Water Quality Conditions and Trends in the Chickasaw National Recreation Area, National Park Service: 1987 – 2009

EDWARDS AQUIFER RESEARCH & DATA CENTER

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Stephen D. Porter, Justin Kirk, and Glenn Longley

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Front cover photo: Travertine Creek at Travertine Nature Center

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by

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In cooperation with National Park Service, Southern Plains Network
Cooperative Agreement J2122080014
Robert Bennetts, PhD; Inventory and Monitoring Network Coordinator

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Summary

- Fundamental objectives of the National Park Service's Inventory and Monitoring Program ("vital signs") include developing an inventory of existing water quality data, establishing water quality benchmarks, identifying potential water quality problems and establishing a water quality database for each park. Chickasaw National Recreation Area (NRA) personnel have been monitoring the quality of streams, springs, and lakes in the NRA since 1987. However, a large percentage of the data were available only in written field journals and not readily available for review and analysis. This report presents a compilation of those data in digital format (CHIC_WQ.xls), an analysis of water quality conditions and trends based on those data, and recommendations for future monitoring activities.

- Major water resources in the NRA include Lake of the Arbuckles (Arbuckle Lake), Veterans Lake, and three streams that provide inflow to Arbuckle Lake (Buckhorn Creek, Rock Creek, and Guy Sandy Creek). Antelope Springs and Buffalo Springs are source waters of Travertine Creek, a major tributary to Rock Creek. Arbuckle Lake currently is on the Oklahoma Department of Environmental Quality's 303(d) list of impaired waters because of low dissolved-oxygen concentrations that may adversely affect warm-water aquatic communities.

- Water quality was monitored during two distinct periods of time, from 1987 to 1994 ("historical data" collected at 16 old sites), and from 2000 to 2009 ("recent data" collected at 13 new sites). Because of notable differences between historical and recent datasets at six sites in common, associated, in part, with differences in sampling frequency—year round (historical data) vs. warm-weather seasons (recent data)—as well as differences in median values for certain water quality constituents, datasets were analyzed separately.

- Median water temperature values were higher in the recent dataset than the historical dataset, whereas recent pH values were significantly lower than found in the historical dataset. Nitrate-nitrogen concentrations were orders of magnitude larger in the recent dataset when compared with historical data. These differences are most likely associated with differences in analytical methods: spectrophotometric used for the historical dataset, and a nitrogen probe to used obtain recent nitrate data that are regarded as unreliable.

- Analysis of historical (1987-94) data indicated good water quality conditions and a relative lack of water-quality trends. Annual median temperatures in Antelope, Buffalo, and Lowrance Springs (19.9^{o} C) were relatively consistent and higher than median annual temperatures in NRA streams (13.8^{o} C – 16.3^{o} C). By contrast, median pH values were significantly lower in the springs (7.3 – 7.4) than in streams (8.0 – 8.3).

- Specific conductance values were similar among springs and streams, with median values ranging from 500 μS/cm to 700 μS/cm. Sites with relatively larger specific conductance values are influenced by runoff from urban areas. Total alkalinity and hardness values were representative of relatively hard water, with median alkalinity ranging from 242 mg/L to 327 mg/L, and median hardness varying from 242 mg/L to 335 mg/L. Water turbidity generally was low, with medians ranging from about one nephelometric turbidity unit (NTU) in the springs to about 4 NTUs at most stream sites. Somewhat higher turbidity (9.3 NTUs) was observed at a Guy Sandy Creek site proximate to agricultural activities.

- Median dissolved oxygen (DO) concentrations were significantly higher in streams (6.4 mg/L – 9 mg/L) than in springs (0.6 mg/L – 4.6 mg/L). The frequency of departure from Oklahoma water quality standards (DO$\geq$5.0 mg/L) generally was low (less than 2.5% of all observations) except at several sites influenced by urban or agricultural runoff, where DO values less than 5 mg/L were observed in 10 to 29 percent of all observations at those sites.

- Median nutrient concentrations generally were low in comparison with national stream data reported by the U.S. Geological Survey's National Water Quality Assessment (NAWQA) Program. Median nitrate-nitrogen concentrations ranged from 0.11 mg/L to 0.69 mg/L, with slightly higher concentrations in springs than streams. Median total phosphorus concentrations varied from 0.1 mg/L to 0.2 mg/L, and were similar among spring and stream sites.

- Few temporal trends were observed in water-quality constituent values during 1987-94, although upstream-to-downstream differences in median nitrate concentrations were noted in Buckhorn Creek, as well as similar differences in median dissolved oxygen concentrations in Rock Creek. Minor increases in DO concentrations and water turbidity over time were noted in the Guy Sandy Creek basin.

- Analysis of recent (2000-09) data also indicated good water quality conditions in NRA streams, springs, and lakes. Median water temperatures were higher at lake sites (23.5^{o}C – 26.5^{o}C) than stream sites (22.3^{o}C – 23.7^{o}C), and cooler in the springs (17.9^{o}C). Water temperature appears to have increased at lake sites during the period of record; however, recent measurements of temperature have been restricted to warm weather months, potentially giving a false impression of increasing temperature trends.

- Median pH values reported during 2000-09 were lower (and more variable) than those observed during 1987-94. Median pH values were larger at lake sites (8.1 – 8.3) than in streams or springs (7.3 – 8.0). An unusual decline in pH values, followed by a return to expected values, was observed at all sites during the first half of the period of record. Reasons for this anomaly are poorly understood but could be a function of greater sample representation of cool season conditions during the early part of the period and (or) differences in instrumentation or sampling protocols. No significant trends for pH were noted during 2005-09.

- Median values for specific conductance were similar to those reported during 1987-94. Median values were lower at lake sites (306 µS/cm – 369 µS/cm) than at spring or stream sites 510 µS/cm – 780 µS/cm, and values for Veterans Lake were significantly lower than for Arbuckle Lake. Specific conductance values in Upper Guy Sandy Creek have decreased since 2006; however, no trends were noted at other stream sites.

- Median DO concentrations were similar among stream and lake sites; however, concentrations were significantly lower in the springs. Similar to pH values, an unusual decline of DO concentrations (followed by recovery) was observed during the first half of the period of record. Reasons for this anomaly may be similar to those speculated for pH. The frequency of departure from Oklahoma water quality standards was similar to that observed in the historical dataset, from nine percent to 26 percent of all observations at stream and lake sites. Although DO concentrations in Antelope Springs appear to have increased since 2006, median concentrations have remained relatively constant at most stream and lake sites.

- Although water turbidity has remained low in the springs, median values were somewhat higher in the recent dataset than in the historical dataset, particularly in Upper Guy Sandy Creek and Buckhorn Creek. Water turbidity at those sites appears to have increased during the past year (2009), whereas no trends were observed in other NRA streams.

- *Escherichia coli* (*E. coli*) bacteria are present in four swimming areas in the NRA, with median and geometric-mean values exceeding the Oklahoma water quality criterion of 126 colonies per 100 mL at Panther Falls and Black Sulfur. The criterion also was exceeded in more than 25 percent of samples collected from the Little Niagara and Bear Falls swimming areas.

- Considerations for improving water quality monitoring at NRA stream and lake sites include documented quality control and quality assurance procedures, measurement of selected indicators of eutrophication at lake sites (e.g. nutrient concentrations, continuous measurements of dissolved-oxygen concentrations, and phytoplankton abundance), and annual monitoring of macroinvertebrate (and possibly benthic algae) communities and habitat conditions at stream sites.

Acknowledgements

We commend Chickasaw National Recreation Area personnel for supporting a water quality monitoring program over the past 22 years. The value of routine monitoring data for documenting changes or trends in environmental conditions often is realized only in retrospect. We thank Steve Burrough (Natural Resource Program Manager) and Emily Clark (Hydrologic Technician) for supplying field records of historical data and Excel files of recent water quality data, including fecal-indicator bacteria data from swimming areas. We also thank Dr. Robert E. Bennetts, National Park Service Southern Plains Network coordinator, and Evan Gwilliam, National Park Service, Sonoran Desert Network ecologist, for overall support of this project. We thank Rene Barker, EARDC, Texas State University for assistance with obtaining precipitation data and several photos included in this report. Colleague reviews of a draft version of this manuscript by Rene Barker and ___________ improved the quality of this report and are much appreciated.

Introduction

Background

The National Park Service (NPS) has long recognized that the protection and restoration of its water resources and associated aquatic life is critical for the continued appreciation by park visitors. Fundamental components of the NPS's Inventory and Monitoring (I & M) Program are designed to "understand, maintain, restore, and protect the inherent integrity of the natural resources" (e.g. Perkins et al. 2005; 2006). Specific objectives of the I & M Program are to: (1) inventory existing water quality data, (2) establish water quality benchmarks, (3) identify potential water quality problems, and (4) establish a water quality database for each park. In 1993, the NPS's Water Resources Division initiated its Baseline Water Quality Data Inventory and Analysis Project to characterize baseline water quality information for every park with appreciable water resources.

Chickasaw National Recreation Area (NRA) is part of the NPS's Southern Plains Network (SOPN), one of the 32 networks included in the I & M Program and one of seven networks in the Intermountain Region of the NPS. A long-term monitoring program has been established for the 11 SOPN national park units in Colorado, Kansas, New Mexico, Oklahoma, and Texas. The program monitors ecological indicators, or ***vital signs***, to track conditions and (or) identify changes in relevant ecosystems within or near park boundaries (http://www.nature.nps.gov/im/units/sopn/monitoring.cfm). Vital signs are key conditions or processes that most effectively indicate the health of ecosystems (Perkins et al. 2006), including water-resource features such as chemical, biological, and physical indicators of condition and trends. Examples of vital-sign constituents monitored by SOPN park units include water temperature, pH, dissolved oxygen concentrations, specific conductance, and *Escherichia coli* (*E. coli*) bacteria in surface and ground water resources.

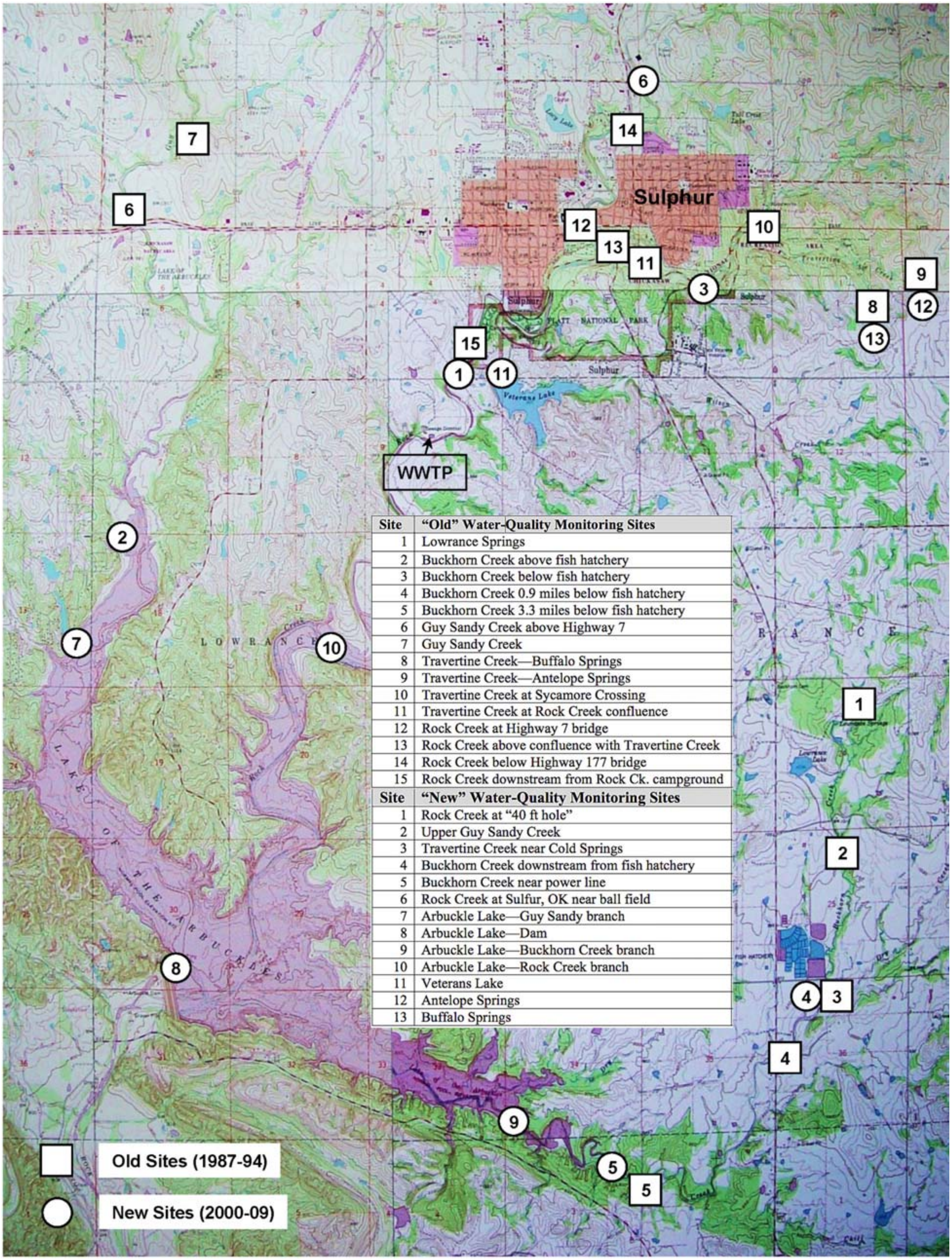
A review of water-resource monitoring activities in parks within the SOPN Network was conducted by water-quality scientists from the Edwards Aquifer Research & Data Center (EARDC 2007) at Texas State University in San Marcos, TX. Analysis of available data for Chickasaw NRA revealed elevated levels of fecal-coliform bacteria in Rock Creek and Travertine Creek, and reports of "significant eutrophication" in the Lake of the Arbuckles and inflow tributaries; however, considerable water-quality monitoring data were available only in field reports and not available for analysis during the review (EARDC 2007). This report presents a compilation of those previously unanalyzed data in digital format, an analysis of water-quality conditions and trends based on those data, and recommendations for future monitoring activities. A similar study for the Pecos National Historical Park was conducted by Porter and Longley (2009).

Study Area

Chickasaw NRA was established in 1906 to protect unique recreational, cultural, and aquatic resources—including streams, lakes, and both freshwater and highly mineralized springs. The NRA includes 15.5 square miles (9,889 acres) of the Arbuckle Mountain geographic region (Red River drainage basin) in south-central Oklahoma, a relatively short drive from two major metropolitan areas, Oklahoma City (90 miles) and Dallas-Fort Worth (120 miles). The NRA lies within a transition zone between Eastern deciduous forests and Western prairies in the Subtropical Humid climatic zone, a warm continental climate characterized by hot humid summers, with maximum temperatures in the upper 90s (^{o}F), and cool winters with minimum temperatures in the low 20s. Annual precipitation varies from 18.9 (1963) to 64.3 (1990) inches per year (115-year mean = 37.7 inches), with the majority falling during summer. Land cover in the basin primarily is agricultural or forested; the town of Sulphur, OK (population 4,838 in 2008) is located on the northern boundary of the NRA (Fig. 1).

Major surface water resources in the NRA include the Lake of the Arbuckles (Arbuckle Lake; surface area of 3,130 acres), Veterans Lake (64 acres), and three streams that provide inflow to Arbuckle Lake: Guy Sandy Creek, forming the northwestern branch of the lake; Rock Creek, forming the northern branch; and Buckhorn Creek, forming the southeastern branch of the lake (Fig. 1). Travertine Creek, a tributary to Rock Creek is another significant surface-water resource in the NRA. Pool reaches of these streams, such as Little Niagara, Bear Falls, Panther Falls, and Black Sulfur, are used as public swimming areas. The Sulphur, Oklahoma wastewater-treatment plant (WWTP) discharge is located on Rock Creek downstream from the Chickasaw NRA campground. Arbuckle Lake, a recreational and flood-control reservoir constructed by the U.S. Bureau of Reclamation during the mid-1960s, as well as Veterans Lake, provide drinking-water supplies for the park as well as several small towns in the region (Hanson and Cates 1994). Recreational uses of Arbuckle and Veterans Lakes include fishing, swimming, and boating. Arbuckle Lake currently (2010) is on the Oklahoma Department of Environmental Quality’s 303(d) list of impaired waters because of low dissolved oxygen concentrations that may adversely affect warm-water aquatic communities.

Major groundwater resources for which water quality data were available include Antelope and Buffalo Springs (source waters for Travertine Creek) and Lowrance Springs (source waters for Buckhorn Creek). Numerous other springs and wells exist in the Chickasaw NRA, including Sulphur Bromide Spring, Bromide Spring, Medicine Spring, Hillside Spring, Pavilion Spring, Black Sulphur Spring, and various wells and unnamed springs (refer to EARDC 2007, Table CHIC; Figs. CHICa-c).



Site	"Old" Water-Quality Monitoring Sites
1	Lowrance Springs
2	Buckhorn Creek above fish hatchery
3	Buckhorn Creek below fish hatchery
4	Buckhorn Creek 0.9 miles below fish hatchery
5	Buckhorn Creek 3.3 miles below fish hatchery
6	Guy Sandy Creek above Highway 7
7	Guy Sandy Creek
8	Travertine Creek—Buffalo Springs
9	Travertine Creek—Antelope Springs
10	Travertine Creek at Sycamore Crossing
11	Travertine Creek at Rock Creek confluence
12	Rock Creek at Highway 7 bridge
13	Rock Creek above confluence with Travertine Creek
14	Rock Creek below Highway 177 bridge
15	Rock Creek downstream from Rock Ck. campground
Site	**"New" Water-Quality Monitoring Sites**
1	Rock Creek at "40 ft hole"
2	Upper Guy Sandy Creek
3	Travertine Creek near Cold Springs
4	Buckhorn Creek downstream from fish hatchery
5	Buckhorn Creek near power line
6	Rock Creek at Sulfur, OK near ball field
7	Arbuckle Lake—Guy Sandy branch
8	Arbuckle Lake—Dam
9	Arbuckle Lake—Buckhorn Creek branch
10	Arbuckle Lake—Rock Creek branch
11	Veterans Lake
12	Antelope Springs
13	Buffalo Springs

Figure 1. Names and locations of water-quality monitoring sites in Chickasaw NRA.

Water Quality Monitoring

Monitoring Activities

Water quality was monitored in the Chickasaw National Recreation Area during two distinct periods of time. The first monitoring period began during 1987 (from March 8 to July 24, depending on the site location) and ended on March 4, 1994. The data were recorded in a series of field journals, identified by "Thomas M. Taylor, Resource Management Specialist, Chickasaw NRA," that were provided by Steve Burrough, the current Natural Resource Program Manager (Steve_Burrough@nps.gov). Water-quality data for 12 constituents measured at 16 sites were entered into spreadsheet format (CHIC_WQ.xls), a supplemental file associated with this report. Water-quality constituents available from this dataset include water temperature (WT), pH, specific conductance (COND), turbidity (TURB), and concentrations of the following variables: dissolved oxygen (DO), total alkalinity (TALK), total hardness (HARD, dissolved ammonia nitrogen (NH_3), dissolved nitrite nitrogen (NO_2), dissolved nitrate nitrogen (NO_3), total phosphorus (PO_4), and dissolved sulfate (SO_4). Analytical methods were not specified in the field journals; however, standard field meters and spectrophotometric methods were presumed to have been used in the study (Steve Burrough, personal communication). Locations of 15 monitoring sites, based on narrative descriptions in the field journals and (or) information in NPS records (Table 1, Other ID; refer to EARDC 2007), were plotted on U.S. Geological Survey 1:24,000 topographic maps (Fig. 1); latitudes and longitudes of those sites can be found in Table 1. Site 16, "Rock Creek at Jumas Ranch Road crossing," could not be located with certainty so it does not appear in Figure 1 or Table 1; however, a summary of data for this site is presented in this report. Collectively, these sites are referred to as "old sites."

Table 1. List of "old" water-quality monitoring sites in Chickasaw NRA (1987-94).

Site	Water Body	Latitude	Longitude	Other ID
1	Lowrance Springs	34.458338	-96.938893	CHIC0044
2	Buckhorn Creek above fish hatchery	34.445699	-96.942671	CHIC0037
3	Buckhorn Creek below fish hatchery	34.433838	-96.943892	CHIC0030
4	Buckhorn Creek 0.9 miles below fish hatchery	34.426170	-96.950503	CHIC0017
5	Buckhorn Creek 3.3 miles below fish hatchery	34.414226	-96.967809	CHIC0006
6	Guy Sandy Creek above Highway 7	34.506871	-97.034353	CHIC0144
7	Guy Sandy Creek	34.515281	-97.027740	CHIC0147?
8	Travertine Creek—Buffalo Springs	34.502587	-96.939004	CHIC0088
9	Travertine Creek—Antelope Springs	34.504670	-96.941031	CHIC0128
10	Travertine Creek at Sycamore Crossing	34.503948	-96.955476	CHIC0108
11	Travertine Creek at Rock Creek confluence	34.504313	-96.970993	------------
12	Rock Creek at Highway 7 bridge	34.506587	-96.975920	CHIC0144
13	Rock Creek above confluence with Travertine Creek	34.504420	-96.971087	CHIC0119
14	Rock Creek below Highway 177 bridge	34.515616	-96.968616	CHIC0149
15	Rock Creek downstream from Rock Ck. campground	34.492641	-96.991696	------------

The second monitoring period considered for this report began during 2000 (between March 8 and July 24, depending on the site), and continued through August 25, 2009. The data were reported in a series of Excel spreadsheet files provided by Emily Clark, a hydrologic technician at Chickasaw NRA (Emily_E_Clark@nps.gov), and are included in the supplemental file associated with this report (CHIC_WQ.xls). Water quality constituents available in this dataset include eight variables, including WT, pH, COND, TURB, DO, percentage of oxygen saturation (DOSAT), total dissolved solids (TDS, a meter reading based on COND), and NO_3 for 13 sites, hereafter referred to as "new sites" (Fig. 1; Table 2). All measurements were conducted with field meters (specify?). Nitrate concentrations were measured with a nitrogen probe (model?). According to Chickasaw NRA personnel, considerable problems were encountered with the calibration and use of the nitrogen probe (Steve Burrough, pers. comm.). Descriptions and locations of the new monitoring sites, in addition to a correspondence between old and new site numbering systems, were provided by Emily Clark and are presented in Figure 1 and Table 2. In addition, water samples are analyzed for *Escherichia coli* (*E. coli*) bacteria, using the Colilert© method, at four recreational areas: Little Niagara, Bear Falls, Panther Falls, and Black Sulphur (Emily Clark, digital communication).

Table 2. List of "new" water-quality monitoring sites in Chickasaw NRA (2000-09).

Site	Water Body	Latitude	Longitude	Old Site
1	Rock Creek at "40 ft hole"	34.491406	-96.992628	~ 15
2	Upper Guy Sandy Creek	34.475419	-97.033097	-----
3	Travertine Creek near Cold Springs	34.500700	-96.960922	~ 10
4	Buckhorn Creek downstream from fish hatchery	34.433947	-96.944218	~ 3
5	Buckhorn Creek near power line	34.415398	-96.972338	~ 5
6	Rock Creek at Sulfur, OK near ball field	34.520648	-96.966770	~ 14
7	Arbuckle Lake—Guy Sandy branch	34.466505	-97.040949	-----
8	Arbuckle Lake—Dam	34.435673	-97.027860	-----
9	Arbuckle Lake—Buckhorn Creek branch	34.420239	-96.983979	-----
10	Arbuckle Lake—Rock Creek branch	34.466019	-97.007282	-----
11	Veterans Lake	34.492003	-96.986527	-----
12	Antelope Springs	34.504631	-96.940192	9
13	Buffalo Springs	34.502567	-96.938947	8

Annual Precipitation during Monitoring Periods

Differences in water quality conditions often occur when years of drought are compared to those with above-average rainfall and runoff. Similarly, differences in stream flow or discharge can influence water quality conditions measured at monitoring sites because of relative differences in the proportion of groundwater discharges relative to erosion and runoff from land surfaces following rainfall events. No continuous streamflow or precipitation monitoring is conducted in the Chickasaw NRA. Annual precipitation for the area was estimated using PRISM data obtained from Oregon State University (http://prism.oregonstate.edu/). The PRISM model uses rainfall data reported from regional atmospheric-monitoring locations with a statistical kriging process to generate an estimate of annual precipitation for a specific location (e.g. for Sulphur, OK) over a long-term period of record (1895 to present; Appendix, Fig. 41). Estimated annual precipitation during the Chickasaw water quality monitoring period is shown in Figure 2. With the exception of 1988, annual precipitation generally was above the long-term mean during 1987-2002. Rainfall has been highly variable since 2000, was above average during 2000-02, 2004, 2007, and 2009 and below average during 2003, 2005-06, and 2008.

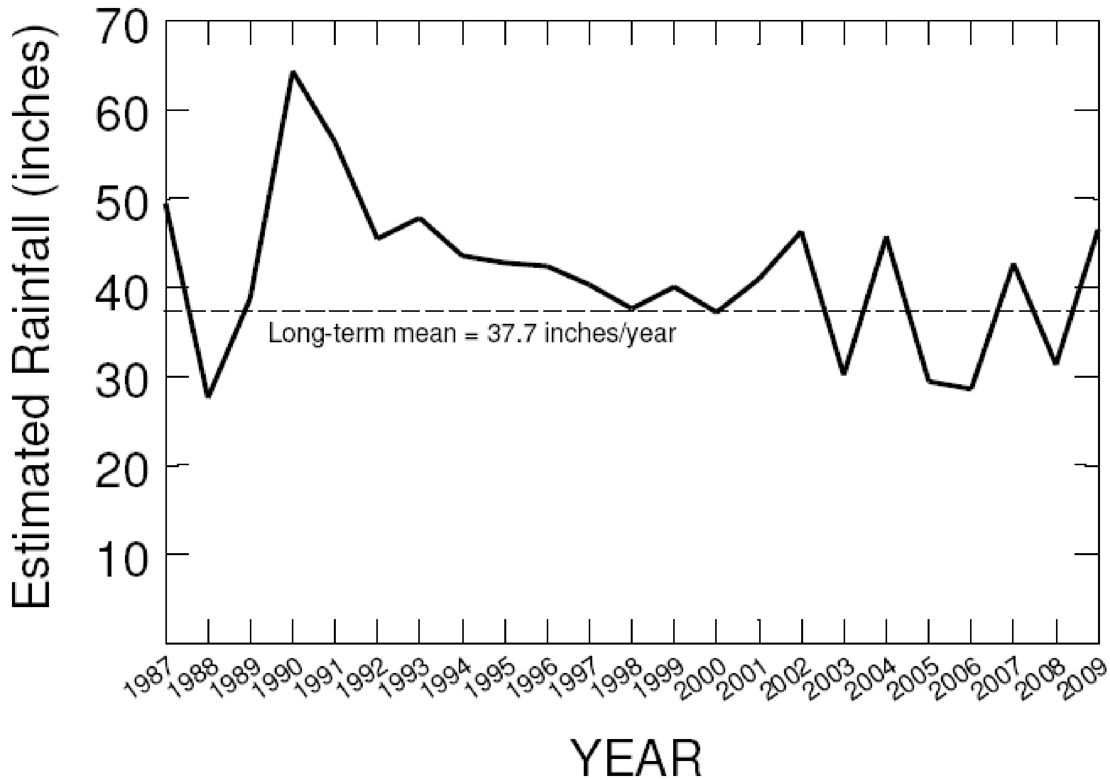


Figure 2. Estimated rainfall during period of water-quality monitoring.

Comparison of Water Quality Monitoring Periods of Record

Boxplot graphs were used to compare median values and interquartile ranges for constituents and sites reported in both periods of record, where "OLDSITEs" represent the database from monitoring during 1987-94 and "NEWSITEs" represent the database from monitoring during 2000-09. Median values for water temperature were higher at all sites in common for the most recent period of record (2000-09) compared with the historical (1987-94) dataset, whereas recent median pH values were lower than historical median values (Figs. 3 and 4). Although the differences observed between historical and recent values could represent changes in water quality between the periods of record, it appears more likely that these results reflect differences associated with year-round monitoring, historically, and monitoring primarily during warm-weather seasons samples more recently. Differences in pH values may be associated with monitoring protocols.

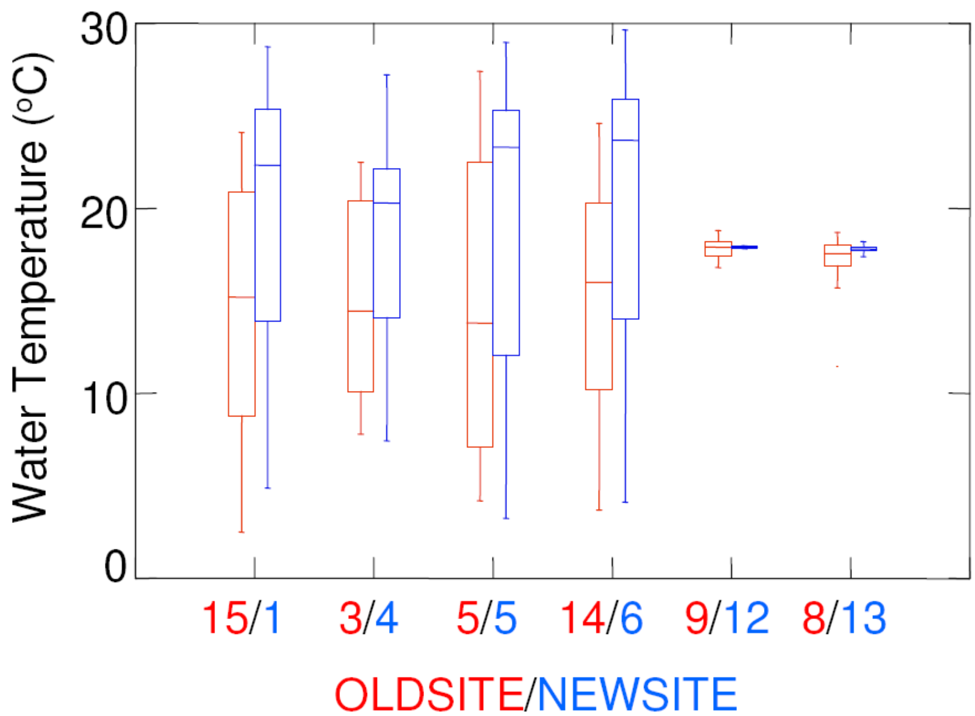


Figure 3. Comparison of historical (red) and recent (blue) monitoring data for water temperature. Refer to Tables 1 and 2 for old and new site descriptions.

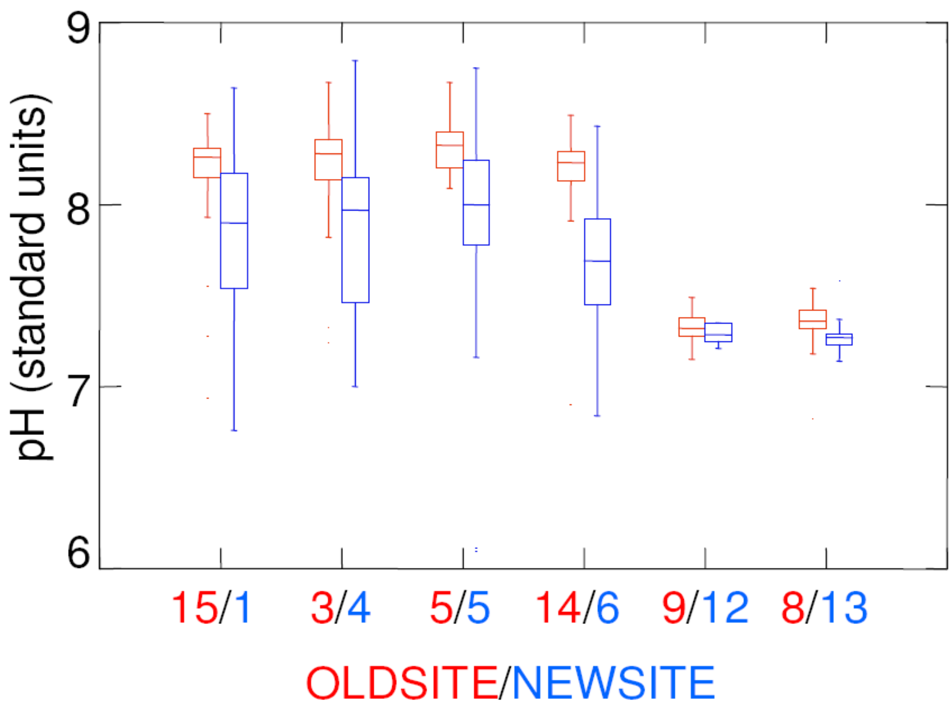


Figure 4. Comparison of historical (red) and recent (blue) monitoring data for pH. Refer to Tables 1 and 2 for old and new site descriptions.

Median dissolved-oxygen (DO) concentrations generally were similar between historical and recent data; however, recent DO values for Antelope Springs (Fig. 5, sites 9/12) and Buffalo Springs (Fig. 5, sites 8/13) were significantly higher (and with greater variance) than in the historical database. Values for specific conductance and turbidity were in a similar range in the historical and recent databases; however, median values for nitrate-nitrogen NO_3 concentrations were considerably higher (and with greater variance) in the recent database than observed in the historical database. Average NO_3 concentrations at stream and lake sites in the recent dataset varied from about 5 mg/L to 16 mg/L (maximum concentrations from 35 mg/L to 95 mg/L), whereas average and maximum ranges of NO_3 concentrations in the historical dataset were 0.11 to 0.69 mg/L and 0.17 to 0.98 mg/L, respectively (refer to Tables 4 and 5). By comparison, median NO_3 concentrations reported by the U.S. Geological Survey's National Water Quality Assessment (NAWQA) Program for thousands of analyses of water from streams and lakes across the U.S. were about 0.7 mg/L. We conclude that recent NO_3 data reported for water bodies in Chickasaw NRA are unreliable due to the method used for obtaining these data (nitrogen probe), and that standard analytical methods should be considered for measuring nutrient concentrations in future monitoring activities.

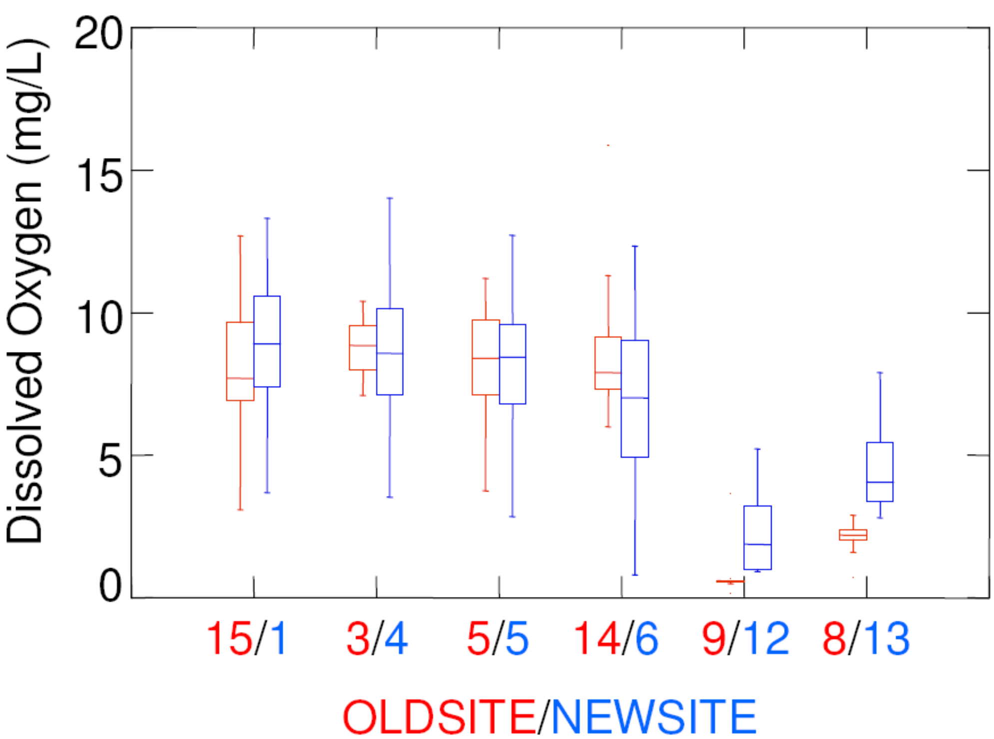


Figure 5. Comparison of historical (red) and recent (blue) monitoring data for dissolved oxygen. Refer to Tables 1 and 2 for old and new site descriptions.

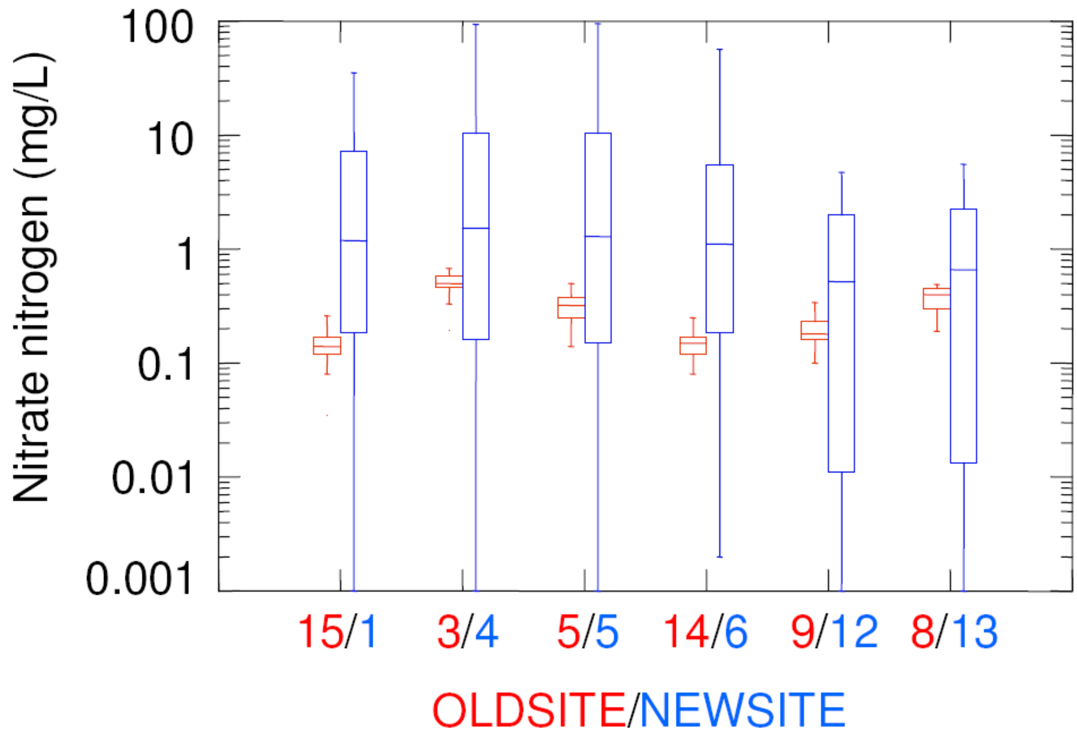


Figure 6. Comparison of historical (red) and recent (blue) monitoring data for nitrate nitrogen. Refer to Tables 1 and 2 for old and new site descriptions.

Because of the disparity in historical and recent study designs (for example, design of the monitoring network), comparison of historical and recent data, lack of written collection and quality-assurance protocols, and the long period of separation between datasets (over six years), we elected to treat the historical and recent datasets as separate populations of data rather than combine the datasets for trend analyses. Advantages of this approach are that, because of differences in monitoring-network design and constituents monitored, water quality conditions and trends in streams that discharge to Arbuckles Lake can be more thoroughly assessed (historical data set) and conditions at lake sites may be compared with those at stream sites (recent data set).

Water Quality Conditions and Trends

Approach

Statistical summaries of water quality data were generated for each constituent and site; the summaries are presented in the Appendix, Table 4 (historical data) and Table 5 (recent data). Water quality trends were evaluated using a graphical model, LOWESS (Cleveland 1979, 1981; Cleveland and Devlin (1988). LOWESS, also known as locally weighted regression analysis or locally weighted scatterplot smoothing, is a modeling method based on linear and nonlinear least-squares regression. LOWESS combines much of the simplicity of linear least-squares regression with the flexibility of nonlinear regression. It does this by fitting simple models to localized subsets of the data to derive a function that describes the deterministic part of variation in the data, point by point. One of the primary attractions of this method is that a global function is not required to fit a specific LOWESS model to the data. A polynomial function is fit to the data using weighted least-squares regression, giving greater weight to data points near where the response is being estimated and lesser weight to data points further away. For the trends produced in this report, a "tension factor" of 0.5 was used. All statistical and graphical results were produced with SYSTAT v. 11 (SYSTAT Software, Inc. 2004). LOWESS trend lines were plotted by stream basin (historical data for "old" sites) or by water-body type (e.g. streams or lakes; recent data for "new" sites) to show differences in condition among sites over time.

Historical Water Quality Conditions at "OLD" sites (1987-94)

Water quality data are available for three major stream basins that provide inflow to Arbuckles Lake: Buckhorn Creek, Rock Creek, and Guy Sandy Creek (Fig. 1). Lowrance Springs (Old Site 1) is located in the Buckhorn Creek basin, whereas Buffalo and Antelope Springs (Old Sites 8 and 9, respectively, are located in the Rock Creek basin.

Buckhorn Creek Basin

A statistical summary for the five monitoring sites in the Buckhorn Creek basin can be found in Table 4. Median water temperature in Lowrance Spring, the source waters for Buckhorn Creek, was a relatively constant 17.9^{o} C throughout the period of record (Fig. 7) with little seasonal variability (mean=18^{o} C, standard deviation=0.6^{o} C). Median water temperature at downstream sites varied from 15.2^{o} C at site 2 (above the fish hatchery) decreasing in a downstream direction to 13.8^{o}C at site 5 (3.3 miles below the fish hatchery). No significant trend was noted in water temperature at any site; however, median downstream decreases in temperature were more observable during the beginning and end of the period of record than during 1989-92 (Fig. 7). Median pH values (Table 4, Fig. 8) varied from 7.4 in Lowrance Springs to 8.3 at sites 3-5, with slightly lower median pH (8.2) at site 2. No significant differences were noted among sites 2-5 through the period of record. Median specific conductance for sites in the Buckhorn Creek basin ranged from 534-583 μS/cm (Table 4; Fig. 9) and no significant differences were noted among sites through the period of record. Dissolved oxygen (DO) concentrations generally were low in Lowrance Springs (median=4.6 mg/L), whereas concentrations at sites downstream generally were favorable for aquatic life, with median values ranging from 8.4 mg/L at site 5 to 9 mg/L at site 4, below the fish hatchery. With the exception of Lowrance Springs, the frequency of departures from Oklahoma water-quality standards (DO less than 5 mg/L) was low, less than 2.5 percent of all samples. No significant differences were noted among sites 2-5 through the period of record (Fig. 10).

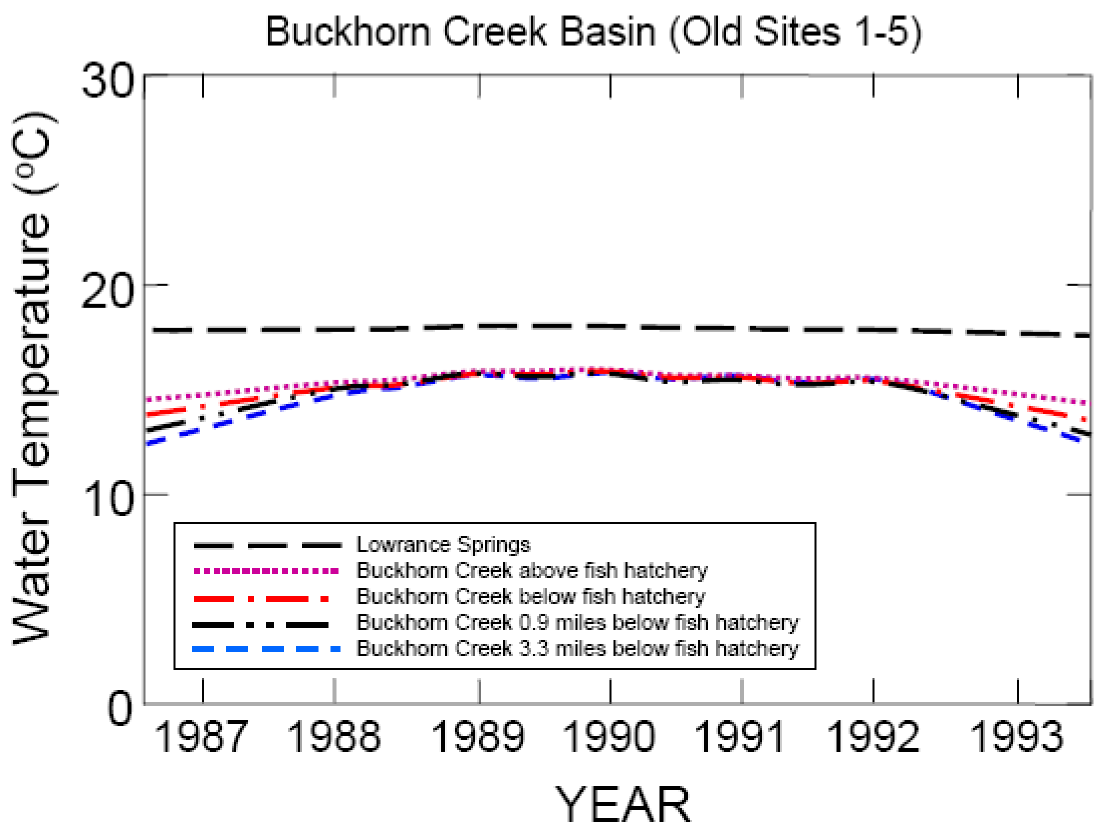


Figure 7. LOWESS trend lines for water temperature in the Buckhorn Creek basin.

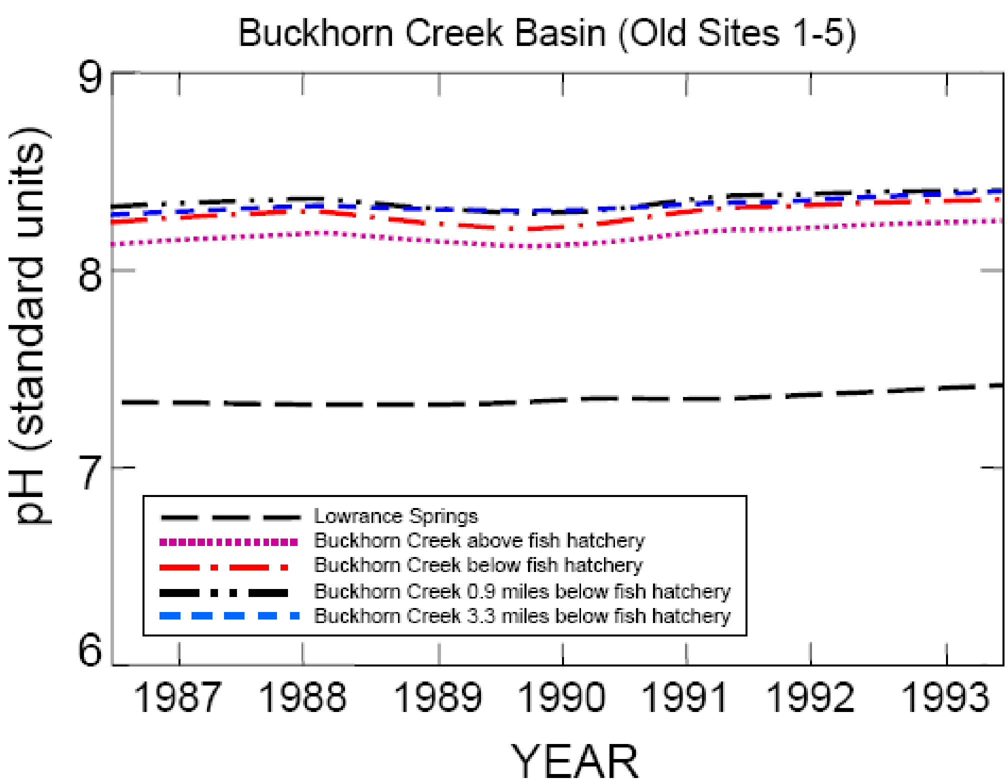


Figure 8. LOWESS trend lines for pH in the Buckhorn Creek basin.

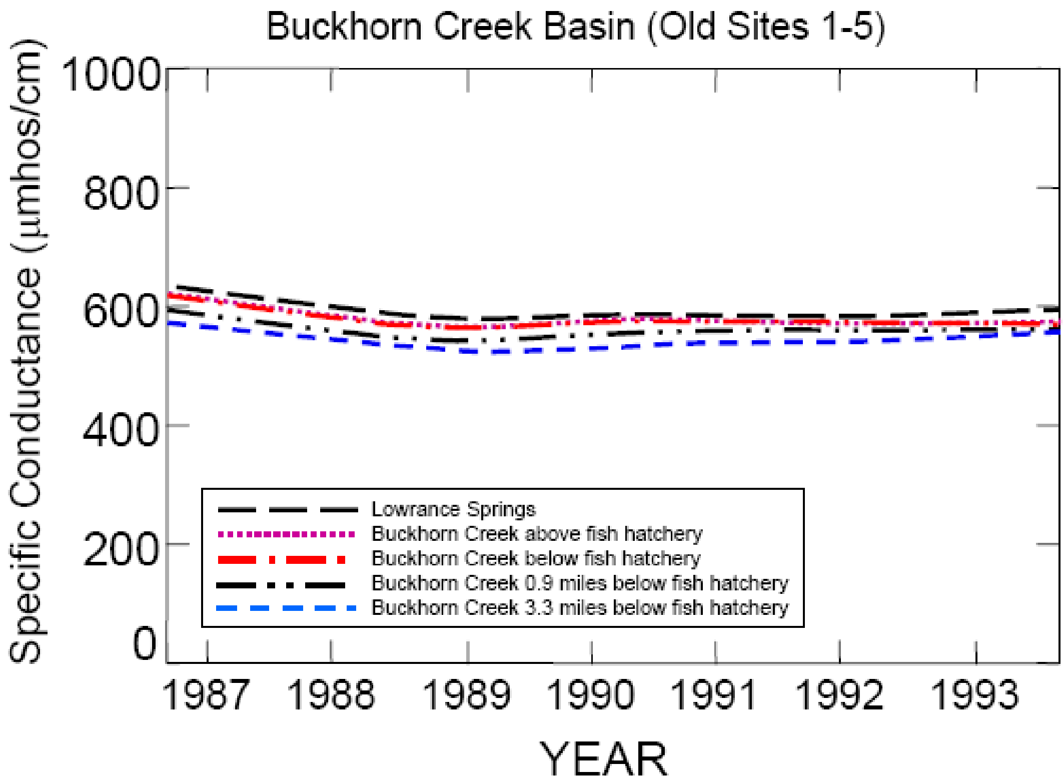


Figure 9. LOWESS trend lines for specific conductance in the Buckhorn Creek basin.

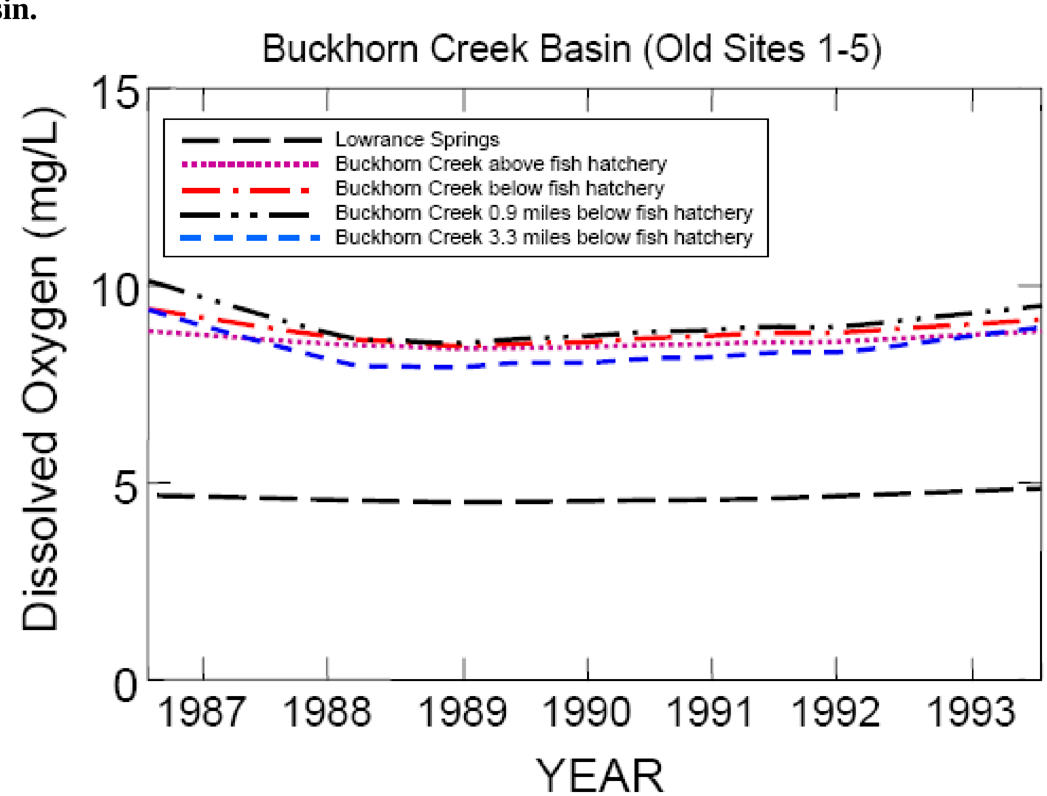


Figure 10. LOWESS trend lines for dissolved oxygen in the Buckhorn Creek basin.

Turbidity generally was low at sites in the Buckhorn Creek basin, whereas total alkalinity and hardness were relatively high. Median turbidity values ranged from 1.1 nephelometric turbidity units (NTUs) at Lowrance Springs to about 4.7 NTUs at sites downstream from the fish hatchery (Table 4). Median total alkalinity values ranged from 283 mg/L to 327 mg/L, with concentrations decreasing from Lowrance Springs downstream. Median total hardness concentrations varied from 297 mg/L to 336 mg/L, indicating relatively hard water. Median sulfate (SO_4) concentrations were relatively low, ranging from 14 mg/L to 17 mg/L (Table 4). No significant differences among sites or trends in turbidity, total alkalinity, hardness, or sulfate were noted.

Nutrient concentrations generally were low in the Buckhorn Creek basin; however, concentrations of nitrate nitrogen (NO_3) were somewhat larger than sites in other Chickasaw NRA stream basins. Median concentrations of ammonia nitrogen (NH_3) varied from 0.04 mg/L at Lowrance Springs to 0.10 mg/L below the fish hatchery (site 3; Table 4). Nitrite-nitrogen (NO_2) concentrations were low throughout the basin, with median values of about 0.002 mg/L. Median NO_3 concentrations were highest at Lowrance Springs (Table 4, 0.69 mg/L) and decreased with distance downstream to 0.32 mg/L at site 5 (Fig. 11). Total phosphorus (PO_4) concentrations were relatively low, varying from 0.15 mg/L upstream to 0.10 mg/L downstream (Fig. 12). No temporal trends in any nutrient concentrations were observed.

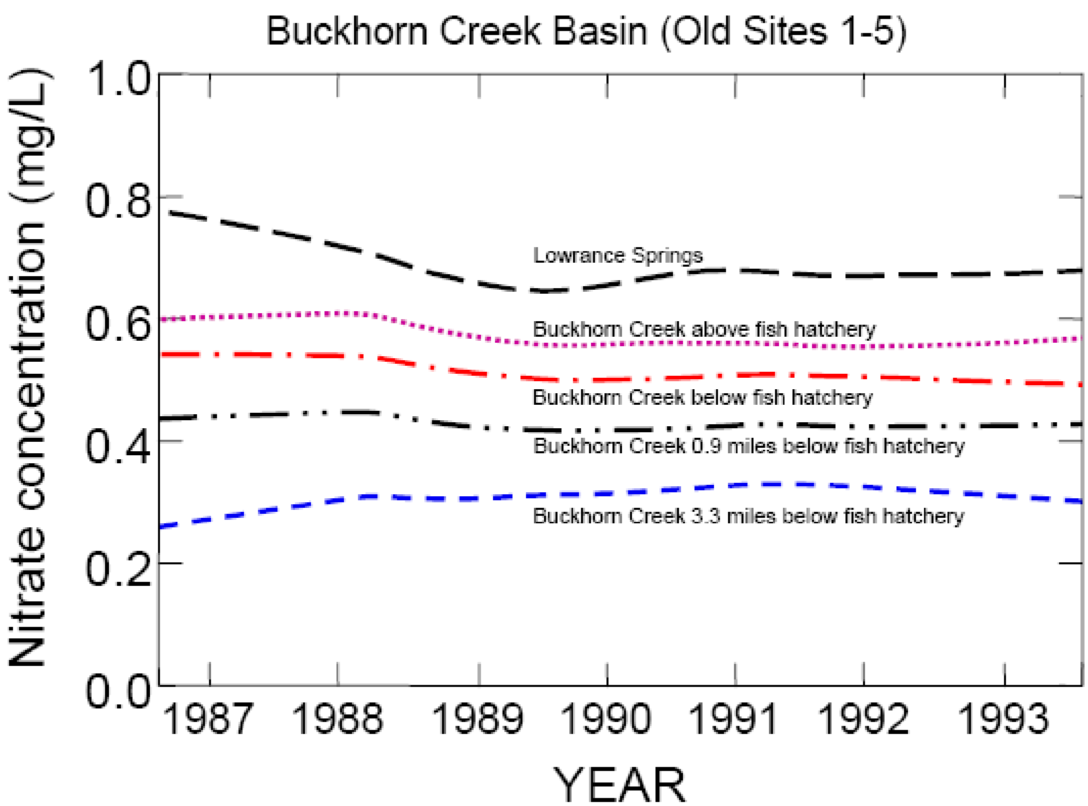


Figure 11. LOWESS trend lines for nitrate-nitrogen concentrations in the Buckhorn Creek basin.

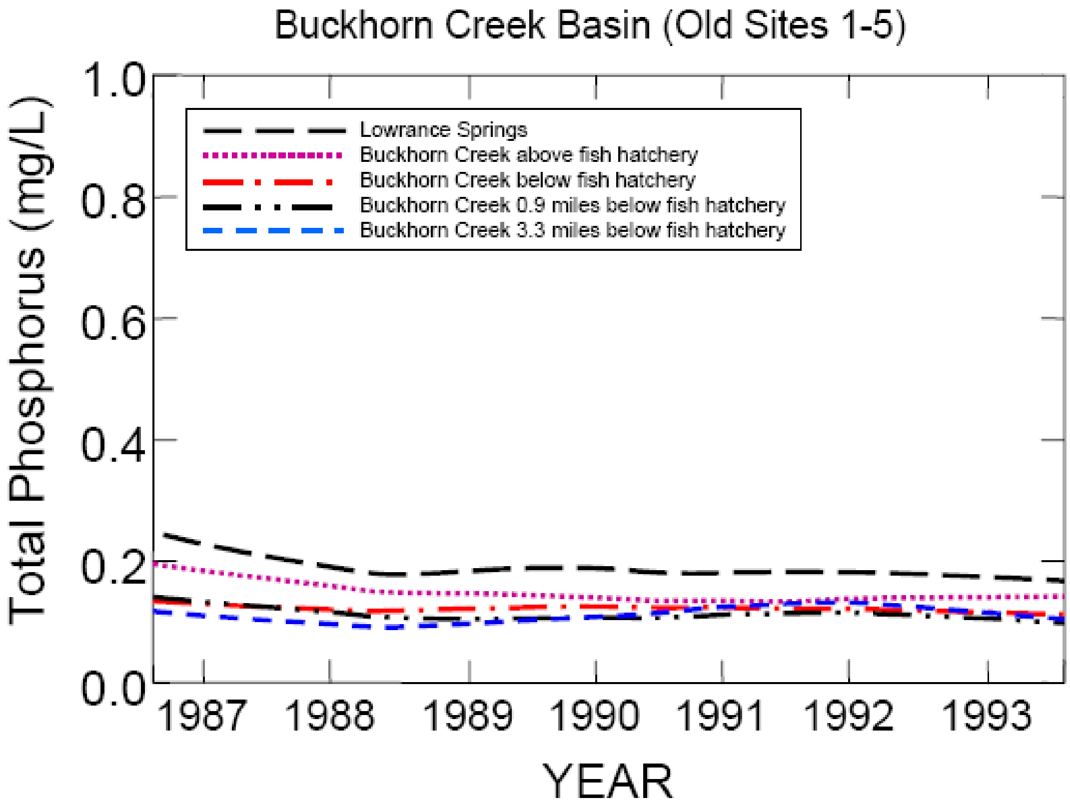


Figure 12. LOWESS trend lines for total phosphorus concentrations in the Buckhorn Creek basin.

Rock Creek Basin

A statistical summary for the nine monitoring sites in the Rock Creek basin can be found in the Appendix (Table 4). Median water temperatures in Buffalo Springs (17.9^{o} C) and Antelope Springs (17.6^{o} C) were constant throughout the period of record (Fig. 13). Median water temperature varied little among other sites in the Rock Creek basin, ranging from 15.3^{o} C to 16.3^{o} C. No temporal trends in water temperature were noted. Median pH values in Buffalo and Antelope Springs (7.4 and 7.3, respectively) were lower than observed at stream sites in the basin, where values ranged from 8.0 at site 13 (Rock Creek above the confluence with Travertine Creek; Fig. 14) to 8.3 (several sites). No temporal trends in pH were noted through the period of record. Median specific conductance values ranged from 540 µS/cm at site 10 (Travertine Creek at Sycamore Crossing) to around 700 µS/cm at sites 15 and 16 (downstream portions of Rock Creek). Median specific conductance values in Buffalo and Antelope Springs were 560 and 571 µS/cm, respectively (Table 4). No temporal trends for specific conductance were noted through the period of record (Fig. 15). Relatively-higher COND values at sites in the Rock Creek basin, compared to those in the other stream basins, may reflect the influence of urban runoff of salts from roads and residences in the small town of Sulphur, Oklahoma.

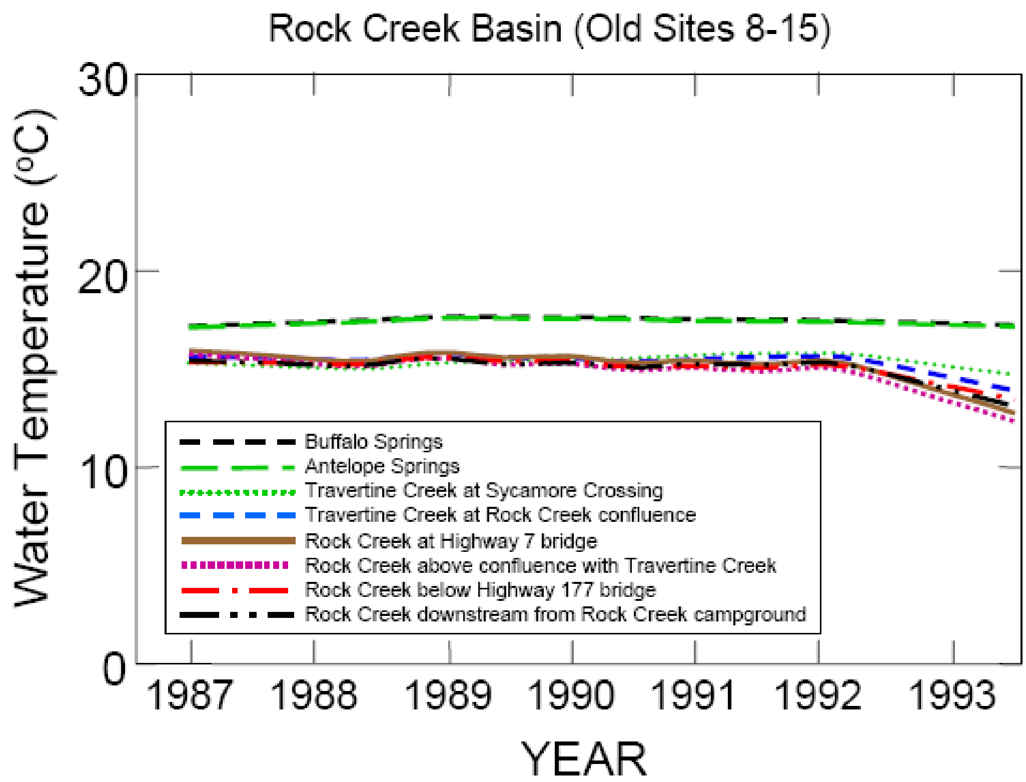


Figure 13. LOWESS trend lines for water temperature in the Rock Creek basin.

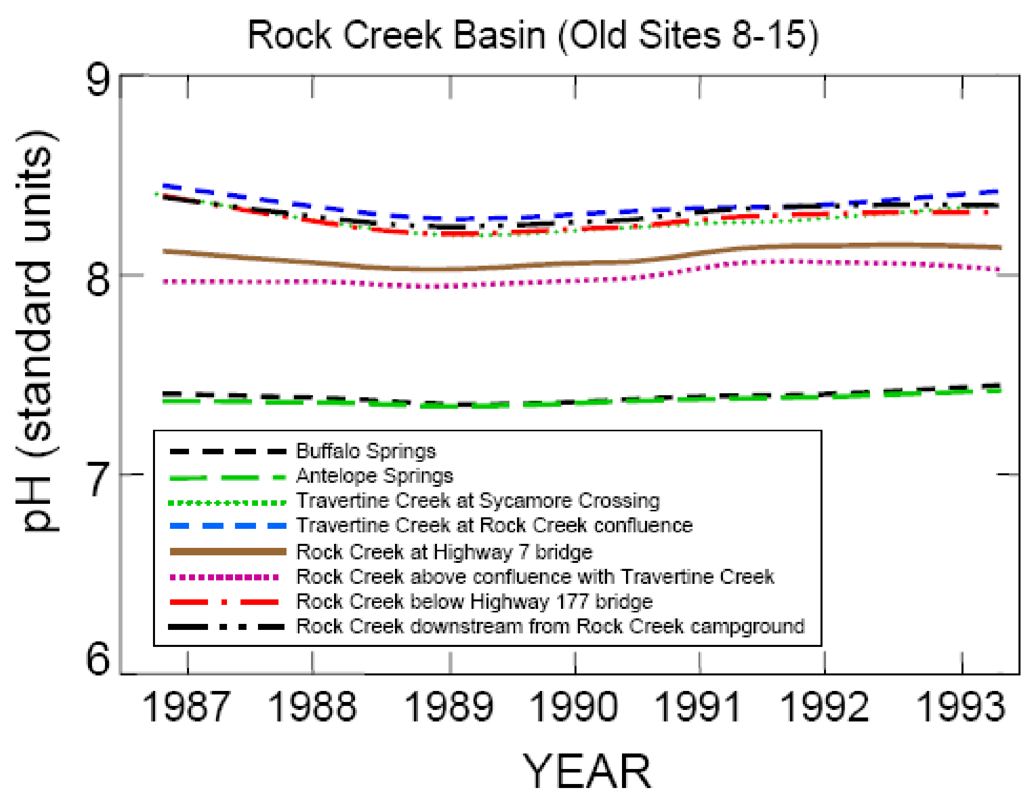


Figure 14. LOWESS trend lines for pH in the Rock Creek basin.

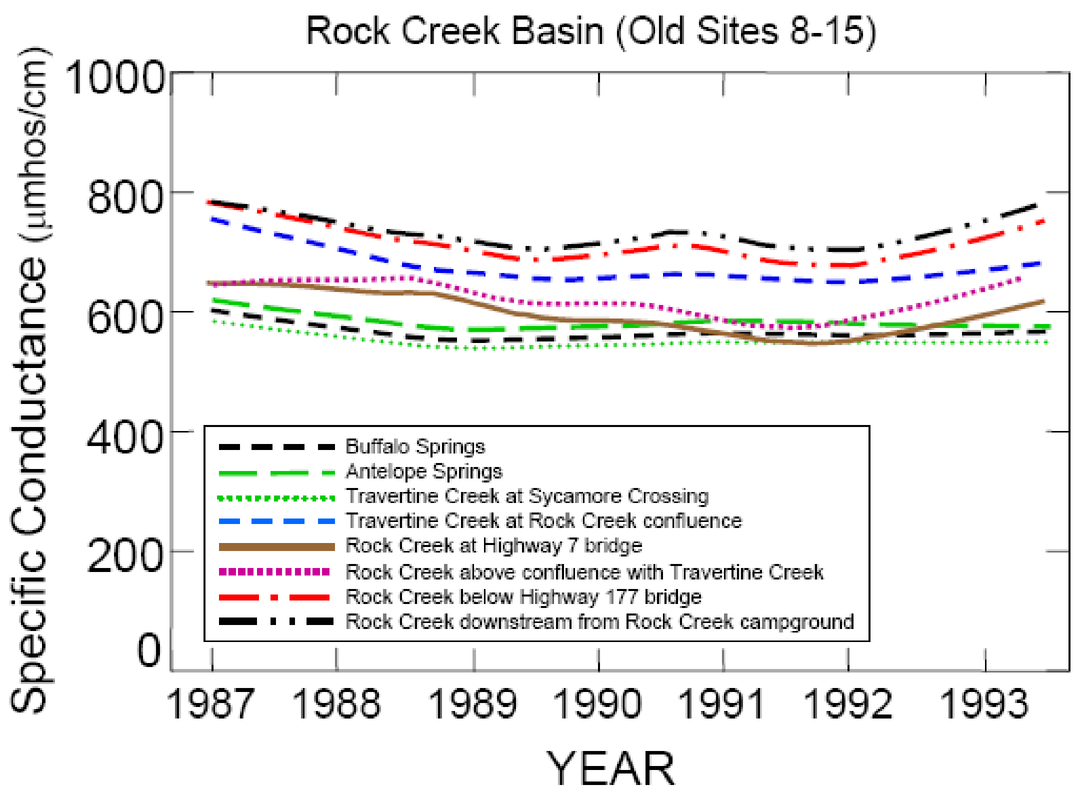


Figure 15. LOWESS trend lines for specific conductance in the Rock Creek basin.

Median DO concentrations were low in Buffalo and Antelope Springs (2.2 and 0.6 mg/L, respectively), and median DO concentrations in basin streams varied from 6.8 mg/L at site 13 (Rock Creek above the confluence with Travertine Creek) to 8.8 mg/L at site 11 (Travertine Creek above the confluence with Rock Creek; Fig. 16). With the exception of Buffalo and Antelope Springs (where DO concentrations were less than 5 mg/L in 98 percent of observations), dissolved-oxygen concentrations generally were favorable for aquatic life. The frequency of departures from Oklahoma water-quality standards (DO less than 5 mg/L) was low, less than 2.5 percent of observations, in Travertine Creek and at Rock Creek sites downstream from the Travertine Creek confluence. By contrast, the frequency of departure from water-quality standards was relatively higher at two Rock Creek sites upstream from the Travertine Creek confluence, for example, 19 percent of observations at site 12 and 29 percent of observations at site 13 (refer to Fig. 1). Similar to results for specific conductance, runoff from urban roads and residences may be contributing oxygen-demanding substances to Rock Creek, resulting in water-quality contamination and potential adverse effects to aquatic organisms.

Turbidity was very low in Buffalo and Antelope Springs (medians of 1.1 NTUs), as well as in streams in the basin, where median turbidity varied from about 2.5 NTUs in Travertine Creek to 4.4 NTUs at several Rock Creek sites (Table 4). Median total alkalinity values varied from 242 mg/L to 325 mg/L, and median total hardness varied from 251 mg/L to 335 mg/L, with highest values observed in the springs. Median SO_4

concentrations ranged from 16 mg/L to 20 mg/L. No significant differences among sites or trends in turbidity, total alkalinity, hardness, or sulfate were noted.

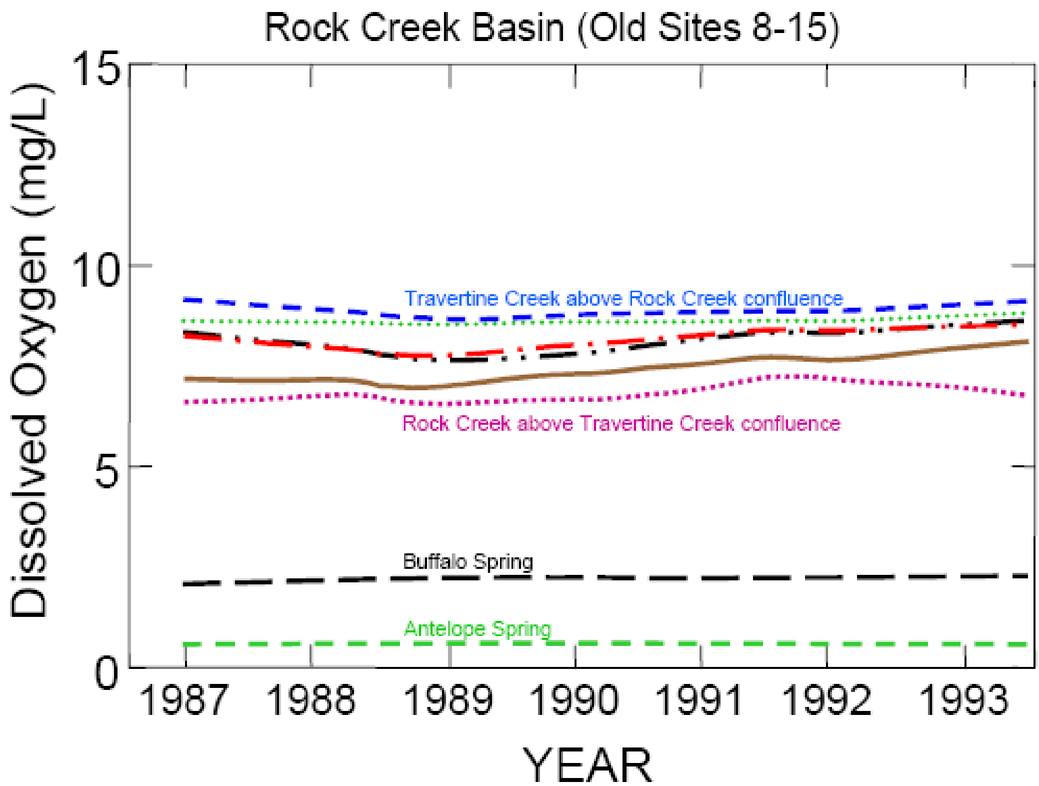


Figure 16. LOWESS trend lines for dissolved oxygen concentrations in the Rock Creek basin.

Nutrient concentrations in the Rock Creek basin generally were low. Median NH_3 concentrations ranged from 0.02 mg/L to 0.10 mg/L, median NO_2 concentrations were 0.002 mg/L at all sites, and median NO_3 concentrations varied from 0.12 mg/L to 0.40 mg/L (Table 4). Median total phosphorus concentrations ranged from 0.095 mg/L to 0.165 mg/L. Similar to the Buckhorn Creek basin, the largest NO_3 concentrations were found in samples from groundwater discharges, in this case, Buffalo Springs (Fig. 17; Table 4). Total phosphorus concentrations were slightly higher at sites influenced by urban drainage, for example, sites 12 and 13 (Fig. 18). No temporal trends were noted for any nutrient concentrations in the Rock Creek basin (Figs 17 and 18).

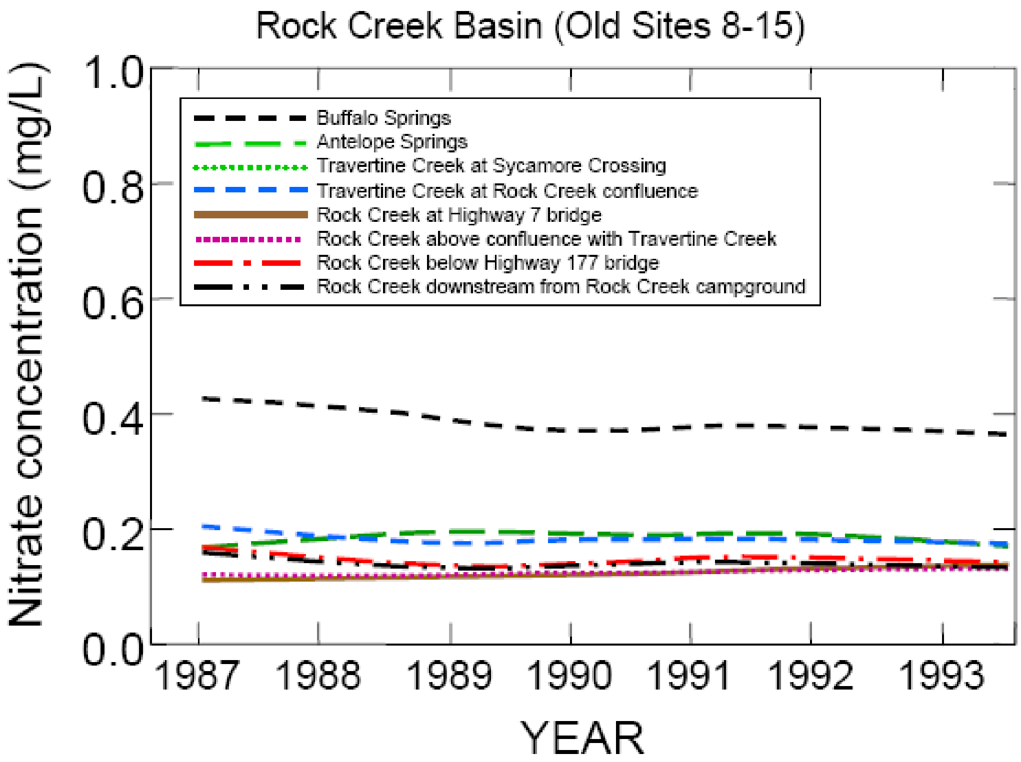


Figure 17. LOWESS trend lines for nitrate concentrations in the Rock Creek basin.

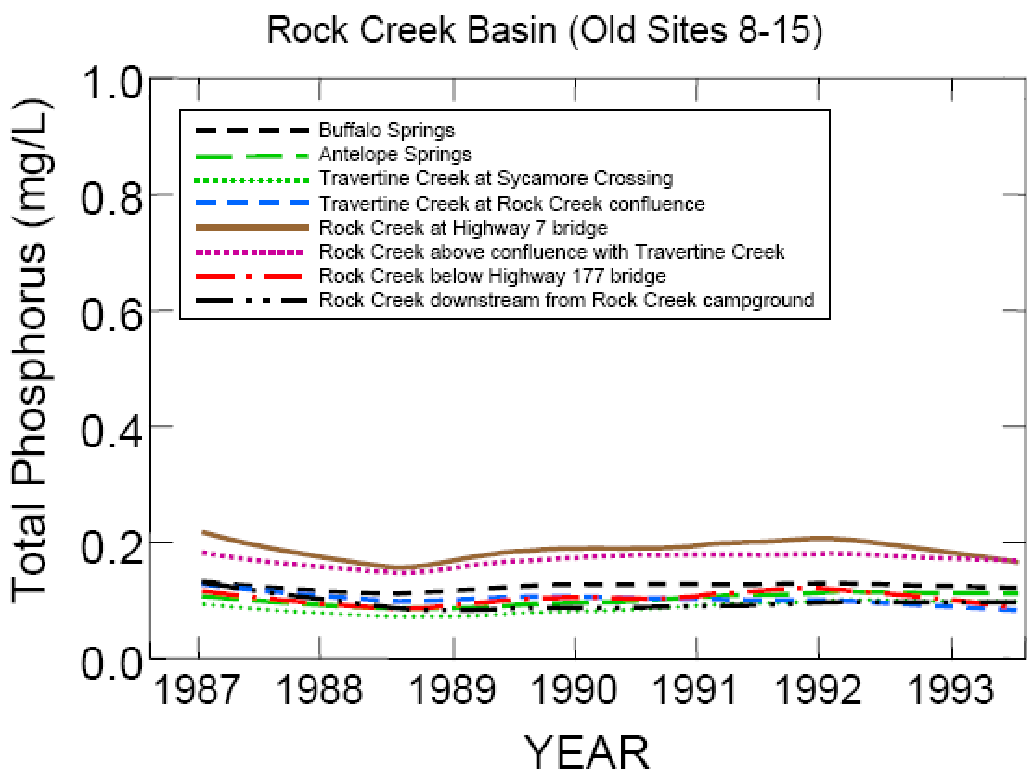


Figure 18. LOWESS trend lines for total phosphorus concentrations in the Rock Creek basin.

Guy Sandy Creek Basin

Two stream sites were monitored in the Guy Sandy basin (Fig. 1), one near Highway 7 (site 6) and the other at an upstream location near a poultry farm (site 7; Steve Burrough, NPS, personal communication). Concerns were raised about potential increases in agricultural activities in the basin (EARDC 2007). Median water temperature was slightly higher at site 7 (15.4^{o} C) than at site 6 (14.6^{o} C), whereas average pH was identical (8.0) at both sites (Table 4). No temporal trends were noted for water temperature or pH. Median values for specific conductance were larger at site 6 (527 μS/cm) than at site 7 (500 μS/cm); however, no trends were observed at either site. Median concentrations of DO were higher at site 6 (7.6 mg/L) than at site 7 (6.4 mg/L), and the frequency of departure from Oklahoma water-quality standards (5 mg/L) was higher at site 7 (21.5 percent of observations) than at site 6 (10 percent). Whereas median DO concentrations at site 7 increased slightly during the period of record (Fig. 19), whereas no long-term change is indicated in the historic record for site 6.

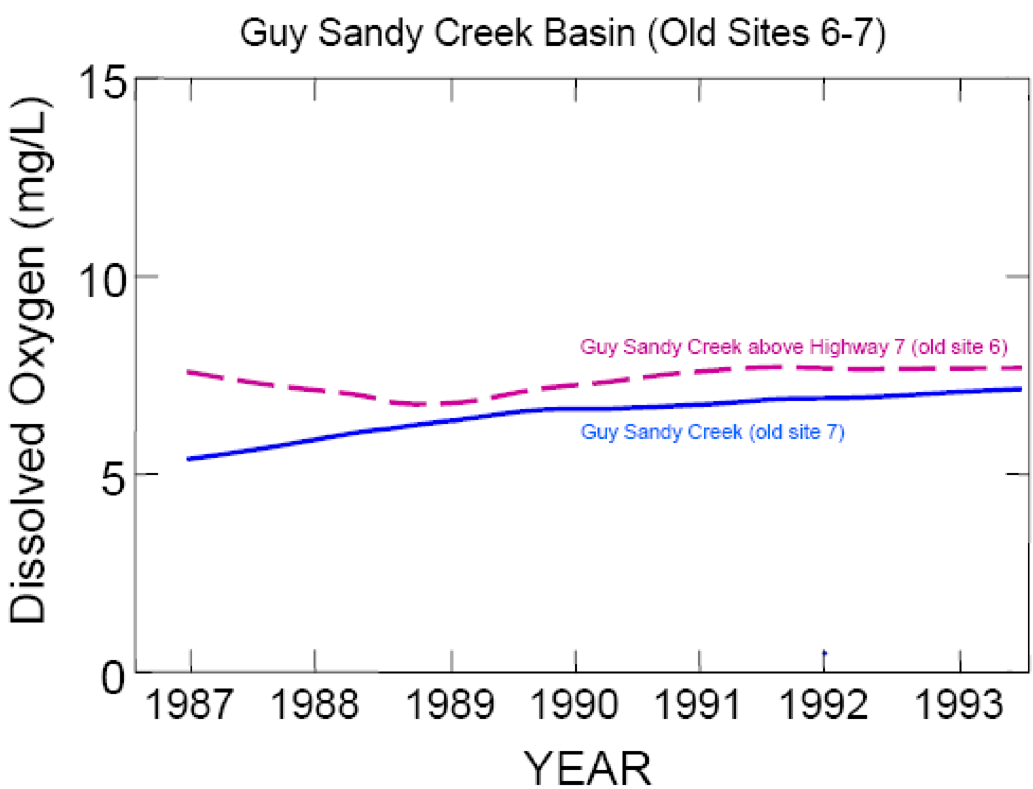


Figure 19. LOWESS trend lines for dissolved oxygen concentrations in the Guy Sandy Creek basin.

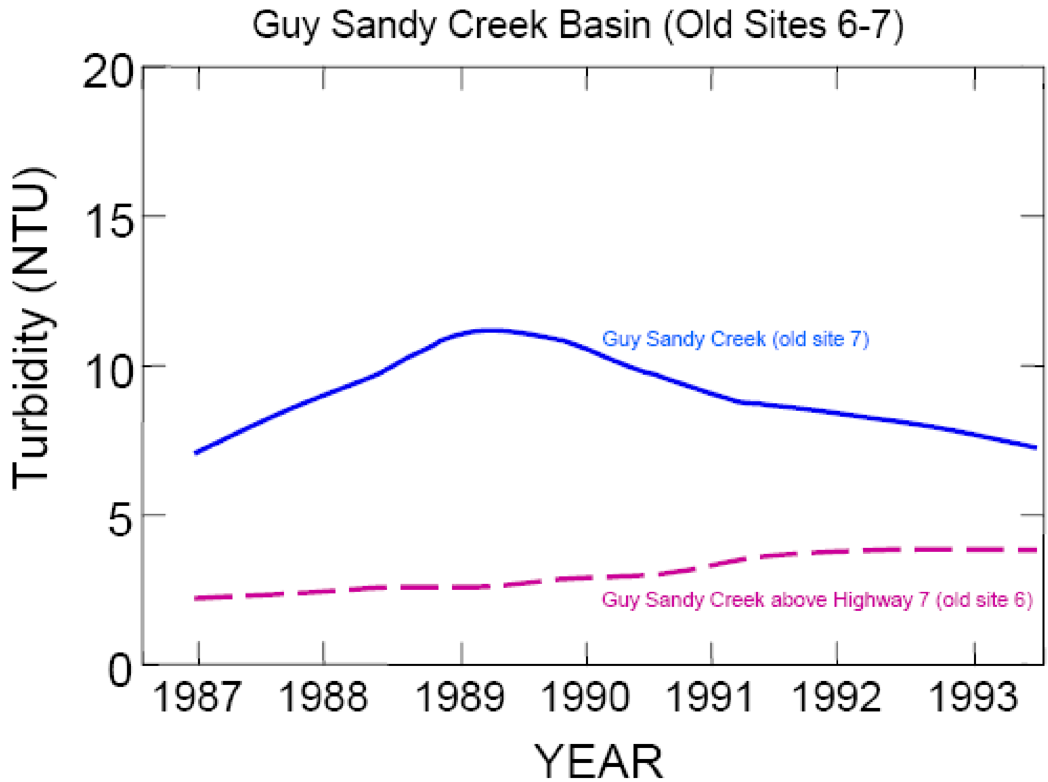


Figure 20. LOWESS trend lines for turbidity in the Guy Sandy Creek basin.

Median water turbidity at site 7 (9.3 NTUs) was the highest of all sites in the historical monitoring program (Table 4), whereas median turbidity at site 6 (3.1 NTUs) was within the range of other stream sites. Turbidity increased at site 7 (Fig. 20, solid blue line) during 1987-89, but decreased in the following years; turbidity at site 6 (Fig. 20, purple dashed line) appears to have increased during the period of record. Increases in turbidity may reflect land disturbance activities and subsequent erosion of soils into Guy Sandy Creek. Total alkalinity, hardness, and sulfate concentrations were similar to other sites in the historical database.

Despite increases in turbidity, nutrient concentrations in the Guy Sandy Creek basin were similar to those at other sites during the period of record. Median NH_3 concentrations were higher at site 7 (0.13 mg/L) than at site 6 (0.05 mg/L), whereas median NO_2 (0.002 mg/L) and NO_3 (0.11 mg/L) concentrations were the same (Table 4). Median total phosphorus concentrations were slightly larger at site 7 (0.195 mg/L) than at site 6 (0.180 mg/L), although these values are within the range of other sites in the historical database. No long-term trends in nutrient concentrations were noted during the period of record (Figs. 21 and 22).

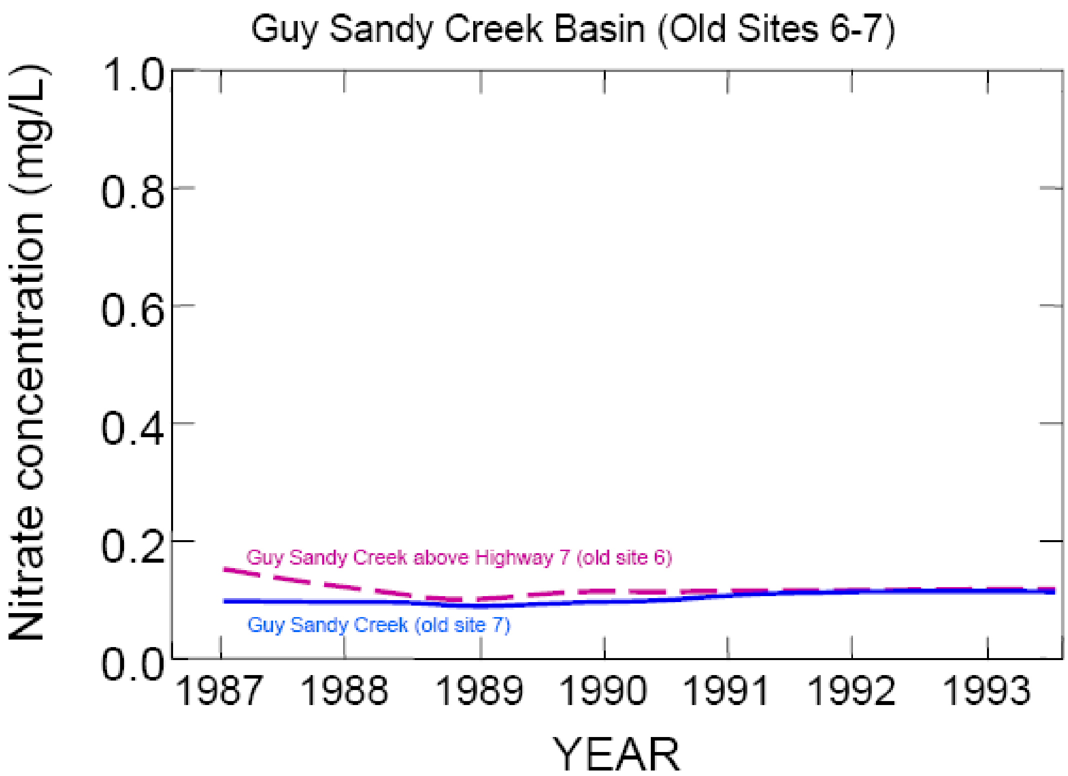


Figure 21. LOWESS trend lines for nitrate concentrations in the Guy Sandy basin.

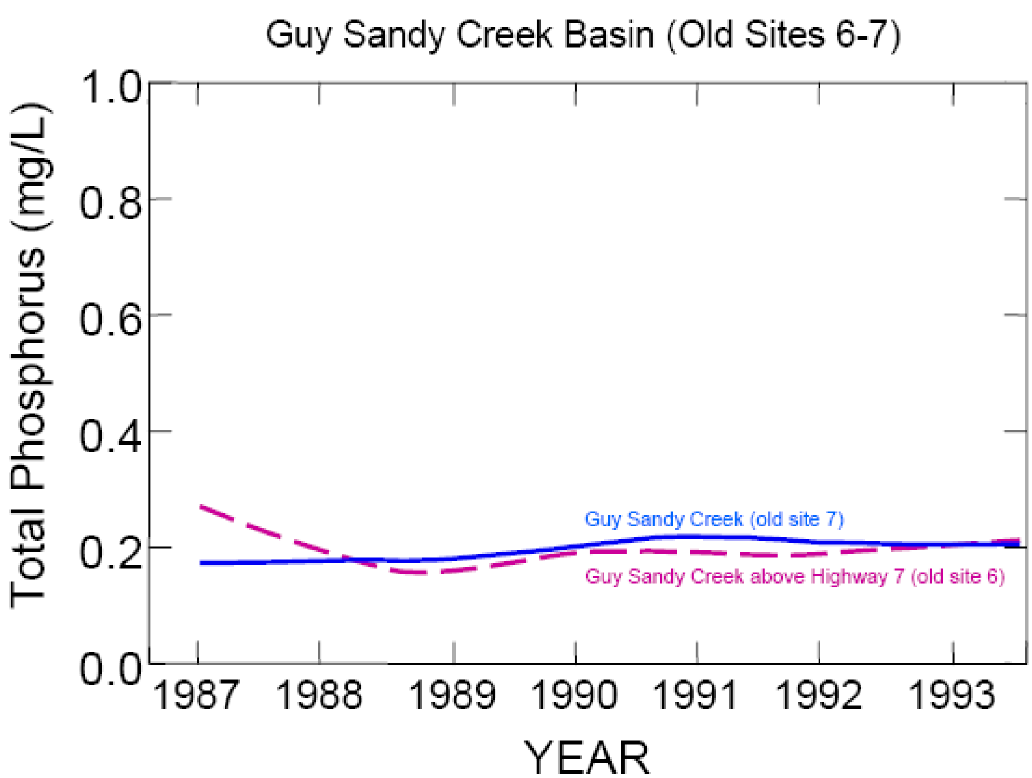


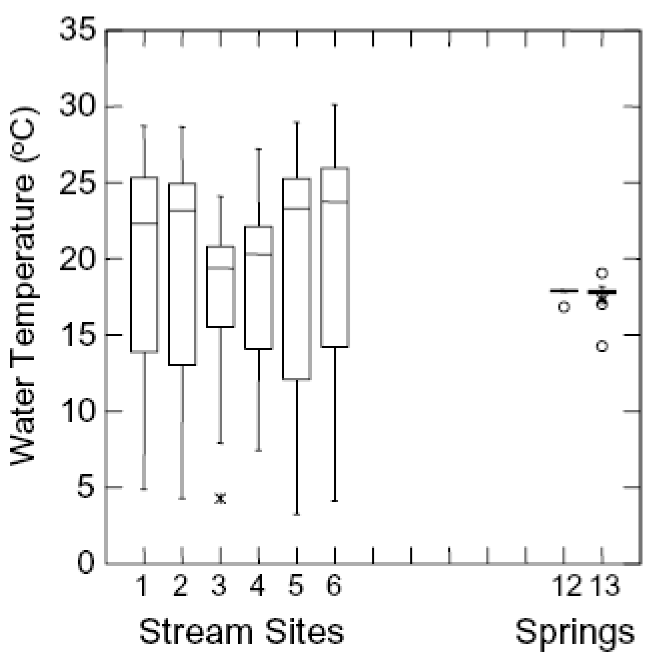
Figure 22. LOWESS trend lines for total phosphorus concentrations in the Guy Sandy basin.

Recent Water Quality Conditions at "NEW" sites (2000-09)

Water quality data are available for six stream sites, five lake sites, and two springs (Table 2; Fig. 1). Comparable historical (1987-94) data are available for four of the stream sites ("new" sites 1, 4, 5, and 6), whereas comparable data are available for Antelope Springs (site 12) and Buffalo Springs (site 13). Differences between historical and recent data at common sites were discussed previously and presented in Figures 3-6.

Stream and Spring Sites

A statistical summary for the six "new" stream sites in the Chickasaw NRA can be found in Table 5. Median water temperature ranged from 19.4^o C in Travertine Creek to about 23^o C at other stream sites, whereas median temperature was lower in Antelope Springs (17.9^o C) and Buffalo Springs (17.8^o C). All values were higher than in the historical database, most likely because the majority of recent measurements were taken during warm-weather seasons.



Median water temperature was relatively lower in Travertine Creek (Fig. 23, site 3), probably because of the proximity of the site to source-water springs. Median temperature also was relatively cooler in Buckhorn Creek below the fish hatchery (site 4), most likely for a similar reason, in this case, proximity to Lowrance Springs (Fig. 1). Median temperatures were similar (22.3^o C – 23.7^o C) among other stream sites in the recent dataset.

Figure 23. Water temperature in streams and springs.

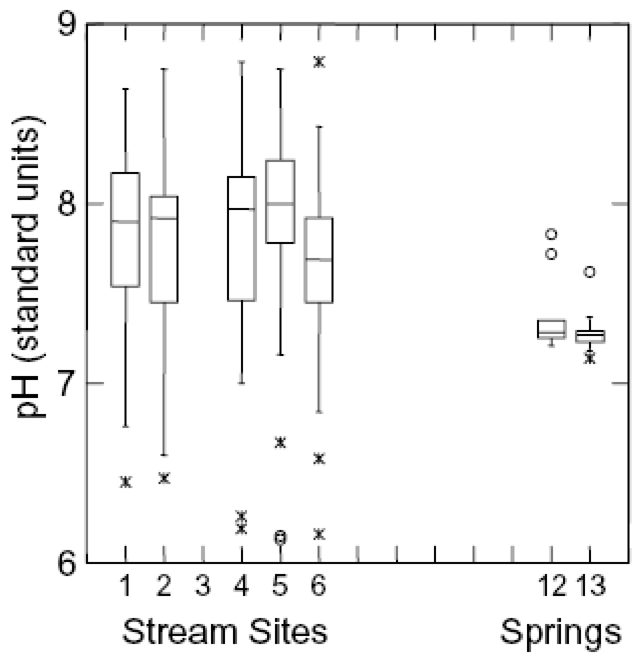


Figure 24. pH values in streams and springs.

Median pH values were lower in the springs (pH = 7.3) than in the streams, where pH ranged from 7.7 to 8.0 (Fig. 24). All median pH values were lower than observed, historically, at common sites in the Chickasaw NRA (refer to Fig. 4). Trend values for pH were relatively larger at site 5 (Buckhorn Creek near power line) than at other sites (Fig. 25). An unusual decrease in pH values was observed between year 2000 and year 2003 (Fig. 25). Potential reasons for this decrease are poorly understood; however, this factor partially explains the larger-than-expected variance in recent observations compared with the historical data (Fig. 4).

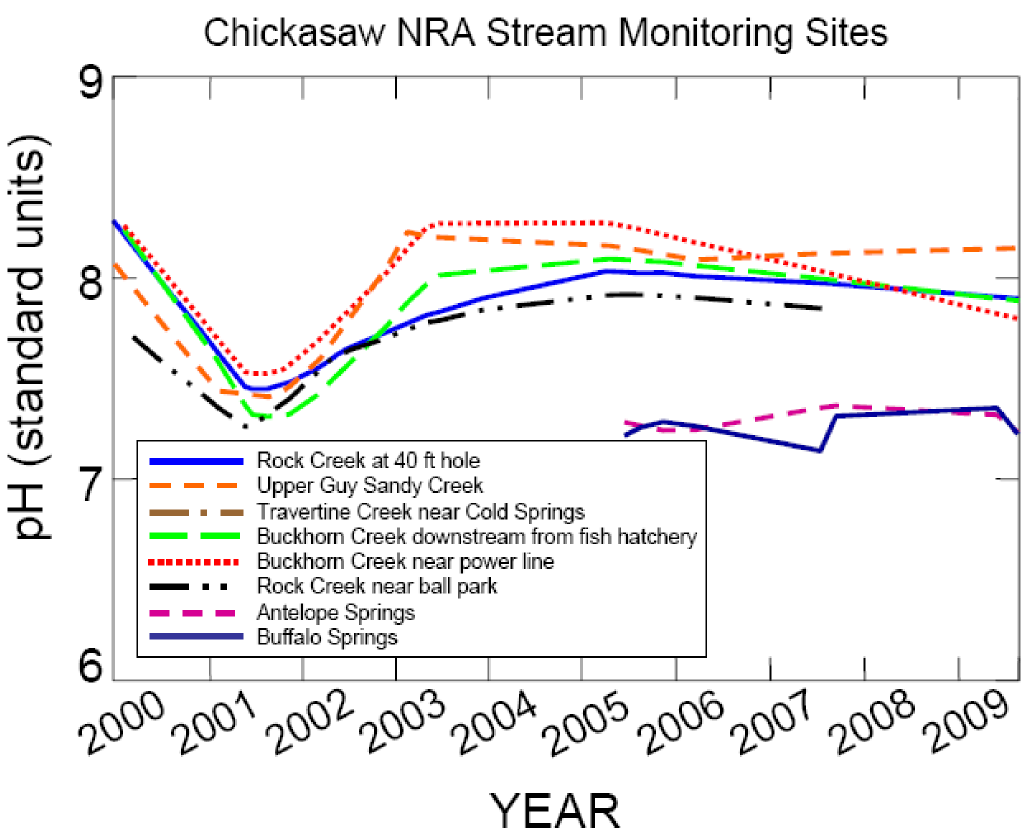
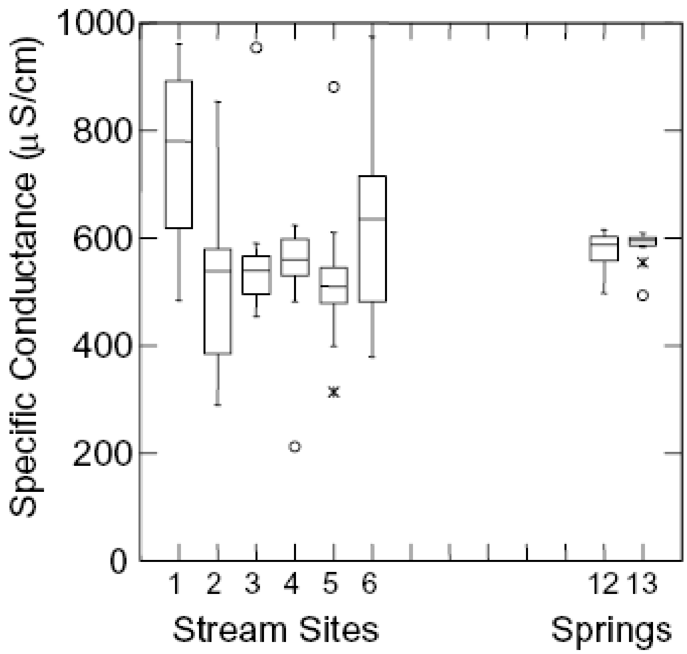


Figure 25. LOWESS trend lines for pH in streams and springs.



Median values for specific conductance varied from 510 µS/cm in Buckhorn Creek near power line (site 5) to 780 µS/cm in Rock Creek (site 1). A decrease in specific conductance values during 2000 to 2003 (similar to the one noted above for pH) was observed at the two Rock Creek sites (sites 1 and 6) but not at other stream sites in the database (Fig. 27). Overall, median specific conductance values at sites in common were similar between the historical and recent databases, and no trends were noted apart from those in Rock Creek (above) and Upper Guy Sandy Creek.

Figure 26. Specific conductance values in stream and springs.

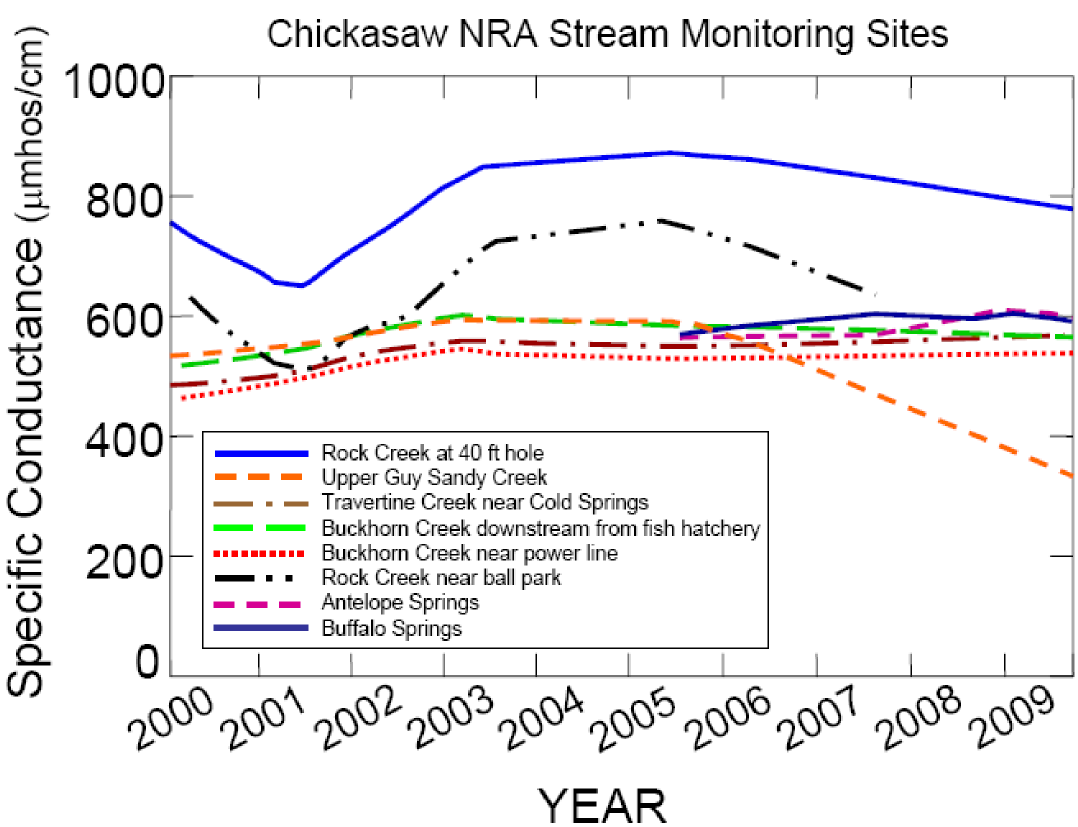
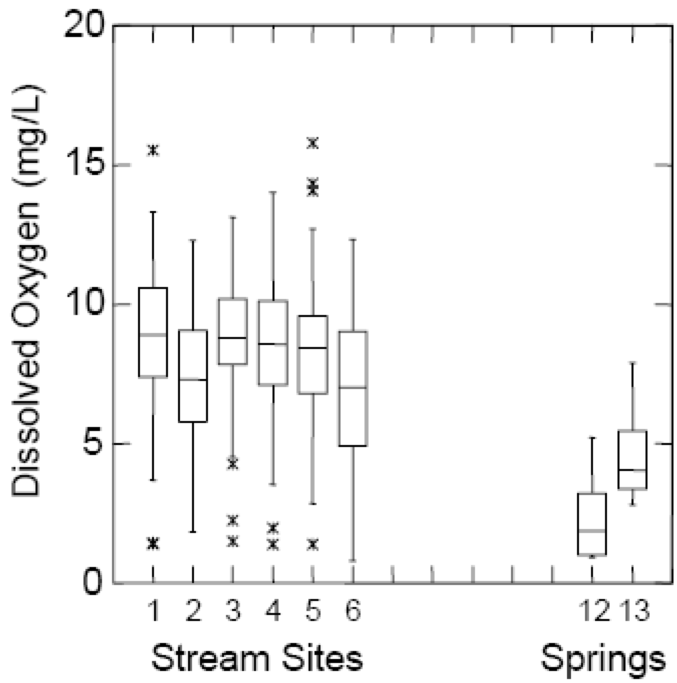


Figure 27. LOWESS trend lines for specific conductance in streams and springs.



Median concentrations of dissolved oxygen were lower in Antelope Springs and Buffalo Springs (1.9 mg/L and 4.1 mg/L, respectively) than in NRA streams (Fig. 28; Table 5). Median DO concentrations ranged from 7.0 mg/L at site 6 (Rock Creek "near ball field") to 8.9 mg/L at site 1 (Rock Creek at "40 ft hole"). Median DO in the springs, as well as at site 1, was larger than observed in the historical dataset, whereas recent values were similar to (or lower than) historical median values at sites 4-6 (Fig. 5). The frequency of samples departing from water-quality standards ranged from nine percent at sites 3 and 4, to 26 percent at site 6 (Table 5)

Figure 28. Dissolved oxygen concentrations in streams and springs.

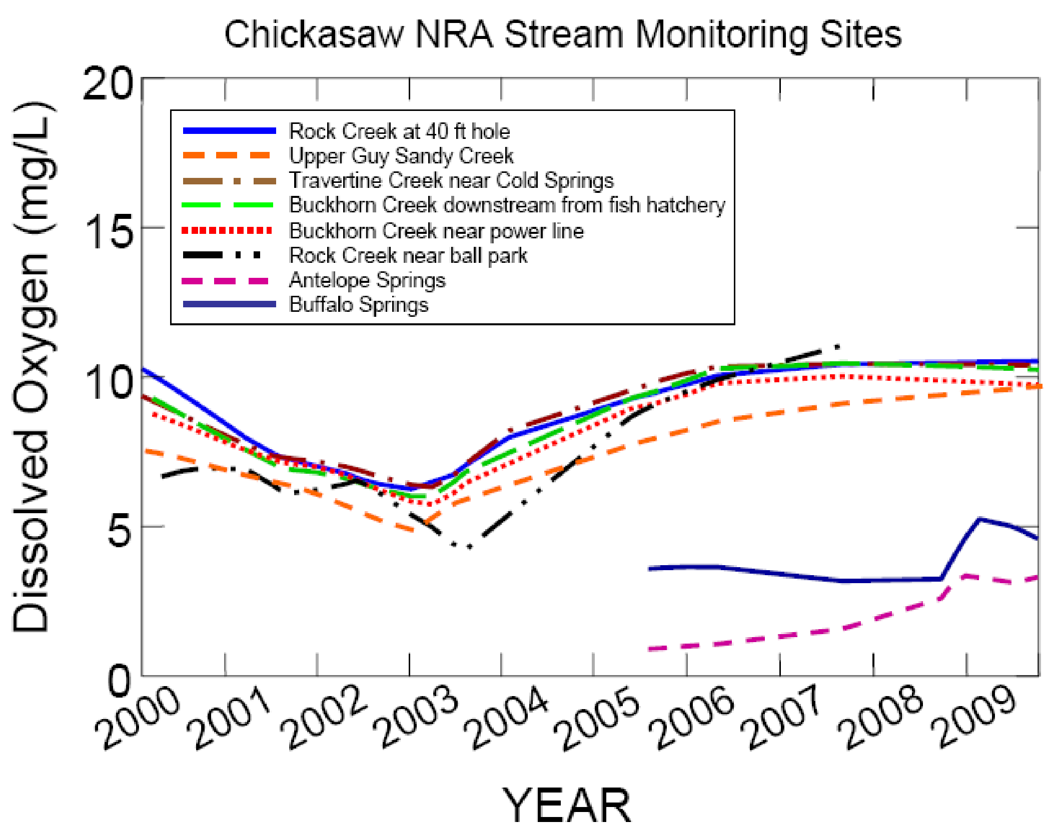
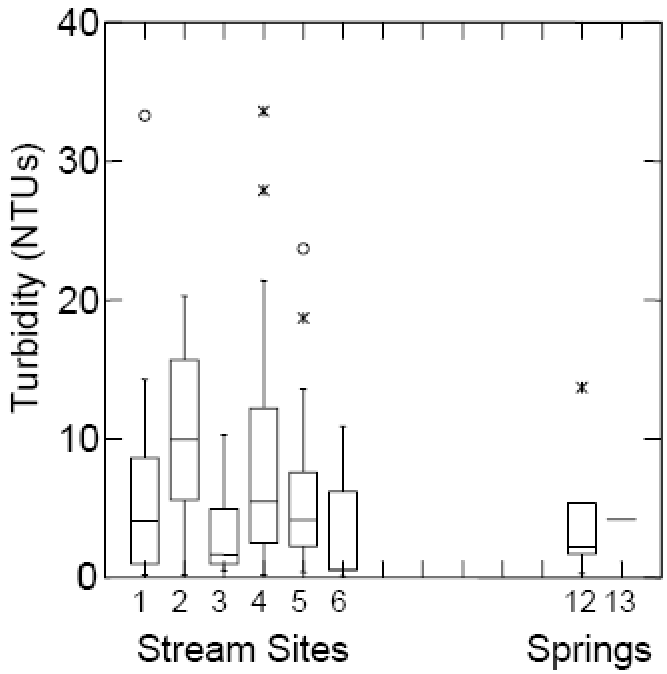


Figure 29. LOWESS trend lines for dissolved oxygen in streams and springs.

Median dissolved oxygen concentrations decreased at all stream sites between years 2000 and 2003, but increased from 2003 to 2006 to levels observed in 2000 (Fig. 29). Values through the period of record generally have been similar among stream sites, although DO concentrations in Upper Guy Sandy Creek (site 2) and Rock Creek “near ball field” (site 6) generally were lower than at other stream sites (Figs. 28 and 29). Although DO concentrations in Antelope Springs appear to have increased steadily since 2006, concentrations have remained relatively constant at most stream sites since 2006(Fig. 29).



Median water turbidity ranged from 0.1 NTUs at site 6 (Rock Creek “near ball field”) to 10 NTUs at site 2 (Upper Guy Sandy Creek). Turbidity also was elevated at site 4 (Buckhorn Creek downstream from fish hatchery). Turbidity in Buckhorn Creek and Upper Guy Sandy Creek appears to have increased during the past year (2009; Fig. 31), whereas no trends were observed during the period of record in other streams and springs.

Figure 30. Turbidity in streams and springs.

A statistical summary of nitrate (NO_3) data is presented in the Appendix (Table 5). As mentioned previously, average and maximum NO_3 concentrations are much larger than expected, and the recent data obtained with a nitrogen probe are, for the purpose of this report, considered unreliable.

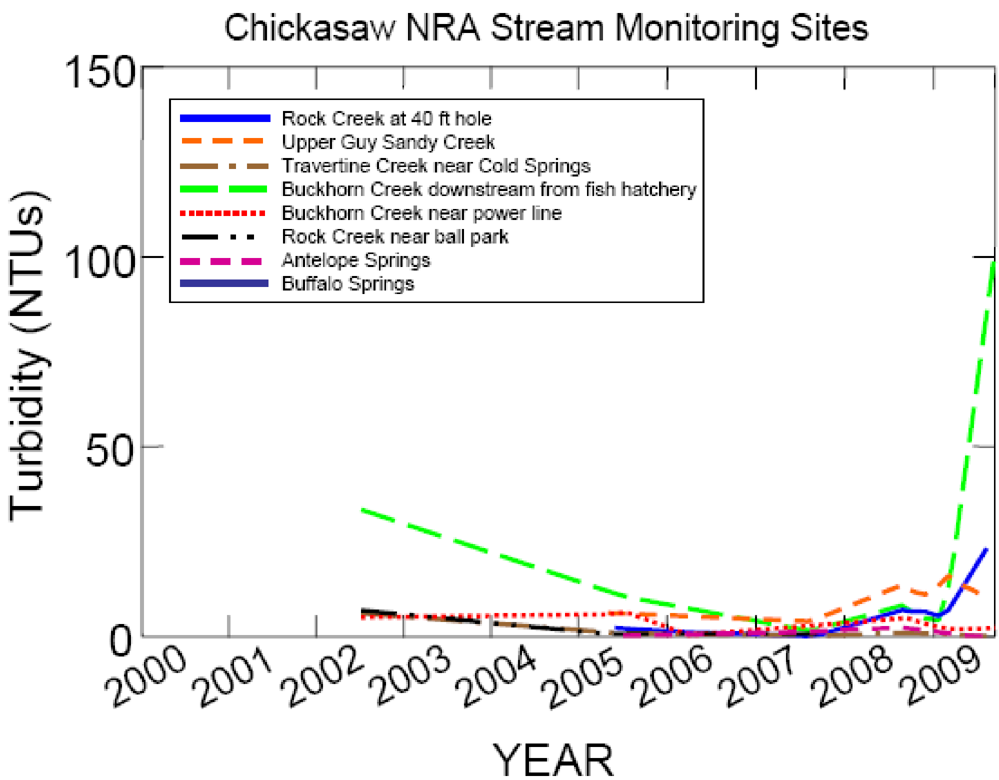


Figure 31. LOWESS trend lines for turbidity in streams and springs.

Lake Sites

A statistical summary for the five lake sites in the Chickasaw NRA is provided in Table 5. As was the case for the stream and spring sites, the distribution of recent data is skewed toward measurements obtained during warm-weather seasons (refer to dates associated with recent sampling activity in the database: CHIC_WQ.xls. Median water temperature was similar among lake sites, ranging from 23.5° C at site 10 (Arbuckle Lake—Rock Creek Branch; Fig. 1) to 26.5° C at site 7 (Guy Sandy Creek Branch). With the exception of Veterans Lake, water temperature appears to have increased (Fig. 33); however, recent measurements in Arbuckle Lake have been restricted to warm-weather months, potentially creating a false impression of rising LOWESS-model trends with respect to water temperature.

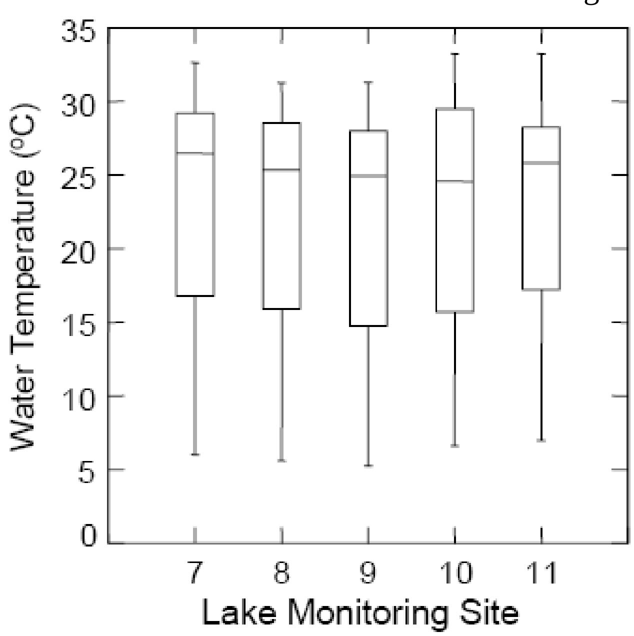


Figure 32. Water temperature at lake sites.

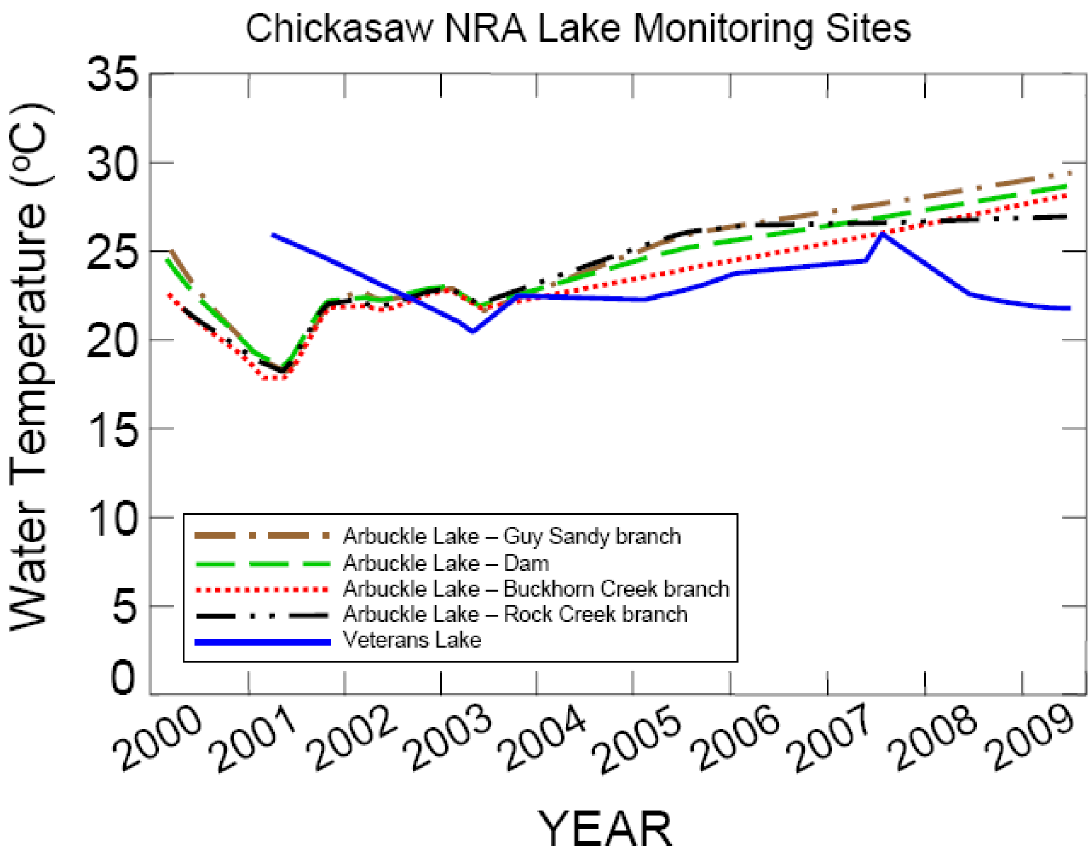
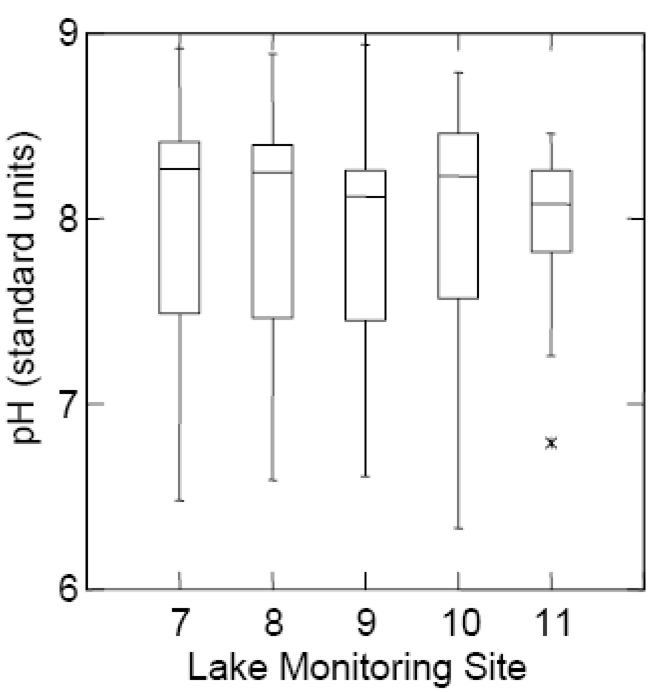


Figure 33. LOWESS trend lines for water temperature at lake sites.



Median pH values also were similar among lake sites, ranging from 8.1 to 8.3 (Fig. 34). Similar to results reported for streams and springs, median pH values in Lake of the Arbuckles decreased between years 2000 and 2003, then returned to values observed during 2000, followed by decreases through the period of record (Fig. 35). By contrast, pH values in Veterans Lake show an increasing trend from 2001 through 2009. Reasons for these differences are poorly understood.

Figure 34. pH values at lake sites.

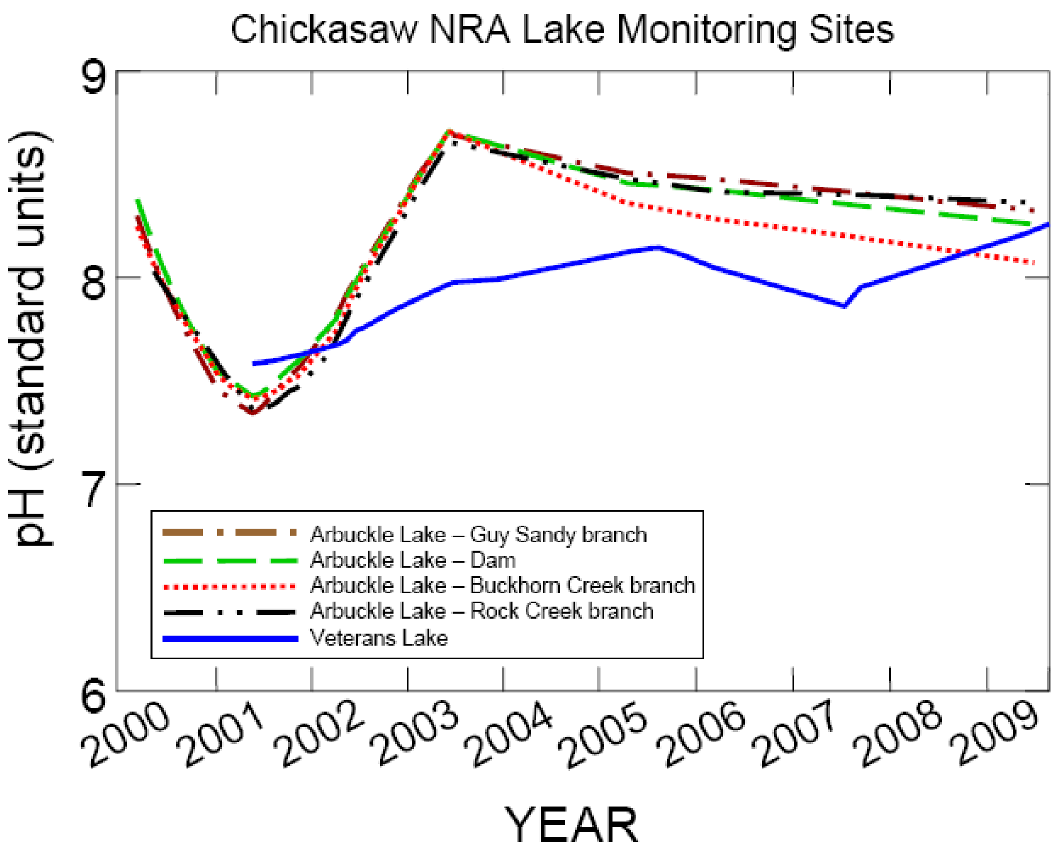
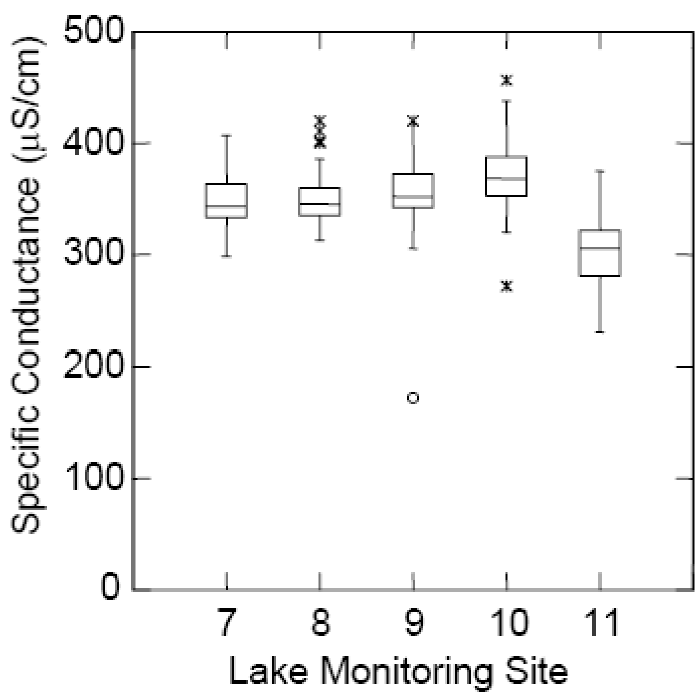
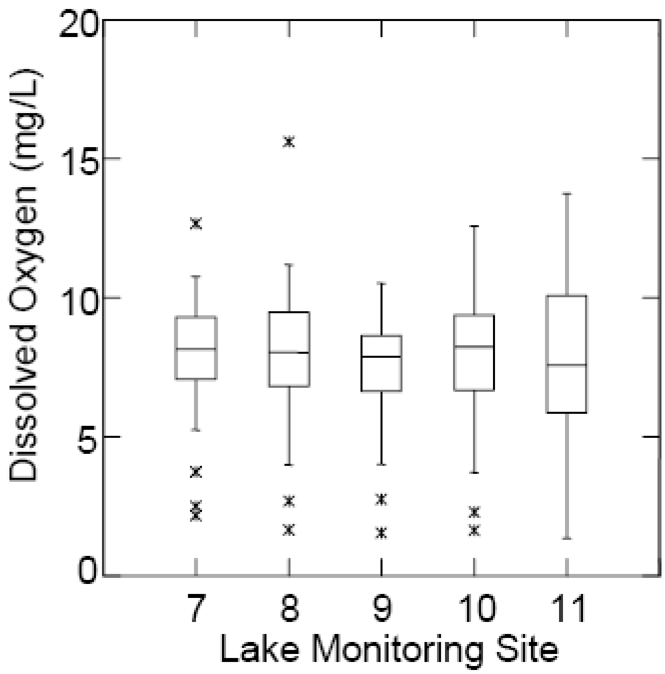


Figure 35. LOWESS trend lines for pH at lake sites.



Median specific conductance values were significantly lower (306 µS/cm) in Veterans Lake (site 11) than at Arbuckle Lake sites (343-369 µS/cm; Table 5; Fig. 36). Median conductance values at lake sites were all significantly lower than in streams and springs, where the range was 510-780 µS/cm. Specific conductance in Arbuckle Lake was highest in the Rock Creek branch (site 10) and lowest in the Guy Sandy Branch (site 7). No trends in specific conductance values were noted at any lake site.

Figure 36. Specific conductance values at lake sites.



Median dissolved oxygen concentrations were similar among lake sites (Fig. 37), ranging from 7.6 mg/L in Veterans Lake (site 11) to 8.3 mg/L near the dam and in the Guy Sandy branch of the lake. Median DO concentrations at lake sites declined between the year 2000 and 2004, with many observations less than the Oklahoma water-quality criterion of 5 mg/L. Departures from the DO criterion ranged from 9 percent of samples near the dam and Guy Sandy branch of the lake to about 19 percent of samples at other lake sites. DO concentrations decreased during 2000-03, and generally have increased since 2004 (Fig. 38).

Figure 37. Dissolved oxygen concentrations at lake sites.

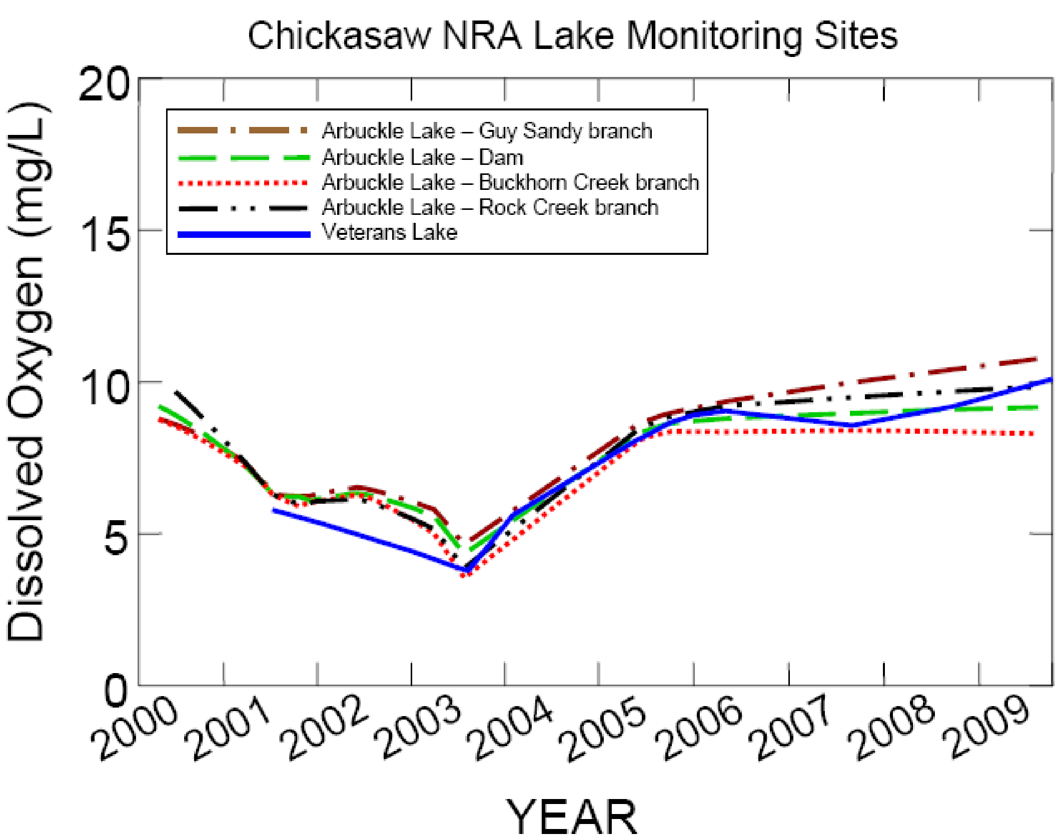
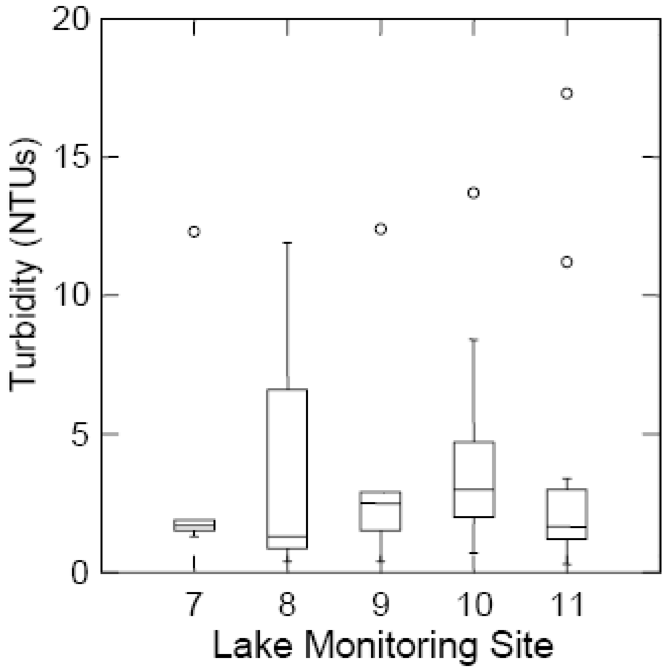


Figure 38. LOWESS trend line for dissolved oxygen at lake sites



Median water turbidity values generally were low at all lake sites, with lowest values found near the dam (Fig. 39). Although there were no temporal trends in water turbidity at lake sites through the period of record, occasion periods of higher turbidity have occurred, with values exceeding 88 NTUs in 10 percent or more samples at sites 8-10 (Table 5).

Figure 39. Water turbidity at lake sites

Fecal-Indicator Bacteria at Chickasaw NRA Swimming Areas

The Colilert© method was used for estimating the abundance of *Escherichia coli* (*E. coli*) bacteria at four swimming areas in the NRA: Little Niagara, Bear Falls, Panther Falls, and Black Sulfur (Emily Clark, hydrologic technician, Chickasaw NRA; digital communication). The Oklahoma primary contact standard for *E. coli* bacteria is a geometric mean of no more than 126 colonies per 100 mL in 6 or more samples from a site. A statistical summary of this data is presented in Table 3.

Table 3. Summary statistics for *E. coli* bacteria at NRA swimming areas.

	Little Niagara	Bear Falls	Panther Falls	Black Sulfur
Number of observations	113	112	112	110
Minimum	7	<1	23	<1
Maximum	1,120	613	921	2,419
Geometric mean	**95**	**109**	**142**	**141**
Mean	142	143	192	240
Standard deviation	171	103	185	345
10%ile	38	52	64	47
25%ile	54	73	83	88
50%ile (Median)	88	114	135	130
75%ile	158	186	189	222
90%ile	281	278	408	565

The geometric mean of all samples analyzed for *E.coli* bacteria was exceeded at the Panther Falls and Black Sulfur swimming areas (Table 3), and values exceeded the criterion in more than 25 percent of samples collected from the Little Niagara and Bear Falls swimming areas. Median *E. coli* levels were similar among swimming areas during 2003-06 and, with the exception of Panther Falls, appear to be decreasing since then, particularly E. coli levels at the Little Niagara and Bear Falls locations (Fig. 40). Because levels of *E. coli* bacteria are elevated in all NRA swimming areas (despite compliance with Oklahoma water-quality criteria at certain locations and for specific periods of time), further study should be considered to better understand the sources of fecal contamination (fecal material from mammals, including humans). Additional consideration should be given to posting warnings at swimming areas when the geometric mean for *E. coli* in six or more consecutive samples exceeds 126 colonies per 100 mL.

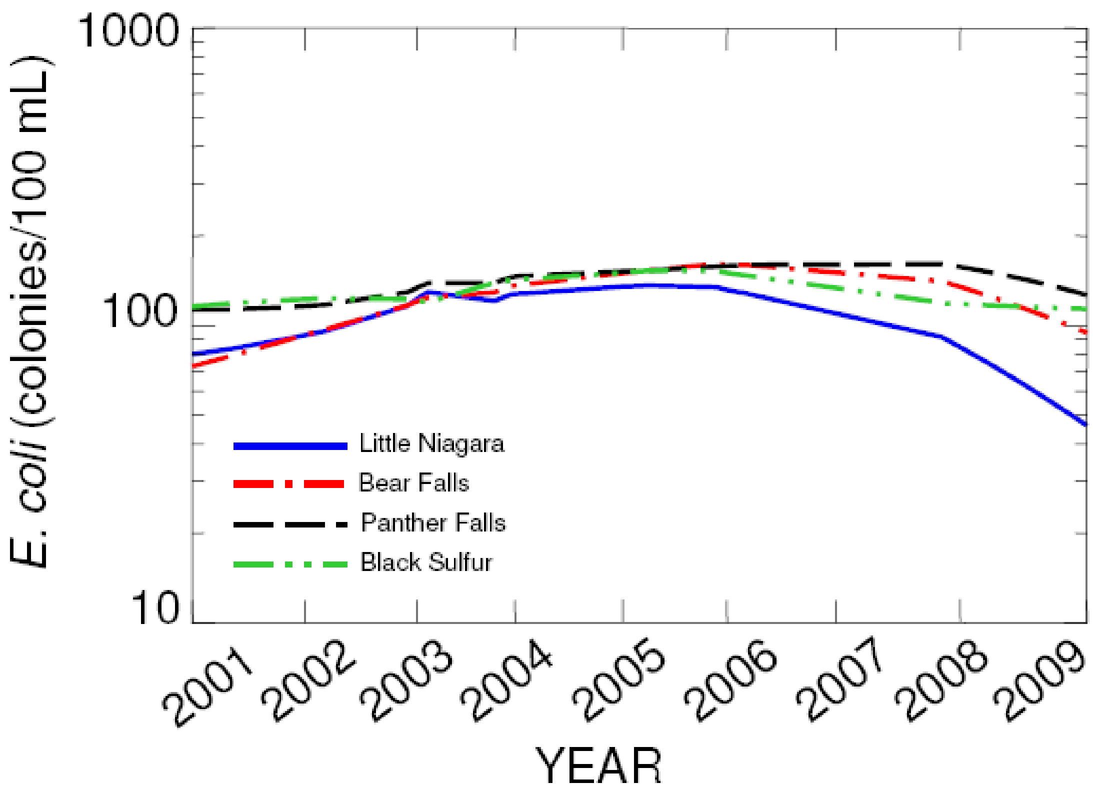


Figure 40. LOWESS trend lines for *Escherichia coli* bacteria in swimming areas.

Considerations for Improving Water Quality Monitoring

Water quality monitoring of temperature, dissolved oxygen, specific conductance, pH, and fecal-indicator bacteria is a key component of the National Park Service's Vital Sign Program in the Southern Plaines Network (Perkins et al. 2005; 2006). Oakley et al. (2003) provide general guidelines for long-term monitoring protocols that include sections describing background and objectives; sampling design; field methods; data handling, analysis, and reporting; personnel requirements and training; and operational requirements. Written quality assurance and quality control plans are a fundamental component of water quality monitoring. Quality assurance plans include consideration of manufacturer's operating manual(s) for water quality meters and probes, protocols for collecting fecal-indicator bacteria (*E. coli*) samples, proper calibration of water quality meters, and training for inexperienced personnel. A quality assurance plan also considers the monitoring design and objectives. Because dissolved oxygen and pH are known to vary during daylight hours, particularly in productive streams stimulated by nutrient enrichment, the timing of field measurements should be standardized. A log book should be maintained with each water quality meter, and information concerning battery voltage (if reported) and date of last replacement or charge, calibration and repair information, the name of the investigator, date, and field remarks. Protocols for field measurements of temperature, dissolved oxygen, specific conductance, pH, turbidity, and other water quality properties are presented by Wilde (variously dated), available on-line at: http://water.usgs.gov/owq/FieldManual/Chapter6/Ch6_contents.html.

Reference standard buffer solutions for pH and specific conductance are available from major laboratory supply companies. Two standards are recommended for pH measurements in the Chickasaw NRA, a buffer solution of pH 7.0 (blue) and pH 10.0 (yellow). Measurements of pH that are inconsistent with Oklahoma water quality standards (pH less than 6.0 or more than 9.0) should be verified with a re-calibrated meter and (or) by a colleague making an independent measurement. Protocols for calibration, measurement, maintenance, and troubleshooting pH meters are presented by Ritz and Collins (2008). Similarly, two specific-conductance (conductivity) standards are recommended, a solution with a conductivity value near the lowest conductivity value in the dataset (300 μS/cm) and another solution with a value near the 90th percentile of the dataset (about 900 μS/cm; refer to Tables 4 and 5). The standard method for reporting specific conductance is in reference to a specific temperature (25 ^{o}C). The observer should consult the manufacturer's manual to determine whether this correction is applied to the meter reading, particularly if the measurement is being made at a different temperature. Correction factors for converting readings from conductivity meters without temperature compensation are given by Radtke et al. (2005).

Dissolved oxygen meters and probes should be calibrated in accordance with manufacturer's instructions (e.g. in a water vapor-saturated environment at a known temperature and atmospheric pressure). Protocols for calibration, measurement, maintenance, and troubleshooting dissolved oxygen meters are presented by Lewis (2006). Values less than the Oklahoma water quality criterion (5 mg/L) should be verified with a re-calibrated meter and (or) by a colleague making an independent measurement. Unexpectedly high values (more than 12 mg/L or 120 percent oxygen saturation) also should be verified in a similar manner. A table listing the solubility of oxygen in water at various temperatures and atmospheric pressures is presented by Lewis (2006).

Quality control plans are designed to evaluate the accuracy and precision of water quality measurements. Repeated measures and independent colleague measurements are examples of quality control practices. Precision of water quality measurements can be estimated by obtaining three consecutive readings and calculating the coefficient of variation (relative standard deviation) by dividing the standard deviation by the mean of the three readings, then multiplying by 100 to express results as a percentage. Water quality data should be entered into a digital data base as soon as practical following field activities. Newly acquired data should be evaluated with reference to historical data ranges to identify potential errors or outliers in sufficient time to repeat field measurements, if necessary. Consistent, verifiable violations of water quality standards or criteria should be reported and discussed with Oklahoma Department of Environmental Quality personnel.

Potential eutrophication issues in Arbuckle Lake were suggested by observations of relatively high percentages of oxygen saturation near the dam, as well as in the Guy Sandy and Rock Creek branches of the reservoir. The 303(d) listing of Arbuckle Lake as impaired by low dissolved oxygen concentrations also may relate to excessive growths of phytoplankton or other aquatic plants. Excessive primary production often results in supersaturated (greater than 100%) concentrations of dissolved oxygen during daytime periods of active phytoplankton growth; however, high rates of respiration can result in low DO concentrations during the night or, particularly, following senescence of large algal and (or) vascular plant populations. The current monitoring strategy is not sufficient to provide understanding of eutrophication processes in Arbuckle and Veterans Lake.

We recommend that water samples should be collected at all lake sites, at a minimum frequency of every other month, and analyzed for nutrient concentrations plus an indicator of phytoplankton abundance using standard analytical methods (e.g. American Public Health Association et al. 2005; Moulton et al. 2002). Indicators of phytoplankton density include analysis of chlorophyll *a* concentrations and (or) identification and enumeration of algal species. Chlorophyll *a* results provide only an estimate of phytoplankton abundance; however, algal-species counts provide a more accurate estimate of algal abundance, in addition to an improved understanding of trophic condition and limiting nutrient status. Continuous, hourly monitoring of dissolved oxygen and pH also can provide estimates of stream metabolism, for example: rates of oxygen production by algae and (or) macrophytes (photosynthesis) and rates of oxygen demand by stream microorganisms (respiration).

We also recommend that annual monitoring of macroinvertebrate communities (and possibly benthic algae communities), in association with stream habitat conditions, should be considered at all stream sites during a season when maximum diversity (number of species) is expected (e.g. Spring). Aquatic biological and habitat assessments should be conducted following a period of relatively-stable, antecedent hydrologic conditions. Recommended protocols include those employed by the USGS National Water-Quality Assessment Program (NAWQA; Moulton et al. 2002) or the U.S. Environmental Protection Agency’s Environmental Monitoring and Assessment Program (EMAP; Barbour et al. 1999).

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Table 4. Summary statistics for "old" water quality monitoring sites (1987-94).
DO, dissolved oxygen, mg/L; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; TALK, total alkalinity, mg/L; NH_3, ammonia nitrogen, mg/L; NO_3, nitrate nitrogen, mg/L; NO_2, nitrite nitrogen, mg/L; PO_4, total phosphorus, mg/L; SO_4, sulfate, mg/L; percentage DO < 5 mg/L, percentage of data with DO concentrations less than 5 mg/L.

OLDSITE 1 (Lowrance Springs)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	83	84	85	85	85	85	85	85	85	62	85	83
Minimum	2.2	6.7	16.6	294	0.2	301	221	0.000	0.240	0.000	0.030	9
Maximum	9.8	8.4	19.7	641	7.3	501	397	0.650	0.980	0.820	0.790	19
Mean	4.6	7.4	18.0	577	1.6	330	331	0.080	0.674	0.016	0.210	15
Standard deviation	0.7	0.3	0.6	53	1.5	23	30	0.118	0.134	0.104	0.139	2
10%ile	4.2	7.2	17.3	521	0.3	315	320	0.010	0.520	0.001	0.080	12
25%ile	4.4	7.3	17.5	568	0.7	322	330	0.020	0.580	0.002	0.117	14
50%ile (Median)	4.6	7.4	17.9	583	1.1	327	336	0.040	0.690	0.002	0.150	14
75%ile	4.8	7.4	18.5	610	2.1	331	341	0.080	0.752	0.003	0.285	16
90%ile	5.0	7.8	18.9	625	3.3	336	349	0.160	0.830	0.004	0.420	16
percentage DO < 5 mg/L	89.0											

OLDSITE 2 (Buckhorn Creek above fish hatchery)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	88	90	90	91	91	91	90	91	89	68	91	88
Minimum	4.2	7.1	9.3	296	1.0	239	223	0.020	0.240	0.000	0.040	11
Maximum	10.7	8.7	20.3	661	14.8	444	3335	0.700	0.860	0.740	0.700	44
Mean	8.5	8.1	15.7	575	5.4	328	366	0.126	0.575	0.016	0.186	15
Standard deviation	0.9	0.3	3.1	60	3.2	22	317	0.119	0.130	0.093	0.128	4
10%ile	7.6	7.7	11.8	520	2.2	315	321	0.040	0.444	0.000	0.076	13
25%ile	7.9	8.0	12.6	559	3.2	322	332	0.050	0.490	0.002	0.100	14
50%ile (Median)	8.7	8.2	15.2	583	4.1	326	337	0.080	0.550	0.002	0.150	15
75%ile	9.0	8.2	18.9	610	7.4	334	343	0.137	0.657	0.002	0.208	16
90%ile	9.4	8.4	19.4	633	9.7	345	350	0.274	0.760	0.003	0.380	18
percentage DO < 5 mg/L	2.3											

Table 4. Summary statistics for “old” water quality monitoring sites (1987-94, cont’d).
DO, dissolved oxygen, mg/L; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; TALK, total alkalinity, mg/L; NH_3, ammonia nitrogen, mg/L; NO_3, nitrate nitrogen, mg/L; NO_2, nitrite nitrogen, mg/L; PO_4, total phosphorus, mg/L; SO_4, sulfate, mg/L; percentage DO < 5 mg/L, percentage of data with DO concentrations less than 5 mg/L.

OLDSITE 3 (Buckhorn Creek below fish hatchery)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	88	91	90	90	91	91	90	89	90	68	91	88
Minimum	4.4	7.1	7.8	51	0.9	207	216	0.000	0.220	0.000	0.000	9
Maximum	10.4	8.8	22.5	639	22.6	400	353	0.500	0.680	0.660	0.710	23
Mean	8.7	8.2	15.3	547	6.4	312	320	0.118	0.509	0.012	0.162	15
Standard deviation	1.1	0.3	5.0	82	4.4	21	15	0.080	0.098	0.080	0.128	2
10%ile	7.3	7.8	9.2	440	2.6	298	307	0.044	0.390	0.000	0.060	13
25%ile	8.0	8.1	10.1	539	3.2	302	314	0.067	0.460	0.001	0.100	14
50%ile (Median)	8.9	8.3	14.5	566	4.7	316	321	0.100	0.500	0.002	0.120	15
75%ile	9.6	8.4	20.4	588	9.1	322	330	0.140	0.580	0.003	0.185	16
90%ile	9.9	8.5	21.7	608	12.7	328	335	0.190	0.640	0.004	0.322	16
percentage DO < 5 mg/L	2.3											

OLDSITE 4 (Buckhorn Creek 0.9 miles below fish hatchery)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	88	90	89	90	91	91	89	89	91	68	91	88
Minimum	4.1	7.1	5.8	298	0.8	137	277	0.020	0.210	0.000	0.002	10
Maximum	13.8	8.9	25.2	624	28.9	335	352	0.500	0.630	0.590	0.980	36
Mean	8.9	8.3	15.1	547	6.7	292	309	0.115	0.428	0.011	0.152	18
Standard deviation	1.6	0.3	6.4	53	5.0	29	16	0.075	0.100	0.071	0.136	5
10%ile	6.8	7.8	7.3	472	2.8	271	289	0.050	0.272	0.001	0.060	13
25%ile	7.9	8.2	8.6	538	3.4	287	294	0.070	0.370	0.002	0.080	14
50%ile (Median)	9.0	8.3	13.9	560	4.7	299	312	0.090	0.430	0.002	0.110	16
75%ile	10.0	8.5	21.4	572	10.0	306	320	0.130	0.480	0.003	0.170	20
90%ile	10.9	8.6	23.5	594	12.5	314	330	0.206	0.568	0.005	0.286	24
percentage DO < 5 mg/L	1.1											

Table 4. Summary statistics for "old" water quality monitoring sites (1987-94, cont'd).
DO, dissolved oxygen, mg/L; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; TALK, total alkalinity, mg/L; NH_3, ammonia nitrogen, mg/L; NO_3, nitrate nitrogen, mg/L; NO_2, nitrite nitrogen, mg/L; PO_4, total phosphorus, mg/L; SO_4, sulfate, mg/L; percentage DO < 5 mg/L, percentage of data with DO concentrations less than 5 mg/L.

OLDSITE 5 (Buckhorn Creek 3.3 miles below fish hatchery)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	84	86	86	87	87	87	85	85	87	64	87	85
Minimum	3.8	7.2	4.2	270	0.7	142	235	0.030	0.080	0.000	0.000	10
Maximum	11.2	8.8	27.4	614	34.2	304	342	0.500	0.690	0.320	0.600	42
Mean	8.2	8.3	14.9	517	5.3	275	294	0.102	0.314	0.008	0.134	20
Standard deviation	1.7	0.3	7.6	71	4.3	26	21	0.080	0.097	0.040	0.100	7
10%ile	5.9	7.8	5.4	451	2.4	250	266	0.040	0.210	0.001	0.042	14
25%ile	7.1	8.2	7.1	499	3.1	264	286	0.050	0.250	0.002	0.080	15
50%ile (Median)	8.4	8.3	13.8	534	4.2	283	297	0.080	0.320	0.002	0.100	17
75%ile	9.8	8.4	22.5	555	5.8	290	308	0.110	0.378	0.003	0.170	23
90%ile	10.3	8.5	25.1	590	10.7	298	315	0.200	0.430	0.005	0.264	31
percentage DO < 5 mg/L	2.4											

OLDSITE 6 (Guy Sandy Creek above Highway 7)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	80	81	82	82	82	82	73	80	82	59	82	80
Minimum	2.9	6.9	0.2	305	0.3	145	204	0.000	0.030	0.000	0.024	10
Maximum	11.1	8.7	26.4	670	42.5	316	355	0.170	0.510	0.162	0.790	50
Mean	7.3	8.0	15.0	518	3.9	259	258	0.056	0.128	0.005	0.240	22
Standard deviation	1.9	0.3	7.7	79	5.0	40	32	0.027	0.077	0.021	0.164	6
10%ile	5.0	7.6	4.8	417	1.1	198	216	0.030	0.060	0.001	0.100	14
25%ile	6.0	7.9	6.8	475	2.0	240	228	0.040	0.080	0.002	0.140	17
50%ile (Median)	7.6	8.2	14.6	527	3.1	270	261	0.050	0.110	0.002	0.180	22
75%ile	8.8	8.3	22.1	576	4.6	288	282	0.070	0.150	0.003	0.280	26
90%ile	9.7	8.3	24.3	611	6.0	298	292	0.080	0.200	0.003	0.520	29
percentage DO < 5 mg/L	10.0											

Table 4. Summary statistics for "old" water quality monitoring sites (1987-94, cont'd).
DO, dissolved oxygen, mg/L; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; TALK, total alkalinity, mg/L; NH_3, ammonia nitrogen, mg/L; NO_3, nitrate nitrogen, mg/L; NO_2, nitrite nitrogen, mg/L; PO_4, total phosphorus, mg/L; SO_4, sulfate, mg/L; percentage DO < 5 mg/L, percentage of data with DO concentrations less than 5 mg/L.

OLDSITE 7 (Guy Sandy Creek)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	79	82	82	82	82	82	53	80	82	59	82	80
Minimum	0.5	7.0	0.1	319	2.0	139	202	0.010	0.010	0.000	0.040	4
Maximum	10.8	12.3	31.2	827	51.7	2559	328	1.000	0.260	0.020	23.000	225
Mean	6.6	8.0	16.7	496	11.0	256	248	0.192	0.108	0.002	0.498	22
Standard deviation	2.1	0.5	8.9	85	7.7	261	29	0.198	0.055	0.003	2.519	24
10%ile	4.0	7.6	4.8	381	3.5	159	216	0.050	0.037	0.001	0.100	13
25%ile	5.1	7.9	8.0	455	6.7	191	228	0.065	0.060	0.001	0.130	15
50%ile (Median)	6.4	8.0	15.4	500	9.3	242	244	0.130	0.110	0.002	0.195	18
75%ile	8.2	8.1	24.5	551	13.2	261	264	0.240	0.140	0.002	0.280	24
90%ile	9.6	8.3	27.9	607	19.6	279	287	0.390	0.183	0.003	0.450	27
percentage DO < 5 mg/L	21.5											

OLDSITE 8 (Travertine Creek--Buffalo Springs)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	79	81	82	82	82	82	82	80	82	59	82	80
Minimum	1.0	6.9	11.8	368	0.2	296	210	0.000	0.110	0.001	0.020	10
Maximum	16.9	8.2	18.7	622	95.0	404	628	0.350	0.490	0.430	1.200	45
Mean	2.4	7.4	17.5	553	3.3	327	331	0.037	0.374	0.010	0.167	17
Standard deviation	1.7	0.2	0.9	43	10.7	13	42	0.048	0.088	0.056	0.187	4
10%ile	1.8	7.2	16.8	505	0.6	319	289	0.010	0.240	0.001	0.040	14
25%ile	2.0	7.3	16.9	530	0.7	320	327	0.020	0.300	0.002	0.080	15
50%ile (Median)	2.2	7.4	17.6	560	1.1	325	333	0.020	0.400	0.002	0.115	16
75%ile	2.4	7.4	18.0	578	1.7	330	340	0.030	0.450	0.002	0.180	18
90%ile	2.6	7.5	18.3	598	5.0	335	351	0.085	0.473	0.003	0.303	21
percentage DO < 5 mg/L	98.7											

Table 4. Summary statistics for "old" water quality monitoring sites (1987-94, cont'd).

DO, dissolved oxygen, mg/L; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; TALK, total alkalinity, mg/L; NH_3, ammonia nitrogen, mg/L; NO_3, nitrate nitrogen, mg/L; NO_2, nitrite nitrogen, mg/L; PO_4, total phosphorus, mg/L; SO_4, sulfate, mg/L; percentage DO < 5 mg/L, percentage of data with DO concentrations less than 5 mg/L.

OLDSITE 9 (Travertine Creek--Antelope Springs)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	80	81	82	82	82	82	82	80	82	59	82	80
Minimum	0.4	6.86	16.8	340	0.3	297	237	0.000	0.100	0.000	0.020	12
Maximum	17.3	8.4	20.1	638	8.2	351	402	0.160	0.400	0.154	0.470	24
Mean	1.0	7.4	17.8	567	1.6	325	333	0.030	0.199	0.004	0.134	18
Standard deviation	2.6	0.2	0.6	48	1.5	9	22	0.028	0.064	0.020	0.106	3
10%ile	0.5	7.2	17.1	519	0.5	318	320	0.010	0.127	0.001	0.047	15
25%ile	0.6	7.3	17.4	550	0.8	321	329	0.015	0.160	0.001	0.060	16
50%ile (Median)	0.6	7.3	17.9	571	1.1	324	335	0.020	0.180	0.002	0.100	18
75%ile	0.6	7.4	18.2	599	1.9	330	340	0.030	0.230	0.002	0.150	19
90%ile	0.7	7.5	18.4	618	2.6	336	349	0.065	0.273	0.003	0.310	21
percentage DO < 5 mg/L	97.5											

OLDSITE 10 (Travertine Creek at Sycamore Crossing)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	80	82	82	82	82	82	81	80	82	59	82	80
Minimum	3.4	7.0	9.0	295	0.5	170	242	0.000	0.120	0.001	0.000	9
Maximum	12.3	11.3	25.2	652	28.0	383	410	0.200	0.720	0.260	0.750	22
Mean	8.6	8.2	15.5	535	3.4	314	324	0.030	0.222	0.002	0.110	18
Standard deviation	1.0	0.4	3.4	56	3.5	314	320	0.038	0.237	0.007	0.144	17
10%ile	7.9	7.8	11.0	484	1.2	304	296	0.010	0.147	0.001	0.050	14
25%ile	8.1	8.1	12.4	515	1.6	309	317	0.020	0.190	0.002	0.080	17
50%ile (Median)	8.5	8.2	16.0	540	2.5	314	324	0.030	0.222	0.002	0.110	18
75%ile	9.1	8.3	18.6	578	3.9	320	330	0.040	0.280	0.002	0.160	19
90%ile	9.7	8.4	19.2	586	6.3	327	335	0.070	0.310	0.005	0.313	20
percentage DO < 5 mg/L	1.2											

Table 4. Summary statistics for "old" water quality monitoring sites (1987-94, cont'd).
DO, dissolved oxygen, mg/L; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; TALK, total alkalinity, mg/L; NH_3, ammonia nitrogen, mg/L; NO_3, nitrate nitrogen, mg/L; NO_2, nitrite nitrogen, mg/L; PO_4, total phosphorus, mg/L; SO_4, sulfate, mg/L; percentage DO < 5 mg/L, percentage of data with DO concentrations less than 5 mg/L.

OLDSITE 11 (Travertine Creek at Rock Creek confluence)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	80	81	82	81	82	82	81	80	82	59	82	80
Minimum	3.0	6.9	5.9	311	0.7	176	203	0.000	0.100	0.000	0.010	11
Maximum	12.2	8.7	25.2	988	8.0	322	420	0.160	0.350	0.186	0.400	24
Mean	8.9	8.2	15.5	677	2.9	293	314	0.060	0.186	0.005	0.132	19
Standard deviation	1.4	0.3	4.7	140	1.3	20	31	0.039	0.047	0.024	0.093	3
10%ile	7.9	7.8	9.7	538	1.5	278	293	0.010	0.127	0.001	0.050	15
25%ile	8.2	8.2	10.8	584	2.0	284	305	0.030	0.150	0.002	0.080	17
50%ile (Median)	8.8	8.3	15.9	629	2.7	296	313	0.050	0.180	0.002	0.100	19
75%ile	9.6	8.4	19.8	789	3.4	304	327	0.090	0.210	0.003	0.180	21
90%ile	10.6	8.5	21.0	893	4.3	311	340	0.120	0.243	0.005	0.300	23
percentage DO < 5 mg/L	2.5											

OLDSITE 12 (Rock Creek at Highway 7 bridge)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	80	82	82	79	82	82	76	80	82	59	82	80
Minimum	2.7	7.0	2.0	345	0.7	157	200	0.040	0.050	0.001	0.000	12
Maximum	16.1	8.6	27.3	1000	19.5	626	520	0.310	0.230	0.115	24.000	55
Mean	7.6	8.0	15.4	599	5.7	246	260	0.110	0.129	0.006	0.505	21
Standard deviation	2.9	0.3	8.0	133	3.6	56	49	0.054	0.032	0.015	2.632	6
10%ile	3.7	7.6	4.9	437	2.7	196	220	0.050	0.100	0.002	0.060	16
25%ile	5.7	7.9	7.7	516	3.2	221	236	0.070	0.110	0.002	0.090	18
50%ile (Median)	7.3	8.1	15.5	581	4.3	242	251	0.100	0.120	0.002	0.165	20
75%ile	9.9	8.2	23.0	714	7.3	264	278	0.140	0.140	0.003	0.270	24
90%ile	11.1	8.3	25.4	798	9.3	289	286	0.175	0.180	0.008	0.510	26
percentage DO < 5 mg/L	18.7											

Table 4. Summary statistics for "old" water quality monitoring sites (1987-94, cont'd).

DO, dissolved oxygen, mg/L; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; TALK, total alkalinity, mg/L; NH_3, ammonia nitrogen, mg/L; NO_3, nitrate nitrogen, mg/L; NO_2, nitrite nitrogen, mg/L; PO_4, total phosphorus, mg/L; SO_4, sulfate, mg/L; percentage DO < 5 mg/L, percentage of data with DO concentrations less than 5 mg/L.

OLDSITE 13 (Rock Creek above confluence with Travertine Creek)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	79	82	82	78	82	82	76	80	82	59	82	80
Minimum	1.4	7.0	1.5	357	2.0	159	206	0.000	0.070	0.001	0.040	12
Maximum	16.2	8.7	26.7	923	19.5	379	508	0.270	0.200	0.108	24.000	243
Mean	6.9	8.0	15.1	633	5.4	253	267	0.103	0.127	0.005	0.478	24
Standard deviation	3.0	0.3	7.9	137	3.2	40	48	0.052	0.026	0.014	2.633	25
10%ile	3.2	7.5	4.3	465	2.7	208	218	0.050	0.100	0.001	0.060	16
25%ile	4.3	7.8	7.9	527	3.4	226	237	0.060	0.110	0.002	0.080	17
50%ile (Median)	6.8	8.0	15.3	628	4.3	255	260	0.100	0.120	0.002	0.145	21
75%ile	9.4	8.1	22.4	743	6.5	286	290	0.130	0.147	0.003	0.270	24
90%ile	10.3	8.2	24.8	827	9.3	294	301	0.170	0.170	0.008	0.393	27
percentage DO < 5 mg/L	29.1											

OLDSITE 14 (Rock Creek below Highway 177 bridge)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	80	82	82	79	82	82	81	80	82	59	82	80
Minimum	3.3	6.9	3.7	339	1.5	214	204	0.020	0.080	0.001	0.000	11
Maximum	16.1	8.6	24.6	1000	14.2	339	337	0.190	0.250	0.190	19.600	42
Mean	8.3	8.2	15.5	707	4.9	278	293	0.094	0.150	0.005	0.397	20
Standard deviation	1.6	0.3	5.5	128	2.3	18	27	0.040	0.037	0.024	2.154	5
10%ile	7.0	7.8	8.5	583	2.8	258	264	0.050	0.107	0.001	0.050	15
25%ile	7.3	8.1	10.2	625	3.3	265	276	0.060	0.120	0.002	0.070	17
50%ile (Median)	7.9	8.2	16.1	681	4.4	280	294	0.100	0.150	0.002	0.100	20
75%ile	9.2	8.3	20.3	809	5.9	289	314	0.120	0.170	0.003	0.160	22
90%ile	10.0	8.3	22.1	870	7.2	298	324	0.160	0.200	0.004	0.412	25
percentage DO < 5 mg/L	1.2											

Table 4. Summary statistics for "old" water quality monitoring sites (1987-94, cont'd).

DO, dissolved oxygen, mg/L; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; TALK, total alkalinity, mg/L; NH_3, ammonia nitrogen, mg/L; NO_3, nitrate nitrogen, mg/L; NO_2, nitrite nitrogen, mg/L; PO_4, total phosphorus, mg/L; SO_4, sulfate, mg/L; percentage DO < 5 mg/L, percentage of data with DO concentrations less than 5 mg/L.

OLDSITE 15 (Rock Creek downstream from Rock Creek campground)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	80	82	82	79	82	82	80	80	82	59	82	80
Minimum	3.1	7.0	2.5	332	1.6	187	210	0.020	0.040	0.001	0.020	10
Maximum	15.8	8.6	24.1	1000	15.3	332	329	0.250	0.260	0.181	21.800	36
Mean	8.2	8.2	15.0	715	5.1	266	288	0.078	0.143	0.005	0.382	20
Standard deviation	1.9	0.3	6.6	134	2.6	26	27	0.042	0.039	0.023	2.396	4
10%ile	6.2	7.6	6.3	577	2.1	224	254	0.035	0.100	0.002	0.040	16
25%ile	6.9	8.2	8.8	639	3.3	251	271	0.050	0.120	0.002	0.050	18
50%ile (Median)	7.7	8.3	15.4	698	4.4	276	291	0.070	0.140	0.002	0.090	20
75%ile	9.7	8.3	20.9	810	6.4	283	309	0.100	0.170	0.002	0.140	22
90%ile	10.2	8.4	22.9	898	8.4	290	323	0.140	0.184	0.004	0.266	26
percentage DO < 5 mg/L	1.2											

OLDSITE 16 (Rock Creek at Jumas Ranch Road crossing)

	DO	PH	WT	COND	TURB	TALK	HARD	NH_3	NO_3	NO_2	PO_4	SO_4
Number of observations	13	13	13	9	13	13	12	12	12	12	12	12
Minimum	3.9	7.0	2.5	469	0.9	194	205	0.010	0.060	0.002	0.060	15
Maximum	16.2	8.4	27.2	1000	15.4	285	314	0.160	0.170	0.095	0.230	39
Mean	8.1	8.1	16.9	760	5.4	256	280	0.071	0.116	0.010	0.114	23
Standard deviation	3.4	0.4	8.1	151	4.1	28	31	0.043	0.032	0.027	0.056	7
10%ile	4.4	7.4	4.5	564	1.6	211	227	0.031	0.081	0.002	0.060	17
25%ile	6.0	8.0	12.2	708	3.0	237	279	0.045	0.098	0.002	0.070	19
50%ile (Median)	7.7	8.3	16.3	720	3.9	265	287	0.060	0.111	0.003	0.095	22
75%ile	9.2	8.3	23.2	833	6.9	276	301	0.085	0.140	0.003	0.150	24
90%ile	13.3	8.4	26.3	972	12.4	283	308	0.146	0.167	0.031	0.209	34
percentage DO < 5 mg/L	7.7											

Table 5. Summary statistics for "new" water quality monitoring sites (2000-09)
DO, dissolved oxygen, mg/L; DOSAT, oxygen saturation, percentage; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; NO_3, nitrate nitrogen, mg/L.

SITE 1 (Rock Creek at "40 ft hole")

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	45	45	38	47	34	20	28
Minimum	1.4	17	6.5	4.9	484	0.0	0.000
Maximum	15.5	197	8.6	28.7	961	216.5	35.240
Mean	8.9	98	7.8	19.9	761	18.4	4.967
Standard deviation	3.0	33	0.5	7.0	138	48.4	8.069
10%ile	4.9	57	7.1	8.2	595	0.0	0.040
25%ile	7.4	84	7.5	13.8	618	0.5	0.185
50%ile (Median)	8.9	102	7.9	22.3	780	3.8	1.185
75%ile	10.6	115	8.2	25.3	892	9.7	7.390
90%ile	12.7	132	8.3	27.2	909	42.5	14.501
percentage DO < 5 mg/L	11.1						

SITE 2 (Upper Guy Sandy Creek)

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	38	39	31	39	38	20	24
Minimum	1.8	23	6.5	4.3	290	0.0	0.000
Maximum	12.3	173	8.8	28.6	854	216.5	60.730
Mean	7.5	84	7.7	19.3	500	27.9	7.336
Standard deviation	2.6	28	0.5	7.6	129	55.7	15.953
10%ile	4.4	46	7.0	7.7	329	0.0	0.027
25%ile	5.8	69	7.5	12.8	385	3.8	0.180
50%ile (Median)	7.3	85	7.9	23.2	538	10.0	0.893
75%ile	9.1	97	8.0	25.2	579	17.3	5.655
90%ile	11.5	112	8.2	27.3	621	99.3	19.777
percentage DO < 5 mg/L	15.8						

SITE 3 (Travertine Creek near Cold Springs)

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	45	46	--	46	45	20	29
Minimum	1.5	19	--	-8.5	454	0.0	0.001
Maximum	13.1	200	--	24.1	954	10.3	69.660
Mean	8.7	96	--	17.4	539	1.3	7.816
Standard deviation	2.5	30	--	6.2	74	2.6	16.790
10%ile	5.0	57	--	9.2	483	0.0	0.124
25%ile	7.8	86	--	15.4	495	0.0	0.163
50%ile (Median)	8.8	98	--	19.4	539	0.0	1.090
75%ile	10.2	109	--	20.8	566	1.3	6.796
90%ile	11.7	126	--	23.0	578	5.0	21.934
percentage DO < 5 mg/L	8.9						

Table 5. Summary statistics for "new" water quality monitoring sites (2000-09) (cont'd). DO, dissolved oxygen, mg/L; DOSAT, oxygen saturation, percentage; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; NO_3, nitrate nitrogen, mg/L.

SITE 4 (Buckhorn Creek downstream from fish hatchery)

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	44	44	37	46	44	21	29
Minimum	1.4	18	6.2	-9.3	212	0.0	0.001
Maximum	14.0	152	8.8	27.2	623	110.4	93.830
Mean	8.6	92	7.8	18.2	555	20.5	10.596
Standard deviation	2.8	29	0.6	6.3	64	32.2	20.728
10%ile	4.9	48	7.0	10.6	519	0.2	0.120
25%ile	7.1	80	7.4	13.9	530	2.3	0.158
50%ile (Median)	8.6	98	8.0	20.3	560	6.0	1.520
75%ile	10.1	106	8.2	22.1	597	23.0	10.387
90%ile	12.1	119	8.3	23.7	607	79.2	36.480
percentage DO < 5 mg/L	9.1						

SITE 5 (Buckhorn Creek near power line)

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	44	44	35	46	45	22	29
Minimum	1.4	19	6.1	3.3	314	0.0	0.001
Maximum	15.8	169	8.8	29.0	881	94.2	94.840
Mean	8.5	91	7.9	19.6	514	8.9	11.467
Standard deviation	2.9	29	0.6	7.4	79	20.1	22.584
10%ile	4.8	54	7.2	7.4	451	0.0	0.058
25%ile	6.8	80	7.8	12.1	478	0.0	0.147
50%ile (Median)	8.4	92	8.0	23.3	510	2.9	1.290
75%ile	9.6	108	8.2	25.3	544	6.0	10.855
90%ile	12.4	119	8.4	26.7	581	20.2	40.082
percentage DO < 5 mg/L	11.4						

SITE 6 (Rock Creek at Sulfur, OK near ball field)

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	31	31	33	33	31	10	27
Minimum	0.8	11	6.2	4.1	379	0.0	0.000
Maximum	12.3	127	8.8	30.1	975	10.9	56.590
Mean	7.1	80	7.6	20.8	634	1.8	7.075
Standard deviation	2.8	31	0.5	7.8	175	3.7	14.315
10%ile	3.8	41	6.9	6.0	404	0.0	0.090
25%ile	4.8	60	7.4	14.1	476	0.0	0.183
50%ile (Median)	7.0	81	7.7	23.7	635	0.1	1.110
75%ile	9.1	106	7.9	26.0	717	0.6	5.565
90%ile	10.3	117	8.1	28.7	898	8.6	23.248
percentage DO < 5 mg/L	25.8						

Table 5. Summary statistics for "new" water quality monitoring sites (2000-09) (cont'd). DO, dissolved oxygen, mg/L; DOSAT, oxygen saturation, percentage; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; NO_3, nitrate nitrogen, mg/L.

SITE 7 (Arbuckle Lake--Guy Sandy branch)

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	33	33	31	33	33	10	24
Minimum	2.2	24	6.5	6.0	298	0.0	0.001
Maximum	12.7	165	8.9	32.6	407	124.2	70.110
Mean	7.9	94	8.0	22.8	350	14.3	9.880
Standard deviation	2.3	31	0.7	8.3	29	38.8	16.927
10%ile	4.9	51	6.9	9.4	322	0.0	0.090
25%ile	7.0	84	7.4	15.9	333	0.0	0.165
50%ile (Median)	8.2	97	8.3	26.5	343	1.4	1.451
75%ile	9.4	111	8.4	29.3	366	1.9	14.860
90%ile	10.4	128	8.6	30.7	400	68.3	27.755
percentage DO < 5 mg/L	9.1						

SITE 8 (Arbuckle Lake--Dam)

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	33	33	31	33	33	10	24
Minimum	1.7	21	6.6	5.6	313	0.0	0.002
Maximum	15.6	201	8.9	31.3	420	171.3	68.410
Mean	7.8	93	8.0	22.4	352	18.5	9.545
Standard deviation	2.6	34	0.6	8.0	27	53.8	16.055
10%ile	4.8	47	7.0	10.0	325	0.0	0.099
25%ile	6.7	82	7.4	15.5	335	0.0	0.170
50%ile (Median)	8.0	93	8.3	25.3	345	0.0	1.516
75%ile	9.5	111	8.4	28.6	362	1.3	16.285
90%ile	10.3	129	8.5	29.9	400	91.6	23.147
percentage DO < 5 mg/L	9.1						

SITE 9 (Arbuckle Lake--Buckhorn Creek branch)

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	31	31	29	31	31	9	22
Minimum	1.5	21	6.6	5.3	172	0.0	0.002
Maximum	10.5	132	8.9	31.3	420	138.4	71.720
Mean	7.3	86	7.9	21.7	353	17.6	10.024
Standard deviation	2.1	27	0.6	8.2	43	45.5	17.227
10%ile	4.2	40	7.0	7.8	327	0.0	0.078
25%ile	6.6	75	7.4	14.5	342	0.0	0.170
50%ile (Median)	7.9	94	8.1	24.9	352	1.5	1.566
75%ile	8.6	102	8.3	28.1	374	5.3	19.820
90%ile	9.6	108	8.5	29.5	405	88.0	26.950
percentage DO < 5 mg/L	19.3						

Table 5. Summary statistics for "new" water quality monitoring sites (2000-09) (cont'd). DO, dissolved oxygen, mg/L; DOSAT, oxygen saturation, percentage; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; NO_3, nitrate nitrogen, mg/L.

SITE 10 (Arbuckle Lake--Rock Creek branch)

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	31	31	28	31	30	10	22
Minimum	1.6	22	6.3	6.6	272	0.0	0.001
Maximum	12.6	164	8.8	33.2	456	171.3	70.160
Mean	7.7	92	7.9	22.5	373	20.9	12.297
Standard deviation	2.6	32	0.7	8.4	39	53.0	18.496
10%ile	4.3	41	6.8	8.9	333	0.4	0.067
25%ile	6.6	82	7.4	14.8	351	0.7	0.140
50%ile (Median)	8.0	96	8.2	24.1	369	3.3	2.030
75%ile	9.5	109	8.4	29.6	388	8.4	28.700
90%ile	10.6	125	8.5	31.4	433	92.5	33.944
percentage DO < 5 mg/L	19.3						

SITE 11 (Veterans Lake)

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	32	32	25	34	33	21	19
Minimum	1.3	14	6.8	-0.4	231	0.0	0.000
Maximum	13.7	189	8.5	33.2	579	74.5	66.970
Mean	7.6	85	8.0	21.5	312	6.2	8.829
Standard deviation	3.1	36	0.4	9.0	60	16.2	16.340
10%ile	3.7	29	7.3	7.5	250	0.2	0.010
25%ile	5.9	64	7.8	13.8	282	0.9	0.645
50%ile (Median)	7.6	92	8.1	25.7	306	1.6	2.940
75%ile	10.1	103	8.3	28.3	324	3.1	8.468
90%ile	11.3	116	8.4	30.1	366	13.6	28.000
percentage DO < 5 mg/L	18.7						

SITE 12 (Antelope Springs)

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	15	16	10	16	14	16	7
Minimum	0.9	10	7.2	16.8	497	0.0	0.0000
Maximum	5.2	55	7.8	18.0	615	13.7	4.7100
Mean	2.4	25	7.4	17.8	579	1.5	1.3830
Standard deviation	1.5	15	0.2	0.3	33	3.6	1.8500
10%ile	0.9	10	7.2	17.8	535	0.0	0.0000
25%ile	1.0	11	7.3	17.8	557	0.0	0.0170
50%ile (Median)	1.9	23	7.3	17.9	588	0.0	0.5180
75%ile	3.5	35	7.4	17.9	602	1.0	2.6750
90%ile	4.9	48	7.8	18.0	614	5.1	4.3990
percentage DO < 5 mg/L	93.3						

Table 5. Summary statistics for "new" water quality monitoring sites (2000-09) (cont'd). DO, dissolved oxygen, mg/L; DOSAT, oxygen saturation, percentage; PH, pH, standard units; WT, water temperature, degrees Celsius; COND, specific conductance, microSiemens per centimeter; TURB, water turbidity, nephelometric turbidity units; NO_3, nitrate nitrogen, mg/L.

SITE 13 (Buffalo Springs)

	DO	DOSAT	PH	WT	COND	TURB	NO_3
Number of observations	16	17	10	17	15	17	7
Minimum	2.8	30	7.1	14.3	493	0.0	0.000
Maximum	7.9	83	7.6	19.1	609	4.2	5.560
Mean	4.5	48	7.3	17.6	584	0.2	1.626
Standard deviation	1.5	16	0.1	1.0	30	1.0	2.181
10%ile	2.9	31	7.2	17.1	554	0.0	0.000
25%ile	3.4	33	7.2	17.6	584	0.0	0.024
50%ile (Median)	4.1	43	7.3	17.8	595	0.0	0.657
75%ile	5.5	60	7.3	18.0	601	0.0	3.131
90%ile	6.6	70	7.5	18.2	607	0.0	5.193
percentage DO < 5 mg/L	68.7						

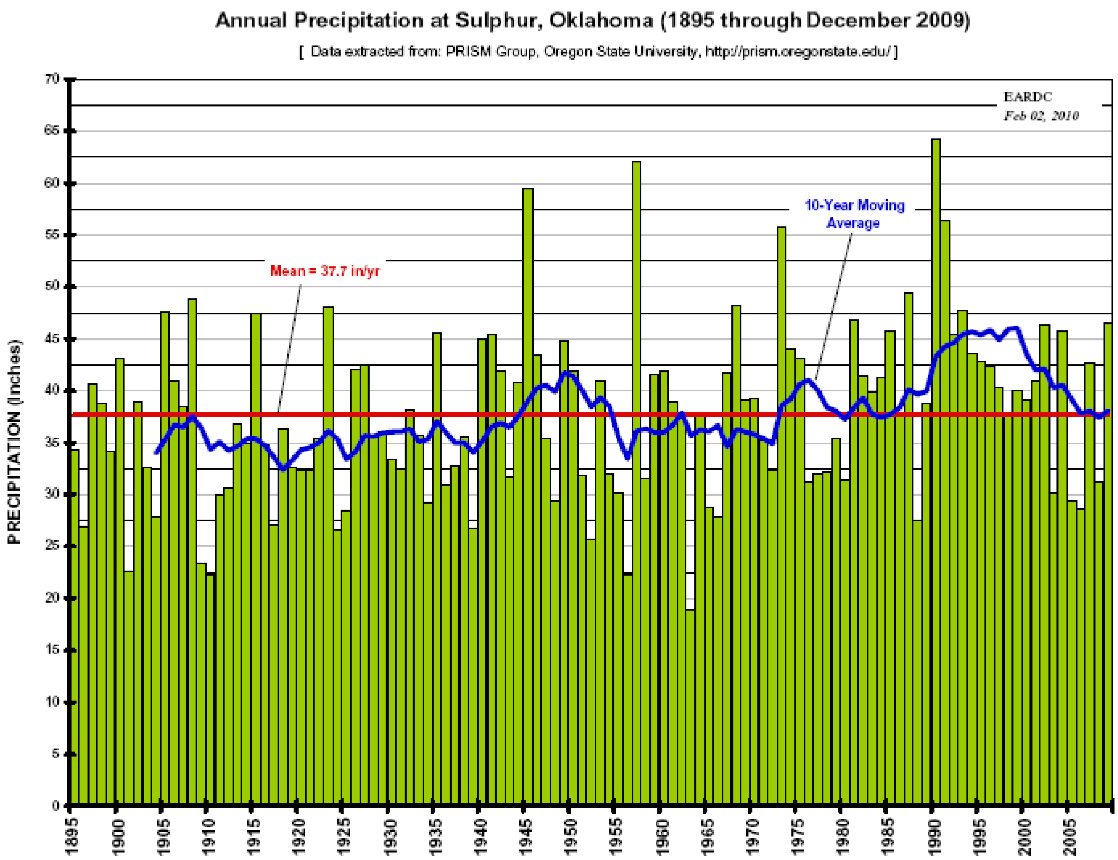

Figure 41. Long term precipitation record for Sulphur, Oklahoma.

1	2
3	4
5	6

Back Cover Photos

1: Antelope Spring
2: Buffalo Spring
3: Travertine Creek
4: Arbuckle Lake
5: Travertine Creek
6: Veterans Lake