Development of a Probability Survey Design for Lakes & Reservoirs Final Report

Approved August 31, 2010

Oklahoma Water Resources Board, 3800 N. Classen Blvd., Oklahoma City, OK 73118

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Cover Page Photo: Lake Lloyd Vincent, Ellis County (NLA-06608-3616), August, 2007

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Executive Summary

This probability based survey collected samples representing lakes, ponds and reservoirs ≥10 acres in Oklahoma. The Oklahoma State Lakes Survey (OSLS) represents the first time 100 percent of the state's lakes have been assessed in any fashion. The Oklahoma Water Resources Board (OWRB) estimates the bodies of water in this category at approximately 3,056 lakes, ponds and reservoirs within the State of Oklahoma, with a cumulative surface area of approximately 671,777 acres. The OSLS was patterned after and executed in conjunction with U.S. Environmental Protection Agency's (EPA) National Lake Assessment (NLA). The EPA added 18 additional lakes to the 35 Oklahoma lakes already in the national draw. This made for a statistically robust state level probabilistic survey while following NLA methods with few exceptions. Because of the expansion of the probabilistic survey to more than 50 lakes, water quality status could now be inferred within at least a 95 percent confidence.

The OSLS largely adhered to the processes and procedures given in the NLA as an intensive, one-time summer sampling event. For each lake sampled, 11 sites were visited: one index site near the lake outlet in deeper water and 10 habitat sites sampled at regular intervals along the shoreline. This scheme yielded data sufficient to characterize the physical, chemical and biological structure of each lake. The index site yielded the bulk of the open water information while the 10 habitat sites described near shore activities and littoral community structure. Water chemistry data drawn from the probabilistic survey is preliminary and will be verified with the final quality assured data. Data collection did not allow for deterministic assessment of beneficial uses following the Use Support Assessment Protocols (USAP), but for one measure. Therefore, conclusions have been based on threshold values from the literature and Oklahoma Water Quality Standards (OWQS), but do not provide impairment decisions for Oklahoma.

Applying the probabilistic scheme to Oklahoma's lake, pond and reservoir population of ≥ 10 acres, the following predictions were extrapolated:

Potential water quality impairments

- 32% impaired by low dissolved oxygen (depth profile)
- 35% with excessive turbidity
- 50% as hypereutrophic

Trophic State

- 63% as eutrophic or greater
- 19% as nitrogen limited
- 4% as phosphorus limited

Although fixed station long-term monitoring is not likely to be replaced by probability monitoring, the survey provided a high resolution snapshot of statewide lake conditions. This demonstrated the utility of probabilistic sampling to account for all of Oklahoma's waterbodies. Overall, the probabilistic surveys' water chemistry and habitat data suggested that Oklahoma's lakes and reservoirs are experiencing various levels of eutrophication. Driven by an unusually large runoff volume, the excess of nutrients may be largely non-point source (suggested by the fact that over 85% of all lakes, ponds and reservoirs in Oklahoma do not receive point source discharges). Analysis of land use would help to confirm that the excess nutrients are anthropogenic in nature for the larger reservoirs. Along with the excess nutrients, an important

aspect of the littoral zone, aquatic plants, was largely absent. Based on the habitat survey, the best fish communities are predicted within the Boston Mountains, Cross Timbers and Central Great Plains ecoregions.

Survey limitations are derived primarily from the scheme of one sample site and event. This spatial and temporal limitation precluded beneficial use assessment and severely limited reporting in Oklahoma's Integrated Report. Recommendations to overcome these and other limitations were given. Outputs of the OSLS include this reporting effort, a broad based (physical, chemical and biological) database, state personnel trained sufficiently to assist with the design and implementation of future probabilistic surveys and finally the Oklahoma Beneficial Use Monitoring Program (BUMP) has incorporated a probabilistic scheme into its lakes program.

Outcomes from this project include:

1. utilization of the broad based dataset for water quality standards development,
2. highlighting "blind spots" in the current lake monitoring scheme,
3. suggesting a different approach for deriving reference lakes conditions, and finally,
4. a clearer understanding of probabilistic sampling, which can be a more effective tool for water quality management in Oklahoma.

Introduction

Oklahoma's Beneficial Uses Monitoring Program (BUMP) is responsible for assessing beneficial use attainment of public waterbodies in Oklahoma. The BUMP samples approximately 130 public lakes on a three-year rotation using multiple fixed sites. All of the large lakes, all which are managed by the U.S. Army Corps of Engineers (USACE) for flood control, are included. Sites are distributed to represent three functional zones of the larger reservoirs:

- in the central pool area near the dam (lacustrine zone)
- in the upper portion of the lake and in the major arms of the waterbody (riverine zone)
- in the area between the lacustrine zone and the riverine zone (transitional zone).

Each lake is sampled four times per rotation, once per season, and the data is processed through Oklahoma's Use Support Assessment Protocols (USAP) to determine whether the lake is meeting the beneficial uses designated in the Oklahoma Water Quality Standards (OWQS). In addition to beneficial use attainment, the program assesses the trophic state of each lake. Basic water quality parameters monitored by BUMP in lakes includes: Secchi disk depth, color, surface chlorophyll-a, turbidity, nitrogen, phosphorus, minerals, and multi-parameter (temperature, specific conductance, pH, dissolved oxygen, etc.) profiles from the surface to the bottom of the lake. The OWRB estimates that there are a total of 9,768 lakes, ponds and reservoirs in Oklahoma with a cumulative surface area of 705,991 acres. BUMP monitoring of 130 reservoirs accounts for 627,204 surface acres of water within the three-year rotation, comprising approximately 89 percent of the total surface area and less than 1.5 percent of the waterbody population count. While addressing the majority of surface acres of public waters in Oklahoma, this fixed station scheme yields no information for the balance of waterbodies in the state.

Assessment of beneficial use support in Oklahoma follows the guidelines outlined in the Use Support Assessment Protocols promulgated into Oklahoma Administrative Code (OAC) 785-46: Subchapter 15. In general, the USAP states that environmental data must be collected to take seasonal conditions into consideration. A minimum of 20 samples is required on lakes of more than 250 surface acres to assess beneficial use support for water quality parameters such as dissolved oxygen, pH and temperature. The protocols also address the issue of how the data should be used spatially for lake monitoring. Unless demonstrated to the contrary, a single site was not considered representative of an entire lake or an arm of the lake that was greater than 250 surface acres in size. To ensure temporal representativeness seasonality is to be represented in the sampling scheme. Results of beneficial use assessments and trophic state designations are reported in the State's Integrated Report, satisfying Oklahoma's reporting requirements for sections 305 (b) and 303(d) of the Clean Water Act (CWA). Lake beneficial use attainment status is reported on a surface acre basis for Oklahoma. Of the 636,797 lake surface acres delineated in Oklahoma Assessment Database (and reported in the 2006 Integrated Report), 586,589 acres are reported as impaired (category 5), while 14,541 are reported as having insufficient or no data to determine their status (category 3). The surface area of waterbodies listed as attaining some uses and having insufficient or no data available to determine remaining uses (category 2) numbers 35,667 acres. The number of acres that are assigned to fully meeting their designated beneficial uses (category 1) is zero, as are the number of acres assigned as impaired or threatened but not requiring a total maximum daily load (TMDL) (category 4).

While instructive, the BUMP's fixed station lake sampling scheme does not currently provide a comprehensive picture of the status of 100 percent of Oklahoma's lakes.

The EPA's national probabilistic sampling of all waterbodies provided the impetus and opportunity for Oklahoma to perform a statewide probabilistic sampling initiative. The results of probabilistic surveys on a percentage of the state's lakes, ponds and reservoirs can be used to project the status of Oklahoma's waterbodies within a defined amount of uncertainty. For example, the EPA's National Lakes Assessment National Lakes Assessment (NLA) is designed to proportionally determine the water quality status of lakes in the continental United States with 95 percent confidence (EPA technical fact sheet, 2006). This involved the sampling of some 909 individual waterbodies across the continental United States. (For details regarding the NLA please visit http://www.epa.gov/owow/lakes/lakessurvey/.)

The design and plan for the NLA was based upon the spatial information within the National Hydrologic Database (NHD). Figure 1 charts the NHD estimate for total number and cumulative area of all lakes, reservoirs and ponds in Oklahoma. Comparison of the OWRB's lakes GIS database against the NHD, show the NHD total within 1% of the OWRB total. It is important to note that both the NLA and OSLS are probabilistic and are based on the number or count of lakes, reservoirs and ponds as opposed to accounting by surface area. Six size classes were designated from 4 – 10 hectare (ha) to >5,000 ha. Weights were assigned to each size class based on the proportion of the total count each size class represents, and the number of sites sampled within each size class. For example, the >5,000 ha size class had the lowest weight assigned, as this category accounted for less than 1% of the total lake count; while the >4 ha size category had the highest weight, as this group accounted for greater than 20% of the defined population. The weight of each sampled lake or site represented its proportion of the sample population. For example the largest lake in the sample, Keystone Lake, had a sample weight of 0.259% representing some quarter percent of the sampled population while 2 ponds (4 ha or smaller) each had a sample weight of 25%, representing some quarter of the entire state. In hindsight, it would have been preferable to have had sampled more of the smaller (≤4 ha) ponds in Oklahoma to reduce the bias that each individual site within this size category exerted upon the statewide population estimates.

Oklahoma's State Lakes Survey was patterned after, and executed in conjunction with, the National Lakes Assessment. The EPA added 18 additional lakes to the 35 Oklahoma lakes already in the national draw, which made for a statistically robust state level probabilistic survey, while following NLA methods with few exceptions. By expanding the probabilistic survey in Oklahoma to more than 50 lakes, Oklahoma now could infer the water quality status of the state with at least a 95% confidence. Major differences between the OSLS and BUMP lakes assessment include spatial, temporal and sample size and are as follows:

- BUMP quarterly sampling (spanning all 4 seasons) has been abbreviated to a one-time sample event in the summer for the OSLS.
- Water quality sample sites have also been abbreviated for the OSLS to one site within the lacustrine zone as compared to BUMP samples throughout all reservoir zones.
- Field observations have been expanded to include extensive shoreline surveys for the OSLS including habitat assessments while BUMP) does not perform a habitat assessment. .

- BUMP biological collections of chlorophyll-a have been expanded to include lacustrine zone plankton (invertebrates and algae) and littoral zone macroinvertebrates.
- Only dissolved oxygen collected as part of the OSLS sample scheme meets the requirements for beneficial use assessment (USAP).

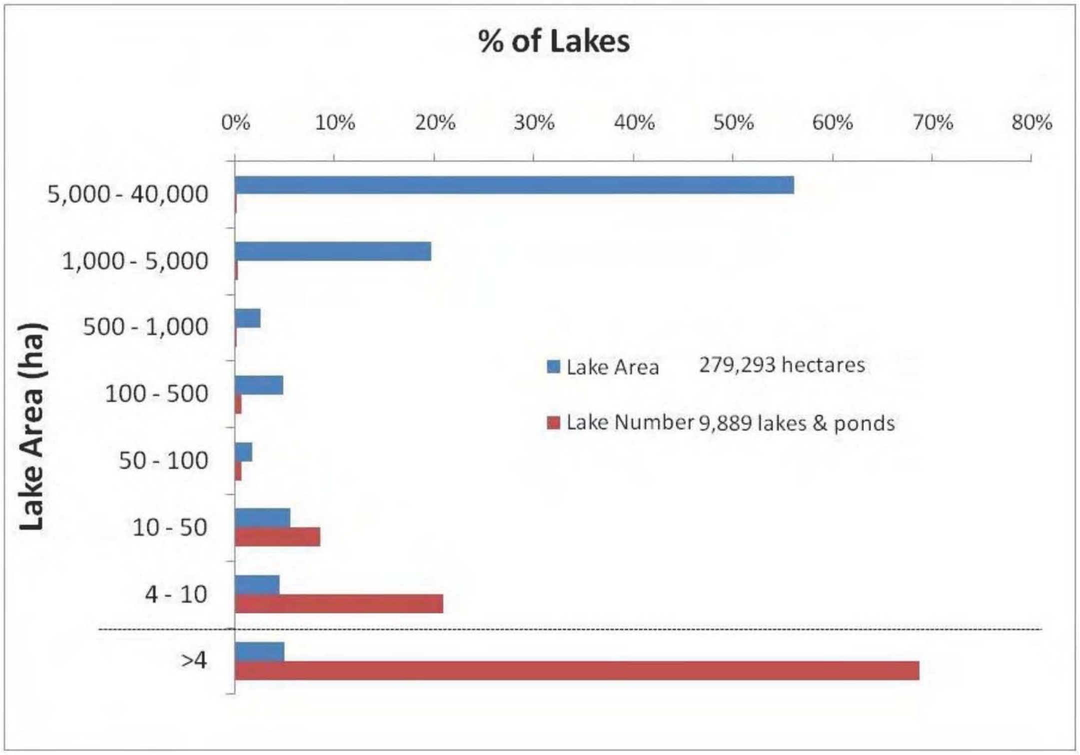


Figure 1. Frequency (percent of total) plot of Oklahoma Lakes, Ponds and Reservoirs by size category. The dashed horizontal line represents the proportion of the database (>4 ha in size) not accounted for by either survey.

Because of the differences between the OSLS and the BUMP lakes monitoring program, BUMP continued routine 2007 lake sampling and selected lakes which would ensure that a large portion of the OSLS sample draw was represented in the 2007 BUMP sample regimen. This coordination allowed for:

a) the Oklahoma State Lake Survey to provide evaluation beyond probability plots of state water quality parameters and
b) BUMP to provide uninterrupted beneficial use assessment.

Because of the time required for analysis of biological samples such as phytoplankton and benthic macroinvertebrates, not all parameters and samples collected for the OSLS are reported here.

Design of the National Lakes Assessment (NLA) dictated an intensive one-time sample event during the summer of 2007. Figure 2 summarizes the processes and organization used to develop the NLA. As the field implementation arm of the NLA in Oklahoma, the OWRB was positioned to simply expand the NLA sample effort into Oklahoma's State Lakes Survey.

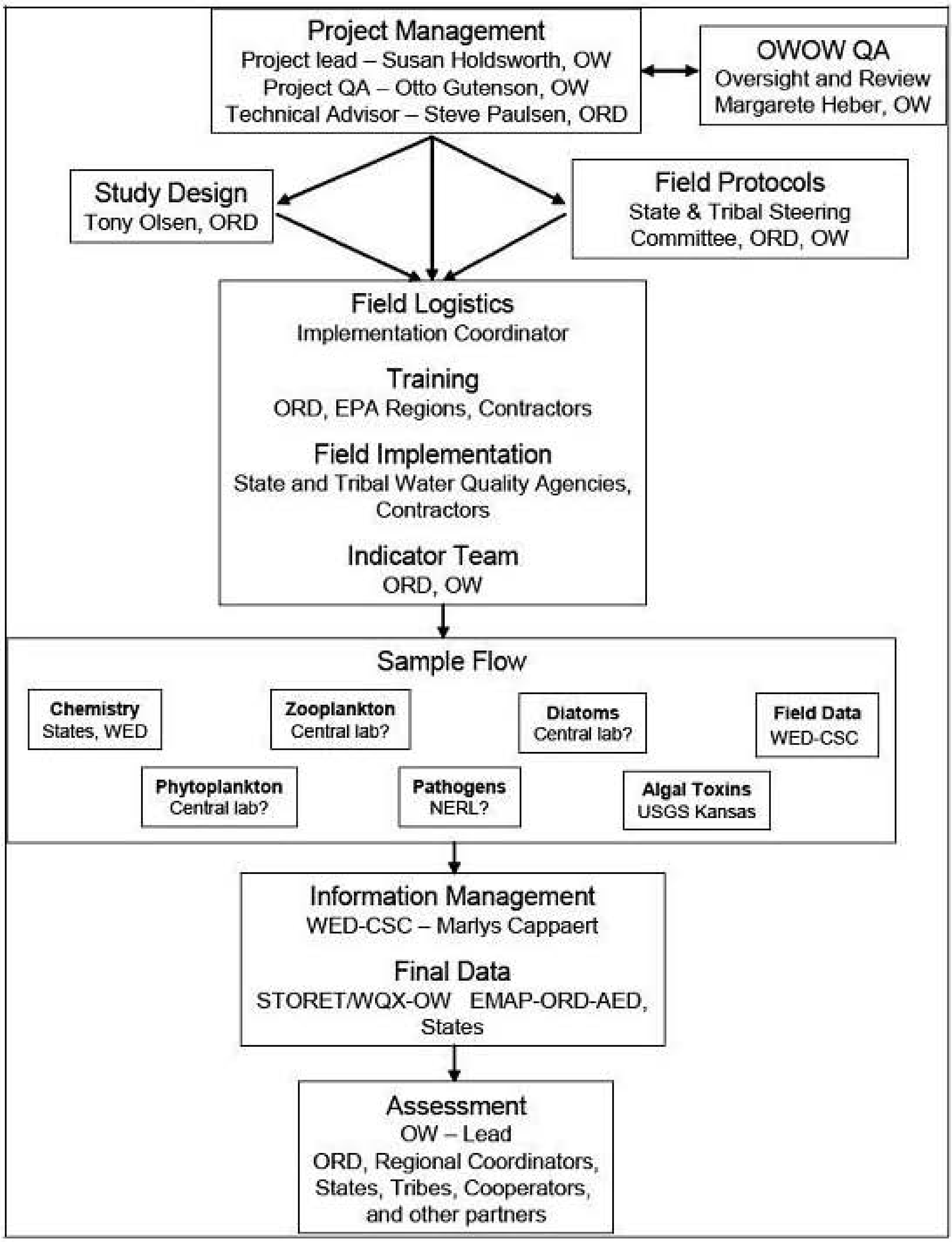


Figure 2. Project organization chart taken from the Survey of the Nation's Lakes QAPP (EPA, 2007)

Methods & Materials

The OSLS largely adhered to the processes and procedures given in the NLA (Figure 3). For each lake sampled, 11 sites were visited: one index site near the lake outlet in deeper water and

10 habitat sites sampled at regular intervals along the shoreline. This scheme yielded data sufficient to characterize the physical, chemical and biological structure of each lake. The index site yielded the bulk of open-water information, while the 10 habitat sites described near shore activities and littoral community structure.

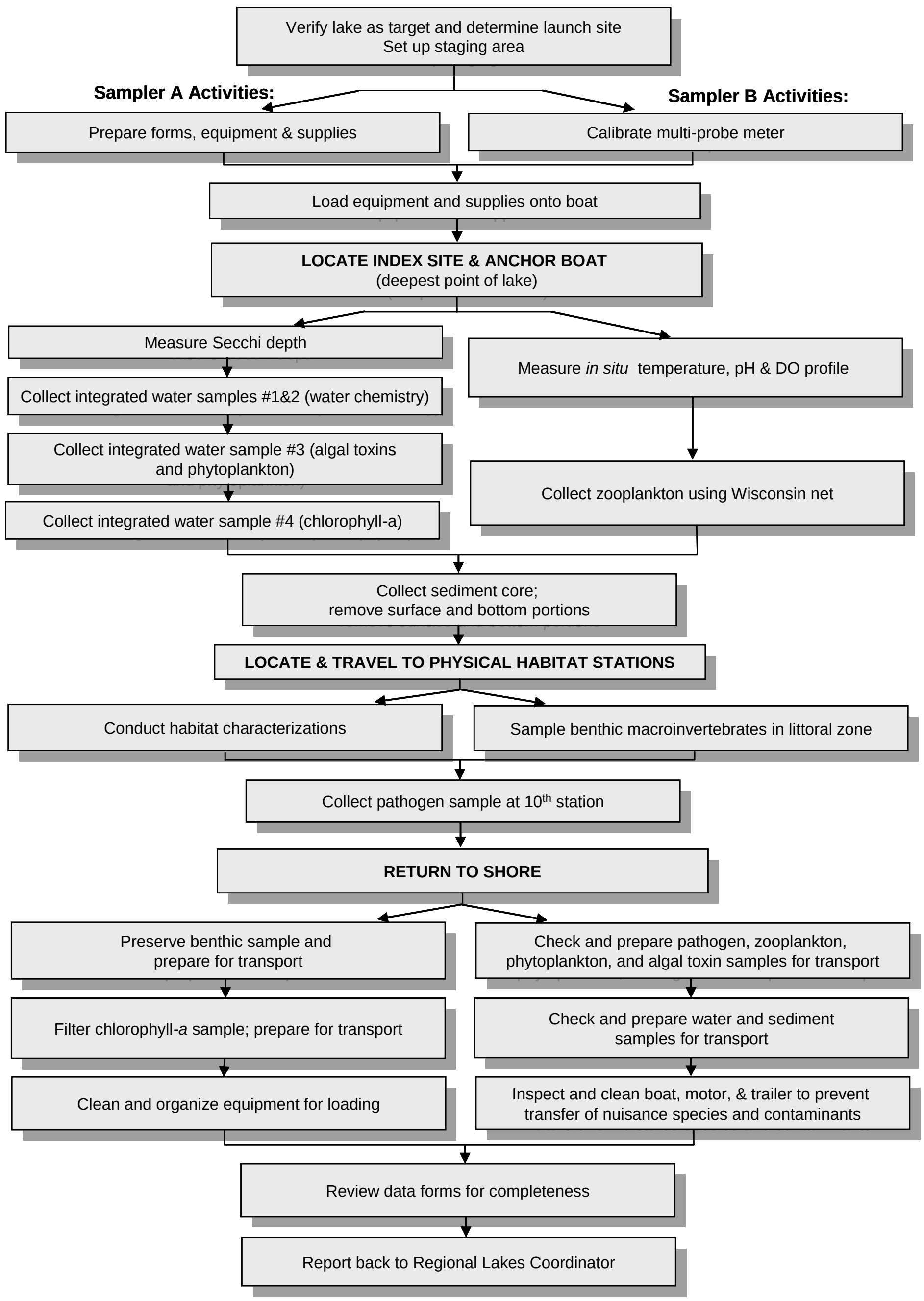


Figure 3. NLA sample scheme for field activities and lake sampling (EPA, 2007)

Lakes sampled through BUMP comprise the bulk of the water resources in Oklahoma used for recreational (swimming and fishing) and water supply purposes. Of the 53 lakes assessed in the probabilistic survey, 31 were also BUMP lakes. The probabilistic monitoring survey assessed three smaller, high-use reservoirs across the state that had never been monitored by the OWRB, as well as 19 private waterbodies.

The Oklahoma State Lakes Survey vs. the National Lakes Assessment

In the course of field implementation of the OSLS, the OWRB did note some deviation from the protocols set in the Quality Assurance Project Plan (QAPP) and standard operating procedures (SOPs) of the National Lakes Assessment. In addition, the Oklahoma State Lakes Survey did not participate in the identical sample analysis as the NLA. The following details these two types of variances.

General sample and analysis type for the NLA are given in the box titled “Sample Flow” in Figure 2 (page 10). While following the protocols of the NLA, the OSLS did not perform sediment sampling (for diatom and mercury analysis) and littoral zone net sweeps for benthic macroinvertebrate enumeration. These parameters were not deemed instructive for the bulk of Oklahoma’s reservoirs. Reconstruction of recent diatom assemblage from the sediment was determined not to yield much more information. Few Oklahoma reservoirs are likely to be diatom dominated, while enumeration of the current phytoplankton assemblage will accurately describe sample conditions. Past analysis for mercury in sediment has resulted in below detection limit reports while the Oklahoma Department of Environmental Quality (ODEQ) regularly monitors for mercury in fish flesh. The OWRB decided to rely on the ongoing ODEQ program and not invest in additional sediment monitoring at this time. Because of the relative scarcity of habitat in Oklahoma’s lakes, the OWRB decided to wait for results of NLA littoral zone maroinvertebrate sweeps to assess its utility for Oklahoma.

The EPA implemented some changes to field protocols just prior to sampling. For documentation purposes, these variances are noted. In general, the sample process followed that outlined in Figure 3 with the exception of eight variations. The largest change in protocol was changing the location of the index site from the deepest portion to the middle of the lake (not accounting for the arms of the reservoir). All variations between the QAPP and Field Operations Manual are presented as Appendix A for further reference.

Not all parameters or observations sampled for the OSLS have been reported. Two factors account for this: the large quantity of observations, and incomplete laboratory analysis. Many of the habitat site observations were categorical and not easily presented in probability plots. Only select observations were presented here. In addition, while EPA was very helpful in prioritizing Oklahoma’s needs and releasing analysis for our reporting, not all laboratory data were available at the time of reporting. For the most part, this consisted of laboratory or wet chemistry test results. The data that are available are useful enough to characterize the state of Oklahoma’s waters for the reported parameters.

Based on water chemistry data, the OSLS focused on trophic status indicators. These indicators were:

- *total phosphorus* - an essential macro nutrient that can indicate potential for excessive algal growth,
- *total nitrogen* - another essential macro nutrient that can also be a limiting reagent,
- *turbidity* - a measurement of suspended particulates,

- *Secchi disk depth* - a measurement of available light and nutrients.
- *Dissolved oxygen* - was included for the assessment of the Fish and Wildlife Propagation beneficial use.
- *Chlorophyll-a* - a measure of a common algae pigment and direct trophic indicator.
- Other parameters such as *temperature*, *specific conductivity*, and *pH* were noted.

The habitat assessment had many aspects, and the focus was on macrophyte coverage (emergent, submergent, and density) and the presence or absence of invasive species.

Results

This report is split into three major parts. The first part is the presentation of probabilistic data along with comparisons to Oklahoma Water Quality Standards (OWQS). While data collection did not allow for deterministic assessment of beneficial uses, conclusions based on threshold values in the OWQS are indicative of conditions during the summer of 2007. The probabilistic survey sample regimen did not satisfy spatial or temporal requirements for beneficial use determination. Trophic indicators of chlorophyll-*a*, total phosphorus, total nitrogen and Secchi disk depth follow physical parameters. Turbidity is reported along with trophic indicators because of the ability of suspended sediments to limit algal growth. The second part of the report has the data categorized by level III ecoregions and includes discussion of the habitat data. The last part of the report discusses the pros and cons of the statewide probabilistic sample scheme. Prior to the reporting of sample results, climatic factors will be examined.

Climate

The presentation of climatic data is critical to placing Oklahoma water quality data into context. In the two years prior to field implementation, the state of Oklahoma experienced severe drought, which ended spring of 2007. In fact, 2007 was one of the wettest on record for the central Oklahoma region (**Error! No bookmark name given.**). Ironically, reconnaissance was one on sites to make sure the lake would meet the minimum sample criteria during drought times, while sampling took place following flood conditions.

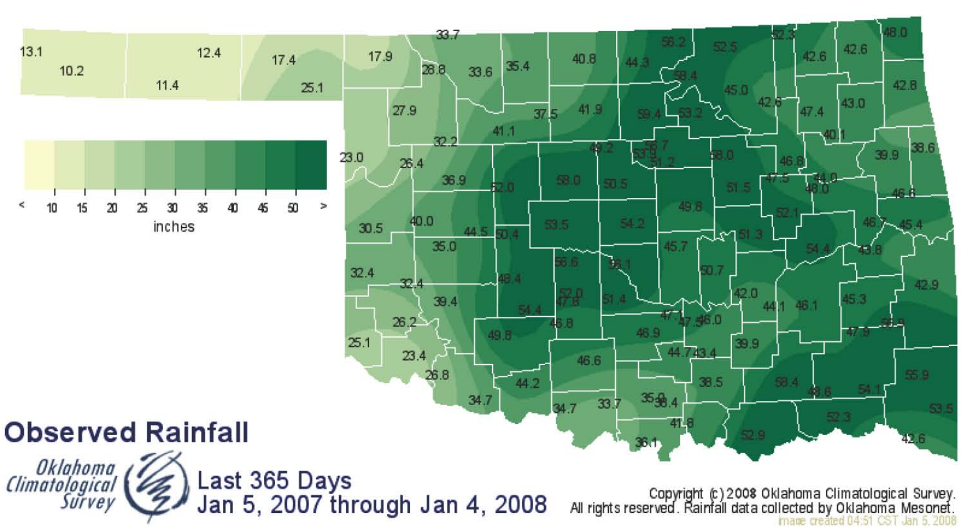


Figure 4. Observed rainfall in Oklahoma for 2007 (January 5, 2007 – January 4, 2008).

Table 1 depicts the last four years of total rainfall data for the state. This highlights the disparity between the preceding two years and the 2007 sample season.

Table 1. Four years of total, departure from normal and percent of normal rainfall

Year	Total Rainfall (in.)	Departure from Normal	%of Normal
2007	41.26	+4.57	112%
2006	28.59	-7.96	78%
2005	26.93	-9.62	76%
2004	38.45	+1.9	105%

Data courtesy of Oklahoma Climatological Survey 2008

Probabilistic Data

For brevity, not all parameters were presented as probability plots. Physical parameters of temperature, specific conductance and pH are presented in narrative summaries, while other more diagnostic parameters are presented as probability plots. Probability plots have been constructed for all OSLS data. Several parameters, dissolved oxygen, turbidity, pH and color can be directly compared to Oklahoma Water Quality Standards (OWQS) while the remainder of reported parameters primarily relate to trophic state. Comparisons against Oklahoma water Quality Standards do not constitute impairment decisions except for dissolved oxygen water column data. All other comparisons (such as those for turbidity, pH and color) are used to illustrate the apparent magnitude or potential for impairment not an actual impairment conclusion to be reported in the State's 303d list.

The highest surface sample temperature was 37.74 (°C), the lowest was 23.36 (°C), and the average was 27.75 (°C). The highest surface sample for specific conductivity was 8,434 (μs/cm), the lowest was 57.60 (μs/cm), and the average was 591.61 (μs/cm). The highest surface sample for pH was 9.81 (the Oklahoma water quality standard maximum is 9.0), the lowest was 6.95 (the Oklahoma water quality standard minimum is 6.5), and the average was 7.94. The pH values of most all surface samples fell within the range of neutral (7.0-7.99) or basic (≥8). Neutral pH range was 55.4 percent (56/101) and basic range was 44.6 percent (45/101). These parameters will further be addressed in the **Ecoregion** section of this report.

Oklahoma Water Quality Standards

Dissolved oxygen can be compared to the OWQS using both surface values and depth readings. A lognormal probability plot for surface dissolved oxygen (mg/L) showed that all the surface data values met the Oklahoma water quality standards screening level requirement of 4 mg/L of surface dissolved oxygen. A scatter plot of dissolved oxygen (mg/L) data at all depths is depicted (Figure 5). Oklahoma Water Quality Standards for dissolved oxygen within the water column state: "If greater than 70 percent of the water column at any given sample site in a lake or an arm of a lake is less than 2 mg/L due to other than naturally occurring conditions, the Fish and Wildlife Propagation beneficial use shall be deemed to be not supported." Of the 53 sampled sites two (2) met the conditions to conclude not supporting. Weighting of these two (2) sites estimates 28% of the population not supporting (impaired) for low dissolved oxygen. The standards continue, "If 50 percent or more, but not greater than 70 percent, of the water column at any given sample site in a lake or arm of a lake is less than 2 mg/L due to other than naturally occurring conditions, the Fish and Wildlife Propagation beneficial use shall be deemed to be partially supported." Of the 53 sites eight (8) met these conditions to conclude as partially supporting. Weighting of these eight (8) sites estimates that 32% of the population were deemed partially supporting (impaired) for low dissolved oxygen.

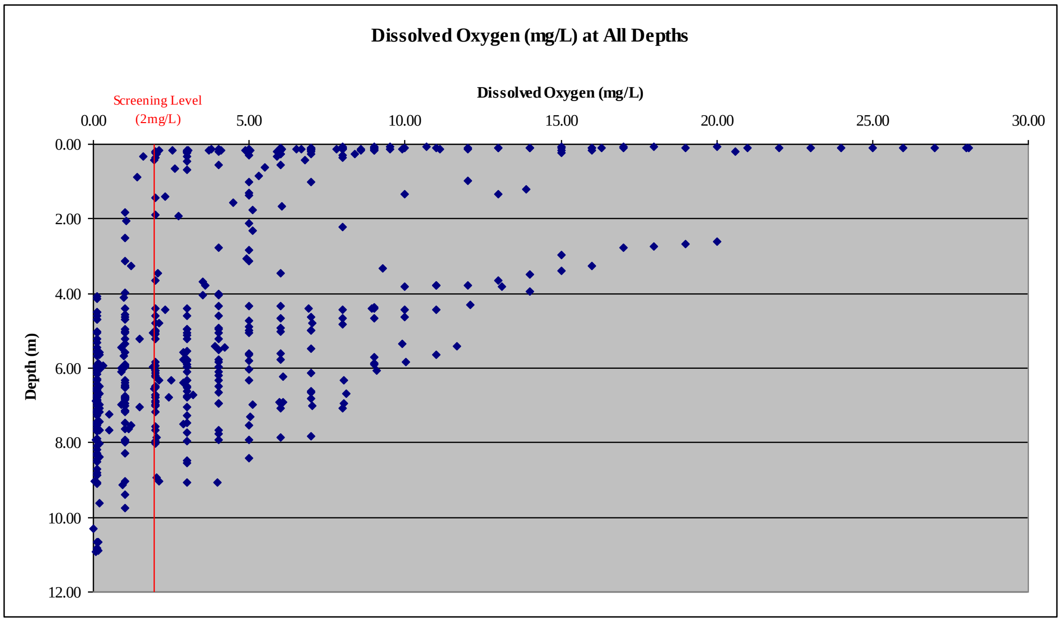


Figure 5. Scatter plot of all dissolved oxygen (mg/L) data. Water quality screening level indicated as red vertical line.

Oklahoma Water Quality Standards lists 25 nephelometric turbidity units (NTU) as the turbidity threshold for impaired fish and wildlife propagation. A cumulative distribution function plot of surface turbidity (NTU) showed a 35 percent exceedance of the 25 NTU standard (Figure 6). Of particular note is NLA site 1336. Turbidity for this site was 25.7 NTU with a weight of 25%. Should this site have been just less than 25 NTU instead of just over 25 NTU then the estimate of lakes exceeding water quality standards would have been 10% not 35%. All pH samples were within water quality standard, between 6.5 and 9.0 Standard Units (S.U.) (Figure 7). Color was similar, as all samples were below the limit of 70 Platinum color units (PCU) (Figure 8).

The potential for a large shift in the perception of statewide conditions based on the laboratory report of one site adds to the uncertainty and erodes confidence of probability based statements.

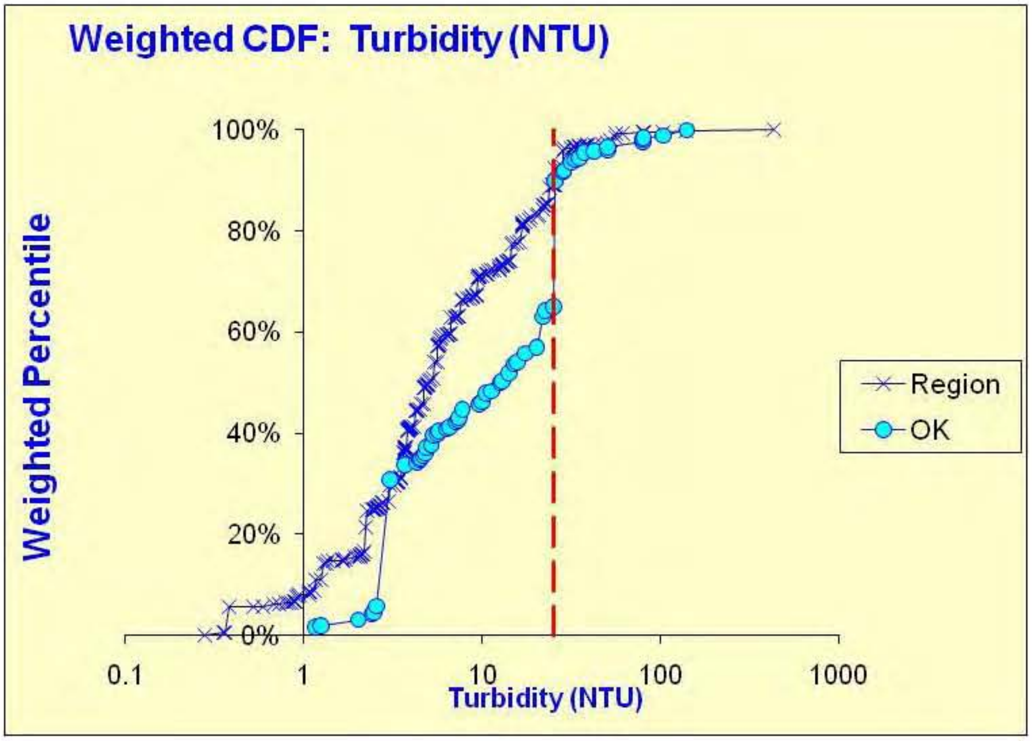


Figure 6. 2007 cumulative function distribution plot of turbidity (NTU) with water quality standard (25) indicated. Regional (including Texas and Kansas with all Oklahoma) data has been represented for comparative purposes.

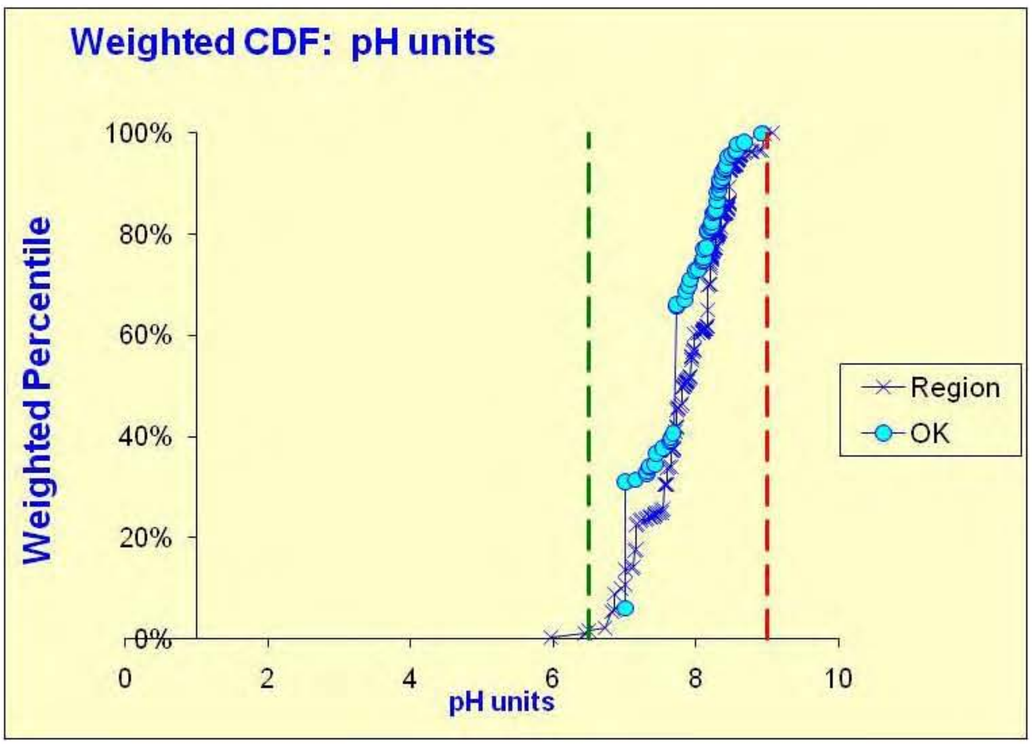


Figure 7. 2007 cumulative function distribution plot of pH (standard units) with upper and lower bounds for water quality standards. Regional (including Texas and Kansas with all Oklahoma) data has been represented for comparative purposes.

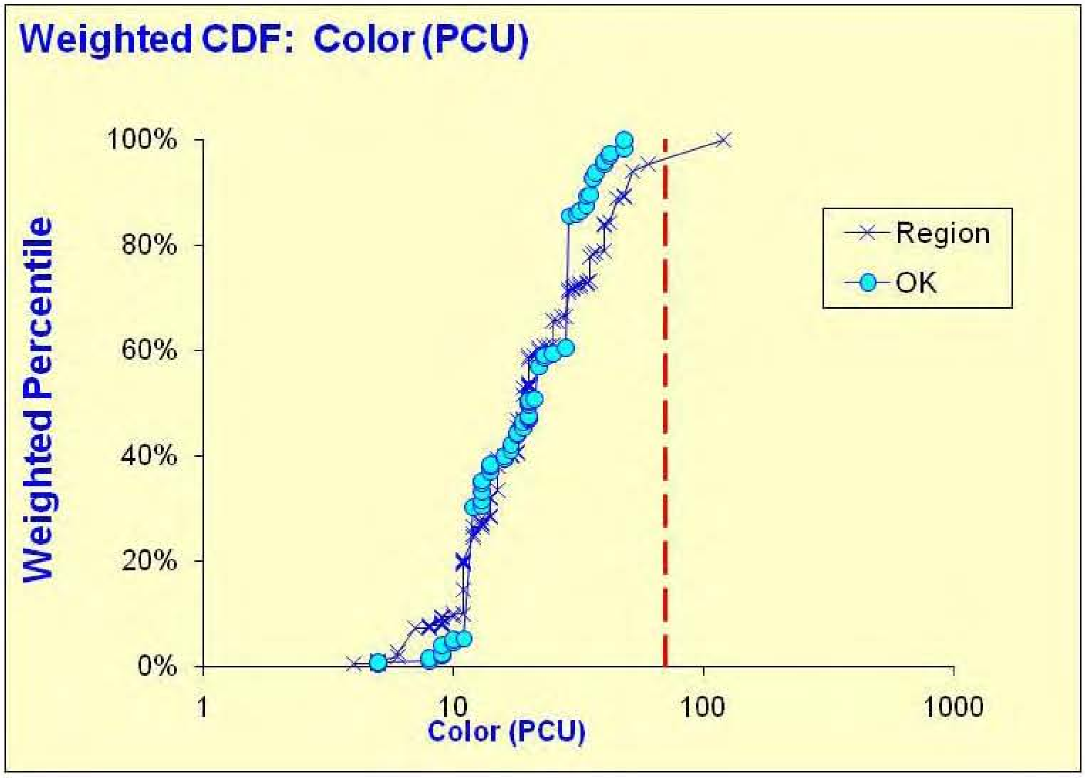


Figure 8. 2007 cumulative function distribution plot of color (PCU) with water quality standard (70) indicated. Regional (including Texas and Kansas with all Oklahoma) data has been represented for comparative purposes.

Trophic Indicators

Trophic state, in simplest terms, is the amount of productivity or plant growth in a waterbody. Contributors to trophic state include macronutrients such as nitrogen and phosphorus. At times the nitrogen: phosphorus ratio can be diagnostic. Oklahoma uses Carlson's Trophic State Index (TSI), a common denominator across the nation, to express trophic state (Carlson, 1977). TSI can be calculated by using chlorophyll-*a*, Secchi depth, or total phosphorus data. In Oklahoma, chlorophyll-*a* is used as a direct measure of trophic state, Secchi disk depth as an indirect measure, and total phosphorus as an indicator of trophic potential. The excessive turbidity noted across the state often limits the expression of nutrients as productivity. Lines for the break point between eutrophic and hypereutrophic (60 TSI), and between eutrophic and oligotrophic (40 TSI) have been included in each of the three trophic state indicator plots.

All Secchi depth TSI samples fell within the eutrophic or greater range; representing 36% as eutrophic and 64% hypereutrophic (Figure 9). Caution should be used in interpreting these results with regard to algal biomass. The relative high turbidity, noted earlier in the report, indicates inorganic suspended solids are the most likely contributor to the relatively high Secchi disk TSI (low Secchi disk depth). Because of the high turbidity, the high Secchi disk depth TSI are not considered a good indicator of primary production or algal biomass.

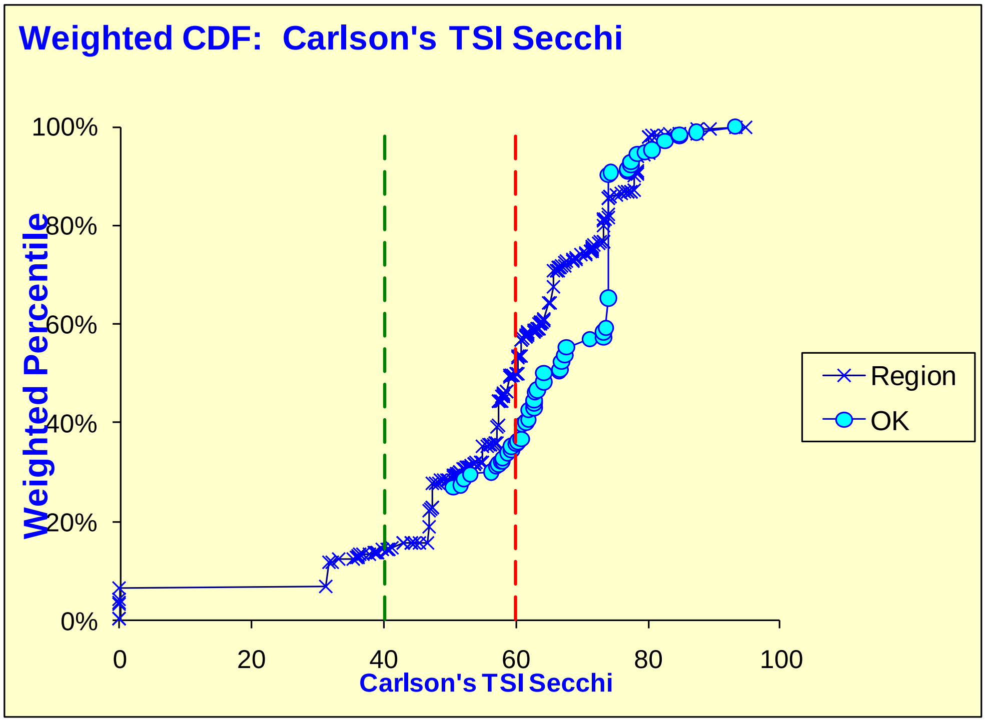


Figure 9. 2007 cumulative function distribution plot of Carlson's TSI Secchi Disk with 60 TSI (break from eutrophic to hypereutrophic) the upper bound and 40 TSI (break from mesotrophic to oligotrophic) the lower bound. Regional (including Texas and Kansas with all Oklahoma) data has been represented for comparative purposes.

Chlorophyll-a is the primary pigment for all photosynthetic plants and the common pigment for all algae. Chlorophyll-a TSI represented a disproportionately high number of lakes with elevated productivity; with 50% as hypereutrophic, 14% as eutrophic, 33% as mesotrophic and 4% as oligotrophic (Figure 10). This suggests the majority of Oklahoma's lakes, ponds and reservoirs were experiencing excess productivity in 2007. Total phosphorus TSI indicated the potential for even greater productivity with 60% as hypereutrophic, 5% as eutrophic, 33% as mesotrophic and 2% as oligotrophic (Figure 13**)**. Comparisons between these two trophic state metrics suggest that light limitation has kept algae growth lower than its potential. Perhaps more troubling than that, is fully half of the state was predicted to experience excessive algae growth in 2007. Review of previous BUMP reports does not match the probabilistic prediction. That the smaller private lakes and ponds are not sampled raises the potential for a gross underestimation of excessive algae growth in Oklahoma by the fixed station BUMP sample regime. Additional measures of productivity, such as total and dissolved organic carbon, were also available. While no benchmark values are available for comparison purposes, some drinking water treatment operators experience increased treatment difficulty when the organic carbon approaches 8 mg/l (Figure 11). Some 17% are estimated to exceed 8mg/L.

Detection of algal produced toxins is a way to assess the impact of excessive productivity to an ecosystem. While algae are often beneficial and harmless, some bloom forming algal species are capable of releasing toxins into the aquatic environment. This type of event is referred to as a Harmful Algal Bloom (HAB). The OSLS sample was from the index or open water site of the lake while most HABs are manifested along the lake shore. The majority of the freshwater HAB problems reported in the United States and worldwide are due to one group of algae, cyanobacteria or blue-green algae. Cyanobacteria can produce a variety of harmful toxins including: hepatotoxins, neurotoxins, or dermatoxins that may be harmful or lethal to animals and humans (Graham et. al. 2008). Recently a quick strip test has been developed for the detection of one type of cyanotoxin, microcystin. Microcystin is a ubiquitous cyanotoxin; the most common cyanotoxin detected in the USA and produced by a plethora of cyanobacterial genus. It is thought that detection of microcystin could serve as an indicator of cyanotoxins in general. The cumulative distribution plot suggests about 60% of the lakes, ponds and reservoirs in Oklahoma do not have summer time detectable levels (below 0.1 µg/L) of microcystin (Figure 12). The other side of that is that 40% did have microcystin detected, although, some 36% of lakes had low levels of microcystin detected (below 0.5 µg/L). The highest microcystin detected was 9.5 µg/L; just below the 10 µg/L low risk threshold for recreational use of water. The World Health Organization (WHO) recommends a 1 µg/L threshold for finished drinking water (**1998**).

Overall, the detected microcystin suggests little risk for open water recreational exposure. However, shoreward recreation (such as wading) may pose a greater risk. This greater risk is due to the propensity of HABs to form along the shoreline of a waterbody while algae blooms and scums are rare in open water sites. An additional consideration is that some 40% detection occurred during one sample event. The high percentage within one season raises the question of HAB toxin presence throughout the year.

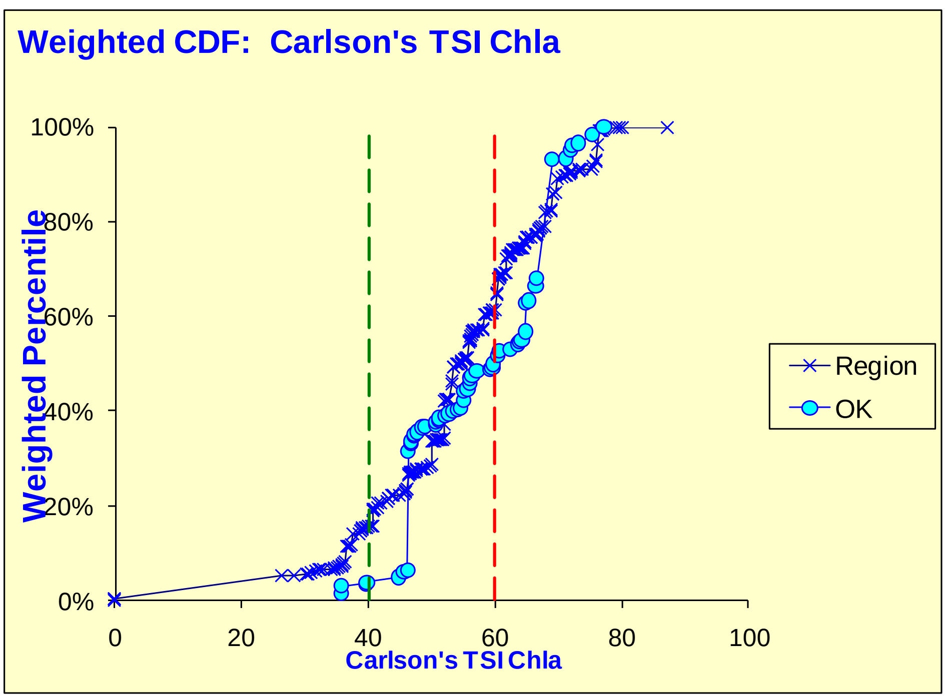


Figure 10. 2007 cumulative function distribution plot of Carlson's TSI chlorophyll-a with 60 TSI (break from eutrophic to hypereutrophic) the upper bound and 40 TSI (break from mesotrophic to oligotrophic) the lower bound. Regional (including Texas and Kansas with all Oklahoma) data has been represented for comparative purposes.

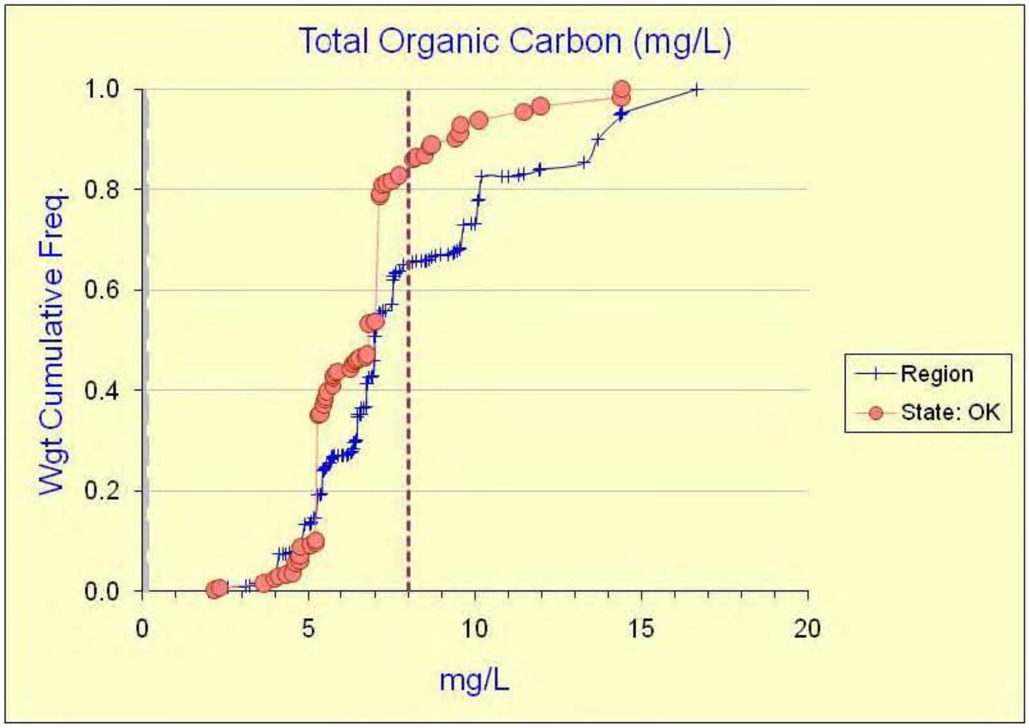


Figure 11. 2007 cumulative function distribution plot of Total Organic Carbon (mg/L). Regional (including Texas and Kansas with all Oklahoma) data have been represented for comparative purposes. The dashed line at 8mg/L approximates a threshold where drinking water treatments increase considerably.

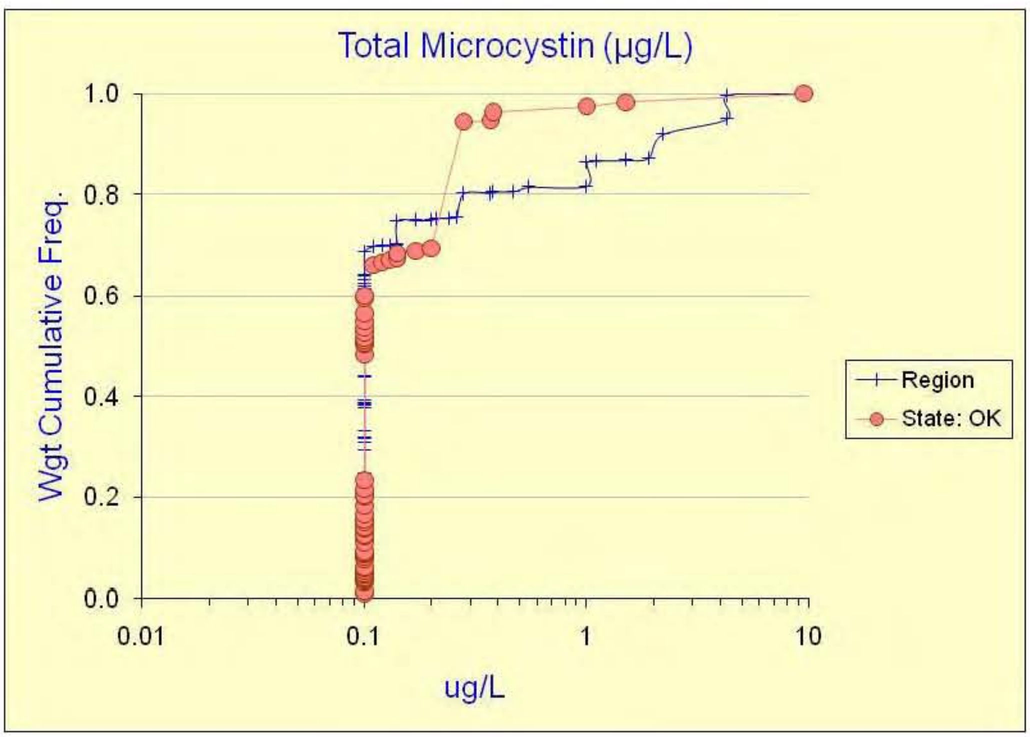


Figure 12. 2007 cumulative function distribution plot of Total Microcystin (µg/L). Regional (including Texas and Kansas with all Oklahoma) data have been represented for comparative purposes.

Total phosphorus TSI indicated the potential for even greater productivity, with 60% as hypereutrophic, 7% as eutrophic, 33% as mesotrophic and 2% as oligotrophic (Figure 13**)**. A lognormal probability plot of total phosphorus showed 28.0 percent (15/54) of all the points plotted were less than mesotrophic or lower in trophic potential. Sixty-one percent (33/54) of the TSI data values fall within the potential for hypereutrophic (excessive) algae growth.

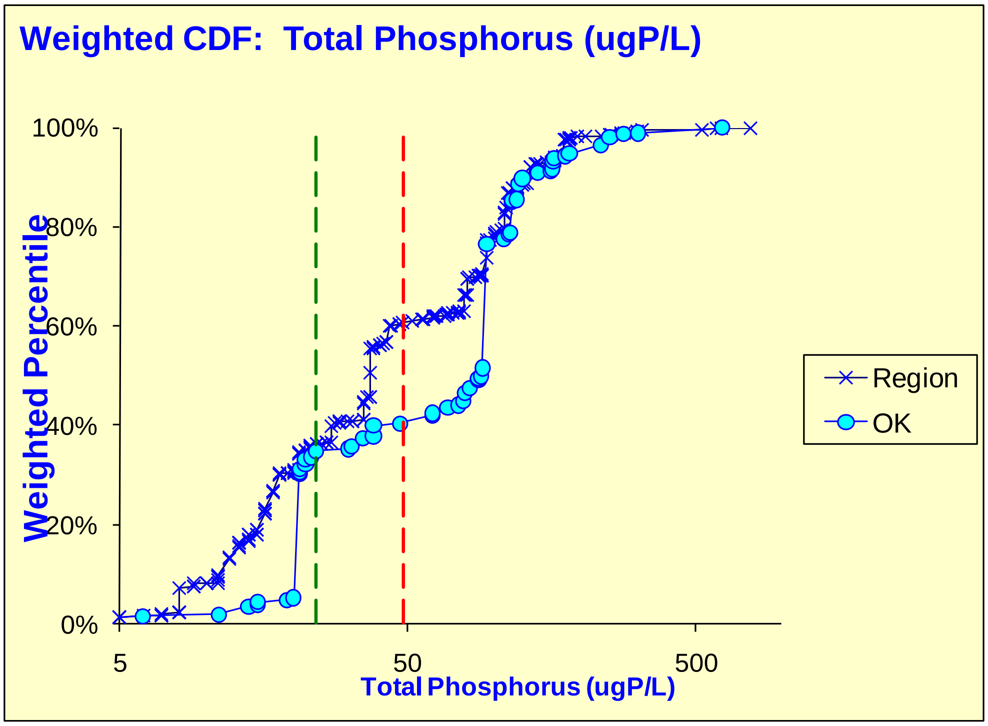


Figure 13. 2007 cumulative function distribution plot of total phosphorus (µg/L) with break from eutrophic to hypereutrophic and break from mesotrophic to oligotrophic indicated as vertical dashed lines. Regional (including Texas and Kansas with all Oklahoma) data have been represented for comparative purposes.

The highest value recorded for total nitrogen was 3.4 mg/L, and the lowest sample was 0.26 mg/L (Figure 15). No simple metric was available for trophic comparison. However, put together, total nitrogen and phosphorus can be instructive.

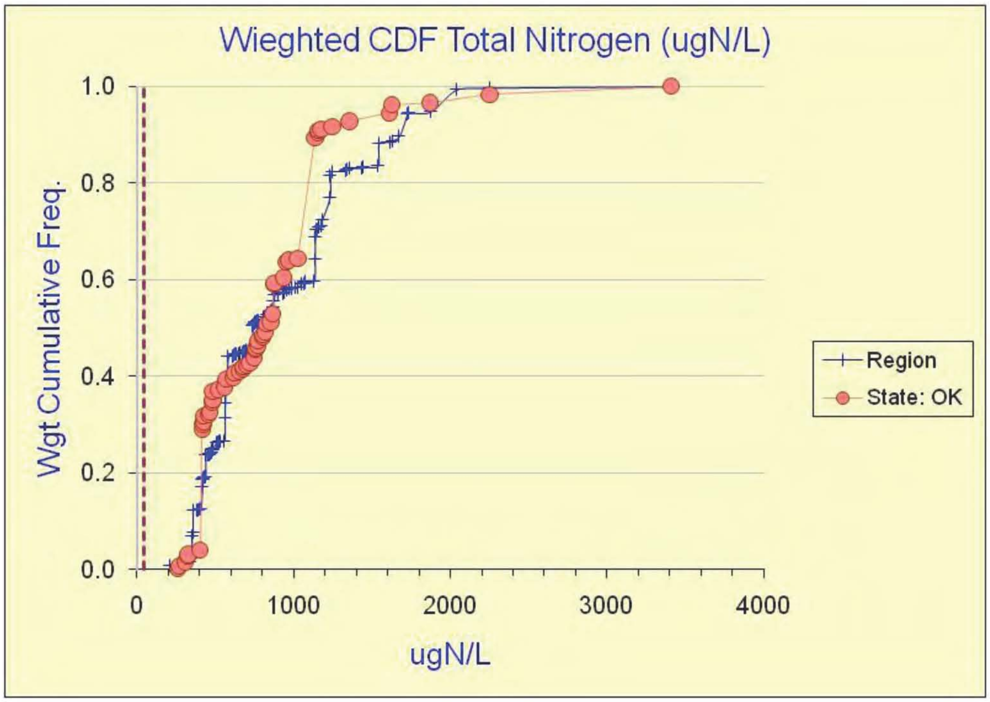


Figure 14. 2007 cumulative function distribution plot of total nitrogen (μg/L). Regional (including Texas and Kansas with all Oklahoma) data have been represented for comparative purposes.

The probability plot showing the total nitrogen to total phosphorus molar ratio (TN:TP) is depicted in Figure 15. Break points predicting chemical nutrient limitations between nitrogen, phosphorus and co-limitation have been added following the scheme presented by Dzialowski et. al.(2005). This represents the most up-to-date work regarding chemical limitation of phytoplankton productivity in the region. Here the TN:TP ratio is divided into nitrogen limited systems with a ratio of <18 nitrogen:1 phosphorus, co-limited systems with ratios between 20 and 46:1, and phosphorus limited systems with >65:1. There is a noted gray area between each of these classifications where the data does not fall in one particular category. In this case, no assignment is made. The waterbody percentages break down to 19 % phosphorus limited, 2% undetermined, 69 % co-limited, 6 % undetermined and 4 % nitrogen limited.

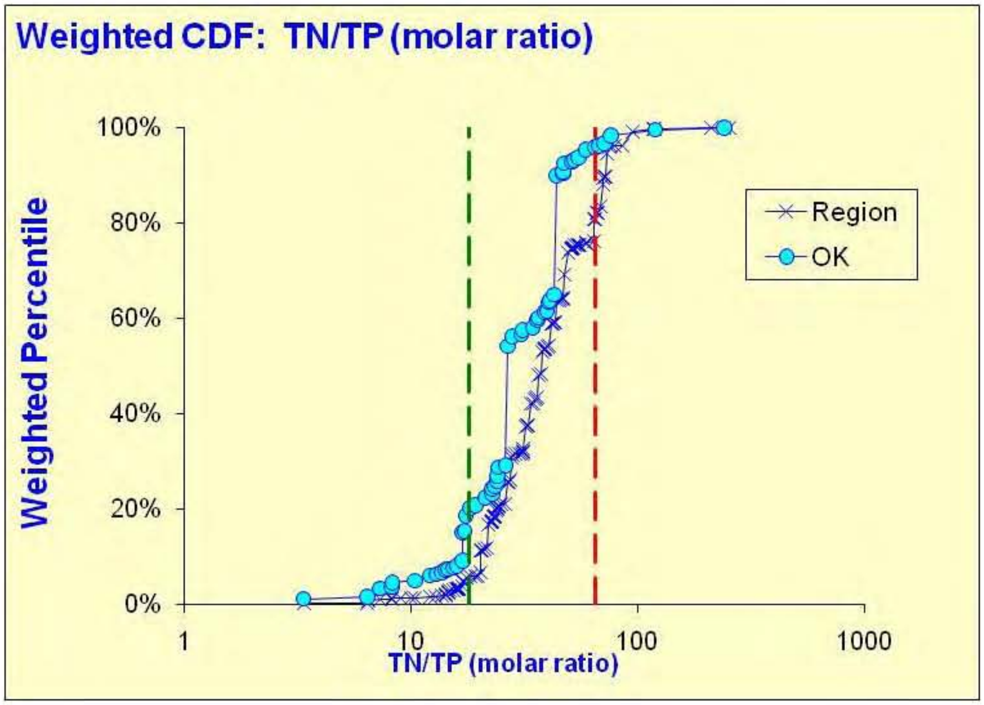


Figure 15. 2007 cumulative function distribution plot of total nitrogen to total phosphorus (molar ratio) with breaks given for phosphorus limited (>65:1) and nitrogen limited (<18:1). Regional (including Texas and Kansas with all Oklahoma) data have been represented for comparative purposes.

Longitudinal Gradients

Because of the overlap between the OSLS and the BUMP annual beneficial use assessment, additional comparisons were possible. The OWRB was concerned that a single water quality sample site per lake in the probabilistic scheme would over simplify and mischaracterize the overall water quality of Oklahoma's lakes due to the longitudinal gradients (distant zones of water quality) often present. In short, Oklahoma's reservoirs do not fit the format of a glacially formed lake. The majority of Oklahoma's lakes are impoundments with regulated flow. In many cases, several arms are created upon impoundment, and tributary water is distinctly different. To address this issue, some preliminary estimates were performed.

Two reservoirs were selected – Keystone Lake and Skiatook Lake – as these are typical of Oklahoma's larger reservoirs, and were included in the probabilistic survey. Both are run-of-the-river reservoirs. Keystone Lake is situated at the juncture of two major rivers (creating two major and almost separate arms), while Skiatook Lake represents an upland reservoir tributary to a large river. Eight years of summertime data were used for Keystone Lake (1998-2006) and nine years worth for Skiatook Lake (1996-2007). Each lake's site data were grouped into three categories (riverine, transition and lacustrine) and presented as box and whisker plots. Using these groupings as guidance, surface areas were assigned to each reservoir zone. Table 2 **i**llustrates the potential for error in assigning water quality attributes by surface acre based solely on lacustrine zone samples. Here we see that the lacustrine sites represent 40 to 50 % of the total surface area of Keystone and Skiatook lakes respectively. Oklahoma reports water quality status in surface acres within any particular category. For example, impaired waters are listed by the acreage (as in the Oklahoma 303d list). Extrapolation of the OSLS results to surface area of a given zone's quality, presents potential for error. The 2007 OSLS probabilistic sampling parameters of total phosphorus (mg/L), Secchi disk depth (m) and turbidity (NTU) were compared to noted in-lake gradients to check the potential for error with surface area extrapolations.

BUMP data recorded for Keystone Lake clearly displays water quality longitudinal gradients, with total phosphorus and turbidity highest at the riverine sites and lowest at the lacustrine sites (Figure 16). While, Secchi disk depth is the lowest in the riverine portion and greatest by the dam. Comparison of index site data showed this data were closest to riverine water quality. The longitudinal gradient in Skiatook Lake is evident, but not as strong as represented in Keystone Lake (Figure 17). Index site data for Skiatook Lake was almost diametrically opposite that of Keystone Lake. Here, data represented a water quality closer to the lacustrine zone.

In summary, flow must be taken into account should results from the one index site be extrapolated to the whole lake. Not accounting for flow could result in mischaracterizing 25 to 75 % of the system's surface area.

Table 2. Estimate of lake surface area by longitudinal zone for Keystone and Skiatook Lakes

Keystone Lake Zone Estimates

	Acres	Percentage
Total Acres*	23,894	-
Lacustrine	9,705	40.6%
Transitional	8,411	35.2%
Riverine	5,778	24.2%

* Water Atlas Acres: 23,610

Skiatook Lake Zone Estimates

	Acres	Percentage
Total Acres*	10,767	-
Lacustrine	5,321	49.4%
Transitional	2,662	24.7%
Riverine	2,784	25.9%

* Water Atlas Acres: 10,190

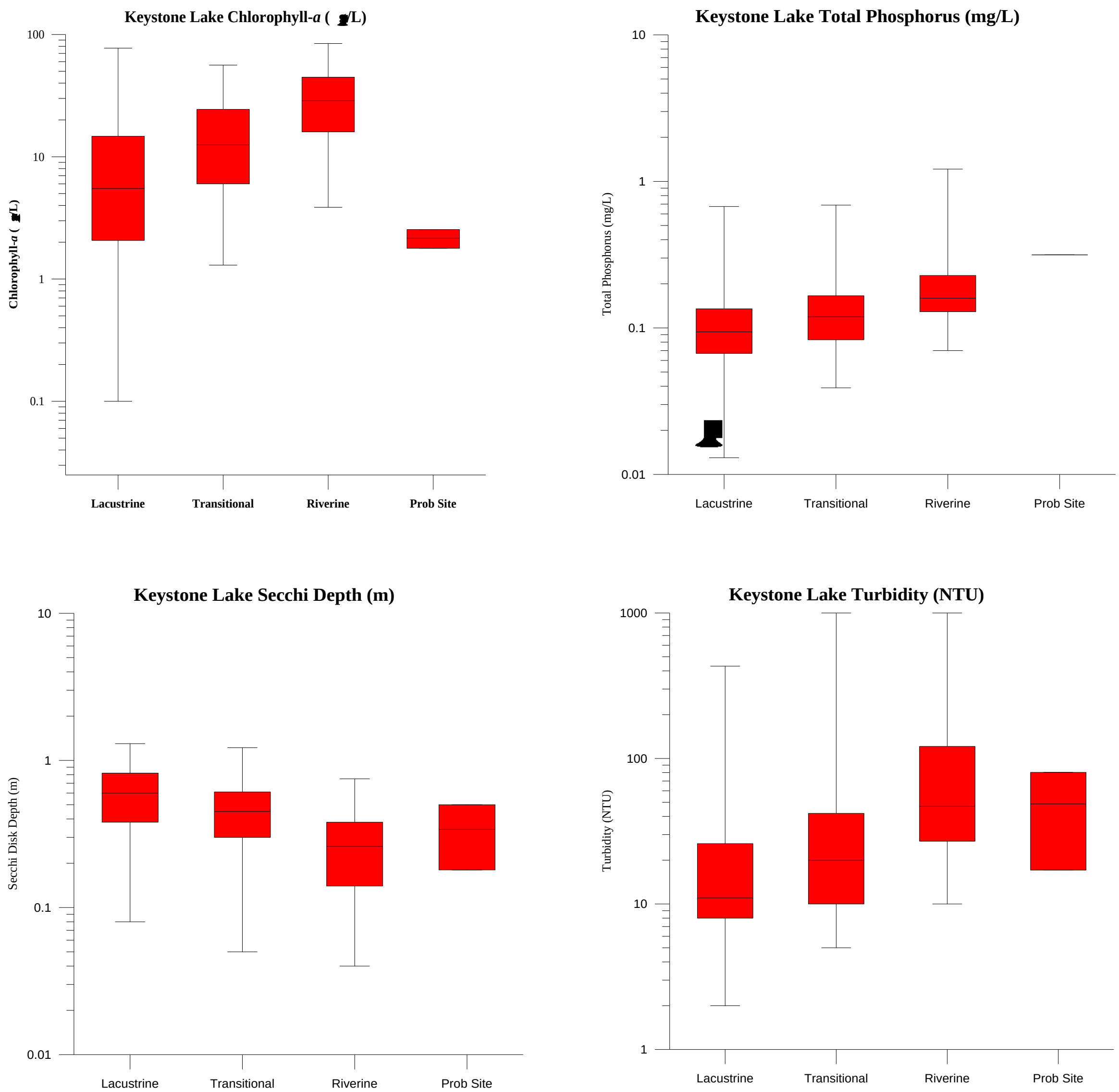


Figure 16. Box and whisker plot comparing Keystone Lake probabilistic data (far right bar or box in all plots) to Keystone Lake BUMP data estimated for lacustrine, transitional and riverine zones for chlorophyll-*a*, total phosphorus, Secchi depth, and turbidity.

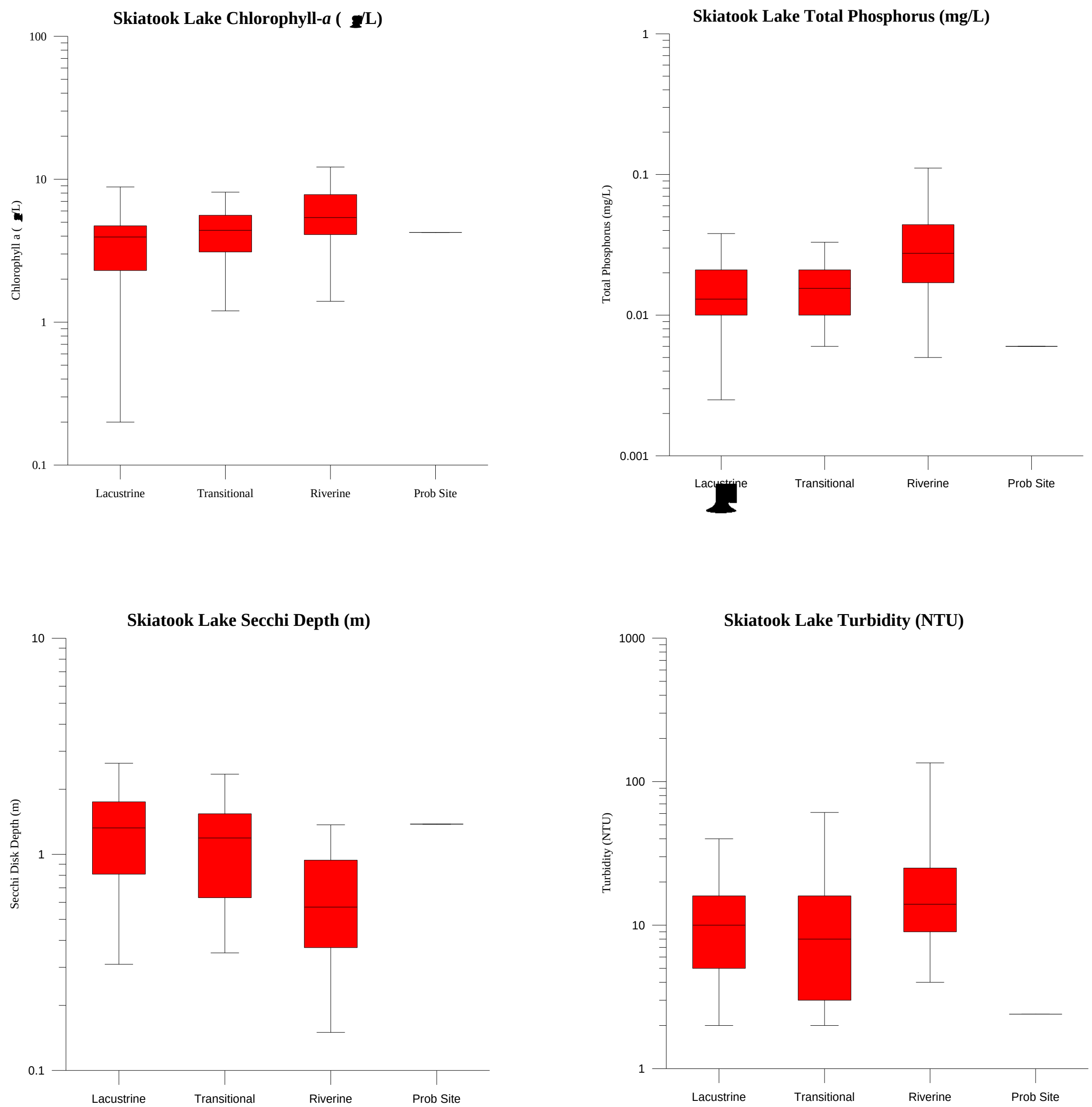


Figure 17. Box and whisker plot comparing Skiatook Lake probabilistic data (far right bar of each plot) to Skiatook Lake BUMP lacustrine, transitional and riverine zone data for chlorophyll-*a*, total phosphorus, Secchi depth, and turbidity

To better understand the driving force behind these two widely varied lake results, the hydraulic regimen for the sample month was compared against long-term monthly averages (Table 3) Monthly rainfall totals show that Keystone Lake experienced significantly higher than average rainfall in June, while discharge of pooled floodwaters upstream appeared to extend into September. The relatively high discharge of Skiatook, relative to inflow for August, indicates release of flood waters pooled earlier in the season. Perhaps the more diagnostic measure was the estimated residence time, tau (σ), for each sample month. Skiatook Lake had a tau 7 to 35 times greater than Keystone. The significantly longer residence time of Skiatook Lake, an upland run-of-the-river reservoir, could have allowed for settling of suspended particles and phosphorus. The fact that Keystone Lake has a large impoundment regulating flow upstream had a greater impact on monthly hydraulic residence. The BUMP data set clearly shows longitudinal gradients in Oklahoma reservoirs. Comparison of the gradients to NLA data indicates incongruence's. Explanation of these differences is likely a combination of relative residence time and position within the drainage basin. Either way, it is clear that the NLA sample scheme is incapable of describing longitudinal gradients.

Table 3. Hydraulic parameters for Keystone and Skiatook Lake, comparing long-term monthly averages vs. sample month totals. Keystone Lake was resampled as a quality control measure for the NLA.

Parameter	Unit	Keystone Lake		Skiatook Lake
		June	September	August
Inflow: Monthly Average	**acre-feet**	104,281	10,998	10
Inflow: Sample Month Total	**acre-feet**	3,128,428	329,950	319
Outflow: Monthly Average	**acre-feet**	88,022	15,507	1,301
Outflow: Sample Month Total	**acre-feet**	2,640,651	465,215	40,318
Annualized Tau (σ)	**yr^{-1}**	**0.02**	**0.10**	**0.70**
Mean Rainfall	**inch**	4.1	3.4	3.2
Sample Month Total Rainfall at dam	**inch**	6.5	2.7	0.6
Sample Month Total Rainfall w/in Basin	**inch**	13.4	2.5	1.5

Ecoregion

Ecological land classification is a process of delineating and classifying ecologically distinctive areas of the earth's surface. Each area can be viewed as a discrete system which has resulted from the mesh and interplay of the geological, land form, soil, vegetative, climatic, wildlife, water and human factors which may be present. The dominance of any one or more of these factors varies with the given ecological land unit. This holistic approach to land classification can be applied incrementally on a scale-related basis; from very site-specific ecosystems to very broad ecosystems (Wiken, 1986).

There are 12 level three (Woods, et. al, 2005) ecoregions that lie within Oklahoma. The sites sampled during the survey are within nine of those ecoregions. Those ecoregions are Arkansas Valley, Boston Mountains, Central Great Plains, Central Irregular Plains, Cross Timbers, Flint Hills, Ouachita Mountains, South Central Plains, and the Southwestern Tablelands. As a whole, habitat metrics represented generally low values across all ecoregions. Few significant differences were noted due to two issues: variance and sample size. Most deterministic was sample size. While the sample size was adequate to represent the entire state on a probabilistic basis, the sample size for each ecoregion was generally small; only two of the nine had greater than four sample sites. There were the Cross Timbers (n=18) and the Central Great Plains (n=23). Because of the smaller sample size, data presented on an ecoregional level are presented in a statistically significant but not a probabilistic perspective.

Trophic measures did show significant differences between these two ecoregions when a nonparametric one-way multiple comparison was applied (using Tukey's familywise error rate). In short, statistical analysis showed the Central Great Plains as more turbid (with lower Secchi disk depth) and nutrient laden. While chlorophyll-a mean values were almost one trophic level apart (with the Central Great Plains highest at 60 TSI) the confidence intervals for chlorophyll-a were too large to allow statistical significance. Comparison of the various trophic indices show that the Central Great Plains region should have had a much lower transparency than the Cross Timbers. In the case of Secchi disk depth (Carlson's) trophic index, the Central Great Plains mean was 72, while the Cross Timbers was 62. While both regions had high mean values, the difference between the ecoregions represents one trophic level. Median turbidity for the Central Great Plains was 32.6 NTU with 11 of the 23 sites above the water quality standard of 25; while the Cross Timbers median was 15.1 NTU with 2 sites exceeding water quality standards (80 and 79 NTU). Comparison of mean phosphorus (Carlson's) trophic index between the two regions showed a difference of almost two (18 units) trophic levels. The Central Great Plains mean was 72, indicating the potential for hypereutrophic algae growth, while the Cross Timbers mean was 54, indicating the potential for eutrophic algae growth. While both are high, the mean phosphorus of the Central Great Plains region represents an excessive amount of phosphorus. Comparison of chlorophyll-a was the difference between the Cross Timbers status of eutrophic (mean TSI of 52) and the Central Great Plains status of hypereutrophic (mean TSI of 60). Comparison between trophic indices indicates a much greater potential for algae growth in the Central Great Plains if light transparency were greater.

The following general descriptions of the level three ecoregions have been adapted from *The Oklahoma Wetlands Reference Guide* (OCC, 2000), courtesy of the Oklahoma Conservation Commission. These ecoregion summaries have a brief background of the ecoregions themselves, following which water chemistry, nutrients, and habitat are discussed. A habitat survey was conducted for 50 of the 53 sites. These consisted of 10 sites evenly spaced along the lake perimeter.

The habitat survey had many aspects. One focal point was on the overall assessment reported for each lake. This was separate from the 10 individual sites. This report focused on one aspect of that assessment, macrophyte coverage (emergent, submergent, and density). Another focal point of this report, the presence or absence of invasive species, was part of the 10 habitat sites for each lake. Each habitat site was observed for several types of invasive plants and invertebrates including the littoral plot for Zebra or Quagga Mussel, Eurasian watermilfoil, Hydrilla, Curly pondweed, African waterweed, Brazilian waterweed, European water chestnut, Water hyacinth, Parrot feather, Yellow floating heart, and Giant salvinia and the shoreline/riparian plot for Purple loosestrife, Knotweed (Giant or Japanese), Hairy willow herb and Flowering rush. All parameters, except for invasive species, were measured by rare (<5 %), sparse (5-25 %), moderate (25-75 %) and extensive (>75 %) coverage.

Arkansas Valley

"The Arkansas Valley forms a geological break along the eastern portion of the state between the Boston Mountains to the north and the Ouachita Mountains to the south. Some of the natural communities found in this ecoregion are more common in the Cross Timbers area. Dry forests and woodland communities dominate rugged areas and extend into the plains. The trees are relatively short and a significant portion of the vegetation cover is provided by grass species. Tallgrass prairie communities are often scattered between dry upland forests and the bottomland hardwood forests that occur along streams. Lush forests occur along streams and rivers and are often taller than those in the uplands. Many have two or three understory layers" (adapted from Oklahoma Conservation Commission, 2000).

Three of the sites sampled were within the Arkansas Valley ecoregion. Two of those sites were public lakes, which included Coalgate Lake (NLA06608-0472) and Lake Wister (3320). Both of these lakes are monitored on a rotation basis within the Beneficial Uses Monitoring Program (BUMP) for the state. The third site was a privately owned lake (4929).

Water Chemistry and Nutrients
Based on dissolved oxygen data, Coalgate Lake (0472) did not support the Fish and Wildlife Propagation beneficial use according to Oklahoma Water Quality Standards (OWQS), and the private lake (4929) only partially supported the Fish and Wildlife Propagation beneficial use (Table 4**).** All other standards were met. The sites within this ecoregion were eutrophic and hypereutrophic based on chlorophyll-*a*, total phosphorus, total nitrogen and Secchi depth data.

Table 4. Arkansas Valley ecoregion parameter, use support, water quality standard and trophic state data

Ecoregion: Arkansas Valley Overall					
Parameter	n=	Ave.	High	Low	Use Support/Standard/Trophic Status
Temp	19	24.2	31.8	16.4	N/A
pH	28	7.0	8.2	6.5	Meets Standard
Spc. Cond.	28	172.3	526.3	52.8	N/A
DO (mg/L)	28 & 3	3.5	10.9	0.09	Does Not Support (1/3)/Partially Supports (1/3)/Supports (1/3)
Chl-a (ug/L)	3	25.5	38.3	19.1	Hypereutrophic
TP (ug/L)	3	95.7	121.0	77.9	Eutrophic
TN (mg/L)	3	0.79	0.95	0.61	Eutrophic Plus
Turbidity (NTU)	3	19.1	28.6	3.7	Meets Standard
Secchi (m)	3	0.57	0.94	0.39	Eutrophic

Habitat Assessment

Sixty-seven percent (2/3) of emergent and 100 % (3/3) of submergent macrophytes had rare coverage, while 33 % (1/3) of emergent macrophytes had sparse coverage. Overall macrophyte density was evenly split between rare, sparse and moderate coverage. There were no littoral or shoreline (riparian) invasive species.

Boston Mountains

"The Boston Mountains ecoregion is located in northeastern Oklahoma. The topography consists of rugged hills and low mountains similar to the Ozark Mountains ecoregion. The Boston Mountains are composed of Pennsylvanian sandstone whereas the Ozarks are mainly Mississippian limestones. Forest communities grow in moist soils producing closed canopies and often have dense shade. Ridge tops and south-facing slopes support grassland communities and bottomland hardwood forests occur along flood plains of larger streams" (adapted from Oklahoma Conservation Commission, 2000).

Both of the sites within this ecoregion are public lakes. Lake Tenkiller (NLA06608-0332) is sampled by BUMP and Lake Vian (1356) has never been previously sampled.

Water Chemistry and Nutrients
Based on dissolved oxygen data, Lake Tenkiller (0332) partially supported the Fish and Wildlife Propagation beneficial use standards (Table 5). All other parameters were within OWQS. The sites within this ecoregion were mesotrophic based on chlorophyll-*a*, total phosphorus data and oligotrophic based on total nitrogen data.

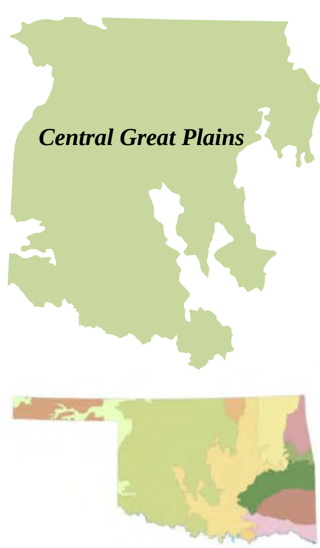
Table 5. Boston Mountains ecoregion parameter, use support, water quality standard and trophic state data

Ecoregion: Boston Mountains Overall					
Parameter	**n=**	**Ave.**	**High**	**Low**	**Use Support/Standard/Trophic Status**
Temp	38	24.3	34.6	12.9	N/A
pH	38	7.8	8.6	6.5	Meets Standard
Spc. Cond.	38	203.8	273.7	80.1	N/A
DO (mg/L)	38 & 2	3.2	8.0	0.08	Supports/Partially Supports
Chl-*a* (ug/L)	2	5.7	6.4	4.9	Mesotrophic
TP (ug/L)	2	16	21	11	Mesotrophic
TN (mg/L)	2	0.34	0.42	0.26	Oligotrophic
Turbidity (NTU)	2	2.1	3.0	1.2	Meets Standard
Secchi (m)	1	1.93*	N/A	N/A	N/A

* other data point >1.5

Habitat Assessment
Due to the size of Lake Tenkiller (0332), habitat surveys were not conducted. Lake Vian (1356) was the only site observed for macrophytes. At that site, emergent and submergent macrophyte coverage was 100 % moderate. Macrophyte density was 100 % extensive. No invasive species were observed at Lake Vian.

Central Great Plains



“Grasslands cover most of the Central Great Plains ecoregion with woodlands scattered in ravines and along streams. Narrow bands of crosstimbers vegetation extend into the prairie from the east. The Wichita Mountains and the Gypsum Hills provide unique habitats. Mesas and deeply eroded canyons characterize the Gypsum Hills and Redbed Clay Plains. Many plant species are adapted to high concentrations of salt in the soil.
The rolling redbed plains surround the gypsum hills and the soils have a high content of iron and are derived from Permian sandstone and shale. Salt flats and springs occur throughout the ecoregion. Sand dunes occur along all major rivers except the Washita River and are most extensive on the north banks. Woody plants are not abundant due to lack of water but do occur in the sandstone canyons in Caddo and Canadian counties” (adapted from Oklahoma Conservation Commission, 2000).

Twenty-one sites were situated in the Central Great Plains ecoregion plus a resample. Twelve of those sites were public lakes, which included Canton (NLA06608-4056), Crowder (4659), Cushing (0012 resample), Dave Boyer (Walters) (1524), Fort Cobb (1372), Fort Supply (1568), Frederick (0180), Hefner (1804), Overholser (4472), Perry (0440), Ponca (4440), and Rocky (1564). There were nine privately owned ponds and lakes (NLA06608-0204, 0284, 0540, 0616, 0696, 0972, 1336, 1488, and 4206).

Water Chemistry and Nutrients

Based on dissolved oxygen data, Ponca Lake (4440) and two other private lakes (0696 and 1488) partially supported the Fish and Wildlife Propagation beneficial use (Table 6). Out of 22 lakes, 16 (72 %) did not meet the turbidity standard (0012, 0180, 0284, 0440, 0540, 0616, 0696, 0972, 1488, 1524, 1568, 1804, 4056, 4206, 4440, and 4472). All other parameters were within OWQS. The sites within this ecoregion were hypereutrophic based on chlorophyll-*a*, total phosphorus and Secchi depth data, and mesotrophic based on total nitrogen data.

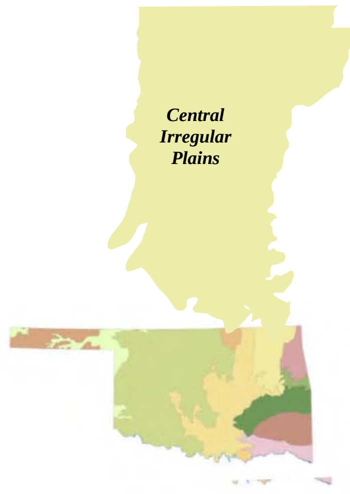
Table 6. Central Great Plains ecoregion parameter, use support, water quality standard and trophic state data

Ecoregion: Central Great Plains Overall					
Parameter	**n=**	**Ave.**	**High**	**Low**	**Use Support/Standard/Trophic Status**
Temp	147	25.6	30.7	15.9	N/A
pH	147	8.0	9.8	6.8	Meets Standard
Spc. Cond.	147	1031.6	8423.0	157.7	N/A
DO (mg/L)	147 & 22	5.8	9.6	0.10	Partially Supports (3/22)/ Supports (18/22)
Chl-a (ug/L)	22	36.1	114.6	1.70	Hypereutrophic
TP (ug/L)	19	162.6	619.4	14.1	Hypereutrophic
TN (mg/L)	19	1.1	2.3	0.48	Mesotrophic
Turbidity (NTU)	22	35.2	140.0	7.3	Does Not Meet Standard (16/22)
Secchi (m)	21	0.4	>2.0	0.14	Hypereutrophic

Habitat Assessment

Eighty-six percent of emergent (18/21) and 90 % (18/20) of submergent macrophytes had rare coverage. Fourteen percent (3/21) of emergent macrophytes had moderate coverage and 10 % of submergent (2/20) had extensive coverage. Forty-eight percent (10/21) of the overall macrophyte density was rare, thirty-three percent (7/21) were sparse, and approximately 10 % (2/21) were moderate and extensive. There were no littoral or shoreline (riparian) invasive species.

Central Irregular Plains



"This ecoregion is a band of tallgrass prairie separating the forested Ozark Highlands from the Cross Timbers ecoregion. There are many diverse wildflowers that live among the tall grasses and fire is important in maintaining these grasslands. Dry upland forests and woodlands within the tall grass area are short and have an open canopy. Broad flood plains support forests that are heavily shaded and there are many caves that have formed in limestone outcroppings" (adapted from Oklahoma Conservation Commission, 2000).

Two sites fell within the Central Irregular Plains ecoregion. Both were public lakes. The first, Copan Lake (NLA06608-1960), is sampled by BUMP and the second, Newt Graham Lake (4949), has never been sampled by BUMP.

Water Chemistry and Nutrients

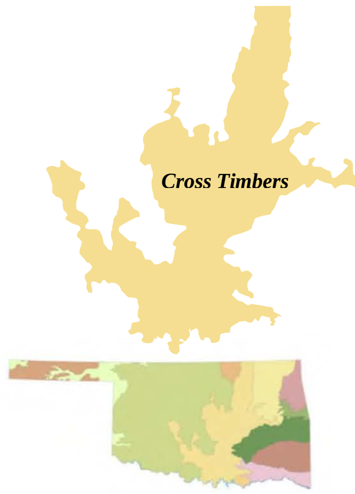
The sites in this ecoregion were eutrophic based on chlorophyll-*a*, total phosphorus and Secchi depth data and oligotrophic based on total nitrogen data (Table 7). Copan Lake (1960) did not meet the turbidity standard of 25 NTU. All other parameters were within OWQS.

Table 7. Central Irregular Plains ecoregion parameter, use support, water quality standard and trophic state data

Ecoregion: Central Irregular Plains Overall					
Parameter	**n=**	**Ave.**	**High**	**Low**	**Use Support/Standard/Trophic Status**
Temp	22	28.8	31.5	28.3	N/A
pH	22	7.7	8.4	7.4	Meets Standard
Spc. Cond.	22	218.6	233.0	190.1	N/A
DO (mg/L)	22 & 2	7.0	10.7	5.40	Supports
Chl-*a* (ug/L)	1		14.8		Eutrophic
TP (ug/L)	2	95.0	108.0	82.0	Eutrophic
TN (mg/L)	2	0.51	0.62	0.40	Oligotrophic
Turbidity (NTU)	2	23.5	37.3	9.7	Meets Standard (1/2)/ Does Not Meet Standard (1/2)
Secchi (m)	2	0.56	0.83	0.30	Eutrophic

Habitat Assessment
Fifty percent (1/2) of emergent macrophytes had rare coverage, and 50 % had sparse coverage. One hundred percent (2/2) submergent macrophytes had rare coverage. Overall, macrophytes were recorded at 50 %(1/2) rare and 50 % (1/2) moderate coverage for this region. No littoral or shoreline (riparian) invasive species were observed.

Cross Timbers



"The rolling sandstone hills of the Cross Timbers ecoregion support a mosaic of natural communities and are a transition zone between the large eastern forests and the western grasslands. In the more level northern and southern portions of the ecoregion, prarie communities cover most of the landscape, with woodlands on slopes, in draws, and along streams and rivers. Throughout the central pact of the ecoregion, dry upland forests (cross timbers) blanket the hills and bottomland forests occur along streams. Prairies are scattered throughout this ecoregion. The Arbuckle Mountains are a distinct feature within this ecoregion and clear, cool, fast-running, spring-fed streams are common" (adapted from Oklahoma Conservation Commission, 2000).

There were 19 sites plus one resample within the Cross Timbers ecoregion. Ten of the sites were public lakes monitored by BUMP. These included Birch (NLA06608-4643), Duncan (0756), Fuqua (0152), Hudson (4504), Jean Neustadt (0856), Keystone (0120 resample), Konawa (1868), Okemah (0268), Skiatook (0376), and Sportsman (1164). Two other sites were public but not monitored by BUMP. These included Mountain (0408) and Veterans (4610) Lakes. Seven sites were privately owned lakes or ponds (1016, 1240, 1420, 1432, 3480, 4382, and 4828).

Water Chemistry and Nutrients

The sites in this ecoregion were eutrophic based on chlorophyll-*a*, total phosphorus and Secchi depth data, and oligotrophic based on total nitrogen data (Table 8). According to dissolved oxygen data, Skiatook Lake (0376) and three private lakes (1016, 1240, and 4382) partially met the standard. Veterans Lake (4610) did not meet the standard. Two sites did not have dissolved oxygen data available (0152 and 1432). All other parameters were within OWQS.

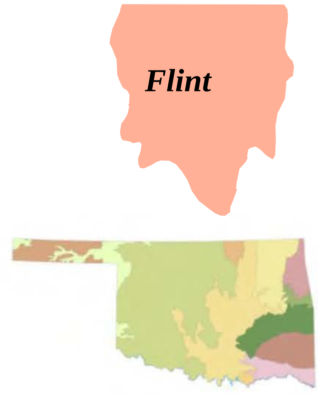
Table 8. Cross Timbers ecoregion parameter, use support, water quality standard and trophic state data

Ecoregion: Cross Timbers Overall					
Parameter	**n=**	**Ave.**	**High**	**Low**	**Use Support/Standard/Trophic Status**
Temp	196	25.2	37.8	13.0	N/A
pH	196	7.4	8.8	6.6	Meets Standard
Spc. Cond.	196	455.5	1628.0	90.0	N/A
DO (mg/L)	196 & 19	3.9	10.8	0.08	Does Not Support (1/20) Partially Supports (4/20) and Supports(15/20)
Chl-a (ug/L)	20	11.3	38.9	1.80	Eutrophic
TP (ug/L)	19	67.2	315.0	3.0	Eutrophic
TN (mg/L)	18	0.74	3.4	0.27	Oligotrophic
Turbidity (NTU)	20	15.4	23.5	2.0	Meets Standard
Secchi (m)	20	0.94	1.4	0.20	Eutrophic

Habitat Assessment

Fifty-three percent (10/19) of emergent and 41 % (7/17) of submergent macrophytes had rare coverage. Thirty-seven percent (7/19) emergent macrophytes and 47 % (8/17) submergent had sparse coverage. Five percent (1/19) of emergent and 12 % (2/17) of submergent macrophytes had moderate coverage. Five percent (1/19) of emergent macrophytes had extensive coverage. Overall, macrophytes were recorded at 16 % (3/19) density, 42 % (8/19) sparsity, 32 % (6/19) moderation, and 11 % (2/19) extensive coverage. Eurasian watermilfoil was observed in 22 of 179 sites within the littoral zone. The three sites that had these invasive species were Lake Fuqua (0152) and two private lakes (4382, 4828). No invasive species were observed for the shoreline (riparian) plot.

Flint Hills



"This ecoregion has lush, tall grass prairies. Dry upland forests are relatively short with open canopies. Bottomland forests form narrow borders along streams, which allows light to penetrate beneath the canopy, resulting in lush forest floor vegetation" (adapted from Oklahoma Conservation Commission, 2000).

Two sites fell within the Flint Hills ecoregion. Both were public lakes monitored by BUMP. They were Bluestem (NLA06608-0824) and Kaw (4320) Lakes.

Water Chemistry and Nutrients

The sites in this ecoregion were hypereutrophic according to total phosphorus, eutrophic according to Secchi depth data and mesotrophic according to chlorophyll-*a* and total nitrogen data (Table 9). All parameters were within OWQS.

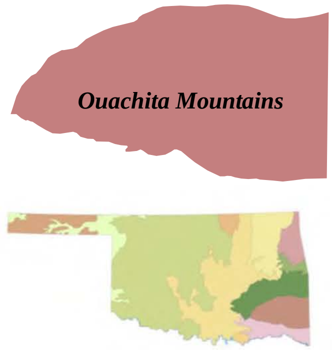
Table 9. Flint Hills ecoregion parameter, use support, water quality standard and trophic state data

Ecoregion: Flint Hills Overall					
Parameter	**n=**	**Ave.**	**High**	**Low**	**Use Support/Standard/Trophic Status**
Temp	31	26.1	27.5	19.7	N/A
pH	31	7.7	8.2	7.2	Meets Standard
Spc. Cond.	31	461.3	675.7	183.6	N/A
DO (mg/L)	31 & 2	3.8	6.3	0.08	Supports
Chl-*a* (ug/L)	2	4.4	6.2	2.50	Mesotrophic
TP (ug/L)	2	99.5	177.0	22.0	Hypereutrophic
TN (mg/L)	2	1.1	1.9	0.31	Mesotrophic
Turbidity (NTU)	2	9.1	11.2	7.1	Meets Standard
Secchi (m)	2	0.90	1.1	0.80	Eutrophic

Habitat Assessment

One hundred percent (2/2) of emergent and submergent macrophytes had rare coverage. Therefore, macrophytes overall were recorded as sparse. No invasive species were observed in this region.

Ouachita Mountains



"Over Seventy five percent of the area in the Ouachita Mountains is forested. The primary vegetation is hardwood pine forest. Steep mountains characterize the area, as well as valleys underlain by folded and faulted shale, slate, quartzite, sandstone and chert. Elevation ranges from 800 meters at the mountain tops to 100 meters at the lowest valleys" (adapted from Oklahoma Conservation Commission, 2000).

One site fell within the Ouachita Mountains ecoregion. That site was a privately owned lake (NLA06608-4414).

Water Chemistry and Nutrients

The site in this ecoregion was eutrophic according to chlorophyll-*a*, total phosphorus and Secchi depth data, and oligotrophic according to total nitrogen data (Table 10). All parameters were within OWQS.

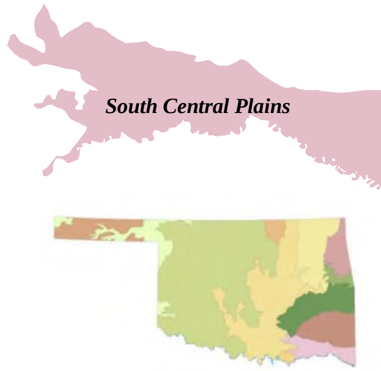
Table 10. Ouachita Mountains ecoregion parameter, use support, water quality standard and trophic state data

Ecoregion: Ouachita Mountains Overall					
Parameter	**n=**	**Ave.**	**High**	**Low**	**Use Support/Standard/Trophic Status**
Temp	5	29.1	30.7	26.3	N/A
pH	5	7.7	8.3	6.6	Meets Standard
Spc. Cond.	5	109.4	184.7	89.9	N/A
DO (mg/L)	5 & 1	5.8	9.1	0.20	Supports
Chl-*a* (ug/L)	1	12.1			Eutrophic
TP (ug/L)	1	38.0			Eutrophic
TN (mg/L)	1	0.5			Oligotrophic
Turbidity (NTU)	1	5.3			Meets Standard
Secchi (m)	1	0.88			Eutrophic

Habitat Assessment

One hundred percent (1/1) of emergent and submergent macrophytes had sparse coverage. One hundred percent of the overall macrophyte density was moderate. No invasive species were observed.

South Central Plains



"The South Central Plains ecoregion contains some of Oklahoma's most unusual biological communities and are found only in the southeast portion of the state. Moist upland forests dominate and these forests are tall with dense canopies. The shade is so dense in some stands that only ferns and other shade-tolerant plants can grow there. In natural stands, trees are of various ages and heights, and create layers of vegetation. Swamps are prevalent natural community in this ecoregion. They occur in low-lying areas along rivers and streams. Grassland communities are also found in this ecoregion. Forest and woodland openings are dominated by grass species. Pimple prairies, which are associated with mima mound topography, are a unique grassland type in this area" (adapted from Oklahoma Conservation Commission, 2000).

One site fell within the South Central Plains ecoregion. That site is a privately owned lake (NLA06608-0984).

Water Chemistry and Nutrients

The site in this ecoregion was hypereutrophic according to chlorophyll-*a* and Secchi depth data (Table 11). Nutrient samples were not available for this region. All parameters were within Oklahoma water quality standards.

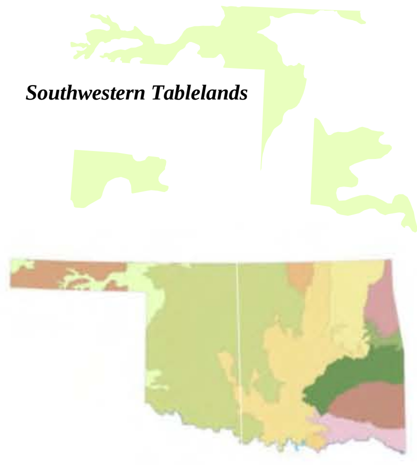
Table 11. South Central Plains ecoregion parameter, use support, water quality standard and trophic state data

Ecoregion: South Central Plains Overall					
Parameter	**n=**	**Ave.**	**High**	**Low**	**Use Support/Standard/Trophic Status**
Temp	4	26.8	26.8	26.7	N/A
pH	4	7.2	7.4	7.1	Meets Standard
Spc. Cond.	4	102.9	102.2	103.8	N/A
DO (mg/L)	4 & 1	3.6	4.7	0.89	Supports
Chl-a (ug/L)	1	32.6			Hypereutrophic
TP (ug/L)	N/A	N/A			N/A
TN (mg/L)	N/A	N/A			N/A
Turbidity (NTU)	1	21.9			Meets Standard
Secchi (m)	1	0.38			Hypereutrophic

Habitat Assessment

One hundred percent (1/1) of emergent and submergent macrophytes had sparse coverage. One hundred percent (1/1) of the overall macrophyte density was moderate. No invasive species were observed.

Southwestern Tablelands



"In Oklahoma, the shinnery oak scrub community is found only in this ecoregion. Shinnery oak forms dense, circular clumps called mottes. These trees reproduce by root suckering, so all the tress in a motte may be actually a single plant. Mixed grass prairie dominates other upland areas in most of the ecoregion, but gives way to shortgrass prairie in the Panhandle. Bottomland forests occur along rivers and streams and sand dunes occur along all major rivers in this ecoregion, especially along their northern banks."

Two sites fell within the Southwestern Tablelands ecoregion. Both sites are monitored by BUMP and include Carl Etling (NLA06608-4064) and Lloyd Vincent (3616).

Water Chemistry and Nutrients

The sites in this ecoregion were eutrophic according to total phosphorus, and Secchi depth data mesotrophic according to chlorophyll-*a* data and oligotrophic according to total nitrogen data (Table 12). All parameters were within OWQS.

Table 12. Southwestern Tablelands ecoregion parameter, use support, water quality standard and trophic state data

Ecoregion: Southwestern Tablelands Overall					
Parameter	**n=**	**Ave.**	**High**	**Low**	**Use Support/Standard/Trophic Status**
Temp	14	26.6	28.5	21.7	N/A
pH	14	7.9	8.2	7.3	Meets Standard
Spc. Cond.	14	805.5	863.1	774.3	N/A
DO (mg/L)	14 & 2	4.6	6.8	0.17	Supports
Chl-*a* (ug/L)	2	5.9	10.2	1.70	Mesotrophic
TP (ug/L)	2	30.6	47.0	15.0	Eutrophic
TN (mg/L)	2	0.61	0.77	0.46	Oligotrophic
Turbidity (NTU)	2	4.6	4.8	4.5	Meets Standard
Secchi (m)	2	1.1	1.3	0.31	Eutrophic

Habitat Assessment

One hundred percent (2/2) of emergent and submergent macrophytes had rare coverage. One hundred percent (2/2) of the overall macrophyte density was sparse. No invasive species were observed.

Summary

When looking at trophic state, state standards and use support indications, how did separated ecoregion data compare to the data as a whole? Overall indications are: that ecoregions are not the driving factor for the trophic state, the meeting of Oklahoma's Water Quality Standards and beneficial use support standards (Table 13). Looking at the data, there seems to be some indication that nutrient influx, not ecoregions, is the driving factor for the health of the lakes.

Lake assessments reported general conditions of the habitat and the reports focus was on emergent and submergent macrophyte percent coverage. A summarized view of overall habitat reporting in Table 14 shows that emergent plants are mostly rare or sparse except for the Boston Mountains. Submergent plants were rare or sparse except for the Boston Mountains, Central Great Plains, and the Cross Timbers. Overall macrophyte density was rare, sparse or moderate, except in the Central Great Plains and the Cross Timbers. Invasive species were only found in the Cross Timbers region.

Based on this data, the Boston Mountain, Central Great Plains and Cross Timber ecoregions indicate the greatest potential to provide habitat for fish and wildlife. Based on the presence of available habitat, these results would predict more robust fishery populations for the Boston Mountains, Cross Timbers and Central Great Plains ecoregions. Additional comparison with the macroinvertebrate, zooplankton, and phytoplankton data could provide additional insight into the impact of aquatic plant communities on littoral food web structure.

Table 13. Combined ecoregion parameter, use support, water quality standard and trophic state data

Ecoregion: Overall					
Ecoregion	**Parameter**	**Ave.**	**High**	**Low**	**Use Support/Standard/Trophic Status**
Arkansas Valley	DO (mg/L)	3.5	10.9	0.09	Does Not Support (2/3)/Supports (1/3)
Boston Mountains	DO (mg/L)	3.2	8.0	0.08	Supports/Partially Supports
Central Great Plains	DO (mg/L)	5.8	9.6	0.10	Partially Supports (3/21)/ Supports (18/21)
Central Irregular Plains	DO (mg/L)	7.0	10.7	5.40	Supports
Cross Timbers	DO (mg/L)	3.9	10.8	0.08	Does Not Support (1/20) Partially Supports (4/20) and Supports(15/20)
Flint Hills	DO (mg/L)	3.8	6.3	0.08	Supports
Ouachita Mountains	DO (mg/L)	5.8	9.1	0.20	Supports
South Central Plains	DO (mg/L)	3.6	4.7	0.89	Supports
Southwestern Tablelands	DO (mg/L)	4.6	6.8	0.17	Supports
Arkansas Valley	Chl-*a* (ug/L)	25.5	38.3	19.1	Hypereutrophic
Boston Mountains	Chl-*a* (ug/L)	5.7	6.4	4.9	Mesotrophic
Central Great Plains	Chl-*a* (ug/L)	36.1	114.6	1.70	Hypereutrophic
Central Irregular Plains	Chl-*a* (ug/L)		14.8		Eutrophic
Cross Timbers	Chl-*a* (ug/L)	11.3	38.9	1.80	Eutrophic
Flint Hills	Chl-*a* (ug/L)	4.4	6.2	2.50	Mesotrophic
Ouachita Mountains	Chl-*a* (ug/L)		12.1		Eutrophic
South Central Plains	Chl-*a* (ug/L)		32.6		Hypereutrophic
Southwestern Tablelands	Chl-*a* (ug/L)	5.9	10.2	1.70	Mesotrophic
Arkansas Valley	pH	7.0	8.2	6.5	Meets Standard
Boston Mountains	pH	7.8	8.6	6.5	Meets Standard
Central Great Plains	pH	8.0	9.8	6.8	Meets Standard
Central Irregular Plains	pH	7.7	8.4	7.4	Meets Standard
Cross Timbers	pH	7.4	8.8	6.6	Meets Standard
Flint Hills	pH	7.7	8.2	7.2	Meets Standard
Ouachita Mountains	pH	7.7	8.3	6.6	Meets Standard
South Central Plains	pH	7.2	7.4	7.1	Meets Standard
Southwestern Tablelands	pH	7.9	8.2	7.3	Meets Standard
Arkansas Valley	Secchi (m)	0.57	0.94	0.39	Eutrophic/High Algal Growth Potential
Boston Mountains	Secchi (m)	1.93*	N/A	N/A	N/A
Central Great Plains	Secchi (m)	0.4	>2.0	0.14	Hypereutrophic
Central Irregular Plains	Secchi (m)	0.56	0.83	0.30	Eutrophic/High Algal Growth Potential
Cross Timbers	Secchi (m)	0.94	1.4	0.20	Eutrophic/High Algal Growth Potential
Flint Hills	Secchi (m)	0.90	1.1	0.80	Eutrophic/High Algal Growth Potential
Ouachita Mountains	Secchi (m)		0.88		Eutrophic/High Algal Growth Potential
South Central Plains	Secchi (m)		0.38		Hypereutrophic/High Algal Growth Potential
Southwestern Tablelands	Secchi (m)	1.1	1.3	0.31	Eutrophic
					* Secchi Depth trophic state based on Carlson's Trophic Index
Arkansas Valley	Spc. Cond.	172.3	526.3	52.8	N/A
Boston Mountains	Spc. Cond.	203.8	273.7	80.1	N/A
Central Great Plains	Spc. Cond.	1031.6	8423.0	157.7	N/A
Central Irregular Plains	Spc. Cond.	218.6	233.0	190.1	N/A
Cross Timbers	Spc. Cond.	455.5	1628.0	90.0	N/A
Flint Hills	Spc. Cond.	461.3	675.7	183.6	N/A
Ouachita Mountains	Spc. Cond.	109.4	184.7	89.9	N/A
South Central Plains	Spc. Cond.	102.9	102.2	103.8	N/A
Southwestern Tablelands	Spc. Cond.	805.5	863.1	774.3	N/A
Arkansas Valley	Temp	24.2	31.8	16.4	N/A
Boston Mountains	Temp	24.3	34.6	12.9	N/A
Central Great Plains	Temp	25.6	30.7	15.9	N/A
Central Irregular Plains	Temp	28.8	31.5	28.3	N/A
Cross Timbers	Temp	25.2	37.8	13.0	N/A
Flint Hills	Temp	26.1	27.5	19.7	N/A
Ouachita Mountains	Temp	29.1	30.7	26.3	N/A
South Central Plains	Temp	26.8	26.8	26.7	N/A
Southwestern Tablelands	Temp	26.6	28.5	21.7	N/A
Arkansas Valley	TN (mg/L)	0.79	0.95	0.61	Eutrophic/High Algal Growth Potential
Boston Mountains	TN (mg/L)	0.34	0.42	0.26	Oligotrophic
Central Great Plains	TN (mg/L)	1.1	2.3	0.48	Mesotrophic
Central Irregular Plains	TN (mg/L)	0.51	0.62	0.40	Oligotrophic
Cross Timbers	TN (mg/L)	0.74	3.4	0.27	Oligotrophic
Flint Hills	TN (mg/L)	1.1	1.9	0.31	Mesotrophic
Ouachita Mountains	TN (mg/L)		0.5		Oligotrophic
South Central Plains	TN (mg/L)		N/A		N/A
Southwestern Tablelands	TN (mg/L)	0.61	0.77	0.46	Oligotrophic
					*Total Nitrogen trophic state based on Wetzel's Index Points
Arkansas Valley	TP (ug/L)	95.7	121.0	77.9	Eutrophic/High Algal Growth Potential
Boston Mountains	TP (ug/L)	16	21	11	Mesotropic
Central Great Plains	TP (ug/L)	162.6	619.4	14.1	Hypereutrophic/High Algal Growth Potential
Central Irregular Plains	TP (ug/L)	95.0	108.0	82.0	Eutrophic/High Algal Growth Potential
Cross Timbers	TP (ug/L)	67.2	315.0	3.0	Eutrophic/High Algal Growth Potential
Flint Hills	TP (ug/L)	99.5	177.0	22.0	Hypereutrophic/High Algal Growth Potential
Ouachita Mountains	TP (ug/L)		38.0		Eutrophic
South Central Plains	TP (ug/L)		N/A		N/A
Southwestern Tablelands	TP (ug/L)	30.6	47.0	15.0	Eutrophic
					*Total Phosphorus trophic state based on Carlson's Trophic Index
Arkansas Valley	Turbidity (NTU)	19.1	28.6	3.7	Meets Standard
Boston Mountains	Turbidity (NTU)	2.1	3.0	1.2	Meets Standard
Central Great Plains	Turbidity (NTU)	35.2	140.0	7.3	Does Not Meet Standard
Central Irregular Plains	Turbidity (NTU)	23.5	37.3	9.7	Meets Standard (1/2)/ Does Not Meet Standard (1/2)
Cross Timbers	Turbidity (NTU)	15.4	23.5	2.0	Meets Standard
Flint Hills	Turbidity (NTU)	9.1	11.2	7.1	Meets Standard
Ouachita Mountains	Turbidity (NTU)		5.3		Meets Standard
South Central Plains	Turbidity (NTU)		21.9		Meets Standard
Southwestern Tablelands	Turbidity (NTU)	4.6	4.8	4.5	Meets Standard

Table 14. Summarized overall habitat data by ecoregion

	AV	BM*	CGP	CIP	CT	FT	OM	SCP	ST
n=	**3**	**1/2**	**20/21**	**2**	**19**	**1/2**	**1**	**1**	**2**
Emergent Plants	Rare Sparse	Moderate	Rare Sparse	Rare Sparse	Rare Sparse	Rare	Sparse	Sparse	Rare
Submergent Plants	Rare	Moderate	Rare Extensive	Rare	Rare Sparse Extensive	Rare	Sparse	Sparse	Rare
Overall Macrophyte Density	Rare Sparse Moderate	Extensive	Rare Sparse Moderate Extensive	Rare Moderate	Rare Sparse Moderate Extensive	Sparse	Moderate	Moderate	Sparse
Invasive Species	None	None	None	None	Littoral Zone Eurasian watermilfoil 3 sites	None	None	None	None

Discussion

State of the State's Waters

The OWRB estimates there are approximately 3,056 lakes, ponds and reservoirs within the State of Oklahoma, with a cumulative surface area of approximately 671,777 acres. The Oklahoma State Lake Survey was able to assess conditions of all 3,056 waterbodies with some accuracy (±5percent). Extrapolation of OSLS to surface area should be performed cautiously, as only one sample was taken per waterbody with no accounting for seasonal or longitudinal variability. However, some extrapolations are possible. Application of the probabilistic scheme to Oklahoma's lake, pond, and reservoir population of ≥ 10 acres predicts the potential for:

- 28% impaired by low dissolved oxygen (depth profile)
- 35% impaired by excessive turbidity
- 50% as hypereutrophic
- 19% as nitrogen limited
- 4% as phosphorus limited

These results suggest some 1000 to 2500 total maximum daily loads (TMDLs) may be needed to address every potentially impaired lentic waterbody, while some 4 percent of the population has good potential for limited algae growth (phosphorus limited systems). Climate may be a large contributor to this troubling assessment of Oklahoma's lakes and ponds. With greater than 94% of the lakes, ponds and reservoirs within the target population in watersheds without point source discharges, it is evident that non-point source pollution is also a contributor to the nutrient rich conditions assessed.

The unusually wet 2007 summer sample season resulted in inflow and outflow volumes (some 30 times for central Oklahoma reservoirs) greater than normal. This is especially true for the sample months of June and September for Keystone and August for Skiatook Lake. The greatly reduced hydraulic residence time highlights a driving force behind OSLS sample results; high recharge increased the influx of nutrients and suspended solids. Higher than normal turbidity, lower than normal Secchi disk depth and higher percentages of nutrients support this idea. Comparisons of probabilistic data to the normal longitudinal data collected from Keystone Lake show a strong climatic (runoff driven) influence. While higher than normal flow biased much of the data, basic ecoregional differences were detected for physical parameters such as specific conductance. (These varied from 8,434 µS/cm in the northwest to 58 µS/cm in the southeast).

Data from the Oklahoma State Lake Survey suggest a large portion of Oklahoma's lakes, ponds and reservoirs experienced hypereutrophic productivity. Available data suggest that a relatively high proportion of Oklahoma's lakes were possibly light-limited. In general, aquatic plants were not common in the littoral zone of Oklahoma's lakes, ponds and reservoirs. Based on the habitat survey, the best fish communities are predicted within the Boston Mountains, Cross Timbers and Central Great Plains ecoregions. The unusually wet summer sample season, resulting in higher than normal rainfall and runoff, is a likely contributor to the particularly eutrophied waters sampled.

Probabilistic sampling in the summer of 2007 predicts some 60 % of Oklahoma lakes, ponds and reservoirs 10 acres or greater as phosphorus rich with a TP-TSI $\geq$ 60. Looking at the TP/TN ratio would lead one to extrapolate that approximately 4% of the state's lakes, ponds, reservoirs are phosphorus limited, 19% nitrogen limited and 64% co-limited. These support the conclusion of a phosphorus rich sample season. The expression of this nutrient rich environment was upheld with some 50% of the state as excessive algae growth (TSI 60+ chlorophyll-a). Another potential measure of excessive productivity would be the prediction that some 40% of the state's waters contained low levels of microcystin in the open water. Nutrient poorer waters would predict a low percentage of microcystin detected waters.

Approximately 35 % of the state is estimated to have had turbidity $\geq$ 25 nephelometric turbidity units (NTU), exceeding Oklahoma Water Quality Standards (OWQS). Additional sampling was needed to comply with Oklahoma's Use Support Assessment protocol (USAP) to determine whether beneficial uses were impaired by turbidity. One parameter measure, dissolved oxygen throughout the water column, did satisfy USAP and was able to determine impairments. Probabilistic sampling predicts 28 % of the states lakes, ponds and reservoirs would have failed the water column criteria for dissolved oxygen resulting in an impaired conclusion. One site had surface pH above OWQS, recorded at 9.8 compared to the standard maximum of 9.0. However, data from one site exceeding standards is not sufficient to make an impairment determination. Examination of percent saturation for dissolved oxygen indicated that excessive productivity is the likely reason for the high pH value.

Limitations

Several limitations to the probabilistic survey were noted. While a probabilistic survey presents a cost effective method to describe the entire state population, three primary considerations limit the application in Oklahoma: 1. representativeness (reconciliation to OWQS), 2. reporting the number of waterbodies verses acres to satisfy Integrated Report requirements, and finally, 3. weighting within the draw. Some of these limitations have been presented earlier; such as how limited sample size (one sample site and event) does little to allow for beneficial use assessment of individual lakes, ponds and reservoirs, while not accounting for seasonality (temporal consideration) nor is it adequate for waterbodies larger than 250 acres. Further limitations include longitudinal gradients and weighting.

Two run-of-the-river reservoirs were selected to compare the probabilistic sample design against the fixed station long-term data set. Comparisons were made to identify the potential for erroneous assignments by inferring water quality attributes at the dam to the entire surface area: i.e., not accounting for longitudinal gradients from the upper end to the dam of a reservoir. Comparisons using Keystone Reservoir and Skiatook Lake showed the probabilistic samples were inconsistent from the long term data. Overall, the comparison highlighted the effect of retention time on reservoir longitudinal gradients. The results also underscored the need to distribute sites throughout Oklahoma's large reservoirs. Without additional sample sites it was not possible to assess whether the one OSLS site results could be applied to just the lacustrine zone or to a greater proportion of the lake surface area (Table 2). This also points out the shortcoming of basing an assessment on the number of waterbodies verses the acres.

While the OSLS accounted for all lakes, ponds and reservoirs in Oklahoma this survey was not able to provide acreage of water in a given condition for the Integrated Report. To contrast, Oklahoma's fixed station lakes assessment program (BUMP) samples the largest,130 of the 9,770 lakes, ponds and reservoirs in the state. The efficiency of the fixed station sample scheme was to assess approximately 89% of the surface acres while only sampling ≥1.5% of the total number of lakes ponds and reservoirs in the state (Figure 1). Probabilistic sampling was seen as a cost effective method to approximate the assessment of the tens of thousands of smaller waterbodies across the state. Unfortunately, the first probabilistic survey of Oklahoma's lakes, ponds and reservoirs will be a bit suspect because of the number of lakes sampled in each weight category. In short, the category with the largest number of waterbodies was represented by the lowest number of samples. Figure 18 shows the distribution of Oklahoma's lakes, ponds and reservoirs by probabilistic category. Here approximately 85% of the population falls into the two smallest size categories, <10 acres and 10 – 50 acres. Unfortunately, the category with the largest weight ended up with the least number of sample sites, two (Figure 19). This resulted in the data from each of these two sites receiving a weighting factor of about 25%. Implications of this were highlighted when examining the turbidity results. One of the sites in the <10 acre size category had a turbidity of 25.1 NTU resulting in 35% estimate of the population exceeded OWQS for turbidity (Figure 20). Should the water quality sample have been 24.9, 0.2 NTU lower, for this site, the conclusion would have shifted to a 10% exceedance.

The potential for a shift based on disproportionate sampling argues against using the data results for prioritizing water quality management programs in Oklahoma until this issue is resolved. Future planning should incorporate a means to ensure proper distribution sample sites within all weighting categories.

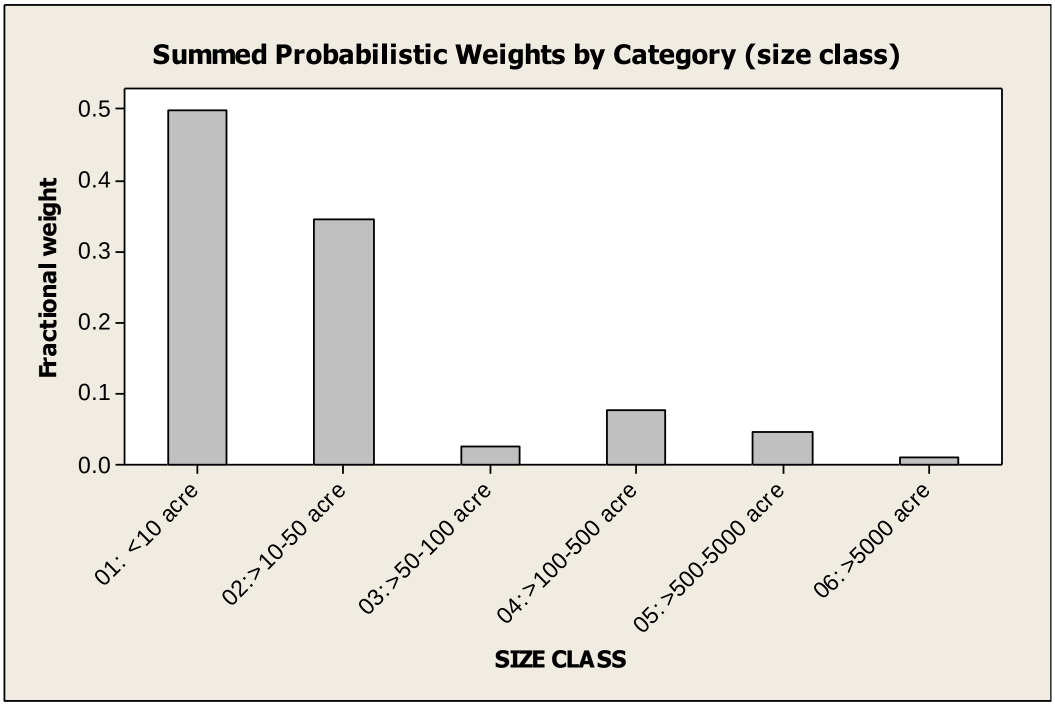


Figure 18. Weighting or percentage distribution of Oklahoma lakes, ponds and reservoirs by size class.

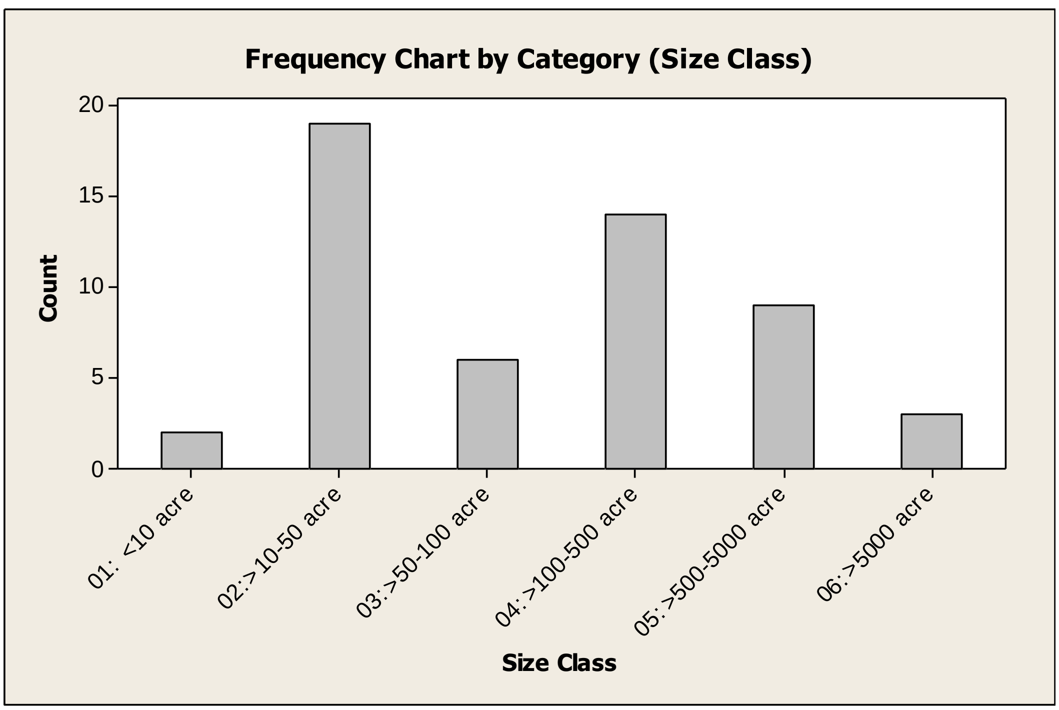


Figure 19. Number (distribution) of sample sites by size class for Oklahoma lakes, ponds and reservoirs.

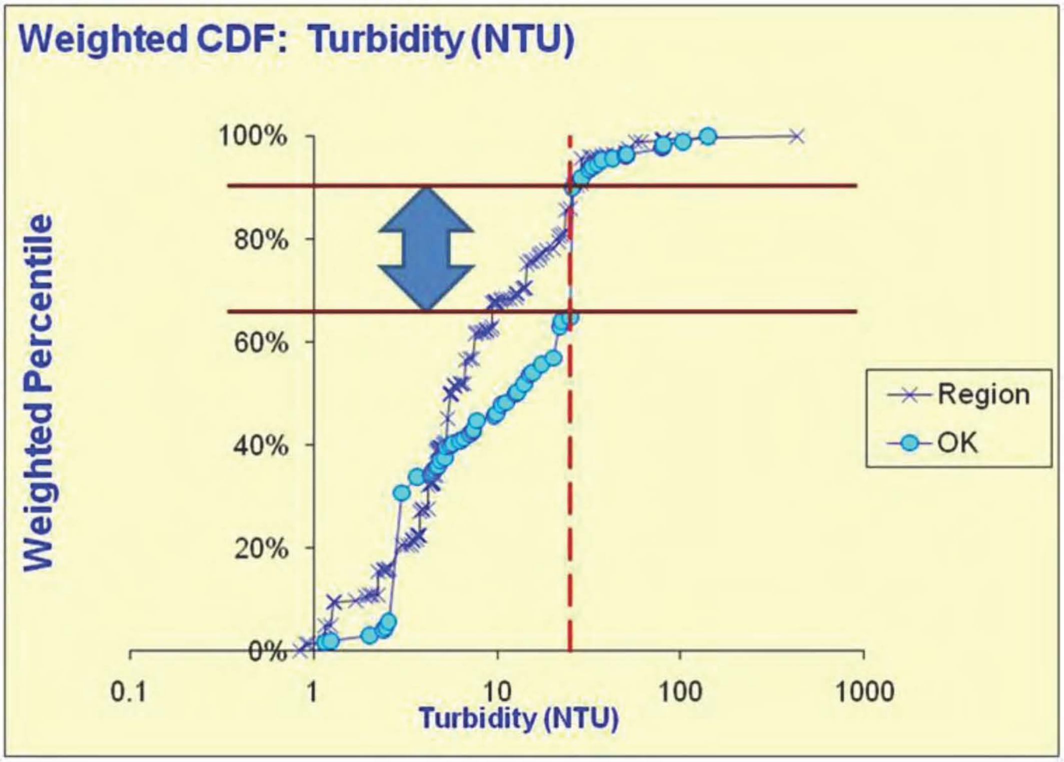


Figure 20. 2007 turbidity cumulative function distribution plot highlighting the uncertainty associated when a weighting category is under-represented. Regional (including Texas and Kansas with all Oklahoma) data have been represented for comparative purposes. Dashed vertical line represents Oklahoma Water Quality Standard of 25 NTU.

Outputs

- The state of Oklahoma performed its first assessment of all Oklahoma lakes, ponds and reservoirs ≥10 acres by sampling 53 sites within a probabilistic scheme at a cost of approximately $500,000
- First formal examination of water quality in Oklahoma lakes, ponds & reservoirs ≥10 acres by ecoregion
- The combination of the state and national survey also trained enough personnel to help in the design and implementation of a probabilistic program that includes biological parameters
- A broad based (physical, chemical and biological) data base has been established within the National Lakes Assessment enabling segregation of data by size, ecoregion, etc.
- Oklahoma’s Beneficial Use Monitoring Program BUMP) has now incorporated a probabilistic scheme to its lakes program

Outcomes

- A broad database with ecoregional data (including EPA regional neighbors) opens the door for development of nutrient and biological standards.
- Oklahoma water quality staff has utilized the compiled data set to examine and develop topics for the triennial review process.
- Illumination of how the current fixed assessment is bias toward flood control structures (for by area assessments) and bias against smaller pond and wetland like systems.
- Illuminates perhaps a larger WQ issue is with our rural water supply meeting disinfectant byproduct rules (a negative consequence of cultural eutrophication)
- The development of a protocol or criteria verses choosing one lake or static site for determining reference conditions has garnered consideration in view of Oklahoma's highly variable hydraulic regime.
- Highlights the importance for having a more complete lakes monitoring program to not only asses based on water chemistry but also upon the biota.
- The reliance upon two sites to describe 50% of the target population suggests the 2007 probabilistic results are not ready to directly influence prioritization of Oklahoma's water quality management programs.

Recommendations

The value of probabilistic survey was clearly demonstrated over the course of the project. Unfortunately, several issues detract from the results. These require addressing prior to implementing another statewide survey. The following lists perhaps the three most important detractors and potential means to address.

1. *A primary detractor was in the reliance of using two sites to effectively describe 50% of the target population. This has cast doubt upon the accuracy of Oklahoma State Lake Survey water quality results.* Perhaps the simplest action would be to coordinate with EPA's Office of Research and Development to determine a minimum sample number for the highest proportion of the sample population. An alternate venue could be to develop a hybrid sample scheme incorporating BUMP sampling of larger reservoirs representative of classic zonation while allocating probabilistic efforts to describe the more abundant and smaller size class of lakes and ponds.

2. *Another detractor was the selection of one site to represent the lake and a sample frequency of once during the season of peak productivity (summer).* Sample frequency should be expanded to include all 4 seasons hedging against climatic extremes in any one season. Using a 4 season sample frequency with a minimum of 5 sites per lake per sample event is needed to allow proper execution of USAP. While sampling to this degree would be cost prohibitive perhaps discussion within the State's informal water quality standards USAP workgroup could identify a means of providing preliminary beneficial use assessments on a categorical basis as opposed to an individual waterbody basis. Identifying a means to incorporate probabilistic lake sampling into a form of USAP would provide a long stride toward surface area (acres of a given condition) based assessments.

3. *Finally, the inability to translate survey results into acres of waters under a given condition, minimized survey value to CWA 303(d) and 305(b) reporting requirements*. There are several options to address. Some would require segregating BUMP fixed station sites between the three classic reservoir zones. Should one sample site be retained for the survey, results could be reported for the lacustrine zone only. Riverine zones could be aggregated to yield a picture of how this zone functions, and how this could be applied to the transition zone. Alternatively, adoption of a hybrid assessment scheme could expand the reporting ability by incorporating the probabilistic survey to provide a generic status descriptor for the smaller waterbodies that comprise 97.7% by count and 11% by surface area (not covered by the fixed stations). A critical issue for either suggestion would be how to yield a preliminary beneficial use assessment for the probabilistically sampled portion of the target population. Resolution of this issue would determine the value of survey results toward water quality management programs in Oklahoma.

However the probabilistic sample scheme is modified, it is critical that a relatively standardized scheme be employed to allow for consistent comparison between periods. Accomplishing this will allow results to directly impact Oklahoma water quality management programs.

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