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STREAM BANK EROSION RATES OF SMALL MISSOURI STREAMS

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Abstract: Sedimentation of surface waters in the United States is a significant environmental concern. Investigating land use impacts on stream bank erosion rates is intended to lead to the development of improved management practices and provide the basis for targeting the placement of management practices to mitigate this problem. The overall objective of this research was to determine the effect of stream order, adjacent land use, and season on stream bank erosion rates. Study sites were established in 2007 and 2008 within Crooked and Otter Creek watersheds, two claypan watersheds located in northeast Missouri. Detailed site information was recorded, including eroded stream bank length, soil descriptions, gullies, debris dams, cattle access areas, and point bars. A factorial experimental design was implemented with four land uses (cropped, forest, pasture, and riparian forest) and three stream orders (1st, 2nd, 3rd). Each treatment was replicated three times for each stream order, except for the cropped 3rd order treatment as only one suitable treatment could be found. Erosion pins were installed based on bank height and length at each site to measure bank erosion/deposition rates. The effect of different seasons was assessed by measuring the length of the exposed pins three times per year (March, July, and November). Statistical analyses were performed to determine the effect of stream order, land use, and season on erosion rates. The results showed that the seasonal effect was highly significant, with much greater erosion rates in the winter of 2008 compared to the other seasons. Land use was significant when low magnitude deposition was observed and was not significant in any of the seasons in which erosion occurred.

Key Words: stream order, land use, claypan watersheds, erosion pins.

INTRODUCTION

Sedimentation is a significant environmental problem, with estimated mitigation costs of $16 billion annually in North American (Wynn and Mostaghimi 2006). Stream banks contribute substantially to stream sediment (Zaimes et al. 2006; Piercy and Wynn 2008; Fox et al. 2007). Simon et al. (1996) reported that stream bank erosion accounted for up to 80% of the in-stream sedimentation in watersheds of the loess area of the Midwestern United States. Recent work utilizing stable isotopes has shown that stream bank erosion can account for the majority of suspended sediment present in streams during high flow conditions (Wilson et al. 2008). The impact of sediment on aquatic habitats and populations and the implications of soil loss on agricultural productivity have been widely recognized by state and federal conservation agencies as a major soil and water quality issue in agricultural watersheds (Wilson and Kuhnle 2006). As a result, the influences of various management practices have been extensively examined.

However, despite extensive research, a general consensus on which management practices are best for stabilizing banks and reducing sediment delivery has not emerged (Nerbonne and Vondrack 2001). In addition, because of the runoff-prone nature of claypan soils, it has been widely assumed that overland erosion from cropped fields is the primary source of sediment in the streams of claypan watersheds (Jamison et al. 1968). Therefore, no published information has been reported on stream bank erosion and its contribution to the sediment load in claypan watersheds.

As researchers and management specialists look to understand the causes and effects of these water quality issues, the need for further investigation is apparent. Investigating land use impacts on stream bank erosion rates is intended to lead to development of improved management practices and provide the basis for targeting the placement of “best management practices” (BMPs) within watersheds to mitigate stream bank erosion. The overall objectives of this study were to investigate the effects of adjacent land use, season, and stream order on stream bank erosion rates in two watersheds of the Central Claypan Region of northeastern Missouri. The results presented here include only 3rd order streams as data analysis of 1st and 2nd order streams has not been completed.

MATERIALS AND METHODS

To identify differences in stream bank erosion rates based on adjacent land use, study sites were established in Crook and Otter Creek watersheds, located in northeastern Missouri. The Crooked Creek watershed is 284 km^2 with 56% of the area used for cropland, followed by pasture (26.5%) and forest (14.5%). The Otter Creek watershed encompasses a 271 km^2 area, with 64.6% in cropland, 20.3% in pasture, and 12.6% in forest (Lerch et al. 2008). These watersheds were selected because they are representative of the intensively row-cropped claypan watersheds of Major Land Resource Area 113 (Central Claypan Region) (Lerch and Blanchard 2003; Lerch et al. 2008). A factorial experimental design was implemented to evaluate the effects of land use and season on stream bank erosion of 3rd order streams. Land use treatments included riparian forest, forest, pasture, and cropped. Data was collected three times annually. The three seasons were defined as follows: Season 1-December-March; Season 2-April-July; and Season 3–August-November. Four sets of seasonal measurements have been made since 2007. Each treatment was replicated three times with the exception of the riparian forest in the first season of measurement, during which time only a single site had been established. Additionally, one 3rd order crop site has been established so far but two other suitable treatment sites have not been located for the 3rd order crop treatment.

Site selection was based primarily on the continuous presence of a given land use treatment. All sites have a minimum of 400 m of continuous land use on both sides and had to be 3rd order based on the stream ordering system of the National Hydrography Dataset (Dewald and Roth 1998). To determine the amount of total eroded length, surveys were conducted using hand-held GPS units (Juno ST, Trimble Navigation Ltd, City, State, or Dell X51 with GlobalSat BC-337 Compact Flash GPS Receiver, Dell Computers Inc., Round Rock, TX) and Trac-Mate software (Farm Works Software, Version 12.16, CTN Data Services, Inc., Hamilton, IN) to measure distances between eroding and non-eroding sections along each bank. Eroding banks were identified based on criteria from the U.S. Department of Agriculture - Natural Resource

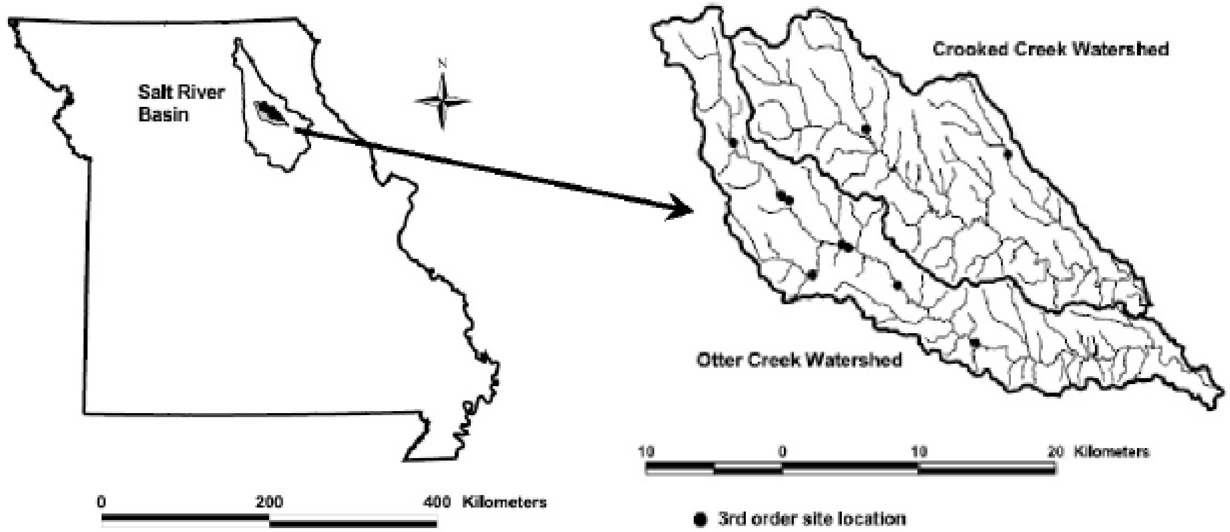

Figure 1. Third order stream site locations in Crooked and Otter Creek watersheds.

Conservation Service (USDA-NRCS) developed for calculating erosion and sediment delivery from visual inspection of stream banks and as used in previous stream bank erosion studies conducted by collaborating members from ISU (USDA-NRCS 1998; Zaimes et al. 2006). Banks identified as eroded possessed one or more of the following characteristics: 2/3 of the bank face devoid of vegetative growth or roots; less than 1/3 of bank face protected by roots; overhanging vegetation with eroded undercut face; near vertical slope; and apparent bank failures, such as slumps and slides.

After surveys were conducted, each 400-m reach was sub-divided into four 100-m sub-reaches. The total eroded length for each sub-reach was then calculated using the GPS data from the survey. Erosion pins made of rolled steel (76.2 cm long and 6.2 mm diameter) were then installed perpendicular to the bank face at each site to measure stream bank erosion. Pin plot placement was randomly assigned within each sub-reach, with pins installed in at least 20% of the eroded length in that sub-reach. Arrangement of pins was based on bank height. For banks of 1 m or less, pins were placed approximately at half bank height. For banks greater than 1 m but less than 2 m, pins were placed at 1/3rd and 2/3rd bank height. Three rows of pins were installed for banks over 2 m, with rows at 1/4, 1/2, and 3/4 bank height. Laterally, pins were spaced 2 m apart. An example of pin placement on a 3rd order stream is seen in Figure 2. Pins were inserted horizontally into eroded banks with 10.2 cm of 76.2 cm left exposed and spray painted to aid in locating the pins. Each pin arrangement was recorded and each pin plot was marked with a white stake and neon flagging to aid in location of pin plots during subsequent visits. A GPS coordinate was also obtained at each white stake in the event that the stake's location was altered between visits. Pin plots were installed beginning in late June through August 2007, with one site installation during November 2007. Each pin was measured for deposition or erosion three times annually by measuring the length of the exposed pin. Bank area of each pin plot was computed based on height and length measurements. To date, four sets of seasonal data were collected: Season 3–2007; Season 1–2008; Season 2–2008; and Season 3–2008.

Figure 2. Pin arrangement on 3rd order stream. Banks are approximately 2.5m high.

Bulk density samples were taken over the course of the summer and fall 2008. Fifty percent, or a minimum of three, of the plots at each site were sampled. Bulk density cores were taken from each major soil horizon. Soil profile descriptions were recorded for each horizon from which a corresponding bulk density sample was collected. Horizon descriptions included general soil color, texture, structure, and horizon depth. Bulk density samples were dried in an oven at 110ºC for a minimum of 3 days, brought to room temperature in a desiccator, and weighed. Bulk densities were computed on a depth-weighted basis for each pin plot, and then averaged over the number of plots sampled to obtain a depth-weighted average for each site

Following computation of the net pin length for a given seasonal data set, the mass of eroded or deposited bank sediment was computed based on the average net pin length (m) for an entire pin plot multiplied by the plot area (m^2) and average site bulk density (kg m^{-3}). This mass (kg) was then divided by the pin plot length (m) to give a linear erosion rate (kg m^{-1}) for each pin plot. The average linear erosion rates of the pin plots were then multiplied by the total eroded length (m) of each site (based on the initial GPS surveys described above), giving the total mass (kg) of eroded or deposited sediment for the site. The linear erosion or deposition rate of each site was then computed by dividing the total eroded or deposited mass for a site by 800 m (400-m reach with two banks per reach) to give the final linear erosion or deposition rate (kg m^{-1}) on a stream reach basis for each treatment.

Statistical analysis included a two-way analysis of variance (ANOVA) to determine the significance of the two main effects (season and land use), and their interaction, on erosion rates. Because the seasonal effect in the two-way ANOVA was significant (based on $\alpha = 0.10$), a one-way ANOVA was performed to determine the effect of land use, within each of the four seasons, on stream bank erosion rates for 3rd order streams. Missing values for the riparian treatment sites in Season 3 - 2007 were replaced with zeros in the two-way ANOVA and were left as missing in one-way ANOVAs. The substitution of zero for the missing values in the two-way ANOVA did not change the conclusion from this analysis. Data from the crop site was not included in analysis but the data is included in tables and graphs for comparative purposes. For any significant ANOVA, the F-protected least significant difference value (F-LSD) was calculated at $\alpha = 0.05$ level of significance. This level of significance was greater than the p-value of the significant ANOVAs. The F-LSD for the season 3-2007 land use data was calculated using the ANOVA preformed with missing values in the riparian treatment but assuming the same number of replications for each treatment.

RESULTS AND DISCUSSION

The seasonal effect on stream bank erosion rates was found to be highly significant for the study period ($p<0.0001$). Seasonal means across land uses are reported in Table 1. Inspection of the graph (Figure 3) reveals that the erosion rates in Season 1-2008, which represent the erosion that occurred from December 2007 through March 2008, greatly exceeded those in other seasons. Season 1-2008 had significantly greater average erosion rates (130 kg m^{-1}) than any other season measured. Season 2-2008 (9.86 kg m^{-1}) and 3-2008 (10.3 kg m^{-1}) had moderate to low levels of erosion, while Season 3-2007 (-5.43 kg m^{-1}) showed low levels of deposition for all land uses.

Table 1. Summary of mean erosion rates (kg m^{-1}) by season and land use.

Land-Use	Season				Land-Use Mean	Between Season F-LSD
	3-2007	1-2008	2-2008	3-2008		
Forest	-3.78	33.2	13.6	9.32	13.1	—
Pasture	-12.0	171	6.23	5.91	42.8	—
Riparian Forest	-0.51	184	9.74	15.7	52.3	—
Seasonal Mean	-5.43	130	9.86	10.3	36.1	44.0
Within Season F-LSD	5.71	—	—	—	—	
Crop*	4.32	198	56.2	-10.3	62.1	—

*Not included in ANOVA tests

The effects of season on stream bank erosion rates found in this study were consistent with past findings. Wolman (1959) observed the highest erosion rates during the winter months (December-March) and lower erosion rates in the summer. Zaimes et al. (2006) report similar results with the largest magnitude erosion occurring in the spring and early summer and little erosion occurring in the fall. Wolman (1959) attributed some winter erosion to freeze thaw mechanisms but concluded that winter erosion was largely a result of high flow events occurring when the bank materials were already “thoroughly wetted.” Flow events in summer months occurred when bank materials were dry and therefore did not produce erosion rates that were as large as those seen in the winter. Even when summer flow events greatly exceeded those occurring in the winter the resulting erosion was less (Wolman, 1959). Furthermore, a study by Hooke (1979) revealed that while soil moisture was the most important factor controlling stream bank erosion, significant erosion only occurred in association with peak discharge. Zaimes et al. (2006) identified precipitation pattern as a major factor contributing to the seasonal effect on bank erosion, finding the most erosion occurred following many medium sized precipitation events or two large precipitation events that occurred close together. This pattern fits that described by Wolman (1959), where banks become “thoroughly wetted” during the first precipitation event and then were eroded during subsequent precipitation events.

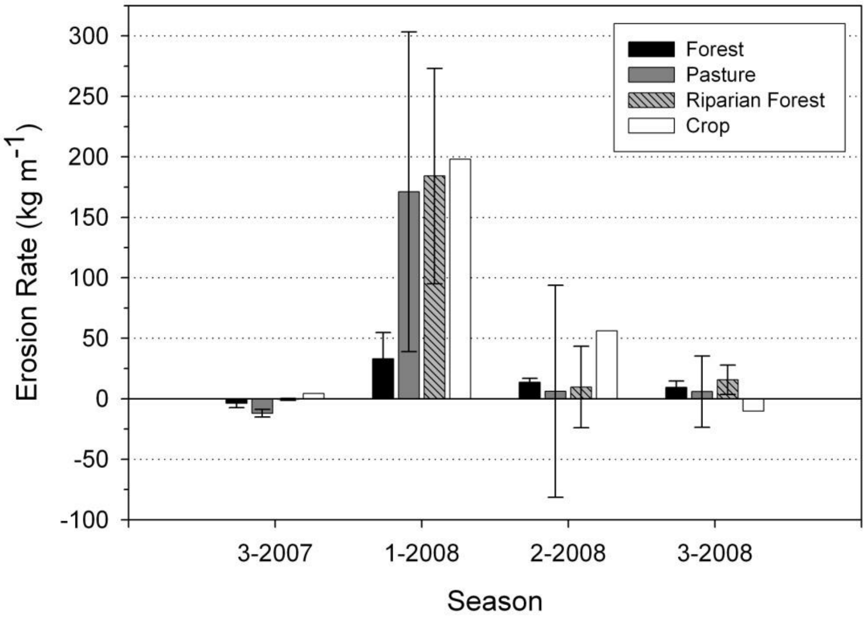

Figure 3. Mean erosion rate for each land-use during each season measured.

Considering the erosion data in light of the discharge data for Crook Creek (U.S. Geological Survey, 2009) (figure 4) reveals an extreme example of the Wolman pattern, where many moderate-sized events in February and March 2008 produced considerably more erosion than that caused by the numerous runoff events which occurred from April through September 2008. Moreover, not only were the runoff events closely spaced during this time, occurring at almost weekly intervals, three events were also of much greater magnitude than any of the erosive events that occurred during the winter of 2008. The high frequency of summer events suggested that wet bank conditions would persist through Seasons 2 and 3 of 2008, and the disparity between seasonal erosion rates was therefore not entirely explained by the Wolman pattern. Zaimes et al. (2006) attributed additional seasonal differences in erosion rates to differences in vegetative cover density. They reasoned that lack of vegetation in the winter leaves banks completely exposed and vulnerable to scour, while lack of evapotranspiration prevents banks from drying. This combination maintains saturated conditions and weak cohesion of bank material, resulting in a high degree of vulnerability to erosion during the winter months. In contrast, dense vegetative cover in the summer months protects banks from scour and evapotranspiration dries bank material, mitigating the erosive effects of an exceptionally wet year that had multiple sequential flow events.

Land use was a much less important factor to stream bank erosion than the observed seasonal effect. Averaged across all seasons, the erosion rate was 13.1 kg m^{-1} for forest, 42.8 kg m^{-1} for pasture, 52.3 kg m^{-1} for riparian forest, and 96.3 kg m^{-1} for crop (Table 1). The two-way ANOVA testing the effect of season and land use on stream bank erosion rates showed that the erosion rates for different land uses were not significantly different (p=0.21). This may be explained, in part, by the overwhelming importance of season on stream bank erosion processes which may mask land use effects within a given season. The results of the one-way ANOVAs

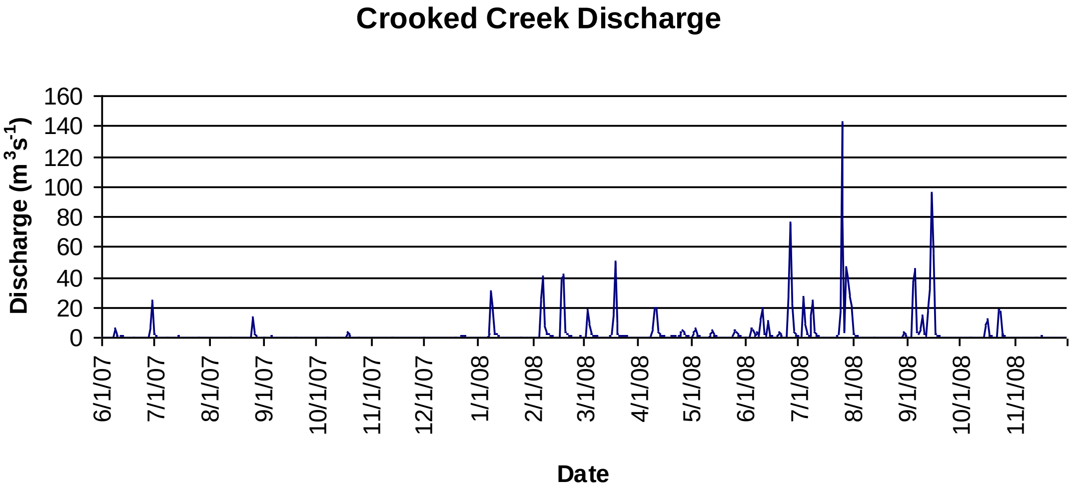

Figure 4. Average Daily Discharge of Crooked Creek from June 2007 to Dec 2008.

showed that erosion rates for the different land use treatments were significantly different only during Season 3-2007 (p=0.06). Subsequent seasonal measurements did not show any statistical difference between the erosion rates for the different land use treatments. These results are partly explained by the highly variable erosion rates that were measured among and within treatments, which made the variance extremely high, making it difficult to discern differences in land use treatment. Comparison of treatment means within Season 3-2007 using the F-LSD test showed the deposition rate was significantly greater in pasture than in forest or riparian forest. Erosion rates in forest and riparian forest were not statistically different.

While this study showed significant differences between land use only under depositional conditions, past studies have also found significant differences between land use treatments under eroding conditions. Zaimes et al. (2004) found second order streams flanked by row-crop and pasture fields experienced higher erosion rates than those with adjacent riparian forest buffers. The presence of cattle negatively affects the ability of plant roots to hold soil and trampling on and along banks causes destabilization (Belsky et al., 1999). Pasture sites have been observed by the authors to be prone to slumping because of cattle access to the streams. Furthermore, pasture sites had few trees, and they were generally not large trees that impart stability to the stream banks. Destabilized bank material may be a sediment source during depositional conditions at pasture sites, which provides a possible explanation for the land use effects between the treatment sites in Season 3-2007. Another possible sediment source at the pasture sites was overland erosion. If overland erosion rates were greater at the pasture sites compared to the riparian forest and forest sites, then deposition of this material during low and moderate intensity runoff events could also explain the higher deposition rates of the pasture sites. In addition, sediment transported from upstream sources may also be deposited once reaching larger 3rd order streams. However, at the 3rd order scale, the effects of upstream sediment sources should be similar across the land use treatments as the upstream land use at all sites would be dominated by cropland. Stream data from 1st and 2nd order streams may also provide insight to the impacts of upstream sediment sources as specific land use effects can more easily be isolated at these smaller scales.

CONCLUSIONS

The results of this study to date point to season as the most important factor controlling stream bank erosion rates. Erosion rates were highest for Season 1-2008 (winter months) and lowest during the summer and fall, despite frequent and high-magnitude runoff events in 2008. Land use was significant only in Season 3-2007 (August-November), when conditions resulted in net deposition across all land use treatments. Under erosive conditions, treatment differences were masked by the highly variable erosion rates within and between treatments. These results show the highly variable nature of stream bank erosion in these landscapes and bring to light the difficulty in management.

Unfortunately, seasonal weather patterns cannot be controlled, and managers must look for other ways to control stream bank processes; our preliminary results suggest that cattle access to streams can destabilize banks and provide a source of sediment to streams adjacent to this land use. Targeting the placement of BMPs may best be accomplished using in-stream assessment tools that identify eroding reaches on a site-by-site basis. For instance, the Rapid Assessment of Stream Conditions Along Length (RASCAL) survey, an in-stream GPS-based assessment tool, has been used by the Department of Natural Resources to identify stream properties such as riparian zone cover, livestock access points, bank stability, etc. for the placement of BMPs (Kiel 2008). Analysis of our complete data set to include 1st and 2nd order stream treatments may further highlight land use effects and offer more insight into targeting of practices to mitigate stream bank erosion.

LITERATURE CITED

Belsky, A.J., Matzke, A., Uselman, S., 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54(3): 419-431.

Dewald, T. G., Roth, K.S. 1998. The National Hydrography Dataset - Integrating the USEPA Reach File and USGS DLG , In: Conference Proceedings: 1998 ESRI User Conference, Environmental Systems Research Institute, Redlands, CA.

Fox, G.A., Wilson, G.V., Simon, A., Langendon, E.J., Akay, O., Fuchs, J.W., 2007. Measuring stream bank erosion due to groundwater seepage: correlation to bank pore water pressure, precipitation, and stream stage. Earth Surface Processes and Landforms 32: 1558-1573.

Hooke, J.M., 1979. An analysis of the processes of river bank erosion. Journal of Hydrology 42: 39-42.

Jamison, C.V., Smith, D.D., Thornton, J.F., 1968. Soil and water research on a claypan soil. USDA-ARS Technical Bulletin NO. 1379. pp. 111.

Kiel, A., 2008. Methods to measure success: assessment tools. The Heartland Water Quality Coordination Initiative's Nutrient and Pesticide Management Team Roundtable, Nebraska City, NE. January 2008. Online: http://www.oznet.ksu.edu/waterquality/Impacts_RT.htm. accessed: March 2, 2008.

Lerch, R.N., Blanchard, P.E., 2003. Watershed vulnerability to herbicide transport in Northern Missouri and Southern Iowa streams. Environmental Science and Technology 37: 5518-5527.

Lerch, R.N, Sadler, E.J., Kitchen, N.R., Sudduth, K.A., Kremer, R.J., Meyers, D.B., Baffaut, C., Anderson, S.H., Lin, C., 2008. Overview of the Mark Twain/Salt River basin conservation effects assessment project. Journal of Soil and Water Conservation 63(6): 345-359.

Nerbonne, B.A., Vondrack, B., 2001. Effects of local land use on the physical habitat, benthic macroinvertebrates, and fish in the Whitewater River, Minnesota, USA. Environmental Management 28(1): 87-99.

Piercy, C., Wynn, T., 2008. Predicting root density in streambanks. Journal of American Water Resources Association 44(2): 469-508.

Simon, A., Rinaldi, M., Hadish, G., 1996. Channel evolution in the loess area of the Midwestern United States. Proceedings, Sixth Federal Interagency Sedimentation Conference, Las Vegas, March 10–14. pp. III-86–III-93.

U.S. Department of Agriculture, Natural Resources Conservation Services, 1998. Erosion and Sediment Delivery. Field Office Technical Guide Notice Number. IA-198, U.S. Department of Agriculture and Natural Resource Conservation Service, Des Moines, Iowa, pp. 13.

U.S. Geological Survey, 2009. Crooked Creek near Paris, MO daily discharge data June 2007 to February 2009. Online: http://waterdata.usgs.gov/nwis/uv?05503800. accessed: February 19, 2009.

Wilson, C.G., Kuhnle, R.A. 2006. Determining Relative Contributions of Eroded Landscape Sediment to the Suspended Load of Goodwin Creek Using ^{7}Be and ^{210}PbXS. USDA-ARS National Sedimentation Laboratory Research Report. No. 53. pp. 34.

Wilson, C.G., Kuhnle, R.A., Bosch, D.D., Steiner, J.L., Starks, P.J., Tomer, M.D., Wilson, G.V., 2008. Quantifying relative contributions from sediment sources in Conservation Effects Assessment Project watersheds. Journal of Soil and Water Conservation 63(6): 523-532.

Wolman, M.G., 1959. Factors influencing erosion of a cohesive river bank. American Journal of Science. 257:204-216.

Wynn, T., Mostaghimi, S., 2006. The effects of vegetation and soil type on stream bank erosion, Southwestern, Virginia, USA. Journal of American Water Resources Association 42(1): 1085-1101.

Zaimes, G.N., Schultz, R.C., Isenhart, T.M., 2004. Stream bank erosion adjacent to riparian forest buffers, row-crop fields, and continuously-grazed pastures along Bear Creek in central Iowa. Journal of Soil and Water Conservation 59(1): 19-27.

Zaimes, G.N., Schultz, R.C., Isenhart, T.M., 2006. Riparian uses and precipitation influences on stream bank erosion in central Iowa. Journal of American Water Resources Association 42(1):83-97.