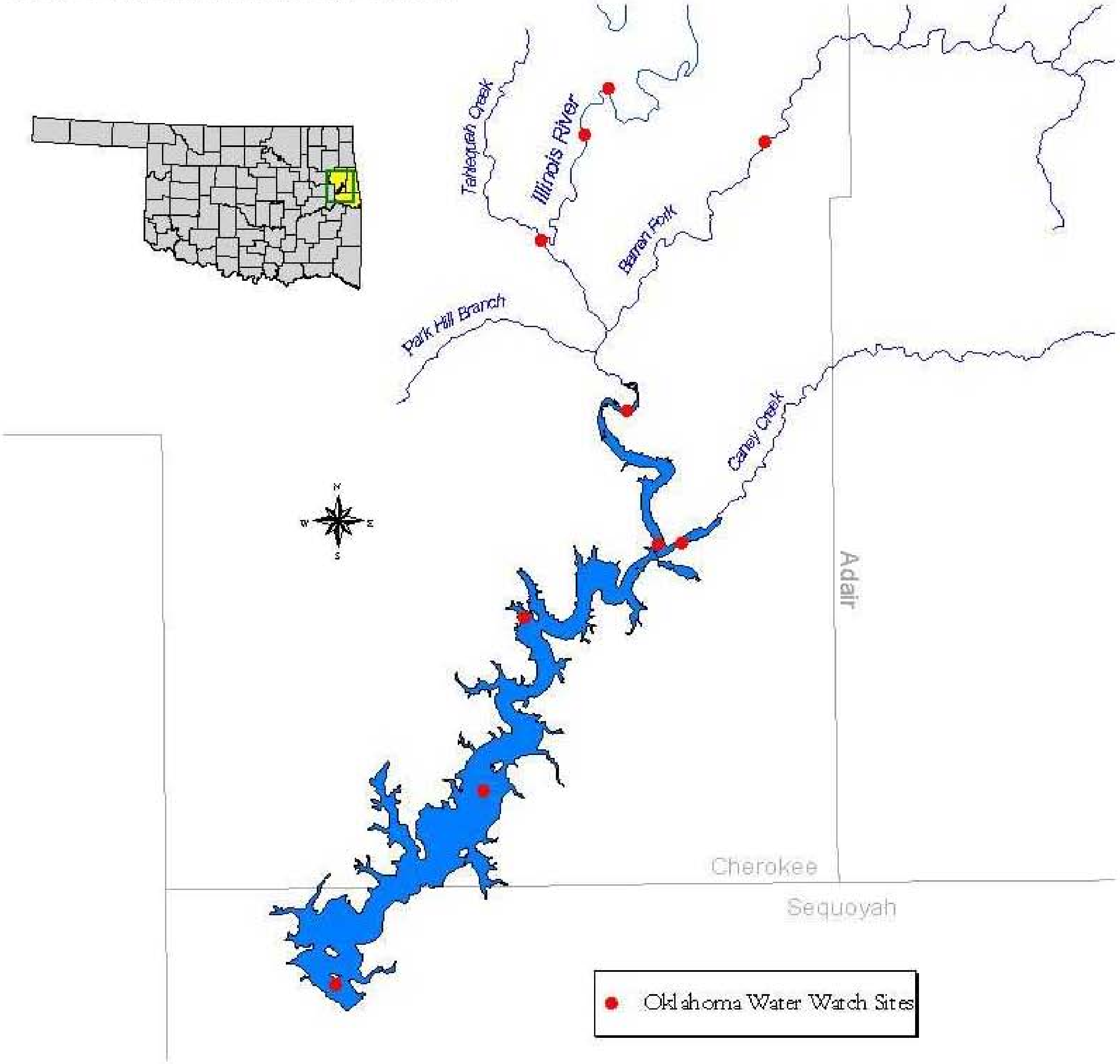
OKLAHOMA WATER WATCH

GREATER TENKILLER AREA ASSOCIATION & ILLINOIS RIVER OWW CHAPTERS

DRAFT 1997-2002 DATA SUMMARY



STATE OF OKLAHOMA
WATER RESOURCES BOARD

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Executive Summary

Tenkiller Ferry Lake is an important recreational outlet in the state of Oklahoma due to its historically good water quality. The primary tributary to the reservoir, the Illinois River, is designated as a Scenic River and is protected and managed to assure its high water quality. The Greater Tenkiller Area Association (GTAA) has participated in the Oklahoma Water Watch (OWW) Volunteer Monitoring Program since October of 1996, and the Illinois River chapter was initiated in August of 1999. Since initiation, volunteer monitors in both chapters have tested for water quality at six in-lake sites and three river sites on both the Barren Fork and the Illinois River. Volunteer monitors have dedicated approximately 5000 person hours to collect water quality data.

In 1996, a U.S. EPA Clean Lakes Phase I Diagnostic and Feasibility Study was subcontracted by the Oklahoma Water Resources Board to Oklahoma State University. Improvements implemented as a result of the investigation resulted in a 40% phosphorus load reduction to the reservoir. Since the Clean Lakes project, numerous other federal, state, and local projects, including best management practices, have been implemented in the watershed. Results have also been documented. In 1999, through the §319 Non-point source program, funds became available to assist OWW volunteer data collection activities through equipment purchases and volunteer recruitment. OWW volunteers continue to collect in-lake vertical profile and chlorophyll-*a* data. Volunteers currently monitor three sites in the watershed and 20 additional volunteers were certified in the fall of 2002. This valuable water quality data on the Tenkiller basin will assist the OWRB in documenting water quality trends and determining the trophic status of the reservoir.

The data collected by OWW volunteers can be summarized as follows: high productivity in surface waters by high summertime D.O. concentrations, resulting in super-saturation, elevated pH, and high ortho-phosphorus and chlorophyll-*a* concentrations in late summer. With a maximum of over four meters, Tenkiller Secchi disk depths are relatively good compared to other Oklahoma reservoirs. The upper end of the reservoir is more turbid than the lower end, and statistical trend tests for this data set show that Secchi disk depth in general is going down.

The River sites on both the Barren Fork and the Illinois are experiencing low D.O. in late summer/early fall, which may be a threat to their designated uses (CWAC). Nitrate nitrogen data, when compared to BUMP data, show that there are differences between the two data sets with OWW data slightly lower. No trends in nitrates can be detected at Sites 10 and 11; however, a decreasing trend in the data occurs at Site 12. Box and Whisker plots show all three sites are relatively similar (all high detections during March 2002). For ortho-phosphorus, differences between BUMP and OWW data sets show OWW data are slightly higher than BUMP data at Sites 11 and 12 with no difference at Site 10. No trends can be detected at Sites 11 and 12, but an increasing trend can be detected at Site 10. Box and Whisker plots show Site 11 has higher concentrations (mean, median, and maximum) than the other sites. Since Site 10 is a larger data set and directly comparable based on location, statistical results are likely more accurate for this site. Consistent with BUMP data, no ammonia concentrations can be detected at any of the sites.

Introduction

Tenkiller Ferry Lake is located in northeastern Oklahoma in Cherokee and Sequoyah counties. The U.S. Army Corps of Engineers (USACOE) completed lake construction in 1953. The conservation pool of the lake is 632 feet. Flood control storage ranges from 632 to 667 feet (OWRB, 1990). Lake area is approximately 12,900 acres with a shoreline length of 130 miles. The total drainage area is 4,170 sq. km or 1,610 sq. miles with about 53% in Oklahoma and 47% in Arkansas (Lyhane, 1987). The primary inflow to the lake is the Illinois River, comprising approximately 75% of the drainage area into the lake; the secondary tributary is Caney Creek with approximately 25% of the drainage area (OWRB, 2001).

In 1996, the Oklahoma Water Resources Board subcontracted a U.S. EPA Clean Lakes Phase I Diagnostic and Feasibility Study to Oklahoma State University. Improvements implemented as a result of the investigation resulted in a 40% phosphorus load reduction to the reservoir. Due to the importance of the Illinois River and Tenkiller Ferry Lake, it was essential to monitor and document success of best management practices (BMP) implementation and point source controls in meeting phosphorus-loading goals. In 1997, the OWRB began a rigorous monitoring program as part of the §104(b)3 program to document the effectiveness of non-point pollution controls in both Oklahoma and Arkansas. The OWRB then used §319 funds to expand the Oklahoma Water Watch (OWW) program, obtaining monitoring equipment to conduct in-lake profiling at the six in lake Phase I sites and adding volunteer monitoring sites in the watershed. The utilization of volunteers has not only assisted in data collection efforts but has also involved local stakeholders in the preservation and restoration of their lake.

This report was compiled for two chapters of volunteer monitors of the Oklahoma Water Watch Program—the Greater Tenkiller Area Association (GTAA) and the Illinois River Chapter, which includes the Barren Fork. The report summarizes data collection efforts and identifies water quality trends over time. This report was also compiled to meet the final output for the §319 USEPA grant requirement.

Although the reservoir was originally constructed for flood control and hydroelectric power, it has also become a public water supply source for many area municipalities as well as an enormous recreational resource (Nolen et al., 1988). The economic benefits recreation provides both the area and the state as a whole are immense. Primary recreational activities at the lake include boating, fishing, camping, swimming, and sightseeing. The lake is also popular among SCUBA divers due to its unique water clarity and aesthetic qualities. The Illinois River, which flows directly into the lake, is used by thousands of people every year for canoeing, camping, and fishing. It is evident that clarity and quality of the area water are the primary factors attracting visitors.

The GTAA has participated in the Oklahoma Water Watch (OWW) Volunteer Monitoring Program since October of 1996. The Illinois River chapter was initiated in August of 1999. Volunteer monitors in both chapters test for water quality indicators including dissolved oxygen, air and water temperature, Secchi disk depth, pH, water color, nitrate nitrogen, ammonia nitrogen, ortho-phosphorus, turbidity, and chlorophyll-*a*. (The latter two parameters are in-lake only.) Volunteer monitors have dedicated approximately 5000 person hours to collect water quality data.

Volunteer monitors are extremely helpful in obtaining baseline water quality data, which is used to indicate baseline water quality, identify trends, and promote citizen participation in protecting, managing, and restoring our water resources. State agencies do not have enough resources to collect this data on their own; without volunteers, the data would not be available. Since local citizens are very familiar with the lake and the surrounding area, they can also offer unique insight into possible problem areas and solutions. Volunteer monitoring activities also serve to heighten public awareness concerning pollution problems in and around the Illinois River basin, allowing all citizens to gain a better understanding of water quality conditions.

Three teams of volunteers currently monitor the lake and river. John Ellis of the Greater Tenkiller Area Association has been with the Water Watch program since 1996. He has monitored as many as nine sites and currently monitors five in-lake sites with a Hydrolab® unit and collects nutrient and chlorophyll-*a* samples. David Jurkiewicz and Ed Fite monitor two sites on the Illinois River and one site on the Barren Fork for both basic and advanced parameters, and use a Hydrolab® to assist in basic parameter data collection. Mr. Jurkiewicz has been with the program since 1999 and Mr. Fite was certified in 2001. A third group, established in the fall of 2002, includes twenty additional volunteers. Their data were not available in time for this report. These volunteers are collecting basic and advanced parameters both at in-lake and shoreline sites, performing in-lake profiling, and collecting chlorophyll-*a* samples.

A section covering basic Limnology, or the study of freshwater, specifically lakes, has been included in this report to provide general information to volunteers about the parameters they monitor, how they fit into Oklahoma Water Quality Standards, and how the OWRB uses the information to interpret data results. The Materials and Methods section of the report was written not only for volunteers but also for individuals outside the program who are interested in how OWW operates.

Education, Outreach, and Recruitment Strategy

The Oklahoma Scenic Rivers Commission (OSRC) conducted the Education and Outreach component of this project. Educational workshops were performed for Middle School age kids to adults that included pre- and post-tests. A slide presentation introduced basic information about water quality (such as the concept of a watershed), pollutants that affect water quality, sources of pollutants, and the importance of riparian areas or buffer zones. The presentation also showed solutions to these problems implemented by agencies, businesses, communities, and various other groups, but focused on actions individuals can take to prevent further degradation of water quality. Additionally, Project Wet activities were used to help further the educational experience. Four workshops were held between January and June of 2001. For complete information on this component of the project, refer to Appendix A of this report (unfortunately this appendix is not available in electronic format).

Additional requirements of the §319 project were to address the recruitment strategy for volunteer monitors. Both OWW and OSRC cooperated in this effort. At the onset of the §319 project (spring and summer of 2000), OSRC took an active role in participating in OWW by establishing a central location for volunteers to be trained, check out equipment, and receive necessary assistance. OSRC solicited volunteers by local word of mouth and through newspaper advertisement. The first official training with the §319 project included approximately fifteen volunteers, six of whom were trained for nutrient testing in addition to the basic parameters. Unfortunately, due to a change of staff at OSRC, this group was not maintained. However, one volunteer did continue with the program, consistently monitoring one site on the Barren Fork and on site on the Illinois River. In the summer of 2001, he was joined by the OSRC Director, and as a team they picked up an additional site and currently monitor three sites, two on the Illinois River and one on the Barren Fork, with a Hydrolab® and collect surface nutrient data. The volunteer with the GTAA was trained prior to the §319 project. However, this project provided equipment and additional support to his efforts, which in turn resulted in six years of in-lake data at approximately five sites summarized in this report. This §319 project was also the stepping-stone for twenty additional volunteers who are now trained and collecting data for future analysis.

Limnology 101

Data collected by volunteers consist primarily of the basic parameters--air and water temperature, dissolved oxygen (D.O.), pH, color, and water clarity--and advanced parameters--ortho-phosphorus, nitrate nitrogen, and ammonia nitrogen. Additionally, some monitors collect water to perform filtration for chlorophyll-*a* and turbidity analysis, use a multi-parameter sonde instrument (Hydrolab®) to collect data at specified intervals throughout the water column, and collect bottom samples for nutrient analysis. This section briefly describes the parameters measured by volunteers and how they fit into reservoir limnology. Some of the language for this section was borrowed from the *Lakes of Missouri Volunteer Monitoring Program*.

Dissolved Oxygen (D.O.)

Oxygen is produced during photosynthesis of plants and consumed during respiration and decomposition. Because it requires light, photosynthesis occurs only during daylight hours. Respiration and decomposition, on the other hand, occur 24 hours a day. This difference can account for large daily variations in D.O. concentrations. D.O. concentrations steadily decline during the night and are the lowest just before dawn, when photosynthesis resumes. This is why it is important to always measure D.O. at the same time of day. Other sources of oxygen come from the air mixing with flowing, turbulent water. Therefore, rivers and streams may deliver oxygen to a lake or reservoir, especially if they are turbulent (http://www.fish.washington.edu).

For most organisms, oxygen in the environment is a requisite for life (Cole, 1983). D.O. in surface water, under normal conditions, has an inverse relationship with water temperature. Colder waters have the capability to trap more D.O. Therefore, in the winter months, when air and water temperatures are low, it is likely to see higher D.O. concentrations in surface waters. In the summer months, as temperatures rise, the capacity of the water to retain high concentrations of D.O. will decline. The anomaly to this theory is that during the summer, peak sunlight can result in extreme photosynthesis in a productive water body, which will supersaturate the system with D.O. This is reflected with D.O. concentrations higher than 10mg/L at the surface and percent saturation of greater than 100 to 110%. The negative impact from this high D.O. concentration occurs during darkness, when respiration occurs, which results in extreme drops in D.O., usually seen prior to sunrise. The levels can be so low that fish kills may occur. Diurnal (daily) fluctuations in D.O. are documented by diurnal studies that record D.O. hourly for 24 hours.

Oklahoma's Water Quality Standards and D.O.

Beneficial use designations for streams and lakes may be found in Appendix A of Oklahoma Administrative Code (OAC) 785:45 (Chapter 45 of the Oklahoma Water Resources Board rules). Table 1 provides those beneficial uses assigned to the Illinois River, Barren Fork, and Tenkiller Lake. The Use Support Assessment Protocols (USAP) outlined in OAC 785:46-15-5 require that D.O. concentrations in streams for cool water aquatic communities (CWAC) shall be ≥5.0mg/L from June 1 through October 15, and ≥6.0mg/L the remainder of the year. D.O. criteria for lakes, assessed slightly differently, are based on water column concentrations. For example, the Fish and Wildlife Propagation (FWP) beneficial use is deemed to be not supported if greater than 70% of the water column D.O. concentrations are less than 2mg/L, which outlines the importance of D.O. data collected in vertical profiles. USAP goes on to state that lakes are partially supporting the FWP beneficial use if only 50% (but not more than 70%) of the water column is less than 2mg/L, and fully supporting if less than 50% falls below 2mg/L.

Table 1. Beneficial use assignments for the Illinois River Watershed

Beneficial Use Assignments	
Upper Illinois River from Tenkiller Dam, including Tenkiller Reservoir upstream to the Barren Fork confluence	Public and Private Water Supply, Fish and Wildlife Propagation - Cool Water Aquatic Community, Agriculture Beneficial Use, Recreation Beneficial Use- Primary Body Contact Recreation, and Aesthetics
Barren Fork	Public and Private Water Supply, Fish and Wildlife Propagation - Cool Water Aquatic Community, Agriculture Beneficial Use, Recreation Beneficial Use--Primary Body Contact Recreation, Aesthetics, Limitations- Outstanding Resource Waters
Upper Illinois River upstream of Barren Fork confluence	Public and Private Water Supply, Fish and Wildlife Propagation - Cool Water Aquatic Community, Agriculture Beneficial Use, Recreation Beneficial Use- Primary Body Contact Recreation, Aesthetics, Limitations- Outstanding Resource Waters, Remarks- Scenic River

Water Temperature and Stratification

Temperature is an important component in lake turnover and stratification. Deep reservoirs in Oklahoma, including Tenkiller Ferry Lake, tend to see some type of thermal stratification in the summer months. Stratification is dependent on the density of water, which changes as the temperature of water changes. An important concept to understand is that water’s maximum density occurs at approximately 4°C. As it cools below 4°C to become ice, it actually gets lighter or less dense due to the way water forms ice crystals, which is why ice floats. During winter months in Oklahoma, exclusive of when lakes may freeze at the surface, lakes stay primarily mixed with water temperature less than 10°C. As the spring sun starts to warm up the surface waters, distinct layers begin to develop with colder waters at the bottom and warmer waters at the surface. Summer stratification is complete when three main layers are formed—epilimnion, metalimnion, and hypolimnion. During summer stratification, the hypolimnion, or bottom layer, may become anoxic due to lack of photosynthesis and/or oxygen introduced by wind mixing. A greater than 1°C temperature change between the layers is the point of thermal stratification. As fall approaches and surface waters begin to cool off, the surface and bottom waters become mixed. Uniform temperature throughout the water column is usually evident during mixing. At this point the lake is mixed and fall turnover is occurring. The problems associated with fall turnover result when nutrients trapped in the colder, deep layers of the reservoir become available to the warmer surface waters in the photic zone resulting in unsightly algal blooms.

pH

In addition to temperature and D.O., pH, a measure of the acidic or basic (alkaline) nature of a solution, is a basic parameter measured by all volunteers. The concentration of the hydrogen ion [H+] activity in a solution determines the pH. A pH of 7 is considered to be neutral. Substances with pH less than 7 are acidic; substances with pH greater than 7 are basic, or alkaline. The scale is logarithmic, which means that one standard unit change is a ten-fold change in acidity or alkalinity. For example, a substance with a pH of 5 is ten times more acidic than a substance with a pH of 6. Because organisms in aquatic ecosystems have adapted to the pH conditions of natural waters, even small pH fluctuations can interfere with the reproduction and survival of those organisms. Because it can be a useful indicator of specific types of contaminates or biological processes, pH is an important water quality parameter.

The buffering capacity of water affects its pH. Photosynthesis may alter the equilibrium of carbon dioxide (CO_2), which results in a rise of pH values (or alkaline), whereas in respiration the reaction moves in the other direction lowering pH (Cole, 1983). Low pH values (or acidic waters) are usually found in natural water rich in dissolved organic matter (i.e., swamps, bogs, or marshes), typically seen in southeastern Oklahoma. Acidic precipitation, or acid rain, can also lower the pH of surface waters. OWQS for pH for both lakes and streams falls within the same criteria. The USAP states that the acceptable range or screening interval for pH is between 6.5 and 9 standard units (s.u.). USAP goes on to state the FWP beneficial use will be deemed fully supported if no more than 10% of sample concentrations fall outside the screening interval, partially supported if 10–25% fall outside the screening interval, and not supported if >25% fall outside.

Secchi Disk Depth

Another parameter measured by all volunteers and a factor that may indirectly reflect lake productivity is Secchi disk depth. The Secchi disk is an 8-inch diameter disk with contrasting black and white quadrants. The disk was developed in 1865 by Fr. Pietro Secchi, a scientific observer to the Pope (NALMS, 1996). It is believed as his research vessel traveled around the Mediterranean Sea, he discovered the dirty dishes the cook threw out the windows were visible at different depths in different areas of the sea. From this discovery, an easy to use measurement for water clarity was born. The disk is lowered into the water and the depth in which it disappears is recorded.

The disk measures water clarity by estimating the depth of light penetration into the lake water. Suspended in the lake are both organic (algae) and inorganic (sediments, silt, etc.) materials that inhibit sunlight penetration and thus affect the depth of visibility. Similarly, the depth of sunlight penetration directly affects photosynthesis and algal growth. Therefore, by measuring Secchi disk depth, we can better understand light penetration conditions that may affect productivity. Secchi disk depth does not, however, differentiate between organic and inorganic turbidity.

Turbidity

Turbid water can result from excessive algae and or sediment. Sediment usually increases as a result of soil erosion in the watershed following storms; high levels of sediment are found more frequently in reservoirs with major inflowing streams (Holdren, et al, 2001). There are several methods in measuring turbidity. Turbidity may be measured using a turbidity tube, which is a crude method of measurement where a thin tube is filled with water until a Secchi design at the base of the tube is no longer visible. This tube is then calibrated to give a nephlometric turbidity unit (NTU). A more precise but more expensive method to measure turbidity is through the use of a turbidimeter. A turbidimeter electronically measures the scatter of light through a sample and also gives a NTU. Without algal enumeration or chlorophyll-*a* data it is difficult to assess if turbidity is from algae (organic matter) or sediment (inorganic matter). OWW volunteers use both methods to determine turbidity if funding is available to purchase the turbidimeter. The OWRB uses a turbidimeter.

Through USAP Oklahoma has established criteria for turbidity (using a turbidimeter). For reservoirs, turbidity greater than 25NTU is not supporting the FWP beneficial use, while a turbidity of greater than 50NTU for rivers is not supporting.

Color

Color indicates the suspended solids in the water in addition to the dissolved substances that may alter the water's appearance. Oklahoma has water quality standards (WQS) set for apparent color. However, the OWW program does not measure color to this level of accuracy; therefore, no WQS apply to OWW color parameters. The OWW program uses a Borger Color System booklet to match the water's surface color. This information is strictly used to detect differences in colors–-green versus brown versus transparent. This information is useful as it describes the volunteers' perception of water color at the time of sampling. For example, shades of greens may indicate suspended algae, whereas shades of browns may indicate suspended sediments or dirt. This information, combined with Secchi disk depth, may help identify influences affecting transparency.

Nutrients and Chlorophyll

Oklahoma law has recently implemented a total phosphorus (TP) criteria for scenic rivers of 0.037 mg/L; otherwise, Oklahoma's WQS and USAP have not yet developed complete criteria for nutrients. Nitrates concentrations for public and private water supplies (PPWS) are restricted to 10 mg/L (or ppm). Strides are being made toward a more comprehensive nutrient assessment and how it relates to the health of a stream or lake. In Oklahoma, for lakes, Trophic State Indices (TSI) are used to relate productivity of lakes to beneficial use support. Calculations for determining TSI use total phosphorus, total nitrogen, and chlorophyll-*a* concentrations.

Algae require many different nutrients to grow, and of these nutrients, nitrogen and phosphorus are the most important because they occur in the smallest supply relative to the needs of algae. Nitrogen occurs in natural water as nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), and organically bound nitrogen (found in proteins and recycled by plants and animals). Nitrogen can enter water from human and animal waste, decomposing organic matter, and fertilizer runoff. Poorly operated wastewater treatment plants, septic systems, and sewage leaks can add nitrogen to water bodies too. Phosphorus is also present in natural waters usually as phosphate, which is a by-product of living plants and animals. Phosphorus also comes from wastewater treatment plants, septic tanks, fertilizers, and detergents. Generally, as nitrogen and phosphorus increase in a lake, so does the amount of algae. Nitrogen and phosphorus may also be found in soils, and in association with soil runoff, can be transported to streams and lakes. Often the nutrient levels of a lake reflect that of the soils and land use surrounding the lake. For the most part, natural levels of nitrogen and phosphorus are not enough to cause severe algal blooms or water quality concerns. Typically, levels that do cause concern are human induced. The following is a list of some of the most common human activities that can increase nitrogen and phosphorus levels in lakes (OCC, 2000).

- Excessive fertilizer applications to lawns, golf courses, and fields
- Runoff from feedlots and pastures
- Releases from sewage treatment plants
- Drainage from improperly working septic systems
- Increased soil erosion from farm fields and construction sites

Numerical ranges for nitrogen and phosphorus may vary dramatically in Oklahoma lakes, and without existing WQS criteria it is even more difficult to assess what is within an acceptable range for Oklahoma. Lakes may have high nutrients and low productivity due to excessive suspended solids and the resulting light limitation. On the other hand, clearer lakes with low suspended solids may only have minimal levels of these nutrients yet experience productivity problems. Therefore, in Oklahoma, the OWRB has implemented through USAP the use of Carlson's Trophic State Indices (Carlson, 1977) using chlorophyll-*a* concentrations to determine the “health” of a reservoir based on its trophic state.

Chlorophyll is the green pigment used by plants or algae for photosynthesis. The OWRB and other state agencies use chlorophyll-*a* concentrations as a biological indicator for the amount of algae in the water. Because all algae contain chlorophyll, this is typically a reliable method for estimating biomass, or productivity.

Algae, like other plants, require sunlight, nutrients, and carbon dioxide to live. When animals such as zooplankton or small fish eat the algae, they acquire the energy stored in the algal cells. When bigger fish eat these organisms the energy moves up the food chain to the next level. Thus, algae are the origin of much of the energy passed through the food web and are an important part of a lake’s ecosystem. Additionally, the oxygen produced as a by-product of the photosynthesis of algae is a major source of D.O. in our lakes.

However, excessive amounts of algae can be detrimental to a lake or stream. Large growths of algae are known as algal blooms. In addition to aesthetic problems, algal blooms can cause taste and odor problems with drinking water treatment plants. Algal blooms may also affect the recreational value of a lake by hindering swimming, boating, and fishing. When algae populations exceed the forage demand, those algae that are not consumed tend to die and sink to the bottom of the lake. Decomposition or bacterial breakdown of these dead algae uses up the D.O. in the lake water, resulting in anoxic conditions. When large amounts of algae die off, oxygen levels can dramatically decrease and may result in a fish kill.

The third nutrient OWW trains volunteers to test for is ammonia. Low-level ammonia nitrogen may occur naturally in water as a result of the biological decay of plant and animal matter. Higher concentrations may be found in raw sewage and industrial effluents. The principal form of toxic ammonia is NH_3. Ammonia toxicity levels are affected by dissolved oxygen concentrations, temperature, pH, and carbon dioxide concentrations. Ammonia levels in surface water increase with increasing pH and temperature. Plants are more tolerant of ammonia than animals, and invertebrates are more tolerant than fish. High levels of NH_3 may affect hatching and growth rates of fish.

Although no OWQS criteria exist for ammonia either, it is typically found in very low concentrations under aerobic conditions. In the presence of oxygen it is quickly converted to nitrite (NO_2) and nitrate (NO_3). Concentrations in unpolluted waters can range from 0 to 5mg/L, whereas in anaerobic conditions concentrations may exceed 10mg/L (Nanny, 1998).

Trophic State Indices

Oklahoma uses the Carlson TSI to classify lakes in terms of trophic state or productivity. Carlson (1977) stated that chlorophyll-*a* seems to be the most acceptable parameter to use in calculating TSI and estimating algal biomass in lakes. In accordance with historical OWRB calculations and Carlson’s suggestion to use chlorophyll-*a* concentration, 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:

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

The resultant value from this equation can then be used to classify the lake as oligotrophic, mesotrophic, eutrophic, or hypereutrophic (Table 2). Oklahoma’s WQS requires a minimum of 20 samples throughout the sample period, averaged to accurately calculate the TSI number. Table 2 shows the range of TSI values and defines the trophic state class.

Table 2. Carlson's Trophic State Indices definitions for Oklahoma lakes

Carlson TSI No.	**Trophic State**	**Definition**
< 40	Oligotrophic	Low primary productivity. Water tends to be clear. Lakes that are very turbid (brown to red color) have low productivity due to light limitation.
41 – 50	Mesotrophic	Moderate primary productivity. Water may be slightly greenish in color. Lakes that are turbid may have limited productivity due to light limitation.
51 – 60	Eutrophic	High primary productivity. Water is not clear and may be greenish to brown in color. Recreation may be impaired during algal blooms, and anoxic conditions may be present during the summer.
> 61	Hypereutrophic	Excessive primary productivity. Recreation is likely impaired.

Eutrophication

In relation to trophic state, an additional useful term is eutrophication, the aging process a lake goes through when nutrients and algal growth increase over time. In a classical sense, a lake begins as oligotrophic and moves through mesotrophy and eutrophy. In natural lakes, this process of increasing productivity is natural and occurs over thousands of years. In man-made lakes or reservoirs, the process occurs much faster from inputs of nutrients and soil erosion that naturally occurred where the river is now impounded. The problem most Oklahoma reservoirs face is anthropogenic eutrophication, which describes the accelerated increase of nutrient levels and soil erosion due to human influences. A gradual increase in productivity is acceptable, but rapid changes due to human activity are usually not desirable.

Reservoir Zones

Longitudinal zonation plays a vital role in light and nutrient availability for productivity and trophic status in reservoirs. Longitudinal gradients are important in terms of basin morphology, flow velocity, water residence time, suspended solids, light and nutrient availability (Thornton, 1990). Figure 1 shows the three typical zones to reservoirs: riverine zone, transition zone, and lacustrine zone. The riverine zone, located in the headwaters of the reservoir, is characterized by higher flow, shorter water residence time, higher levels of suspended solids and nutrients, and limited light availability as a result of increased suspended solids. The transition zone is characterized by higher productivity in conjunction with increasing reservoir width, decreasing flow velocity, increased water residence time, sedimentation of suspended solids, and increased light availability. The lacustrine zone is located nearest the dam and typically has longer water residence time, lower concentrations of dissolved nutrients and suspended particles, and higher water transparency (deeper Secchi disk depths) (Thornton, 1990).

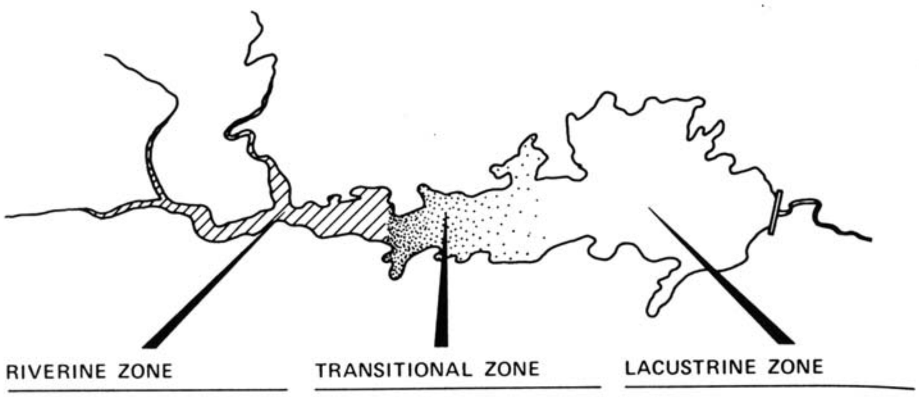

Figure 1. Longitudinal zonation that is typical in man-made lakes or reservoirs

Materials and Methods

To Become a Monitor

To obtain certification, each volunteer must undergo the three phases of OWW training. In Phase I, volunteers are given information about the program's goals, a brief history of the program, and future objectives and expectations. Phase I also covers safety, water quality concepts, kit maintenance, site selection, and testing procedures. The second phase of training allows the volunteer to gain hands-on experience with the monitoring kits, conducting all tests as if in the field with minimal assistance from the Training Coordinator. During Phase III, the newly trained volunteer is observed while completing the testing procedures competently without assistance from the Training Coordinator. If all of the testing procedures are completed correctly, the volunteer monitor is ready for certification.

Once certified, the volunteer monitor spends an average of three and a half hours a month sampling and testing water quality. Each volunteer or group of volunteers is issued a water quality monitoring kit. Volunteers test Basic Parameters which include; pH, water and air temperature, water color, dissolved oxygen, Secchi disk depth, and physical site characteristics (Table 3). Some volunteers become further certified to perform testing for Advanced Parameters. These include ammonia nitrogen, nitrate nitrogen, and ortho-phosphorus. Further involvement includes performing in-lake profiling, using a Hydrolab® multi-probe water monitoring instrument, chlorophyll-*a* sample collection and filtering, and turbidity. These new advanced parameters are ideally collected from a boat away from shoreline interference.

Table 3. Oklahoma Water Watch water quality parameters

<table>
<tr><th colspan="3">Basic Water Quality Parameters</th></tr>
<tr><td>Air Temperature</td><td>Dissolved Oxygen</td><td>Color</td></tr>
<tr><td>Water Temperature</td><td>pH</td><td>Secchi Disk Depth</td></tr>
<tr><th colspan="3">Advanced Parameters</th></tr>
<tr><td>Ammonia Nitrogen</td><td>Nitrate Nitrogen</td><td>Ortho-phosphorus</td></tr>
<tr><th colspan="3">New Advanced Parameters</th></tr>
<tr><td>Hydrolab® (Vertical Profile)</td><td>Turbidity</td><td>Chlorophyll-*a*</td></tr>
</table>

Water Quality Tests

For detailed procedures and quality control specifications for the tests used by OWW, refer to the OWW Handbook and the EPA approved QAPP (included as Appendix B in this report). The temperature, color, D.O., and pH tests are performed using LaMotte testing equipment. Air and water temperature are recorded using a LaMotte armored thermometer (-5 to +45 Degrees Celsius). Color is determined by matching the water color to a color chip in the Borger Color System booklet. D.O. is measured by a modified Winkler titration/azide method. Percent D.O. saturation was determined using the water temperature and D.O. concentration. The pH test is a basic colorimetric test using a pH wide range indicator reagent resulting in a measurable color change. Turbidity was measured for project using a turbidity tube designed in Australia. The turbidity tube is approximately 40 cm (±2 cm) in length and 2 cm in diameter. The tube is open on one end and is clear with a Secchi disk image at the closed end. The turbidity tube is used to measure water clarity by filling it with sample water until the Secchi disk is barely visible. Turbidity is measured by reading the graduations marked on the side of the tube, measurements are in JTU's (Jackson Turbidity Units). Jackson units will approximate nephelometric units but will not be identical. For example, turbidity of a specified concentration of formazin suspension is defined as 40 nephelometric units, this suspension has an approximate turbidity of 40 Jackson units (Standard Methods, 1989).

Nutrient tests at Lake Tenkiller are performed using a HACH battery-operated Pocket Colorimeter™ Filter Photometer. Nutrient tests for the Illinois River are performed using the traditional OWW colorimetric tests outlined in the OWW Handbook. The pocket colorimeter instruments are factory programmed and use pre-measured, unit-dose HACH reagents. The instruments are 'zeroed' or calibrated with a sample blank. The sample is then treated and the results are read directly in concentration units. Both the electronic and the manual test procedures use the same methods. Again, all test procedures are detailed in the QAPP (Appendix B). The ammonia nitrogen test is performed according to the salicylate method, the nitrate nitrogen analysis uses the cadmium method, and the ortho-phosphorus test uses the ascorbic acid method.

The color disc kits feature a continuous-gradient color wheel for comparisons. A blank (sample water) is inserted in the holder to the left of the color box as a reference in color comparison, compensating for color in the sample. After rotating the color wheel, a color match can be obtained between the blank and the treated sample. The accuracy for color disc kits is typically ± 10% or ± the smallest increment. However, this is subject to individual color perception. All tests are performed on blank samples of deionized (DI) water before each test is performed on sample water. This process accounts for background color changes and may detect equipment contamination. Color changes are matched to a color wheel from which a "value" is obtained. The volunteer records both the DI blank value and the value from the environmental sample. The DI blank value is then subtracted from the environmental sample to give a true value.

Nitrate nitrogen generally occurs in natural waters at low concentrations. Therefore, some detectable concentrations of nitrates should be expected. Nitrate nitrogen tests results using the HACH tests include nitrite concentrations. Phosphorus may be found in natural waters in several forms. The most common form measured by water quality laboratories is total phosphorus. This is the concentration used for TSI calculations and in reference to water quality standards. Ortho-phosphorus is the dissolved form readily available for algae assimilation. OWW measures ortho-phosphorus primarily due to test capabilities. Total phosphorus analysis requires a digestion process, which involves a boiling step that is not suitable for volunteer monitoring. Ammonia is less likely to be detected in natural waters because it is quickly used by algae and broken down in the presence of oxygen. Therefore, it is common not to see detectable quantities of ammonia under normal conditions.

Chemical Test Limitations

Basic water quality parameters listed in Table 3 are performed using LaMotte chemical tests and or a Hydrolab®. For detailed information on test procedures, refer to the QAPP or the OWW Handbook. These basic LaMotte tests have proven highly effective for volunteers to achieve accurate results and are the basis of the program. For the nutrient tests, also listed in Table 3, HACH chemical tests are used. Again, the HACH tests used for this project are both electronic and manual colorimetric tests with different levels of accuracy. The estimated detection limit and repeatability for the battery-operated nutrient tests is 0.01 mg/L and the accuracy level is +/-2%. The accuracy for the color wheel is +/-10% (range can be found in Table 4). However, due to individual differences in deciphering colors between volunteers, the manual tests that are read using a color wheel and matching colors should be considered with limited utility. They are excellent screening tools to serve as an early warning system, which would not be documented by routine monitoring by state agencies. Regardless of the equipment used, the data collected using these tests are useful in determining long-term trends, a primary goal of OWW.

Problems with the ortho-phosphorus test include glassware contamination issues. It is important that glassware used for measuring phosphorus be acid-washed: soaked in dilute 10% hydrochloric acid (HCl) solution and then rinsed thoroughly with DI water. Phosphorus-containing detergents should never be used to wash glassware associated with the ortho-phosphorus test. Other problems with the ortho-phosphorus test are in reading the color wheel. The blue color can be influenced dramatically by background light and eyesight limitation. A small difference in color determination may result in a significant difference in data result. That being said, steps are being taken to resolve all of these concerns. However, they are noted in this section of the report to document the limitations of the nutrient tests. Discrepancies are identified in the QCA sessions.

Reported Data

There are six OWW sites on Tenkiller Lake. Three of these sites (Sites 1, 2, and 5) are also monitored by the Beneficial Use of Monitoring Program (BUMP). Therefore, references may be made to volunteer-collected data and "professionally" collected data in the lake section. However, no direct comparisons were made due to differences between collection times. Statistical trends analyses were performed on lake nutrient and Secchi disk data to detect any positive or negative trends. There are three sites in the watershed, two on the Illinois River and one on the Barren Fork. There is a BUMP site at the same location on the Barren Fork, and another at Tahlequah on the Illinois River between the two OWW sites. Comparisons were made on these sites looking at statistical differences between the two program data sets and between the sites.

Surface data analysis was performed for each site, ending in October 2002 for the lake and November 2002 for the river. To aid in the interpretation of results, lake data were graphed for individual parameters including Secchi disk depth by site, D.O. and pH values plotted against OWQS, whole lake median concentrations for nutrients, chlorophyll-*a* TSI, and turbidity values also plotted against OWQS. Lake profile data were used in comparison to USAP outlined in the OAC 785:46-15-5 to determine use support. River results were determined individually for each site. D.O. and pH values were plotted with appropriate OWQS. Nutrient data were plotted with data collected through the BUMP for comparison purposes.

Units of measure used for this report for D.O., nitrate nitrogen, ortho-phosphorus, and ammonia nitrogen are reported in milligrams per liter, which is abbreviated as mg/L, and is equivalent to parts per million or ppm. Chlorophyll-*a* is reported in micrograms per liter or µg/l, which is equivalent to milligrams per cubic meter or $mg/m^{3.}$ Secchi disk depth is reported in centimeters, and temperature is reported in degrees Celsius.

Color was analyzed by assigning a color (e.g., green, brown, transparent, etc.) to each of the Borger Color System numbers. All reported numbers were then categorized according to color, for each site. A percentage of report values are provided as the analysis for color. It is important to note that the determination of color for this report is in no way related to the apparent color parameter listed in OWQS, which is analyzed by a certified water quality laboratory. The color analysis in this report is a generalization of reported BCS numbers related to an assigned color and a record of volunteer perception.

Statistical Methods

An analysis of central tendency was made for mean, median, and range for all surface water quality data. Trend analyses were performed on Secchi disk depth, turbidity (when applicable), and nutrient parameters to determine if concentrations were decreasing or increasing. Seasonal

Kendall test for trends from WQStat Plus v. 1.5 for Windows software was used for these analyses. For trend tests, sample size (n) should be greater than 40. Occasionally, sample sizes were too small to meet this criterion, and analysis of trends in these data sets should be viewed as questionable. Box and whisker plots were used to visualize seasonal distribution of data and differences between sites. For the river data, a non-parametric analysis of variance (ANOVA) was used to determine significant differences between data at upstream versus downstream sites, between data sets (OWW and BUMP), and between rivers. If differences were found to be significant, Box and Whisker plots were then used to determine which site was higher in concentration. Again, significance was determined at the 95% confidence level. River data sets were too small to use Seasonall Kendall's test for trends; therefore, Mann/Kendall's test for trends was used when possible. This test suggests if there are increases or decreases in data points and does not account for seasonality.

Quality Assurance

The Quality Control Assessment (QCA) session process is detailed in the QAPP (Appendix B). This section is an overview of the data collected by the two OWW chapters. Volunteer monitor participation in QCA sessions, required annually by the OWW program, guarantees the usability of the data. OWW sets rigorous margins for accuracy and precision to ensure that volunteer-collected data are reliable and valid. Accuracy is based upon the exactness of the test, while precision is determined by the ability to replicate results. For all three advanced parameters, ammonia nitrogen, nitrate nitrogen, and ortho-phosphorus, there is an accuracy range of +/- 10%. (The lowest value that the HACH color wheels can accurately detect is 0.02 mg/L. Any sample value below that may be reported as zero). During a QCA session, volunteers run four replicates on a known sample to test their accuracy and precision. Table 4 lists the range, precision, and accuracy of those tests used by OWW.

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

Variable	**Range**	**Precision**	**Accuracy**
Dissolved Oxygen	0 to 20 mg/L	0.30 mg/L	± 0.60mg/L
pH	3.0 - 10.5	0.25	± 0.50
Temperature (air & water)	-5 -50°C	0.25°C	± .50°C
Secchi disc	0 - 3.0 m	2 cm	± 5 cm
Nitrate Nitrogen	0 - 1.0 mg/L (low-range)	0.04 mg/L	± 0.10 mg/L
	0 - 10.0 mg/L (high-range)	0.4 mg/L	± 1.0 mg/L
Ortho-phosphorus	0 - 1.0 mg/L (low-range)	0.04 mg/L	± 0.1 mg/L
	0 - 5.0 mg/L (mid-range)	0.2 mg/L	±0.5 mg/L

Variable	Range	Precision	Accuracy
	0 - 50.0 mg/L (high-range)	2.0 mg/L	±5.0 mg/L
Ammonia Nitrogen	0 - 2.5 mg/L	0.10 mg/L	± 0.20 mg/L

Another factor in determining quality volunteer data is completeness, which is a comparison of the total amount of data collected to the amount of data needed to establish a complete data set. The OWW program requires volunteers to submit a minimum of 6 months of data in a one-year period. Most chapters, including the GTAA and Illinois River, exceed this requirement by submitting monthly data sheets. However, due to inclement weather and other ancillary factors, it is not always possible to perform the tests every month, which leads to some data gaps. However, OWW quality control guidelines state that for a rating of 100% completeness, six data sheets per site must be submitted to and accepted by OWW annually. Of the six or more data sheets submitted, at least 85% (5 data sheets) must be accepted as complete and accurate for a given calendar year with properly filled out information.

For the most part, the GTAA chapter received a rating of more than 100% completeness with the exception of the time period between October 2000 and September 2001. Completeness for the Illinois River Chapter also received a rating of more than 100%. Since data collection began in July of 2000 for Site 10 on the Barren Fork, twenty-five of twenty-nine months have been monitored. Since data collection began on the Illinois River, fourteen out of fourteen months were monitored for Site 11 (Echota Bend), and nine out of ten months were monitored at Site 12 (Town Branch).

Figure 2 plots the most recent QCA session results for the GTAA Chapter. The figure shows the upper and lower limits for all three nutrient parameters, the known value, and the four replicate values recorded by the volunteer. It is difficult to distinguish between known and replicate values due to the closeness in proximity, reiterating the success of the volunteer in conducting these tests for accuracy and precision.

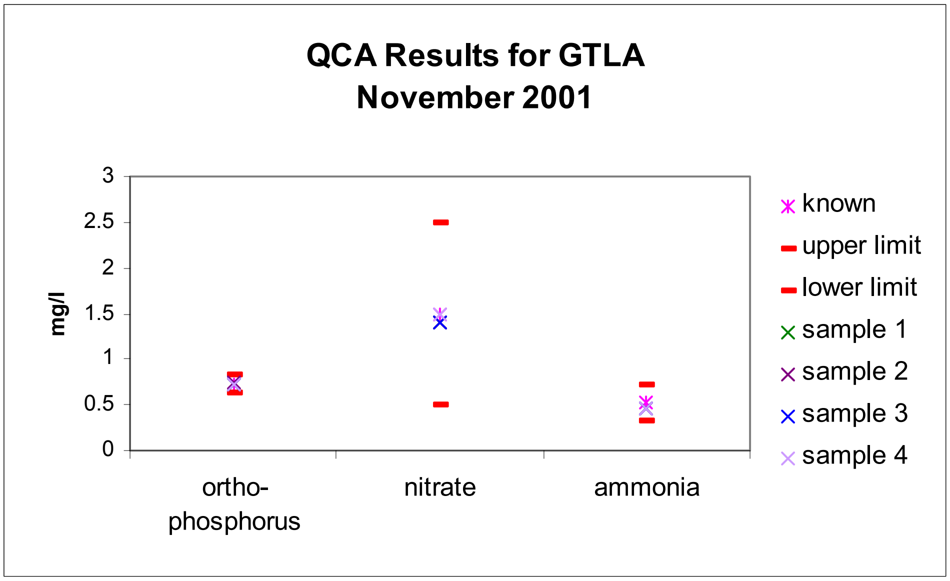

Figure 2. QCA session results for Greater Tenkiller Ferry Lake Association

Figure 3 plots the QCA results from the most recent QCA session with the Illinois River Chapter. There was a problem detected with the ammonia test reaching a level of accuracy, but after consultation with HACH Company, it was determined the particular lot of chemicals used were not of quality. For this reason, volunteers now track lot numbers so data discrepancies can be traced to chemicals used. Another problem that has been identified at QCA sessions is cross-contamination. OWW staff has implemented a more rigorous way to prevent future cross-contamination by developing a QCA Plus session, where all glass and plastic ware are washed with a 10% hydrochloric acid solution (HCl) at each session.

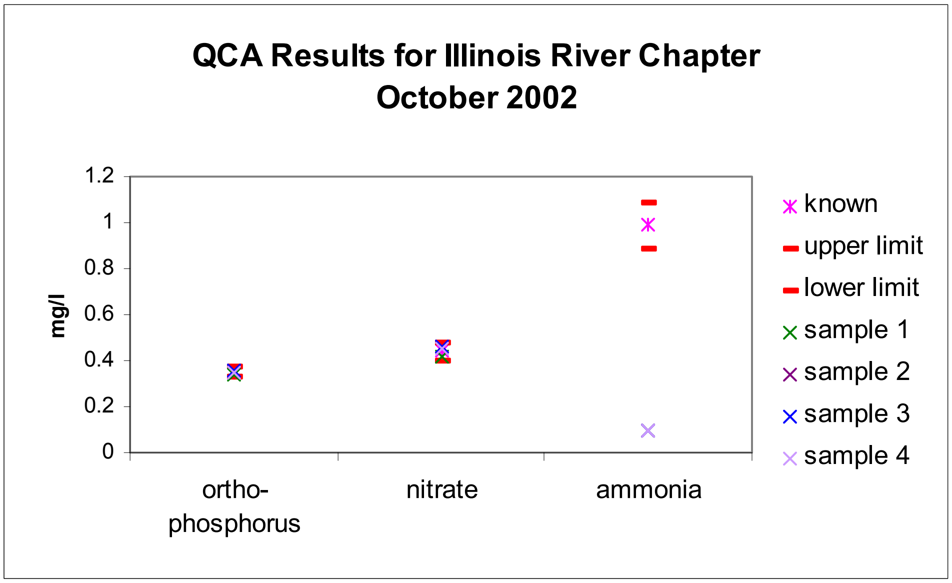

Figure 3. QCA session results for the Illinois River Chapter

Both the GTAA and the Illinois River Chapters use Hydrolab® instruments to measure basic parameters including D.O., pH, and temperature. The OWW QCA Officer reviews calibration logs during the QCA session. These units are considered fully operating to manufactures specifications if calibrated successfully. Therefore no other form of QCA is conducted for these parameters.

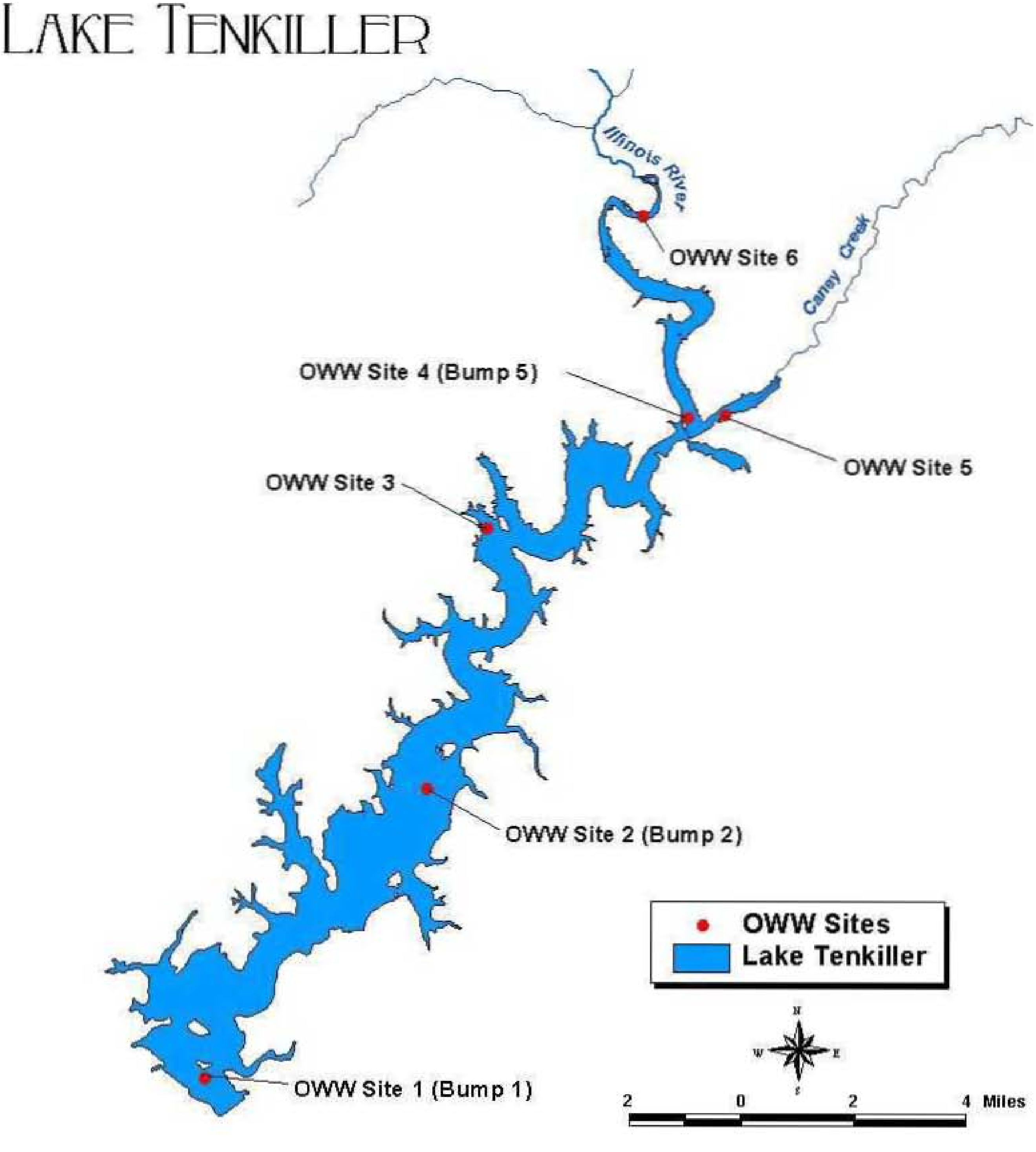

Figure 4. Monitoring Sites on Tenkiller Ferry Lake.

Lake Results

There were six established sites on Tenkiller Lake (referred to as Tenkiller from this point forward), three of which correlated with the BUMP sites (Figure 4). Site 1 is near the dam (BUMP Site 1) and is located in the lacustrine zone of the lake. Site 2 (BUMP Site 2) and Site 3 are in the transition zone of the lake, and Site 4 (BUMP Site 5, the confluence of Caney Creek), Site 5 located in Caney Creek Cove, and Site 6 at Horseshoe Bend are located in the riverine zone of the lake. Although not all sites were monitored consistently, the available data will be discussed in this section. At the onset of this project only surface data had been collected. Shortly following, beginning in May of 1998 a Hydrolab® was used to collect vertical profile data and bottom samples for nutrients were also collected. Chlorophyll-*a* and turbidity data were collected beginning in October of 1998. Turbidity is determined using a turbidity tube explained in the Methods section of this report. Over 1,215 basic data points were collected for Tenkiller from October of 1996 through October of 2002. BUMP sampled the lake in 2000 and 2002 for a variety of parameters, and these data are referenced if applicable to the discussion.

Secchi Disk Depth

Whole lake Secchi disk depths ranged from 28 cm to 424 cm with an average of 139cm and a median value of 110cm (n=153). High Secchi disk readings indicate good water clarity while low Secchi disk readings indicate poor water clarity. Trend analyses from whole lake medians indicate a decreasing trend in Secchi depth (July 1997 through August 2002, n=45). It is important to note that these data are not evenly distributed with different numbers of samples throughout the sample period. Inconsistencies in sample numbers can result in biased results. A decreasing trend would indicate water clarity as getting worse or having shallower depths of visibility. Seasonally, spring has the shallowest depths, due to rain and associated runoff. Station to station differences in Secchi depth results that Site 5 had the shallowest depth, or worst clarity with a maximum depth of 157cm, and an average of 73cm (n=20), while Site 1 had the deepest depths, or best clarity with a maximum of 424cm, and an average of 226cm (n=28). It is typical for the best water clarity to be found in the lacustrine zone of reservoirs because particulates have time to settle out as water flows down the system. Site 5 is located any Caney Creek, the riverine zone, which is shallower and boat induced bottom disturbance may likely be a factor in shallower Secchi disk depths at this site. Figure 5 shows whole lake median Secchi disk depths plotted over time.

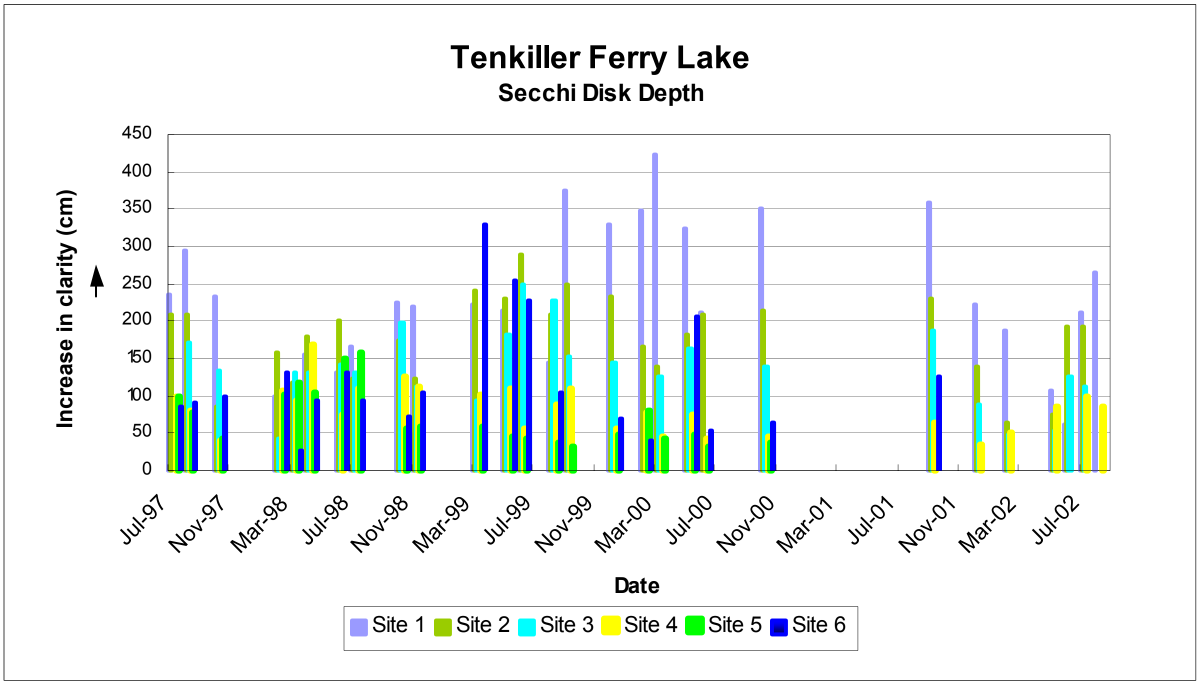

Figure 5. Secchi Disk Depth for Tenkiller Ferry Lake

Color Analysis

Percent color reported by the volunteers was determined for each site from all reported values. Table 5 reflects the percents of browns, greens, and transparents on a site-by-site basis. It is important to note that color data collected by volunteers are not equivalent to apparent color collected by the BUMP, and measured by a laboratory.

Table 5. Percent Color Reports for Tenkiller Ferry Lake

Site	Light Brown	Brown	Light Green	Green	Transparent
1 (n=28)	4%	11%	74%	11%	-
2 (n=23)	4%	4%	75%	-	17%
3 (n=24)	-	17%	75%	8%	-
4 (n=33)	6%	9%	82%	-	3%
5 (n=23)	9%	4%	70%	13%	4%
6 (n=21)	10%	5%	66%	19%	-

Overall the number of light green reports, expected to be indicative of algae growth, were the greatest percentage for all sites. Light browns and browns were relatively small percents and may likely be representing suspended solids from seasonal rains. Site 2 was reported as the highest percent of transparent or clear water. Site 2 is relatively deep and located between the lacustrine and transition zones. This site is also protected by high cliffs, which may result in reduced wave action or internal mixing.

pH

Surface pH values for the lake ranged from 7- 9.5 s.u. (n = 149), with fifteen samples exceeding the OWQS criteria of 9.0 s.u. Elevated pH, detected in nine of the fifteen samples during summer months, usually indicate high photosynthetic activity. Photosynthesis uses carbon from the water and reduces the concentrations of hydrogen ion, which in turn, raises pH readings to more alkaline conditions. Sites 3 and 4 had the majority of the high pH values. Figure 6 plots pH values according to sites.

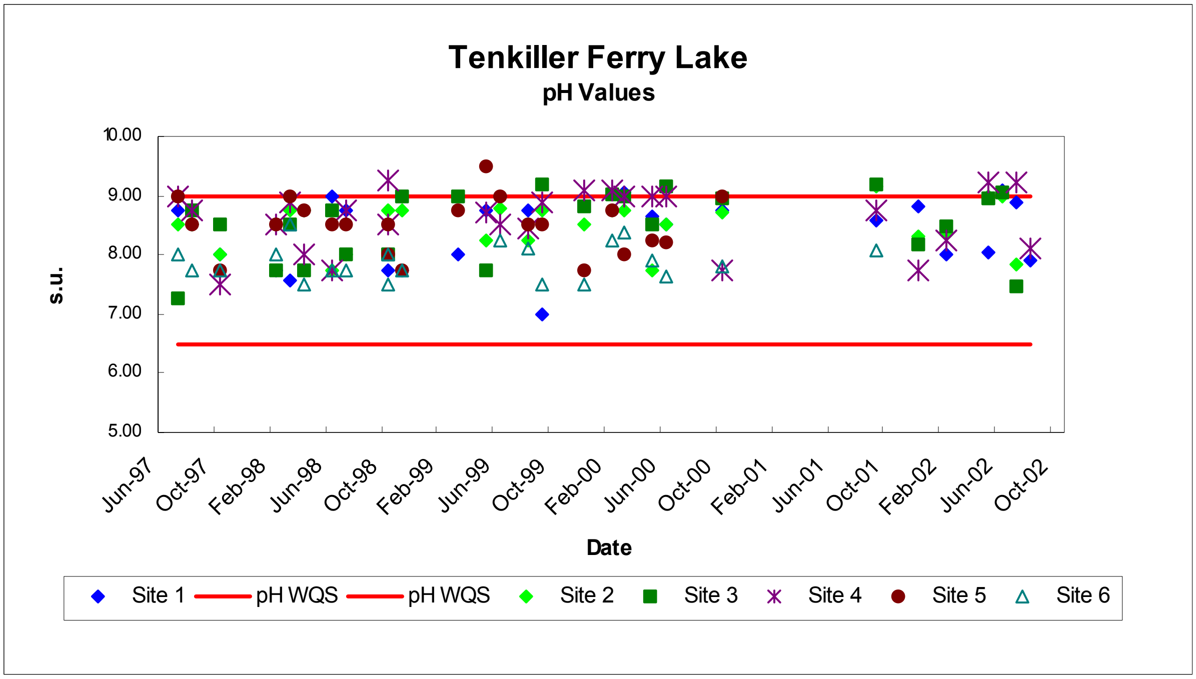

Figure 6. pH values for Tenkiller Ferry Lake

Surface Dissolved Oxygen Concentrations

Surface dissolved oxygen concentrations ranged from 5.9 to 15.9mg/L with an average of 9.68 mg/L (n=132). Colder water holds more dissolved oxygen than warm, so it is typical to see higher D.O. concentrations in the winter than in the summer months. D.O. also comes from photosynthetic activity and wind and recreation-induced wave action on the lake surface. Surface D.O. concentrations for all sites were relatively high for Tenkiller with greater than 45% over 10mg/L and less than 6% less than 7mg/L. Also of the 45% of concentrations over 10mg/L, 81% were super-saturated with percent saturation greater than 100%. Although high D.O. is good for the biotic environment of the lake, high concentrations (greater the 10mg/L) may likely be a direct result of extreme productivity. Additionally, high productivity, or photosynthesis can lead to diurnal fluctuations, or extreme low concentrations in the early morning hours, just prior to sunrise. These data, paired with chlorophyll-*a* concentrations, may identify if this is a concern. Chlorophyll-*a* is discussed in a future section. A diurnal study that measures D.O. concentrations at a set interval for a 24-hour period would also assist in identifying if these high concentrations are resulting in extreme fluctuations the might pose a threat to the fish and wildlife. Figure 7 plots D.O. versus temperature for Site 1 to show the inverse relationship typical for these two parameters.

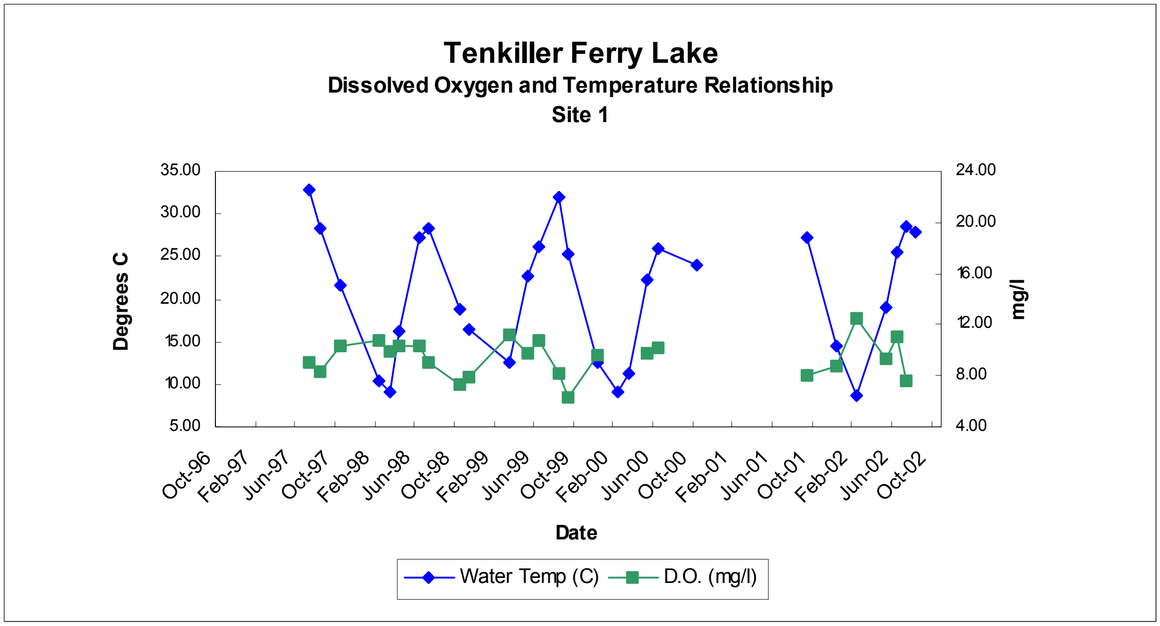

Figure 7. Dissolved oxygen and temperature relationship at Site 1, near the dam for Tenkiller Ferry Lake

Ammonia Nitrogen

Ammonia nitrogen surface values ranged from 0.01 to 5mg/L with a mean of 0.65 mg/L and a median of 0.15 mg/L (n= 106). The high value of 5mg/L was reported in June of 1998 at Site 3. Trend analysis for whole lake median ammonia values showed no significant trend at the 95%, 90%, or 80% confidence intervals. Seasonally, higher concentrations were detected in the winter months (November through January). Sample year 1998 had the highest concentrations calculated by maximum value, mean, and median. Likewise Site 3 reflected the highest concentrations by maximum value, mean, and median. Figure 8 plots the median of all sites combined for surface ammonia concentrations.

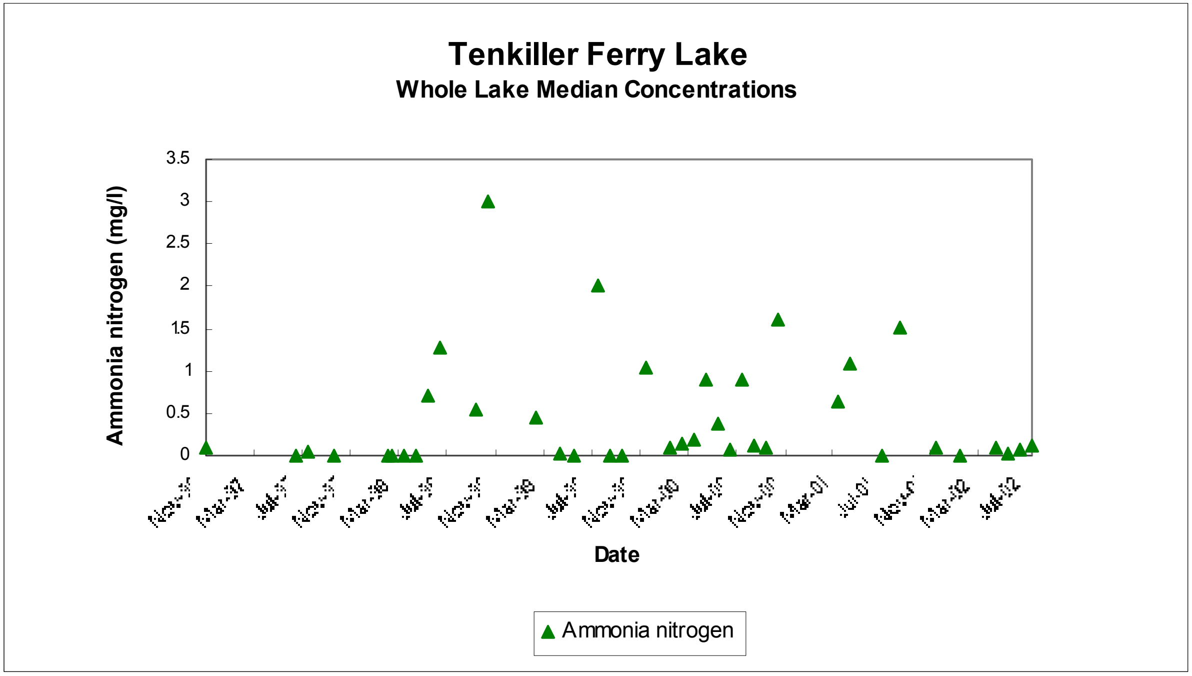

Figure 8. Ammonia nitrogen concentrations for Tenkiller Ferry Lake

Nitrate Nitrogen

Surface nitrate nitrogen values for the data set ranged from 0.02 to 3.0 mg/L with a mean of 1.23 mg/L and a median of 1.20 mg/L (n= 112). Trend analysis showed no significant trend in surface nitrate concentrations. Seasonally, early spring (February through April) had the highest average and median concentrations, while sample year 2002 was higher than the previous years, yet not significantly. Site 6, which is located in the riverine zone of the lake, had the highest mean and median compared to other sites. Figure 9 plots the median of all sites combined for surface nitrate concentrations.

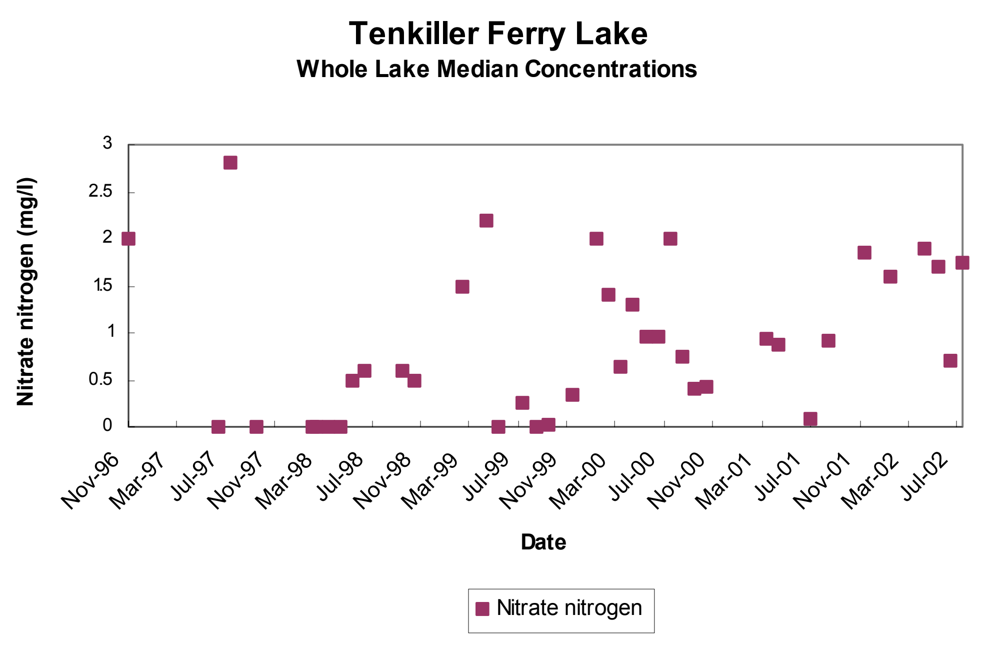

Figure 9. Nitrate nitrogen concentrations for Tenkiller Ferry Lake

Ortho-phosphorus

Surface ortho-phosphorus concentrations ranged from 0.01 to 3.30 mg/L with a mean of 0.40 mg/L and a median of 0.15 mg/L (n=95). The high concentration of 3.30 mg/L was detected twice at site 2 in September and October of 2000. Sample year 2000 had higher concentrations than other sample years. Trend analysis for ortho-phosphorus showed a significant decreasing trend at all three confidence levels. Seasonally, summer (May through July) and late summer (August through October) were higher than cooler seasons with both means and medians. The high of 3.30 mg/L was detected in late summer, which means the maximum and mean values were skewed for this season. Site differences showed that all sites were similar in medians with the average of site 2 higher. Figure 10 plots the median of all sites combined for surface ortho-phosphorus concentrations.

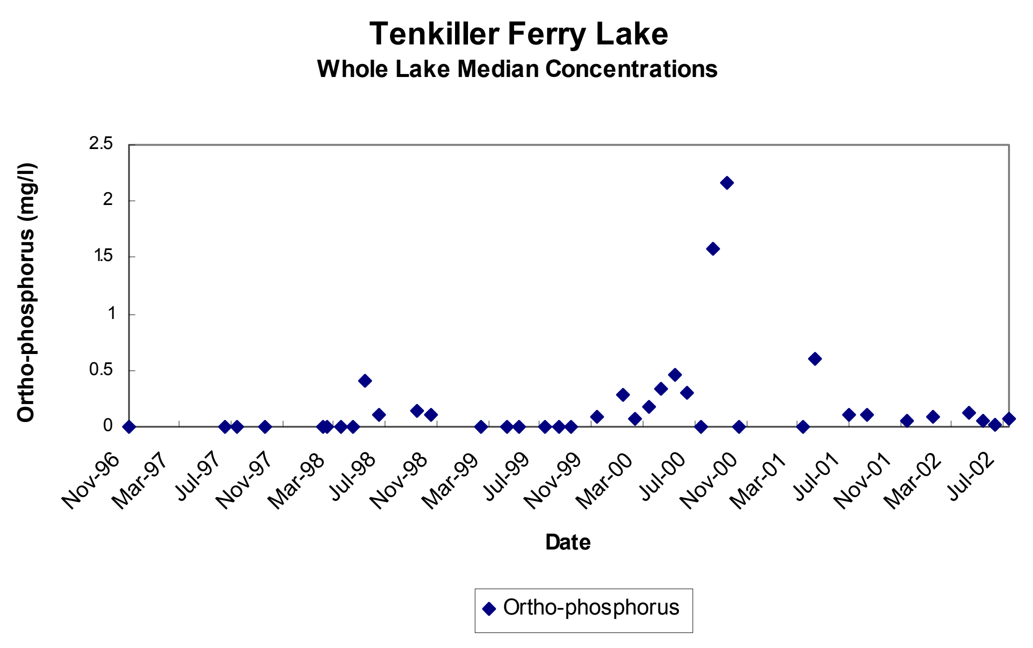

Figure 10. Ortho-phosphorus concentrations for Tenkiller Ferry Lake

Chlorophyll-*a*

Chlorophyll-*a* samples were collected at sites 1, 3, 4, and 6. Data were collected sporadically at the different sites with the earliest samples collected in July of 1997 and the most recent in June 2002 (data used to generate this report ended in October 2002). For all samples collected, chlorophyll-*a* ranged from 2.18 to 38.94µg/l (n=23) with an average of 15.66µg/ and a median of 11.9µg/. The high value was collected from Site 6 in the riverine zone, or headwaters of the lake, during July of 2000. Overall the high chlorophyll-*a* values did not correlate with the high D.O. concentrations, supersaturation, or elevated pH. However, the highest D.O. concentration of 15.86mg/L detected at Site 4 in September of 2001 was also the highest chlorophyll-*a* concentration. The OWRB uses chlorophyll-*a* concentrations to calculate a Trophic State Index (TSI), using Carlson's methodology (Carlson, 1977) to determine the trophic state of the lake. USAP requires a minimum of 20 samples to calculate the TSI. Based on the OWW data set, the TSI ranged from 38 to 66 (n=23), with an average of 54 and a median of 55. (Table 2 in the Limnology 101 section defines Trophic State Indexes.) OWW data classify the lake as eutrophic (average of 54) with high productivity, greenish to brown in color. Figure 11 plots the TSI calculated from chlorophyll-*a* concentrations.

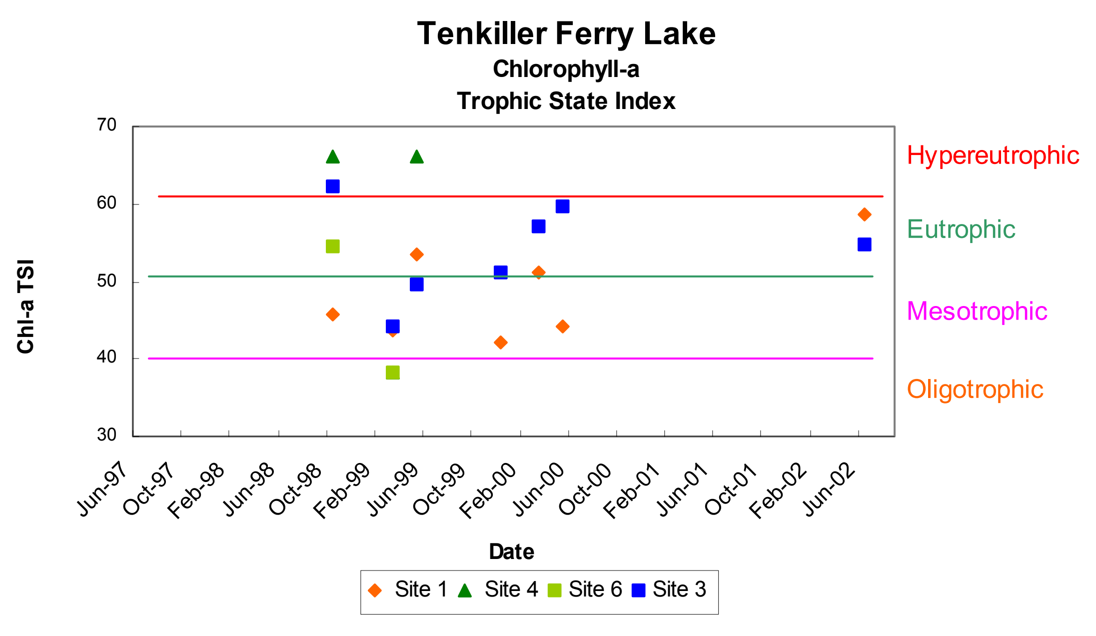

Figure 11. Chlorophyll-*a* TSI for Tenkiller Ferry Lake

The last data set collected by the BUMP was for the 2000 data report. Samples were collected for three of the four quarters from December 1999 through June 2000. Spring and summer samples were then used to calculate the TSI, which was 61, hypereutrophic with excessive productivity. Since then the OWRB has moved to annual averages for TSI determination. Therefore, this value may be biased high due to the lack of factoring in winter samples. Regardless, the lake appears to be experiencing extreme productivity during the summer months. Comparisons were made between the BUMP data (n=9) and the OWW data (n=7) from Site 1 only. Data were available from the same time period (August 1996 through July of 2002) but not necessarily during the same months. Nevertheless, Box and Whisker plots and the Rank Von Neumann test for differences were conducted. Both tests showed there was no significant difference between the two data sets. This information may prove beneficial in the future for volunteer monitoring. It is OWW's goal to obtain more consistent volunteer-collected data and compare it to "professionally" collected data to substantiate the use of volunteers for water quality monitoring.

Turbidity

Turbidity for Tenkiller ranged from 3 to 38JTUs (n=72) with an average and median of 15 JTUs. Low values were reported at both Site 1 in May 2000 and Site 2 in July 2000. The high value was recorded at Site 2 in September of 2000. Seven of the 72 samples exceeded Oklahoma's Water Quality Standard of 25 NTUs. These data were recorded in either late summer, indicative of extreme algal growth, or early spring, indicative of spring rains. Figure 12 plots whole lake median turbidity values. Trend analysis for whole lake medians showed no significant trend. Seasonally, late summer months (August to October) showed slightly higher median and averages. Sites 4, 5 and 6 had similar medians, but the average at Site 5 was higher than all other sites. Secchi disk depth was shallowest at Site 5 too. Lake turbidity values did represent classic reservoir limnology with lowest values at Site 1 near the dam and increasing up reservoir. Turbidity values mirrored Secchi Disk Depths showing the same results.

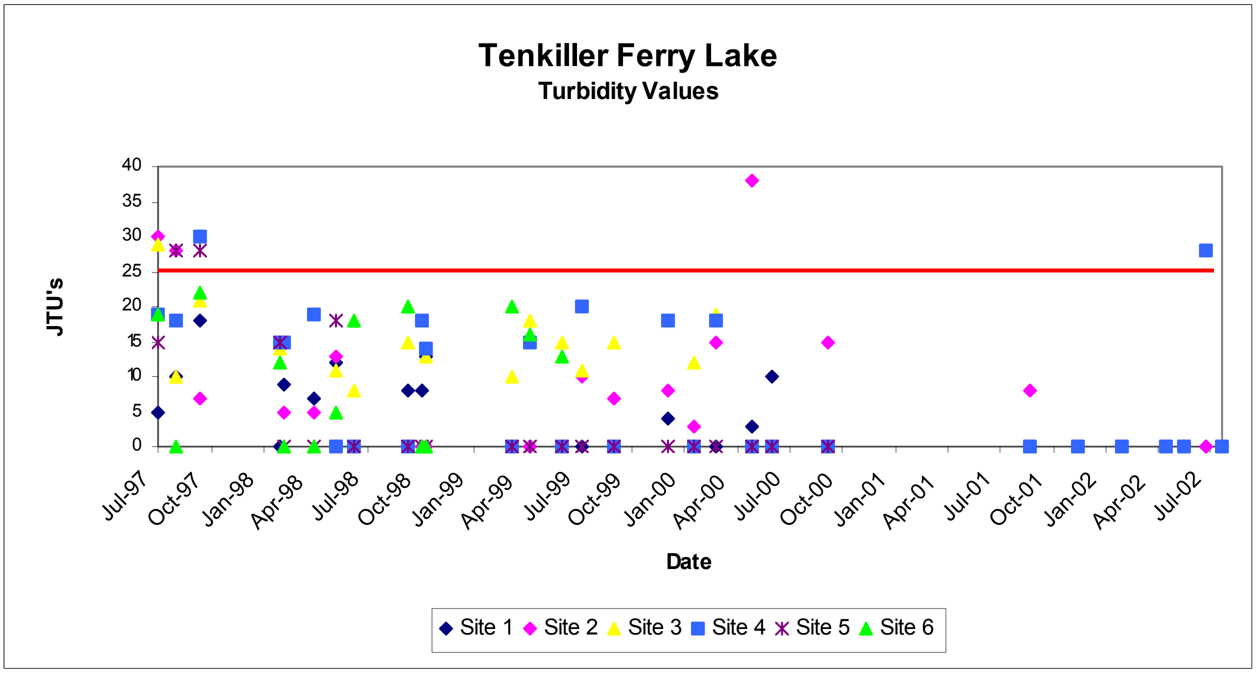

Figure 12. Turbidity values for Tenkiller Ferry Lake

Lake Profiling

Dissolved Oxygen and Thermal Stratification

Thermal stratification of the water column can have profound effects on biological functions within the aquatic ecosystem. It may result in chemical, physical, and biological differences between the water layers (epilimnion, metalimnion, and hypolimnion). Vertical profiling helps to determine thermal stratification, anoxia, and pH levels throughout the water column. For Tenkiller, lake profiling began in August 1999 and continues to the present. Water quality measurements including water temperature, D.O., pH, and conductivity are taken at each site at the surface and every 2 meters down through the water column surpassing the thermocline, using a multi-probe water sampling unit, Hydrolab®. For this report, no bottom data were recorded. Therefore, inferences are made for depths at each site. For Sites 1 and 2, BUMP site depth was used from the same sample month/season, not necessarily the same year. Site 3 and 4 do not correlate with BUMP sites. Therefore, no depth determination can be made. Sites 5 and 6 have limited discussion due to limited data collection.

Sites 1, 2, 3, 4, and 6 have relative consistent data collection omitting one year between October 2000 and September 2001. Thermal stratification did exist during summer months (May through September) at Sites 1, 2, and 3 with temperature changes greater than 2° C within 2 meters at various depths. Since these three sites are relatively deep for the reservoir, stratification is expected. Nine of the ten stratification events were coupled with anoxic conditions occurring at or just below the change in temperature. The hypolimnion became anoxic ten additional sample months without thermal stratification being present. Super-saturation of dissolved oxygen was usually present at the lake surface when the hypolimnion became anoxic. These conditions may be representative of extreme productivity occurring at the lake surface during daylight hours, or photosynthesis, followed by dying algal cells sinking to the bottom where bacterial decomposition results in low oxygen levels. Anoxic conditions at the bottom of reservoirs also cause additional biological processes that may result in release of nutrients, primarily phosphorus, from the lake sediments. During fall turnover, the oxygen poor, nutrient enriched hypolimnetic waters come to the surface where sunlight can cause noxious algal blooms and taste and odor problems for drinking water supplies.

For Sites 1 and 2, when depth data could be approximated, percent water column where dissolved oxygen concentrations fell below 2mg/L was determined. At Site 1, six sample events had anoxic conditions. In August of 1999, 82% of the water column was less than 2mg/L, which is not supporting the Fish and Wildlife Propagation (FWP) beneficial use. Anoxic conditions occurred at all sites sampled at that time. Air temperature was 37°C (99° F), or hot. Three of the sample events had anoxic conditions between 50 and 70%, which is partially supporting the FWP beneficial use, while the remaining two had less than 50% of the water column at less than 2mg/L, which is fully supporting the FWP beneficial use. For Site 2, six sample events had anoxic conditions, one exceeded the 70% criteria in July of 2002, and one fell between the 50 to 70% criteria in August of 1999. The remaining four fell below the 50% criteria, posing a threat to the FWP beneficial use.

pH

Like the surface water quality data, elevated pH was found at Sites 1, 2, 3 and 4. Most usually, elevated pH was associated with summer months, but it was also detected during winter months of December, February, and March. No true depth data exist for these sites at the time sampled, so percent water column may not be calculated. However, percent number of samples may be determined. Thus, for Site 1 is 1%, Site 2 is 16%, Site 3 is 19%, and Site 4 is 24% number of samples exceeded criteria. It is interesting to note that the percent of elevated pH increased in the upper part of the reservoir. This is likely indicative of raised pH due to photosynthesis, or primary productivity, which increases in the transition zone to the riverine zone. Also, 78% (14 of 18) of the detected elevated pH coincided with super-saturation of dissolved oxygen, further supporting increased productivity.

Specific Conductance

Specific conductance, or conductivity, is the measure of the resistance of a solution to electrical flow. Conductivity serves as an indirect measurement of dissolved solids. The highest conductivity reading recorded from the five-year data set was 298 µs/cm. This value is relatively low for Oklahoma reservoirs (OWRB, 2001), yet typical for eastern Oklahoma. Reservoirs constructed on the Red River, North Canadian, and Arkansas River, which are saline in nature, record specific conductance readings in excess of 1000 µs/cm. The specific conductance for Tenkiller indicates that dissolved solids are not likely a problem.

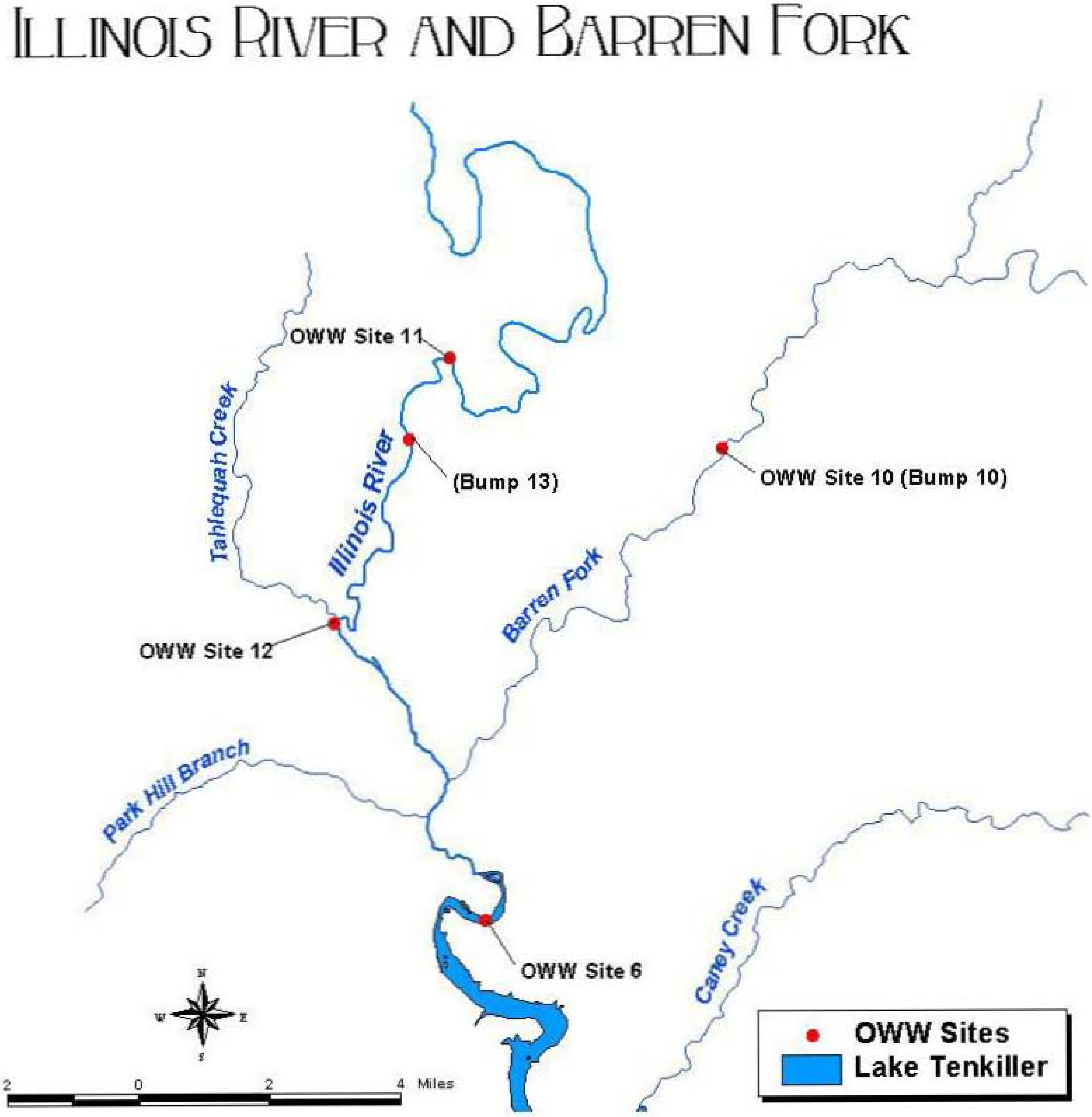

Figure 13. Monitoring sites on the Illinois and Barren Fork Rivers

River Results

The River Results section consists of three volunteer monitoring sites (Figure 13): OWW 10, located on the Barren Fork just below Highway 51 bridge near Eldon; OWW 11, on the Illinois River in the Echota Bend public camping area off of Highway 10; and OWW 12, which is also on the Illinois River below OWW 11, located below the confluence of Town Branch just east of Tahlequah. The OWRB samples the site on the Barren Fork, referred to as BUMP 10. Direct comparisons will be made between these two data sets when possible. The OWRB also monitors a site on the Illinois River that is between Sites 11 and 12. Some statistical analyses may be made to determine differences in water quality of these sites, but direct comparisons will not be made.

OWW Site 10

Basic and advanced parameters have been collected at this site since July of 2000. Although this Site is continually monitored, for report purposes, data through November of 2002 were used, resulting in approximately twenty-five sample events for the following analyses. Figure 14 shows Site 10 on the Barren Fork River under Highway 51 bridge.

Figure 14. Site 10 on the Barren Fork River below Hwy 51 Bridge

Dissolved Oxygen and Temperature Relationship

Surface dissolved oxygen and temperature fluctuations followed a typical inverse relationship. D.O. ranged from 4.23 to 11.40mg/L (n=21), with an average of 6.9mg/L and a median of 7.34mg/L. Higher levels of D.O. were detected in the colder winter months, while the lower levels were detected in warmer summer months. D.O. levels fell below Oklahoma's WQS criteria for a Cold Water Aquatic Community (CWAC) of 5mg/L in September and October of 2002, and 6mg/L in November of 2002. Documenting D.O. levels over a 24-hour period may help in determining if extreme fluctuations are occurring.

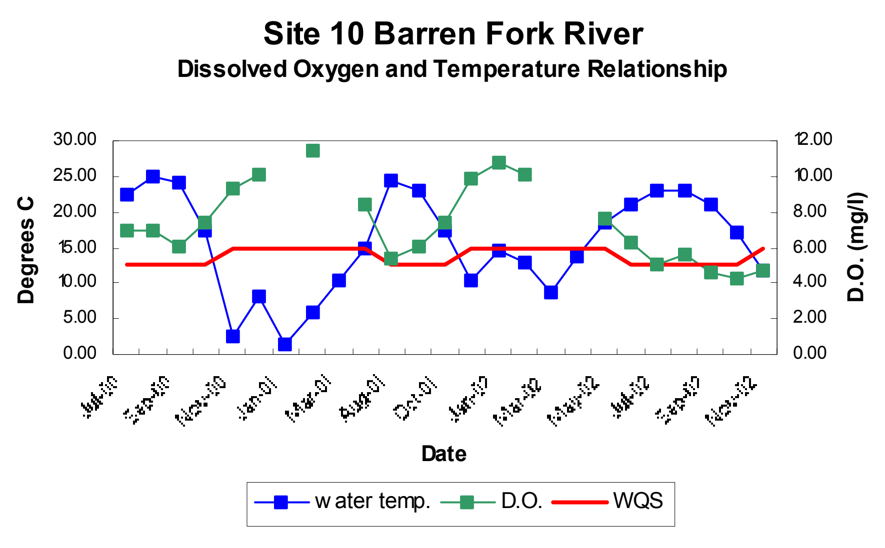

Figure 15. Dissolved oxygen, water temperature, and the water quality standard for D.O. at Site 10, the Barren Fork River

pH

Surface pH at the Barren Fork ranged from 6.8 to 7.8 s.u. (n=25), well within Oklahoma's WQS of 6.5 to 9.0 s.u. Average pH was 7.12 s.u. and the median was 7.00 s.u. Figure 16 depicts pH values for OWW 10 on the Barren Fork plotted over time.

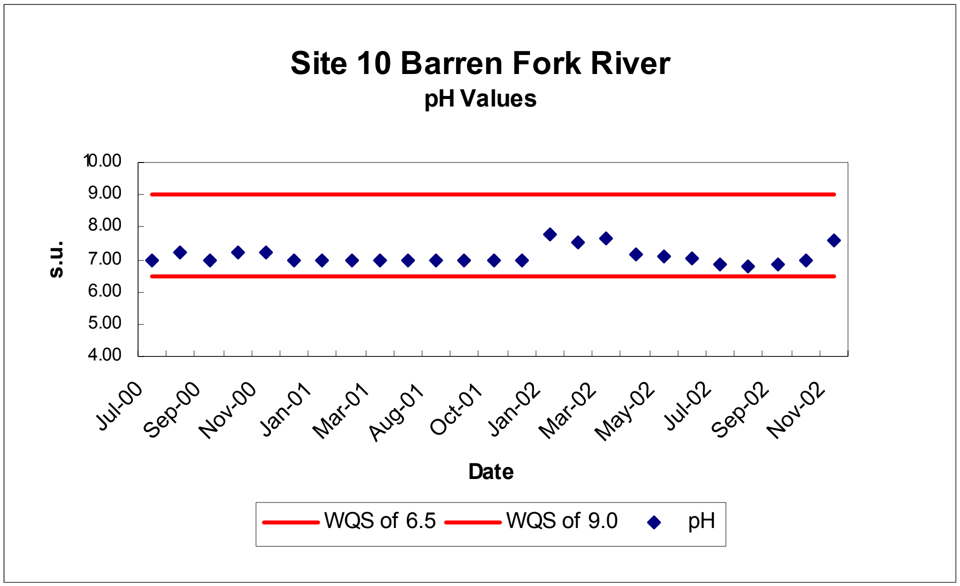

Figure 16. pH values at Site 10, the Barren Fork River

Ammonia Nitrogen

No ammonia nitrogen values have been detected since July of 2000 (n=24). This is not an uncommon fact given that the low-level ammonia nitrogen naturally occurring in water (result of the biological decay of plant and animal matter) easily dissolves in water. At this location, the Barren Fork is a free flowing, gravel bottom stream free from decaying plant matter. With non-detects, trend analysis did not show any trends, but this information is important in documenting background concentrations. If future ammonia concentrations are detected, it can be more cautiously assumed that a contamination problem is occurring versus background concentrations. The BUMP had one detection in the entire data set for ammonia nitrogen (n=31).

Nitrate Nitrogen

Nitrate nitrogen concentration ranged from 0.22 to 6.60 mg/L (n=25) with an average of 0.99 mg/L and a median of 0.70 mg/L. The high concentration was detected in March of 2002. Trend analysis showed that there was no significant trend in the nitrate concentrations at any level. Seasonally, spring (February through April) had considerably higher concentrations (maximum, range, mean, and median, n=6) than the other seasons. The BUMP also collects data at this site. Trend analysis on the BUMP data from approximately the same time frame (July 2000 through October 2002) also did not show any significant trend. An Analysis of Variance (ANOVA) statistical test showed there were differences between the two (BUMP and OWW) data sets at the 5% level, with the BUMP data set slightly higher. Figure 17 plots nitrate concentrations from both BUMP and OWW data sets.

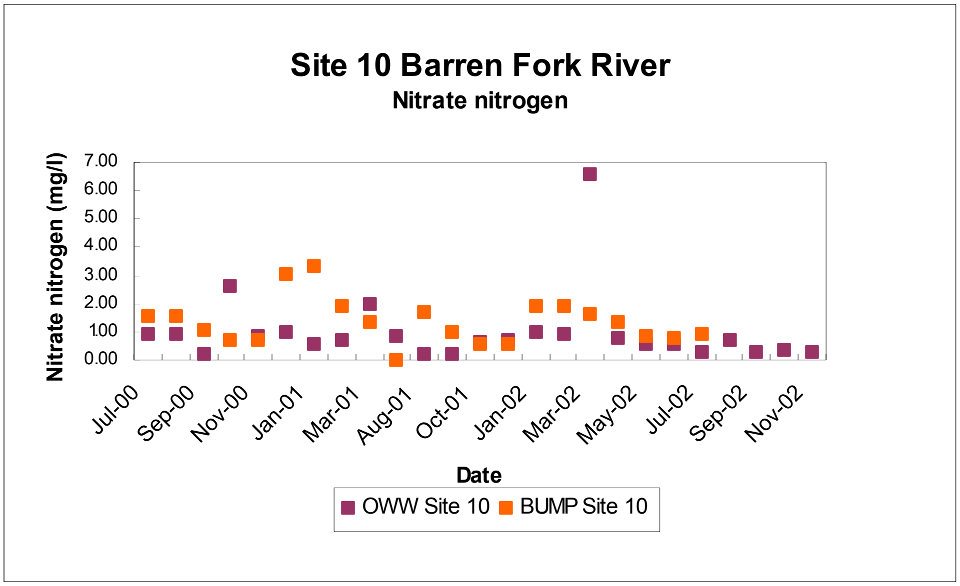

Figure 17. Nitrate nitrogen concentrations at Site 10, the Barren Fork River

Ortho-phosphorus

Ortho-phosphorus concentration ranged from 0.00 to 0.28 mg/L (n=24) with an average of 0.07 mg/L and a median of 0.00 mg/L. Trend analysis for ortho-phosphorus shows a significant increasing trend at all three confidence levels. Seasonally, mean and median concentrations are highest in the late spring/early summer seasons (May through July, n=4). Other than December of 2000 there were no detections of ortho-phosphorus for the first 15 months of sampling. As of February of 2002, there have been detections every month, which may explain the increasing trend. Trend analysis on the BUMP ortho-phosphorus data for approximately the same time frame (July 2000 through September 2002, n=19) showed no significant trend in data. An Analysis of Variance (ANOVA) statistical test showed no differences between the two (BUMP and OWW) data sets. BUMP data are plotted with OWW data in Figure 18 for comparison. Continued monitoring of this site will identify future trends to see if ortho-phosphorus is a growing problem.

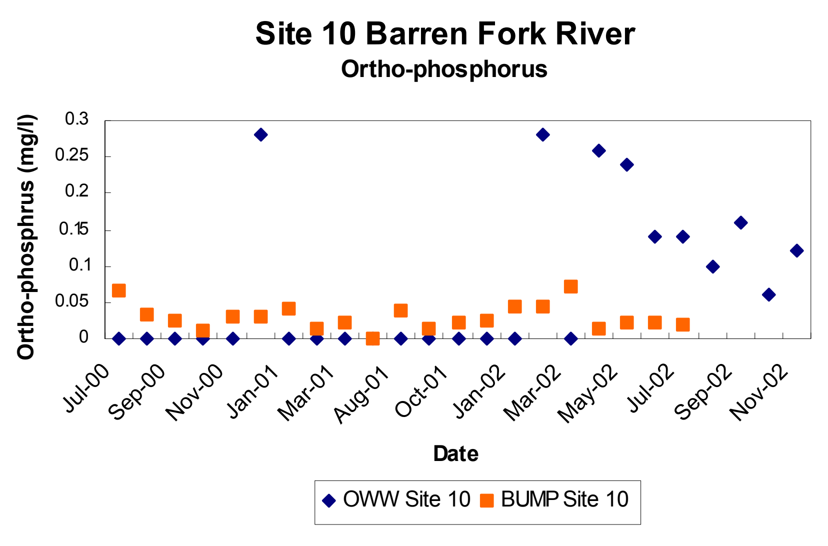

Figure 18. Ortho-phosphorus concentrations at Site 10, the Barren Fork River

OWW Site 11

Basic and advanced parameters have been collected at this site since October of 2000. Data have been collected consistently (monthly) since sampling began. Fourteen samples have been collected for analysis in this report (data cutoff was November 2002). This data set is too small to perform the Seasonal Kendall's test for trends, which accounts for seasonality of data. However, the Sen's Slope/Mann-Kendall Trend Analysis, which is a non-parametric test for temporal trend to determine a general increase or decrease in observed values over time (Intelligent Decision Technologies, Inc., 1998), may be used. Figure 19 shows an OWW volunteer at Site 11, Echota Bend on the Illinois River.

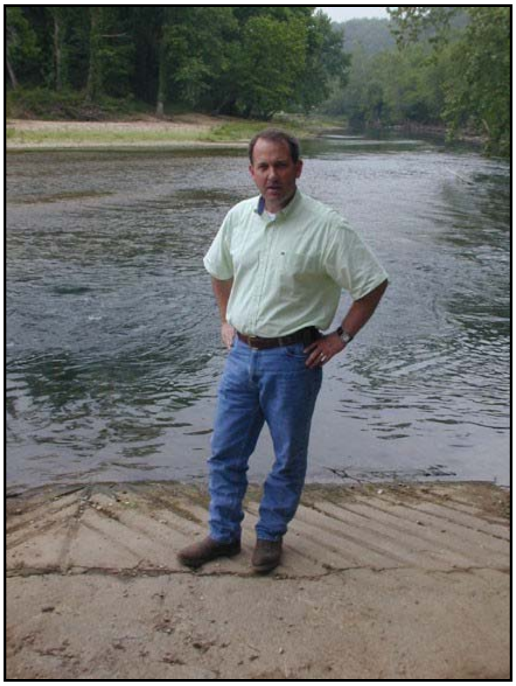

Figure 19. OWW volunteer at Site 11, Echota Bend on the Illinois River

Dissolved Oxygen and Temperature Relationship

Surface dissolved oxygen and temperature fluctuations followed a typical inverse relationship. D.O. ranged from 4.27 to 11.20mg/L (n=12), with an average of 7.21mg/L and a median of 7.45mg/L. Higher levels of D.O. were detected in the colder winter months, while the lower levels were detected in warmer months. D.O. levels fell below the criteria for Oklahoma's WQS for Cold Water Aquatic Community (CWAC) of 5mg/L in September and October of 2002. Figure 20 plots the inverse relationship of water temperature and D.O.

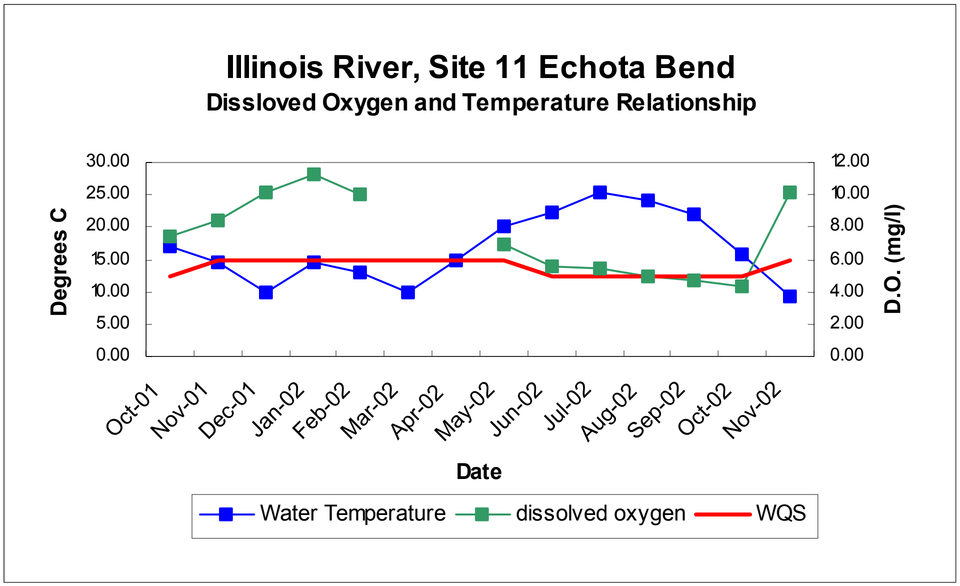

Figure 20. Dissolved oxygen, water temperature and the D.O. WQS at Site 11

pH

Surface pH at the Barren Fork ranged from 6.80 to 7.96 s.u. (n=14), well within Oklahoma's WQS of 6.5 to 9.0 s.u. Average pH was 7.20 s.u. and the median was 7.28s.u. Figure 21 depicts pH values for OWW 11 on the Illinois River plotted over time.

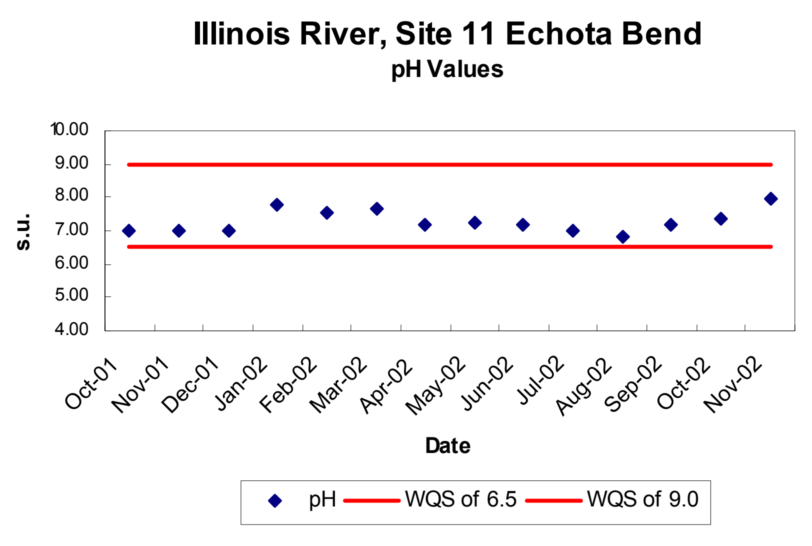

Figure 21. pH values at Site 11

Ammonia Nitrogen
No ammonia nitrogen values have been detected since October of 2001 (n=14). Again, this is not uncommon. With non-detects, trend analysis did not show any trends, but this information is important in documenting background concentrations. BUMP data are not collected directly at this site like at Site 10. However, there is a BUMP monitoring station just downstream (BUMP 13). At that BUMP station, ammonia was only reported once in the entire data set (n=31); all other report values were below detection limits.

Nitrate Nitrogen
Nitrate nitrogen concentration ranged from 0.26 to 7.00mg/L (n=14) with an average of 0.60mg/L and a median of 1.10mg/. The high concentration was also detected in March of 2002. The Sen's Slope trend test (does not account for seasonality) showed no significant trend. Seasonally (data distribution using Box and Whisker plots), early spring concentrations were higher than the other seasons (n=3), including the high concentration of 7.00mg/L. BUMP does not collect data at this Site. However, data from BUMP 13, which is just downstream, are used for comparison purposes. An Analysis of Variance (ANOVA) statistical test showed there were differences between the two data sets at the 5% level, with the BUMP data set significantly higher in concentration of nitrates. Figure 22 plots nitrate concentrations from both BUMP and OWW data sets.

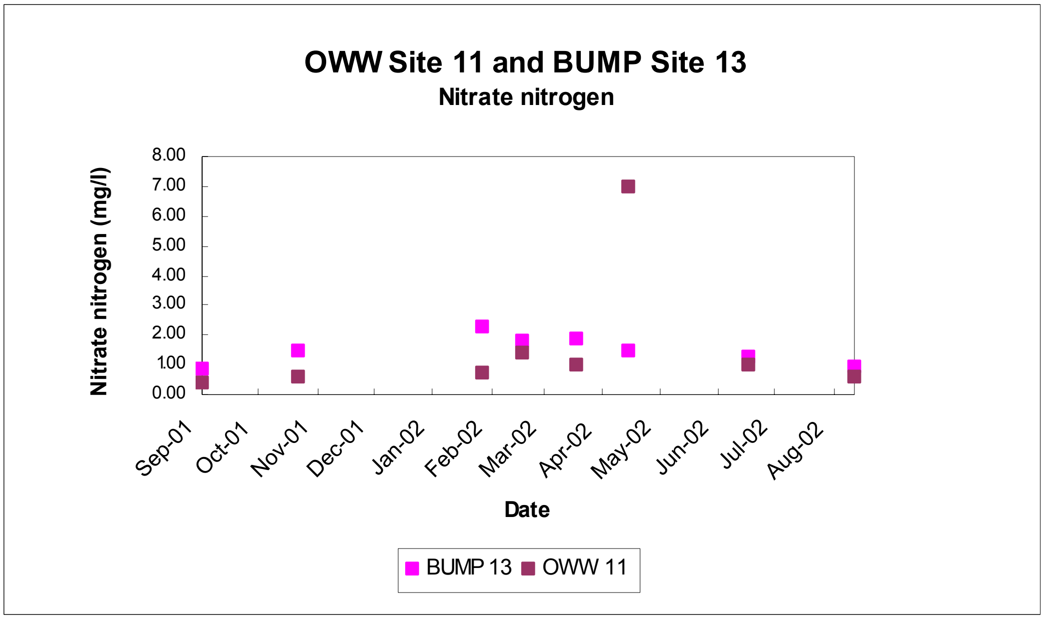

Figure 22. Nitrate nitrogen concentrations at OWW Site 11 and the BUMP monitoring station downstream

Ortho-phosphorus

Ortho-phosphorus concentration ranged from 0.00 to 2.20 mg/L (n=14) with an average of 0.43 mg/L and a median of 0.50 mg/L. The high concentration was an outlier detected in December of 2001. The Sen's Slope trend test showed no significant trend in the data. Seasonally, winter had the higher concentrations of ortho-phosphorus (n=4). Median values plotted within box and whisker plots were very similar. Therefore, the one high value in December of 2001 may have skewed results. Ortho-phosphorus data collected at this site were also compared to BUMP 13. An Analysis of Variance (ANOVA) statistical test showed differences between the two data sets with the OWW data set higher. BUMP data are plotted with OWW data in Figure for purposes of comparison.

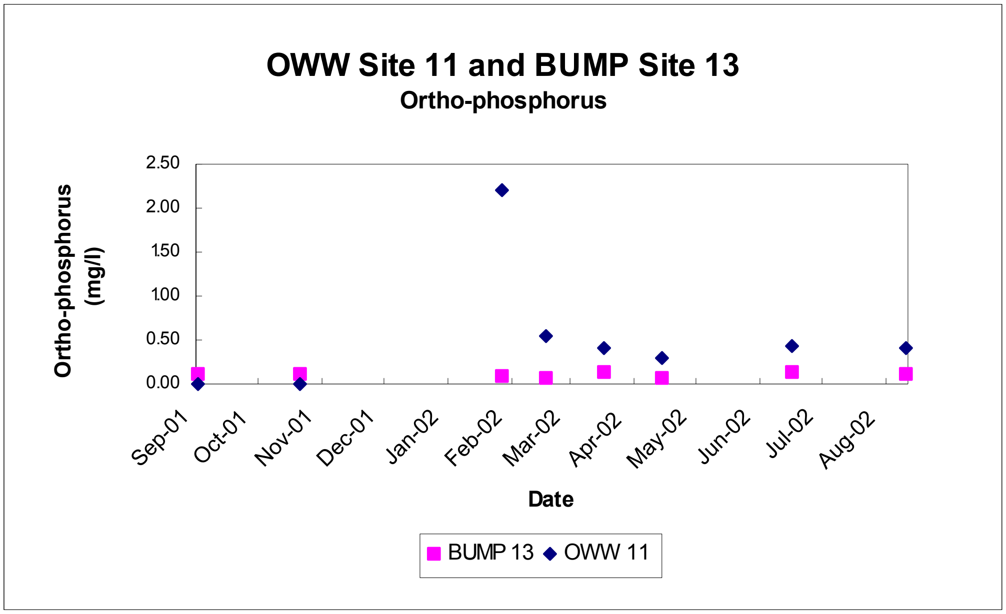

Figure 23. Ortho-phosphorus concentrations at OWW Site 11 and the BUMP monitoring station downstream

OWW Site 12

Basic and advanced parameters have been collected at this site since January of 2002. Ten samples were collected and used in this report (data cutoff was November 2002). Again this data set is small, so the Sen's Slope/Mann-Kendall test for trends will be used instead of the Seasonal Kendall's test. Figure 24 shows an OWW volunteer at Site 12 on the Illinois River.

Figure 24. OWW volunteer at Site 12, the Illinois River just below Town Branch

Dissolved Oxygen and Temperature Relationship

Surface dissolved oxygen and temperature fluctuations followed a typical inverse relationship. D.O. ranged from 4.24 to 11.30 mg/L (n=8), with an average of 5.96mg/L and a median of 5.01mg/L. D.O. levels were lowest in late summer (September). D.O. levels were below Oklahoma's WQS for a Cold Water Aquatic Community (CWAC) in July, August, September, and October. Future data will assist in determining if there is a threat to water quality standards. Figure 25 plots the inverse relationship of water temperature and D.O and the WQS.

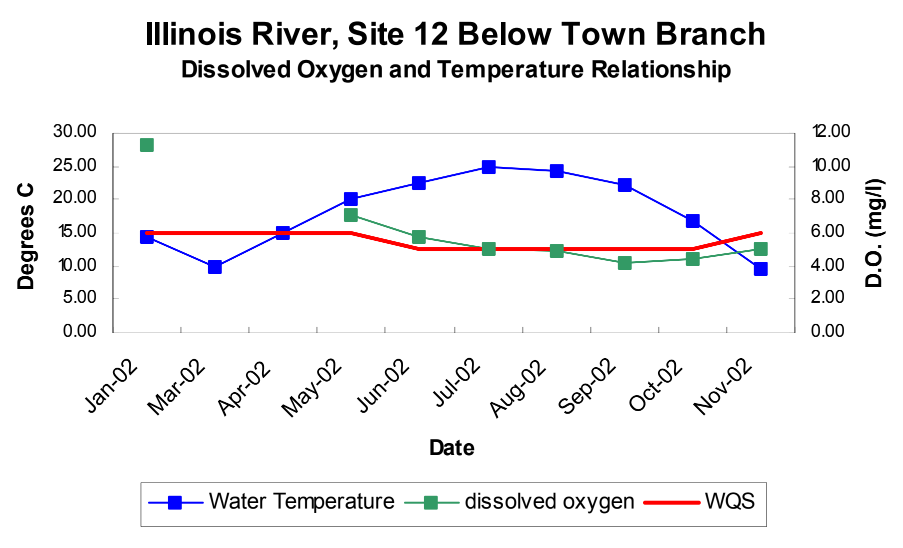

Figure 25. Dissolved oxygen, water temperature and D.O. WQS at Site 12

pH

Surface pH at Site 12 ranged from 6.90 to 8.00 s.u. (n=10), well within Oklahoma's WQS of 6.5 to 9.0 s.u. Average pH was 7.28 s.u., and the median was 7.40 s.u. Figure 26 depicts pH values for Site 12 on the Illinois River plotted over time.

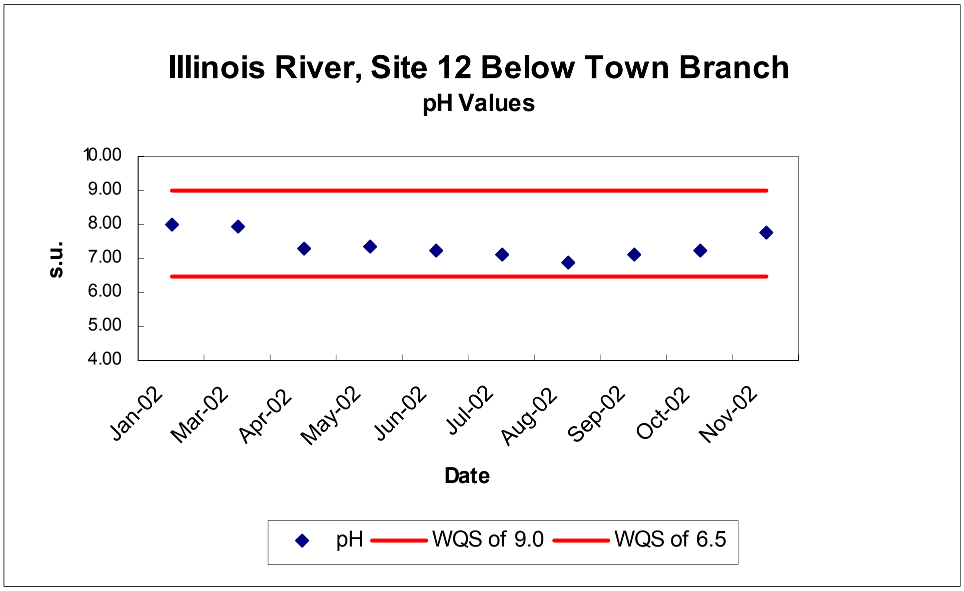

Figure 26. pH values for Site 12

Ammonia Nitrogen

Like other sites, no ammonia nitrogen values have been detected. Again, this information is important to document background concentrations. Likewise, BUMP data collected just upstream only show ammonia once in the entire data set (n=31); all other report values were below detection limits.

Nitrate Nitrogen

Nitrate nitrogen concentration ranged from 0.18 to 3.80 mg/L (n=10) with an average of 0.52 mg/L and a median of 0.92 mg/. The high concentration was detected in March of 2002, which is when the high at Site 11, or upstream, was also detected. The Sen's Slope trend test showed a significant downward trend at all confidence levels. The data set was too small to accurately determine seasonal distributions, with one to two observations in a particular season. BUMP data are collected upstream from this site. An Analysis of Variance (ANOVA) statistical test showed there were differences between the two data sets at the 5% level, with the BUMP data set significantly higher in concentration of nitrates. Figure 27 plots nitrate concentrations from both BUMP and OWW data sets.

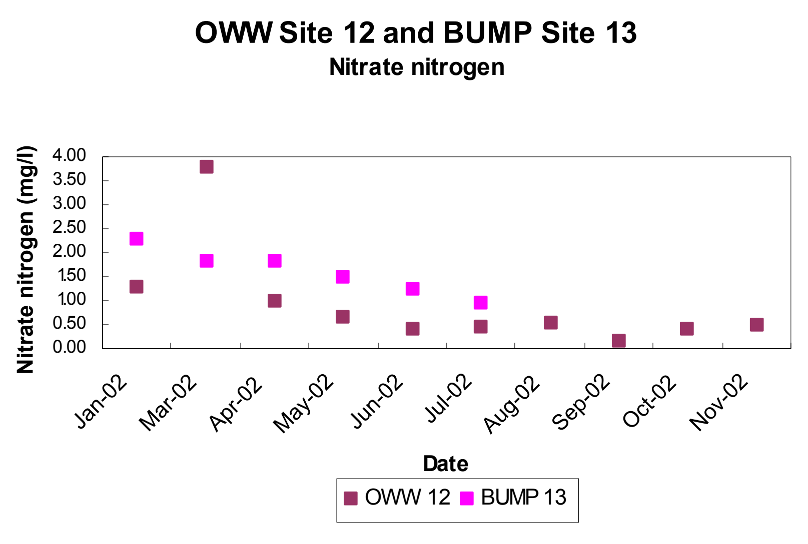

Figure 27. Nitrate nitrogen concentrations at OWW Site 12 and the BUMP monitoring station upstream

Ortho-phosphorus

Ortho-phosphorus concentration ranged from 0.14 to 0.50 mg/L (n=10) with an average of 0.36 mg/L and a median of 0.36 mg/L. The Sen's Slope trend test showed no significant trend in the data. Again, seasonal distributions cannot be determined due to the small size of the data set. Ortho-phosphorus data collected at this site were also compared to the BUMP monitoring station upstream. An Analysis of Variance (ANOVA) statistical test showed that the data sets were different with the OWW set significantly higher. BUMP data are plotted with OWW data in Figure 28 for purposes of comparison.

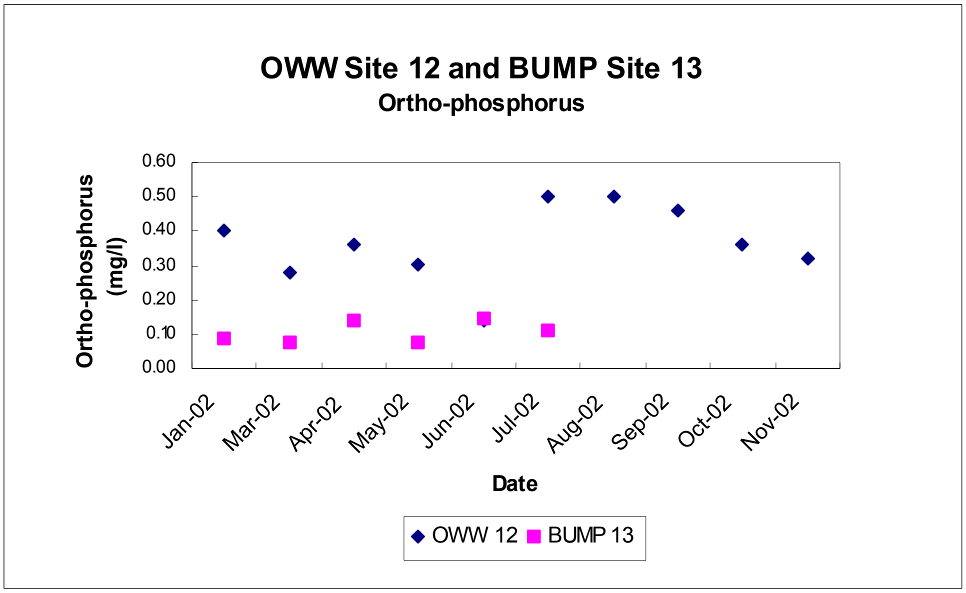

Figure 28. Ortho-phosphorus concentrations at OWW Site 12 and the BUMP monitoring station upstream

Conclusions

OWW data collections for the lake show high productivity in the surface waters through high surface D.O. concentrations, super-saturation, and elevated pH. Chlorophyll-*a* samples were collected at random and less consistent than other parameters. However, it is important to note that high chlorophyll-*a* concentrations may or may not have been detected during the months of high D.O. and elevated pH. Volunteer chlorophyll-*a* data converted to a TSI classify the lake as eutrophic with a TSI of 54 (n=23). This is slightly lower than BUMP data, which classified the lake as hypereutrophic with a TSI of 61 in 2000 (n=12). However, in 2000 BUMP used growing season concentrations only. No trends were detected for ammonia or nitrogen. However, ortho-phosphorus did show a decreasing trend. High concentrations of nutrients were detected in both the transition and the riverine zones of the lake. D.O. profile data show that the lake does thermally stratify in the summer months and anoxic conditions occur in the hypolimnion, which is not uncommon for deep mid western reservoirs. The FWP beneficial use was not supported twice throughout the sample period at Site 1 and 4 with greater than 70% of the water column with less than 2 mg/L of D.O. Vertical profile pH data also show elevated pH at the surface, of which 78% were noted alongside super-saturation, or high D.O. concentrations, further supporting extreme productivity at the surface of the lake.

Secchi disk depth and turbidity data mirrored each other by identifying Site 5 as the most turbid with the shallowest Secchi depth. Site 5 is located in Caney Creek is likely influenced by increased boat activity and turbulent creek water. Site 1 had the deepest depths and lowest turbidities, expected for deep reservoirs. Color data also supported turbidity data, with greater percents of greens and browns in the upper end. It is important to note that in color data results, over 80% of reports were greens and light greens, which further supports high productivity at the lake surface.

For the rivers, all three sites experienced low D.O. concentrations for their beneficial use designation of CWAC in late summer and fall of 2002. These data were submitted just before data cutoff for this report. Therefore, newly submitted data will help to identify if this is a current problem. OWRB staff is concerned with these results and are proposing a diurnal study to document D.O. concentrations throughout a 24-hour period to determine if extreme D.O. fluctuations may be occurring. All pH data are well within WQS. No ammonia levels were detected throughout the study period at any of the sites. BUMP ammonia data were also below detection limit. Nitrates had broad ranges (below drinking water standards) at all three sites. The high concentrations at all three sites were detected in March 2002. No trends were detected for nitrates at Sites 10 and 11. However, at Site 12 there was a decreasing trend. ANOVA showed that there were differences between OWW and BUMP data sets with BUMP data sets slightly higher. Therefore, the OWW nitrate test may be resulting in a conservative estimate. Ortho-phosphorus also had broad ranges, highest at Site 11, Echota Bend. Site 10 showed an increasing trend. No trends were detected at Sites 11 and 12. ANOVA showed a difference between OWW and BUMP data sets at Sites 11 and 12 with OWW data slightly higher, but no difference at Site 10. Site 10 was the largest data set and directly comparable due to location, which may reflect a more accurate statistical outcome.

Literature Cited

Carlson, R. & Simpson, J. (1996, February) The Big Dipper. North American Lake Management Society: LakeLine.

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

Cole, G.A. (1983). Textbook of Limnology (3rd ed.). St. Louis, MO: Mosby Company.

Environmental Protection Agency (1986) Quality Criteria for Water (The Gold Book) EPA#: 440/5-86-001

Lyhane, T.E. 1987. Hydrologic Investigation of the Illinois River. Technical Report 87:3. OWRB, Stream Water Division.

Nolen, S., J. H. Carroll, D. L. Combs, J. C. Staves, and J. N. Veenstra. 1988. Limnology of Tenkiller Ferry Lake, Oklahoma, 1985-1986. U. S. Army Corps of Engineers.

Oklahoma Conservation Commission Water Quality Programs (2000-2015). Oklahoma's Nonpoint Source Management Program and Nonpoint Source Assessment Report. Oklahoma City, OK: Sooner Printing.

Oklahoma Water Resources Board. (1998). Oklahoma Water Watch Volunteer Monitoring Handbook. Oklahoma City, OK: Author.

Oklahoma Water Resources Board. (1999). Oklahoma Water Watch Quality Assurance Project Plan: Citizens Water Quality Monitoring Program. Oklahoma City, Oklahoma: Author.

Oklahoma Water Resources Board (2001). Oklahoma's Water Quality Standards, OAC 785:45.

Oklahoma Water Resources Board (2001). Oklahoma's Water Quality Standards Implementation, OAC 785:46.

Oklahoma Water Resources Board (2001). Monitoring of Tenkiller Ferry Lake near Horseshoe Bend and Caney Creek to Support Lake Tenkiller TMDL and BMP activities. Oklahoma City, Oklahoma: Author.

Pope, F.E., Obrecht, D.V., Jones, J.R. (2000). Lakes of Missouri Volunteer Program Data Report. Columbia, MO: University of Missouri.

Standard Methods. (1989) For the Examination of Water and Wastewater. 17th Edition. American Public Health Association.

Thornton, K.W., Kimmel, B.L., & Payne, F.E (Eds.). (1990). Reservoir Limnology: Ecological Perspectives. New York, NY: John Wiley & Sons, Inc.

Wetzel, R.G. (1983). Limnology. (2nd ed.). Orlando, FL: Saunders College Publishing.

Holdren, C., W. Jones, and J. Taggart, 2001. Managing Lakes and Reservoirs. North American Lake Management Society and Terrene Institute in cooperation with Off. Water Assess. Watershed Prot. Div U.S.E.P.A., Madison WI.

Appendix A

Appendix B