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Environmental effects of agricultural conservation: A framework for research in two watersheds in Oklahoma's Upper Washita River Basin

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Abstract: Agriculture in the Upper Washita River Basin represents mixed crop-livestock systems of the Southern Plains. Research in the Little Washita River Experimental Watershed and the Fort Cobb Reservoir Experimental Watershed addresses interactive effects of variable climate, land use, and management on environmental quality. The Little Washita River watershed provides opportunities to explore impacts of flood retarding impoundments within a watershed. The Fort Cobb Reservoir watershed provides opportunities to study effects of agricultural conservation on a large eutrophic reservoir. Analysis of 1940 to 2005 data from the Fort Cobb Reservoir watershed showed that precipitation increased 33%, corresponding runoff increased 101%, and sediment yield increased 183% when comparing multi-year wet periods to multi-year dry periods. Depth to groundwater exhibited seasonal and interannual variation. A rapid geomorphic assessment indicated that unstable stream channels dominate the stream networks. Phosphorus concentration in streams was correlated to multiple attributes of the contributing areas, including contributing area, slope, stream density, and channel stability. Anticipated outcomes are improved understanding of environmental effects of conservation, new approaches to mitigation of water quality problems, and tools to support strategic placement of conservation practices on the landscape to achieve environmental goals.

Key words: climate variability—Conservation Effects Assessment Project (CEAP)—groundwater—soil quality—water quality

Land owners, water managers, conservationists, and policy makers all need better understanding and quantitative measures of the impacts of agricultural conservation within the landscape. The Conservation Effects Assessment Project (CEAP) is a multifaceted project that was developed to help provide such understanding and quantitative measurements (Richardson et al. 2008). As part of the croplands CEAP, a watershed study was established in the basin of the Washita River, which flows into Lake Texoma just above the Red River. The Upper Washita River hydrologic unit (referred to as the Upper Washita River Basin in this paper) is a 8,319-km^2 (3,212-mi^2) area located in west central Oklahoma, with agricultural systems and environmental issues that are typical in the southern Great Plains (figure 1). The region is sparsely populated with predominantly mixed cropland and grazing land. Irrigation water is drawn from reservoirs or groundwater for localized irrigation, but agriculture is largely rainfed. Persistent, multi-year periods of above- and below-average annual precipitation (figure 2) cause significant variation in hydrologic and other environmental processes (Garbrecht and Rossel 2002; Garbrecht et al. 2006).

The USDA Agricultural Research Service (ARS) has conducted watershed research in the Upper Washita River Basin since 1961 (Garbrecht et al. 2007), particularly in the Little Washita River Experimental Watershed (LWREW). In 2004, the research facility was expanded to include the Fort Cobb Reservoir Experimental Watershed (FCREW) as part of the CEAP watershed assessment studies (figure 1). The FCREW was selected for in-depth study because it has been identified by the Oklahoma Water Resources Board, Oklahoma Department of Environmental Quality, and Oklahoma Conservation Commission as a focal point to apply land conservation practices in order to improve water quality (Oklahoma Water Resources Board 2003; Storm et al. 2003; Steiner et al. 2004). The Fort Cobb Reservoir and its watershed had been the focus of monitoring and assessments for several years, thus providing baseline data against which future environmental conditions could be assessed (e.g., Becker 2001; Fairchild et al. 2004). Fort Cobb Reservoir is on the Oklahoma 303(d) list (list of water bodies that do not meet the water quality standards as given in the Clean Water Act) due to excessive sedimentation and trophic state of the lake. A draft management plan has been developed to reduce phosphorus (P) loads, primarily from agricultural sources. Nitrogen (N) is also of concern in some stream segments in some seasons. Earlier assessments indicated that agricultural pesticide residues are of minimal concern in alluvium (Smith et al. 1986) or groundwater (Becker 2001) in this region. Badger et al. (2003) reported a large and growing economic impact for two lakes in Oklahoma, indicating that impairment of the lake for municipal water supply, recreation, and fish and wildlife may be an important factor in local economies in and near the watershed.

The overall research objective is to quantify interactive effects of variable climate, dynamic land use, and land management, particularly conservation practices, on surface and subsurface water resources for the Little Washita River and Fort Cobb Reservoir watersheds. The specific objectives of this paper are to (1) describe the hydrologic, climatic, and agricultural framework for watershed assessment, (2) provide results from hydrologic, water quality, and soil investigations, and (3) elucidate factors that impact hydrologic and water quality responses to conservation practices.

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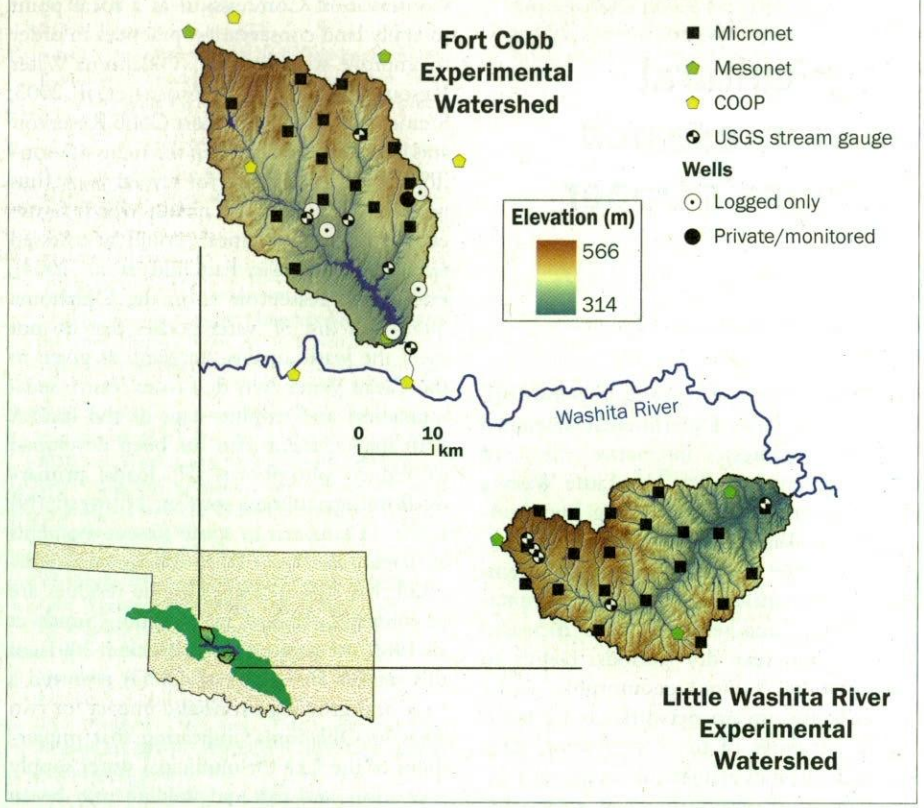
Figure 1

Research subwatersheds within the Washita River Basin showing data collection sites for stream flow, wells, and climate stations from the USDA Agricultural Research Service Micronet, Oklahoma Mesonet, and National Weather Service Cooperative Observer Program (COOP) networks.



Materials and Methods

Research Watershed Description. The 610-km^2 (236-mi^2) (above stream gauge) LWREW has mixed agricultural land use including pasture and rangeland (68%), cropland (20%, mostly rainfed), forest (8%), and miscellaneous uses (4%). The topography is rolling with a maximum relief of 180 m (590 ft) and sandy to loamy soils that are highly heterogeneous, with 64 soil series and 162 phases identified in the watershed (Allen and Naney 1991). The 786 km^2 (304 mi^2) (above the dam) FCREW also has mixed agricultural land use, including cropland (56%, about one-third is irrigated), pasture and rangeland (33%), forests and shrub land (5%, mostly along the streams), water (2%), and roads and miscellaneous (4%). Soils in the FCREW are also highly heterogeneous, with the moderately erosive fine sandy loams dominating in the eastern portion of the watershed, highly erosive fine sandy loams and loamy soils prevalent in the north central and south central areas of the watershed, and moderately erosive silt loams in the western portion of the watershed. Cattle graze the range and pasture lands, and six swine and two cattle confined feeding operations are located in the FCREW (figure 3). In the Upper Washita River Basin, the Rush Springs aquifer is an important water source for domestic, irrigation, and public supplies. The aquifer underlies 46% of the LWREW and about 80% of the FCREW (Becker and Runkle 1998).

In the research area, the climate is subhumid, receiving about 800 mm (31.4 in) of annual precipitation (1971 to 2000 normal for Caddo County) (Oklahoma Climatology Survey 2005) with the largest monthly means coming in May, June, September, and October. Summers are typically long, hot, and relatively dry with normal daily mean temperatures in July of 28.6°C (83.5°F). Winters are typically short, temperate, and dry with normal daily mean temperatures in January of 3.0°C (37.4°F) with a average annual temperature gradient of about 1.7°C (3°F) from southeast to northwest and an average annual precipitation gradient of about 75 mm (3 in) from east to west across the research area that spans roughly 100 km (56 mi).

Meteorological Measurements. From 1961 to 1985, a dense network (~5 km [3 mi] spacing) of precipitation gauges was maintained in the Upper Washita River Basin (Garbrecht et al. 2007) From 1985 to February 2005, 45 weather stations (42 ARS Micronet and 3 Oklahoma Mesonet) were located in the LWREW. In February 2005, 22 ARS Micronet stations were removed from the LWREW, and 15 were established in the FCREW (figure 1). Each Micronet station provides 5-minute measurements of air temperature, relative humidity, rainfall, solar radiation, and soil temperature at three depths using methods of the Oklahoma Mesonet as described by McPherson et al. (2007). Volumetric soil water content is measured at each Micronet station at 30-minute intervals and at 5–, 25–, and 45-cm (2–, 10–, and 18-in) depths using the Stevens Hydro Probe. Data are reported by radio telemetry to the Oklahoma Climate Survey for quality assurance, processing, and dissemination on the Internet (USDA Agricultural Research Service 2008). Four Oklahoma Mesonet stations are located in or near the LWREW (Chickasha, Ninnekah, Acme, and Apache), and three are near FCREW (Fort Cobb, Hinton, and Weatherford). The US National Weather Service has several Cooperative Observer Program stations in the area.

Streamflow Measurements. Steamflow is monitored by the US Geological Survey in collaboration with the Oklahoma Water Resources Board and the USDA ARS at sites shown in figure 1. The streamflow data and details of methodology are available on the Internet (US Geological Survey 2008). In both watersheds, streamflow record periods are long, but at most sites the records have gaps, a reflection of changing research priorities and limited resources to operate the gauges. In 1963, a stream gauge (drainage area 538 km^2 [208 mi^2]) was established on the LWREW to measure streamflow and suspended sediment until 1985. In 1979, another gauge (drainage area 160 km^2 [62 mi^2]) was established to measure streamflow and sediment also until 1985. In 1992, both gauges were reactivated, one at the 160 km^2 site and the other slightly downstream from the old site at a 610 km^2 (236 m^2) drainage area site. Eight additional gauges were established on Little Washita River tributaries in the mid-1990s to provide a baseline data

set and to identify regions in the watershed for more focused investigation. Five of these eight gauges were decommissioned in 2004. In the FCREW, continuous measurements have been made on Cobb Creek (now below the dam) since 1939. The US Geological Survey made measurements above the Fort Cobb reservoir on Lake Creek from 1969 to 1978, on Willow Creek from 1970 to 1978, and on Cobb Creek, near Eakley, from 1968 to present. In 2004, gauges at Lake Creek (near Eakley) and Willow Creek were re-established, and in October 2005, a new site was established on the upper portion of Lake Creek (near Sickles).

Groundwater Measurements. Drilling exploration in FCREW was conducted using a Failing F-6 truck-mounted drill rig. In 2006 and 2007, three exploratory holes were drilled to obtain stratigraphic information required by groundwater flow models. Each exploratory hole was approximately 30-m (100-ft) deep, and down-hole, geophysical logging based on natural gamma radiation was used to determine and delineate geologic units. Cores were taken at selected intervals for textural analysis, and cutting samples were used to calibrate and validate geophysical logs. A privately owned well in the Lake Creek subwatershed (figure 1) was monitored weekly for depth to groundwater from January 2006, to January 2008. A down-hole slug test using the method of Bouwer and Rice (1976) was performed on a well at the USDA ARS Grazinglands Research Laboratory property (northeast of watershed boundaries) to obtain hydraulic conductivity of geologic units, many of which also underlie the Upper Washita River Basin.

Water Quality Measurements. At the Cobb Creek (near Eakley), Lake Creek (near Eakley), and Willow Creek gauge sites, six low flow (i.e., base flow) and six high flow (defined as a 30% or more increase in stream discharge over that of the previous day) events per year have been collected (2004 to 2007) to measure stream temperature, specific conductance, dissolved oxygen, pH, alkalinity, ammonia, nitrite-N, nitrite-N plus nitrate-N, Kjeldahl-N, orthophosphate (all filtered), total P (unfiltered), and suspended sediment concentration with sand/fine splits. Calibration equations relating stream discharge to selected water quality variables, including sediment, were developed following the methods of Pickup et al. (2003), Sether et al. (2004), and Tortorelli and Pickup (2006).

Figure 2

Annual precipitation and persistent variations record for the Fort Cobb Reservoir watershed (1940 to 2005), annotated with USDA Agricultural Research Service research events, including establishment and closure of the Southern Great Plains Research Watershed (SGPRW), establishment of the Little Washita River Experimental Watershed (LWREW), and establishment of the Fort Cobb Reservoir Experimental Watershed (FCREW).

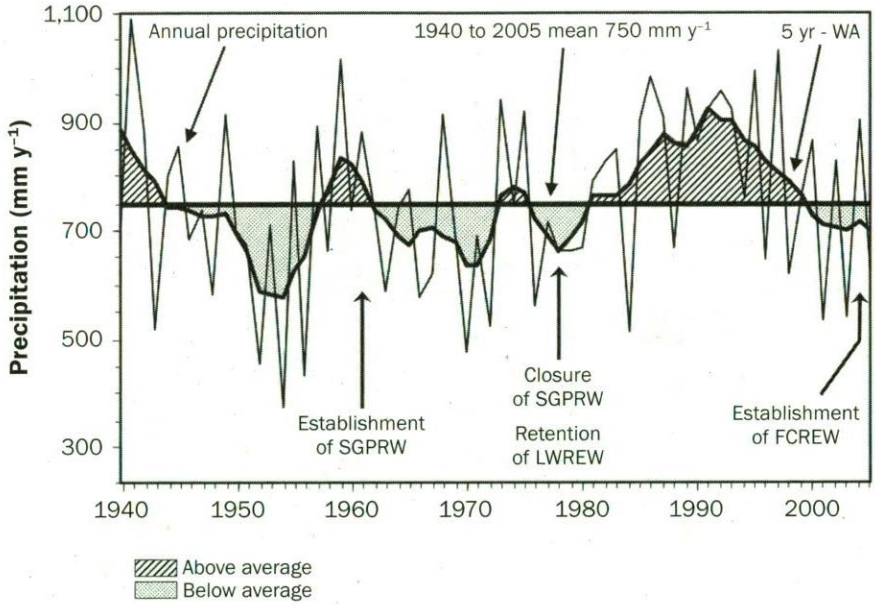


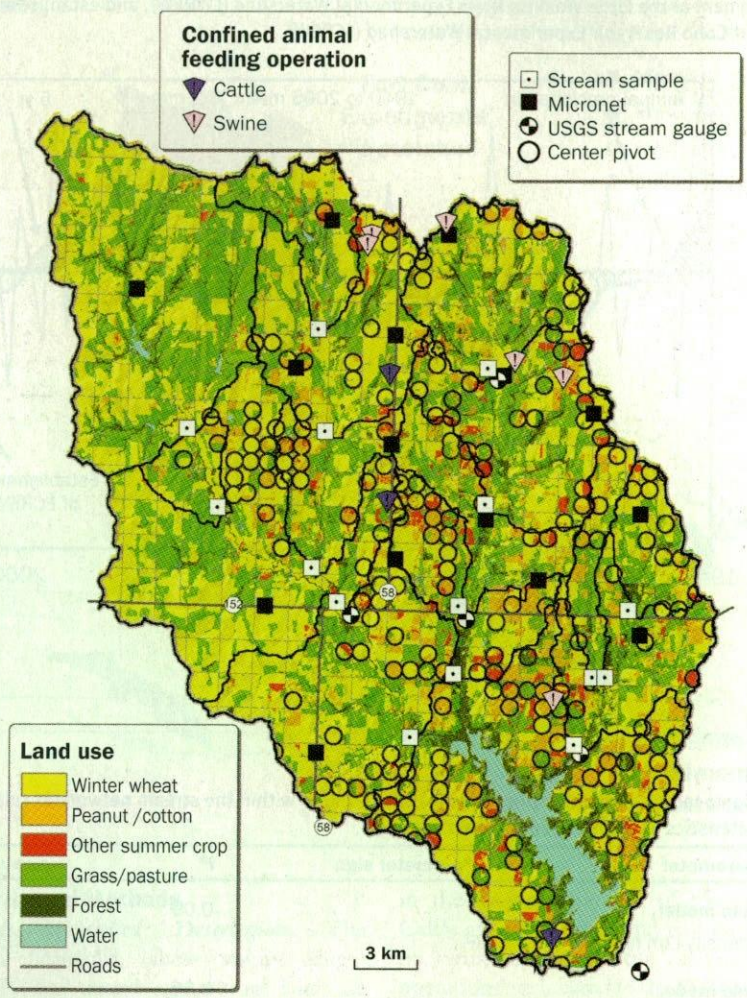
Table 1

Regression analysis of average phosphorus concentration within the stream network as related to characteristics of the contributing area.

Model parameter	Parameter sign	r^2	*p*-value
1. Variable model		0.09	
Stream density (km ha^{-1})	–		0.291
2. Variable model		0.35	
Stream density (km ha^{-1})	–		0.051
Soil (% sandy)	+		0.063
3. Variable model		0.40	
Area (ha)	+		0.359
Stream density (km ha^{-1})	–		0.046
Soil (% sandy)	+		0.072
4. Variable model		0.60	
Slope, average (%)	+		0.009
Slope, maximum (%)	–		0.063
Stream density (km ha^{-1})	–		0.018
Unstable channel (%)	+		0.043
5. Variable model		0.77	
Area (ha)	+		0.043
Slope, average (%)	+		0.002
Slope, maximum (%)	–		0.019
Stream density (km ha^{-1})	–		0.004
Unstable channel (%)	+		0.010

Figure 3

Land use map in the Fort Cobb Reservoir watershed with center pivot sites (as delineated by Storm et al. 2003), confined animal feeding unit sites, and research measurement sites.



In addition, from December 2004, through December 2007, bi-weekly 1-L (0.95-qt) grab samples of stream water were collected from just below the surface and away from the bank at 15 sites distributed throughout the stream network in the FCREW (figure 3). The samples were analyzed for water soluble P, bioavailable P, total P, sediment, total Kjeldahl N, total N, nitrate nitrogen, carbon, and ammonia concentrations using methods conforming to US Environmental Protection Agency (1983) procedures. Additionally, a Horiba W23XD water quality probe was used bi-weekly at each of the sites to measure pH, conductivity, turbidity, dissolved oxygen, temperature, oxidation reduction potential, and compute total dissolved solids. The average P concentrations from December 2004 through December 2007 were regressed against subwatershed characteristics: contributing area, stream density, average slope, maximum slope, percent sandy soil, percent cropland, percent of unstable stream channels, and percent gypsum bed outcroppings using the SELECTION/MAXR model of the regression procedure for one variable, two variables, etc. (SAS Institute 2003).

Unit Source Watersheds and Data from Other Studies: In 1980, a number of unit source areas, defined as self-contained hillslope drainage areas with single land use and management, were established in the LWREW, representing cropland, rangeland, and highly erosive sites (Garbrecht et al. 2007). Runoff, N, P, and sediment samples were collected at these sites on a per-storm basis until 1985. Hydrologic data are available for model calibration from various subwatersheds within the Upper Washita Basin, starting in 1961. Measurements of N and P compounds were made on the main stem and tributaries of the Little Washita River during the early 1980s.

Soil Measurements. Soils were sampled at each Micronet site to provide particle size fractions and soil texture information at the 5–, 25–, and 45-cm (2–, 10–, and 18-in) depths to calibrate the soil water content sensors. In addition, soil samples were collected from 41 fields in the FCREW from four contrasting management systems: (1) conventionally tilled summer annual crop; (2) no-till summer annual crop; (3) cropland converted to perennial forage (e.g., peanut [*Arachis hypogaea* L.] fields converted to bermudagrass [*Cynodon dactylon* (L.) Pers.] pasture or hay); and (4) native grass land (dominated by summer perennial prairie grasses). Farm surveys were conducted to collect management history from each sampled field. Soils were collected from two erosive soil types for each of the four management schemes, with 10 replications (fields) for each management/soil combination. Twenty soil cores representing the 0– to 5-cm and 5– to 10-cm (2– to 4-in) layers were collected from each field and composited. Samples from these sites were sent to the Oklahoma State University Soil and Forage Testing Laboratory for analysis of soil test P and N, and additional samples were taken to the USDA ARS National Soil Tilth Laboratory for a multi-site analysis.

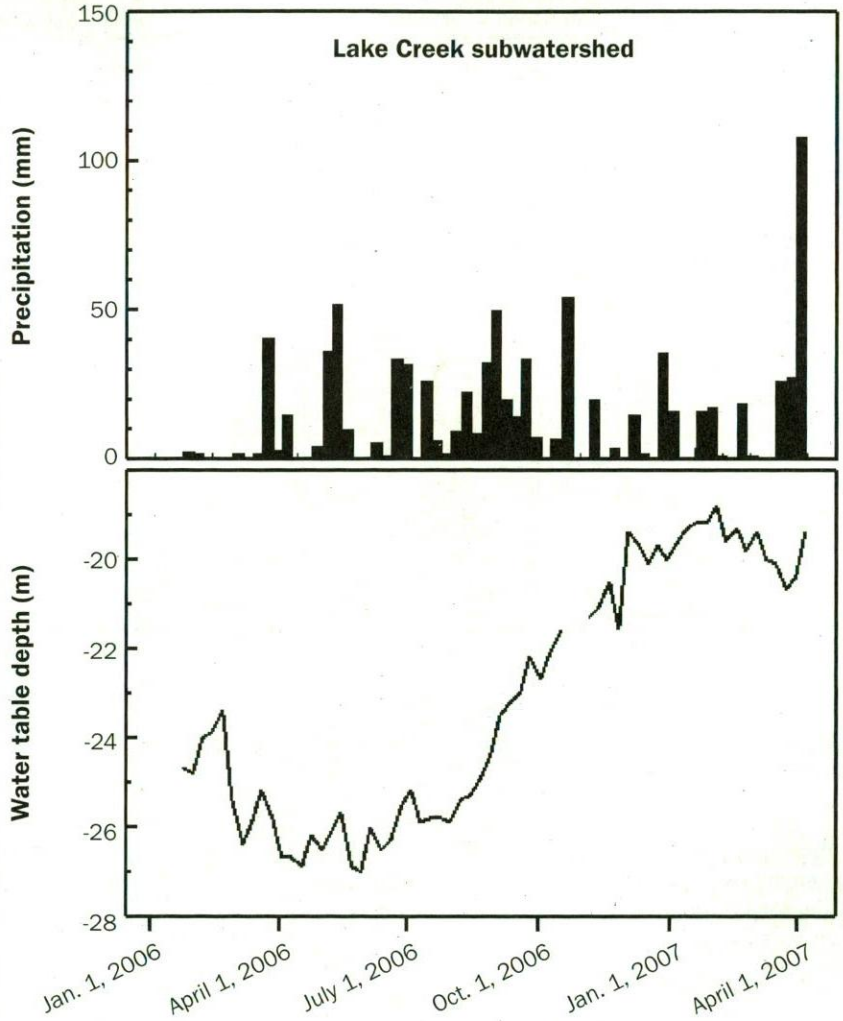
Land Use/Land Cover Measurements. Historical cropping patterns were compiled at the county level from USDA National Agricultural Statistics Service data for Caddo County, Oklahoma, and extended backward into the 1940s using the US Census Bureau's five-year report for Caddo County located at the CAUDILL Library, Washington, DC. A remote sensing-based study was initiated in 2005 to determine land use and seasonal patterns of land cover. Remotely sensed images (Landsat TM, 30-m [98.5-ft] resolution) of the LWREW and FCREW were acquired for March 9, June 13 and 29, July 31, September 1 and 17, and November 4, 2005, for the purpose of developing a landuse map. Ground truth data were collected on March 24, June 3, 16, 29, and 30, August 1, and November 3 by going to as many as 32 sites in the LWREW and 36 sites in the FCREW. At each site (generally road intersections) each team recorded

on paper and photographed the land cover conditions in the northeast, southeast, southwest, and northwest directions. Additionally, the latitude and longitude of each site were obtained via global positioning system. The groundtruth data were returned to the laboratory and compiled for later use. All ground-truth data and remotely sensed images were delivered to the Department of Geography at Oklahoma State University where a supervised classification of the monthly images was performed by first fixing water, roads, and forest and then classifying other uses for each image based on ground truth data. The monthly landcover images were assembled, filtered using a morphometric function, and reviewed to produce a final map representing the land uses for 2005. Because of the difficulty in differentiating one summer crop from another, peanuts and cotton (*Gossypium hirsutum* L.) were classified together and a generalized category was used for other summer crops.

Land Management and Conservation Practices. Agronomic management practices were compiled by Storm et al. (2006) for predominant cropping systems in the watersheds. In addition, farm surveys associated with soil quality studies (above) have been compiled. Conservation practices receiving technical or financial assistance from 2001 to present have been identified at a farm level by the Fort Cobb Water Quality Project and the Oklahoma state office of the USDA Natural Resources Conservation Service.

Geomorphology and Sediment Source Tracking. A rapid geomorphic assessment (Simon 1989; Simon and Rinaldi 2000; Simon et al. 2004) of the LWREW and FCREW was conducted in February 2006, to determine the overall geomorphic evolution of each watershed and to identify reaches along streams that are unstable or have potential for bank failure. Preliminary results of the rapid geomorphic assessment were used to identify reaches of the Lake Creek subwatershed subject to stream bank instabilities. At these unstable reaches, sediment source tracking studies were initiated in the summer of 2006 (Wilson et al. 2003, 2005) to identify the source (upland vs. stream bank) of clays and silts within the stream during storm runoff. Additional methodological detail and results of the rapid geomorphic assessment are given in Simon and Klimetz (2008) and of sediment source tracking are given in Wilson et al. (2008).

Figure 4
Depth to water and precipitation (weekly) in Lake Creek subwatershed, 2006 to 2007.



Results and Discussion

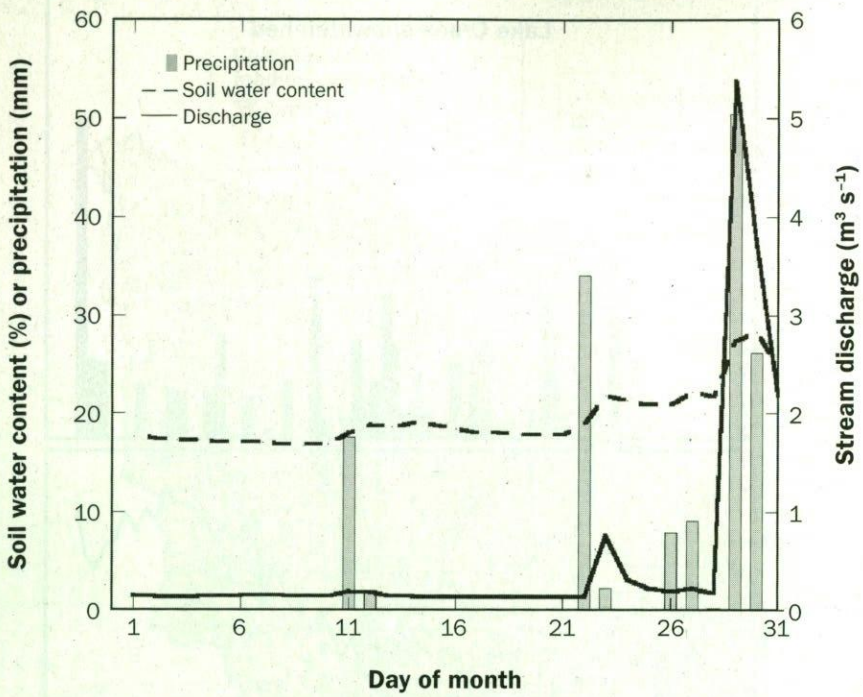
Because of the croplands focus of the initial CEAP research, results described in this paper are predominately from the FCREW. Research in the LWREW has contributed primarily to model evaluation and calibration for CEAP (Van Liew et al. 2007a, 2007b; Moriasi et al. 2007). Van Liew et al. (2003) also reported that flood retarding structures reduced peak flows by 39% for a 5-year return storm and by 483% for a 10-year storm in a 160 km^2 (62 mi^2) area of the LWREW where 65% of the area was controlled by 13 flood retarding structures. During major storms in mid-May 2007, the 2,105 upland flood control structures in Oklahoma, of which 42 are located in the LWREW, were credited with avoiding $33 million of flood damage, indicating their importance as a conservation measure (Oklahoma Conservation Commission 2008). Future analyses will be balanced across both watersheds and across croplands and grazing lands conservation practices.

Climate, Hydrology, and Sediment Yield. The long-term climate record for Oklahoma shows that persistent multi-year precipitation variations recur at irregular intervals (figure 2). A relatively long and strong "wet period" prevailed in the 1980s and 1990s. In recent years, precipitation trends gradually changed towards drier conditions. In 2004, at the onset of CEAP, the region was in this drier precipitation pattern. Multi-year precipitation variations were found to lead to corresponding observed multi-year variations in stream flow in the Fort Cobb watershed (Garbrecht et al. 2006).

The 2004 and 2005 instantaneous discharge and sediment yield measurements

Figure 5

Average daily soil water content (0 to 45 cm), daily precipitation, and average daily stream discharge in Lake Creek, March 2007.



Note: Soil water content and precipitation are averaged from five measurement sites in the contributing area above the stream discharge measurement site.

from three gauging stations in FCREW were combined to develop a sediment yield versus discharge rating curve that was used to estimate sediment yield into the reservoir using the available stream flow record (J. Garbrecht 2008). The two-year sampling period is short, but additional data from continued sampling will verify the rating curve or allow future development, if needed, of rating curves from each monitored stream. The analysis indicated that a 33% increase in average annual precipitation led to a 101% increase in runoff and 183% increase in estimated sediment yield, when moving from a dry climatic period to a wet climatic period. Thus, the conservation effects that are the focus of CEAP must be analyzed within the context of the persistent, multi-year precipitation variations which could easily mask management impacts if not accounted for.

Interannual variability in precipitation dominates a wide range of hydrologic and biogeochemical processes in addition to runoff. Results from the FCREW (figure 4) indicate that groundwater level is influenced by interannual differences in precipitation, as well as seasonal patterns associated with drawdown of the groundwater level in summer, during the primary irrigation and evapotranspiration season. Depth to groundwater was about 27 m (89 ft) during the spring through early fall, when evapotranspiration rates are highest and most irrigation pumping occurs, compared to about 24 m (79 ft) in January 2006, (dry conditions) and 19 m (62 ft) in January 2007 (wetter conditions). Interannual variability in precipitation also resulted in large interannual variation in evapotranspiration and carbon fluxes in this region. Meyers (2001) reported that evapotranspiration rates in droughty summers were about one-half of rates observed in wetter summers. Additionally, he reported that the area was an atmospheric carbon source during a dry summer compared to a carbon sink in a wetter summer.

During the drought of 2005 and 2006, stream flow was low and often minimally responsive to precipitation. In March 2007, soil water content was initially low, and storms on March 11 and March 22 did not result in significant runoff (figure 5). However, when soil water content had recharged, storms on March 29 and 30 resulted in a large spike in stream flow. Interactive effects of antecedent soil water content, precipitation amount, and precipitation intensity must be well understood before being able to address the additional impact of land management and conservation effects on runoff and solute transport that are central themes of this CEAP watershed assessment study.

Water Quality. The mean total P concentration averaged from December 2004 through March 2007 (n = 60) indicates that Lake Creek had somewhat higher concentrations of total P at the outlet to the lake than Cobb and Willow Creeks, but that all major subwatersheds had areas of higher and lower average total P concentration than observed at the outlets to the lake. Average P concentration over the period was significantly related to contributing area, stream density, average and maximum slope, and the percent of unstable channels (table 1). The highest average total P concentration was measured in Cherry Dale Creek, a short spring-fed tributary of Willow Creek. Becker (2001) reported groundwater flow in the region near our sampling site was south to southeast. Based on the high P concentration at the Cherry Dale site, compared to the others, this portion of the watershed will be the focus of additional research to elucidate surface runoff and groundwater contributions to nutrient concentrations in the stream.

Soils. Most of the soils at the Micronet sites in both the FCREW and LWREW are sandy textured soils (sand, sandy loam, loamy sand, or sandy clay loam). Sandy loam soils account for over 50% of the textural classes observed at the FCREW Micronets and for about 35% of those at the LWREW Micronets.

Land Use and Management. In the 1940s and 1950s, about 135,000 ha (333,000 ac), or 45%, of Caddo County was in crop production and included peanuts, wheat (*Triticum aestivum* L), sorghum [*Sorghum bicolor*, (L.) Moench], cotton, corn (*Zea mays* L.), oats (*Avena sativa* L.), and barley (*Hordeum vulgare* L.) (data not shown). In 2005, land use in FCREW (figure 3) was pasture/rangeland (33%), winter wheat and small grains (43%), peanut and cotton (9%), other summer crop (4%), forest and shrubs (5%), roads and miscellaneous (4%), and water (2%). Prevailing agronomic management practices for dominant cropping systems compiled by Storm et al. (2006) using extensive farm surveys are being applied in simulation studies. Additional agronomic data, at a county level, from the USDA National Agricultural Statistics

Table 2
Conservation practices supported with public funds in the Fort Cobb Reservoir watershed.

	USDA NRCS*				Oklahoma Conservation Commission†			
Conservation practice	Contracts	Area (ha)	Length (km)	Structures	Contracts	Area (ha)	Length (km)	Structures
Reduced tillage, no-tillage	NA	437			29	6,880		
Land conversion								
Conservation Reserve Program	3	NA	NA					
Annual to hay/pasture	NA	2,216			NA	2,646		
Stream corridor	NA	400			NA	113		
Fencing, use exclusion								
Structural	11	NA	NA					
Waterway					NA		2.7	
Terrace					NA		2.1	
Pipe drops					NA			37
Creek jacks					NA			30
Septic rehabilitation					5			5
Water management	17	1,117						
Total	40	4,170			122	9,639	4.8	72

Note: NA = data not available.

* Data from 2002 to 2006 provided by Phil Perryman, district conservationist, Caddo County, Anadarko, Oklahoma.

† Data from 2001 to 2006; M. Ramming; Fort Cobb project coordinator, West Caddo Conservation District, Fort Cobb, Oklahoma.

Service and the historical Agricultural Census data will be used to compile historical trends in cropping patterns, fertilization rates, and average yields for future environmental and economic analyses.

From Oklahoma Water Resources Board records, we estimated that about 3,500 ha (9,000 ac) were irrigated in 1958. A few of the older solid-set or side-role irrigation systems are still used in the watershed, but most irrigation in the watershed now is by center-pivot systems. If all pivot sites shown in figure 3 (from Storm et al. 2003) made a complete rotation irrigating 52 ha (132 ac), it would constitute about 10,000 ha (26,000 ac) irrigated by center-pivot systems. Many of these pivots only supply water to a portion of the land, so further quantification of the irrigation component of the water balance over time is required. Using a timeline of increasing irrigation acreage over time improved Soil and Water Assessment Tool (SWAT) model performance compared to validation runs that assumed a static (current) irrigated area (Garbrecht et al. 2007).

Conservation Practices. A number of conservation practices have been implemented on the FCREW in recent years including adoption of no-tillage management, conversion of cropland to grassland, installation of fencing to exclude cattle from streams, various structural practices, and water management practices (table 2). In a simulation study, Geza et al. (2004) estimated that the water quality in the watershed would be highly responsive to conversion from peanut to perennial crops, and that conversion to switchgrass as a bioenergy crop, rather than conversion under Conservation Reserve Program contracts, would allow for lower incentive payments. In their study, conversion to minimum-tillage wheat was simulated to allow for even lower incentive payments than for conversion to perennial biofuels cropping, but minimum-tillage wheat provided less reduction in environmental risks than conversion to perennial systems.

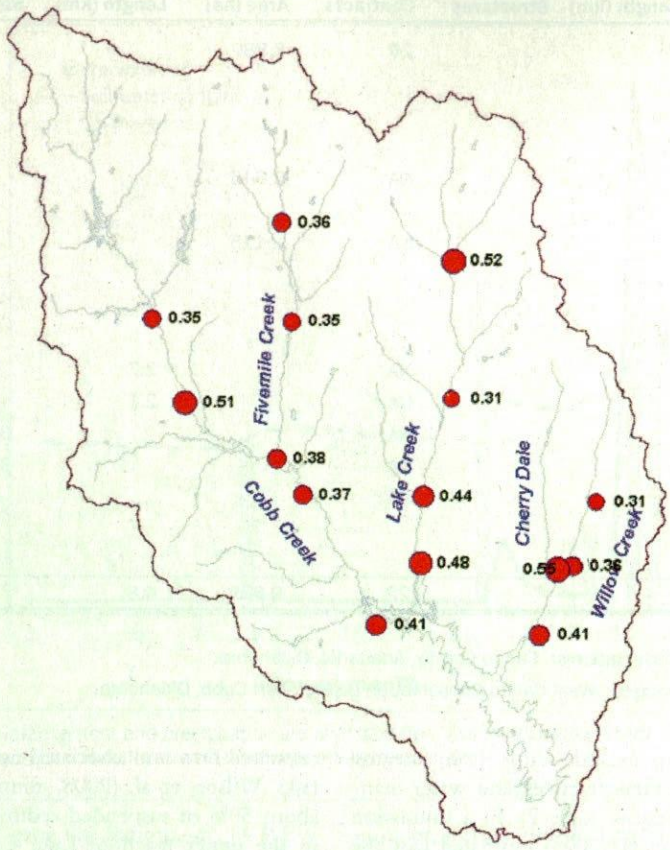
Sharpley et al. (1996) analyzed paired unit source watersheds in the LWREW from 1980 to 1992 and found that treatment of gullies (smoothing, vegetation establishment, and retention structure) on one of two eroding watersheds resulted in a 82% reduction in sediment loss, a 61% reduction in total P, and a 56% reduction in total N, compared to the untreated gully. Simon and Klimetz (2008) also identified gully and channel erosion as a dominant potential source of sediment in these two watersheds, indicating the need for conservation practices that address concentrated flow and associated environmental risks. Wilson et al. (2008) found that only about 50% of suspended sediment sampled in the upper reach of Lake Creek during runoff from one storm in August 2006, was from upland eroded surface soils. Clearly, solutions to water quality problems in this watershed must include conservation practices that address concentrated flow and channel processes.

Analysis of soils from farmers' fields in no-tillage rotation, conventionally tilled wheat, cropland converted to perennial grasses, and native grasses, showed that P and N levels were higher in no tillage fields when compared to conventional fields, and that soil nutrient levels in former cropland converted to perennial grasses or pastures were lower still (figure 7). Since the proposed total maximum daily load plan for this watershed is based on P, future research is needed on seasonal and management impacts on soil nutrient concentrations as well as delivery of nutrients in solution from fields with contrasting management practices.

Key Driving Forces and Conservation Challenges. Results indicate that improved understanding of the complex interactive effects of climate, land use, and land management is required to improve our quantitative

Figure 6

Total phosphorus (mg P L^{-1}) within the stream network, averaged from December 2004 through March 2007.



understanding of environmental issues in agricultural watersheds of the Upper Washita River Basin. In the FCREW, with improvement of water quality in the nutrient-limited reservoir as an endpoint, nutrient movement in solution and attached to sediment is and must remain a key focus. However, reduction of the nutrient load from the watershed will not resolve, in itself, the large nutrient load that is already in reservoir and lake sediments. Because of uncertainty about the role of base flow in nutrient transport, four exploratory wells and five additional groundwater monitoring wells are planned for 2008 where groundwater elevations can be measured using pressure transducers equipped with data recording equipment. These sites will allow access for groundwater sampling (figure 1) in which water samples will be analyzed for N species and forms of water soluble P. Performance of hydraulic conductivity measurements of geologic units are scheduled on installed monitoring wells in summer 2008 using the down-hole slug test method described by Bouwer and Rice (1976).

Results indicate that delineating rill, gully, and channel sources of sediment and quantifying the storage and rate of movement of sediments and nutrients within watersheds must remain a high research priority. Conservation practices must address stabilization of the stream corridor and riparian buffers, as well as reducing vulnerability to upland rill erosion. There are visible signs of wind erosion that deposits soil in ditches, near fence rows, and in other portions of the landscape, where the poorly aggregated particles are subject to subsequent water transport. It will be a great challenge to develop models and practices that address interactive effects of wind and water transport of sediment and associated nutrients.

There are numerous nonagricultural sediment and nutrient sources in the watershed that must be accounted for and included in the search for solution to water quality deterioration, including road maintenance practices, residential and recreational septic systems, and wildlife. Fairchild et al. (2004) indicated that the highest observed level of *E. coli* near the municipal water intake site for the city of Anadarko was associated with a period with large numbers of over-wintering waterfowl present at the reservoir.

Conservation Opportunities. Conversion to reduced tillage and more intense crop rotations has increased in the FCREW in the past few years, partially driven by increasing fuel costs. The Oklahoma Conservation Commission has focused on increasing no-tillage in the watershed. No-till workshops attracted about 150 producers in August 2006, and about 300 in February 2007, indicating a high and increasing interest. Water quality improvements in Lake Creek within the FCREW were recently identified as a nonpoint source program success story (Butler 2007), where educational efforts and best management practice installation were identified as contributing factors in improvement of the Index of Biological Integrity scores between 1990 and 1998, resulting in removal of the Lake Creek from the 303(d) list.

Another practice being adopted in the watershed is fencing or exclusion of cattle from streams. In many of these areas, vegetation has very quickly re-established on the stream banks and fenced riparian area (M. Rammig, Oklahoma Conservation Commission, personal communication 2004). Given findings of Simon and Klimetz (2008) of the large amount of unstable channels in the watershed and of Wilson et al. (2008) of the large fraction of suspended sediment during storm runoff that is from concentrated flow or channel areas, the importance of riparian vegetation to enhance stream bank stability is very significant.

Next Steps. A great deal of research focusing on cropland conservation, established since 2004 as part of CEAP, is ongoing and will continue to provide more detailed results. It is important to continue to analyze the multitude of results emerging in order to address complex interactive processes that impact effectiveness of conservation practices. The study initiated to evaluate the Soil Management Assessment Framework (SMAF) (Andrews et al. 2004) will provide the basis for future studies on the hydrologic implications of soil quality improvement. Field study results will be used to parameterize field-scale simulation sites

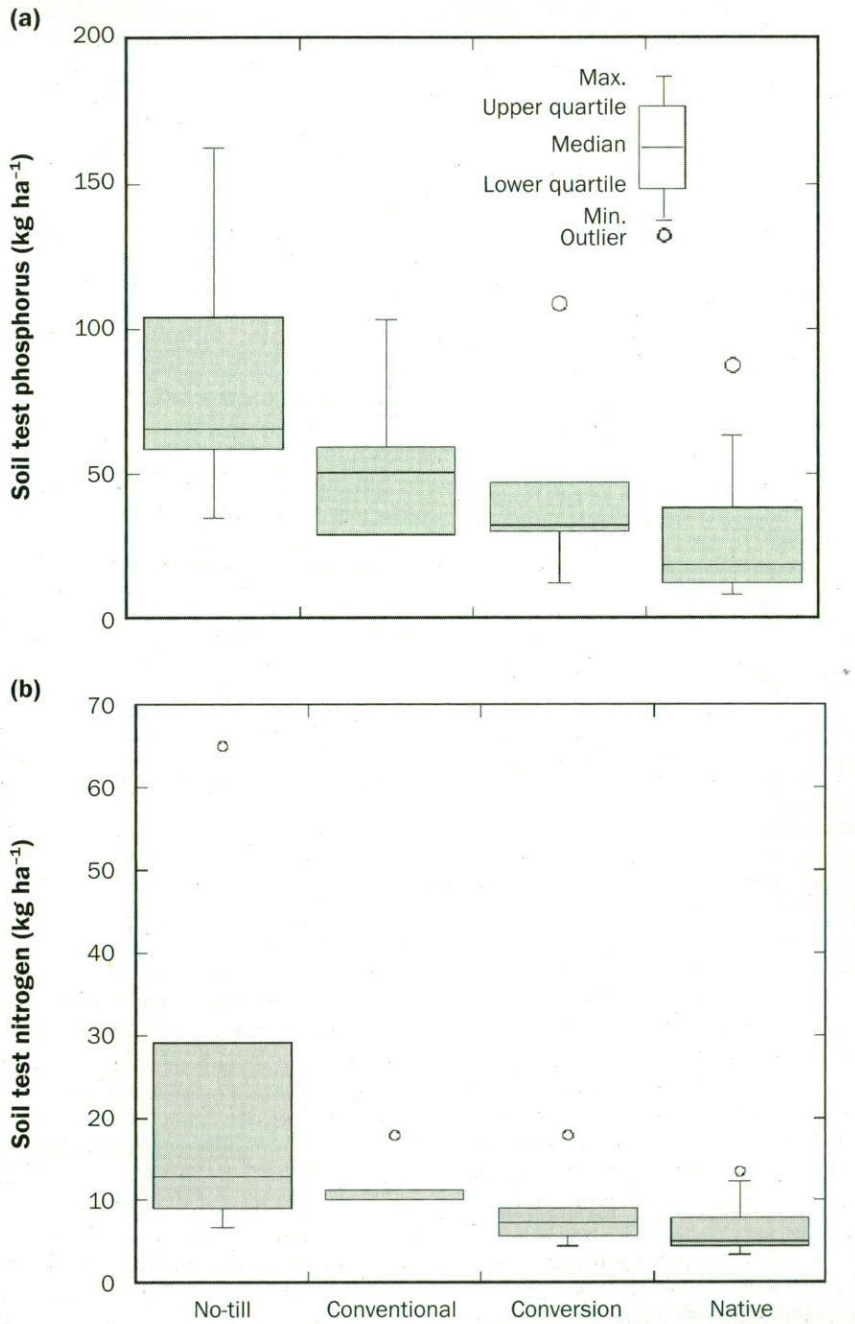
for key management regimes. A modeling study will be conducted to quantify potential impacts of contrasting land management and conservation practices, including subsequent impact of changed soil properties on surface and subsurface hydrology. The simulated effects of land management on surface runoff, infiltration, soil moisture distribution, and the movement of N from the soil surface to below the root zone will be quantified. As this research matures, spatial and temporal scaling studies will help build understanding of scaling from edge of field to delivery to the reservoir. Temporal analysis will also focus on definition of a "design storm" for particular practices to achieve particular levels of environmental protection. Based on these findings, in-field experimentation, simulation, and promotion of conservation, channel processes and gully erosion must be addressed.

Summary and Conclusions

The goals of the CEAP watershed assessments studies are broad and long term (Richardson et al. 2008). Since 2004, research in the Upper Washita River Basin in southwestern Oklahoma has been expanded from the Little Washita River subwatershed, where ARS research was established in 1961, to a second subwatershed above the Fort Cobb Reservoir. The research configuration provides the framework to address conservation concerns of rainfed and irrigated cropping as well as pasture and native rangelands. Recent acceleration in conversion from intensively tilled systems to conservation tillage systems (as fuel prices have increased) offers the opportunity to quantify changes in soil biological, chemical, and physical properties of the soils under changing management regimes. Data analysis within the watershed should provide insight into fate and transport of contaminants that originate at the field scale. In addition, gully erosion, stream bank failure, and channel processes are all conservation concerns in this watershed that must be addressed through conservation practices. Research and assessments on scaling from field to watershed and fate and transport analyses must include a suite of models appropriate to the complex array of conservation concerns. Results clearly indicate that multi-year precipitation variations are a key factor impacting hydrologic and other environmental processes. If climate issues are not included in the CEAP assessments, these impacts could easily mask the conservation and management effects that are the target of the research.

Figure 7

Effects of agricultural management system on (a) phosphorus (Mehlich 3), and (b) nitrate-nitrogen concentrations (from 42 on-farm soil quality study sites, sampled in November 2006).



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