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Conservation practice effects on sediment load in the Goodwin Creek Experimental Watershed

R.A. Kuhnle, R.L. Bingner, C.V. Alonso, C.G. Wilson, and A. Simon

Abstract: Water quality and aquatic habitat due to unstable stream channels and high sediment concentrations during storm runoff events are major environmental concerns on the 2,132 ha (5,266 ac) Goodwin Creek Experimental Watershed in north Mississippi. Effects of enrolling erodible lands in the Conservation Reserve Program (CRP) and instream grade stabilization structures were evaluated using measured rainfall, runoff, and sediment concentration data and model simulations. Signatures of naturally occurring radionuclides indicated that 78% of the total sediment load originated from channel sources. The change of land to a CRP-like state (reducing cultivated land from 26% to 8%) reduced erosion and runoff from fields and thus decreased total sediment concentration by 63% between 1982 to 1990. Simulations using the Fluvial Routing Analysis and Modeling Environment model indicated that mean sediment yields would increase from 15% to over 200%, depending upon location in the watershed, if in-channel structures were not present. The combined effect of the grade control structures and the change of lands to a CRP-state was to reduce sediment yields by 78% near the outlet of the watershed.

Key words: agicultural watersheds—Conservation Effects Assessment Project (CEAP)—conservation practices—sediment load

Unstable channels and excess sediment have been shown to have negative impacts on aquatic biota in watersheds (Shields et al. 1994; Kuhnle et al. 2001). Damage due to sediment in North America has been estimated at $\$16 \times 10^9$ annually (Osterkamp et al. 1998). Knowledge of the effect of agricultural management practices on sediment yield has been derived predominantly from studies on plots or field-sized watersheds (e.g. McGregor et al. 1969; Dendy et al. 1979). Mean runoff and sediment yield were found to be 57% and 99% less, respectively, on field-sized watersheds with natural vegetation as compared to cultivated crops (Dendy et al. 1979). Results from other studies of field-sized watersheds have shown that peak runoff rates were three times greater for a soybean (*Glycine max* [L.] Merr.) field as compared to a grass field (Grissinger 1996; Dabney 1998). Studies using rainfall simulators on plots determined that runoff was greater on recently tilled and no-till sites when compared to Conservation Reserve Program (CRP) sites (Gilley and Doran 1997; Gilley et al. 1997). Increases in runoff and flow velocity become magnified through sediment yield because the erosivity of runoff is proportional to the square of flow velocity, and sediment transport capacity of runoff is proportional to the fifth power of flow velocity (Meyer and Wischmeier 1969). While plot and small watershed studies have provided valuable information on the effect of conservation practices on runoff and sediment yield, they may not be representative of the scales and complexity that typically exist on larger watersheds (Spraberry and Bowie 1969; Bowie and Mutchler 1986; Dabney 1998).

Design of effective management practices for sediment control requires that the sources be identified. Past studies have shown that this is possible if unique signatures of naturally occurring radionuclides exist in sediment sources (Wilson and Kuhnle 2006 a, 2006b). Field studies to determine the effect of management processes on water quality on larger more complex watersheds are rare (Potter 1991; Edwards et al. 1997) and seldom include sediment as a main topic of study. Difficulties associated with the collection of a sufficient number of representative samples during runoff events, along with seasonal differences and variation in runoff and precipitation events, make studies on the effect of management practices on sediment load difficult to conduct. The Goodwin Creek Experimental Watershed (GCEW) was designed to use the latest technology for the collection of runoff and sediment data and presents an excellent opportunity to quantitatively evaluate management practice effects on sediment yield at the watershed scale.

The Bluff Hills region of the state of Mississippi contains the GCEW as well as other Demonstration Erosion Control (DEC) project watersheds. Related studies have been conducted on DEC watersheds and have characterized the sediment and flow conditions in these unstable channels. Management practices and their effect on sediment load have generally not been considered on DEC watersheds. Many of the sediment and channel stability problems in the DEC watersheds are similar to those of the GCEW (Grissinger and Murphey 1982; US Army Corps of Engineers 1992). In addition, studies on the stability of channels and their contribution to annual sediment loads on the GCEW have been completed based on previous data collection efforts (Grissinger 1996; Grissinger and Bowie 1984; Grissinger et al. 1991). There have been several studies that have related the effect of unstable habitat and high sediment loads on aquatic organisms on DEC streams (Kuhnle et al. 2001; Shields et al. 1994, 2007).

The GCEW was designated one of twelve benchmark watersheds of the Conservation Effects Assessment Project in 2005, with the major focus of research on the watershed dealing with the effect of conservation practices on watershed sediment load. Effects

Roger A. Kuhnle is a research hydraulic engineer, **Ronald L. Bingner** is an agricultural engineer, and **Carlos V. Alonso** is a research leader at the National Sedimentation Laboratory, USDA Agricultural Research Service (ARS), Oxford, Mississippi. **Christopher G. Wilson** is a research scientist in the Department of Civil and Environmental Engineering, University of Iowa, Iowa City, Iowa. **Andrew Simon** is a geologist for the National Sedimentation Laboratory, USDA ARS.

Figure 1
Map of watershed with elevation contours, station numbers, and rain gauge locations.

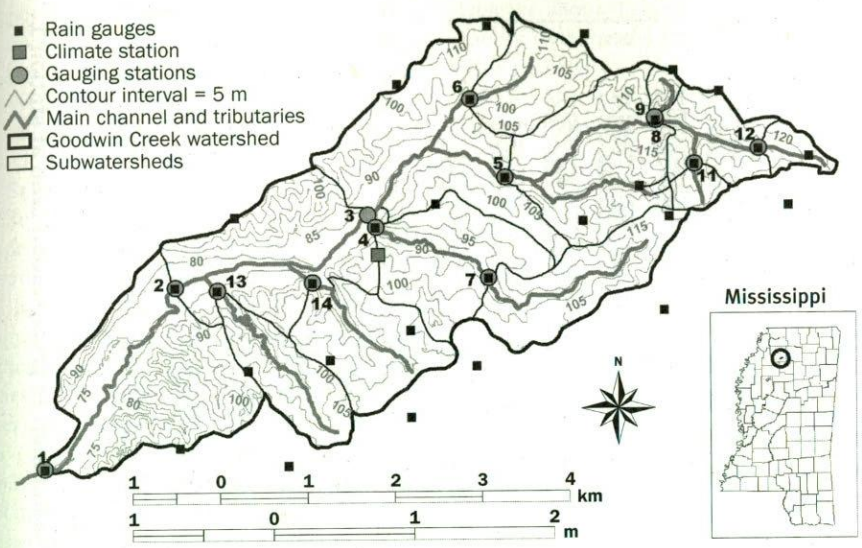
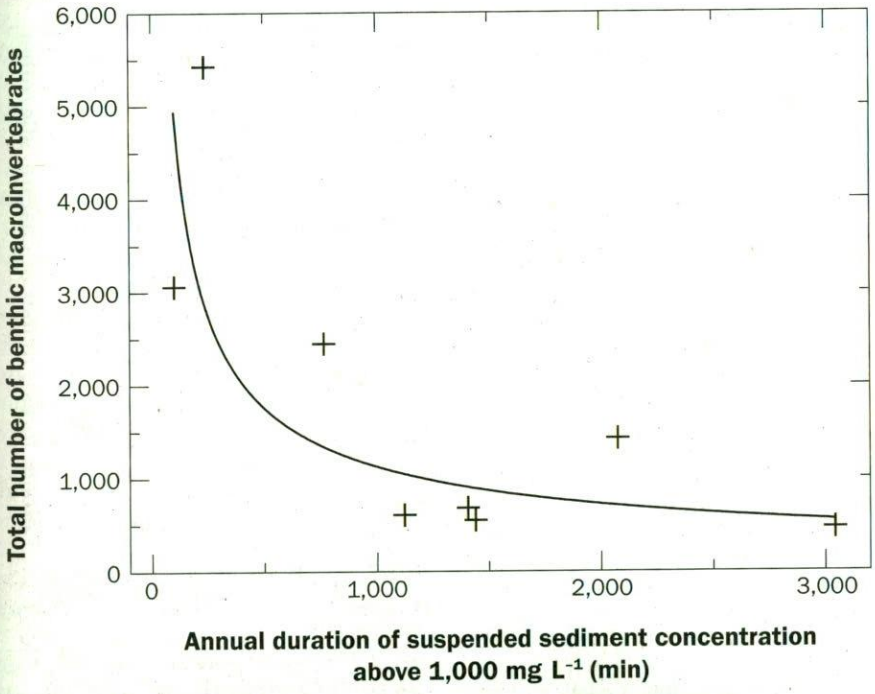


Figure 2
The effect of duration at sediment concentrations above 1,000 mg L^{-1} on benthic macroinvertebrates.



Note: Data were collected from Goodwin Creek Experimental Watershed and Demonstration Erosion Control watersheds in northern Mississippi (Kuhnle et al. 2001).

of converting highly erodible lands under cultivation to less erodible uses through the CRP, using signatures of naturally occurring radionuclides to identify relative sources of sediment, and controlling channel grade with instream structures (USDA Natural Resources Conservation Service conservation practice no. 410), using the Fluvial Routing Analysis and Modeling Environment (FRAME) model (Langendoen et al. 1998) are being evaluated on GCEW. Our hypotheses are that (1) converting highly erodible cultivated lands into CRP status will decrease watershed runoff and sediment loads, (2) determining relative sources of sediment will document the watershed processes responsible for the sediment problems, and (3) instream grade control structures will significantly decrease the supply of channel derived sediment lost from the watershed.

Materials and Methods

Watershed Description. The GCEW (Alonso and Bingner 2000) is located in Panola County, Mississippi, in a region with erodable soils, high rainfall (1,358 mm y^{-1} [53.5 in yr^{-1}]), and relatively steep slopes in the main channel (mean slope = 0.004). The drainage area is 2,132 ha (5,266 ac) and lies in the bluff hillls physiographic subprovince just east of the Mississippi River alluvial valley (figure 1). The upland areas of the watershed are blanketed with a thin layer of late-Wisconsin-age loess. Soils on the watershed predominantly consist of silt and are easily eroded when the surface cover is removed. Currently, most of the cultivation is located along the streams on the local alluvium. The main crops on GCEW during monitoring were cotton (*Gossypium hirsutum* [L.]) and soybean, with lesser amounts of grain sorghum (*Sorghum bicolor* [L.] Moench) and corn (*Zea mays* [L.]). Channels in GCEW are deeply incised and generally oversized for their drainage area. In a number of locations the banks are vertical, devoid of vegetation, and subject to undercutting and collapse. Total sediment yields from the watershed have been determined (Kuhnle et al. 1989) to be among the highest in the nation (13.2 t ha^{-1} y^{-1} [6 tn ac^{-1} yr^{-1}] at station 1). Suspended sediment concentrations regularly reach into the thousands of parts per million by weight during storm runoff events, which usually occur in the late winter and spring months of the year.

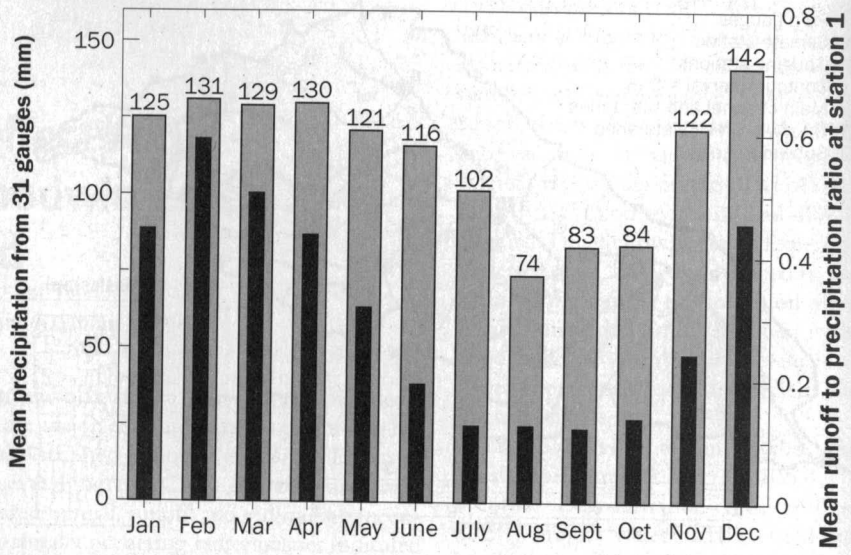
The primary environmental concerns of the watershed are water quality and aquatic habitat affected by unstable conditions and high sediment concentrations during storm runoff events. High bed material transport rates cause frequent adjustments to channel substrate elevations and sediment size distributions that result in a lack of stable pool habitat (Shields et al. 1994). High concentrations of suspended sediment have been shown to be detrimental to fish and aquatic invertebrates in Goodwin Creek and other watersheds in northern Mississippi (figure 2) (Newcombe and MacDonald 1991; Newcombe and Jensen 1996; Kuhnle et al. 2001).

Precipitation on the watershed is primarily from frontal storms in winter and spring months with widely scattered and variable thunderstorms in the summer and fall periods. Generally, the main source of the precipitation is warm moist air from the Gulf of Mexico. Monthly precipitation is nearly constant for the first one half of the year with a significant drop for July through October and an increase at the end of the year (figure 3). Most of the precipitation occurs as rainfall with very little snow or sleet. The mean annual precipitation, calculated from a Thiessen area weighted mean of 31 rain gauges distributed throughout the watershed, was 1,358 mm (53.5 in) for the period of 1982 to 2002.

In 1980, the watershed land use was nearly evenly split among cultivated, forest/timber, and pasture/idle uses. Runoff data collection began on the GCEW in 1981 with 14 supercritical flow structures designed and installed by the Vicksburg District of the US Army Corps of Engineers. These structures have effectively stabilized the bed elevation of the channels, and their effect on the sediment yield of the watershed has been evaluated using the FRAME model (Langendoen et al. 1998). The FRAME model simulated changes in the cross-sections of the channels for scenarios with and without the supercritical flow structures located at 10 gauging stations of the watershed (Bingner et al. 1996; Bingner 1998).

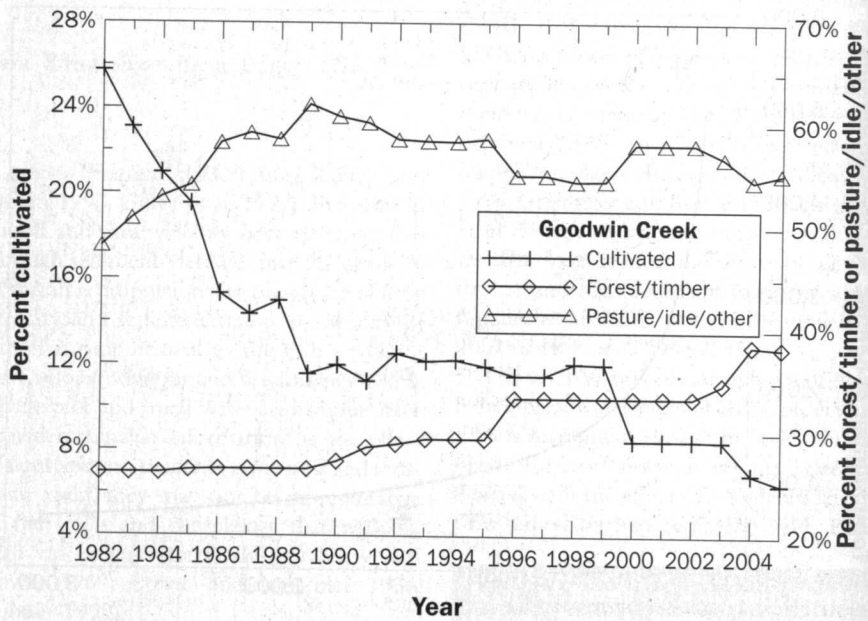
Watershed Monitoring Infrastructure. Supercritical flow flumes were constructed at the outlet of each subbasin (figure 1, numbered locations) in 1978 and 1979 (Blackmarr 1995; Bingner 1998). The structures were patterned after similar supercritical flow structures installed in the USDA Agricultural Research Service Walnut Gulch watershed (Smith et al. 1982; Nichols et al. 2004) and serve as combination grade control, flow measurement, and sediment measurement stations (Willis et al. 1986). The flumes were designed to maintain supercritical flows across a wide range of flows to ensure that sediment was not deposited on the structure bottom (Smith et al. 1982). The structures have a longitudinal slope of 0.04 and were constructed of reinforced concrete supported on sheet piling. The smaller flumes at stations 4 to 9

Figure 3
Goodwin Creek Experimental Watershed mean monthly rainfall at 31 gauges for period 1982 to 2002 (gray bars).



Notes: Mean annual precipitation is 1,358 mm. Mean monthly runoff to precipitation ratio at station 1 for period 1982 to 2002 (black bars).

Figure 4
Changes of land use with time on the Goodwin Creek Experimental Watershed.



and 11 to 14 (figure 1) are "V" shaped with slopes of 0.5. The larger flumes at stations 1, 2, and 3 have "V" shapes with compound slopes of 0.2 on the bottom width of 9.14 m (30.0 ft), and slopes of 0.5 on the higher part of the structure (Bowie and Sansom 1986; Blackmarr 1995).

Samples of sediment in transport were collected during runoff events in the supercritical flow flumes when the flow depth in the structure was above 0.3 m (1 ft). Sediment data collected at station 1 (figure 1) are the focus of this study. Three different techniques were used to sample the fines (<0.062 mm [<0.00244 in] in diameter), the sand (0.062 to 2.0 mm [0.00244 to 0.079 in] in diameter), and the gravel (>2.0 mm). This separation in sampling techniques is necessary because of the different sources and processes involved in the transport of these three sizes of sediment. The fines have been found to be well-mixed throughout the channel cross-section (Kuhnle et al. 2000), which allows them to be sampled automatically from a point within the supercritical flow flumes using automatic pump samplers. Sands and gravels have been found to have patchy and variable distributions across the supercritical flow flumes and thus required several samples across the structures to yield a representative mean concentration for a given flow rate (Willis et al. 1986; Kuhnle 1992; Kuhnle et al. 1996). The collection of representative samples of sands and gravels required watershed personnel to be on site to manually operate samplers during runoff events (Blackmarr 1995; Kuhnle et al. 2000).

Spatial distribution of rainfall on the GCEW is measured using a network of 31 rain gauges distributed over the watershed area (figure 1). Rain gauges are co-located with each supercritical flow flume except at stations 4 and 9, and at 19 other sites throughout the watershed. Air temperature probes have been installed at gauging stations 2, 3, 12, and at the climatological data station (station 50, figure 1). Water temperature is also measured at three gauging stations.

Ground surveys of land use have been conducted by USDA Agricultural Research Service watershed staff every year on the GCEW from 1982 to the present (Blackmarr 1995). These surveys have indicated that cultivated land on Goodwin Creek decreased from 26% to 12% from 1982 to 1989. This was followed by a period from 1990 to 1999 where the percentage of cultivated land was stable at about 12%. After this period the amount of cultivated land decreased to about 8% (figure 4).

Evaluation of Conservation Reserve Program Status. One conservation practice that has had a significant effect on the watershed has been the removal of highly erodible land from crop production using the CRP. This program is overseen by the USDA Farm Service Agency and has eligibility requirements for croplands such that one of the following must be met: have a weighted average erosion index of 8 or higher, be an expiring CRP acreage, or be located in a national or state CRP conservation priority area. To assess the potential eligibility of the cropland on Goodwin Creek for the CRP, the erosion index (*EI*) representative of the cropland on Goodwin Creek was calculated (RUSLE v. 1.05, Renard et al. 1997):

$$EI = \frac{A}{T}, \qquad (1)$$

where T is the tolerable soil loss rate assumed equal to the average value of 8.3 t ha^{-1} y^{-1} (3.7 tn ac^{-1} yr^{-1}) for the Loring-Grenada-Memphis soil association (Soil Conservation Service 1963), which covers approximately 80% of the GCEW, and A is the average annual soil loss per unit area (t ha^{-1} y^{-1}):

$$A = RKLSCP, \qquad (2)$$

where R is the rainfall-runoff erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the cover management factor, and P is the support practice factor. Representative values of variables in equation 2 for GCEW are as follows (Foster et al. 1981; Renard et al. 1997):

$$R = 5960;\ K = 0.059;\ C = 1;\ P = 1, \qquad (3)$$

where the units of R are MJ mm (ha h y)$^{-1}$ and for K are t ha h (ha MJ mm)$^{-1}$. The value of K was determined from the average of published values for the Loring-Grenada-Memphis soil association (Soil Conservation Service 1963). The variables C and P are set equal to unity to indicate that no conservation measures are assumed. This leaves the value of LS in equation 2. Calculated values of LS for the areas of the GCEW with the Loring-Grenada-Memphis soil association yield a weighted average value of 0.71 using topographic analysis techniques (Binger and Theurer 2001), which is significantly greater than the 0.19 value which yields values of erosion index greater than 8. Thus, most lands away from the valley bottoms on the GCEW would be considered highly erodible and eligible for the CRP. The cultivated fields located in the valley bottoms of the watershed have gentle slopes and may have values of LS less than 0.19. However, the close proximitry of these fields to streams indicates they are in a conservation priority area and would be eligible for CRP status. Therefore, it is a reasonable assumption that nearly all of the cropland on the GCEW would be eligible to become part of the CRP. According to the USDA Natural Resources Conservation Service, actual CRP lands on the watershed in the period 1987 to 2002 covered 104 ha (257 ac) or 5% of the watershed area. To evaluate the effect of removing potentially erodible land from production using the CRP, the assumption was made that all of the land that was removed from cultivation between 1982 and 2002 was in a CRP-like state. This assumption was supported by observations from annual land use surveys and from aerial photos.

Definition of Land Use Year. To facilitate the comparisons between runoff, sediment loadings, and land use changes, land use years were defined from April 1 to March 31 of the next year. April 1 closely corresponds with the start of agricultural practices for the year in this area. The land use year was divided into three four-month periods, which represent soil preparation and planting (April to July), tilling and harvesting (August to November), and minimal disturbance of the soil (December to March). These periods have been found to be useful to relate the runoff and sediment transport more directly to the effects of changing land use (Kuhnle et al. 1996).

Sediment Concentration. The GCEW is characterized by large annual variations in precipitation and runoff (figure 5). The two primary variables measured on the watershed are sediment concentration and flow depth in the supercritical flow structures, which are directly related to flow discharge. Therefore, to make effective comparisons of the sediment load from year to year, sediment concentration, rather than sediment mass was considered. The mean sediment concentration (C_{ma}, in parts per million by dry weight) was calculated as follows:

$$C_{ma} = \frac{Y_a}{R_a} \times 10^6 , \quad (4)$$

where Y_a is the total mass of sediment that moved past a given point in the channel over the time period, and R_a is the total mass of runoff during sediment transport events that moved past a given point measured for that period (Kuhnle et al. 1996). Total mass of fine sediment was calculated using flow data and concentrations from samples when available and a mean rating curve when samples were not available (Willis et al. 1986). Total mass of sand and gravel were calculated using flow data and relations between flow and transport rate generated from the collected samples of sand and gravel (Kuhnle et al. 1989; Kuhnle 1992; Willis 1991).

Results and Discussion

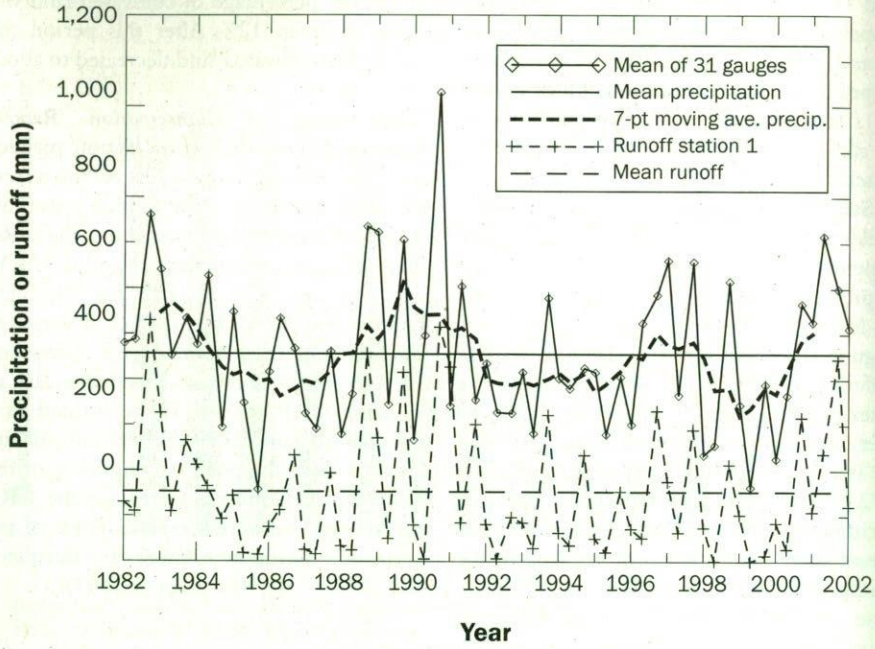
The period of record of GCEW shows evidence for three above average and three below average periods of precipitation and runoff that each encompass several years (figure 5). These cycles may have important effects on the rate of erosion and transport of sediment in the watershed, which will have implications for calibrating simulation models using data from specifiic precipitation periods. Sediment movement has been shown to be a steep nonlinear function of flow strength (Vanoni 1975; Kuhnle 1992; Yang 2003), and thus these cycles may confound correlations between management practices and sediment erosion and sediment yield on the watershed (Garbrecht 2006).

Runoff Versus Precipitation. The monthly ratio of runoff to precipitation is similar in shape to the average monthly rainfall (figure 3) and is reinforced by the seasonal variation in evapotranspiration. The relation of runoff versus precipitation was investigated for each four-month period of the land use year for the periods of 1982 to 1990 and 1992 to 2002. The first time period (1982 to 1990) is characterized by a nearly continuous decrease in the amount of cultivated land, while the second period (1992 to 2002) is characterized by a nearly constant amount of cultivated land (figure 4). Runoff at station 1 versus precipitation was found to be reasonably well described by linear relations (table 1). The only significant difference (F-test, $p = 0.05$) in slopes of the runoff versus precipitation relations for the two time periods was for the first period (April to July) of the land use year (figure 6). It is evident that the amount of runoff during April to July for a given amount of precipitation was less for precipitation amounts over about 400 mm (15.7 in) for the 1992 to 2002 period.

Sediment Load. The concentration of fine (<0.062 mm [<0.00244 in]) sediment decreased appreciably from 1982 to about 1991 as analyzed from data collected near the mouth of the watershed at station 1 (figure 7). The trend of sediment concentration for the time period 1982 to 1991 is expressed by a linear fit to the concentration values. For the period 1990 to 2002, a statistical test (t-test, 95% confidence level) provided no evidence that the slope of the fitted line was different from zero. The mean concentration for this time period is therefore represented as a horizontal line in figure 7. Concentrations of fine sediment have decreased by 62% (from about 3,000 to 1,000 parts per million by weight), and the concentration of total sediment has decreased by 63% from 1982 to 1991. This period of decreasing concentration has been followed by a period of no trend in sediment concentrations from 1991 to 2002. The trends in sediment concentration correspond closely with the decrease in cultivated land (figure 4) on the watershed.

Figure 5

Four-month periods of precipitation and stormflow runoff for station 1.



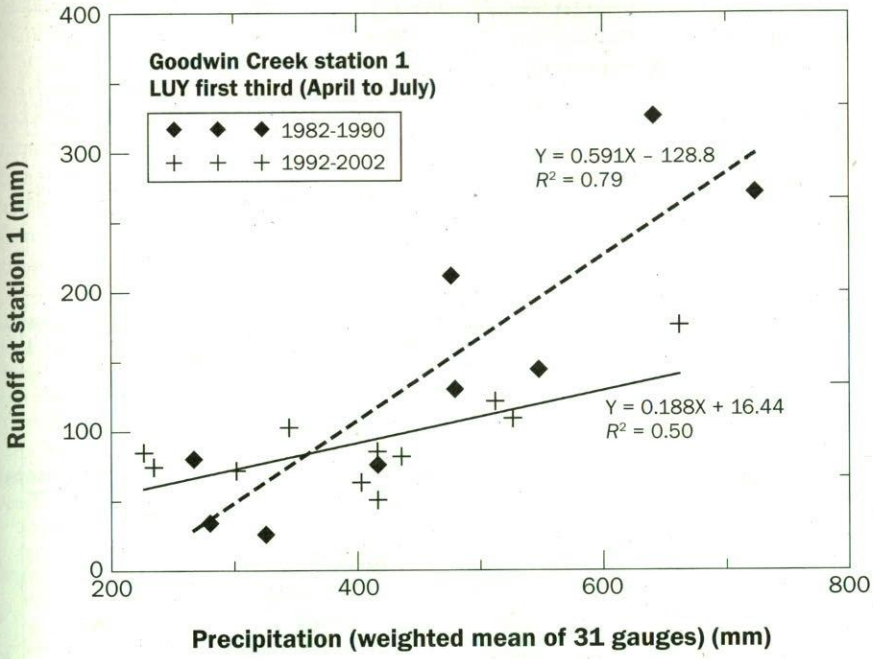
Note: Base flow values were not included in the runoff totals.

Table 1

Slope, intercepts, and correlation coefficients for linear relations between runoff and precipitation for station 1 for four-month periods.

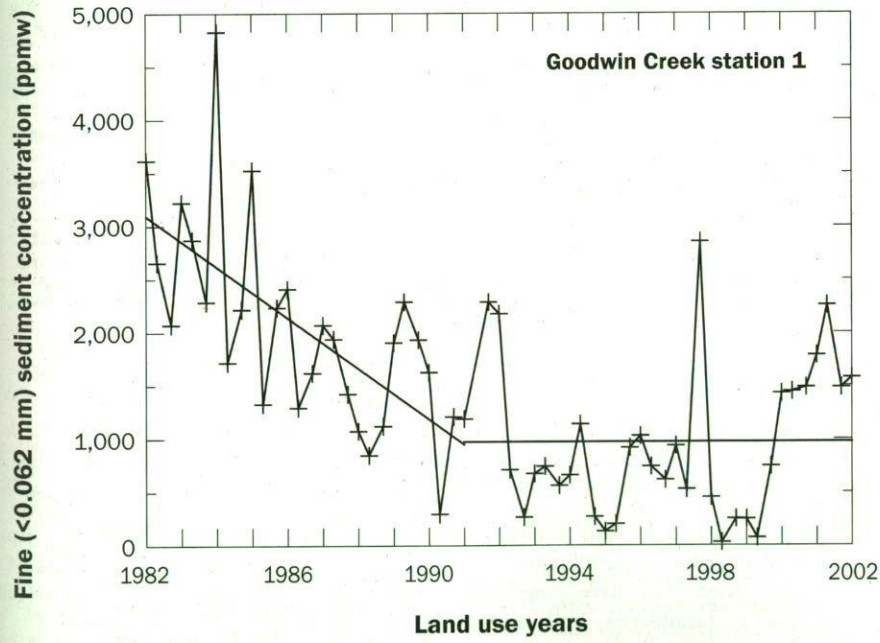
Years and land use period	Slope	y-intercept	r^2
1982 to 2002: April to July	0.427	-68.6	0.62
1982 to 2002: August to November	0.367	-92.2	0.69
1982 to 2002: December to March	0.672	-86.0	0.75
1982 to 1990: April to July	0.591	-128.8	0.79
1992 to 2002: April to July	0.188	16.44	0.50
1982 to 1990: August to November	0.409	-111.3	0.60
1992 to 2002: August to November	0.354	-86.4	0.74
1982 to 1990: December to March	0.672	-82.5	0.92
1992 to 2002: December to March	0.653	-79.7	0.41

Figure 6
Runoff versus precipitation relations for 1982 to 1990 and 1992 to 2002 for the period April to July of the land use year.



Note: Each point represents total precipitation and runoff for the four-month period.

Figure 7
Concentration of fine (>0.062 mm in diameter) sediment for Goodwin Creek station 1.



Note: Points were calculated from values derived from physical samples and from a concentration versus flow relation for periods when there were no samples.

The fraction of the total sediment load that consists of fines has remained nearly constant over the period of record (data not shown). Fine and sand concentrations have decreased by nearly two thirds, while concentrations of sand and gravel have decreased by 66% and 39%, respectively from 1982 to 1991 (table 2). Sand and gravel concentrations also have shown no trend from 1991 to 2002 (Kuhnle et al. 1996).

Sediment Sources Determination. Signatures of naturally occurring radionuclides, ^{7}Be and $^{210}Pb_{xs}$, have been used successfully to determine the proportion of fine sediments in the main channel near station 2 that originated from surface soils and channel banks. This determination is possible because the unique signatures of the surface soils and channel banks allows a two end member mixing model to be used to derive relative amounts of the two sources in the transported fine sediment in the channel near station 2. Collected data suggest that eroded surface soils are more abundant during the early parts of a runoff event, while collapsed bank sediment is the predominant source later in a runoff event (figure 8) (Wilson and Kuhnle 2006a, 2006b; Wilson et al. 2008). Use of radionuclides yielded a determination that 63% of fine sediment originated from channel sources. Nearly all of the sediment yield of sand and gravel was attributed to channel sources because overland and rill flows are generally not of sufficient strength to entrain sand and gravel (Meyer et al. 1983). Adding the fines from channel sources to the sand and gravel loads (table 2), which are assumed to be derived from channel sources, yields that 78% of the total sediment load was derived from channel sources. This result compared favorably to indirect methods from previous studies that yielded values of 75% and 85% (Grissinger et al. 1991) or 64% and 79% (Kuhnle et al. 1996) for the fraction of fine and total sediment load which originated from channel sources, respectively.

Effect of Channel Structures on Sediment Load. All precipiation, runoff, and sediment data collection on the GCEW began three to four years after the supercritical structures were constructed. Information from repeatedly surveyed cross-sections (Bingner 1998) indicated that the majority of the changes to the elevation of the beds of the channel system resulting from the construction of the structures were completed before the flow

and sediment data collection began. Lateral instability has continued after the construction of the structures, which accounts for an important source of sediment on the GCEW (Grissinger and Murphey 1982). For this reason, the measured data on the watershed will not give an indication of the effect of the structures on flow or sediment load before this time. The measured data, however, would be expected to provide an indication of the changes caused by land use on runoff and sediment yield.

Determinations on the effect of the supercritical flow structures, located at each of the gauging stations (figure 1), on flow and sediment yield were made by Bingner (1998). Simulations were conducted of the GCEW using the FRAME model in which the effect of the supercritical flow structures on the sediment yield was made for a period of ten years with and without structures. It was concluded that the structures had very little effect on runoff discharge (Bingner et al. 1996; Bingner 1998). However, flow stage changed by up to 1 m for the with versus without structures simulations. Simulations indicated that sediment yield without structures for the period 1982 to 1991 would have increased from 15% to 237% for total sediment and from 20% to 250% for fine sediment (table 3). The structures were found to have an increasing impact for channel reaches in the upstream parts of the watershed. Observations indicate that one of the most unstable reaches on the watershed is located upstream of station 8. Therefore, the high predicted increase appears to be reasonable.

Table 2

Percent of decreases and of sediment sizes of fines, sand, and gravel at Goodwin Creek station 1.

	Fines (<0.062 mm)	Sand (0.062 to 2.0 mm)	Gravel (>2.0 mm)
Percent of total load	59%	37%	4%
Percent reduction in concentration 1982–1990	62%	66%	39%

Figure 8

Fractions of land surface and bank sources of fine sediment in Goodwin Creek Main Channel near station 2 (from Wilson and Kuhnle 2006b).

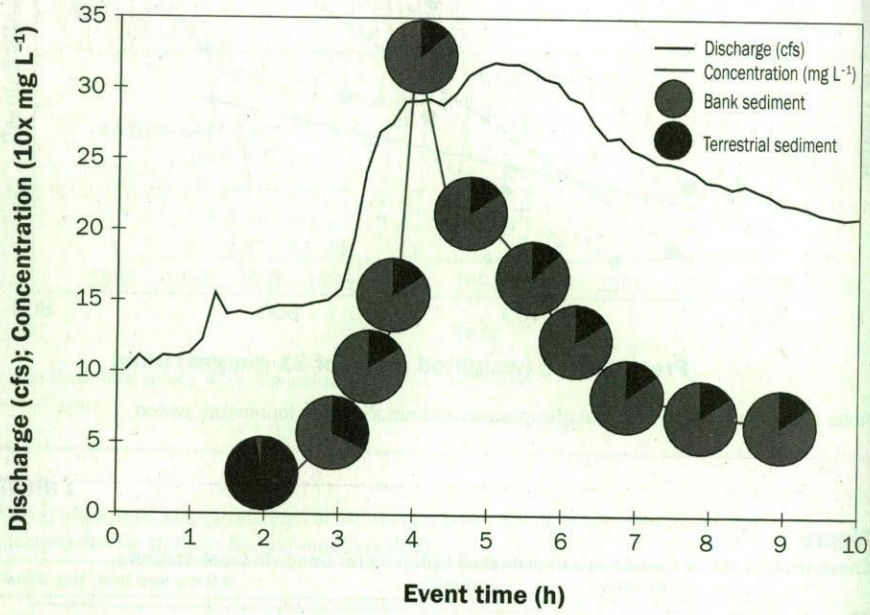


Table 3

Average annual sediment yield (SY) (t ha^{-1} y^{-1}) for with and without structures on main channel of Goodwin Creek Experimental Watershed for 1982 to 1991 period (after Bingner 1998).

	Measured	Simulated		Measured	Simulated	
Station	Total SY	With struture total SY	Without structure total SY	Fine SY	With structure fine SY	Without structure fine SY
1	14.5	15.7	18.1	10.7	9.8	11.8
2	12.4	15.5	20.9	8.1	9.7	12.9
3	14.7	11.6	16.6	7.5	7.5	10.2
5	–	12.5	22.2	8.8	7.3	12.9
8	–	10.9	36.7	9.5	5.2	18.2

Summary and Conclusions

Data collected on the GCEW represent hydrologic and sediment transport processes that typify the Bluff Hills region, a region of high energy rainfall and potentially erosive soils. Results using the signatures of naturally occurring radionuclides on the GCEW indicate that approximately three fourths of the sediment in the watershed originates from channel sources. The conversion of cropland into a CRP-like state has caused both erosion and runoff from fields to be reduced. This has led to a 63% decrease in the total sediment concentration from 1982 to 1990. The effectiveness of the change of crop land to a CRP-like state on the channel dominated erosion of the GCEW was caused not only by the decrease in sediment sources but also by the decrease of runoff from the land surface during the April to July period and the resultant reduction in channel erosion. For watersheds that have potentially erodible channel boundaries, both runoff and sediment production must be considered in evaluating the effect of a conservation practice on sediment load in the channels. Controlling sediment supply from the land surface without controlling runoff will greatly reduce the effectiveness of a management practice on the sediment concentration in the streams of a watershed.

The effect of the instream grade control structures on the watershed were evaluated using simulation results from the FRAME model. Results indicate that removal of

the structures would have caused sediment transport in the main channel of the watershed to have increased by 237% at an upstream location, just downstream of a highly unstable reach of channel, and by 15% at station 1 near the mouth of the watershed. The combined effect of the change of erodable land to CRP and construction of grade control structures was to decrease sediment load for a given flow by 78% near the outlet of the GCEW.

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