Published in Proc. of Conf. "50 Years of Soil and Water Research in a Changing Agricultural Environment", USDA-ARS National Sedimentation Laboratory, Sept 3-5 2008, Oxford, MS.

Conservation and Sediment Yield on the Fort Cobb Reservoir Watershed

Jurgen D. Garbrecht, Patrick J. Starks, and Daniel N. Moriasi

USDA, Agricultural Research Service, Grazinglands Research Laboratory
7027 West Cheyenne Str., El Reno, Oklahoma, OK 73036

Abstract

Prior to about 1950, conservation practices on the Fort Cobb Reservoir watershed in West-Central Oklahoma were few and mostly demonstration type projects. Extensive soil conservation measures were implemented in the second half of the 20th century. Fortuitously, the U.S. Geological Survey collected instantaneous suspended-sediment and discharge measurements on major channels during 1943-1948 and again in 2004-2007. These data offered the opportunity to estimate the reduction of watershed-scale suspended-sediment yield as a result of upstream conservation practices. Average annual suspended-sediment yield at the watershed outlet for 1943-1948 was estimated to be 760 [Mg/yr/km^2], and for 2004-2007 it was 108 [Mg/yr/km^2]. The substantial reduction in suspended-sediment yield was related to conversion of cropland to grassland, and to a wide range of conservation practices implemented in the second half of the 20th century. While it is generally difficult to identify conservation impacts on sediment yield at the watershed outlet during the short time span of a conservation project, this study shows that targeted and widespread conservation efforts in Central Oklahoma can lead, over time, to a sizable reduction in watershed sediment yield, as was the case for the Fort Cobb Reservoir watershed.

Introduction

Over half a century of soil and water conservation research and demonstrations leave little doubt that agricultural conservation practices at field and small catchment scales (~1 to100 [ha]) are highly effective at reducing overland soil erosion and sediment delivery to channels (Berg et al., 1988; McGregor et al., 1990). However, soil conservation practices and channel stabilization may not always translate into an immediate sediment yield reduction at the outlet of a large watershed (> ~10'000 [ha]) (Trimble, 1999; Santhi et al., 2005; Shields, 2008). Hence, the apparent disconnect between upstream conservation practices and reduction in sediment yield at the watershed outlet, at least within customary project durations of a few years. Factors that may confound causal connection between conservation and sediment yield include: limited participation in conservation programs; protracted implementation of conservation practices; temporal and spatial variability of soil erosion and sediment transport; and watershed sediment storage and flushing effects. Furthermore, watershed-scale sediment storage effects, conditions for and recurrence of sediment remobilization, dynamics of shifting sediment sources, and spatial and temporal propagation of perturbations in sediment budget within the watershed system are all very difficult to quantify, yet they are pertinent to the assessment of sediment yield at the watershed outlet (Trimble and Crosson, 2000; Pearson et al., 2006; Walling, 1999; Vente et al., 2007).

In this study, a unique opportunity to demonstrate conservation impacts on watershed sediment yield was seized upon by contrasting sediment yield and discharge measurements taken by the U.S. Geological Survey (USGS) on the Fort Cobb Reservoir watershed during 2004-2007 with similar measurements taken more than half a century earlier. Sediment yield reduction at the watershed outlet over a span of 60 years was estimated and interpreted in terms of land use conversion, conservation practices, urban development, and variations in climate.

Watershed Description

The Fort Cobb Reservoir dam in Central Oklahoma was constructed in 1959. The reservoir receives inflow from a 787 km^2 agricultural watershed consisting primarily of crop and range/pasture land. The USGS operated up to five discharge gauges in the watershed, and also collected instantaneous suspended-sediment and discharge data on a rainfall-runoff event basis (Figure 1; Table 1). Thirty event-based suspended-sediment and discharge measurements were taken at the Cobb Creek gauge near Fort Cobb during 1943-1948, and a total of 105 measurements were taken at four other gauges in the watershed during 2004-2007 (Table 1).

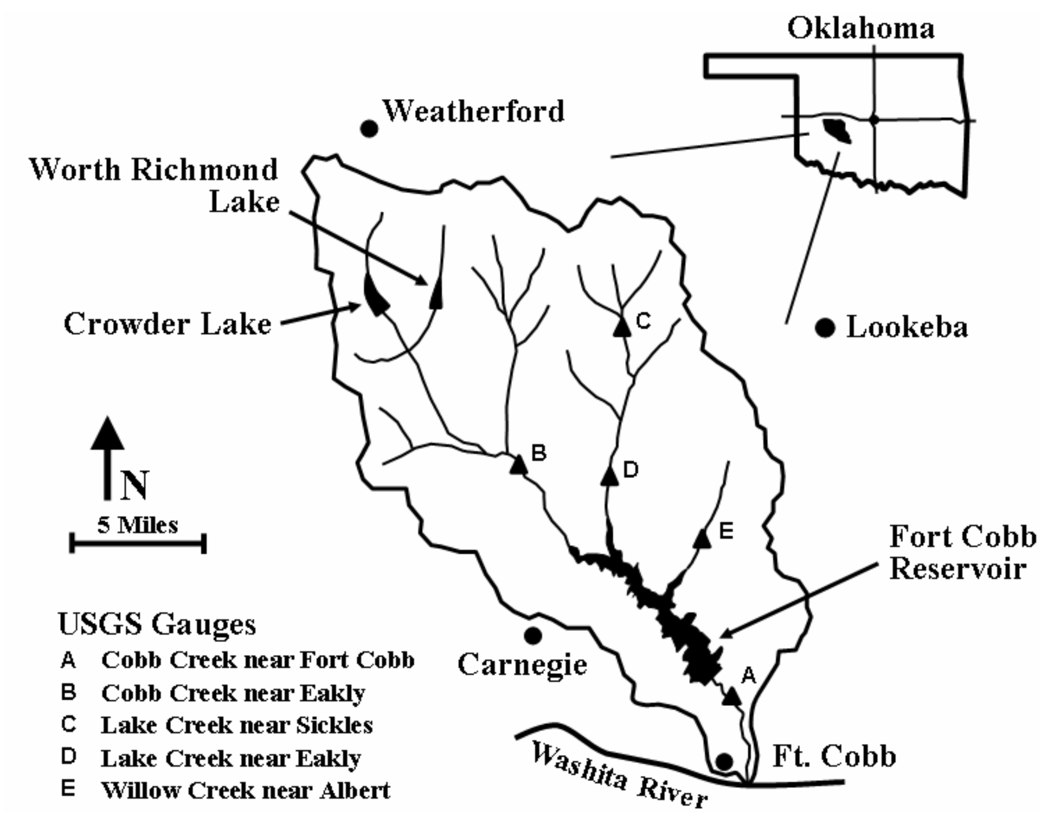

Figure 1. Fort Cobb Reservoir watershed outline and locations of U.S. Geological Survey discharge and suspended-sediment gauging sites.

Table 1. Identification number and characteristics of U.S. Geological Survey discharge and suspended-sediment gauging sites.

Gauge Name	USGS Gauge Number	Drainage Area [km^2]	Period of Observations	Number of Data Points	Data Source
Cobb Creek nr Eakly	07325800	342	Nov 2004 – Sep 2007	35	USGS
Lake Creek nr Sickles	07325840	49	Jun 2006	1*	USGS
Lake Creek nr Eakly	07325850	154	Nov 2004 – Sep 2007	35	USGS
Willow Creek nr Albert	07325860	75	Nov 2004 – Sep 2007	35	USGS
Cobb Creek nr Fort Cobb	07326000**	826	May 1943 – Dec 1948	30	USGS

* Not a permanent suspended-sediment collection site; only one suspended-sediment measurement was made.
** After 1959, discharge below the dam reflects gate controlled discharge releases.

Land Use and Conservation Practices for 1943-1948 and 2004-2007

Land use for 1943-1948

Storm et al. (2007) estimated land use in the watershed for 1940-1957 based on historical crop data and land use distribution information from remote sensing images (US Dept. of Commerce, 1952; NASS, 2007). For 1940-1957, it was estimated that about 72% of the watershed was in production agriculture, about 25% was in pasture and range, and the remaining 3% was in forest, roads, and urban areas. For this study, estimated land use for 1940-1957 was assumed to adequately represent land use for 1943-1948.

Conservation practices for 1943-1948

The extent of conservation practices in the Fort Cobb Reservoir watershed during the 1940s was rather limited and of little practical significance. For this study, it was assumed that conservation practices were essentially non-existent before the 1950s.

Land use for 2004-2007

At the beginning of the 21st century, three separate land use studies were conducted on the Fort Cobb watershed. The average land use from these three studies was assumed to adequately represent the land use conditions for the 2004-2007 timeframe. It was estimated that about 52% of the watershed was in production agriculture, 36% was in grass/pasture lands, and the remaining area was in forest (9%), water (2%) and roads/urban (1%).

Conservation practices for 2004-2007

Estimates of conservation practices for 2004-2007 were based on authors’ interviews of State and District Conservation personnel (February and April 2008). Caddo County covers approximately 70% of the central and eastern Fort Cobb Reservoir watershed. Soils in Caddo

County are sandy, fertile, and extensively cultivated, yet they are also vulnerable to erosion and produce most of the sediment delivered to channels. Soils in the far western portion of the watershed are more stable and not as extensively cultivated. For this study, land use, management and conservation practices in Caddo County, the major contributor of eroded sediments, were assumed to adequately represent relevant soil erosion and sediment delivery conditions in the Fort Cobb Reservoir watershed.

Some 80% to 90% of cropland that needs terraces has been terraced over the last 50 years. Over the last decades about 50% of the cropland was in conservation tillage, minimum disturbance tillage, or no-till. This proportion is likely to grow over time as fuel prices continue to rise. Also, gullies were reshaped and grade stabilization structures were installed as part of cost-sharing conservation programs and some conservation treatments were installed without cost-sharing assistance. In addition to the mentioned cropland conservation practices, selected stream bank sections within the watershed were stabilized, small impoundments and Soil Conservation Service flood retarding structures were constructed in the late 1950s and early 1960s, and a number of gravel/dirt roads were paved. Despite these efforts, several long unstable channel reaches still exist and were identified by a geomorphic assessment conducted in 2007 by the USDA-ARS National Sedimentation Laboratory of Oxford, Mississippi (Simon and Klimetz, 2008), and controlling soil erosion continues to be a priority to protect fragile and erosion prone soils in Caddo County.

1943-1948 and 2004-2007 Sediment Rating Curves

Thirty instantaneous suspended-sediment and discharge measurements were collected by the USGS at the Cobb Creek gauge near Fort Cobb at various times during 1943-1948 (Table 1; Figure 1). These data reflected watershed sediment yield and discharge under pre-conservation conditions. Another 105 sediment and discharge measurements were taken at four separate gauges during 2004-2007 (Table 1; Figure 1). These gauges were: Lake Creek near Sickles; Lake Creek near Eakly; Willow Creek near Albert; and Cobb Creek near Eakly (Figure 1). These data reflected sediment yield and discharge after a broad range of conservation practices were implemented in the second half of the 20^{th} century. To facilitate data comparison between gauges and across time periods, all sediment and discharge data were reformulated on a unit area basis.

A second-order regression was fitted to the 1943-1948 sediment and discharge data (Figure 2). This sediment-discharge rating curve represented land use and management conditions during the 1940s and 1950s. A separate rating curve, representing land use and conservation conditions during 2004-2007, was developed based on similar sediment and discharge measurements taken between 2004 and 2007 at four separate gauges (Figure 1). The near perfect overlap of the 2004-2007 sediment and discharge data at the four gauges (Figure 3) indicated that a single second-order regression curve ($r^2 = 0.97$) adequately represented sediment and discharge relationships at the four gauging stations. Furthermore, drainage area of the four gauges encompassed about 70% of the watershed area above the Cobb Creek gauge near Fort Cobb. The previous considerations led to the inference that the 2004-2007 sediment-discharge rating curve is likely a fair approximation for the rating curve that would have existed at Cobb Creek gauge near Fort Cobb in 2004-2007 had the reservoir not been constructed in 1959.

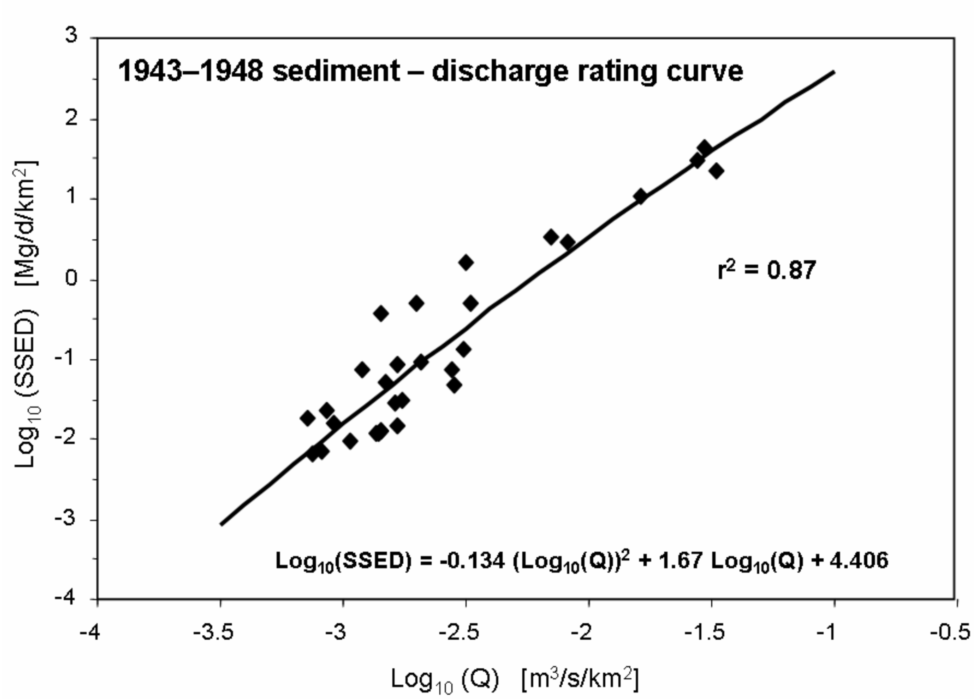

Figure 2. Instantaneous suspended-sediment (SSED) - discharge (Q) rating curve at Cobb Creek near Fort Cobb representative for 1943-1948 land use and conservation conditions.

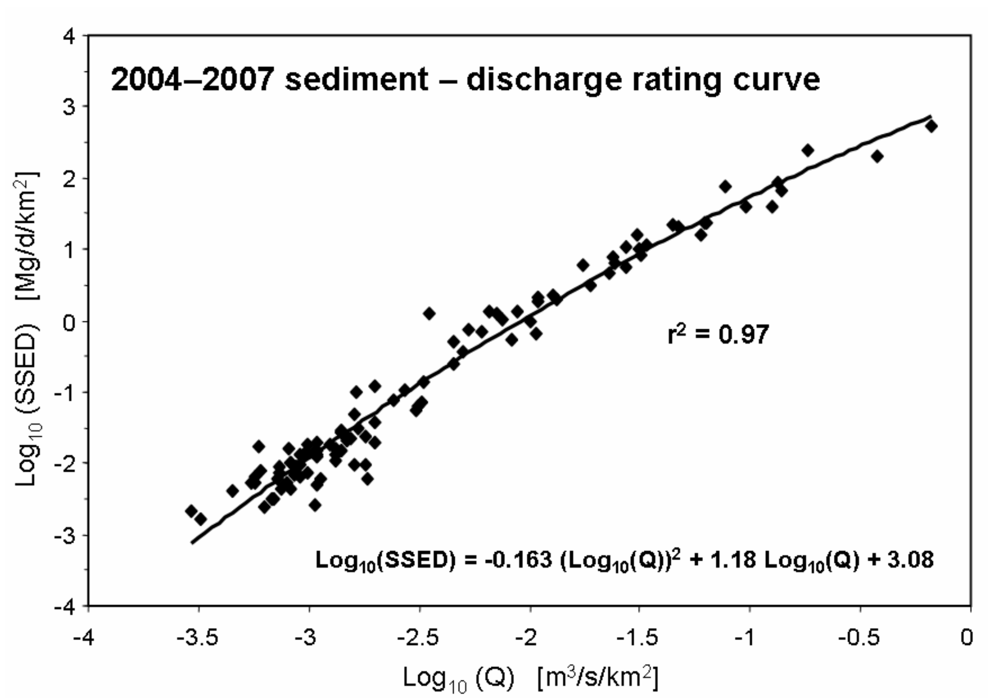

Figure 3. Instantaneous suspended-sediment (SSED) - discharge (Q) rating curve at Cobb Creek near Fort Cobb representative for 2004-2007 land use and conservation conditions.

Sediment Yield Reduction

Annual suspended sediment yield for pre- and post-conservation conditions was estimated by evaluating separately each of the two sediment-discharge rating curves with observed 1940-1957 discharge values at Cobb Creek near Fort Cobb. Average annual sediment yield for the pre-conservation period was estimated to be 760 [$Mg/yr/km^2$], and for the post-conservation period it was 108 [$Mg/yr/km^2$] or only 15% of the sediment yield of the pre-conservation period. This large difference in watershed sediment yield between pre- and post-conservation periods was attributed primarily to conversion of cropland to grassland and implementation of a broad range of conservation practices during the second half of the 20th century.

Further analysis with more recent discharge data at the Cobb Creek gauge near Fort Cobb was not possible because the Fort Cobb Reservoir dam was constructed in 1959 a few miles upstream of the gauge. Indeed, discharge measured at that gauge after 1959 reflected gate-controlled reservoir releases during high flow events, and was not representative of natural watershed rainfall-runoff patterns.

Discussion

Changes in watershed sediment yield are traditionally associated with land use conversion, conservation practices, stream channel stabilization, urbanization, and/or climate variability, among the most important factors. There are only two small rural communities in the Fort Cobb watershed that have not grown very much over time, and urbanization was likely not a leading factor affecting watershed sediment yield. Effects of climate variability and associated change in hydrologic regime on sediment yield were minimized by evaluating the two sediment-discharge rating curves (representing pre- and post conservation conditions) with the same 1940-1957 daily discharge data at Cobb Creek gauge near Fort Cobb. Also, suspended-sediment and discharge data underlying the rating curves were not believed to be significantly affected by climate variations because average annual rainfall between the two periods of interest was not very different, and, more importantly, decisions on when and how often to sample was not based on climatic considerations. Instead, low-flow samples were taken on days following a period without rain, during low channel flow conditions, and at different times and seasons during the year. High-flow sampling was initiated whenever a sizable runoff-producing storm was forecast, though in hindsight the forecasted storm sometimes did not produce the desired surface runoff over the area of interest.

Given these considerations, one is justifiably led to believe that land use conversion and conservation practices implemented in the second half of the 20th century must have led to the identified sediment yield reduction. Indeed, starting in the late 1950s and through the beginning of the 21st century, close to 30% of erosion-prone cropland was converted to range and pasture land. Soil erosion on this converted cropland gradually stopped, and total sediment delivery from cropland erosion to channels was ultimately reduced by over 30%. Furthermore, during the last decade, conventional tillage practices have given way to conservation tillage or no-till on about 50% of the cropland. The implementation of conservation tillage practices likely further reduced sediment delivery from cropland to channels.

Additional reductions in soil erosion and sediment yield were attributed to terracing of cropland, gully shaping, grade control structures, channel stabilization efforts, sediment trapping by impoundments and reservoirs, and farm road surfacing. Unfortunately, associated soil erosion and sediment yield reduction could not be quantified because neither was measured, and archived historical records were sparse, at best. However, it is very likely that these conservation practices also contributed significantly to the reduction of sediment yield at the watershed outlet. Considering all presented data, factors and inferences, there is little doubt that the cumulative and integrated effects of all conservation practices implemented in the second half of the 20th century contributed to reducing soil erosion and, over time and with some delay, to lowering sediment yield at the watershed outlet in 2004-2007.

Summary and Conclusions

Effects of conservation practices on watershed sediment yield were investigated for the Fort Cobb Reservoir watershed. Pertinent instantaneous suspended sediment and discharge data for the periods of interest were obtained from the USGS and reformulated on an unit-area basis to facilitate data inter-comparison between gauge locations and across time periods. A sediment-discharge rating curve was developed with data collected during 1943-1948 and reflected land use and management conditions prevailing in that era (i.e. no conservation practices). A second sediment-discharge rating curve was developed from data collected during 2004-2007 and reflected land use and conservation conditions prevailing during those years (i.e. with extensive conservation practices). Annual sediment yield at the watershed outlet was estimated using the sediment rating curves and the 1940-1957 daily discharge at the Cobb Creek gauge near Fort Cobb. Average annual sediment yield was 760 [Mg/yr/km^2] for the 1943-1948 pre-conservation period and 108 [Mg/yr/km^2] for the 2004-2007 land use and conservation conditions.

The substantial reduction in annual sediment yield between 1943-1948 and 2004-2007 was related to conversion of land use and implementation of conservation practices. The gradual implementation and cumulative effects of land use conversion and broad range of conservation measures over a 60- to 70-year time span was likely the cause of the reduction in today’s watershed sediment yield over that from the 1940s. While it may be difficult to identify beneficial impacts of conservation practices on sediment yield at the watershed outlet during the short time span of a conservation project, this study demonstrated that targeted, widespread and sustained conservation efforts can lead, in time, to sizable reduction in sediment yield at the watershed outlet, as was the case for the Fort Cobb reservoir watershed.

References

Berg W.A., Smith S.J., and Coleman G.A. 1988. Management effects on runoff, soil, and nutrient losses from highly erodible soils in the Southern Plains. Journal of Soil and Water Conservation, 43(5):407-410.

McGregor K.C., Mutchler C.K., and Roemkens M.J.M. 1990. Effects of tillage with different crop residues on runoff and soil loss. Transactions of ASAE,33(5):1551-1556.

NASS. 2007. National Agricultural Statistics Service, United States Department of Agriculture, Webb Site: http://www.nass.usda.gov; accessed May 2006.

Pearson A.J., Wainwright J., Brazier R.E., and Powell D.M. 2006. Is sediment delivery a fallacy? Earth Surface processes and Landforms, 31:1325-1328.

Santhi C., Srinivasan R., Arnold J.G., and Williams J.R. 2005. A modeling approach to evaluate the impacts of water quality management plans implemented in a watershed in Texas. Journal of Environmental Modelling and Software, 21(2006):1141-1157.

Shields F.D. Jr. 2008. Long-term evaluation of regional erosion control. Journal of Soil and Water Conservation, 63(2):50A.

Simon A., and Klimetz L. 2008. Relative magnitudes and sources of sediment in benchmark watersheds of the conservation effects assessment program (CEAP). Journal of Soil and Water Conservation, in press.

Storm D.E., Busteed P.R., and White M.J. 2007. Hydrologic modeling of the Fort Cobb Basin, Oklahoma, using SWAT 2005. Final Report to USDA, ARS, Grazinglands Research Laboratory, April 2, 2008. Biosystems and Agricultural Dept., Div. of Agricultural Sciences and Natural Resources, Oklahoma State University.

Trimble S.W. 1999. Decreased rates of alluvial sediment storage in the Coon Creek Basin, Wisconsin, 1975-1993. Science, 285(5431):1244-1246.

US Dept. of Commerce. 1952. Census of Agriculture:1950, Counties and State Economic Areas, Oklahoma. Agricultural Division, Vol. 1, Part 25, United States Government Printing Office.

Walling D.E. 1999. Linking land use, erosion and sediment yield in river basins. Hydrobiologia, 410:223-240.

Vente J., Poesen J., Arabkhedri M., and Verstraeten G. 2007. The sediment delivery problem revisited. Progress in Physical Geography, 31(2):155-178.