and an average of 0.10 mg/l. All three high values were found in November of each sample year. Again, the lake was not stratified during these sample dates, anoxia was not present, and therefore no release of phosphorus would be expected from the bottom sediments. Resuspension of bottom sediments at the sediment-water interface may be responsible for higher concentrations of TP detected in the bottom samples. Figure 29 depicts TP concentrations throughout the sample period.

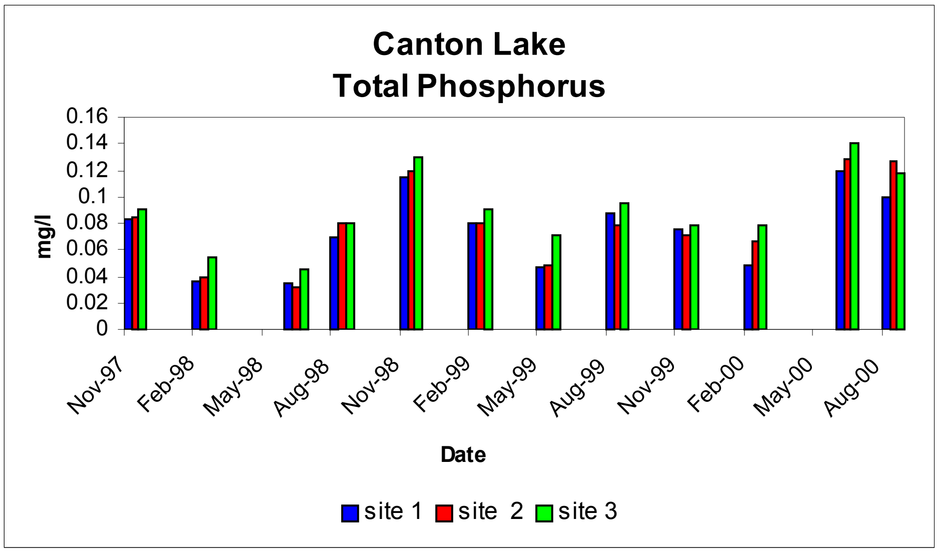


Figure 29. Canton Lake TP concentrations, November 1997 through August 2000.

<u>Ortho-phosphorus</u>

Ortho-phosphorus collected at the surface ranged from 0.005- 0.034 mg/l (n= 12) in 1998, 0.005- 0.055 mg/l (n= 9) in 1999 and 0.005-0.033 mg/l (n= 12) in 2000. Overall ortho-phosphorus ranged from 0.005- 0.055 mg/l (n= 33) and an average of 0.015 mg/l. The high values for each sample year were found in November of 1997 and 1998 at Site 1 and August 2000 at Site 3. It is important to note high values were present at all sites during these months. The bottom samples for ortho-phosphorus concentrations overall ranged from 0.005- 0.055 mg/l (n= 9), with an average 0.02 mg/l. Again, the high concentration was found in November of 1998, corresponding with the high value found at the surface on that sample date.

Biological

<u>Trophic State Indices</u>

TSI calculations were determined for Canton Lake by using the average of all Chlorophyll-<u>a</u>, Secchi disk depth and total phosphorus values for the entire sample year and the average of growing season (May and August) values. All TSI's were calculated based on averages of the report value. Because of the relationship between chlorophyll and TP and its linkage to biomass, chlorophyll is often a major component of trophic state indices (Carlson, 1977) and water quality criteria (USEPA, 2000). Canton Lakes CHL TSI did not classify it as an NLW. Again, the OWRB uses a CHL TSI ≥ 62 to determine if the waterbody should be listed as an NLW, or nutrient limited watershed. Table 20 summarizes all TSI's calculated for Canton Lake.

Table 20. Summary of calculated TSI's for Canton Lake.

	n=		CHL TSI		SD TSI		TP TSI	
Year	Annual	Growing	Annual	Growing	Annual	Growing	Annual	Growing
1998	12	6	54	55	69	69	69	62
1999	9	3	59	46	69	65	68	66
2000	12	6	59	60	74	74	78	75
All	33	15	57	54	71	69	72	67

mesotrophic eutrophic hypereutrophic

Both SD TSI and TP TSI classify the lake as hypereutrophic. Criteria for these two parameters are not listed in OWQS, so they are not used in beneficial use assessment. Total phosphorus TSI, however does indicate that there is an abundance of available phosphorus in the lake, which has the potential to increase productivity during appropriate conditions. The SD TSI indicated there are likely suspended solids and or algal biomass affecting transparency. The CHL TSI, which is the most accepted parameter in assessing Oklahoma's Lakes, classified Canton Lake as eutrophic, with one mesotrophic classification during the growing season in 1999. It is important to note that during the spring and summer months in 1999 there was a greater amount of rainfall than 1998 and 2000. According the USGS Monthly Streamflow Statistics web page, the gaging station at Seiling, just upstream of Canton Lake, May and August of 1999 average flows where 695 cfs and 109 cfs, compared to 1998 flows of 492 cfs and 35 cfs, and 2000 flows of 295 cfs and 56 cfs. Rainfall has the potential to flush the reservoir of algal biomass, which may be what is reflected in the lower value during that sample period.

<u>Total Nitrogen:Total Phosphorus Ratio</u>

The TN:TP ratio is often used to determine which nutrient is the "limiting" factor for algal productivity. Generally, algae and macrophytes contain three essential elements; phosphorus, nitrogen and carbon in the representative ratio of 1P:7N:40C (Wetzel, 1983). According to USEPA (2000) TN:TP ratios less than 7:1 are nitrogen limited, and greater than 10:1 are phosphorus limited. TN:TP ratios for the project period (n= 33) ranged from a low 6:1 in June of 2000 to a high of 29:1 in June of 1998. The average TN:TP ratio for the entire project was 14:1 indicating phosphorus limitation. The ratio calculated from the TN average (0.998 mg/l) and the TP average (0.081 mg/l) was 12:1, also indicating phosphorus limitation. Three samples, all detected in August of 2000, were below 7:1, or nitrogen limited. Figure 30 depicts TN:TP ratios for Canton Lake. Low ratios in shallow hypereutrophic lakes are typically the result of high TP loads from point or non point sources in the watershed rather than a shortage of nitrogen (USEPA, 2000). Overall Canton Lake is phosphorus limited, meaning there is an abundance of nitrogen. Generally phosphorus is more easily controlled than nitrogen due to the presence of nitrogen in the atmosphere, and capabilities of blue green algae to fix atmospheric nitrogen. Therefore watershed best management practices that control phosphorus should be implemented to decrease algal productivity in Canton Lake.

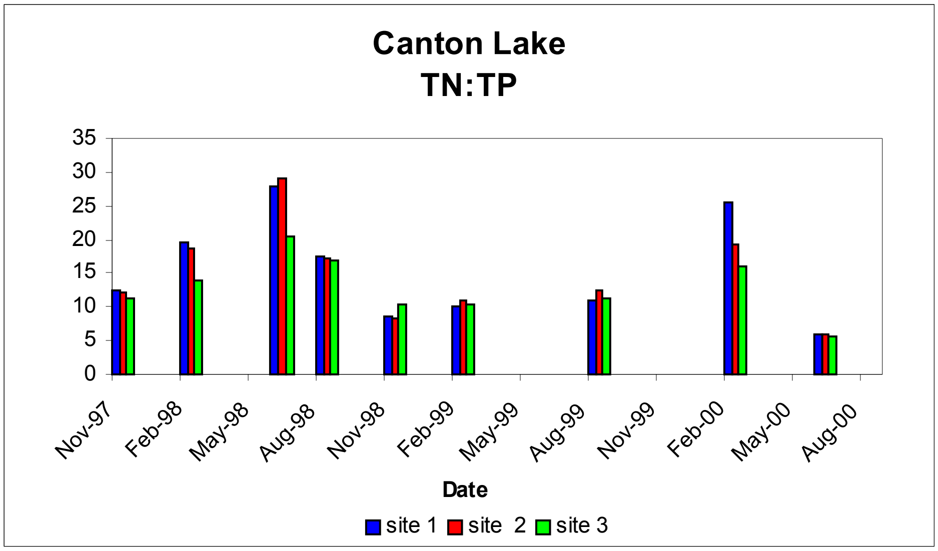


Figure 30. Canton Lake TN:TP ratios from November 1997 through August 2000.

Fecal Coliform

Oklahoma Water Quality Standards states for Primary Body Contact Recreation beneficial use the geometric mean of fecal coliform may not exceed 400 colonies (cfu) per 100ml and 25% of the samples may not exceed the screening level of 400 cfu per 100ml. Samples must be collected during the recreational season from May 1 through September 30, with no less than 10 samples. The geometric mean of samples collected from Canton Lake was 21 cfu per 100ml (n=26) and no samples exceeded the prescribed screening level, therefore OWQS were being met for Primary Body Contact Recreation beneficial use.

Lake Overholser Water Quality

Lake Overholser was sampled quarterly from November 1997 through August of 2000 at two sites representing the lacustrine zone (Site 1, near the dam) and the transition zone (Site 2). Lake Overholser is not a mainstream reservoir, it is offset from the North Canadian River. Due to this there is no true riverine zone, therefore a Site 3 was not established. The data was analyzed annually as well as cumulatively to represent the entire sampling period. Each sample year was from November of the proceeding year through August of the year indicated, for sample years 1998, 1999 and 2000. Water quality samples were collected at the surface and 0.5m from the bottom at Site 1, near the dam when water depth was greater than 3 meters. Winter samples (November 1999 and February 2000) were not collected due to low lake levels and the inability to collect quality data.

In summary, Lake Overholser was classified as hypereutrophic from both annual and growing season CHL TSI averages for the entire sample period indicating that excessive primary productivity and nutrient levels may be threatening its beneficial uses. This lake has the potential to be listed as a “Nutrient Limited Watershed” (NLW) in the next OWQS revision. The TN:TP ratio indicated the lake is nitrogen limited, which is likely from the abundance of phosphorus instead of a lack of nitrogen. This lake is a classic hypereutrophic lake that is nearing the end of its useful life for many beneficial uses. Lake Overholser is likely avoiding severe algal blooms and consequential taste and odor problems due to its high turbidity (reflected in both turbidity data and Secchi disk depth TSI) affecting light attenuation. Turbidity was both organic and inorganic. Water quality studies should continue in the future to more accurately identify the specific nature of turbidity and watershed practices that may be contributing to the water quality degradation and implement best management practices to control phosphorus.

Physical Characteristics

<u>Turbidity and Secchi Disk Depth</u>
The lake-wide average turbidity for each sample year was 18.27 NTU (n=8) in 1998, 57.91 NTU (n= 8) in 1999 and 26.5 NTU (n= 4) in 2000 (Figures 31-33), with an overall average of 35.7 NTU (n=20). OWQS for turbidity (lake) is 25 NTU. In 1998, 25% of the turbidity values exceeded OWQS with a range of 5.7- 35 NTU, 89% of the 1999 values exceeded with a range of 23.8- 114 NTU and in 2000, 50% of the turbidity values exceeded OWQS with a range of 15-36 NTU. The high value of 114 NTU was detected in November of 1998 at Site 2, likewise the Site 1 value was 99 NTU on that same sample date. Review of streamflow statistics from the USGS Monthly Streamflow Statistics web page did not reflect high flow during that sample month. Turbidity may likely be a result of Lake Overholser shallowness (maximum depth 3-4 m). In-lake wind mixing and resuspension of bottom sediments and or agal productivity, in addtion to inflowing waters are all likely contributors to Overholser’s turbidity.

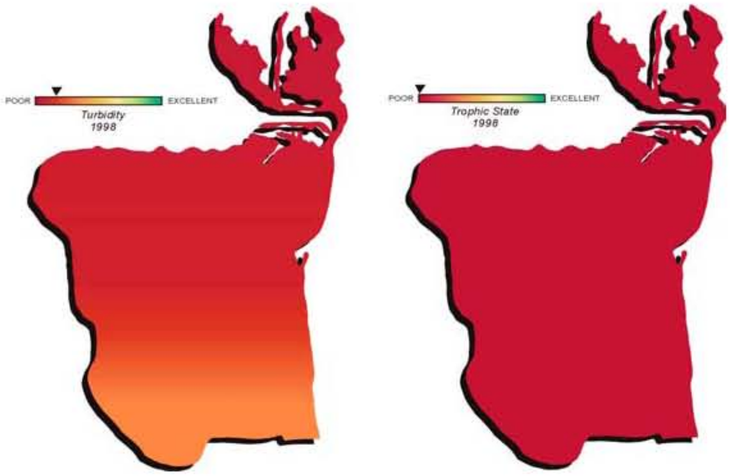


Figure 31. Turbidity and Chlorophyll-a trophic state index for Lake Overholser in 1998.

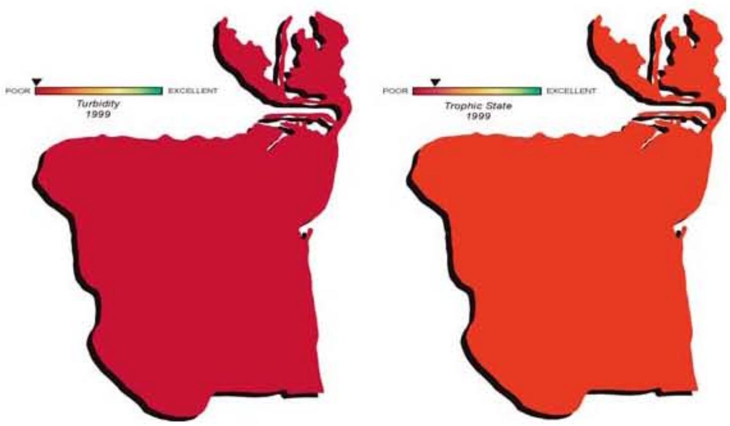


Figure 32. Turbidity and Chlorophyll-a trophic state index for Lake Overholser in 1999.

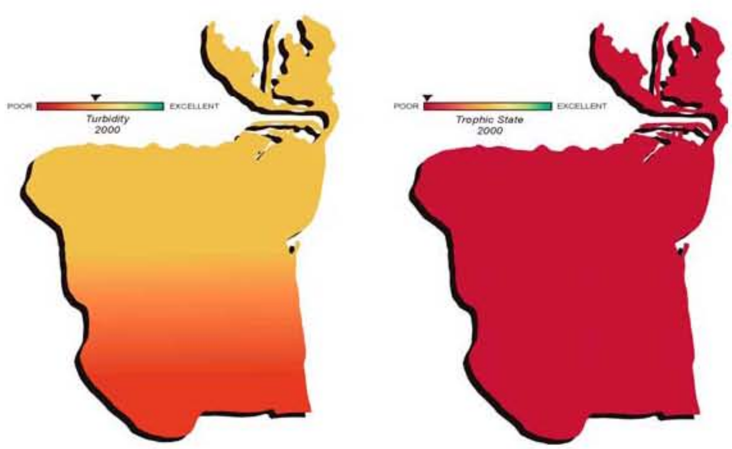


Figure 33. Turbidity and Chlorophyll-a trophic state index for Lake Overholser in 2000.

The average annual Secchi disk depth for each year was 43, 24 and 25 centimeters, while the overall average Secchi disk depth was 31 centimeters (n= 20). The minimum secchi disk depth of 13 cm occurred in November of 1998 at Site 2, reflecting the high turbidity values detected at this same site and time.

Salinity, Specific Conductance and Oxidation-Reduction Potential

Lake Overholser salinity values ranged from 0.4- 0.6 ppt in 1998, 0.16- 0.4 ppt in 1999 and 0.43- 0.50 ppt in 2000, while overall salinity ranged from 0.16- 0.6 ppt (n= 74). These values are higher than most Oklahoma reservoirs (OWRB, 2000), however, they are similar to reservoirs in the North Canadian River drainage basin.

Specific conductance ranged from 767- 1059 µS/cm in 1998, 334- 689 µS/cm in 1999 and 823-903 µS/cm in 2000, while overall specific conductance ranged from 334 µS/cm to 1059 µS/cm. Thes values show that there are high concentrations of electrical conducting compounds such as chlorides, salts, or other analogous materials present relative to other Oklahoma reservoirs (BUMP, 2000). Again, typical for lakes in the North Canadian River drainage basin.

Oxidation-reduction potentials were positive at all sample sites and ranged from 197- 410 mV in 1998, from 243- 420 mV in 1999 and from 231- 480 mV during 2000, while overall conditions ranged from 197- 480 mV. Therefore reducing conditions were not present during any of the sampling period.

Chlorides, Sulfates and Total Dissolved Solids

Chlorides were analyzed in surface water quality samples throughout the three-year sample period. Chloride concentrations ranged from 66- 116 mg/l in 1998, 44-66 mg/l in 1999 and 92-97 mg/l in 2000. Overall, chlorides ranged from 44- 116 mg/l (n= 22), with an average of 80.7 mg/l. Bottom samples ranged from 46- 115 mg/l (n= 7) and averaged 79 mg/l. None of the chloride values exceeded the OWQS numerical criteria of 250mg/l.

Sulfate concentrations ranged from 130- 174 mg/l in 1998, 66.8- 128 in 1999 and 114- 185 mg/l in 2000. Overall, sulfate concentrations ranged from 66.8- 185 mg/l (n= 22), with an average of 133 mg/l, with the high concentration detected in April of 2000. Bottom sulfate concentrations ranged from 69- 180 mg/l, with an average of 128 mg/l (n= 7). Again, none of the sulfate values exceeded OWQS numerical criteria of 250 mg/l.

Total dissolved solids (TDS) were measured throughout the water column at one-meter intervals using the Hydrolab®. The TDS concentrations ranged from 232- 678 mg/l in 1998, 214- 438 mg/l in 1999 and 526- 577 mg/l in 2000. Overall, TDS concentrations ranged from 214 mg/l-678 mg/l (n= 74), with an average concentration of 529 mg/l. None of the TDS values are over the OQWS numerical criteria of 750 mg/l.

pH, Temperature and Dissolved Oxygen

The pH was slightly alkaline with values (in standard units) ranging from 8.24- 8.79 in 1998, 7.8-8.65 in 1999 and 7.38- 8.63 in 2000. Overall pH values ranged from 7.38- 8.79 (n= 79) with an average of 8.35. Lake Overholser was well within OWQS range of 6.5- 9.0 standard units.

The lake was noted to be not thermally stratified at any time during the three-year sample period and appeared to be well mixed at all sites. Wind mixing and the shallowness of this reservoir (maximum depth approximately 3.9 m) most likely aide in keeping the water column mixed. Temperature ranged from 6.4 °C to 27.6 °C, with cooler temperatures in the winter months and warmer in the summer.

Dissolved oxygen concentrations only dropped below 5mg/l twice during the sample period at Site 1 in August of 1998 and August of 1999, both low values were detected at the bottom (2.8 and 2.7 m, respectively). However, OWQS states that 70% of the water column must be below 2 mg/l to not support the Fish and Wildlife Propagation (FWP) beneficial use (USAP 785:46-15-5), therefore Lake Overholser was not in violation of OWQS. Figure 34 depicts dissolved oxygen/ temperature relationships from four different seasons within the three-year sample period.

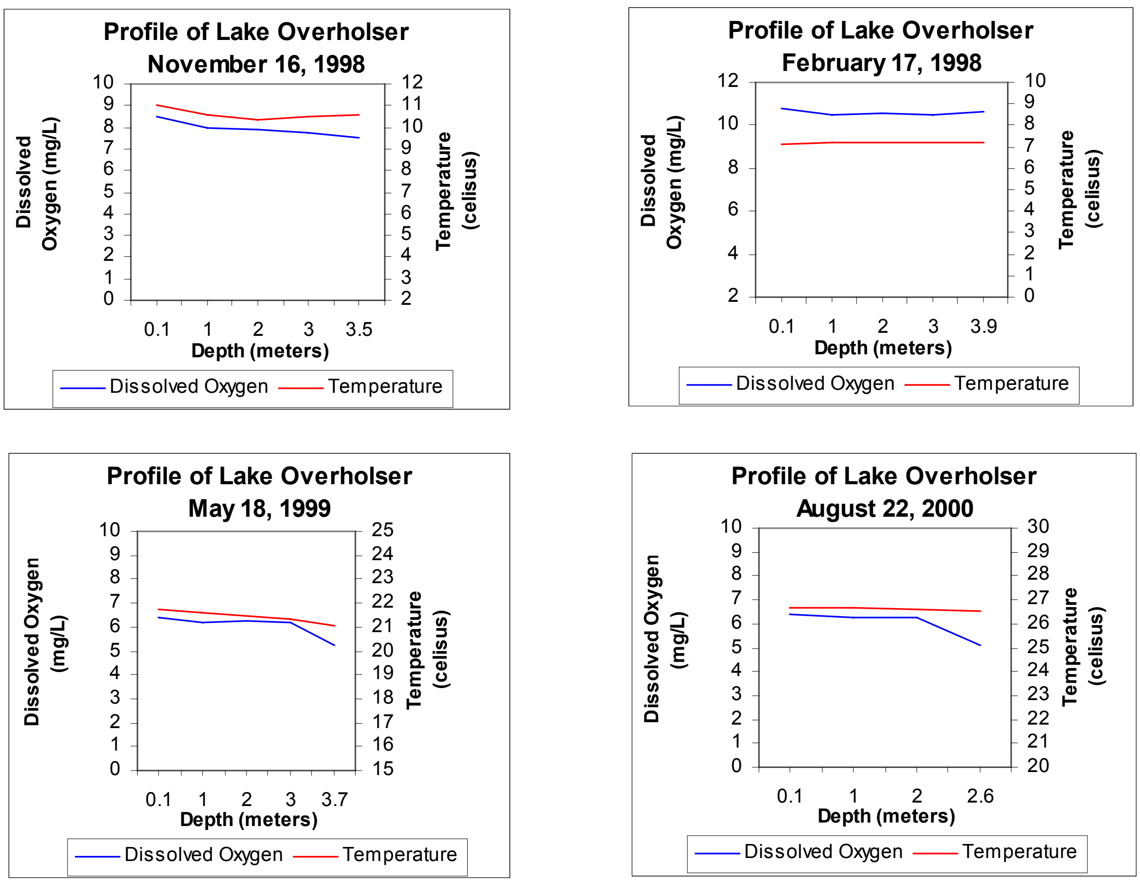


Figure 34. Vertical dissolved oxygen and temperature profiles representing four seasons measured at Site 1 in Lake Overholser.

Chemical Characteristics

Nitrogen

Total nitrogen (TN) collected at the surface ranged from 0.817- 1.657 mg/l (n= 8) during 1998, 1.265- 1.805 mg/l (n= 6) during 1999 and 0.83- 1.548 mg/l (n= 4) for 2000, with an overall range of 0.817- 1.805 mg/l (n= 18). The high concentrations occurred in August of 1998 at Site 1, February of 1999 at Site 2 and April 2000 at Site 2. The overall average TN was 1.250 mg/l, classifying the lake between mesotrophic and eutrophic, with moderate to high productivity (Wetzel, 1983). Bottom samples collected at Site 1 for TN ranged over the three year sample period from 0.945- 1.456 mg/l, with an overall average 1.13 mg/l (n= 5). The high concentration at the bottom was detected in November of 1998, unlike the high at the surface detected in February of 1999. The shallow lake was not stratified during any of these sample dates. There is no evident pattern in TN data. Nitrogen exists in many forms, and several different forms were analyzed, however total nitrogen was the primary parameter of interest in regards to TN:TP ratios and assessing trophic conditions for this project. Figure 35 depicts nitrogen concentrations throughout the project period.

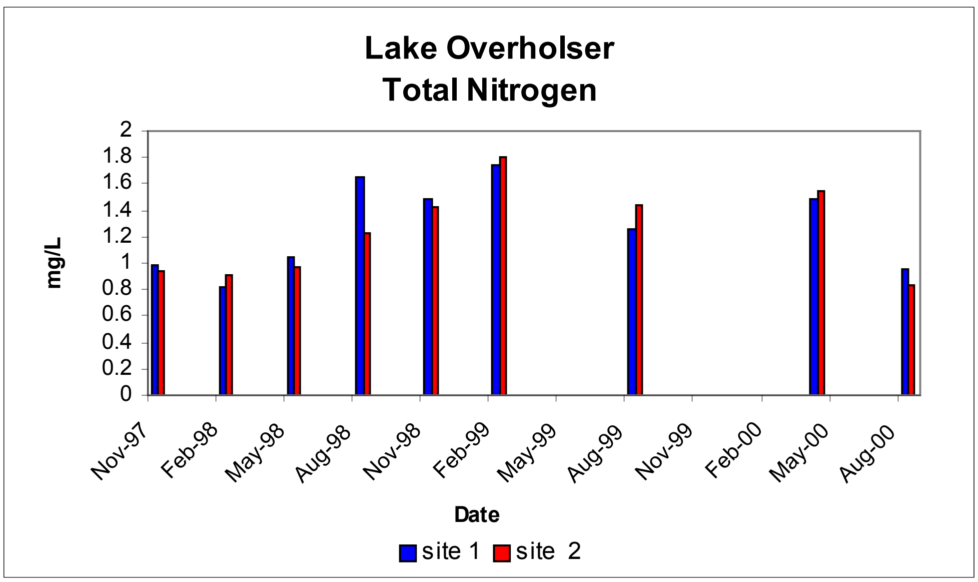


Figure 35. Lake Overholser TN concentrations, November 1997 through August 2000.

Phosphorus

Total phosphorus (TP) collected at the surface ranged from 0.152- 0.22 mg/l (n= 8) during 1998, 0.20- 0.307 mg/l (n= 8) during 1999 and 0.249- 0.279 mg/l (n= 4) for 2000. Overall TP ranged from 0.152- 0.307 mg/l (n= 20), with an average of 0.232 mg/l. The high values for each sample year occurred in November of 1997, February of 1999 and August of 2000. According to USEPA (2000), a total phosphorus concentration of >0.1 mg/l classify the lake/reservoir as hypereutrophic. Thus, the overall TP average for Lake Overholser (0.231 mg/l) classified it as hypereutrophic. The low values for all three-sample years also exceeded 0.1 mg/l reaffirming the conclusion that an excessive amount of phosphorus was present in the lake. Overall bottom samples collected at Site 1 for TP ranged from 0.081- 0.175 mg/l with an average of 0.134 mg/l (n=6). The high values were found in November of 1997 and 1998, and May of 2000 (no November sample was collected that sample year). Bottom phosphorus concentrations were generally less than the surface samples, however they were still very high. Due to the high concentration of phosphorus in this reservoir a brief discussion of chlorophyll-a data will be included in the Biological Section. Figure 36 depicts TP concentrations throughout the sample period.

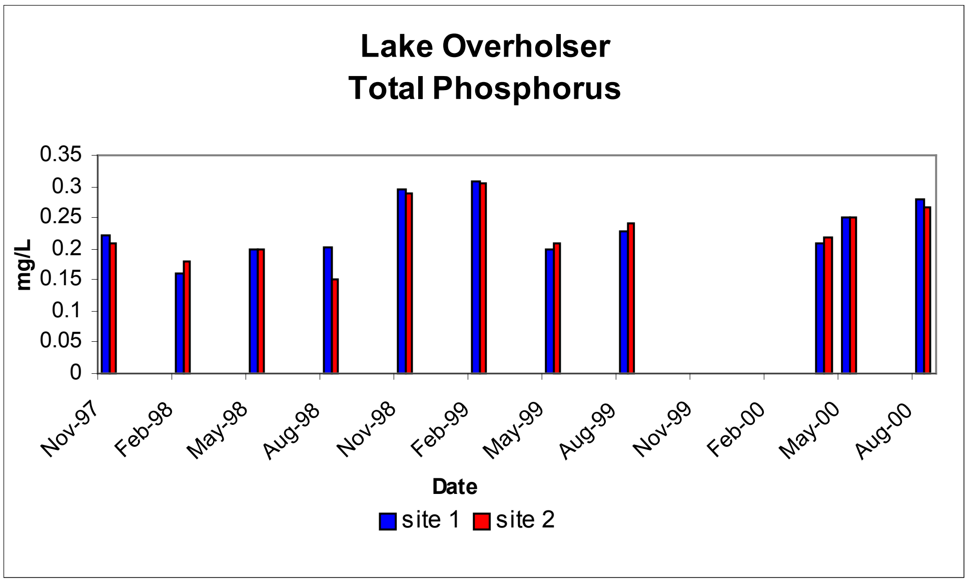


Figure 36. Lake Overholser TP concentrations, November 1997 through August 2000.

Ortho-phosphorus

Ortho-phosphorus collected at the surface ranged from 0.041- 0.16 mg/l (n= 8) in 1998, 0.09-0.173 mg/l (n= 8) in 1999 and 0.08-0.109 mg/l (n= 4) in 2000. Overall ortho-phosphorus ranged from 0.041- 0.173 mg/l (n= 20) with an average of 0.115 mg/l. The high concentrations were detected in November 1997, November of 1998 and May 2000. November of 1997 high ortho-phosphorus concentrations correspond with the high TP values detected at the same time. The high ortho-phosphorus concentration for 1999 was detected in November (1998) of 0.173 mg/l, however ortho-phosphorus was also high in February 1999 (0.170 mg/l) which corresponded with the high TP concentration. Also, it is important to note that the months high values were reported both sites were relatively high compared to the rest of that sample year. No bottom samples for ortho-phosphorus were available for 1998 and 1999 sample years, with only one value for 2000, therefore no report on bottom concentrations was possible.

Biological

Trophic State Indices

Table 21 summarizes all TSI's calculated for Lake Overholser. Averages for the growing season (May and August) and annual averages were calculated for all three parameters; chlorophyll-a, secchi disk depth and total phosphorus. In addition, averages for the entire data set were also calculated for both the annual and growing season. All TSI's were calculated based on averages of reported values. Because of the relationship between chlorophyll and TP and its linkage to biomass, chlorophyll is often a major component of trophic state indices (Carlson, 1977) and water quality criteria (USEPA, 2000). The OWRB uses a CHL TSI $\geq$ 62 for lakes to be considered a "nutrient-limited watershed" (NLW) with threatened beneficial uses due to nutrient impacts. All CHL TSI's, except for one were above the 62 threshold, therefore it is recommended that Lake Overholser be listed as a NLW in the next OWQS revision.

Table 21. Summary of calculated TSI's for Lake Overholser.

	n=		CHL TSI		SD TSI		TP TSI	
Year	Annual	Growing	Annual	Growing	Annual	Growing	Annual	Growing
1998	8	4	63	68	73	75	80	80
1999	8	4	59	63	81	78	85	82
2000	6	4	64	64	80	80	84	84
All	22	12	62	65	78	78	83	82

mesotrophic eutrophic hypereutrophic

Overall, all three parameters classified the lake as hypereutrophic, with the exception of one chlorophyll-a annual average in 1999. As stated in the Canton Lake section of this report there was a greater amount of rainfall in 1999, which may be reflected in the slightly lower concentrations of chlorophyll-a during this time period. The CHL TSI, which is the most accepted parameter in assessing Oklahoma's Lakes (OWRB, 2000), and estimating algal biomass (Carlson, 1977) classified Lake Overholser as hypereutrophic, with the possibility of being listed as an "NLW". Secchi disk depth (SD) and total phosphorus (TP) are not listed in OWQS and are not used in beneficial use assessment. The total phosphorus TSI, however does indicate that there is an abundance of available phosphorus in the lake, which has the potential to increase productivity during appropriate conditions. This is also reflected in the total phosphorus data discussed in the Chemical Section. The SD TSI indicated there was likely suspended solids and or algal biomass affecting transparency. In the event Secchi disk depth improved, then sunlight availability combined with the abundance of TP could cause severe algal blooms.

Chlorophyll-a

Chlorophyll-a data for Lake Overholser ranged from 1.2 – 94.5 µg/l, with an average of 26.58 µg/l for 1998, 4.77- 55.27 µg/l, average of 18.5 µg/l for 1999 and 24.71- 47.7 µg/l, average of 30 µg/l for 2000. The high values were found in August of each sample year, which is the height of growing season, and expected maximum biomass. Overall chlorophyll-a values ranged from 1.2 – 94.5 µg/l, with and average if 24.58 µg/l (n=22). Wetzel (1983) states chlorophyll-a ranges from 3- 78 mg/m3 (µg/l) are indicative of eutrophic conditions and 100- 150 mg/m3 (µg/l) are hypereutrophic. Based on Wetzel, Lake Overholser would be classified as eutrophic, with ranges nearing hypereutrophic.

Total Nitrogen:Total Phosphorus Ratio

Lake Overholser TN:TP ratios ranged from 5:1 to 8:1 in 1998, 5:1 to 6:1 in 1999, and 3:1 in 2000 (no range). All ratios (except the high in August of 1998) indicated nitrogen limitation (<7:1) according to USEPA (2000). Overall TN:TP ratios averaged from the entire data set ranged from 3:1 to 8:1, with an average of 5:1 (n= 20). The ratio calculated from the TN average (1.25 mg/l) and the TP average (0.231 mg/l) was 5:1, also indicating nitrogen limitation. Only two ratios were above 5.9, both in August of 1998, Sites 1 and 2, 8.24 and 8.03, respectively. Figure 37 depicts TN:TP ratios for all three sites from each sample event. Nitrogen limitation, or low ratios in shallow hypereutrophic lakes are typically the result of high TP loads from point or non point sources in the watershed rather than a shortage of nitrogen (USEPA, 2000). USEPA (2000) also suggest nitrogen limited ecosystems in the Midwest are common when lakes are impacted from sewage. Overall Lake Overholser was nitrogen limited with low ratios.

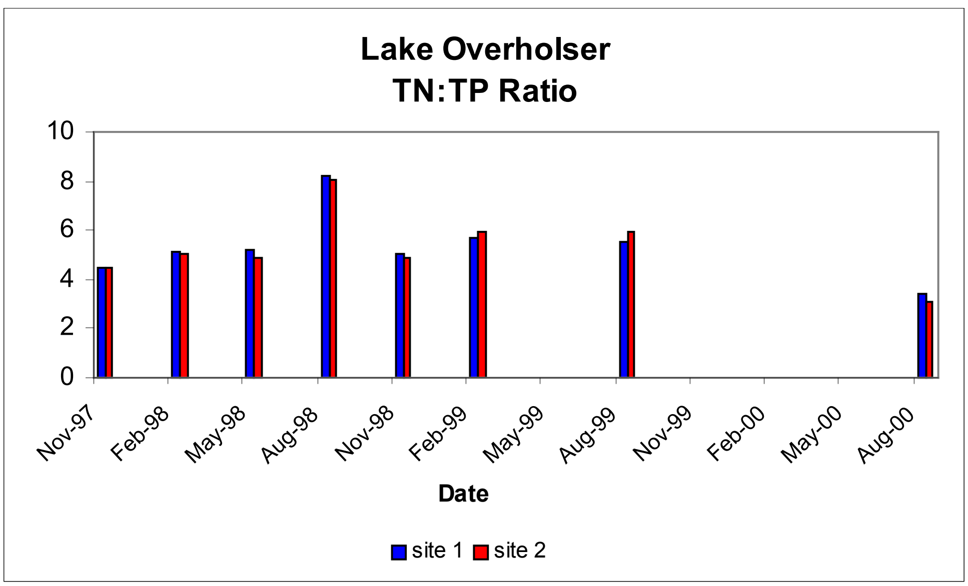


Figure 37. Lake Overholser TN:TP ratios, November 1997 through August 2000.

Fecal Coliform

Oklahoma Water Quality Standards states for Primary Body Contact Recreation beneficial use the geometric mean of fecal coliform may not exceed 400 colonies (cfu) per 100ml and 25% of the samples may not exceed the screening level of 400 cfu per 100ml. Samples must be collected during the recreational season from May 1 through September 30, with no less than 10 samples. The geometric mean of samples collected from Lake Overholser was 61 cfu per 100ml (n=26) with 24% samples exceeded the prescribed screening level, therefore OWQS were being met. Although the percent of samples was below OWQS, Lake Overholser had greater concentrations of fecal coliform compared to the other five Oklahoma City reservoirs.

Historical Water Quality Trend Analysis

Historical data for Lake Overholser was obtained from Oklahoma City for nitrates, phosphates, and turbidity from January 1980 through October 1999. Nitrate concentrations ranged from below detection limit to 4.0 (n= 77) mg/l for the quarterly samples taken from January 1980 through January 1999. Phosphates ranged from below detection limit to 2.7 mg/l (n= 77) over the same period. Turbidity ranged from 3.8- 182 NTU (n= 61). The historic data was analyzed using a Seasonal Kendall trend analysis. No trend was detected in turbidity data. A negative trend was detected for both the nitrate and phosphate data at a 95% confidence level. A further regression analysis of the data revealed an R-Squared value of 0.60 for nitrates and 0.022 for phosphates. Conclusions from this data showed that over the period tested there were a significant decrease in nitrate values and a minor decrease in phosphate levels at Lake Overholser.

Lake Hefner Water Quality

Lake Hefner was sampled quarterly from November 1997 through August of 2000 at two sites representing the lacustrine zone (Site 1, near the dam) and the transition zone (Site 2). Lake Hefner is not a mainstream reservoir, it is offset from the North Canadian River, and serves as a holding basin for withdrawl by the City of Oklahoma City's Hefner Treatment Plant. Likewise, there is no true riverine zone, therefore a Site 3 was not established. The data was analyzed annually for comparisons between sample years as well as cumulatively to represent the entire sampling period. Each sample year was from November of the proceeding year through August of the year indicated, for sample years, 1998, 1999 and 2000. A winter sample in February 2000 was not collected due to hazardous wind conditions.

Lake Hefner was classified as eutrophic from both annual and growing season CHL TSI averages for the entire sample period indicating that excessive primary productivity and nutrient levels may be impacting beneficial uses. Lake Hefner was studied by the OWRB in the early 1990's, as a USEPA Clean Lakes Phase I Diagnostic and Feasibility Study. CHL TSI from the Phase I study also classified the lake as eutrophic. Total phosphorus concentrations collected as part of the most recent sampling effort were lower than those detected in the Phase I Study, however total nitrogen was higher in the current study (0.965 mg/l) than in the Phase I Study (0.61 mg/l). TN:TP ratios between the two studies similarly reflected the changes in TN and TP concentrations. The current study TN:TP indicates phosphorus limitation (14:1), whereas the Phase I Study indicated nitrogen limitation (7:1). Turbidity was similar between the two studies. Water quality studies should continue in the future to more accurately identify specific watershed practices that contribute to the water quality degradation of the lake and implement phosphorus control best management practices.

Physical Characteristics

Turbidity and Secchi Disk Depth

The lake-wide average turbidity for each sample year was 6.2 NTU (n=8) in 1998, 10.3 NTU (n= 6) in 1999 and 8.1 NTU (n= 6) in 2000 (Figures 38-40), with an overall average of 8.1 NTU (n=20). Oklahoma's WQS for turbidity (lake) is 25 NTU. None of the turbidity values from the entire data set exceeded OWQS. Turbidity, inorganic and or algal biomass, is not creating problems in Lake Hefner. The inflow into Lake Hefner is completely controlled, only high quality water is diverted into this reservoir.

The average annual Secchi disk depth for each year was 86, 65 and 66 centimeters, while the overall average Secchi disk depth was 74 centimeters (n= 19). These values are above average, compared to other Oklahoma reservoirs (OWRB, 2000).

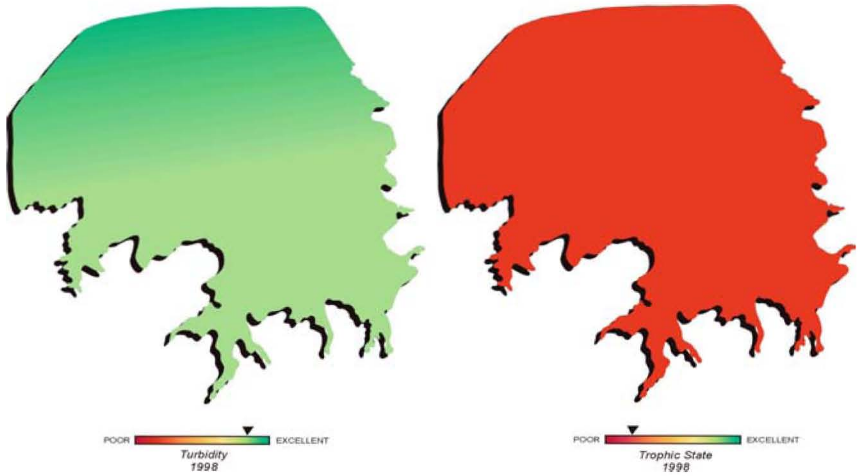


Figure 38. Turbidity and Chlorophyll-a trophic state index for Lake Hefner in 1998.

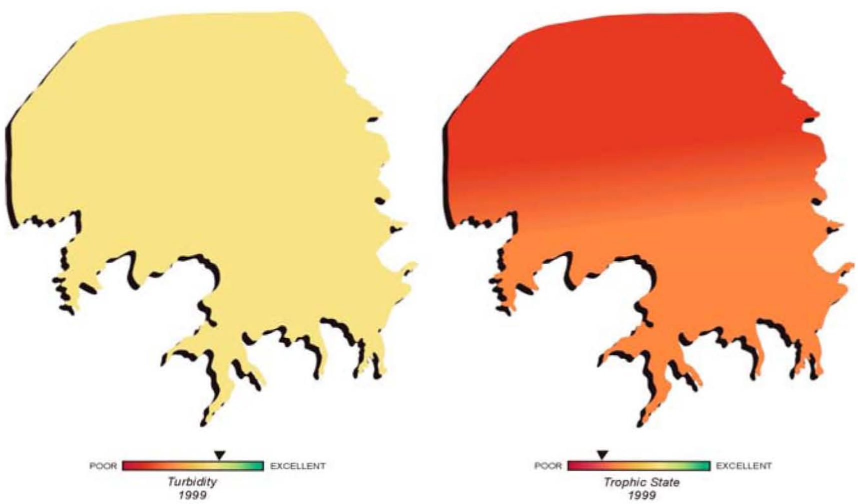


Figure 39. Turbidity and Chlorophyll-a trophic state index for Lake Hefner in 1999.

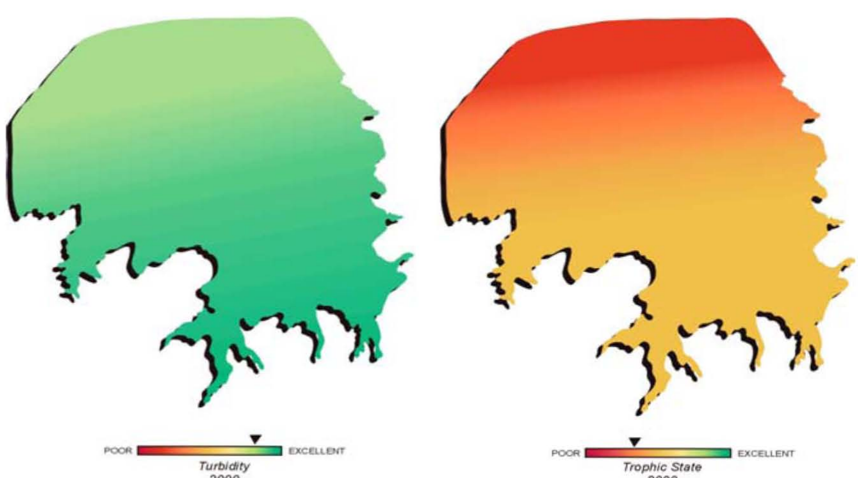


Figure 40. Turbidity and Chlorophyll-a trophic state index for Lake Hefner in 2000.

Salinity, Specific Conductance and Oxidation-Reduction Potential

Lake Hefner salinity values ranged from 0.5- 0.7 ppt in 1998, 0.26- 0.54 ppt in 1999 and 0.47- 0.50 ppt in 2000, while overall salinity ranged from 0.26- 0.7 ppt (n= 246). These values are higher than most Oklahoma reservoirs (OWRB, 2000), however, they are lower than other reservoirs in the North Canadian River drainage basin.

Specific conductivity ranged from 954- 1344 µS/cm in 1998, 510- 1029 µS/cm in 1999 and 896- 949 µS/cm in 2000, while overall specific conductance ranged from 510 µS/cm (May of 1999, throughout the water column at both Sites 1 and 2) to 1344 µS/cm (August 1998, bottom, Site 2), with an average of 933 µS/cm (n= 268). Specific conductivity values for Lake Hefner show that there were high concentrations of electrical conducting compounds such as chlorides, salts, or other analogous materials present relative to other Oklahoma reservoirs (BUMP, 2000). Again, typical for lakes in the North Canadian River drainage basin, or as in the case of Lake Hefner, receives its water from the North Canadian River.

Oxidation-reduction potentials ranged from 267- 570 mV in 1998, from -22- 435 mV in 1999 and from 202- 495 mV during 2000, while overall conditions ranged from -22- 570 mV, with an average of 364 mV (n= 268). The low value was detected in August 1998, at 14.8 meters at Site 1, the hypolimnion experienced reducing conditions. ORP values were below 100 mV for the bottom 2 meters of the reservoir, or less than 15% of the water column. Wetzel (1983) suggests that this reduction of sulfate to sulfides, and the oxidation of H_2S plays a significant role in the mobilization of phosphorus and other nutrients from the lake sediments.

Chlorides, Sulfates and Total Dissolved Solids

Chlorides were analyzed in surface water quality samples throughout the three-year sample period. Chloride concentrations ranged from 103- 128 mg/l in 1998, 103- 118 mg/l in 1999 and 108- 122 mg/l in 2000. Overall chlorides ranged from 103- 128 mg/l (n= 22), with an average of 113.5 mg/l. Bottom samples ranged from 102- 128 mg/l (n= 11) with an overall average of 110 mg/l. None of the chloride values exceeded the OWQS of 250mg/l.

Sulfate concentrations ranged from 159- 199 mg/l in 1998, 156- 188 mg/l in 1999 and 144- 192 mg/l in 2000. Overall, sulfates concentrations ranged from 144- 199 mg/l (n= 22), with an average of 170 mg/l. Bottom samples ranged from 146- 199 mg/l (n= 11), with an average of 173 mg/l. Again, none of the sulfate values exceeded the OWQS of 250 mg/l.

Total dissolved solids (TDS), measured at one-meter intervals, ranged from249- 860 mg/l in 1998, 326- 659 mg/l in 1999 and 580- 608 in 2000. Over the three-year sample period, TDS ranged from 249- 860 mg/l, with an average concentration of 529 mg/l (n= 74). Two of the report values, 860 mg/l and 839 mg/l at 14.5 and 14 meters, respectively, at Site 2, in August of 1998 were the only TDS concentrations above the OWQS of 750 mg/l. However, these values were not in excess of the Yearly Mean Standard (9,042 mg/l) or the Sample Standard (12,466 mg/l) listed in Appendix F, OWQS, therefore the Agriculture beneficial use is fully supported.

pH, Temperature and Dissolved Oxygen

The pH was slightly alkaline with values (in standard units) ranging from 8.05- 8.84 in 1998, 7.52- 8.47 in 1999 and from 8.02- 8.71 in 2000. Overall, pH values ranged from 7.52- 8.84 with an average of 8.2 (n= 268). Lake Hefner was well within the OWQS range of 6.5- 9.0 standard units.

Temperature ranged from 6.4 °C to 28.1 °C, with warmer temperatures in the summer months and cooler in the winter. Thermal stratification was present only once during the three-year sample period in May of 1998 between 9 and 10 meters. Lake Hefner is an open reservoir with little shoreline protection and is thus subject to high winds which aide in keeping the lake well mixed.

Dissolved oxygen values dropped below 2 mg/l only once during the three-year sample period. The lake became anoxic in the bottom one-third of the water column at Site 1 in August 1998. Dissolved oxygen dropped from 2.99 mg/l at 10 meters to 1.48 mg/l at 11 meters while the temperature changed from 27.39°C at 10 meters to 27.34 °C at 11 meters. The dissolved oxygen value at the lake bottom recorded on this sample date was 0.12 mg/l at 14.8 meters, which corresponds with the low ORP, indicative of reducing conditions in the hypolimnion. Approximately 30% of the water column was anoxic (<2 mg/l) on that sample date. August of 1998 and 2000, dissolved oxygen dropped below 5 mg/l only in the bottom few meters. Again, wind mixing aided in keeping the water column mixed, preventing temperature stratification, and should prevent dissolved oxygen stratification. OWQS states that 70% of the water column must be below 2 mg/l to not support the Fish and Wildlife Propagation (FWP) beneficial use (USAP 785:46-15-5), therefore Lake Hefner was not in violation of OWQS. Figure 41 depicts dissolved oxygen/ temperature relationships from four different seasons within the three-year sample period.

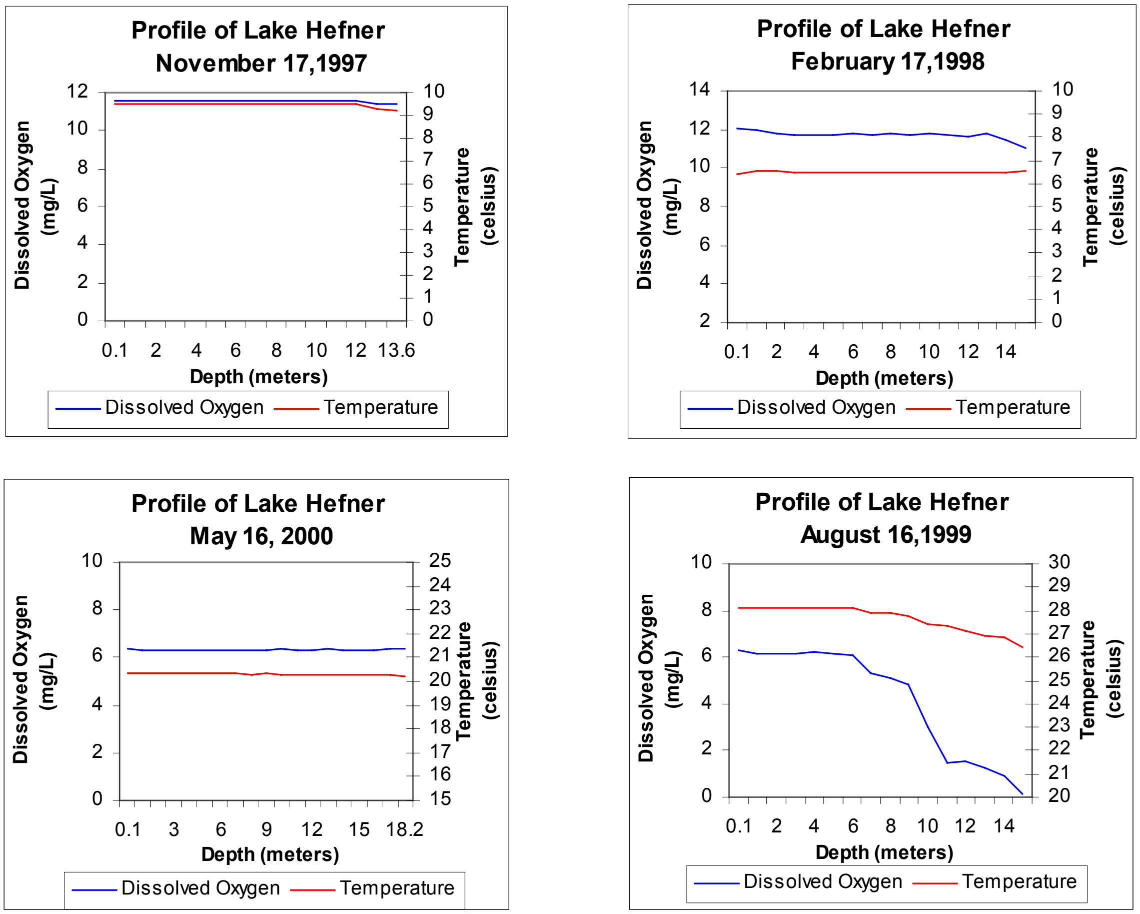


Figure 41. Vertical dissolved oxygen and temperature profiles measured at the lacustrine site at Lake Hefner representing four seasons sampled.

Chemical Characteristics

Nitrogen

Total nitrogen (TN) collected at the surface ranged from 0.824- 1.133 mg/l (n= 8) during 1998, 0.975- 1.265 mg/l (n= 6) during 1999 and 0.735- 0.765 mg/l (n= 2) for 2000, with an overall range was 0.735- 1.265 mg/l (n= 16). The high values occurred in August of 1998 and February of 1999. These high values correspond with the high values detected in Lake Overholser on those same dates. The overall average TN from the three-year sample period was 0.965 mg/l (n=16). Bottom samples collected at Site 1 for TN ranged over the three year sample period from 0.64- 1.295 mg/l, with an overall bottom average of 0.99 mg/l (n= 8). The high value at the bottom was detected in February of 1999, corresponding with the high value detected at the surface. According to Wetzel (1983), the overall average TN concentration of 0.965 mg/l would classify Lake Hefner in the mesotrophic to eutrophic range. This overall average is greater than the average from the Clean Lakes Phase I Study (1995) data collected in 1990- 1991 of 0.61 mg/l TN. Nitrogen exists in many forms, and several different forms were analyzed, however total nitrogen was the primary parameter of interest in regards to TN:TP ratios. Figure 42 depicts total nitrogen concentrations throughout the project period.

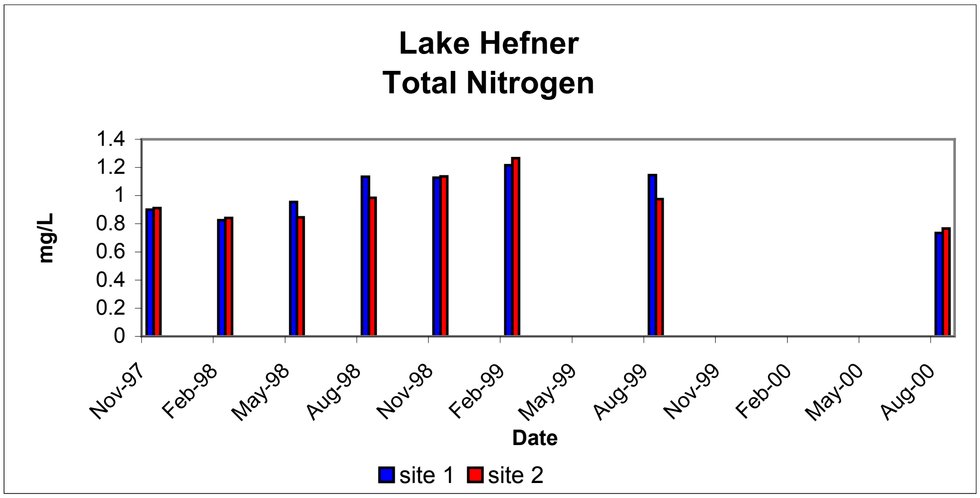


Figure 42. Lake Hefner TN concentrations, November 1997 through August 2000.

Phosphorus

Total phosphorus (TP) collected at the surface ranged from 0.04- 0.07 mg/l (n= 8) during 1998, 0.051- 0.11 mg/l (n= 8) during 1999 and 0.059- 0.112 mg/l (n= 6) for 2000. Overall TP ranged from 0.04- 0.112 mg/l (n= 22), with an average of 0.072 mg/l. The high concentrations were detected in November and February of 1998 (sample year), May of 1999 and May of 2000. The 1999 high concentration was detected in both November (Site 2) and May (Site 1 and 2). According to USEPA (2000), a total phosphorus concentration of >0.1 mg/l classify the lake/reservoir as hypereutrophic, while Wetzel (1983) further breaks down the classification into mesotrophic at 0.027 mg/l and eutrophic at 0.084 mg/l. Thus, the overall TP average for Lake Hefner (0.072 mg/l) classified the lake in the mesotrophic to eutrophic range, similar to the TN classifications. The Clean Lakes Phase I Study (1995) average TP concentration was 0.11 mg/l, higher than TP concentrations seen in the current study. Overall bottom samples collected at Site 1 for TP ranged from 0.067- 0.14 mg/l and had an average of 0.09 mg/l (n= 11). The high value was found in May of 1999, the lake was not thermally stratified at this time. Figure 43 depicts TP concentrations throughout the sample period.

Ortho-phosphorus

Ortho-phosphorus collected at the surface ranged from 0.005- 0.04 mg/l (n= 8) in 1998, 0.005- 0.08 mg/l (n= 8) in 1999 and 0.013-0.053 mg/l (n= 4) in 2000. Overall ortho-phosphorus ranged from 0.005- 0.08 mg/l (n= 20) and an average of 0.034 mg/l. The high values were detected in November 1997 (Sites 1 and 2), November of 1998 (Site 2) and May of 1999 (Sites 1 and 2),

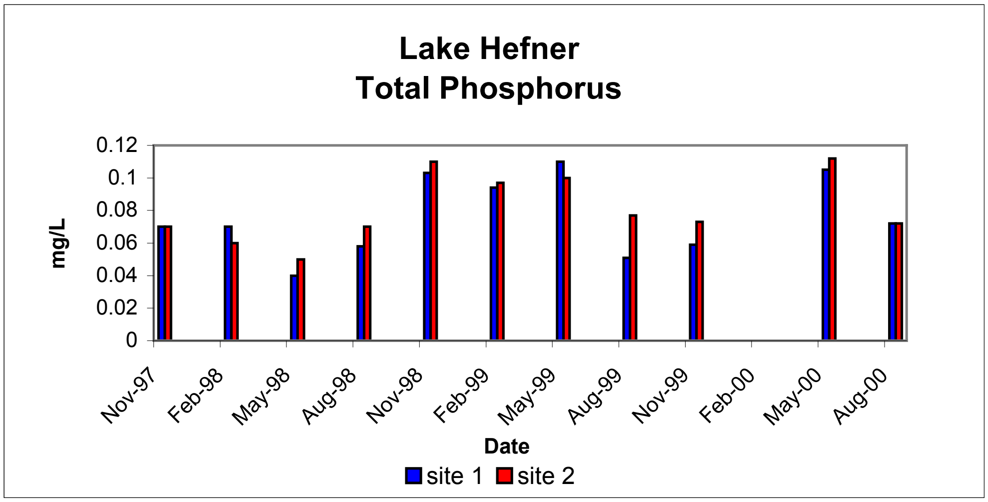


Figure 43. Lake Hefner TP concentrations, November 1997 through August 2000.

May 2000 (Site 2). These high ortho-phosphorus values correspond with the high total phosphorus values. Overall, bottom concentrations ranged from 0.011- 0.08 mg/l with an average of 0.05 mg/l (n= 10). The high ortho-phosphorus concentration was detected on the same sample date and site as the surface high value in May of 1999.

Biological

Trophic State Indices

Table 22 summarizes all TSI's calculated for Lake Hefner. Averages for the growing season (May and August) and annual averages were calculated. In addition, averages for the entire data set were also calculated for both the annual and growing season. Averages were calculated on the reported value, then TSI's were determined based on that average. Because of the relationship between chlorophyll and TP and its linkage to biomass, chlorophyll is often a major component of trophic state indices (Carlson, 1977) and water quality criteria (USEPA, 2000). The OWRB uses a Chlorophyll-a TSI $\geq$ 62 for lakes to be considered a "nutrient-limited watershed" and may be threatened due to nutrients.

All CHL TSI calculations classify Lake Hefner as eutrophic characterized by accelerated or high productivity. Secchi disk depth SD TSI (SD) and total phosphorus (TP) TSI classify Lake Hefner as hypereutrophic. The SD TSI indicated there were likely suspended solids and or algal biomass affecting transparency. Although Secchi disk depth data indicates Lake Hefner is above average for Oklahoma's Lakes in transparency, the TSI calculation ranks the Lake in the hypereutrophic class. The SD TSI calculation was developed for northern temperate lakes, and is not generally accurate for Oklahoma lakes. A Secchi disk depth of one meter may be considered above average for Oklahoma reservoirs, however for a northern lake that depth may be considered as impaired. This discrepancy is one reason that SD TSI is not used in Oklahoma for classifying reservoirs. Total phosphorus concentrations were diverse. Several high values (>0.1 mg/l) were detected in 1999 and 2000 for TP, which is likely reflected in the high TSI's (upper 60's) for these years. The high TP TSI indicates that there is an abundance of available phosphorus in the lake, which has the potential to increase productivity during appropriate conditions. Overall, and following OWRB guidelines, Lake Hefner is eutrophic using the CHL TSI.

Table 22. Summary of calculated TSI's for Lake Hefner.

	n=		CHL TSI		SD TSI		TP TSI	
Year	Annual	Growing	Annual	Growing	Annual	Growing	Annual	Growing
1998	8	4	55	59	62	62	63	62
1999	8	4	55	57	66	64	69	68
2000	6	4	56	55	66	65	68	69
All	22	12	55	57	65	63	67	66

mesotrophic eutrophic hypereutrophic

Total Nitrogen:Total Phosphorus Ratio

Lake Hefner TN:TP ratios ranged from 12:1 to 24:1 (n= 8) in 1998, 10:1 to 22:1 (n= 6) in 1999 and 10:1 to 11:1 (n= 2) in 2000. Overall TN:TP ratios averaged from the entire data set ranged from 10:1 to 24:1, with an average of 13:1 (n= 16). This indicated that the lakes was phosphorus limited. All ratios in the entire data set are greater than 10:1, or phosphorus limited. Figure 44 depicts TN:TP ratios for all three sites for all sample events. Most reservoirs in Oklahoma are phosphorus limited. Phosphorus limitation indicates there is an abundance of nitrogen in the presence of phosphorus. During anoxic conditions, phosphorus can be released from bottom sediments resulting in algal blooms, which can cause taste and odor problems. Phosphorus control measures should be implemented to minimize the potential for internal phosphorus release.

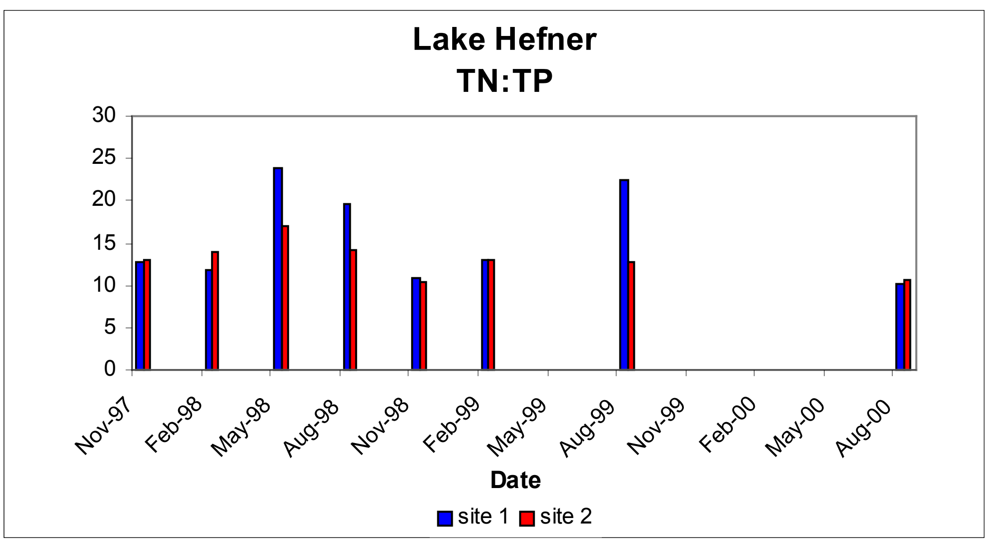


Figure 44. Lake Hefner TN:TP ratios, November 1997 through August 2000.

Fecal Coliform

Oklahoma Water Quality Standards states for Primary Body Contact Recreation beneficial use the geometric mean of fecal coliform may not exceed 400 colonies (cfu) per 100ml and 25% of the samples may not exceed the screening level of 400 cfu per 100ml. Samples must be collected during the recreational season from May 1 through September 30, with no less than 10 samples. The geometric mean of samples collected from Lake Hefner was 26 cfu per 100ml (n=15) with no samples exceeding the prescribed screening level, therefore OWQS were being met.

Historical Water Quality Trend Analysis

Historical data for Lake Hefner was obtained from Oklahoma City for nitrates and phosphates from collected quarterly from January 1980 through October 1999. Nitrates ranged from 0- 2.64 mg/l (n= 78) and phosphates ranged from below detection limit to 1.28 mg/l (n= 76). The historic data was analyzed using a Seasonal Kendall trend analysis. No significant trend was found in any of the data at any of the confidence levels used.

Lake Stanley Draper Water Quality

Lake Stanley Draper was sampled quarterly from November 1997 through August of 2000 at three sites representing the lacustrine zone (Site 1, near the dam), transition zone (Site 2) and the riverine zone (Site 3, headwaters of the reservoir). The data was analyzed annually for comparisons between sample years as well as cumulatively to represent the entire sampling period. Each sample year was from November of the proceeding year through August of the year indicated, for sample years, 1998, 1999 and 2000.

Lake Stanley Draper was found to be very turbid, likely due to inorganic suspended solids from shoreline erosion and being transported from Lake Atoka via the pipeline. Over 85% of the collected turbidity samples (n= 30) were in violation of OWQS of 25 NTU, with an average turbidity of 40 NTU. Minerals were relatively low compared to other Oklahoma reservoirs (OWRB, 2000), as expected for reservoirs in Southeast Oklahoma (Lake Draper receives the majority of its water from Lake Atoka). The TN:TP ratio indicated the lake was phosphorus limited, with an excess of nitrogen in relation to phosphorus. Total nitrogen would classify the lake, based on Wetzels (1983) numbers, as oligotrophic to mesotrophic, indicative of low primary productivity. Likewise, the CHL TSI also classified Stanley Draper as oligotrophic. However, Carlson's TP TSI classifies the lake as approaching hypereutrophic, while Wetzel's (1983), using the average concentration of TP (0.046 mg/l), classifies Draper as mesotrophic. Carlson's SD TSI was greatly influenced by the high turbidity, classifying the lake in the hypereutrophic range for all measures. The high concentrations of both nitrogen and phosphorus, and high Secchi Depth TSI, with low CHL TSI and chlorophyll-a concentrations indicated that light limitation is the primary controlling factor for productivity.

Observations during sampling trips revealed extensive human impacts that were accelerating shoreline erosion. These included removed shoreline vegetation as well as unpaved roads that end at the shoreline. The lack of shoreline vegetation further contributes to the high turbidity that is imported from Lake Atoka. Shoreline stabilization efforts could go a long way toward improving the turbidity in Lake Stanley Draper.

Physical Characteristics

Turbidity and Secchi Disk Depth

The lake-wide average turbidity over the three years was 30.18 in 1998, 51.44 in 1999 and 38.5 NTU in 2000 (Figures 45- 47). There were only 2 sample events where turbidity was less than the OWQS of 25 NTU. Once in August of 1998 (Sites 1, 2, and 3, 20, 18 and 20 NTU respectively) and August of 2000 (Sites 1 and 2, both 24 NTU). Overall, the average from the entire sample period was 39.9 NTU (n=30).

The average annual Secchi disk depth was 42, 27 and 33 centimeters for each sample year (1998, 1999 and 2000), while the overall average secchi disk depth was 33 centimeters (n= 29). These Secchi disk depths are less than average for Oklahoma's reservoirs (OWRB, 2000).

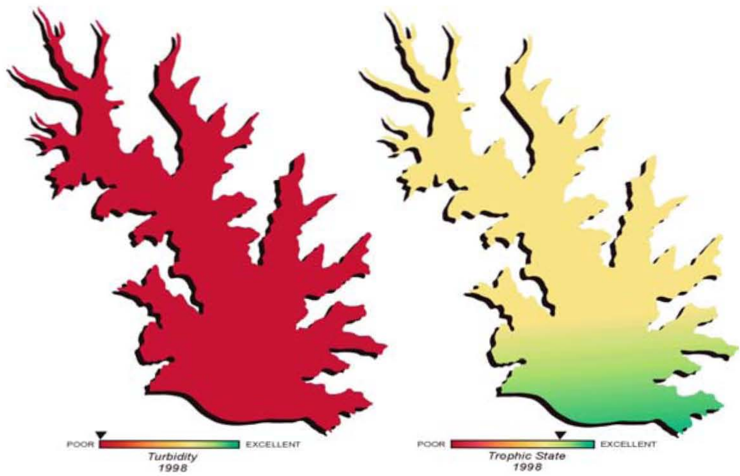


Figure 45. Turbidity and Chlorophyll a trophic state index for Lake Stanley Draper in 1998.

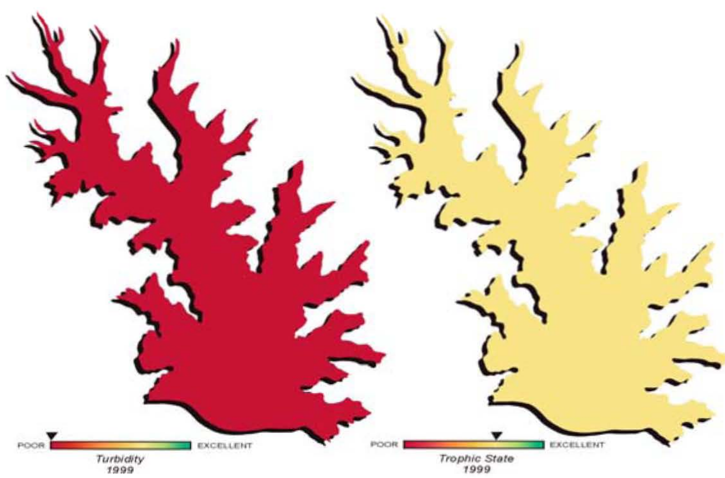


Figure 46. Turbidity and Chlorophyll a trophic state index for Lake Stanley Draper in 1999.

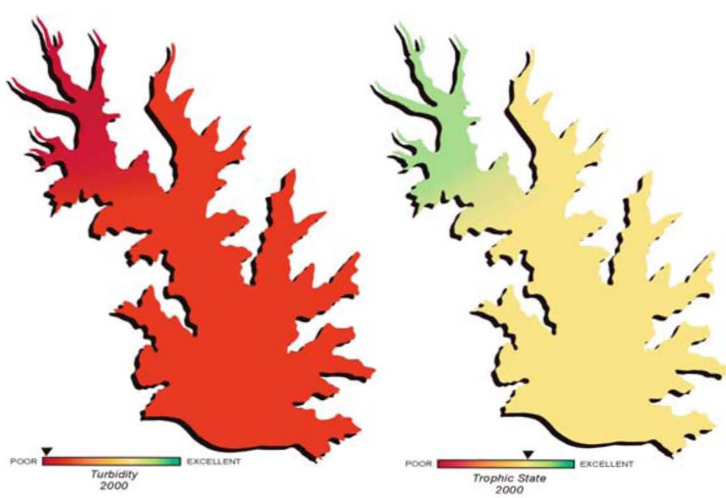


Figure 47. Turbidity and Chlorophyll a trophic state index for Lake Stanley Draper in 2000.

Salinity, Specific Conductance and Oxidation-Reduction Potential

Lake Draper salinity values ranged from 0- 0.1 ppt in 1998, 0- 0.03 ppt in 1999 and 0.03- 0.04 ppt in 2000, while overall average salinity was 0.03 ppt (n= 548). Salinity values were relatively low for Oklahoma reservoirs (OWRB, 2000).

Specific conductance ranged from 50- 138 μS/cm in 1998, 36- 105 μS/cm in 1999 and 90.3- 111.2 μS/cm in 2000, while overall specific conductance ranged from 36 μS/cm - 138 μS/cm (n= 546). The low value was found at all sites and throughout the water column in May of 1999, while the high value was found near the bottom at Site 2 in November of 1997. These ranges indicated that very low concentrations of electrical current conducting compounds (i.e. salts) were present in the lake. Like salinity, these values are relatively low for Oklahoma reservoirs (OWRB, 2000).

Oxidation-reduction potentials were positive at all sample sites and ranged from 175- 425 mV in 1998, from 282- 493 mV in 1999 and from 293- 591 mV during 2000, while overall conditions ranged from 175- 591 mV, with an average of 396 mV (n= 548). There were no reducing conditions (<100 mV) present throughout the entire sampling period.

Chlorides, Sulfates and Total Dissolved Solids

Chlorides were analyzed in surface water quality samples throughout the three-year sample period. Chloride concentrations ranged from 5- 8 mg/l in 1998, 4- 16 mg/l in 1999 and 5- 10 mg/l in 2000. Overall, the cumulative average for chlorides was 6.6 mg/l (n= 35). None of the Chloride values exceeded the OWQS of 250mg/l.

Sulfates ranged from 13.3- 16 mg/l in 1998, 12.5- 20.9 mg/l in 1999 and 7.8- 23.6 mg/l in 2000. The cumulative average was 14.98 mg/l (n= 35). None of the sulfate concentrations exceeded OWQS of 250mg/l.

The total dissolved solids (TDS) concentrations for the lake, collected at one meter intervals using a Hydrolab®, were 32- 88 mg/l in 1998, 23- 67 mg/l in 1999 and 57.8- 71.2 mg/l in 2000. Overall, the average TDS concentration was 66 mg/l (n= 548). The TDS standard listed in OWQS is 750 mg/l. Lake Stanley Draper TDS does not violate OWQS.

pH, Temperature and Dissolved Oxygen

The pH was neutral with values ranging from 6.71- 8.34 in 1998, 6.54- 7.72 during 1999 and from 6.71- 7.78 s.u. in 2000, overall pH values ranged from 6.54- 8.34, with an average of 7.4 s.u. (n= 548). Lake Stanley Draper was within OWQS range of 6.5- 9.0 standard units.

The lake was thermally stratified during August of each year. In 1998 and 1999 stratification occurred between 9 –10 meters, whereas in August of 2000 stratification appeared only at Site 2 between 8- 9 meters. Other than August, thermal stratification was only present once in May 2000 at Site 2 between 13 and 14 meters. Temperature ranged from 6.6° C to 32.9° C , with warmer temperatures in the summer months and cooler in the winter months. The high temperatures were detected at the surface during August 1998 (Sites 1 (32.9° C), 2 (30.65° C) and 3 (31.9° C) also where thermal stratification was strong. Temperature changes at Site 1 changed 4.8 ° C between 0.1 and one meter depths. Turbidity likely affected light attenuation, therefore affecting temperatures below the shallow photic zone.

The lake did not become anoxic (<2mg/l), however D.O. minimums, occurring in August of each year, were 2.81 mg/l in 1998 at Site 2 (14m), 2.21 mg/l in 1999 at Site 1 (25m) and Site 2 (16m) and 2.59 mg/l in 2000 at Site 1 (25.4m). The lake was also, thermally stratified during August of each year. Dissolved oxygen dropped below 5mg/l at all sites during the August sample trips, while in 2000 at both Sites 1 and 2, the complete water column was below 5 mg/l. OWQS states that a 70% or more of the water column must be less than 2mg/l for Fish and Wildlife Propagation (FWP) beneficial use is not supported (USAP 785:46-15-5). Therefore, Lake Stanley Draper is meeting the FWP beneficial use based on USAP OAC 785, since dissolved oxygen does not drop below 2 mg/l throughout the entire sample period. Anoxic conditions do not seem to be a problem in this reservoir at this time, probably due in part to wind mixing and light limiting productivity. Figure 48 depicts dissolved oxygen/ temperature relationships for four different seasons within the three-year sample period.

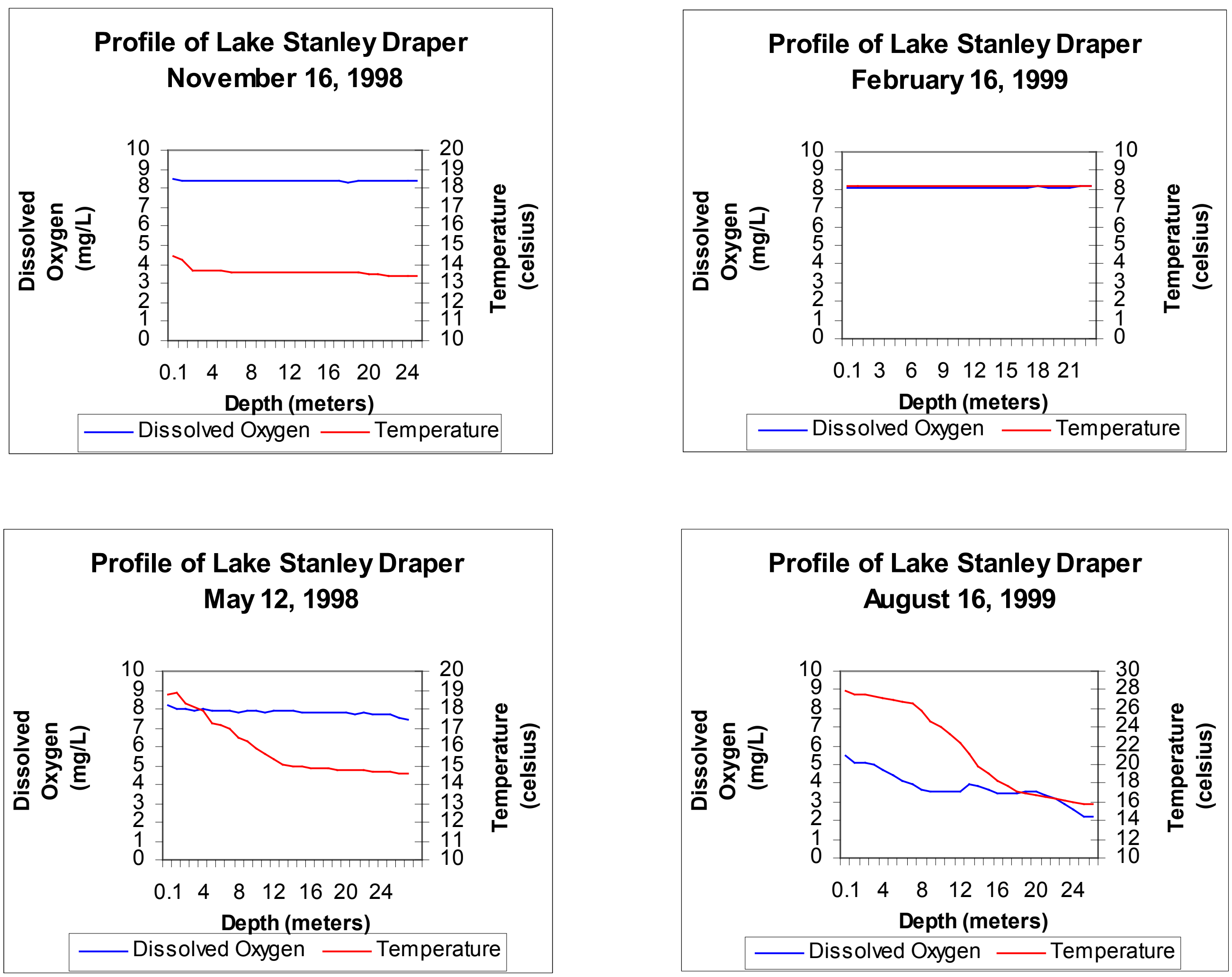


Figure 48. Vertical dissolved oxygen and temperature profiles representing four seasons measured at Site 1 in Lake Stanley Draper.

Chemical Characteristics

Nitrogen

Total nitrogen (TN) collected at the surface ranged from 0.269- 0.615 mg/l (n= 11) during 1998, 0.278- 0.705 mg/l (n= 12) during 1999 and 0.375- 1.075 mg/l (n= 12) for 2000, with an overall range of 0.269- 1.075mg/l (n= 35) and average of 0.555 mg/l (n= 35). The high concentrations occurred at Site 1 in November of 1997, August of 1998 and February 2000. Bottom samples collected at Site 1 for TN ranged from 0.363- 0.785 mg/l, with an overall average from the three sample years of 0.553 mg/l (n= 11). The high concentrations were detected on the same sample dates that high concentrations were detected at the surface. Only the 1998 sample (August) correlated with thermal stratification. Again, Wetzel (1983) uses TN concentrations less than 0.661 mg/l for oligotrophic conditions, 0.753 mg/l for mesotrophic and greater than 1.9 mg/l are indicative of eutrophic to hypereutrophic conditions. The overall average TN (0.555 mg/l), classified the lake as oligotrophic. Figure 49 depicts nitrogen concentrations throughout the project period.

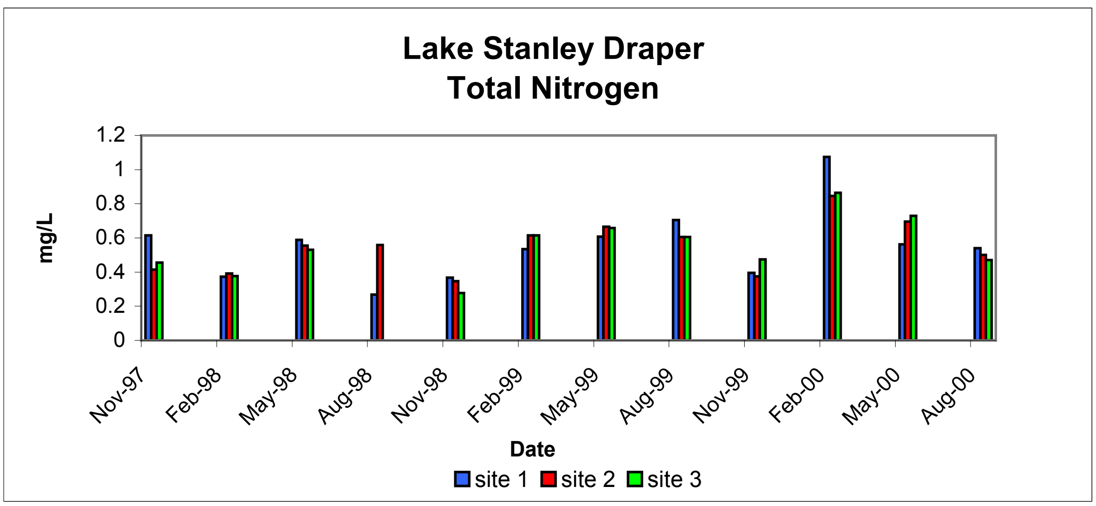


Figure 49. Lake Stanley Draper TN concentrations, November 1997 through August 2000.

Phosphorus

Total phosphorus (TP) collected in the epilimnion ranged from 0.022- 0.05 g/l (n= 11) during 1998, 0.035- 0.065 mg/l (n= 12) during 1999 and 0.035- 0.076 mg/l (n= 12) for 2000, with an overall range of 0.022- 0.076 mg/l(n= 35), and an average of 0.046 mg/l. The high values occurred in August of 1998 (Site 1), November of 1998 (Site 3) and August of 2000 (Site 1). The overall average surface phosphorus concentration was 0.046 mg/l (n=35), which would classify Lake Stanley Draper as mesotrophic, with low to moderate primary productivity (Wetzel,1983). Bottom samples collected at Site 1 for TP ranged from 0.04- 0.064 mg/l in 1998, 0.028- 0.075 mg/l in 1999 and 0.038- 0.065 mg/l in 2000, with an overall average of 0.052 mg/l (n=11), which again classified the lake as mesotrophic. The high values were detected in November 1997, August 1999 and May 2000. November of 1997 and May of 2000 the lake was not thermally stratified. In August 1999, thermal stratification was present, and although not anoxic (<2 mg/l), dissolved oxygen concentrations in the water column were less than 3 mg/l in the bottom four meters (22- 26 meters) of the lake. Figure 50 depicts TP concentrations throughout the sample period.

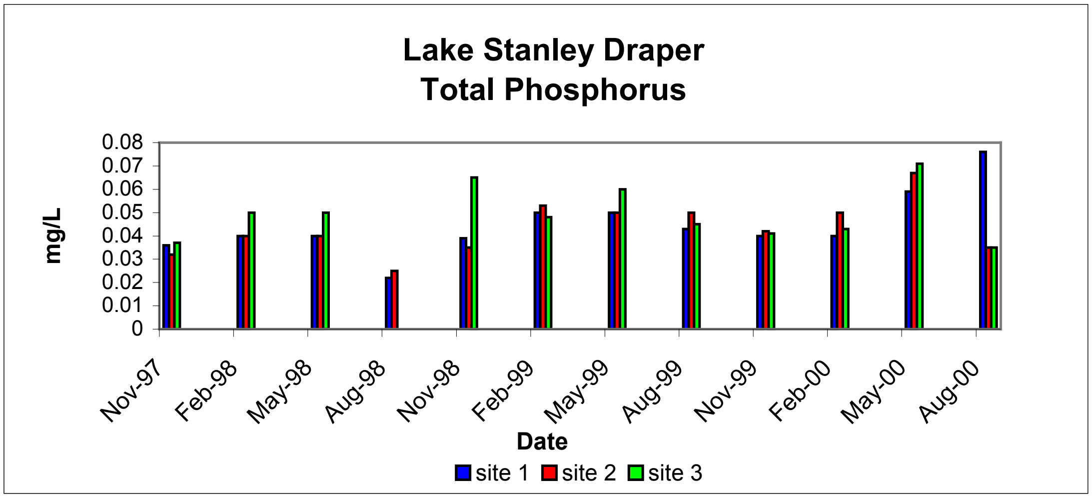


Figure 50. Lake Stanley Draper TP concentration, November 1997 through August 2000.

<u>Ortho-phosphorus</u>

Ortho-phosphorus collected at the surface was 0.005 mg/l (minimum detection limit) for all samples (n= 11) in 1998, 0.005- 0.01 mg/l (n= 12) in 1999 and 0.005-0.038 mg/l (n= 12) in 2000. Overall ortho-phosphorus ranged from 0.005- 0.038 mg/l (n= 35) and an average of 0.005 mg/l. The bottom samples for ortho-phosphorus concentrations overall ranged from 0.005- 0.034 mg/l, with an average of 0.009 mg/l (n=11).

Biological

<u>Trophic State Indices</u>

Trophic State Indices were calculated using Chlorophyll-<u>a</u> (CHL), Secchi Depth (SD), and Total Phosphorus (TP), as the trophic indicator parameters. All TSI calculations were determined for Lake Stanley Draper by using the average all Chlorophyll-<u>a</u> values for the entire sample year and the average of growing season (May and August) values. TSI values were compared to the OWQS to determine if the beneficial uses were met. Lakes with a Chlorophyll-a TSI ≥ 62 are considered a “nutrient limited watershed” and are threatened due to nutrient impacts. None of Lake Stanley Drapers CHL TSI values would classify the lake as a nutrient limited watershed. Table 23 summarizes all TSI’s calculated for Lake Stanley Draper.

The CHL TSI classifies Lake Draper as oligotrophic, bordering on mesotrophic, with a low level of primary productivity. However, SD TSI classifies the lake as hypereutrophic, which reflects high turbidity, likely inorganic. TP TSI classifies the lake as borderline eutrophic to hypereutrophic, meaning there is an abundance of available phosphorus in the lake, which has the potential to increase primary productivity if sunlight were able to penetrate into the water column. Based on these three parameters it is evident that turbidity is affecting light attenuation, which in turn is limiting primary productivity (reflected in low chlorophyll-a values) and the high TP TSI value confirms that phosphorus is available, however not being utilized. Again, CHL TSI is the accepted parameter for classifying Oklahoma reservoirs, therefore Lake Stanley Draper would be classified as oligotrophic.

Table 23. Summary of calculated TSI's for Lake Stanley Draper.

	n=		CHL TSI		SD TSI		TP TSI	
	Annual	Growing	Annual	Growing	Annual	Growing	Annual	Growing
1998	10	5	34	37	73	73	59	61
1999	12	6	41	42	79	81	60	60
2000	12	6	40	40	76	74	61	65
All	34	17	39	39	76	76	60	62

oligotrophic; mesotrophic; eutrophic; hypereutrophic

<u>Total Nitrogen:Total Phosphorus Ratio</u>

The TN:TP ratio is often used to determine which nutrient is the "limiting" factor for algal productivity. Average TN:TP ratios for each sample year were 13:1 in 1998, 11:1 in 1999 and 13:1 in 2000. Over the entire project period TN:TP ratios ranged from a low of 4:1 (detected in November of 1998 at Site 3) to 27:1 (February 2000 at Site 1), with an overall average of 13:1, which indicated phosphorus limitation. The ratio calculated from the TN average (0.555 mg/l) and the TP average (0.046 mg/l) was 12:1, also phosphorus limited. Figure 51 depicts TN:TP ratios throughout the sample period. Again, TN:TP ratios less than 7:1 are nitrogen limited, and greater than 10:1 are phosphorus limited (USEPA, 2000). One sample was below 7:1, while 37% were between 7:1 and 10:1 (no limiting nutrient) and 63% were phosphorus limited. Overall Lake Stanley Draper was phosphorus limited, meaning there was an abundance of nitrogen in

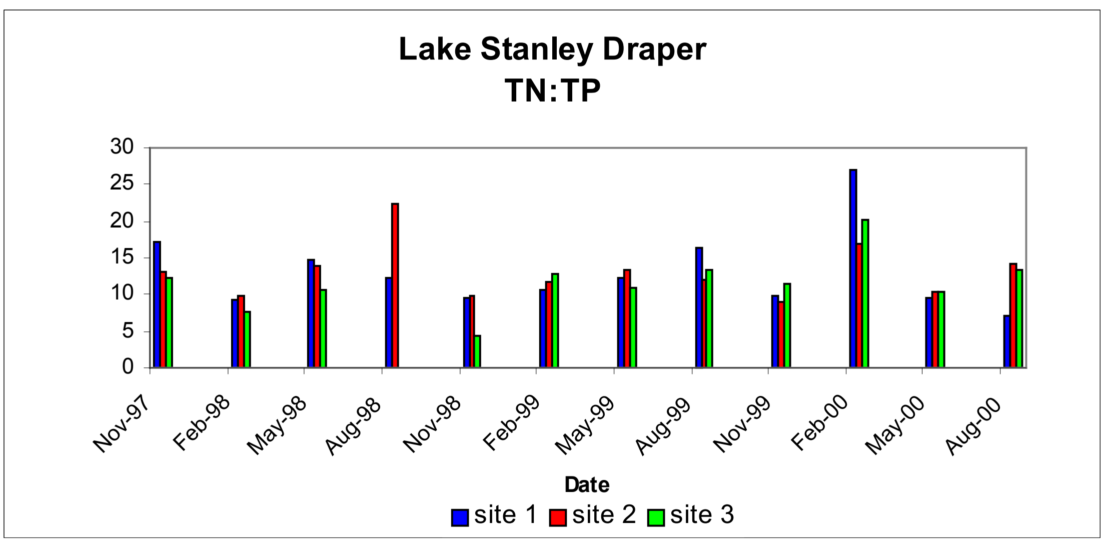


Figure 51. Lake Stanley Draper TN:TP ratios, November 1997 through August 2000.

relation to phosphorus. Lake Stanley Draper receives the majority of its water from Lake Atoka, therefore Draper's problems may likely be attributed to Lake Atoka.

Fecal Coliform

Oklahoma Water Quality Standards states for Primary Body Contact Recreation beneficial use the geometric mean of fecal coliform may not exceed 400 colonies (cfu) per 100ml and 25% of the samples may not exceed the screening level of 400 cfu per 100ml. Samples must be collected during the recreational season from May 1 through September 30, with no less than 10 samples. The geometric mean of samples collected from Lake Stanley Draper was 39 cfu per 100ml (n=26) with only one sample exceeding the prescribed screening level of 400 cfu per 100 ml. Therefore OWQS were being met.

Historical Water Quality Trend Analysis

Historical data for Lake Stanley Draper was obtained from Oklahoma City for nitrates, phosphates and turbidity from January 1980 through October 1999. Nitrates ranged from 0.01-4 mg/l (n= 78), phosphates ranged from below detection limit to 3.4 mg/l (n= 78) and turbidity ranged from 4.1- 59.6 NTU (n= 78). The historic data was analyzed using a Seasonal Kendall trend analysis. A negative trend was detected in the phosphate data at a 90% confidence level. A further regression analysis of the data revealed an R-Squared value of 0.059. Conclusions from this data showed that over the period tested there was a decrease in phosphate levels at Lake Stanley Draper. There was no trend detected in either the nitrate or the turbidity data.

Atoka Lake Water Quality

Atoka Lake was scheduled to be sampled quarterly from November 1997 through August of 2000 at two sites representing the lacustrine zone (Site 1, near the dam) and the transition zone (Site 2). The data was analyzed annually for comparisons between sample years as well as cumulatively to represent the entire sampling period. Each sample year was from November of the proceeding year through August of the year indicated for sample years 1998, 1999 and 2000. The lake was not accessible due to low water levels in November 1997 and August of 1998, resulting in two sample events for the 1998 sample year.

In summary, Lake Atoka had relatively low primary productivity principally due to its very high turbidity. The high turbidity limits algae populations which in turn minimize taste and odor-related water supply concerns. High inorganic turbidity also inhibits light attenuation, which inhibits productivity, hence low chlorophyll-a concentrations. Turbidity values throughout the entire sample period greatly exceeded the OWQS of 25 NTU. This presents a serious threat to its Fish and Wildlife Propagation beneficial use. Shoreline erosion and landuse practices have contributed to this high turbidity. Atoka Lake was classified as mesotrophic from both annual and growing season CHL TSI averages for the entire sample period, re-emphasizing turbidity effects on agal growth. The TN:TP ratio indicated the lake was neither phosphorus nor nitrogen limited. Secchi disk depth and SD TSI both indicate that light limitation is likely the primary controlling factor for productivity. Water quality studies should continue in the future to more accurately identify specific watershed practices that contribute to the water quality degradation of the lake.

Shoreline erosion and landuse practices have contributed to this high turbidity. Another concern may be the effect of livestock grazing, erosion and nutrient export. Continuous grazing compacts soil, decreases vegetation cover and adds manure loads (Beaulac and Reckhow, 1982). Reduction or removal of this impact would improve soil stability in watershed areas. Shoreline stabilization efforts could also contribute to improvements in lake turbidity. By encouraging and promoting forest/shrub cover within the watershed both erosion and in-lake turbidity problems could be reduced (Omernik, 1976; Atkinson *et al*., 1989; Morgan and Nalepa, 1982; Rast and Lee, 1983).

Physical Characteristics

Turbidity and Secchi Disk Depth

The lake-wide average turbidity over the three years was 56 in 1998, 79 in 1999 and 86 NTU in 2000 (Figures 52- 54). Overall turbidity ranged from 49 to 108 NTU (n= 20), with an average of 74 NTU. All twenty samples throughout the study period exceeded OWQS of 25 NTU, threatening its designated FWP beneficial use.

The average annual Secchi disk depth was 22.8, 19.6 and 18.5 centimeters, while the overall average Secchi disk depth was 19.5 centimeters (n= 18). These depths are less than average for Oklahoma reservoirs (OWRB, 2000). Atoka Lake is a turbid reservoir likely due to erosion occurring from both the watershed and along the shoreline.

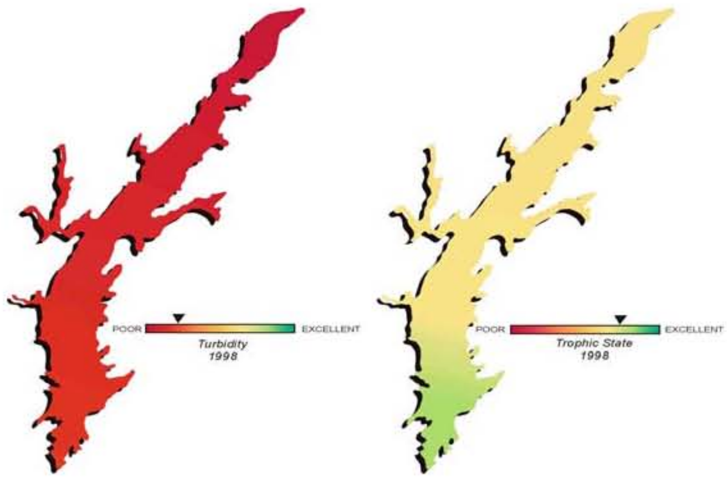


Figure 52. Turbidity and Chlorophyll a trophic state index for Lake Atoka in 1998.

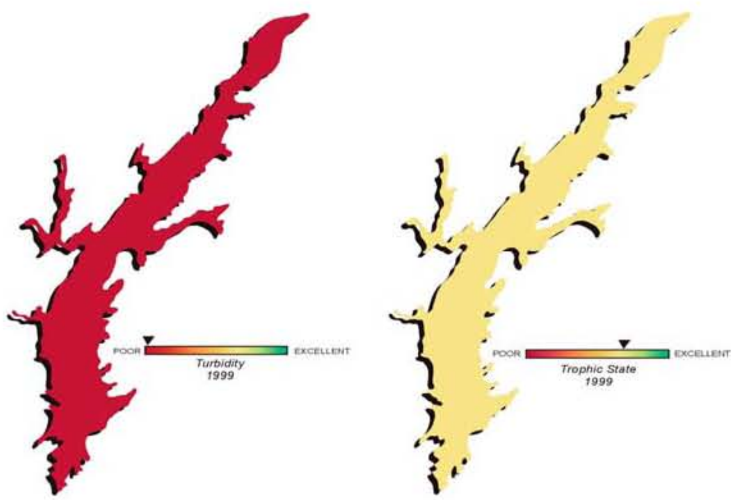


Figure 53. Turbidity and Chlorophyll a trophic state index for Lake Atoka in 1999.

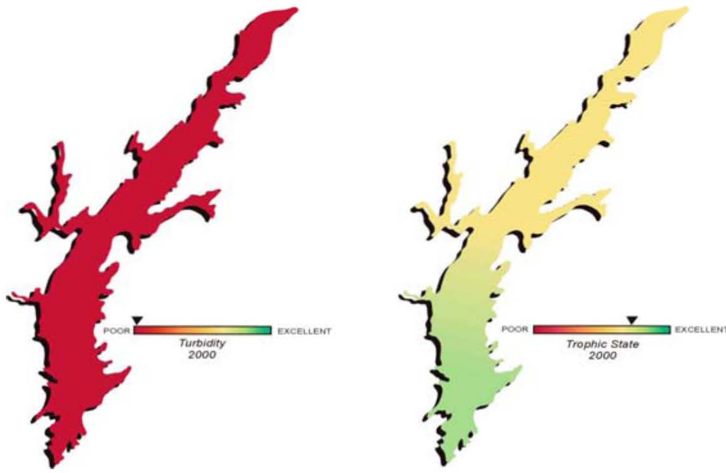


Figure 54. Turbidity and Chlorophyll a trophic state index for Lake Atoka in 2000.

Salinity, Specific Conductance and Oxidation-Reduction Potential
Atoka Lake salinity values ranged from 0- 0.03 ppt in 1998, 0- 0.03 ppt in 1999 and 0- 0.08 ppt in 2000, while overall average salinity was 0.02 ppt (n= 213). These values are normal for Oklahoma reservoirs (OWRB, 2000).

Specific conductivity ranged from 32- 89 µS/cm in 1998, 47.5- 81.6 µS/cm in 1999 and 74.4-177.5 µS/cm in 2000. Overall the average specific conductance value was 78.2 µS/cm (n= 213). The highest value from the entire data set, 177.5 µS/cm was detected at the bottom of Site 1 in September 2000. These values are low compared to other Oklahoma reservoirs (OWRB, 2000). These low concentrations reflect low levels of electrical conducting compounds such as chlorides, salts, or other analogous materials present.

Oxidation-reduction potentials were positive at all sample sites, however ORP dropped below 100mV in the bottom few meters at Site 1 in June 1998. Annual ORP ranges were from 54- 377 mV in 1998, 240- 545 mV in 1999 and 180- 458 mV during 2000, while the overall average ORP was 321 mV (n= 194). ORP's of less than 100mV usually occur during anoxic conditions and may play a significant role in mobilization of phosphorus from the lake sediments through the reduction-oxidation of hydrogen sulfides (Wetzel, 1983).

Chlorides, Sulfates and Total Dissolved Solids
The average chlorides concentration, collected at the surface, was 5.6 mg/l in 1998 (n= 4), 6.4 mg/l in 1999 and 5.5 mg/l in 2000. The average from the three year sample period was 5.5 mg/l (n= 20). Chloride concentrations were well within OWQS of 250 mg/l.

Sulfate concentrations average for each sample year was 14.3 mg/l in 1198, 9 mg/l in 1999 and 19 mg/l in 2000, with an overall average of 14 mg/l (n= 20). All sulfate concentrations were within OWQS of 250 mg/l.

TDS concentrations average for each sample year was 50 mg/l in 1998, 39 in 1999 and 57 in 2000. The overall average TDS concentration was 47 mg/l (n= 194). All TDS concentrations were below OWQS of 750 mg/l. Therefore, Atoka is supporting its Agriculture beneficial use.

<u>pH, Temperature and Dissolved Oxygen</u>
The pH was neutral with values ranging from 6.73- 7.8 in 1998, 5.98- 7.77 during 1999 and from 6.71-7.78 s.u. in 2000. The overall average pH value was 7.3 s.u. (n= 213). These values were well within OWQS range of 6.5- 9.0 s.u.

Temperature ranged from 7.91 degrees celsius to 29.05 degrees celsius, with warmer temperatures in the summer months and cooler in the winter months. Thermal stratification was only present once during the study period in June 1998 between 8 and 9 meters. However distinct thermoclines were present at the surface between 0.1 meter and one meter in February and June 1998 and May 1999 (greater than a 4.5 °C change).

Dissolved oxygen dropped below 5mg/l during the spring and summer sampling months of each sample year. Dissolved oxygen concentrations dropped below 2 mg/l at Site 1 in August of each sample year (excluding August 1998 when no sample was collected). In the spring and summer sample months of 2000 the entire water column, at both Sites 1 and 2, was below 5mg/l. OWQS states that a 70% or more of the water column must be less than 2mg/l for FWP beneficial use is not supported (USAP 785:46-15-5). Of the two sample events when anoxic conditions were present, 43% (1999) and 33% (1998) of the water column was below 2 mg/l, therefore, Atoka Lake is meeting the FWP beneficial use based on USAP OAC 785. Figure 55 depict dissolved oxygen/ temperature relationships for four different seasons within the three-year sample period.

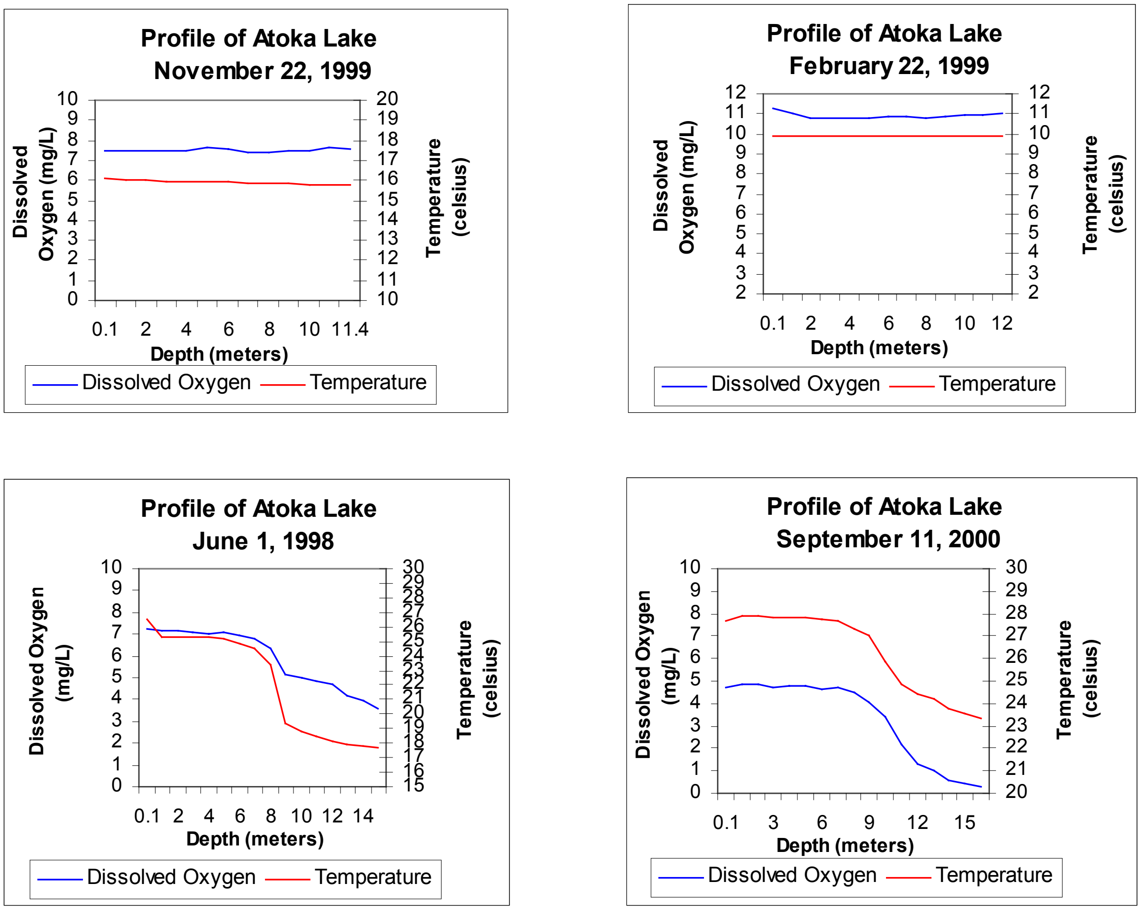


Figure 55. Vertical dissolved oxygen and temperature profiles representing four seasons measured at Site 1 in Atoka Lake

Chemical Characteristics

Nitrogen

For sample year 1998 only two sample events occurred and in one of those events, TN data failed quality assurance/ quality control. Therefore no report will be made on 1998 TN data. Total nitrogen (TN) collected at the surface for 1999 and 2000 ranged from 0.806- 0.905 mg/l (n= 4) and 0.275- 1.035 mg/l (n= 8), respectively, with an overall average of 0.75 mg/l (n= 14). The high values occurred at Site 1 in May 1999 and Site 2 in May 2000. The overall average TN concentration of 0.75 mg/l, classifies the lake as mesotrophic (Wetzel, 1983). Bottom samples collected at Site 1 for TN ranged throughout the entire sample period from 0.2- 1.0 mg/l, with an overall average from the three sample years of 0.7 mg/l. This was very similar to surface concentrations. Figure 56 depicts nitrogen concentrations throughout the project period.

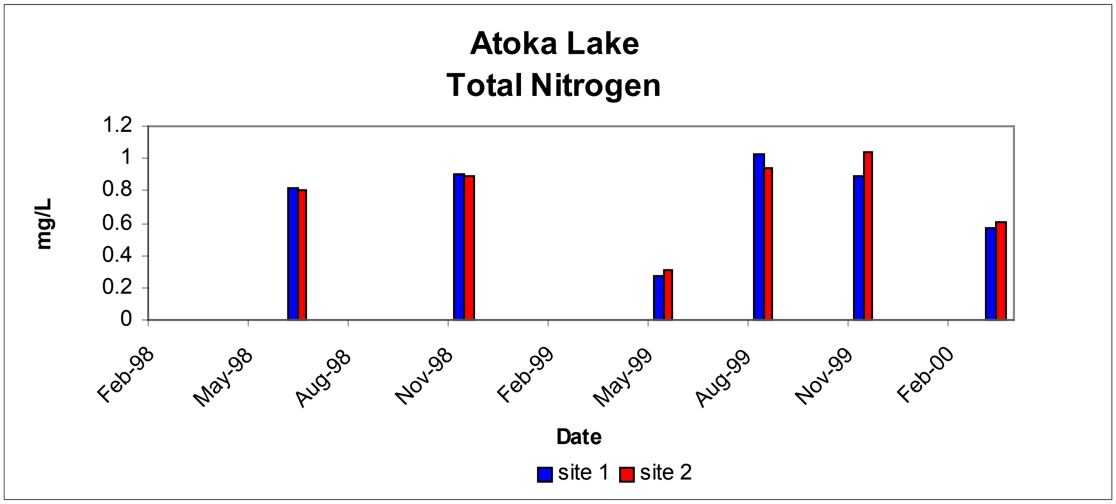


Figure 56. Atoka Lake TN concentration, November 1997 through August 2000.

Phosphorus

Total phosphorus (TP) collected at the surface ranged from 0.06- 0.08 g/l (n= 4) during 1998, 0.089- 0.141 mg/l (n= 8) during 1999 and 0.107- 0.18 mg/l (n= 8) for 2000, with an overall range of 0.06- 0.18 mg/l, and an average of 0.11 mg/l (n= 20). The high values occurred in February and June of 1998, August of 1999 and May of 2000, all at Site 2. It is common to see higher concentrations of nutrients in the upper reaches of reservoirs. Phosphorus, and other nutrients, will tend to settle out of the water column as the water moves down the main body of the lake and flow diminishes, resulting in lower concentrations towards the dam. Wetzel (1983) states that TP concentrations of 0.084 mg/l indicate eutrophic conditions. USEPA (2000) uses concentrations of TP greater than 0.1 mg/l for hypereutrophic conditions. The overall average phosphorus concentration of 0.11 mg/l would classify Atoka Lake as hypereutrophic. Bottom samples collected at Site 1 for TP ranged from 0.082- 0.241 mg/l for the entire sample period, with an average of 0.2 mg/l (n=11). The high values were found in August 1999 (0.24 mg/l) and 2000 (0.22 mg/l). August 1998 samples were not collected due to lake low levels. These high values correspond with anoxic conditions (dissolved oxygen <2 mg/l), therefore it is likely to detect phosphorus release from the bottom sediments. If light limitation were not a factor, during fall turnover, this phosphorus could become available for primary productivity resulting in severe algal blooms and or taste and odor problems. Figure 57 depicts TP concentrations throughout the sample period.

Ortho-phosphorus

Ortho-phosphorus collected at the surface ranged from 0.005- 0.009 mg/l (n= 4) in 1998, 0.006- 0.019 mg/l (n= 6) in 1999 and 0.006-0.098 mg/l (n= 8) in 2000. Overall ortho-phosphorus ranged from 0.005- 0.098 mg/l (n= 18) and an average of 0.02 mg/l. The high values for each sample year were found in February of 1998 at site 1, August of 1999 at Site 1 and August 2000 at Site 2. The bottom samples for ortho-phosphorus concentrations overall ranged from 0.005- 0.116 mg/l (n= 8), with an average 0.024 mg/l. The high concentration was found in August 2000, and did correlate with the high surface ortho-phosphorus however, Site 2 ortho-

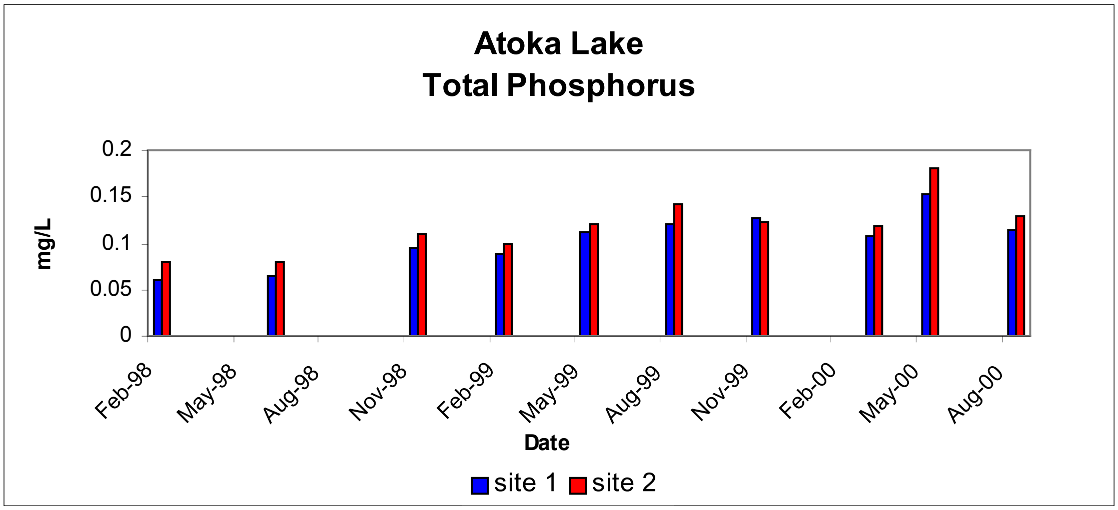


Figure 56. Atoka Lake TP concentration, November 1997 through August 2000.

phosphorus value was higher than Site 1 (no bottom samples were collected at Site 2). August 1999 also detected the high bottom ortho-phosphorus value for that sample year. The lake was stratified at both these sample events, resulting in the possible release of phosphates from the bottom sediments. One possible method for controlling phosphorus in Atoka Lake would be to control suspended particles and locking phosphorus in the lake bottom.

Biological

Trophic State Indices
All TSI calculations were determined for Atoka Lake by using the average of all values for the entire sample year and the average of the growing season (May and August) values. Chlorophyll-a TSI values were compared to the OWQS to determine if beneficial uses were being met. Lakes with a (CHL) TSI ≥ 62 are considered a "nutrient limited watershed" and are threatened due to nutrient impacts. Table 24 summarizes all TSI's calculated for Atoka Lake.

Table 24. Summary of calculated TSI's for Atoka Lake.

	n=		CHL TSI		SD TSI		TP TSI	
Year	Annual	Growing	Annual	Growing	Annual	Growing	Annual	Growing
1998	4	2	44	40	81	81	66	66
1999	6	2	44	43	83	85	72	74
2000	10	4	45	45	85	84	75	78
All	20	8	44	43	83	83	71	72
	oligotrophic		mesotrophic		eutrophic		hypereutrophic	

The CHL TSI would classify Atoka Lake as mesotrohpic. Therefore based on OWQS Atoka Lake is not a "nutrient limited watershed" or threatened by nutrients. However, both SD TSI and TP TSI classify the lake as hypereutrophic. Total phosphorus TSI does indicate that there is an abundance of available phosphorus in the lake, which has the potential to increase productivity during appropriate conditions. This is also represented in the high concentrations of total and ortho-phosphorus chemical data. Fortunately, the high SD TSI indicates there are likely suspended solids affecting light penetration, thus inhibiting algal productivity. Again, the CHL TSI is the most accepted parameter in assessing Oklahoma's Lakes, classifies Atoka Lake as mesotrophic in all three years; growing season, annual and cumulative.

<u>Total Nitrogen:Total Phosphorus Ratio</u>

The TN:TP ratio is often used to determine which nutrient is the "limiting" factor for algal productivity. TN:TP ratios for the project period (n= 14) ranged from 2:1 in November of 1999 to 12:1 in February of 1998. The average TN:TP ratio for the entire project was 8:1, neither nitrogen nor phosphorus limited. The ratio calculated from the TN cumulative average (0.75 mg/l) and the TP cumulative average (0.11 mg/l) was 7:1, which is borderline nitrogen limited to no specific limiting nutrient. Six samples were below 7:1, or nitrogen limited all detected in 2000, while only one was above 10:1 detected in February 1998. Low ratios in shallow hypereutrophic lakes are typically the result of high TP loads (USEPA, 2000). Again, confirming the high phosphorus concentrations and the high TP TSI. It is likely that the limiting factor to primary productivity in Atoka Lake is light availability. Atoka's turbidity is preventing severe algal blooms. Figure 58 depicts the TN:TP ratios from the entire sample period.

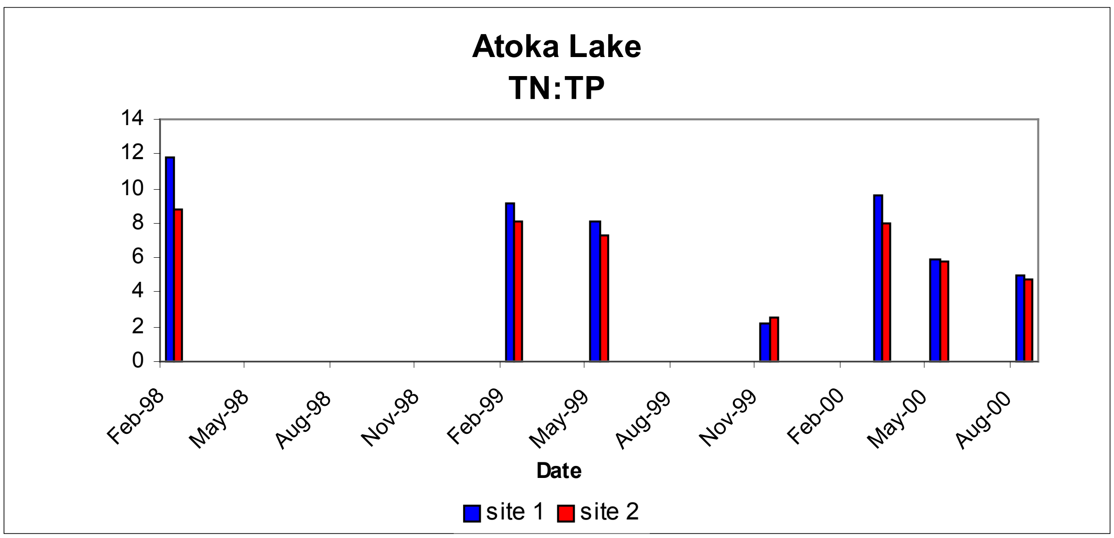


Figure 58. Atoka Lake TN:TP ratios, November 1997 through August 2000.

Fecal Coliform

Oklahoma Water Quality Standards states for Primary Body Contact Recreation beneficial use the geometric mean of fecal coliform may not exceed 400 colonies (cfu) per 100ml and 25% of the samples may not exceed the screening level of 400 cfu per 100ml. Samples must be collected during the recreational season from May 1 through September 30, with no less than 10 samples. The geometric mean of samples collected from Atoka Lake was 26 cfu per 100ml (n=14) with no samples exceeding the prescribed screening level, therefore OWQS were being met.

Historical Water Quality Trend Analysis

Historical data for Atoka Lake was obtained from Oklahoma City for nitrates and phosphates collected quarterly from January 1980 through October 1999. Nitrates ranged from 0- 2.64 mg/l (n=76) and phosphates ranged from 0- 1.28 (n= 74). The historic data was analyzed using a Seasonal Kendall trend analysis. A negative trend was detected in the phosphate data at a 95% confidence level. A further regression analysis of the data revealed an R-Squared value of 0.232. Conclusions from this data showed that over the period tested there was a decrease in phosphate levels at Atoka Lake. There was no detectable trend in nitrates.

McGee Creek Reservoir Water Quality

McGee Creek Reservoir was sampled quarterly from November 1997 through August of 2000 at three sites representing the lacustrine zone (Site 1, near the dam), and the two riverine zones that form this reservoir, Site 2 the McGee Creek arm and Site 3 the Potapo Creek arm. The data was analyzed annually for comparisons overtime as well as cumulatively to represent the entire sampling period.

Overview of the data, McGee Creek Reservoir was classified as mesotrophic from both annual and growing season CHL TSI averages for the entire sample period. The TN:TP ratio indicated the lake is phosphorus limited, meaning there is more nitrogen available relative to phosphorus, and phosphorus is the controlling nutrient in regards to productivity. Both TN and TP concentrations were low compared to the other five reservoirs, and classified the lake as oligotrophic (Wetzels, 1983). The lake was strongly stratified during the spring, summer, and fall sample months, resulting in anoxia and low pH's, both in violation of OWQS. Water quality studies should continue in the future too more accurately identify if the anoxic and acidic (low pH) conditions are natural or if they are indicative of an impairment.

Physical Characteristics

Turbidity and Secchi Disk Depth
The lake-wide average turbidity over the three years was 7.3 in 1998, 4.9 in 1999 and 4.8 NTU in 2000 (Figures 59-31). None of the samples exceeded the OWQS of 25 NTU. Overall, the average turbidity from the entire sample period was 5.6 (n= 36), well below OWQS.

The average annual Secchi disk depth in centimeters was 114.5 in 1998, 127.8 in 1999 and 121.6 in 2000, while the overall average secchi disk depth was 121.6 centimeters (n= 36). McGee Creek Reservoir has very good water clarity relative to Oklahoma reservoirs, and indicated by the deep Secchi disk depths and low turbidity (OWRB, 2000).

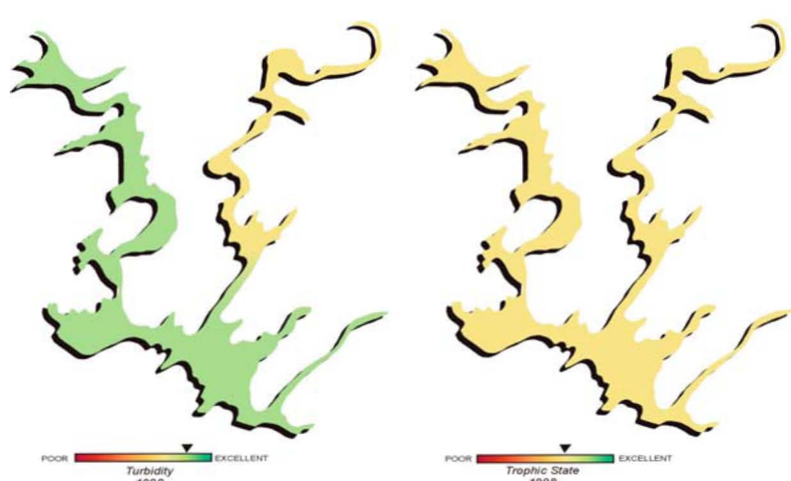


Figure 59. Turbidity and Chlorophyll a trophic state index for McGee Creek Lake in 1998.

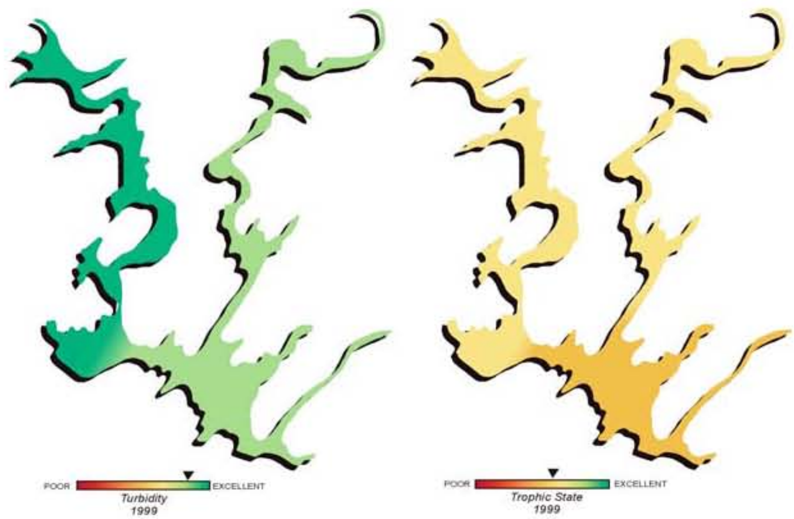


Figure 60. Turbidity and Chlorophyll a trophic state index for McGee Creek Lake in 1999.

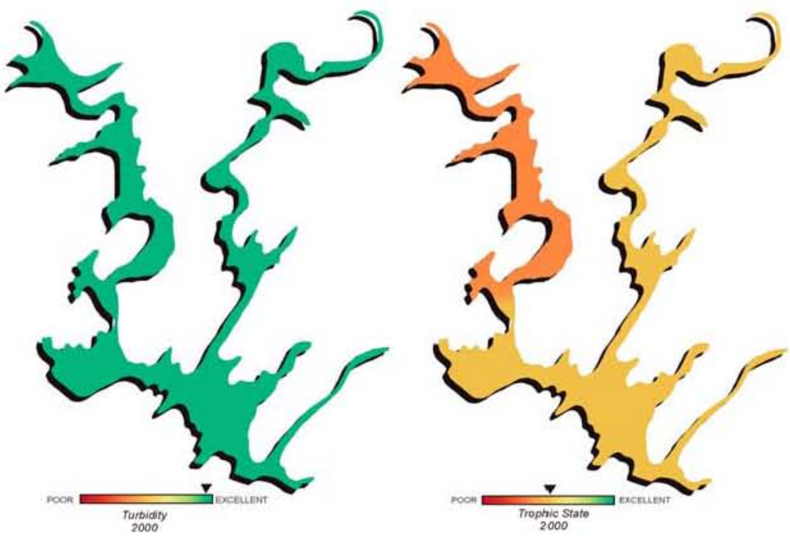


Figure 61. Turbidity and Chlorophyll a trophic state index for McGee Creek Lake in 2000.

Salinity, Specific Conductance and Oxidation-Reduction Potential

McGee Creek salinity values ranged from 0- 0.01 ppt in 1998, 0- 0.02 ppt in 1999 and 0- 0.13 ppt in 2000, while overall salinity ranged from 0- 0.13 ppt (n= 678). These values are normal for Oklahoma reservoirs (OWRB, 2000). Salinity higher than 0.1 ppt is an above average reading, however of the 678 salinity readings for McGee Creek reservoir only one was above, 0.13 ppt at the bottom (26.2 meters) of Site 1 in August 2000 resulting in no concern.

Specific conductivity ranged from 42- 86.5 µS/cm in 1998, 6.9- 60.8 µS/cm in 1999 and 12.7- 264.5 µS/cm in 2000, while overall specific conductance ranged from 6.9 µS/cm to 264.5 µS/cm. Conductivity and low salinity values indicated that very low concentrations of electrical conducting compounds (i.e. salts) were present in the lake. These values are relatively low for Oklahoma reservoirs.

Oxidation-reduction potentials were positive at all sample sites and ranged from 101- 434 mV in 1998, from 19- 405 mV in 1999 and from 71- 452 mV during 2000, while overall conditions ranged from 19- 452 mV. In general, reduction process can occur as the redox potential declines below 100 mV as a result of bacterial decomposition (Wetzel, 1983) with the unfavorable concomitant release of phosphorus bound to sediments.

Chlorides, Sulfates and Total Dissolved Solids

Chlorides were analyzed for in surface water quality samples throughout the three year sample period. Chloride concentrations ranged from 4.2- 7 mg/l in 1998, 3.5- 8mg/l in 1999 and 4- 6 mg/l in 2000, with an overall average was 5.6 mg/l (n= 36). None of the Chloride values exceed OWQS of 250mg/l.

Sulfates ranged from 1- 15 mg/l in 1998, 2- 3.92 mg/l in 1999 and 0.56- 8.4 mg/l in 2000, with an overall average of 3.8 mg/l (n= 36). All values are well below OWQS of 250 mg/l.

The total dissolved solids (TDS) values for the lake were 27- 38 mg/l for 1998, 4.4- 38.9 mg/l for 1999 and 8.1- 169 mg/l for 2000, with an overall average of 26.4 mg/l (n= 36). All values are well below OWQS of 750 mg/l. These values were very low compared to average levels seen in most Oklahoma reservoirs (OWRB, 2000).

pH, Temperature and Dissolved Oxygen

The pH was slightly acidic with values (in standard units) ranging from 5.7- 8 in 1998, 5.6- 7.8 during 1999 and from 6- 7.7 in 2000. Overall pH values ranged from 5.6- 8 (n= 678), with an average of 6.6. McGee Creek exceeds of the FWP beneficial use with 37% of samples (n=232) in 1998, 35% of samples (n= 463) and 41% of samples in 2000 less than 6.5 standard units. In addition, percentages based on averages of values from the water column at each site, with an n= 12 also exceeds WQS, with 33% of samples at Site 1 less than 6.5 s.u. Site 2 (McGee Creek) had 16% of samples less than 6.5 which is partially supporting, while at Site 3 (Potapo Creek) only 8% of samples were less than 6.5, or fully supporting. The low pH's were generally found in the spring and summer months when the lake was stratified and anoxic conditions were present, and in November 1999 the entire water column at all 3 sites was below 6.5. For listing purposes it is unknown if these pH violations are due to natural causes, therefore site specific pH criteria should be investigated for McGee Creek Reservoir.

The lake was thermally stratified in the summer months. Stratification would appear in the upper few meters in May (June) and deeper in the August samples. Change in temperature within one-meter depth ranged from 1.01 ° C to greater the 4.5° C (August 1999, Site 2 between 6 and 7 meters, August 2000, Site 2 between 6 and 7 meters and Site 3 between 5 and 6 meters). Outside of the summer months, thermal stratification also occurred in February 1998 and November 1999, both at Site 1. Of the 12 sample events only 4 did not show thermal stratification. Temperature ranged from 7.43 ° C to 30.87 ° C, with warmer temperatures in the summer months and cooler in the winter.

Dissolved oxygen concentrations dropped below 5mg/l in all samples (n= 36) except in February of each sample year (n= 9) and November of 1997 (n= 3). Of the 36 samples, 20 (or 56%) experienced anoxic conditions, or dissolved oxygen below 2 mg/l. OWQS states that the Fish and Wildlife Propagation beneficial use is not supported if >70% of the water column is less than 2mg/l (dissolved oxygen) based on USAP OAC 785. McGee Creek Reservoir failed to meet its designated beneficial use four times; August 1998, Site 1 (70%), August 1999, Sites 1 (76%) and 2 (73%) and August 2000, Site 1 (78%). All anoxic conditions occurred at or below the thermocline. Dissolved oxygen concentrations based on lake volume were calculated using bathymetric data collected by this project to determine the volume of the reservoir from the depth where D.O. dropped below 2 mg/l. Of the seven sample events when anoxia was present, five were greater than 70% volume. Figure 62, depicts dissolved oxygen/ temperature relationships for four different seasons within the three-year sample period. The August 17, 1998 graph depicts a heterograde curve with an increase in dissolved oxygen at the metalimnion. This phenomenon could be caused by a couple of situations. Most likely there is a metalimnion chlorophyll-a maxima resulting in the positive heterograde. This also suggests that chloropyhll-a surface grab samples undersetimates algal biomass because higher [chl-a] should be detected at the [O_2} maxima. In spring/ early summer months, occasionally inflow of colder oxygen rich waters enter the reservoir and begin to sink below the epilimnion. Another cause could be a result of algae sinking down the water column, especially during the heat of the day, resulting in an oxygen rich layer beneath the epilimnion (Wetzel, 1983). This phenomenon was also detected in May of 2000, although not as distinct. More frequent monitoring would be needed to better detect the exact situation.

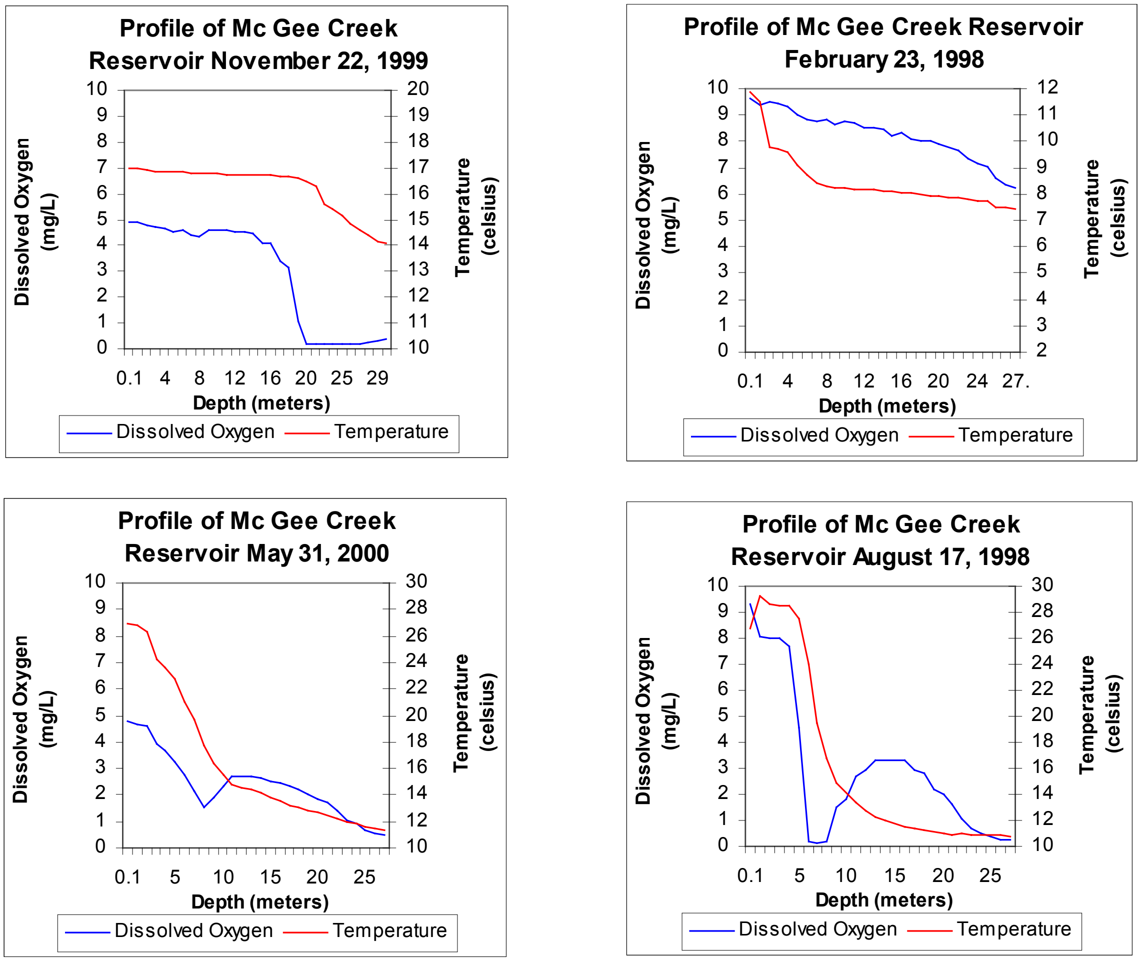


Figure 21. Vertical dissolved oxygen and temperature profiles representing four seasons measured at Site 1 in McGee Creek Reservoir.

Chemical Characteristics

Nitrogen

Total nitrogen (TN) collected in the epilimnion ranged from 0.185- 0.435 mg/l (n=9) during 1998, 0.365- 0.695 mg/l (n= 6) during 1999 and 0.221- .895 mg/l (n= 12) for 2000, with an overall range was 0.185- .895 mg/l (n= 27). The high values occurred in November of 1997 at Site 1, May of 1999 at Site 2 and February 2000 at Site 1. The overall average TN was 0.458 mg/l (n= 27). Figure 63 depicts TN concentrations collected at the surface throughout the sample period. Hypolimnetic samples collected at Site 1 for TN ranged from 0.365-1.439 mg/l, with an overall average from the three sample years of 0.688 mg/l (n= 9). The high values for each sample year were in August 1998, February 1999 and November 1999. Wetzel (1983) uses TN values less than 0.661 mg/l for oligotrophic conditions, under this classification McGee Creek Reservoir would be classified as oligotrophic.

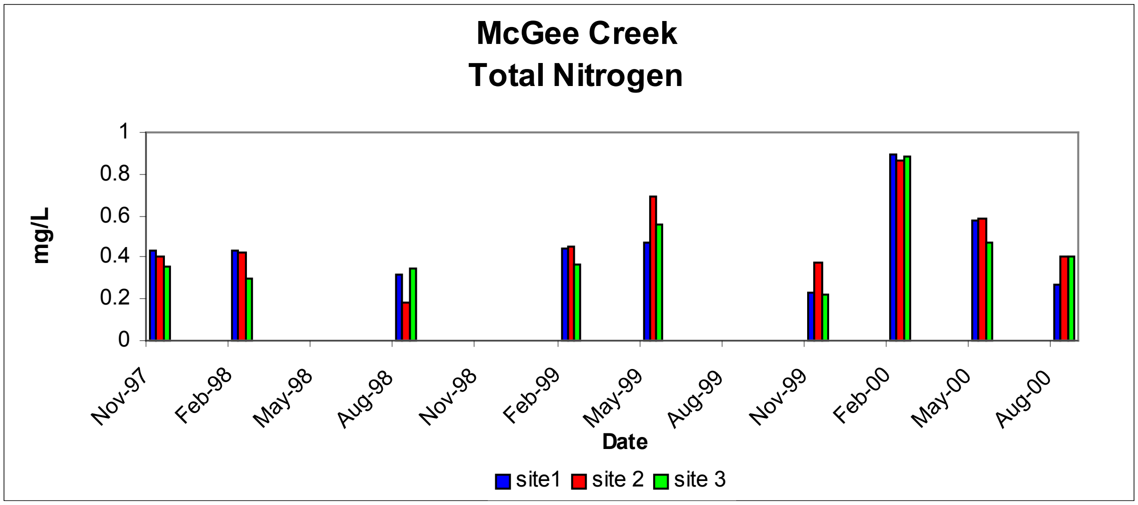


Figure 63. McGee Creek TN concentrations, November 1997 through August 2000.

Phosphorus

Total phosphorus (TP) collected in the epilimnion ranged from 0.01- 0.031 g/l (n= 12) during 1998, 0.015- 0.032 mg/l (n= 12) during 1999 and 0.012- 0.06 mg/l (n= 12) during 2000, with an overall range of 0.01- 0.06 mg/l 9 (n= 36), and an average of 0.023 mg/l. The high values occurred in November 1997 (Site 2), May of 1999 (Site 2) and May of 2000 (Sites 1, 2 and 3). Site 2 is the McGee Creek arm of the reservoir. Figure 64 depicts TP concentrations throughout the sample period. Based on Wetzel (1983), the average TP concentrations of 0.023 mg/l would classify McGee Creek Reservoir as borderline oligotrophic- mesotrophic, with moderate to low primary productivity. Hypolimnetic samples collected at Site 1 for TP ranged from 0.028-

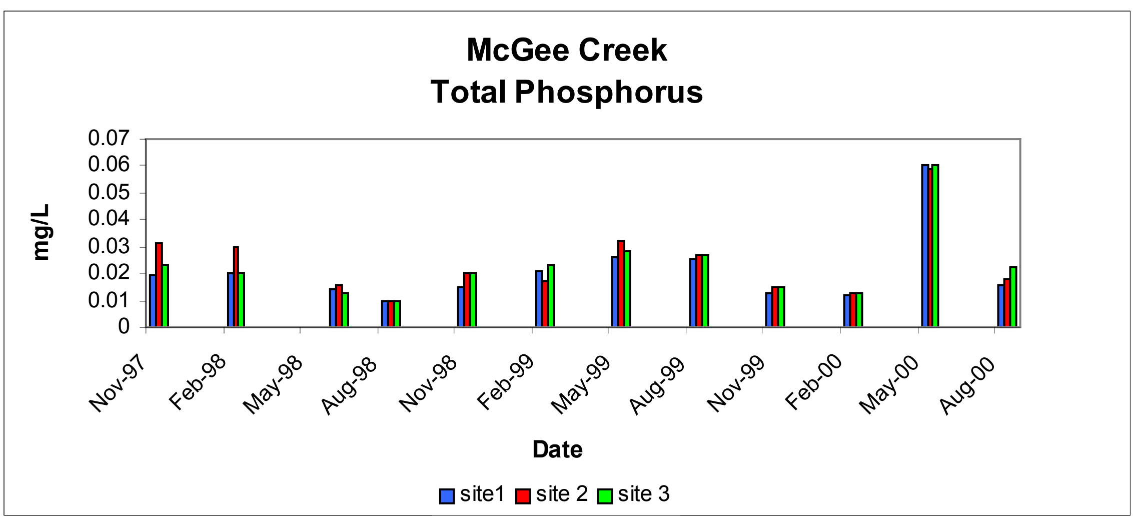


Figure 64. McGee Creek TP concentrations, November 1997 through August 2000.

0.04 mg/l for 1998, 0.021- 0.073 mg/l for 1999 and 0.021- 0.198 mg/l for 2000, with an overall hypolimnetic sample range of 0.021- 0.198 mg/l (n=11) and an average of 0.062 mg/l. High values were found in August of 1998, August of 1999 and November of 1999. The lake was thermally stratified during all of these samples collections with anoxic (dissolved oxygen >2 mg/l) conditions present. In August and November 1999, ORP values were less than 100mV in the hypolimnion, therefore release of phosphorus from the bottom sediments is likely.

Ortho-phosphorus

Ortho-phosphorus collected from the epilimnion was 0.005 mg/l for all samples in 1998, 0.005- 0.008 mg/l in 1999 and was again 0.005 mg/l in 2000. Overall ortho-phosphorus ranged from 0.005- 0.008 mg/l (n= 33) and an average of 0.005 mg/l. The only variation from the 0.005 mg/l ortho-phosphorus value was found in August of 1999. It is important to note that the laboratory minimum detection limit (MDL) for the ortho-phosphorus test is 0.005 mg/l. The hypolimnetic samples for ortho-phosphorus concentrations overall ranged from 0.005- 0.128 mg/l, with an average 0.021 mg/l. The high concentration, found in November of 1999, corresponds with the high total phosphorus detected at the same location/time and anoxic conditions.

Biological

Trophic State Indices

TSI calculations were determined for McGee Creek Reservoir by using the average of all chlorophyll-a values for the entire sample year and the average of growing season (May and August) values. TSI values were compared to the OWQS to determine if its beneficial uses were being met. Lakes with a CHL TSI $\geq$ 62 are considered a “nutrient limited watershed” and are threatened due to nutrient impacts. Table 25 summarizes all TSI’s calculated for McGee Creek Reservoir.

Table 25. Summary of calculated TSI’s for McGee Creek Reservoir.

	n=		CHL TSI		SD TSI		TP TSI	
Year	Annual	Growing	Annual	Growing	Annual	Growing	Annual	Growing
1998	12	6	41	43	58	54	46	40
1999	9	3	45	43	56	56	50	52
2000	12	6	45	48	57	56	51	57
All	33	15	44	45	57	55	49	51
	oligotrophic		mesotrophic		eutrophic		hypereutrophic	

CHL TSI classify McGee Creek Reservoir as mesotrophic, indicating moderately low productivity. SD TSI would classify the lake as eutrophic. This is a classic example of why SD TSI is not an accepted parameter for classifying Oklahoma reservoirs. The SD TSI was developed for northern temperate natural lakes, which would be much clearer than Oklahoma’s clearest lake. McGee Creek has high water clarity compared to other reservoirs in Oklahoma. Of the six Oklahoma City reservoirs, McGee Creek has the lowest SD TSI value/ classification. TP TSI is borderline mesotrophic/ eutrophic, indicating there is a moderate amount of phosphorus available for productivity. McGee Creek also has the lowest TPTSI compared to the other OKC reservoirs.

Total Nitrogen:Total Phosphorus Ratio

The TN:TP ratio average for each sample year was 21:1 in 1998, 21:1 in 1999 and 29:1 in 2000. The TN:TP ratios for the project period (n= 27) ranged from 8:1 (May of 2000) to 75:1 (February of 2000). The high value corresponds with high total nitrogen concentrations and relatively low total phosphorus found on that sample date. The average TN:TP ratio for the entire project was 25:1, phosphorus limited. The ratio calculated from the TN average (0.458 mg/l) and the TP average (0.023 mg/l) was 20:1, also phosphorus limited. No samples were below 7:1, or nitrogen limited while only 3 samples fell between 7:1 and 10:1, all detected in May 2000, following the high ratios detected in February 2000. Figure 65 depicts TN:TP ratios throughout the sample period. The vertical profile for dissolved oxygen detected the heterograde curve found at the metalimnion in May 2000 sample at Site 1, which could indicate photosynthetic activity. Overall McGee Creek Reservoir is phosphorus limited, which is typical for oligotrophic - mesotrophic lakes, meaning, phosphorus is the limiting nutrient in the presence of an excess of nitrogen (Wetzel, 1983). Generally phosphorus is more easily controlled than nitrogen due to the presence of nitrogen in the atmosphere, and capabilities of nitrogen fixing bacteria.

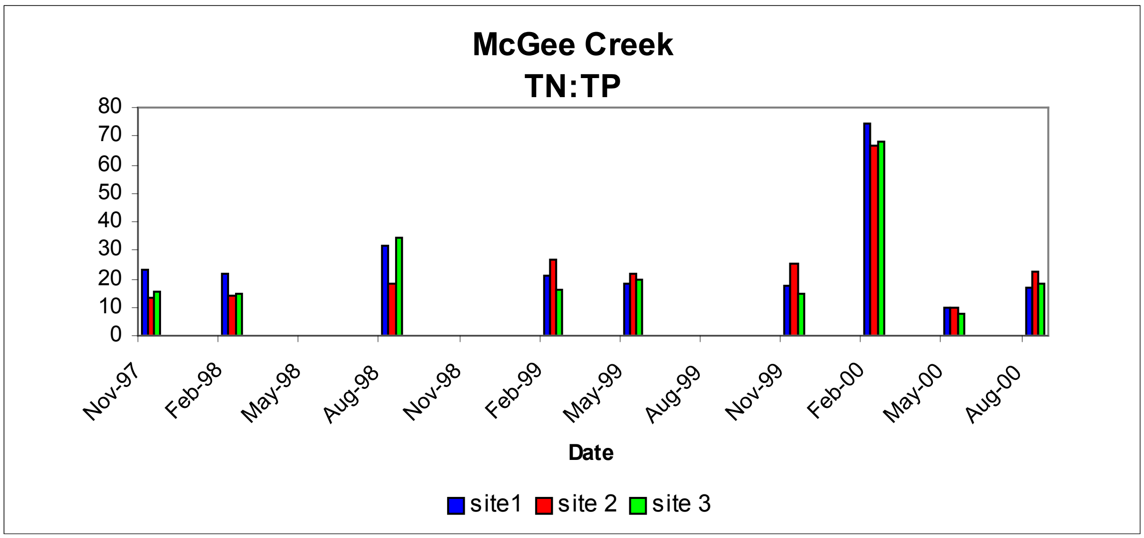


Figure 65. McGee Creek TN:TP ratios, November 1997 through August 2000.

Fecal Coliform

Oklahoma Water Quality Standards states for Primary Body Contact Recreation beneficial use the geometric mean of fecal coliform may not exceed 400 colonies (cfu) per 100ml and 25% of the samples may not exceed the screening level of 400 cfu per 100ml. Samples must be collected during the recreational season from May 1 through September 30, with no less than 10 samples. The geometric mean of samples collected from McGee Creek Reservoir was 18 cfu per 100ml (n=21) with no samples exceeding the prescribed screening level, therefore OWQS were being met.

Historical Water Quality Trend Analysis

Historical data for McGee Creek Reservoir was obtained from Oklahoma City for nitrates and phosphates from April 1992 through October 1999. Nitrates ranged from 0.01- 0.5 mg/l (n=27) and phosphates ranged from 0.01- 0.24 mg/l (n= 27). Though for true statistic purposes the data should have represented a minimum of ten years, the seven years worth of historic data was analyzed using a Seasonal Kendall trend analysis. A positive trend was detected in both the nitrate and phosphate data at a 95% confidence level. A further regression analysis of the data revealed an R-Squared value of 0.278 for nitrates and 0.107 for phosphates. Conclusions from this data showed that over the period tested, though below the ten year minimum, there was an increase in nitrate and phosphate values at McGee Creek Reservoir.

Nonpoint Source Cause Codes and Potential Sources

Table 26 lists causes and potential sources for nonpoint source pollution documented in each assessed lake through the Oklahoma's Non-point source pollution program. This information was identified in the 319 Lakes Assessment report (OWRB, 2000). The list was compiled based on Oklahoma's 303(d) list, the OCC 1988 319 Assessment Report, and NRCS landuse information.

Table 26. List of potential sources of pollution in the watershed and/or lake.

Lake Name	Cause Code	Potential Sources
Atoka	• Metals • Nutrients • Siltation • Suspended Solids	• Nonpoint Source • Non-irrigated Crop Production • Pasture Land • Range Land
Canton	• Pesticides • Siltation	• Non-irrigated Crop Production • Irrigated Crop Production • Pasture Land • Range Land
Hefner	• Pesticides • Nutrients	• Agriculture • Non-irrigated Crop Production • Irrigated Crop Production • Aquaculture • Storm Sewers (Other than end of pipe) • Surface runoff • Pasture Land • Range Land
McGee Creek	• Organic Enrichment /DO	• Non-irrigated Crop Production • Pasture Land • Animal Holding/Management • Silviculture
Overholser	• Nutrients • Exotic Species	• Non-irrigated Crop Production • Irrigated Crop Production • Pasture Land • Animal Holding/Management • Silviculture, • Highway/Road/Bridge • Land Development • Petroleum Activities • Streambank Modification/Destabilization Highway Maintenance and Runoff

Stanley Draper	• Pesticides • Siltation • Suspended Solids	• Dam Construction • Bridge Construction • Removal of Riparian Vegetation • Streambank Modification/Destabilization • Urban Runoff • Range Land • Highway Maintenance and Runoff

Part IV: Bathymetric Mapping

As a part of this project the OWRB performed bathymetric mapping of Oklahoma City's water supply lakes. Data acquisition for Canton Lake mapping was performed in 1995 by the U.S. Army Corps of Engineers and was therefore not repeated for this study.

The following tables (Table 27- 31) list available morphometric features for each of the five reservoirs mapped by this study. Historic data may not be complete and mapping methods have changed dramatically with new technology, however this information is reported for general comparisons. Lake Hefner's capacity in 1998 is greater than that in 1990. This may be a result of the construction of Hefner Parkway and the shoreline development along the east shore altering lake morphometry and lake volume.

Table 27. Lake Hefner morphometric features, historical and current.

Lake Hefner				
Source	USGS (1950)	Clean Lakes Phase I (OWRB, 1990)	Oklahoma Water Atlas (OWRB, 1990)	**OWRB Bathymetric Mapping (1998)**
Elevation	NA	1199 ft	1199 ft	**1199 ft**
Surface Area	2587 acres	2,409 acres	2,500 acres	**2,514 acres**
Capacity	75,681 ac-ft	61,507 ac-ft	75,000 ac-ft	**68,868 ac-ft**
Maximum Depth	90 ft	76 ft	NA	**76.48 ft**
Shoreline	NA	NA	18 miles	**NA**

Table 28. Lake Overholser morphometric features, historical and current.

Lake Overholser					
Source	Original Data 1919, (OWRB, 1982)	Reservoirs of Oklahoma (ODWC, 1973)	Oklahoma Water Atlas (OWRB, 1990)	Clean Lakes Phase I (OWRB, 1983)	**OWRB Bathymetric Mapping (2000)**
Elevation	NA	NA	1242 ft	NA	**1242 ft**
Surface Area	670 ha/ 1658 acres	680 hectares/ 1683 acres	606 ha/ 1500 acres	NA	**1567 acres**
Capacity	19,600 ac-ft	17,000 ac-ft	15,000 ac-feet	15,463 ac-ft	**13,913 ac-ft**
Maximum Depth	17.1 ft	5.5 meters	NA	NA	**14.4 ft**
Shoreline	6.8 miles/ 10.95 km	7 miles	7 miles	NA	**NA**

Table 29. Lake Stanley Draper morphometric features, historical and current.

Lake Stanley Draper			
Source	Phase I Dam Inspection Report (1980)	Oklahoma Water Atlas (OWRB, 1990)	**OWRB Bathymetric Mapping (1999)**
Elevation	1191 ft	1191 ft	**1191 ft**
Surface Area	2900 ac	2900 ac	**2,459 ac**
Capacity	114,500 ac- ft	100,000 ac-ft	**87,296 ac-ft**
Maximum Depth	NA	NA	**92.8 ft**
Shoreline	NA	34 miles	**NA**

Table 30. Lake Atoka morphometric features, historical and current.

Atoka Lake				
Source	Reservoirs of Oklahoma, (ODWC 1973)	Clean Lakes Phase I (OWRB, 1983)	Oklahoma Water Atlas (OWRB, 1990)	**OWRB Bathymetric Mapping (2000)**
Elevation	NA	589.7 ft	590 ft	**590 ft**
Surface Area	5900 acres	2388 ha/ 5,911 acres	5700 acres	**5,477 acres**
Capacity	125,000 ac-ft	95,055 ac-ft	125,000 ac-ft	**105,195 ac-ft**
Maximum Depth	30.0 ft / 9.14 m	18.3 m	NA	**59.9 ft**
Shoreline	80.0 mi / 128.7 km	56 miles / 91.3 km	59 miles	**NA**

Table 31. McGee Creek Reservoir morphometric features, historical and current.

McGee Creek Reservoir			
Source	Environmental Statement (Bureau of Reclamation, 1978)	Oklahoma Water Atlas (OWRB, 1990)	**OWRB Bathymetric Mapping (2000)**
Elevation	577.0 ft	577.1 ft	**577.1 ft**
Surface Area	3580 acres (proposed)	3,810 acres	**3632 acres**
Capacity	109,800 ac-ft (proposed)	113,930 ac-ft	**100,146 ac-ft**
Max. Depth	116 ft (proposed)	116 ft	**103.48 ft**

Some storage loss is expected in man made reservoirs. Federally constructed reservoirs are initially constructed with a planned 100-year lifespan. Table 32 reflects the net loss of storage capacity based on the initial storage from the Oklahoma Water Atlas (1990). This source of information was most complete for the five reservoirs, therefore the net loss maybe the loss from that particular time of publication and may not reflect total net loss since impoundment.

Table 32. Current versus historical storage in Oklahoma City water supply lakes.

Lake	Initial Storage (ac-ft)	2000 Storage (ac-ft)	Net Loss (ac-ft)
Hefner	75,000	68,868	6,132
Overholser	15,000	13,913	1,087
Draper	100,000	87,296	12,704
Atoka	125,000	105,195	19,805
McGee Creek	113,930	100,146	13,784
Total	428,930	375,418	53,512

The following pages contain the maps for Lakes Hefner, Overholser, Draper, Atoka and McGee Creek. The bathymetric maps give contours appropriate to the lake bottom morphometry of each lake. Maximum and minimum depths are given in feet below the normal pool elevation. Surface area is for normal pool elevation. The areas covered by each depth contour are given in the map keys. Current lake volume in acre-feet is also listed in the key.

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