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Synopsis of Integrated Science to Support the Assessment of Conservation Practices in the Fort Cobb Reservoir Watershed, Southwestern Oklahoma

Chapter 10 of

Assessment of Conservation Practices in the Fort Cobb Reservoir Watershed, Southwestern Oklahoma

Compiled by the U.S. Geological Survey and the Agricultural Research Service

Scientific Investigations Report 2010–5257

U.S. Department of the Interior
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By W.J. Andrews, Carol J. Becker, Jean L. Steiner, John A. Daniel, Jurgen D. Garbrecht, Daniel N. Moriasi, Patrick J. Starks, Carol S. Mladinich, Mahesh Rao, Siewe Siewe, Roger N. Clark, Richard A. Wise, James F. Fairchild, Ann L. Allert, and S. Jerrod Smith

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
	Volume	
metric ton per day	1.102	ton per day (ton/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (μg/L).

Synopsis of Integrated Science to Support the Assessment of Conservation Practices in the Fort Cobb Watershed, Southwestern Oklahoma

By W.J. Andrews,[1] Carol J. Becker,[1] Jean Steiner,[2] John A. Daniel,[2] Jurgen D. Garbrecht,[2] Daniel N. Moriasi,[2] Patrick J. Starks,[2] Carol S. Mladinich,[1] Mahesh Rao,[3] Siewe Siewe,[3] Roger N. Clark,[1] Richard A. Wise,[1] James F. Fairchild,[1] Ann L. Allert,[1] and S. Jerrod Smith[1]

Abstract

The Fort Cobb Reservoir in southwestern Oklahoma is an artificial impoundment constructed by the Bureau of Reclamation for water supplies, flood control, and recreation. Success of best-management practices in reducing inflows of sediments and phosphorus to the reservoir prompted the U.S. Department of Agriculture in 2003 to designate the watershed for study as part of the Conservation Effectiveness Assessment Project to quantify environmental benefits derived from agricultural conservation programs. The U.S. Geological Survey, as part of the Central Region Integrated Science Program, studied land uses, soils, geology, and water quality in the watershed through field and remote sensing investigations in collaboration with the Agricultural Research Service from 2004 to 2007. These investigations indicated that though progress has been made in reducing inflows of sediment and nutrients in the basin, targeting best-management practices to small intermittent streams draining to the reservoir and to the Cobb Creek subwatershed may effectively augment efforts to improve eutrophic to hypereutrophic conditions that continue to affect the reservoir. Multidisciplinary data gathered for this report provide information about interactions between land uses, geologic features, other watershed properties, and eutrophication of a major reservoir that would not otherwise have been provided by more limited investigations of water quality or aquatic ecology.

Introduction

The watershed of the Fort Cobb Reservoir in southwestern Oklahoma (fig. 1) was investigated by hydrologists, agronomists, biologists, geologists, and remote-sensing experts of the U.S. Geological Survey (USGS) and the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA) from 2004 to 2007 to investigate relations between land uses, geology, water quality, soil properties, quality of aquatic habitat, and sources and distribution of sediment and nutrients to the reservoir. Because best-management practices, such as conversion of cropland to pastureland, construction of grade-stabilization structures, and increasing no-till practices on cropland were expected to decrease erosion and transport of sediments and nutrients to the reservoir and improve water quality and the health of aquatic ecosystems in tributaries to the reservoir, the USDA in 2003 selected the watershed for study as part of the Conservation Effectiveness Assessment Project to quantify environmental benefits derived from agricultural conservation programs (Oklahoma Conservation Commission, 2007; Steiner and others, 2007; State of Oklahoma, 2010). The Fort Cobb Reservoir watershed is 1 of 14 Benchmark Watersheds studied by the ARS to evaluate the effects of USDA-Natural Resources Conservation Service conservation practices on selected environmental endpoints such as

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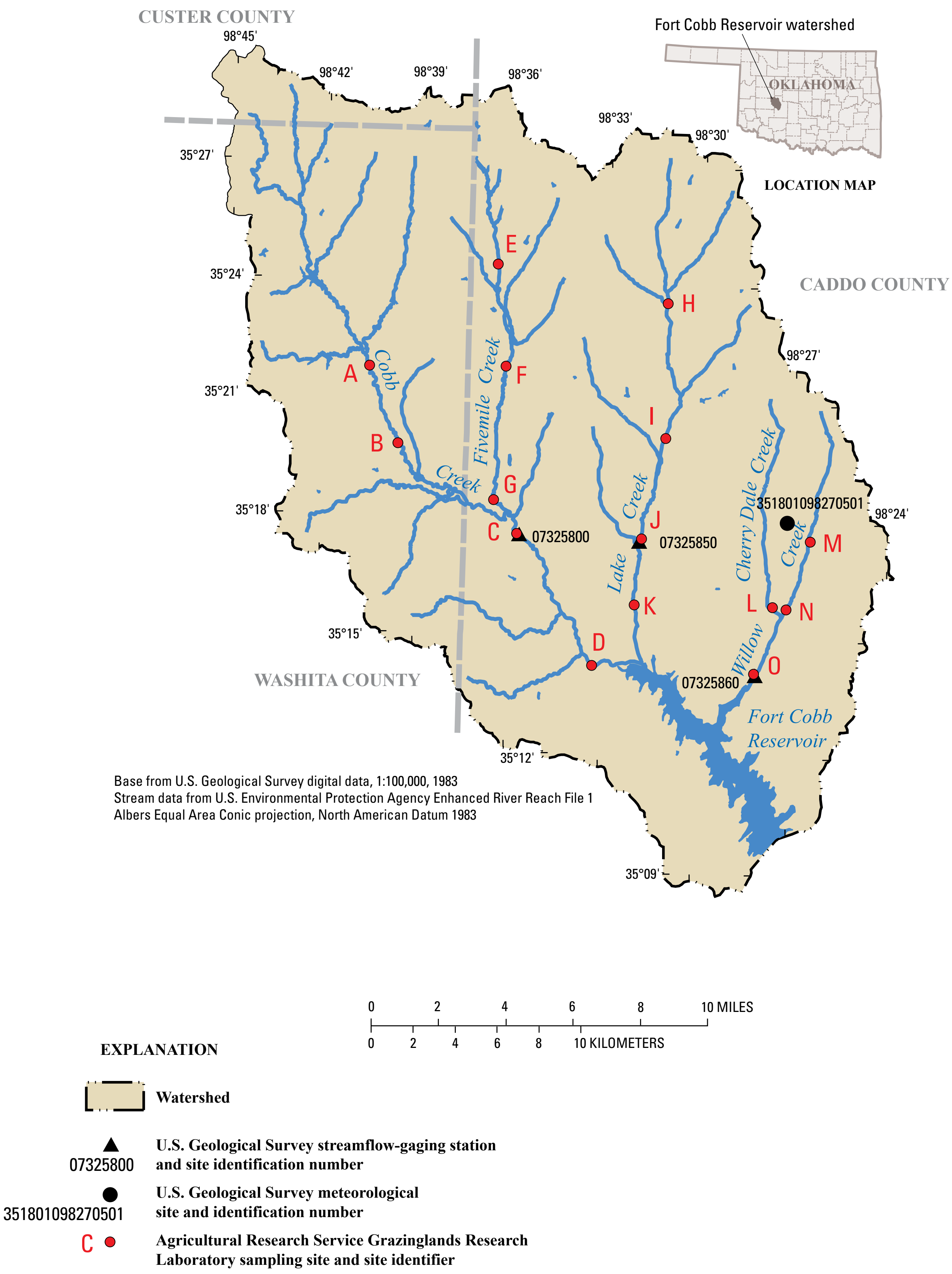


Figure 1. Location of the Fort Cobb Reservoir and watershed in the Upper Washita River basin, southwestern Oklahoma.

(1) water quality, (2) sediment reduction, and (3) wildlife habitat. Agricultural activities and vulnerability of soils to erosion have led to water-quality issues, especially sedimentation and nutrient enrichment, in the Fort Cobb Reservoir and three primary tributaries: Cobb, Lake, and Willow Creeks (Steiner and others, 2007). Staff of the USGS implemented multidisciplinary investigations of land use and water quality in the watershed to augment evaluation of physical, chemical, geographic, and biological indicators of the watershed being implemented by the ARS and other partners. This chapter summarizes and includes additional discussion of information presented in chapters 1 through 9 of this report.

Watershed Description

The Fort Cobb Reservoir was constructed in 1959 in southwestern Oklahoma as part of the Washita River Watershed Project by the Bureau of Reclamation. The reservoir, which is used for water supplies, flood control, and recreation, covers an area of about 16.6 square kilometers, has 72 kilometers of shoreline, and stores as much as 177,000,000 cubic meters of water. Mean annual precipitation in the watershed from 1980 through 2005 was 811 millimeters (mm) with average annual temperatures ranging from 13 to 16 degrees Celsius. Soil textures in the watershed range from sandy loams to silty loams that are underlain by cross-bedded sandstones with interbedded dolomite and gypsum of the Rush Springs Formation or massive gypsum, sandstones, siltstones, mudstones, and dolomite of the Marlow Formation, both of Permian age. Landsat images and ground-truthing indicated that cultivated crops, including winter wheat, small grains, sorghum, and cotton, cover between 51 (2001) and 56 (2005) percent of the watershed, with pasture accounting for another 34 (2005) to 40 (2001) percent.

Purpose and Scope

The purposes of this chapter are to provide a synopsis of integrated science described in the previous chapters of this report and to emphasize relations between basin characteristics and the quality of water in streams discharging to the Fort Cobb Reservoir.

Methods

This chapter summarizes previously shown text and illustrations and presents some new graphs based on data collected for previous chapters in this report to show relations between subwatershed characteristics and water quality in tributaries of the Fort Cobb Reservoir. Locations of distribution of data groups, whether grouped by streamflow-gaging station, season, or flow condition, are compared in this chapter through use of the non-parametric Wilcoxon rank-sum test (Wilcoxon, 1945) (also known as the Mann-Whitney test). For this test, the p-value is a measure of likelihood that the null hypothesis (no difference between locations of distribution of two groups) is true. In this chapter, one-sided p-values of 0.05 or less of the Wilcoxon rank sum test support a 95 percent or greater confidence that the locations of distributions of two compared groups of numbers are significantly different (the alternative hypothesis).

Soil properties (organic carbon, clay content, sand content, silt content, and saturated hydraulic conductivity) for subwatersheds of the Fort Cobb Reservoir watershed were determined from STATSGO data (Natural Resources Conservation Service, 2009), using ESRI ArcMap™ software (Environmental Systems Research Institute, Inc., 2007). Mean land-surface slopes in those subwatersheds were determined from digital-elevation models (U.S. Geological Survey, 2009a). Forested areas within 100 meters of Cobb, Lake, and Willow Creeks were determined from the 2001 National Land Cover Database (U.S. Geological Survey, 2009b) by using ESRI ArcMap software (Environmental Systems Research Institute, 2007). All nitrogen compounds in this report are reported in milligrams per liter (mg/L) as nitrogen. Orthophosphate is reported in milligrams per liter as phosphorus.

Integrated Science Related to Streamflow, Water Quality, and Subwatershed Characteristics

Streamflow

Water in the Fort Cobb Reservoir comes primarily from inflows of three creeks (Cobb, Lake, and Willow), diffuse groundwater seepage, and land-surface runoff. Streamflows in the watershed tend to be greatest in the spring months of March, April, and May, decrease through the summer months, and subsequently increase during October and November (fig. 2). Cobb Creek carries the greatest proportion of streamflow in the watershed—about 73 percent. Masses of suspended-sediment transported in Cobb Creek, Lake Creek, and Willow Creek tended to increase substantially with streamflow, particularly at the Cobb and Willow Creek streamflow-gaging stations (fig. 3). Suspended-sediment concentrations in water samples collected from those three creeks generally were greater during the growing season (May-September) than during dormancy (October-April). Cobb Creek also had higher loads and yields during the growing season whereas Lake and Willow Creek were similar during both seasons. Basins of these three creeks had similar sediment yields (fig. 4).

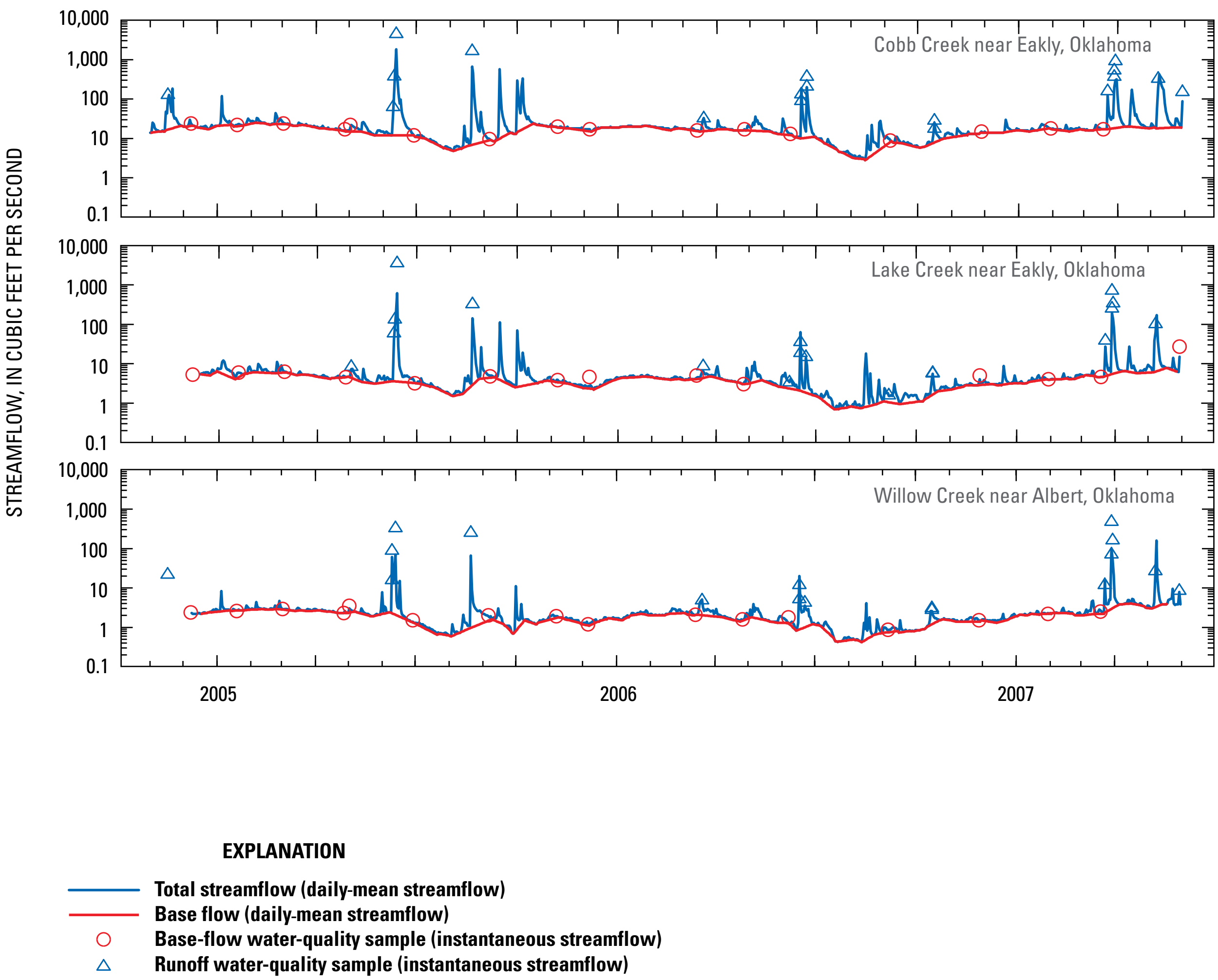


Figure 2. Daily-mean streamflows and streamflows at times of sampling at three streamflow-gaging stations on tributaries of the Fort Cobb Reservoir, 2004–2007.

Water Quality

Water samples collected from Cobb Creek generally had greater concentrations of nitrate nitrogen and total nitrogen than water samples from Lake Creek and Willow Creek, but water samples collected at the streamflow-gaging stations on each of the creeks had similar distributions of concentrations of ammonia nitrogen (NH_4^+-N) and organic nitrogen (fig. 5). Organic nitrogen was the largest component of total nitrogen in water samples collected from the three creeks; 70 to 80 percent of nitrogen measured in stream samples was in the form of organic nitrogen transported into streams during runoff (figs. 5 and 6). Nitrate nitrogen (NO_3-N) concentrations were greatest in base-flow samples and in samples collected during the dormant season (October through April) from Cobb Creek and Lake Creek, whereas nitrite nitrogen (NO_2^--N), ammonia nitrogen, and organic nitrogen concentrations were greatest in runoff samples and in samples collected during the growing season (May through September) (figs. 5 and 6). Total nitrogen concentrations generally were greatest in streams during runoff during the growing season, similar to concentrations of suspended sediment (figs. 4, 7, and 8).

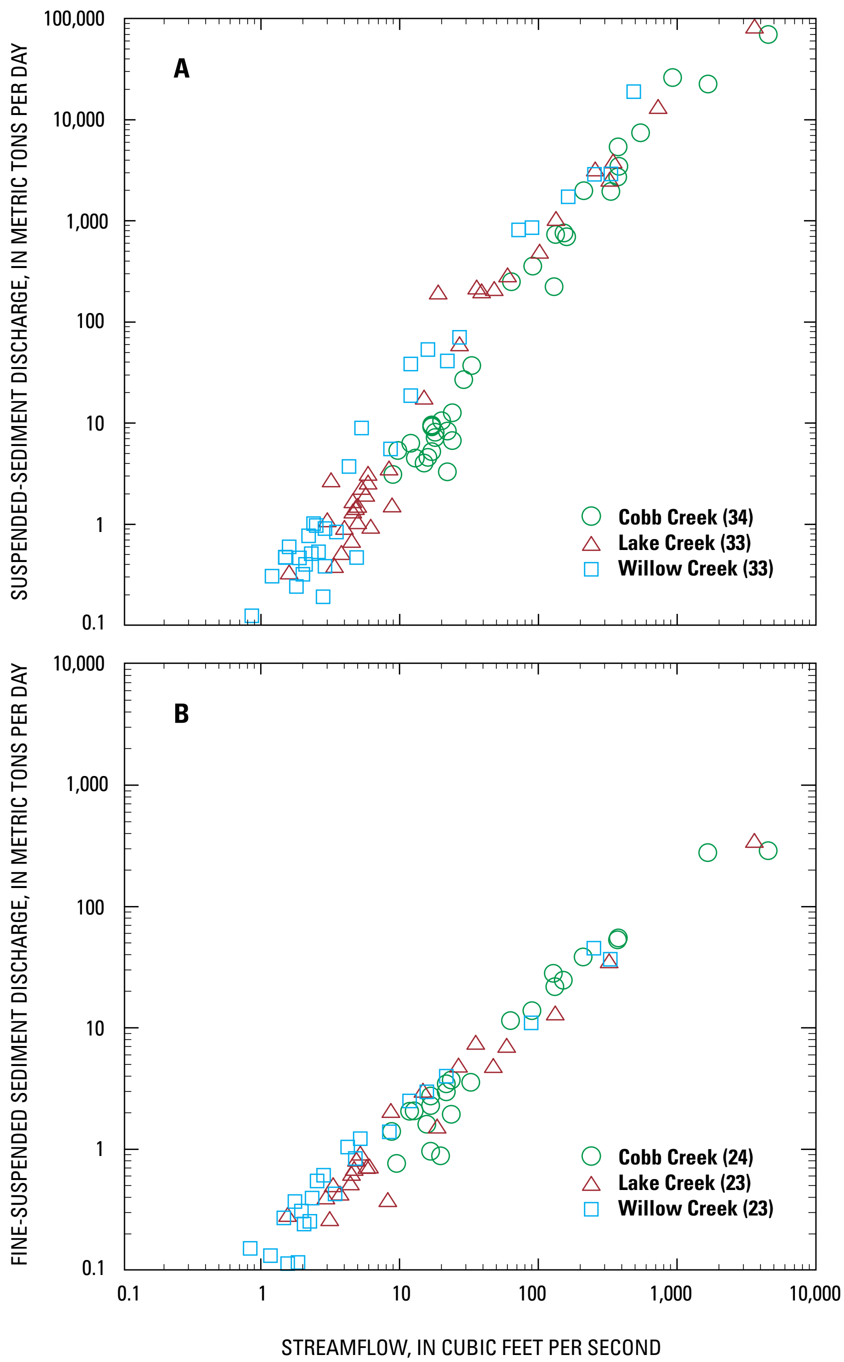


Figure 3. (*A*) calculated suspended-sediment discharge and (*B*) fine-suspended sediment (silt and clay, less than 0.063 millimeters) discharge at three U.S. Geological Survey streamflow-gaging stations on tributaries of the Fort Cobb Reservoir, 2004-2007.

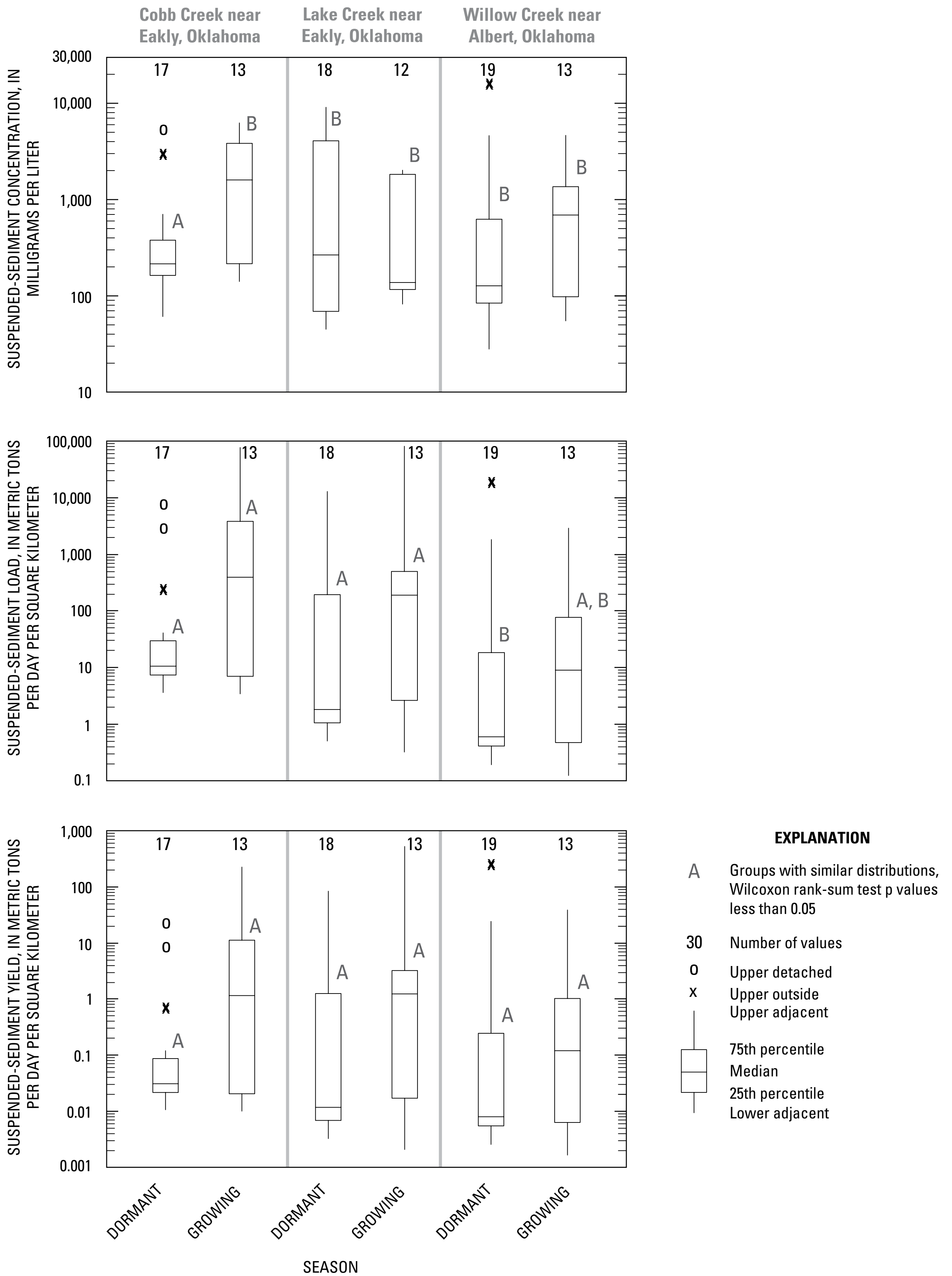


Figure 4. Instantaneous suspended-sediment concentrations, loads, and yields during dormant and growing seasons at three streamflow-gaging stations on tributaries of the Fort Cobb Reservoir, 2004–2007.

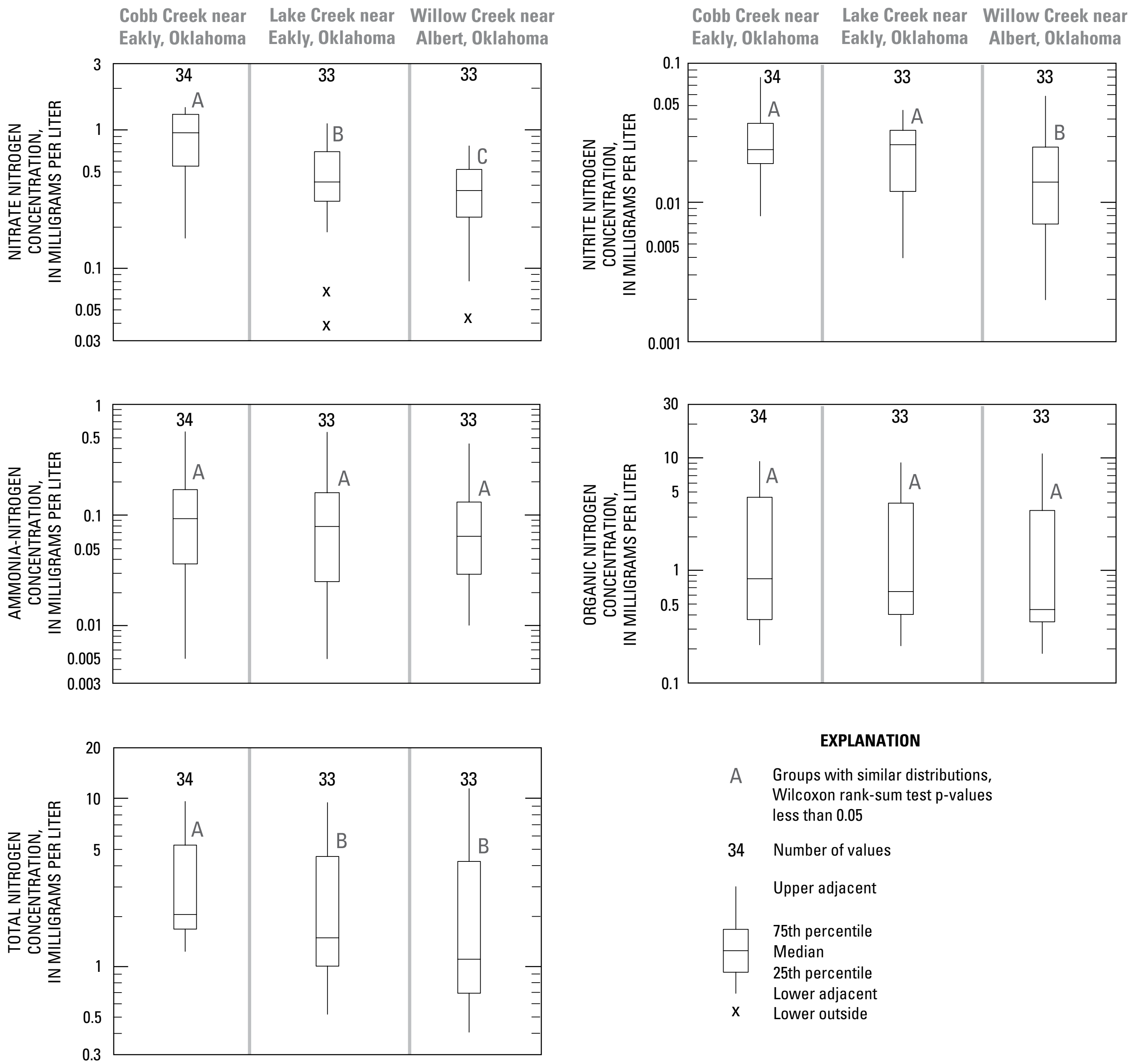


Figure 5. Nitrogen-compound concentrations in surface-water samples collected at three streamflow-gaging stations on tributaries of the Fort Cobb Reservoir, 2004–2007.

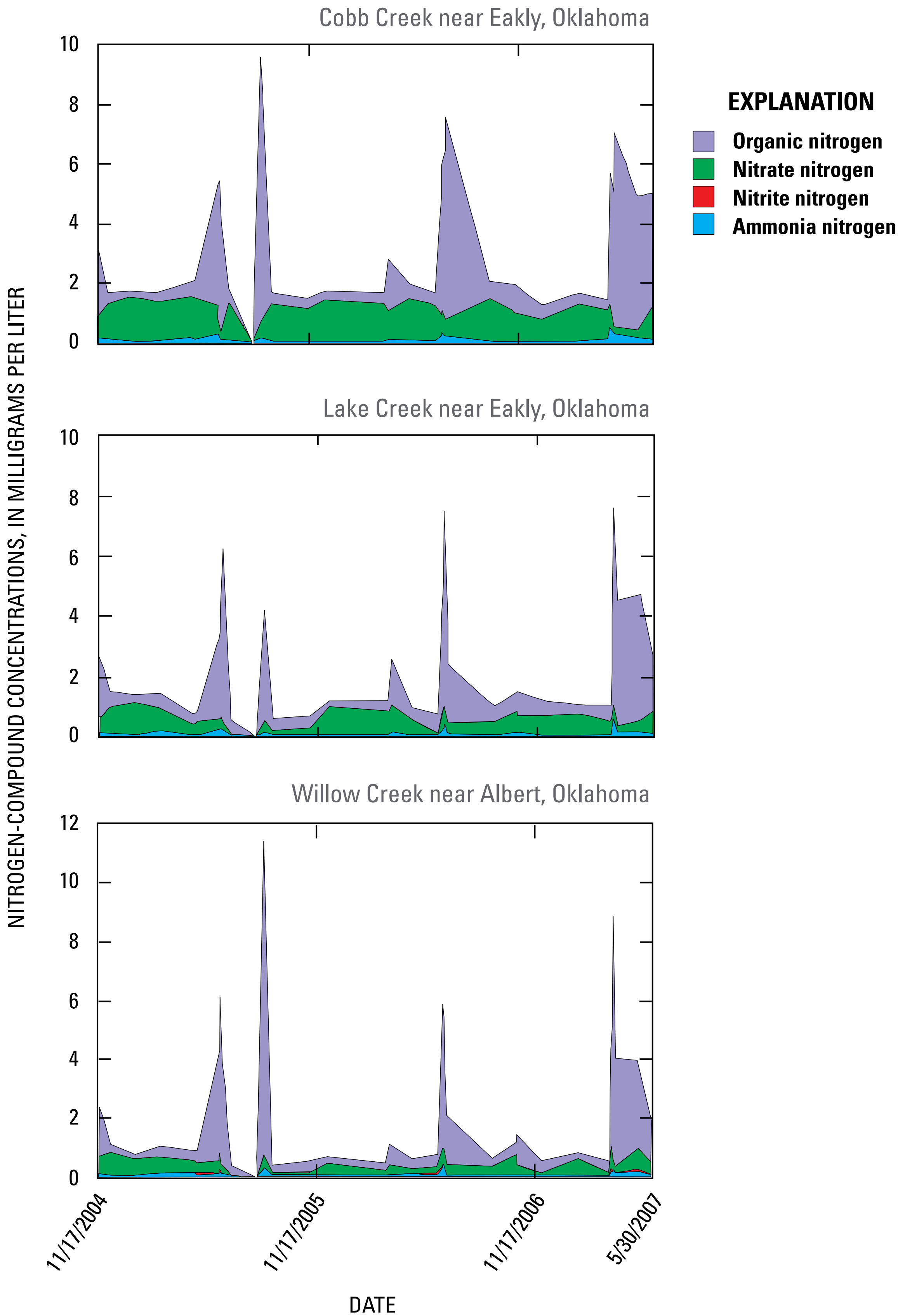


Figure 6. Nitrogen-compound concentrations with time in surface-water samples collected at three streamflow-gaging stations on tributaries of the Fort Cobb Reservoir, 2004–2007.

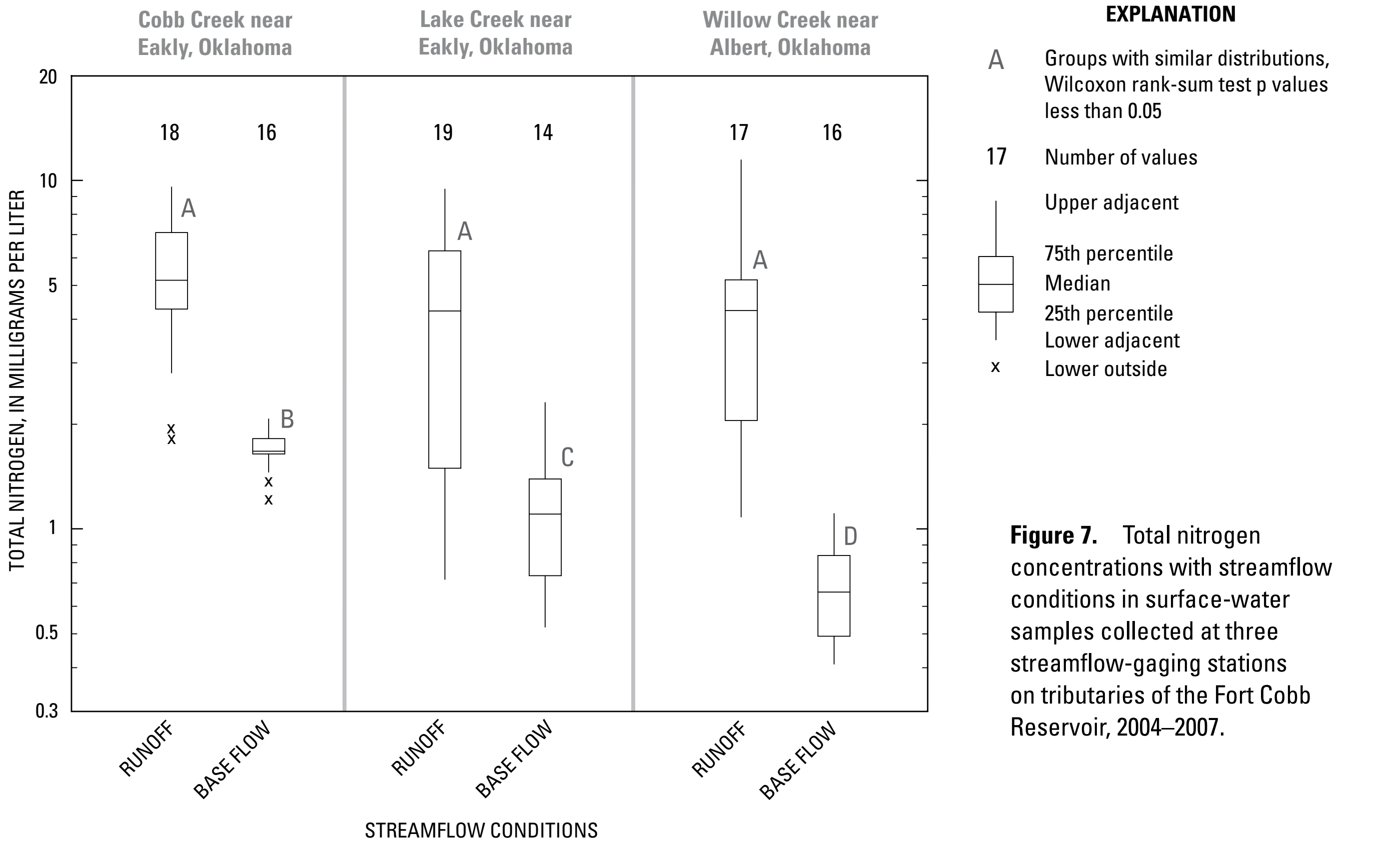


Figure 7. Total nitrogen concentrations with streamflow conditions in surface-water samples collected at three streamflow-gaging stations on tributaries of the Fort Cobb Reservoir, 2004–2007.

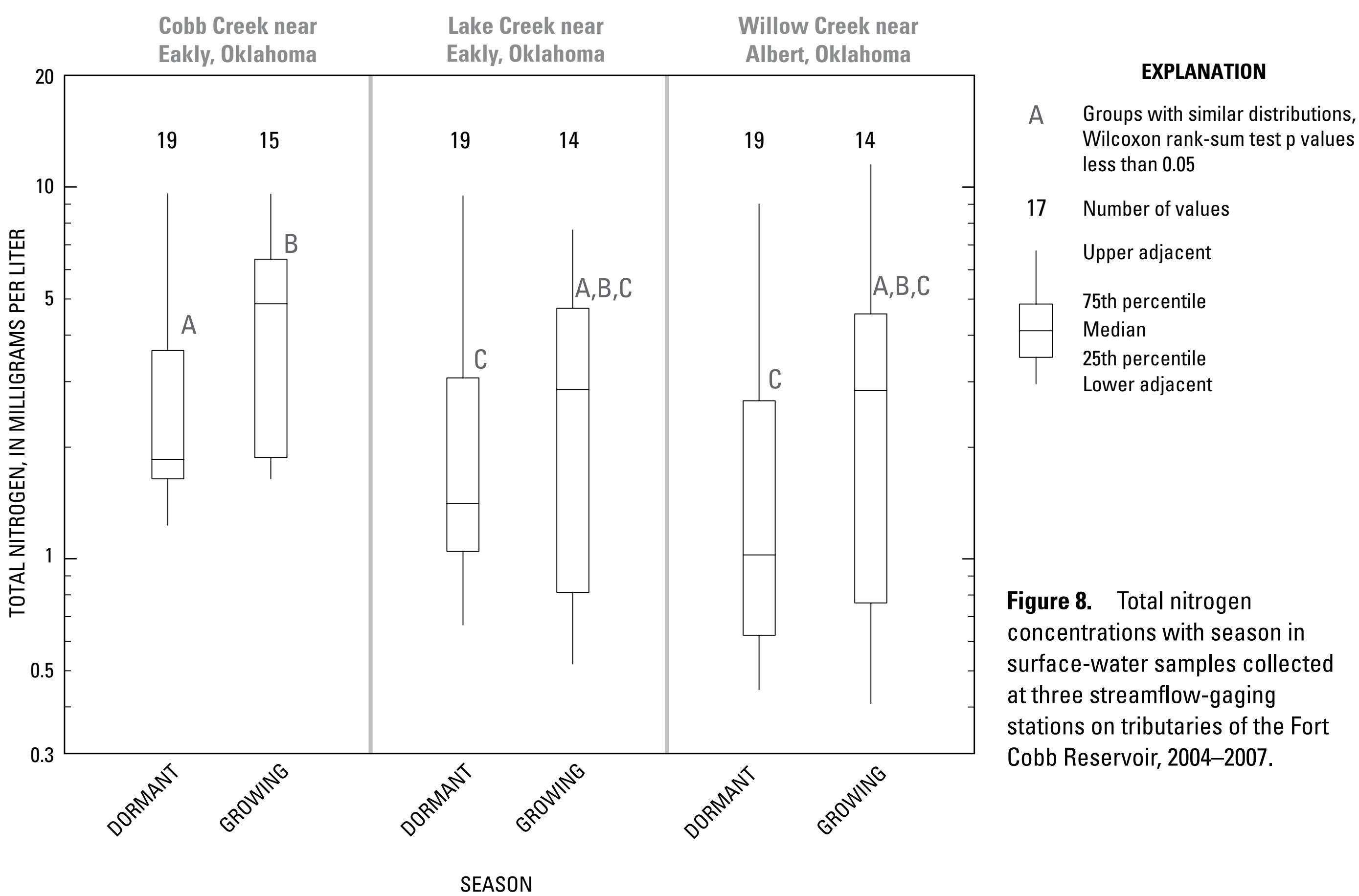


Figure 8. Total nitrogen concentrations with season in surface-water samples collected at three streamflow-gaging stations on tributaries of the Fort Cobb Reservoir, 2004–2007.

Total (unfiltered) phosphorus concentrations were similar in water samples collected at the streamflow-gaging stations on Cobb, Lake, and Willow Creeks, with water samples from Lake Creek generally having lesser concentrations of dissolved and orthophosphate forms of phosphorus (fig. 9). Sixty stream samples collected from December 2004 through March 2007 by the ARS at 15 creek sites in the watershed indicated that the greatest concentrations of dissolved phosphorus and orthophosphate were measured at Cherry Dale Creek, a tributary of Willow Creek. Stream samples collected by the USGS showed that total phosphorus, dissolved phosphorus, and orthophosphate phosphorus concentrations, similar to concentrations of organic nitrogen and sediment, generally were greater at greater streamflows (fig. 10). Total, dissolved, and orthophosphate phosphorus concentrations in water samples collected at the three streamflow-gaging stations generally were greater during the growing season (May-September) than in the dormant season (October-April) in Cobb and Willow Creeks (fig. 11), which may be an artifact of the greatest streamflows generally taking place in late spring (fig. 2). Water samples collected at the three streamflow-gaging stations in the subwatersheds of the Fort Cobb Reservoir were nearly all phosphorus-limited (fig. 12), meaning that addition of small amounts of phosphorus can substantially increase plant growth (Vaccari and others, 2006, p. 426). Phosphorus limitation of eutrophication indicates that best-management practices that can control runoff or seepage of phosphorus to streams and groundwater may be the best means for maintaining or improving water quality in the Fort Cobb watershed, particularly in the Cobb Creek subwatershed, which generally had the greatest phosphorus loads and yields (fig. 13). Although nitrogen loads also tended to be greater in water samples collected at the Cobb Creek streamflow-gaging station, nitrogen yields from the basins draining to these three streamflow-gaging stations were similar (fig. 13).

Inflows of nutrient-enriched water cause the Fort Cobb Reservoir to be eutrophic (trophic state index 50-70) or hypereutrophic (trophic state index greater than 70) (figs. 14 and 15) and dominated by blue-green algae, with the greatest nutrient and chlorophyll-*a* concentrations in the reservoir being measured in the upper reaches, near the influent locations of the major tributaries. Excessive growth of algae and other aquatic plants in hypereutrophic conditions can produce taste-and-odor-causing organic compounds in drinking water, disrupt ecosystems (by impeding water visibility and reducing dissolved oxygen concentrations), and cause aesthetic problems (such as turbidity, vegetation mats, and foul odors). For the three primary streams draining to the reservoir, nutrients were primarily delivered to the reservoir during storm runoff along with large sediment loads. Water in the three primary tributaries of the reservoir generally was phosphorus-limited (fig. 12), whereas in the reservoir, nitrogen limitation (Vaccari and others, 2006, p. 426) was detected in late summer, favoring growth of nitrogen-fixing blue-green algae that fix atmospheric nitrogen into bioavailable forms, supplying additional nitrogen to the reservoir. The reservoir generally had little thermal stratification, though reductions in dissolved oxygen concentration can take place with depth (figs. 16 and 17).

Subwatershed Characteristics and Water Quality

Soil properties and land uses may affect seepage and runoff of nutrients to local streams and, ultimately, the Fort Cobb Reservoir. Soils in the Cobb Creek subwatershed generally are finer in texture than soils in the Lake Creek and Willow Creek subwatersheds (fig. 18), have much smaller hydraulic conductivities than soils in those two watersheds (fig. 19), and have greater slopes (fig. 20). Such differences in soil texture, soil hydraulic conductivities, and land-surface slope between the three watersheds may have contributed to the slightly greater concentrations of total nitrogen (fig. 5) and total phosphorus concentrations during runoff conditions (fig. 10) in water-quality samples collected at the streamflow-gaging station on Cobb Creek. The Lake and Willow Creek subwatersheds proportionately had about 50 percent more forested areas within 100 meters of those streams and tributaries than the Cobb Creek watershed (fig. 21). Such forested cover near streams in the Lake and Willow Creek subwatersheds can intercept runoff from agricultural and other areas and decrease streambank erosion, possibly being another causative factor for relatively greater concentrations of total phosphorus from the Cobb Creek subwatershed during runoff conditions.

Linear regressions (Helsel and Hirsch, 1992) of mean values of landscape features compared to median nutrient concentrations in water samples collected at the streamflow-gaging stations in these three subwatersheds indicate the median total nitrogen concentration was significantly negatively correlated with mean saturated hydraulic conductivity (p-value of regression less than 0.05, table 1). This correlation may be a result of lesser nitrification of nitrogen and/or greater runoff of organic nitrogen from less permeable soils in the Cobb Creek subwatershed (figs. 6, 7, 8, and 19). Although p-values of the linear regressions between median total nitrogen concentration and a soil-texture index and percent forested land within 100 meters of streambanks were greater than 0.05, relatively large coefficient of variation (r^2) values (greater than 0.7) of the correlations between those constituents indicate possible relations between those landscape and water-quality variables (table 1). Similarly, relatively large r^2 values (greater than 0.8), but p-values greater than 0.05, for correlations between median runoff total phosphorus concentrations and the soil texture index and percent forested land within 100 meters of streambanks indicate a possible association (but not a significant association at α=0.05) between phosphorus runoff and those landscape features (table 1). Mean slopes of land surface

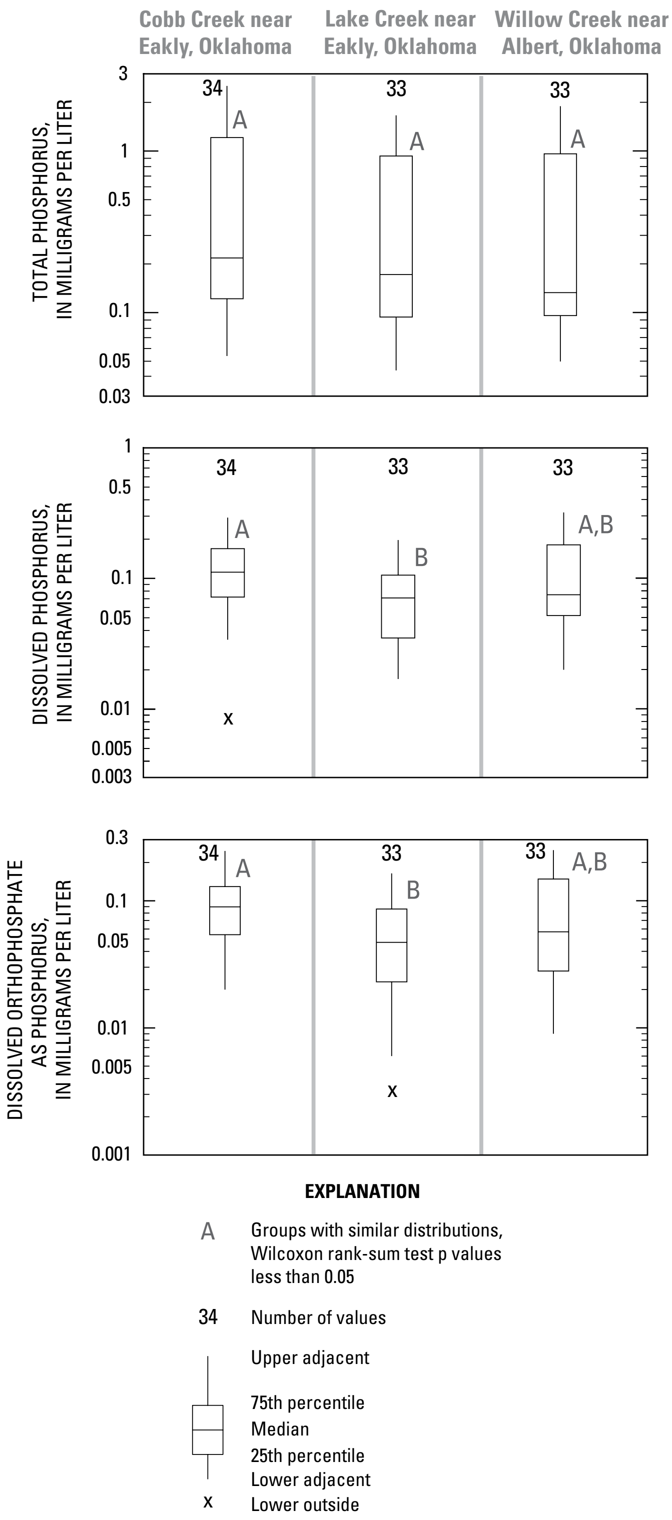


Figure 9. Total phosphorus, dissolved phosphorus, and dissolved orthophosphate phosphorus concentrations in surface-water samples collected at three streamflow-gaging stations on tributaries of the Fort Cobb Reservoir, 2004–2007.

generally had the least significant correlations to median total nitrogen concentrations and median runoff total phosphorus concentrations (table 1).

Satellite-based Hyperion imaging spectroscopy (fig. 22) and ground-truthing indicated multiple sources of nutrients causing increased chlorophyll abundance in the reservoir. The three major streams draining to the reservoir contribute nutrients leading to eutrophication, but minor streams draining cultivated fields near the reservoir appeared to be disproportionate contributors of nutrients, causing greater amounts of chlorophyll than in areas receiving inflows from the larger creeks (fig. 22). Increasing conservation practices on small streams draining directly to the reservoir may have a greater effect in mitigating eutrophication in the reservoir than additional installation of such measures on the larger creeks draining to the reservoir.

Multidisciplinary data gathered for this report compose a holistic assessment of interactions between land uses and other watershed properties in eutrophication of a major reservoir. Additional sampling during the full range of flow at additional stream sites in the Fort Cobb Reservoir watershed and monitoring of groundwater quality and seepage rates would provide a more complete understanding regarding sources and yields of nutrients to this reservoir. Such data would facilitate targeting of best management plans to areas producing the greatest loads or yields to the reservoir. Additional ground-truthing of crops and biological sampling coordinated with flight times of Hyperion imagery would facilitate interpretation of relations between specific crop types and cultural practices to water quality in this and other watersheds. Additional information that could be used to evaluate nutrient contributions of surface runoff compared to that of streambank erosion, such as surveys made with ground-based light detection and ranging (lidar) devices would enhance the knowledge base for improving best-management practices.

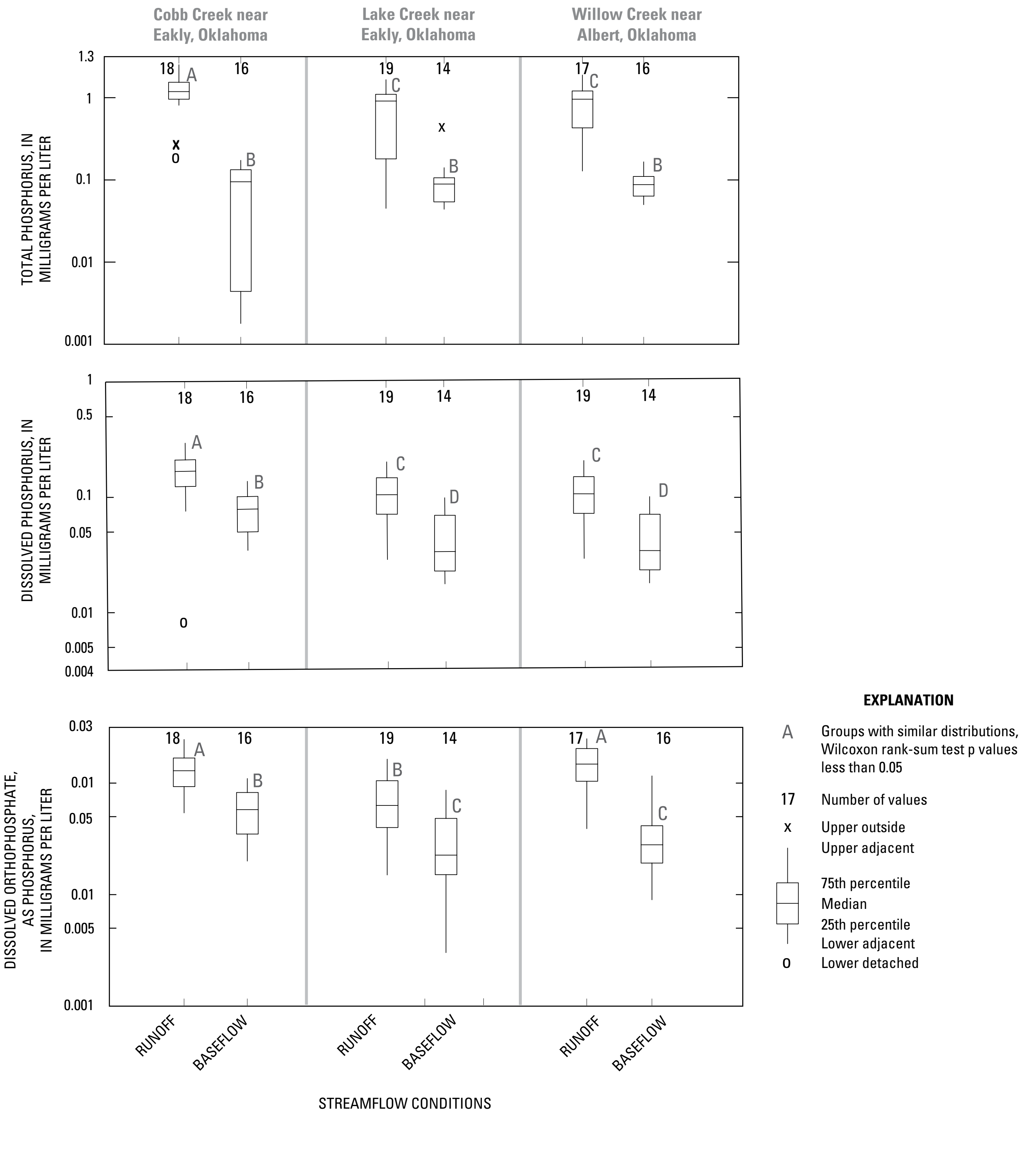


Figure 10. Total phosphorus, dissolved phosphorus, and dissolved orthophosphate-phosphorus concentrations with streamflow conditions in surface-water samples collected at three streamflow-gaging stations on tributaries of the Fort Cobb Reservoir, 2004–2007.

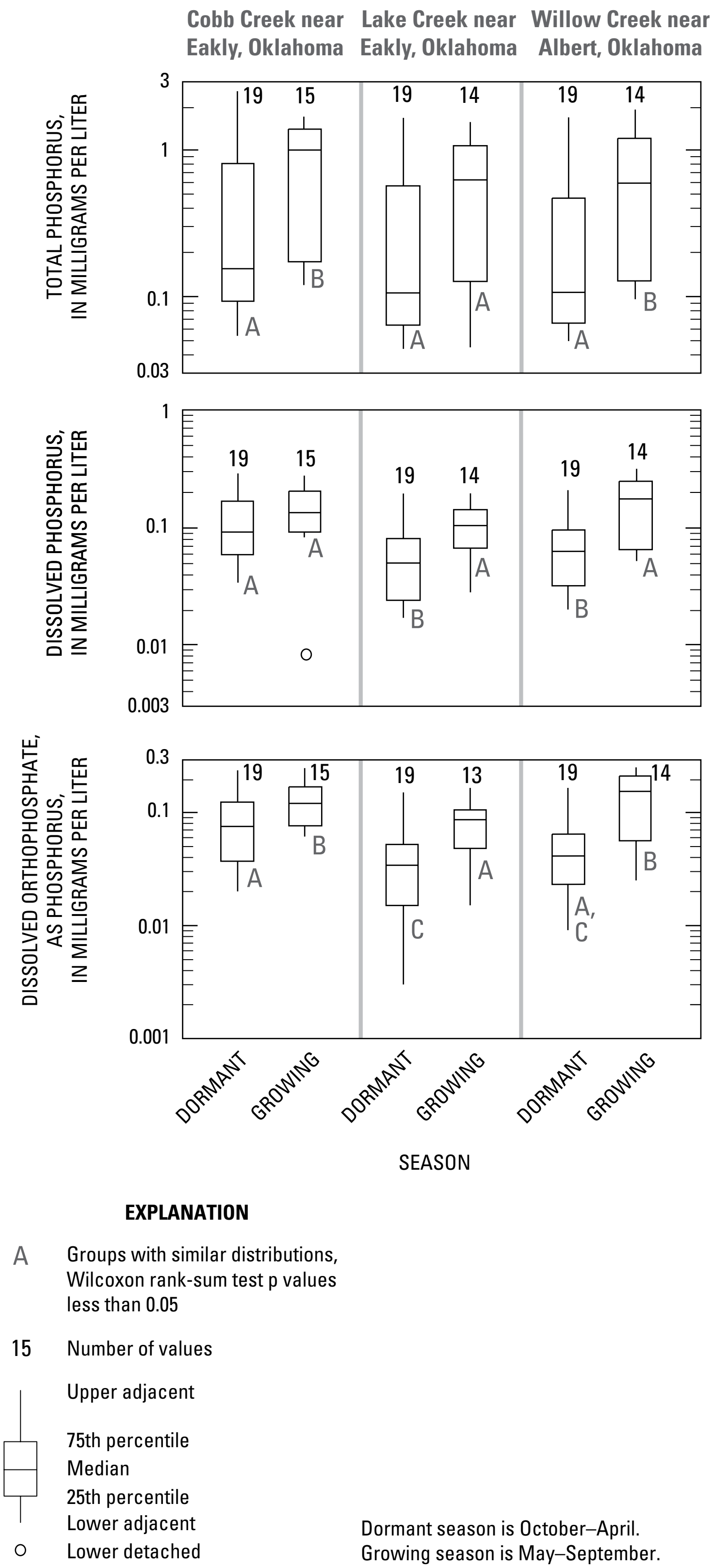


Figure 11. Total phosphorus, dissolved phosphorus, and dissolved orthophosphate phosphorus concentrations with season in surface-water samples collected at three streamflow-gaging stations on tributaries of the Fort Cobb Reservoir, 2004–2007.

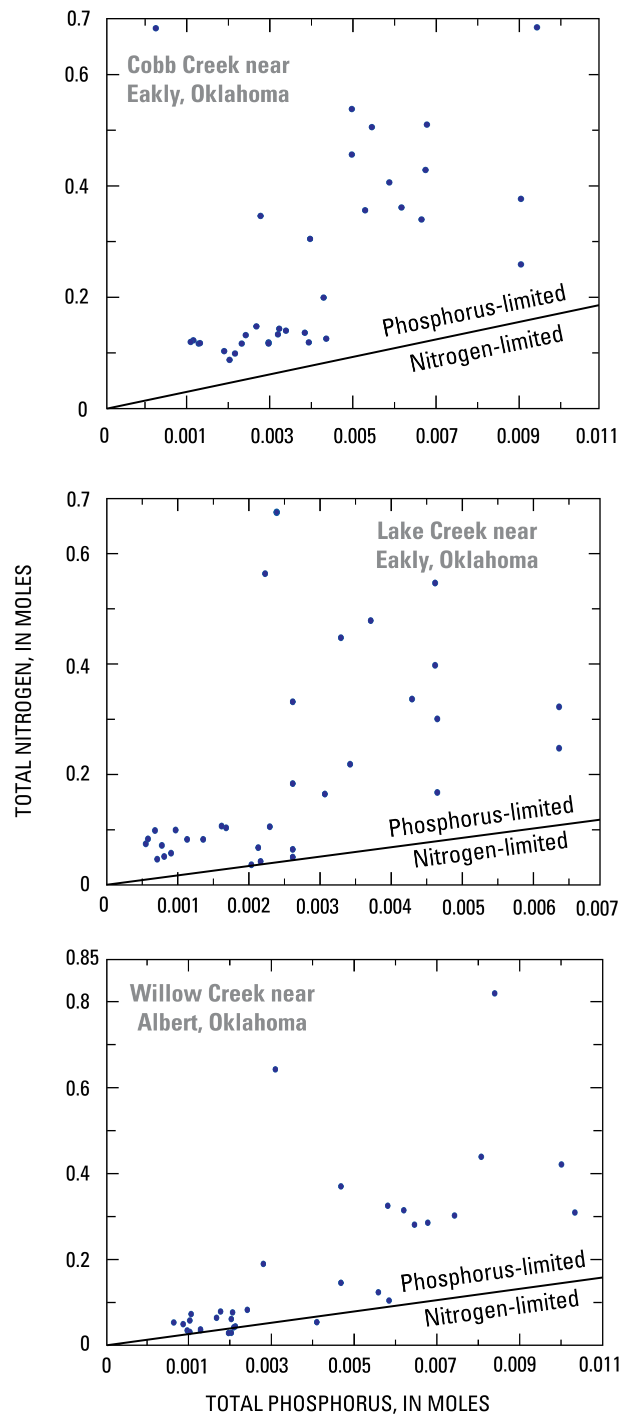


Figure 12. Moles of total nitrogen and total phosphorus and nutrient-limitation status in surface-water samples collected at three streamflow-gaging stations on tributaries of the Fort Cobb Reservoir, 2004–2007.

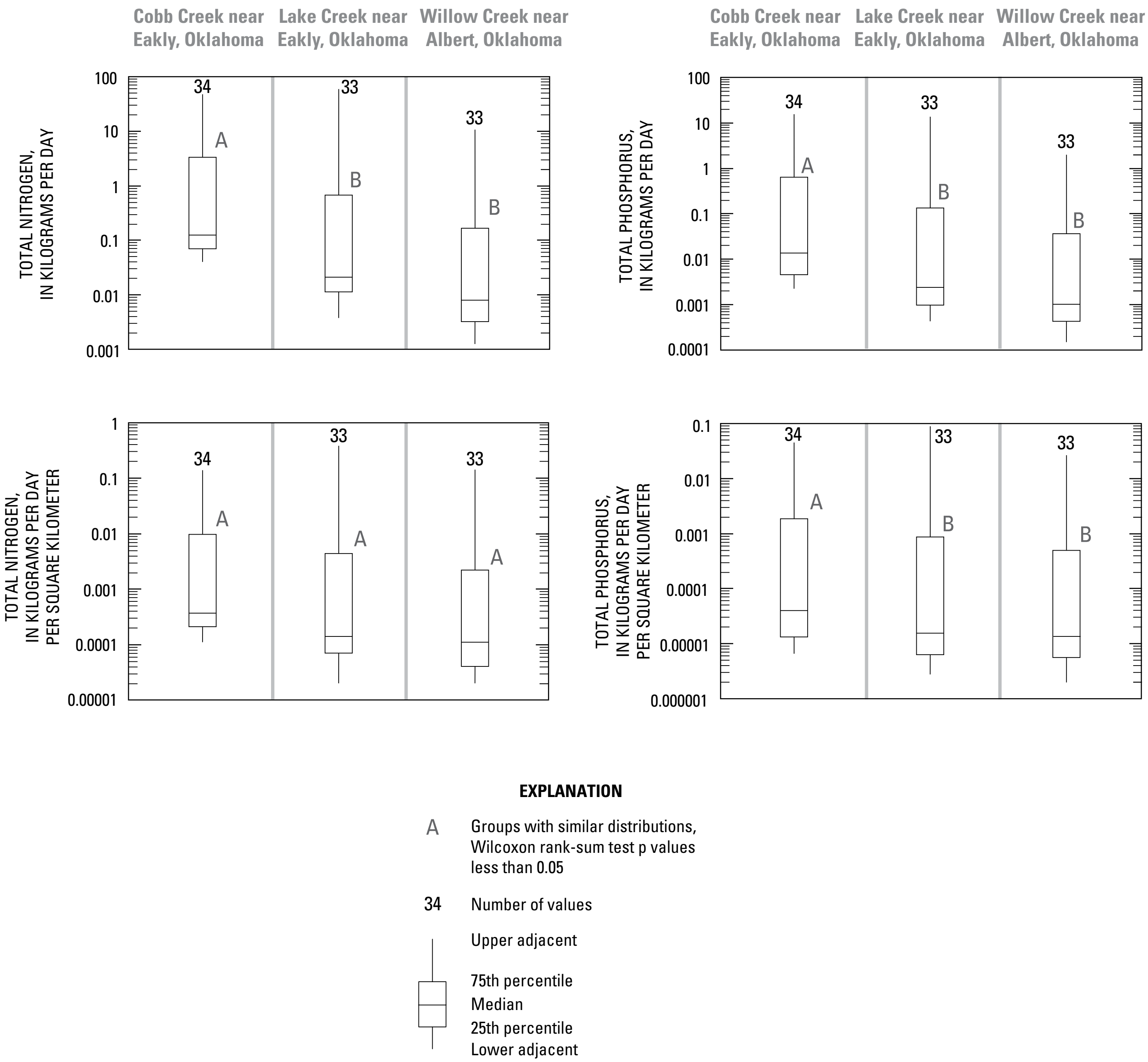


Figure 13. Loads and yields of total nitrogen and total phosphorus in surface-water samples collected at three streamflow-gaging stations on tributaries of the Fort Cobb Reservoir, 2004–2007.

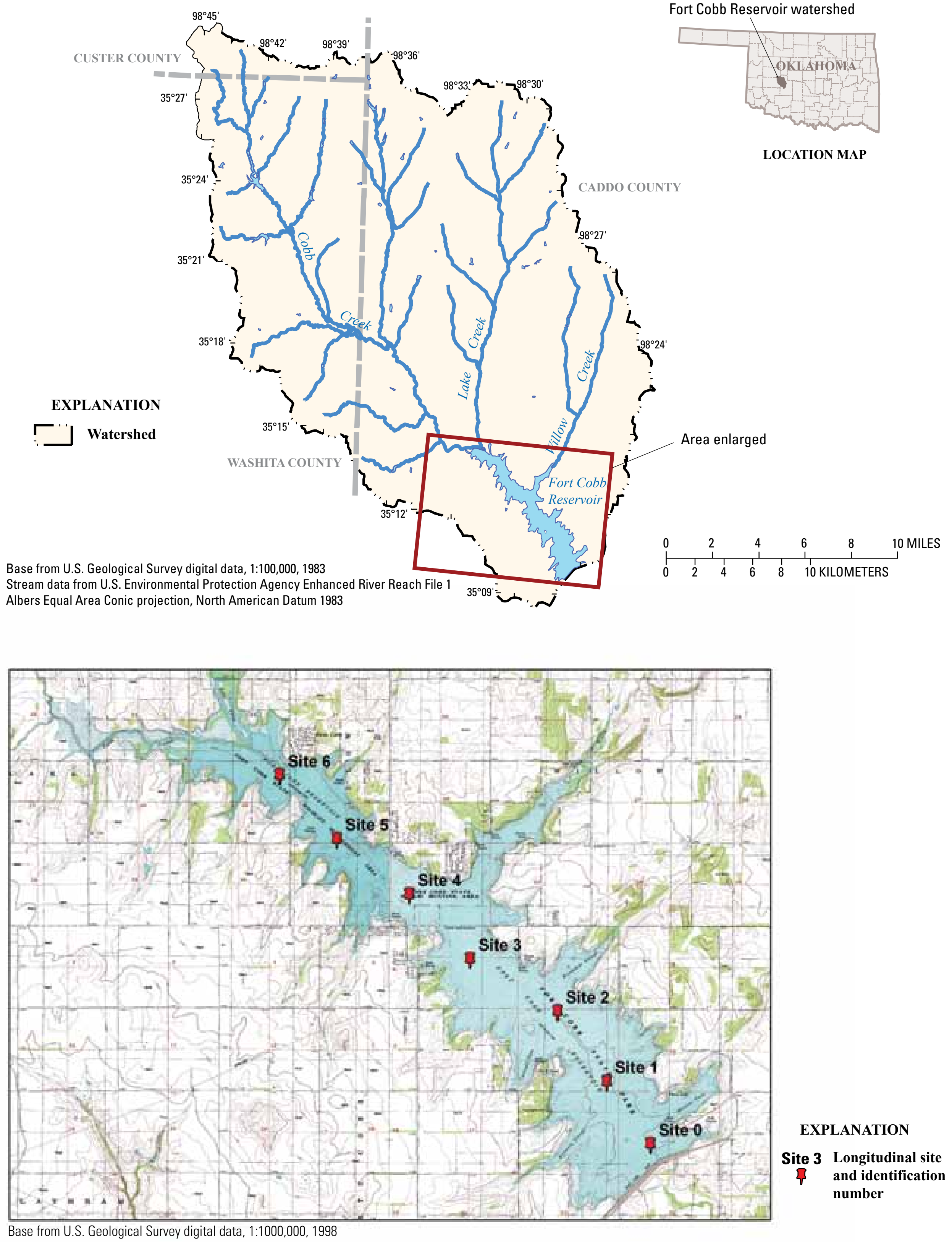


Figure 14. Locations of sites used to measure trophic-state indices and profiles of temperature and dissolved oxygen concentration in the Fort Cobb Reservoir, April, June, and September 2006.

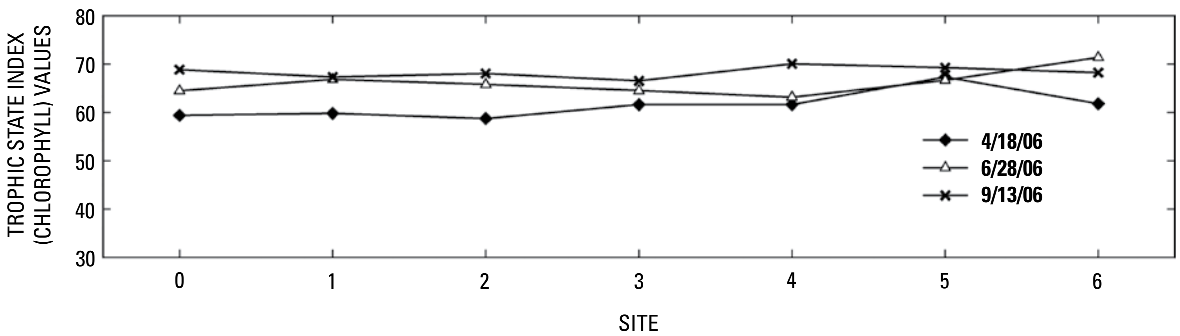


Figure 15. Longitudinal graph of trophic-state indices for selected sites sampled in the Fort Cobb Reservoir in April, June, and September 2006.

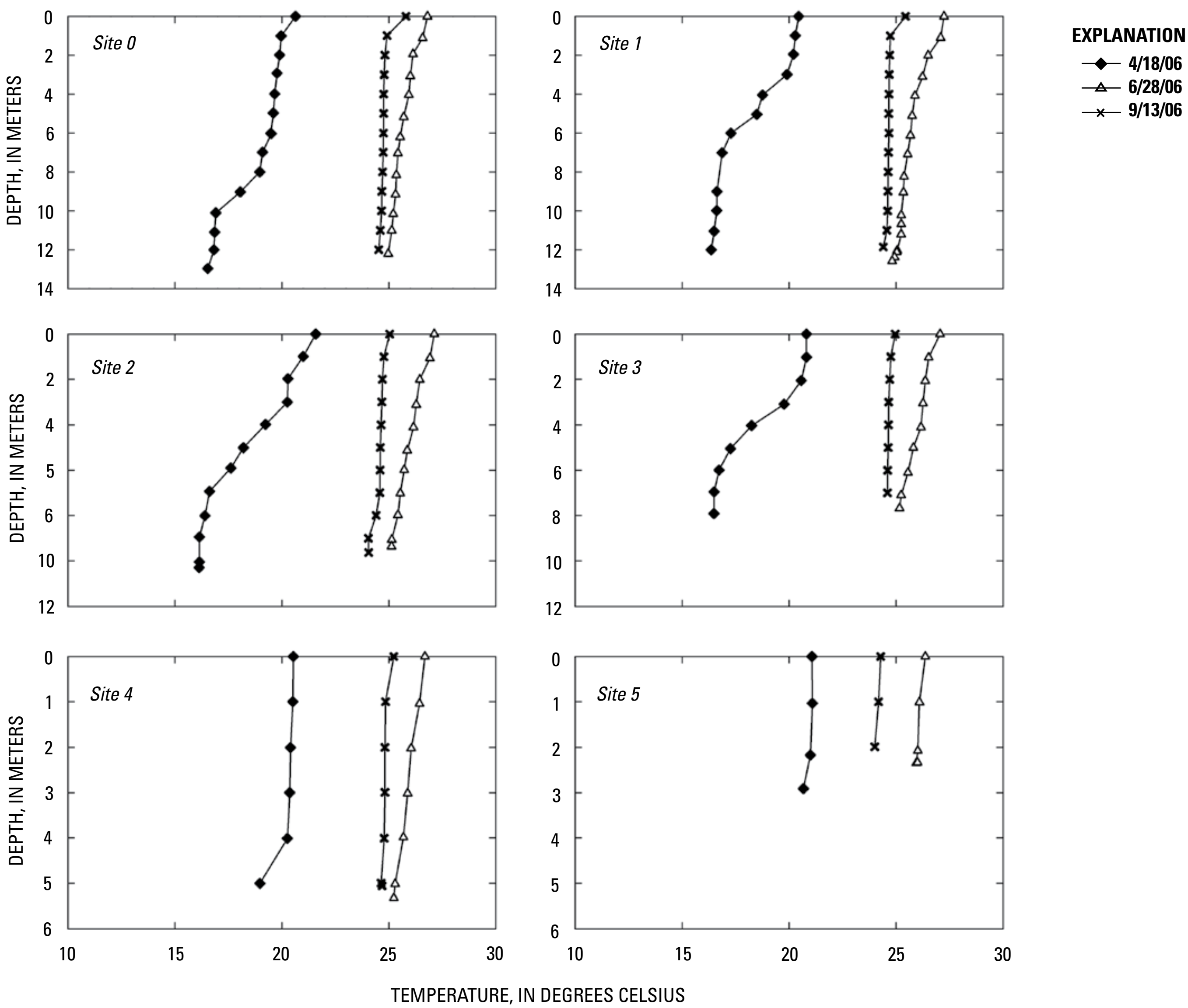


Figure 16. Water temperature with depth at selected sites on the Fort Cobb Reservoir sampled in April, June, and September 2006.

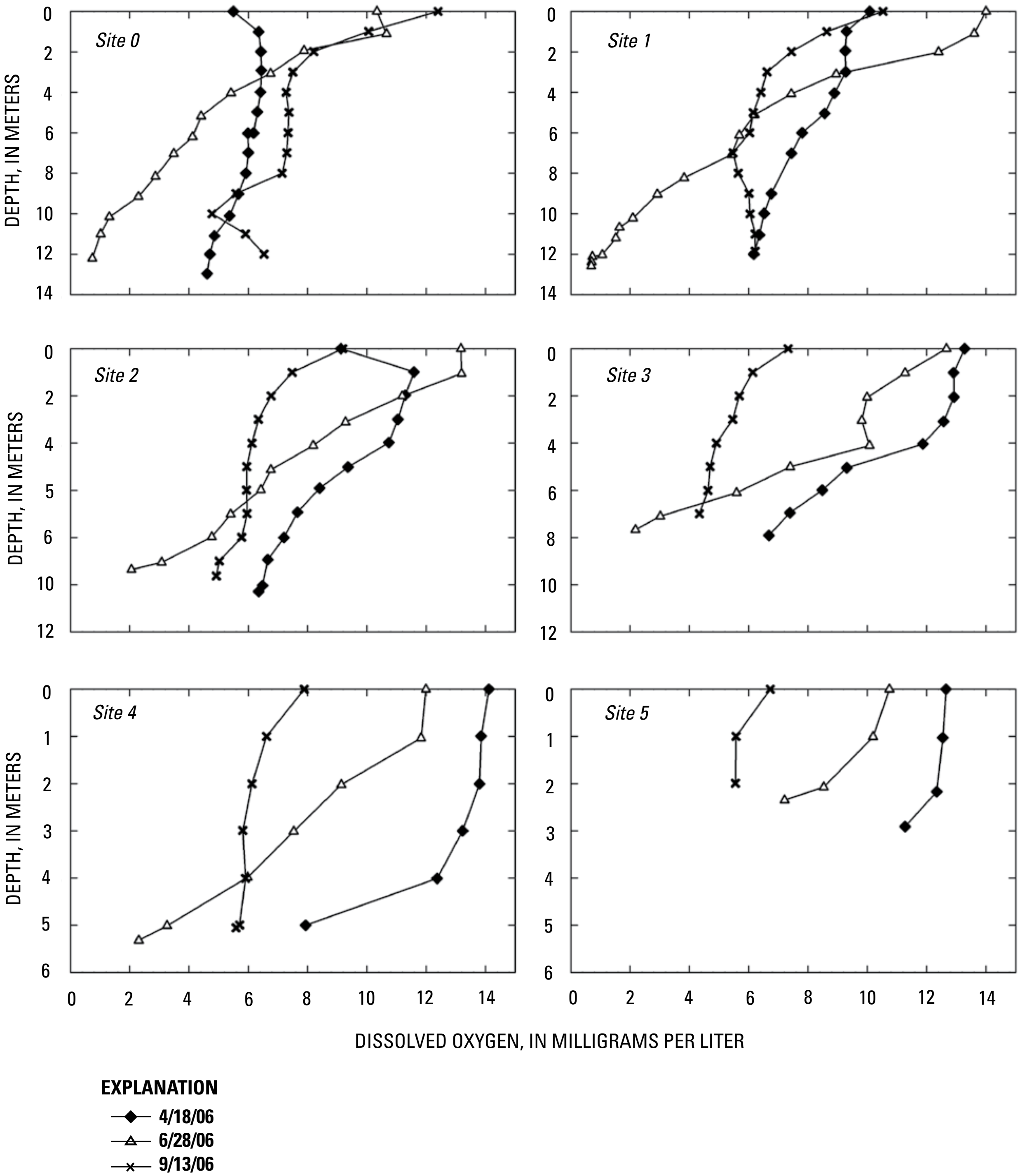


Figure 17. Dissolved oxygen concentration with depth at selected sites on the Fort Cobb Reservoir sampled in April, June, and September 2006.

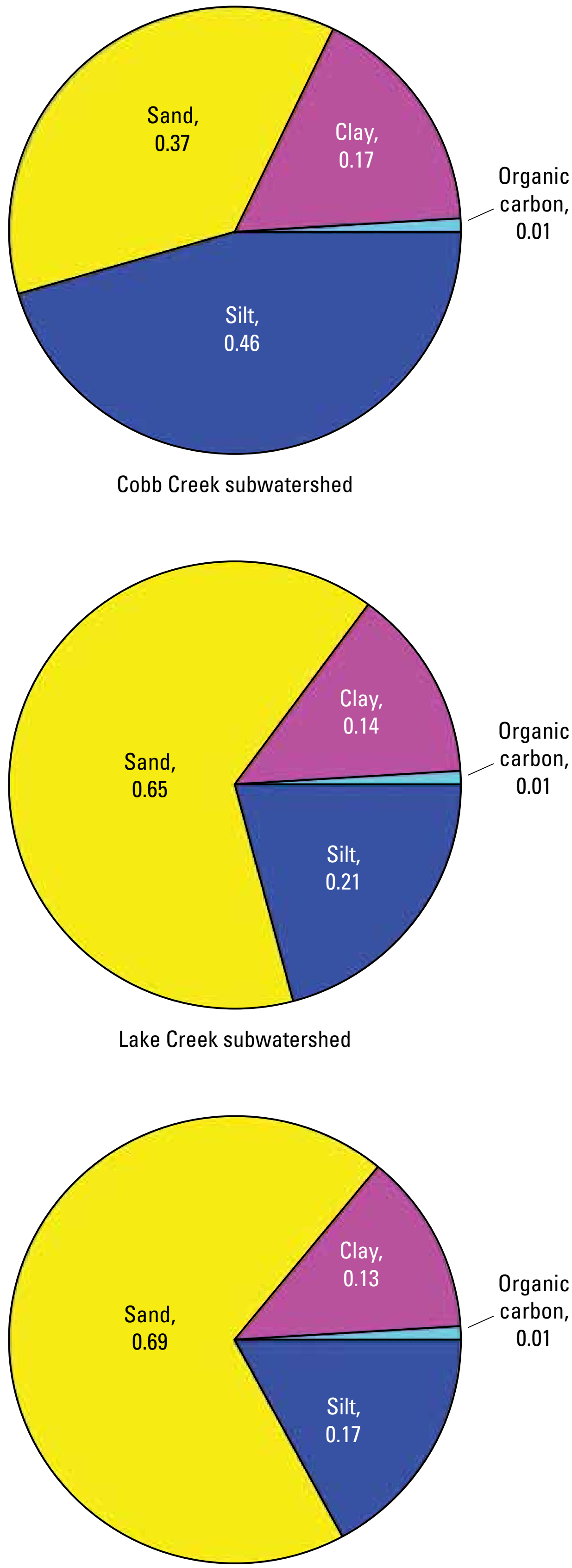


Figure 18. Mean percentages of soil textures in three subwatersheds draining to the Fort Cobb Reservoir.

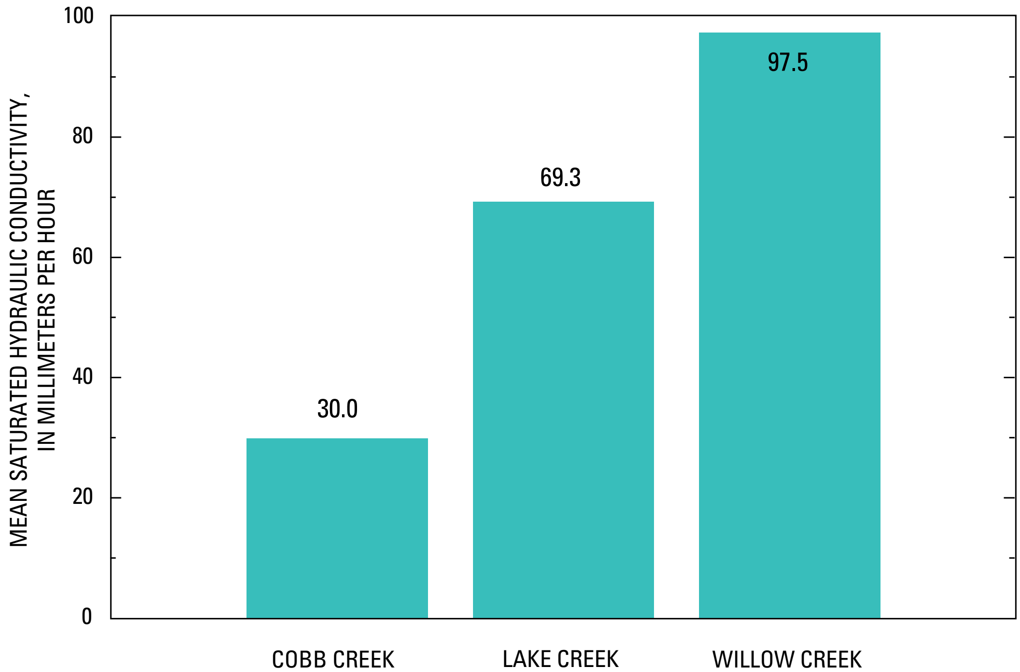


Figure 19. Mean saturated hydraulic conductivity of soils in three subwatersheds draining to the Fort Cobb Reservoir.

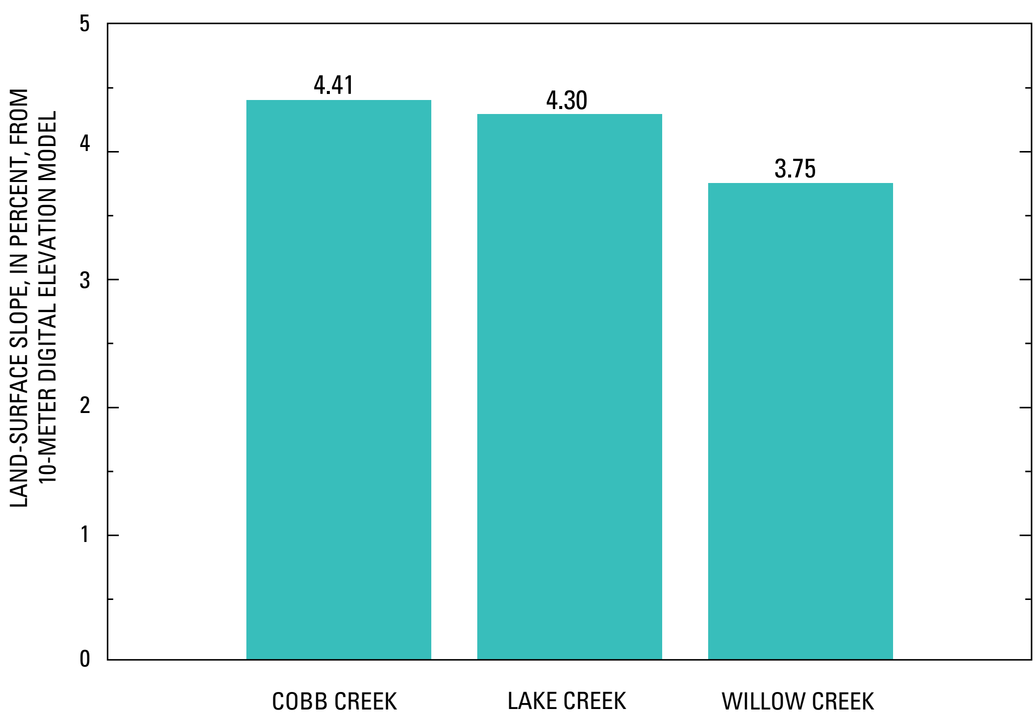


Figure 20. Mean land-surface slopes in three subwatersheds draining to the Fort Cobb Reservoir.

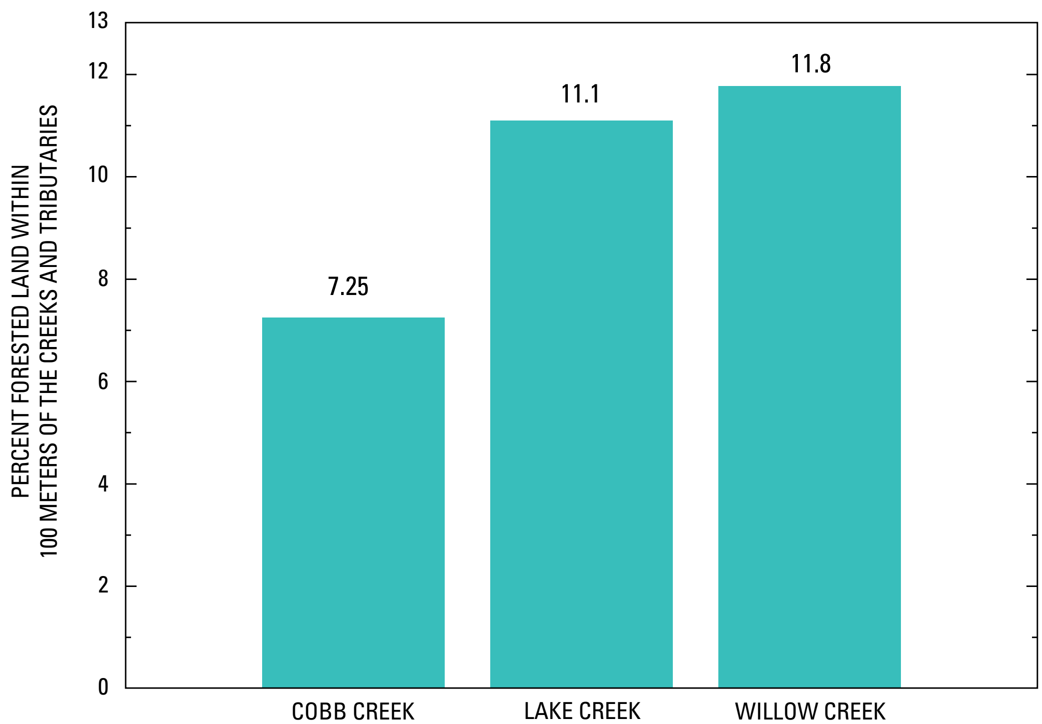
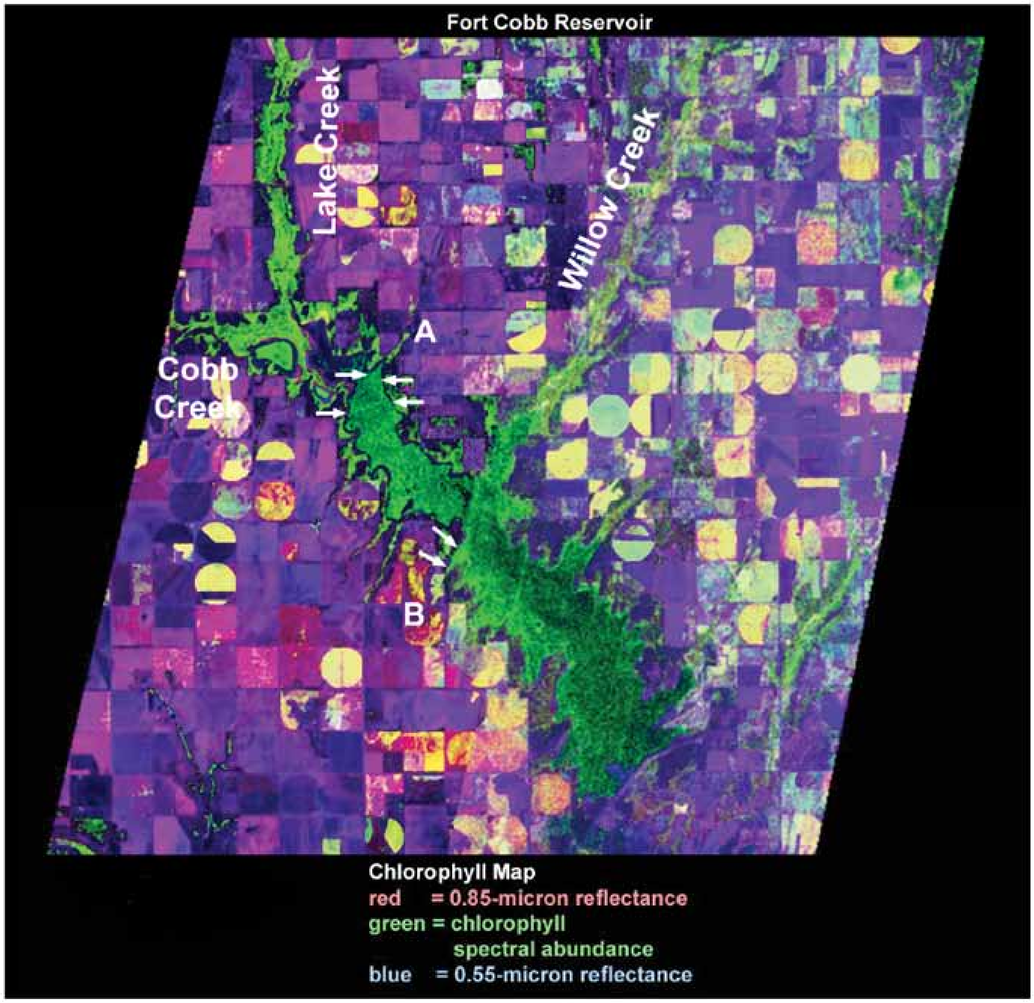


Figure 21. Percentages of forested land uses within 100 meters of the banks of Cobb, Lake, and Willow Creeks and tributaries upstream of three sampled streamflow-gaging stations.

Table 1. Linear regression statistics for landscape features of the Cobb Creek, Lake Creek, and Willow Creek subwatersheds compared to median total nitrogen concentration and median total runoff phosphorus concentration, 2004–2007.

[%, percent; r^2, coefficient of variation; *p*-values of less than 0.05, indicating statistically significant relations, are shown in **bold font**]

Dependent variable	Independent variable	Linear regression equation	Adjusted r^2 value	*p*-value
Median total nitrogen concentration (TN)	Soil Texture Index STI=(%clay+%silt)/%sand	TN=0.628(STI)+0.983	0.786	0.212
Median runoff total phosphorus concentration (ROTP)	Soil Texture Index STI=(%clay+%silt)/%sand	ROTP=0.198(STI)+0.840	0.879	0.158
Median total nitrogen concentration (TN)	Mean saturated hydraulic conductivity (K)	TN=-0.0138(K)+2.45	0.999	**0.0145**
Median runoff total phosphorus concentration (ROTP)	Mean saturated hydraulic conductivity (K)	ROTP=-0.0035(K)+1.25	0.355	0.384
Median total nitrogen concentration (TN)	Mean slopes of soils (S)	TN=1.17(S)-3.32	0.566	0.309
Median runoff total phosphorus concentration (ROTP)	Mean slopes of soils (S)	ROTP=0.197(S)+0.201	-0.532	0.679
Median total nitrogen concentration (TN)	Percent forested land within 100 meters of streambanks (F)	TN=-0.184(F)+3.40	0.865	0.167
Median runoff total phosphorus concentration (ROTP)	Percent forested land within 100 meters of streambanks (F)	ROTP=-0.0557(F)+1.58	0.804	0.203



EXPLANATION

A, B--areas of relatively large estimated chlorophyll concentrations where small tributaries discharge to the reservoir.

0 1 Mile
0 1 Kilometer

Figure 22. Hyperion image showing relative chlorophyll-*a* abundance in the Fort Cobb Reservoir, September 9, 2006, to October 24, 2006.

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