2013

Stream Bank Erosion in Grazed Pasture Stream Reaches of Southern Iowa, USA

Mustafa Tufekcioglu
Artvin Coruh University

Richard C. Schultz
Iowa State University, rschultz@iastate.edu

Thomas M. Isenhart
Iowa State University, isenhart@iastate.edu

James R. Russell
Iowa State University, jrussell@iastate.edu

John L. Kovar
United States Department of Agriculture

Stream Bank Erosion in Grazed Pasture Stream Reaches of Southern Iowa, USA

Abstract
Stream bank erosion in agricultural landscapes is a major pathway for non-point source sediment and phosphorus loading of receiving waters. The objective of this study was to assess the relationship between the numbers of high stream stage events, as they directly reflect higher erosive stream flow, and contribute to stream bank soil erosion. The erosion pin method was utilized to measure the change in stream bank erosion in response to differences in the number of high stream stage events, which were monitored by pressure transducers. The measured seasonal (summer and fall) erosion rates were correlated with stream stage data to assess their impact on stream bank erosion. Approximately 75% of the variability in stream bank erosion was found to be directly linked to the higher/erosive stream flow.

Keywords
streambank erosion, stage-erosion relationship, grazing pasture system

Disciplines
Hydrology | Natural Resources Management and Policy

Comments
This proceeding is from the *International Caucasian Forestry Symposium* (2013): 529.

Stream Bank Erosion in Grazed Pasture Stream Reaches of Southern Iowa, USA

Mustafa Tufekcioglu[1], Richard C. Schultz[2], Thomas M. Isenhart[3], James R. Russell[4], and John L. Kovar[5]

[1]Assist. Prof., Faculty of Forestry, Artvin Coruh University, Artvin, Turkey; [2]Prof., and [3]Assoc. Prof., Department of Natural Resource Ecology and Management, Iowa State University, Ames, Iowa 50011, USA; [4]Prof., Department of Animal Science, Iowa State University, Ames, Iowa 50011, USA; [5]Soil Scientist at National Laboratory for Agriculture and Environment, Soil Tilth, USDA-ARS, Ames, Iowa 50011, USA.
E-Mail: mtufekcioglu61@gmail.com

Abstract:

Stream bank erosion in agricultural landscapes is a major pathway for non-point source sediment and phosphorus loading of receiving waters. The objective of this study was to assess the relationship between the numbers of high stream stage events, as they directly reflect higher erosive stream flow, and contribute to stream bank soil erosion. The erosion pin method was utilized to measure the change in stream bank erosion in response to differences in the number of high stream stage events, which were monitored by pressure transducers. The measured seasonal (summer and fall) erosion rates were correlated with stream stage data to assess their impact on stream bank erosion. Approximately 75% of the variability in stream bank erosion was found to be directly linked to the higher/erosive stream flow.

Key terms: streambank erosion, stage-erosion relationship, grazing pasture system

Introduction:

The most common water quality problem in the United States is non-point source (NPS) pollution. Among these pollutants, sediment accounts for 47% of the total (United States Environmental Protection Agency, 1997). Increased sediment load can create many negative impacts in a stream. It can decrease water quality and result in the deterioration of aquatic life (Iowa Department of Natural Resources, 1997). Gully and stream banks are major contributors of NPS sediment and phosphorus (Zaimes et al., 2004). Bank erosion can contribute significant amounts of sediment to fluvial systems accounting for more than 50% of a catchment's sediment export (Laubel et al., 1999; 2003). Row crop cultivation and grazing are the most widely recognized agricultural practices (Striffler et al., 1964). Both land-use practices can contribute high amounts of phosphorus and sediment to surface waters (Zaimes and Schultz, 2002). The quantification of sediment and phosphorus loss from agricultural landscapes is essential to develop practices that maintain both sustainability of agricultural practices and ecological integrity (Dinnes et al., 2001). The effects of land use change on stream flow and discharge, channel incision and form and ultimately on stream bank erosion have been well-documented by a number of other studies as well (Straub, 2004; Karwan et al., 2001; Wallbrink and Olley, 2004; Fitzpatrick, 2001). The objective of the study was to assess the relationship between stream bank erosion rates during summer and fall seasons and stream flow depths within several watersheds in Southern Iowa. The null hypothesis was that variability in stream bank erosion rates was not affected and/or correlated by the variation in stream stages.

Study sites and treatments:

Six cooperating beef cow-calf farms along stream reaches of the Rathbun Lake watershed in southern Iowa were selected to conduct the study. The Southern Iowa Drift Plain is dominated by many rills, gullies, stepped erosion surfaces, integrated drainage networks, creeks, and rivers created by long geologic weathering processes (Prior, 1991). In this region, stream bank erosion takes place in glacial materials deposited about 500, 000 years ago. The major riparian soil association in the Rathbun watershed is the Olmitz-Vesser-

Cola Association (USDA Soil Survey, 1971). These soils are identified as loam, silt loam, and silt clay loam, respectively. The soils in this complex are moderately well drained to poorly drained. Land-use within the 143,323 hectares of the Rathbun Watershed consisted of 38% pasture and hayland, 30% crop land, 12% CRP, 13% woodland and 7% urban/road/water (Braster et al., 2001).

Riparian grazing treatments were classified by stocking rates which ranged from 3 to 19 cow-days $m^{-1}yr^{-1}$. Cow-days per stream length were calculated as the product of the number of cows and number of days they were on the pasture divided by stream length. Out of the six, stream reaches for four sites (site 2, site 3, site 4 and site 5) were classified as first –order streams (Strahler, 1957; & Table 1) and the other two sites were located on second (site 1) and third order streams (site 6).

Table 1. Studied pasture stream reach (site) characteristics including pasture size, bank height, stocking rates, stream reach bed slope, stream bed sinuosity, catchment size and total erosion rate.

Site Id	Pasture size (ha)	Bank height (m)	Stream bed slope (%)	Stream sinuosity	Catchment size (ha)	Total erosion rates (cm)
Site 1	55	1.5	0.4	1.5	2,007	0.5
Site 2	29	1.2	0.8	1.4	393	3
Site 3	107	1.1	0.6	2.0	472	4
Site 4	25	1.0	1.6	1.1	709	9
Site 5	3	1.6	1.6	1.3	579	37
Site 6	29	2.9	1.5	1.2	5,660	40

Note: The total erosion rates represent the sum of the erosion rates from fall 2007, summer 2008, fall 2008, summer 2009 and fall 2009.

Stream bank erosion pins:

The erosion pin method has been used to quantify sediment loss from bank erosion (Wolman, 1959). This method has been found to be practical for short time-scale studies needing high accuracy for measuring small changes in bank surfaces that may be subject to deposition or erosion (Lawler, 1993). After surveying the total length of severe and very severe eroded stream banks, fifteen percent of these bank lengths in each pasture were randomly selected for installation of erosion pins. The number of pin plots varied from 4 to 9 depending on the total length of eroded stream banks per pasture. Erosion pin plots had 2 rows of 6 to 34 pins, 1 m apart, at 1/3 and 2/3 of the stream bank height, resulting in 3 to 17 columns with pins directly above one another, depending on eroded length. When the bank height was less than 1 m only one pin row was installed. Pin dimensions of 762 mm long and 6.4 mm in diameter were used based on rates of up to 500 mm per erosion event observed in previous studies in this region (Zaimes et al., 2006). Pin installments took place in November 2006. Exposed pin lengths (cm) were measured during the winter/spring (last week of November through first week of May), summer (first week of May through first week of August) and fall (first week of August through last week of November) seasons of 2007, 2008 and 2009. For each measurement period, the previous measurement of the pins was subtracted from the most recent measurement. When the difference was positive, the exposed pin measurement represented erosion; if it was negative the pin measurement represented deposition. An erosion rate of 600 mm was assumed in the case where pins were lost during an erosion event. Seasonal erosion rates were correlated with stream stage to assess the relationship between stream bank erosion and stage. Since there was no stream stage data recorded during the winter/spring months, only summer and fall erosion data were correlated with the stream stage data.

Stream stage data:

Water table depth in the near riparian zone at each of six sites was recorded within monitoring wells installed approximately 0.5 – 1 m away from the stream bank edge. Sites were selected as having near-average stream bank height for a given stream reach with uniform stream cross-sections (Fig. 1). Soil borings were completed using a 152 mm diameter hand auger to a depth below the stream thalweg. A 1.5 m long factory-slotted PVC well screen and PVC riser were installed in the boreholes. A silica sand filter pack was poured around the screen, bentonite chips were added to provide a seal and drill cuttings were backfilled in the rest of the borehole. Each well was equipped with a pressure transducer (Level Troll 300 Pressure transducer, In-Situ, Inc.) to record hourly water level fluctuations from September 2007 to November 2009.

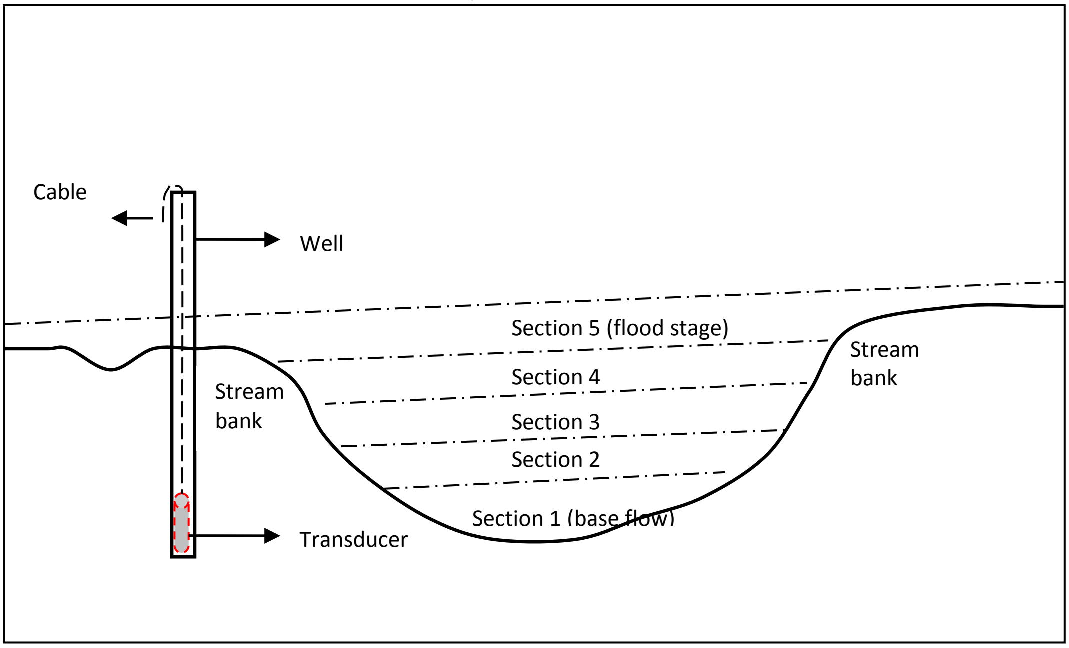

Figure 1. Location of the transducer on stream bank and five different preset stream stage sections and their predicted erosion response values (section 1= 0, section 2= 1, section 3 = 1, section 4= 1 and section 5= 1). The assigned/predicted erosion values for each section were based on the assumption that there is a linear relationship between stream bank erosion rate and stage. Note: since depth of flow within section 1 represents base flow condition, its effect on bank erosion was not accounted for in the relationship between stage and erosion rate.

Because of freezing concern, transducers were taken out of the wells during the winter/spring months (December through March). The total cross-sectional area of the stream was divided into four equal sections with respect to its vertical bank height and defined as section 1 (base flow), section 2, section 3, section 4 and section 5 (flood stage; Fig. 1). Stream stage data were classified into the number of times water reached each section and events were correlated with erosion rates in each season to determine if there was a relationship between bank erosion and stage. Since section 1 is the base flow condition where there is minimal erosive flow and/or no bank erosion, it was not included in the correlation analysis. Similar study by Larsen et al. (2006a) also removed lower stream discharge from the cumulative effective stream power, which improves the statistical relationship between bank erosion and stream power.

Data analysis:

The relationship between stream stage and stream bank erosion was examined using the mixed procedure within the Statistical Analysis Systems (SAS Institute, 2003). Change in stream stage (occupancy of the sections by stream flow in numbers of times) was used as an independent variable to explain the variation in the natural logarithm of stream bank erosion. The natural logarithm was used in place of the un-transformed stream bank erosion to achieve homogeneity in error variance. Site was included in the model, as a random effect, to account for the possible correlation between repeated measurements on the same site. A significance level of $p < 0.1$ was used since bank erosion is affected by many spatial, temporal, climatic and anthropogenic impacts. To assess the fit of our model to the data, we considered the correlation between the predictions from the model and the observed responses. This statistic has a similar interpretation to that of R^2 in linear models.

Result and discussion:

In this study there was a significant relationship between stream bank erosion rates and the frequency of high stream stages. While this study did not find a relationship between cattle stocking rate and stream bank erosion rate, it did find a significant relationship between stocking rates and eroding stream bank length. More detail regarding this relationship was presented in the companion study conducted on the same grazed pasture sites as well as ungrazed controls (Tufekcioglu et al., 2012) Such results highlight the complexity of the interactions between riparian land use, stream hydrology, and stream bank erosion.

Stream bank erosion rate and stream stage data:

Higher winter/spring average erosion rates were observed from the six sites, ranging from 11 to 26 cm, compared to ranges in the summer of 1-12 cm and in the fall of 1-6 cm. The differences in erosion rates between the winter/spring and both summer and fall seasons were large. This could be due to high moisture content of the stream bank soil during winter/spring season that also coincides with the increase in stream discharge or stage (Tufekcioglu et al., 2012).

There was a significant relationship between the frequency of high stream stage events and bank erosion for all four of the vertical stream bank sections; section 2 ($p= 0.04$; $R^2= 0.74$), section 3 ($p= 0.03$; $R^2= 0.75$), section 4 ($p= 0.09$; $R^2= 0.73$), flood section 5 ($p= 0.1$; $R^2= 0.73$), and the total cumulative stage (including section 2, 3, 4 and 5, except section 1) ($p= 0.03$; $R^2= 0.75$). The higher p values for sections 4 and 5 suggest a weaker relationship between erosion and the frequency of high stream stage, perhaps similar to the nonlinear relationship found by Larsen et al. (2006a). Since the total cumulative stage represents all sections from the cross-sectional area, it was used to examine the following relationships between stream stage and erosion rate for each individual site.

At site 1, the total number of high stream stage occupancy events from all the seasons and sections was 77 and the corresponding erosion rate was 0.5 cm. There was a highly correlated relationship between total stream stage occupancies and erosion rates across the seasons ($R^2= 0.99$). In site 2, total high stream stage occupancy was 63 and the corresponding erosion rate was 3 cm. This relationship between total stream stage occupancy and erosion rates was also highly correlated too ($R^2= 0.64$). Site 3 had the highest number of total stages of all sites (101), which was highly correlated to the observed erosion rate (4 cm; $R^2= 0.84$). At site 4, the total high stream stage occupancy was 83, which was highly correlated with the observed erosion rate of 9 cm, higher than site 3 ($R^2= 0.97$). At sites 5 and 6, total high stream stage occupancy were 71 and 55, respectively, and erosion rates were 37 and 40 cm, which were higher than sites 1- 4. Site 5 ($R^2= 0.19$) had lower correlation between total stream stage and erosion rates than site 6 ($R^2= 0.81$). By looking at the relationships from all the sites, approximately 75 % of the variability in bank erosion can directly be explained by the change in stream stage which in many ways incorporates differences among site characteristics such as stream bed and bank slope, bank height, and sinuosity. The remaining 25 % may be due to bank soil antecedent moisture prior to each rainfall event, differences in duration of the stage. In general, an increase in total high stream stage occupancy translates to an increase in bank erosion, but the intensity of this relationship is unique to each site. When looking at different sites from different watersheds, there were differences in stream morphologic characteristics (Table 1) even though they were on the same stream order class, which would affect the hydrology of the stream and its power to erode. For example, the magnitude of erosion in response to similar total high stream stage occupancy is larger in Sites 4, 5 and 6, where sinuosity was lower and streambed slope was higher (Table 1). As a result, we can conclude that although the relationships between stream stage and bank erosion were acting in a similar manner among the studied sites (R^2=0.75), the magnitudes of the erosion in each site were different due to individual site characteristics (bank height, stream bed slope and sinuosity).

In this study, change in stream hydrology or stream stage variation in response to precipitation was the major factor related to bank erosion rates. This relation suggested that best management practices at the watershed scale should be directed towards those practices that would reduce the frequency and magnitude of high stream stage. Such a decrease in the frequency and duration of high flows would likely reduce stream bank contribution to suspended and bedded sediment and P loads to receiving waters. Additionally, the strong relationship between high erosive stream power or stage and bank erosion rates can be further used to predict changes in channel migration pattern (Larsen et al., 2006b), channel slope, sinuosity and perhaps the time line to reach the equilibrium (reference) conditions, defined by Simon and Klimetz (2008) with respect to specific features of geology, climate and agricultural land use/cover for a given land form. The stability of the stream bank soil is controlled by two main anthropogenic factors. First is the adjacent land use such as row-crop, grazed pasture, grass filter and/or forest buffer. It has been well-documented that riparian areas with perennial vegetation cover and without livestock and machinery impacts have lower rates of stream bank erosion (Laubel et al., 1999, 2003; Zaimes et al., 2004, 2008). Mixed stands of riparian woody and grass species increase bank stability and soil strength by mechanically reinforcing soil (soil-root binding) and dewatering bank soil through increased evapotranspiration (Simon and Collison, 2002). Second is the change in stream flow characteristics (particularly rapidly rising flow peaks - steep rising limbs of the hydrograph with high peaks and duration) in response to long-term changes in amount and pattern of precipitation and land use/cover at the watershed scale.

Stream flow generation is strongly influenced by agricultural activities that alter native plant communities (Bormann at al., 1999). In many cases, these activities may cause increases in stream flow (Schultz et al., 2009). This increase is illustrated in a study by Novotny and Stefan (2007), who observed that regardless of the uncertainty of the specific dominant factors such as a rise in precipitation and/or change in the land use/cover, the overall number of days with higher stream flow/discharge was increased in five major river basins of Minnesota. Such changes likely increase the risk for stream bank erosion. Nanson and Hickin (1986) stated that sediment size and stream power, a product of discharge and channel slope, may be the major factors affecting bank erosion. Larsen et al. (2006a) found that cumulative effective stream power was significantly correlated with bank erosion ($R^2 > 0.70$), similar to the relationship between stream bank erosion and stream stage found in this study.

Conclusions:

Study results suggest that stream bank erosion rates across grazing pasture sites were highly correlated with the frequency of high stream stage events, but that the magnitude of the erosion among the studied stream reaches was different because of differences in stream morphologic characteristics (stream order, stream bed slope and sinuosity) and the intensity of the grazing practices on stream bank that influence the morphology of the banks. In conclusion, effective/erosive stream flows (mainly measured by stream stage that pass through stream bank sections 2 and 3 in this study), with greater number of events per year, are most likely to increase stream bank erosion rates at most and resulting more soil loss. Conservation practices that reduce these rates will be those that increase soil-water infiltration, reduce the frequency of high stream flow events, and increase bank stability through perennial vegetation cover or reducing disturbance within the riparian zone.

References

Bormann, H., B. Diekkruger, and M. Hauschild. 1999. Impact of landscape management on the hydrological behavior of small agricultural catchments. Physics and Chemistry of the Earth 24 (4): 291-296.

Braster, M., T. Jacobsen, V. Sitzmann. 2001. Assessment and Management Strategies for the Rathbun Lake Watershed. http://www.iowadnr.gov/Portals/idnr/uploads/water/watershed/files/rathbunwmp1.pdf Accessed on 10/22/2012.

Dinnes, Dana L., D. L. Karlen, D. B. Jaynes, T. C. Kaspar, J. L. Hatfield, T. S. Colvin, and C.A. Cambardella. 2001. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. American Society of Agronomy 94:153-171.

Fitzpatrick, F.A. 2001. Effects of land cover change, floods, and stream position on geomorphic processes- Implication for restoration activities. Proceedings of the 2001 Wetlands Engineering and River Restoration Conferences. 537-550.

Iowa Department of Natural Resources. 1997. Water quality in Iowa during 1994 and 1995. Iowa Department of Natural Resources, Environmental Protection Division, Water Resources Section. Des Moines, IA.

Karwan, D.L., J.D. Allan, K.M. Bergen. 2001. Changing near-stream land use and river channel morphology in the Venezuelan andes. J. Am. Water Resour. Assoc. 37 (6), 1579-1587.

Larsen, E.W., A.K. Fremier, S.E. Greco. 2006a. Cumulative effective stream power and bank erosion on the Sacramento River, California, USA. J. Am. Water Resour. Assoc. 42 (4), 1077-1097.

Larsen, E.W., E.H. Girvetz, A.K. Fremier. 2006b. Assessing the effects of alternative setback channel migration model. J. Environ. Manage. 37 (6), 880-897.

Laubel, A., B. Kronvang, A.B. Hald, C. Jensen. 2003. Hydromorphological and biological factors influencing sediment and phosphorus loss via bank erosion in small lowland rural streams in Denmark. Hydrol. Process. 17, 3443-3463.

Laubel, A., L. M. Svenden, B. Kronvang, and S. E. Larsen. 1999. Bank erosion in a Danish lowland stream system. Hydrobiologia 410:279-285.

Lawler, D.M., 1993. The measurement of river bank erosion and lateral channel change: A review. Earth, Surf. Proc. Land. 18 (9), 777-821.

Level Troll 300 Pressure transducer, In-Site Inc. Instrument for ground water, surface water, and industrial applications. http://www.in-situ.com/products/Water-Level/Level-TROLL-Family/Level-TROLL-300 Instrument.

Nanson, G.C., E.J. Hickin, 1986. A statistical analysis of bank erosion and channel migration in Western Canada. Geol. Soc. of Am. Bull. 97, 497-504.

Novotny, E.V., H.G. Stefan. 2007. Stream flow in Minnesota: Indicator of climate change. J. Hydrol. 334, 319-333.

Prior, J.C., 1991. Landforms of Iowa. Iowa Department of Natural Resources University of Iowa Press, Iowa City, Iowa.

SAS (Statistical Analysis System) Institute., 2003. SAS Release 9.1 ed. SAS Inst., Cary, North Carolina.

Schultz, R.C., T.M. Isenhart, J.P. Colletti, W.W. Simpkins, R.P. Udwatta, P.L. Schultz. 2009. Riparian and Upland Buffer Practices. Chapter 8, in: H.E. Garrett, (Ed.) North American Agroforestry: An integrated Science and Practice, 2nd Ed. American Society of Agronomy, Madison, WI.

Simon, A., A.J.C. Collison. 2002. Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. Earth Surf. Proc. Land. 27, 527-546.

Simon, A. and L. Klimetz. 2008. Relative magnitudes and sources of sediment in benchmark watersheds of the Conservation Effects Assessment Project. Journal of Soil and Water Conservation 63 (6), 504-522.

Strahler, A.N., 1957. Quantitative analysis of watershed geomorphology. Transaction of the American Geophysical Union. 38, 913-920.

Straub, T.D., 2004. St. Louis metro east region sediment and geomorphic study. Proceedings of the 2004 World Water and Environmetal Resources Congress: Critical Transitions in Water and Environmetal Resources Management. pp 4463-4474.

Striffler, W. D. 1964. Sediment, streamflow, and land use relationship in Northern Lower Michigan. United States Forest Service Professional Paper LS-16.St. Paul, MI

Tufekcioglu, M., M.T. Isenhart, R.C. Schultz, D.A. Bear, J.L. Kovar, and J.R. Russell. 2012.

Stream bank erosion as a source of sediment and phosphorus in grazed pastures of the Rathbun Lake Watershed in Southern Iowa, USA. J. of Soil Water Conserv. 67 (6), 545-555.

United State Department of Agriculture. Soil Conservation Service. Soil Survey. Wayne County, Iowa 1971.

United States Environmental Protection Agency. 1997. Nonpoint source pollution: the nation's largest water quality problem. Environmental Protection Agency (EPA) 841-F-96-004A. Unites States E.P.A. Washington, DC.

Wallbrink, P., J. Olley. 2004. Sources of fine grained sediment in incised and un-incised channels, Jugiong Creek, NSW, Australia. Int. Assoc. Hydrol. Sci. 288, 165-169.

Wolman, M.G., 1959. Factors influencing erosion of a cohesive river bank. Am. J. Sci. 257, 204-216.

Zaimes, G. N., and R.C. Schultz. 2002. Phosphorus in agricultural watersheds. Dept. of Forestry, Iowa State University, Ames, Iowa

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

Zaimes, G.N., R.C. Schultz, T.M. Isenhart. 2006. Riparian land-uses and precipitation influences on stream bank erosion in central Iowa. J. Am. Water Resour. Assoc. 42, 83-97.

Zaimes, G.N., R.C. Schultz, T.M. Isenhart. 2008. Stream bank soil and phosphorus losses under different riparian land-uses in Iowa. J. Am. Water Resour. Assoc. 44(4), 935-947.